

Data Storage Technology Comparisons

Dr. Romney R. Katti
Jet Propulsion Laboratory
4800 Oak Grove Drive
California Institute of Technology
Pasadena, California 91109

1 Introduction

The role of data storage [1] and data storage technology is an integral, though conceptually often underestimated, portion of data processing technology. Data storage is important in the mass storage mode in which generated data is buffered for later use. But data storage technology is also important in the data flow mode when data are manipulated and hence required to flow between databases, datasets and processors. This latter mode is commonly associated with memory hierarchies which support computation.

VLSI devices can reasonably be defined as electronic circuit devices such as channel and control electronics as well as highly integrated, solid-state devices that are fabricated using thin film deposition technology. VLSI devices in both capacities play an important role in data storage technology. In addition to random access memories (RAM), read-only memories (ROM), and other silicon-based variations such as PROMs, EPROMs, and EEPROMs, integrated devices find their way into a variety of memory technologies which offer significant performance advantages. These memory technologies include magnetic tape, magnetic disk, magneto-optic disk, and vertical Bloch line memory. In this paper, some comparison between selected technologies will be made to demonstrate why more than one memory technology exists today, based for example on access time and storage density at the active bit and system levels.

2 Role of Integrated Devices in Data Storage Technology

The memory element that is most commonly considered as a highly integrated memory is semiconductor RAM. This memory can be implemented in many ways, but generally is configured to consist of a memory element, such as a single capacitive transistor or a multi-transistor flip-flop, replicated in a two-dimensional matrix in which each element is accessed through a row and column address. Research and developmental investigations are looking at cell sizes which can achieve 256 Megabits on a single chip, but the currently available commercial chips typically provide 64 kilobits to 4 Megabits. Because of radiation immunity, reliability, power consumption, and other spaceflight requirements, chip

capacities which have recently been launched in spacecraft are in the 1 kilobit to 4 kilobit range. Efforts are underway to develop and qualify 64 kilobit chips for spaceflight.

Though the memory portion in RAM memory cells appears to offer high density, because each memory element requires access to various power, ground, blocking, precharge, column address, and row address lines, the effective, realizable storage density at the system level is degraded. Overall data transfer rates can also be poor for certain applications because the data rate equals the access rate and a single bit is accessed per unity cycle time.

To improve density and data transfer rate, memory elements which reduce the access and support overhead per stored bit are considered. Block access memories such as magnetic disk systems, magneto-optic disk systems, and vertical Bloch line (VBL) memory are intended to fill this void. For example, disk systems use a single read/write transducer to access sector of data arranged in tracks, and VBL memory propagates magnetic information within a crystal to integrated sensors. Storage density is increased because data bits are placed together as close as is physically possible without adding area around each bit for reading and writing each bit. The average data transfer rate can be increased for contiguous records by accepting an access time delay, usually around 100 *musec* for magneto-optic disks, 10 to 40 *musec* for magnetic disks, and 100 *musec* to 1 *musec* for VBL memory, but achieving high data rate once the access is complete.

The block access systems just described achieve high a real density, but their structures do not maximize volumetric storage density. To achieve greater volumetric storage density, tape systems are used. Tape systems are mechanical systems which essentially wrap data bits into rolls made from ribbons of material that are made to be as compact as can reliably be manufactured. The increase in volumetric storage density, however, comes at the cost of increased access times, which are typically in the tens of seconds. Data transfer rates can be kept high if lengthy data streams at high data rate are recorded for lengths of time which exceed access times. In certain applications, the advantage of storage density may overwhelm the disadvantage of increased access times.

Examples of integrated devices are now provided. In magnetic disk drives, the recording head is an integrated magnetic device made using thin film magnetic material deposition. Such an inductive head is shown in Figure 1. The figure has been extracted from the book "Magnetic Recording" by C.D. Mee and E.D. Daniel [2]. The active magnetic material is commonly made from sputtered and/or plated permalloy ($\text{Ni}_{0.8}\text{Fe}_{0.2}$). VBL Memory is an integrated, solid-state, nonvolatile, radiation hard memory in which the active storage film is an epitaxially-grown garnet, which is a magnetic oxide. A layout of a VBL memory chip is shown in Figure 2.

3 Results and Discussion

Comparing widely differing technologies is typically a challenging enterprise. There are also many issues which need to be addressed in a data storage system for spaceflight, such as environmental issues, radiation, mass, volume, power, reliability, durability, cost,

etc. However, certain assumptions can be made which produce trends which are observed in actual systems. Persons interested in this subject are encouraged to make their own assumptions and conduct their own analysis. In this analysis, the technologies of RAM, magnetic disk, magneto-optic disk, VBL, and magnetic tape will be compared at various levels of advancement. A comparison will be made of a real and volumetric bit densities at the active memory element level, and this will be compared to a real and volumetric bit densities at the memory system level. The active memory element refers to the memory cell unit which includes active media, while the system memory element includes overhead including media substrates and read/write transducers.

Shown in Figure 3, for a range of technologies, is a graph indicating the surface area of a bit of data at the active bit level, the volume of a bit at the active bit level, and the volume of a bit at the system level. The numerical values assumed for the bits are summarized in Table 1. Several trends are apparent and are now discussed.

First, the volume of a bit at the system level, after accounting for example for media substrates and read/write transducers, is two to four orders of magnitude greater than the volume of a bit at the active media level. This indicates that the mechanical trappings in data storage systems consume a considerable amount of volume. Further, because of this, high a real density values do not always automatically yield volumetrically efficient systems. Second, at the system bit volume level, RAM systems tend to be volumetrically inefficient when compared to block access and serial access systems. Third, this trend correlates with the trend that volumetrically efficient systems tend to have longer access times. Fourth, while technological progress is also being made in block access and serial access systems. Thus, block and serial access systems are continuing to offer system performance advantages over RAM systems.

Data from existing systems can also be reviewed and compared to the observations made above. Shown in Figure 4 is a graph of access time vs. capacity. The trend observed here, in which access time increases as capacity increases, is consistent with the conclusion drawn above.

Other conclusions can be drawn from existing data storage systems. Figure 5 shows that as capacity increases, data rate increases. Since the time duration for which data needs to be recorded tends not to decrease, capacity must then increase as data rate increases. This trend is apparent in Figure 6, in which capacity per unit of data rate actually increases as capacity increases.

As the capacity of systems increases, the efficiency of data storage systems increases, in terms of capacity achieved per unit of power and unit of volume. These trends are shown in Figures 7 and 8, respectively. For reference and to facilitate comparisons, graphs of capacity as a function of power and volume are also provided, as shown in Figures 9 and 10.

Figure 11 shows the mass of data storage systems plotted against volume. It is observed that as mass increases, volume increases. This is interpreted as stating that mechanical and electronics issues are dominant in existing systems. Thus, improvements in future data storage systems are needed not only in data storage technology components, but also in the mechanical and electronic components.

The reliability of data storage systems is plotted against capacity in Figure 12. One observation indicates that tape systems achieve high capacity, but that the existing formats, involving fixed head and rotary head recorders, achieve high and low levels of durability respectively.

4 Conclusion

Comparison of data storage technology and systems have been made using postulated data storage values as well as actual system values. Several trends have been observed with the data, and three are now summarized. First, as storage density increases, average access time also increases. This indicates that present and upcoming technologies tend not to have the ability to satisfy both high capacity and rapid access to data. Second, while advances are being made in RAM technology, advances are also being made in the block access and serial access memories. Thus, for the foreseeable future, efficient data systems will consist of multiple memory technologies, and not just RAM. Third, storage density at the active bit level tends to be a thousand to a million times greater than storage density at the usable system level. This suggests that features such as packaging, and VLSI control and channel electronics, which include signal conditioning, coding, and EDAC/compression functions, are very important to data storage systems.

5 Acknowledgements

The work performed in this report was conducted at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored under a contract by the National Aeronautics and Space Administration.

