INTRODUCTION

MNOS storage elements have been used to realize a block-oriented all electronic secondary memory module. This nonvolatile storage unit offers 10-microsecond data access and reliable error free operation. BORAM modules provide an immediately available cost effective alternative to electromechanical storage in severe environment applications. The text below describes an 18-million-bit advanced development model of a BORAM module and briefly outlines the growth potential of MNOS BORAM systems.

BORAM CONCEPT

The acronym BORAM and the concept of a block-oriented memory were originated at ECOM in June of 1963. Motivated by frustration with the characteristics of available secondary storage, ECOM personnel drew up a set of desired performance goals. It was reasoned that if data were manipulated in blocks, significant simplification in addressing and control circuitry could be achieved. BORAM was constrained to an all electronic implementation, but otherwise no particular storage technology was specified.

During the next ten years ECOM diligently sought a practical realization of the BORAM. The Electronics Command worked with several contractors to explore the feasibility of magneto-sonics, ferro-electrics, traveling domain walls, magnetic wires, bubbles, electron beams, and MNOS. Of these options only the MNOS approach was confirmed to be currently ready for production.

A BORAM module can be configured for many different data structures. In the advanced development model information to be stored is processed in bytes consisting of 8 data bits and 1 parity bit. A block is defined to be a sequentially ordered set of 2048 bytes. The BORAM module can store 1024 blocks. Any block can be addressed and written or read. An operation (read or write) will always begin with the first byte of the addressed block, and then will proceed to the higher order bytes in sequence.

MODULE FUNCTIONAL STRUCTURE

Figure 1 identifies the six functional parts of the BORAM module. The storage section provides nonvolatile read/write storage for 18,874,368 bits. It contains MNOS memory chips, associated drivers and buffers, and power switching circuitry.

The I/O section performs all communication with the external controller. It accepts control signals and data, and outputs status signals and data. Internal to the module it issues commands to the data buffer and control section, and transmits the block address to the block selection section.

An important aspect of the module design is that it can be used with different computer systems simply by insertion of a different I/O card. At the heart of the I/O section is a small microprogrammed controller. Changes in microprogram customize the I/O logic for a particular installation. Other custom elements such as the line drivers and receivers also appear on this card.

A small data buffer and the module control circuitry are located on one PC card. The control circuitry responds to requests from the I/O section and provides signals to operate the storage section and the data buffer. This circuitry also generates all timing signals and data bits for error detection purposes.

Dynamic shift registers are employed within the BORAM storage chips for data input and output. Synchronous transfer of data between the buffer and the storage section avoids any possible loss of data. Transfers between the buffer and I/O are asynchronous and long delays may be tolerated. The buffer also performs a data format conversion...
function. Data enters the BORAM module in 9-bit bytes and is converted to an 18-bit format as it enters the storage section.

The block selection section accepts a block address from the I/O section and generates the signals which enable the appropriate drivers and memory chips in the storage section.

Self-test electronics are powered down during normal module operation. A front panel switch and readout allow manual confirmation of the module performance.

PHYSICAL STRUCTURE

The BORAM module is intended to be a general purpose storage unit for military applications. Ground fixed, airborne inhabited, and ground mobile operating, environments are specified. The operating ambient temperature range is 

As shown in Figure 2 the module is housed in a rugged case. It can be mounted and used in the case, or the rear portion of the case can be removed and the module can be mounted on chassis slides.

The front panel fin structure serves to transfer heat to the external environment and also provides a mounting surface for the module controls and indicators. As indicated in Table I, the unit weighs 120 pounds and occupies 4 cubic feet.

STORAGE ELEMENT

The BORAM storage element is a drain-source protected MNOS memory transistor (see Reference 1). This Westinghouse proprietary transistor structure avoids the read window closure degradation that is characteristic of non-protected MNOS transistor designs.

Nonprotected memory transistors generally become unusable after about $10^6$ clear/write cycles. Tests on drain-source protected transistors are still in progress and have exceeded $10^8$ clear/write cycles. No significant read window closure has been observed.

Elimination of degradation is an essential prerequisite for application of MNOS in BORAM systems. Figure 3 shows the wide range of cycling which can be experienced by a memory transistor within a BORAM. The plot assumes the operating parameters specified for the advanced development model, and operating time is defined as the actual time the module is engaged in a read or write operation. Obviously a $10^6$ cycle limitation could not provide a satisfactory system operating life.

