Dataquest
a company of
The Dun & Bradstreet Corporation
1290 Ridder Park Drive, San Jose, CA 95131-2398
(408) 437-8000 Telex 171973 Fax (408) 437-0292

December 1992

Dear Client:

Enclosed you will find a new 1992 binder for your Memories Worldwide Service.

Please move the 1992 Market Statistics, Vendor Profiles, and Dataquest Perspectives into the new binder behind the appropriate tab. Please keep the remaining 1991 documents in the existing binder for historical purposes.

Attached you will find a checklist of what should be in the new 1992 binder after the documents have been filed.

You will soon be receiving your 1993 Dataquest binders for storage of all 1993 deliverables.

If you have any questions please contact me at (408) 437-8320.

Sincerely,

Kimberlie C. Southern
Operations Coordinator

1992
Binder

MEMORIES WORLDWIDE
Binder Checklist

SECTION TITLE	COPYRIGHT	MISSING
Title Page		______
Disclaimer	1991	______
Market Trends (Tab)		______
Market Statistics (Tab)		______
Worldwide MOS Memory Forecast	08/31/92 ✓	______
MOS Memory Unit Shipments 90-91	08/24/92 ✓	______
Worldwode MOS Memory Market Share 89-91	07/06/92 ✓	______
Vendor Profiles (Tab)		______
MMRY-SEG-VP-9201 (Micron Technology)	09/14/92 ✓	______
Perspectives (Tab)		______
MMRY-SEG-DP-9203	08/24/92 ✓	______
MMRY-SEG-DP-9202	04/06/92 ✓	______
MMRY-SEG-DP-9201	03/30/92 ✓	______

Memories *Worldwide*

Dataquest

Dataquest Incorporated
1290 Ridder Park Drive
San Jose, CA 95131-2398
(408) 437-8000
Telex: 171973
Fax: (408) 437-0292

United Kingdom
Dataquest UK Limited
Roussel House,
Broadwater Park
Denham, Nr Uxbridge,
Middx UB9 5HP
England
0895-835050
Telex: 266195
Fax: 0895 835260-1-2

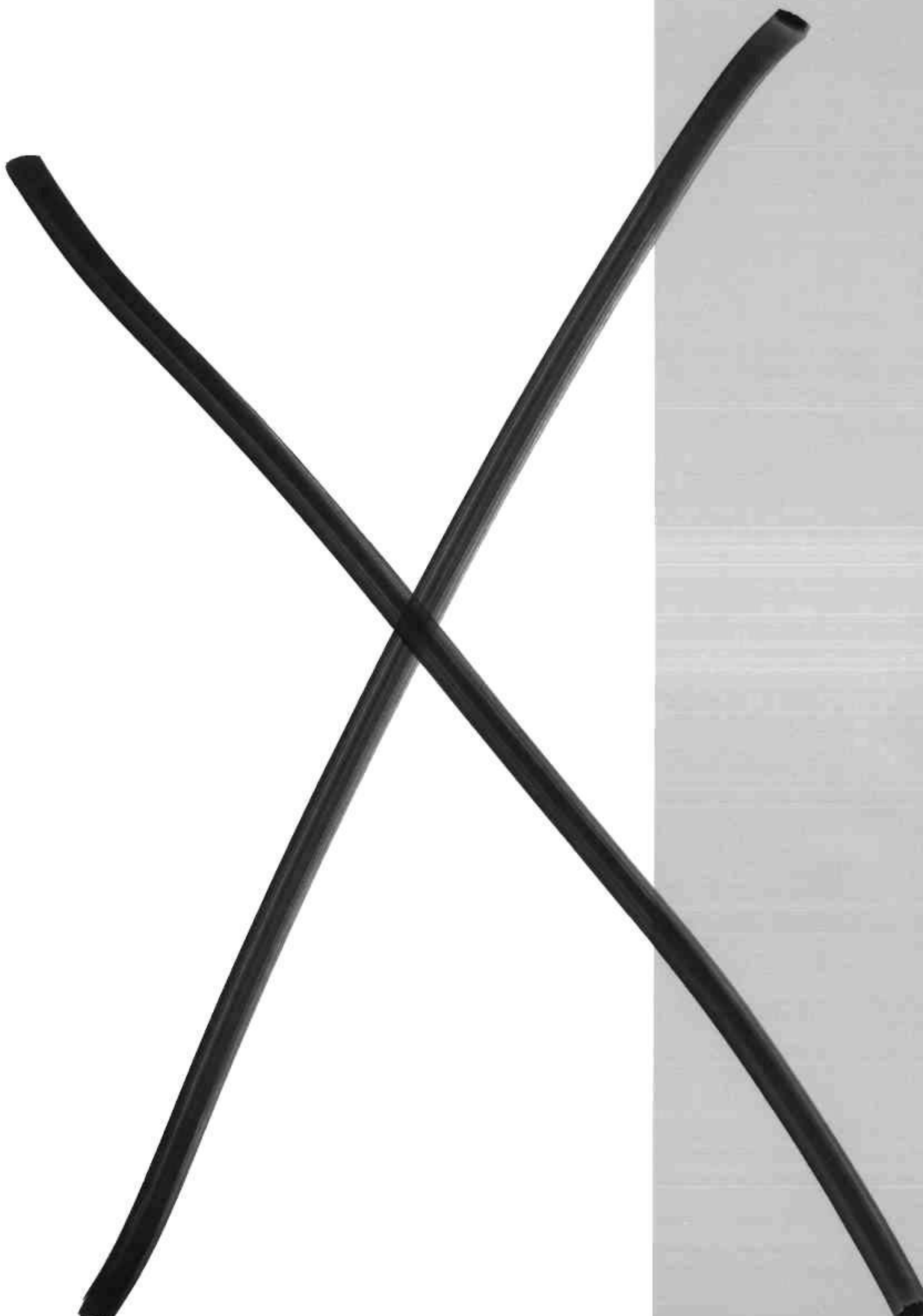
France
Dataquest Europe SA
Tour Galliéni 2
36, avenue du Général-de-Gaulle
93175 Bagnolet Cedex
France
(1)48 97 31 00
Telex: 233 263
Fax: (01)48 97 34 00

Germany
Dataquest GmbH
Kronstadter Strasse 9
8000 Munich 80
West Germany
011 49 89 93 09 09 0
Fax: 011 49 89 930 3277

Japan
Dataquest Japan Limited
Shinkawa Sanko Building 2 Fl
1-3-17 Shinkawa
Chuo-kuTokyo 104
Japan
011-81-3-5566-0411
Telex: 781-32768
Fax: 011-81-3-5566-0425

Korea
Dataquest Korea
Dacheung Building Room 1105
648-23 Yorksam-dong
Kangnam-gu, Seoul 135-80
Korea
011-82-2-552-2332
Fax: 011-82-2-552-2661

Dataquest Incorporated
Ledgeway/Dataquest
The Corporate Center
550 Cochituate Road
Framingham, MA 01701
(508) 370-5555
Fax: (508) 370-6262



Dataquest

• Market Statistics

Dataquest

1/28/92
Worldwide DRAM Consumption by Application
(Billions of Bit)

	1988	1989	1990	1991	1992	1993	1994	1995
DRAM Production								
Merchant	482,028	706,912	1,053,609	1,599,111	2,578,920	3,948,151	6,008,553	8,683,681
Captive (est.)	0	70,943	154,262	237,884	325,365	450,284	681,167	1,022,519
Total	482,028	777,855	1,207,871	1,836,995	2,904,285	4,398,435	6,689,720	9,706,200
Consumption by Computers								
Mainframe	28,820	35,693	42,280	60,211	90,317	116,326	157,920	200,160
Super	4,665	5,576	10,496	22,560	32,856	55,880	82,320	120,960
Mini	9,020	16,128	21,960	31,744	47,520	68,608	82,800	103,680
Office	89,520	122,256	154,240	200,800	267,776	349,760	456,400	572,160
Workstation	21,818	37,402	61,792	132,000	254,144	447,816	922,544	1,584,000
PC Total	178,118	232,154	337,184	471,204	732,447	1,239,624	1,998,016	2,773,767
Handheld	0	425	1,818	7,188	17,554	74,832	181,720	319,399
Notebook	0	134	2,511	8,781	20,750	50,784	138,152	287,200
Laptop	6,163	18,392	32,883	50,155	90,984	147,096	247,520	343,944
Desktop	171,955	213,203	299,972	405,080	603,159	966,912	1,430,624	1,823,224
PC Add-in Memory	42,050	81,877	179,523	267,113	393,612	571,314	748,421	928,042
Total Memory	374,011	531,086	807,475	1,185,632	1,818,672	2,849,328	4,448,421	6,282,769
% by Computers	77.6%	75.1%	76.6%	74.1%	70.5%	72.2%	74.0%	72.4%
Consumption by Application								
Computers	374,011	531,086	807,475	1,185,632	1,818,672	2,849,328	4,448,421	6,282,769
Other DP	n/a	n/a	130,544	224,100	403,380	629,273	975,373	1,560,597
Others	n/a	n/a	115,386	189,379	356,868	469,550	584,759	840,315
Total	374,011	531,086	1,053,405	1,599,111	2,578,920	3,948,151	6,008,553	8,683,681

Source: Dataquest (January 1992)

Worldwide MOS Memory Market Share, 1989-1991

July 6, 1992

Source: Dataquest

Market Statistics

Memories *Worldwide*

MMRY-SEG-MS-9201

Dataquest

Worldwide MOS Memory Market Share

July 6, 1992

Source: Dataquest

Market Statistics

Dataquest®

File behind the *Market Statistics* tab inside the binder labeled **Memories** *Worldwide*

Published by Dataquest Incorporated

Worldwide MOS Memory Market Share, 1989-1991

Table of Contents

Note: All tables show estimated data.

Table		Page

Note: All tables show estimated data.

Note: All tables show estimated data.

Worldwide MOS Memory Market Share, 1989-1991

Introduction

This document contains detailed information on Dataquest's view of the MOS memory IC market. Included in this document are:

- 1989-1991 market share estimates

Analyses of the MOS memory market by company provide insight into high-technology markets and reinforce estimates of consumption, production, and company revenue.

Worldwide market share estimates combine data from many countries, each of which has a different and fluctuating exchange rate. Estimates of non-U.S. market consumption or revenue are based upon the average exchange rate for the given year. Refer to the section entitled "Exchange Rates" for more information regarding these average rates. As a rule, Dataquest's estimates are calculated in local currencies and then converted to U.S. dollars.

More detailed data on this market may be requested through Dataquest's client inquiry service. Qualitative analysis of these data is provided in the *Dataquest Perspectives* located in the binder of the same name.

Segmentation

This section outlines the market segments that are specific to this document. Dataquest's objective is to provide data along lines of segmentation that are logical, appropriate to the industry in question, and immediately useful to clients.

For a detailed explanation of Dataquest's market segmentation, refer to the *Dataquest Research and Forecast Methodology* document located in the Source: Dataquest binder. For a complete listing of all market segments tracked by Dataquest, please refer to the *Dataquest High-Technology Guide: Segmentation and Glossary.*

Dataquest defines the MOS memory market as DRAM, SRAM, EPROM, mask ROM, EEPROM, flash memory, and other MOS memory. MOS memory is defined as a MOS IC in which binary data are stored and electronically retrieved.

Merchant versus Captive Consumption: Dataquest includes all revenue, both merchant and captive, for semiconductor suppliers selling to the merchant market. The data exclude completely captive suppliers where devices are manufactured solely for the company's own use. A product that is used internally is valued at market price rather than at transfer or factory price.

Definitions

This section lists the definitions that are used by Dataquest to present the data in this document. Complete definitions for all terms associated with Dataquest's segmentation of the high-technology marketplace can be found in the *Dataquest High-Technology Guide: Segmentation and Glossary.*

Product Definitions

DRAM: Includes dynamic RAM, multiport-DRAM (M-DRAM), and video-DRAM (V-DRAM). DRAMs have memory cells consisting of a single transistor, and require regular externally cycled memory cell refreshes. These are volatile memories and addressing is multiplexed.

SRAM: Includes static RAM, multiport-SRAM (M-SRAM), battery backed-up SRAM (BB-SRAM), and pseudo-SRAM (P-SRAM). SRAMs have memory cells consisting of a minimum of four transistors, except a P-SRAM, which has a memory cell consisting of a single transistor and is similar to a DRAM. SRAMs do not require externally cycled memory cell refreshes. These are volatile memories and addressing is not multiplexed (except in the case of P-SRAM).

EPROM: Includes erasable programmable read-only memory. Included are ultraviolet EPROM (UV EPROM) and one-time programmable read-only memory (OTPROM). EPROMs have memory cells consisting of a single transistor, and do not require any memory cell refreshes. These devices are nonvolatile memories.

Nonvolatile MOS Memory IC: Includes EPROM, mask ROM, EEPROM, and flash. Dataquest defines the mask ROM market as mask-programmable read-only memory. Mask ROM is a form of memory that is programmed by the manufacturer to a user specification using a mask step. Mask ROM is programmed in hardware rather than software. These devices are considered nonvolatile memories. Dataquest defines the EEPROM market as electronically erasable programmable read-only memory. This market includes serial EEPROM (S-EEPROM), parallel EEPROM (P-EEPROM), and electronically alterable read-only memory (EAROM). EEPROMs have memory cells consisting of a minimum of two transistors, and do not require memory cell refreshes. This market also includes nonvolatile RAM (NV-RAM), also known as shadow RAM. These semiconductor products are a combination of SRAM and EEPROM technologies in each memory cell. The EEPROM functions as a shadow backup for the SRAM when power is lost. Dataquest defines the flash market as a nonvolatile product designated as flash EPROM/EEPROM that incorporates either 5V or 12V programming supplies and one-transistor (1T) or two-transistor (2T) memory cells with electrical programming and fast bulk/chip erase.

Other MOS Memory IC: Includes all other MOS memory not already accounted for in the preceding categories. This category includes MOS content addressable memory (CAM), MOS cache-tag RAM, MOS first-in/first-out memory (FIFO), MOS last-in/first-out memory (LIFO), and ferroelectroic memory.

Bipolar Memory: Includes bipolar digital semiconductor products in which binary data are stored and electronically retrieved. Included are ECL or TTL random access memory (RAM), read-only memory (ROM), programmable ROM (PROM), last-in/first-out (LIFO) memory, and first-in/first-out (FIFO) memory; not included are products made with mixed bipolar CMOS (that is, BiCMOS) with TTL or ECL outputs, which are classified as MOS.

Regional Definitions

North America: Includes United States and Canada

United States: Includes 48 contiguous states, Washington, D.C., Alaska, Hawaii, and Puerto Rico

Europe: Western Europe

Japan: Japan

Asia/Pacific-Rest of World: All other countries

Line Item Definitions

Factory revenue is defined as the amount of money received by a semiconductor vendor for its goods; revenue from the sale of semiconductors sold either as finished goods, die, or wafers to another semiconductor vendor for resale is attributed to the semiconductor vendor who sells the product to a distributor or equipment manufacturer.

Market Share Methodology

Dataquest utilizes both primary and secondary sources to produce market statistics data. In the fourth quarter of each year, Dataquest surveys all major participants within each industry. Selected companies are resurveyed during the first quarter of the following year to verify final annual results. This primary research is supplemented with additional primary research and secondary research to verify market size, shipment totals, and pricing information. Other sources of data utilized by Dataquest include:

- Information published by major industry participants
- Estimates made by knowledgeable and reliable industry spokespersons
- Government data or trade association data
- Published product literature and price lists
- Interviews with knowledgeable manufacturers, distributors, and users
- Relevant economic data
- Information and data from online and/or CD-ROM data banks

- Articles in both the general and trade press
- Reports from financial analysts
- End-user surveys

Dataquest believes that the estimates presented in this document are the most accurate and meaningful statistics available.

Despite the care taken in gathering, analyzing, and categorizing the data in a meaningful way, careful attention must be paid to the definitions and assumptions used herein when interpreting the estimates presented in this document. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between data and numbers provided by Dataquest and those provided by other suppliers.

Notes on Market Share

In the process of conducting data collection and preparing market statistics information, Dataquest will sometimes consolidate or revise the numbers of a particular company, model, series, or industry. In this section, any such changes contained within this document are outlined for your reference.

Notes to Market Share Tables

1. GEC Plessey revenue includes MEDL and Plessey revenue from 1990 forward.
2. Gould AMI revenue from 1991 forward does not include foundry revenue.
3. Harris revenue includes GE Solid State revenue from 1989 forward.
4. Inmos revenue is included in SGS-Thomson revenue from 1989 forward.
5. Macronix revenue is included under Asia/Pacific Companies from 1991 forward.
6. Other North American Companies and Other Asia/Pacific Companies revenue has been restated to reflect the fewer number of companies published in 1991.
7. Philips revenue includes Signetics revenue.

Exchange Rates

Dataquest uses an average annual exchange rate in converting revenue to U.S. dollar amounts. The following table outlines these rates for 1989 through 1991.

	1989	1990	1991
Japan (Yen/U.S.$)	138	144	136
France (Franc/U.S.$)	6.39	5.44	5.64
Germany (Deutsche Mark/U.S.$)	1.88	1.62	1.66
United Kingdom (U.S.$/Pound Sterling)	1.50	1.79	1.77

Table 1-1
Each Company's Factory Revenue from Shipments of MOS Memory to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	15,405	12,128	12,841	100.0	100.0	100.0
North American Companies	3,651	2,977	3,298	23.7	24.5	25.7
Advanced Micro Devices	258	253	270	1.7	2.1	2.1
AT&T	13	13	4	.1	.1	.0
Atmel	47	54	78	.3	.4	.6
Catalyst	31	35	32	.2	.3	.2
Cypress Semiconductor	149	166	186	1.0	1.4	1.4
Dallas Semiconductor	10	14	21	.1	.1	.2
Gould AMI	25	14	11	.2	.1	.1
Harris	37	24	23	.2	.2	.2
Honeywell	2	2	0	.0	.0	.0
Integrated Device Technology	158	132	128	1.0	1.1	1.0
Intel	433	371	395	2.8	3.1	3.1
Int'l Microelectronic Prod.	17	8	6	.1	.1	.0
ITT	10	0	10	.1	.0	.1
Microchip Technology	94	60	57	.6	.5	.4
Micron Technology	395	286	455	2.6	2.4	3.5
MOSel	20	31	75	.1	.3	.6
Motorola	407	395	412	2.6	3.3	3.2
NCR	8	4	3	.1	.0	.0
National Semiconductor	132	137	112	.9	1.1	.9
Performance Semiconductor	16	19	18	.1	.2	.1
SEEQ Technology	40	33	33	.3	.3	.3
Texas Instruments	1,095	741	738	7.1	6.1	5.7
Vitelic	66	64	85	.4	.5	.7
VLSI Technology	23	8	0	.1	.1	.0
WaferScale Integration	28	27	23	.2	.2	.2
Xicor	87	68	91	.6	.6	.7
Other North American Companies	50	18	32	.3	.1	.2
Japanese Companies	9,678	7,095	7,141	62.8	58.5	55.6
Fujitsu	1,188	913	909	7.7	7.5	7.1
Hitachi	1,396	1,224	1,330	9.1	10.1	10.4
Matsushita	362	265	217	2.3	2.2	1.7
Mitsubishi	1,117	745	762	7.3	6.1	5.9
NEC	1,594	1,233	1,242	10.3	10.2	9.7
NMB Semiconductor	127	96	60	.8	.8	.5
Oki	441	350	380	2.9	2.9	3.0
Ricoh	28	26	8	.2	.2	.1

(Continued)

Table 1-1 (Continued)
Each Company's Factory Revenue from Shipments of MOS Memory to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Rohm	5	13	28	.0	.1	.2
Sanyo	118	86	82	.8	.7	.6
Seiko Epson	137	55	37	.9	.5	.3
Sharp	434	454	476	2.8	3.7	3.7
Sony	215	204	183	1.4	1.7	1.4
Toshiba	1,681	1,431	1,425	10.9	11.8	11.1
Yamaha	0	0	2	.0	.0	.0
Other Japanese Companies	835	0	0	5.4	.0	.0
European Companies	716	731	682	4.6	6.0	5.3
Eurosil	0	0	1	.0	.0	.0
GEC Plessey	0	8	0	.0	.1	.0
Matra MHS	31	37	35	.2	.3	.3
MEDL	7	0	0	.0	.0	.0
Philips	60	96	75	.4	.8	.6
Plessey	3	0	0	.0	.0	.0
SGS-Thomson	239	278	273	1.6	2.3	2.1
Siemens	376	312	298	2.4	2.6	2.3
Asia/Pacific Companies	1,360	1,325	1,720	8.8	10.9	13.4
Goldstar	82	96	249	.5	.8	1.9
Hualon Microelectronics Corp.	NA	39	27	NA	.3	.2
Hyundai	210	115	248	1.4	.9	1.9
Macronix	31	7	31	.2	.1	.2
Samsung	935	971	1,066	6.1	8.0	8.3
Silicon Integrated Systems	NA	17	15	NA	.1	.1
United Microelectronics	102	66	58	.7	.5	.5
Winbond Electronics	NA	14	26	NA	.1	.2

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-2
Each Company's Factory Revenue from Shipments of MOS DRAMs to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	9,104	6,525	6,982	100.0	100.0	100.0
North American Companies	1,705	1,235	1,384	18.7	18.9	19.8
Intel	70	88	69	0.8	1.3	1.0
Micron Technology	355	213	365	3.9	3.3	5.2
MOSel	0	0	20	0.0	0.0	0.3
Motorola	320	292	276	3.5	4.5	4.0
Texas Instruments	899	584	575	9.9	9.0	8.2
Vitelic	61	58	79	0.7	0.9	1.1
Japanese Companies	6,012	3,991	4,011	66.0	61.2	57.4
Fujitsu	748	536	503	8.2	8.2	7.2
Hitachi	757	617	661	8.3	9.5	9.5
Matsushita	241	168	132	2.6	2.6	1.9
Mitsubishi	729	466	515	8.0	7.1	7.4
NEC	1,052	754	743	11.6	11.6	10.6
NMB Semiconductor	127	96	60	1.4	1.5	0.9
Oki	390	305	346	4.3	4.7	5.0
Sanyo	14	18	31	0.2	0.3	0.4
Sharp	100	67	60	1.1	1.0	0.9
Sony	0	3	3	0.0	0.0	0.0
Toshiba	1,268	961	957	13.9	14.7	13.7
Other Japanese Companies	586	0	0	6.4	0.0	0.0
European Companies	361	298	287	4.0	4.6	4.1
Siemens	361	298	287	4.0	4.6	4.1
Asia/Pacific Companies	1,026	1,001	1,300	11.3	15.3	18.6
Goldstar	61	85	228	0.7	1.3	3.3
Hyundai	160	77	186	1.8	1.2	2.7
Samsung	805	839	886	8.8	12.9	12.7

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-3
Each Company's Factory Revenue from Shipments of MOS SRAMs to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	3,171	2,584	2,576	100.0	100.0	100.0
North American Companies	536	524	551	16.9	20.3	21.4
Advanced Micro Devices	52	33	16	1.6	1.3	0.6
AT&T	5	5	4	0.2	0.2	0.2
Atmel	1	1	1	0.0	0.0	0.0
Catalyst	7	4	0	0.2	0.2	0.0
Cypress Semiconductor	106	124	125	3.3	4.8	4.9
Harris	31	18	17	1.0	0.7	0.7
Honeywell	2	2	0	0.1	0.1	0.0
Integrated Device Technology	107	71	45	3.4	2.7	1.7
Intel	1	15	15	0.0	0.6	0.6
Micron Technology	40	73	90	1.3	2.8	3.5
MOSel	17	12	36	0.5	0.5	1.4
Motorola	80	99	132	2.5	3.8	5.1
NCR	1	1	2	0.0	0.0	0.1
National Semiconductor	26	22	15	0.8	0.9	0.6
Performance Semiconductor	16	19	18	0.5	0.7	0.7
Texas Instruments	2	2	4	0.1	0.1	0.2
Vitelic	5	6	6	0.2	0.2	0.2
VLSI Technology	7	7	0	0.2	0.3	0.0
Other North American Companies	30	10	25	0.9	0.4	1.0
Japanese Companies	2,246	1,756	1,742	70.8	68.0	67.6
Fujitsu	276	237	261	8.7	9.2	10.1
Hitachi	429	406	449	13.5	15.7	17.4
Matsushita	25	22	20	0.8	0.9	0.8
Mitsubishi	247	183	151	7.8	7.1	5.9
NEC	263	237	241	8.3	9.2	9.4
Oki	23	20	14	0.7	0.8	0.5
Rohm	5	7	9	0.2	0.3	0.3
Sanyo	82	55	37	2.6	2.1	1.4
Seiko Epson	137	55	37	4.3	2.1	1.4
Sharp	76	94	109	2.4	3.6	4.2
Sony	208	193	172	6.6	7.5	6.7
Toshiba	226	247	242	7.1	9.6	9.4
Other Japanese Companies	249	0	0	7.9	0.0	0.0

(Continued)

Table 1-3 (Continued)
Each Company's Factory Revenue from Shipments of MOS SRAMs to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
European Companies	129	98	82	4.1	3.8	3.2
GEC Plessey	0	4	0	0.0	0.2	0.0
Matra MHS	31	37	35	1.0	1.4	1.4
MEDL	7	0	0	0.2	0.0	0.0
Philips	3	8	9	0.1	0.3	0.3
SGS-Thomson	88	49	38	2.8	1.9	1.5
Asia/Pacific Companies	260	206	201	8.2	8.0	7.8
Goldstar	11	6	17	0.3	0.2	0.7
Hualon Microelectronics Corp.	NA	10	10	NA	0.4	0.4
Hyundai	49	30	48	1.5	1.2	1.9
Samsung	100	92	93	3.2	3.6	3.6
Silicon Integrated Systems	NA	2	2	NA	0.1	0.1
United Microelectronics	100	64	22	3.2	2.5	0.9
Winbond Electronics	NA	2	9	NA	0.1	0.3

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-4
Each Company's Factory Revenue from Shipments of MOS EPROMs to the World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	NA	NA	1,358	NA	NA	100.0
North American Companies	NA	NA	774	NA	NA	57.0
Advanced Micro Devices	NA	NA	225	NA	NA	16.6
Atmel	NA	NA	30	NA	NA	2.2
Catalyst	NA	NA	2	NA	NA	0.1
Cypress Semiconductor	NA	NA	37	NA	NA	2.7
Intel	NA	NA	205	NA	NA	15.1
Microchip Technology	NA	NA	33	NA	NA	2.4
National Semiconductor	NA	NA	81	NA	NA	6.0
Texas Instruments	NA	NA	136	NA	NA	10.0
WaferScale Integration	NA	NA	23	NA	NA	1.7
Other North American Companies	NA	NA	2	NA	NA	0.1
Japanese Companies	NA	NA	367	NA	NA	27.0
Fujitsu	NA	NA	86	NA	NA	6.3
Hitachi	NA	NA	59	NA	NA	4.3
Mitsubishi	NA	NA	67	NA	NA	4.9
NEC	NA	NA	81	NA	NA	6.0
Oki	NA	NA	3	NA	NA	0.2
Sharp	NA	NA	3	NA	NA	0.2
Toshiba	NA	NA	68	NA	NA	5.0
European Companies	NA	NA	217	NA	NA	16.0
Philips	NA	NA	59	NA	NA	4.3
SGS-Thomson	NA	NA	158	NA	NA	11.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-5
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to the World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	3,013	2,845	3,071	100.0	100.0	100.0
North American Companies	1,309	1,090	1,195	43.4	38.3	38.9
Advanced Micro Devices	203	209	237	6.7	7.3	7.7
AT&T	8	8	0	0.3	0.3	0.0
Atmel	46	53	77	1.5	1.9	2.5
Catalyst	24	31	32	0.8	1.1	1.0
Cypress Semiconductor	22	21	37	0.7	0.7	1.2
Gould AMI	25	14	11	0.8	0.5	0.4
Harris	1	1	0	0.0	0.0	0.0
Intel	362	268	311	12.0	9.4	10.1
Int'l Microelectronic Prod.	17	8	6	0.6	0.3	0.2
ITT	10	0	10	0.3	0.0	0.3
Microchip Technology	94	60	57	3.1	2.1	1.9
MOSel	0	6	8	0.0	0.2	0.3
Motorola	7	4	4	0.2	0.1	0.1
National Semiconductor	106	115	97	3.5	4.0	3.2
SEEQ Technology	40	33	33	1.3	1.2	1.1
Texas Instruments	194	155	159	6.4	5.4	5.2
VLSI Technology	16	1	0	0.5	0.0	0.0
WaferScale Integration	28	27	23	0.9	0.9	0.7
Xicor	87	68	91	2.9	2.4	3.0
Other North American Companies	19	8	2	0.6	0.3	0.1
Japanese Companies	1,419	1,347	1,382	47.1	47.3	45.0
Fujitsu	164	140	145	5.4	4.9	4.7
Hitachi	210	201	220	7.0	7.1	7.2
Matsushita	96	75	65	3.2	2.6	2.1
Mitsubishi	141	96	96	4.7	3.4	3.1
NEC	279	242	258	9.3	8.5	8.4
Oki	28	25	20	0.9	0.9	0.7
Ricoh	28	26	8	0.9	0.9	0.3
Rohm	0	6	19	0.0	0.2	0.6
Sanyo	22	13	9	0.7	0.5	0.3
Sharp	257	292	306	8.5	10.3	10.0
Sony	7	8	8	0.2	0.3	0.3
Toshiba	187	223	226	6.2	7.8	7.4
Yamaha	0	0	2	0.0	0.0	0.1

(Continued)

Table 1-5 (Continued)
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
European Companies	211	290	275	7.0	10.2	9.0
Eurosil	0	0	1	0.0	0.0	0.0
GEC Plessey	0	4	0	0.0	0.1	0.0
Philips	57	88	66	1.9	3.1	2.1
Plessey	3	0	0	0.1	0.0	0.0
SGS-Thomson	151	198	208	5.0	7.0	6.8
Asia/Pacific Companies	74	118	219	2.5	4.1	7.1
Goldstar	10	5	4	0.3	0.2	0.1
Hualon Microelectronics Corp.	NA	29	17	NA	1.0	0.6
Hyundai	1	8	14	0.0	0.3	0.5
Macronix	31	7	31	1.0	0.2	1.0
Samsung	30	40	87	1.0	1.4	2.8
Silicon Integrated Systems	NA	15	13	NA	0.5	0.4
United Microelectronics	2	2	36	0.1	0.1	1.2
Winbond Electronics	NA	12	17	NA	0.4	0.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-6
Each Company's Factory Revenue from Shipments of Other MOS Memory to the World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	117	174	212	100.0	100.0	100.0
North American Companies	101	128	168	86.3	73.6	79.2
Advanced Micro Devices	3	11	17	2.6	6.3	8.0
Cypress Semiconductor	21	21	24	17.9	12.1	11.3
Dallas Semiconductor	10	14	21	8.5	8.0	9.9
Harris	5	5	6	4.3	2.9	2.8
Integrated Device Technology	51	61	83	43.6	35.1	39.2
MOSel	3	13	11	2.6	7.5	5.2
NCR	7	3	1	6.0	1.7	0.5
Other North American Companies	1	0	5	0.9	0.0	2.4
Japanese Companies	1	1	6	0.9	0.6	2.8
Sanyo	0	0	5	0.0	0.0	2.4
Sharp	1	1	1	0.9	0.6	0.5
European Companies	15	45	38	12.8	25.9	17.9
SGS-Thomson	0	31	27	0.0	17.8	12.7
Siemens	15	14	11	12.8	8.0	5.2

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 1-7
Each Company's Factory Revenue from Shipments of Bipolar Memory to the World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	460	431	356	100.0	100.0	100.0
North American Companies	160	126	89	34.8	29.2	25.0
Advanced Micro Devices	85	65	52	18.5	15.1	14.6
Harris	0	5	2	0.0	1.2	0.6
Integrated Device Technology	0	0	3	0.0	0.0	0.8
Motorola	4	3	3	0.9	0.7	0.8
National Semiconductor	49	25	13	10.7	5.8	3.7
Raytheon	12	18	8	2.6	4.2	2.2
Texas Instruments	10	10	3	2.2	2.3	0.8
Other North American Companies	0	0	5	0.0	0.0	1.4
Japanese Companies	253	259	231	55.0	60.1	64.9
Fujitsu	135	144	113	29.3	33.4	31.7
Hitachi	97	95	99	21.1	22.0	27.8
NEC	21	20	19	4.6	4.6	5.3
European Companies	47	46	36	10.2	10.7	10.1
Philips	47	45	36	10.2	10.4	10.1
SGS-Thomson	0	1	0	0.0	0.2	0.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-1
Top 20 Companies' Factory Revenue from Shipments of MOS Memory to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Toshiba	1,431	1,425	0	11.1
2	3	Hitachi	1,224	1,330	9	10.4
3	2	NEC	1,233	1,242	1	9.7
4	4	Samsung	971	1,066	10	8.3
5	5	Fujitsu	913	909	0	7.1
6	6	Mitsubishi	745	762	2	5.9
7	7	Texas Instruments	741	738	0	5.7
8	8	Sharp	454	476	5	3.7
9	13	Micron Technology	286	455	59	3.5
10	9	Motorola	395	412	4	3.2
11	10	Intel	371	395	6	3.1
12	11	Oki	350	380	9	3.0
13	12	Siemens	312	298	-4	2.3
14	14	SGS-Thomson	278	273	-2	2.1
15	16	Advanced Micro Devices	253	270	7	2.1
16	24	Goldstar	96	249	159	1.9
17	21	Hyundai	115	248	116	1.9
18	15	Matsushita	265	217	-18	1.7
19	18	Cypress Semiconductor	166	186	12	1.4
20	17	Sony	204	183	-10	1.4
		All Others	1325	1327	0	10.3
		North American Companies	2,977	3,298	11	25.7
		Japanese Companies	7,095	7,141	1	55.6
		European Companies	731	682	-7	5.3
		Asia/Pacific Companies	1,325	1,720	30	13.4
		Total Market	12,128	12,841	6	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-2
Top 10 Companies' Factory Revenue from Shipments of MOS DRAMs to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Toshiba	961	957	0	13.7
2	2	Samsung	839	886	6	12.7
3	3	NEC	754	743	-1	10.6
4	4	Hitachi	617	661	7	9.5
5	5	Texas Instruments	584	575	-2	8.2
6	7	Mitsubishi	466	515	11	7.4
7	6	Fujitsu	536	503	-6	7.2
8	11	Micron Technology	213	365	71	5.2
9	8	Oki	305	346	13	5.0
10	9	Siemens	298	287	-4	4.1
		All Others	952	1144	20	16.4
		North American Companies	1,235	1,384	12	19.8
		Japanese Companies	3,991	4,011	1	57.4
		European Companies	298	287	-4	4.1
		Asia/Pacific Companies	1,001	1,300	30	18.6
		Total Market	6,525	6,982	7	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-3
Top 10 Companies' Factory Revenue from Shipments of MOS SRAMs to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Hitachi	406	449	11	17.4
2	4	Fujitsu	237	261	10	10.1
3	2	Toshiba	247	242	-2	9.4
4	3	NEC	237	241	2	9.4
5	5	Sony	193	172	-11	6.7
6	6	Mitsubishi	183	151	-17	5.9
7	8	Motorola	99	132	33	5.1
8	7	Cypress Semiconductor	124	125	1	4.9
9	9	Sharp	94	109	16	4.2
10	10	Samsung	92	93	1	3.6
		All Others	672	601	-11	23.3
		North American Companies	524	551	5	21.4
		Japanese Companies	1,756	1,742	-1	67.6
		European Companies	98	82	-16	3.2
		Asia/Pacific Companies	206	201	-2	7.8
		Total Market	2,584	2,576	0	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-4
Top 10 Companies' Factory Revenue from Shipments of MOS EPROMs to the World
(Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	NA	Advanced Micro Devices	NA	225	NA	16.6
2	NA	Intel	NA	205	NA	15.1
3	NA	SGS-Thomson	NA	158	NA	11.6
4	NA	Texas Instruments	NA	136	NA	10.0
5	NA	Fujitsu	NA	86	NA	6.3
6	NA	National Semiconductor	NA	81	NA	6.0
6	NA	NEC	NA	81	NA	6.0
8	NA	Toshiba	NA	68	NA	5.0
9	NA	Mitsubishi	NA	67	NA	4.9
10	NA	Philips	NA	59	NA	4.3
10	NA	Hitachi	NA	59	NA	4.3
		All Others	NA	133	NA	9.8
		North American Companies	NA	774	NA	57.0
		Japanese Companies	NA	367	NA	27.0
		European Companies	NA	217	NA	16.0
		Asia/Pacific Companies	NA	0	NA	0.0
		Total Market	NA	1,358	NA	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-5
Top 10 Companies' Factory Revenue from Shipments of MOS Nonvolatile Memory to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	2	Intel	268	311	16	10.1
2	1	Sharp	292	306	5	10.0
3	3	NEC	242	258	7	8.4
4	5	Advanced Micro Devices	209	237	13	7.7
5	4	Toshiba	223	226	1	7.4
6	6	Hitachi	201	220	9	7.2
7	7	SGS-Thomson	198	208	5	6.8
8	8	Texas Instruments	155	159	3	5.2
9	9	Fujitsu	140	145	4	4.7
10	10	National Semiconductor	115	97	-16	3.2
		All Others	802	904	13	29.4
		North American Companies	1,090	1,195	10	38.9
		Japanese Companies	1,347	1,382	3	45.0
		European Companies	290	275	-5	9.0
		Asia/Pacific Companies	118	219	86	7.1
		Total Market	2,845	3,071	8	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-6
Top 10 Companies' Factory Revenue from Shipments of Other MOS Memory to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Integrated Device Technology	61	83	36	39.2
2	2	SGS-Thomson	31	27	-13	12.7
3	3	Cypress Semiconductor	21	24	14	11.3
4	5	Dallas Semiconductor	14	21	50	9.9
5	7	Advanced Micro Devices	11	17	55	8.0
6	4	Siemens	14	11	-21	5.2
6	6	MOSel	13	11	-15	5.2
8	8	Harris	5	6	20	2.8
9	49	Sanyo	0	5	NM	2.4
10	10	Sharp	1	1	0	0.5
		All Others	3	6	100	2.8
		North American Companies	128	168	31	79.2
		Japanese Companies	1	6	500	2.8
		European Companies	45	38	-16	17.9
		Asia/Pacific Companies	0	0	NM	0.0
		Total Market	174	212	22	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 2-7
Top 10 Companies' Factory Revenue from Shipments of Bipolar Memory to the World (Millions of U.S. Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Fujitsu	144	113	-22	31.7
2	2	Hitachi	95	99	4	27.8
3	3	Advanced Micro Devices	65	52	-20	14.6
4	4	Philips	45	36	-20	10.1
5	6	NEC	20	19	-5	5.3
6	5	National Semiconductor	25	13	-48	3.7
7	7	Raytheon	18	8	-56	2.2
8	8	Texas Instruments	10	3	-70	0.8
8	10	Motorola	3	3	0	0.8
8	90	Integrated Device Technology	0	3	NM	0.8
		All Others	6	7	17	2.0
		North American Companies	126	89	-29	25.0
		Japanese Companies	259	231	-11	64.9
		European Companies	46	36	-22	10.1
		Asia/Pacific Companies	0	0	NM	0.0
		Total Market	431	356	-17	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-1
Each Company's Factory Revenue from Shipments of MOS Memory to North America
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	5,772	4,325	4,510	100.0	100.0	100.0
North American Companies	2,126	1,578	1,742	36.8	36.5	38.6
Advanced Micro Devices	125	115	114	2.2	2.7	2.5
AT&T	13	13	3	0.2	0.3	0.1
Atmel	28	31	44	0.5	0.7	1.0
Catalyst	13	13	9	0.2	0.3	0.2
Cypress Semiconductor	119	128	148	2.1	3.0	3.3
Dallas Semiconductor	8	12	13	0.1	0.3	0.3
Gould AMI	21	10	10	0.4	0.2	0.2
Harris	27	12	17	0.5	0.3	0.4
Honeywell	2	2	0	0.0	0.0	0.0
Integrated Device Technology	119	88	94	2.1	2.0	2.1
Intel	252	205	206	4.4	4.7	4.6
Int'l Microelectronic Prod.	17	8	6	0.3	0.2	0.1
ITT	0	0	3	0.0	0.0	0.1
Microchip Technology	55	32	14	1.0	0.7	0.3
Micron Technology	286	201	341	5.0	4.6	7.6
MOSel	16	13	25	0.3	0.3	0.6
Motorola	191	176	193	3.3	4.1	4.3
NCR	7	3	3	0.1	0.1	0.1
National Semiconductor	68	72	49	1.2	1.7	1.1
Performance Semiconductor	14	14	14	0.2	0.3	0.3
SEEQ Technology	31	24	25	0.5	0.6	0.6
Texas Instruments	537	295	285	9.3	6.8	6.3
Vitelic	30	28	37	0.5	0.6	0.8
VLSI Technology	22	5	0	0.4	0.1	0.0
WaferScale Integration	26	25	13	0.5	0.6	0.3
Xicor	53	43	48	0.9	1.0	1.1
Other North American Companies	46	10	28	0.8	0.2	0.6
Japanese Companies	2,911	2,053	2,053	50.4	47.5	45.5
Fujitsu	237	193	164	4.1	4.5	3.6
Hitachi	388	320	352	6.7	7.4	7.8
Matsushita	69	54	44	1.2	1.2	1.0
Mitsubishi	321	188	297	5.6	4.3	6.6
NEC	467	349	338	8.1	8.1	7.5
NMB Semiconductor	40	39	23	0.7	0.9	0.5
Oki	211	154	138	3.7	3.6	3.1
Ricoh	1	0	0	0.0	0.0	0.0

(Continued)

Table 3-1 (Continued)
Each Company's Factory Revenue from Shipments of MOS Memory to North America
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Rohm	0	0	2	0.0	0.0	0.0
Sanyo	0	1	2	0.0	0.0	0.0
Seiko Epson	29	12	9	0.5	0.3	0.2
Sharp	50	48	46	0.9	1.1	1.0
Sony	63	59	38	1.1	1.4	0.8
Toshiba	735	636	600	12.7	14.7	13.3
Other Japanese Companies	300	0	0	5.2	0.0	0.0
European Companies	148	169	144	2.6	3.9	3.2
GEC Plessey	0	3	0	0.0	0.1	0.0
Matra MHS	2	3	2	0.0	0.1	0.0
MEDL	4	0	0	0.1	0.0	0.0
Philips	21	38	20	0.4	0.9	0.4
Plessey	1	0	0	0.0	0.0	0.0
SGS-Thomson	67	75	72	1.2	1.7	1.6
Siemens	53	50	50	0.9	1.2	1.1
Asia/Pacific Companies	587	525	571	10.2	12.1	12.7
Goldstar	14	23	62	0.2	0.5	1.4
Hyundai	110	45	93	1.9	1.0	2.1
Macronix	21	4	4	0.4	0.1	0.1
Samsung	387	416	409	6.7	9.6	9.1
United Microelectronics	55	36	1	1.0	0.8	0.0
Winbond Electronics	NA	1	2	NA	0.0	0.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-2
Each Company's Factory Revenue from Shipments of MOS DRAMs to North America (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	3,600	2,429	2,601	100.0	100.0	100.0
North American Companies	947	602	696	26.3	24.8	26.8
Intel	60	71	48	1.7	2.9	1.8
Micron Technology	252	144	275	7.0	5.9	10.6
Motorola	151	130	118	4.2	5.4	4.5
Texas Instruments	456	231	219	12.7	9.5	8.4
Vitelic	28	26	36	0.8	1.1	1.4
Japanese Companies	2,166	1,361	1,362	60.2	56.0	52.4
Fujitsu	126	100	74	3.5	4.1	2.8
Hitachi	215	166	185	6.0	6.8	7.1
Matsushita	49	37	32	1.4	1.5	1.2
Mitsubishi	248	132	235	6.9	5.4	9.0
NEC	407	300	285	11.3	12.4	11.0
NMB Semiconductor	40	39	23	1.1	1.6	0.9
Oki	199	143	134	5.5	5.9	5.2
Sharp	24	16	13	0.7	0.7	0.5
Toshiba	558	428	381	15.5	17.6	14.6
Other Japanese Companies	300	0	0	8.3	0.0	0.0
European Companies	53	50	49	1.5	2.1	1.9
Siemens	53	50	49	1.5	2.1	1.9
Asia/Pacific Companies	434	416	494	12.1	17.1	19.0
Goldstar	10	23	60	0.3	0.9	2.3
Hyundai	89	25	72	2.5	1.0	2.8
Samsung	335	368	362	9.3	15.2	13.9

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-3
Each Company's Factory Revenue from Shipments of MOS SRAMs to North America
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,053	903	889	100.0	100.0	100.0
North American Companies	393	353	383	37.3	39.1	43.1
Advanced Micro Devices	23	15	12	2.2	1.7	1.3
AT&T	5	5	3	0.5	0.6	0.3
Atmel	1	1	1	0.1	0.1	0.1
Catalyst	5	3	0	0.5	0.3	0.0
Cypress Semiconductor	86	101	101	8.2	11.2	11.4
Harris	23	8	12	2.2	0.9	1.3
Honeywell	2	2	0	0.2	0.2	0.0
Integrated Device Technology	82	41	32	7.8	4.5	3.6
Intel	1	15	8	0.1	1.7	0.9
Micron Technology	34	57	66	3.2	6.3	7.4
MOSel	14	7	19	1.3	0.8	2.1
Motorola	37	44	75	3.5	4.9	8.4
NCR	1	1	2	0.1	0.1	0.2
National Semiconductor	25	21	13	2.4	2.3	1.5
Performance Semiconductor	14	14	14	1.3	1.6	1.6
Texas Instruments	2	2	2	0.2	0.2	0.2
Vitelic	2	2	1	0.2	0.2	0.1
VLSI Technology	6	5	0	0.6	0.6	0.0
Other North American Companies	30	9	22	2.8	1.0	2.5
Japanese Companies	499	451	444	47.4	49.9	49.9
Fujitsu	72	61	65	6.8	6.8	7.3
Hitachi	119	106	112	11.3	11.7	12.6
Mitsubishi	55	44	48	5.2	4.9	5.4
NEC	50	40	43	4.7	4.4	4.8
Oki	9	8	3	0.9	0.9	0.3
Sanyo	0	0	2	0.0	0.0	0.2
Seiko Epson	29	12	9	2.8	1.3	1.0
Sharp	12	16	17	1.1	1.8	1.9
Sony	63	59	38	6.0	6.5	4.3
Toshiba	90	105	107	8.5	11.6	12.0

(Continued)

Table 3-3 (Continued)
Each Company's Factory Revenue from Shipments of MOS SRAMs to North America
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
European Companies	38	20	15	3.6	2.2	1.7
GEC Plessey	0	2	0	0.0	0.2	0.0
Matra MHS	2	3	2	0.2	0.3	0.2
MEDL	4	0	0	0.4	0.0	0.0
Philips	0	1	1	0.0	0.1	0.1
SGS-Thomson	32	14	12	3.0	1.6	1.3
Asia/Pacific Companies	123	79	47	11.7	8.7	5.3
Goldstar	2	0	2	0.2	0.0	0.2
Hyundai	21	13	15	2.0	1.4	1.7
Samsung	45	30	28	4.3	3.3	3.1
United Microelectronics	55	36	1	5.2	4.0	0.1
Winbond Electronics	NA	0	1	NA	0.0	0.1

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-4
Each Company's Factory Revenue from Shipments of EPROMs to North America (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	NA	NA	438	NA	NA	100.0
North American Companies	NA	NA	317	NA	NA	72.4
Advanced Micro Devices	NA	NA	83	NA	NA	18.9
Atmel	NA	NA	12	NA	NA	2.7
Catalyst	NA	NA	1	NA	NA	0.2
Cypress Semiconductor	NA	NA	31	NA	NA	7.1
Intel	NA	NA	75	NA	NA	17.1
Microchip Technology	NA	NA	11	NA	NA	2.5
National Semiconductor	NA	NA	32	NA	NA	7.3
Texas Instruments	NA	NA	58	NA	NA	13.2
WaferScale Integration	NA	NA	13	NA	NA	3.0
Other North American Companies	NA	NA	1	NA	NA	0.2
Japanese Companies	NA	NA	67	NA	NA	15.3
Fujitsu	NA	NA	20	NA	NA	4.6
Hitachi	NA	NA	14	NA	NA	3.2
Mitsubishi	NA	NA	10	NA	NA	2.3
NEC	NA	NA	3	NA	NA	0.7
Toshiba	NA	NA	20	NA	NA	4.6
European Companies	NA	NA	54	NA	NA	12.3
Philips	NA	NA	18	NA	NA	4.1
SGS-Thomson	NA	NA	36	NA	NA	8.2

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-5
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to North America (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,041	877	882	100.0	100.0	100.0
North American Companies	709	528	543	68.1	60.2	61.6
Advanced Micro Devices	100	91	90	9.6	10.4	10.2
AT&T	8	8	0	0.8	0.9	0.0
Atmel	27	30	43	2.6	3.4	4.9
Catalyst	8	10	9	0.8	1.1	1.0
Cypress Semiconductor	15	11	31	1.4	1.3	3.5
Gould AMI	21	10	10	2.0	1.1	1.1
Harris	1	1	0	0.1	0.1	0.0
Intel	191	119	150	18.3	13.6	17.0
Int'l Microelectronic Prod.	17	8	6	1.6	0.9	0.7
ITT	0	0	3	0.0	0.0	0.3
Microchip Technology	55	32	14	5.3	3.6	1.6
Motorola	3	2	0	0.3	0.2	0.0
National Semiconductor	43	51	36	4.1	5.8	4.1
SEEQ Technology	31	24	25	3.0	2.7	2.8
Texas Instruments	79	62	64	7.6	7.1	7.3
VLSI Technology	16	0	0	1.5	0.0	0.0
WaferScale Integration	26	25	13	2.5	2.9	1.5
Xicor	53	43	48	5.1	4.9	5.4
Other North American Companies	15	1	1	1.4	0.1	0.1
Japanese Companies	245	240	246	23.5	27.4	27.9
Fujitsu	39	32	25	3.7	3.6	2.8
Hitachi	54	48	55	5.2	5.5	6.2
Matsushita	20	17	12	1.9	1.9	1.4
Mitsubishi	18	12	14	1.7	1.4	1.6
NEC	10	9	10	1.0	1.0	1.1
Oki	3	3	1	0.3	0.3	0.1
Ricoh	1	0	0	0.1	0.0	0.0
Rohm	0	0	2	0.0	0.0	0.2
Sanyo	0	1	0	0.0	0.1	0.0
Sharp	13	15	15	1.2	1.7	1.7
Toshiba	87	103	112	8.4	11.7	12.7

(Continued)

Table 3-5 (Continued)
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to North America
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
European Companies	57	79	63	5.5	9.0	7.1
GEC Plessey	0	1	0	0.0	0.1	0.0
Philips	21	37	19	2.0	4.2	2.2
Plessey	1	0	0	0.1	0.0	0.0
SGS-Thomson	35	41	44	3.4	4.7	5.0
Asia/Pacific Companies	30	30	30	2.9	3.4	3.4
Goldstar	2	0	0	0.2	0.0	0.0
Hyundai	0	7	6	0.0	0.8	0.7
Macronix	21	4	4	2.0	0.5	0.5
Samsung	7	18	19	0.7	2.1	2.2
Winbond Electronics	NA	1	1	NA	0.1	0.1

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-6
Each Company's Factory Revenue from Shipments of Other MOS Memory to North America (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	78	116	138	100.0	100.0	100.0
North American Companies	77	95	120	98.7	81.9	87.0
Advanced Micro Devices	2	9	12	2.6	7.8	8.7
Cypress Semiconductor	18	16	16	23.1	13.8	11.6
Dallas Semiconductor	8	12	13	10.3	10.3	9.4
Harris	3	3	5	3.8	2.6	3.6
Integrated Device Technology	37	47	62	47.4	40.5	44.9
MOSel	2	6	6	2.6	5.2	4.3
NCR	6	2	1	7.7	1.7	0.7
Other North American Companies	1	0	5	1.3	0.0	3.6
Japanese Companies	1	1	1	1.3	0.9	0.7
Sharp	1	1	1	1.3	0.9	0.7
European Companies	0	20	17	0.0	17.2	12.3
SGS-Thomson	0	20	16	0.0	17.2	11.6
Siemens	0	0	1	0.0	0.0	0.7

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 3-7
Each Company's Factory Revenue from Shipments of Bipolar Memory to North America (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	180	160	131	100.0	100.0	100.0
North American Companies	94	73	52	52.2	45.6	39.7
Advanced Micro Devices	47	36	26	26.1	22.5	19.8
Harris	0	5	2	0.0	3.1	1.5
Integrated Device Technology	0	0	2	0.0	0.0	1.5
Motorola	3	3	2	1.7	1.9	1.5
National Semiconductor	29	11	6	16.1	6.9	4.6
Raytheon	11	14	8	6.1	8.8	6.1
Texas Instruments	4	4	1	2.2	2.5	0.8
Other North American Companies	0	0	5	0.0	0.0	3.8
Japanese Companies	59	60	60	32.8	37.5	45.8
Fujitsu	41	43	39	22.8	26.9	29.8
Hitachi	17	16	20	9.4	10.0	15.3
NEC	1	1	1	0.6	0.6	0.8
European Companies	27	27	19	15.0	16.9	14.5
Philips	27	27	19	15.0	16.9	14.5

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-1
Each Company's Factory Revenue from Shipments of MOS Memory to Japan
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	5,629	4,196	4,228	100.0	100.0	100.0
North American Companies	421	406	470	7.5	9.7	11.1
Advanced Micro Devices	41	47	58	0.7	1.1	1.4
Atmel	3	3	7	0.1	0.1	0.2
Catalyst	10	9	13	0.2	0.2	0.3
Cypress Semiconductor	7	8	8	0.1	0.2	0.2
Dallas Semiconductor	1	1	0	0.0	0.0	0.0
Gould AMI	1	1	1	0.0	0.0	0.0
Harris	8	7	1	0.1	0.2	0.0
Integrated Device Technology	10	12	3	0.2	0.3	0.1
Intel	45	30	37	0.8	0.7	0.9
Microchip Technology	8	3	19	0.1	0.1	0.4
Micron Technology	2	2	16	0.0	0.0	0.4
MOSel	1	9	25	0.0	0.2	0.6
Motorola	98	103	91	1.7	2.5	2.2
National Semiconductor	4	3	4	0.1	0.1	0.1
Performance Semiconductor	1	0	0	0.0	0.0	0.0
SEEQ Technology	3	3	3	0.1	0.1	0.1
Texas Instruments	163	152	162	2.9	3.6	3.8
Vitelic	3	2	5	0.1	0.0	0.1
WaferScale Integration	0	0	3	0.0	0.0	0.1
Xicor	8	5	13	0.1	0.1	0.3
Other North American Companies	4	6	1	0.1	0.1	0.0
Japanese Companies	5,131	3,694	3,621	91.2	88.0	85.6
Fujitsu	750	546	577	13.3	13.0	13.6
Hitachi	768	689	719	13.6	16.4	17.0
Matsushita	221	154	147	3.9	3.7	3.5
Mitsubishi	604	366	290	10.7	8.7	6.9
NEC	847	664	667	15.0	15.8	15.8
NMB Semiconductor	24	16	8	0.4	0.4	0.2
Oki	156	126	129	2.8	3.0	3.1
Ricoh	25	26	8	0.4	0.6	0.2
Rohm	5	11	18	0.1	0.3	0.4
Sanyo	108	69	59	1.9	1.6	1.4
Seiko Epson	108	43	24	1.9	1.0	0.6
Sharp	335	353	376	6.0	8.4	8.9
Sony	122	109	110	2.2	2.6	2.6
Toshiba	656	522	487	11.7	12.4	11.5

(Continued)

Table 4-1 (Continued)
Each Company's Factory Revenue from Shipments of MOS Memory to Japan
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Yamaha	0	0	2	0.0	0.0	0.0
Other Japanese Companies	402	0	0	7.1	0.0	0.0
European Companies	17	23	27	0.3	0.5	0.6
Matra MHS	1	1	0	0.0	0.0	0.0
Philips	13	7	5	0.2	0.2	0.1
SGS-Thomson	3	15	22	0.1	0.4	0.5
Asia/Pacific Companies	60	73	110	1.1	1.7	2.6
Goldstar	3	14	20	0.1	0.3	0.5
Hyundai	3	2	5	0.1	0.0	0.1
Macronix	8	1	6	0.1	0.0	0.1
Samsung	46	55	73	0.8	1.3	1.7
United Microelectronics	0	0	5	0.0	0.0	0.1
Winbond Electronics	NA	1	1	NA	0.0	0.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-2
Each Company's Factory Revenue from Shipments of MOS DRAMs to Japan
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	2,893	1,992	1,948	100.0	100.0	100.0
North American Companies	220	216	235	7.6	10.8	12.1
Micron Technology	2	2	15	0.1	0.1	0.8
MOSel	0	0	13	0.0	0.0	0.7
Motorola	77	75	72	2.7	3.8	3.7
Texas Instruments	138	137	130	4.8	6.9	6.7
Vitelic	3	2	5	0.1	0.1	0.3
Japanese Companies	2,635	1,733	1,663	91.1	87.0	85.4
Fujitsu	491	325	321	17.0	16.3	16.5
Hitachi	388	322	325	13.4	16.2	16.7
Matsushita	127	81	80	4.4	4.1	4.1
Mitsubishi	313	177	147	10.8	8.9	7.5
NEC	437	298	295	15.1	15.0	15.1
NMB Semiconductor	24	16	8	0.8	0.8	0.4
Oki	131	102	102	4.5	5.1	5.2
Sanyo	14	15	21	0.5	0.8	1.1
Sharp	65	44	42	2.2	2.2	2.2
Sony	0	3	3	0.0	0.2	0.2
Toshiba	492	350	319	17.0	17.6	16.4
Other Japanese Companies	153	0	0	5.3	0.0	0.0
Asia/Pacific Companies	38	43	50	1.3	2.2	2.6
Goldstar	3	13	9	0.1	0.7	0.5
Hyundai	0	0	2	0.0	0.0	0.1
Samsung	35	30	39	1.2	1.5	2.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-3
Each Company's Factory Revenue from Shipments of MOS SRAMs to Japan (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,545	1,109	1,081	100.0	100.0	100.0
North American Companies	49	60	40	3.2	5.4	3.7
Advanced Micro Devices	8	8	2	0.5	0.7	0.2
Catalyst	1	0	0	0.1	0.0	0.0
Cypress Semiconductor	6	7	7	0.4	0.6	0.6
Harris	6	5	0	0.4	0.5	0.0
Integrated Device Technology	7	9	1	0.5	0.8	0.1
Micron Technology	0	0	1	0.0	0.0	0.1
MOSel	1	3	8	0.1	0.3	0.7
Motorola	19	27	19	1.2	2.4	1.8
Performance Semiconductor	1	0	0	0.1	0.0	0.0
Texas Instruments	0	0	2	0.0	0.0	0.2
Other North American Companies	0	1	0	0.0	0.1	0.0
Japanese Companies	1,484	1,018	995	96.1	91.8	92.0
Fujitsu	165	140	162	10.7	12.6	15.0
Hitachi	250	237	260	16.2	21.4	24.1
Matsushita	25	21	19	1.6	1.9	1.8
Mitsubishi	176	109	69	11.4	9.8	6.4
NEC	158	148	146	10.2	13.3	13.5
Oki	7	6	9	0.5	0.5	0.8
Rohm	5	6	8	0.3	0.5	0.7
Sanyo	72	44	26	4.7	4.0	2.4
Seiko Epson	108	43	24	7.0	3.9	2.2
Sharp	60	72	83	3.9	6.5	7.7
Sony	115	99	100	7.4	8.9	9.3
Toshiba	94	93	89	6.1	8.4	8.2
Other Japanese Companies	249	0	0	16.1	0.0	0.0
European Companies	4	4	2	0.3	0.4	0.2
Matra MHS	1	1	0	0.1	0.1	0.0
Philips	0	2	1	0.0	0.2	0.1
SGS-Thomson	3	1	1	0.2	0.1	0.1

(Continued)

Table 4-3 (Continued)
Each Company's Factory Revenue from Shipments of MOS SRAMs to Japan
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	8	27	44	0.5	2.4	4.1
Goldstar	0	1	11	0.0	0.1	1.0
Hyundai	3	2	3	0.2	0.2	0.3
Samsung	5	23	27	0.3	2.1	2.5
United Microelectronics	0	0	2	0.0	0.0	0.2
Winbond Electronics	NA	1	1	NA	0.1	0.1

NA = Not available

NM = Not meaningful

Source: Dataquest (July 1992)

Table 4-4
Each Company's Factory Revenue from Shipments of MOS EPROMs to Japan (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	NA	NA	414	NA	NA	100.0
North American Companies	NA	NA	134	NA	NA	32.4
Advanced Micro Devices	NA	NA	53	NA	NA	12.8
Atmel	NA	NA	6	NA	NA	1.4
Intel	NA	NA	31	NA	NA	7.5
Microchip Technology	NA	NA	10	NA	NA	2.4
National Semiconductor	NA	NA	3	NA	NA	0.7
Texas Instruments	NA	NA	27	NA	NA	6.5
WaferScale Integration	NA	NA	3	NA	NA	0.7
Other North American Companies	NA	NA	1	NA	NA	0.2
Japanese Companies	NA	NA	260	NA	NA	62.8
Fujitsu	NA	NA	54	NA	NA	13.0
Hitachi	NA	NA	34	NA	NA	8.2
Mitsubishi	NA	NA	53	NA	NA	12.8
NEC	NA	NA	72	NA	NA	17.4
Oki	NA	NA	3	NA	NA	0.7
Sharp	NA	NA	3	NA	NA	0.7
Toshiba	NA	NA	41	NA	NA	9.9
European Companies	NA	NA	20	NA	NA	4.8
Philips	NA	NA	4	NA	NA	1.0
SGS-Thomson	NA	NA	16	NA	NA	3.9

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-5
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Japan (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,184	1,080	1,181	100.0	100.0	100.0
North American Companies	145	116	185	12.2	10.7	15.7
Advanced Micro Devices	33	38	54	2.8	3.5	4.6
Atmel	3	3	7	0.3	0.3	0.6
Catalyst	9	9	13	0.8	0.8	1.1
Gould AMI	1	1	1	0.1	0.1	0.1
Intel	45	30	37	3.8	2.8	3.1
Microchip Technology	8	3	19	0.7	0.3	1.6
Motorola	2	1	0	0.2	0.1	0.0
National Semiconductor	4	3	4	0.3	0.3	0.3
SEEQ Technology	3	3	3	0.3	0.3	0.3
Texas Instruments	25	15	30	2.1	1.4	2.5
WaferScale Integration	0	0	3	0.0	0.0	0.3
Xicor	8	5	13	0.7	0.5	1.1
Other North American Companies	4	5	1	0.3	0.5	0.1
Japanese Companies	1,012	943	958	85.5	87.3	81.1
Fujitsu	94	81	94	7.9	7.5	8.0
Hitachi	130	130	134	11.0	12.0	11.3
Matsushita	69	52	48	5.8	4.8	4.1
Mitsubishi	115	80	74	9.7	7.4	6.3
NEC	252	218	226	21.3	20.2	19.1
Oki	18	18	18	1.5	1.7	1.5
Ricoh	25	26	8	2.1	2.4	0.7
Rohm	0	5	10	0.0	0.5	0.8
Sanyo	22	10	7	1.9	0.9	0.6
Sharp	210	237	251	17.7	21.9	21.3
Sony	7	7	7	0.6	0.6	0.6
Toshiba	70	79	79	5.9	7.3	6.7
Yamaha	0	0	2	0.0	0.0	0.2
European Companies	13	18	22	1.1	1.7	1.9
Philips	13	5	4	1.1	0.5	0.3
SGS-Thomson	0	13	18	0.0	1.2	1.5

(Continued)

Table 4-5 (Continued)
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Japan
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	14	3	16	1.2	0.3	1.4
Macronix	8	1	6	0.7	0.1	0.5
Samsung	6	2	7	0.5	0.2	0.6
United Microelectronics	0	0	3	0.0	0.0	0.3

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-6
Each Company's Factory Revenue from Shipments of Other MOS Memory to Japan (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	7	15	18	100.0	100.0	100.0
North American Companies	7	14	10	100.0	93.3	55.6
Advanced Micro Devices	0	1	2	0.0	6.7	11.1
Cypress Semiconductor	1	1	1	14.3	6.7	5.6
Dallas Semiconductor	1	1	0	14.3	6.7	0.0
Harris	2	2	1	28.6	13.3	5.6
Integrated Device Technology	3	3	2	42.9	20.0	11.1
MOSel	0	6	4	0.0	40.0	22.2
Japanese Companies	0	0	5	0.0	0.0	27.8
Sanyo	0	0	5	0.0	0.0	27.8
European Companies	0	1	3	0.0	6.7	16.7
SGS-Thomson	0	1	3	0.0	6.7	16.7

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 4-7
Each Company's Factory Revenue from Shipments of Bipolar Memory to Japan (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	191	194	165	100.0	100.0	100.0
North American Companies	20	15	7	10.5	7.7	4.2
Advanced Micro Devices	9	5	3	4.7	2.6	1.8
Motorola	1	0	0	0.5	0.0	0.0
National Semiconductor	6	6	3	3.1	3.1	1.8
Texas Instruments	4	4	1	2.1	2.1	0.6
Japanese Companies	169	178	157	88.5	91.8	95.2
Fujitsu	87	94	71	45.5	48.5	43.0
Hitachi	68	71	73	35.6	36.6	44.2
NEC	14	13	13	7.3	6.7	7.9
European Companies	2	1	1	1.0	0.5	0.6
Philips	2	1	1	1.0	0.5	0.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-1
Each Company's Factory Revenue from Shipments of MOS Memory to Europe
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	2,417	2,050	2,129	100.0	100.0	100.0
North American Companies	687	591	621	28.4	28.8	29.2
Advanced Micro Devices	71	61	61	2.9	3.0	2.9
AT&T	0	0	1	0.0	0.0	0.0
Atmel	10	12	20	0.4	0.6	0.9
Catalyst	6	8	8	0.2	0.4	0.4
Cypress Semiconductor	21	28	26	0.9	1.4	1.2
Dallas Semiconductor	1	1	4	0.0	0.0	0.2
Gould AMI	1	1	0	0.0	0.0	0.0
Harris	1	3	5	0.0	0.1	0.2
Integrated Device Technology	24	18	22	1.0	0.9	1.0
Intel	102	84	93	4.2	4.1	4.4
ITT	9	0	5	0.4	0.0	0.2
Microchip Technology	6	4	15	0.2	0.2	0.7
Micron Technology	60	46	45	2.5	2.2	2.1
MOSel	2	2	4	0.1	0.1	0.2
Motorola	60	76	72	2.5	3.7	3.4
National Semiconductor	28	31	27	1.2	1.5	1.3
Performance Semiconductor	1	4	3	0.0	0.2	0.1
SEEQ Technology	6	6	4	0.2	0.3	0.2
Texas Instruments	250	181	171	10.3	8.8	8.0
Vitelic	3	1	4	0.1	0.0	0.2
VLSI Technology	1	3	0	0.0	0.1	0.0
WaferScale Integration	2	2	4	0.1	0.1	0.2
Xicor	22	18	25	0.9	0.9	1.2
Other North American Companies	0	1	2	0.0	0.0	0.1
Japanese Companies	1,040	808	803	43.0	39.4	37.7
Fujitsu	110	87	67	4.6	4.2	3.1
Hitachi	158	140	159	6.5	6.8	7.5
Matsushita	61	46	8	2.5	2.2	0.4
Mitsubishi	97	63	86	4.0	3.1	4.0
NEC	214	164	164	8.9	8.0	7.7
NMB Semiconductor	42	10	5	1.7	0.5	0.2
Oki	45	30	57	1.9	1.5	2.7
Ricoh	1	0	0	0.0	0.0	0.0
Rohm	0	0	3	0.0	0.0	0.1
Sanyo	1	1	8	0.0	0.0	0.4
Seiko Epson	0	0	3	0.0	0.0	0.1

(Continued)

Table 5-1 (Continued)
Each Company's Factory Revenue from Shipments of MOS Memory to Europe
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Sharp	21	22	23	0.9	1.1	1.1
Sony	24	23	21	1.0	1.1	1.0
Toshiba	228	222	199	9.4	10.8	9.3
Other Japanese Companies	38	0	0	1.6	0.0	0.0
European Companies	480	447	417	19.9	21.8	19.6
Eurosil	0	0	1	0.0	0.0	0.0
GEC Plessey	0	5	0	0.0	0.2	0.0
Matra MHS	28	32	32	1.2	1.6	1.5
MEDL	3	0	0	0.1	0.0	0.0
Philips	20	29	26	0.8	1.4	1.2
Plessey	2	0	0	0.1	0.0	0.0
SGS-Thomson	129	143	134	5.3	7.0	6.3
Siemens	298	238	224	12.3	11.6	10.5
Asia/Pacific Companies	210	204	288	8.7	10.0	13.5
Goldstar	4	8	33	0.2	0.4	1.6
Hyundai	19	11	25	0.8	0.5	1.2
Macronix	1	1	0	0.0	0.0	0.0
Samsung	186	184	226	7.7	9.0	10.6
United Microelectronics	0	0	3	0.0	0.0	0.1
Winbond Electronics	NA	0	1	NA	0.0	0.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-2
Each Company's Factory Revenue from Shipments of MOS DRAMs to Europe (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,537	1,155	1,205	100.0	100.0	100.0
North American Companies	282	224	222	18.3	19.4	18.4
Intel	3	5	11	0.2	0.4	0.9
Micron Technology	55	36	35	3.6	3.1	2.9
Motorola	47	61	45	3.1	5.3	3.7
Texas Instruments	175	122	127	11.4	10.6	10.5
Vitelic	2	0	4	0.1	0.0	0.3
Japanese Companies	774	523	517	50.4	45.3	42.9
Fujitsu	72	55	43	4.7	4.8	3.6
Hitachi	111	89	99	7.2	7.7	8.2
Matsushita	61	46	8	4.0	4.0	0.7
Mitsubishi	85	36	57	5.5	3.1	4.7
NEC	152	110	106	9.9	9.5	8.8
NMB Semiconductor	42	10	5	2.7	0.9	0.4
Oki	36	24	55	2.3	2.1	4.6
Sanyo	0	0	7	0.0	0.0	0.6
Sharp	5	4	2	0.3	0.3	0.2
Toshiba	172	149	135	11.2	12.9	11.2
Other Japanese Companies	38	0	0	2.5	0.0	0.0
European Companies	298	238	224	19.4	20.6	18.6
Siemens	298	238	224	19.4	20.6	18.6
Asia/Pacific Companies	183	170	242	11.9	14.7	20.1
Goldstar	4	7	32	0.3	0.6	2.7
Hyundai	9	6	13	0.6	0.5	1.1
Samsung	170	157	197	11.1	13.6	16.3

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-3
Each Company's Factory Revenue from Shipments of MOS SRAMs to Europe (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	354	365	377	100.0	100.0	100.0
North American Companies	68	69	83	19.2	18.9	22.0
Advanced Micro Devices	18	10	2	5.1	2.7	0.5
AT&T	0	0	1	0.0	0.0	0.3
Catalyst	1	1	0	0.3	0.3	0.0
Cypress Semiconductor	12	14	13	3.4	3.8	3.4
Harris	1	3	5	0.3	0.8	1.3
Integrated Device Technology	14	8	9	4.0	2.2	2.4
Intel	0	0	7	0.0	0.0	1.9
Micron Technology	5	10	10	1.4	2.7	2.7
MOSel	1	1	3	0.3	0.3	0.8
Motorola	12	14	26	3.4	3.8	6.9
National Semiconductor	1	1	2	0.3	0.3	0.5
Performance Semiconductor	1	4	3	0.3	1.1	0.8
Vitelic	1	1	0	0.3	0.3	0.0
VLSI Technology	1	2	0	0.3	0.5	0.0
Other North American Companies	0	0	2	0.0	0.0	0.5
Japanese Companies	183	199	200	51.7	54.5	53.1
Fujitsu	19	16	12	5.4	4.4	3.2
Hitachi	36	41	47	10.2	11.2	12.5
Mitsubishi	8	24	22	2.3	6.6	5.8
NEC	51	44	46	14.4	12.1	12.2
Oki	4	3	1	1.1	0.8	0.3
Sanyo	1	1	1	0.3	0.3	0.3
Seiko Epson	0	0	3	0.0	0.0	0.8
Sharp	4	5	8	1.1	1.4	2.1
Sony	24	23	21	6.8	6.3	5.6
Toshiba	36	42	39	10.2	11.5	10.3
European Companies	83	68	58	23.4	18.6	15.4
GEC Plessey	0	2	0	0.0	0.5	0.0
Matra MHS	28	32	32	7.9	8.8	8.5
MEDL	3	0	0	0.8	0.0	0.0
Philips	3	4	3	0.8	1.1	0.8
SGS-Thomson	49	30	23	13.8	8.2	6.1

(Continued)

Table 5-3 (Continued)
Each Company's Factory Revenue from Shipments of MOS SRAMs to Europe
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	20	29	36	5.6	7.9	9.5
Goldstar	0	1	1	0.0	0.3	0.3
Hyundai	10	5	9	2.8	1.4	2.4
Samsung	10	23	22	2.8	6.3	5.8
United Microelectronics	0	0	3	0.0	0.0	0.8
Winbond Electronics	NA	0	1	NA	0.0	0.3

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-4
Each Company's Factory Revenue from Shipments of MOS EPROMs to Europe (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	NA	NA	303	NA	NA	100.0
North American Companies	NA	NA	186	NA	NA	61.4
Advanced Micro Devices	NA	NA	53	NA	NA	17.5
Atmel	NA	NA	6	NA	NA	2.0
Catalyst	NA	NA	1	NA	NA	0.3
Cypress Semiconductor	NA	NA	6	NA	NA	2.0
Intel	NA	NA	55	NA	NA	18.2
Microchip Technology	NA	NA	7	NA	NA	2.3
National Semiconductor	NA	NA	21	NA	NA	6.9
Texas Instruments	NA	NA	33	NA	NA	10.9
WaferScale Integration	NA	NA	4	NA	NA	1.3
Japanese Companies	NA	NA	26	NA	NA	8.6
Fujitsu	NA	NA	9	NA	NA	3.0
Hitachi	NA	NA	4	NA	NA	1.3
Mitsubishi	NA	NA	3	NA	NA	1.0
NEC	NA	NA	4	NA	NA	1.3
Toshiba	NA	NA	6	NA	NA	2.0
European Companies	NA	NA	91	NA	NA	30.0
Philips	NA	NA	17	NA	NA	5.6
SGS-Thomson	NA	NA	74	NA	NA	24.4

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-5
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Europe (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	511	503	512	100.0	100.0	100.0
North American Companies	322	281	289	63.0	55.9	56.4
Advanced Micro Devices	52	50	57	10.2	9.9	11.1
Atmel	10	12	20	2.0	2.4	3.9
Catalyst	5	7	8	1.0	1.4	1.6
Cypress Semiconductor	7	10	6	1.4	2.0	1.2
Gould AMI	1	1	0	0.2	0.2	0.0
Intel	99	79	75	19.4	15.7	14.6
ITT	9	0	5	1.8	0.0	1.0
Microchip Technology	6	4	15	1.2	0.8	2.9
Motorola	1	1	1	0.2	0.2	0.2
National Semiconductor	27	30	25	5.3	6.0	4.9
SEEQ Technology	6	6	4	1.2	1.2	0.8
Texas Instruments	75	59	44	14.7	11.7	8.6
VLSI Technology	0	1	0	0.0	0.2	0.0
WaferScale Integration	2	2	4	0.4	0.4	0.8
Xicor	22	18	25	4.3	3.6	4.9
Other North American Companies	0	1	0	0.0	0.2	0.0
Japanese Companies	83	86	86	16.2	17.1	16.8
Fujitsu	19	16	12	3.7	3.2	2.3
Hitachi	11	10	13	2.2	2.0	2.5
Mitsubishi	4	3	7	0.8	0.6	1.4
NEC	11	10	12	2.2	2.0	2.3
Oki	5	3	1	1.0	0.6	0.2
Ricoh	1	0	0	0.2	0.0	0.0
Rohm	0	0	3	0.0	0.0	0.6
Sharp	12	13	13	2.3	2.6	2.5
Toshiba	20	31	25	3.9	6.2	4.9
European Companies	99	131	127	19.4	26.0	24.8
Eurosil	0	0	1	0.0	0.0	0.2
GEC Plessey	0	3	0	0.0	0.6	0.0
Philips	17	25	23	3.3	5.0	4.5
Plessey	2	0	0	0.4	0.0	0.0
SGS-Thomson	80	103	103	15.7	20.5	20.1

(Continued)

Table 5-5 (Continued)
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Europe
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	7	5	10	1.4	1.0	2.0
Hyundai	0	0	3	0.0	0.0	0.6
Macronix	1	1	0	0.2	0.2	0.0
Samsung	6	4	7	1.2	0.8	1.4

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-6
Each Company's Factory Revenue from Shipments of Other MOS Memory to Europe
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	15	27	35	100.0	100.0	100.0
North American Companies	15	17	27	100.0	63.0	77.1
Advanced Micro Devices	1	1	2	6.7	3.7	5.7
Cypress Semiconductor	2	4	7	13.3	14.8	20.0
Dallas Semiconductor	1	1	4	6.7	3.7	11.4
Integrated Device Technology	10	10	13	66.7	37.0	37.1
MOSel	1	1	1	6.7	3.7	2.9
European Companies	0	10	8	0.0	37.0	22.9
SGS-Thomson	0	10	8	0.0	37.0	22.9

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 5-7
Each Company's Factory Revenue from Shipments of Bipolar Memory to Europe (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	71	55	43	100.0	100.0	100.0
North American Companies	41	31	25	57.7	56.4	58.1
Advanced Micro Devices	27	22	21	38.0	40.0	48.8
Integrated Device Technology	0	0	1	0.0	0.0	2.3
National Semiconductor	13	5	3	18.3	9.1	7.0
Raytheon	1	4	0	1.4	7.3	0.0
Japanese Companies	18	14	10	25.4	25.5	23.3
Fujitsu	6	6	3	8.5	10.9	7.0
Hitachi	6	2	2	8.5	3.6	4.7
NEC	6	6	5	8.5	10.9	11.6
European Companies	12	10	8	16.9	18.2	18.6
Philips	12	10	8	16.9	18.2	18.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-1
Each Company's Factory Revenue from Shipments of MOS Memory to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,587	1,557	1,974	100.0	100.0	100.0
North American Companies	417	402	465	26.3	25.8	23.6
Advanced Micro Devices	21	30	37	1.3	1.9	1.9
Atmel	6	8	7	0.4	0.5	0.4
Catalyst	2	5	2	0.1	0.3	0.1
Cypress Semiconductor	2	2	4	0.1	0.1	0.2
Dallas Semiconductor	0	0	4	0.0	0.0	0.2
Gould AMI	2	2	0	0.1	0.1	0.0
Harris	1	2	0	0.1	0.1	0.0
Integrated Device Technology	5	14	9	0.3	0.9	0.5
Intel	34	52	59	2.1	3.3	3.0
ITT	1	0	2	0.1	0.0	0.1
Microchip Technology	25	21	9	1.6	1.3	0.5
Micron Technology	47	37	53	3.0	2.4	2.7
MOSel	1	7	21	0.1	0.4	1.1
Motorola	58	40	56	3.7	2.6	2.8
NCR	1	1	0	0.1	0.1	0.0
National Semiconductor	32	31	32	2.0	2.0	1.6
Performance Semiconductor	0	1	1	0.0	0.1	0.1
SEEQ Technology	0	0	1	0.0	0.0	0.1
Texas Instruments	145	113	120	9.1	7.3	6.1
Vitelic	30	33	39	1.9	2.1	2.0
WaferScale Integration	0	0	3	0.0	0.0	0.2
Xicor	4	2	5	0.3	0.1	0.3
Other North American Companies	0	1	1	0.0	0.1	0.1
Japanese Companies	596	540	664	37.6	34.7	33.6
Fujitsu	91	87	101	5.7	5.6	5.1
Hitachi	82	75	100	5.2	4.8	5.1
Matsushita	11	11	18	0.7	0.7	0.9
Mitsubishi	95	128	89	6.0	8.2	4.5
NEC	66	56	73	4.2	3.6	3.7
NMB Semiconductor	21	31	24	1.3	2.0	1.2
Oki	29	40	56	1.8	2.6	2.8
Ricoh	1	0	0	0.1	0.0	0.0
Rohm	0	2	5	0.0	0.1	0.3
Sanyo	9	15	13	0.6	1.0	0.7
Seiko Epson	0	0	1	0.0	0.0	0.1
Sharp	28	31	31	1.8	2.0	1.6

(Continued)

Table 6-1 (Continued)
Each Company's Factory Revenue from Shipments of MOS Memory to Asia/Pacific-Rest of World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Sony	6	13	14	0.4	0.8	0.7
Toshiba	62	51	139	3.9	3.3	7.0
Other Japanese Companies	95	0	0	6.0	0.0	0.0
European Companies	71	92	94	4.5	5.9	4.8
Matra MHS	0	1	1	0.0	0.1	0.1
Philips	6	22	24	0.4	1.4	1.2
SGS-Thomson	40	45	45	2.5	2.9	2.3
Siemens	25	24	24	1.6	1.5	1.2
Asia/Pacific Companies	503	523	751	31.7	33.6	38.0
Goldstar	61	51	134	3.8	3.3	6.8
Hualon Microelectronics Corp.	NA	39	27	NA	2.5	1.4
Hyundai	78	57	125	4.9	3.7	6.3
Macronix	1	1	21	0.1	0.1	1.1
Samsung	316	316	358	19.9	20.3	18.1
Silicon Integrated Systems	NA	17	15	NA	1.1	0.8
United Microelectronics	47	30	49	3.0	1.9	2.5
Winbond Electronics	NA	12	22	NA	0.8	1.1

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-2
Each Company's Factory Revenue from Shipments of MOS DRAMs to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	1,074	949	1,228	100.0	100.0	100.0
North American Companies	256	193	231	23.8	20.3	18.8
Intel	7	12	10	0.7	1.3	0.8
Micron Technology	46	31	40	4.3	3.3	3.3
MOSel	0	0	7	0.0	0.0	0.6
Motorola	45	26	41	4.2	2.7	3.3
Texas Instruments	130	94	99	12.1	9.9	8.1
Vitelic	28	30	34	2.6	3.2	2.8
Japanese Companies	437	374	469	40.7	39.4	38.2
Fujitsu	59	56	65	5.5	5.9	5.3
Hitachi	43	40	52	4.0	4.2	4.2
Matsushita	4	4	12	0.4	0.4	1.0
Mitsubishi	83	121	76	7.7	12.8	6.2
NEC	56	46	57	5.2	4.8	4.6
NMB Semiconductor	21	31	24	2.0	3.3	2.0
Oki	24	36	55	2.2	3.8	4.5
Sanyo	0	3	3	0.0	0.3	0.2
Sharp	6	3	3	0.6	0.3	0.2
Toshiba	46	34	122	4.3	3.6	9.9
Other Japanese Companies	95	0	0	8.8	0.0	0.0
European Companies	10	10	14	0.9	1.1	1.1
Siemens	10	10	14	0.9	1.1	1.1
Asia/Pacific Companies	371	372	514	34.5	39.2	41.9
Goldstar	44	42	127	4.1	4.4	10.3
Hyundai	62	46	99	5.8	4.8	8.1
Samsung	265	284	288	24.7	29.9	23.5

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-3
Each Company's Factory Revenue from Shipments of MOS SRAMs to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	219	207	229	100.0	100.0	100.0
North American Companies	26	42	45	11.9	20.3	19.7
Advanced Micro Devices	3	0	0	1.4	0.0	0.0
Cypress Semiconductor	2	2	4	0.9	1.0	1.7
Harris	1	2	0	0.5	1.0	0.0
Integrated Device Technology	4	13	3	1.8	6.3	1.3
Micron Technology	1	6	13	0.5	2.9	5.7
MOSel	1	1	6	0.5	0.5	2.6
Motorola	12	14	12	5.5	6.8	5.2
Performance Semiconductor	0	1	1	0.0	0.5	0.4
Vitelic	2	3	5	0.9	1.4	2.2
Other North American Companies	0	0	1	0.0	0.0	0.4
Japanese Companies	80	88	103	36.5	42.5	45.0
Fujitsu	20	20	22	9.1	9.7	9.6
Hitachi	24	22	30	11.0	10.6	13.1
Matsushita	0	1	1	0.0	0.5	0.4
Mitsubishi	8	6	12	3.7	2.9	5.2
NEC	4	5	6	1.8	2.4	2.6
Oki	3	3	1	1.4	1.4	0.4
Rohm	0	1	1	0.0	0.5	0.4
Sanyo	9	10	8	4.1	4.8	3.5
Seiko Epson	0	0	1	0.0	0.0	0.4
Sharp	0	1	1	0.0	0.5	0.4
Sony	6	12	13	2.7	5.8	5.7
Toshiba	6	7	7	2.7	3.4	3.1
European Companies	4	6	7	1.8	2.9	3.1
Matra MHS	0	1	1	0.0	0.5	0.4
Philips	0	1	4	0.0	0.5	1.7
SGS-Thomson	4	4	2	1.8	1.9	0.9

(Continued)

Table 6-3 (Continued)
Each Company's Factory Revenue from Shipments of MOS SRAMs to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	109	71	74	49.8	34.3	32.3
Goldstar	9	4	3	4.1	1.9	1.3
Hualon Microelectronics Corp.	NA	10	10	NA	4.8	4.4
Hyundai	15	10	21	6.8	4.8	9.2
Samsung	40	16	16	18.3	7.7	7.0
Silicon Integrated Systems	NA	2	2	NA	1.0	0.9
United Microelectronics	45	28	16	20.5	13.5	7.0
Winbond Electronics	NA	1	6	NA	0.5	2.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-4
Each Company's Factory Revenue from Shipments of MOS EPROMs to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	NA	NA	203	NA	NA	100.0
North American Companies	NA	NA	137	NA	NA	67.5
Advanced Micro Devices	NA	NA	36	NA	NA	17.7
Atmel	NA	NA	6	NA	NA	3.0
Intel	NA	NA	44	NA	NA	21.7
Microchip Technology	NA	NA	5	NA	NA	2.5
National Semiconductor	NA	NA	25	NA	NA	12.3
Texas Instruments	NA	NA	18	NA	NA	8.9
WaferScale Integration	NA	NA	3	NA	NA	1.5
Japanese Companies	NA	NA	14	NA	NA	6.9
Fujitsu	NA	NA	3	NA	NA	1.5
Hitachi	NA	NA	7	NA	NA	3.4
Mitsubishi	NA	NA	1	NA	NA	0.5
NEC	NA	NA	2	NA	NA	1.0
Toshiba	NA	NA	1	NA	NA	0.5
European Companies	NA	NA	52	NA	NA	25.6
Philips	NA	NA	20	NA	NA	9.9
SGS-Thomson	NA	NA	32	NA	NA	15.8

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-5
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Asia/Pacific-Rest of World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	277	385	496	100.0	100.0	100.0
North American Companies	133	165	178	48.0	42.9	35.9
Advanced Micro Devices	18	30	36	6.5	7.8	7.3
Atmel	6	8	7	2.2	2.1	1.4
Catalyst	2	5	2	0.7	1.3	0.4
Gould AMI	2	2	0	0.7	0.5	0.0
Intel	27	40	49	9.7	10.4	9.9
ITT	1	0	2	0.4	0.0	0.4
Microchip Technology	25	21	9	9.0	5.5	1.8
MOSel	0	6	8	0.0	1.6	1.6
Motorola	1	0	3	0.4	0.0	0.6
National Semiconductor	32	31	32	11.6	8.1	6.5
SEEQ Technology	0	0	1	0.0	0.0	0.2
Texas Instruments	15	19	21	5.4	4.9	4.2
WaferScale Integration	0	0	3	0.0	0.0	0.6
Xicor	4	2	5	1.4	0.5	1.0
Other North American Companies	0	1	0	0.0	0.3	0.0
Japanese Companies	79	78	92	28.5	20.3	18.5
Fujitsu	12	11	14	4.3	2.9	2.8
Hitachi	15	13	18	5.4	3.4	3.6
Matsushita	7	6	5	2.5	1.6	1.0
Mitsubishi	4	1	1	1.4	0.3	0.2
NEC	6	5	10	2.2	1.3	2.0
Oki	2	1	0	0.7	0.3	0.0
Ricoh	1	0	0	0.4	0.0	0.0
Rohm	0	1	4	0.0	0.3	0.8
Sanyo	0	2	2	0.0	0.5	0.4
Sharp	22	27	27	7.9	7.0	5.4
Sony	0	1	1	0.0	0.3	0.2
Toshiba	10	10	10	3.6	2.6	2.0
European Companies	42	62	63	15.2	16.1	12.7
Philips	6	21	20	2.2	5.5	4.0
SGS-Thomson	36	41	43	13.0	10.6	8.7

(Continued)

Table 6-5 (Continued)
Each Company's Factory Revenue from Shipments of MOS Nonvolatile Memory to Asia/Pacific-Rest of World
(Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Asia/Pacific Companies	23	80	163	8.3	20.8	32.9
Goldstar	8	5	4	2.9	1.3	0.8
Hualon Microelectronics Corp.	NA	29	17	NA	7.5	3.4
Hyundai	1	1	5	0.4	0.3	1.0
Macronix	1	1	21	0.4	0.3	4.2
Samsung	11	16	54	4.0	4.2	10.9
Silicon Integrated Systems	NA	15	13	NA	3.9	2.6
United Microelectronics	2	2	33	0.7	0.5	6.7
Winbond Electronics	NA	11	16	NA	2.9	3.2

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-6
Each Company's Factory Revenue from Shipments of Other MOS Memory to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	17	16	21	100.0	100.0	100.0
North American Companies	2	2	11	11.8	12.5	52.4
Advanced Micro Devices	0	0	1	0.0	0.0	4.8
Dallas Semiconductor	0	0	4	0.0	0.0	19.0
Integrated Device Technology	1	1	6	5.9	6.3	28.6
NCR	1	1	0	5.9	6.3	0.0
European Companies	15	14	10	88.2	87.5	47.6
Siemens	15	14	10	88.2	87.5	47.6

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Table 6-7
Each Company's Factory Revenue from Shipments of Bipolar Memory to Asia/Pacific-Rest of World (Millions of U.S. Dollars)

	Revenue			Market Share (%)		
	1989	1990	1991	1989	1990	1991
Total Market	18	22	17	100.0	100.0	100.0
North American Companies	5	7	5	27.8	31.8	29.4
Advanced Micro Devices	2	2	2	11.1	9.1	11.8
Motorola	0	0	1	0.0	0.0	5.9
National Semiconductor	1	3	1	5.6	13.6	5.9
Texas Instruments	2	2	1	11.1	9.1	5.9
Japanese Companies	7	7	4	38.9	31.8	23.5
Fujitsu	1	1	0	5.6	4.5	0.0
Hitachi	6	6	4	33.3	27.3	23.5
European Companies	6	8	8	33.3	36.4	47.1
Philips	6	7	8	33.3	31.8	47.1
SGS-Thomson	0	1	0	0.0	4.5	0.0

NA = Not available
NM = Not meaningful
Source: Dataquest (July 1992)

Dataquest

Dataquest Research and Sales Offices:

Dataquest Incorporated
1290 Ridder Park Drive
San Jose, California 95131-2398
United States
Phone: 01-408-437-8000
Facsimile: 01-408-437-0292

Dataquest Incorporated
Dataquest/Ledgeway
550 Cochituate Road
Framingham, Massachusetts 01701-9324
United States
Phone: 01-508-370-5555
Facsimile: 01-508-370-6262

Dataquest Incorporated Invitational
Computer Conferences Division
3151 Airway Avenue, C-2
Costa Mesa, California 92626
United States
Phone: 01-714-957-0171
Facsimile: 01-714-957-0903

Dataquest Australia
Suite 1, Century Plaza
80 Berry Street
North Sydney, NSW 2060
Australia
Phone: 61-2-959-4544
Facsimile: 61-2-929-0635

Dataquest Europe Limited
Roussel House, Broadwater Park
Denham, Uxbridge
Middlesex UB9 5HP
England
Phone: 44-895-835050
Facsimile: 44-895-835260/1

Dataquest Europe SA
Tour Galliéni 2
36, avenue du Général-de-Gaulle
93175 Bagnolet Cedex
France
Phone: 33-1-48-97-3100
Facsimile: 33-1-48-97-3400

Dataquest GmbH
Kronstadter Strasse 9
8000 Munich 80
Germany
Phone: 49-89-930-9090
Facsimile: 49-89-930-3277

Dataquest Germany
In der Schneithohl 17
6242 Kronberg 2
Germany
Phone: 49-6173/61685
Facsimile: 49-6173/67901

Dataquest Hong Kong
Rm. 4A01
HKPC Building
78 Tat Chee Avenue
Kowloon, Hong Kong
Phone: 852-788-5432
Facsimile: 852-788-5433

Dataquest Japan Limited
Shinkawa Sanko Building
1-3-17 Shinkawa, Chuo-ku
Tokyo, 104
Japan
Phone: 81-3-5566-0411
Facsimile: 81-3-5566-0425

Dataquest Korea
Daeheung Building 1105
648-23 Yeoksam-dong
Kangnam-gu
Seoul 135-080, Korea
Phone: 82-2-556-4166
Facsimile: 82-2-552-2661

Dataquest Singapore
4012 Ang Mo Kio Industrial Park 1
Ave. 10, #03-10 to #03-12
Singapore 2056
Phone: 65-4597181
Telex: 38257
Facsimile: 65-4563129

Dataquest Taiwan
Room 801/8th Floor
Ever Spring Building
147, Sec. 2, Chien Kuo N. Rd.
Taipei, Taiwan R.O.C. 104
Phone: 886-2-501-7960
886-2-501-5592
Facsimile: 886-2-505-4265

Dataquest Thailand
300/31 Rachdapisek Road
Bangkok 10310
Thailand
Phone: 66-2-275-1904/5
66-2-277-8850
Facsimile: 66-2-275-7005

0012973

Memories Worldwide

User Wants and Needs

Memories *Worldwide*
MMRY-SEG-UW-9201
December 28, 1992

Dataquest®

Memories Worldwide

User Wants and Needs

Published by Dataquest Incorporated

December 1992
0014238

Table of Contents

List of Figures

List of Figures (Continued)

List of Figures (Continued)

List of Tables

Chapter 1
Executive Summary

This report is a snapshot of North American static RAM (SRAM) usage during the year 1992. Through the efforts of numerous interviewers, analysts, and with the help of SRAM manufacturers and users, Dataquest has compiled a list of applications of SRAMs that draws trends out of each application and helps improve understanding of the issues used to determine which SRAM is to be used.