References

- [1] R.R. Katti and H.L. Stadler, "Survey of Data Storage Systems for Spaceflight Applications," Report to NASA/OAST, Civil Space Technology Initiative, JPL D-6924, Internal Report, May 31, 1989.
- [2] C.D. Mee and E.D. Daniel, eds. "Magnetic Recording, Volume I: Technology," McGraw-Hill, New York, 1987.

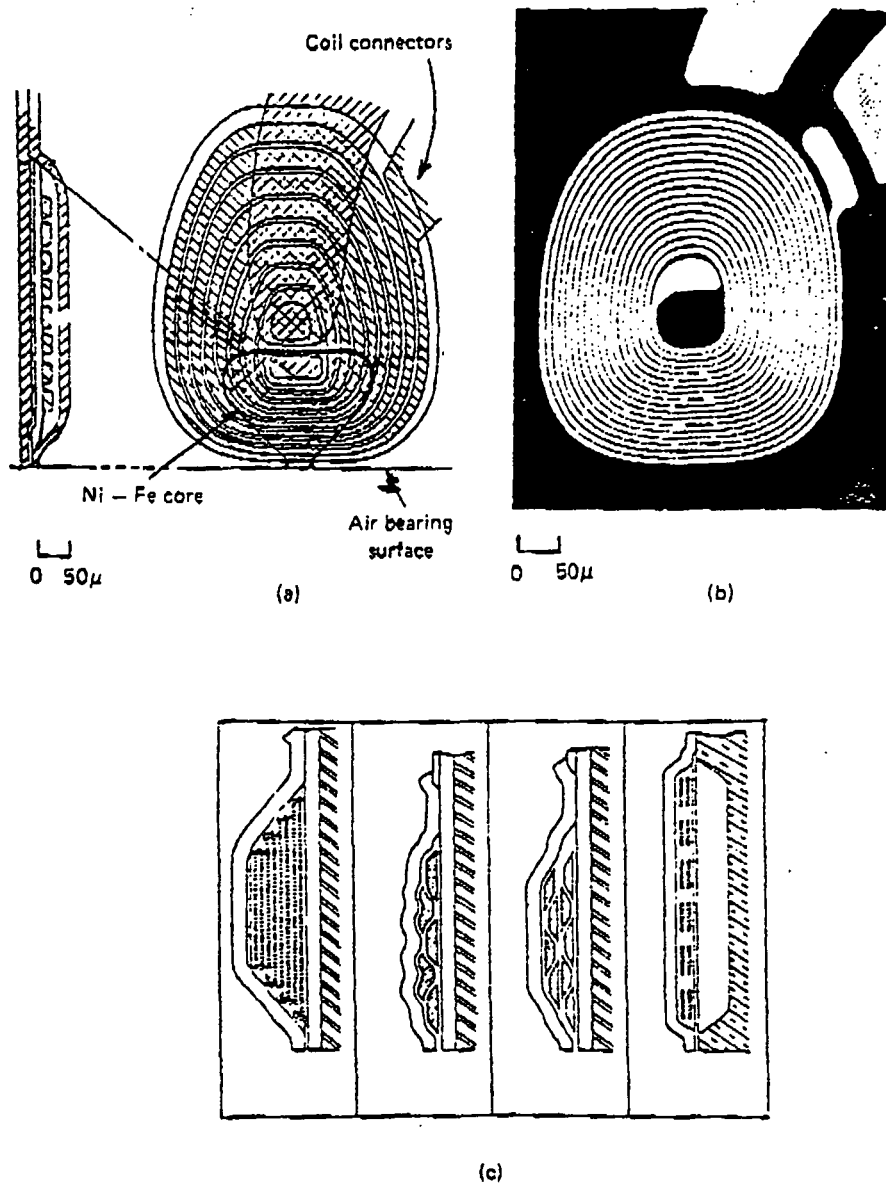


Figure 1: Design, Micrograph, and Cross-Sectional Views of Inductive, Thin Film Magnetic Recording Heads.

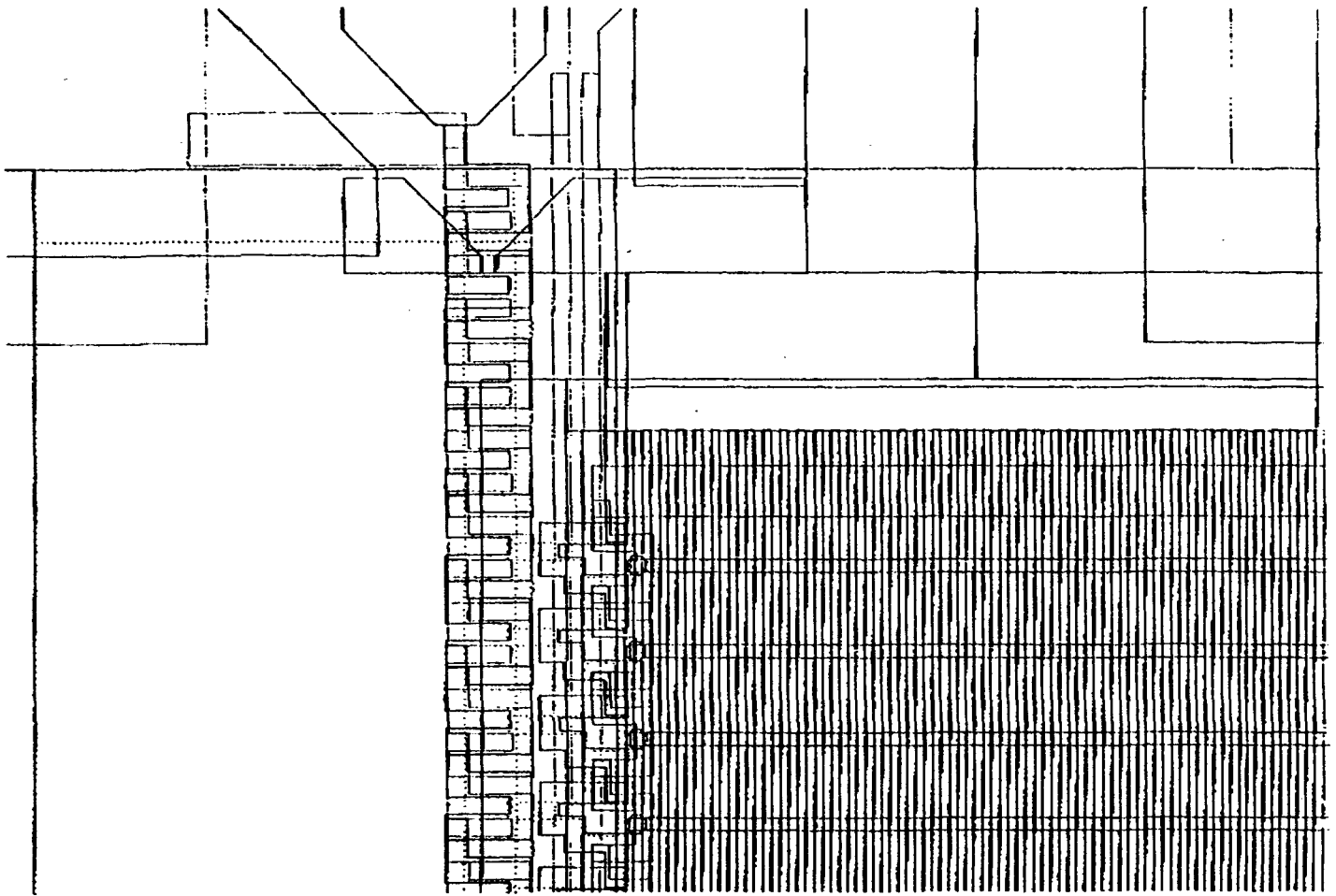


Figure 2: Layout of Vertical Bloch Line Memory.