STORAGE SECTION

Data is stored in memory chips which have been designated as "BORAM 6000" integrated circuits (see Reference

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<tr>
<th>CHARACTERISTIC</th>
<th>MAGNITUDE</th>
<th>UNITS</th>
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<tr>
<td>STORAGE CAPACITY</td>
<td>18,874,368</td>
<td>BITS</td>
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<tr>
<td>READ ACCESS TIME</td>
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<td>MICROSECONDS</td>
</tr>
<tr>
<td>DATA TRANSFER RATE</td>
<td>$2 \times 10^6$</td>
<td>BYTES/SEC</td>
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2). Each chip provides 2048 bits of nonvolatile, nondestructive readout storage. The chip contains a fully decoded RAM organized as 64 words by 32 bits, and two 16-bit two-phase dynamic shift registers. All data I/O takes place serially via the shift registers. This scheme considerably reduces the operating speed requirements imposed on the RAM.

The memory chip features a read access time of about 5 microseconds and a register shift rate of 3.3 megahertz over the operating temperature range. For the BORAM module use conditions retention time exceeds 4000 hours.

The primary building block of the storage section is a hybrid microcircuit which contains 16 of the BORAM 6000 chips. This package will store 32,768 bits. Nine microcircuits are placed on a printed circuit card with associated driver, buffer, and power switching circuitry.

Power switching is particularly effective in the storage section. When the section is engaged in a read or write, approximately 10 watts are dissipated. When the module is active, but the storage section is not engaged in a read or write, about 1.7 watts (<0.1 microwatts/bit) are dissipated. The bulk of module power is required for functions outside the storage section.

**NONVOLATILE TECHNOLOGY COMPARISON**

Because MNOS BORAM is a new technology, it seems worthwhile to try to position it approximately within the context of other technology options. Figure 4 shows that BORAM offers about three orders of magnitude improvement in access time over fixed head drums and discs. At present it appears practical to build BORAM modules as large as \(10^8\) bits. This exceeds the capacity of fixed head systems and encroaches on many moving head designs.

Table II contrasts the characteristics of some specific existing military storage systems against the BORAM advanced development models. Obviously these systems constitute only one sample of what a technology can achieve, and this data should be treated accordingly. Parameter computations encompassed total operating configuration including such items as drives, controllers and power supplies.

Slow versions of plated wire and core can be used to configure secondary storage with faster access time than the BORAM, but serious penalties would be incurred in cost, volume, weight, and power. In every category except cost the BORAM offers advantages over fixed head drum and disc configurations. The moving head system enjoys more than an order of magnitude cost advantage, but the BORAM has equivalent or better characteristics in the other categories.

Comparison of the reliability of these alternatives is a more complex task. Reliability is a function of the use environment. For rugged environments like the ground mobile application electromechanical systems should be avoided.
Here BORAM is the most cost effective all electronic implementation option.

In mild environments the BORAM is expected to have about twice the MTBF of a high reliability fixed head system of the same capacity. Because of the newness of the MNOS BORAM this expectation has not yet been verified by actual test.

**MNOS BORAM GROWTH POTENTIAL**

As the MNOS technology matures significant reductions will occur in cost/bit, and the storage capacity of a single BORAM module will increase. These changes will be brought about by the usual "learning curve" improvements associated with integrated circuits and by the introduction of new memory chips with higher bit density.

Figure 5 presents a conservative projection of the trend for module selling prices. By 1978 MNOS BORAM modules will have a cost advantage over fixed head disc/drum systems for military applications. Eventually the MNOS BORAM will become cost competitive with militarized moving head disc systems.

From reliability considerations it can be shown that a practical limit to BORAM module size is 10,000 to 30,000 memory chips. If error correction and/or redundancy is incorporated in the module, even larger configurations become practical. The nonvolatility of the memory chip allows the bulk of the system to remain powered down, and thus the chip failure rate is reduced to that of a nonoperating chip.

Figure 6 shows how the expected increases in bit density per chip will affect module storage capacity. In 1974 a 4K chip will be available, and 100-megabit modules will be feasible. Eventual growth to 1000-megabit modules is within the capability of the technology.

**SUMMARY**

Block-oriented random access memory has evolved from its initial conception at ECOM as a set of idealized performance requirements to a practical working model. This 18-megabit module was implemented using MNOS memory chips designed especially for the BORAM application. Module organization and circuit design has achieved a flexible high utility configuration suitable for use in rugged environments.

MNOS BORAM provides advantages in access time, size, weight, power and reliability when compared against fixed head electromechanical systems. At present MNOS BORAM is a cost effective alternative to electromechanical memories in severe environment applications. In the near future BORAM will compete with a large class of electromechanical memories on a direct cost basis.

**REFERENCES**