Some of the broader trends to emerge from this survey are as follows:

- Most designs are expected to use the same device next year as used this year.
- Of those companies planning to upgrade the device they use, the majority plan to upgrade to the next higher density above the density they currently purchase.
- The plastic dual-in-line package is still preferred by a majority of companies. However, it is not preferred in the highest volume applications.
- The 256Kb density is preferred by a majority of companies, followed by both the 64Kb and 1Mb devices, which are on nearly equal footing.

Chapter 2
Methodology

A three-pronged approach was used in the compilation of this report. First, SRAM manufacturers were interviewed about the major North American applications of SRAMs from their own viewpoint. Many contributed names of major users, device preferences, and estimated usage. Second, Dataquest interviewed by telephone more than 200 SRAM buyers, and asked about their end applications, speed and density usage, package preferences, and projections of future usage. Last, the resultant data were taken back to certain SRAM manufacturers for a "sanity" check.

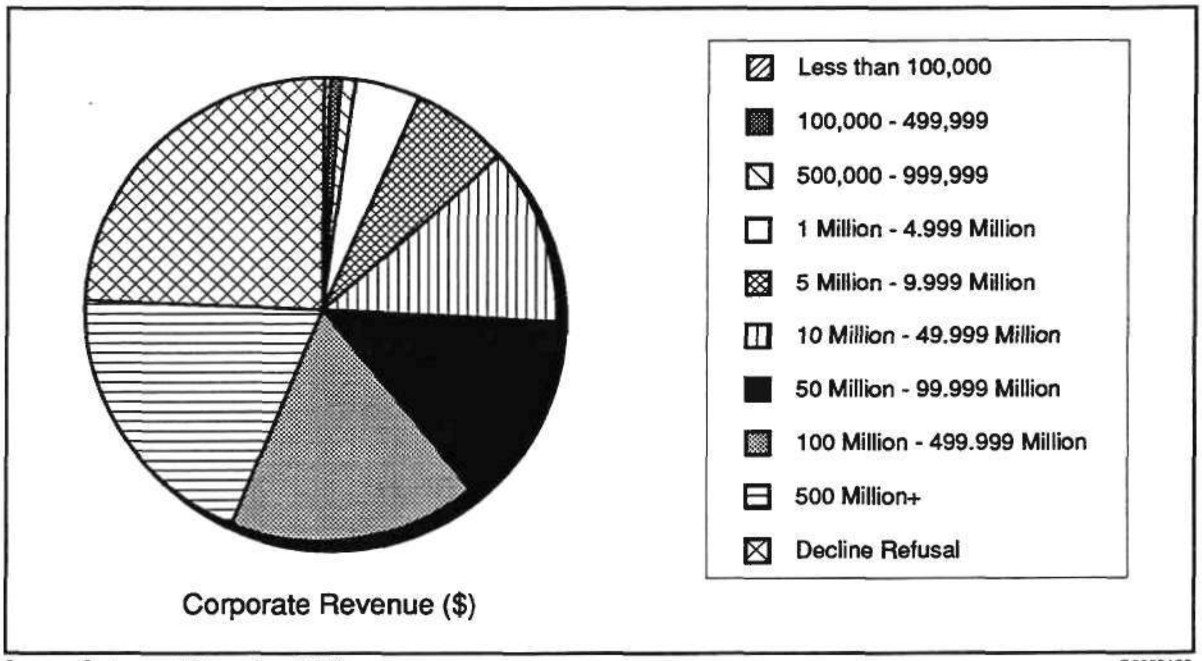
A statistical rather than rigorous approach was followed in the user telephone interviews. With certain exceptions, each respondent was asked to answer only about the single application that used the most significant dollar amount of SRAMs, and then was asked only to answer about the most significant SRAM used in the design. Although this approach probably caused us to overlook several applications going on in the same facility at the same time, or to overlook different types of SRAMs that would be used together in a specific application, it allowed us to garner a wider variety of users, because long questionnaires are patently unpopular. This approach gave us a sampling that we believe is statistically significant.

Exceptions were made when dealing with multidivisional companies that used corporate procurement offices, offices that procured all SRAMs for all projects from a single office. These companies were questioned about their five most significant SRAM uses, and all of the SRAMs used in these applications.

Where appropriate, information from other groups within Dataquest is presented to show the growth or decline of the end markets for each application examined.

Figure 2-1 shows corporate revenue of the respondents. Figure 2-2 shows employee head counts. The average company surveyed had an employee head count of about 550 and average annual revenue of about $150 million.

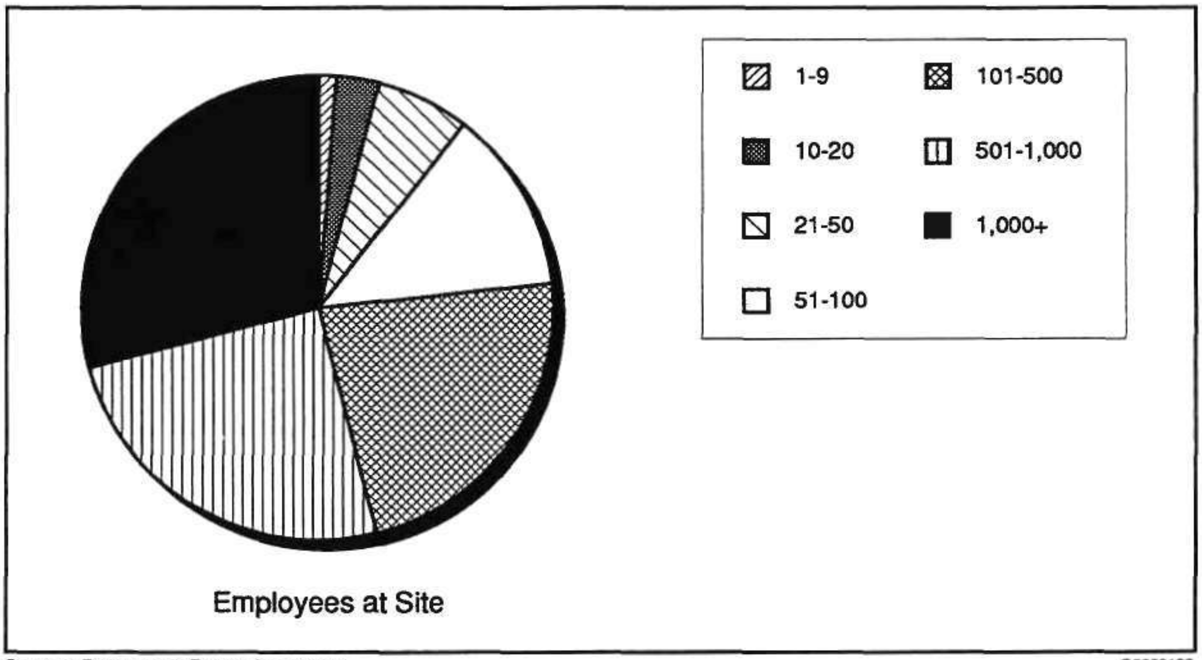
Figure 2-1
Revenue of Responding Corporations



Source: Dataquest (December 1992)

G2003128

Figure 2-2
Number of Employees at This Location



Source: Dataquest (December 1992)

G2003129

Chapter 3
Applications Types

After discussions with several manufacturers of SRAMs, and based upon data resident within Dataquest, the survey was written to focus on a list of nine major applications groups: audio/visual, consumer electronics, data processing (including everything from palmtop computers through corporate mainframes), instrumentation and test, military and aerospace electronics, office equipment (not including personal computers and telecommunications equipment), hand-held devices that do not fit within any of the other categories mentioned in this list, industrial control and monitoring, and telecommunications equipment.

Each major category was broken into subcategories wherever appropriate, and in some cases, these subcategories were broken into further groups. As an example, data processing contains a subcategory of computers and PCs. Applications that fall into these categories include register storage, caches of all types, and main memory in certain designs. Figure 3-1 shows the percent of responses received in each top-level applications category.

The categories listed nearly correlate to the six standard semiconductor markets used in Dataquest's electronic equipment production as reported by Dataquest's Semiconductor Applications and Markets (SAM) group in its *MarketTrends: Electronic Equipment* (publication number SAWW-SVC-MT-9201). These markets are: data processing, communication, industrial, consumer, military/aerospace, and transportation. Forecasts for these markets are in Figure 3-2, and can be used with the data in the following sections to help to forecast trends for distinct devices.

In Dataquest's *1993 Semiconductor Procurement Insights User Wants and Needs* report (publication number SPWW-SVC-UW-9202), a different list of applications was surveyed and asked to rank their SRAM purchases as a percent of their overall MOS purchases for 1992. Applications investigated in this survey were: personal computers, other data processing, premise communications, public telecommunications, instrumentation and test, consumer and automotive, and military/aerospace. Figure 3-3 shows an overview of all responses; these data will be broken out into a more readable form in each of the following sections.

Automotive, Consumer

The weakest response to the survey came from the automotive and consumer electronics sector. This comes as little surprise, because there is not much North American activity in the consumer electronics sector and because automotive electronics currently use SRAM only as a fraction of an existing (controller) semiconductor device. The North American region does not compete well in the consumer global market, and has let the predominant portion of it fall into the hands of Japan and the Asia/Pacific countries.

Of the few respondents who replied that they were involved in consumer electronics, device preferences centered mostly around slow 256Kb SRAMs (see Figure 3-4). There was also limited interest in 4Mb devices, although unit volume purchases were almost nonexistent.

SRAMs do not compete well in North American consumer and automotive applications for overall MOS dollar expenditure levels (see Figure 3-5). According to the *Semiconductor Buyer Perceptions* survey, 40 percent of combined automotive and consumer respondents answered that they would purchase from zero to 9 percent of their MOS budget in SRAM, and another 40 percent put their expenditure at 10 to 19 percent. The remainder placed their percentage at 90 percent and above, a figure that probably reflects the disparity in the markets served by different sorts of equipment (that is, engine controllers versus video games).

Further illustration of this can be found in Figure 3-6, which is a forecast of the cost of the electronics (including audio electronics) of the average U.S.-built vehicle from 1989 to 1996. In the narrow price band Dataquest has forecast, there is little room to design less-integrated systems around costly, and possibly nonessential devices such as SRAMs.

One interesting twist is that our survey uncovered a less-known market to SRAM manufacturers, one we will call "audio/visual." Typical respondents manufacture specialized digital audio processing equipment and imaging processors for broadcast television. Density preferences in this group, which are shown in Figure 3-7, are spotty, with interviewees answering to a widespread usage of 16Kb, 256Kb, and 4Mb devices (the last being used in prototype quantities to date). Widest usage is of the 32Kx8 at 100ns in plastic DIP, averaging 13,000 units per year per purchasing organization.

Data Processing

The data processing category has been broken into two levels of subcategories because of the widespread use of SRAMs in every aspect of data processing, including main memories, modem boards, LAN controllers, CPU caches, hard disks, terminals, and many other related devices. The largest volume (58 percent) of responses came from the computers and PCs section of the market, with I/O devices following at 38 percent (see Figure 3-8). Less than 4 percent of the responses came from manufacturers that claimed that their major application of SRAMs was in any other category. This seems a bit peculiar in light of the expected growth of the laptop and notebook computer areas (see Figure 3-9), but is probably more because of a lack of widespread use of SRAMs in these applications.

Figure 3-9 is an updated version of a figure used in a December 23, 1991 article entitled "On the Verge of 3 Volts" in the Semiconductors Worldwide: Products, Markets, and Technologies *Dataquest Perspective,* Vol. 1, No. 5. Certain pundits believe that power consumption can be reduced in battery-operated PCs through the addition of cache memories, but the verdict has not yet been returned on this question. It appears that few PC designers attempt to use cache memories as a power-saving device.

Before delving into the details, we will take a top-level look at the data processing market. All five of the most widespread SRAMs are represented by one respondent or another to be the most important density (from an expenditure perspective) in use at their facility. Naturally, the 4Mb and 16Kb densities garnered the fewest responses, and the 256Kb density took the largest number (see Figure 3-10). When we examine the market more closely, though, we see that the use of denser devices parallels the use of slower access times, and vice versa.

Table 3-1 scales to the overall size of the worldwide total available market for SRAMs. The numbers in this table are derived from data from Dataquest's Computer and Peripheral Systems group. Shifts in this market, and in the PC and personal workstation market, are shown in Figures 3-11 and 3-12.

Figure 3-13 shows SRAM as a percent of overall MOS purchases in a piece of data processing equipment. It is interesting to note that, while all other data processing responses are strikingly divided, all of the PC manufacturers polled placed their SRAM purchases at 10 to 19 percent of their overall board purchases. This meshes well with the fact that a typical cache in a 486-based PC is implemented using $10 to $25 worth of SRAM, while the CPU is priced at about $100 to $200. The split in the "other data processing" category between 39 percent and 60 percent of system cost most probably results in the breadth of this category, which includes workstations and computers on one end, and keyboards and I/O cards on the other.

Figure 3-14 shows the number of respondents whose major end use of SRAMs fell into one of a number of subcategories in the data processing category. The largest number of responses (39 percent) was by manufacturers of desktop PCs, whose major application for SRAMs was as a cache in those PCs. This was followed by an equal number of responses (14 percent) by manufacturers using SRAM as cache in workstations and minicomputers, or as main memory in deskside computers. About half as many said that caches in laptop computers or mainframe computers were their major SRAM application, and the remainder used SRAM in writable control stores (a dying field) or other data processing applications.

For PC caches, a surprisingly large number of respondents still use 16Kb devices, yet the 256Kb and 1Mb densities dominate this market (see Figure 3-15). Usage of the 16Kb devices was reported to consist solely of 4Kx4-bit organizations in relatively low volumes, leading us to believe that the response represents only the use of 4Kx4 cache-tags, along with a possibility that the users of these devices are paying more per system for these narrowly sourced devices than they are for the cache data SRAMs, a plausible scenario given the last year's price drops for 64Kb and 256Kb SRAMs. Although 4Mb densities were reported by a segment of the respondents, unit volumes were low enough to support only prototype quantities.

Workstation caches reported a more balanced mix of 16Kb and 64Kb devices (see Figure 3-16), with the 256Kb totally missing from the sample (as the most important SRAM purchased for the application) and 1Mb and 4Mb devices consuming the lion's share of the responses. We believe that the use of higher-density parts is indicative of the trend of certain workstation manufacturers to try to pack the most wallop into their machines, while others (for example, Precision Architecture machines) are so hell-bent for speed that issues of SRAM density fade in comparison. On the other side of the argument, 1Mb SRAMs are used by some respondents in more modest speeds, but in relatively high volumes averaging 63,000 units per year. Once again, the 4Mb density is used only in prototype quantities by the respondents questioned.

Minicomputer caches accounted for a nearly equivalent portion of the survey as did workstation caches, but showed less divided results (see Figure 3-17). No 4Mb usage was revealed, while equivalent 1Mb and 16Kb responses were given to Dataquest. The largest two sectors are the equal number of respondents who said they used SRAMs of 64Kb and 256Kb densities, the two densities that made up the majority of parts purchased by a wide margin.

Mainframe computer manufacturers (see Figure 3-18) are a horse of a different color. One-third of our respondents use 256Kb SRAMs, one-third use 1Mb devices, and the last third use 4Mb devices. This proportion stands to reason, because leading-edge SRAM suppliers compete to be the first to supply the 4Mb SRAM to certain supercomputer manufacturers. Still, unit volume implies that, of those who would disclose their volume usage to Dataquest, the 256Kb makes up about 90 percent of all units used in this application.

The last computer type for which significant information was gained was deskside computers that use SRAM for their main memory. It comes as no surprise that the least expensive high-speed SRAMs, from a price-per-bit viewpoint, were used in the majority of the applications. Figure 3-19 shows that 256Kb SRAMs were the choice of the overwhelming majority of respondents, while the 1Mb and 16Kb devices were the only others to be given as choices for this application. The vast majority of units used in this application comprise slower 32Kx8s.

Of the respondents in the data processing category who stated that their major SRAM application was in I/O devices, the number of responses does not closely correlate to the volume usage of SRAMs in the design categories (see Figure 3-20). One important application, disk drive caches, elicited relatively few responses, even though it accounts for an important part of the North American SRAM market. For this reason, the discussion will detail points not immediately obvious from the graphics.

Figure 3-21 shows Dataquest's worldwide disk drive production unit forecast, as reported by Dataquest's Computer and Peripheral Systems group. This market is the epitome of the global industry, where design and limited manufacture is performed in first-world nations, with the majority of production happening in developing countries such as Thailand and Singapore. As a result, the location of buys is variable, but is most often outside of North America, even though the majority of businesses are headquartered in the United States. Because this survey only covers North American purchases, volumes are deceptively low. The trends in Figure 3-21 show that rapid growth is occurring in 3.5-, 2.5-, and 1.8-inch disk drives. Caches in these drives serve two purposes: If used with a desktop computer, or other computer with unlimited power availability, the SRAM disk drive cache is simply used to improve apparent latency. If a cached disk drive is used in a limited (battery)-power application, the disk is powered down when not in use, and the cache serves to allow the disk not to power up in about 30 percent of the attempted accesses by the computer.

Popular densities for disk drives are 1Mb and 256Kb densities (see Figure 3-22), usually at speeds of 70 to 100ns, and always in 8-bit widths. Surface-mount devices were the exclusive choice of the respondents. This is a fast moving market, and one significant manufacturer claimed to be using more 64Kb devices than 256Kb devices six months before the study was performed, and not to be using any at the time of the study. In this light, and given the fact that at least one disk drive manufacturer now uses DRAMs instead of SRAMs in this application, it would not be surprising to see a rapid abandonment of the 256Kb density in favor of the 1Mb (to occur after this report is published, it is hoped), and an eventual total abandonment of SRAMs in favor of wide-word DRAMs by all disk drive manufacturers.

Page printers that replicate an entire page at one time comprise both laser printers and LED printers. Dataquest's unit production forecast for page printers manufactured in North America is shown in Figure 3-23, a forecast regularly provided to subscribers of Dataquest's Document and Imaging Service. Typical SRAM usage in page printers is for cache memories and tends to follow the device types used in PCs and workstations, because the CPU used in page printers is often similar to those used in PC and workstation applications. It is not unusual for the processing engine used in a page printer to be more powerful than the resources in the PC or workstation that sends the document to the printer.

A surprisingly large number of respondents, slightly less than 25 percent of those who used SRAMs primarily in data processing I/O applications, said that CRT terminals were their most important SRAM application. Worldwide unit production of display terminals is regularly forecast by Dataquest's Computer and Peripheral Systems group, and the current version is shown in Figure 3-24. Dataquest expects the slump encountered in 1991 to be relatively long-lived in this market, and for production not to match 1990 levels until 1995. Both 64Kb and 1Mb devices were popular with many respondents (see Figure 3-25), with 16Kb and 256Kb densities used, but by not as many respondents.

Figure 3-26 shows the network interface card (NIC) unit forecast from Dataquest's Telecommunications service. SRAMs are used as buffers in LAN cards, and as a result do not need to be too large. Typically, only one or two SRAMs are used per card, if any are used at all. Alternatives include first-in/first-out memories (FIFOs) as well as certain lower-performance software techniques.

One-third of the respondents each used 256Kb, 16Kb, and 64Kb SRAMs (see Figure 3-27). Unit volumes ranged from tens of thousands of units to hundreds of thousands for all those densities represented in the chart.

The final data processing I/O market for which this survey attained meaningful results was fax/modems. Figure 3-28 shows that manufacturers of these boards have a preference for 4Mb SRAMs, with one-third expressing a primary need for 256Kb SRAMs. The major quantities used were the 4Mb device. However, because of a large percentage of nonresponses to the question of organization, Dataquest is led to believe that the main organization used in this application is the 512Kx8 pseudo-SRAM.

A large percentage of the respondents (25 percent) answered that they had major data processing I/O SRAM applications that fit into none of the listed categories. Although we tried to find a way to group some of these responses into a new category, they were too far-flung to allow us to accomplish this task.

Instrumentation and Test, and Industrial Control and Monitoring

Figure 3-29 is a detail from Figure 3-3 in Dataquest's *Semiconductor Procurement Insights* survey. For the instrumentation and test market and the industrial control and monitoring market, interviewees were asked what percentage of their overall MOS dollar purchases comprised SRAM. Generally, the instrumentation and test field broke into two categories: those with SRAM purchases accounting for less than 30 percent of their overall MOS purchases (about 70 percent) and those with SRAM purchases accounting for 50 percent or more of their MOS purchases (the other 30 percent). Industrial control and monitoring equipment manufacturers offered a spread of responses, covering the entire range of zero to 100 percent, with a surprisingly large number responding that SRAM accounted for 90 to 100 percent of their overall MOS purchases. This could imply that SRAMs are used in industrial control and monitoring applications with non-MOS devices, with boards rather than with discrete MOS semiconductors.

Focusing first on the instrumentation and test applications, we see that the respondents were somewhat evenly divided in their use of 64K, 256Kb, and 1Mb devices, with a small portion using 16Kb SRAMs (see Figure 3-30). Volume usage of the 16Kb is significantly lower than this figure indicates, and volumes for the other densities were generally lower than for other markets, with few respondents answering that their annual unit volume was in the hundreds of thousands. Speed usage for these manufacturers is widespread, but nearly all said they use either an x1 or x8 organization. We found little use of 4-bit-wide parts in this market. Similarly, strong preferences appeared for DIPs and SOJ/SOIC packages. Few respondents used anything else.

The profile of the instrumentation and test respondents is shown in Figure 3-31. The strongest showing was in medical instrumentation, which is a broad field, but does not account for a major portion of overall unit sales. Second was the "other" category, in which the responses showed absolutely no overlap.

Respondents who said that their main SRAM application was digital storage oscilloscopes (DSO) or logic analyzers mainly used very fast 256Kb and 1Mb devices, with an element using a small quantity of ECL I/O 16Kb synchronous SRAMs (see Figure 3-32).

Figure 3-33 shows density preferences of those whose major SRAM application was in battery-operated instruments. Virtues often sought in these applications are wide word width, high integration, small package size, low overall power consumption as measured by low operating current, and low-voltage operation. Half these respondents said that their major expenditure was on 256Kb parts, with 25 percent going to the 1Mb density, and the other quarter to the 64Kb density.

Medical instrumentation manufacturers were more evenly divided in their use of 64Kb, 256Kb, and 1Mb densities, as would be expected given the breadth of this field, and the current point in each of these SRAM densities' life cycles (see Figure 3-34). Medical applications range from battery-operated pulse-rate recorders to sophisticated imaging systems found in ultrasound, NMR, CAT, and PET scanners.

The next three categories—integrated circuit testers, system testers, and global positioning system receivers—elicited responses of insufficient quality to provide useful information about their SRAM usage patterns. There is a growing trend in the fields of IC testers and system testers, however, toward the use of SRAMs with ECL I/O levels in order to support the escalating speed of clocks in today's systems. Global positioning systems are likely to have their SRAM decisions driven by power consumption (especially for battery-operated devices), package size, and cost more than by any other criterion.

Respondents whose main SRAM application was stated to be remote monitoring and measurement equipment were divided two-to-one in their use of SRAMs in 64Kb and 256Kb densities (see Figure 3-35). The lack of responses favoring 1Mb SRAMs probably owes to a shortage of suppliers of 1Mb SRAMs in extended temperature ranges, as well as to the fact that much of this remote monitoring equipment has relatively long qualification periods and life cycles.

In the industrial control and monitoring field, the North American industrial electronics equipment production market is expected to grow to a level about 40 percent larger than its current $35.4 billion level by 1996 (see Figure 3-36). This estimate is generated by Dataquest's Semiconductor Applications and Markets service. SRAM density preferences for respondents who placed themselves in this category were scattered across all available SRAM densities (see Figure 3-37). Average unit volumes were highest for the 256Kb density, at about 20,000 units per year, with other densities selling an average of thousands or hundreds of units per year to any single respondent. Those who responded that their most important SRAM purchases occurred in the 4Mb density used only a smattering of the product, and used only the fully static device, not a pseudo-static version. The vast majority of respondents picked the 8-bit width as their preferred device, with packages centering around SOIC/SOJ and plastic DIP.

Military/Aerospace

Figure 3-38 is the U.S. Department of Defense's projected procurements budget through 1996. This accounts for the vast majority of military/aerospace spending in North America. The radical drop in 1993 spending will probably have resounding repercussions through all supporting industries, and is certain to continue to be felt by the electronics industry well after the $62 billion level is again reached in 1995. Despite reduced North American defense electronics spending, growth in civil aerospace electronics spending will help grow the overall market by more than 10 percent (see Figure 3-39 from Dataquest's Semiconductor Applications and Markets service).

Military and aerospace respondents in the *Semiconductor Procurement Insights* survey predominantly put their SRAM purchases as a percentage of overall MOS in the lower two-thirds category, with 42 percent responding that their SRAM expenditure only made up from zero to 9 percent of their overall MOS expenditure (see Figure 3-40).

Of those who do use SRAMs, the survey found that densities from 64Kb to 4Mb were being used as the major SRAMs, with the predominant number of responses favoring the 64Kb, 256Kb, and 1Mb densities (see Figure 3-41). Average annual volume per respondent for 64Kb devices was 4,000 units, while the 256Kb was at 20,000 and the 1Mb at 13,000. Only a few hundred 4Mb devices were used by all respondents combined, none of these parts being pseudo-SRAMs. Speeds used covered the available spectrum from 15ns to 150ns. Sixty-five percent used 8-bit widths, with the balance evenly split between 4-bit and 1-bit organizations. A surprisingly large 65 percent used commercial plastic packaging.

Applications within the military and aerospace category were split among radar, satellites and satellite support, navigational aids, and other applications that did not overlap into a single sort of application (see Figure 3-42). A limited response was received from sonar manufacturers.

The overwhelming preference of radar manufacturers responding to the survey was for 1Mb SRAMs (see Figure 3-43). 256Kb devices ranked second. The penchant for using higher densities probably owes to the need to manage numerous data points simultaneously in imaging applications such as this.

Navigational equipment is just the opposite, with the lion's share of the responses favoring the 64Kb density (see Figure 3-44). This stands to reason, because the application requires relatively little storage to accomplish its basic task, and the only use for a larger SRAM would be to add discretionary differentiating features such as historical information. As mentioned previously, although a number of respondents named the 4Mb device as the one upon which they spent the most, the unit volumes are tiny.

Satellite manufacturers were the final group of respondents in the military and aerospace category to comprise a sample of significant size. Given that qualification standards are hard to meet for such equipment, it is not surprising to see that the majority of the respondents claimed that 256Kb and 64Kb densities made up the majority of their dollar purchases. Those using 4Mb SRAMs consumed so few as to contribute negligibly to overall sales, despite their strong showing on the chart of responses (see Figure 3-45).

Office Equipment

Relatively few of the respondents gave information about the office equipment market, probably because this market, like consumer electronics, is not heavily supported by North American manufacturers.

Figure 3-46 shows device preferences for those who responded that office equipment was their major SRAM application. All used slow (greater than 100ns) devices in either plastic DIP or PLCC packages. Volumes ranged from tens of thousands of units for 1Mb SRAMs through an average of 2,000 for the 256Kb device, to prototype quantities of the 4Mb device.

Telecommunications

Dataquest's Telecommunications service provided the unit forecast for the U.S. telecommunications market shown in Figure 3-47. The axis on the left shows the number of PBX lines in thousands; all other curves are measured, again in thousands of units, on the right-hand axis. Although unit consumption for major capital equipment is expected to grow considerably, PBX lines are not expected to grow, but to remain around 5.5 million lines over the forecast period.

Figure 3-48 shows responses from the *Semiconductor Procurement Insights* survey regarding SRAM as a percent of all MOS purchases. A word of explanation is warranted here regarding nomenclature. Premise communications devices comprise PBXs and voice/data terminals, while public telecommunications devices comprise T-1 multiplexers, other central office switching equipment, voice messaging systems, and automatic call distributors.

Figure 3-49 shows SRAM preferences of the telecommunications market in general, based upon responses from the *Memory User Wants and Needs* survey. As should be expected, the largest number of responses came from users of 256Kb and 1Mb densities, with a strong showing for the 64Kb density and fewer responses for 16Kb devices. Most of the devices sold were of an 8-bit organization, in either plastic DIP or SOJ/SOIC packages, in volumes averaging about 58,000 units per year. Speed preferences were spread across a wide spectrum. Responses also came in for the 4Mb density, but volumes purchased were low.

The breakout of telecommunications respondents in North America showed a poor turnout from manufacturers of automatic dialers and fax machines, because of the overall lack of North America-based manufacturers of such devices. Figure 3-50 shows a strong response from manufacturers of central office switching systems, followed by manufacturers of voice/data terminals and PBXs. These three markets will be more deeply explored in the following figures.

Figure 3-51 shows SRAM usage of respondents whose major SRAM application is in PBXs. These respondents by and large were users of the 256Kb density, with a good portion going to the 1Mb SRAM, and some purchasing the 4Mb part. As a general rule, SRAM requirements in PBXs are more oriented toward density rather than speed, and this is supported by Figure 3-51.

Central office switching equipment, shown in Figure 3-52, uses SRAMs to store connection information, and in certain state machines and cache memories for the controlling microprocessor or CPU. Small but high-speed memories are the norm in this sort of application. As a result, the survey revealed a number of manufacturers who continued to use the 64Kb density, although the largest number of respondents claimed the 1Mb density as the one that contributed the most to their SRAM dollar purchases. Because this is the main growth market shown in Figure 3-47, it is worth further investigation by SRAM manufacturers.

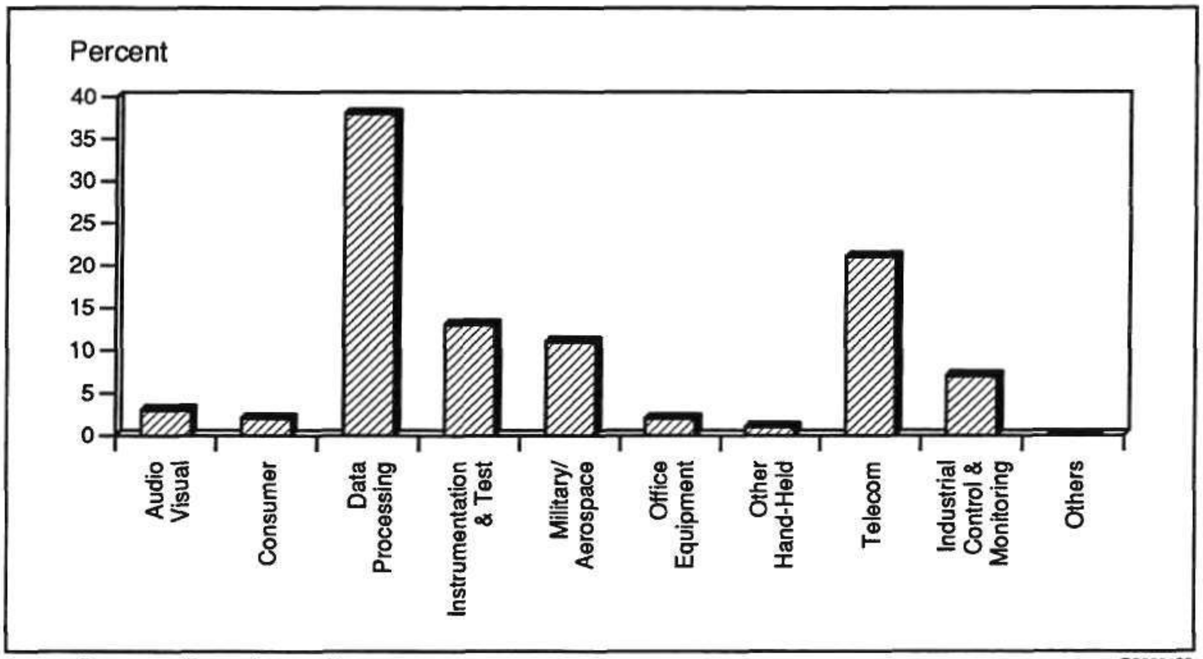
Figure 3-53 shows the cross section of responses received from manufacturers who said that the majority of their SRAM purchases were made for voice/data terminals. The low cost of 64Kb and 256Kb SRAMs probably accounts for the fact that two-thirds of the respondents named these densities as the ones upon which they spent the most. The voice/data terminal market is price-sensitive. This is probably also the reason that 16Kb SRAMs appear in this figure, but not in any of the preceding telecommunications charts. Certain 16Kb SRAMs sell for less than $1.

Table 3-1
Worldwide Computer Systems Forecast, Unit Shipments

	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Supercomputer	1,008	1,062	1,229	1,424	1,645	1,909	2,210	15.8
Mainframe	15,115	14,142	13,640	13,167	12,721	12,299	11,900	-3.4
Midrange	727,712	754,917	754,537	754,418	754,548	754,912	755,500	0.0
Workstation	407,624	528,915	677,000	1,130,000	2,217,000	3,802,000	6,500,000	65.2
Superworkstation	19,703	15,925	12,500	14,950	17,400	20,300	22,500	7.2
Traditional Workstation	120,100	230,618	246,000	317,150	370,700	416,700	476,900	15.6
Entry-Level Workstation	267,821	282,371	418,200	547,900	828,900	1,365,000	2,000,600	47.9
Personal Workstation	0	0	300	250,000	1,000,000	2,000,000	4,000,000	NM
PC Subtotal	23,935,200	24,987,000	26,710,000	29,836,000	33,774,000	39,127,000	42,648,000	11.3
Transportable	101,000	78,000	42,000	24,000	15,000	10,000	7,000	-38.0
Laptop AC	349,000	124,000	65,000	37,000	28,000	24,000	21,000	-29.9
Laptop DC	2,491,000	2,764,000	3,101,000	3,392,000	3,669,000	3,933,000	4,114,000	8.3
Notebook	408,000	1,136,000	1,794,000	2,816,000	4,393,000	6,809,000	9,464,000	52.8
Pen-Based	10,000	41,000	122,000	800,000	1,759,000	3,289,000	5,098,000	162.4
Hand-Held	217,000	238,000	763,000	2,042,000	3,877,000	6,188,000	7,314,000	98.4
Desktop	19,773,200	19,626,000	19,441,000	19,078,000	18,204,000	16,899,000	14,527,000	-5.8
Deskside	587,000	981,000	1,383,000	1,648,000	1,829,000	1,975,000	2,104,000	16.5
Total	25,086,659	26,286,036	28,156,406	31,735,009	36,759,914	43,698,120	49,917,610	12.1

NM = Not meaningful
Source: Dataquest (December 1992)

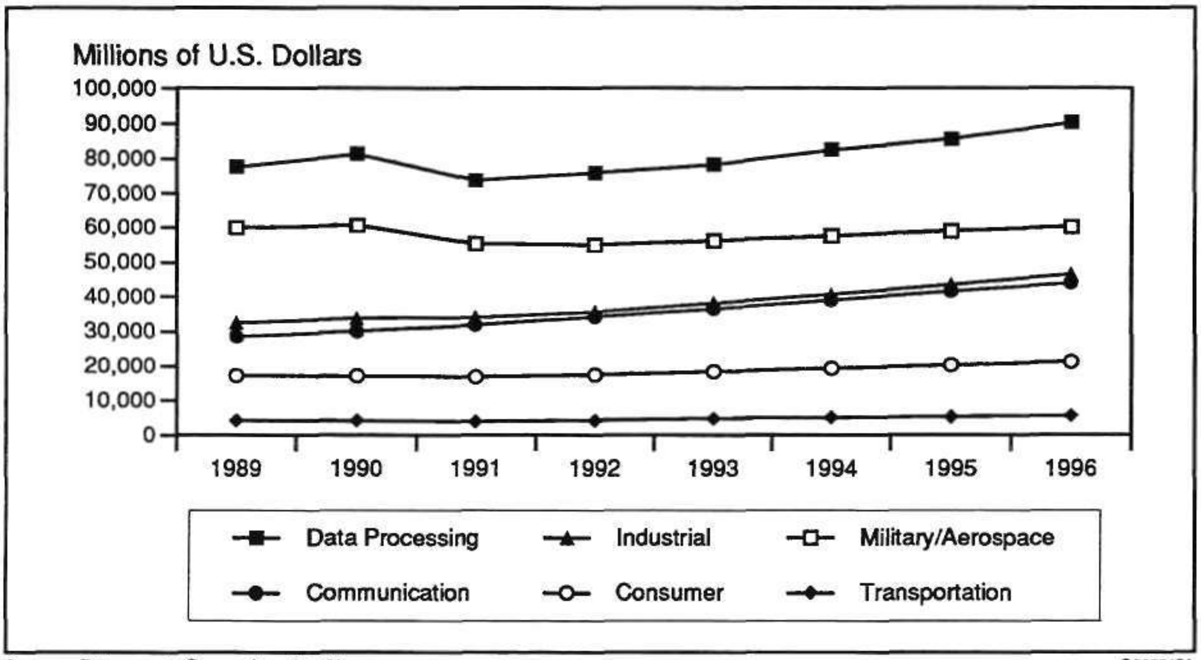
Figure 3-1
Percent of Responses, by Application Type



Source: Dataquest (December 1992)

G2003130

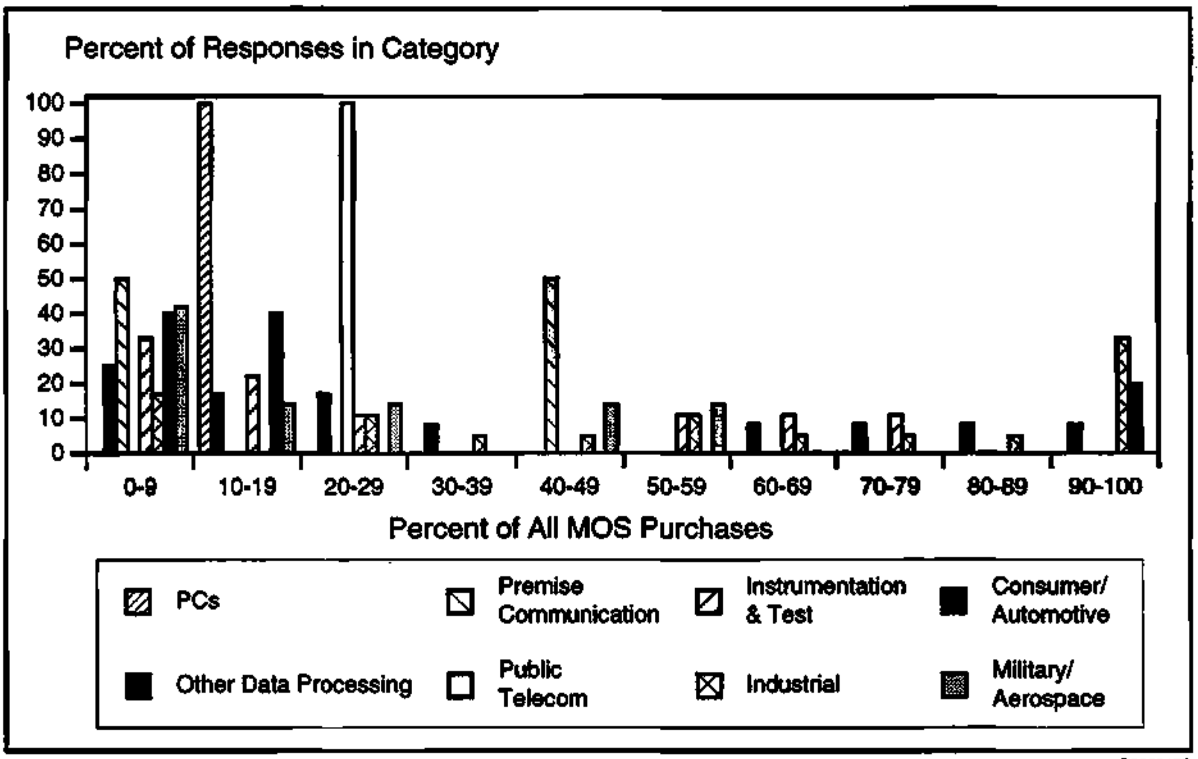
Figure 3-2
North American Electronic Equipment Production, 1989-1996



Source: Dataquest (December 1992)

G2003131

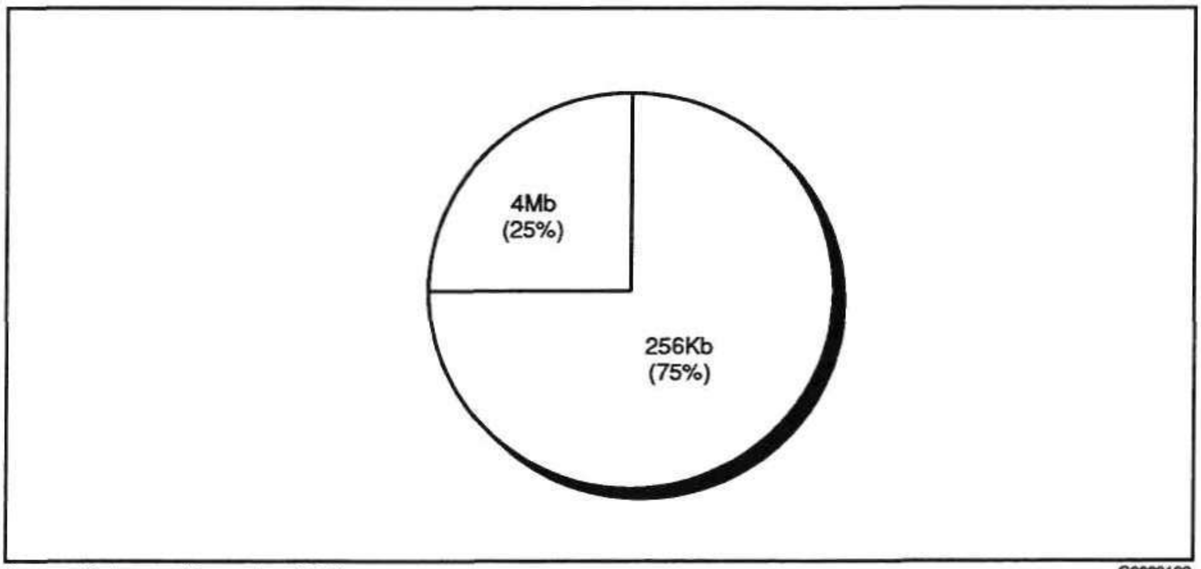
Figure 3-3
SRAM As a Percent of All MOS Purchases, by Application



Source: Dataquest (December 1992)

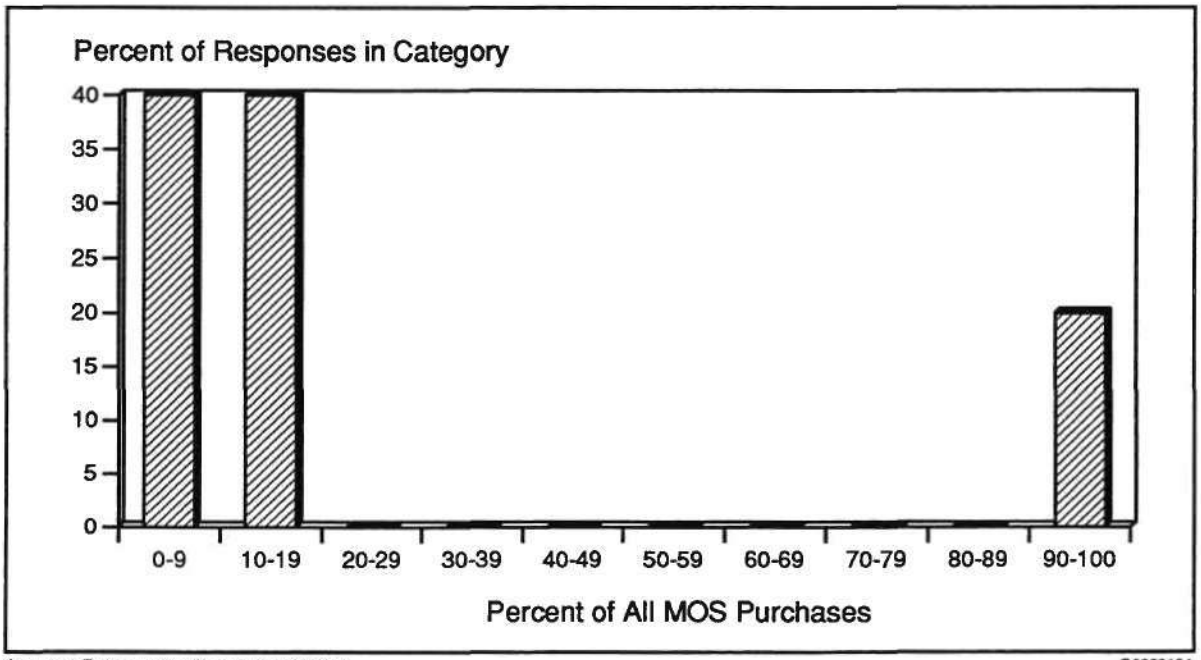
G2003132

Figure 3-4
Density Preferences: Consumer Electronics Manufacturers



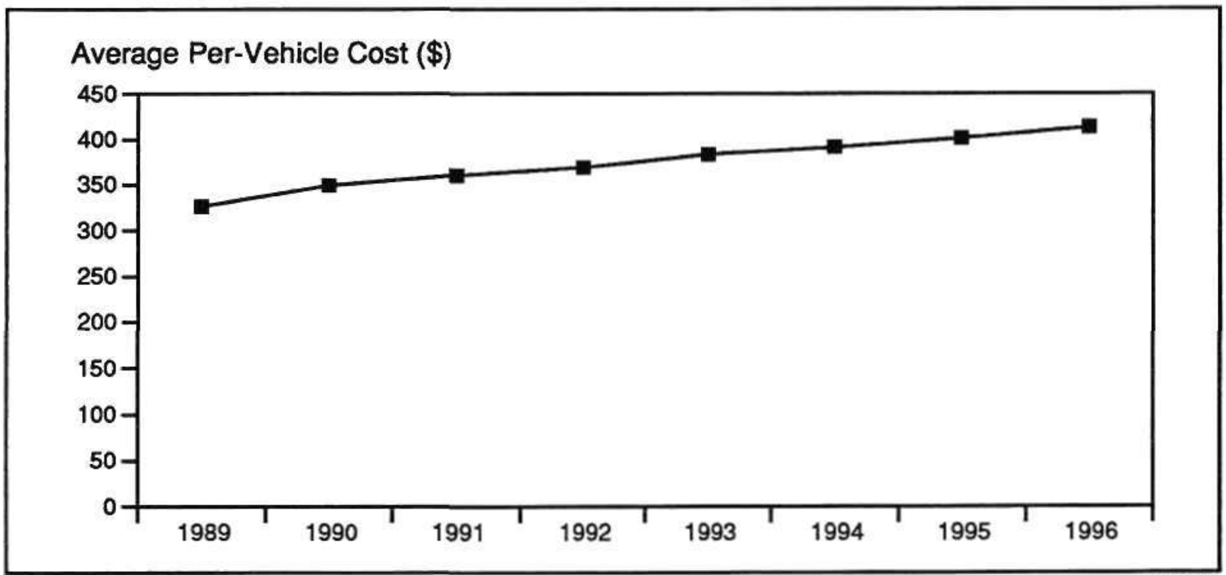
Source: Dataquest (December 1992)
G2003133

Figure 3-5
SRAM As a Percent of All MOS Purchases, Consumer/Automotive



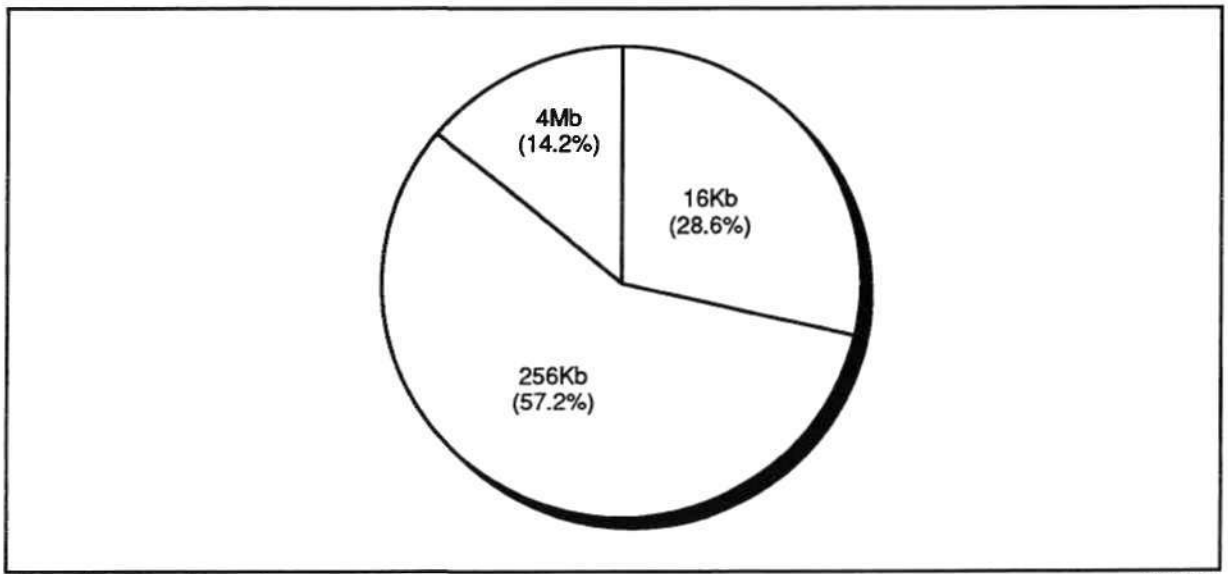
Source: Dataquest (December 1992)
G2003134

Figure 3-6
Cost of Electronics in Average U.S. Vehicle, 1989-1996



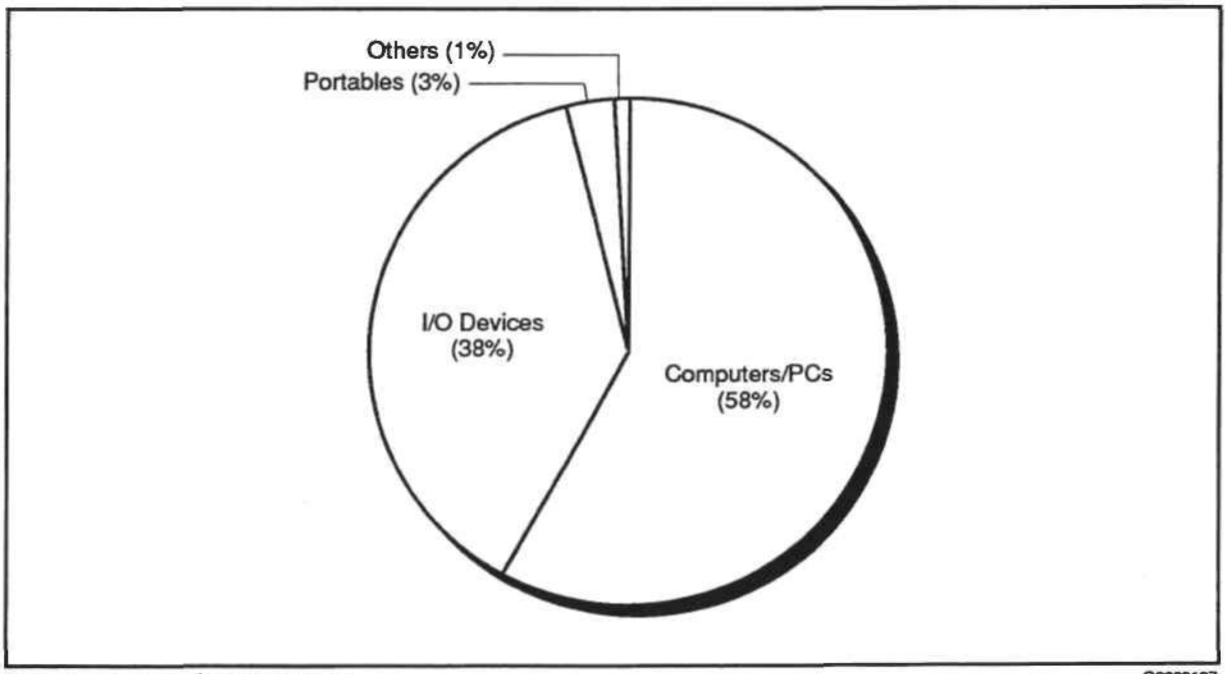
Source: Dataquest (December 1992) G2003135

Figure 3-7
Density Preferences: Audio/Visual Manufacturers



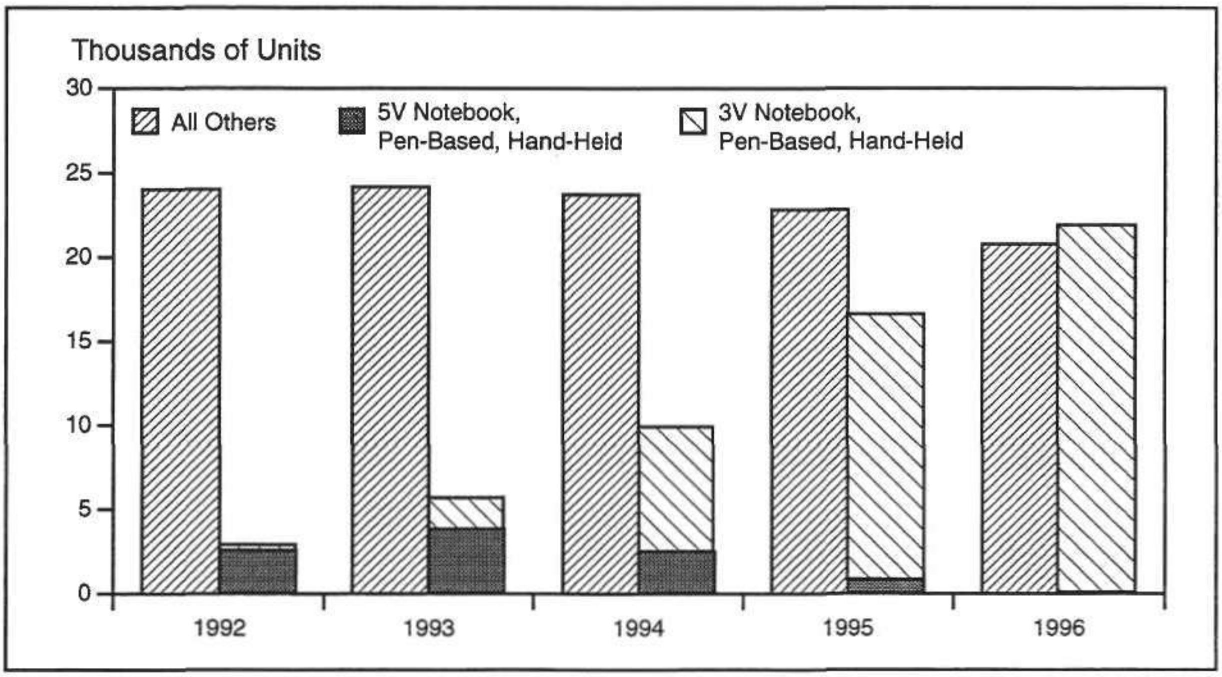
Source: Dataquest (December 1992) G2003136

Figure 3-8
Breakout of Data Processing Responses



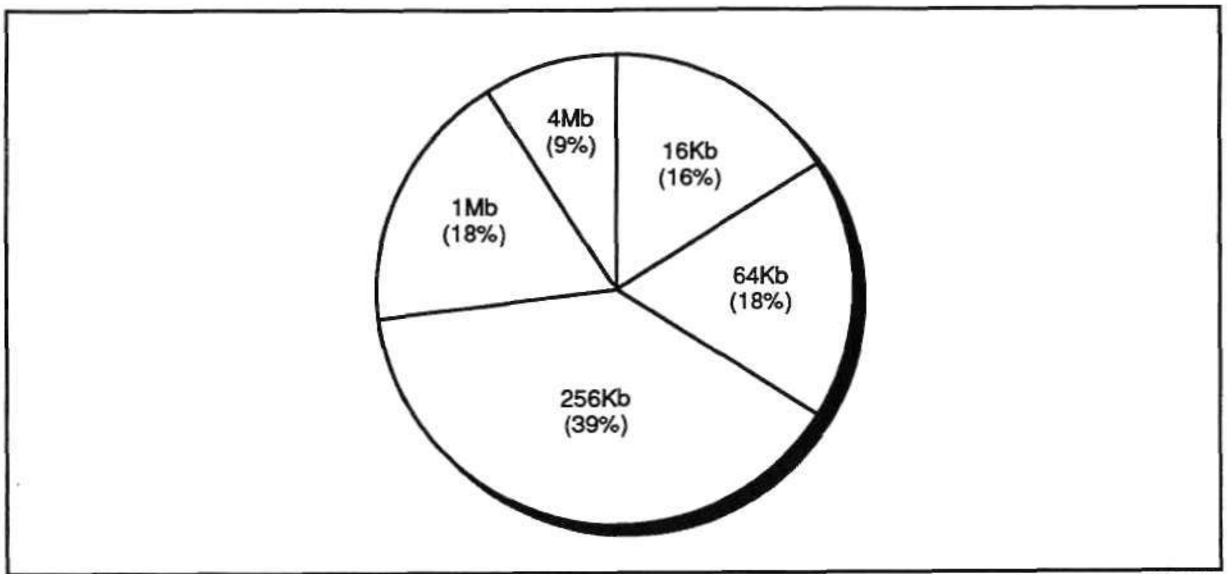
Source: Dataquest (December 1992) G2003137

Figure 3-9
Worldwide PC Shipments Forecast



Source: Dataquest (December 1992) G2003138

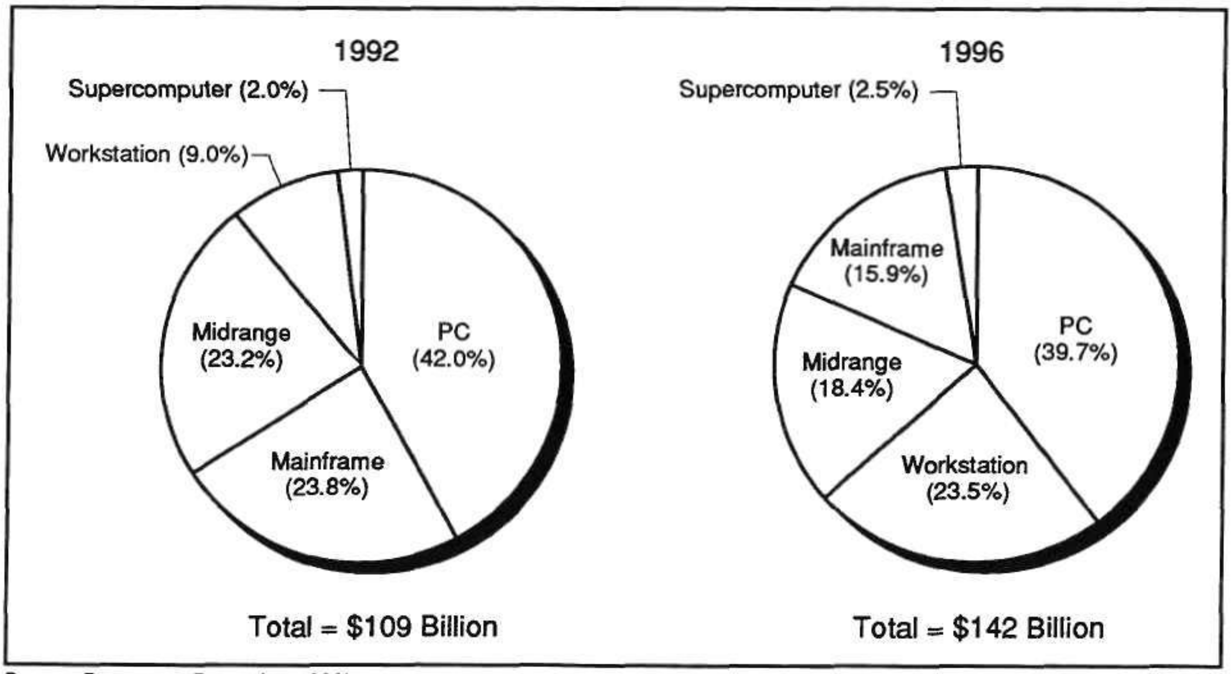
Figure 3-10
Density Preferences: Data Processing Manufacturers



Source: Dataquest (December 1992)

G2003139

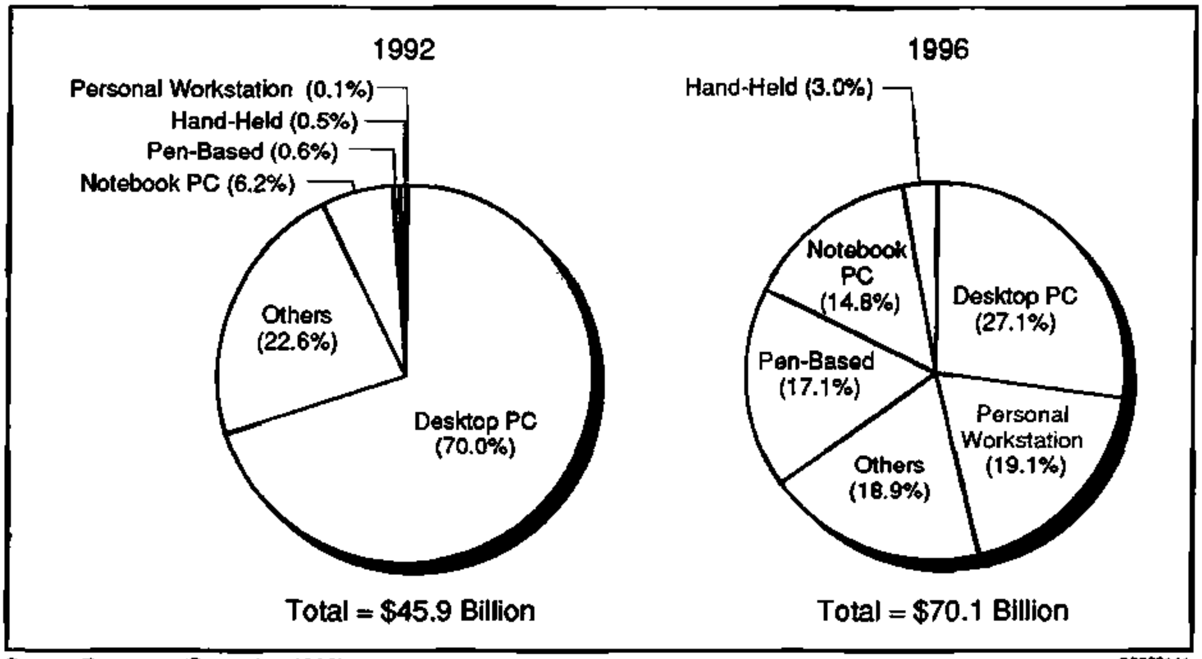
Figure 3-11
Worldwide Computer Systems Market Mix



Source: Dataquest (December 1992)

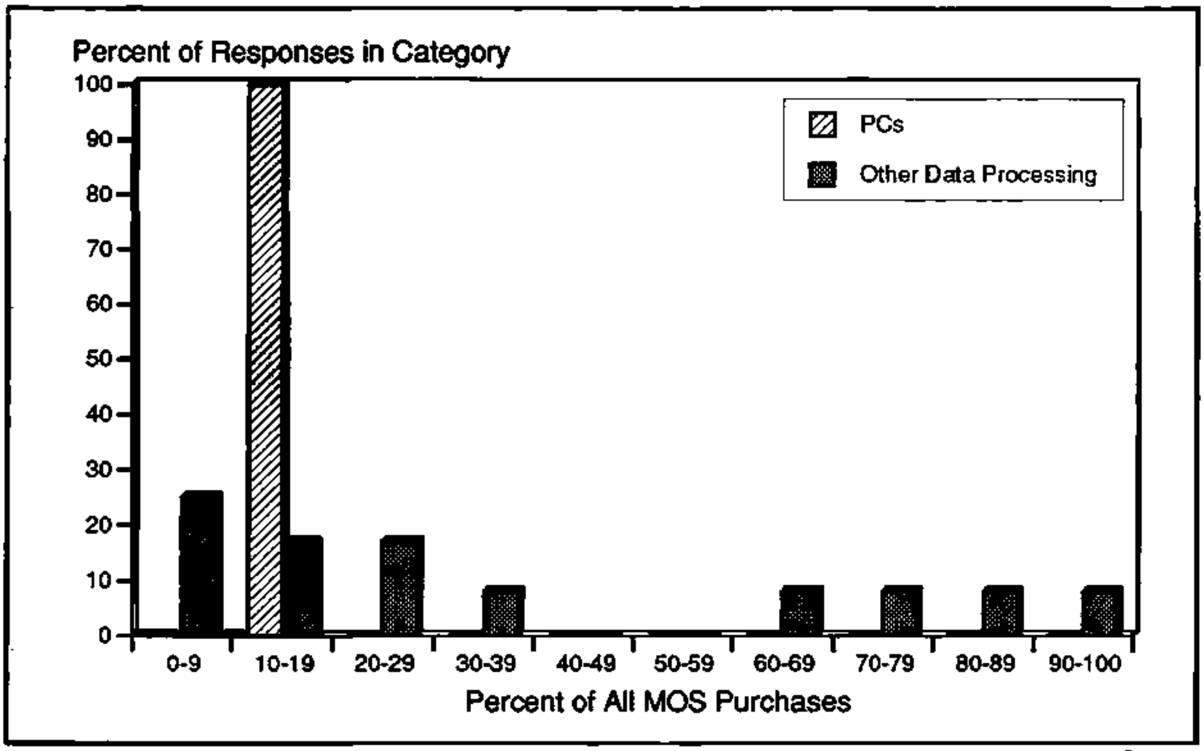
G2003140

Figure 3-12
Worldwide PC and Personal Workstation Market Mix



Source: Dataquest (December 1992) G2003141

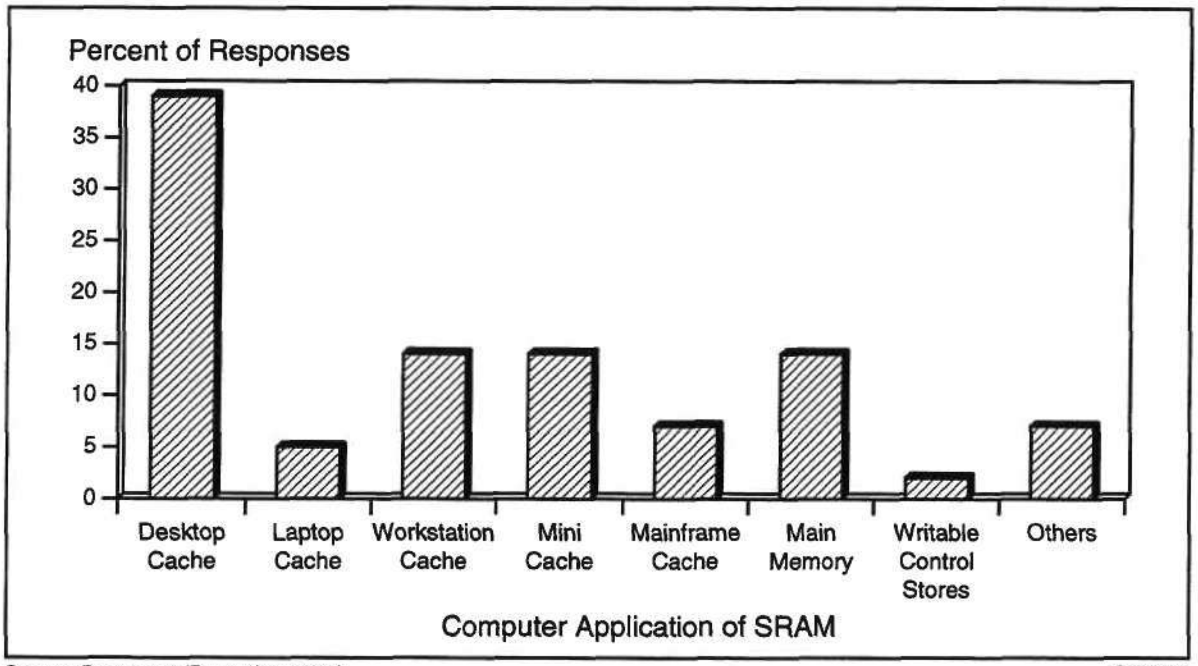
Figure 3-13
SRAM As a Percent of All MOS Purchases, Data Processing



Source: Dataquest (December 1992)

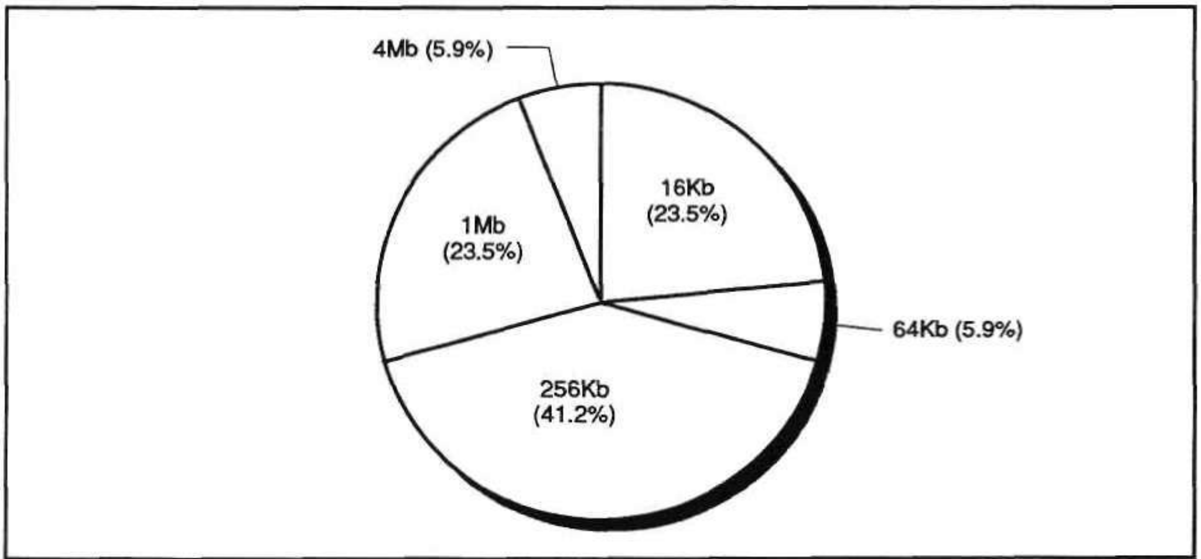
G2003142

Figure 3-14
Computer Manufacturers, by Application Type



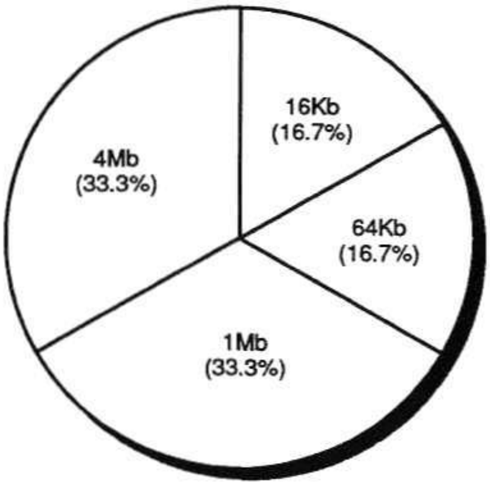
Source: Dataquest (December 1992)
G2003143

Figure 3-15
Density Preferences: PC Caches



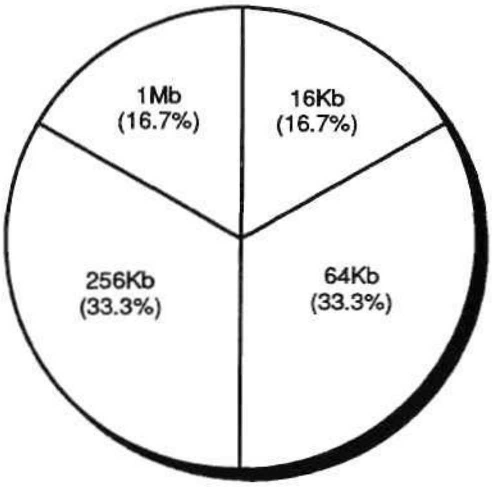
Source: Dataquest (December 1992)
G2003144

Figure 3-16
Density Preferences: Workstation Caches



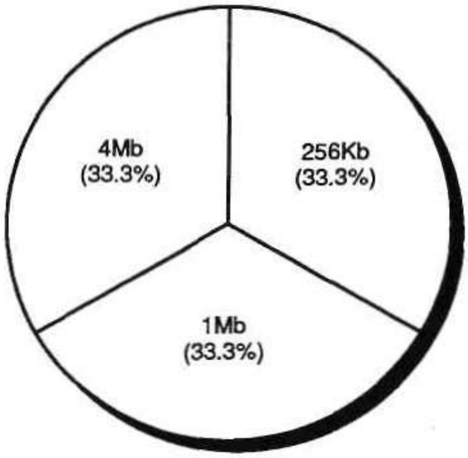
Source: Dataquest (December 1992) G2003145

Figure 3-17
Density Preferences: Minicomputer Caches



Source: Dataquest (December 1992) G2003146

Figure 3-18
Density Preferences: Mainframe Computer Caches

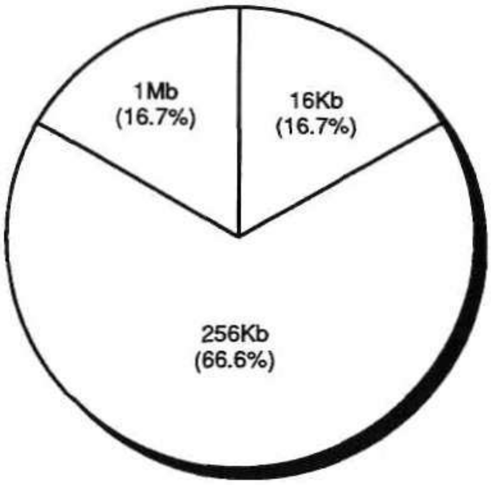


Note: Segments do not add to 100 percent because of rounding.