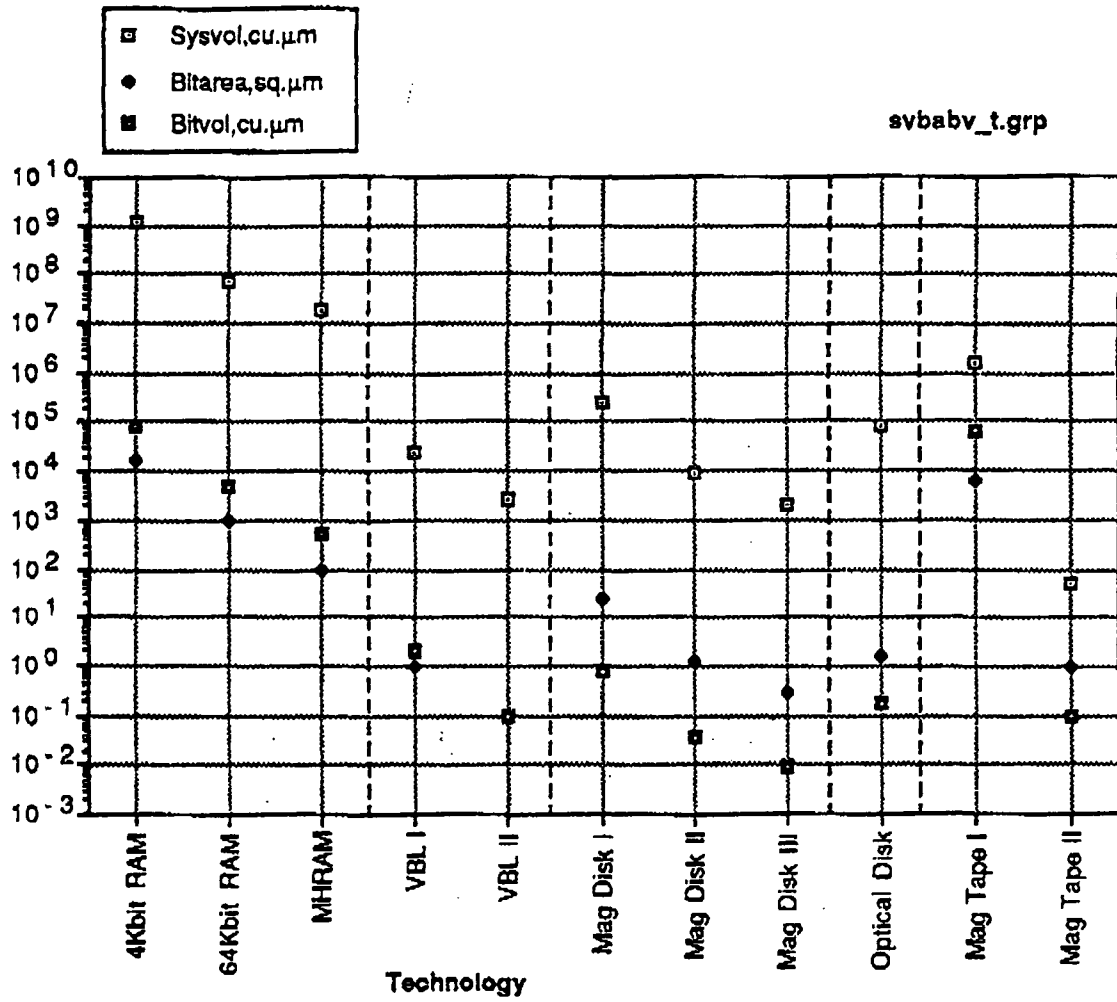
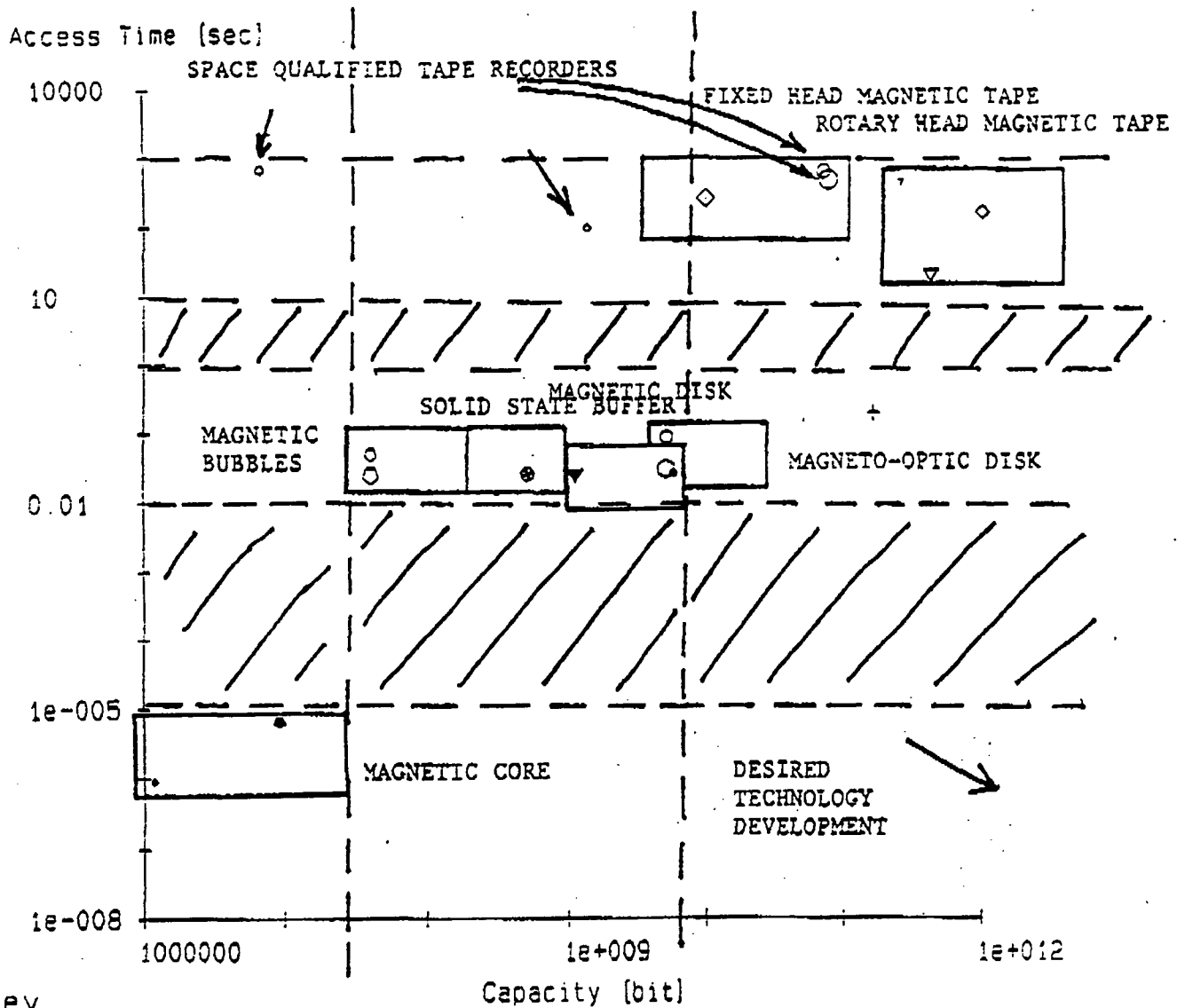


Figure 3: Graph of Bit Performance vs. Technology.