Source: Dataquest (December 1992)

G2003147

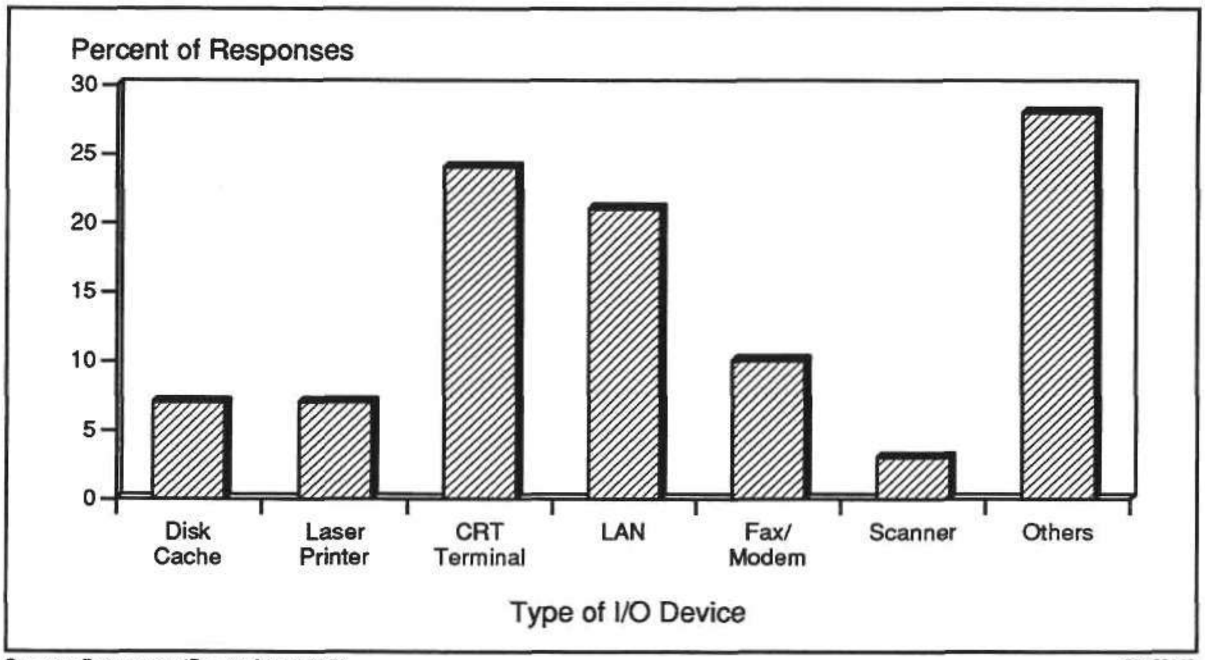
Figure 3-19
Density Preferences: Main Memory in Deskside Computers



Source: Dataquest (December 1992)

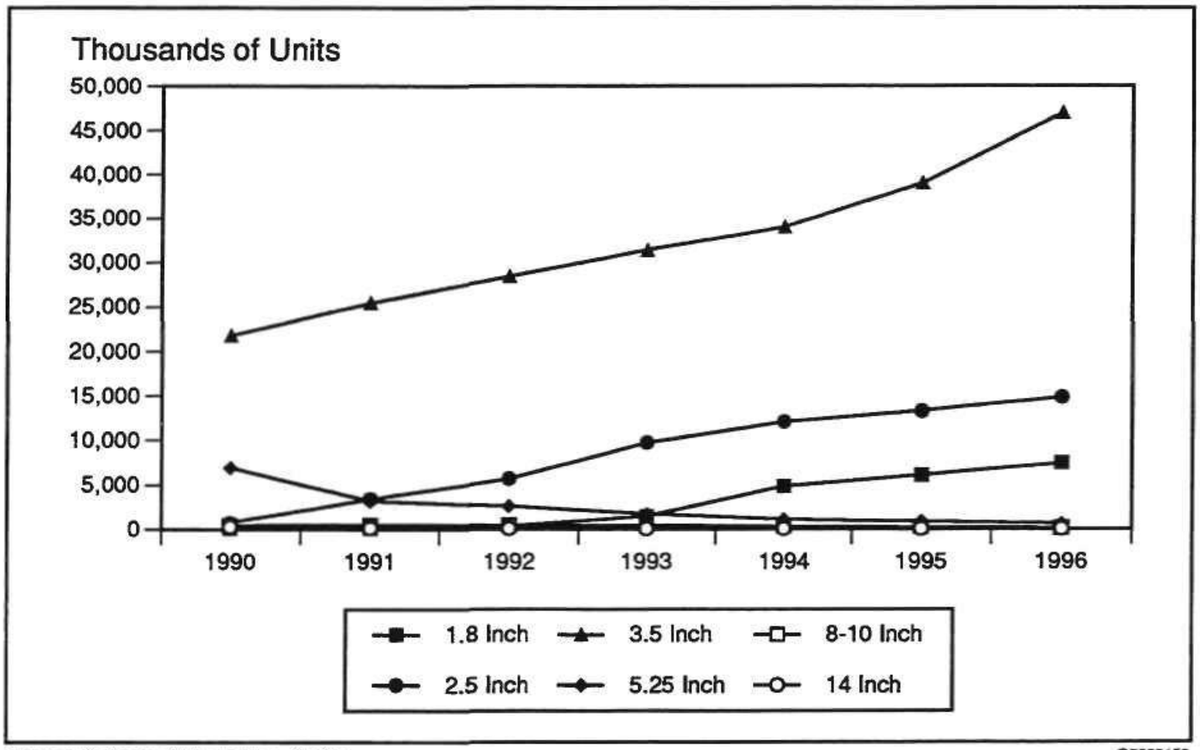
G2003148

Figure 3-20
I/O Device Manufacturers, by Application



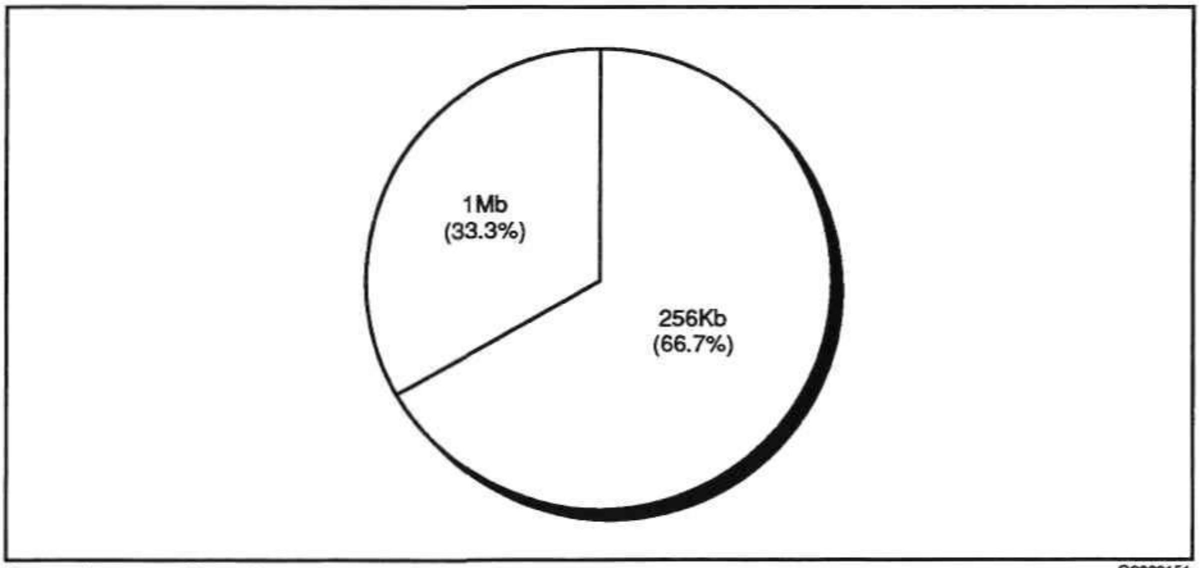
Source: Dataquest (December 1992) G2003149

Figure 3-21
Worldwide Disk Drive Production, 1990-1996



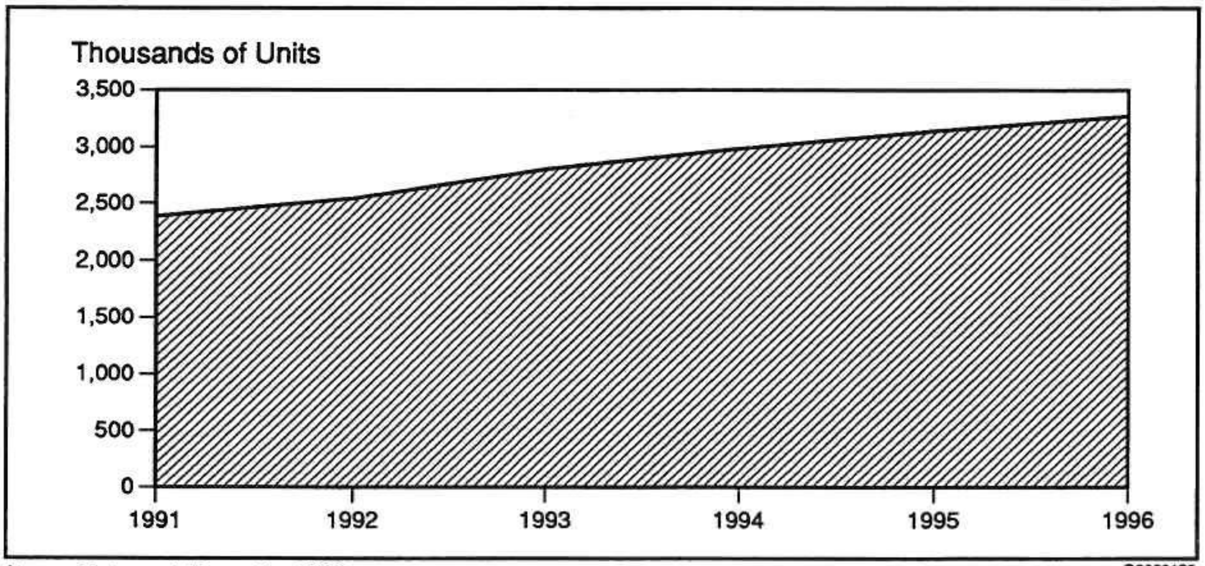
Source: Dataquest (December 1992) G2003150

Figure 3-22
Density Preferences: Disk Cache Manufacturers



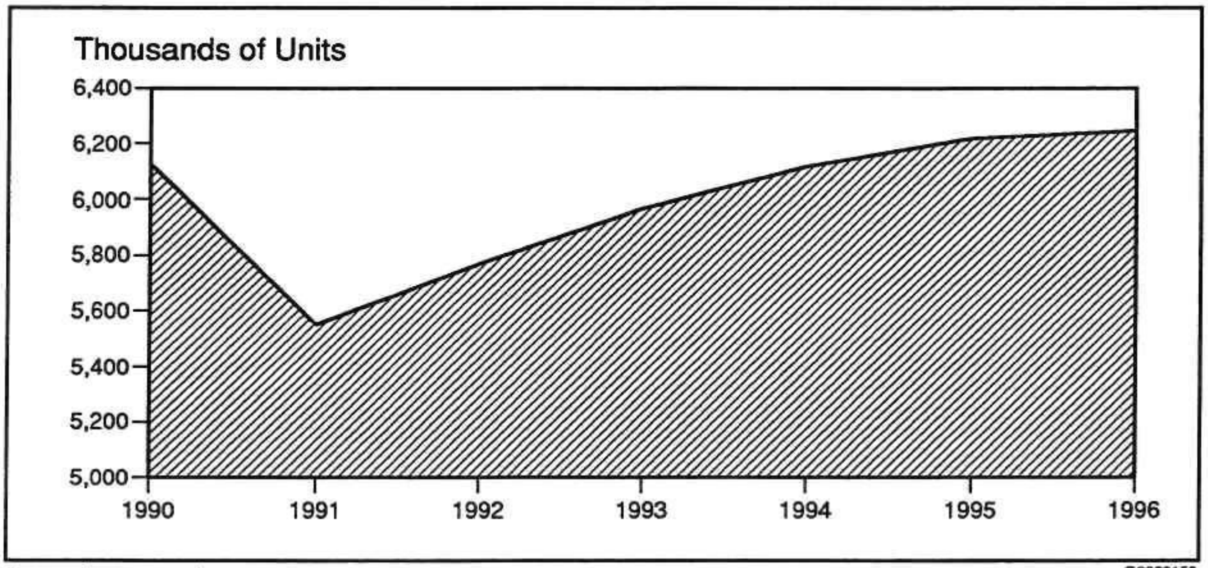
Source: Dataquest (December 1992) G2003151

Figure 3-23
North America Page Printer Forecast, 1991-1996



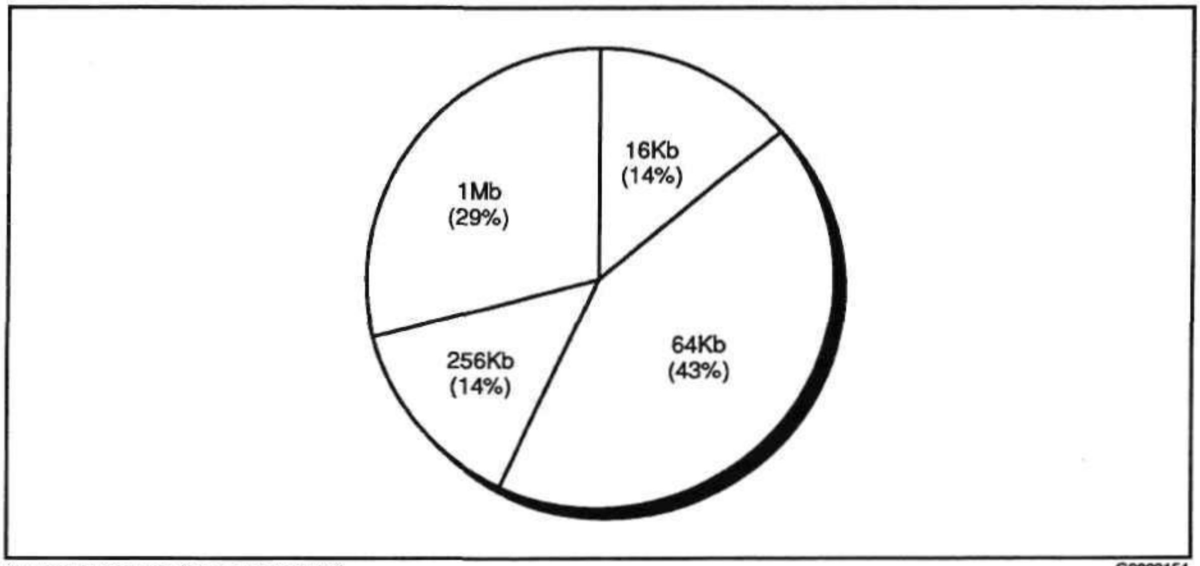
Source: Dataquest (December 1992) G2003152

Figure 3-24
Worldwide Display Terminal Production, 1990-1996



Source: Dataquest (December 1992) G2003153

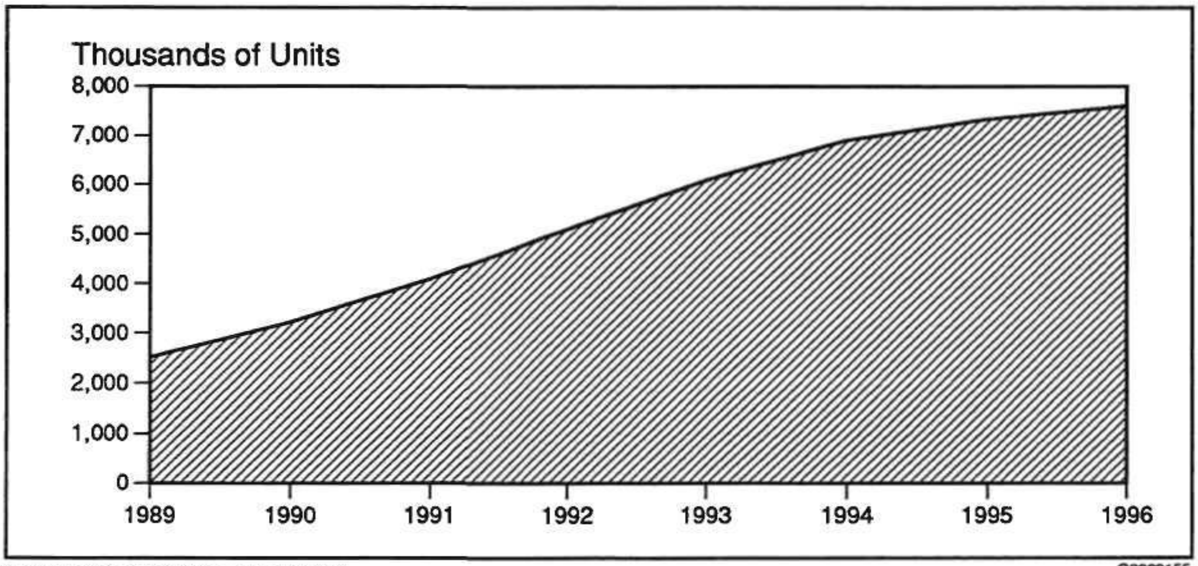
Figure 3-25
Density Preferences: CRT Terminal Manufacturers



Source: Dataquest (December 1992)

G2003154

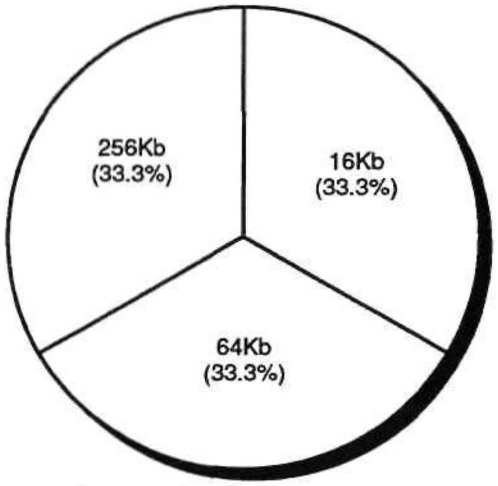
Figure 3-26
U.S. Network Interface Card Forecast, 1989-1996



Source: Dataquest (December 1992)

G2003155

Figure 3-27
Density Preferences: LAN Board Manufacturers

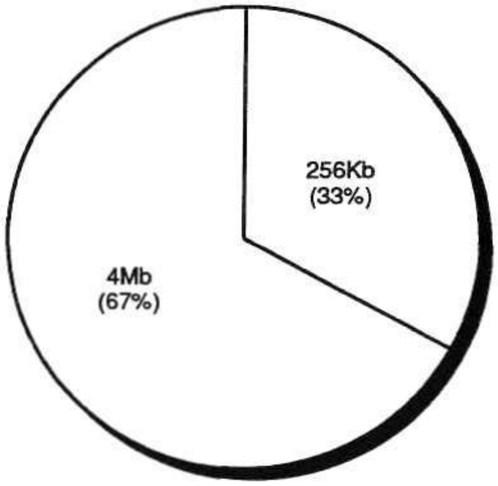


Note: Segments do not add to 100 percent because of rounding

Source: Dataquest (December 1992)

G2003156

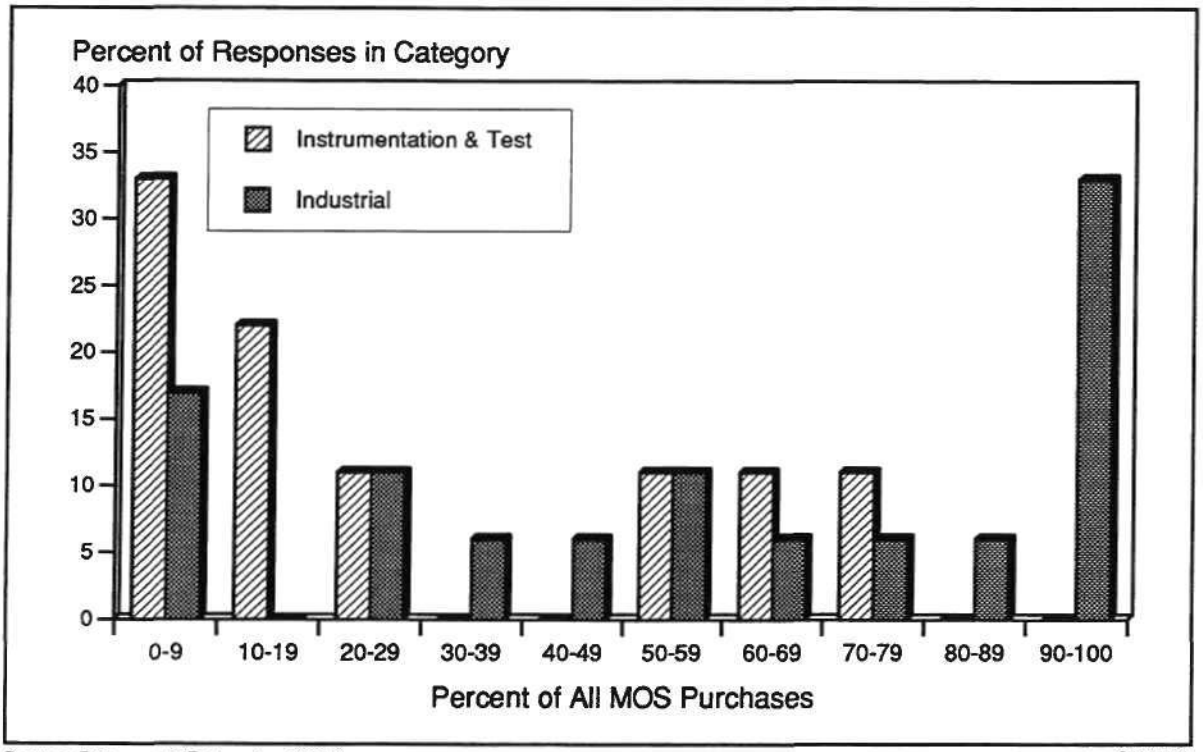
Figure 3-28
Density Preferences: Fax/Modem Board Manufacturers



Source: Dataquest (December 1992)

G2003157

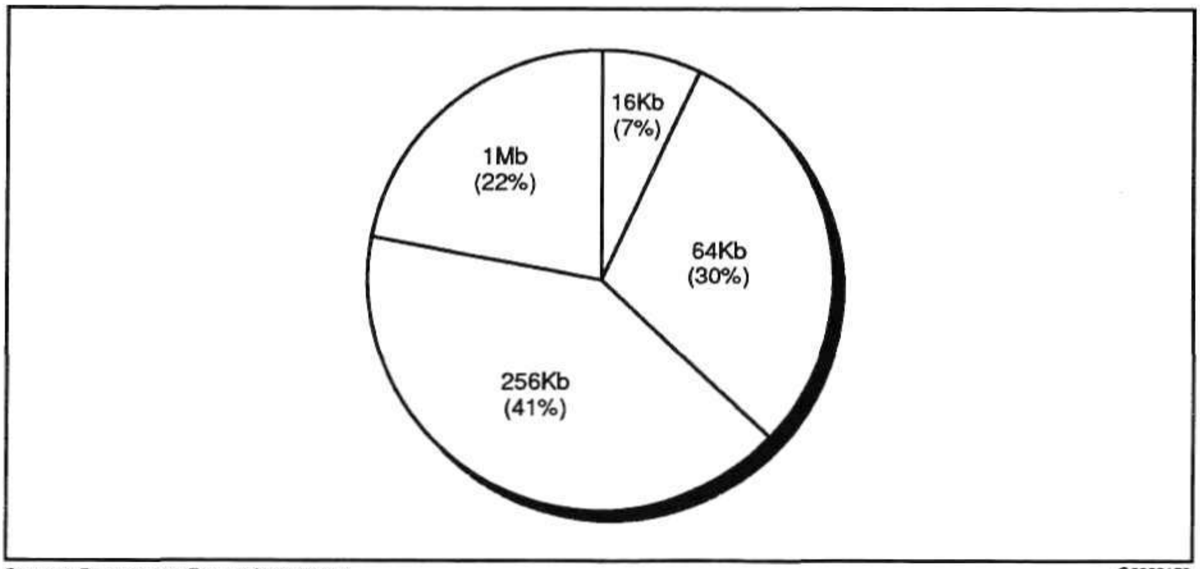
Figure 3-29
SRAM As a Percent of All MOS Purchases, Instrumentation/Industrial



Source: Dataquest (December 1992)

G2003158

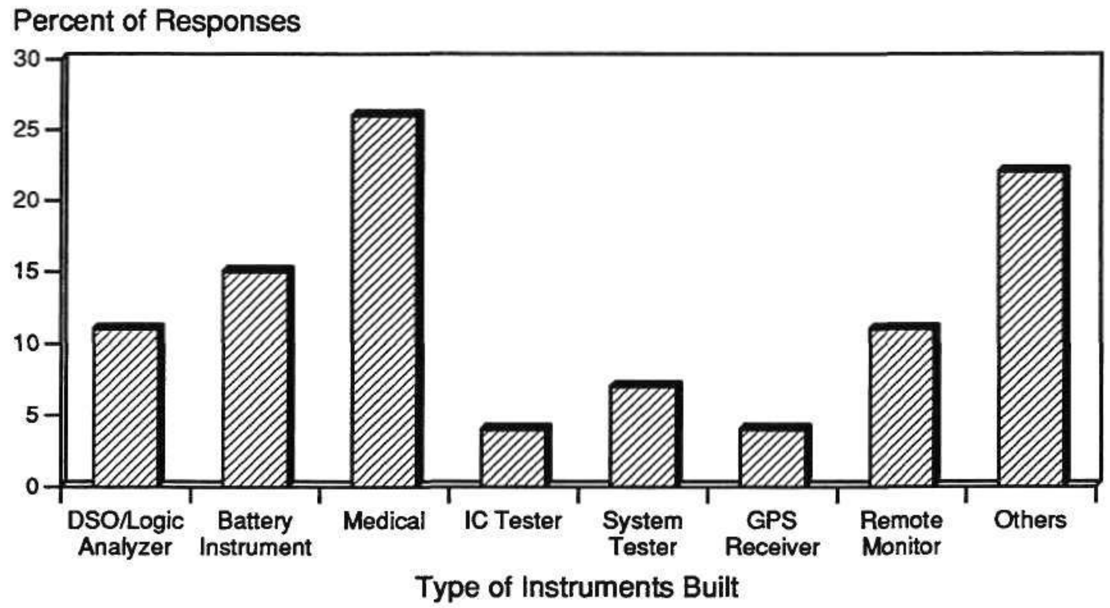
Figure 3-30
Density Preferences: Instrumentation Test Manufacturers



Source: Dataquest (December 1992)

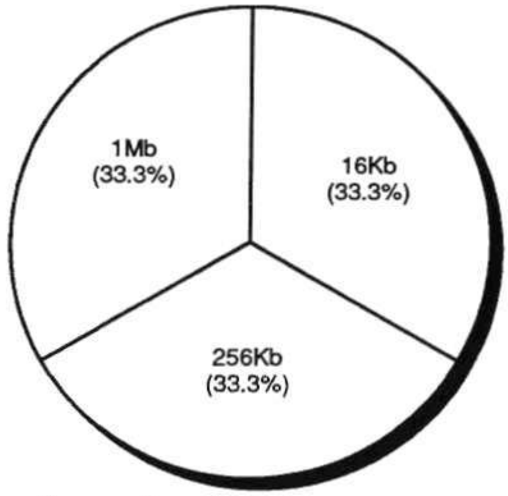
G2003159

Figure 3-31
Instrumentation Test Manufacturers, by Application



Source: Dataquest (December 1992) G2003160

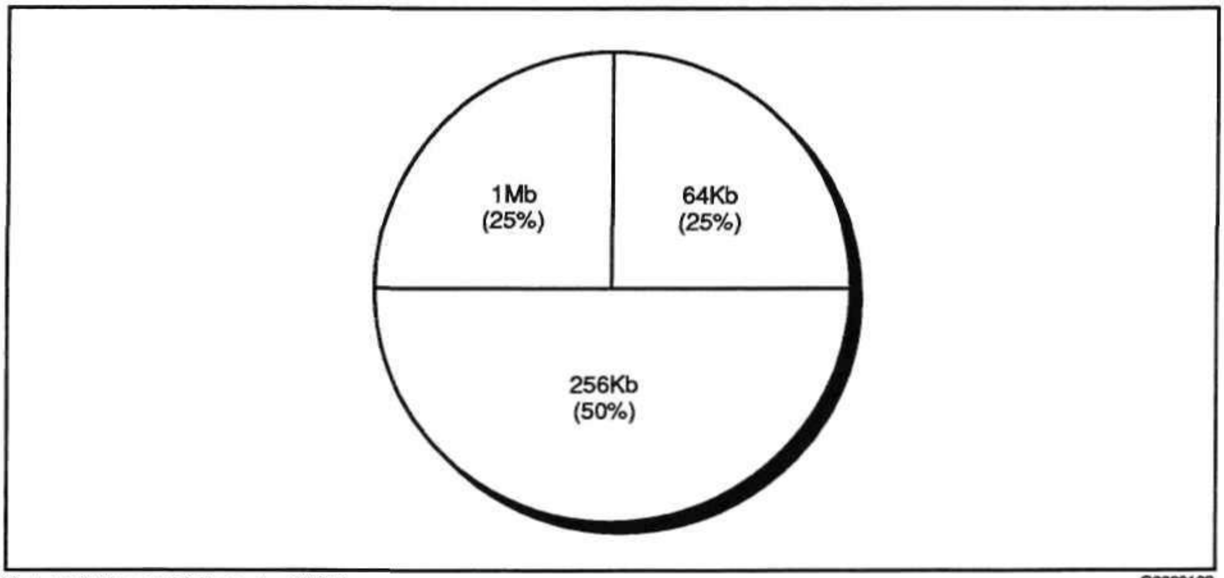
Figure 3-32
Density Preferences: Digital Storage Oscilloscopes/Logical Analyzers



Note: Segments do not add to 100 percent because of rounding

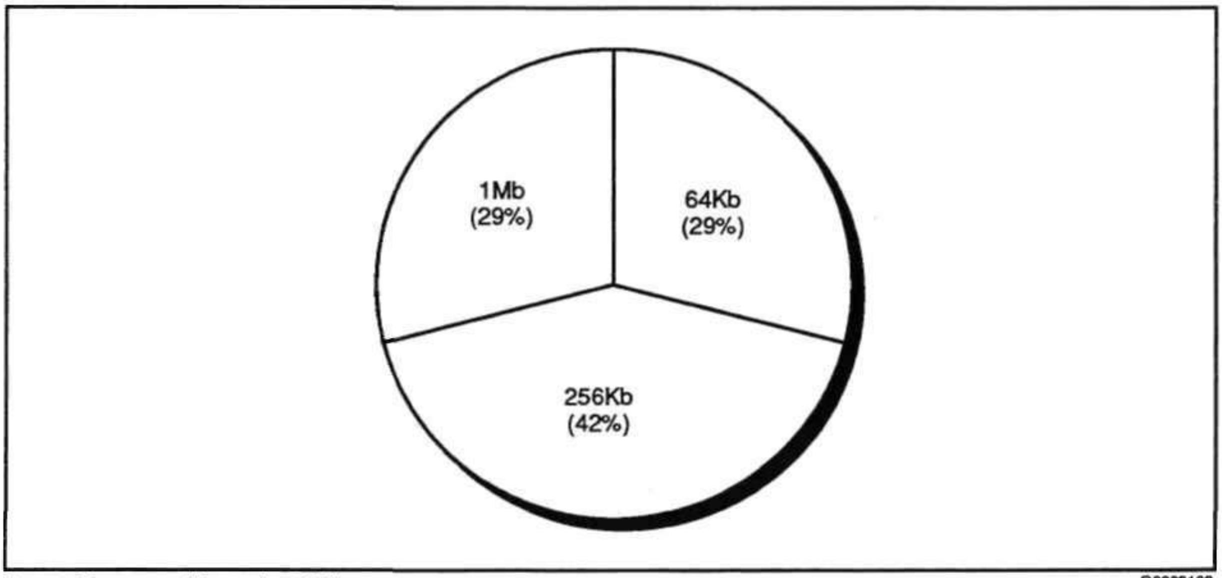
Source: Dataquest (December 1992) G2003161

Figure 3-33
Density Preferences: Battery-Operated Instruments



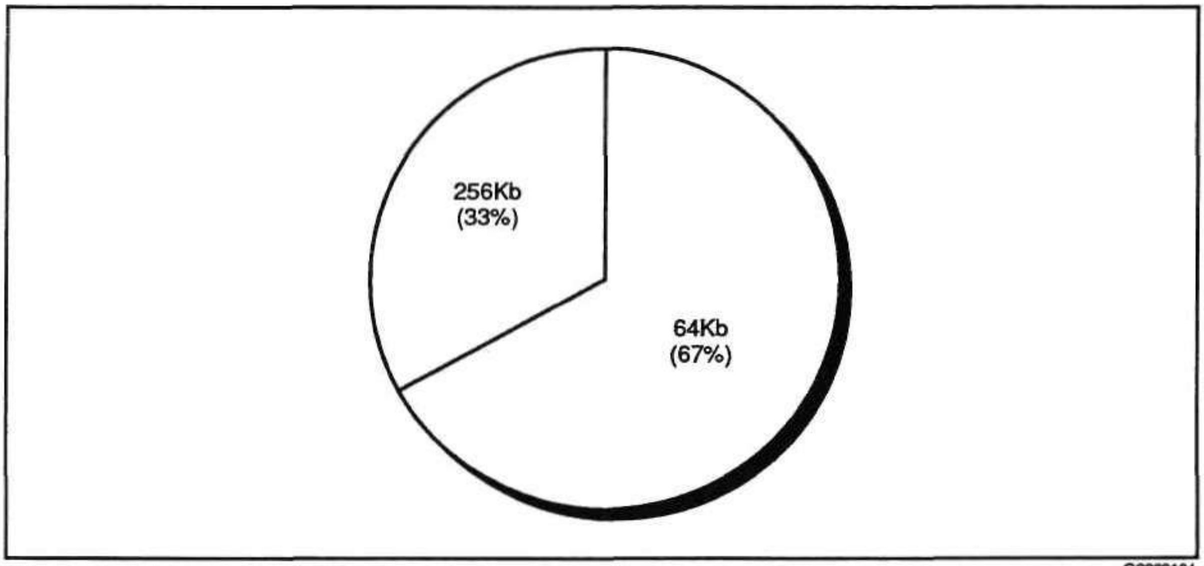
Source: Dataquest (December1992) G2003162

Figure 3-34
Density Preferences: Medical Instrumentation



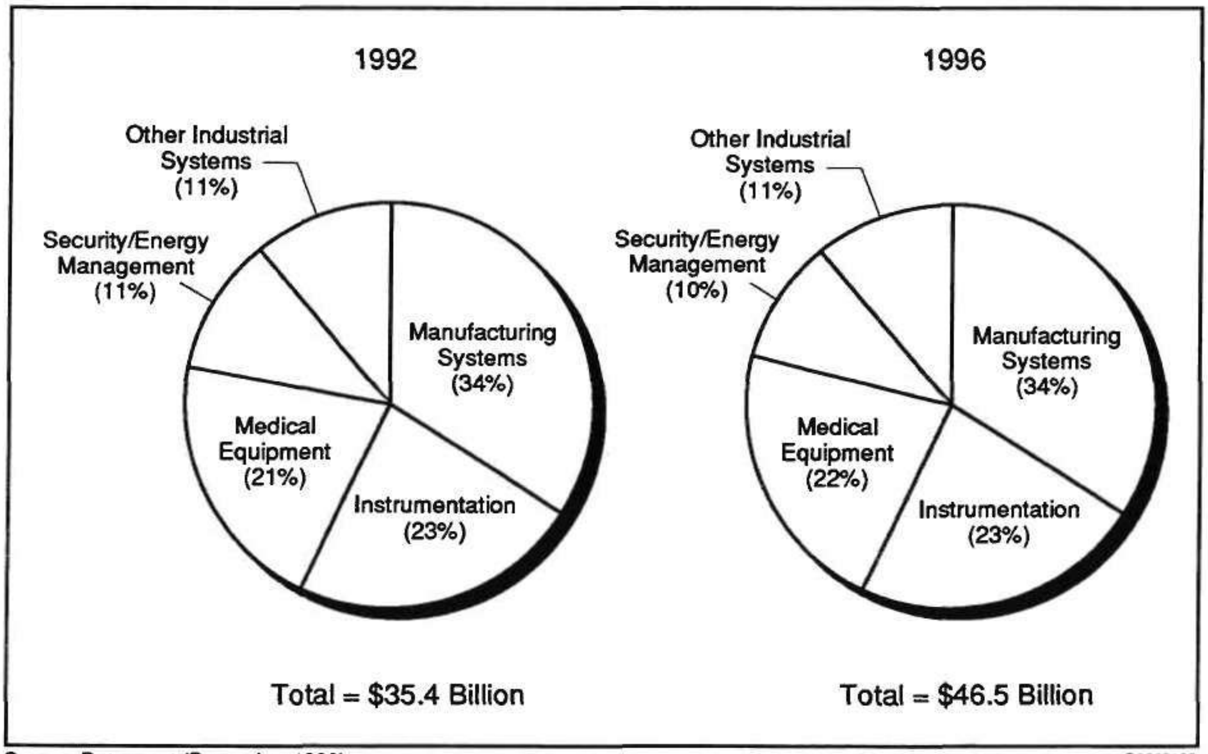
Source: Dataquest (December1992) G2003163

Figure 3-35
Density Preferences: Remote Measurement Equipment



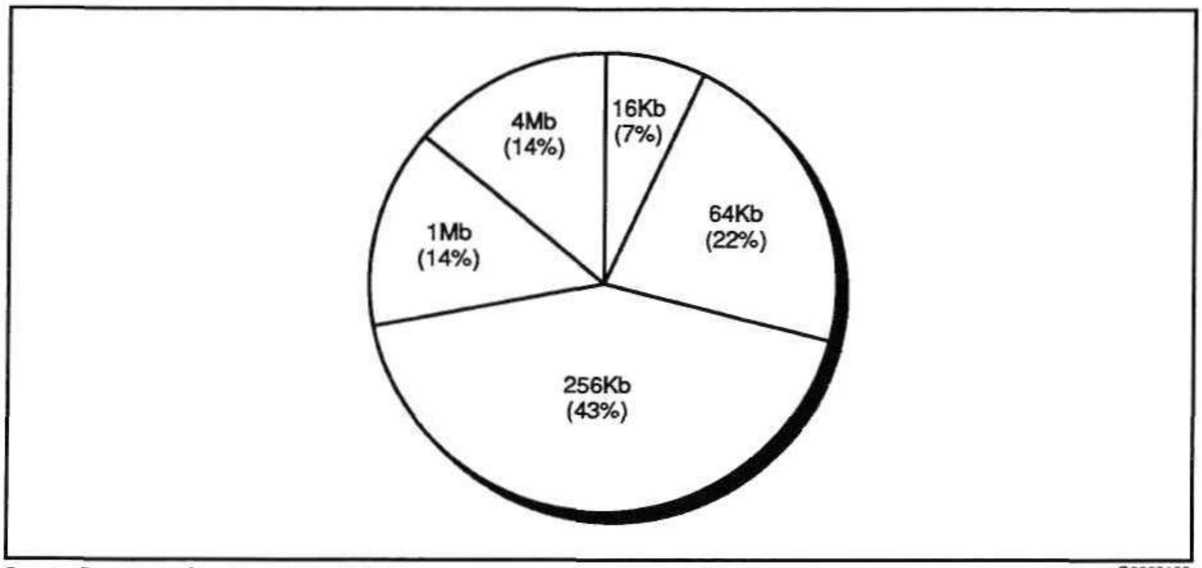
Source: Dataquest (December1992)
G2003164

Figure 3-36
North American Industrial Electronics Production



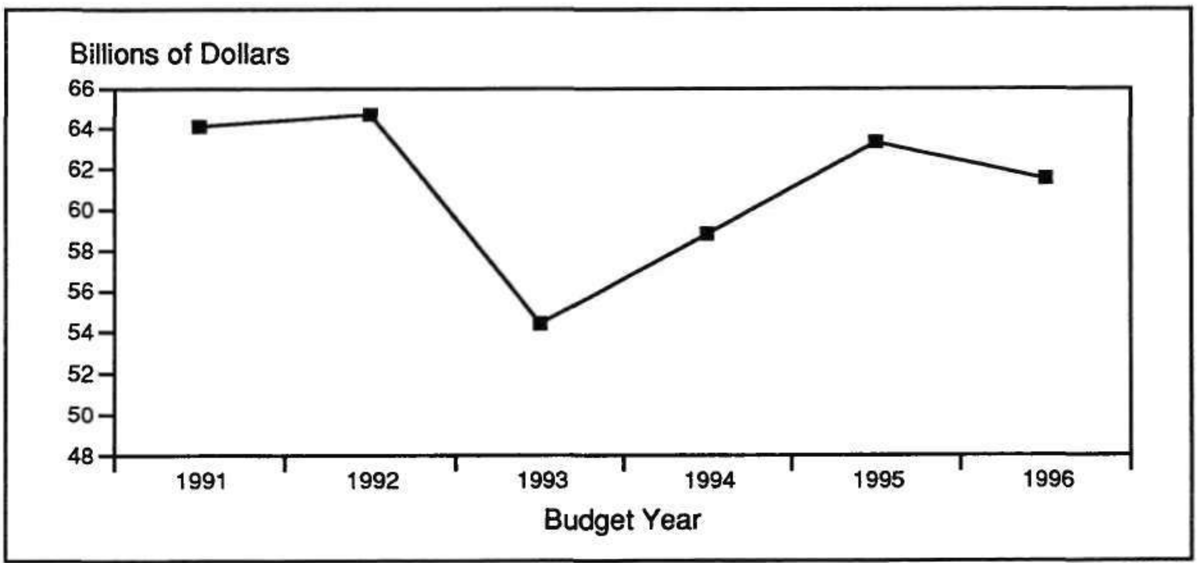
Source: Dataquest (December 1992)
G2003165

Figure 3-37
Density Preferences: Industrial Control and Monitoring Manufacturers



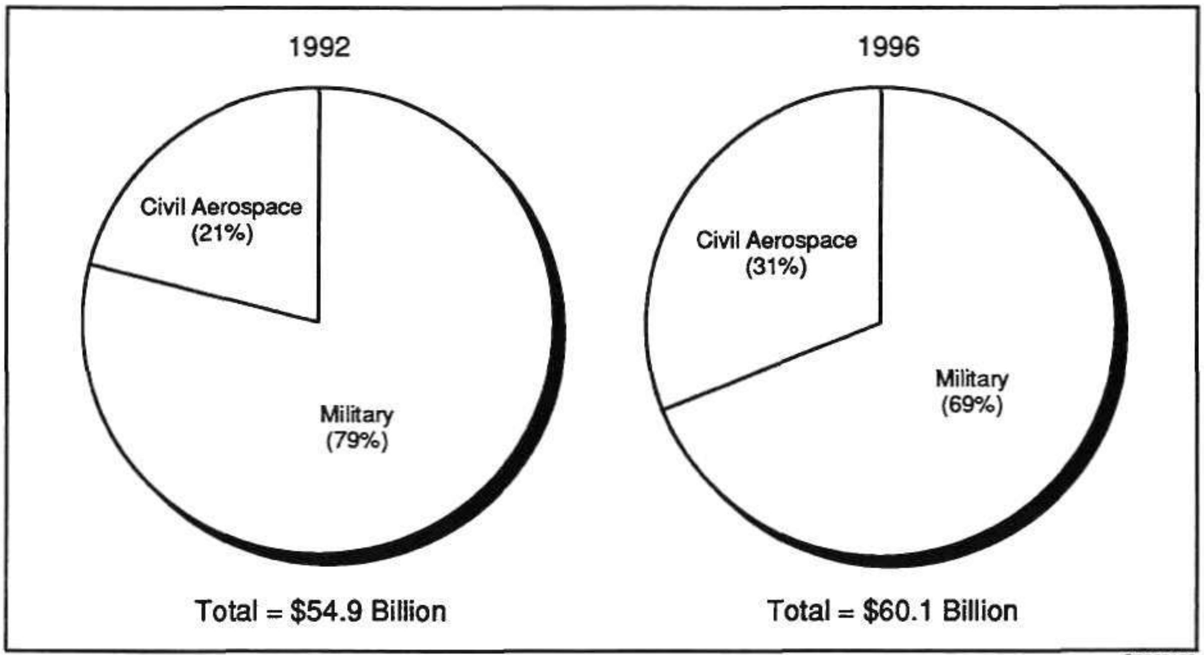
Source: Dataquest (December 1992)
G2003166

Figure 3-38
U.S. Defense Budget Procurements, 1991-1996



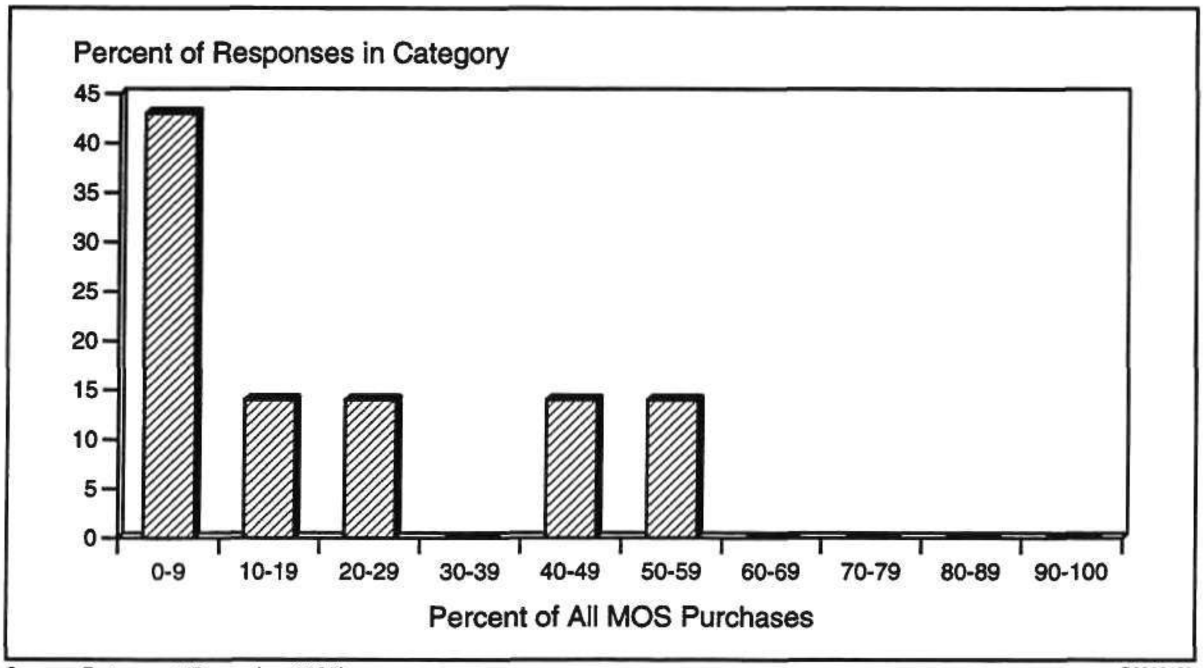
Source: U.S. Department of Defense
G2003167

Figure 3-39
North American Military and Civil Aerospace Electronics Production



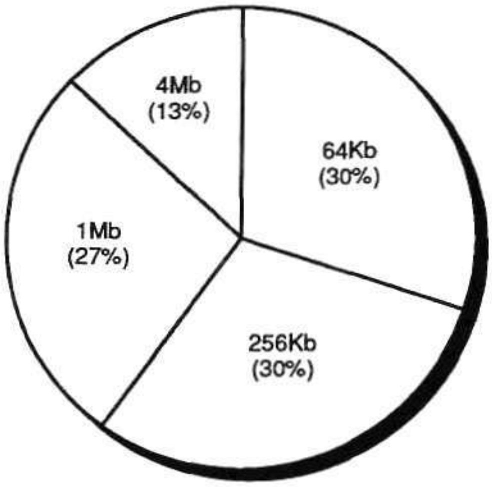
Source: Dataquest (December 1992)
G2003168

Figure 3-40
SRAM As a Percent of All MOS Purchases, Military/Aerospace



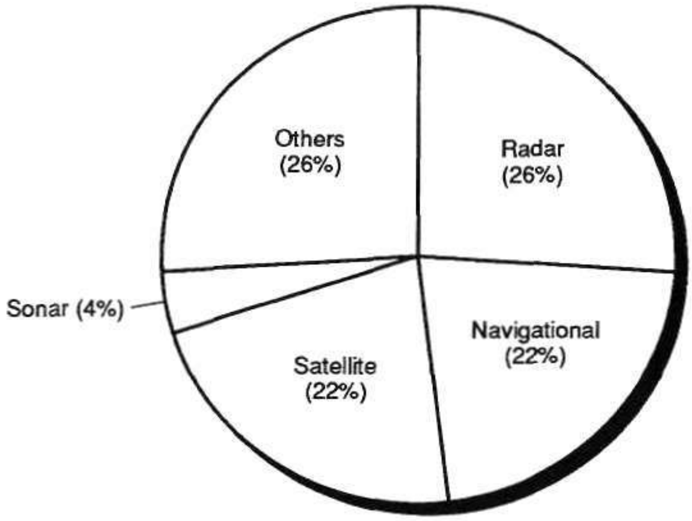
Source: Dataquest (December 1992)
G2003169

Figure 3-41
Density Preferences: Military/Aerospace Manufacturers



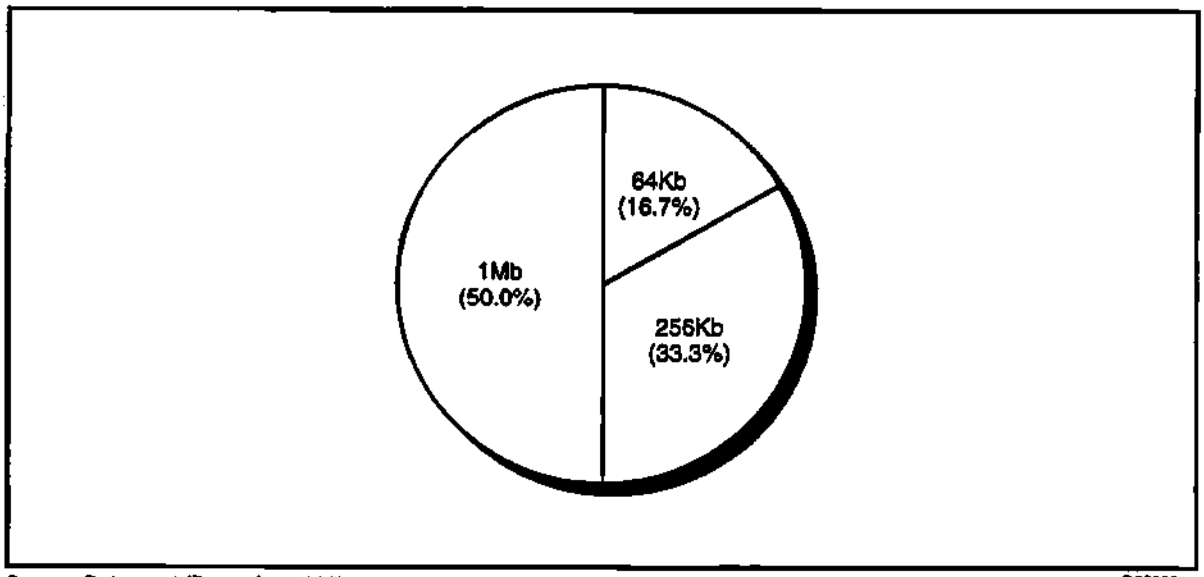
Source: Dataquest (December 1992) G2003170

Figure 3-42
Military/Aerospace Manufacturers, by Application



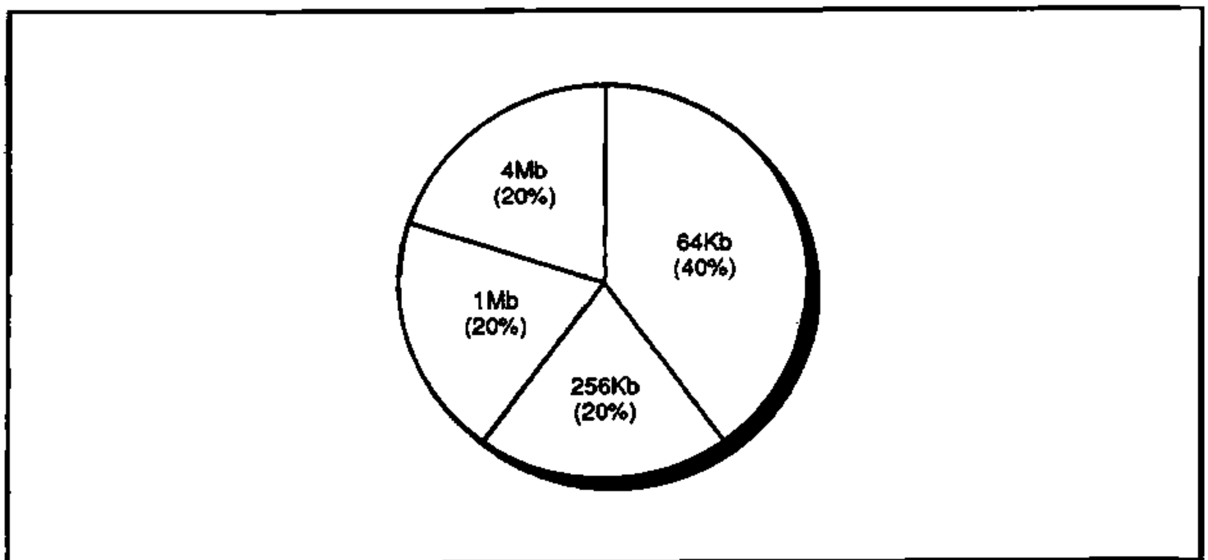
Source: Dataquest (December 1992) G2003171

Figure 3-43
Density Preferences: Radar Manufacturers



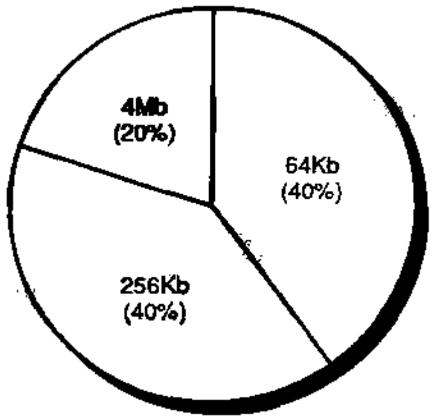
Source: Dataquest (December 1992) G2003094

Figure 3-44
Density Preferences: Navigational Equipment Manufacturers



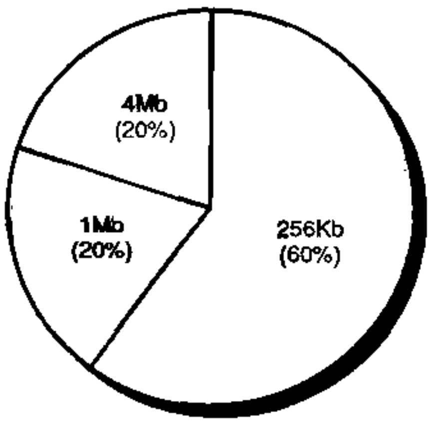
Source: Dataquest (December 1992) G2003095

Figure 3-45
Density Preferences: Satellite Manufacturers



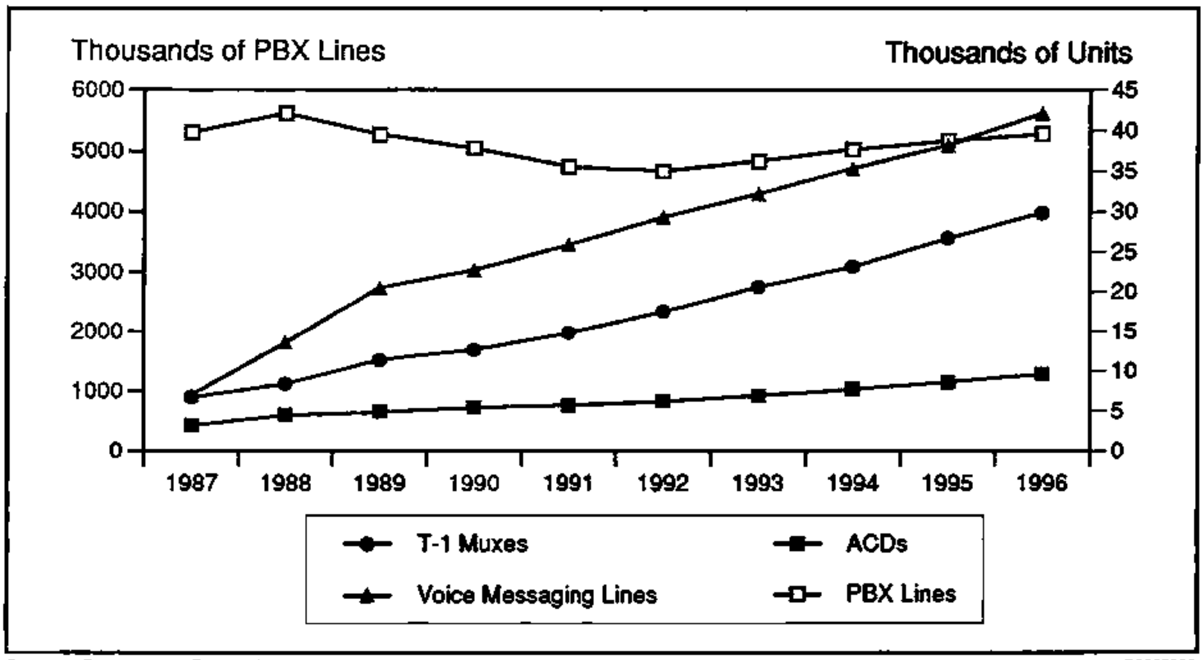
Source: Dataquest (December 1992) G2003096

Figure 3-46
Density Preferences: Office Equipment Manufacturers



Source: Dataquest (December 1992) G2003097

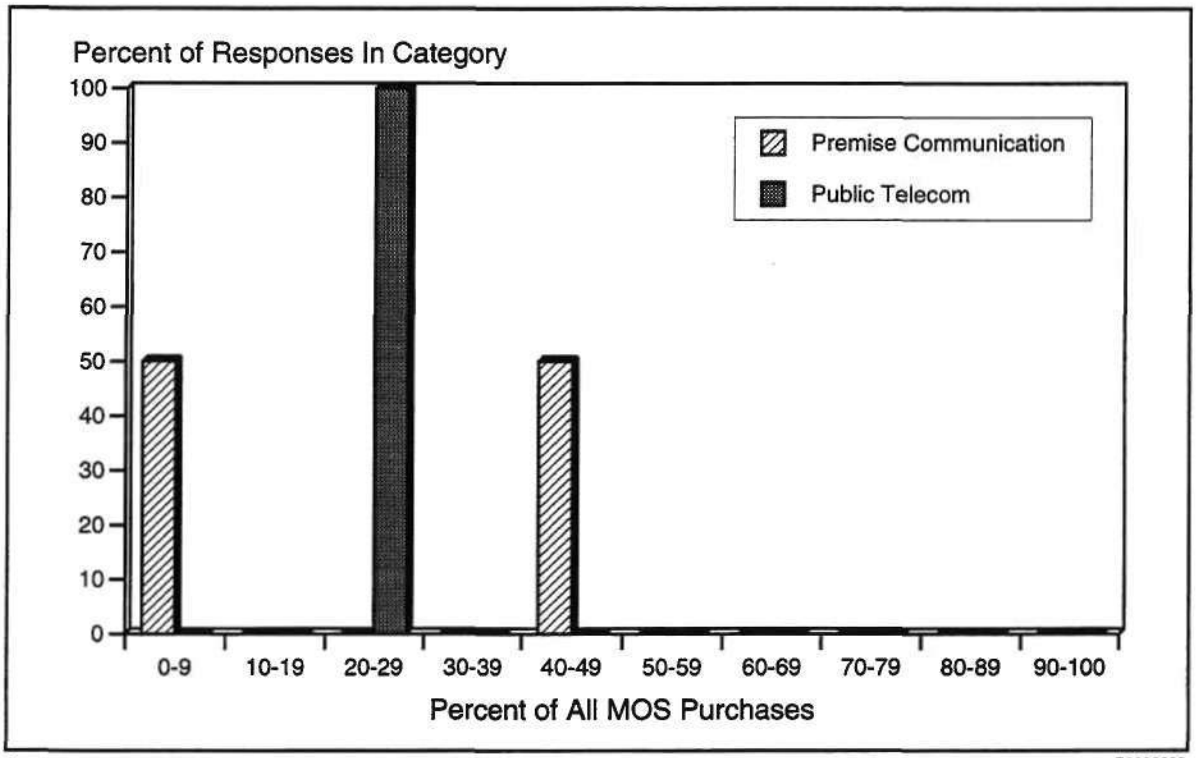
Figure 3-47
U.S. Telecom System Shipments, 1987-1996



Source: Dataquest (December 1992)

G2003098

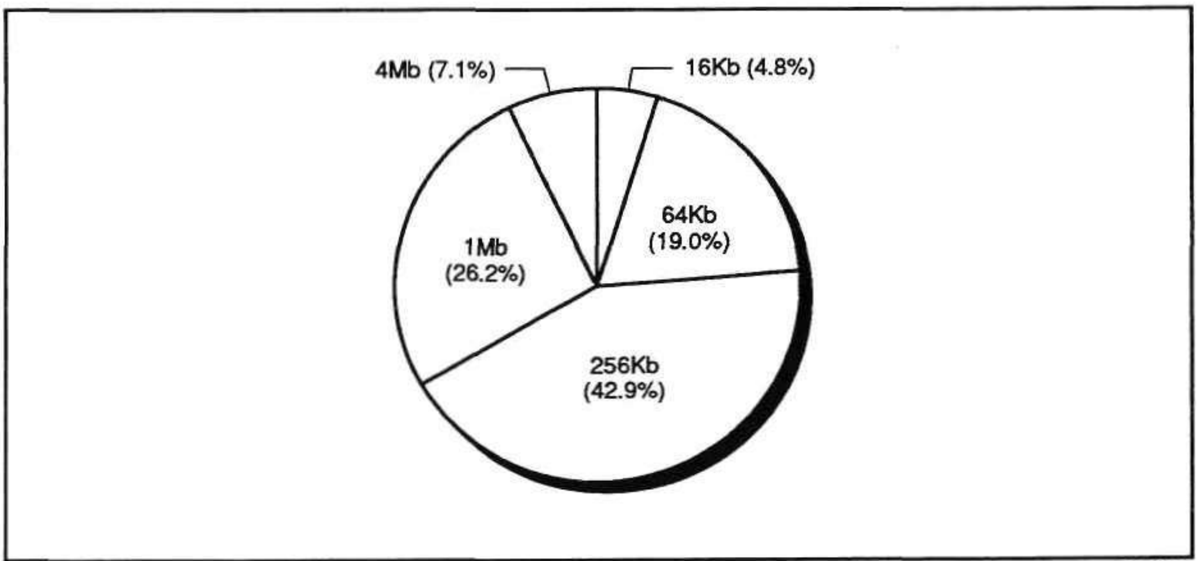
Figure 3-48
SRAM As a Percent of All MOS Purchases, Telecommunications



Source: Dataquest (December 1992)

G2003099

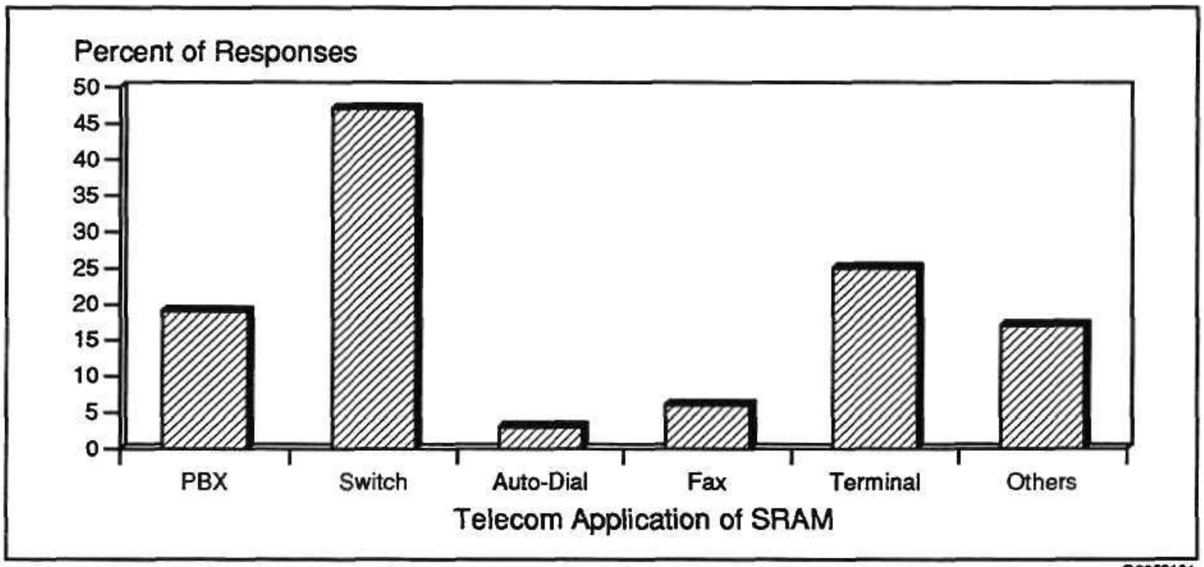
Figure 3-49
Density Preferences: Telecommunications Manufacturers



Source: Dataquest (December 1992)

G2003100

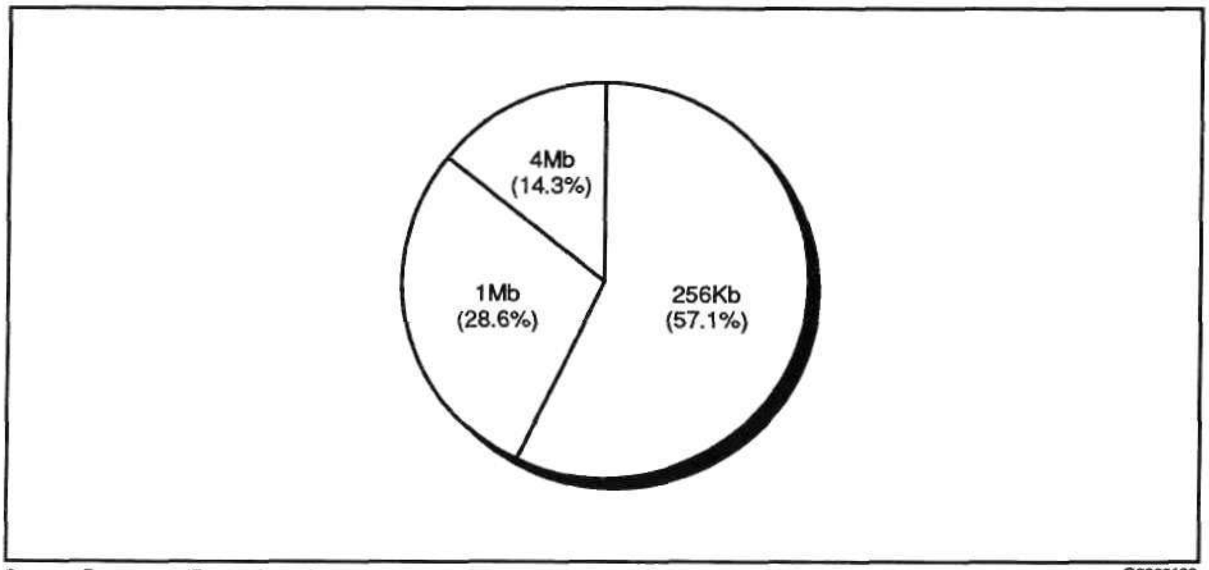
Figure 3-50
Telecommunications Equipment Manufacturers, by Application



Source: Dataquest (December 1992)

G2003101

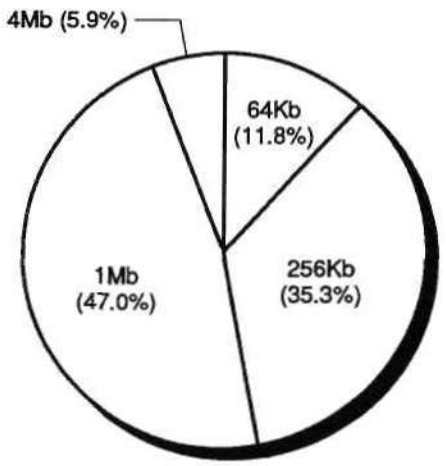
Figure 3-51
Density Preferences: PBX Switch Manufacturers



Source: Dataquest (December 1992)

G2003102

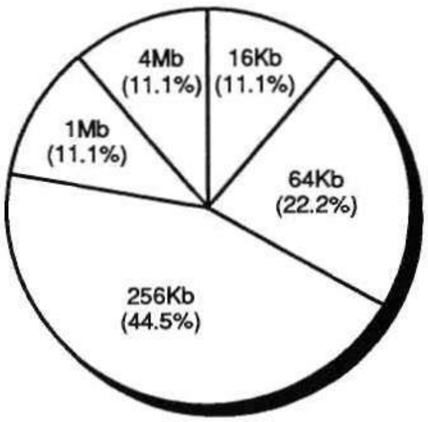
Figure 3-52
Density Preferences: Central Office Digital Switching Equipment



Source: Dataquest (December 1992)

G2003103

Figure 3-53
Density Preferences: Voice/Data Terminals



Source: Dataquest (December 1992)

G2003104

Chapter 4
Usage Trends

Figure 4-1 is a compilation of all responses by density preference. As in the earlier application-related splits, the vast majority of responses indicated that the 256Kb density was the single density that contributed most to their dollar spending on SRAMs. This is followed by almost even proportions going to the 64Kb and 1Mb densities, and likewise nearly equal portions going to the 16Kb and 4Mb densities.

Figure 4-2 shows speed preferences by device density. Slow devices (slower than a 70ns access time) accounted for the majority of responses for all densities except for the 4Mb SRAM, and the fastest speed grades were only mentioned in the mainstream densities of 64K, 256K, and 1Mb. Except in the case of the 256Kb SRAM, the 45ns to 70ns speed grade appears to be displacing the slow speed grade step by step as SRAM generations progress. A similar trend can be seen in the ramping of popularity of the 20ns to 35ns speed grade from the 16Kb density through the 1Mb density. The reverse of this trend appears to hold with the 10ns to 15ns speed grade, but this is most probably because, until recently, the less dense a part was, the faster it could be expected to operate. Designers were specifying smaller-than-ideal SRAMs in order to meet their speed needs.

The survey examined usage expectations for next year (see Figure 4-3). More than 60 percent of respondents anticipated no change in their purchasing pattern for their most important SRAM in the coming year. The next largest number of respondents expected to increase purchases of this device, while the smallest number expected to decrease usage. Details of these responses are shown in Figures 4-4 through 4-13.

Oddly enough, the trend shown in Figure 4-4 is the inverse of what would normally be expected. More than 70 percent of the users of the product nearest to obsolescence, the 16Kb SRAM, believed that there would be no change in their purchasing pattern for the device over the next year, while the device that is just now reaching its peak usage, the 1Mb, showed the smallest percentage of "no change" responses, at about 40 percent. This may have something to do with the fact that the tally is presented by the number of responses instead of units purchased. If we weight the responses by the average unit purchase data used to generate Figures 4-14, 4-16, 4-18, 4-20, and 4-22, the results show that the smallest unit volume players are the least likely to expect a change. The reason is time to market. Smaller players, or those playing into smaller markets, are often less responsive than the true tigers whose unit consumption is high. So those who purchase the highest volume are the most likely to move quickly to respond to competitive change. For example, the average unit consumption of 16Kb users expecting no change is only 14 percent of the annual unit volume of those expecting change, and for the 64Kb density, the ratio is down to 6.4 percent.

Of those expecting to see change, it is only natural that the respondents most expecting to see an increase in consumption are those using the most advanced densities: 1Mb and 4Mb SRAMs (see Figure 4-5). Figure 4-6 shows the expected percent increase in unit consumption of those who responded that an increase was expected. Bets are guarded, with the largest block expecting a modest zero to 24 percent increase in unit consumption.

Figure 4-7 attempts to find a relationship between the respondents who anticipate use decrease and the density that is currently their most important SRAM. It appears that, for whatever reason, the same general level of response is attained (about 5 percent) regardless of the density used. The variance is small enough as to be dismissable as noise. Figure 4-8 shows that the respondents expecting a decrease were also guarded, predominantly expressing beliefs that unit consumption decreases would be smaller rather than larger.

Nearly all of those respondents who expected to use a different device next year expect to use a denser device, rather than a different organization of the same density, or a lower-density device. The proportion of respondents planning to purchase new parts as their major SRAM purchase is shown by the density of the current device in Figure 4-9. Once again, it is interesting that those who expect the largest change are those who are using the most current devices, just as it was in Figure 4-4. It seems more rational to expect those using products that are more mature to be the first to anticipate density increases. Once again, we attribute this to the makeup of the base of respondents using the lower-density devices.

Naturally, the bulk of the respondents expecting to use a higher-density part plan to use the parts that will not be in a decline phase: the 1Mb and 4Mb densities (see Figure 4-10). Nearly equivalent numbers of respondents plan to upgrade to 64Kb and 256Kb densities, despite the maturity of the 64Kb part. Figure 4-11 is perhaps a more revealing perspective of the same information. It shows the migration path of those planning to make a change. By far, the largest portion of users plan simply to move to the next density, with a few respondents planning to stay within the same generation, and another few planning to skip a generation and move to the density-after-next (for example, from 16Kb to 256K).

Moving to another slice of the pie shown way back in Figure 4-3, respondents planned to upgrade the speed of the parts they purchase within the next year, but otherwise to stay with the same density and organization (see Figure 4-12). The largest changes are expected from users of 64Kb devices, most likely to be cache parts on the leading edge of speeds, which are used in RISC caches for demanding CPUs such as the R3000 and Hewlett-Packard's Precision Architecture. Dataquest believes that the lower responses for the 256Kb and 1Mb densities can be attributed to the relatively wide availability of high-speed versions of these devices during the six-month period preceding this survey.

Figure 4-13 shows the number of respondents expecting to see their end applications phased out by the end of next year. As was the case with the anticipated decrease of Figure 4-7, all responses fell within the 6 percent area, with differences in response by density apparently caused by random sampling noise.

By Density

The following paragraphs split out volume and package preference trends by device density.

16Kb

Figure 4-14 shows 16Kb SRAM unit purchases by respondent. Volume peaks in the 1,000 to 9,999 region, with only 5 percent of the respondents claiming to make purchases larger than 100,000 units annually. This will be seen to pale by comparison to the purchasing profiles for higher-density SRAMs. The package preference by respondent is shown in Figure 4-15. All respondents use plastic packages, with more than 50 percent still using plastic DIP. The majority of other respondents chose PLCC and SOIC/SOJ packages, with responses evenly split between the two. The popularity of the PLCC probably can be attributed to the fact that the SOIC and SOJ packages were not available until this device had entered the maturity phase of its life cycle.

Because Figure 4-15 is broken out by response, rather than by unit volume, it does not account for unit sales in showing package preference. Owing largely to the highest volume application reported during this survey, the volume by package type breaks out greatly in favor of the PLCC, which accounted for 63 percent of all devices reported, followed by plastic DIP at 20 percent and SOIC/SOJ at 17 percent.

64Kb

Figure 4-16 is not all that different from Figure 4-14, except that fewer respondents claimed to be using extremely small unit volumes of the device, with a higher peak now appearing in the modest 1,000 to 9,999 area. Volumes for the 64Kb device, like those for the 16Kb device, generally reflect that the bulk of those users for whom these parts represent their most significant SRAM purchases are not major market players.

Package preferences by respondent in the 64Kb market are also similar to those in the 16Kb market (see Figure 4-17). Plastic DIPs account for more than 50 percent of the responses, and a strong showing exists for the ceramic DIP because of some military responses. The SOIC/SOJ package was a latecomer to these two devices, which partly accounts for the strength of the responses favoring the plastic DIP package. PLCCs had a short period of grace in the 64Kb market before being largely displaced in the 256Kb and denser markets by the SOIC and SOJ packages. As a result, Figure 4-17 contains a small wedge of respondents who purchase a major volume of their SRAMs in the PLCC package. Some respondents also indicated that they were using bare SRAM dice, probably to be used in multichip modules, which are speed-driven and are well matched to the leading-edge speeds required by some RISC CPUs, as we found in the paragraph discussing Figure 4-12.

When responses were weighted to units consumed, a different partitioning evolved, with 88 percent of the packages used being SOICs and SOJs, 10 percent plastic DIPs, and less than 1 percent either ceramic DIP or PLCC. All respondents who said they used more than 100,000 units were using SOIC and SOJ packages.

256Kb

Figure 4-18 is indicative of the maturity stage of the 256Kb SRAM's life cycle. The bulk of the respondents said they were purchasing more than 1,000 units per year of their most important device, and about 15 percent purchased 100,000 or more units per year.

Package usage differs from that of less-dense devices, in that the SOIC and SOJ packages were used by more than one-third of the respondents (see Figure 4-19), whereas they were used by about one-fourth of the respondents whose major volume device was either 16Kb or 64Kb. Usage among respondents was divided almost exclusively between SOIC/SOJ and plastic DIP, with 56 percent going to the SOIC and SOJ packages, and 44 percent to the plastic DIP. Only about 10 percent of the respondents used packages that were neither plastic DIP nor SOIC/SOJ, and none of these devices accounted for as much as 1 percent of the total units purchased by all 256Kb respondents combined.

1Mb

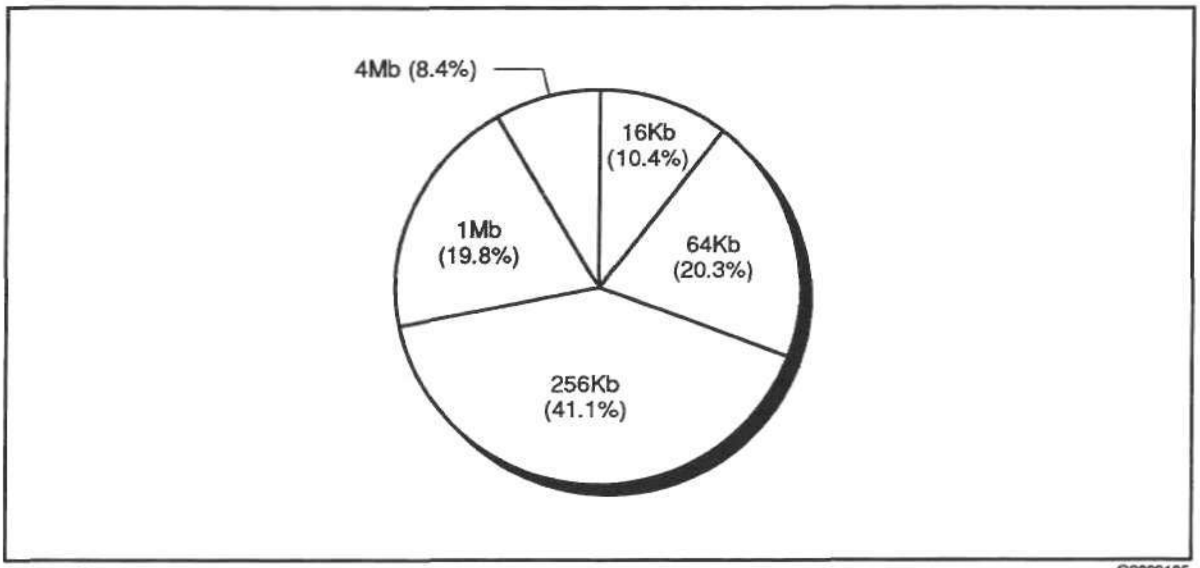
As in the 256Kb market, the 1Mb market is established and not in a decline phase, so the statistics of Figure 4-20 are reasonable. Seventy percent of the responses were from companies whose annual unit volume was more than 1,000 units, and more than 12 percent were purchasing 100,000 or more units per year.

For a change, DIP packages accounted for less than half of the responses (see Figure 4-21), with surface-mount accounting for nearly 60 percent of the responses, and more than 70 percent of the units used. PLCCs make a surprisingly strong showing, in spite of the limited supplier base, accounting for 4 percent of the units reported, but are overwhelmed by the use of SOICs and SOJs, which accounted for a full 68 percent of all units. This density had the largest percentage of respondents who declined telling their package preference, accounting for 19 percent of the units tallied.

4Mb

Our survey results were not statistically significant for the 4Mb device, so package preferences and shipment volumes will not be shown graphically. Dataquest estimates that fewer than 10,000 units of 4Mb SRAM shipped in 1992, and that, while significant volumes of 4Mb P-SRAMs were used by two North American manufacturers of hand-held computers, the 4Mb P-SRAM is not generally popular in the system design community.

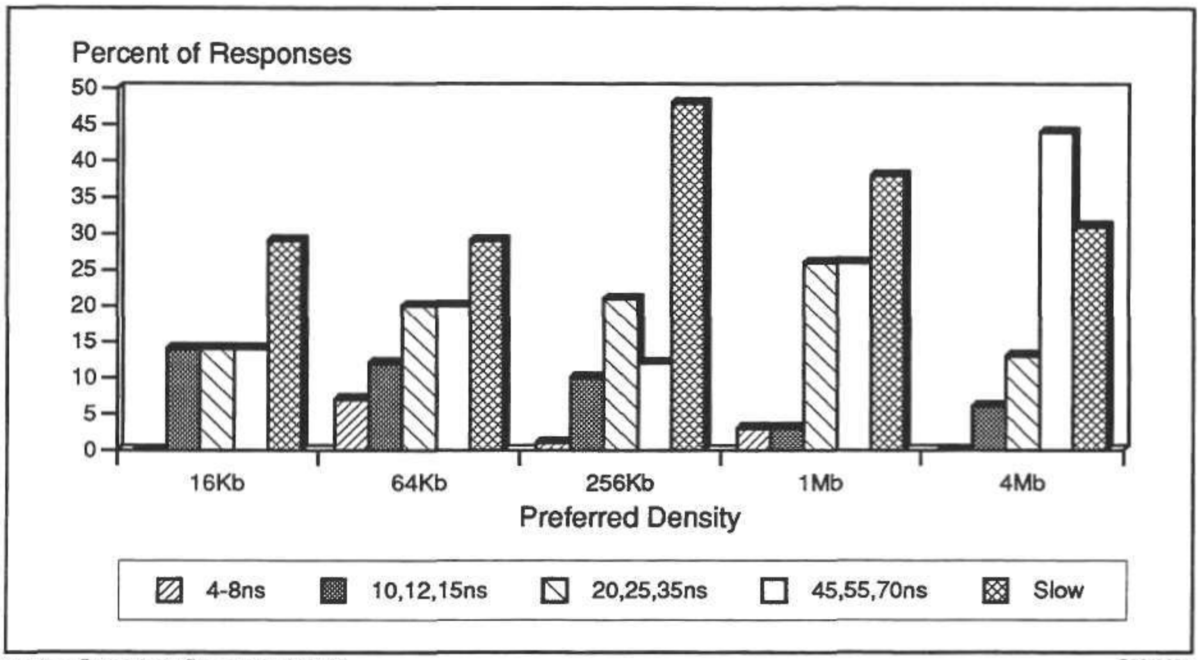
Figure 4-1
Density Preferences: All Manufacturers



Source: Dataquest (December 1992)

G2003105

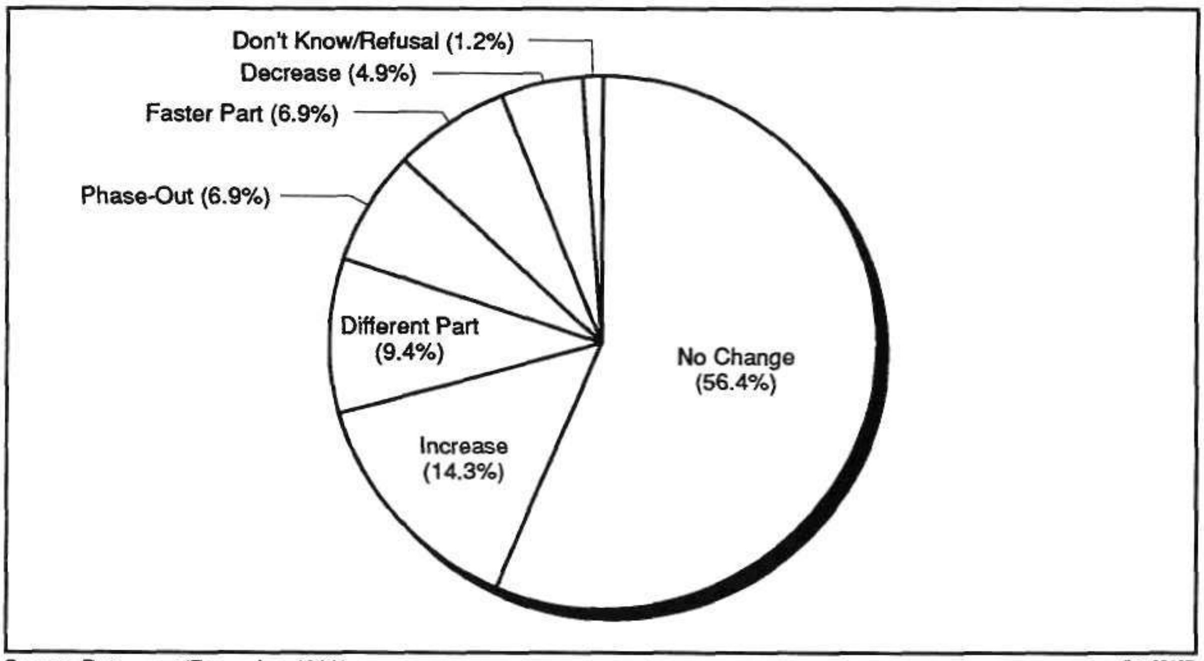
Figure 4-2
Speed Preference, by Device Density



Source: Dataquest (December 1992)

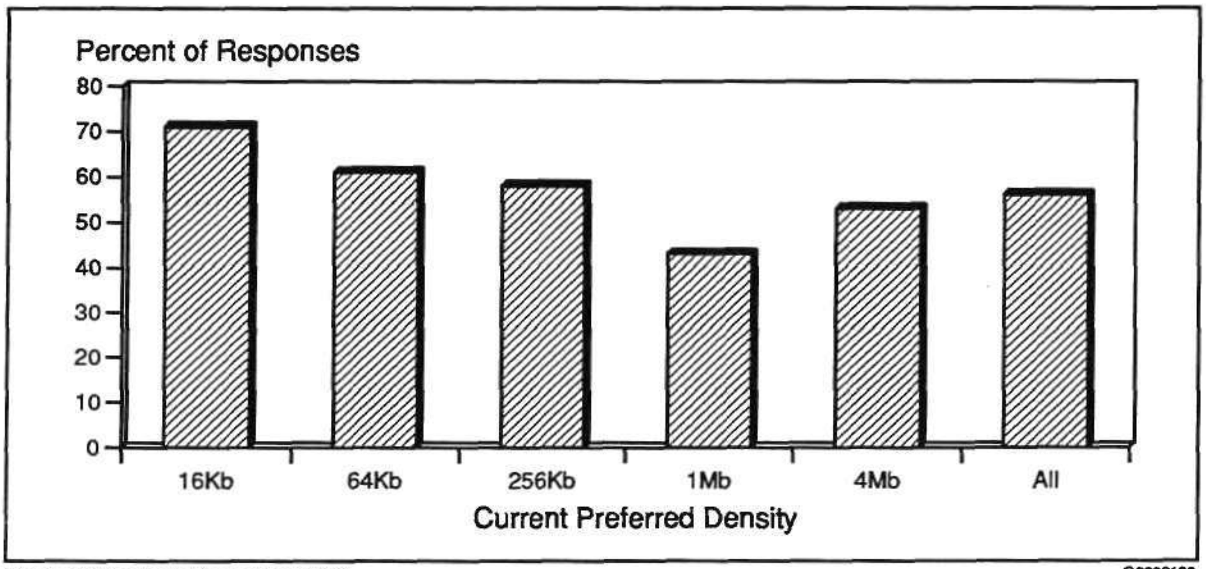
G2003106

Figure 4-3
SRAM Usage Expectations for Next Year



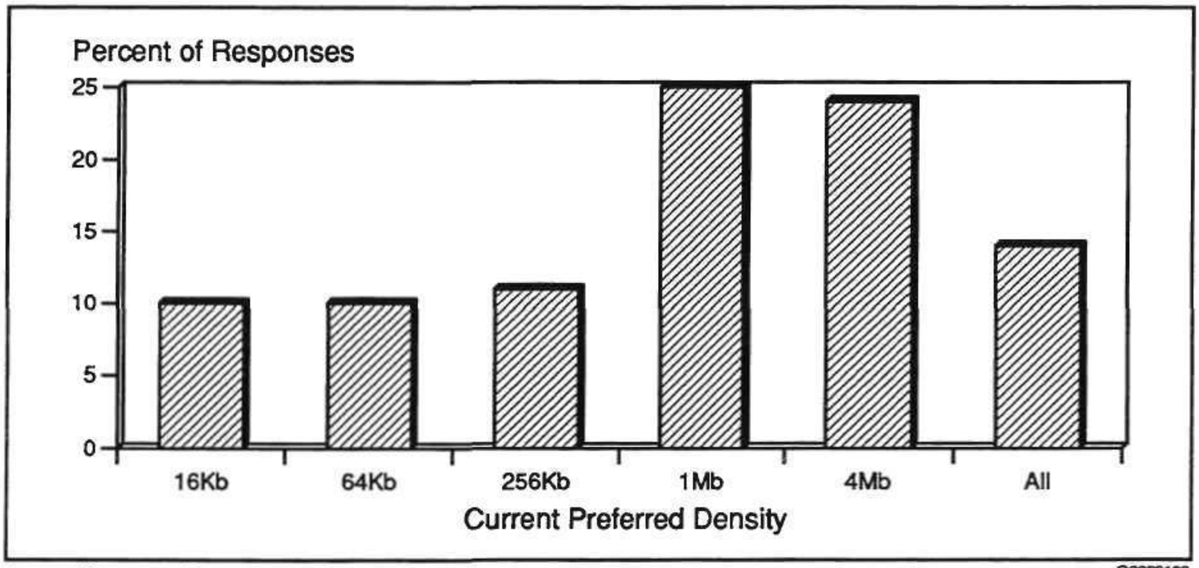
Source: Dataquest (December 1992) G2003107

Figure 4-4
Responses Anticipating No Change, by Device Density



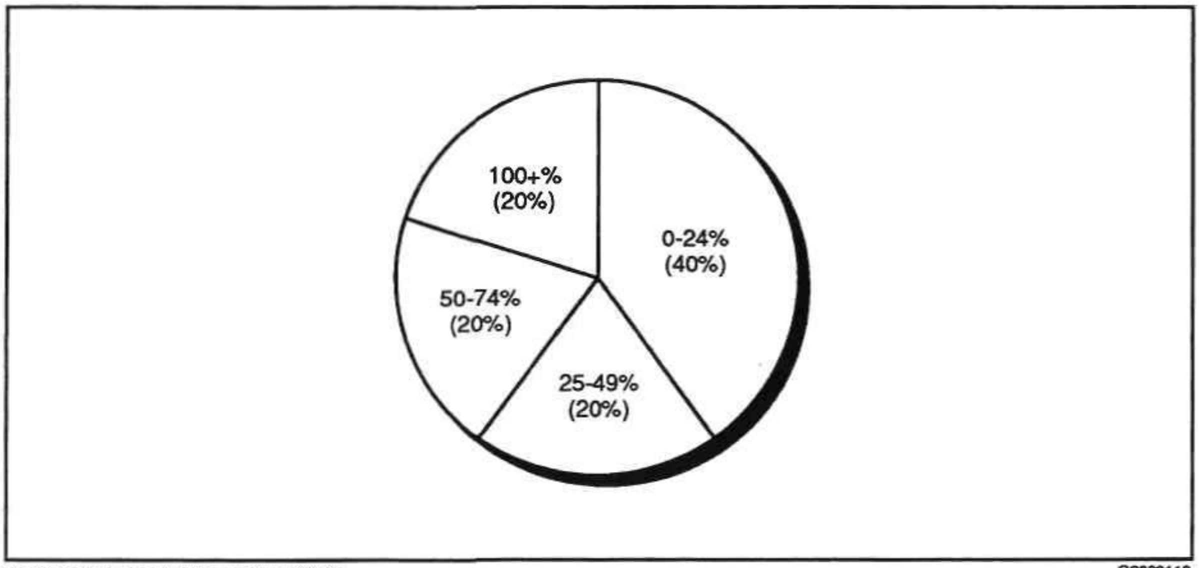
Source: Dataquest (December 1992) G2003108

Figure 4-5
Responses Anticipating Use Increase, by Device Density



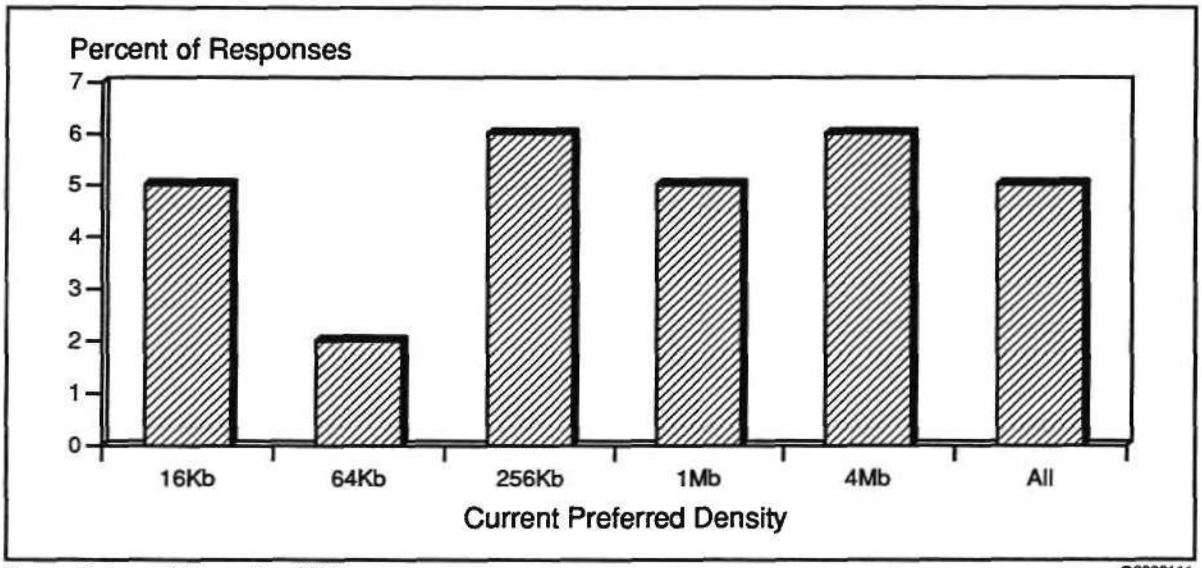
Source: Dataquest (December 1992)
G2003109

Figure 4-6
Expected Unit Consumption Increase Next Year



Source: Dataquest (December 1992)
G2003110

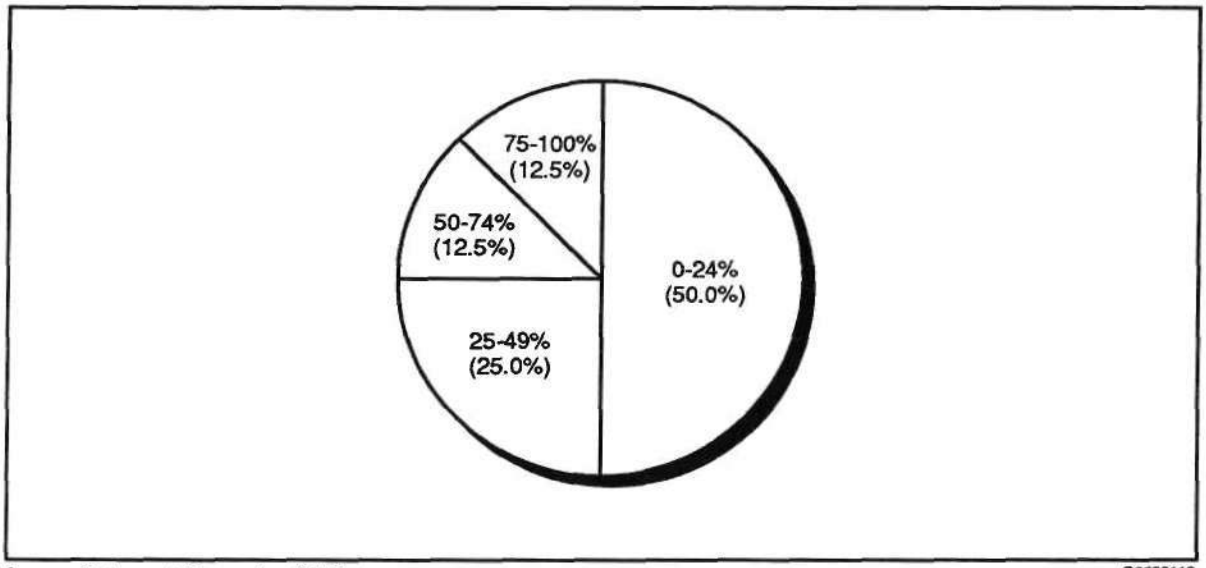
Figure 4-7
Responses Anticipating Use Decrease, by Device Density



Source: Dataquest (December 1992)

G2003111

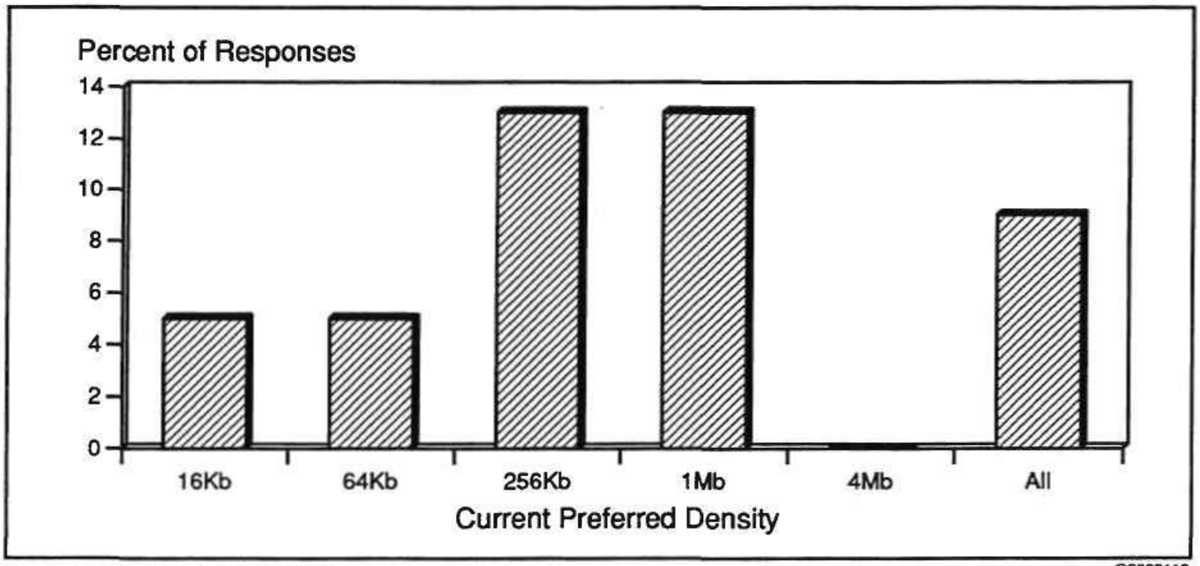
Figure 4-8
Expected Unit Consumption Decrease Next Year



Source: Dataquest (December 1992)

G2003112

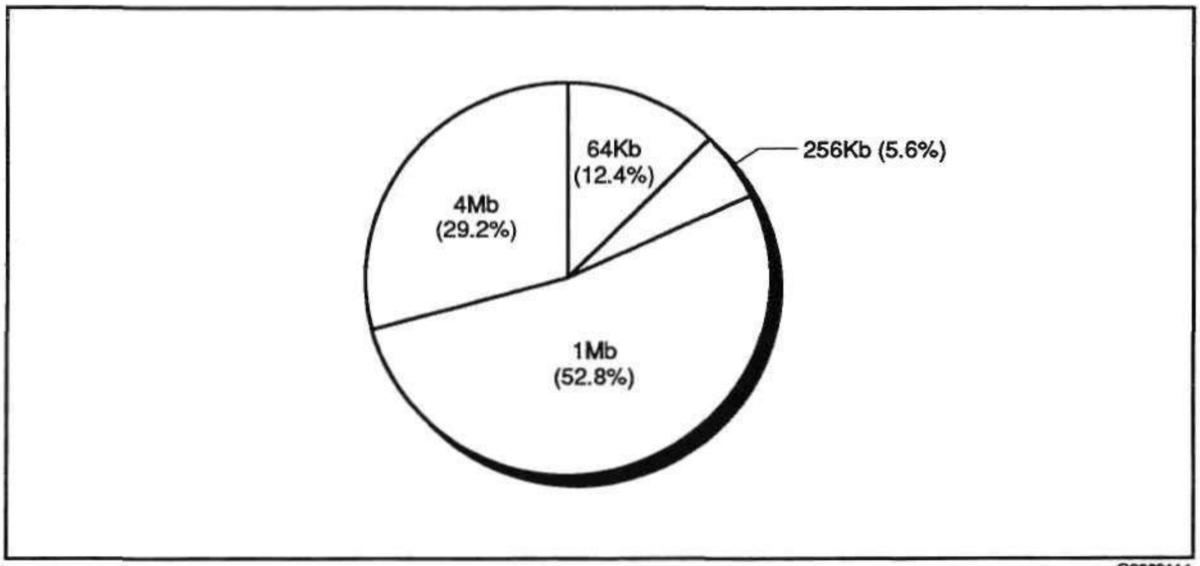
Figure 4-9
Responses Anticipating Different Device Use, by Device Density



Source: Dataquest (December 1992)

G2003113

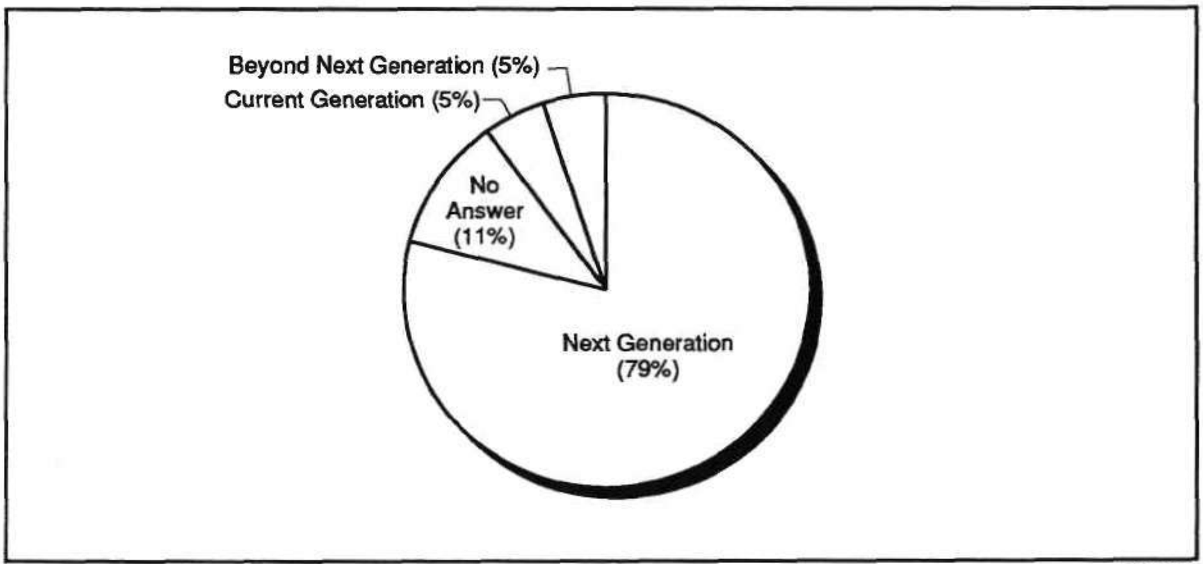
Figure 4-10
New Part Planned for Next Year



Source: Dataquest (December 1992)

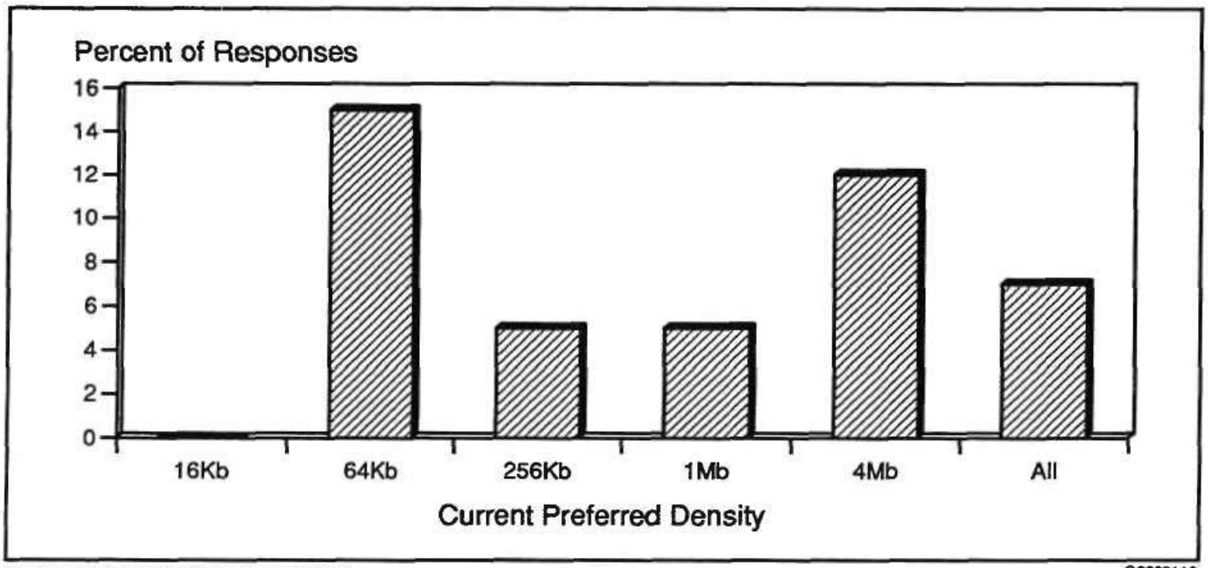
G2003114

Figure 4-11
Anticipated Migration to New Part



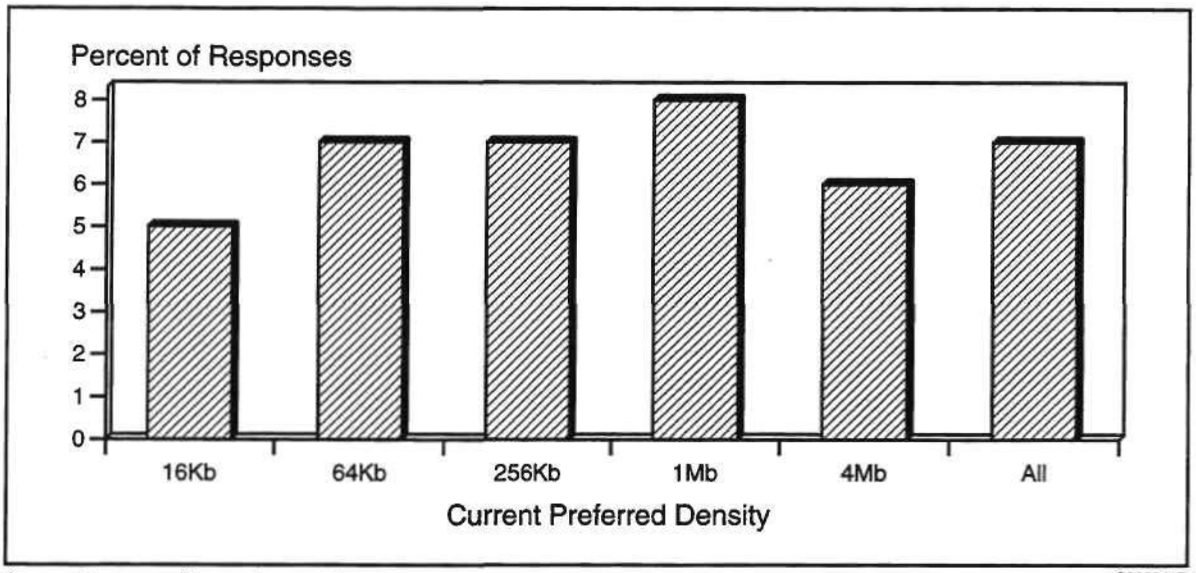
Source: Dataquest (December 1992)
G2003115

Figure 4-12
Responses Expecting to Upgrade Speed, by Device Density



Source: Dataquest (December 1992)
G2003116

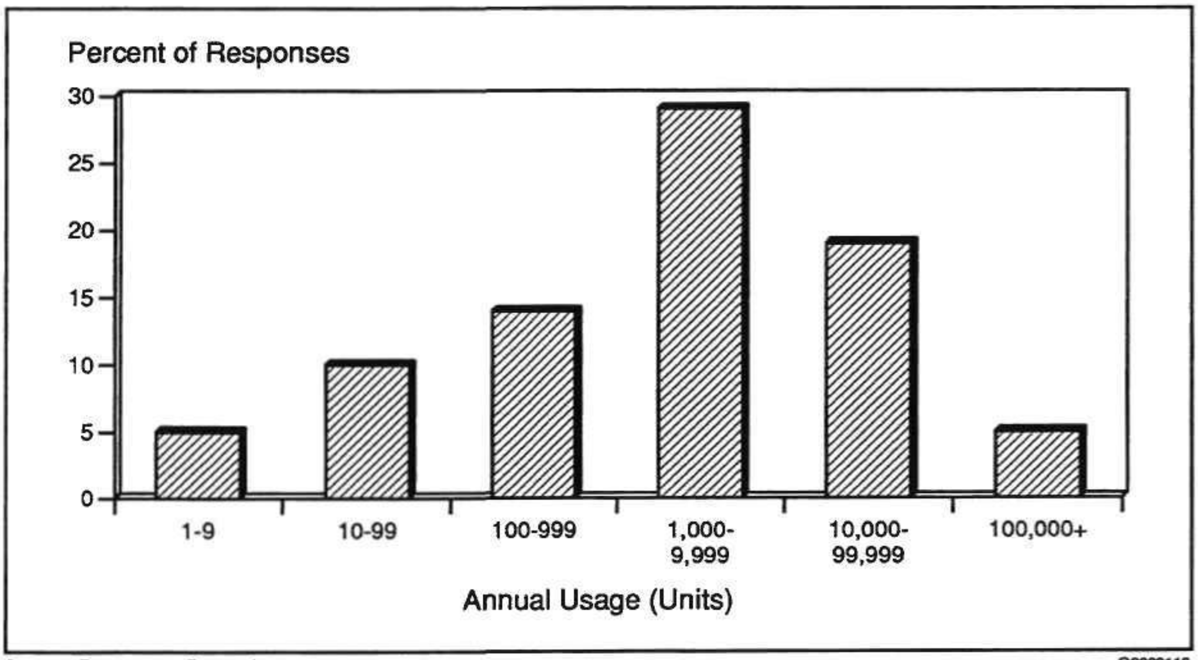
Figure 4-13
Responses Anticipating Application Phaseout, by Device Density



Source: Dataquest (December 1992)

G2003117

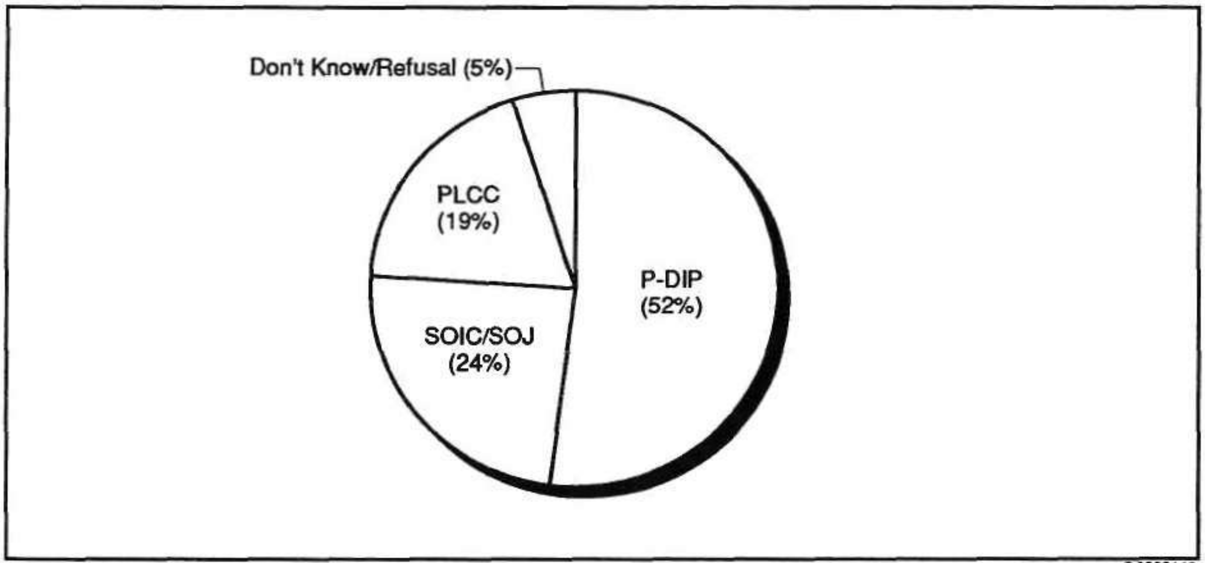
Figure 4-14
Volume of 16Kb Purchases



Source: Dataquest (December 1992)

G2003118

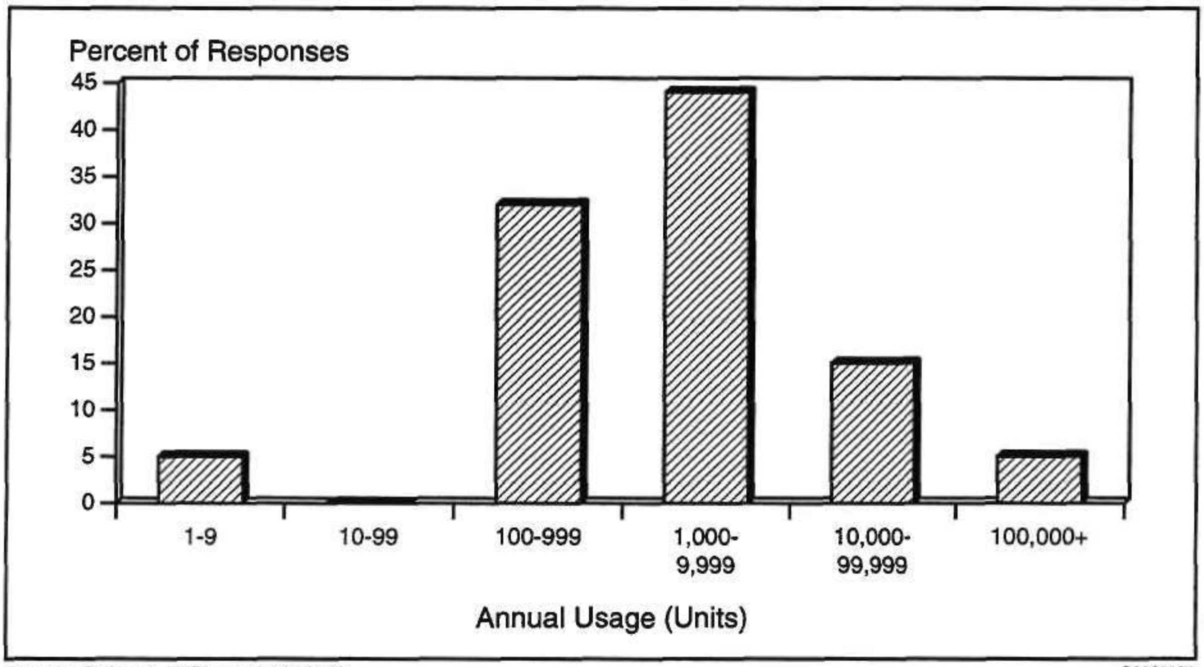
Figure 4-15
Package Preference for 16Kb SRAMs



Source: Dataquest (December 1992)

G2003119

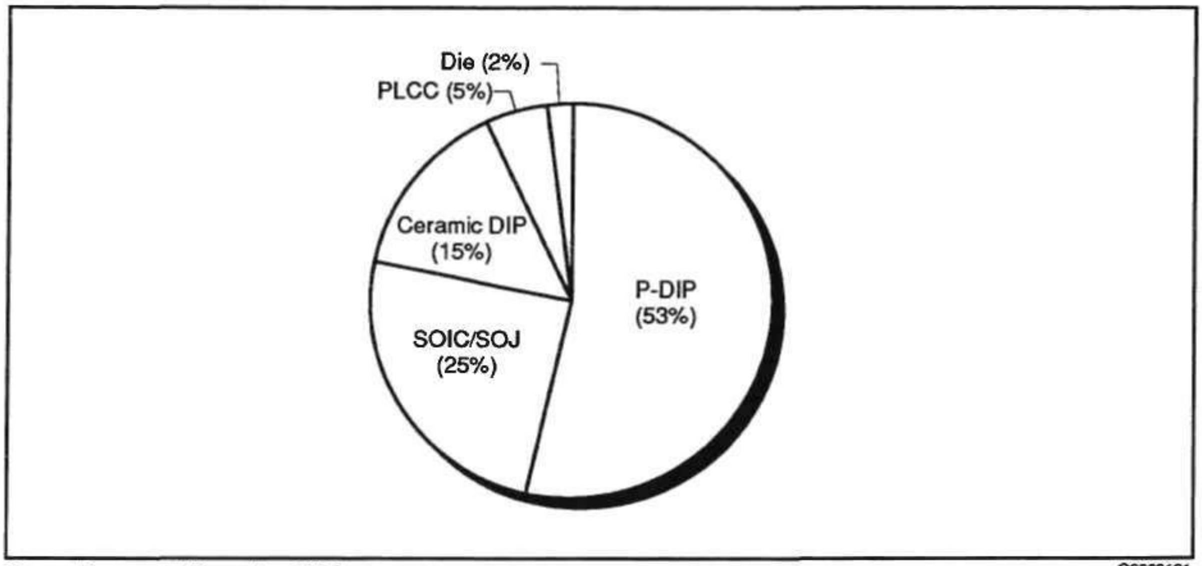
Figure 4-16
Volume of 64Kb Purchases



Source: Dataquest (December 1992)

G2003120

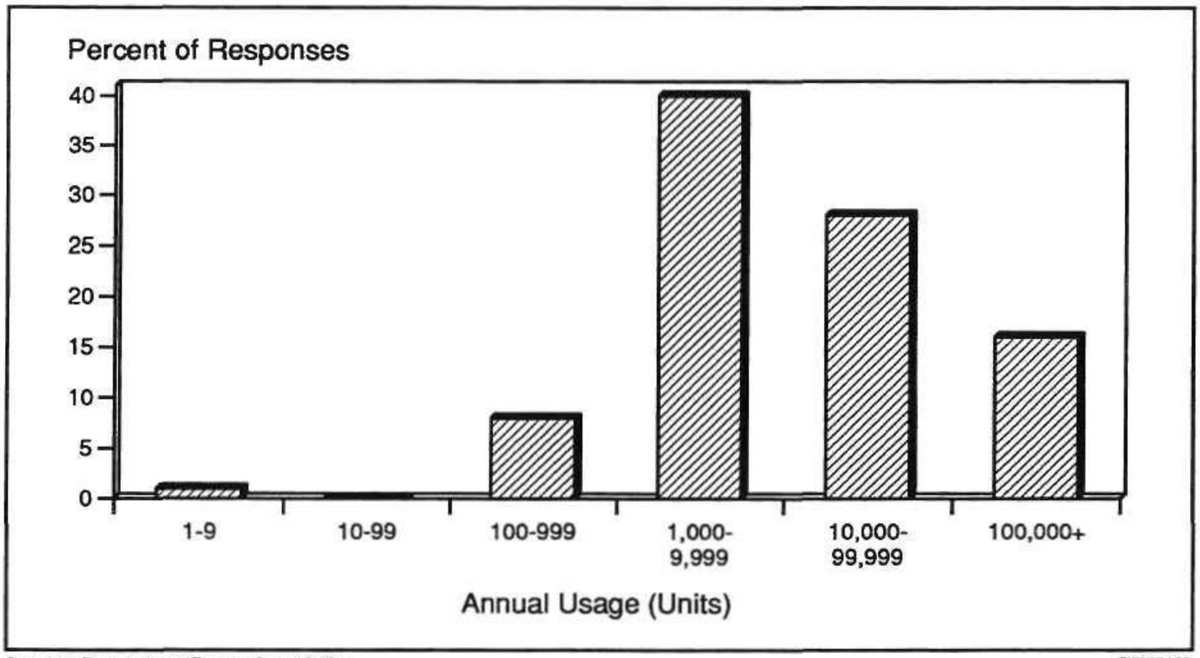
Figure 4-17
Package Preference for 64Kb SRAMs



Source: Dataquest (December 1992)

G2003121

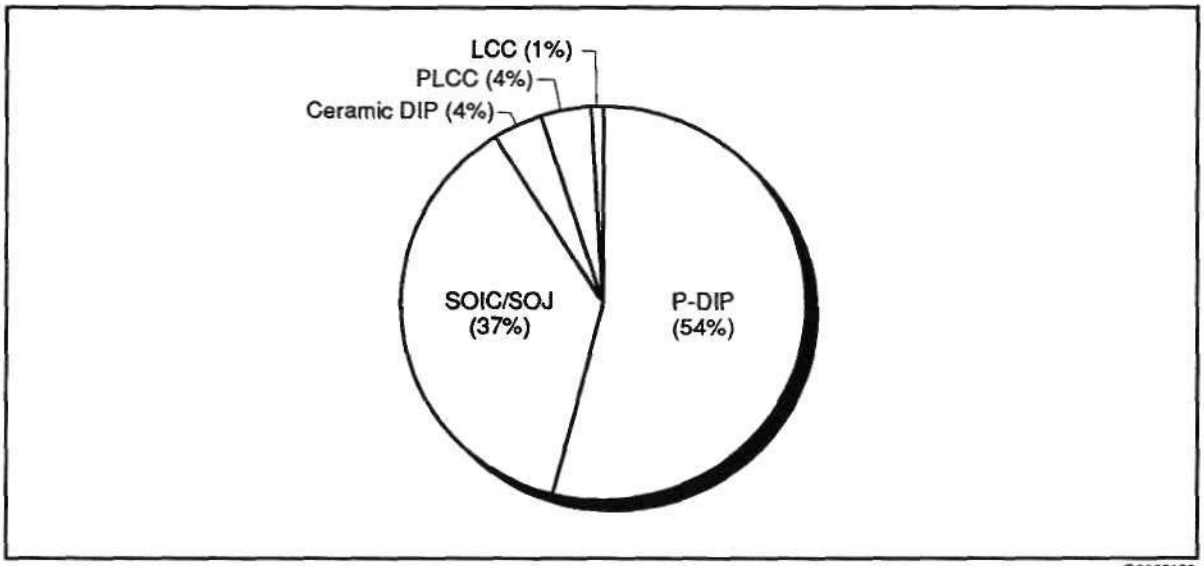
Figure 4-18
Volume of 256Kb Purchases



Source: Dataquest (December 1992)

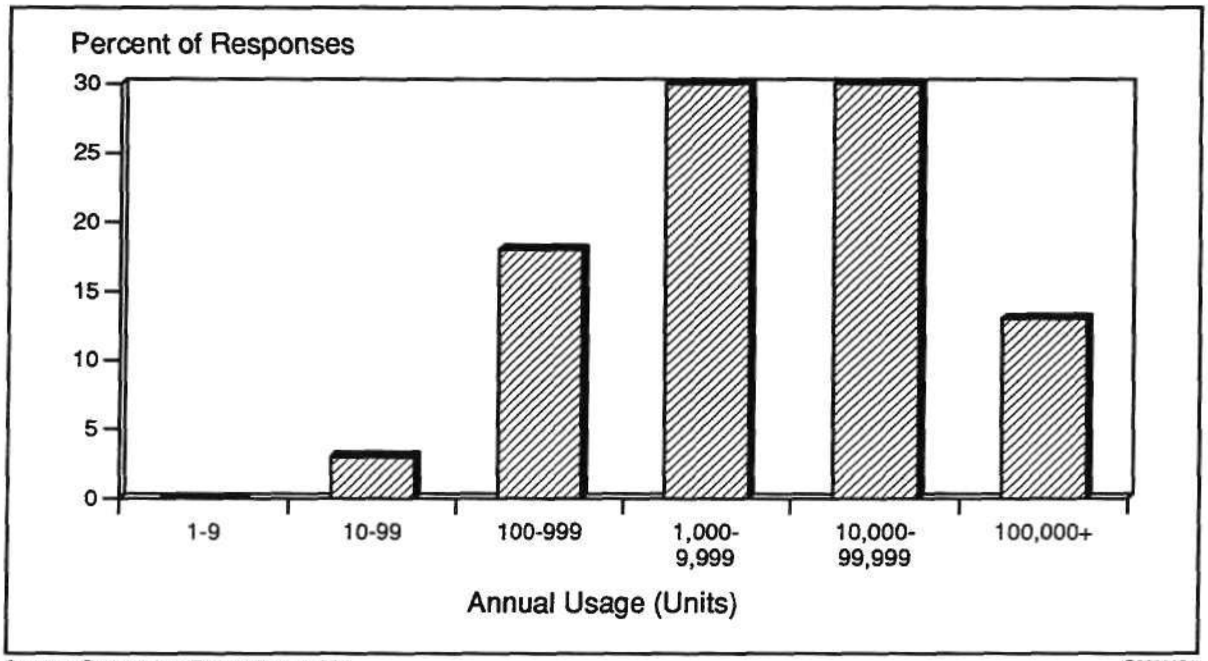
G2003122

Figure 4-19
Package Preference for 256Kb SRAMs



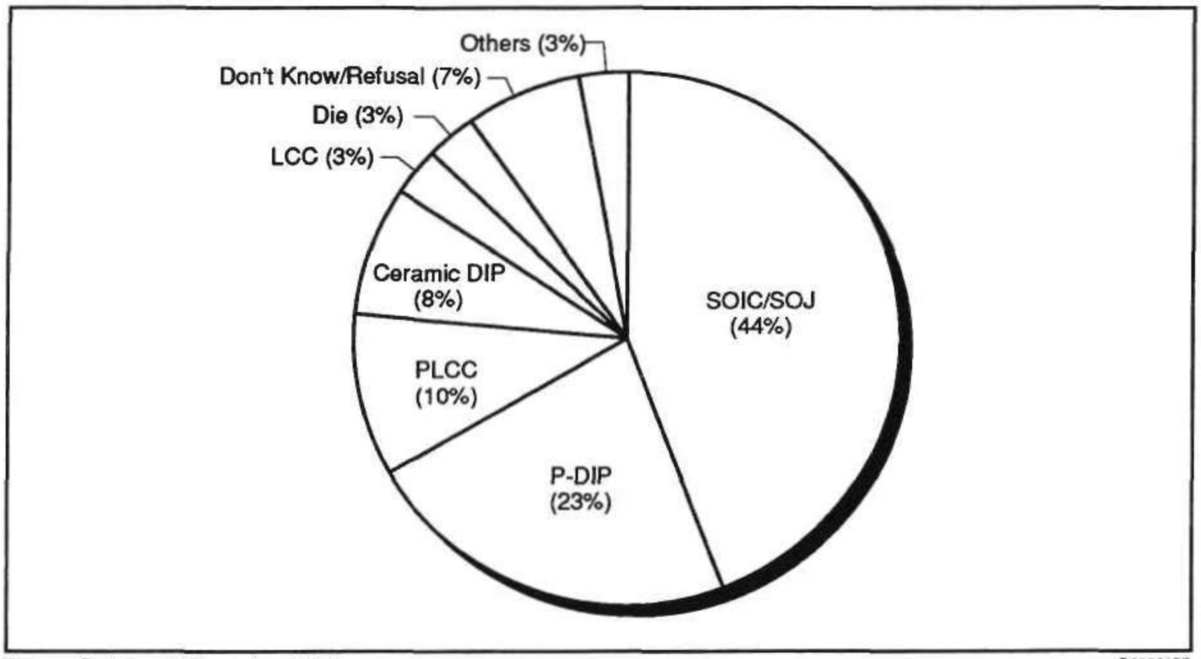
Source: Dataquest (December 1992) G2003123

Figure 4-20
Volume of 1Mb Purchases



Source: Dataquest (December 1992) G2003124

Figure 4-21
Package Preference for 1MB SRAMs



Source: Dataquest (December 1992)

G2003125

Dataquest®

a company of
The Dun & Bradstreet Corporation

Dataquest Incorporated
1290 Ridder Park Drive
San Jose, California 95131-2398
United States
Phone: 01-408-437-8000
Facsimile: 01-408-437-0292

Dataquest Incorporated
Dataquest/Ledgeway
The Corporate Center
550 Cochituate Road
Framingham, Massachusetts 01701-9324
United States
Phone: 01-508-370-5555
Facsimile: 01-508-370-6262

Dataquest Europe Limited
Roussel House Broadwater Park
Denham, Near Uxbridge
Middlesex UB9 5HP
England
Phone: 44-895-835050
Facsimile: 44-895-835260/1

Dataquest Japan Limited
Shinkawa Sanko Building
1-3-17 Shinkawa Chuo-ku
Tokyo 104
Japan
Phone: 81-3-5566-0411
Facsimile: 81-3-5566-0425

Offices in
Costa Mesa, Munich,
Paris, and Seoul

Representative Agencies in
Bangkok, Hong Kong,
Kronberg, North Sydney,
Singapore, and Taipei

Worldwide MOS Memory Forecast

August 31, 1992

Source: Dataquest

Market Statistics

Dataquest

Memories *Worldwide*

MMRY-SEG-MS-9203

Worldwide MOS Memory Forecast

August 31, 1992

Source: Dataquest

Market Statistics

Dataquest®

File behind the ***Market Statistics*** tab inside the binder labeled **Memories** ***Worldwide***

Published by Dataquest Incorporated

Worldwide MOS Memory Forecast

Table of Contents

Note: All tables show estimated data.

Note: All tables show estimated data.

Worldwide MOS Memory Forecast

Introduction

This document contains detailed information on Dataquest's view of the MOS memory market. Included in this document is:

- 1992-1996 MOS memory forecast

Analyses of the MOS memory market provide insight into high-technology markets and reinforce estimates of consumption, production, and company revenue.

More detailed data on this market may be requested through our client inquiry service. Dataquest's qualitative analysis of these data can be found within the *Dataquest Perspectives* located within the binder of the same name.

Segmentation

This section defines the market segments that are specific to this document. For a complete description of all market segments tracked by Dataquest, please refer to the *Dataquest High-Technology Guide: Segmentation and Glossary.*

Dataquest defines the MOS memory market as DRAM, SRAM, EPROM, ROM, EEPROM, and flash memory. In this quarterly memory shipment volume, Dataquest segments the MOS memory market by product type and density according to the following scheme:

- DRAM (densities from 64K through 256Mb)
- Fast SRAM (densities from 16K through 16Mb)
- Slow SRAM (densities from 16K through 16Mb)
- EPROM (densities from 16K through 16Mb)
- ROM (densities from 32K through 256Mb)
- EEPROM (densities from 256b through 1Mb)
- Flash memory (densities from 256K through 64Mb)

Definitions

This section lists the definitions that are used by Dataquest to present the data in this document. Complete definitions for all Dataquest terms can be found in the *Dataquest High-Technology Guide: Segmentation and Glossary.*

Product Definitions

DRAM: Includes Dynamic RAM, Multiport-DRAM (M-DRAM), and Video-DRAM (V-DRAM). DRAMs have memory cells consisting of a single transistor, and require regular externally cycled memory cell refreshes. These are volatile memories and addressing is multiplexed.

SRAM: Includes Static RAM, Multiport-SRAM (M-SRAM), Battery Backed-Up SRAM (BB-SRAM), and Pseudo-SRAM (P-SRAM). SRAMs have memory cells consisting of a minimum of four transistors (P-SRAMs have memory cells consisting of a single transistor and are similar to DRAMs). SRAMs do not require externally cycled memory cell refreshes. These are volatile memories and addressing is not multiplexed (except in the case of P-SRAM).

EPROM: Erasable Programmable Read-Only Memory. This product classification includes Ultraviolet EPROM (UV EPROM) and One-Time Programmable Read-Only Memory (OTPROM). EPROMs have memory cells consisting of a single transistor, and do not require any memory cell refreshes. These devices are considered nonvolatile memories.

Mask ROM: Mask-Programmable Read-Only Memory. Mask ROM is a form of memory that is programmed by the manufacturer to a user specification using a mask step. Mask ROM is programmed in hardware rather than software. These devices are considered nonvolatile memories.

EEPROM: Electronically Erasable Programmable Read-Only Memory. Included are Serial EEPROM (S-EEPROM), Parallel EEPROM (P-EEPROM), and Electronically Alterable Read-Only Memory (EAROM). EEPROMs have memory cells consisting of a minimum of two transistors, and do not require memory cell refreshes. This product classification also includes Nonvolatile RAM (NV-RAM), also known as Shadow RAM. These semiconductor products are a combination of SRAM and

EEPROM technologies in each memory cell. The EEPROM functions as a shadow backup for the SRAM when power is lost. These devices are considered nonvolatile memories.

Flash Memory: Includes nonvolatile products designated as Flash EPROM/EEPROM that incorporate either 5V or 12V programming supplies and one-transistor (1T) or two-transistor (2T) memory cells with electrical programming and fast bulk/chip erase. These devices are considered nonvolatile memories.

Regional Definitions

North America: Includes United States and Canada

United States: Includes 48 contiguous states, Washington, D.C., Alaska, Hawaii, and Puerto Rico

Europe: Western Europe

Japan: Japan

Asia-Pacific/Rest of World: All other countries

Line Item Definitions

Factory revenue: Calculated by multiplying a product's overall unit shipment total by the product's ASP.

Unit shipments: All unit shipments, both merchant and captive, for memory suppliers selling to the merchant market; excludes totally captive suppliers, where devices are manufactured solely for the company's own use.

Average selling price (ASP): The average billing price per unit that is paid for a product when it leaves the factory; takes into account discounts given to the distribution channel and multiple-purchase discounts. Prices are averaged over all companies, package types, lot sizes, and the entire speed mix, and they represent sales to both military and commercial accounts.

Number of bits: Calculated by multiplying a product's unit shipment total by the number of bits that a single unit of that product contains.

Price per bit (PPB): Calculated by dividing a product's ASP by the number of bits that a single unit of that product contains. This number is reported in microdollars; there are 1 million microdollars per U.S. dollar. For an overall product category (for example, DRAM), this metric is calculated by dividing the category's total factory revenue by its total number of bits.

Forecast Methodology

Dataquest publishes five-year unit shipments and factory revenue forecasts for the MOS memory market. In doing so, Dataquest utilizes a variety of forecasting techniques (both qualitative and quantitative) that vary by technology area. An overview of Dataquest forecasting techniques can be found in the *Dataquest Research Methodology Guide*.

MOS Memory Forecast Methodology

The following is Dataquest's MOS memory forecast methodology:

- Survey the leading memory vendors throughout the year for company expectations, as well as for their views of the markets that they participate in.
- Examine statistics provided by a number of industry organizations (such as WSTS and MITI) for up-to-date monthly trends.
- Perform time-series analysis as well as supply judgmental industry knowledge to product and applications trends.

MOS Memory Forecast Assumptions

The following are assumptions for market cycle issues:

- Price elasticity is the basic driving mechanism for all MOS memories. Prices are now about 30 percent of those the industry offered at the end of the last cyclical upturn (summer 1989). These reductions will drive the next cyclical upturn, which we believe is now under way.

- The market growth will go through another "typical" growth cycle, with significant expansion beginning in 1992, accelerating in 1993, peaking in 1994, and contracting in 1995. We assume that this cycle will exhibit about the same evolutionary path as the strong growth cycles that crested in 1988-1989, 1983-1984, 1979-1980, and 1973-1974.
  - During those cycles, which ran from 16 to 20 quarters in length, the quarterly revenue run rate grew fourfold to tenfold from trough to the following peak. During the subsequent contractions, which ran three to four quarters, the quarterly revenue run rate dropped 25 to 50 percent, before stabilizing and establishing a new base. Prices per bit dropped 50 to 80 percent during these contractions.
  - We expect this cycle to be more moderate, both in its expansionary and contraction phase, because of the slower overall growth rate of the market, the increased attention being paid to profitability in all corporate strategies, and the restrictions put on pricing by the intervention of various government agencies in Europe and the United States.
- We expect that, for this forecast period, MOS memory will gain in its share of the overall semiconductor industry revenue, as a part of a natural cyclical pattern, but that in the contraction phase it will retreat from the cyclical high-water mark of 1994.
- The capacity-demand balance that existed in the market, and the net strength of demand, has historically determined the market dynamics of revenue and profitability. Demand for bits has always grown, though from time to time not enough to compensate for declining per-bit prices brought on by supply excesses. This has caused a market contraction.
- Prices have risen just once (in 1988) during the supply-constrained shortage. We do not anticipate such a severe imbalance that would again raise prices in any but a temporary way; that is, there may be product imbalances, such as package types, or organization mix, but we do not expect any aggregate, across-the-board shortages.

Regional Issues

The weakness of the Japanese market in the first half of 1992 will serve as a significant constraint on worldwide memory market growth for 1992. We expect demand in Japan to be turned around by year-end, and all four regions of the word will advance in concert in the early part of 1993. The secular trend calls for Asia-Pacific/ROW taking an increasing share of the MOS memory market, at the expense of both Japan and the United States. We expect Europe to manage to retain its present share of consumption by a tariff structure that encourages domestic production of both MOS memories and the systems using them.

Worldwide Economic Growth Expectations

Overall, the world economies continue to face an uncertain future, and there is some concern that we will drift back into a recession. The Dataquest view of future economic activity anticipates the growth rates for 1992 through 1996 shown at the bottom of this page.

DRAM Forecast Assumptions

The following sections detail our DRAM forecast assumptions.

Estimated Real GDP Growth Rates, 1991-1996 (Percentage)

	1991	1992	1993	1994	1995
United States	-0.7	2.1	2.5	2.3	2.6
Europe	2.1	1.2	2.9	3.5	3.7
Japan	4.4	2.0	3.3	3.5	4.0
Asia-Pacific/ROW	7.5	6.8	7.2	7.4	7.7

Bit Growth

In the short term, we assume that the DRAM market is stumbling through the beginning of a cyclical upturn that will accelerate the bit-growth rate, absorb available capacity, slow the PPB rate of decline, and improve profits through the end of 1994. At that time, as supply again passes demand, the market will weaken and revenue will contract.

Over the long term, we expect to see a continued decline in the rate of bit growth rate, to average about 60 to 65 percent per year from 1992 through 1996, and continue to slow thereafter.

Product Life Cycles and Trends

We assume that the price crossover from the 4Mb to the 16Mb DRAM will occur in late 1994 or early 1995, thereby giving the 4Mb product a slightly longer lifetime than earlier generations. We further expect this lengthening trend to continue at the 16Mb and 64Mb densities.

As bit growth slows and processing becomes more expensive, we expect the floor price, under which the product cannot be sold profitably, to rise from generation to generation. This trend will be a contributing factor in the gradual lengthening of DRAM product lifetimes. (This trend may be slowed through advanced-technology cost-sharing joint ventures, such as have been increasingly frequent in the memory/DRAM business.)

Although 1Mb DRAMs showed a new resurgence of life early in 1992, we do not expect their life-cycle curves to be significantly different from those of their predecessors; that is, the three-generations-at-a-time hypothesis may be real, but will in fact be very similar from what has gone before.

Product Differentiation

Though the DRAM market is becoming differentiated with the growth of wide DRAMs, LP, 3.3V DRAMs, and new architectures, we believe that the forecast period here will continue to be dominated by mostly standard, mainstream parts. Even in the outer years, more than 80 percent of the units will continue to be 5V, and more than 70 percent are expected to be x1 or x4.

Impact of Flash

Over the long term, flash memories will have minor impact on DRAMs, and only in those applications where software is downloaded into DRAM and read repeatedly. In the longer term, flash has the potential for significant cost-per-bit advantages because of superior scaling and reduced cell complexity.

At the major market interfaces with DRAMs and flash memories, we expect SRAMs and DRAMs to continue to coexist in the forecast period, though several high-data-rate DRAM architectures may absorb both standard DRAM and SRAM while creating new, bit-hungry applications. Flash's greatest impact is expected to be at the later 16Mb and 64Mb densities, and will mostly be an NVM replacement and new-market development product.

Major Applications

Software is emerging as the silent driver of DRAM demand. It is no longer so easy to count hardware/boxes and multiply to get DRAM demand. Software moves independently, often finding its way into the installed base long after the hardware has been sold.

At present, fully 70 percent of DRAMs go into small computer systems, from hand-helds to workstations. Another 15 percent go to other EDP and office equipment, such as laser printers, fax machines, and copiers. The remainder go elsewhere. But despite this categorical concentration, the DRAM end-use market is actually quite broad, as distributed processing power finds its way into all manner of electronic equipment and computers of all sizes are made useful in a broad range of endeavors and activities. PCs, or PC-like small systems, are found in the home, at school, in industrial environments, in white-collar office and small business, and at virtually every retail outlet.

This pervasiveness is both good and bad. It is a good buffer and will prevent any rapid deterioration of demand, as was seen in earlier cycles. But because demand is diffused, explosive growth is also precluded from ever repeating the 1983 to 1984 first PC wave.

At the same time, the aftermarket for DRAMs has also grown, which appears to be buffering the industry from the strong upturns and downturns experienced in the past. The installation of the STA in 1986, we believe, has helped moderate the aggressive price cutting in the down cycle, and kept production costs close to market prices.

Graphics applications are becoming major forces driving the market. However, these applications will see their greatest growth period after the 16Mb comes into volume production in the mid-1990s.

SRAM Forecast Assumptions

The following are our SRAM forecast assumptions:

- Historical trends will tend to repeat themselves over the next five years. These drive the following:
  - Market composition by density of device
  - Price per bit, and relative PPB for various densities
  - Migration toward faster devices
  - Migration toward wider parts
- PC caches will continue to consume the lion's share of fast SRAMs, even as battery-operated PCs grow in stature.
- Static RAM ASPs will track dynamic RAM ASPs, however, slower SRAMs will be sold at a bargain as the demand for faster parts tends to obsolete speeds slower than 100ns.
- Pseudo-static RAMs will grow in acceptance from their limited stance today.
- There will continue to be a speed gap in all SRAM densities where sales will be low.
- Applications for slow SRAMs will continue to be far-flung.
- There will be a cyclical softening of the market in 1995.
- The economy will strongly impact the bit-growth rate of slow SRAMs and the ASPs of fast SRAMs.
- The SRAM market will grow more quickly than will the DRAM market, but will continue to stay the significantly smaller of the two.
- The SRAM market is not seriously threatened by new technologies such as flash, cached DRAM, Rambus, and microprocessors with on-board cache. These technologies will coexist with SRAM, and may even create the opportunity for new SRAM applications.

Nonvolatile Memory Forecast Assumptions

EPROM

This market segment will remain relatively flat for the forecast period and may in fact drop off more rapidly than the present forecast indicates. Flash is starting to replace EPROM/OTP devices in many applications including data processing, telecom, industrial, and automotive. This trend will accelerate, especially for higher densities. The future of EPROMs for densities above 16Mb is rather bleak.

EEPROM

The low densities is where the action is and is expected to continue to be. Consumer applications are driving this market segment, which is expected to experience significant unit growth. As with all silicon for consumer applications, the ASPs will be low. The high-density EEPROMs (parallel devices with densities above 1Mb) are dead. No activity is expected here because flash memories effectively perform the same function at a fraction of the cost.

ROM

The ROM market segment is the least volatile and is expected to sustain reasonable growth rates. The applications are still driven by consumer electronics such as games. No replacement technology appears in the horizon at this time, and ROMs still represent the lowest-cost (albeit least-flexible) solution.

Flash

Flash is the brightest spot within nonvolatile memories and will replace high-density

EEPROMs and EPROMs. They should be used in some portable applications in lieu of DRAMs/P-SRAMs. ASPs are dropping rapidly and should cross over DRAM price per bit within the forecast's horizon.

Exchange Rates

As mentioned previously, Dataquest utilizes an average annual exchange rate in converting revenue to U.S. dollar amounts. The following table outlines these rates for 1989 through 1991.

	1989	1990	1991
Japan (Yen/U.S.$)	138	144	136
France (Franc/U.S.$)	6.39	5.44	5.64
Germany (Deutsche Mark/U.S.$)	1.88	1.62	1.66
United Kingdom (U.S.$/Pound Sterling)	1.50	1.79	1.77

At the same time, the aftermarket for DRAMs has also grown, which appears to be buffering the industry from the strong upturns and downturns experienced in the past. The installation of the STA in 1986, we believe, has helped moderate the aggressive price cutting in the down cycle, and kept production costs close to market prices.

Graphics applications are becoming major forces driving the market. However, these applications will see their greatest growth period after the 16Mb comes into volume production in the mid-1990s.

SRAM Forecast Assumptions

The following are our SRAM forecast assumptions:

- Historical trends will tend to repeat themselves over the next five years. These drive the following:
  - Market composition by density of device
  - Price per bit, and relative PPB for various densities
  - Migration toward faster devices
  - Migration toward wider parts
- PC caches will continue to consume the lion's share of fast SRAMs, even as battery-operated PCs grow in stature.
- Static RAM ASPs will track dynamic RAM ASPs, however, slower SRAMs will be sold at a bargain as the demand for faster parts tends to obsolete speeds slower than 100ns.
- Pseudo-static RAMs will grow in acceptance from their limited stance today.
- There will continue to be a speed gap in all SRAM densities where sales will be low.
- Applications for slow SRAMs will continue to be far-flung.
- There will be a cyclical softening of the market in 1995.
- The economy will strongly impact the bit-growth rate of slow SRAMs and the ASPs of fast SRAMs.
- The SRAM market will grow more quickly than will the DRAM market, but will continue to stay the significantly smaller of the two.
- The SRAM market is not seriously threatened by new technologies such as flash, cached DRAM, Rambus, and microprocessors with on-board cache. These technologies will coexist with SRAM, and may even create the opportunity for new SRAM applications.

Nonvolatile Memory Forecast Assumptions

EPROM

This market segment will remain relatively flat for the forecast period and may in fact drop off more rapidly than the present forecast indicates. Flash is starting to replace EPROM/OTP devices in many applications including data processing, telecom, industrial, and automotive. This trend will accelerate, especially for higher densities. The future of EPROMs for densities above 16Mb is rather bleak.

EEPROM

The low densities is where the action is and is expected to continue to be. Consumer applications are driving this market segment, which is expected to experience significant unit growth. As with all silicon for consumer applications, the ASPs will be low. The high-density EEPROMs (parallel devices with densities above 1Mb) are dead. No activity is expected here because flash memories effectively perform the same function at a fraction of the cost.

ROM

The ROM market segment is the least volatile and is expected to sustain reasonable growth rates. The applications are still driven by consumer electronics such as games. No replacement technology appears in the horizon at this time, and ROMs still represent the lowest-cost (albeit least-flexible) solution.

Flash

Flash is the brightest spot within nonvolatile memories and will replace high-density

EEPROMs and EPROMs. They should be used in some portable applications in lieu of DRAMs/P-SRAMs. ASPs are dropping rapidly and should cross over DRAM price per bit within the forecast's horizon.

Exchange Rates

As mentioned previously, Dataquest utilizes an average annual exchange rate in converting revenue to U.S. dollar amounts. The following table outlines these rates for 1989 through 1991.

	1989	1990	1991
Japan (Yen/U.S.$)	138	144	136
France (Franc/U.S.$)	6.39	5.44	5.64
Germany (Deutsche Mark/U.S.$)	1.88	1.62	1.66
United Kingdom (U.S.$/Pound Sterling)	1.50	1.79	1.77

Table 1-1
Factory Revenue from Shipments of MOS Memory to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
DRAM	8,323.4	6,436.6	6,849.4	7,802.6	9,936.9	12,220.8	10,415.1	11,769.2	11.4
EEPROM	319.6	292.1	326.2	373.8	446.2	467.5	430.4	420.8	5.2
EPROM	1,809.1	1,445.8	1,362.4	1,275.5	1,381.8	1,318.9	1,270.4	1,183.4	-2.8
Flash	11.1	35.3	119.6	273.8	557.5	1,199.9	1,716.8	1,989.7	75.5
ROM	1,069.2	1,131.7	1,197.6	1,277.2	1,343.4	1,415.5	1,571.1	1,692.4	7.2
SRAM	3,329.1	2,433.6	2,569.3	2,811.1	3,722.4	4,435.8	5,538.2	6,816.1	21.5
Total/Average	14,861.6	11,775.2	12,424.6	13,813.9	17,388.1	21,058.4	20,941.9	23,871.4	14.0
Percent Change (%)	22.0	-20.8	5.5	11.2	25.9	21.1	-0.6	14.0	

Source: Dataquest (August 1992)

Table 1-2
Shipments of MOS Memory to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
DRAM	1,254.3	1,335.7	1,285.9	1,377.8	1,425.0	1,445.0	1,156.0	1,156.0	-2.1
EEPROM	118.3	127.1	212.9	281.6	349.9	422.9	470.7	523.6	19.7
EPROM	402.1	424.0	476.0	480.3	476.0	463.7	429.0	386.7	-4.1
Flash	0.6	2.7	11.8	33.0	77.3	163.0	268.7	349.8	97.0
ROM	299.4	315.4	383.3	367.0	370.0	318.6	276.7	255.4	-7.8
SRAM	630.5	620.5	703.6	759.1	766.2	787.1	797.3	914.6	5.4
Total/Average	2,705.1	2,825.3	3,073.6	3,298.8	3,464.4	3,600.2	3,398.4	3,586.1	3.1
Percent Change (%)	7.7	4.4	8.8	7.3	5.0	3.9	-5.6	5.5	

Source: Dataquest (August 1992)

Table 1-3
Average Selling Price for Shipments of MOS Memory to the World, 1989-1996 (U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
DRAM	6.64	4.82	5.33	5.66	6.97	8.46	9.01	10.18	13.8
EEPROM	2.70	2.30	1.53	1.33	1.28	1.11	0.91	0.80	-12.1
EPROM	4.50	3.41	2.86	2.66	2.90	2.84	2.96	3.06	1.3
Flash	17.21	13.23	10.13	8.30	7.21	7.36	6.39	5.69	-10.9
ROM	3.57	3.59	3.12	3.48	3.63	4.44	5.68	6.63	16.2
SRAM	5.28	3.92	3.65	3.70	4.86	5.64	6.95	7.45	15.3
Total/Average	5.49	4.17	4.04	4.19	5.02	5.85	6.16	6.66	10.5
Percent Change (%)	13.3	-24.1	-3.0	3.6	19.9	16.5	5.4	8.0	

Source: Dataquest (August 1992)

Table 1-4
Shipments of MOS Memory to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
DRAM	641.6	964.1	1,535.0	2,707.7	4,510.2	7,267.9	8,480.0	12,042.1	51.0
EEPROM	1.0	1.3	2.1	2.8	3.8	4.5	4.5	4.8	17.7
EPROM	132.6	182.4	221.0	305.2	438.2	578.9	678.2	730.9	27.0
Flash	0.3	1.7	10.4	37.3	117.9	433.8	1,047.3	1,706.4	177.2
ROM	425.5	681.5	954.7	1,204.1	1,760.5	2,353.9	3,661.3	5,329.6	41.0
SRAM	72.5	90.5	127.0	237.7	425.9	661.6	1,055.6	1,611.2	66.2
Total/Average	1,273.6	1,921.5	2,850.3	4,494.8	7,256.6	11,300.8	14,926.9	21,425.1	49.7
Percent Change (%)	45.1	50.9	48.3	57.7	61.4	55.7	32.1	43.5	

Source: Dataquest (August 1992)

Table 1-5
Price per Bit for Shipments of MOS Memory to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
DRAM	13.0	6.7	4.5	2.9	2.2	1.7	1.2	1.0	-26.2
EEPROM	311.6	224.0	153.8	135.3	116.0	102.9	96.2	87.9	-10.6
EPROM	13.6	7.9	6.2	4.2	3.2	2.3	1.9	1.6	-23.5
Flash	39.9	21.0	11.5	7.3	4.7	2.8	1.6	1.2	-36.7
ROM	2.5	1.7	1.3	1.1	0.8	0.6	0.4	0.3	-24.0
SRAM	45.9	26.9	20.2	11.8	8.7	6.7	5.2	4.2	-26.9
Total/Average	11.7	6.1	4.4	3.1	2.4	1.9	1.4	1.1	-24.2
Percent Change (%)	-15.9	-47.5	-28.9	-29.5	-22.0	-22.2	-24.7	-20.6	

Source: Dataquest (August 1992)

Table 2-1
Factory Revenue from Shipments of DRAMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
64K	112.3	38.1	20.0	0	0	0	0	0	
256K	2,445.5	1,323.4	620.7	345.8	175.0	123.3	73.8	39.9	-42.2
1Mb	5,601.6	4,231.0	3,776.0	2,415.0	1,395.0	812.5	379.5	295.8	-39.9
4Mb	164.0	844.1	2,400.0	4,719.8	6,511.9	6,105.0	3,685.0	2,576.0	1.4
16Mb	0	0	32.7	322.0	1,855.0	5,180.0	6,270.0	8,482.5	204.0
64Mb	0	0	0	0	0	0	6.8	375.0	
Total/Average	8,323.4	6,436.6	6,849.4	7,802.6	9,936.9	12,220.8	10,415.1	11,769.2	11.4
Percent Change (%)	23.8	-22.7	6.4	13.9	27.4	23.0	-14.8	13.0	

Source: Dataquest (August 1992)

Table 2-2
Shipments of DRAMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
64K	65.3	25.7	13.5	0	0	0	0	0	
256K	780.1	620.5	299.1	190.0	125.0	85.0	41.0	21.0	-41.2
1Mb	407.5	665.0	835.4	750.0	450.0	250.0	115.0	87.0	-36.4
4Mb	1.3	24.4	137.7	435.0	815.0	925.0	670.0	460.0	27.3
16Mb	0	0	0.1	2.8	35.0	185.0	330.0	585.0	435.8
64Mb	0	0	0	0	0	0	0	3.0	
Total/Average	1,254.3	1,335.7	1,285.9	1,377.8	1,425.0	1,445.0	1,156.0	1,156.0	-2.1
Percent Change (%)	-3.2	6.5	-3.7	7.1	3.4	1.4	-20.0	0	

Source: Dataquest (August 1992)

Table 2-3
Average Selling Price for Shipments of DRAMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
64K	1.72	1.48	1.48	-	-	-	-	-	
256K	3.13	2.13	2.08	1.82	1.40	1.45	1.80	1.90	-1.7
1Mb	13.74	6.36	4.52	3.22	3.10	3.25	3.30	3.40	-5.5
4Mb	125.01	34.59	17.43	10.85	7.99	6.60	5.50	5.60	-20.3
16Mb	-	-	246.60	115.00	53.00	28.00	19.00	14.50	-43.3
64Mb	-	-	-	-	-	-	225.00	125.00	
Total/Average	6.64	4.82	5.33	5.66	6.97	8.46	9.01	10.18	13.8
Percent Change (%)	27.9	-27.4	10.5	6.3	23.1	21.3	6.5	13.0	

Source: Dataquest (August 1992)

Table 2-4
Shipments of DRAMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
64K	4.3	1.7	0.9	0	0	0	0	0	
256K	204.5	162.7	78.4	49.8	32.8	22.3	10.7	5.5	-41.2
1Mb	427.3	697.3	876.0	786.4	471.9	262.1	120.6	91.2	-36.4
4Mb	5.5	102.4	577.4	1,824.5	3,418.4	3,879.7	2,810.2	1,929.4	27.3
16Mb	0	0	2.2	47.0	587.2	3,103.8	5,536.5	9,814.7	435.8
64Mb	0	0	0	0	0	0	2.0	201.3	
Total/Average	641.6	964.1	1,535.0	2,707.7	4,510.2	7,267.9	8,480.0	12,042.1	51.0
Percent Change (%)	33.1	50.2	59.2	76.4	66.6	61.1	16.7	42.0	

Source: Dataquest (August 1992)

Table 2-5
Price per Bit for Shipments of DRAMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
64K	26.2	22.6	22.5	-	-	-	-	-	
256K	12.0	8.1	7.9	6.9	5.3	5.5	6.9	7.2	-1.7
1Mb	13.1	6.1	4.3	3.1	3.0	3.1	3.1	3.2	-5.5
4Mb	29.8	8.2	4.2	2.6	1.9	1.6	1.3	1.3	-20.3
16Mb	-	-	14.7	6.9	3.2	1.7	1.1	0.9	-43.3
64Mb	-	-	-	-	-	-	3.4	1.9	
Total/Average	13.0	6.7	4.5	2.9	2.2	1.7	1.2	1.0	-26.2
Percent Change (%)	-7.0	-48.5	-33.2	-35.4	-23.5	-23.7	-27.0	-20.4	

Source: Dataquest (August 1992)

Table 3-1
Factory Revenue from Shipments of SRAMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K 10-19ns	0	0	5.1	2.0	1.0	0.7	0.5	0.3	-42.4
16K 20-44ns	0	0	33.4	16.6	8.8	5.3	3.5	2.2	-41.9
16K 45-70ns	0	0	13.0	6.7	4.0	3.0	2.3	1.6	-34.2
16K >70ns	143.3	77.2	0	0	0	0	0	0	
16K <70ns	341.8	116.9	63.1	17.2	13.3	7.5	5.5	5.4	-38.9
64K 0-9ns	0	0	0	15.5	30.2	25.9	8.9	3.1	
64K 10-19ns	0	0	42.4	23.6	20.3	15.5	8.7	5.0	-34.7
64K 20-44ns	0	0	235.2	88.6	79.1	54.0	28.0	16.0	-41.6
64K 45-70ns	0	0	62.6	45.9	29.8	22.0	12.0	7.2	-35.1
64K <70ns	480.0	380.2	0	0	0	0	0	0	
64K >70ns	516.5	367.8	316.6	230.5	49.6	47.0	24.2	15.1	-45.6
64K >70ns PSRAM	10.0	3.2	6.3	5.6	2.8	1.4	0.1	0	
256K 0-9ns	0	0	0	98.2	130.3	173.7	114.5	80.4	
256K 10-19ns	0	0	46.4	74.4	92.7	165.6	93.9	84.4	12.7
256K 20-44ns	0	0	273.1	338.0	291.5	423.9	279.7	205.0	-5.6
256K 45-70ns	0	0	57.5	98.2	104.3	151.8	104.3	83.0	7.6
256K <70ns	349.6	341.2	0	0	0	0	0	0	
256K >70ns	1,138.9	703.2	718.2	570.3	557.4	255.4	119.2	125.6	-29.4
256K >70ns PSRAM	173.6	97.5	162.0	109.5	138.7	103.2	60.1	20.4	-33.9
1Mb 0-9ns	0	0	0	0	0	18.0	75.0	139.0	

(Continued)

Table 3-1 (Continued)
Factory Revenue from Shipments of SRAMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
1Mb 10-19ns	0	0	110.2	78.5	87.3	149.2	321.4	405.4	29.8
1Mb 20-44ns	0	0	45.5	161.2	285.2	338.4	924.9	961.8	84.1
1Mb 45-70ns	0	0	58.9	154.0	161.4	187.9	373.3	373.0	44.6
1Mb <70ns	0	68.8	0	0	0	0	0	0	
1Mb >70ns	105.1	191.0	244.2	548.5	782.3	732.5	514.3	737.4	24.7
1Mb >70ns PSRAM	70.2	86.6	61.2	51.3	71.5	79.6	84.2	83.5	6.4
4Mb 0-9ns	0	0	0	0	0	0	53.1	148.8	
4Mb 10-19ns	0	0	0	1.0	27.5	71.0	253.5	491.0	
4Mb 20-44ns	0	0	0	0.8	31.7	69.9	276.2	504.3	
4Mb 45-70ns	0	0	0	9.5	246.8	201.6	588.1	709.8	
4Mb <70ns	0	0	0	19.0	399.0	976.2	1,025.2	1,185.2	
4Mb >70ns PSRAM	0	0	14.4	46.7	75.9	143.7	136.2	190.7	67.8
16Mb >70ns	0	0	0	0	0	0	4.0	132.3	
16Mb >70ns PSRAM	0	0	0	0	0	12.0	43.6	99.1	
Total/Average	3,329.1	2,433.6	2,569.3	2,811.1	3,722.4	4,435.8	5,538.2	6,816.1	21.5
Percent Change (%)	43.7	-26.9	5.6	9.4	32.4	19.2	24.9	23.1	

Source: Dataquest (August 1992)

Table 3-2
Shipments of SRAMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K 10-19ns	0	0	1.5	0.7	0.4	0.3	0.2	0.2	-36.4
16K 20-44ns	0	0	13.9	7.4	4.4	3.3	2.5	1.8	-33.9
16K 45-70ns	0	0	10.4	5.4	3.2	2.4	1.8	1.3	-34.2
16K <70ns	40.9	31.7	0	0	0	0	0	0	
16K >70ns	150.9	91.0	90.2	21.5	13.3	7.5	3.6	2.1	-52.7
64K 0-9ns	0	0	0	0.8	2.0	2.6	1.9	1.1	
64K 10-19ns	0	0	10.2	7.4	7.4	6.2	3.5	2.2	-26.1
64K 20-44ns	0	0	64.8	46.6	39.5	30.0	14.7	8.6	-33.2
64K 45-70ns	0	0	29.6	27.0	18.1	12.9	6.7	4.0	-33.0
64K <70ns	59.5	69.2	0	0	0	0	0	0	
64K >70ns	190.4	199.6	185.9	159.0	38.2	29.4	14.2	8.4	-46.2
64K >70ns PSRAM	3.5	1.7	3.7	3.8	2.2	1.1	0.1	0	
256K 0-9ns	0	0	0	0.9	2.9	11.6	11.4	13.4	
256K 10-19ns	0	0	1.9	6.0	11.6	25.5	22.9	24.1	66.1
256K 20-44ns	0	0	28.1	82.4	95.6	141.3	93.2	68.3	19.4
256K 45-70ns	0	0	10.8	29.8	34.8	53.3	36.0	28.1	21.1
256K <70ns	12.1	21.4	0	0	0	0	0	0	
256K >70ns	145.7	168.4	179.5	203.7	202.7	94.6	42.6	42.6	-25.0
256K >70ns PSRAM	22.2	23.3	40.5	54.8	69.4	59.0	35.4	11.3	-22.5
1Mb 0-9ns	0	0	0	0	0	0.4	3.6	8.7	

(Continued)

Table 3-2 (Continued)
Shipments of SRAMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
1Mb 10-19ns	0	0	0.6	1.2	4.0	10.4	35.7	57.9	153.7
1Mb 20-44ns	0	0	1.0	8.9	24.8	39.6	132.1	156.4	176.4
1Mb 45-70ns	0	0	2.3	14.0	20.8	29.6	66.7	66.6	95.8
1Mb <70ns	0	1.0	0	0	0	0	0	0	
1Mb >70ns	1.4	6.2	18.2	59.6	120.3	124.1	102.9	149.0	52.2
1Mb >70ns PSRAM	3.9	7.0	9.4	13.7	26.0	29.5	30.1	28.3	24.6
4Mb 0-9ns	0	0	0	0	0	0	0.5	2.0	
4Mb 10-19ns	0	0	0	0.0	0.2	1.1	7.2	21.8	
4Mb 20-44ns	0	0	0	0.0	0.4	2.3	12.6	30.8	
4Mb 45-70ns	0	0	0	0.1	3.7	7.2	28.0	44.6	
4Mb >70ns	0	0	0	0.2	9.5	37.5	60.3	87.8	
4Mb >70ns PSRAM	0	0	1.1	4.4	10.8	24.0	24.3	34.7	100.9
16Mb >70ns	0	0	0	0	0	0	0.0	1.3	
16Mb >70ns PSRAM	0	0	0	0	0	0.5	2.5	7.1	
Total/Average	630.5	620.5	703.6	759.1	766.2	787.1	797.3	914.6	5.4
Percent Change (%)	23.0	-1.6	13.4	7.9	.9	2.7	1.3	14.7	

Source: Dataquest (August 1992)

Table 3-3
Average Selling Price for Shipments of SRAMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K 10-19ns	-	-	3.30	3.00	2.50	2.25	2.10	2.00	-9.5
16K 20-44ns	-	-	2.40	2.25	2.00	1.60	1.40	1.25	-12.2
16K 45-70ns	-	-	1.25	1.25	1.25	1.25	1.25	1.25	0.0
16K <70ns	3.50	2.44	-	-	-	-	-	-	
16K >70ns	2.27	1.28	0.70	0.80	1.00	1.00	1.50	2.50	29.0
64K 0-9ns	-	-	-	19.00	15.00	10.00	4.75	2.80	
64K 10-19ns	-	-	4.18	3.20	2.75	2.50	2.50	2.25	-11.6
64K 20-44ns	-	-	3.63	1.90	2.00	1.80	1.90	1.85	-12.6
64K 45-70ns	-	-	2.11	1.70	1.65	1.70	1.80	1.80	-3.2
64K <70ns	8.07	5.49	-	-	-	-	-	-	
64K >70ns	2.71	1.84	1.70	1.45	1.30	1.60	1.70	1.80	1.1
64K >70ns PSRAM	2.85	1.88	1.72	1.45	1.30	1.20	1.30	-	
256K 0-9ns	-	-	-	110.00	45.00	15.00	10.00	6.00	
256K 10-19ns	-	-	24.31	12.50	8.00	6.50	4.10	3.50	-32.1
256K 20-44ns	-	-	9.71	4.10	3.05	3.00	3.00	3.00	-20.9
256K 45-70ns	-	-	5.33	3.30	3.00	2.85	2.90	2.95	-11.1
256K <70ns	28.97	15.94	-	-	-	-	-	-	
256K <70ns	7.82	4.18	4.00	2.80	2.75	2.70	2.80	2.95	-5.9
256K >70ns PSRAM	7.84	4.19	4.00	2.00	2.00	1.75	1.70	1.80	-14.8
1Mb 0-9ns	-	-	-	-	-	45.00	21.00	16.00	

(Continued)

Table 3-3 (Continued)
Average Selling Price for Shipments of SRAMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
1Mb 10-19ns	-	-	200.00	65.00	22.00	14.35	9.00	7.00	-48.9
1Mb 20-44ns	-	-	46.94	18.05	11.50	8.55	7.00	6.15	-33.4
1Mb 45-70ns	-	-	25.47	11.00	7.75	6.35	5.60	5.60	-26.1
1Mb <70ns	-	68.78	-	-	-	-	-	-	
1Mb >70ns	74.30	30.76	13.39	9.20	6.50	5.90	5.00	4.95	-18.0
1Mb >70ns PSRAM	17.85	12.29	6.50	3.75	2.75	2.70	2.80	2.95	-14.6
4Mb 0-9ns	-	-	-	-	-	-	110.00	75.00	
4Mb 10-19ns	-	-	-	500.00	125.00	67.00	35.00	22.50	
4Mb 20-44ns	-	-	-	250.00	72.00	30.00	22.00	16.40	
4Mb 45-70ns	-	-	-	100.00	66.00	28.00	21.00	15.90	
4Mb >70ns	-	-	-	95.00	42.00	26.00	17.00	13.50	
4Mb >70ns PSRAM	-	-	13.54	10.50	7.00	6.00	5.60	5.50	-16.5
16Mb >70ns	-	-	-	-	-	-	180.00	99.50	
16Mb >70ns PSRAM	-	-	-	-	-	26.10	17.15	14.00	
Total/Average	5.28	3.92	3.65	3.70	4.86	5.64	6.95	7.45	15.3
Percent Change (%)	16.8	-25.7	-6.9	1.4	31.2	16.0	23.3	7.3	

Source: Dataquest (August 1992)