Technology	BitLength,um	Systlength,um	Bitwidth,um	Sysewidth,um	Bitdepth,um	Sysdepth,um	Bitarea,ca,um	Sysarea,sq,um	Bitvol,cu,um	Sysvol,cu,um
1 4Kbit RAM	128.400	343.630	126.490	343.630	3.000	10000.000	15999.720	118081.577	79998.601	1180815769.0
2 64Kbit RAM	31.800	85.910	31.600	85.910	3.000	10000.000	998.560	7380.529	4982.800	73805281.000
3 MHRAM	10.000	49.700	10.000	37.200	5.000	10000.000	100.000	1848.840	500.000	18488400.000
4 VBL I	1.000	1.000	1.000	1.000	2.000	25000.000	1.000	1.000	2.000	25000.000
5 VBL II	0.316	0.316	0.316	0.316	1.000	25000.000	0.100	0.100	0.100	2496.400
6 Mag Disk I	0.500	0.500	50.000	50.000	0.030	10000.000	25.000	25.000	0.750	250000.000
7 Mag Disk II	0.250	0.250	5.000	5.000	0.030	7000.000	1.250	1.250	0.037	8760.000
8 Mag Disk III	0.100	0.100	3.000	3.000	0.030	7000.000	0.300	0.300	0.009	2160.000
9 Optical Disk	1.000	1.000	1.700	1.700	0.100	60000.000	1.700	1.700	0.170	85000.000
10 Mag Tape I	4.000	4.000	1600.000	1600.000	10.000	250.000	6400.000	6400.000	64000.000	1600000.000
11 Mag Tape II	0.100	0.100	10.000	10.000	0.100	50.000	1.000	1.000	0.100	50.000

Table 1: Summary Table of Assumed Bit Dimensions.



Key

- | | |
|--|--------------------------------------|
| ○ DDS-5000EC (SPOT-1, 2) Tape Recorder | ○ 1990 Magnetic Bubble System |
| ○ DDS-6000EC (JERS-1) Tape Recorder | ○ DR650RE Magneto-Optic Disk System |
| ○ DDS-6000EC (Landsat) Tape Recorder | ○ Tahiti-I Magneto-Optic Disk System |
| • QDS-9000 Tape Recorder | + Spaceflight Optical Disk Recorder |
| ▽ PV6410 Rotary Tape Recorder | • Ruggedized Advanced Disk System |
| ▽ PV6210 Rotary Tape Recorder | • Militarized Advanced Disk System |
| • NASA STR-108 Tape Recorder | ▼ Mobile Mass Storage Disk System |
| ◇ ROR-300 Tape Recorder | • MESA-64RH Core Memory System |
| ◇ 20-MBS Tape Recorder | • MEGA-9 Core Memory System |
| ○ 1986 Magnetic Bubble System | ● SSR1-512B Solid State Recorder |

R. Katti JPL
Data Storage Survey

Figure 4: Graph of Access Time vs. Capacity for Existing Data Storage Systems.

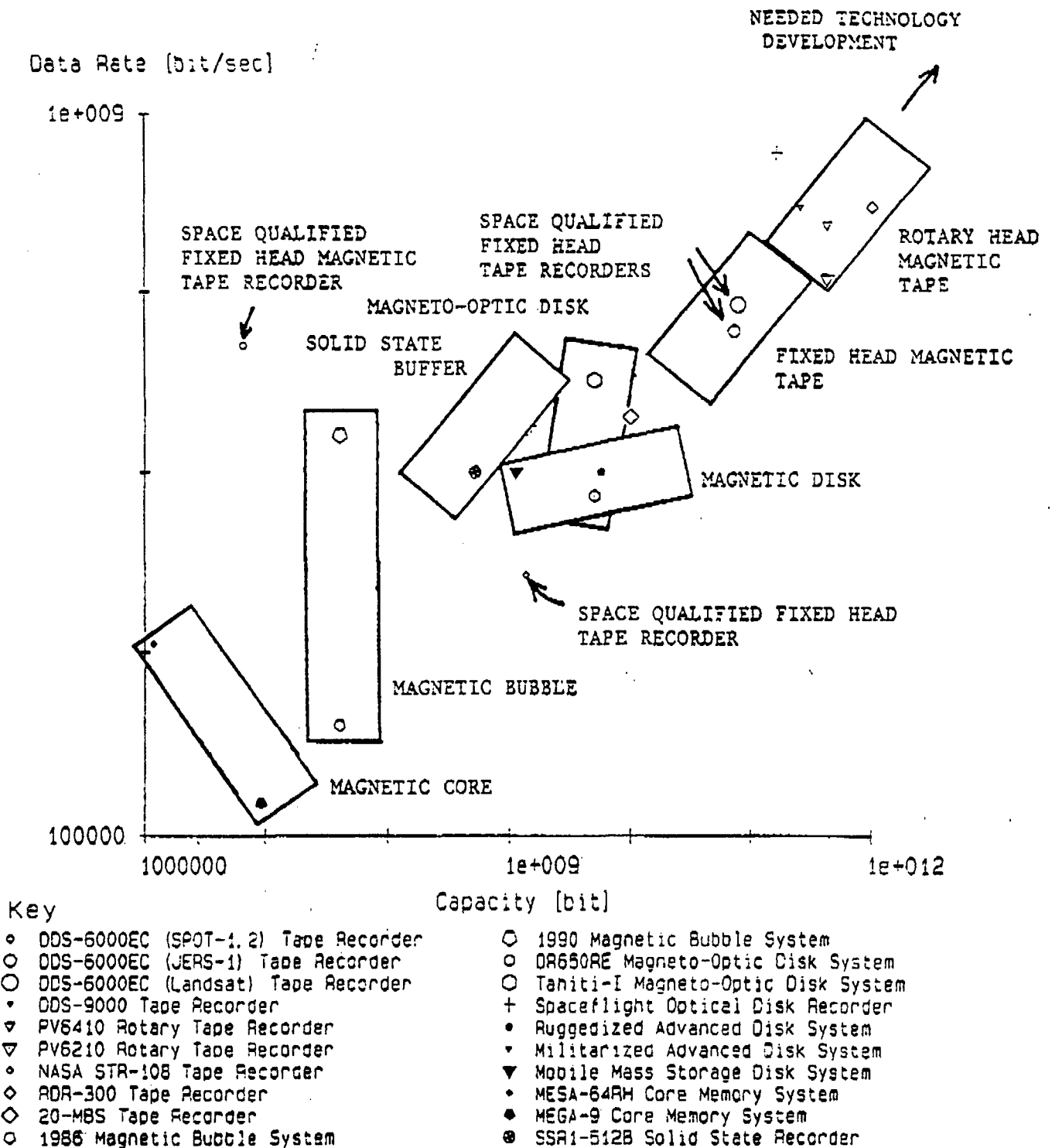
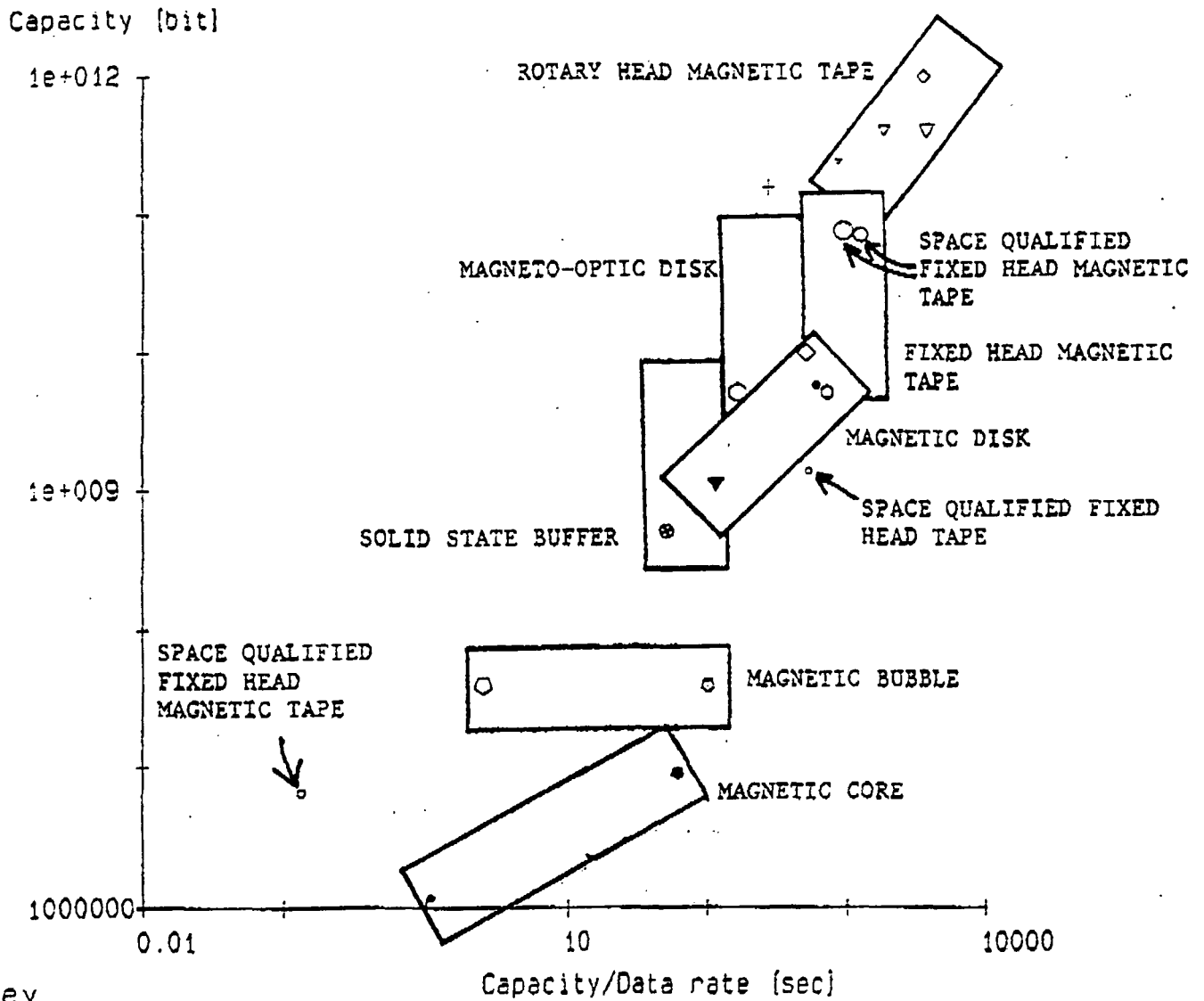