Table 3-4
Shipments of SRAMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K 10-19ns	0	0	0	0	0	0	0	0	-36.4
16K 20-44ns	0	0	0.2	0.1	0.1	0.1	0	0	-33.9
16K 45-70ns	0	0	0.2	0.1	0.1	0	0	0	-34.2
16K <70ns	0.7	0.5	0	0	0	0	0	0	
16K >70ns	2.5	1.5	1.5	0.4	0.2	0.1	0.1	0	-52.7
64K 0-9ns	0	0	0	0.1	0.1	0.2	0.1	0.1	
64K 10-19ns	0	0	0.7	0.5	0.5	0.4	0.2	0.1	-26.1
64K 20-44ns	0	0	4.2	3.1	2.6	2.0	1.0	0.6	-33.2
64K 45-70ns	0	0	1.9	1.8	1.2	0.8	0.4	0.3	-33.0
64K <70ns	3.9	4.5	0	0	0	0	0	0	
64K >70ns	12.5	13.1	12.2	10.4	2.5	1.9	0.9	0.5	-46.2
64K >70ns PSRAM	0.2	0.1	0.2	0.3	0.1	0.1	0	0	
256K 0-9ns	0	0	0	0.2	0.8	3.0	3.0	3.5	
256K 10-19ns	0	0	0.5	1.6	3.0	6.7	6.0	6.3	66.1
256K 20-44ns	0	0	7.4	21.6	25.1	37.0	24.4	17.9	19.4
256K 45-70ns	0	0	2.8	7.8	9.1	14.0	9.4	7.4	21.1
256K <70ns	3.2	5.6	0	0	0	0	0	0	
256K >70ns	38.2	44.1	47.1	53.4	53.1	24.8	11.2	11.2	-25.0
256K >70ns PSRAM	5.8	6.1	10.6	14.4	18.2	15.5	9.3	3.0	-22.5
1Mb 0-9ns	0	0	0	0	0	0.4	3.7	9.1	

(Continued)

Table 3-4 (Continued)
Shipments of SRAMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
1Mb 10-19ns	0	0	0.6	1.3	4.2	10.9	37.4	60.7	153.7
1Mb 20-44ns	0	0	1.0	9.4	26.0	41.5	138.5	164.0	176.4
1Mb 45-70ns	0	0	2.4	14.7	21.8	31.0	69.9	69.8	95.8
1Mb <70ns	0	1.0	0	0	0	0	0	0	
1Mb >70ns	1.5	6.5	19.1	62.5	126.2	130.2	107.9	156.2	52.2
1Mb >70ns PSRAM	4.1	7.4	9.9	14.4	27.3	30.9	31.5	29.7	24.6
4Mb 0-9ns	0	0	0	0	0	0	2.0	8.3	
4Mb 10-19ns	0	0	0	0	0.9	4.4	30.4	91.5	
4Mb 20-44ns	0	0	0	0	1.8	9.8	52.7	129.0	
4Mb 45-70ns	0	0	0	0.4	15.7	30.2	117.5	187.2	
4Mb >70ns	0	0	0	0.8	39.9	157.5	252.9	368.2	
4Mb >70ns PSRAM	0	0	4.4	18.7	45.5	100.5	102.0	145.4	100.9
16Mb >70ns	0	0	0	0	0	0	0.4	22.3	
16Mb >70ns PSRAM	0	0	0	0	0	7.7	42.7	118.7	
Total/Average	72.5	90.5	127.0	237.7	425.9	661.6	1,055.6	1,611.2	66.2
Percent Change (%)	67.3	24.9	40.3	87.1	79.2	55.3	59.6	52.6	

Source: Dataquest (August 1992)

Table 3-5
Price per Bit for Shipments of SRAMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K 10-19ns	-	-	201.4	183.1	152.6	137.3	128.2	122.1	-9.5
16K 20-44ns	-	-	146.5	137.3	122.1	97.7	85.4	76.3	-12.2
16K 45-70ns	-	-	76.3	76.3	76.3	76.3	76.3	76.3	0
16K <70ns	213.8	148.9	-	-	-	-	-	-	
16K >70ns	138.3	78.4	42.7	48.8	61.0	61.0	91.6	152.6	29.0
64K 0-9ns	-	-	-	289.9	228.9	152.6	72.5	42.7	
64K 10-19ns	-	-	63.7	48.8	42.0	38.1	38.1	34.3	-11.6
64K 20-44ns	-	-	55.3	29.0	30.5	27.5	29.0	28.2	-12.6
64K 45-70ns	-	-	32.3	25.9	25.2	25.9	27.5	27.5	-3.2
64K <70ns	123.1	83.8	-	-	-	-	-	-	
64K >70ns	41.4	28.1	26.0	22.1	19.8	24.4	25.9	27.5	1.1
64K >70ns PSRAM	43.5	28.6	26.2	22.1	19.8	18.3	19.8	-	
256K 0-9ns	-	-	-	419.6	171.7	57.2	38.1	22.9	
256K 10-19ns	-	-	92.7	47.7	30.5	24.8	15.6	13.4	-32.1
256K 20-44ns	-	-	37.1	15.6	11.6	11.4	11.4	11.4	-20.9
256K 45-70ns	-	-	20.3	12.6	11.4	10.9	11.1	11.3	-11.1
256K <70ns	110.5	60.8	-	-	-	-	-	-	
256K >70ns	29.8	15.9	15.3	10.7	10.5	10.3	10.7	11.3	-5.9
256K >70ns PSRAM	29.9	16.0	15.3	7.6	7.6	6.7	6.5	6.9	-14.8
1Mb 0-9ns	-	-	-	-	-	42.9	20.0	15.3	

(Continued)

Table 3-5 (Continued)
Price per Bit for Shipments of SRAMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
1Mb 10-19ns	-	-	190.7	62.0	21.0	13.7	8.6	6.7	-48.9
1Mb 20-44ns	-	-	44.8	17.2	11.0	8.2	6.7	5.9	-33.4
1Mb 45-70ns	-	-	24.3	10.5	7.4	6.1	5.3	5.3	-26.1
1Mb <70ns	-	65.6	-	-	-	-	-	-	
1Mb >70ns	70.9	29.3	12.8	8.8	6.2	5.6	4.8	4.7	-18.0
1Mb >70ns PSRAM	17.0	11.7	6.2	3.6	2.6	2.6	2.7	2.8	-14.6
4Mb 0-9ns	-	-	-	-	-	-	26.2	17.9	
4Mb 10-19ns	-	-	-	119.2	29.8	16.0	8.3	5.4	
4Mb 20-44ns	-	-	-	59.6	17.2	7.2	5.2	3.9	
4Mb 45-70ns	-	-	-	23.8	15.7	6.7	5.0	3.8	
4Mb >70ns	-	-	-	22.6	10.0	6.2	4.1	3.2	
4Mb >70ns PSRAM	-	-	3.2	2.5	1.7	1.4	1.3	1.3	-16.5
16Mb >70ns	-	-	-	-	-	-	10.7	5.9	
16Mb >70ns PSRAM	-	-	-	-	-	1.6	1.0	0.8	
Total/Average	45.9	26.9	20.2	11.8	8.7	6.7	5.2	4.2	-26.9
Percent Change (%)	-14.1	-41.5	-24.7	-41.5	-26.1	-23.3	-21.7	-19.4	

Source: Dataquest (August 1992)

Table 4-1
Factory Revenue from Shipments of EPROMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	22.9	12.6	11.7	10.8	9.5	8.2	7.0	5.3	-14.6
32K	40.3	18.2	25.3	21.4	17.1	14.3	10.8	8.2	-20.2
64K	170.5	88.3	99.9	85.0	64.0	55.8	43.5	36.0	-18.5
128K	174.3	103.2	74.6	57.6	45.0	36.0	30.0	25.5	-19.3
256K	519.6	360.9	450.0	341.3	277.5	212.5	176.6	136.0	-21.3
512K	442.0	278.8	204.8	160.6	128.0	99.0	77.6	67.2	-20.0
1Mb	410.1	479.5	299.3	299.0	268.8	226.9	177.6	155.3	-12.3
2Mb	25.3	69.7	99.9	143.8	220.5	231.8	181.5	156.8	9.4
4Mb	4.1	34.8	96.8	153.8	332.5	348.0	421.2	375.0	31.1
8Mb	0	0	0	2.4	19.0	75.0	101.3	142.5	
16Mb	0	0	0	0	0	11.4	43.5	75.6	
Total/Average	1,809.1	1,445.8	1,362.4	1,275.5	1,381.8	1,318.9	1,270.4	1,183.4	-2.8
Percent Change (%)	-5.4	-20.1	-5.8	-6.4	8.3	-4.5	-3.7	-6.9	

Source: Dataquest (August 1992)

Table 4-2
Shipments of EPROMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	8.0	5.9	5.3	4.9	4.4	3.9	3.5	2.8	-11.8
32K	13.7	8.1	10.8	9.3	7.6	6.5	5.0	3.9	-18.5
64K	55.0	39.2	57.3	50.0	40.0	36.0	29.0	24.0	-16.0
128K	54.0	45.5	41.6	36.0	29.0	24.0	20.0	17.0	-16.4
256K	152.7	157.7	204.8	175.0	150.0	125.0	107.0	85.0	-16.1
512K	84.1	98.3	71.9	73.0	64.0	55.0	47.0	42.0	-10.2
1Mb	33.7	63.8	66.3	92.0	96.0	89.0	74.0	69.0	0.8
2Mb	0.7	4.6	11.9	25.0	49.0	61.0	55.0	49.0	32.6
4Mb	0.1	1.0	6.1	15.0	35.0	58.0	78.0	75.0	65.4
8Mb	0	0	0	0.1	1.0	5.0	9.0	15.0	
16Mb	0	0	0	0	0	0.3	1.5	4.0	
Total/Average	402.1	424.0	476.0	480.3	476.0	463.7	429.0	386.7	-4.1
Percent Change (%)	11.9	5.5	12.3	0.9	-0.9	-2.6	-7.5	-9.9	

Source: Dataquest (August 1992)

Table 4-3
Average Selling Price for Shipments of EPROMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	2.86	2.15	2.24	2.20	2.15	2.10	2.00	1.90	-3.2
32K	2.95	2.24	2.33	2.30	2.25	2.20	2.15	2.10	-2.1
64K	3.10	2.25	1.74	1.70	1.60	1.55	1.50	1.50	-3.0
128K	3.23	2.27	1.79	1.60	1.55	1.50	1.50	1.50	-3.5
256K	3.40	2.29	2.20	1.95	1.85	1.70	1.65	1.60	-6.2
512K	5.25	2.84	2.85	2.20	2.00	1.80	1.65	1.60	-10.9
1Mb	12.15	7.52	4.51	3.25	2.80	2.55	2.40	2.25	-13.0
2Mb	33.80	15.25	8.37	5.75	4.50	3.80	3.30	3.20	-17.5
4Mb	59.32	35.16	15.99	10.25	9.50	6.00	5.40	5.00	-20.7
8Mb	-	-	-	24.00	19.00	15.00	11.25	9.50	
16Mb	-	-	-	-	-	38.00	29.00	18.90	
Total/Average	4.50	3.41	2.86	2.66	2.90	2.84	2.96	3.06	1.3
Percent Change (%)	-15.4	-24.2	-16.1	-7.2	9.3	-2.0	4.1	3.3	

Source: Dataquest (August 1992)

Table 4-4
Shipments of EPROMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	-11.8
32K	0.4	0.3	0.4	0.3	0.2	0.2	0.2	0.1	-18.5
64K	3.6	2.6	3.8	3.3	2.6	2.4	1.9	1.6	-16.0
128K	7.1	6.0	5.5	4.7	3.8	3.1	2.6	2.2	-16.4
256K	40.0	41.3	53.7	45.9	39.3	32.8	28.0	22.3	-16.1
512K	44.1	51.5	37.7	38.3	33.6	28.8	24.6	22.0	-10.2
1Mb	35.4	66.9	69.6	96.5	100.7	93.3	77.6	72.4	.8
2Mb	1.6	9.6	25.0	52.4	102.8	127.9	115.3	102.8	32.6
4Mb	0.3	4.1	25.4	62.9	146.8	243.3	327.2	314.6	65.4
8Mb	0	0	0	0.8	8.4	41.9	75.5	125.8	
16Mb	0	0	0	0	0	5.0	25.2	67.1	
Total/Average	132.6	182.4	221.0	305.2	438.2	578.9	678.2	730.9	27.0
Percent Change (%)	46.3	37.5	21.2	38.1	43.6	32.1	17.2	7.8	

Source: Dataquest (August 1992)

Table 4-5
Price per Bit for Shipments of EPROMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	174.4	131.0	136.4	134.3	131.2	128.2	122.1	116.0	-3.2
32K	90.1	68.5	71.2	70.2	68.7	67.1	65.6	64.1	-2.1
64K	47.3	34.4	26.6	25.9	24.4	23.7	22.9	22.9	-3.0
128K	24.6	17.3	13.7	12.2	11.8	11.4	11.4	11.4	-3.5
256K	13.0	8.7	8.4	7.4	7.1	6.5	6.3	6.1	-6.2
512K	10.0	5.4	5.4	4.2	3.8	3.4	3.1	3.1	-10.9
1Mb	11.6	7.2	4.3	3.1	2.7	2.4	2.3	2.1	-13.0
2Mb	16.1	7.3	4.0	2.7	2.1	1.8	1.6	1.5	-17.5
4Mb	14.1	8.4	3.8	2.4	2.3	1.4	1.3	1.2	-20.7
8Mb	-	-	-	2.9	2.3	1.8	1.3	1.1	
16Mb	-	-	-	-	-	2.3	1.7	1.1	
Total/Average	13.6	7.9	6.2	4.2	3.2	2.3	1.9	1.6	-23.5
Percent Change (%)	-35.3	-41.9	-22.2	-32.2	-24.6	-27.7	-17.8	-13.6	

Source: Dataquest (August 1992)

Table 5-1
Factory Revenue from Shipments of ROMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	0.5	0	0	0	0	0	0	0	
32K	1.5	0.8	0.9	0.2	0	0	0	0	
64K	19.8	11.8	9.1	5.1	0	0	0	0	
128K	11.9	8.4	13.1	4.6	2.2	1.2	0	0	
256K	62.3	53.1	66.7	33.0	23.5	11.7	1.9	0.2	-67.6
512K	109.5	62.7	53.0	38.8	20.9	6.7	1.8	0.2	-68.1
1Mb	402.7	285.2	334.4	277.9	191.1	132.6	53.2	27.0	-39.5
2Mb	168.0	200.0	179.3	134.8	116.3	85.5	63.8	36.5	-27.3
4Mb	267.1	385.9	306.4	338.6	294.3	195.0	124.8	71.3	-25.3
8Mb	16.3	92.3	213.7	280.2	370.2	361.5	385.2	313.2	7.9
16Mb	9.6	31.4	21.1	55.5	150.5	239.3	257.9	318.5	72.2
32Mb	0	0	0	108.5	161.0	245.1	367.2	383.0	
64Mb	0	0	0	0	13.5	130.5	233.7	430.5	
128Mb	0	0	0	0	0	6.5	81.7	104.4	
256Mb	0	0	0	0	0	0	0	7.5	
Total/Average	1,069.2	1,131.7	1,197.6	1,277.2	1,343.4	1,415.5	1,571.1	1,692.4	7.2
Percent Change (%)	12.2	5.8	5.8	6.6	5.2	5.4	11.0	7.7	

Source: Dataquest (August 1992)

Table 5-2
Shipments of ROMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	0.2	0	0	0	0	0	0	0	
32K	0.9	0.5	0.4	0.1	0	0	0	0	
64K	12.0	7.4	5.5	3.3	1.0	0	0	0	
128K	7.0	5.1	8.7	3.2	1.8	1.1	0	0	
256K	34.6	31.6	37.7	22.0	17.4	9.0	1.5	0.2	-64.9
512K	43.8	26.7	26.6	19.9	11.0	3.6	1.0	0.1	-67.3
1Mb	120.2	103.7	130.9	123.5	91.0	66.3	28.0	15.0	-35.2
2Mb	39.1	52.6	57.9	49.0	46.5	38.0	29.0	17.4	-21.4
4Mb	39.9	74.2	76.5	91.5	107.0	78.0	52.0	31.0	-16.5
8Mb	1.4	11.9	36.6	47.1	72.3	76.1	85.6	72.0	14.5
16Mb	0.3	1.7	2.5	4.3	14.7	29.0	38.2	49.0	80.9
32Mb	0	0	0	3.1	7.0	12.9	27.2	38.3	
64Mb	0	0	0	0	0.3	4.5	12.3	28.7	
128Mb	0	0	0	0	0	0.1	1.9	3.6	
256Mb	0	0	0	0	0	0	0	0.1	
Total/Average	299.4	315.4	383.3	367.0	370.0	318.6	276.7	255.4	-7.8
Percent Change (%)	22.8	5.4	21.5	-4.3	0.8	-13.9	-13.2	-7.7	

Source: Dataquest (August 1992)

Table 5-3
Average Selling Price for Shipments of ROMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	2.50	-	-	-	-	-	-	-	
32K	1.60	1.60	2.29	2.20	-	-	-	-	
64K	1.65	1.60	1.65	1.55	-	-	-	-	
128K	1.70	1.65	1.51	1.45	1.20	1.12	-	-	
256K	1.80	1.68	1.77	1.50	1.35	1.30	1.25	1.20	-7.5
512K	2.50	2.35	1.99	1.95	1.90	1.85	1.80	1.75	-2.6
1Mb	3.35	2.75	2.55	2.25	2.10	2.00	1.90	1.80	-6.8
2Mb	4.30	3.80	3.10	2.75	2.50	2.25	2.20	2.10	-7.5
4Mb	6.70	5.20	4.00	3.70	2.75	2.50	2.40	2.30	-10.5
8Mb	11.90	7.75	5.84	5.95	5.12	4.75	4.50	4.35	-5.7
16Mb	32.00	19.00	8.32	12.90	10.24	8.25	6.75	6.50	-4.8
32Mb	-	-	-	35.00	23.00	19.00	13.50	10.00	
64Mb	-	-	-	-	45.00	29.00	19.00	15.00	
128Mb	-	-	-	-	-	65.00	43.00	29.00	
256Mb	-	-	-	-	-	-	-	75.00	
Total/Average	3.57	3.59	3.12	3.48	3.63	4.44	5.68	6.63	16.2
Percent Change (%)	-8.6	0.5	-12.9	11.4	4.3	22.4	27.8	16.7	

Source: Dataquest (August 1992)

Table 5-4
Shipments of ROMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	0	0	0	0	0	0	0	0	
32K	0	0	0	0	0	0	0	0	
64K	0.8	0.5	0.4	0.2	0.1	0	0	0	
128K	0.9	0.7	1.1	0.4	0.2	0.1	0	0	
256K	9.1	8.3	9.9	5.8	4.6	2.4	0.4	0.1	-64.9
512K	23.0	14.0	13.9	10.4	5.8	1.9	0.5	0.1	-67.3
1Mb	126.0	108.8	137.3	129.5	95.4	69.5	29.4	15.7	-35.2
2Mb	82.0	110.4	121.5	102.8	97.5	79.7	60.8	36.5	-21.4
4Mb	167.2	311.3	321.0	383.8	448.8	327.2	218.1	130.0	-16.5
8Mb	11.5	99.9	307.2	395.1	606.5	638.4	718.1	604.0	14.5
16Mb	5.0	27.7	42.4	72.1	246.6	486.5	640.9	822.1	80.9
32Mb	0	0	0	104.0	234.9	432.9	912.7	1,285.1	
64Mb	0	0	0	0	20.1	302.0	825.4	1,926.0	
128Mb	0	0	0	0	0	13.4	255.0	483.2	
256Mb	0	0	0	0	0	0	0	26.8	
Total/Average	425.5	681.5	954.7	1,204.1	1,760.5	2,353.9	3,661.3	5,329.6	41.0
Percent Change (%)	63.2	60.2	40.1	26.1	46.2	33.7	55.5	45.6	

Source: Dataquest (August 1992)

Table 5-5
Price per Bit for Shipments of ROMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
16K	152.6	-	-	-	-	-	-	-	
32K	48.8	48.8	70.0	67.1	-	-	-	-	
64K	25.2	24.4	25.2	23.7	-	-	-	-	
128K	13.0	12.6	11.5	11.1	9.2	8.5	-	-	
256K	6.9	6.4	6.8	5.7	5.1	5.0	4.8	4.6	-7.5
512K	4.8	4.5	3.8	3.7	3.6	3.5	3.4	3.3	-2.6
1Mb	3.2	2.6	2.4	2.1	2.0	1.9	1.8	1.7	-6.8
2Mb	2.1	1.8	1.5	1.3	1.2	1.1	1.0	1.0	-7.5
4Mb	1.6	1.2	1.0	0.9	0.7	0.6	0.6	0.5	-10.5
8Mb	1.4	0.9	0.7	0.7	0.6	0.6	0.5	0.5	-5.7
16Mb	1.9	1.1	0.5	0.8	0.6	0.5	0.4	0.4	-4.8
32Mb	-	-	-	1.0	0.7	0.6	0.4	0.3	
64Mb	-	-	-	-	0.7	0.4	0.3	0.2	
128Mb	-	-	-	-	-	0.5	0.3	0.2	
256Mb	-	-	-	-	-	-	-	0.3	
Total/Average	2.5	1.7	1.3	1.1	0.8	0.6	0.4	0.3	-24.0
Percent Change (%)	-31.2	-33.9	-24.5	-15.5	-28.1	-21.2	-28.6	-26.0	

Source: Dataquest (August 1992)

Table 6-1
Factory Revenue from Shipments of EEPROMs to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	27.4	16.9	17.8	15.0	13.2	11.2	8.1	5.9	-19.9
512b	0	0	5.6	8.3	10.0	10.2	11.0	11.5	15.6
1K	45.1	48.7	62.1	63.7	67.5	64.4	47.6	33.4	-11.7
2K	39.2	38.3	51.9	60.2	62.0	65.0	65.5	68.9	5.8
4K	44.1	54.1	28.3	48.8	63.0	72.5	78.8	89.3	25.8
8K	0	0	0.4	1.9	3.0	6.6	9.3	9.5	90.7
16K	31.3	27.1	31.9	30.6	36.3	48.2	64.8	78.0	19.6
64K	68.8	59.3	74.1	83.1	92.3	89.7	90.8	101.5	6.5
256K	60.5	45.0	48.1	46.5	50.0	59.0	28.7	17.0	-18.8
512K	0	0	0.9	0	0	0	0	0	
1Mb	3.1	2.8	5.3	15.8	49.0	40.8	26.0	6.0	2.6
Total/Average	319.6	292.1	326.2	373.8	446.2	467.5	430.4	420.8	5.2
Percent Change (%)	16.9	-8.6	11.7	14.6	19.4	4.8	-7.9	-2.2	

Source: Dataquest (August 1992)

Table 6-2
Shipments of EEPROMs to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	34.2	22.5	24.8	23.0	22.0	20.0	18.0	15.0	-9.6
512b	0	0	6.8	11.0	14.3	17.0	20.0	23.0	27.6
1K	41.0	48.7	100.1	130.0	150.0	165.0	140.0	115.0	2.8
2K	15.7	17.4	38.9	57.3	77.5	100.0	131.0	153.0	31.5
4K	11.0	19.7	13.4	25.0	42.0	63.0	87.5	119.0	54.7
8K	0	0	0.2	0.9	1.5	3.8	6.2	9.5	129.3
16K	7.1	7.3	11.3	13.6	17.7	25.5	37.0	52.0	35.6
64K	8.4	10.3	14.8	17.5	20.5	23.0	27.5	35.0	18.8
256K	0.8	1.2	2.5	3.1	3.7	5.0	3.1	2.0	-4.1
512K	0	0	0	0	0	0	0	0	
1Mb	0	0	0.1	0.2	0.7	0.6	0.4	0.1	11.9
Total/Average	118.3	127.1	212.9	281.6	349.9	422.9	470.7	523.6	19.7
Percent Change (%)	17.7	7.4	67.5	32.3	24.3	20.8	11.3	11.2	

Source: Dataquest (August 1992)

Table 6-3
Average Selling Price for Shipments of EEPROMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	0.80	0.75	0.72	0.65	0.60	0.56	0.45	0.39	-11.4
512b	-	-	0.82	0.75	0.70	0.60	0.55	0.50	-9.4
1K	1.10	1.00	0.62	0.49	0.45	0.39	0.34	0.29	-14.1
2K	2.50	2.20	1.33	1.05	0.80	0.65	0.50	0.45	-19.5
4K	4.00	2.75	2.11	1.95	1.50	1.15	0.90	0.75	-18.7
8K	-	-	2.51	2.25	2.00	1.75	1.50	1.00	-16.8
16K	4.40	3.73	2.82	2.25	2.05	1.89	1.75	1.50	-11.8
64K	8.19	5.75	5.01	4.75	4.50	3.90	3.30	2.90	-10.4
256K	75.29	38.19	19.46	15.00	13.50	11.80	9.25	8.50	-15.3
512K	-	-	44.88	-	-	-	-	-	
1Mb	165.00	100.00	92.56	79.00	70.00	68.00	65.00	60.00	-8.3
Total/Average	2.70	2.30	1.53	1.33	1.28	1.11	0.91	0.80	-12.1
Percent Change (%)	-0.7	-14.9	-33.4	-13.4	-3.9	-13.3	-17.3	-12.1	

Source: Dataquest (August 1992)

Table 6-4
Shipments of EEPROMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	0	0	0	0	0	0	0	0	-9.6
512b	0	0	0	0	0	0	0	0	27.6
1K	0	0	0.1	0.1	0.2	0.2	0.1	0.1	2.8
2K	0	0	0.1	0.1	0.2	0.2	0.3	0.3	31.5
4K	0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	54.7
8K	0	0	0	0	0	0	0.1	0.1	129.3
16K	0.1	0.1	0.2	0.2	0.3	0.4	0.6	0.9	35.6
64K	0.6	0.7	1.0	1.1	1.3	1.5	1.8	2.3	18.8
256K	0.2	0.3	0.6	0.8	1.0	1.3	0.8	0.5	-4.1
512K	0	0	0	0	0	0	0	0	
1Mb	0	0	0.1	0.2	0.7	0.6	0.4	0.1	11.9
Total/Average	1.0	1.3	2.1	2.8	3.8	4.5	4.5	4.8	17.7
Percent Change (%)	36.4	27.2	62.6	30.3	39.2	18.0	-1.4	6.9	

Source: Dataquest (August 1992)

Table 6-3
Average Selling Price for Shipments of EEPROMs to the World, 1989-1996
(U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	0.80	0.75	0.72	0.65	0.60	0.56	0.45	0.39	-11.4
512b	-	-	0.82	0.75	0.70	0.60	0.55	0.50	-9.4
1K	1.10	1.00	0.62	0.49	0.45	0.39	0.34	0.29	-14.1
2K	2.50	2.20	1.33	1.05	0.80	0.65	0.50	0.45	-19.5
4K	4.00	2.75	2.11	1.95	1.50	1.15	0.90	0.75	-18.7
8K	-	-	2.51	2.25	2.00	1.75	1.50	1.00	-16.8
16K	4.40	3.73	2.82	2.25	2.05	1.89	1.75	1.50	-11.8
64K	8.19	5.75	5.01	4.75	4.50	3.90	3.30	2.90	-10.4
256K	75.29	38.19	19.46	15.00	13.50	11.80	9.25	8.50	-15.3
512K	-	-	44.88	-	-	-	-	-	
1Mb	165.00	100.00	92.56	79.00	70.00	68.00	65.00	60.00	-8.3
Total/Average	2.70	2.30	1.53	1.33	1.28	1.11	0.91	0.80	-12.1
Percent Change (%)	-0.7	-14.9	-33.4	-13.4	-3.9	-13.3	-17.3	-12.1	

Source: Dataquest (August 1992)

Table 6-4
Shipments of EEPROMs to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	0	0	0	0	0	0	0	0	-9.6
512b	0	0	0	0	0	0	0	0	27.6
1K	0	0	0.1	0.1	0.2	0.2	0.1	0.1	2.8
2K	0	0	0.1	0.1	0.2	0.2	0.3	0.3	31.5
4K	0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	54.7
8K	0	0	0	0	0	0	0.1	0.1	129.3
16K	0.1	0.1	0.2	0.2	0.3	0.4	0.6	0.9	35.6
64K	0.6	0.7	1.0	1.1	1.3	1.5	1.8	2.3	18.8
256K	0.2	0.3	0.6	0.8	1.0	1.3	0.8	0.5	-4.1
512K	0	0	0	0	0	0	0	0	
1Mb	0	0	0.1	0.2	0.7	0.6	0.4	0.1	11.9
Total/Average	1.0	1.3	2.1	2.8	3.8	4.5	4.5	4.8	17.7
Percent Change (%)	36.4	27.2	62.6	30.3	39.2	18.0	-1.4	6.9	

Source: Dataquest (August 1992)

Table 6-5
Price per Bit for Shipments of EEPROMs to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256b	3,125.0	2,929.7	2,796.3	2,539.1	2,343.8	2,187.5	1,757.8	1,523.4	-11.4
512b	-	-	1,598.3	1,464.8	1,367.2	1,171.9	1,074.2	976.6	-9.4
1K	1,074.2	976.6	605.5	478.5	439.5	380.9	332.0	283.2	-14.1
2K	1,220.7	1,074.2	650.6	512.7	390.6	317.4	244.1	219.7	-19.5
4K	976.6	671.4	514.8	476.1	366.2	280.8	219.7	183.1	-18.7
8K	-	-	306.4	274.7	244.1	213.6	183.1	122.1	-16.8
16K	268.3	227.7	172.0	137.3	125.1	115.4	106.8	91.6	-11.8
64K	125.0	87.8	76.5	72.5	68.7	59.5	50.4	44.3	-10.4
256K	287.2	145.7	74.2	57.2	51.5	45.0	35.3	32.4	-15.3
512K	-	-	85.6	-	-	-	-	-	
1Mb	157.4	95.4	88.3	75.3	66.8	64.8	62.0	57.2	-8.3
Total/Average	311.6	224.0	153.8	135.3	116.0	102.9	96.2	87.9	-10.6
Percent Change (%)	-14.3	-28.1	-31.3	-12.1	-14.2	-11.3	-6.6	-8.6	

Source: Dataquest (August 1992)

Table 7-1
Factory Revenue from Shipments of Flash Memory to the World, 1989-1996
(Millions of U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256K	5.2	10.3	17.0	39.0	67.7	90.0	74.4	43.4	20.6
512K	1.1	1.7	17.5	36.6	73.5	104.0	108.0	73.6	33.2
1Mb	4.9	22.5	51.5	99.0	156.8	222.8	292.6	322.0	44.3
2Mb	0	0.8	33.6	63.9	97.5	171.6	243.2	334.8	58.4
4Mb	0	0	0	16.1	39.8	100.8	170.0	235.8	
8Mb	0	0	0	19.2	105.8	381.6	585.0	619.2	
16Mb	0	0	0	0	16.5	129.2	230.6	304.5	
32Mb	0	0	0	0	0	0	0	3.6	
64Mb	0	0	0	0	0	0	13.0	52.8	
Total/Average	11.1	35.3	119.6	273.8	557.5	1,199.9	1,716.8	1,989.7	75.5
Percent Change (%)	256.4	218.4	238.9	128.9	103.6	115.2	43.1	15.9	

Source: Dataquest (August 1992)

Table 7-2
Shipments of Flash Memory to the World, 1989-1996
(Millions of Units)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256K	0.5	1.4	3.0	7.8	16.5	25.7	24.0	15.5	38.7
512K	0	0.1	2.3	6.0	15.0	26.0	30.0	23.0	58.3
1Mb	0.1	1.2	4.9	13.2	28.0	49.5	77.0	92.0	79.7
2Mb	0	0	1.6	4.5	10.0	22.0	38.0	62.0	108.8
4Mb	0	0	0	0.9	3.0	12.0	25.0	41.0	
8Mb	0	0	0	0.6	4.5	24.0	60.0	86.0	
16Mb	0	0	0	0	0.3	3.8	14.5	29.0	
32Mb	0	0	0	0	0	0	0	0.1	
64Mb	0	0	0	0	0	0	0.2	1.2	
Total/Average	0.6	2.7	11.8	33.0	77.3	163.0	268.7	349.8	97.0
Percent Change (%)	338.1	314.3	342.4	179.6	134.2	110.9	64.8	30.2	

Source: Dataquest (August 1992)

Table 7-3
Average Selling Price for Shipments of Flash Memory to the World, 1989-1996 (U.S. Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256K	10.86	7.58	5.62	5.00	4.10	3.50	3.10	2.80	-13.0
512K	23.89	13.10	7.59	6.10	4.90	4.00	3.60	3.20	-15.9
1Mb	39.13	19.54	10.49	7.50	5.60	4.50	3.80	3.50	-19.7
2Mb	-	31.63	21.50	14.20	9.75	7.80	6.40	5.40	-24.1
4Mb	-	-	-	17.90	13.25	8.40	6.80	5.75	
8Mb	-	-	-	32.00	23.50	15.90	9.75	7.20	
16Mb	-	-	-	-	55.00	34.00	15.90	10.50	
32Mb	-	-	-	-	-	-	-	36.00	
64Mb	-	-	-	-	-	-	65.00	44.00	
Total/Average	17.21	13.23	10.13	8.30	7.21	7.36	6.39	5.69	-10.9
Percent Change (%)	-18.6	-23.1	-23.4	-18.1	-13.1	2.1	-13.2	-11.0	

Source: Dataquest (August 1992)

Table 7-4
Shipments of Flash Memory to the World, 1989-1996
(Trillions of Bits)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256K	0.1	0.4	0.8	2.0	4.3	6.7	6.3	4.1	38.7
512K	0	0.1	1.2	3.1	7.9	13.6	15.7	12.1	58.3
1Mb	0.1	1.2	5.1	13.8	29.4	51.9	80.7	96.5	79.7
2Mb	0	0.1	3.3	9.4	21.0	46.1	79.7	130.0	108.8
4Mb	0	0	0	3.8	12.6	50.3	104.9	172.0	
8Mb	0	0	0	5.0	37.7	201.3	503.3	721.4	
16Mb	0	0	0	0	5.0	63.8	243.3	486.5	
32Mb	0	0	0	0	0	0	0	3.4	
64Mb	0	0	0	0	0	0	13.4	80.5	
Total/Average	0.3	1.7	10.4	37.3	117.9	433.8	1,047.3	1,706.4	177.2
Percent Change (%)	640.7	505.0	519.5	257.6	216.2	268.0	141.4	62.9	

Source: Dataquest (August 1992)

Table 7-5
Price per Bit for Shipments of Flash Memory to the World, 1989-1996
(Micro Dollars)

	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
256K	41.4	28.9	21.5	19.1	15.6	13.4	11.8	10.7	-13.0
512K	45.6	25.0	14.5	11.6	9.3	7.6	6.9	6.1	-15.9
1Mb	37.3	18.6	10.0	7.2	5.3	4.3	3.6	3.3	-19.7
2Mb	-	15.1	10.3	6.8	4.6	3.7	3.1	2.6	-24.1
4Mb	-	-	-	4.3	3.2	2.0	1.6	1.4	
8Mb	-	-	-	3.8	2.8	1.9	1.2	0.9	
16Mb	-	-	-	-	3.3	2.0	0.9	0.6	
32Mb	-	-	-	-	-	-	-	1.1	
64Mb	-	-	-	-	-	-	1.0	0.7	
Total/Average	39.9	21.0	11.5	7.3	4.7	2.8	1.6	1.2	-36.7
Percent Change (%)	-51.9	-47.4	-45.3	-36.0	-35.6	-41.5	-40.7	-28.9	

Source: Dataquest (August 1992)

Dataquest

Dataquest Research and Sales Offices:

Dataquest Incorporated
1290 Ridder Park Drive
San Jose, California 95131-2398
United States
Phone: 01-408-437-8000
Facsimile: 01-408-437-0292

Dataquest Incorporated
Dataquest/Ledgeway
550 Cochituate Road
Framingham, Massachusetts 01701-9324
United States
Phone: 01-508-370-5555
Facsimile: 01-508-370-6262

Dataquest Incorporated Invitational Computer Conferences Division
3151 Airway Avenue, C-2
Costa Mesa, California 92626
United States
Phone: 01-714-957-0171
Facsimile: 01-714-957-0903

Dataquest Australia
Suite 1, Century Plaza
80 Berry Street
North Sydney, NSW 2060
Australia
Phone: 61-2-959-4544
Facsimile: 61-2-929-0635

Dataquest Europe Limited
Roussel House, Broadwater Park
Denham, Uxbridge
Middlesex UB9 5HP
England
Phone: 44-895-835050
Facsimile: 44-895-835260/1

Dataquest Europe SA
Tour Galliéni 2
36, avenue du Général-de-Gaulle
93175 Bagnolet Cedex
France
Phone: 33-1-48-97-3100
Facsimile: 33-1-48-97-3400

Dataquest GmbH
Kronstadter Strasse 9
8000 Munich 80
Germany
Phone: 49-89-930-9090
Facsimile: 49-89-930-3277

Dataquest Germany
In der Schneithohl 17
6242 Kronberg 2
Germany
Phone: 49-6173/61685
Facsimile: 49-6173/67901

Dataquest Hong Kong
Rm. 4A01
HKPC Building
78 Tat Chee Avenue
Kowloon, Hong Kong
Phone: 852-788-5432
Facsimile: 852-788-5433

Dataquest Japan Limited
Shinkawa Sanko Building
1-3-17 Shinkawa, Chuo-ku
Tokyo, 104
Japan
Phone: 81-3-5566-0411
Facsimile: 81-3-5566-0425

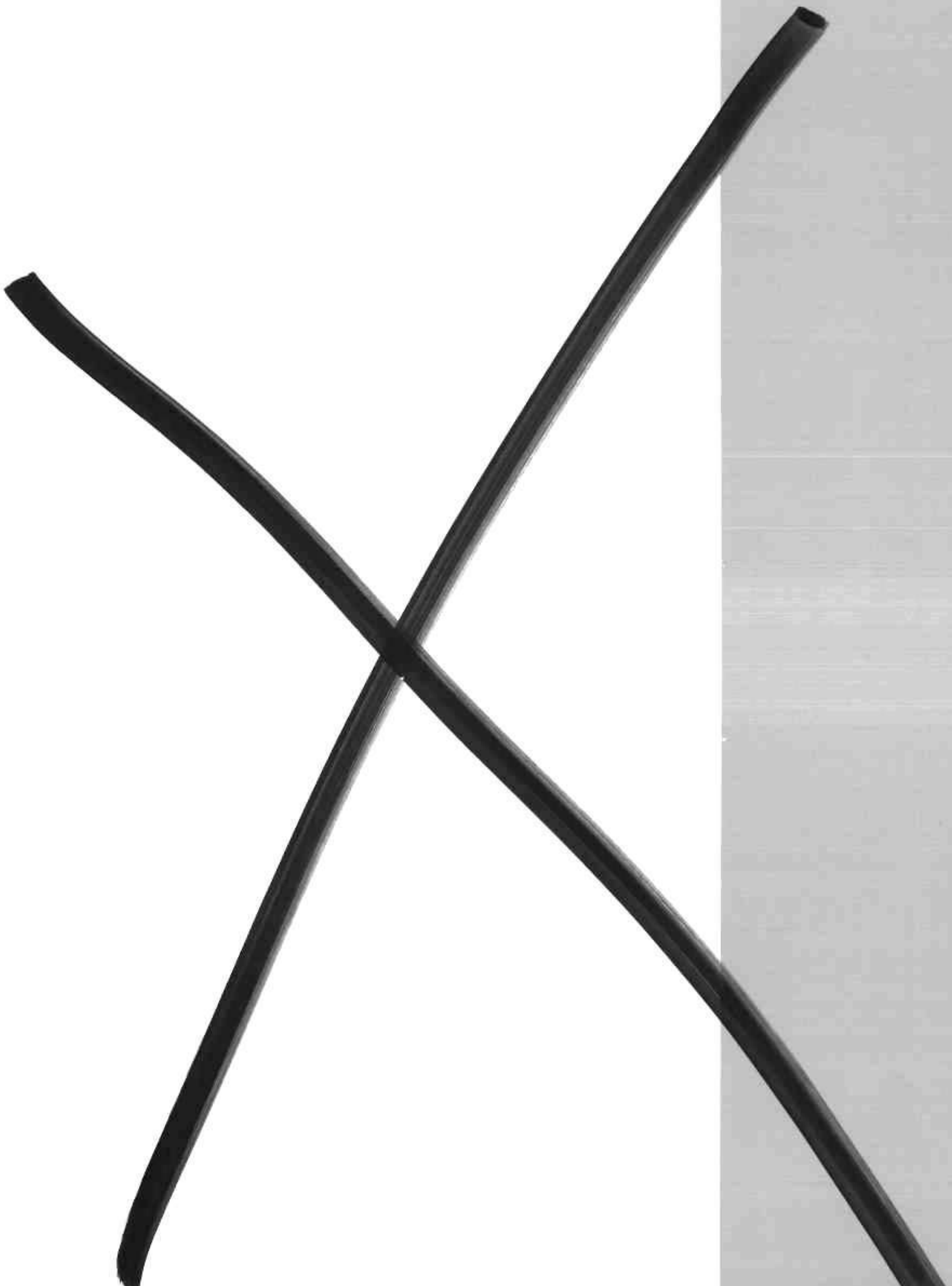
Dataquest Korea
Daeheung Building 1105
648-23 Yeoksam-dong
Kangnam-gu
Seoul 135-080, Korea
Phone: 82-2-556-4166
Facsimile: 82-2-552-2661

Dataquest Singapore
4012 Ang Mo Kio Industrial Park 1
Ave. 10, #03-10 to #03-12
Singapore 2056
Phone: 65-4597181
Telex: 38257
Facsimile: 65-4563129

Dataquest Taiwan
Room 801/8th Floor
Ever Spring Building
147, Sec. 2, Chien Kuo N. Rd.
Taipei, Taiwan R.O.C. 104
Phone: 886-2-501-7960
886-2-501-5592
Facsimile: 886-2-505-4265

Dataquest Thailand
300/31 Rachdapisek Road
Bangkok 10310
Thailand
Phone: 66-2-275-1904/5
66-2-277-8850
Facsimile: 66-2-275-7005

13379



Dataquest

Dataquest Vendor Profile

Memories *Worldwide*
September 14, 1992

Micron Technology

Corporate Statistics

Headquarters and Facilities Location	Boise, Idaho
Chairman and CEO	Joseph L. Parkinson
President and COO	Steven R. Appleton
Fiscal Year Ends	August 31
Employees	4,095 at year-end 1991
FY1991 Revenue	$425 million
FY1991 Net Profit after Taxes	$5.1 million
Shareholders' Equity	$495 million
Shares Outstanding	37.8 million
Products	82 percent DRAMs, 18 percent SRAMs
Leadership Area	Largest U.S. domestic producer of DRAMs

Micron Technology was founded in 1978 as a design house, but by 1982 it had emerged as a bona fide DRAM producer. Over the past decade, it has faced—and faced down—innumerable challenges as it progressed from the 64K to 4Mb DRAM density, and from no annual revenue to a $500 million annual run rate for a wide family of DRAMs and SRAMs. Micron has been the smallest continuous player in the DRAM business, with total revenue 10 to 100 times smaller than that of its competitors. It has outlasted a host of companies far better financed, including Intel, Mostek, and National Semiconductor. It has had to think smart to survive, whether it was in its innovative capital-conserving and cost-reduction methods, its use of the ITC to bring to task the Goliaths of the East that were dumping product in the world's DRAM markets, or in its enticing investment from a major user to accelerate facility expansion.

But as the smallest DRAM-focused DRAM supplier, Micron now faces the biggest challenges of its decade-long existence. And, being the smallest, perhaps it also shows us a glimpse of what all others will encounter in their turn.

For more information on Micron Technology or the memories industry, call Lane Mason at (408) 437-8120

Table 1 shows several time series for Micron Technology's financial performance since its inception. The table shows the financial roller

Dataquest
a company of The Dun & Bradstreet Corporation

MMRY-SEG-VP-9201

Table 1
Micron By the Numbers (Millions of Dollars)

FY Ending	First Quarter Ending 12/5	Second Quarter Ending 2/28	Third Quarter Ending 5/31	Fourth Quarter Ending 8/31	Year	Net PPE	R&D	Cap. Exp.	Royalties	Net PPT
9/79-8/82										
Revenue					4.8	NA	2.9	2.5		
Profit (%)					-7.3					
8/31/83										
Revenue	0.6	2.2	4.3	6.0	13.1	18.4	0.2	10.6		
Profit (%)	-2.01	-1.39	0.34	0.43	-2.63					
8/31/84										
Revenue	8.3	12.3	29.4	37.4	87.4	77.0	2.7	65.1		
Profit (%)	2.05	2.91	13.1	10.91	28.97					
8/31/85										
Revenue	37.2	18.2	14.4	6.1	75.9	104.5	6.6	43.1		
Profit (%)	10.45	2.82	-5.75	-7.37	0.15					
8/31/86										
Revenue	5.0	9.4	14.4	20.0	48.8	97.7	2.9	11.6		
Profit (%)	-11.60	-9.78	-6.71	-5.84	-33.93					
8/31/87										
Revenue	18.8	20.1	22.8	29.5	91.2	84.3	5.3	9.4	0.3	
Profit (%)	-9.68	-10.95	-3.72	1.42	-22.93					
8/31/88										
Revenue	43.2	58.3	85.6	113.4	300.5	117.4	[illegible]	44.3	18.1	
Profit (%)	8.43	16.94	29.28	43.33	97.98					

(Continued)

Table 1 (Continued)
Micron By the Numbers (Millions of Dollars)

FY Ending	First Quarter Ending 12/5	Second Quarter Ending 2/28	Third Quarter Ending 5/31	Fourth Quarter Ending 8/31	Year	Net PPE	R&D	Cap. Exp.	Royalties	Net PPT
8/31/89										
Revenue	110.4	113.8	119.2	103.0	446.4	326.0	21.4	199.1	41.8	4.7
Profit (%)	32.18	29.18	28.78	15.96	106.1					
8/31/90										
Revenue	66.5	77.5	84.1	105.3	333.4	385.1	35.6	78.9	33.8	105.1
Profit (%)	0.04	0.01	1.81	3.04	4.90					
8/31/91										
Revenue	80.3	94.5	126.8	123.8	425.4	389.3	35.8	52.0	41.6	96.9
Profit (%)	-9.27	-2.24	7.02	9.57	5.08					
8/31/92										
Revenue	111.8	128.2	131.1	135.0*	506.1*	390.0*	36.0*	50.0*	50.0*	84.0*
Profit (%)	0.63	1.46	1.66	2.2*	5.95*					

NA = Not available
*Dataquest estimate
Source: Micron Technology

coaster the company has been on. But Micron rose from the depths of 1985-1986 to consistently run more than $130 million in revenue per quarter recently. The reversals of 1990-1991 were not nearly so severe as those of the earlier cycle, and Micron scraped by with just two quarters of red ink and revenue that dropped only 45 percent from peak prior levels.

In addition, the table tracks technology portfolio measures: R&D spending, acquisitions of product and process technology (PPT), and royalty payments. For the physical plant, both capital spending and net PPE at year-end are also included.

Micron's Forte: Doing a Lot with a Little

Micron has been able to survive, and prosper from time to time, because it has some excellent design skills and an uncanny knack for making the smallest die that requires the fewest mask steps to produce. The former collection of skills make for more gross and net die per wafer, while the latter make for reduced capital requirements for a given level of unit production.

In 1983 and 1984, the early days of Micron's participation in the DRAM market, the company often was considered something of a joke. It was thought to be too small to be a serious supplier, and it peddled a 64K DRAM plagued with soft errors. Its answer—a first-pass 256K DRAM with error correction—was a good idea, but it was probably four DRAM generations before its time.

Even in 1988-1989, when the industry was far short of meeting demand, Micron squeezed millions out of the 256K DRAM market, even as its critics complained, among other things, that its parts cut too many corners and it could not meet demanding systems requirements.

Micron's critics did not fully appreciate the changing nature of the DRAM market during that time frame: The IBMs, HPs, and Digitals, with their big-system specifications and 5- to 10-year MTBFs, were rapidly being replaced by a cost-driven, low-end systems market. There was another DRAM market, cost-sensitive and without lengthy and exacting qualifications, where Micron found ample room to play (and where the Koreans were to follow a few years later).

At the same time, despite occasional early rejections from certain key accounts, Micron gradually made its way back as its quality, reliability, and device performance improved. Eventually, its account base looked pretty much like that of everyone else, including IBM, Digital, Compaq, Apple, and Acer.

After suffering mightily in DRAMs in 1985-1986, Micron branched into SRAMs, which now make up almost 20 percent of its business. It has differentiated the DRAM and SRAM product lines, as well, with dual-port DRAMs, three-port DRAMs, Quad-CAS DRAMs, byte-wide 4Mb and word-wide 1Mb and 4Mb DRAMs, and VideoRAMs. On the SRAM side, it now has 16K-1Mb SRAMs, plus latched and synchronous 16Kx16 and 16Kx18 SRAMs and FIFOs.

Still, these differentiated products sell into markets that are not large enough to protect Micron from the crushing pressures of a market that has been too far down for too long.

The Micron Way

Table 2 shows several examples of the skills that Micron has brought to cost-reduced DRAMs. The table shows die sizes and mask counts for successive generations of Micron's 256K, 1Mb, and 4Mb DRAMs.

At present, Micron is completing the transition to the "hypershrink" 1Mb DRAM and the "ministack" 4Mb DRAM. Compared with standard industry parts, the 1Mb is about 75 percent as large as the next smallest competitive part, and the 4Mb (present generation) is about the same as other manufacturers, with two more revs to come.

Indeed, faced with escalating costs of new facilities, and process that only becomes more complex, many competitors that earlier turned up

Table 2
Micron Technology DRAM Mask and Die Size Progression

Density	Device Name	Die Size	Introduction Date	Masks
256K	Production 1	40.00 sq. mm.	7/84	9
	Production 2	32.49 sq. mm.	12/85	9
	Shrink 1	23.39 sq. mm.	4/87	7
	Shrink 2	19.10 sq. mm.	5/91	7
1Mb	Production 1	56.8 sq. mm.	10/87	13
	Production 2	44.74 sq. mm.	10/89	11
	Shrink	36.67 sq. mm.	10/90	10
	Supershrink	24.26 sq. mm.	3/91	10
	Hypershrink	17.64 sq. mm.	12/91	10
4Mb	Production 1	100.10 sq. mm.	3/90	13
	Production 2	75.87 sq. mm.	6/91	12
	Ministack	61.29 sq. mm.	3/92	12
	Shrink	48.32 sq. mm.	TBD	11
	Supershrink	46.45 sq. mm.	TBD	10
16Mb	Prototype	140.39 sq. mm.	2/92	16

TBD = To be determined
Source: Micron Technology, Dataquest estimates (September 1992)

their noses at Micron's capabilities are taking another look. Micron has the following collection of proven methods:

- Extending the useful life of its equipment
- Reducing mask counts and thereby increasing throughput without compromising performance
- Making the smallest die in the industry

Technology Laggard

Though Micron has working samples of 16Mb DRAMs and several advanced development programs up into the 64Mb stratosphere, traditionally it has been a technology laggard. It typically was late to market with generation after generation (preferring to make millions on last year's part). It has only sparingly invested in the distant future, choosing instead to concentrate on refining the present money generation by cost reduction. This habit, too, is gaining Micron some attention in the industry, as companies see much of their far-advance investment coming to naught.

At the same time, Micron has been an innovator—not always mindful of the market, but still with a nice portfolio of innovative DRAM and SRAM designs. Forget for the time being its 64K soft-error problems and its 256K and 1Mb forays into ECC, and pay attention instead to the fact that, like Samsung, it has risen from a virtual nonplayer to a substantial position in the DRAM market in a decade, but with immeasurably smaller resources at its disposal. Today it is the largest domestic producer of DRAMs (No. 8 worldwide) and the No. 7 supplier of fast SRAMs. Micron was early with a Quad-CAS 1Mb DRAM, won accolades for its three-port DRAM, and impressed all with its SRAM successes.

Still, Micron's profits today are marginal, which reflects both on the tough market environment and its own continuous die revision upgrades that have been played out over the past two years as it moved from producing one die revision for 1Mb and 4Mb DRAM to the next. Now that Micron is sold on its last 1Mb revision, it can focus on yield improvement. But its 4Mb has two more revisions to go.

The following analysis provides a pro forma rollout of the revenue run rate that Micron may be able to generate. Micron is running about 12,000 150mm wafers per week through its facility and is at near capacity, given its mix of SRAM and DRAM products. It is generating about $10 million per week in revenue, or about $800 per wafer.

With the reduced mask-count 4Mb DRAMs now being input into the line, Micron may be able to keep the number of wafer outs at about the same level while shifting the product output more to 4Mb DRAMs. Micron's newest 4Mb device requires the same number of masks steps as its 1Mb product.

1Mb DRAM Potential

At its peak, in 1993-1994, Micron may be able to yield 600 to 650 net die per wafer from its hypershrink 1Mb DRAM, and generate revenue of about $1,600 to $1,700 per wafer.

4Mb DRAM Potential

The present incoming ministack version is a die size of about 61 square millimeters, which has about 210 gross die per wafer; the outgoing "production die" has 170 gross die per wafer. The supershrink 4Mb die, which will be Micron's production vehicle in 1994, will have about 280 gross die per wafer. With a 75 percent line yield, upward of 200 net die per wafer may be yielded, for revenue of $1,200 to $1,300 per wafer in 1994.

To achieve these potential improvements, Micron must stabilize production around a single die iteration and concentrate on yield improvement. It is not inconceivable that Micron could produce up to $800 million from its existing facilities in the 1994 time frame, compared with its estimated $506 million for FY1992.

Still, lacking at upturn in demand and profitability, Micron will likely be unable to fund the next increment of expansion, which must be put in place in the next two years to be ready for 1995-1996.

The Twin Peaks: Capital and Intellectual Property

It has been known for some time that participation in the DRAM business requires immense amounts of capital. Of all the fables put forth over the past decade about the DRAM market—cannot sit out a generation, need of a captive user, bi-rule and pi-rule, increasing PPB from generation to generation— holding most true is that massive sums must be expended to participate.

Though the capital is ultimately recovered through depreciation, at some point in the cycle it must be made available by someone, and in large sums. Micron's earlier building programs in 1983-1985 and again in 1988-1990 combined the cyclical profits of the DRAM industry with infusions of equity funding from outside in three secondary placements during 1986-1987, and in a $76 million investment from its largest European customer, Amstrad plc, in 1989, plus equity offerings for an additional $170 million.

This time, the down cycle has persisted longer than might ordinarily have been expected, keeping recent profits low. Over the 12 quarters of FY1990 to FY1992, Micron's after-tax earnings have been about $16 million on sales of $1,164 million—hardly enough to go the next round.

At the same time, the capital requirements to fund the next round of capacity expansion and substantially expand capacity for new 4Mb production and the early 16Mb DRAM market are immense even in comparison to the sums expended in 1989-1990. It takes about $350 million to get 9,000 monthly starts using 200mm wafers on a

0.6-μm design today, which is enough to stay competitive through about 1996-1997. But without a profit bubble as seen in 1983-1984, or again in 1988-1989, there is small hope of either funding the expansion or enticing investors to part with their money.

Micron certainly needs capacity to grow; it is now running at near capacity and has its finest "small die" and "few masks" designs already into production. If the market is to grow better than 50 percent by 1994, as many expect, Micron must have the capacity in place or miss a great opportunity to gain market share.

Micron's board has been reluctant to issue more stock (indeed, the recent price, at $15.75, is 25 percent lower than what Amstrad paid in 1989). It is not known how well the market might receive such an offering, given the state of DRAM profits recently. Micron is said to be actively seeking a partnership that will help it with the capacity upside.

Intellectual Property

Like everyone in the semiconductor industry, Micron's consciousness of the importance of intellectual property has been raised dramatically since 1987, when Texas Instruments renewed its patent licensing agreements with its licensees. Indeed, Micron said the following in its 1987 and 1988 Form 10Ks:

- In 1987: "The Company has received notice of infringement of patents from certain semiconductor manufacturers with respect to certain aspects of the Company's processes and devices. If any infringement has, in fact, occurred, Micron is of the opinion that any necessary licenses or other rights under patents could be obtained on conditions which would not have a materially adverse effect on the Company."
- In 1988: "While the Company intends to seek patent protection on as much of its technology as possible, due to the rapidly changing technology in the semiconductor industry, Micron believes that its future success will be dependent, in large measure, upon the technical expertise and creative skills of its personnel."

The license agreements it had in place at the close of FY1988 were with Shell Development Company, Motorola, Standard Microsystems, ATT, and Intel. All were modest in their financial consequences as originally written. But the deal with Intel was to explode less than 15 months later, resulting in a "renegotiation" of the original agreement and a $50 million licensing settlement with Intel for DRAM, SRAM, and VRAM technologies being used by Micron in its products.

Also, at that time, Micron had already received notice from Texas Instruments that it was believed to be infringing TI's patents. Though Micron resisted settlement on TI's terms, it had already set aside a reserve of $17.6 million in the event of an unfavorable resolution. Eventually, in May 1989, Micron settled with TI for $38.2 million.

So, while Micron maintained outwardly the position that technology was changing fast enough that, with its own creative powers, it could avoid major impacts from others' technology positions, like many others it had small understanding of what was to come. Intellectual property rights (IPR) emerged in the late 1980s as the most important source of competitive advantage, income, and profits.

This period made for a realization of the immense value and costs of proper treatment of IPR at Micron. It doubled its efforts to achieve a patent portfolio for itself that it hoped would absorb the brunt of the impact from IPR heavies bearing down on them, all seeking a king's ransom for their own intellectual property.

As of year-end FY1992 (August 31, 1992), Micron had been granted about 192 U.S. patents (see Table 3).

One can imagine that many of the critical MOS IC, DRAM, and SRAM patent structures and circuits are already claimed by companies that were in the market before Micron came into existence. Indeed, Intel, TI, and IBM have proven to be the big patent winners in the IPR wars over the past five years. So, despite the rapid rate of technical change that Micron hoped would save it from pain, the MOS pioneers, for the time being, are reaping vast sums in royalty and licensing fees from the new DRAM makers, Micron included.

Though Micron is rapidly building up its own patent war chest, and the patents of the pioneers are slowly expiring, Micron is still due to pay to play for the next several years. For now, Micron has put in place a series of licensing agreements that give it access to the essential technology to participate in the SRAM, VRAM, and DRAM markets (see Table 4).

Micron Technology has paid out more than $270 million for acquisition of product and process technology and for annual royalty payments since FY1988. This compares with Micron's direct R&D expenses over the same period of about half that amount ($138 million) and its after-tax profits of $220 million.

Table 3
Micron Technology Patents at Year-End 1992

Year	Patents
1986	1
1987	1
1988	1
1989	12
1990	44
1991	106
1992	192

Source: Micron Technology and U.S. Patent Office

Table 4
Micron's Technology Licenses

Company	Item	Date	Terms
Shell Development Company	Basic MOS patents	1985	Paid in full
ATT	XLC (Memory plus sensors)	10/86, 1/89	Fee plus ongoing per unit
Intel	Tech XLC; DRAM, SRAM, VRAM	3/88, 1/90	$50 million plus per-unit?
Motorola	XLC	1988	Ongoing
Texas Instruments	XLC	5/89, 9/92?	$38.2 million plus per-unit
Standard Micro Systems	MOS patents, XLC	3/88	$9.3 million stock purchase; fee, paid in full
IBM	4Mb DRAM technology	11/89	$50 million
	Tech XLC, joint technology development		
Wang Labs	SIMMs license	12/91	Per-unit fee
Hitachi	Tech XLC	7/89	Fee plus per-unit
Samsung	EEPROM, SRAM rights, XLC	6/86	Samsung buys uT Stock
Sanyo	Micron Lic 64Kx16	10/89	Royalty to uT

Source: Micron Technology Form 10K, Dataquest (September 1992)

Micron capitalizes its purchases of product and process technology and amortizes those costs over the patent term, the useful life of the technology, or the term of the agreement, whichever is shortest. Royalties paid and amortization of capital costs are ascribed to production and R&D costs. Costs incurred to establish patents are also capitalized.

Micron's 1989 agreement with Texas Instruments is set to expire soon, and Micron warns in its recent third-quarter interim report that "... the Company's cross-license agreement with Texas Instruments, Inc. expires September 3, 1992. There can be no assurance that the cross-license agreement can be renewed on acceptable terms." If this year's royalty income for Texas Instruments is any indication of an increase in the aggressiveness with which it pursues favorable cross-license agreements, Micron may not get off as well as it did in 1989. TI's royalty income is up 45 percent to $218 million in the first half of 1992, compared with $150 million in the first half of 1991.

Alliances

In addition to licensing technology, Micron has engaged in many alliances over the years to acquire and develop technologies deemed necessary to carry out its business. It is a founding member of Sematech, though it has announced plans to withdraw at year-end.

In 1989, Micron signed an agreement with Sanyo for Sanyo to buy Micron's DRAMs both for its own use and to resell into the Japanese market. About a year later, this agreement was expanded to provide for Sanyo to actually produce for use and sell Micron's 64Kx16 DRAM into Japan.

More recently, on July 15, 1992, Micron and NEC announced a joint cross-OEM arrangement to sell each other's SRAM and DRAM products under their own brand names. It was offered as a rationale that this would reduce the product development cycle and cost. However, there may be more to this agreement than first was made public.

Micron's Options: Capacity Expansion

Given its reluctance to float more stock (at least for now), Micron is said to be actively seeking a partner that could help it gain access to additional wafer fab capacity. The options are rather limited, but, as in the past, Micron is certain to strike a creative deal that will serve the interests of all parties.

Customer-Funded Fab

The first option is a Texas Instruments-like partner-funded front end. Since 1988, TI has gained essentially an entire new front end, and control over many times that amount, through the use of creative ventures with its customers and others interested in getting into the semiconductor business. Both Dallas DMOS 4.2 and Avezzano, Italy were built, in part, using advance payments from key TI customers (plus subsidies from the Italian government). KTI, a joint venture with Kobe Steel, was essentially funded by Kobe Steel, with TI providing the technical wherewithal. Its joint venture with Acer, now coming up with the 4Mb DRAM, was more than half funded by Acer, and another 24 percent of the stock is held by a variety of Taiwan interests. TECH Semiconductor is a joint venture among HP, Canon, and the Singapore government.

Such a venture is appealing to Micron because it would limit Micron's monetary contribution, as well as its equity share. But, for the most part, it controls the output.

Micron may have an opportunity to take advantage of the same concern that drove Acer to invest in TI: dependence of the Taiwanese computer businesses on imported DRAMs, largely from other Asian companies. Also, because Micron is (so far) a paid-up licensee of TI (and others') patents, this could be another advantage for Taiwan interests choosing to partner with Micron instead of another DRAM maker.

Foundry

Another option is to use foundries to make its product. For Micron, this could be difficult because the manufacturing-intensity of the product means that Micron itself needs to have tight control over the process and facility to maintain its technical advantages. This would almost be impossible in a facility shared with strangers, because the processes must be compatible.

Shared Facility

A third option is a joint venture with another semiconductor manufacturer operating in a shared facility. This could be a partner that wanted to gain from some of Micron's low-cost manufacturing techniques, or to reduce its own exposure to royalty payments by benefiting from Micron's patent portfolio, which is more filled out. An example of such a venture is the Altera-Cypress facility in Round Rock, Texas.

Lease a Fab

A fourth option is to lease an underutilized facility from another party and run it on a contract basis. Such an arrangement would allow Micron to make lease payments out of current revenue and avoid ownership and equity dilution, but gain access to additional capacity. An example is Alliance Semiconductor's aborted leasing of the ATT facility in Lee Summit, Missouri in mid-1989.

Lease options are attractive and a trend in the semiconductor industry. All companies must decide where to apply their capital to greatest effect. As in the airline business, a group of capital/capital equipment providers may spring up to support the technology providers in the semiconductor industry. As also was the case in the airline industry, banks may be reluctant to extend loans to companies in such an expensive, competitive business as DRAM manufacturing.

Bargain-Basement Facility

Cypress picked up a quality facility from CDC last year, at a very attractive price. One rumor floating around concerning Micron has it tied up with IBM's Manassas, Virginia facility.

The prospect of Micron having access to NEC's Roseville, California facility is attractive, as well, and its existing deal may grow to include such a tie-up.

Micron's Options: Intellectual Property Rights

Few companies can pay out 10 percent of sales for royalty payments, plus another 7 percent for their own R&D, and still put money in the bank at the end of the day. As Micron feverishly expands its patent portfolio to gain leverage in its negotiations with other patent traders, there are recent court rulings that might help it avoid such excessive payments.

Last month, the initial Cyrix ruling held that, since SGS-Thomson was fully cross-licensed with Intel (via Intel's earlier agreement with Mostek, which STM bought in 1985), STM could foundry the 387 for Cyrix without violating Intel's patent rights. The ruling is being appealed by Intel. Texas Instruments may have similar designs with its own agreement with Cyrix over Cyrix's 486.

In a 1991 ruling, the courts also prohibited SMSC from transferring its full cross-license rights with Texas Instruments to third parties. The limits of this ruling could also have an impact on Micron's ability to reduce its royalty payments.

Significant cross-licensing umbrellas may be available to Micron to reduce its liability to Texas Instruments in particular, or any of its licensers, such as Intel, IBM, or others.

Dataquest Perspective

What might we expect? Over the next 6 to 12 months, we can expect Micron to push ahead in its traditional cost-reduction program. We expect to see significant results as the pace of die revision transition slows. At the same time, we can also expect Micron to use its increasingly valuable technical assets to establish a partnership with another party that will supply expanded capacity for Micron at a far reduced cost to Micron than it would face were it to do it by itself.

Finally, the aversion of Micron's management to additional funding may be temporary. Securities analysts—and probably Micron management—look for improved earnings from Micron as the business improves over the next 6 to 12 months as part of a cyclical upturn. Improved earnings mean improved stock price, so the longer Micron can wait before any equity offering, the greater the yield. But so excessive was capacity as 1992 began that a year with 75 percent DRAM bit growth, significant by recent standards, so far has failed to absorb all excess and arrest DRAM price declines.

But this cannot go on forever. Japanese companies have announced cutbacks in capital spending of about 30 percent for the present year, the Micron-initiated antidumping petition and similar EC rulings are less than a month away, and the summer quarter has been mild by comparison with earlier years. Micron could be positioned quite well for 1993 and beyond if it can strike the right deal with the right partner and reduce both its capital burden and its royalty burden at the same time.

Dataquest

Dataquest Perspective

Memories *Worldwide*

MMRY-SEG-DP-9204 December 14, 1992

In This Issue...

Market Analysis

DRAM Market Trying to Keep Afloat in Choppy Waters

As a result of last month's ruling concerning Korean DRAM makers dumping their product in the U.S market, coupled with a similar ruling in the European Community (EC) a month earlier, the DRAM market is currently in a minor state of turmoil. Although the U.S. Department of Commerce (DOC) will not make its final ruling until March, at which time it will set forth the final dumping margins, it is already clear that the preliminary rulings are having an impact, introducing a significant element of uncertainty into the market.

Strong demand had already absorbed much of the excess capacity existing at the beginning of 1992; therefore, the recent ruling came on top of what was a natural tightening of the market with some price stability. The ruling introduced a high noise element into the changing market, making it more difficult to discern what is happening in the larger supply-demand balance.

Still, the manner in which this particular episode has been played out leaves much to be desired. In the midst of many conflicting impressions, advice, and analysis, Dataquest offers the following commentary on the events of the past month.

The Effort to Find the Truth

Micron filed its petition on April 22, 1992, but the preliminary dumping margins were not made public until October 21—a full half year later. The DOC reported that Samsung's preliminary dumping margin was 87 percent. This was based on "best information available" rather than on the data Samsung submitted, which was at least in part rejected by the DOC.

Samsung has shipped more than $1 billion in DRAMs in 1992, and few really believe that

Samsung lost the $800 million in DRAMs as suggested by DOC's preliminary dumping penalty ruling. The ruling was a surprise to both Samsung and GoldStar. Why the DOC couldn't have worked more closely with all Korean companies to insure that the amounts listed in the preliminary ruling were more accurate is hard to understand. While DOC accountants have just returned from Korea after examining the books of the three defendants, there is no reason they couldn't have been there during the summer, to ensure that the preliminary ruling was close to accurate.

The other logic behind antidumping laws is that companies dump product to drive the competition from the market, after which they raise prices and reap immense profits.

By failing to do so, and by reporting as high a number as it did, the DOC has caused unnecessary turmoil in the market at a high cost to users, and it has imposed unnecessary costs on DRAM makers as well.

But the DOC can't take all the blame. Those who are party to the complaint are not entirely blameless.

Afterthought: Where Was the Korean Forethought?

Micron first rattled its saber concerning antidumping charges in late 1990, and its threat has been intense since early 1992 when GoldStar and Hyundai began to make great efforts to increase their U.S. market share. Micron has stated, in a press release to its DRAM customers, that it also met with representatives of all three Korean DRAM makers, as well as with U.S. officials in Washington, D.C., three times in the prior two years in an attempt to halt the alleged dumping—obviously without the desired result.

It is hard to understand why the Koreans didn't substantiate their costs relative to the reconstructed cost formulations. Surely the Koreans knew of the Japanese experience, the resulting fair market value agreements, and the intricacies of the reconstructed costs. The Koreans should have known at all times what their costs and sales prices were (on the DOC cost basis) in every region. They should have been able to produce DOC-acceptable cost and price data on a moment's notice, thereby avoiding the uproar that has resulted.

Furthermore, it is clear that GoldStar and Samsung were not altogether cooperative with the DOC's preliminary investigation, failing to produce adequate cost documentation even as the six-month deadline was about to expire.

Third-Country Prices

While it is written in U.S. law that the absence of adequate data in the home market is sufficient reason to use comparable third-country data (as was the case of using Hyundai's Singapore sales data), it certainly puts Samsung and GoldStar at a disadvantage because each is required to use its own Korean sales data for price comparison. Singapore is the essence of a highly competitive (low price) market, while Korea has the significant element of controlled-access.

Logic of Antidumping Legislation

On a global scale, the Korean market offers a vanishingly small opportunity when compared with the rest of Asia, the United States, and Europe. Dataquest estimates that 1992 Korean consumption was about 3 percent of the world DRAM market. A logical argument in favor of antidumping laws is that companies subsidize their dumped export sales with high domestic prices. Given the external sales ratios of the Koreans (about 90 percent), 4Mb DRAMs would have to cost $100 in Korea, without loss of sales volumes, to make up for the lost profits resulting from underpriced export sales.

The other logic behind antidumping laws is that companies dump product to drive the competition from the market, after which they raise prices and reap immense profits. Certainly, the profits reaped by Japanese DRAM makers in 1988 and 1989, after U.S. competition exited the market, were immense. But Samsung was probably the single most important DRAM supplier to help restore equilibrium in the market beginning in 1989. And it was Hyundai and GoldStar that were the acknowledged "price aggressors" from the fourth quarter of 1991 through the third quarter of 1992, responsible for dropping 4Mb prices from $16.00 to $10.00 and gaining market share on a monthly basis.

A third, and important, reason for dumping laws is to be able to protect domestic industry from unfair trade practices.

Today, with the Japanese still controlling 55 percent of the DRAM market, there is no way "Korea, Inc." can raise prices without giving up market share to the Japanese (and to Texas Instruments, Micron, Siemens, and Motorola). As much as Micron needs to be protected by the antidumping laws, which have a valid basis in economic theory and have been historically applied in other industries, the DRAM industry structure does not lend itself to either of these two logical antidumping arguments.

As the events of 1985 and 1986 show, such concern is not without merit. Mostek, Intel, Inmos, and several others dropped from the DRAM market during this period because of severe financial losses, in part because of each company's failure to recognize the commitment necessary to be a long-term DRAM player. The market today is much different, to a large degree because of the Korean presence and Korea's willingness to match Japanese suppliers DRAM for DRAM. There currently is no anticompetitive hegemony among producers, and DRAM users (as long as they are not also producers) may have the best position available today—immense companies with substantial technical and financial resources competing for market share gains in the DRAM market.

But with the financial and economic problems in Japan, the perceived threat of a vertically integrated Japanese industry conquering all that stands before it is vastly diminished. Judging from recent public positioning, Japanese semiconductor companies have embraced the new religion of profitability. Korean companies, on the other hand, are far less capable of damaging established systems businesses worldwide because they hold such a small position in PCs, notebooks, mainframes, telecommunications, and other electronics products. In fact, the Koreans pose far more of a threat to Japanese consumer electronic equipment makers than to any European or U.S. electronic equipment maker. Indeed, if it weren't for Siemens in Europe and Micron Technology in the United States, U.S. and European policymakers might be well-advised to allow dumping so that the lowest possible DRAM prices exist for their systems makers. Although TI is nominally a U.S. maker of DRAMs, almost all of its production is in Japan, Taiwan, Italy, and in the near future Singapore. The rationale of "DRAMs for process driving" is also being scrutinized as never before—one *can* drive process technology without DRAMs.

Injury to the Domestic Industry

A third, and important, reason for dumping laws is to be able to protect domestic industry from unfair trade practices. In this case, the matter is complicated by the fact that the domestic industry is a complex fixture. Micron is the only fully domestic merchant supplier. IBM is making noise about moving from behind its captive curtain to enter the merchant market, but so far it can only be a beneficiary of excessively competitive merchant pricing practices. Texas Instruments has been losing money in DRAMs for some time, but most of its present product is from its own manufacturing in Miho (Japan), Avezzano (Italy), and from Hyundai, which has acted as a DRAM foundry for TI for several years. Motorola makes 1Mb DRAMs in the United States, but receives its 4Mb DRAMs from Toshiba and Tohoku SC in Japan, as well as from GoldStar. Motorola also has an OEM-into-Japan arrangement with Mitsubishi. It is therefore not easy to determine, for purposes of the law, what constitutes the domestic industry. Apparently, three of the six International Trade Commission (ITC) commissioners wanted to consider domestic SIMM module makers as a part of the domestic industry because they compete against Korean-made SIMM makers, who may have an unfair transfer price advantage.

Finally, in the irony of all ironies, all Japanese manufacturers that now have facilities in the United States (including Hitachi, Fujitsu, Toshiba, NEC, Mitsubishi, and Matsushita) are now a part of the domestic industry that is protected by U.S. antidumping legislation. Of course these companies were all signatories in the original 1986 Semiconductor Trade Agreement that sought to halt dumping of DRAMs in the United States. Back then, however, they were the ones agreeing not to dump DRAMs.

What constitutes the "injured domestic industry" is not entirely clear at this point, except it is clear that Micron Technology is definitely a part of the domestic industry. Micron has, under the terms of the law, a valid claim. Whether the others do, or whether they can truly be considered in making the injury case, depends to a degree on the amount of added value that occurs in the United States.

More on Origins of the Law

Having large financial resources and a willingness to lose money to achieve market dominance has for many years been considered an unfair advantage under U.S. law. This is not the case, however, under the laws of several of the United States' important trading partners. Specifically, the particular legal basis for Micron's antidumping claim can be traced through the Super 301 of the mid-1980s, back through the 1974 trade legislation, and back further to the original law embodied in the Smoot-Hawley Tariff of 1930. Elements of the cost calculation can be traced even further back to 1921 legislation, passed during the sharp post-World War I recession in which the U.S. GNP dropped 20 percent (and recovered) in the space of 18 months. What was true then is still true today—economic contractions lead to price competition, which leads to protective legislation.

Silence of the Lambs

Petitions were filed by U.S. DRAM users in 1985 and 1986 in an attempt to exempt certain SIMMs from tariffs, allowing them to be shipped duty-free into the U.S. market. SIMMs were ruled to be DRAMs for purposes of the law. The result was the same this time.

The present antidumping proceeding has offered an opportunity for DRAM users and other interested parties to express any concerns they might have about the outcome and impact of the present course. According to a DOC spokesman, DRAM users have filed no such statements.

For the time being, the Computer Systems Policy Project (CSPP) is mute. Remember that DRAM users, because of a lack of an organized response structure, were shut out from the discussions and decisions that resulted in the Semiconductor Trade Agreement in 1986. DRAM users are on record in a formal March 1990 statement as being opposed to allowing the sale of dumped DRAMs in the U.S. market. Accepting this provision was likely a result of some arm-twisting by the Semiconductor Industry Association because DRAM users surely showed no reluctance to buy 256K DRAMs in 1985, when prices dropped below $2.00, forcing U.S. DRAM makers to exit the market one by one. DRAM users hopefully recognized that they really did need a healthy U.S. semiconductor industry.

Only those with very short memories cannot remember the Japanese DRAM hegemony as the market moved from surplus to shortage in 1987 and 1988.

Likewise, the Computer and Business Equipment Manufacturers Association (CBEMA), which took a position during the 1987 dumping crisis, is silent. By its own account, it also is not paying much attention to what is happening in the dumping discussion.

Among the various scenarios that may result from the current upheaval is one that would put U.S. DRAM users, already under immense price pressure for their own system-level products, at a significant disadvantage in the procurement of DRAMs that are competitively priced with those from non-U.S. makers. A two-tiered market—with high U.S. prices and low Asian prices—is a conceivable outcome given the present direction of the proceedings.

At the same time, board-stuffing and procurement operations of some U.S. systems companies are now located in Asia, which is currently outside the jurisdiction of U.S. trade law. In addition, Asian motherboard output, including sales into the United States, is specifically excluded from the dumping provisions.

Those Who Cannot Remember the Past Are Condemned to Repeat It

Only those with very short memories cannot remember the Japanese DRAM hegemony as the market moved from surplus to shortage in 1987 and 1988. The situation was not alleviated by an upwelling of domestic DRAM makers in the United States. Notably, National Semiconductor was called, but it declined to reenter the DRAM market. MegaRAM, a business plan for a venture start-up, fell on deaf ears. Intel was preoccupied with microprocessors and later called its departure from the DRAM market the toughest but best decision it ever made. U.S. Memories was stillborn as the market became more balanced in 1990. Alliance Semiconductor, a little start-up running a leased facility in Missouri, bloomed then wilted within months. Eventually, after two years of market tightness, prices began to break late in 1989 and an equilibrium was again possible.

However, without Samsung in the DRAM business in 1988 and 1989, market forces would have taken far longer to bring the market into equilibrium. It has also been Korea that has kept the pressure on prices over the past two years, making it difficult for all DRAM makers—U.S., European, Japanese, and even Korean—to make much money during that time.

Settlement Scenario Issue Number One—Offshore Production

Any immediate resolution that places Korean DRAM production off limits for sale into the United States is destined to be only temporary, and ultimately counterproductive. One has only to build DRAMs within the jurisdictional walls of the affected country. Japanese and U.S. producers that perform diffusion in Europe are exempt from the antidumping provisions of the reference price (RP) system. In an interesting limitation of the law, Japanese producers in the United States (notably NEC in Roseville) are not covered by the Semiconductor Trade Agreement, but TI's Miho plant is covered by the agreement. DRAM makers, without another layer of special considerations, are likely to expand production within the walls of Fortress USA in an attempt to circumvent the present rulings.

Settlement Scenario Issue Number Two—Is Korean DRAM Capacity Out of Play?

The possibility that the Korean DRAM capacity will be removed from the market is almost nil. Some of the present driving forces behind the antidumping movement may be intemperate, but they are not stupid. To remove Korean DRAM capacity at this juncture would create a mess in a market that is naturally getting closer to balance on a daily basis. Micron's president, in remarks made at the recent Electronika trade show, acknowledged the late summer upturn in the market, and the Korean contribution to worldwide DRAM supply is a matter of public record. Such a drastic cure would surely cause far more damage than any alleged dumping has caused, especially since Micron's survival is not threatened. Micron now has six consecutive quarters of profitability, and it is poised to benefit greatly from the market upturn independent of the antidumping outcome.

Dataquest believes that there are many reasons why a comprehensive worldwide antidumping agreement makes sense.

Those who claim that the dumping was a direct consequence of the fact that the Koreans massively overbuilt DRAM capacity in the past three years should look back on the expansionary period of 1984 and 1985 for some perspective. In 1984 and 1985, Japanese capital spending reached levels (in yen) that still haven't been matched eight years later.

Settlement Scenario Issue Number Three—How Big Are the Markets?

The Asian market was less than 8 percent of the world DRAM market in 1986, although it was a major outlet for Japanese and U.S. DRAMs and perhaps the most price-competitive region in the world. But with the booming PC business and weakness in both the Japanese and European markets, Asia outside of Japan is running ahead of both Europe and Japan as a DRAM-consuming region, according to World Semiconductor Trade Statistics data for the past nine months. Not only is there a substantial indigenous computer business in Asia, but more than 75 percent of all PC motherboards are now made in Asia. The tide of U.S. companies moving their board-stuffing operations to Singapore, Taiwan, Hong Kong, and now the People's Republic of China has proceeded unabated. While some may argue that this is temporary and will reverse as the Japanese economy rebounds and European absorption of Eastern Europe moves further along, other smart money is moving into the Far East. For Korean DRAM makers, Asia is their fastest growing market, even faster than the U.S. market.

Why a Comprehensive Agreement Makes Sense

Dataquest believes that there are many reasons why a comprehensive worldwide antidumping agreement makes sense, including the following:

- No significant regional price differentials can be tolerated. Such differentials encourage relocation of productive facilities in response to an economic tilt and support regionalism over globalism at the expense of economic efficiency.
- Asia must be included in the agreement. The only way to do this is through imposed or voluntary (negotiated) restraints on Korean price levels for products it sells into Asia.
- The opinions and interests of worldwide major DRAM users must be recognized and incorporated into the final resolution. Users must recognize that their interest is vital in the resolution of this matter.
- There needs to be a comprehensive global umbrella agreement, perhaps under the auspices of the General Agreement on Tariffs and Trade, that replaces the reference price system in the EC and U.S. DOC/ITC rulings in a fashion similar to either the present U.S.-Japan agreement or the EC-Japan reference price agreement.
- Every effort must be made to insure that the formula by which costs are calculated is well known by all participants and reflects a reasonable consensus of all interested parties, including present DRAM suppliers, Taiwanese would-be participants, and major OEMs that use DRAMs. There is currently a host of different laws in place, and many candidate cost formulas that distort trade and misplace financial incentives for both makers and users.
- It may even be reasonable to extend the scope of the law to include pricing actions within each of the major trading blocks—EC, Asia, and the impending North American Free Trade Zone. Japanese and U.S. companies operating within the walls of Fortress Europe are already exempt from the RP system and are free to sell their product for whatever price they choose. Within the U.S. jurisdiction, NEC Roseville is exempted from the antidumping agreements, but it can be covered under predatory pricing laws.

The big profits of 1989 have gradually disappeared into single-digit profitability, or worse, for DRAM makers.

The final DOC/ITC judgment is still probably six months away, by which time market forces will probably have driven the DRAM market into a condition in which the outcome is almost a moot point. The larger question lies further ahead to when Japan consumption resumes and the accelerating growth of all the economies of all the world increases demand beyond the current effects as a result of the i486 and Windows 3.1.

Dataquest Perspective

Summary and Outlook for 1993 and 1994—Profit Bubble or War of Attrition?

The big profits of 1989 have gradually disappeared into single-digit profitability, or worse, for DRAM makers. Therefore, it was with some surprise that Hyundai's preliminary dumping penalty was less than 6 percent. Hyundai even expressed the belief that the penalty should have been lower. Given the visible pain that Siemens, TI, Micron, and the Japanese DRAM makers have been in for some time, it is surprising that real profits were obtained at all in this extended period of an intensely competitive market. (The reconstructed cost formula requires an 8 percent profit, implying that Hyundai still made a profit of 2 percent on DRAM sales.) The cost formula used is severe and includes more cost elements than most DRAM makers would use in considering the profitability of their own product line.

When and if the final cost data for GoldStar and Samsung are released, we will get more insight into the true costs of DRAM production. If the final dumping margins are modest, and if the Koreans remain intent on continuing to add capacity to address growing demand, then this profit cycle may not be as robust or as long-lasting as any of the past three profitable periods (1979-1980, 1983-1984, or 1988-1989). Such profit pressure would certainly stress some of the present DRAM makers. It has been a difficult three years, and already we are seeing some of the more marginal suppliers drop from the hunt: Oki is in trouble, Sharp has abandoned post-16Mb DRAM development, and Siemens has shifted strategically and allianced into its future. Matsushita, after a significant effort to rise into the higher tier in 1988 and 1989, appears to have lost some of its enthusiasm, if not the need to supply DRAMs into its own systems business.

All DRAM makers need a secular upturn in profitability to fund the next stage of expansion and product development. If the dumping margins are low, and if Korean manufacturers have a cost structure, the financial resources, and a strategic will to keep the pressure on the market, then we may see more DRAM makers reconsider their position and presence in the market.

By Lane Mason

Forward Alliances: Look for Improved DRAM User-Vendor Relations

Even with minimal help from a weak Japanese market, the DRAM market is expected to grow 75 percent this year in terms of bits shipped. This is the strongest growth since 1988 and is a clear response to the 80 percent reduction in DRAM prices per bit that has occurred since DRAM prices began their most recent descent late in the summer of 1989.

DRAM makers lost roughly $4 billion in 1985 and 1986, but they made similar profits during 1988 and 1989.

However, the substantial excess of 0.8µm capacity that existed at the beginning of the year is rapidly vanishing and capital spending cutbacks of 20 to 40 percent in fiscal year 1992 by Japanese suppliers increases the probability that the downward competitive price spiral will slow as we head into 1993 and on into 1994.

The market has recently been further muddied by the antidumping actions in the European Community (EC) and the United States that will have an uncertain impact on the market, but that Dataquest believes will be small compared to the development of the supply-and-demand balance over the coming three quarters. The consequences of these actions may be to keep capacity off the market entirely (highest impact case), shift the regional availability of product, or merely stiffen the tendency of price declines that began in earnest in early 1992. Regardless of this newest twist, much of what follows remains applicable in an environment that is not entirely market-driven.

A New Business Option for a Steady DRAM Market

Now might be a good time for DRAM users to consider making a special effort to ensure volume supplies in a tighter market. Specifically, many of the user/vendor agreements put in place in 1988 and later deserve some review and scrutiny related to their successes and short comings.

Dataquest believes that there can be substantial economic advantages to some more complex supplier/user agreements when compared to deals that are made by sitting across a table negotiating price and delivery on a quarterly or monthly basis. Many creative programs, with equity investments, forward price and quantity guarantees, purchase commitments, and advance product payments have helped moderate the market volatility and reduce the risks for both makers and users that are associated with the traditional arms-length negotiations between independent DRAM producers and DRAM users.

The Background: First 1985-1986, then 1988-1989

Just as World War II is often viewed merely as a continuation (after a pause) of World War I, the supply shortage of 1988 and 1989, and its resolution, had its origin in the demand shortage of 1985 and 1986. DRAM makers lost roughly $4 billion in 1985 and 1986, but they made similar profits during 1988 and 1989.

The proximate cause of these financial swings tells much about the problems inherent in participating in a high-fixed-cost market, one that exhibits price volatility and marginal cost pricing as well as has a high rate of technical change (and obsolescence). DRAM makers lost money not only because bit growth slowed in 1985 (a demand shortfall, with bits shipped up only about 25 percent compared to 1984), but because the excess capacity led to a wide practice of marginal cost pricing, plummeting prices (dumping), and horrendous losses due to underutilized capacity. A major portion of the capacity built in 1984 and 1985 was never put to the test, was obsolete before used, and had to be written off.

This was a period of textbook free-market economics, with users continuing to push for the lowest prices from their suppliers. During this time there were virtually no strategic considerations implemented by DRAM users, and not one iota of collective actions on the part of users to preserve a viable, balanced DRAM supplier base. Makers presented themselves better in 1988 and 1989, allocating not so much by price but by relationships. They were certainly better in recognizing that there were mutually beneficial opportunities to enter into user/maker alliances that served the long-term interests of both parties.

Forward alliances, if properly structured, can work to the benefit of both parties for the duration of the "silicon cycle" and not just in times of severe demand or supply shortage.

The consequences of the semiconductor/DRAM losses from 1985 to 1987 impacted the performance of parent companies and forced them to rethink, at the highest levels of the corporation, their role and risks of participation in the DRAM business. Texas Instruments' Board of Directors in 1985 put explicit limits on the DRAM exposure it would allow the company to face in the future, and it placed a ceiling on TI's future capital investment.

Because of these losses, due in large part to excess capacity, makers were understandably cautious about re-expanding their lines in 1986 (when DRAM demand grew in the early part of the year, but faded by the end of the year), and again at the end of 1987 and early in 1988. As long as the controlling interests in the market were not expanding capacity, capacity in the aggregate would run behind demand, keeping prices high and allowing recovery of some of the losses suffered from 1985 to 1987.

The shortages of 1988 created problems of their own, this time for users who couldn't get product and whose increasing demand had to be fulfilled on the aftermarket or spot market at high prices.

This time, however, the user community was forced to reach out and enter into a host of supply-assurance agreements with makers who now were in a controlling position to dictate terms. Although U.S. Memories failed to pass muster and slipped into ignominy in January 1990, some of the user/vendor relations that had their origins during this time frame are just now coming into fruition.

Much has been learned over the years. Perhaps most important is that forward alliances, if properly structured, can work to the benefit of both parties for the duration of the "silicon cycle" and not just in times of severe demand or supply shortage.

The Problems DRAM Makers Face

Full Capacity Utilization—Build It, and They Will Come

Full capacity utilization is an important factor in the cost of production equation. For leading edge DRAM manufacturing, facilities depreciation costs are about 25 to 30 percent of the total cost of production over the active life of the line. A fab running at one-half capacity utilization will have costs that can be about 15 percent higher than a fully utilized facility, other things being equal.

Economies of Scale

If one assumes that investment in process and product design are made only once, then there are vast scale opportunities that await higher volume producers. More importantly, there are the experience-curve advantages resulting from ever-higher volume production. The downside of this, which has tended to limit manufacturers peak run rates, is exposure to price attrition, a fall-off in demand, and the prospect of underutilized capacity. Big market presence has meant big risk. So while Hitachi increased its 64K DRAM production to 10 million units per month, it topped out at about 5 to 6 million for the 256K and 1Mb DRAMs and is just now moving up to 5 million per month for the 4Mb generation.

Having the Money at the Right Time

The DRAM business is cyclical, generating profits during the 18 to 24 good months per cycle, and trying to hold on to as much as possible during the competitive phase of the cycle. One problem many DRAM makers face is they need to build capacity during the counter cycle when cash is short and the future is uncertain. Once the upturn hits, it is almost too late to expand to chase profits and meet demand. The success of the Japanese in the late 1970s and early 1980s has often been attributed to their ability to build countercyclically, thus having excess capacity when the market cycles back toward strong demand, enabling them to gain market share in the expanding market.

Demand Assurance

One of the principal motivations for the emergence of more complex user/vendor arrangements was the weak enforceability of long-term commitments. Commercial law and the specifics of the actual purchase contract allow for either party to renegotiate or nullify such contracts under a variety of circumstances. As users sought secure suppliers during the heat of the shortages in 1988, they were willing to offer long-term commitments at high prices in return for assured delivery today.

For a number of reasons, a purchase contract in the semiconductor industry is like no other contract.

Vendors, certain that these commitments would be forgotten (breached) as soon as supplies loosened up and prices declined, asked for stronger guarantees and often received them. A variety of new arrangements arose that better divided the costs and risks of DRAM production and use.

Long Investment Payback Horizons

A recognized problem with DRAM production, similar to virtually any advanced technology development, is the extraordinarily long payback horizon. Last summer, for example, IBM, Siemens, and Toshiba entered into a $1-billion 256Mb DRAM development program that is not expected to yield product until about the turn of the century. The uncertainty in the future market has proven to be a major deterrent to steady investment for all but the largest and technologically most competent companies.

The Problems that Users Face

Steady Supplies and Competitive Prices

On the other hand, users face problems that are quite different. Until now, most users would say that they wanted assured deliveries at a competitive price. Increasingly, users are benchmarking their DRAM purchases against the industry. They want to match the best price available to what their systems competitors are paying. However, a disruption in the steady flow of product can lead to delayed system shipments or shipments that are suboptimally configured. Rarely do DRAMs offer significant competitive advantages in systems—the vast majority of the DRAM market is undifferentiated, commodity DRAM.

Needs Assessment—Forecasting One's Own Demand

In 1988, when most big-user volume purchase agreements (VPAs) were maintained at rather stable prices, upsides in demand resulted in severe spot market premiums. Worse still, barring any availability from the established supplier base, the user was forced to enter the aftermarket and pay extortionate, auction prices for products of uncertain history. The aftermarket was a profit boon for new entrant Samsung, and a lifeline for second-tier users without established and stable relationships with major DRAM suppliers.

Similarly, Apple Computer and other companies had to eventually write down DRAM inventory that was bought at high prices on the aftermarket when the market turned and product became more available.

Not Enough DRAMs

For users, the risk was the downside of not being able to ship product because of a lack of DRAMs. As the saying goes, "For want of a nail, the shoe was lost; for want of a shoe, a horse was lost; for want of a horse, a rider was lost...."

For smaller users or fast growth companies outside the top tier of the user base, it was doubly difficult to even get modest allocations, as makers worked hard to accommodate the requirements of their key accounts.

Both Parties Must Face the Purchase Contract

For a number of reasons, a purchase contract in the semiconductor industry is like no other contract. Prices are routinely contractually renegotiated. Orders are frequently canceled, either by buyer or seller and often for the flimsiest of reasons. Allocation, built into the U.S. commercial codes as a standard practice, is in place during much of the cycle as makers control their order books and production levels to manage production and prices and control the amount of product in the aftermarket that may come back to compete with new product.

Forward alliances clearly are a means for independent semiconductor companies to take advantage of a close supplier-user relationship.

In tight markets, users promise to order products for long periods just to get the product today. They later cancel orders, renegotiate prices, or downsize their order when the time comes to take delivery after the market has slacked. Vendors do just the opposite. In slack markets they promise users that their needs will get first consideration when the market tightens up.

What the period from 1985 through 1989 demonstrated was that the traditional user/supplier market resulted in relationships that involved unacceptably high risks given the experiences of 1985 and 1986 for vendors, and 1988 and 1989 for users.

It was from these experiences that companies began to look at innovative relationships that reduced risk for suppliers, provided greater supply assurance for users, provided investment capital to suppliers when needed (before they earned their cyclical profits), and ultimately lower costs of production and product delivery.

The following are five examples of these relationships:

- Amstrad plc - Micron Technology. In September 1988, Amstrad plc bought 4.0 million newly issued shares of Micron Technology stock at $21.50 each, for a net to Micron of $77 million (after fees). Amstrad's then 9.2 percent equity stake entitled it to buy up to 9.2 percent of Micron's DRAM output at the market price. This gave Amstrad an assured source of supply and an independent equity investment in the volatile DRAM business. Micron got new cash to expand its facility, but not a guaranteed sale.

  (Amstrad decided to sell its stake in May 1990, but later retracted its offer. Micron's stock was selling at $13.50 per share. Today, after a recent jump of $5.00 over the past month, Micron stock is selling for about $20.00.)

- Micron Technology - Take or Pay Contracts. In June 1988, Micron announced that about 20 customers had agreed to enter into "take or pay" agreements that had the following conditions:

  - They were long-term purchase agreements, running up to 24 months
  - Prices were referenced to the pricing at the time of the agreement, about $4.05 for 256K DRAMs
  - Prices were allowed to decline or rise as the market dictated, but by no more than 10 cents per quarter
  - Users agreed to take purchased amounts at the agreed price dictated by the formula, or pay anyway

  Micron was thus able to improve its achievable price many quarters out, after the market price might have dropped outside the formula price band. Even with these contracts, some litigation ensued as users sought to renege on their purchase/price commitments. Micron still fared better than if it hadn't set up such arrangements.

Take-or-pay deals are common in other high-fixed cost industries (electrical utilities, natural gas, and water) as a means of assuring a sufficient revenue stream to cover the cost of fixed investments, regardless of the variable amount of product delivered.

- Texas Instruments. Texas Instruments has been the foremost practitioner of externally funded facilities expansion and strong customer supply relationships. In mid-1988, TI began attracting major DRAM users that were concerned about the building concentration of the industry's submicron capacity in Japan. Eventually, this group of users funded TI's accelerated capacity expansion with more than $100 million.

  What was begun in a time of panic, however, proved to have broader appeal, and user investment continued after DRAM prices declined rapidly in late 1989. In these deals, TI got what were essentially advance payments for DRAMs, payments that were then rebated on a pro rata basis as investors later bought their DRAMs from TI.

  Texas Instruments got the facility when it needed it. Users got supply assurance, and eventually got or will get their investment returned. By requiring advance payments, TI assured the commitment of its partners to take the designated amount of product.

- Texas Instruments-Acer. In May 1989, Acer joined TI in a joint venture to build a fab in Taiwan. Acer wanted DRAM supply assurances and greater independence from Japanese DRAM sources. TI was anxious to move ahead on its facility expansion program, almost on a risk-free basis.

  TI-Acer is now nearing volume production of 4Mb DRAMs (1 million per month) on the joint venture's 0.8µm line. This facility also has 16 percent of its shares owned by the China Development Corporation and a special issue of stock sold to several financial institutions.

- TECH Semiconductor. In April 1991, Canon, Hewlett-Packard, and the Singapore Economic Development Corp. (SEDC) joined Texas Instruments in establishing TECH Semiconductor in Singapore. Canon and HP each own a 24 percent share, SEDC and TI own 26 percent each. About $80 million in equity was supplied by the owners, and loans for $160 million were negotiated.

In the TECH Semiconductor, TI-Acer, and KTI (Kobe Steel's JV with TI) joint venture arrangements, the investors are both equity holders in the venture (thus desirous of high prices and profits) and users (thus wanting low prices). Investor-users are not required to take output, but may take a percentage up to their equity shares, usually at the market price. (The KTI venture is different because Kobe Steel doesn't need semiconductors for its own use, but needs the facility as a lever for its entry into the merchant semiconductor market.)

Why Such a Relationship Can Work to Benefit Both Parties

There are several significant costs associated with using the market that are not always apparent, nor readily measurable. They are, nonetheless, real costs that must be recognized from time to time. The following are some of those costs:

- Underutilized capacity. Makers face the cost of underutilized capacity in the event that the industry enters a supply-excess condition. Fixed facility charges that had to be spread over a third or a quarter of the anticipated demand were the proximate cause of the massive losses in 1985 to 1986.
- Information costs of using the market. Although DRAMs sell in high volumes and have a lower marketing and selling cost than other products (as a percent of selling price), there are still some marketing and selling costs. Volume discounts to big customers reflect the savings that are achievable by selling products in large blocks. Traditional user/vendor relationships also lower the costs of defining the market with every new product, an advantage to the established suppliers.
- Inventory costs. Uncertainty of demand or of supply can cause the supplier and user to bear excessive inventory costs.
- Supply disruptions. Many medium and small-sized DRAM users suffered mightily during 1988 and 1989 when small allocations from DRAM suppliers either forced them to ship products with suboptional DRAM configurations or held up systems shipments entirely.

- Price volatility. Price volatility works both ways. In tight markets, users pay premium prices by acquiring incremental product on the spot or in aftermarket purchases. In slack markets, suppliers have to move quantities down to fair market value or reference price levels, guaranteeing inadequate long-term profits.

The arrangements set forth beginning in 1988 and 1989 occupy the middle ground between traditional VPAs and captive production. Attempts are made to reorganize, assess, and assign a real value to various risk elements and design an agreement to minimize their cost impact on the two parties involved.

Potential Cost Savings Quantified

An example of a fully implemented 16Mb relationship between one or more users and a supplier that has already developed a given DRAM product and process is presented in Table 1. One can see the power of this idea, which offers the following benefits:

- Incremental product and process development costs are nil
- The facility can run at an average higher capacity utilization
- Marketing and selling costs are reduced
- Risk is reduced significantly but is also difficult to measure

Therefore, because of the potential for reduced costs, these relations can work to the benefit of both parties by reducing the overall costs of participating in the market. The user can be a profit-making investor in the joint venture and get competitive DRAM prices at the same time.

Forward Alliances Compared to Truly Captive Production

One might ask how forward alliance agreements differ from the captive relationship that exists between NEC Semiconductor and NEC's computer business. The most obvious difference is that a relationship such as NEC's is not available to U.S. companies, which are largely not vertically integrated. Forward alliances clearly are a means for independent semiconductor companies to take advantage of a close supplier-user relationship. In a forward alliance, the relationship (contract) is also negotiated between two or more independent entities, not separate divisions operating within the same company. The risk/price/investment analysis is more well-defined and is performed by different parties who absolutely have different interests in mind. There is no top-level dictate that guides investment and production decisions. Additionally, forward alliances are flexible, temporary partnerships (though surely renewable) allowing a partnering strategy that enables either party to adapt more easily to changing business requirements. Finally, forward alliances can be hedged with one another so that a company can develop a portfolio of forward alliances with a range of partners across the industry. When one is tied to a single biggest customer, certain degrees of freedom are reduced. For example, every fab that

Table 1
Potential Cost Comparison for 16Mb DRAM with Different User/Vendor Relationship

	16Mb Normal	16Mb Forward Alliance
Facility Cost (Millions of Dollars)	350	350
Product/Process Development (Millions of Dollars)	200	0
Average Capacity Utilization (Percent)	75	85
Variable Costs (Millions of Dollars)	244	288
Total Cost (Millions of Dollars)	794	638
Total Die (Millions)	112.6	127.6
Average Cost Per Die ($)	7.05	5.00
Mark-up	2x	1.85x
Price ($)	14.10	9.25

Source: Dataquest (December 1992)

Motorola has could have a different partner, each serving a different and changing requirement of the time.

Forward alliances, like any private activity in a commodity market, will lead to other distortions in the overall market.

If done properly, however, captive relationships similar to the ones that all Japanese companies have could be made to function in the same fashion as forward alliances. NEC Computer could be a major forward alliance partner of NEC Semiconductor if the deal was structured similarly. But as IBM, General Motors, and Digital Equipment are discovering, traditional internal business relationships have an inertia of their own and are often hard to change.

What U.S. industry, and not just the semiconductor industry, has found is that a truly captive relationship under a single management umbrella hides defects in the allocation of resources and assumption of risks. Such an organizational arrangement also limits the user from accessing externally-developed technologies and from taking advantage of price changes from the competitive outside market. The multiplicity of conflicting business objectives in an integrated operation is made explicit by disengaging and renegotiating interdivisional agreements as distinct business interests. Integrated wholes are replaced by smaller business units connected by a network of strategic alliances.

Forward Alliance Issues

The Price Problem

Transfer pricing for products sold under these types of arrangements has proven to be a difficult matter to resolve. Generally, prices are cost-based (plus a fixed percentage), market price-based, or reference price-based, where the price is tied to an external reference price.

Reference price systems can tie the transfer price to an external number such as the historical rates of cost reduction (the experience curve), the EC's own cost-based reference prices, reconstructed costs such as those used in fair market values, or concurrent costs from companion, or sister, facilities.

Market price-based systems can tie the transfer price to the seller's lowest, average, or best prices achieved with other DRAM customers. Or, the transfer prices can be related to the best, average, or highest prices that the user has achieved during the same period.

If one believes that future costs are more or less predictable over long periods (the experience curve), one should then be able to agree on an equitable forward pricing arrangement for up to four or five years. Such an assurance would help to both guarantee the makers of a positive revenue stream and challenge them to beat the curve and make substantial profits.

Forms of Investment

In the examples outlined in this article DRAM purchasers have used several forms of investment, but in all cases something was obtained in return. We have talked about loans, equity investments, advance payments, and more firmly fixed forward price relationships. In return, users and investors either received product or options to buy product at a price specified in the agreement.

Impact on the Larger Market

Forward alliances, like any private activity in a commodity market, will lead to other distortions in the overall market. If more of the industry's production moves through such preordained channels, the remainder of the market is made even more volatile. If 50 percent of the product flow is fixed, an unexpected 25 percent increase in demand creates an apparent 50 percent increase in the half of the market that remains outside the forward-alliance contracts. This is not to say that individual companies cannot benefit from such agreements, nor to say that individual companies that can forecast their own demand won't be entirely better off than those that cannot. Indeed, such agreements can insulate good forecasters from the ravages created in the marketplace by unforeseen events arising from a host of different causes.

Dataquest Perspective

Outlook for the Future

Big producers can undoubtedly produce for less. The DRAM production economies of scale are immense. What traditionally, and undesirably, has gone hand in hand with large-scale economies are risk and exposure to market uncertainties, as well as the sheer capital requirements of making the investments to produce on a massive scale.

Forward alliances address both of these problems for the DRAM producer by allowing producers to receive financing from their customers and by having a guaranteed outlet for the products once they are produced. With next-generation process development and facilities costing $700 million to $1 billion, it is clear that a more effective institutional arrangement among the various elements necessary to make up a market (technology providers, manufacturers, users, and financiers) is possible.

Furthermore, by enabling makers to expand countercyclically the market itself can be steadied over time, thereby reducing price volatility and giving better forward price visibility and availability of product.

The opportunities for more effective user/vendor relations that reduce risk, uncertainty, and cost are just beginning to be explored. The examples outlined in this article relate specifically to high-volume commodity memory products with high fixed costs of production, large-scale economies, and high price volatility. Dataquest believes that there is significant potential for improved price performance in forward DRAM and memory pricing that can be achieved through resource-sharing alliances such as those described here.

The uncertain future that both makers and users face today as we look ahead to 1993 and 1994 may provide the incentive to again explore new user/vendor arrangements that provide both supply and demand assurance and price predictability at a substantial cumulative cost savings over a generation of DRAMs, or over a four- or five-year silicon cycle.

By Lane Mason

For More Information . . .

On the topics in this issue..............................Lane Mason, Director/Principal Analyst	(408) 437-8120
About upcoming Dataquest conferences..	(408) 437-8245
About your subscription or other Dataquest publications..	(408) 437-8285
Via fax request..	(408) 437-0292

Dataquest Perspective

FILE COPY
Do Not Remove

Memories *Worldwide*

MMRY-SEG-DP-9203 August 24, 1992

In This Issue...

Market Analysis

Industry Trends: Will the 1Gb DRAM Be a Reality?

(Note: This article is derived from a speech given by Lane Mason, Dataquest's principal analyst of semiconductor memories, at the recent Semicon West Equipment Trade show in a session sponsored by Dataquest's Semiconductor Manufacturing and Applications group.)

Presuming a straightforward extension of the DRAM technology that has existed from the 4K to 16Mb levels, the technical parameters of the 1Gb DRAM can be specified today, a full decade before we may be expected to see any sort of "engineering samples." But there is growing concern in industry circles whether such a product will ever become a reality, and whether the massive advance investment required to bring the product to market will ever reap a return. Basically, the uncertainties surrounding this question are economic: size of investment, lengthening advance development requirements, and uncertain character of the memory market when such products could be expected to generate revenue and profits.

The Case for Technology

For generation after generation of DRAMs, pessimists have pointed to the impossibility of solving the technical problems they were sure to face as successive DRAM generations came. One after another, these "Maginot Lines" were overrun, and prices came down further than anyone had anticipated.

As early as the 64K generation, some companies had a hard time shrinking their die to get it into a 300-mil package, but now all 4Mb devices can accommodate it. Power per unit has given up ground very slowly, rising from about 300mW at the 4K level, to 550 to 600mW at the 4Mb level. Soft errors were going to kill us as early as the 64K generation, but we hear almost nothing about that today, a decade later. Another killer, test, has itself died a death of ignominy. Ultimate yield would never approach the 90 percent levels we had become accustomed to at the 64K generation, but advanced 1Mb lines now routinely have probe yields exceeding that amount. Redundancy, "the old man walking with the cane," solved all that, and was incorporated into the bag of tools rather effortlessly. Furthermore, companies are consistently able to ramp up to such yields far more quickly than in the early days. Masking layers and other measures directly translatable into capital costs would outstrip profit potential. But Micron Technology will have its 10-mask 4Mb up and running by year-end. IBM's ECC, shown at the 1990 ISSCC, goes further still in showing the ability to quickly get high yield on advanced chips. IBM recently showed a single transistor, suitably sized for a 4Gb DRAM.

If history tells us anything about the technical barriers, it is that they pose weak resistance for the can-do DRAM makers that have promised and delivered thousandfold improvements in price per bit over two decades, and promise continued similar gains into the 1990s, as well.

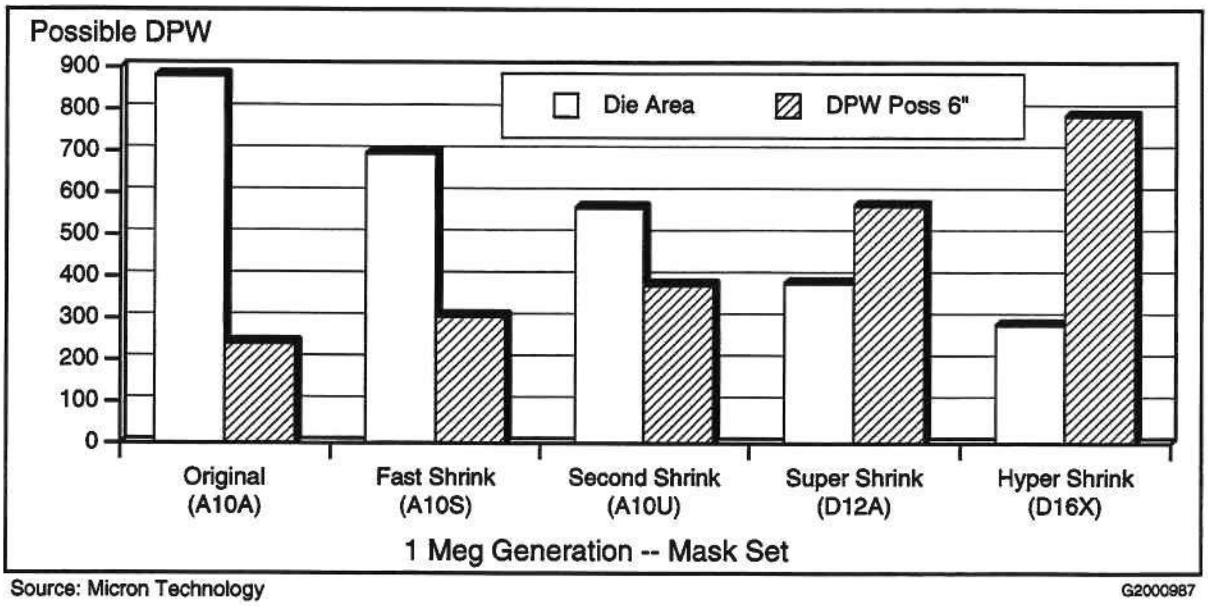
Some noteworthy developments and cost-reduction methodologies will fuel the upcoming phase of advancement and cost reduction. Figure 1 shows Micron Technology's 1Mb product roll-out, showing five generations of device, ending with its now-in-production "hypershrink" 1Mb DRAM, which at 17 square millimeters is about 35 percent smaller than the next-smallest 1Mb DRAM die in the industry. Micron's 10-mask 4Mb DRAM, to cite another of its cost-reduction strengths, will be in full volume production by year-end 1992.

Figure 2 shows WaferScale Integrations' technology waiting in the wings for licensees NSC and AMD to bring high-volume production. For NVM proponents, it should be noted that the achievable EPROM cell size using the AMG is less than half the size of a typical 4Mb DRAM using similar design rules.

These two near-term examples show the types of capabilities that have achieved the economies we have today. Still further out, we are reminded that fully functional 64Mb DRAMs were shown at the 1990 and 1991 ISSCC, and that key elements of the 256Mb DRAM have already been demonstrated. Extrapolating such trends into the 21st century, when the 1Gb DRAM will or won't be a reality, is far more difficult, and requires that other technical issues either be dealt with or ignored. We are confident in the belief that when the problems are sufficiently well-defined, they will be solved.

The following statements, which appeared in Sematech trade press advertising a few months

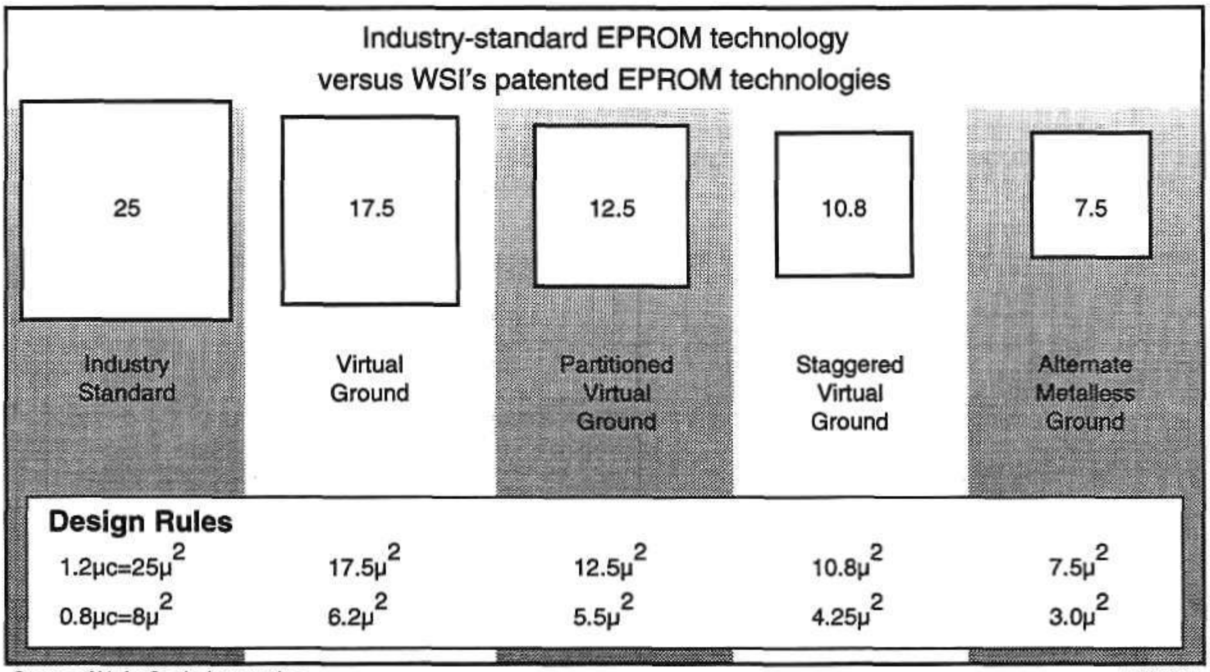
Figure 1
1Mb Possible DPW and Die Size Comparison



Source: Micron Technology

G2000987

Figure 2
Cell Size Comparison



Source: WaferScale Integration

G2000988

ago, show the company's view of the future for the next 15 to 20 years:

- Over the past 35 years, the cost of integrated circuits has decreased an average of 25 to 30 percent per year. The accompanying increase in productivity of more than one million times is expected to continue for at least two more decades, well into the 21st Century.
- In 1990 an integrated circuit manufacturing facility capable of starting 20,000 wafers per month cost $400 million. By 1995 the cost will exceed $1 billion. By 2005 projected costs are in excess of $2 billion.

Sematech might be called the "Inertial Optimist" that foresees continued cost improvements of ICs of the order of 25 to 30 percent per year for the next two decades, which is at least 300-fold improvement in cost by 2012. This is optimism! At the same time, it foresees facilities costing at least $2 billion by 2005.

From a technology viewpoint, these conclusions are all quite reasonable. IBM has already demonstrated the single transistor for a 4Gb DRAM. There appear to be no obvious device technical barriers that cannot be overcome.

So why the concern that we will not be able to replicate the same progress, for as far as the eye can see? The argument is built around several lines of discussion, all of which are fundamentally financial and economic in nature. Indeed, if we are trying to build a single 1Gb DRAM, we can almost do that today. Even today, a wafer full of advanced 4Mb DRAMs has about 1 billion bits on it already. Obviously, we need to tighten up the question a bit, in order to understand the direction the industry takes as it increasingly faces tough issues later in the decade. We need to understand the economics of investment and production, the market development, the likelihood of profitability, and other trends taking place throughout the industry.

A better question is the relationship between the process employed (and suitable facility employing it) and the price per bit of the DRAM device being made. Prices govern the substitution of older products with newer ones. It is absolutely necessary that we achieve a successively lower price per bit to have the 64Mb replace the 16Mb, the 256Mb replace the 64Mb, and the 1Gb replace the 256Mb.

But at the same time, to encourage continuing advanced development of later generations of

DRAM, to make all the investment worthwhile, we need to believe in the prospect of getting a return on our investment. Putting technology aside for the time being, individual companies need to see that the massive sums required to gain the high ground in the 1Gb generation will eventually pay their way.

But there are many trends in the industry besides those that see the 1Gb DRAM as the natural outcome of an additional 10 years' and $1 billion investment. There are trends that heavily impact the prospects of achieving adequate financial return, which are almost certain to deter many "wannabes" from actually being there when the time comes.

Process Development Costs

Costs to develop the basic 0.2μm process for the 1Gb DRAM can be estimated to be from $800 million to $1 billion, expended over seven to eight years in advance of the first prototype development of the product. Both the time and the money spent in advance are lengthening, and the total amount for each is becoming greater. A considerable portion of this expenditure can be saved through the proper time-phasing of process development, through burden-sharing with development partners, and through a broad amortization of the cost across a wide revenue base of products.

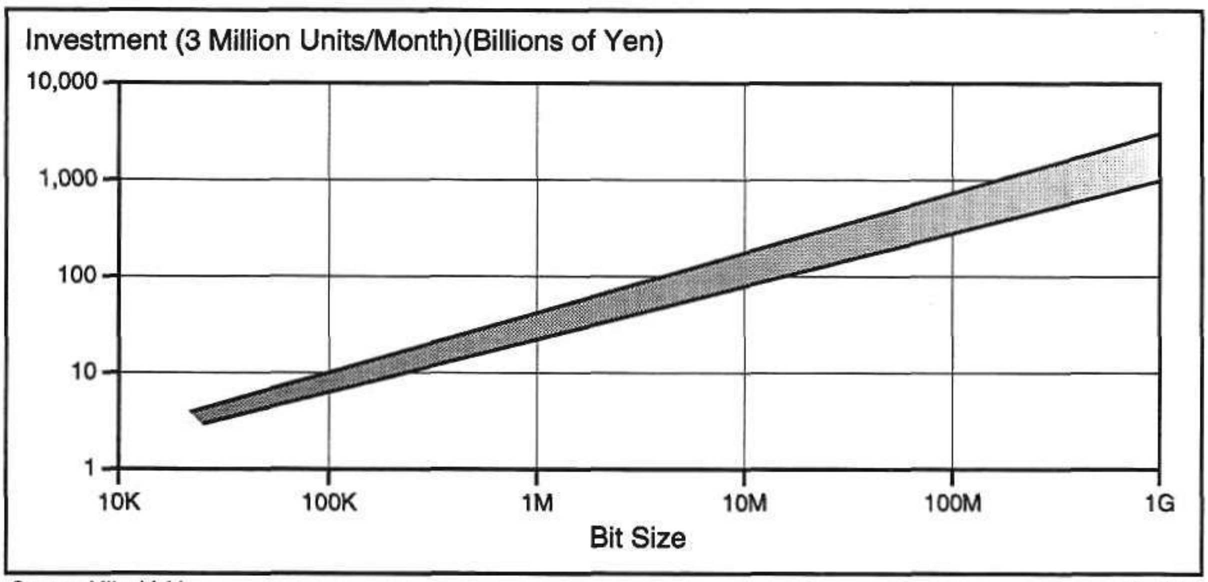
Facility Costs

It comes as no surprise to anyone that each generation of facility costs more than the prior generation, holding the number of wafers or wafer starts the same. Historically, these increased costs have been more than justified by the increase in productivity. This is the important measure of whether the new facility was worth it: Did the depreciation and process amortization per bit decline as a result? So far, that has clearly been the case. Will it be the case into the foreseeable future? We don't know. It depends on the lifetime of the equipment, and the depreciation rates. Figure 3 shows Mitsubishi's estimates of the investment required for successive generations of DRAMs, although others believe that the curve is actually steeper as we move to the right.

Profit Prospects and the Balanced Marketplace

Companies need profits to move to the next level. In theory, this must also be true on a product-by-product basis, though the accounting practices that determine DRAM profitability are hardly clear and clean, except in the smallest, most tightly focused DRAM producers, such as Micron Technology. Historically, DRAM makers have profited significantly in about two of every four or five years—enough to charge ahead with process development and expand facilities for the next-generation product. The most recent

Figure 3
Mitsubishi's Estimated Investment for Successive DRAM Generations



Source: Mitsubishi

G2000989

period of high profitability was during the 1988 to 1989 shortage. Prior to that, DRAM makers made good profits in 1983-1984, and in 1979-1980. But if the period from 1990 to 1992 was typical of the margins achievable over the entire silicon cycle, there would be far fewer DRAM suppliers today.

It may be that a shortage, or at least demand growing faster than supply, is needed every three or so years for the DRAM business to succeed. However, with the Korean DRAM makers keeping the pressure on the dominant Japanese suppliers, it may be harder to get an out-of-balance situation in the market in the future. Every reluctance to follow the prices down has resulted in incremental gains in market share by the Koreans. So long as there is no hegemony, prices and costs of production will travel down in lockstep fashion, denying the opportunity to make the kinds of cyclical profits that appear to be necessary to fuel the continued prosperity of DRAM makers.

However, with major positions in DRAMs held by Koreans and Japanese companies today, there exists a reasonably close balance of supply and demand, making a significant shortage condition—and its period of high profitability—virtually impossible.

Intellectual Property

Intellectual property is another factor that has raised its head in the past five years. There is now an embedded cost of production, in terms of royalty payments to the key DRAM patent holders, of about 10 percent of sales. This amount is now being paid by most of the recent entrants, and smaller amounts by the larger, more established producers such as the major Japanese DRAM makers. With thin margins, few companies can afford to pay out yet another 10 percent of sales to Texas Instruments, Hitachi, STM, and Toshiba for royalties. Already, these payments have impacted the rate at which the price per bit has declined.

Slowing Semiconductor Market Growth

The industry as a whole has seen its revenue growth slow from about 15 percent during the 1980s to an anticipated 10 percent during the 1990s. Historically, growth has opened up new market opportunities, and with the profits growing at the same pace, provided new resources for technical development. While the absolute size of the industry is greater, the scope of its technical effort is also broader. Relatively smaller investment requirements and greater future opportunities in the past led to a "sprint to tomorrow" attitude that has since been moderated by slower growth, tougher competition, and greater financial risks. Returns on investment must be scrutinized carefully.

Absolute Market Size

The sums required by major players in the industry are immense. The capital demands by the semiconductor division are no longer payable out of petty cash. The semiconductor division management must work harder to justify net cash flows from the parent company. One has only to look at the profitability of the semiconductor groups' impact on total corporate earnings, and the recent poor performance of Japanese companies, to see the impact of the next-generation process and facility costs.

Where the Industry Has Found the Best Profitability

The industry has seen its profitability impacted severely since the supply-demand balance was restored in late 1989. Ultimately, companies have to fund their growth out of profits. But aside from major x86 monopoly profits at Intel, after-tax returns for the top 20 companies constituting 95 percent of total industry sales have probably been in the 2 to 3 percent range. The top five U.S. companies (Intel AMD, NSC, TI, and Motorola) have 58 percent of total U.S. company sales; profits for 1991 were about $1.3 billion on sales of $13.4 billion. But if the monopoly x86 profits are excluded from Intel and AMD, that 10 percent drops to 3 to 4 percent, with NSC and TI suffering substantial losses. This hardly gives solace to those that would like to invest hundreds of millions of dollars in new DRAM product and process development. Smaller companies playing in design-rich niches fared much better.

The big three European companies are worse still. STM has been losing money almost since its inception (but has reaped substantial royalty payments for the Mostek and Inmos patents). Siemens has rarely been profitable. Philips' semiconductor group has lost large sums for more than two years. Other European companies have done no better.

In Japan, the aforementioned corporate results attest to semiconductor division and DRAM profitability.

In the slow-growth market of 1990 to 1992, profits have been found in design-rich products, proprietary architectures, copyrighted microcode, and proprietary algorithms, and not in commodity memories such as DRAMs. Although the financial losses in memories have been nowhere near as severe as in prior soft markets, the profit potential increasingly appears to be in the proprietary parts of the market.

Growth needs the fuel of profitability, especially as the trend away from continued "parental support" and semiconductor group accountability gathers momentum. Today, the semiconductor divisions of all European companies and several Japanese companies are under do-or-die dictums because of their negative impact on the parent companies' performance.

Slowing Bit Growth Rate

Those that believe in the experience curve must conclude that the bit growth rate, which has slowed since 1985, will have the certain effect of slowing the rate at which costs of bit production will occur. From the mid-1970s through the mid-1980s, DRAM bits grew at more than 100 percent per year. Since 1985, however, bit growth has averaged just 70 percent per year, and the consensus is for a continued slowing for the remainder of the decade, at a bit growth rate of 50 to 60 percent.

Where Will Demand Come From?

One problem that is clearly in evidence is the make-up of demand for the coming years, even to the extent of increasing bit shipments at a heretofore modest 50 percent per year. Software such as Windows 3.1 has replaced hardware as the primary memory driving force. Software is a new force in DRAM demand, and is subject to production, distribution, and utilization patterns of its own. In its most DRAM-intensive form, even HDTV will use only 8MB, or just four 16Mb chips in the 1995 to 1996 time frame. The ability of memory producers to produce dense DRAMs is running far in advance of users to make use of them.

Who needs a 1Gb DRAM, and will four units of 256Mb DRAM do as well? Or will the interests in the manufacturing community shift from manufacturing excellence that confers no sustainable competitive advantage? Already we have seen that, absent a shortage, returns on intellectual property (via the Intel or the TI method) and design excellence are the two high-profit techniques for the 1990s.

Evidence of PPB Rate of Decline

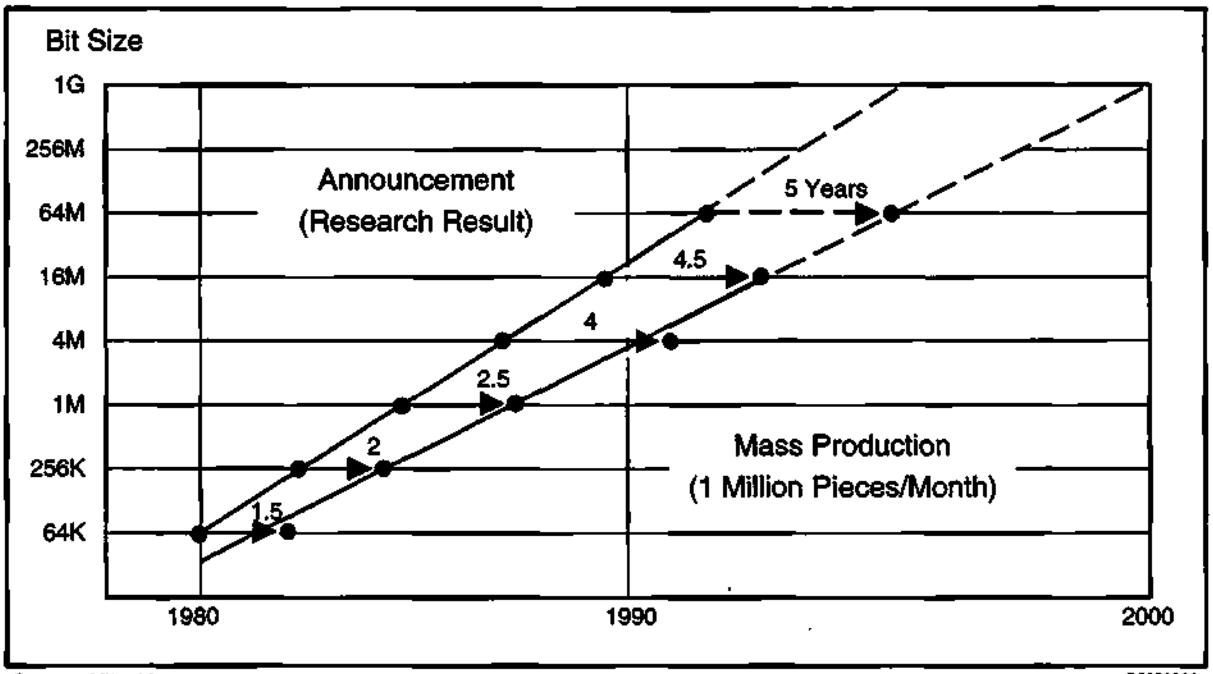
The floor price at which a fully depreciated facility can run a given density of DRAM is increasing from generation to generation. This marginal cost covers only recovery of variable costs. Today, 256Ks, running in near-zero-cost facilities, sell for about $1.60, believed to be about as low as the part can be made. 1Mb DRAMs sell for about $3.00, and almost no one believes that this part will drop much lower and still allow the maker to recover all costs.

Therefore, in just one generation, the floor has risen by more than 75 percent. Most forecasts for the 4Mb DRAM, now selling for about $11.00, are that it will ultimately reach $5.50 to $6.00. This is an *anticipated*, not *achieved* price. One can only guess at the floor price of the 16Mb DRAM, but we have never failed to exceed our expectations and a priori analysis of where the lowest price can be. Careful analysis for the 1Mb, done in 1988, concluded that about $3.80 would be the limit. This was reduced to near $3.50 late in 1990, and spot prices in April were as low as $2.50 for inventory sell-offs. Today, prices are about $3.00 and appear stable.

Payback Period

With advanced development taking large sums five to seven years in advance of major returns, the interest rate become more important in evaluating the return on investment. Figure 4 shows Hitachi's view of the increasing lag between process/product development (read investment) and appearance in the marketplace. Higher interest rates at which capital is diverted into advanced process development mean that future prices necessary to achieve an adequate return will necessarily be higher. Japan is no longer the country of free capital.

Figure 4
Hitachi's View of Process/Product Development versus Market Appearance



Source: Hitachi G2000990

Dataquest Perspective

What Are We to Do?

In the face of such forbidding economic prospects for future generations of DRAMs and other products, what options are available to industry participants to postpone the day of reckoning and keep the technology juggernaut running one or two more generations before slowing down?

Although they do not make the future any less expensive in the aggregate, many trends now in evidence do reduce individual companies' costs and promise a better return on investment for them.

Collective Actions for Cost-Sharing

Collective actions are also attractive. They reduce redundancy of effort and make the collective industry expenditure for R&D and facilities more efficient.

TI highlights three practices that are a part of its strategic effort to mitigate the escalating cost of advanced development and improve its return on investment, as follows:

- Harmonization: Define processes to have the highest possible degree of commonality across product lines. Processes are more transferable, and facilities are more flexible in their application, which reduces costly incompatabilities, and improves their ability to transfer processes from one facility to another and always run the highest-revenue-per-wafer product in the fabs.
- Defend IPR: TI gains a return on its $500 million-per-year R&D investment through embodying that technology in its own products, and through licensing others to use it as well. This cost recovery has proven to be a valuable means of getting an adequate return on that R&D investment.
- Customer-funded facilities: TI has gained about $1 billion in capital costs through its innovative programs that allow it to partner with its customers to build facilities in advance of demand. Indeed, this transfers risk to others and also brings in some capital from the future.

Joint ventures and collective actions, such as Sematech and any of several joint development agreements in advanced DRAMs, are attractive ways of reducing the overall costs of future product development.

By Lane Mason

IBM/Siemens/Toshiba 256Mb DRAM Venture Breaks New Ground in Industry Cooperative Undertaking

The joint venture among IBM, Siemens, and Toshiba announced July 2 is another step in the industry's trend toward massive cooperative ventures to lower the cost and risks associated with advanced process development. In one stroke, it cuts the private cost of process development for the 0.25μm process by two-thirds or more and poses a significant economic challenge to companies that fancied going at it alone.

This article discusses the particulars of this most recent megaventure, along with its significant implications for the development of the industry for the remainder of the 1990s.

Basic Tenets of the Agreement

The basic agreement calls for Toshiba, Siemens, and IBM to collectively develop a 256Mb DRAM design and the 0.25μm process on which it can be manufactured. The limit stops at the end of the development stage and at present has no provision for manufacturing (which might run into a host of antitrust objections). The group estimated that the program would entail aggregate expenditure of more than $1 billion to develop the 256Mb DRAM and qualify it for production late in the decade.

IBM's Advanced Semiconductor Technology Center in East Fishkill, NY will be the principal initial focus of development activity, with supporting projects being undertaken independently by Toshiba and Siemens. The program is expected to employ more than 200 researchers from the three members at its peak.

According to IBM, each participant will also be allowed to resell the technical fruits of the joint venture, making it possible that any of these companies could reduce its net financial commitment significantly by achieving a royalty stream to compensate for the immense development costs. In addition, though the process will initially be developed for the 256Mb DRAM, each party is free to enhance and modify the common process and apply it to other products, including logic devices.

Earlier Agreements

At present, IBM has an agreement to produce 16Mb DRAMs in France with Siemens. These devices are now in production at the existing IBM facility at Corbeil-Essones, and are being marketed by Siemens. IBM and Siemens also have a 64Mb development program in place. Apparently seeking to dispel notions that Siemens was re-evaluating its positioning in DRAMs or semiconductors, Siemens President and CEO Karlheinz Kaske commented that the joint venture "contributes to future applications in telecommunications, and assures our customers of our engagement in microelectronics."

Toshiba and Siemens have a relationship that began with the 1Mb DRAM in 1985, which transferred the Toshiba 1Mb design and process to Siemens in exchange for a fee and continuing technical support.

Also, IBM and Toshiba within the past few months have negotiated a technology agreement to develop solid-state files (SSFs) using Toshiba's NAND Flash technology and IBM's advanced controllers and interface technology.

Clearly, the prior arrangement between Siemens and IBM and the addition of a 256Mb agreement will make it easier to keep the process and product program on a steady path.

Financial Risk and Cost—The Prime Mover for Alliances

All other reasons aside, the prime mover for this agreement is cost and risk. As underscored elsewhere in this issue, the calculus of return on investment on deep process development is horrendous. One has only to look at IBM's massive investments in X-ray lithography to see the difficulty of the problem: year after year, tens or hundreds of millions of dollars were invested to try to catch a receding goal. It is small solace to IBM to be the X-ray leader. It has cost close to a billion dollars, without appreciable return.

Development of a 256Mb technology is a similar program, requiring significant years of investment in advance of any return, fraught with timing uncertainties of market development and pushing into the unknowns of technology development. In sheer magnitude, it is on the same scale, and no one, not even IBM, is rich or smart enough to go it alone. The risks are too great and the costs are too large. Just as oil companies formed the Aleyska consortium to seek oil on Alaska's North Slope in the early 1970s, the semiconductor industry is grouping together to create advanced process knowledge and to share costs.

Global Technology

While this present agreement has a partner in each of the world's markets, in fact the global element of this venture is weak compared to the finance and risk elements. Still, IBM cements its position as a "European" electronics company and lends a hand to Europe's leading supplier of commodity memory chips and arguably its leading semiconductor technology house. Because there are no manufacturing or marketing plans as a part of the compact, however, most of the trade issues are sidestepped or avoided and knowledge will flow freely through the porous borders of the United States, Japan, and Europe.

Perhaps the more important global aspects of this venture may be any difficulties that arise from conducting research in three widely separated locations. Although research tasks can be well defined and divided up, there is certainly a high value in the incessant communication taking place among the research staff. Whether we like it or not, geographic separation has its high overhead costs and inefficiencies.

Increased Pressure on Other DRAM Makers to Do Likewise

Another likely outcome of this announced venture among Toshiba, Siemens, and IBM will be forcing other aspirants to the 0.25µm or 256Mb DRAM realm to find similar means of remaining cost-competitive later in the decade. No independent, go-it-alone DRAM producer can hope to be competitive in future generations while spending three times as much as other participants to develop the process. To date, we have seen three 64Mb/0.35µm deals (NEC/ATT, IBM/Siemens, and Hitachi/Texas Instruments). Already the 256Mb development costs are getting steep enough that they need to be shared. NEC announced earlier in the year that it would spend $150 million for development of the 256Mb DRAM in 1992.

Who Is Driving the Industry?

Such a transnational arrangement serves to refocus the industry's attention on the fact that, despite virtually universal government participation in the semiconductor industry, the prime movers are still private companies pursuing what they perceive as their own best interests. The U.S. government's subsidy of Sematech, at $200 million per year, is about 5 percent of the U.S. industry's R&D budget, and is comparable to this single program. JESSI is of similar scope and magnitude. This undertaking will be financed, at least superficially, by the industry participants themselves.

There are probably lessons here, as well, for managing multiparty development undertakings that require substantial investment and provide returns to each participating party. Deciding the quid pro quo and the research program among disparate parties with similar interests is a formidable problem. How can one be sure that the benefits derived by each party are commensurate with its contribution? There is every incentive to minimize financial and human resource inputs and maximize technology outcomes.

Common Process—Core and Differentiators

The formidable costs faced by companies for development in the subquarter-micron range have been rather cleanly divided into a "common process pool" that has appeared to pose the most significant barrier to 21st-century industry development, and "other," which includes manufacturing costs, marketing, non-DRAM product definition, and specialty process development costs. Process development costs are where the biggest dollars are spent, but they do not provide proportionate profits or value-added in today's marketplace.

From another view, just as TI tries to feed as much revenue as possible off a common set of process tools, equipment, and recipes (both independently and with the Hitachi joint ventures), these three companies seek the same broad amortization across a massive range of product: not only their own product lines (which in 1992 were about $10 billion), but also to others through resale of the technology allowed under the terms of the agreement.

By dramatically reducing the costs of forward process development, "process" pushed back the hierarchy of differentiating capabilities, because these three companies, and likely others later, can build off the same core capabilities. Many observers of the industry have criticized the intense focus of the industry on manufacturing and money, on "process," and on the fine-line capabilities best exemplified by Japanese progress in MOS memories during the 1980s, instead of on looking at where the performance-enhancing opportunities are in silicon-consuming systems.

Today, "process" appears to be becoming an enabling capability, necessary but not sufficient for semiconductor companies' profitability. Value to the customer and sustainable market advantage are increasingly given by proprietary architectures, products well-defined to fit applications, and software. One can read in this agreement then that, provided this 0.25μm capability is made available to parties outside the three principals, a tilt toward design-intensive U.S. companies and away from market domination through process excellence will result. It reduces, though hardly eliminates, the advantages achievable through sheer financial resource.

Dataquest Perspective: A New World Order?

This megaventure quite likely is the largest and most recent fixture in the emerging semiconductor industry structure. In this view, basic technologies will be developed in common, widely shared, and differentiated by each individual practitioner. Fully 20 separate 0.8- and 0.7μm processes were developed for 4Mb DRAM generation. For future generations and the 0.25μm level, as a result of this common development pact, we may see just four to five basic processes offered by groups of collaborators, reducing redundancy and unnecessary process development and freeing industry resources to concentrate on the highest value-added (and, for the maker, profitable) chip design issues.

Process development may be even further separated from production and design in the future, just as the equipment industry, formerly a part of the semiconductor industry, has evolved into a separate standalone industry offering standard products to all device manufacturers.

By Lane Mason

In Future Issues

Look for articles on the following topics in the next Memories Worldwide *Dataquest Perspective:*

- ECL I/O SRAMs
- Wide DRAMs

For More Information . . .

On the topics in this issue........ Lane Mason, Director	(408) 437-8120
About online access	(408) 437-8576
About upcoming Dataquest conferences	(408) 437-8245
About your subscription or other Dataquest publications	(408) 437-8285
Via fax request	(408) 437-0292

Dataquest Perspective

Memories *Worldwide*

FILE COPY
Do Not Remove

MMRY-SEG-DP-9202 April 6, 1992

In This Issue...

Market Analysis

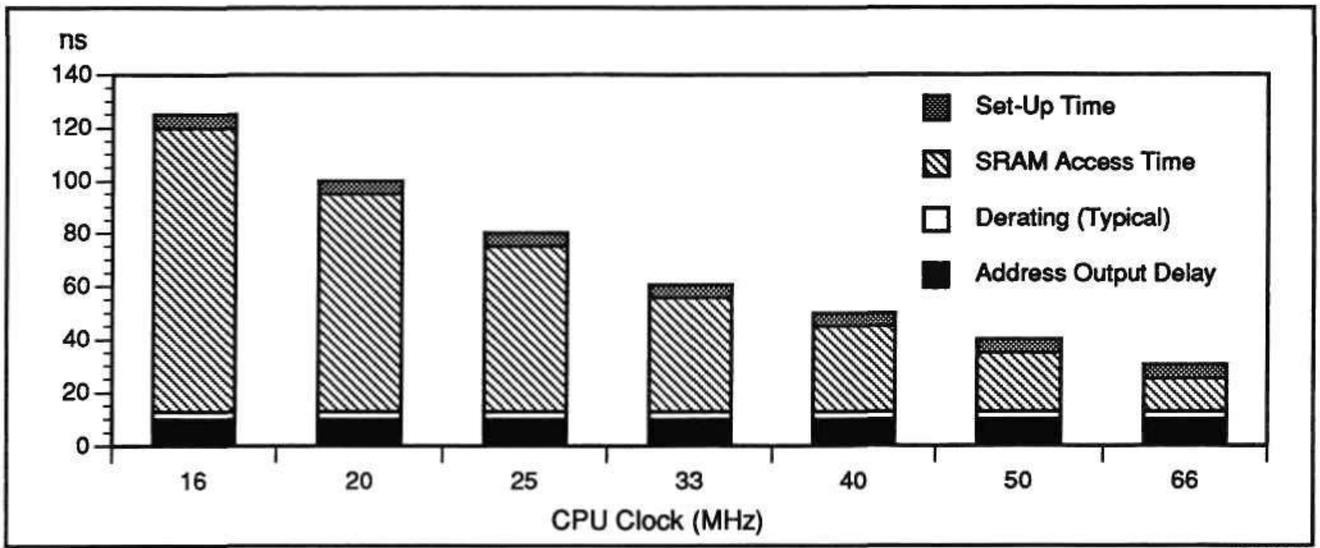
Processor-Specific SRAMs: A Market Slow to Catch On

These are interesting times for static RAM vendors and users alike. Suddenly, nearly all medium- to high-performance general-purpose computing systems are equipped with cache memories. Fast (25ns) SRAMs have recently gained such broad acceptance for use in cache memories that a flood of SRAM vendors has joined the fast SRAM market in anticipation of gaining market share in a high-margin business. Augmented by the current recession, this rush has had the opposite effect and has caused an overabundance of fast SRAMs, driving compression of the average selling prices (ASPs) to the point that the premium for a 25ns part is not that significant in comparison with the price of a 100ns part.

Although this should be wonderful news for the system designer, who needs fast SRAMs to construct a cache memory, it falls short of the mark. Processors' clocks and bus interfaces are now being pushed into speed ranges that make such cache designs extremely difficult. Certain timing specifications vary with processor clock frequency increases, while others do not (see Figure 1). This acts as a lever between the processor and the SRAM used to implement the cache, forcing the SRAM used to triple or quadruple in speed for every doubling in speed of the processor clock.

Some designers are taking advantage of new cache-specific SRAMs being offered by some fast SRAM manufacturers and are able to design for performance that might otherwise be impossible to achieve. These parts are basic static RAMs with some new twists. Features include bank switching, wide data paths, synchronous interfaces, and burst counters. We will examine these new SRAMs in this article.

Figure 1
SRAM Access Time Compression for Faster CPU Clock Rates



Source: Dataquest (April 1992)

G2000051

One difficulty in producing a report like this one is the question of where to cut off the realm of the processor-specific SRAM, or more precisely, which parts should not be counted as processor-specific SRAMs but as integrated cache chips. The definition we will use here is as follows: If there is a significant lever causing the manufacturer of the cache controller to disallow other manufacturers from participating in the SRAM business that should go with that cache controller, then the cache data RAM device will be counted as a part of a cache controller chip set rather than as a processor-specific SRAM. Therefore, we do not count the Intel 82490, which is tightly coupled to the 82495 controller, nor the MOSel MS443, which requires that company's MS441 cache controller to operate. The Intel 82395, the Motorola XC88200, and other all-in-one cache and controller chips also will not be counted. Likewise, we do not include parts that are general-purpose SRAMs but have been screened to better match the specifications of a certain microprocessor, because the success of these parts depends entirely upon the lack of availability of faster parts—a short-term situation at best.

The survey of parts in this article will describe processor-specific SRAMs in terms of their markets or the microprocessors driving the sales of each SRAM. The parts are also categorized by CPU and vendor in Table 1.

Parts, by Processor Supported

The i386

The most widely available processor-specific SRAM to date, and quite possibly the oldest, is the one designed to support Intel's 82385 cache controller for the i386 microprocessor. Originally conceived by Vitelic (now MOSel/Vitelic), the part is unusual in three areas. First, the data path is 16 bits wide, with separate chip enable inputs for each byte of the 16-bit word. Second, it incorporates a flow-through latch on the address input pins. Third, the device is broken into two banks, each of which is 4K words deep and has its own write enable and output enable pins (see Figure 2). A special "mode" pin allows the two banks to be stacked as one, with an additional address pin (offered by Micron as either latched or unlatched) to select which of the two to use, rather than the two sets of enable pins. This address pin is about twice as fast as the other two. The device is referred to by three different organizations: 8Kx16, 2x4Kx16, and 4Kx16x2. We will use the name 2x4Kx16 in this article. The device is available only in a 52-pin PLCC package, and 18-bit-wide

Table 1
Processor-Specific SRAM Offerings

Processor	Organization	Features	AT&T	Cypress	Hitachi	IDT	Logic Devices	Micron	MOSel	Motorola	NEC
Intel i386	2Kx16x2	For C&T 307							MS82C308		
	4Kx16x2	A0-A11 Latched	ATT7C183	CY7C183	HM62A168			MT56C0816			
		A0-A12 Latched	ATT7C184	CY7C184				MT51C3816			
	4Kx18x2	A0-A11 Latched			HM62A188			MT56C0818			
		A0-A12 Latched						MT51C3818			
	8Kx16x2	Address Latch									
	4Kx16	Address Latch				IDT71586					
Intel i486	4Kx18x2	For Intel 82485						MT51C2818			
	4Kx18x2	Burst Cnt/ST Write									
	32Kx9	Burst Cnt/ST Write		CY7B173	HM62A932	IDT71589				MCM62486	
	64Kx9	Burst Cnt/ST Write									
	128Kx9	Burst Cnt/ST Write									
	16Kx16	Burst Cnt/ST Write		CY7B155							
Motorola 68040	32Kx9	Burst Cnt/ST Write		CY7B174						MCM62940	
Sun SPARC	16Kx16	Addr/Data Latches	ATT7C157	CY7C157			L7C157				
		Addr/Data/CS Latch									
Sun Viking	128Kx8	Self-Timed			HM62A8128						
	128Kx9	Self-Timed			HM62A9128		L7C100	MT58C1289			
	32Kx9	Self-Timed								MCM62960	
MIPS R3000	8Kx20x2	2 Address Latches			HM62A2016						μPD46741
	16Kx9(10)x2	2 Address Latches				IDT71B229					μPD46710
	4Kx16	Address Latch				IDT71586					
	8Kx15(16)x2	2 Address Latches									
MIPS R4000	64Kx4	1 Fast Address Input									
	256Kx4	Synchronous									
	32Kx8	1 Fast Address Input									
Moto DSP56001	8Kx20									MCM56824	

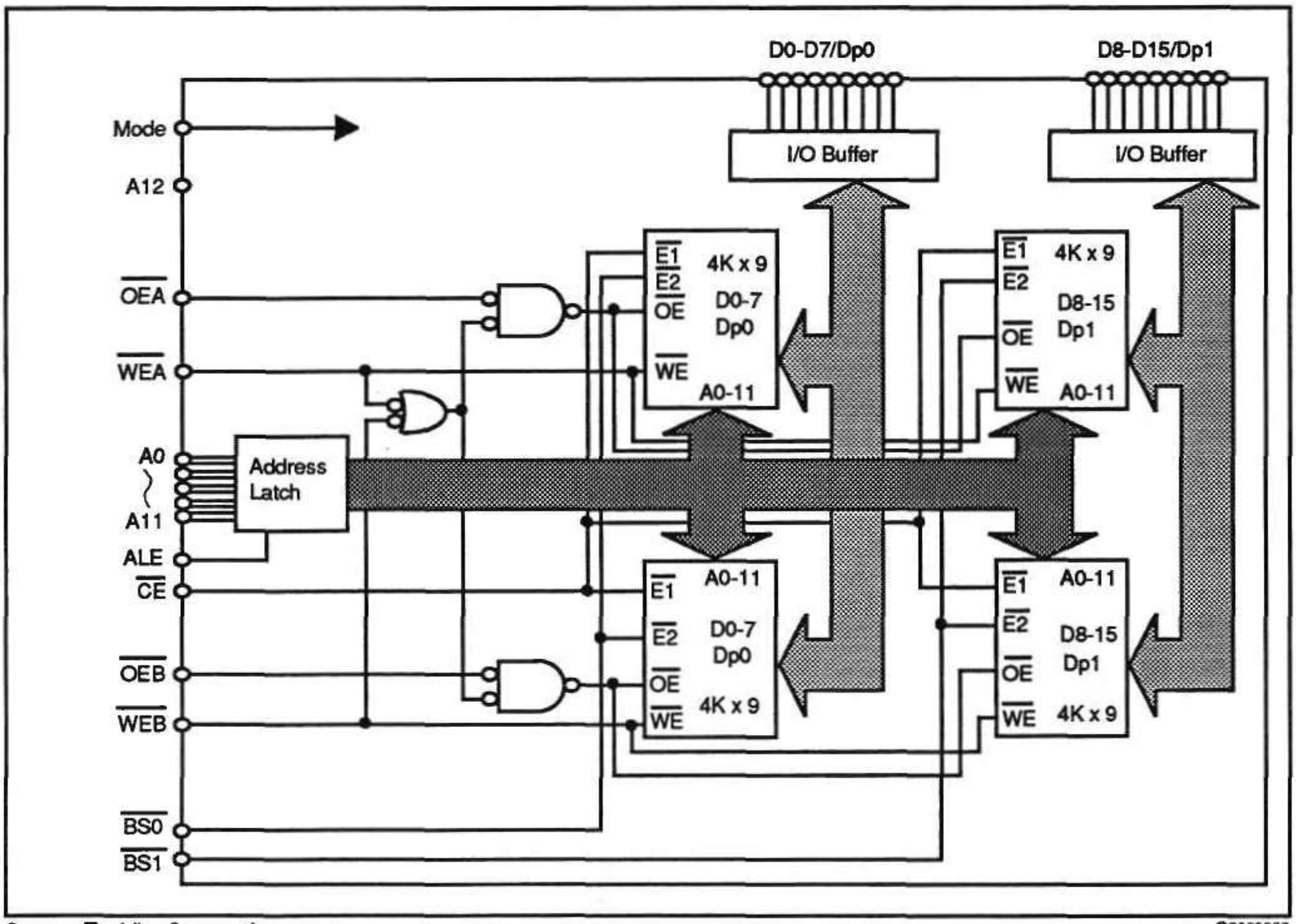
(Continued)

Table 1 (Continued)
Processor-Specific SRAM Offerings

Processor	Organization	Features	Paradigm	Performance	Pioneer	Quality	Samsung	SGS	Sony	Toshiba	Vitelic
Intel i386	2Kx16x2	For C&T 307									
	4Kx16x2	A0-A11 Latched				QS88160	KM78C80		CXK7701	TC55187	V63C328
		A0-A12 Latched				QS88163				TC55188	V63C330
	4Kx18x2	A0-A11 Latched				QS88180					
		A0-A12 Latched				QS88183					
	8Kx16x2	Address Latch		P4C214							
	4Kx16	Address Latch									
Intel i486	4Kx18x2	For Intel 82485									
	4Kx18x2	Burst Cnt/ST Write				QS88181					
	32Kx9	Burst Cnt/ST Write	PSM44259		PI2C2589	QS83291	KM78B86	MK62486			
	64Kx9	Burst Cnt/ST Write		P4C231							
	128Kx9	Burst Cnt/ST Write	PSM44029								
	16Kx16	Burst Cnt/ST Write									
Motorola 68040	32Kx9	Burst Cnt/ST Write	PSM44659				KM78B40	MK62940			
Sun SPARC	16Kx16	Addr/Data Latches			PI2C2157						
		Addr/Data/CS Latch			PI2C2158						
Sun Viking	128Kx8	Self-Timed									
	128Kx9	Self-Timed	PSM44039						CXK77910		
	32Kx9	Self-Timed									
MIPS R3000	8Kx20x2	2 Address Latches									
	16Kx9(10)x2	2 Address Latches									
	4Kx16	Address Latch									
	8Kx15(16)x2	2 Address Latches		P4C215(6)							
MIPS R4000	64Kx4	1 Fast Address Input	PSM44298								
	256Kx4	Synchronous	PSM44028				KM741006		CXK77410		
	32Kx9	1 Fast Address Input				QS83283					
Moto DSP56001	8Kx20										

Source: Dataquest (April 1992)

Figure 2
2x4Kx16 SRAM Block Diagram



Source: Toshiba Corporation G2000052

versions in the same package with a similar pinout are offered by some companies.

A slower SRAM process can be made to appear faster to the CPU by integrating the address latch onto the chip. Internal bank switching through the separate output enable pins also makes the device appear to operate faster than commodity SRAMs. The beauty in this part, though, is not that it solves speed problems so much as the board space it saves. Intel recommends the use of either of two SRAM configurations with its 82385 cache controller: four 8Kx8s with two octal address latches, or sixteen 4Kx4s with four tristatable octal buffers, two octal address latches, and an OR gate (27 chips total). The lower chip count solution offers slightly lower performance than does the high chip count version, because the two versions support direct-mapped and two-way set-associative cache policies, respectively. Nobody chose to use the device in its direct-mapped mode, so the high chip count alternative was the design of choice. By providing the unique 2x4Kx16 architecture, Vitelic was able to reduce designs from 27 ICs to simply 2—a considerable savings in board space.

The part also fits ideally with Chips & Technologies Inc.'s 307 cache controller, which operates in about the same manner as the Intel 82385. MOSel designed a specialty SRAM to support the Chips & Technologies cache controller, which ironically was nearly the same as the Vitelic part, but half as deep. MOSel's MS82C308 works with the Chips cache controller, but is too small to be used with the Intel controller. MOSel made few inroads with its part, yet it is still available.

Compaq Computer Corporation first circulated the Vitelic specification in 1987, in order to accumulate alternate sources for the part. Compaq was the first PC manufacturer to use the Intel cache controller, and all other PC manufacturers, including IBM, were expected to follow suit. The prospective business looked astounding. Sales in 1989 were expected to exceed 4 million units, at an ASP of about U.S.$10. At its peak, about 13 manufacturers had agreed to manufacture the Vitelic SRAM. Then the tables turned.

First, while the alternate sources and Compaq were changing the specification in such a manner as to force Vitelic into a redesign, Integrated Device Technology beat the other vendors to the market with a four-chip solution, a simple 4Kx16 latched SRAM. This product was available early, was widely merchandised, and still looked a lot better than the 27-part alternative, so it ate significantly into the market.

Next, the awaited IBM PC based around Intel's cache controller surprised everybody by not using the controller according to Intel's recommendations. Rather, it doubled the cache size by performing some unobvious tricks with the address pins. Suddenly, everybody else was forced into imitating the IBM design in order to offer a larger cache also. A strange twist is that the IBM approach also reduced the chip count, not by using the Vitelic part, but by using eight 8Kx8s, two octal address latches, and a small bit of random logic, to consume slightly more than ten devices, all of them commodity products, and all of which came in much smaller packages than the 52-pin PLCC. Meanwhile, the first deliveries of the Chips & Technologies cache controller were slipping farther and farther away, and the product was losing its design wins.

Suddenly, the prospective market for the Vitelic part nearly disappeared. Compaq had signed contracts with the first three manufacturers to commit to make the part, so it was unable to back out of a certain level of purchases. Some of these purchases continue today.

Currently, the 2x4Kx16 cache RAM is offered for sale only by Cypress Semiconductor, Micron Technology, Samsung Electronics, Sony, and Toshiba. Of these manufacturers, only Micron and Toshiba ship appreciable volume. Dataquest estimates that the 1991 worldwide market for the 2x4Kx16 was just over 1 million units. Shipments are in decline (see Figure 3). Today's ASP for the part is about U.S.$8.50 for the 25ns version, about 85 percent of the price of four 8Kx8s (as would be used in the IBM cache), and about 30 percent more costly than a 25ns 32Kx8 commodity SRAM, which is twice as dense.

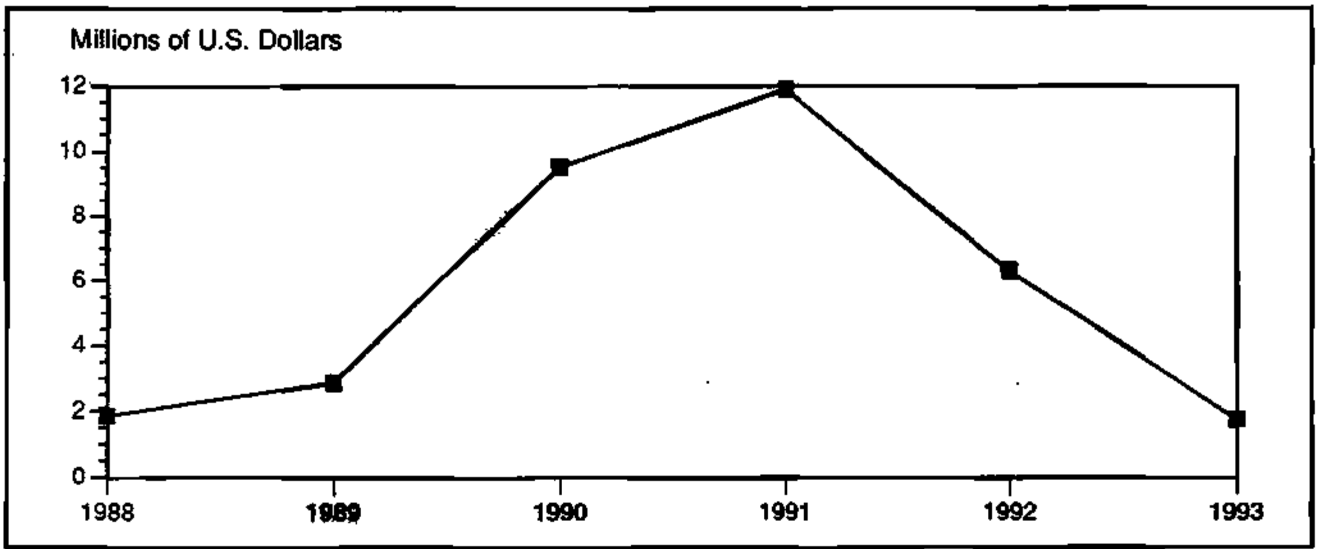
SPARC

The second most widely available processor-specific SRAM is a 16Kx16 part from Cypress Semiconductor, Logic Devices, AT&T, and Pioneer Semiconductor, all of which introduced versions in the order listed. The device includes registers on the data I/O and on the address and write enable inputs (see Figure 4). On the rising edge of the clock input, the address is captured in the address register; on the falling edge, the data input and write enable inputs are sampled. An output hold register maintains output data after a new address has been clocked into the address register. This is the only synchronous SRAM available with this sort of timing.

The device was made in response to a specification for a 32Kx8 synchronous SRAM circulated to several SRAM vendors by Sun Microsystems in 1987. The unusual latch configuration is an ideal fit for the cache/memory management unit chips (CMMUs) offered by Cypress, Fujitsu, and LSI Logic. Surprisingly enough, Cypress loses to its competitors some SRAM sockets in boards in which its own CMMU and integer unit are used. Of course, Fujitsu recently announced that it would build workstations around Cypress's IU and CMMU, so we shouldn't be surprised, should we? The world is sometimes a strange place.

What makes the 16Kx16 part salable, and what drives the market? First, all of Sun's systems use this SRAM to implement a 64KB cache. Every system Sun offers has the same

Figure 3
Worldwide Sales of 2x4Kx16 SRAMs



Source: Dataquest (April 1992)
G2000053

cache size, so Sun uses quite a few of the 16Kx16 cache SRAMs. Dataquest estimates 1991 worldwide SPARC sales of 291,000 units (see Figure 5), mainly from LSI Logic, Fujitsu, and Cypress, each of which had about a third of the market. Sun has taken harsh measures to ensure that clone manufacturers have a hard time attaining good sales channels, and the effect has been to reduce the number of 16Kx16 unit shipments to an amount almost identical to Sun's consumption. Dataquest estimates worldwide 1991 unit sales for the SPARC-compatible 16Kx16 to have been about 300,000 units. ASPs are about U.S.$10 for a 25ns part, down from about U.S.$30 a year ago. We expect sales to ramp slightly in 1992, then to taper off in 1993 as Sun converts designs to the new Viking processor.

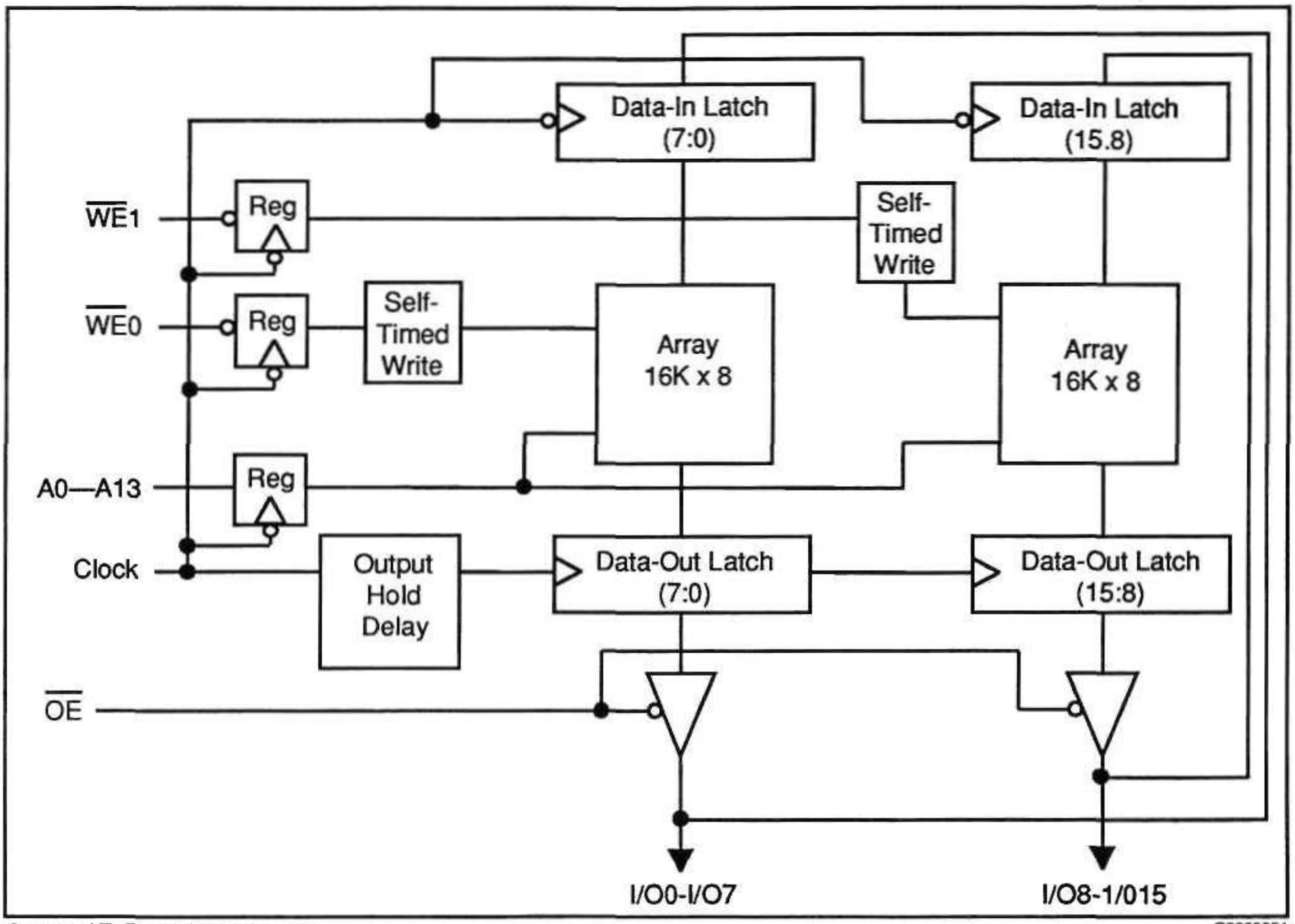
The i486

More attention has been focused on processor-specific SRAMs for the Intel 486 than for any other processor, and as a result there is more variety in this market than in any other. Table 1 shows six different configurations designed for 486 applications. Sales of 486-specific SRAMs are expected to grow considerably from 1992 through 1994, but success will probably be limited to one or two types of devices. Still, the market for these chips is difficult to understand. Many of the 486-specific parts have nothing in common with each other.

The majority of the 486-specific SRAMs offer either or both of two features: bursting and self-timed write cycles. Bursting SRAMs help the 486 to refill its internal cache lines using the fastest refill mechanism available on the 486 processor, the burst read cycle. In a burst read cycle, the processor outputs an address, and the memory can respond by sending the four words within the same general location, each on successive processor clock cycles. This means that the processor can read as many as four words of data every five clock cycles, a significant improvement over the 386's maximum rate of one word every two cycles. Burst refills require the use of address generation outside of the processor, and manufacturers of bursting SRAMs have put this address generation logic into the SRAM chip itself. Burst count sequences are different for different processors, so a chip with a 486 burst address generator will not work optimally with other processors.

Self-timed write cycles are a simple way to conquer the problems of generating clean write cycles. A clean write cycle is nearly impossible to generate at high processor frequencies, especially if the processor has a synchronous

Figure 4
16Kx16 SRAM Block Diagram



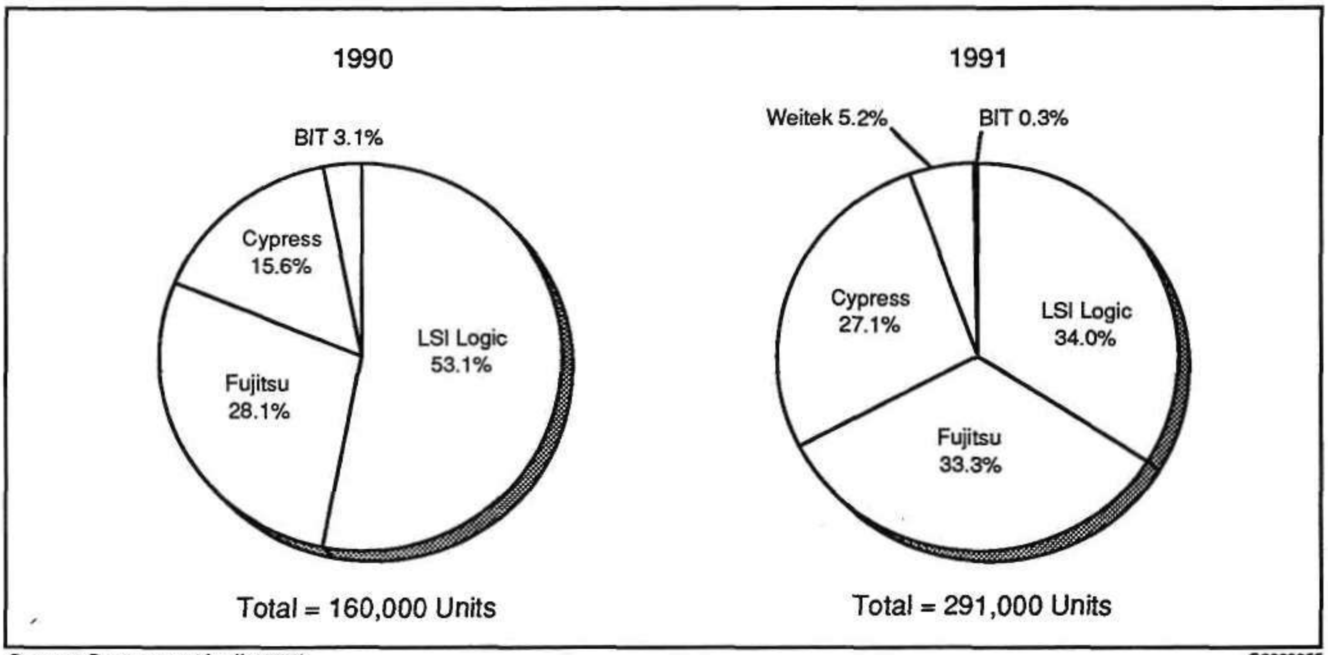
Source: AT&T Semiconductor Inc. G2000054

interface, as does the 486. The problem is barely surmountable if the processor's timing is forgiving enough, but this is not the case with the 486.