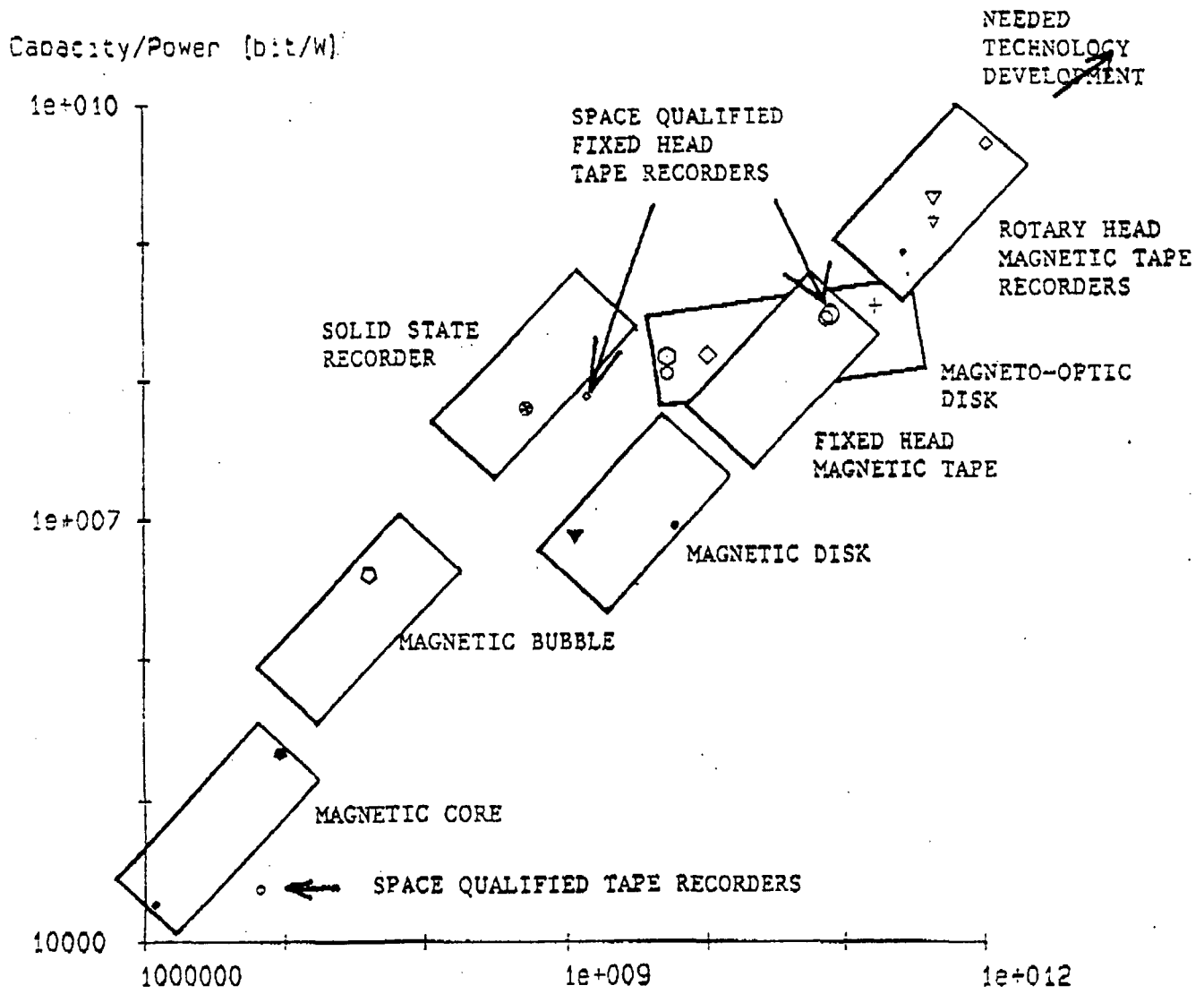
Figure 5: Graph of Data Rate vs. Capacity for Existing Data Storage Systems.