The most widespread 486 support RAM comes in a 32Kx9 organization, which is supplied in two competing pinouts. This sorry state of affairs came about after Compaq circulated the specification for Integrated Device Technology's 32-pin part to attain wide second-sourcing, but failed to tell anybody that IDT was close to sampling the product. A division came about when several sources had already rationalized that a 44-pin package was imperative to the manufacture of their versions of the part. The camp is divided into the 32-pin contingent (IDT, Pioneer, and Quality), and the 44-pin contingent (Motorola, Cypress, SGS, Hitachi, Paradigm, Samsung, and others later). The stances grew firmer when the 44-pin device was standardized by the Joint Electronics Device Engineering Council (JEDEC) in spite of a patent pending to IDT. This should be interesting to watch in a few years. To date, sales of the part are ramping sharply, with the bulk of the market controlled by Motorola and IDT. Unit shipments in 1992 should exceed 1 million units worldwide, at an ASP just under U.S.$20, which compares very favorably against the U.S.$6 ASP now seen for fast 32Kx8 commodity SRAMs.

Other 486 SRAMs featuring a burst counter and self-timed write include a 2x4Kx18 organization to be offered by Quality Semiconductor,

Figure 5
SPARC Processor Market Share by Units



Source: Dataquest (April 1992)
G2000055

a 16Kx16 from Cypress, and a 128Kx9 proposed by Paradigm. Not one of these is alternate-sourced, so Dataquest does not expect them to become well accepted in the market. Another 2x4Kx18 without a burst counter is sole-sourced by Micron to Intel (quite a coup for Micron), and is exclusively used in Intel's 82485 cache module (also known as the TurboCache and the C6). Volumes of this SRAM are reported to be healthy, despite the fact that the 82485 was a year and a half behind schedule once it finally shipped, and as a result was designed out of the majority of its original design wins. (Even Intel's systems group is rumored to be attempting a design-out of the 82485 for cost reasons.) Still, of all the processor-specific SRAMs being offered in support of the 486, the two 32Kx9 organizations are expected to lead the market by a wide margin.

So, will every 486 system use two or more of the 32Kx9? No! Although secondary caches are viewed as necessary differentiators for 486-based systems, their performance is seldom an issue. OPTi, the leading supplier of 486 chip sets, has built its strength upon a non-optimized cache architecture that incurs wait states on all cache cycles. The success of this cache controller has proven that the majority of PC consumers buy cache by size, not by performance. Bursting 32Kx9s are a relatively costly means of obtaining the highest performance from a 486, so the designs using this part will necessarily be those aimed at the more sophisticated PC buyer—the one who buys on benchmarks. Dataquest expects high performance SRAMs to be sold to only about 5 percent of the overall 486 market.

Note that the features found on the 486-specific 32Kx9 are also put to good use in systems based on other processors, despite the fact that the burst counter is optimized for the 486. With a little care, good results can be obtained through the use of these parts in 860, 960, 68030, 68040, and even high-speed 386-based systems. This fact is not as important as it may seem. All of these processors except the 386 are mainly used in closed systems. Designers of closed systems can avoid the need to use costly external caches when performance increases can be realized through redesigning the bus or the software. Such systems also tend not to use cache as a buzzword, and it is not as much of a differentiator as is outright performance. These applications will hardly make a difference to the sales of the 32Kx9 bursting self-timed SRAM. We also do not expect 386 systems to widely use this part, because 386-based desktop system design is viewed by system designers as a mature art, and they are not exploring new horizons.

The 68040

A different version of the 32Kx9 bursting self-timed SRAM in a 44-pin PLCC has had its count sequence optimized for use with the 68040 processor. The part is currently available from Motorola and Cypress, soon to be followed by Paradigm, SGS, Samsung, and possibly others. As just mentioned, few 68040 system designers choose to augment the 68040's 8KB on-chip primary cache with a costly secondary cache, so the market for this chip is nearly nonexistent.

We do not expect to see any improvement in the market for this chip over the life of the 68040.

MIPS R3000

MIPS Computer has recently reversed a prior stance in which it claimed that there was no reason to use anything but commodity SRAMs in an R3000 system. As a result, the company has succeeded in generating interest in processor-specific SRAMs to cater to its R3000 architecture. MIPS' reversal probably can be attributed to the fact that current versions of the R3000 can operate at clock frequencies considerably faster than those originally anticipated by the processor's designers. The R3000's SRAM interface causes design difficulties at clock speeds higher than 20 MHz. The R3000 requires interleaved banks of latched-address SRAM at widths of up to 60 bits per bank.

Although MIPS originally proposed an 8Kx20x2 organization, to satisfy the two-bank scheme, and to provide 64KB of combined instruction and data cache within three 68-pin PLCC packages, semiconductor manufacturers responded to inputs from system designers to implement a six-package version that would offer twice the size of cache, or a total of 128KB. Manufacturers currently shipping the 8Kx20x2 are NEC and Hitachi. The deeper part, a 16Kx10x2 organization, is now only offered by NEC. To make matters confusing, IDT now offers a 16Kx9x2 in a 32-lead, 300-mil SOJ package, a package that allows the design of far smaller boards, but the x9 organization requires the designer to play certain unobvious tricks to keep the package count down to six devices.

Other devices are also touted as R3000 support RAMs, even though they were designed with other applications in mind. The IDT71586 4Kx16, which was designed for 386 applications, is being promoted by IDT to be a reasonable R3000 cache support chip, and several designs now use Motorola's MCM62990 16Kx16 general-purpose synchronous SRAM. Toshiba's and NEC's 15ns 64Kx16s are also popular in both R3000 and R4000 applications.

The Viking

Bolstered by the sales of the SPARC 16Kx16, several SRAM vendors hope to make a pretty penny on the 128Kx9 support chip promoted by Sun to support its Viking processor. This chip is a very standard synchronous architecture, with the only difference being that common I/O is used, so the part has a dead cycle when moving from a write cycle to a read cycle.

Rumors are that Sun promised guaranteed minimum-volume contracts to the first three vendors to commit to manufacture the part. The Viking-specific SRAM is now sampling from Sony and Paradigm, and is being advertised by Micron. Dataquest expects many sources to follow. The product's simplicity lends its use in other applications, so this architecture could take off in a number of non-Viking applications.

MIPS R4000

All eyes are watching the ACE initiative, because its success or failure will determine the health of the SRAMs used to support the R4000 processor. Intel's mere presence in the ACE consortium puts the fate of the R4000 into question.

MIPS has taken a cautious path again with the R4000. This processor contains a small on-chip primary cache, as well as the control logic to support a much larger off-chip secondary cache. This cache control logic can support caches of varying sizes manufactured from industry-standard asynchronous SRAMs of various speeds. The cache configuration is communicated from a PAL or a PROM into the CPU during the system reset.

A hook was placed into the R4000's reset vectors to support a faster configuration of cache, in which one or two address pins are twice as fast as the SRAM's overall access time. A 15ns SRAM might have a single address input that exhibits an address access time of 7ns. Several SRAM vendors have expressed an intent to manufacture this part, with the consensus being that 64Kx4 should be the appropriate size and organization. A general agreement was reached to accelerate the address on pin 11 of this device.

Meanwhile, one of the largest users of the highest-speed version of the R3000—and MIPS' new parent company—Silicon Graphics Inc. (SGI), proposed an altogether new scheme, wherein it plans to use a fast synchronous 256Kx4 organization. It floated the specification about a year ago, and has gotten several responses. The part will soon be provided by Sony, Paradigm, and Samsung, but appears not to be sampling yet.

One unfortunate aspect of the R4000 is that the only version to support external cache is the one in the extraordinarily high pin-count package. The R4000 in the 179-pin package does not support external cache. The part that does support external cache comes in a hefty 447-pin package, which certainly will factor into design decisions, especially because no plastic package is currently being promised. Which package will be used by the majority of ACE systems? Time will tell, but Dataquest favors the less expensive alternative, even if the system designer will be forced into using an external cache controller.

Dataquest Perspective

Processor-specific SRAMs have so far been relatively slow to catch on. This appears to stem from a reluctance on the part of system designers to take advantage of these parts owing to worries that the manufacturers will not be as price competitive as they would be with generic asynchronous SRAMs. This has been augmented by the fact that processor-specific SRAMs sometimes miss the target density of their end applications. Examples are the 2x4Kx16 for the 386 and the 8Kx20x2 for the R3000.

Even the highest-volume processor-specific SRAMs do not sell well. The 2x4Kx32, the best-seller of all processor-specific SRAMs, moved about 1 million units in 1991, and runner-up 16Kx16 only sold 300,000 units. These are not major volumes. Although volumes should increase significantly with the availability of high-speed processors, do not look for these products to displace any important volumes of standard SRAMs. It will probably be late 1992 before sales of processor-specific SRAMs reach an annualized sales rate of well over $10 million. With this in mind, it is not surprising that these products are of decided interest to smaller "boutique" SRAM manufacturers, whose bottom line can be significantly improved through the addition of a million-dollar product. These manufacturers also aim for products whose ASPs stay high, affording better margins than would commodity products.

Threats are also being heard from another front. DRAM manufacturers are eyeing the ASPs of processor-specific SRAMs and are trying to figure ways to divert that revenue into their own pockets. From such thinking come Mitsubishi's and Ramtron's "cached DRAM" approaches, or Rambus's special 500-MBps proprietary DRAM interface. Meanwhile, expect on-chip caches to become bigger and better, reducing the performance advantages to be gained from the addition of external caches.

Another problem is the need to educate the busy system designer on the need for these products. First you need to get their attention, and then you need to know exactly what to say to sell the part. Few SRAM sales organizations are structured this way. SRAMs are commodity products, and educational sales are not commodity approaches. This type of sale is best approached by the manufacturer of the processor, not the manufacturer of the SRAM.

Semiconductor vendors selling processor-specific SRAMs have a lot of work ahead for a relatively small return. Is it worth it? Some seem to think so, but Dataquest does not expect the world to suddenly welcome these parts with a warm embrace.

By Jim Handy

Product Analysis

The Future of the SRAM Market

The static RAM (SRAM) market has grown to its current size because of high-speed access and low power consumption, which has more than compensated for relatively low density. However, the emergence of high-speed DRAMs and flash memories is eroding the traditional competitive edge for slower SRAMs. It is a little easier to enter the SRAM market than the DRAM market because of facility capacity. DRAM requires very advanced technology, and the DRAM business is very risky. The number of SRAM suppliers is larger than that of DRAM suppliers. Therefore, in order to survive in the SRAM market, SRAM suppliers compete with one another through competitive prices. Price erosion is the result.

High-Speed SRAM Market in 1990

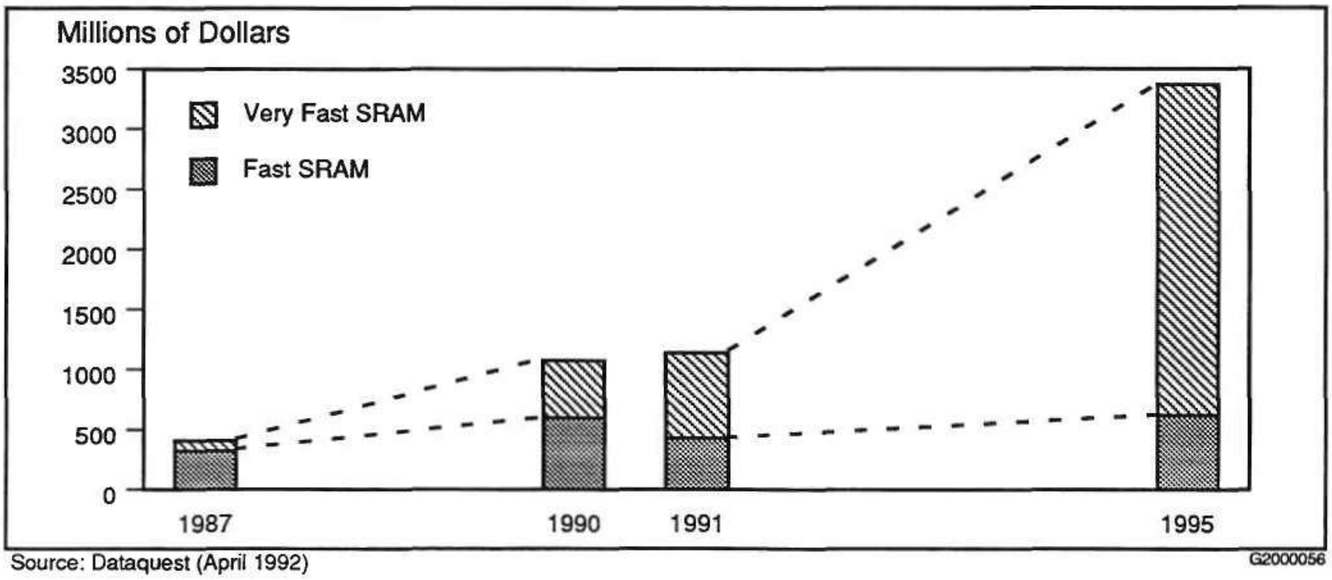
Dataquest estimates that the worldwide high-speed SRAM market increased at a compound annual growth rate (CAGR) of 6.8 percent in 1990 to reach approximately $1,076.7 million (see Figure 1). This is healthy and strong growth compared with the negative growth of the MOS memory market, which was down 20.1 percent from the previous year to $12.5 billion. In fact, only high-speed SRAMs (access time of 70ns and faster) and flash memories recorded growth among MOS memory products in 1990 (see Table 1).

High-speed SRAMs are used mainly for cache and main memories of computers. In particular, cache memories use very fast 64Kb to 256Kb SRAMs with access times of 5 to 35ns, and they are becoming increasingly important to govern the entire system performance. The 5ns bipolar SRAMs are generally used in supercomputers and mainframes, while 10 to 35ns versions are used in minicomputers and workstations. Recently, workstations have required 10ns or faster SRAMs because of the increasing use of reduced-instruction-set computing (RISC) CPUs. Similarly, more and more PCs use cache memories to consume 25 to 35ns 64Kb and 256Kb SRAMs. Applications are further extended to caches for external storage (on disk), where 100ns parts are used. Cache memories for workstations and PCs often use multibit SRAMs to minimize board space, whereas main memories of supercomputers consume a large amount of x1 or x4 versions with large capacities.

High-Speed SRAM Market Trends

Recently, high-speed SRAM demand has been growing rapidly for use as cache memories for 33-MHz or faster complex-instruction-set computing (CISC) and RISC MPUs. On the other hand, profitability has deteriorated recently because of competitive pricing by a large number of vendors. The 33-MHz 386, 486, and RISC MPUs use caches and 256Kb SRAMs used for 33-MHz SPARC and R3000 require access times of 30ns or faster. In particular, R3000 demands

Figure 1
Worldwide Fast SRAM Forecast



Source: Dataquest (April 1992)
G2000056

Table 1
Worldwide MOS Memory Market (Millions of Dollars)

Device	1989	1990	Growth Rate (%) 1989-1990
DRAM	8,968	6,830	-23.8
SRAM (>70ns)	2,364	1,684	-28.8
SRAM (≤70ns)	1,008	1,077	6.8
EPROM	1,808	1,446	-20.0
ROM	1,221	1,157	-5.2
EEPROM	318	314	-1.3
Flash	11	35	218.2
Total	15,698	12,543	-20.1

Source: Dataquest (April 1992)

SRAMs with access times of twice the frequency—15ns or faster. Demand for high-speed SRAMs also comes from emerging microprocessor units (MPUs) with clock frequency of 50 MHz or higher. These facts point to rapid expansion of demand for SRAMs with very high speeds. In fact, these SRAMs have boosted their share of the high-speed SRAM market from 35 percent in 1987 to 39 percent in 1990; their share is expected to grow to 41 percent in 1991 and then over 57 percent in 1995. Nevertheless, there are some hurdles to be cleared before these goals are attained. First, delay due to external standard logic ICs would affect system performance significantly in the high-speed operating environment at the 50-MHz level. One solution to improve performance is to integrate logic circuits into SRAMs to reduce delay by 2ns to 3ns, which is then allocated to memories. In practice, some SRAM systems incorporate the address latch circuit between MPU and memories. This solution is designed to implement application-specific memories optimized for different types of microprocessors. For instance, Motorola Incorporated and NEC Corporation are marketing cache memories dedicated to R3000, SPARC, or i386. Customized SRAMs offer large bit width, integrating the address latch circuit and other functions to reduce chip count for cache system compared with general-purpose high-speed SRAMs. Availability is a major problem, however, necessitating the securing of second sources.

Another problem is that the price remains at a relatively high level because of the small number of suppliers. To secure a stable supply, some U.S. MPU manufacturers are looking for Japanese SRAM makers—a seemingly mutually beneficial deal.

Although an attempt is being made to incorporate cache into MPUs, it is not technologically feasible in the short run to integrate the secondary cache into a single chip, partly because of chip size. Instead, the multichip module is receiving increasing attention as a solution to avoid delay due to external memory and data input/output. By mounting the MPU, cache memories, and other devices on a single module, wiring impedance can be minimized and operating frequency in the module can be increased. On the other hand, even the SRAM with transistor-transistor logic (TTL)-level interface requires 10ns access time or less. To achieve such high speed, while dealing with an accompanying noise problem, upgrading from TTL-level to emitter-coupled logic (ECL)-level interface may be required. For this purpose, the BiCMOS process must be suitable for both TTL and ECL levels and there must be commercialization of the 3.3V system, which allows speed to increase while maintaining compatibility with TTL. The ECL process is also a potential solution for implementation of high-speed versions, but high cost and power consumption are likely to limit its application to some very high speed products. Finally, improvement is expected in packaging. Compared with the conventional package in which the power source and GND pins are arranged at the corners, very high speed SRAMs will have them at the center of the package in order to minimize impedance in lead frame.

Dataquest Perspective

As the increase in processing speed of MPUs leads to the increase in operating speed of workstations and PCs, Dataquest expects cache memories to play an increasingly important role. While the high-speed SRAM market is encroached upon by high-speed DRAMs and the slow SRAM market faces a threat from flash memories, we expect very high speed SRAMs to become a growth center in the SRAM market. Clearly, high speed as well as low power consumption are keys to the future prosperity of the SRAM market. At the same time, Dataquest sees that SRAM manufacturers must survive through the development of cache memories optimized for different MPUs—jointly with capable microprocessor makers—to build up a reliable supply capability. In this sense, the SRAM market is about to enter an industry-wide restructuring period characterized by strategic alliances.

By Akira Minamikawa

Inquiry Summary

Semiconductor Memories Inquiry Highlights

Q: Is flash replacing EPROM?

A: Even though the majority of flash memory ICs conform to Joint Electronics Device Engineering Council (JEDEC) standard pinouts, making them pin-for-pin compatible with EPROM devices, flash memories are not replacing EPROMs directly. The primary reason is, of course, cost. The 1Mb flash EPROM costs about $10, whereas the 1Mb EPROM costs $4. Even if the significant cost differential is ignored, replacing the EPROM in an existing board design with a flash memory does not make sense because the systems usually are not designed to exploit flash's main advantage over EPROM: the ability to alter the stored data without removing the device from its socket/board. As a result flash is used mainly in new designs, where the electrical rewriteability can be designed in. The in-socket reprogrammability that flash offers may more than offset at times its cost disadvantage.

Automotive applications offer plenty of examples. If there is a need to change the data stored in an EPROM, a board along with the subassembly must be physically removed from the automobile; then the EPROM must be physically removed and exchanged. That is a very expensive option. If flash memory were used, the data could be easily altered by connecting the board to a computer using just a cable.

Q: What is the difference between flash EPROMs and flash EEPROMs?

A: Simply stated, flash EPROM requires a 12V supply for programming whereas the flash EEPROM requires a 5V supply. Both EPROM- and EEPROM-derived flash need only a 5V supply for read operations. Flash EEPROM is derived from the full-featured EEPROM (two-transistor cell). The smallest die size is achieved when only bulk-erase capability is desired (electrically erasing all memory locations). But this makes the flash EEPROM equivalent to a flash EPROM from a feature standpoint while incurring a die size/cost penalty of the two-transistor cell. As a result, the only advantage that flash EEPROM with bulk erase capability offers is being a 5V, single-supply device. This in itself would be a significant advantage if flash EEPROM could be produced at a cost parity with flash EPROM. By subdividing the flash memory into sectors (for example, 4Kb or 16Kb each), a finer granularity is achieved. This is desirable for solid-state disk and memory card applications (at a cost penalty, as the die size increases).

Flash EPROM is derived from basic EPROM technology (one-transistor cell). It offers the smallest die size (for standard JEDEC products) and thus the lowest-cost flash products. The disadvantage is that, like the EPROM, all data must be erased at the same time (bulk erase). However, unlike EPROM that requires a time-consuming off-system UV erase, flash EPROM devices can be quickly erased in-system, electrically.

Q: Who offers what technology?

A. Intel leads the EPROM-derived flash camp that also includes AMD, NEC, Hitachi, Mitsubishi, SGS-Thomson, Exel, Catalyst, and Oki. Toshiba and ATMEL offer EEPROM-derived flash. Intel offers a flash EPROM with limited sector erase capability. The 1Mb 28F001BX is segmented into four sectors: one 8KB, two 4KB, and one 112KB. The 28F001BX is quite popular in BIOS applications. Both Hitachi and NEC plan to offer 4Mb flash with block erase capabilities. The Hitachi HN28F4001 is divided into 32 blocks of 16KB. NEC's uPD28F4001 offers a similar organization; the uPD28F4000 is organized as 16K words by 16 blocks. Finally, Toshiba plans to introduce the TC584000, 5V-only 4MB flash EEPROM with block erase capability (4Kb block size).

Q: Name a couple of good applications for flash memory.

A. Automotive, in engine and transmission management control electronics. The availability of 12V makes this a good application for the standard flash EPROM products. The fact that this happens to be the least expensive flash comes as an added bonus in an extremely cost-conscious industry.

In personal computers, flash memory is increasingly used to replace UV EPROMs to store the computer's BIOS. This arrangement allows for easy in-system upgradability of the BIOS code, allowing new features to be integrated into existing systems. The portable PC market seems to be embracing flash technology. It should be noted that this market demands low-voltage devices, and in the long run may drive the 5V and 3V flash memory technology. Palmtop PCs will use flash for mass storage (solid-state disk).

It also should be noted that some flash EEPROM designs are optimizing the overall device die size by sacrificing speed. This is targeted to rigid disk drive applications where speed may be compromised. Here emulation of an existing slow electromechanical system is required (average access time of 10ms to 20ms). The Toshiba TC584000 flash memory fits this category.

By Nicolas Samaras

For More Information . . .

On the topics in this issue	Lane Mason, Director (408) 437-8120
About online access	(408) 437-8576
About upcoming Dataquest conferences	(408) 437-8245
About your subscription or other Dataquest publications	(408) 437-8285
Via fax request	(408) 437-0292

Dataquest Perspective

Memories *Worldwide*

MMRY-SEG-DP-9201 March 30, 1992

In This Issue...

Market Analysis

Preliminary 1991 Worldwide MOS Memory Market Share Estimates

Dataquest has completed its preliminary 1991 MOS memory market share survey. We mailed a survey questionnaire to more than 150 semiconductor vendors in early November. The respondents provided us with detailed breakouts of their revenue and unit shipments based on a combination of year-to-date data and company-generated forecasts for the rest of the year. The collected results are published in this article. We will continue to refine and update the data, and we plan to release our final market share data documents on May 31, 1992.

Market Share Highlights

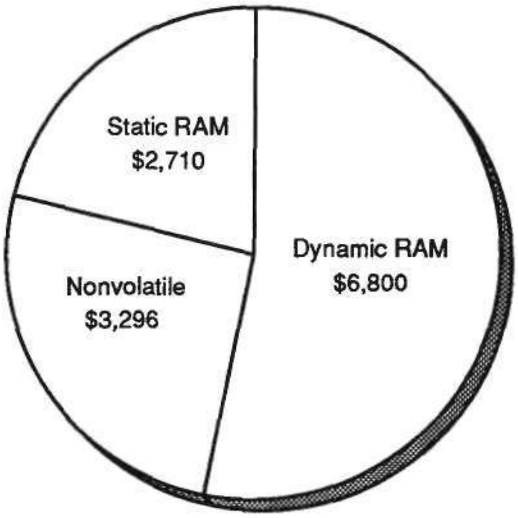
The following analysis covers the three areas of MOS memory tracked by Dataquest: DRAMs, SRAMs, and nonvolatile memories (EPROMs, EEPROMs, ROMs, and Flash memories).

MOS memory grew in 1991 at a relatively moderate 6 percent, in contrast to 1990's disastrous 17 percent decline. Observed in this light, however, MOS memory has made a rather impressive recovery, especially considering the fact that the 4Mb DRAM has not taken off as quickly as some had hoped. Toshiba returned its No. 1 ranking for all MOS memories, shipping more than $1.44 billion. In 1991, Toshiba was followed in order by Hitachi, NEC, Fujitsu, and Samsung.

Highlights of the 1991 MOS memory market include the following:

- Overall dollar growth in DRAMs was 5.0 percent; in SRAMs, 5.0 percent; and in nonvolatile memories, 11.7 percent.

Figure 1
1991 Estimated Worldwide Memory Sales, by Type
(Millions of Dollars)



Source: Dataquest (March 1992)

- Rapid price erosion decreased the growth of SRAM sales significantly.
- Micron Technology became a top-10 player in the DRAM market, at No. 8.
- Rankings of the top 10 SRAM and nonvolatile memory manufacturers remained nearly unchanged.
- Flash memories underwent the most dramatic change, increasing unit shipments by 491 percent.
- Japanese vendors took 60.6 percent of the DRAM market and 71.5 percent of the SRAM market. Japanese market share of nonvolatile memories was far lower at 47.7 percent.

The pie chart in Figure 1 shows the relationship in dollar sales between the DRAM, SRAM, and nonvolatile memory market segments.

By Lane Mason
Jim Handy
Nicolas Samaras

A Year of Transition for DRAMs

The year 1991 was in many ways transitional for DRAMs. Aside from the triennial move from generation to generation, we began to see the long-anticipated emergence of wide DRAMs at the 4Mb level, continued market share gains by Korean manufacturers over the still-dominant Japanese suppliers, and, with the 4Mb ramp-up, the first real impact of the new economics of DRAM production that promise to raise ultimate floor prices from generation to generation in degrees never seen before.

Prices per bit for 4Mb DRAMs crossed over those of 1Mb parts about midyear, and by year-end, 4Mb DRAMs were generating greater revenue and shipping more bits per quarter.

For the most part, the initial 350-mil 4Mb DRAM was replaced by the historical standard 300-mil package and DRAM speeds inched downward. The majority of products are now available at 70ns to 80ns. The market for very-high-speed optimized designs was found wanting, as MPU speeds made cache systems unavoidable.

By year-end, low pricing in the 1Mb market had encouraged several manufacturers to ramp down production and concentrate entirely on the 4Mb and 16Mb devices.

1991 Market Share Movement

Table 1 shows suppliers' 1991 DRAM revenue. Despite an estimated 31 percent price-per-bit (PPB) erosion, the DRAM market managed revenue growth of about 5 percent for the year. Japanese companies, led by No. 1 Toshiba with an estimated $904 million in sales, took 6 of the top 10 places in 1991 DRAM production. No. 2 Samsung was the top 1Mb shipper. Micron Technology, coming off a difficult transition to 1Mb in 1990 that impacted 1990 revenue, showed the top growth rate among the top 10 and had sales estimated at $362 million in 1991. Despite continuing trouble with its 4Mb at several facilities, Texas Instruments was the No. 6 producer, although it dropped about 1 percent in sales to $571 million.

As a portent of things to come, Goldstar and Hyundai each grew shipments more than 140 percent, but remained out of sight of the top 10, for 1991 at least. Overall, Korean

Table 1
1991 DRAM Revenue (Millions of Dollars)

Company	1990 Sales	1991 Sales	Change (%)
Toshiba	947	904	-4.5
Samsung	809	900	11.2
NEC	669	698	4.3
Hitachi	597	675	13.1
Texas Instruments	576	571	-0.9
Fujitsu	497	484	-2.6
Mitsubishi	503	467	-7.2
Micron Technology	294	362	23.1
Oki Semiconductor	293	319	8.9
Siemens	306	287	-6.0
Motorola	292	264	-10.0
Goldstar	75	204	172.0
Hyundai	75	186	148.0
Matsushita	131	116	-11.5
NMB Semiconductor	171	116	-32.2
Vitelic	58	79	36.0
Sharp	72	62	-13.9
Others	110	106	-3.6
Total	6,475	6,800	5.0

Source: Dataquest (March 1992)

companies garnered virtually all of the aggregate DRAM market growth, largely at the expense of the more established Japanese suppliers.

Goldstar and Hyundai have become significant enough players to threaten low-end pricing, and in 1991 became bona fide suppliers of 4Mb DRAMs. Samsung cemented its position as a leading contender for the DRAM crown, shipping 4Mb DRAMs at a rate within striking distance of market leader Hitachi. Samsung's 16Mb parts are said to be on a par with the best in the industry—no price discounts anymore! Samsung will be interesting to watch in 1992 as it challenges for the DRAM lead, as will Hyundai and Goldstar as they upgrade both their products and customer base.

One important advantage that newcomers to the DRAM market have in 1992 and beyond is the changing channels to end users. A growing fraction of the DRAM business is upgrades for PCs bought at mom-and-pop outlets: Blue-chip accounts, with exacting system requirements and lengthy, expensive qualifications, make up a steadily declining share of DRAM demand. Add-on memory is an attractive outlet for the price competitive new kids on the block—Goldstar, Hyundai, and any other late arrivals to the 4Mb race—who want to keep their fabs full and learn the business.

Packaging Trends

The 1Mb generation was the last hurrah for the dual in-line package (DIP), as its share of the business migrated rapidly to SOJ and, it appears, soon to TSOP. DIPs were about 22 percent of 1Mb DRAM unit shipments in 1991, compared with about 4 percent of the 4Mb shipments. ZIPs held steady at about 15 percent of the 4Mb generation. So, after five generations of DRAMs that went into the DIP, we have gone through two major packaging turnovers in just the past two generations, with the last yet to fully express itself in the market.

The single in-line memory module (SIMM) market constituted an estimated 40 percent of DRAM sales at year-end, but was difficult to size because of the prevalence of aftermarket SIMM packagers. During the year, the SIMM issue was further muddied by the Wang lawsuits, which draw a low royalty wall around 30-pin ×9 SIMMs. Manufacturers are watching to see which way the winds blow, pushing the demand over to ×36 modules, while begrudgingly paying the 3 to 4 percent royalty to Wang. As a significant fraction of the DRAMs in SIMMs fill in the upgrade memory needs of the PC and workstation installed base, it looks as though ×9 will continue in a major way for 1992. In addition, there appears to be no rush in newer PCs to design expansion slots to accommodate ×36 modules, though some are doing so.

Pricing

Pricing for all DRAM densities continued through 1991 in an uninterrupted decline. There were no significant "spot" shortages in packages, speed grades, or operating modes. Year-end pricing for 1Mb DRAMs was often below $4, with a bottom of about $3.50 for mainstream parts. This was somewhat lower than many had expected 1Mb bottom prices to be when cost-of-production forecasts were made during the 1988 to 1989 shortage.

Prices for 4Mb DRAMs marched down from about $21 in early 1991 to a fourth-quarter average of about $14, with low-end pricing near $13.50. Off-standard parts, remnants of the 350-mil package inventory, and slow speed grades went for as low as $11.50. Steady pricing erosion continues into 1992.

For the few hundred thousand of the 16Mb DRAMs shipped in 1992, prices began the year at about $300 per unit but declined to about $210 at year end. A few orders were placed during 1991 for volumes ranging from 10,000 to 20,000 pieces to be fulfilled early in 1992. Even at $200, the price-per-bit premium is still about 4× compared with 4Mb devices. The rate at which 16Mb can come down and be cost competitive with 4Mb DRAMs is severely limited by the reconstructed cost-based pricing dictated by a host of fair-pricing initiatives in Europe and the United States.

Wide DRAMs

The market development and opportunity for ×8, ×9, ×16, and ×18 also holds some substantial uncertainties, as applications using only a few megabytes of DRAMs can draw from monolithic DRAMs, SIMMs, PS RAMs, and, soon, self-refreshed 4Mb and 16Mb DRAMs. There are many tough market calls, and an equal number of opportunities. For 1991, fewer than 2 percent of 1Mb DRAMs were organizations other than ×1 or ×4; for 4Mb DRAMs, only about 4 percent were wide DRAMs. This fraction promises to grow substantially for 4Mb, but we will likely have to wait until the 16Mb ramps to see a significant fraction of the market in wide organizations.

During the year, 64K×16 DRAMs were available from several suppliers, though most DRAM suppliers seemed content to wait for the 4Mb market to enter. Users seem eager to get the wide parts as soon as the ×1 and ×4 appear, but have been disappointed by wide price disparities and narrow supplier bases.

VRAMs

The much-maligned video RAM (VRAM) business appears to be not so bad after all. An estimated 16 percent of the 256Ks shipped in 1991 were VRAMs, and 6 percent of the 1Mb DRAMs were actually VRAMs. Considering the fact that VRAMs didn't enter the market until about two years after their standard part cousins, this is not really that bad. As of year-end 1991, only samples of 2Mb and 4Mb VRAMs were available, indicating that both the designs and use were still lagging. Standards remain a problem.

Foundries

Foundry arrangements gained in importance in DRAMs, as Hitachi and Goldstar teamed up (in addition to the long-standing relationship between Hyundai and Texas Instruments). For its own part, TI had continued difficulty bringing up its large production capacity increments into high volume with costs that allowed it to be profitable. It concluded its 1991 year with yet another losing quarter, its sixth in a row.

Other arrangements contributing to total DRAM output for 1991 included Intel buying OEM DRAMs from Samsung and the five-year-old Motorola/Toshiba joint venture for 1Mb and

4Mb DRAMs. Many suppliers are engaged in collaborative alliances at the 16Mb and 64Mb level, and we expect the exorbitant cost of technology development to drive more DRAM makers into each other's arms as time passes.

Foreign Facilities

At year-end, NEC's Roseville, California, 4Mb line joined at least eight other DRAM production sites located outside the home base of the parent company. NEC also produces in Livingston, Scotland. As 1992 opened, TI was producing at its facility in Avezzano, Italy; at its fab in Miho, Japan; and at the joint venture with Acer in Taiwan. Fujitsu has begun prototyping at its facility in Gresham, Oregon, as well as in Newton-Aycliffe, Scotland. Motorola is in production at its plant in East Kilbride in the United Kingdom and at the joint venture with Toshiba in Tohoku, Japan, in the Sendai prefecture. Hitachi, Mitsubishi, and Oki all do some DRAM assembly and test at their foreign facilities, as well. The global diffusion of leading-edge manufacturing continues apace, perhaps not as fast as was envisioned in 1989 and 1990, but steadily nonetheless.

Dataquest Perspective

The coming year promises to be even more exciting. Though demand is lackluster at present, there also is no gaping excess of production capacity. Many issues regarding the market development for differentiated products remain undecided as to market mix, timing, and even standards. Already we have seen some low-voltage parts enter the market, but there is no clear direction as to whether 5V will be converted to 3V on-chip, or will be 3V only. By the time the 16Mb ramps into its own in 1994 or 1995, these are likely to be settled. But not for today.

We may also see the unfolding of IBM's semiconductor strategy in 1992, which is certain to impact the merchant DRAM market. So far, we have seen small quantities sold to Hyundai from IBM Japan, but no decision one way or the other as to the final strategy. IBM President Jack Kuehler indicated in recent *EETimes* and *EBN* articles that IBM's production capabilities will be aimed squarely at the IBM internal systems market, and will thus remain captive. This disclaimer notwithstanding, we believe that IBM will be a major uncertain element in the equation of DRAM supply and demand for the coming years.

16Mb DRAM Future in 1992

At year-end 1991, there was increased talk about the imminent arrival of the 16Mb DRAM. Several companies just now bringing up their 0.5- to 0.6-micron 16Mb fabs gave production schedules running up to a few hundred thousand units per month by summer 1992. Here we will have a dilemma, for a number of reasons. First, the cost structure of the 16Mb is richer still than the 4Mb and promises to retard the rate at which the costs can be reduced into proximity of the 4Mb generation. Second, the user community, which has shifted more toward cost-sensitive PC and consumer applications and away from mainframes, will support early PPB premiums less than in earlier generations. Third, trade relations between the United States and Japan will force something like fully loaded market pricing for 16Mb DRAMs, making it tough for suppliers to get close enough to 4Mb pricing to ramp 16Mb very much until true costs, via yield improvements, are achieved and fixed charges for process and facility are behind them.

For the time being, Rev II and Rev III of the 4Mb DRAMs will take up most of the wafers started on the most advanced lines of the DRAM leaders. After all, 1992 will actually be the first year that the 4Mb products have had the field to themselves, as 1Mb has finally been pushed into the postmaturity status—still substantial business, but no new design wins, and continued production decline that began early in 1991. In our opinion, talk of 16Mb DRAMs ramping in a big way in 1992 is very premature.

Quo Vadis

Overhanging the entire DRAM marketplace, and by implication the semiconductor industry, are a host of return-on-investment and accounting questions. Though cost accounting comprises a rather clear discipline in other industries, there is considerable value spillover, long-term investment accounting, and assignment of accrued costs that make determining actual costs of DRAM production difficult to determine. With the Semiconductor Trade

Agreement (STA) of 1986 and the requirement that companies maintain similar cost-accounting data internally for the STA2 pressing on one side, and the stratospheric costs of process development and facility expansion to produce products of uncertain payback, the DRAM industry has become conservative and careful in its willingness to proceed apace. Since the DRAM shortage cracked apart in the fall of 1989, the market has exhibited a remarkable balance of supply and demand for more than two years. Price declines have been significant since that time, steady and measured—not the roller coaster we saw in 1985-1986 or 1981-1982. The stakes are so large and the investment requirements so great that they are no longer ignorable by parent companies. Caution prevails in investment, production, and pricing.

By Lane Mason

SRAM Suppliers Must Run Faster or Fall Behind

The 1991 SRAM market underwent some changes, in part due to serious price erosion—especially at the high end of the speed range. Preliminary 1991 data report a paltry 6 percent revenue growth, in spite of a healthy unit shipment growth of 16 percent. Three companies introduced 4Mb monolithic SRAMs, although the 1Mb part continued on its 1990 path of slow growth.

Despite all of this activity, the names on the list of top 10 vendors did not change (see Table 1).

Changes in rank included Fujitsu and Toshiba exchanging their second-place and third-place positions. The rankings of the two companies in question were within a very small percentage of each other; when the final numbers are confirmed by Dataquest, these ranking changes may reverse themselves.

By region, Japanese companies produced 70.2 percent of all SRAM dollar sales followed by North American companies at 19.3 percent, Asia/Pacific at 7.3 percent, and European suppliers at 3.1 percent. Figure 1 illustrates how these percentages are broken down into speed categories using a new method of data collection initiated by Dataquest this year. Rather than splitting fast and slow parts by a 70ns delineator as done previously, data are now collected in six speed bins: pseudostatic, slow, 70ns to 45ns, 35ns to 20ns, 15ns to 10ns, and 8ns and faster. (Figure 1 does not show 8ns data.) We expect this method to be useful in predicting market speed trends in a means more usable to our clients. This method will be used in all future versions of Dataquest's SRAM forecast and in certain forms of analysis.

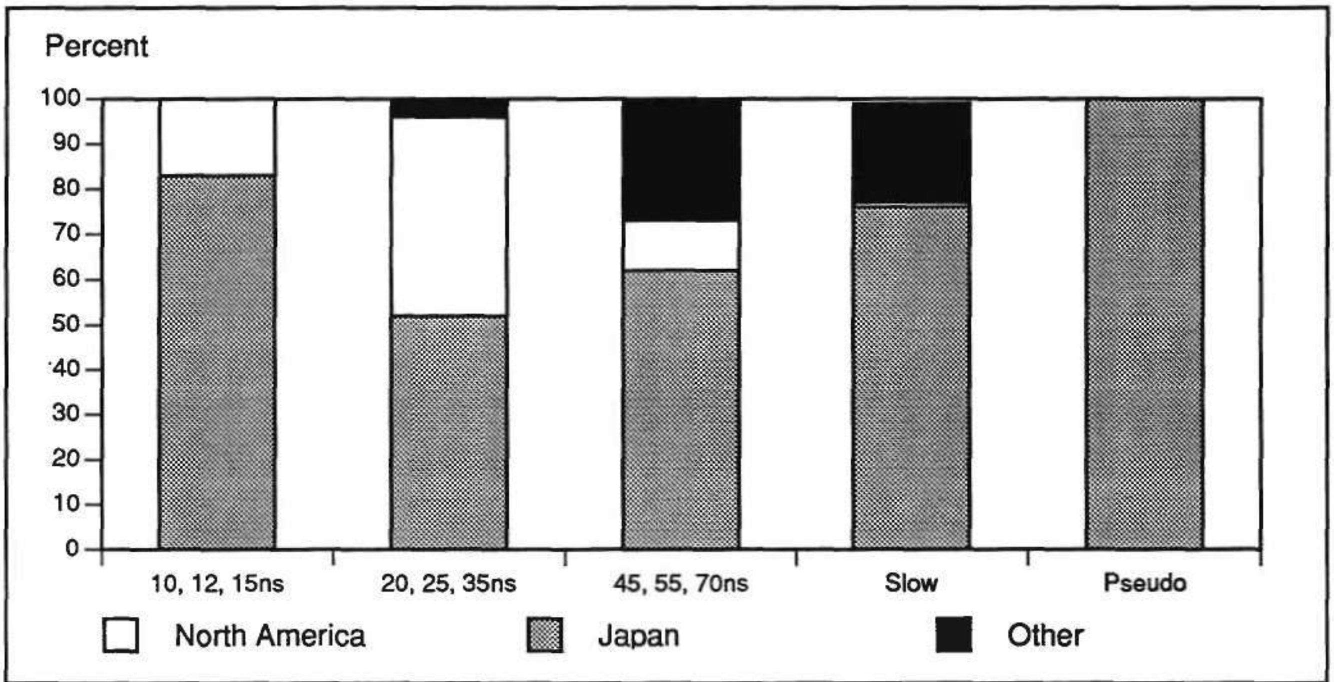
Figure 1 shows that North American suppliers focus their efforts more on high-speed SRAMs,

Table 1
Top 10 SRAM Vendors (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue (U.S.$M)	1991 Revenue (U.S.$M)	1991 Market Share(%)
1	1	Hitachi	427	484	17.9
2	3	Fujitsu	238	271	10.0
3	2	Toshiba	251	269	9.9
4	4	NEC	224	253	9.3
5	6	Sony	195	201	7.4
6	5	Mitsubishi	196	186	6.9
7	7	Cypress	124	123	4.5
8	8	Motorola	99	122	4.5
9	9	Sharp	92	117	4.3
10	10	Samsung	91	103	3.8

Source: Dataquest (March 1992)

Figure 1
SRAM Sales, by Speed



Source: Dataquest (March 1992)

while European and Asia/Pacific vendors focus on slower-speed devices. Japanese semiconductor vendors approach the entire market more evenly despite speed grade, and the pseudostatic market is owned by a handful of Japanese companies. This arrangement is in keeping with the strategies chosen by the vendors in each of these regions. North American SRAM vendors attempt to improve their profitability by spending their efforts on fast devices. The market for these devices may be smaller, but their high average selling prices (ASPs) allow for increased margins. Asia/Pacific SRAM vendors are looking to a neglected part of the market—slow SRAMs, with margins that are slim—in order to gain market share through manufacturing prowess. Vendors in Japan are using a "cover the market" strategy to continue to dominate.

Shifting to a device focus, unit sales growth by organization continued to follow the trends established by the end of 1990. The 256K density led unit sales of slow SRAMs. In fast SRAMs, sales of the 256K density still followed unit sales of the 64K density but crossed over the unit sales figure for fast 16K SRAMs.

Dataquest Perspective

Although overall SRAM unit sales grew by 16 percent, dollar sales grew by only 4 percent, indicating an overall ASP drop of more than 10 percent. The products that were hardest hit were fast SRAMs, which have seen ASPs drop by as much as 70 percent over the past four quarters, bringing their prices down almost to the level of their slower counterparts. Despite this severe price erosion, most high-speed SRAM vendors were not ruined, possibly because they ramped up unit shipments and focused on improving the speed of existing products.

Overall, 1991 was a year fraught with difficulties in the SRAM market, but solid efforts to increase unit shipments and continued pursuit of sales of denser and faster SRAMs have paid off by saving companies from a destructive downward pricing spiral. All manufacturers that left the market appear to have been replaced by start-ups and new entrants, and growth is continuing for fabless SRAM vendors as well as for resellers of products manufactured by outside companies.

By Jim Handy

Nonvolatile Memories: A Year of Bullish Flash Growth

Worldwide revenue for nonvolatile memories increased by 11.8 percent in 1991. Shipments were 1.1 billion, up 16.2 percent from 0.95 billion in 1990. Table 1 presents the ranking for the top 10 companies based on preliminary revenue estimates for 1991.

The company rankings for the top 10 nonvolatile memory suppliers show very little change. Hitachi and Toshiba exchanged places in 1991, according to the preliminary revenue market estimates. However, the figures for those two companies are very close. Flash, EPROM, OTP, EEPROM, ROM, and NV-RAM make up the field of nonvolatile memories.

Flash

Unit shipments of flash memories grew 446 percent, from 2.8 million units to 15.4 million units. Intel remained the leading supplier, with an 85.0 percent unit shipment market share. It should be noted that a total of 10 companies, listed in Table 2, were shipping product in 1991.

EPROM

The EPROM category includes OTP memories. In 1991, EPROM unit shipments grew by a meager 0.3 percent over 1990 as the EPROM market experienced significant pricing pressures. Signetics withdrew from this market, and Advanced Micro Devices (AMD) maintained its No. 1 position (see Table 3).

Table 1
1991 Preliminary Estimated Market Share Ranking:
Worldwide Nonvolatile Memories (Millions of Dollars)

1991 Rank	1990 Rank	Company	1991 Revenue	1990 Revenue	Percent Change	1991 Market Share
1	1	Sharp	357	322	10.9	10.8
2	2	Intel	311	268	16.0	9.4
3	3	NEC	310	253	22.5	9.4
4	5	Hitachi	253	212	19.3	7.7
5	4	Toshiba	251	248	1.2	7.6
6	6	AMD	239	209	14.3	7.3
7	7	SGS-Thomson	201	198	1.5	6.1
8	8	Fujitsu	171	156	9.6	5.2
9	9	TI	167	155	7.8	5.0
10	10	National	110	120	-8.3	3.3
		North American Companies	1,213	1,095	10.8	36.8
		Japanese Companies	1,571	1,446	8.6	47.7
		European Companies	274	290	-5.5	8.3
		Asia/Pacific Companies	238	118	101.7	7.2
		Total Market	3,296	2,949	11.8	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 2
1991 Worldwide Preliminary Flash Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	Intel	13,137	2,413	444.4	85.0
2		AMD	1,115	0	NM	7.2
3	2	Toshiba	415	280	48.2	2.7
4	3	Atmel	351	72	387.5	2.3
5		SGS	203	0	NM	1.3
6	5	Seeq	100	29	244.8	0.6
7		Hitachi	65	0	NM	0.4
8		Mitsubishi	30	0	NM	0.2
9	4	TI	22	34	-35.3	0.1
10		Catalyst	5	0	NM	0.1
		Total	15,443	2,828	446.0	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

Table 3
1991 Worldwide Preliminary EPROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	AMD	71,089	62,658	13.4	16.7
2	3	TI	64,057	58,331	9.9	15.0
3	4	SGS	60,180	57,347	5.0	14.1
4	2	Intel	1,595	9,379	-13.15	12.1
5	5	National	7,145	38,976	-4.7	8.7
6	9	Mitsubishi	22,715	18,036	26.0	5.3
7	7	Signetics	21,502	24,198	-11.1	5.0
8	8	Microchip	19,130	23,220	-17.6	4.5
9	6	Fujitsu	17,790	27,270	-34.7	4.2
10	10	Toshiba	12,250	12,910	-5.1	2.9
11	11	Hitachi	11,770	11,200	5.1	2.8
12	14	Atmel	9,698	5,089	90.6	2.3
13	12	NEC	7,480	9,055	-17.4	1.8
14	13	WaferScale	7,459	5,129	45.4	1.8
15	16	Cypress	3,757	2,609	44.0	0.9
16	17	Sharp	2,605	2,175	19.8	0.6
17	15	Oki	2,075	2,873	-27.8	0.5
18	18	Sony	1,400	1,200	16.7	0.4
19	19	Catalyst	1,308	1,116	17.2	0.3
20	20	Seiko-Epson	220	800	-72.5	0.1
		Total	425,225	423,992	0.3	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 4
1991 Worldwide Preliminary EEPROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	3	SGS	25,800	16,500	56.4	13.9
2	9	Catalyst	25,437	3,921	548.7	13.8
3	2	Xicor	24,502	19,471	25.8	13.3
4	1	National	19,097	20,970	-8.9	10.3
5	4	Oki	16,935	14,625	15.8	9.1
6	12	Hyundai	15,000	3,000	400	8.1
7	7	Microchip	14,649	7,920	84.9	7.9
8	5	Mitsubishi	14,280	14,012	1.9	7.7
9	10	Hitachi	5,350	3,375	58.5	2.9
10	8	Rohm	4,700	5,650	-16.8	2.5
11	6	ICT	4,120	8,300	-50.3	2.2
12	13	Atmel	3,743	2,539	47.4	2.0
13	11	SEEQ	2,728	3,200	-14.7	1.5
14	18	Fujitsu	2,402	240	900.8	1.3
15	19	Samsung	2,132	188	1,034.0	1.1
16	14	Siemens	1,394	1,500	-7.1	0.7
17	15	NEC	670	540	24.1	0.4
18	16	Philips	655	385	70.1	0.3
19	17	Sony	540	380	42.1	0.3
20	20	AMD	344	0	NM	0.2
		Others	316	348	-9.2	0.2
		Total	184,793	127,064	45.4	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

EEPROM

Unit shipments for EEPROMs grew 45.4 percent in 1991. This growth was fueled by the ever-increasing demand for low-density/low-ASP (average selling price) serial EEPROM devices used in consumer electronic products. The EEPROM category includes NV-RAM shipments. Table 4 lists the preliminary ranking of companies in the EEPROM market.

ROM

ROM unit shipments grew by 20.7 percent in 1991 from 399 million to 482 million units. The ROM market growth can be attributed in part to strong demand for electronic games and some migration from EPROM/OTP to ROM (cost reduction) for consumer products. Another area for growth was font cartridges for laser printers (see Table 5).

Table 5
1991 Worldwide Preliminary ROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	Sharp	146,151	132,150	10.6	30.3
2	2	NEC	62,180	67,542	-7.9	12.9
3	4	Fujitsu	43,260	33,445	29.3	9.0
4	5	Ricoh	41,232	30,300	36.1	8.6
5	3	Toshiba	39,740	35,990	10.4	8.3
6	6	Hitachi	27,820	22,680	22.7	5.8
7		Samsung	27,705	0	NM	5.7
8	9	Windbond	17,806	11,600	53.5	3.7
9	7	Matsushita	16,575	20,160	-17.8	3.4
10	10	Sony	14,850	11,050	34.4	3.1
11	11	Macronix	7,972	452	1,663.7	1.6
12	13	Atmel	3,743	2,539	47.4	2.0
13	11	Gould	6,978	7,580	-7.9	1.4
14	13	Mitsubishi	5,300	2,950	79.7	1.1
15	12	IMP	3,492	3,450	1.2	0.7
16		Goldstar	3,105	0	NM	0.6
17	15	Oki	1,736	1,560	11.3	0.4
18	14	Seiko-Epson	1,180	1,200	-1.7	0.2
19	16	NCR	584	1,047	-44.2	0.1
		Total	481,851	399,303	20.7	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

Dataquest Perspective

Overall, nonvolatile memories grew at a rate twice that of DRAMs and almost three times that of SRAMs. EPROM shipments were flat, and the average selling prices suffered. Dataquest believes that the lack of growth in the EPROM market resulted from the declining automotive market and the weak data processing (PC) segment. In a recessional environment where cost cutting became necessary for survival of companies and products, EPROM/OTP was often replaced by ROM. On the other hand, EEPROM unit shipments grew as more and more consumer electronic products (TVs, VCRs, camcorders, cameras) began using serial EEPROMs. Flash was a "hot" market in 1991 and certainly lived up to expectations for substantial growth. Flash devices are now beginning to replace EPROM/OTP devices and at times ROM devices in applications that benefit from flash's flexibility.

By Nicolas Samaras

For More Information . . .

On the topics in this issue .... Lane Mason, Director	(408) 437-8120
About online access	(408) 437-8576
About upcoming Dataquest conferences	(408) 437-8245
About your subscription or other Dataquest publications	(408) 437-8285
Via fax request	(408) 437-0292

Dataquest Perspective

Memories *Worldwide*

MMRY-SEG-DP-9201 March 30, 1992

In This Issue...

Market Analysis

Preliminary 1991 Worldwide MOS Memory Market Share Estimates

Dataquest has completed its preliminary 1991 MOS memory market share survey. We mailed a survey questionnaire to more than 150 semiconductor vendors in early November. The respondents provided us with detailed breakouts of their revenue and unit shipments based on a combination of year-to-date data and company-generated forecasts for the rest of the year. The collected results are published in this article. We will continue to refine and update the data, and we plan to release our final market share data documents on May 31, 1992.

Market Share Highlights

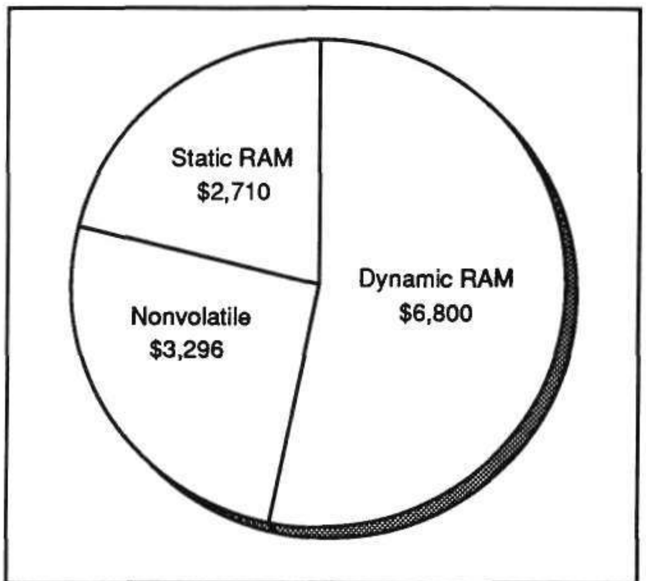
The following analysis covers the three areas of MOS memory tracked by Dataquest: DRAMs, SRAMs, and nonvolatile memories (EPROMs, EEPROMs, ROMs, and Flash memories).

MOS memory grew in 1991 at a relatively moderate 6 percent, in contrast to 1990's disastrous 17 percent decline. Observed in this light, however, MOS memory has made a rather impressive recovery, especially considering the fact that the 4Mb DRAM has not taken off as quickly as some had hoped. Toshiba returned its No. 1 ranking for all MOS memories, shipping more than $1.44 billion. In 1991, Toshiba was followed in order by Hitachi, NEC, Fujitsu, and Samsung.

Highlights of the 1991 MOS memory market include the following:

- Overall dollar growth in DRAMs was 5.0 percent; in SRAMs, 5.0 percent; and in nonvolatile memories, 11.7 percent.

Figure 1
1991 Estimated Worldwide Memory Sales, by Type
(Millions of Dollars)



Source: Dataquest (March 1992)

- Rapid price erosion decreased the growth of SRAM sales significantly.
- Micron Technology became a top-10 player in the DRAM market, at No. 8.
- Rankings of the top 10 SRAM and nonvolatile memory manufacturers remained nearly unchanged.
- Flash memories underwent the most dramatic change, increasing unit shipments by 491 percent.
- Japanese vendors took 60.6 percent of the DRAM market and 71.5 percent of the SRAM market. Japanese market share of nonvolatile memories was far lower at 47.7 percent.

The pie chart in Figure 1 shows the relationship in dollar sales between the DRAM, SRAM, and nonvolatile memory market segments.

By Lane Mason
Jim Handy
Nicolas Samaras

A Year of Transition for DRAMs

The year 1991 was in many ways transitional for DRAMs. Aside from the triennial move from generation to generation, we began to see the long-anticipated emergence of wide DRAMs at the 4Mb level, continued market share gains by Korean manufacturers over the still-dominant Japanese suppliers, and, with the 4Mb ramp-up, the first real impact of the new economics of DRAM production that promise to raise ultimate floor prices from generation to generation in degrees never seen before.

Prices per bit for 4Mb DRAMs crossed over those of 1Mb parts about midyear, and by year-end, 4Mb DRAMs were generating greater revenue and shipping more bits per quarter.

For the most part, the initial 350-mil 4Mb DRAM was replaced by the historical standard 300-mil package and DRAM speeds inched downward. The majority of products are now available at 70ns to 80ns. The market for very-high-speed optimized designs was found wanting, as MPU speeds made cache systems unavoidable.

By year-end, low pricing in the 1Mb market had encouraged several manufacturers to ramp down production and concentrate entirely on the 4Mb and 16Mb devices.

1991 Market Share Movement

Table 1 shows suppliers' 1991 DRAM revenue. Despite an estimated 31 percent price-per-bit (PPB) erosion, the DRAM market managed revenue growth of about 5 percent for the year. Japanese companies, led by No. 1 Toshiba with an estimated $904 million in sales, took 6 of the top 10 places in 1991 DRAM production. No. 2 Samsung was the top 1Mb shipper. Micron Technology, coming off a difficult transition to 1Mb in 1990 that impacted 1990 revenue, showed the top growth rate among the top 10 and had sales estimated at $362 million in 1991. Despite continuing trouble with its 4Mb at several facilities, Texas Instruments was the No. 6 producer, although it dropped about 1 percent in sales to $571 million.

As a portent of things to come, Goldstar and Hyundai each grew shipments more than 140 percent, but remained out of sight of the top 10, for 1991 at least. Overall, Korean

Table 1
1991 DRAM Revenue (Millions of Dollars)

Company	1990 Sales	1991 Sales	Change (%)
Toshiba	947	904	-4.5
Samsung	809	900	11.2
NEC	669	698	4.3
Hitachi	597	675	13.1
Texas Instruments	576	571	-0.9
Fujitsu	497	484	-2.6
Mitsubishi	503	467	-7.2
Micron Technology	294	362	23.1
Oki Semiconductor	293	319	8.9
Siemens	306	287	-6.0
Motorola	292	264	-10.0
Goldstar	75	204	172.0
Hyundai	75	186	148.0
Matsushita	131	116	-11.5
NMB Semiconductor	171	116	-32.2
Vitelic	58	79	36.0
Sharp	72	62	-13.9
Others	110	106	-3.6
Total	6,475	6,800	5.0

Source: Dataquest (March 1992)

companies garnered virtually all of the aggregate DRAM market growth, largely at the expense of the more established Japanese suppliers.

Goldstar and Hyundai have become significant enough players to threaten low-end pricing, and in 1991 became bona fide suppliers of 4Mb DRAMs. Samsung cemented its position as a leading contender for the DRAM crown, shipping 4Mb DRAMs at a rate within striking distance of market leader Hitachi. Samsung's 16Mb parts are said to be on a par with the best in the industry—no price discounts anymore! Samsung will be interesting to watch in 1992 as it challenges for the DRAM lead, as will Hyundai and Goldstar as they upgrade both their products and customer base.

One important advantage that newcomers to the DRAM market have in 1992 and beyond is the changing channels to end users. A growing fraction of the DRAM business is upgrades for PCs bought at mom-and-pop outlets: Blue-chip accounts, with exacting system requirements and lengthy, expensive qualifications, make up a steadily declining share of DRAM demand. Add-on memory is an attractive outlet for the price competitive new kids on the block—Goldstar, Hyundai, and any other late arrivals to the 4Mb race—who want to keep their fabs full and learn the business.

Packaging Trends

The 1Mb generation was the last hurrah for the dual in-line package (DIP), as its share of the business migrated rapidly to SOJ and, it appears, soon to TSOP. DIPs were about 22 percent of 1Mb DRAM unit shipments in 1991, compared with about 4 percent of the 4Mb shipments. ZIPs held steady at about 15 percent of the 4Mb generation. So, after five generations of DRAMs that went into the DIP, we have gone through two major packaging turnovers in just the past two generations, with the last yet to fully express itself in the market.

The single in-line memory module (SIMM) market constituted an estimated 40 percent of DRAM sales at year-end, but was difficult to size because of the prevalence of aftermarket SIMM packagers. During the year, the SIMM issue was further muddied by the Wang lawsuits, which draw a low royalty wall around 30-pin ×9 SIMMs. Manufacturers are watching to see which way the winds blow, pushing the demand over to ×36 modules, while begrudgingly paying the 3 to 4 percent royalty to Wang. As a significant fraction of the DRAMs in SIMMs fill in the upgrade memory needs of the PC and workstation installed base, it looks as though ×9 will continue in a major way for 1992. In addition, there appears to be no rush in newer PCs to design expansion slots to accommodate ×36 modules, though some are doing so.

Pricing

Pricing for all DRAM densities continued through 1991 in an uninterrupted decline. There were no significant "spot" shortages in packages, speed grades, or operating modes. Year-end pricing for 1Mb DRAMs was often below $4, with a bottom of about $3.50 for mainstream parts. This was somewhat lower than many had expected 1Mb bottom prices to be when cost-of-production forecasts were made during the 1988 to 1989 shortage.

Prices for 4Mb DRAMs marched down from about $21 in early 1991 to a fourth-quarter average of about $14, with low-end pricing near $13.50. Off-standard parts, remnants of the 350-mil package inventory, and slow speed grades went for as low as $11.50. Steady pricing erosion continues into 1992.

For the few hundred thousand of the 16Mb DRAMs shipped in 1992, prices began the year at about $300 per unit but declined to about $210 at year end. A few orders were placed during 1991 for volumes ranging from 10,000 to 20,000 pieces to be fulfilled early in 1992. Even at $200, the price-per-bit premium is still about 4× compared with 4Mb devices. The rate at which 16Mb can come down and be cost competitive with 4Mb DRAMs is severely limited by the reconstructed cost-based pricing dictated by a host of fair-pricing initiatives in Europe and the United States.

Wide DRAMs

The market development and opportunity for ×8, ×9, ×16, and ×18 also holds some substantial uncertainties, as applications using only a few megabytes of DRAMs can draw from monolithic DRAMs, SIMMs, PS RAMs, and, soon, self-refreshed 4Mb and 16Mb DRAMs. There are many tough market calls, and an equal number of opportunities. For 1991, fewer than 2 percent of 1Mb DRAMs were organizations other than ×1 or ×4; for 4Mb DRAMs, only about 4 percent were wide DRAMs. This fraction promises to grow substantially for 4Mb, but we will likely have to wait until the 16Mb ramps to see a significant fraction of the market in wide organizations.

During the year, 64K×16 DRAMs were available from several suppliers, though most DRAM suppliers seemed content to wait for the 4Mb market to enter. Users seem eager to get the wide parts as soon as the ×1 and ×4 appear, but have been disappointed by wide price disparities and narrow supplier bases.

VRAMs

The much-maligned video RAM (VRAM) business appears to be not so bad after all. An estimated 16 percent of the 256Ks shipped in 1991 were VRAMs, and 6 percent of the 1Mb DRAMs were actually VRAMs. Considering the fact that VRAMs didn't enter the market until about two years after their standard part cousins, this is not really that bad. As of year-end 1991, only samples of 2Mb and 4Mb VRAMs were available, indicating that both the designs and use were still lagging. Standards remain a problem.

Foundries

Foundry arrangements gained in importance in DRAMs, as Hitachi and Goldstar teamed up (in addition to the long-standing relationship between Hyundai and Texas Instruments). For its own part, TI had continued difficulty bringing up its large production capacity increments into high volume with costs that allowed it to be profitable. It concluded its 1991 year with yet another losing quarter, its sixth in a row.

Other arrangements contributing to total DRAM output for 1991 included Intel buying OEM DRAMs from Samsung and the five-year-old Motorola/Toshiba joint venture for 1Mb and

4Mb DRAMs. Many suppliers are engaged in collaborative alliances at the 16Mb and 64Mb level, and we expect the exorbitant cost of technology development to drive more DRAM makers into each other's arms as time passes.

Foreign Facilities

At year-end, NEC's Roseville, California, 4Mb line joined at least eight other DRAM production sites located outside the home base of the parent company. NEC also produces in Livingston, Scotland. As 1992 opened, TI was producing at its facility in Avezzano, Italy; at its fab in Miho, Japan; and at the joint venture with Acer in Taiwan. Fujitsu has begun prototyping at its facility in Gresham, Oregon, as well as in Newton-Aycliffe, Scotland. Motorola is in production at its plant in East Kilbride in the United Kingdom and at the joint venture with Toshiba in Tohoku, Japan, in the Sendai prefecture. Hitachi, Mitsubishi, and Oki all do some DRAM assembly and test at their foreign facilities, as well. The global diffusion of leading-edge manufacturing continues apace, perhaps not as fast as was envisioned in 1989 and 1990, but steadily nonetheless.

Dataquest Perspective

The coming year promises to be even more exciting. Though demand is lackluster at present, there also is no gaping excess of production capacity. Many issues regarding the market development for differentiated products remain undecided as to market mix, timing, and even standards. Already we have seen some low-voltage parts enter the market, but there is no clear direction as to whether 5V will be converted to 3V on-chip, or will be 3V only. By the time the 16Mb ramps into its own in 1994 or 1995, these are likely to be settled. But not for today.

We may also see the unfolding of IBM's semiconductor strategy in 1992, which is certain to impact the merchant DRAM market. So far, we have seen small quantities sold to Hyundai from IBM Japan, but no decision one way or the other as to the final strategy. IBM President Jack Kuehler indicated in recent *EETimes* and *EBN* articles that IBM's production capabilities will be aimed squarely at the IBM internal systems market, and will thus remain captive. This disclaimer notwithstanding, we believe that IBM will be a major uncertain element in the equation of DRAM supply and demand for the coming years.

16Mb DRAM Future in 1992

At year-end 1991, there was increased talk about the imminent arrival of the 16Mb DRAM. Several companies just now bringing up their 0.5- to 0.6-micron 16Mb fabs gave production schedules running up to a few hundred thousand units per month by summer 1992. Here we will have a dilemma, for a number of reasons. First, the cost structure of the 16Mb is richer still than the 4Mb and promises to retard the rate at which the costs can be reduced into proximity of the 4Mb generation. Second, the user community, which has shifted more toward cost-sensitive PC and consumer applications and away from mainframes, will support early PPB premiums less than in earlier generations. Third, trade relations between the United States and Japan will force something like fully loaded market pricing for 16Mb DRAMs, making it tough for suppliers to get close enough to 4Mb pricing to ramp 16Mb very much until true costs, via yield improvements, are achieved and fixed charges for process and facility are behind them.

For the time being, Rev II and Rev III of the 4Mb DRAMs will take up most of the wafers started on the most advanced lines of the DRAM leaders. After all, 1992 will actually be the first year that the 4Mb products have had the field to themselves, as 1Mb has finally been pushed into the postmaturity status—still substantial business, but no new design wins, and continued production decline that began early in 1991. In our opinion, talk of 16Mb DRAMs ramping in a big way in 1992 is very premature.

Quo Vadis

Overhanging the entire DRAM marketplace, and by implication the semiconductor industry, are a host of return-on-investment and accounting questions. Though cost accounting comprises a rather clear discipline in other industries, there is considerable value spillover, long-term investment accounting, and assignment of accrued costs that make determining actual costs of DRAM production difficult to determine. With the Semiconductor Trade

Agreement (STA) of 1986 and the requirement that companies maintain similar cost-accounting data internally for the STA2 pressing on one side, and the stratospheric costs of process development and facility expansion to produce products of uncertain payback, the DRAM industry has become conservative and careful in its willingness to proceed apace. Since the DRAM shortage cracked apart in the fall of 1989, the market has exhibited a remarkable balance of supply and demand for more than two years. Price declines have been significant since that time, steady and measured—not the roller coaster we saw in 1985-1986 or 1981-1982. The stakes are so large and the investment requirements so great that they are no longer ignorable by parent companies. Caution prevails in investment, production, and pricing.

By Lane Mason

SRAM Suppliers Must Run Faster or Fall Behind

The 1991 SRAM market underwent some changes, in part due to serious price erosion—especially at the high end of the speed range. Preliminary 1991 data report a paltry 6 percent revenue growth, in spite of a healthy unit shipment growth of 16 percent. Three companies introduced 4Mb monolithic SRAMs, although the 1Mb part continued on its 1990 path of slow growth.

Despite all of this activity, the names on the list of top 10 vendors did not change (see Table 1).

Changes in rank included Fujitsu and Toshiba exchanging their second-place and third-place positions. The rankings of the two companies in question were within a very small percentage of each other; when the final numbers are confirmed by Dataquest, these ranking changes may reverse themselves.

By region, Japanese companies produced 70.2 percent of all SRAM dollar sales followed by North American companies at 19.3 percent, Asia/Pacific at 7.3 percent, and European suppliers at 3.1 percent. Figure 1 illustrates how these percentages are broken down into speed categories using a new method of data collection initiated by Dataquest this year. Rather than splitting fast and slow parts by a 70ns delineator as done previously, data are now collected in six speed bins: pseudostatic, slow, 70ns to 45ns, 35ns to 20ns, 15ns to 10ns, and 8ns and faster. (Figure 1 does not show 8ns data.) We expect this method to be useful in predicting market speed trends in a means more usable to our clients. This method will be used in all future versions of Dataquest's SRAM forecast and in certain forms of analysis.

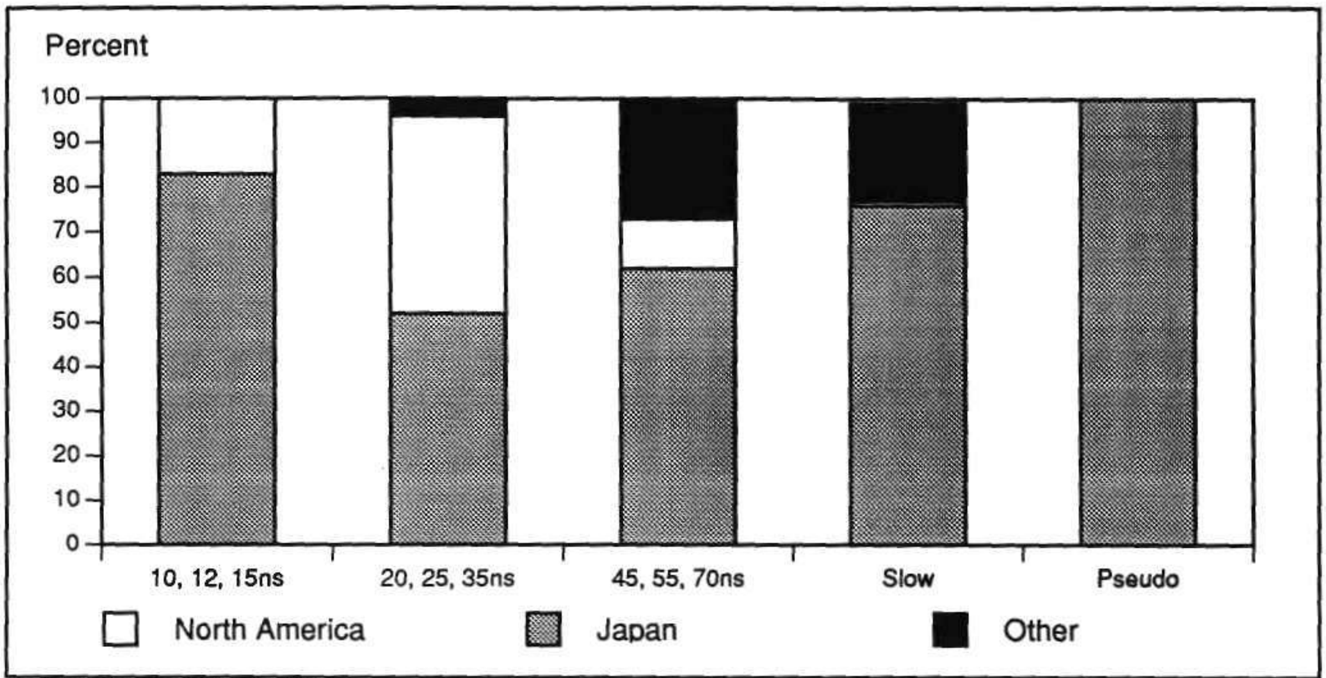
Figure 1 shows that North American suppliers focus their efforts more on high-speed SRAMs,

Table 1
Top 10 SRAM Vendors (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue (U.S.$M)	1991 Revenue (U.S.$M)	1991 Market Share(%)
1	1	Hitachi	427	484	17.9
2	3	Fujitsu	238	271	10.0
3	2	Toshiba	251	269	9.9
4	4	NEC	224	253	9.3
5	6	Sony	195	201	7.4
6	5	Mitsubishi	196	186	6.9
7	7	Cypress	124	123	4.5
8	8	Motorola	99	122	4.5
9	9	Sharp	92	117	4.3
10	10	Samsung	91	103	3.8

Source: Dataquest (March 1992)

Figure 1
SRAM Sales, by Speed



Source: Dataquest (March 1992)

while European and Asia/Pacific vendors focus on slower-speed devices. Japanese semiconductor vendors approach the entire market more evenly despite speed grade, and the pseudostatic market is owned by a handful of Japanese companies. This arrangement is in keeping with the strategies chosen by the vendors in each of these regions. North American SRAM vendors attempt to improve their profitability by spending their efforts on fast devices. The market for these devices may be smaller, but their high average selling prices (ASPs) allow for increased margins. Asia/Pacific SRAM vendors are looking to a neglected part of the market—slow SRAMs, with margins that are slim—in order to gain market share through manufacturing prowess. Vendors in Japan are using a "cover the market" strategy to continue to dominate.

Shifting to a device focus, unit sales growth by organization continued to follow the trends established by the end of 1990. The 256K density led unit sales of slow SRAMs. In fast SRAMs, sales of the 256K density still followed unit sales of the 64K density but crossed over the unit sales figure for fast 16K SRAMs.

Dataquest Perspective

Although overall SRAM unit sales grew by 16 percent, dollar sales grew by only 4 percent, indicating an overall ASP drop of more than 10 percent. The products that were hardest hit were fast SRAMs, which have seen ASPs drop by as much as 70 percent over the past four quarters, bringing their prices down almost to the level of their slower counterparts. Despite this severe price erosion, most high-speed SRAM vendors were not ruined, possibly because they ramped up unit shipments and focused on improving the speed of existing products.

Overall, 1991 was a year fraught with difficulties in the SRAM market, but solid efforts to increase unit shipments and continued pursuit of sales of denser and faster SRAMs have paid off by saving companies from a destructive downward pricing spiral. All manufacturers that left the market appear to have been replaced by startups and new entrants, and growth is continuing for fabless SRAM vendors as well as for resellers of products manufactured by outside companies.

By Jim Handy

Nonvolatile Memories: A Year of Bullish Flash Growth

Worldwide revenue for nonvolatile memories increased by 11.8 percent in 1991. Shipments were 1.1 billion, up 16.2 percent from 0.95 billion in 1990. Table 1 presents the ranking for the top 10 companies based on preliminary revenue estimates for 1991.

The company rankings for the top 10 nonvolatile memory suppliers show very little change. Hitachi and Toshiba exchanged places in 1991, according to the preliminary revenue market estimates. However, the figures for those two companies are very close. Flash, EPROM, OTP, EEPROM, ROM, and NV-RAM make up the field of nonvolatile memories.

Flash

Unit shipments of flash memories grew 446 percent, from 2.8 million units to 15.4 million units. Intel remained the leading supplier, with an 85.0 percent unit shipment market share. It should be noted that a total of 10 companies, listed in Table 2, were shipping product in 1991.

EPROM

The EPROM category includes OTP memories. In 1991, EPROM unit shipments grew by a meager 0.3 percent over 1990 as the EPROM market experienced significant pricing pressures. Signetics withdrew from this market, and Advanced Micro Devices (AMD) maintained its No. 1 position (see Table 3).

Table 1
1991 Preliminary Estimated Market Share Ranking:
Worldwide Nonvolatile Memories (Millions of Dollars)

1991 Rank	1990 Rank	Company	1991 Revenue	1990 Revenue	Percent Change	1991 Market Share
1	1	Sharp	357	322	10.9	10.8
2	2	Intel	311	268	16.0	9.4
3	3	NEC	310	253	22.5	9.4
4	5	Hitachi	253	212	19.3	7.7
5	4	Toshiba	251	248	1.2	7.6
6	6	AMD	239	209	14.3	7.3
7	7	SGS-Thomson	201	198	1.5	6.1
8	8	Fujitsu	171	156	9.6	5.2
9	9	TI	167	155	7.8	5.0
10	10	National	110	120	-8.3	3.3
		North American Companies	1,213	1,095	10.8	36.8
		Japanese Companies	1,571	1,446	8.6	47.7
		European Companies	274	290	-5.5	8.3
		Asia/Pacific Companies	238	118	101.7	7.2
		Total Market	3,296	2,949	11.8	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 2
1991 Worldwide Preliminary Flash Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	Intel	13,137	2,413	444.4	85.0
2		AMD	1,115	0	NM	7.2
3	2	Toshiba	415	280	48.2	2.7
4	3	Atmel	351	72	387.5	2.3
5		SGS	203	0	NM	1.3
6	5	Seeq	100	29	244.8	0.6
7		Hitachi	65	0	NM	0.4
8		Mitsubishi	30	0	NM	0.2
9	4	TI	22	34	-35.3	0.1
10		Catalyst	5	0	NM	0.1
		Total	15,443	2,828	446.0	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

Table 3
1991 Worldwide Preliminary EPROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	AMD	71,089	62,658	13.4	16.7
2	3	TI	64,057	58,331	9.9	15.0
3	4	SGS	60,180	57,347	5.0	14.1
4	2	Intel	1,595	9,379	-13.15	12.1
5	5	National	7,145	38,976	-4.7	8.7
6	9	Mitsubishi	22,715	18,036	26.0	5.3
7	7	Signetics	21,502	24,198	-11.1	5.0
8	8	Microchip	19,130	23,220	-17.6	4.5
9	6	Fujitsu	17,790	27,270	-34.7	4.2
10	10	Toshiba	12,250	12,910	-5.1	2.9
11	11	Hitachi	11,770	11,200	5.1	2.8
12	14	Atmel	9,698	5,089	90.6	2.3
13	12	NEC	7,480	9,055	-17.4	1.8
14	13	WaferScale	7,459	5,129	45.4	1.8
15	16	Cypress	3,757	2,609	44.0	0.9
16	17	Sharp	2,605	2,175	19.8	0.6
17	15	Oki	2,075	2,873	-27.8	0.5
18	18	Sony	1,400	1,200	16.7	0.4
19	19	Catalyst	1,308	1,116	17.2	0.3
20	20	Seiko-Epson	220	800	-72.5	0.1
		Total	425,225	423,992	0.3	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 4
1991 Worldwide Preliminary EEPROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	3	SGS	25,800	16,500	56.4	13.9
2	9	Catalyst	25,437	3,921	548.7	13.8
3	2	Xicor	24,502	19,471	25.8	13.3
4	1	National	19,097	20,970	-8.9	10.3
5	4	Oki	16,935	14,625	15.8	9.1
6	12	Hyundai	15,000	3,000	400	8.1
7	7	Microchip	14,649	7,920	84.9	7.9
8	5	Mitsubishi	14,280	14,012	1.9	7.7
9	10	Hitachi	5,350	3,375	58.5	2.9
10	8	Rohm	4,700	5,650	-16.8	2.5
11	6	ICT	4,120	8,300	-50.3	2.2
12	13	Atmel	3,743	2,539	47.4	2.0
13	11	SEEQ	2,728	3,200	-14.7	1.5
14	18	Fujitsu	2,402	240	900.8	1.3
15	19	Samsung	2,132	188	1,034.0	1.1
16	14	Siemens	1,394	1,500	-7.1	0.7
17	15	NEC	670	540	24.1	0.4
18	16	Philips	655	385	70.1	0.3
19	17	Sony	540	380	42.1	0.3
20	20	AMD	344	0	NM	0.2
		Others	316	348	-9.2	0.2
		Total	184,793	127,064	45.4	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

EEPROM

Unit shipments for EEPROMs grew 45.4 percent in 1991. This growth was fueled by the ever-increasing demand for low-density/low-ASP (average selling price) serial EEPROM devices used in consumer electronic products. The EEPROM category includes NV-RAM shipments. Table 4 lists the preliminary ranking of companies in the EEPROM market.

ROM

ROM unit shipments grew by 20.7 percent in 1991 from 399 million to 482 million units. The ROM market growth can be attributed in part to strong demand for electronic games and some migration from EPROM/OTP to ROM (cost reduction) for consumer products. Another area for growth was font cartridges for laser printers (see Table 5).

Table 5
1991 Worldwide Preliminary ROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	Sharp	146,151	132,150	10.6	30.3
2	2	NEC	62,180	67,542	-7.9	12.9
3	4	Fujitsu	43,260	33,445	29.3	9.0
4	5	Ricoh	41,232	30,300	36.1	8.6
5	3	Toshiba	39,740	35,990	10.4	8.3
6	6	Hitachi	27,820	22,680	22.7	5.8
7		Samsung	27,705	0	NM	5.7
8	9	Windbond	17,806	11,600	53.5	3.7
9	7	Matsushita	16,575	20,160	-17.8	3.4
10	10	Sony	14,850	11,050	34.4	3.1
11	11	Macronix	7,972	452	1,663.7	1.6
12	13	Atmel	3,743	2,539	47.4	2.0
13	11	Gould	6,978	7,580	-7.9	1.4
14	13	Mitsubishi	5,300	2,950	79.7	1.1
15	12	IMP	3,492	3,450	1.2	0.7
16		Goldstar	3,105	0	NM	0.6
17	15	Oki	1,736	1,560	11.3	0.4
18	14	Seiko-Epson	1,180	1,200	-1.7	0.2
19	16	NCR	584	1,047	-44.2	0.1
		Total	481,851	399,303	20.7	100.0

Note: Some columns do not add to totals shown because of rounding.
NM = Not meaningful
Source: Dataquest (March 1992)

Dataquest Perspective

Overall, nonvolatile memories grew at a rate twice that of DRAMs and almost three times that of SRAMs. EPROM shipments were flat, and the average selling prices suffered. Dataquest believes that the lack of growth in the EPROM market resulted from the declining automotive market and the weak data processing (PC) segment. In a recessional environment where cost cutting became necessary for survival of companies and products, EPROM/OTP was often replaced by ROM. On the other hand, EEPROM unit shipments grew as more and more consumer electronic products (TVs, VCRs, camcorders, cameras) began using serial EEPROMs. Flash was a "hot" market in 1991 and certainly lived up to expectations for substantial growth. Flash devices are now beginning to replace EPROM/OTP devices and at times ROM devices in applications that benefit from flash's flexibility.

By Nicolas Samaras

For More Information . . .

On the topics in this issue .... Lane Mason, Director (408) 437-8120
About online access .... (408) 437-8576
About upcoming Dataquest conferences .... (408) 437-8245
About your subscription or other Dataquest publications .... (408) 437-8285
Via fax request .... (408) 437-0292

Dataquest Perspective

FILE COPY
Do Not Remove

Memories *Worldwide*

March 30, 1992

Errata

In the article entitled "Nonvolatile Memories: A Year of Bullish Flash Growth" in Memories Worldwide *Dataquest Perspective* issue 9201, which was dated March 30, 1992, Table 3 had incorrect data. We apologize for any confusion this may have caused and reprint the table here with corrected data.

Table 3
1991 Worldwide Preliminary EPROM Ranking by Unit Shipments
(Thousands of Units)

1991 Rank	1990 Rank	Company	1991 Units	1990 Units	Percent Change	1991 Market Share (%)
1	1	AMD	71,089	62,658	13.4	16.7
2	3	TI	64,057	58,331	9.9	15.0
3	4	SGS	60,180	57,347	5.0	14.1
4	2	Intel	51,595	59,379	-13.15	12.1
5	5	National	37,145	38,976	-4.7	8.7
6	9	Mitsubishi	22,715	18,036	26.0	5.3
7	7	Signetics	21,502	24,198	-11.1	5.0
8	8	Microchip	19,130	23,220	-17.6	4.5
9	6	Fujitsu	17,790	27,270	-34.7	4.2
10	10	Toshiba	12,250	12,910	-5.1	2.9
11	11	Hitachi	11,770	11,200	5.1	2.8
12	14	Atmel	9,698	5,089	90.6	2.3
13	12	NEC	7,480	9,055	-17.4	1.8
14	13	WaferScale	7,459	5,129	45.4	1.8
15	16	Cypress	3,757	2,609	44.0	0.9
16	17	Sharp	2,605	2,175	19.8	0.6
17	15	Oki	2,075	2,873	-27.8	0.5
18	18	Sony	1,400	1,200	16.7	0.4
19	19	Catalyst	1,308	1,116	17.2	0.3
20	20	Seiko-Epson	220	800	-72.5	0.1
		Total	425,225	423,992	0.3	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

For More Information . . .

On the topics in this issue .... Lane Mason, Director (408) 437-8120
About online access .... (408) 437-8576
About upcoming Dataquest conferences .... (408) 437-8245
About your subscription or other Dataquest publications .... (408) 437-8285
Via fax request .... (408) 437-0292

Dataquest
a company of The Dun & Bradstreet Corporation

Dataquest Perspective

Memories
Worldwide

Vol. 1, No. 2 | **December 30, 1991**

Market Analysis

Market Analysis

Those Incredible FIFOs: A Summary of Today's FIFO Business

FIFO Background

First-in/first-out (FIFO) memory devices have existed in the electronics industry for more than 20 years. Strangely enough, the companies that were the first suppliers of FIFOs are not now the dominant FIFO suppliers.

As their name implies, FIFOs are data buffering devices that output data in the same order in which they were input to the device. FIFOs can be broken into two types: register-based and memory-based. The older register-based FIFOs have been around for over two decades and are available mainly in organizations such as 64x4 and 64x5. Memory-based FIFOs were introduced by SGS-Thomson Microelectronics (then called Mostek) in the early 1980s. Small memory-based FIFOs are usually in the range of 256x9 bits and are proposed (but not yet sampled) to become as large as 64Kx9. Today's most popular and most widely second-sourced FIFOs are the 720x series of memory-based FIFOs.

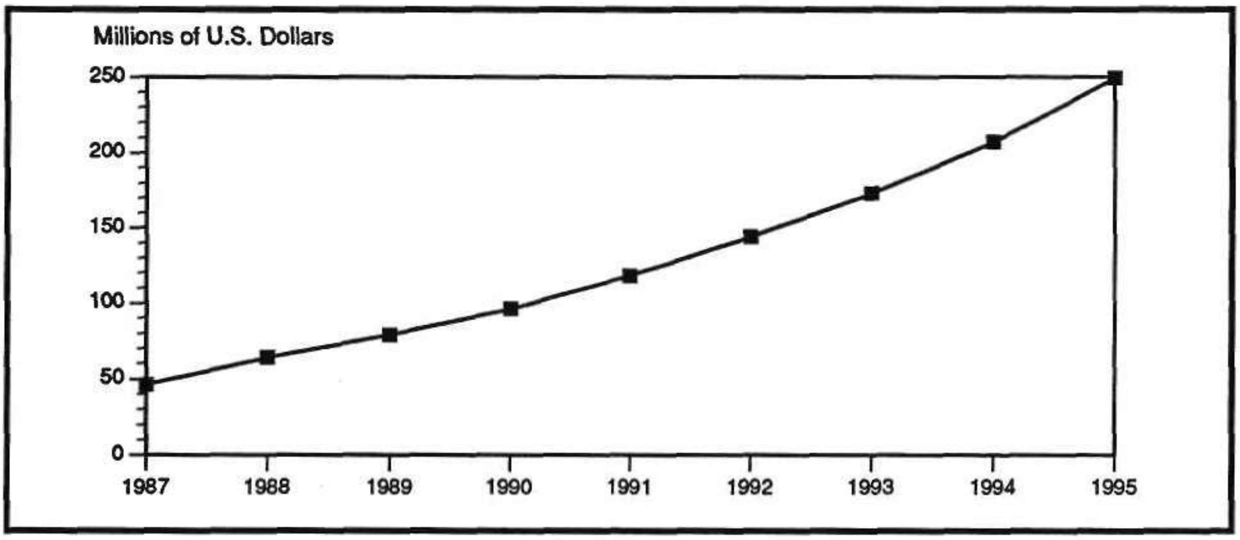
Multiple FIFOs can be used for either depth or width expansion, and modules are available to support multiple FIFOs. Only monolithic FIFOs will be discussed in this article.

The FIFO Market

The estimated worldwide 1991 FIFO market is between $110 million and $120 million and is not expected to increase significantly in 1992 because overall unit growth in the FIFO market is relatively small and ASPs are falling due to the high number of participants (see Figure 1). Despite its small size, 14 manufacturers share the market. Their standard and specialty FIFO offerings combine for 93 different organizations (see Tables 1, 2, and 3). As if this degree of fragmentation were not enough, it appears that other manufacturers are thinking of entering the market and that existing manufacturers are planning to introduce more sole-sourced configurations in an effort to improve ASPs by adding value.

As is true in any fragmented market, certain devices and certain manufacturers are well ahead of the rest. The three major FIFO manufacturers that now dominate the market

Figure 1
Worldwide FIFO Sales



Source: Dataquest (December 1991)

are Advanced Micro Devices Inc. (AMD), Cypress Semiconductor Corporation, and Integrated Device Technology Inc. (IDT). These three companies share about 85 percent of the entire market.

Two kinds of devices dominate: register-based 64×4 and 64×5 FIFOs, and memory-based 256×9 to 2K×9 organizations. Register-based FIFOs are waning in popularity. They are rarely being designed into new systems, not because their function is no longer required (more small FIFOs are being implemented in system designs than ever before) but instead because systems designers now find it more feasible to include the functions of the small FIFO directly onto an application-specific integrated circuit (ASIC) instead of using a separate component. FIFO vendors seem to agree that the dollar sales of the small FIFOs are decreasing, while dollar sales of medium-depth (256×9 to 2K×9) FIFOs are on the increase. Some believe that the crossover point in dollar sales between these two categories has been reached.

Specialty FIFOS are memory-based designs that lend themselves to a narrower set of applications by incorporating logic features such as serial-to-parallel and parallel-to-serial data stream conversion, bidirectionality, and bus matching. Specialty FIFOs are not a large enough segment of the overall FIFO market to warrant a separate analysis.

The FIFO sell is a design-in and not something that can be pursued at the buyer's desk. Suppliers with strong direct sales forces and field-application engineering teams tend to do better, both at getting FIFOs designed in and at winning designs for proprietary specialty FIFOs. Specialty FIFOs command higher average selling prices (ASPs) and can give a supplier a lever on the sales of other components in the system.

Since most systems use a small number of FIFOs, even high-ASP devices contribute a very small percentage of the overall system cost. Buyers tend to focus their negotiating efforts on the devices that contribute more strongly to the system cost and, as a result, are reticent to ask their engineers either to design-out a sole-sourced FIFO or to qualify an alternate vendor. Thus, the business in a particular design tends to stay with the company that achieved the design win. For this reason, companies with highly technical direct sales forces (for example, IDT, AMD, Cypress) tend to do better in the FIFO business than companies with sales forces consisting mainly of sales representatives and distribution, even though companies in the latter category may be able to offer strong price, delivery, and quality incentives.

A surprisingly large portion of today's FIFO market exists in the military. One vendor estimates that the military market accounts for about one-fourth of the entire FIFO market (in dollars), perhaps because of the large number of military applications for digital signal processing (DSP), such as sonar and radar.

FIFOs are used in very diverse applications. The function is found useful in interprocessor communication, often between a DSP chip and a controlling CPU, a combination used in end applications such as sonar and radar. In a similar vein, FIFOs are often used within custom-designed DSP processors as line buffers or similar delays, once again in radar and sonar processing; in local area networks (LANs) and other networks that are widely used in telecommunication; and in extremely high-performance graphics engines.

A more esoteric application is the FIFO's use in array processors such as those made by Floating Point Systems or Intel Scientific Computers. FIFOs fit into any high-speed application where a steady stream of data must be adapted in flow to the fits and jerks of a differently aligned system, or, conversely, if the fits and jerks must themselves be turned back into a steady flow. Such problems abound in LANs, bus interfaces, and laser printers. Except for the array processor application, most of these problems can be solved through the use of a single FIFO; so most systems use very few devices.

As a result, the FIFO has a very broad but shallow market. A typical sales order for FIFOs would amount to between $10,000 and $50,000, with orders rarely reaching the $100,000 level. Everybody uses them, but most designs use just one or two. Unlike in the microprocessors industry, there is tough competition and the barriers to entry are low; therefore the average selling prices (ASPs) are modest.

Figure 1 shows estimated FIFO dollar sales for the years 1987 through 1992. Dollar growth is slow because the number of manufacturers has increased as the overall market has softened, despite a significant increase in unit sales. ASPs have dropped significantly; a device that sold for $30 in 1988 now sells for $7. This difference implies that unit volume is increasing

Table 1
Standard FIFOs Cross Reference

Organi-zation	Output Enable	Flags	AMD	Cypress	Dallas	Hitachi	IDT	Logic Devices	Micron	Mosel	Quality	Samsung	SGS	Sharp	TI	UMC
Low-Density																
16x4	Yes	Fixed													74ALS232	
16x5	Yes	Fixed													74ALS229	
16x5	Yes	No													74S225	
16x5	Yes	Fixed													74ALS233	
64x8	Yes	Fixed													74ALS2232	
64x9	Yes	Fixed													74ALS2233	
256x8	Yes	Fixed												5485		
256x9	No	Fixed	7200				7200	L8C200		7200				5495		
64x4	No	No	67401	7C401			72401	L8C401							74ALS236	
64x4	Yes	No	67C4013	7C403			72403	L8C403							74ALS234	
64x5	Yes	No	67402	7C402			72402	L8C402								
64x5	Yes	No	67C4023	7C404			72404	L8C404								
64x5	Yes	Fixed	67C4033				72413	L8C413							74ALS235	
64x8	Yes	Fixed		7C408A				L8C408						5481		
64x9	Yes	Fixed		7C409A				L8C409						5491		
Medium-Density																
512x9	No	Fixed	7201	7C420	2009		7201	L8C201	52C9005	7201	7201	75C01	4501	5496/540201		4501
512x9	Yes	Fixed	4601					L8C2011								
512x9	No	Prog							52C9007			75C101				
512x9	Yes	Fixed									7211					
1Kx9	No	Fixed	7202	7C424	2010		7202	L8C202	52C9010	7202	7202	75C02	4502	5497/540202		4502
1Kx9	Yes	Fixed					72021	L8C2021								
1Kx9	Yes	Prog							52C9012			75C102				
1Kx9	Yes	Fixed									7212					
1Kx18	Yes	Prog													74ACT7802	
2Kx9	No	Fixed	7203	7C428	2011	63921	7203	L8C203	52C9020	7203	7203	75C03	4503	5498/540203		
2Kx9	Yes	Fixed					72031	L8C2031								
2Kx9	Yes	Prog							52C9022			75C103				
2Kx9	Yes	Prog													74ACT7808	

(Continued)

Table 1 (Continued)
Standard FIFOs Cross Reference

Organi-zation	Output Enable	Flags	AMD	Cypress	Dallas	Hitachi	IDT	Logic Devices	Micron	Mosel	Quality	Samsung	SGS	Sharp	TI	UMC
High-Density																
4K×9	No	Fixed	7204	7C432	2012	63941	7204	L8C204	52C9040	7204	7204	75C04	4504	5499/540204		
4K×9	Yes	Fixed					72041	L8C2041						5492		
4K×9	Yes	Prog							52C9042							
8K×9	No	Fixed	7205	7C460	2013		7205						4508	540205		
8K×9	Yes	Prog							52C9082							
8K×9	No	Prog		7C470												
16K×9	No	Fixed		7C462			7206							540206		
16K×9	No	Prog		7C472												
32K×9	No	Fixed		7C464												
32K×9	No	Prog		7C474												

Source: Dataquest (December 1991)

Table 2
Synchronous FIFOs Cross Reference

Organization	Output Enable	Flags	Cypress	IDT	Quality	SGS	Sharp	TI
64×8	No	Fixed		72420				
64×9	Yes	Prog		72421				
64×18	Yes	Prog						74ACT7813
256×8	No	Fixed		72200				
256×9	Yes	Prog		72201				
256×18	Yes	Prog						74ACT7805
512×8	No	Fixed		72210				
512×9	Yes	Prog	7C451					
512×9	Yes	Fixed	7C441	72211				
512×18	Yes	Prog		72215A			540215	74ACT7803
1K×5	No	Fixed				4505		
1K×8	No	Fixed		72220				
1K×9	Yes	Prog		72221				
1K×18	Yes	Prog		72225A			540225	74ACT7811
1K×36	Yes	Prog					543620	
2K×8	No	Fixed		72230				
2K×9	Yes	Prog	7C453					
2K×9	Yes	Fixed	7C443	72231				
2K×9	No	Fixed			7223			
2K×9	Yes	Prog						74ACT7807
2K×18	Yes	Prog		72235				
4K×8	No	Fixed		72240				
4K×9	Yes	Prog		72241				
4K×9	No	Fixed			7224			
4K×18	Yes	Prog		72245				

Source: Dataquest (December 1991)

Table 3
Specialty FIFOs Cross Reference

Organization	Parallel/Serial	Synch/ Asynch	Output Enable	Flags	Bidirect.	AMD	Cypress	IDT	Quality	Sharp	TI
32x9x2	Parallel	Asynch	Yes	Prog	Yes						74ALS2238
256x16	Par-Ser	Asynch	No	Fixed	No			72105			
256x18	Parallel	Synch	Yes	Prog	Yes			72605			
2x256x36	Parallel	Asynch	Yes	Prog	Yes					5420	
512x9	Parallel	Asynch	No	Fixed	Yes			7271			
512x16	Par-Ser	Asynch	No	Fixed	No			72115			
512x18	Parallel	Asynch	No	Prog	Yes			72511			
512x18	Parallel	Synch	No	Prog	Yes			72615			
512x18x2	Parallel	Synch	No	Prog	Yes						74ABT7819
512x18/1Kx9	Bus Matching	Asynch	No	Prog	Yes			7251			
512x18/1Kx9	Bus Matching	Asynch	No	Prog	Yes			72510			
2x512x8	Parallel	Asynch	No	Yes	Yes	4701					
1Kx9	Parallel	Asynch	No	Fixed	Yes			7272			
1Kx9x2	Parallel	Asynch	Yes	Prog	Yes						74ALS2235
1Kx9x2	Parallel	Asynch	Yes	Prog	Yes						74ALS2236
1Kx16	Par-Ser	Asynch	No	Fixed	No			72125			
1Kx18	Parallel	Asynch	No	Prog	Yes			72521			
1Kx18/2Kx9	Bus Matching	Asynch	No	Prog	Yes			7252			
1Kx18/2Kx9	Bus Matching	Asynch	No	Prog	Yes			72520			
2Kx9	Both	Asynch	Yes	Fixed	No			72103			
2Kx9	Parallel	Asynch	No	Fixed	Yes			7273			
2Kx9	Parallel	Asynch	No	Fixed	Yes		7C439				
2Kx9	Ser-Par	Asynch	Yes	Fixed	No			72132			
2Kx16	Par-Ser	Asynch	No	Fixed	No			72131			
4Kx9	Ser-Par	Asynch	Yes	Fixed	No			72142		5494	
4Kx9	Both	Asynch	Yes	Fixed	No			72104			
4Kx9	Par-Ser	Asynch	No	Fixed	No					5493	
4Kx16	Par-Ser	Asynch	No	Fixed	No			72141			
64Kx4	Parallel	Synch	Yes	Fixed	Yes				7306		
64Kx4	Parallel	Synch	No	No	Yes				7316		

Source: Dataquest (December 1991)

significantly but more slowly than the growth of the supply base. One manufacturer actually claims to have seen its dollar sales decrease from 1990 to 1991 while unit volume almost doubled.

Because the FIFO is needed to solve speed problems that cannot be easily addressed via software buffers or less complex hardware, semiconductor manufacturers place a strong emphasis on the speed of their FIFOs. Currently, the fastest available asynchronous devices run at 66 MHz. Synchronous devices that run at 70 MHz have been recently announced.

At these speeds, system designers have a very difficult time producing clean waveforms on the read and write input pins. To help solve this problem, vendors have designed synchronous FIFOs that can internally synchronize relatively dirty read and write waveforms against two externally generated clock signals. FIFO manufacturers are bullish about future acceptance of synchronous FIFOs, despite the fact that synchronous static RAMs have been available for several years and have met with extremely limited acceptance.

The Players

The following sections profile the players in the industry.

Advanced Micro Devices Inc. (AMD)

AMD inherited a number of FIFO products through its acquisition of Monolithic Memories Inc. in 1989. Because it has not been introducing new designs aggressively, its prospects in the market may be hurt. Still, AMD is the second-largest supplier of FIFOs worldwide and is capable of maintaining this business through sheer size. AMD's sales force is large and good.

Surprisingly, AMD does not support the military FIFO business, despite the company's overall commitment to the military electronics marketplace. AMD uses a Japanese foundry service to fabricate its FIFOs.

Cypress Semiconductor

Cypress has been aggressively pursuing the FIFO market for almost five years. The company's offerings are all high-speed versions of industry-standard organizations. Cypress' penchant for high visibility has helped to assist its efforts at winning a growing share of this market.

Recently, Cypress introduced 70-MHz synchronous FIFOs—the fastest in the market. Cypress is a strong player in the military market, a market that is not as well-supported as one would expect given the number of American FIFO manufacturers. Dataquest estimates that Cypress is the fourth largest FIFO manufacturer and could well become number two by 1993, displacing AMD.

Dallas Semiconductor Corporation

Although Dallas has a number of good FIFO products, it is not a big player in the FIFO market. The company's main focus is battery-supported memory and time-keeping devices, both high-ASP lines, so FIFOs are nearly a commodity by comparison. Dallas sells most of its FIFOs through distributors.

Hitachi

Although Hitachi is a significant player in the standard static RAM business, it does not compete aggressively in FIFOs. The two devices it offers are not highly promoted in the United States, and many of its competitors are unaware that Hitachi even participates in the market.

Integrated Device Technology Inc. (IDT)

The long-term leader in the FIFO marketplace, IDT has the broadest product offering and the dominant share of sales, accounting for about one-third of the total market. Evidence of the company's continued focus on innovation is easily observed in the sheer number of products in Tables 1, 2, and 3. Some of the company's competitors view this focus as a strength because it ensnares new designs using high-ASP proprietary products.

IDT has done pioneering work in bidirectional FIFOs, synchronous FIFOs, and application-specific products.

As with all of its other product lines, IDT pays close attention to the military market. IDT recently lost some market share, apparently because of delivery problems. If this trend continues, IDT could lose its first-place market standing to an astute rival. Still, the company has a strong commitment to the FIFO market, where it reaps about 20 percent of its gross sales.

Logic Devices Inc.

Logic Devices' current woes have affected all phases of its business. As a result, it has not really penetrated the FIFO market and is one of the least significant players in the market.

Micron Technology Inc.

When Micron enters a market, its competitors suffer the consequences. The company's basic operating strategy is to enter only markets where it has a significant cost advantage and drive the price low enough to discourage competition. Other FIFO manufacturers, then, are relieved that Micron's FIFO offerings have not been put into production as early as anticipated.

Micron is about to sample the most widely sourced products, the 720x series of 9-bit wide FIFOs. Dataquest expects these devices to suffer serious price erosion after Micron's entry into production.

Mosel

Although Mosel is a small fabless memory company, it has recently grown significantly with proprietary design wins in the FIFO market. Mosel does not suffer from the lack of a fab, but rather is capable of taking advantage of some of the best semiconductor processing capability available by spreading its business among competing leading-edge fab foundry services.

Mosel's merger with Vitelic has added Vitelic's FIFO products to Mosel's product line, but the Vitelic versions were alternate-sourced and are being discontinued.

Mosel recently announced two specialty FIFOs organized as 64x16 and 256x16. Mosel targeted these devices at Intel Corporation's EISA bus controllers, indicating its desire to get into a proprietary product market and increase ASPs and account control.

Quality Semiconductor Inc.

Quality is a small innovative company that has entered the FIFO market using standard devices with an eye to rapidly introducing newer value-added designs.

Samsung Semiconductor

Samsung is poising itself to become a major force in the FIFO market as it has done in the DRAM market. The company currently offers a limited range of devices, all of which will be alternate-sourced by Micron, and all of which, at 66 MHz, are the fastest asynchronous FIFOs in the market.

Samsung's potential success in this effort revolves around three factors. First, Samsung is a large company that can afford to weather some losses in establishing itself as a major FIFO supplier. Second, the company is a manufacturing powerhouse that has the ability to squeeze costs out of a design. Third, Samsung's new products have all been extremely technologically competitive.

The only potential obstacle to Samsung's eventual dominance of the FIFO market would be a lack of focus. Such a failing would be understood, as FIFO is probably the smallest market Samsung has chosen to enter. Samsung traditionally has not been a semiconductor house that pursues the design-in of new proprietary devices; therefore it will probably try to continue to take existing business from the market innovators rather than design-in proprietary products at a higher ASP.

Samsung's strategy to employ sales representatives rather than direct salespeople will tend to hamper any design-in efforts. The company's goal is to find the big markets and win those first. However, as stated earlier, the FIFO market is broad and shallow and such a feat might be more difficult to accomplish in FIFOs than in DRAMs.

SGS

Although SGS was the inventor of the memory-based FIFO, it lost its lead in this market several years ago, allowing Monolithic Memories (now AMD) and IDT to take over the memory-based FIFO market. Although the company does not have a broad product offering, it is increasing its focus on the FIFO market and expects to grow sales significantly this year over last.

Sharp Microelectronics Technology Inc.

Sharp is taking an interesting stance with its memory business. Whereas the company's standard static RAMs are being sold in the United States mainly by third parties (National Semiconductor Inc., Mosel, and Electronic Designs Incorporated), Sharp has chosen to sell its FIFOs by itself.

Sharp, like Samsung, has phenomenal resources at its disposal, which allows it to withstand narrow margins in gaining market share and probably allows it to boast of a very low die cost. These factors could help push Sharp rapidly to a higher ranking in market share than its current position of number five. Still, this would require a design-in effort, which would require some restructuring of Sharp's field sales force.

Texas Instruments Inc. (TI)

TI apppears to have put itself into the enviable position of identifying business that eludes its competitors. Most FIFO manufacturers believe the company to have about one-third the sales Dataquest has uncovered. The higher figure is possible because TI's graphics processor and DSP strengths offer a total system solution for a customer's DSP and graphics needs. TI is also strong in LAN components, another major FIFO market. Its product offerings consist mainly of shallow FIFOs; the evidence is that TI's part numbers start with the "74ACT" prefix used for its SSI and MSI logic families, and that the bulk of its offering is in low-density parts.

Competitors believe that TI has lost focus on the business, but this looks to be the case only because of TI's long-term emphasis on older designs. Until 1990, TI shipped only bipolar FIFOs; it only recently implemented FIFOs in MOS. The company does not currently offer any members of the 720x series of devices, the most widely sourced FIFOs today. TI is developing a broad new range of devices, many of which are synchronous, and will be using its advanced SSOP packaging technology to its advantage. TI also has innovated non-metastable flags, a vexing problem to other FIFO suppliers, and will use this to offer more reliable operation to system designers.

United Microelectronics Corporation (UMC)

UMC is a Taiwan-based company that specializes in slow ROMs, slow SRAMs, and chip sets. It is currently moving into the more lucrative fast memory marketplace. Although UMC offers FIFOs, it is not an important competitive factor in the market.

Vitelic Corporation

Since the merger with Mosel, Vitelic has de-emphasized its FIFO offering in deference to Mosel. Vitelic is no longer manufacturing its FIFOs and is selling off its inventory. Even combined with the sales of Mosel, Vitelic's sales do not put it into the top five FIFO suppliers. However, Mosel's share of the market is growing quickly and the company could rapidly gain significant market share if it can keep up its current pace.

Dataquest Perspective

Tomorrow's FIFO Market

Several factors could affect the FIFO market over the next few years. First, unit volume is expected to grow about 30 percent per year. Second, the number of competitors is too large for the size of the market. Subsequently, ASPs have come under considerable pressure. Should the 14 vendors shown split the market equally, each would get less than $10 million in sales. Third, the product offering is large, requiring vendors to produce and inventory a remarkable breadth of product types. (Each device listed in Tables 1, 2, and 3 is offered in numerous speed grades, and most are offered in more than two package types.)

Because most FIFO manufacturers also manufacture fast SRAMs, Dataquest expects to see continued rapid price erosion over the long term as manufacturers more aggressively pursue their FIFO business to make up for disappointing performance in the fast SRAM business. Specialty FIFOs are not expected to become a mainstay but will be neglected in favor of multiple-sourced devices at more competitive prices. Given this scenario, we expect a significant share of the commodity synchronous and asynchronous FIFO market to be taken over by companies with strong low-cost manufacturing prowess, unless they determine that the market is too small and fragmented to pursue, while companies with direct sales forces try to compensate for ASP erosion by focusing their efforts on achieving design wins for specialty FIFOs.

Not only are FIFO marketers bullish about the future of synchronous parts, as mentioned earlier, but they also believe that tomorrow's offerings will include significantly faster parts (100-MHz and faster), wider parts (in widths of ×16, ×18, and ×36), and new packaging technology that will allow the wider parts to compete favorably with traditional parts in board space consumption. Depths, too, will continue to grow to match the available SRAM technology.

Still, the market is full of innovators trying to increase their ASPs through the rich feature sets of specialty FIFOs. It is Dataquest's opinion that these innovators could lose significant market share to the production houses (that is, Micron, Sharp, and Samsung) should their focus become too diverted from the top-selling standard products. ■

By Jim Handy

Memory Cards: An Emerging and Potentially Explosive Market

What Are Memory Cards?

A memory card is a portable semiconductor storage device that contains memory ICs. It resembles a thick credit card (3.3mm) with an edge connector at one end (see Figure 1).

Figure 1
Example of Memory Card

Source: Panasonic Industrial Company

Memory cards perform a function similar to that of a floppy disk. They store binary data.

As program or data storage media, memory cards are not new. They have been used in computer games, point-of-sale (POS) systems, photocopiers, and laser printers. More recently, electronic organizers such as the Casio BOSS and the Sharp Wizard along with palmtop PCs such as the Poqet and the HP 95LX have begun using memory cards for data storage. Figure 2 shows their application in portable PCs.

The memory card form factor has not changed much over time, but the type of edge connector and the electrical/mechanical interface have. The edge connector of a memory card is the conduit that allows data to move to and from the card's memory ICs. It defines the card's capabilities. To date, we have seen cards with a variety of connectors including 38-, 40-, 50-, and 60-pin.

Memory Card Varieties

Memory cards contain mostly semiconductor memory ICs that belong to one of the following families: mask ROM, EPROM, OTP, SRAM, DRAM, EEPROM, and flash. DRAM memory cards are relative newcomers and are meant to be used as "extended/expanded" memory with no need for battery backup. SRAM cards with battery backup have been used as solid-state "floppies" in the current generation of electronic organizers. Until recently, SRAM cards (with battery backup) were the only nonvolatile memory cards. Flash memory cards today provide a promising alternative. Items such as language translating software and dictionaries typically come in mask ROM cards, as they are the most dense and least expensive. Functionally, they are huge look-up data tables that need no change. Table 1 lists the various memory card alternatives.

Memory Card Applications

Memory card applications include the following:

- Personal computers
- Factory automation
- Instrumentation and testing
- Avionics
- POS terminals
- Musical equipment
- Medical instrumentation

Figure 2
Memory Card Usage in a Portable PC

Source: Intel Corporation

Table 1
Memory Card Alternatives

Type	Density
ROM	128KB—16MB
EPROM/OTP	128KB—8MB
DRAM	64KB—12MB
SRAM	32KB—4MB
EEPROM	8KB—512KB
Flash	128KB—4MB

Source: Dataquest (December 1991)

On Standards

What inhibited memory card growth in the past was the lack of standards. In June 1989, the Personal Computer Memory Card Industry Association (PCMCIA) was formed in the United States, with a broad-based membership that included semiconductor companies along with software and hardware vendors. The PCMCIA's originally stated goal was to establish a standard for memory cards used with DOS-based PCs. It succeeded rather quickly as standards go. The first revision of a memory card standard was published in August 1990.

Revision 1.0 of the PCMCIA/Japan Electronic Industry Development Association (JEIDA) standard defined the following:

- The form factor—a device the size of a credit card, 3.3mm thick with a 68-pin socket connector
- The interface—parallel type bus, 8-bit/16-bit
- The address space—64Mb

The PCMCIA worked closely with the JEIDA and JEDEC. This close cooperation enabled the prompt international acceptance of the standard. Revision 2.0, as announced in September, addresses XIP (eXecute-In-Place) and I/O functions such as modems and LANs for PCMCIA bus cards. Intel Corporation also announced the Exchangeable Card Architecture (ExCA), a hardware and software implementation of the PCMCIA Revision 2.0 system interface. It is Intel's stated intention to make ExCA an industry standard so that different types of cards (memory, LAN, modem, and wireless communications) from different manufacturers will be interoperable.

Do Memory Cards Replace Hard Disks?

Strictly speaking, memory cards are not hard disk replacements. Rotating media have not been terribly successful with removable hard disks. A number of companies have tried that approach, but technology and costs kept it out of the mainstream. Thus, after a decade of using PCs, we are conditioned to think of hard disks as storage devices that belong inside the PC enclosure. This idea is a technology-dependent perception, and there is no reason why it should be so. On the other hand, memory cards, being a solid-state storage medium, are removable and portable. At a density of 20Mb, is a memory card acting like a "removable hard disk"? We believe that it is.

Memory cards have the following advantages over floppy/hard disks:

- Faster access and transfer rates
- Space, power, and weight reduction
- More ruggedness

However, they do have the following disadvantages:

- Expensive
- Lower capacity

The Cost Issue—How Important Is It?

In 1991, the average selling price (ASP) of a 2.5-inch 40MB hard disk drive was $250.00, which translates to $6.25 per megabyte. The 3.5-inch floppy cost is close to $1.00 per megabyte. By comparison, a 1MB flash card costs approximately $300.00 or $300.00 per megabyte—a substantial disparity! Semiconductor memory certainly costs more.

The question is, "Can you put a floppy disk drive in a palmtop PC to take advantage of that cost disparity?" The answer is, "No." There is not enough power (or space). *The issue, then, is not cost.* Here the removable storage medium dictates the product's capabilities and its success or failure in the marketplace. Without a memory card, a palmtop is nothing more than an electronic organizer. It is the memory card that transforms a palmtop into a full-fledged personal computer.

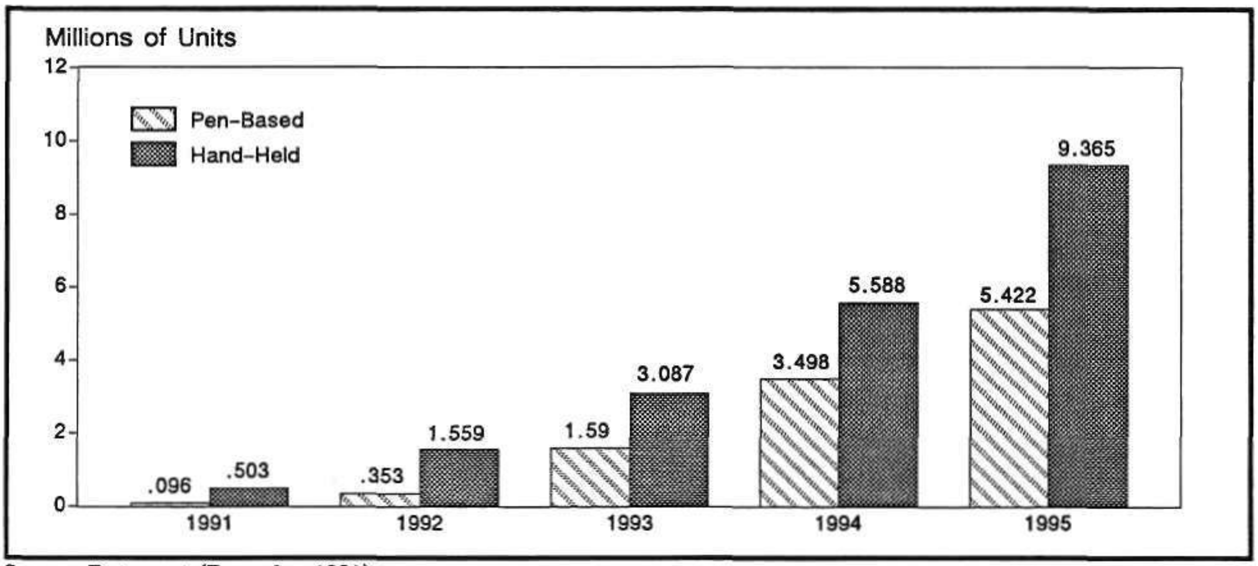
The Memory Card Market

As with any emerging technology, market size projections are difficult at best. The following assumptions may be used to gauge a portion of the total available market:

- The majority of hand-held PCs will use memory cards (80 to 95 percent).
- A portion of pen-based PCs will use memory cards (50 to 80 percent).
- Notebook PCs are forecast to grow from 686,000 units in 1991 to 7 million by 1995. A portion will use memory cards (10 to 20 percent).

Figure 3 provides some useful boundary conditions. Dataquest expects worldwide shipments of pen-based PCs to grow at a compound

Figure 3
Pen-Based and Hand-Help PC Forecast



Source: Dataquest (December 1991)

annual growth rate (CAGR) of 174 percent, from 96,000 units in 1991 to nearly 5.5 million units in 1995. At the same time, hand-held PC shipments will grow at a 108 percent CAGR from 503,000 units in 1991 to approximately 9.4 million in 1995. Together they amount to approximately 600,000 units in 1991, growing to almost 15 million by 1995. Some simple assumptions on memory card average selling prices indicate that this could easily become a billion-dollar-plus market by 1995.

Memory cards used in non-PC applications (which may account for as high as 90 percent of total memory card shipments in 1991 and 40 to 60 percent by 1995) are not included in this discussion. Electronic still photography alone may provide an explosive market for memory cards.

What Are the Key Developments Needed for Memory Cards to Succeed?

Three developments are necessary for the success of memory cards. These developments and the applications where they are needed are as follows:

- Cost reduction—all applications
- Development of data-compression ICs—electronics "filmless" still photography and PCs
- XIP—palmtop PCs

Cost Reduction

Flash memory cards hold the promise for becoming the least expensive form of solid-state storage. From a cell standpoint, flash rivals that of DRAM. Unlike DRAM or SRAM, it is nonvolatile, which means there is no need for battery backup. The need for bulk erasing of current-generation flash ICs creates a problem that requires clever solutions. With SRAM or DRAM cards, a single byte can be erased; EPROM-derived flash most often can be erased at the chip level (i.e., the whole chip). Recently, some vendors have announced products that allow erasure of particular memory segments. A prime example is the Intel 28F001BX 1Mb flash memory, which is segmented into areas of one 8KB, two 4KB, and one 112KB—all of which can be independently erased and programmed. EEPROM-derived flash is far more flexible at a cost premium (larger die). Flash EEPROM cells are larger than flash EPROM. Mask ROM memory cards will be the least expensive for the foreseeable future.

Data Compression ICs

Data compression ICs represent a key development for the electronic photography market and, to a lesser extent, for palmtop and pen-based PCs. Data compression ICs will be the subenabling technology devices. Without them, the future of electronic photography is in doubt. Thirty-six exposures (pictures) can be stored in a 2MB flash memory card in compressed form. If no compression were used, 40MB would be needed!

XIP

Simply stated, XIP allows a memory card to "plug-and-play." That is, once the card is plugged into the PC, program execution begins much in the way a program runs after one types in the program name and hits carriage return. That procedure is in contrast with current-generation PC architectures that need to copy the program code from secondary storage (hard disk or floppy) to main memory (DRAM) before execution. A palmtop PC with XIP capability needs just a single copy of a program, usually stored in the memory card, thus freeing up main memory.

The Players—Solid-State Disks

A number of companies are working on solid-state disk (SSD) replacement—a challenging task, to say the least. SunDisk Incorporated, located in Santa Clara, California, chose to focus primarily on hard disk replacement (solid-state disk) with a proprietary flash memory technology and architecture. The venture-capital-funded start-up launched three SSD products recently, all aimed at pen-based and palmtop PCs. The 2.5/5/10MB SSD plug-and-play subsystems come with an IDE industry-standard interface. The company is producing a 20MB solid-state disk subsystem on two PCMCIA form factor cards and expects to offer 40MB capacity shortly.

Toshiba announced a 4MB 5V EEPROM IC (TC58400) that is aimed at the SSD market. This device is by far the most dense EEPROM introduced to date. Architecturally, it is organized in a way that should facilitate SSD implementations. Toshiba uses a NAND cell structure that is 70 percent of its 4Mb DRAM cell; it is manufactured using a 0.7-micron double-poly CMOS process. The die size is $58.55mm^2$.

Hitachi announced a 5.25-inch form factor SSD based on 4Mb DRAM technology. This product is targeted at CAD/CAM, imaging, and graphics systems that demand a higher I/O throughput than what hard disk drives provide. The Hitachi SSD has access time of 0.35ms, incorporates a SCSI interface, and comes in 32MB or 64MB PC boards. The SSDs may be expanded to a capacity of 320MB. The data can be protected from power failures by using an optional battery-powered backup hard disk drive.

The Players—Memory Cards

Table 2 lists some of the companies active in the memory card market and their products. Other companies include Datakey and ITT-Cannon.

Table 2
Memory Card Offerings

Toshiba	128KB to 1MB	flash
	256KB to 2MB	SRAM
	256KB to 8MB	OTP
	128KB to 4MB	mask ROM*
Intel	1MB to 4MB	flash
Mitsubishi	256KB to 2MB	flash
	64KB to 512KB	SRAM
	128KB to 192KB	EEPROM
	512KB to 16MB	mask ROM
Fujitsu	256KB to 4MB	flash
	64KB to 512KB	SRAM
	16KB to 128KB	EEPROM
	256KB to 1MB	EPROM
	256KB to 2MB	OTP
	512KB to 16MB	mask ROM
Oki	256KB to 2MB	flash
	64KB to 2MB	SRAM
	512KB to 4MB	OTP
	1MB to 8MB	mask ROM
Rohm	128KB to 4MB	flash
	32KB to 1MB	SRAM
	512KB to 3MB	OTP
	512KB to 6MB	mask ROM
Epson	128KB to 2MB	flash*
	32KB to 1MB	SRAM*
	8KB to 64KB	EEPROM*
	128KB to 1MB	OTP*
	128KB to 4MB	mask ROM*
Maxell	64KB to 512KB	SRAM*
	64KB to 256KB	EEPROM*
	256KB to 1MB	EPROM*
	128KB to 1MB	OTP*
	1Mb to 8MB	mask ROM*
Fujisoku	64KB to 1MB	SRAM
	256KB to 1MB	EPROM
	256KB to 2MB	OTP
	1MB to 4MB	mask ROM
Panasonic	to 4MB	flash
	512KB to 4MB	SRAM
	to 512KB	EEPROM
	to 4MB	OTP
	to 8MB	mask ROM
DuPont	256KB to 2MB	SRAM

* by 16 organization
Source: Dataquest (December 1991)

Alternate Technologies—FRAM, novRAM

At least two different technologies may be used in future SSD and memory card implementations, assuming that they become cost competitive. Both of those technologies are nonvolatile (that is, need no battery to retain data) and are easily reprogrammable. FRAM (Ferroelectric RAM) devices are now becoming available from Ramtron International Corporation of Colorado Springs, Colorado. At this point, the 4Kb and 16Kb production offerings may find only limited use in memory cards and SSDs. However Ramtron is working on 64Kb and 256Kb devices and hopes to offer 4Mb densities by 1995. From a technology standpoint, ferroelectric devices have the potential of reaching densities similar to those of DRAM. The other alternative—novRAM—was, until recently, available in low densities (256 bits to 8Kb). However, Simtek Corporation, also of Colorado Springs, has demonstrated that it is possible to substantially increase novRAM densities. The company offers 64Kb devices now and plans to introduce 256Kb and 1Mb products in the future. A novRAM is essentially a combination of SRAM and EEPROM. Every SRAM bit has a corresponding EEPROM bit that is used to store the information when power is removed. Because the SRAM section of the device is used during normal operation, high-speed (30ns) read/write is available. However, the resulting die is larger than either an SRAM or an EEPROM device of the same density.

Some Thoughts on the Future of Memory Cards and PCs

In the past, the computer was the expensive component and the storage medium (floppy disk) the inexpensive one. We've become accustomed to that oddity and do not seem to question it. However, the computer is just a machine that manipulates information. It is the information that is important and valuable, not the machine that manipulates it. So perhaps it is fitting that the information carrier, a memory card, may cost more than the computer it is attached to. In the future, we will be using platforms (palmtop PCs) that cost much less than the storage media (memory cards) they use. Imagine a $50 PC attached to a $100 memory card. At least losing the PC will not be a problem anymore!

Dataquest Perspective

Dataquest believes that memory cards represent an important enabling technology. They have the potential to transform still photography and to make the 35mm film and cameras that use it obsolete. In the process, they will change that industry and provide tremendous opportunities for growth in the consumer electronics market. Memory cards will not eliminate rotating magnetic media any time soon. Instead, they will selectively replace them only when and where it makes sense. The bulk of the memory card growth will not come at the expense of rotating media. Growth will come from the creation of new markets. This should be good news for the semiconductor memory industry.

Ultimately, we believe, memory cards may revolutionize portable PCs by enabling them to become smaller, more rugged, lighter, faster, and perhaps user-friendly in a way that appeals to the vast majority of people who at present have no use for them. In doing so, memory cards may be the enabling technology that will make the PC of the future a true consumer item. ■

By Nicolas Samaras

In Future Issues

Look for articles on the following topics in future issues of Memories Worldwide *Dataquest Perspective:*

- 16MB Update
- Processor-specific SRAMs
- EEPROMs

For More Information . . .

On the topics in this issue .... Memories Worldwide (408) 437-8228
About other Dataquest publications .... Sales (408) 437-8250
About upcoming Dataquest conferences .... Conferences (408) 437-8245
About your subscription .... Customer Service (408) 437-8250
Via fax request .... Fax (408) 437-0292

0012433

Dataquest
a company of The Dun & Bradstreet Corporation

Dataquest Perspective

Memories
Worldwide

Vol. 1, No. 1 **November 25, 1991**

Market Analysis

Major Changes to Occur in the Memory Market

Major changes in the memory market will create opportunities for those who read the trends correctly and adjust accordingly. This article analyzes DRAM changes and opportunities in particular.
By Sam Young *Page 2*

Technology Analysis

Revolutionary Pinouts: Bane or Bounty?

The static RAM market is on the verge of embarking on a new pinout standard—or is it? JEDEC's "revolutionary" pinouts, which place the power and ground pins at the center, rather than the corners of the package, appear to have a rough battle ahead before becoming the industry standard for fast SRAM designs.
By Jim Handy *Page 6*

Market Analysis

Major Changes to Occur in the Memory Market

Changes in the Memory Business

As we move forward into the 1990s, the memory business will see several significant changes. In static random-access memory (SRAM), we will see a continuing increase in the use of high-speed SRAMs—primarily in cache memory applications. Processor-specific features in 16-bit-wide and even 32-bit-wide parts will allow processors with cache systems to run at ever higher frequencies. Very low power SRAMs will come into use in portable computers, and a reduction of the power supply voltage to 3V will extend battery life in portable systems.

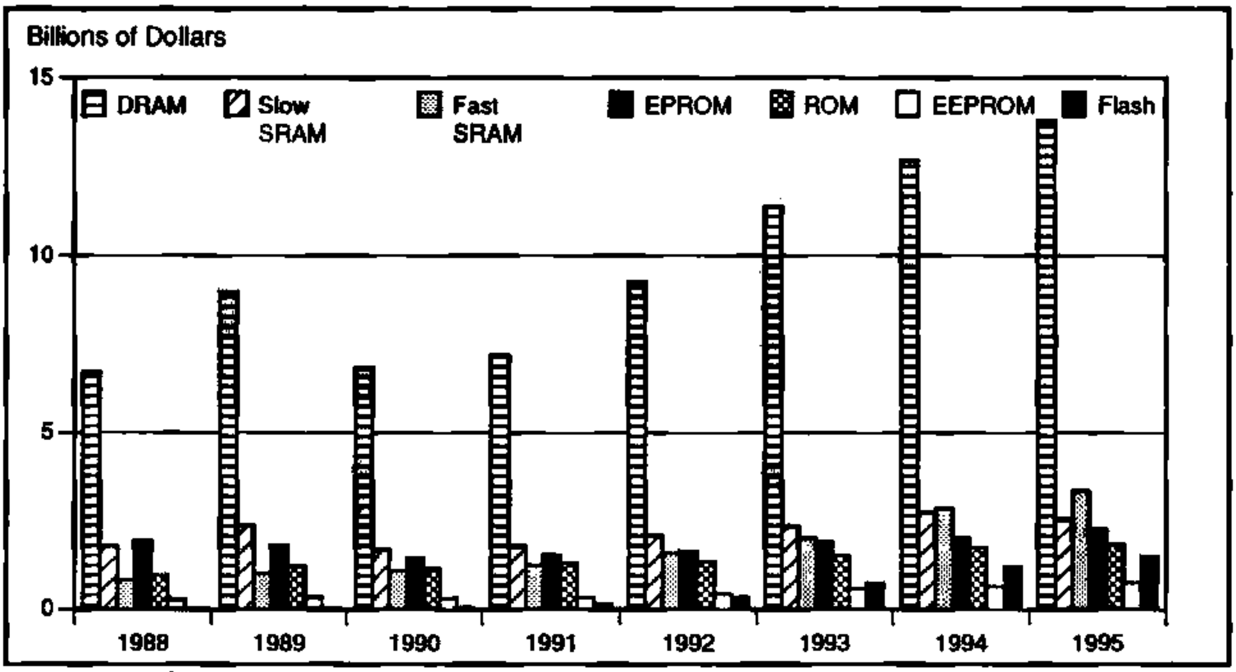
In nonvolatile memory, we will see Flash memories emerge as the fastest growth segment. Revenue will grow to over $1.5 billion by 1995. Flash memory sold in the form of memory cards compatible with the Personal Computer Memory Card Industry Association (PCMCIA) standards will replace magnetic storage in some portable applications. These memory cards, about the size of a credit card, will allow companies to share portable computers among several people without losing any security or privacy because the removable cards will contain the data. Size, weight, ruggedness, and battery life are other obvious advantages for this technology.

Dynamic random-access memory (DRAM), which is by far the largest dollar component of memory (see Figure 1), will undergo the greatest changes. For example, 40 percent of 1995 DRAM revenue will come from products that are just now sampling from most vendors. These changes will create opportunities for those who read the trends correctly and adjust accordingly. The focus of this article is on several of the major changes occurring in DRAMs in the 1990s.

DRAM Trends

The first and most significant trend change is a shift in the word width for DRAMs. In the 1970s, DRAMs were offered in a 1-bit-wide configuration. During the 1980s, a 4-bit-wide configuration became popular. During the 1990s, 8-bit, 9-bit, 16-bit, and 18-bit parts will become major factors for the DRAM production total available market (TAM). Dataquest will provide a detailed analysis of wideword DRAMS in the first half of 1992. For the scope of this

Figure 1
MOS Memory Product Forecast—Revenue



Source: Dataquest (November 1991)

discussion, however, we will use a general analysis to show the magnitude of the change.

Dataquest forecasts that, on a worldwide basis, 40 percent of the DRAM revenue, 35 percent of the DRAM units, and 40 percent of the DRAM bits will be shipped in configurations of 8 bits or greater by 1995. We expect regional differences in the product mix. The calculations and assumptions broken down by DRAM density are shown in Table 1.

The following questions are often asked regarding wideword memories:

- Why wideword?
- What are the price premiums for each configuration?
- Which configuration will be most popular?

Wideword DRAMs Reduce Power Dissipation

Power dissipation savings is the most significant reason for using wideword DRAMs. A typical 4-megabit (Mb) DRAM has an active power dissipation specification of approximately 550 milliwatts (Mw) and a standby specification of 5.5Mw, representing a factor of over 100 in difference between the two specifications. The first obvious question is: So what? Well, if we look at a basic 32-bit-wide system and do some math, we see that if we built this system out of 4-bit-wide memories, the power dissipation would be 550Mw × 8 (which equals 4.4 watts) because each chip must be selected for every active cycle. Using an 8-bit part, 4 chips are active and 4 chips are in standby. This scenario results in a power dissipation of 550Mw × 5.5Mw × 4, which equals 2.22 watts. If a 16-bit

Table 1
Wideword General Analysis

Wideword Analysis—Bits					
Density	Total Bits	% Low	% High	Value Low	Value High
256K	10,486	0	0	0	0
1Mb	235,930	10	20	23,593	47,186
4Mb	3,313,500	35	45	1,159,725	1,491,075
16Mb	5,117,051	40	50	2,046,820	2,558,526
64Mb	6,711	50	60	3,356	4,027
Total Bits	8,683,678			3,233,494	4,100,813
% Total Bits	100			37.24	47.22

Wideword Analysis—Units					
Density	Total Units (M)	% Low	% High	Value Low	Value High
256K	40.0	0	0	0	0
1Mb	225.0	10	20	23	45
4Mb	790.0	35	45	277	356
16Mb	305.0	40	50	122	153
64Mb	0.1	50	60	0	0
Total Units	1,360.1			421	553
% Total Units	100			30.96	40.66

Wideword Analysis—Dollars					
Density	Total $	% Low	% High	Value Low	Value High
256K	84	0	0	0	0
1Mb	878	10	20	88	176
4Mb	6,241	35	45	2,184	2,808
16Mb	6,558	40	50	2,623	3,279
64Mb	30	50	60	0	0
Total $	13,791			4,895	6,263
% Total $	100			35.50	45.41

Source: Dataquest (November 1991)

part is used, then the calculation becomes 2 × 550 + 5.5 × 6, which equals 1.13 watts. Dataquest recognizes that this analysis is a gross oversimplification neglecting refresh currents and the fact that all possible memory cycle time slots are not used; however, the point being made is still quite valid. In summary, wideword DRAMs save power. Even if a wideword DRAM's power specification should have to go up (a point ignored above for simplification), the results would not change significantly.

Wideword DRAMs Increase Memory Modularity

Wideword DRAMs also allow more modularity in the DRAM size. What this means is that the next-generation memory density can be used even if the memory size does not want to increase. In the case of the 1Mb×4 DRAM, if we need 32 bits, the smallest memory size is 4 megabytes. This memory size is about right for 386 systems using Windows software. Until recently the average memory size shipped was only 1 megabyte. If 16Mb DRAMs are used in a ×4 configuration, the smallest memory size is 16 megabytes—definitely too large for most of the personal computers available today or for the next two or three years. Most PC suppliers also prefer to keep the entry system cost down and therefore rarely load the box with large amounts of memory. The current single in-line memory module (SIMM) technology allows for very easy upgrade by the user. For portable computers, the same philosophy should occur with possibly memory cards being the add-on memory vehicle.

DRAM Price Premiums

A frequent question is: What will be the premium for wideword memory? The evasive answer is: Whatever the market will bear. As you might guess, this answer does not go over well. In truth, the market is currently "feeling out" the correct price. Several manufacturers surveyed by Dataquest do not have a clear answer.

In deriving a "rough" estimate, several factors must be considered. A wideword DRAM die costs more to build. Input/output pins require, on the die, an input and output buffer as well as bonding pads. Both of these take up significant die area. As we all know—the larger the die, the higher the cost. The package used is also larger, requiring more bond operations. Highly significant is the fact that the volume is lower, greatly impacting cost. Testing is also an issue, particularly in 16-bit-wide parts.

Dataquest's Price Estimates

Relative to a standard ×4 DRAM, the ×8 will initially cost 1.15 to 1.30 percent more. Within one year after volume production, the premium will drop to between 1.05 and 1.15 percent, with a price nearer to the lower end being the more likely scenario. The ×16 initially will cost 1.25 to 1.35 percent more. Within one year after volume production, the premium will drop to between 1.15 and 1.25 percent, with a price nearer to the lower end being the more likely scenario.

Which Configuration Will Be the Most Popular?

For the next several years, Dataquest forecasts that the 8-bit-wide will win. The reasons are as follows:

- Price—The ×8 configuration wins.
- Packing density—The ×8's smaller package will make it more attractive.
- Availability—The ×8 will cause far less manufacturing and design problems and will be more readily available.
- Convenience—The ×8 solves most issues creating the need for wideword memory with the least amount of pain for both users and manufacturers.

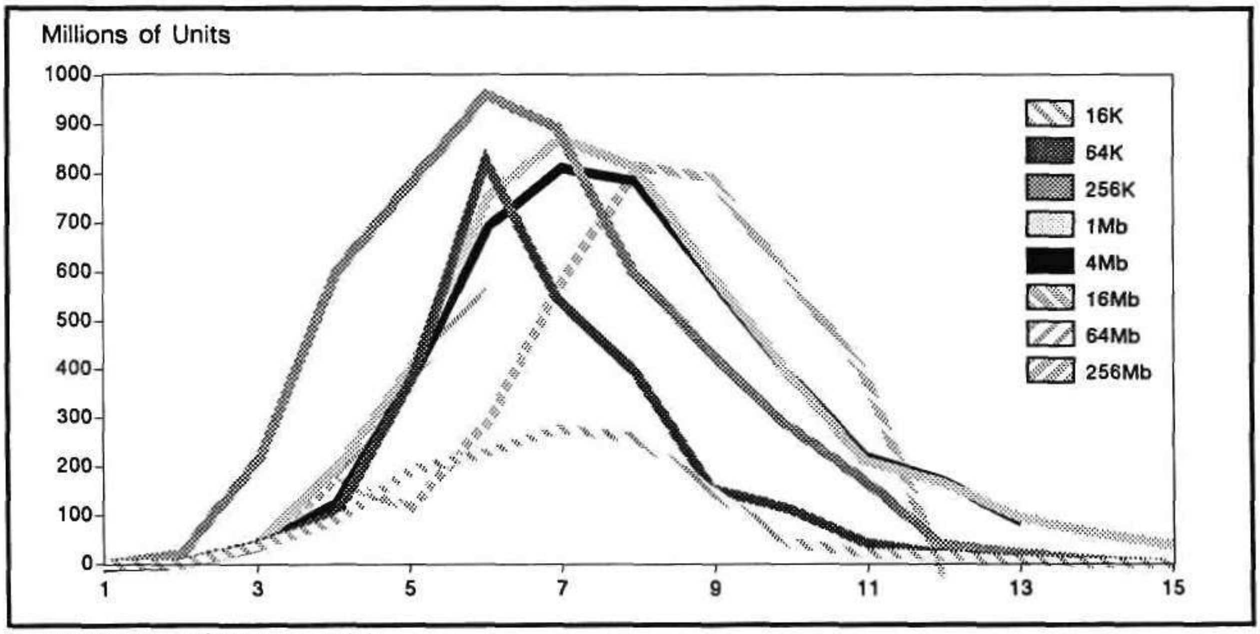
Life Cycles Are Increasing

Historically, each new generation of DRAM occurs every three to four years. During the 1990s, this trend will not change. What will change is the slope of the edges and the peak value. The 256K DRAM—which peaked in 1988 at 956 million units—is the highest peak volume part the industry will see. In the 1990s, the next generation will take longer to reach maximum unit volume and then continue in production for a longer period of time. Figure 2 graphically displays this point.

The 4Mb DRAM is the first generation where the time to ramp into volume production has increased. This DRAM has increased volume slower than most vendors would have preferred. The factors that previously drove acceptance of the next-generation part were the following:

- Price
- Density
- Power dissipation
- Reliability improvement

Figure 2
Product Life Cycle—Units



Source: Dataquest (November 1991)

In previous generations, volume ramp of a new generation would occur when the unit price reached approximately five times the price of the previous unit price. Today that requirement appears to be four times or less. We can explain the change from two directions. At this time, the personal computer accounts for approximately 47 percent of all DRAM sales. The PC manufacturer is under incredible cost pressure and therefore will not increase cost unless absolutely necessary. The desktop PC has adequate room for all the DRAM required using 1Mb technology mounted on SIMMs. Power dissipation is also not a major issue when compared with cost. Because the part count is low, the reliability issue is also not a factor. For the desktop PC, therefore, the main factor is cost. The workstation, mainframe, and minicomputer segments do have other motivations than cost, but they too are under far more price pressure than in previous days, and their demand represents a much smaller part of the TAM. In the first half of 1991, most of the 4Mb production shipments were going to this segment, but the volume was inadequate to meet expectations of the suppliers. In the future, portable computers will emerge that definitely care about power and density. However, concern still exists about shipping minimum-configuration systems. Here come the memory card solutions.

The tail end of the life cycle is increased by two primary factors. First, not all equipment will require the memory size dictated by the next-generation memory device. Low-end PCs are an example. In Europe, the telecom industry absorbed large numbers of lower-density DRAMs long after computer manufacturers phased down. Also, because of the huge investments required to stay in the DRAM business, an extension of life cycles is necessary to recoup investment.

Dataquest Perspective

The technical challenge for each new generation is increasing. It is becoming more and more difficult to cost-effectively bring the next generation to market. The 16Mb DRAM suppliers are motivated to bring prototypes and qualification units to market as early as possible, in response to their customers' desire to cut back on the number of suppliers. It is therefore very advantageous to deliver early. The early samples do not necessarily pull in the volume production capability, however. In

April 1991, vendors were bullish about increasing production on 16Mb devices; most today have pushed ramp plans out by three to six months. One question often asked is: Will the 4Mb DRAM have a short life cycle because of the 16Mb? Dataquest believes that the 4Mb will have a full life cycle.

By Sam Young

Technology Analysis

Revolutionary SRAM Pinouts: Bane or Bounty?

The Problem

Speed and Edge Rates

High-speed SRAM manufacturers are locked in a never-ending battle among themselves to produce the fastest products in the industry. Today, some vendors are offering 64Kb SRAMs in the 8ns range, 256Kb parts that operate as fast as 10ns, and 1Mb devices in the 15-to-20ns range.

As a general rule, the outputs of this speed of transistor-transistor logic (TTL)-compatible device, in order to be useful at the fastest-possible access time, would have to exhibit rise and fall times of about 10 percent of the access time or 0.8ns for an 8ns SRAM. The bandwidth required to support such an output signal works out to a frequency of 625 MHz (a period of one rise time plus one fall time or 1.6ns).

DIP Package Inductance

Figure 1 illustrates an "evolutionary" pinout for the 256K×4 SRAM. The power is supplied on pins 14 and 28 in the corners of the package. In order to reduce the amount of the die consumed by wide ground traces, the output pins, where most of the ground current is produced, are located close to the ground pin. This configuration was developed early in the history of memory devices and has continually been modified in only the slightest manner in order to support increases in memory sizes brought about by semiconductor technology advances; thus, it is called the evolutionary pinout.

In time, the package size used for corner power-ground devices has grown from a 14-pin, 300-mil wide dual in-line package (DIP) through a 52-pin, 600-mil DIP. Although some microprocessors have even been supplied in 900-mil DIPs, standard SRAMs have only grown as large as 32 pins with a 600-mil width. With this package growth come two problems. First, because the package continues to increase in size, the power and ground pins can get farther away from the die, increasing any parasitic elements inherent to the package's lead frame. Second, at higher speeds, no matter how long or short the lead frame is, a single bonding wire to ground has parasitic elements, which hinder the high-frequency switching capability of the chip within the DIP.

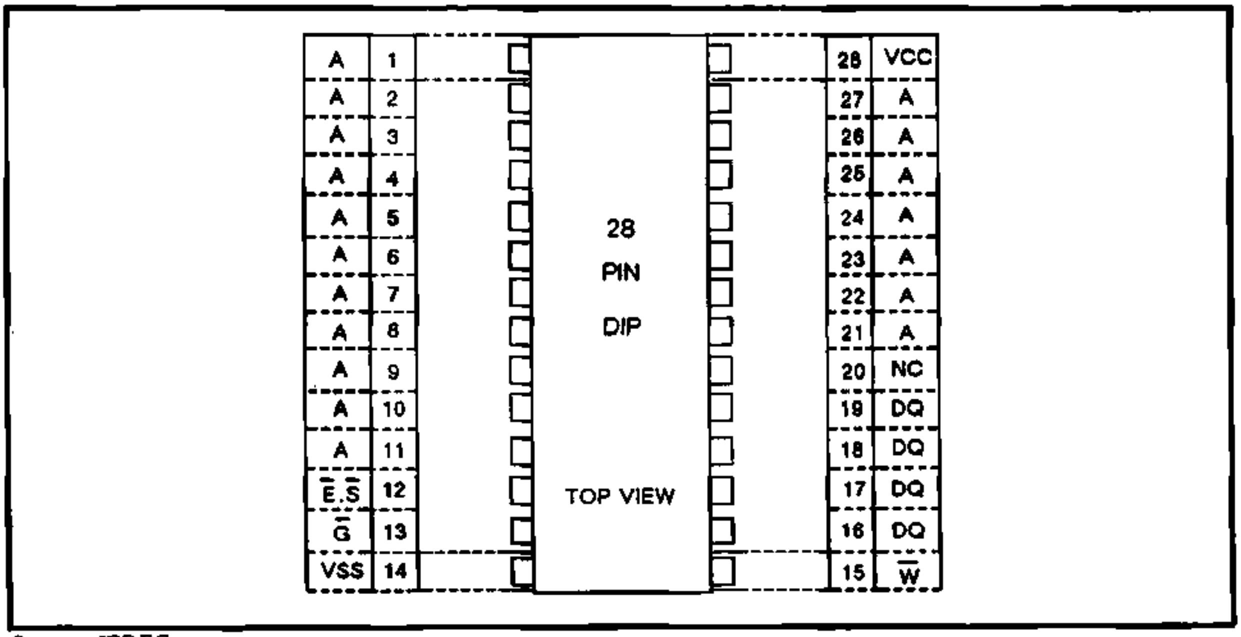
The most important parasitic element in this path is inductance. At the 625-MHz frequency previously mentioned, every nanohenry of inductance presents an impedance nearly equivalent to that of a 4-Ohm resistor.

Ground Impedance and Ground Bounce

A typical DIP package can exhibit between 5 and 10 nanohenrys of inductance on the ground lead. As just mentioned, this inductance comes from two sources—the package lead frame and the bonding wire from the lead frame to the die (as shown in Figure 2). The inductance of these elements has been neglected in the past because of its minor importance at frequencies below 10 MHz. At high frequencies (i.e., very fast edge rates) a 5nH inductance can cause sizable problems.

Looking at Figure 3, we can visualize the scenario for ground bounce. Several I/O pins on the device can move from a logic high level to a logic low level at the same time. When this occurs, the node capacitance (which includes the capacitance of the printed circuit board trace, all of the parasitic capacitances of the driving outputs, all the pins attached to the node, and the gates of any MOS inputs on the node) discharges through the device's ground pin. Because there is inductance between the chip ground bus and the PC board's ground plane, the di/dt (current surge of the discharging capacitance) of this sudden change causes the on-chip ground voltage to raise significantly above the ground reference on the circuit card. The sudden rise in on-chip ground voltage causes all of the chip's input thresholds to move up correspondingly, possibly causing certain input levels to become redefined to be "zeros" where they were previously read as "ones."

Figure 1
256K×4 Evolutionary Pinout



Source: JEDEC

Impact of Ground Bounce on Overall SRAM Speed

With the inputs appearing unsettled, as in the scenario just posed, the outputs cannot settle down themselves. Any of the 20 or so stages within an SRAM design can misinterpret the input value during ground bounce. A single misinterpretation could cause a delay lasting until the ground reference bottomed out, but if the change on that input causes the output to change state, then the ground current will again change, and in the worst case, the component will break into oscillation. Real life lies somewhere between the worst case and a single threshold-crossing, and multiple ground bounces often occur, severely impacting a stage's settling time. That settling adds itself to the RAM's access time, because the RAM's outputs are not considered valid until they have completely stabilized. The fastest SRAM will exhibit a much slower access time in an environment with ground bounce than would be possible in a completely bounce-free environment.

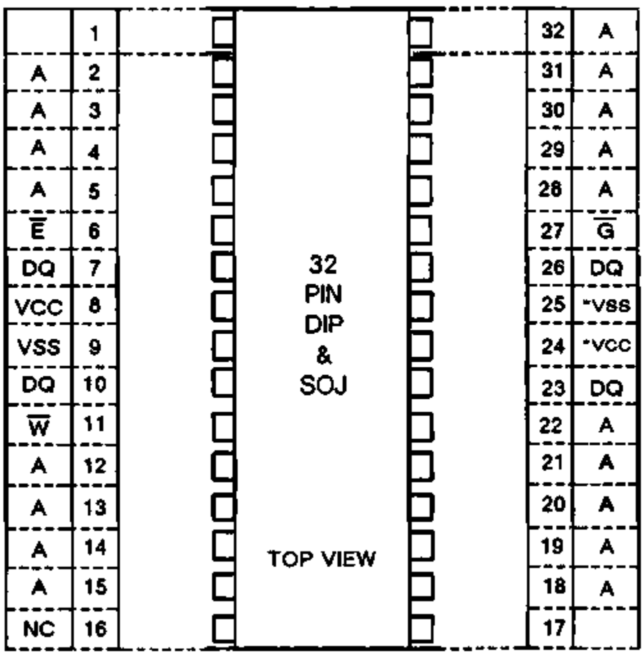
History

The Corner Power-Ground Tradition

Ever since the days of small-scale integration, a convention has been followed to put the power and ground pins of logic devices on diagonally opposite sides of DIP packages. This makes sense because the distance between these pins reduces the possibility that a power to ground short will develop, and because the signal lines can be routed in such a way that they are never required to cross either a power or ground bus. Corner power-ground arrangements can save considerable layout effort, space, and cost in the design of single-sided or two-sided PC boards. Corner power-ground pins on TTL logic devices were probably suggested by PC board layout personnel.

When the first memory devices were introduced, they did not adopt the corner power-ground standard. A problem arose when 4Kb DRAM memories started being shipped in 16-, 18-, and 22-pin packages. In 1973, this chaos brought about an effort by Sam Young of Burroughs Computer (now a DRAM analyst at Dataquest) to work with existing semiconductor memory suppliers to define corner power-ground memory pinouts so that the advantages of the corner power-ground standard could be used in memory systems. Memory suppliers also worked to put in place a new convention in which sockets would be configured to be upgraded, allowing larger memories to be plugged into the same sockets where smaller memories once resided. The Electronic Industries Association's (EIA's) Joint Electronics Devices Engineering Council (JEDEC) group has since worked to establish pinout standards before a density of memory would be designed.

Figure 2
256K×4 with Revolutionary Pinout



*These power pins may be VCC OR VCCA (VSS OR VSSA) as a manufacturer option

Source: JEDEC

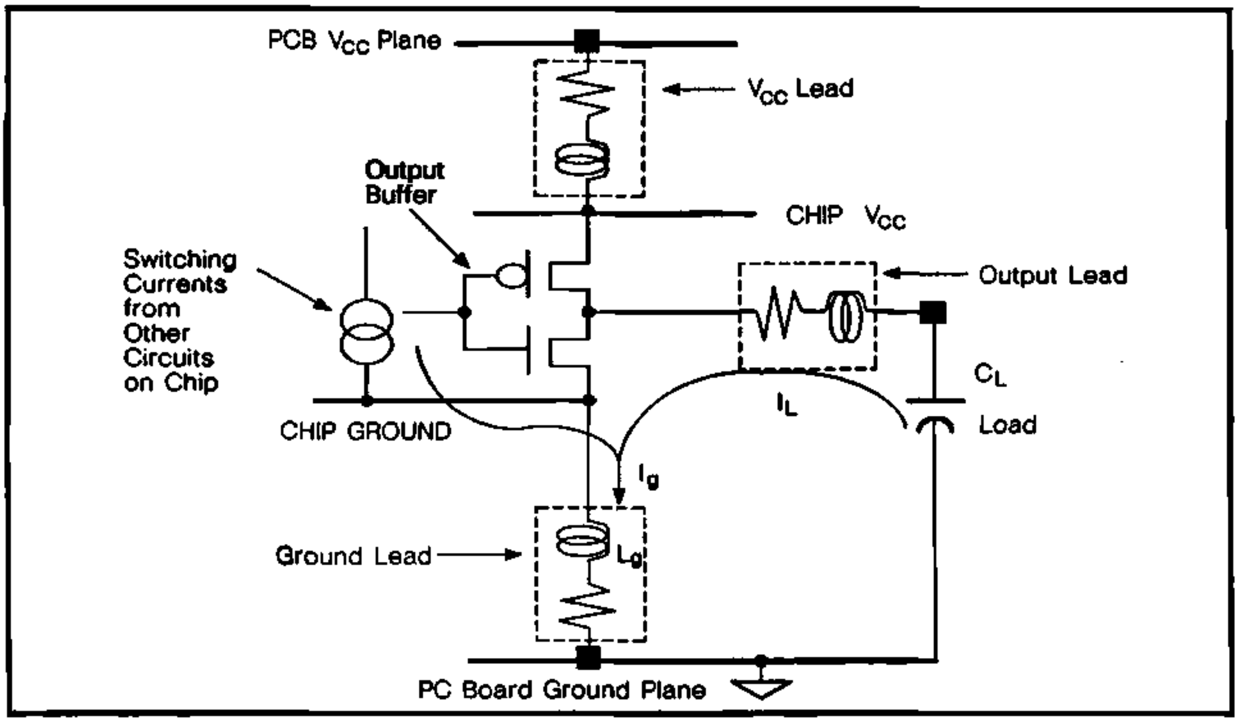
JEDEC Promotion of New Pinouts

For a while, the JEDEC pinouts were anything but controversial. There were rare breaks from a relatively predictable course until speed worries caused one member company to propose a sweeping change that would move the power and ground pins to the center of the package and add multiple power and ground pins, rather than one of each.

There were several reasons why this should be done. First and foremost, although moving the power and ground pins to the center of the package would not offer any reductions in bonding-wire inductance, a substantial improvement could be made in the parasitic elements of both the lead frame and the chip metallization paths. Both of these would allow memory designers to circumvent a significant amount of ground bounce and to produce faster devices using a given technology. Second, high-speed PC boards are now almost exclusively made using multilayer PC boards, removing any advantage or disadvantage to board layout that might have once resulted from the placement of the power and ground pins. Any pin is as easy to route to the ground plane as the next. Finally, DIP packages are now offered in higher pin counts than were possible at the dawn of the corner power-ground era. Twenty years ago, it would have been difficult to justify consuming more than 2 of the 14 or 16 available pins for more power and ground support. Now 32-pin, 300-mil DIPs and 44-pin, 400-mil small-outline J-heads (SOJs) are in mass production, and the impact of adding extra power and ground pins is no longer as great as before.

After much discussion, JEDEC members decided to settle on both "evolutionary" (corner power-ground) and "revolutionary" (center power-ground) versions of current and future pinouts, with the notion that all members would be able to move from the production and consumption of evolutionary to revolutionary devices as they saw fit. The same body also expects to see all proposed pinouts moving to a revolutionary style in the long term.

Figure 3
Parasitic V_{ss} Inductance Ground-Bounce Mechanism



Source: Integrated Device Technology Inc.

TI and Center Power-Ground Logic

In the mid-1980s, Texas Instruments Inc. (TI) tried to strike out on its own and use the center power-ground and multiple power-ground pin ideas to reduce ground bounce in their line of high-speed MSI logic products. Ground bounce is an even bigger problem with logic than it is with RAMs because the outputs of logic devices are expected to cross a threshold only once (RAM outputs are allowed to be dirty before they settle). Sometimes the outputs of a logic gate are used as clock inputs on another device, so any jitter due to ground bounce might cause false triggers in a downstream circuit.

TI's solution suffered from poor market acceptance because of four factors. First, the parts were not drop-in replacements for existing devices. Second, they offered no speed advantage over existing MSI products available from TI's competitors. Third, the added power and ground pins pushed devices out of the standard 20-pin package into a significantly larger 24-pin package, a distinct disadvantage. Fourth, there was no alternate source, and TI's competitors were not committing to supply pin-compatible devices until they saw market acceptance. The more traditional pinout was preferred by users.

You First

Once JEDEC's standards for center power and ground SRAM pinouts were in place, the next step was for the manufacturers to produce them. For a while it seemed that resource constraints were prohibiting most, if not all, companies from freeing a designer to work on a revolutionary device. More likely, the market for evolutionary products was a known, while the revolutionary concept was a gamble. Most static RAM manufacturers probably remember TI's experience in logic pinouts and are now taking a "wait and see" approach, hoping not to get too far behind the market leaders should the revolutionary pinout take off.

Technical Trade-Offs

Package Size

The addition of power and ground pins is an impact to the size of DIP required for a given density SRAM. Although the impact on package cost is small and fades in comparison to savings that can be attained through improved manufacturing techniques, the impact to the size of a printed circuit card is more important. When a 28-pin device is replaced by a 32-pin version of the same function (see Figures 1 and 2), it uses about 14 percent more PC board space. This space could come at an added cost, but is also quite likely to require desirable features to be omitted from a board simply due to a lack of available space.

As mentioned, higher pin-count packages are becoming more widely available, so package availability should not be expected to impact the industry's migration toward the revolutionary pinout.

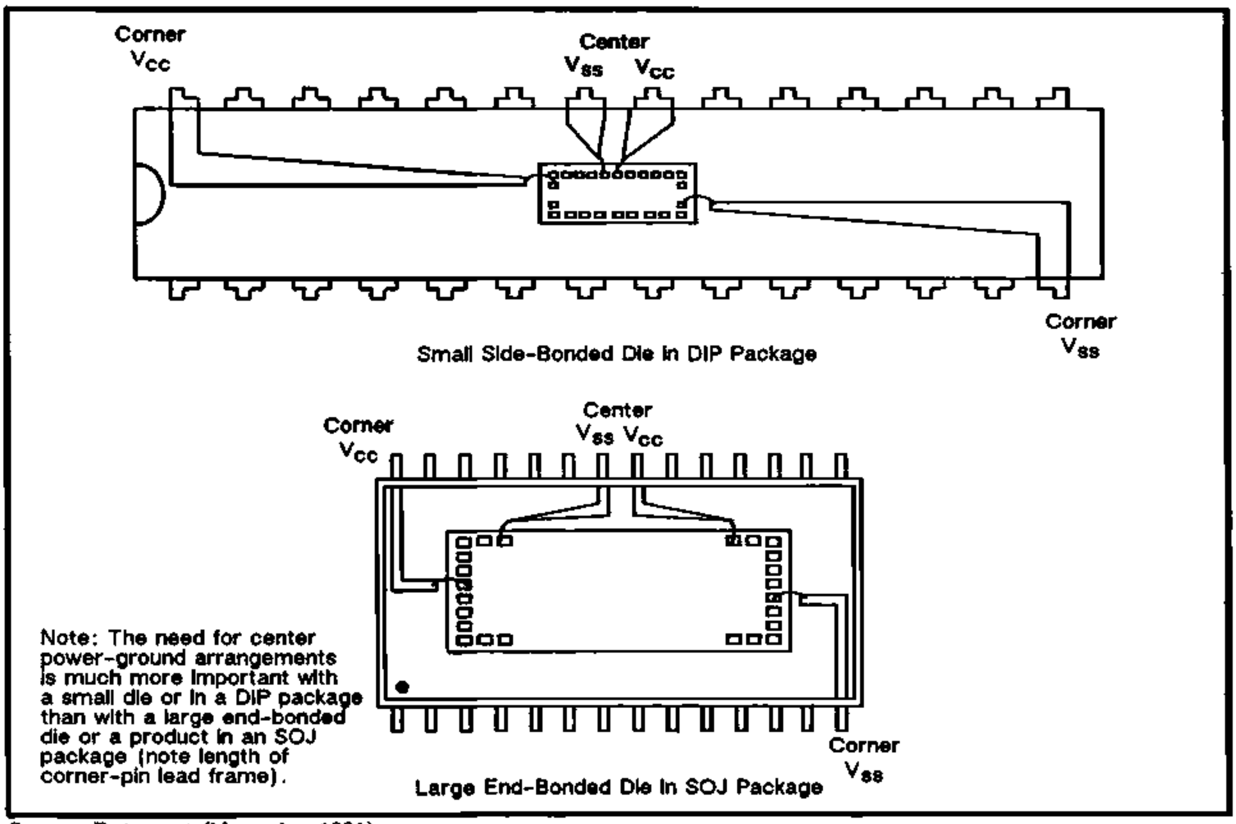
Package Trends vs. Pinout Changes

A strong trend exists among high-speed SRAM system designs to abandon the DIP package in favor of surface-mount packages, usually the SOJ. This trend waters down the need to use the revolutionary pinout for two reasons. First, the lead frame of an SOJ is significantly smaller than that of a DIP, to the point that there is only a slight difference in parasitic inductance between the corner leads and the center leads. Second, most larger RAM designs use end bonding rather than radial bonding. The corner of the lead frame will be closer to the bonding pads than will be the center pin, which means that the lead frame will actually be less inductive on a corner ground pin than it will be on a center ground pin. As die sizes increase to support increasingly larger memory arrays, the length of the lead frame to the power and ground pins diminishes considerably (see Figure 4).

In the future we can expect lead frame inductance to become even less of an issue, once TSOP, tape-automated bonding (TAB), and other extremely dense packaging technologies become commonplace.

Perhaps the biggest contribution the revolutionary pinout will bring to high-speed designs in light of these packaging trends will not be the position of the pins, but rather the increase in the number of power and ground pins that will be supported. The larger the number of ground pins, the lower the ground inductance, because the bonding wires will be in parallel with each other.

Figure 4
Evolutionary and Revolutionary Pinouts



Source: Dataquest (November 1991)

Effects of Future SRAM Organization and Operation

Certain side benefits will result from the adoption of JEDEC's revolutionary pinouts. For example, SRAM manufacturers now feel free to use multiple power and ground pins to support the manufacture of wider high-speed devices. Toshiba Corporation is now sampling a 64K×16 SRAM, which uses multiple ground pins to achieve a speed that rivals that of narrower 64K×4 RAMs despite the device's word width. IDT has moved to supply DIP package versions of its highest-speed, dual-port SRAMs only in center power-ground DIPs, as opposed to the corner power-ground package offered for lower-speed devices.

Another important trend that came into being along with the revolutionary pinouts was the introduction of JEDEC's first standardized synchronous SRAMs. Synchronous SRAMs are another means of tackling some of the trickier problems associated with write cycles in high-speed systems. Certain JEDEC revolutionary pinouts specify standards for synchronous clock inputs and control circuits.

The Players

JEDEC

The Joint Electron Devices Engineering Council (JEDEC) of the Electronic Industries Association (EIA) is the means by which members of the EIA attempt to ensure standardization across the electronics industry. Their accomplishments are commendable considering the extreme pace of the industry and the secrecy that veils the majority of most member companies' future efforts.

JEDEC's JC-42 committee has put a sizable effort into causing the center power-ground revolutionary pinout to become an accepted standard. It is now up to JEDEC's member companies to either produce or consume devices that meet the standard, depending on the nature of their business.

Philips Semiconductor

The main driver for the revolutionary pinout was Philips Semiconductor. Ironically, this company was an insignificant player in the high-speed SRAM market and never shipped an SRAM using the revolutionary pinout. The intent appeared to be that Philips would introduce revolutionary products in 1990 or 1991; however, in 1991, the company decided to abandon its SRAM efforts.

Motorola Incorporated

In the absence of Philips, Motorola appears to be the current champion of the revolutionary pinout. At the moment, Motorola is shipping revolutionary pinout 64K×4 and 32K×8 SRAMs in moderate volume. Motorola claims to be able to reach access times as fast as 10ns with this device.

Mitsubishi Electronics Corporation

Mitsubishi has recently announced plans to sample a 32K×8 revolutionary pinout device late this year, which is expected to boast an access time of 8ns.

Toshiba Corporation

Toshiba has not yet shipped any revolutionary pinout devices, but by nature of its agreements with Motorola, we can expect Toshiba to produce revolutionary 32K×8 and 64K×4 SRAMs sometime soon. So far, it appears that Toshiba's only multiple-ground SRAM is its 15ns 64K×16, a product that has been introduced without fanfare and appears to be easing its way rather slowly into design-ins, despite its barn-burning 15ns speed. This device will replace four 15ns 64K×4s, which until only recently were considered to be the state of the art. At these speeds, the advantage of cutting capacitive loading on a processor's address outputs to one quarter of its previous value should be of major interest to many designers.

Hitachi Ltd.

Hitachi Ltd. has made public its plans to produce revolutionary pinout 1Mb×4 SRAMs late this year, revolutionary pinout 128K×8/9 SRAMs in the first quarter of 1991 and the 64K×16 SRAM, which will be pin compatible with the Toshiba device.

Others

Fujitsu Ltd. and others have strongly voiced support for the revolutionary pinout standards, but there is no word of what will be introduced when. Other companies have kept silent on their endeavors. Only time will tell how well the revolutionary pinout will be accepted from a supplier's level. The only SRAM user we have noticed that has publicly shown its support by purchasing revolutionary pinout devices has been HP/Apollo, whose machines have recently graced Motorola's advertisements.

Dataquest Perspective—The Future

Manufacturers' Plans

At the moment, it appears that none but the bolder manufacturers are starting to produce revolutionary devices and then in a single density—256K. Volume requirements for these products are extremely uncertain and are therefore not forecast in this report. These 256K devices are follow-ons to already successful devices; therefore, the stakes to the supplier of introducing a revolutionary product are low. Also, there is still much room for growth in the high-speed 256K RAM market, so it makes more sense to try revolutionary devices at the 256K density than at lower densities.

Customers' Needs

Historically, considerable attention has been devoted to supporting simple system upgrades via plug-in replacement of slower parts with faster ones as the faster ones become available. Despite all this attention, most SRAM users do not take advantage of this practice. Whatever the reason, the issue of having to redo the board layout will probably not impact the decision of whether to use revolutionary or evolutionary pinout devices. These layouts will happen anyway, and the question then simply boils down to which part to use.

The more important question of availability will continue. Are the revolutionary parts second-sourced? Because JEDEC passed both revolutionary and evolutionary pinouts for several densities, there is no imminent switch-over point after which the user will be forced to use revolutionary pinout devices. The evolutionary/revolutionary decision will be deeply affected by the personal judgement of various personnel within the memory users' organizations. Expect to see a gradual decline in the use of evolutionary pinouts to revolutionary devices as the masses convert.

The Question of Inertia

Dataquest has often seen instances of incredible resistance to moving in a new direction, despite the fact that the new technology offers significant improvements. Many high-speed system designers get into trouble designing systems using TTL levels where ECL would make more sense. Although synchronous SRAMs have existed for at least four years, it is difficult to find applications that take advantage of them.

It appears that even those designers on the forefront of technological advancement occasionally hold on to comfortable tools of the past in spite of the availability of superior solutions. In this light, it would not be at all surprising if revolutionary pinout SRAMs were to get off to a slow start, with system designers breathing a sigh of relief every time an evolutionary device was coaxed into running at speeds previously only attained by revolutionary devices. The real turnaround will be indicated when a manufacturer introduces the revolutionary pinout version of a device first and follows it with the introduction of an evolutionary device (on a device for which both revolutionary and evolutionary standards exist), rather than vise versa.

Chicken and Egg Issues

As with any other advancements, two opposing forces are working against each other to the detriment of progress. On one hand, the customers' buyers and component engineers want to avoid allowing the design-in of a device that is sole-sourced; yet, on the other hand, the potential manufacturers of that device want to know that there will be a ready market for their product once it is introduced. A disadvantage from the supplier's viewpoint is that these devices will only be purchased for the absolute highest-speed applications, and devices that do not match such high speeds will not be salable as speed-downgraded products. It is fortunate for everyone involved that Mitsubishi and Motorola have embraced the 32Kx8 pinout. These devices will certainly fly with these strong suppliers. The fate of JEDEC's other revolutionary pinouts, however, is still in limbo.

By Jim Handy

For More Information . . .

On the topics in this issue	Memories Worldwide (408) 437-8228
About on-line access	On-Line Service (408) 437-8576
About other Dataquest publications	Sales (408) 437-8246
About upcoming Dataquest conferences	Conferences (408) 437-8245
About your subscription	Customer Service (408) 437-8402
Via fax request	Fax (408) 437-0292

0011614