Key

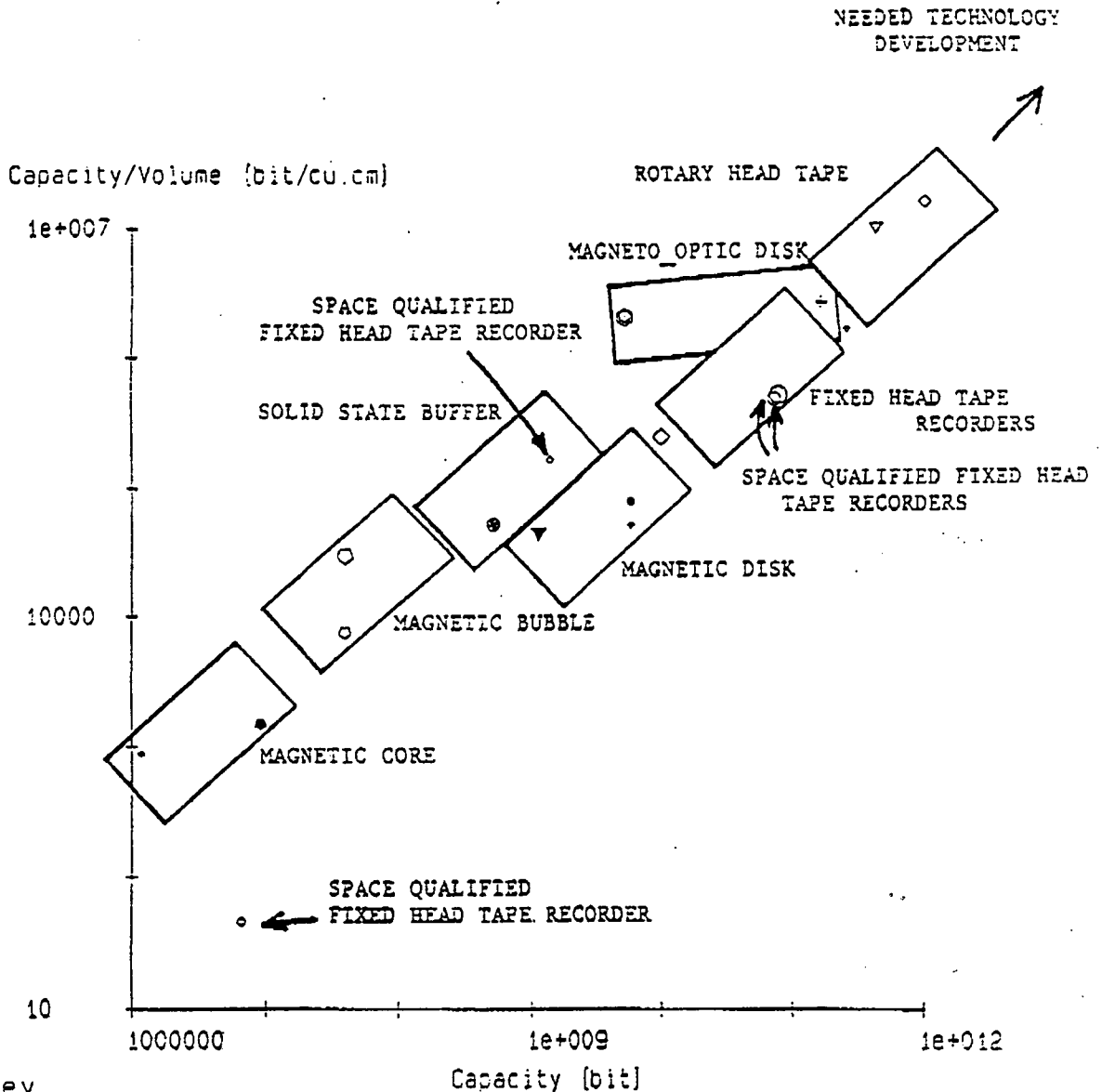
- | | |
|--|--------------------------------------|
| ◦ DDS-6000EC (SPOT-1, 2) Tape Recorder | ⊙ 1990 Magnetic Bubble System |
| ○ DDS-5000EC (JERS-1) Tape Recorder | ⊙ DR650RE Magneto-Optic Disk System |
| ○ DDS-6000EC (Landsat) Tape Recorder | ⊙ Tahiti-I Magneto-Optic Disk System |
| • DDS-9000 Tape Recorder | + Spaceflight Optical Disk Recorder |
| ▽ PV6410 Rotary Tape Recorder | • Ruggedized Advanced Disk System |
| ▽ PV6210 Rotary Tape Recorder | • Militarized Advanced Disk System |
| ◦ NASA STR-108 Tape Recorder | ▼ Mobile Mass Storage Disk System |
| ◇ RDR-300 Tape Recorder | • MESA-64RH Core Memory System |
| ◇ 20-MBS Tape Recorder | • MEGA-9 Core Memory System |
| ○ 1986 Magnetic Bubble System | ● SSR1-512B Solid State Recorder |

Figure 6: Graph of Capacity vs. Capacity per Unit Data Rate for Existing Data Storage Systems.



- Key
- | | |
|---------------------------------------|--------------------------------------|
| ◊ DDS-6000EC (SPOT-1.2) Tape Recorder | ⊙ 1990 Magnetic Bubble System |
| ○ DDS-5000EC (JERS-1) Tape Recorder | ⊙ DR650RE Magneto-Optic Disk System |
| ⊙ DDS-6000EC (Landsat) Tape Recorder | ⊙ Tahiti-I Magneto-Optic Disk System |
| ▼ DDS-9000 Tape Recorder | + Spaceflight Optical Disk Recorder |
| ▽ PV6410 Rotary Tape Recorder | • Ruggedized Advanced Disk System |
| ▽ PV6210 Rotary Tape Recorder | • Militarized Advanced Disk System |
| ◆ NASA STR-108 Tape Recorder | ▼ Mobile Mass Storage Disk System |
| ◆ RDR-300 Tape Recorder | • MESA-64RH Core Memory System |
| ◆ 20-MBS Tape Recorder | • MEGA-9 Core Memory System |
| ⊙ 1985 Magnetic Bubble System | ● SSR1-512B Solid State Recorder |

Figure 7: Graph of Capacity per Unit Power vs. Capacity for Existing Data Storage Systems.



- Key
- | | |
|--|--------------------------------------|
| ◦ DDS-6000EC (SPOT-1, 2) Tape Recorder | ◊ 1990 Magnetic Bubble System |
| ○ DDS-5000EC (JERS-1) Tape Recorder | ○ OR650RE Magneto-Optic Disk System |
| ○ DDS-6000EC (Landsat) Tape Recorder | ○ Tahiti-I Magneto-Optic Disk System |
| ◊ DDS-9000 Tape Recorder | + Spaceflight Optical Disk Recorder |
| ▽ PV6410 Rotary Tape Recorder | • Ruggedized Advanced Disk System |
| ▽ PV6210 Rotary Tape Recorder | • Militarized Advanced Disk System |
| • NASA STR-108 Tape Recorder | ▼ Mobile Mass Storage Disk System |
| ◊ RDR-300 Tape Recorder | • MESA-64RM Core Memory System |
| ◊ 20-MBS Tape Recorder | • MEGA-9 Core Memory System |
| ◊ 1986 Magnetic Bubble System | • SSR1-512B Solid State Recorder |

Figure 8: Graph of Capacity per Unit Volume vs. Capacity for Existing Data Storage Systems.

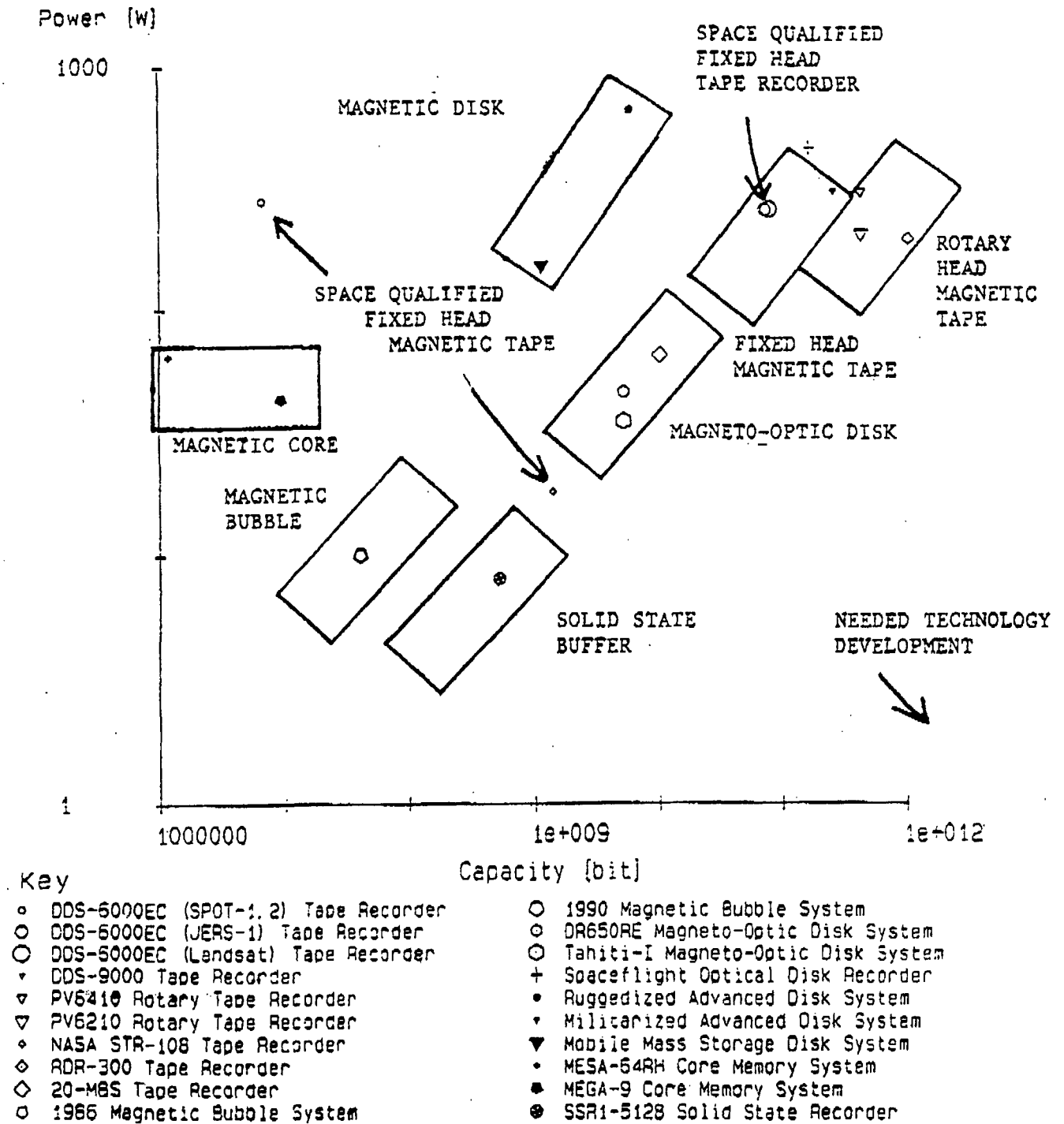
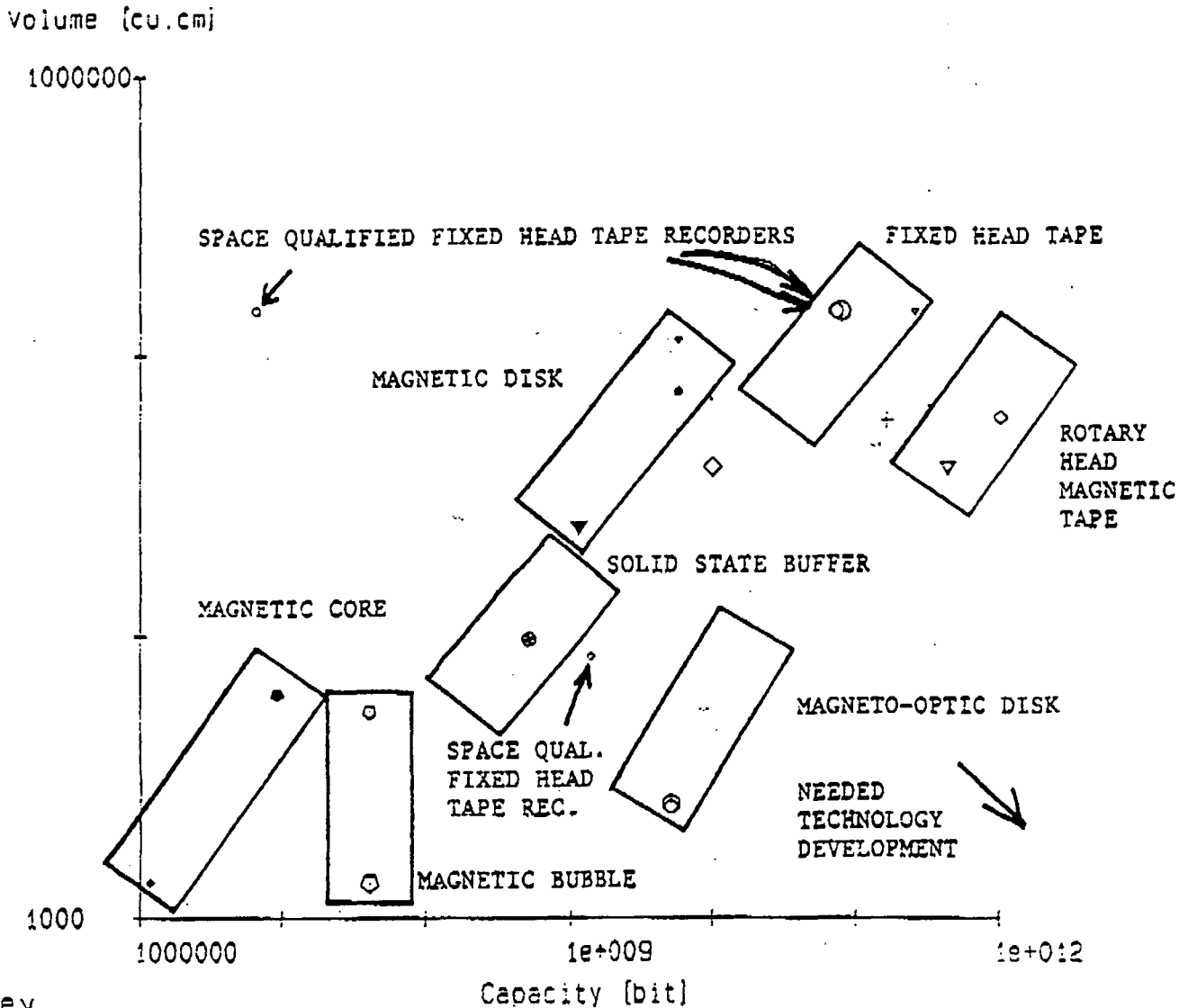


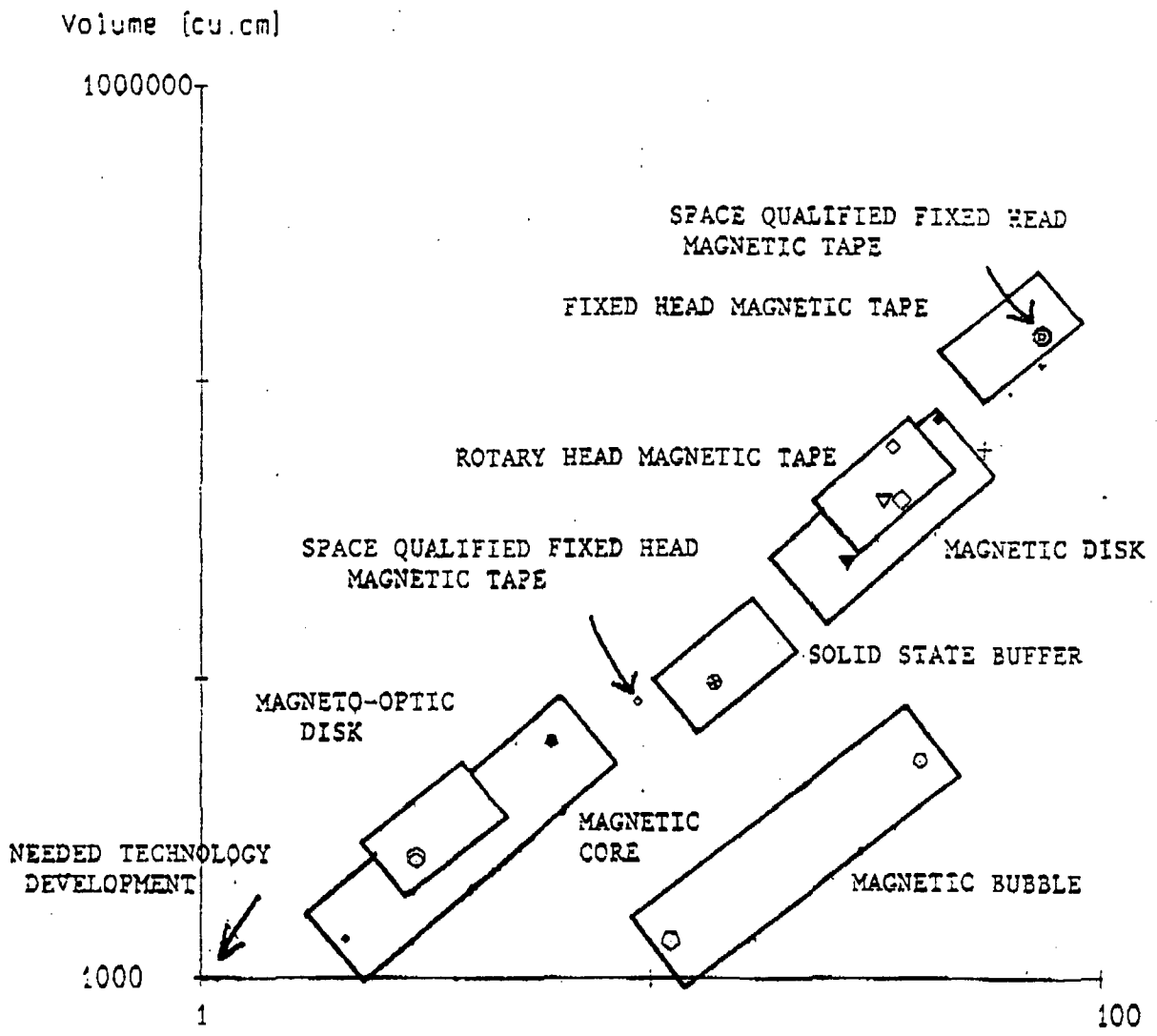
Figure 9: Graph of Capacity vs. Power for Existing Data Storage Systems.



Key

- DDS-6000EC (SPOT-1,2) Tape Recorder
- ◐ DDS-6000EC (JERS-1) Tape Recorder
- DDS-6000EC (Landsat) Tape Recorder
- DDS-9000 Tape Recorder
- ▽ PV6410 Rotary Tape Recorder
- ▽ PV6210 Rotary Tape Recorder
- ◊ NASA STR-108 Tape Recorder
- ◊ RDR-300 Tape Recorder
- ◊ 20-MBS Tape Recorder
- ◊ 1986 Magnetic Bubble System
- ◊ 1990 Magnetic Bubble System
- ◐ DR650RE Magneto-Optic Disk System
- ◐ Tahiti-I Magneto-Optic Disk System
- + Spaceflight Optical Disk Recorder
- Ruggedized Advanced Disk System
- Militarized Advanced Disk System
- ▽ Mobile Mass Storage Disk System
- MESA-54RH Core Memory System
- MEGA-9 Core Memory System
- SSR1-512B Solid State Recorder

Figure 10: Graph of Capacity vs. Volume for Existing Data Storage Systems.



- | Key | Mass [kg] |
|--|--------------------------------------|
| ◦ DDS-5000EC (SPOT-1, 2) Tape Recorder | ⊙ 1990 Magnetic Bubble System |
| ⊙ DDS-5000EC (JERS-1) Tape Recorder | ⊙ DR650RE Magneto-Optic Disk System |
| ⊙ DDS-5000EC (Landsat) Tape Recorder | ⊙ Tahiti-I Magneto-Optic Disk System |
| ▽ DDS-9000 Tape Recorder | + Spaceflight Optical Disk Recorder |
| ▽ PV6410 Rotary Tape Recorder | • Ruggedized Advanced Disk System |
| ▽ PV6210 Rotary Tape Recorder | • Militarized Advanced Disk System |
| ◦ NASA STR-108 Tape Recorder | ▼ Mobile Mass Storage Disk System |
| ◊ RDR-300 Tape Recorder | • MESA-64RH Core Memory System |
| ◊ 2C-MBS Tape Recorder | • MEGA-9 Core Memory System |
| ◊ 1986 Magnetic Bubble System | • SSR1-512B Solid State Recorder |

Figure 11: Graph of Mass vs. Volume for Existing Data Storage Systems.

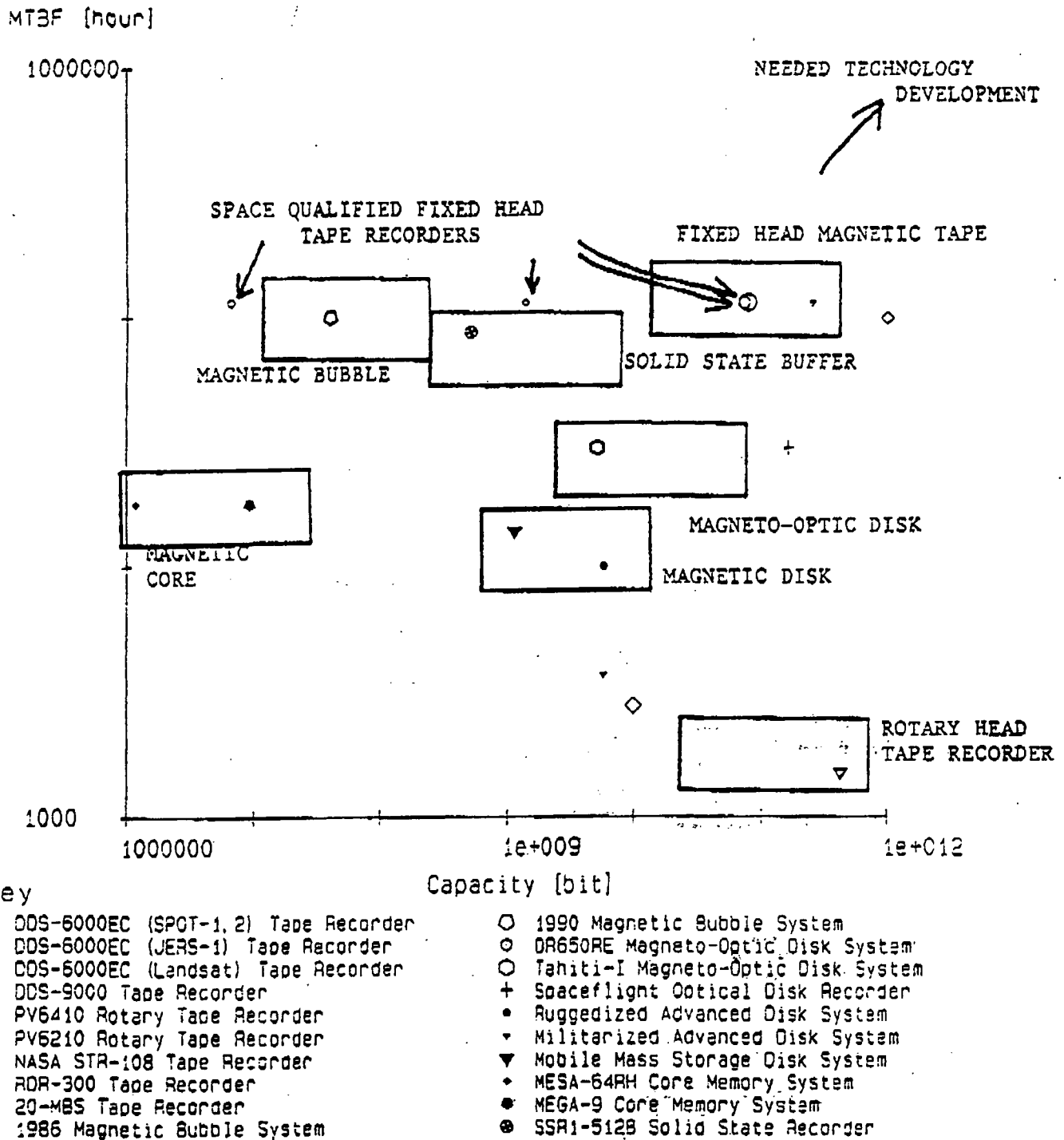


Figure 12: Graph of System Mean Time Before Failure vs. Capacity for Existing Data Storage Systems.