Williams Tube CRT-based random access memory, 1946. Used on the Manchester Mark I. 2048 bits.
Early Memories

Mercury acoustic delay line.
Used in the EDASC, 1947.
$32 \times 17$ bits
Magnetic core memory, 1952. IBM.
Early Memories

Magnetic drum memory. 1950s & 60s. Secondary storage.
## Modern Memory Choices

<table>
<thead>
<tr>
<th>Family</th>
<th>Programmed</th>
<th>Persistence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mask ROM</td>
<td>at fabrication</td>
<td>∞</td>
</tr>
<tr>
<td>PROM</td>
<td>once</td>
<td>∞</td>
</tr>
<tr>
<td>EPROM</td>
<td>1000s, UV</td>
<td>10 years</td>
</tr>
<tr>
<td>FLASH</td>
<td>1000s, block</td>
<td>10 years</td>
</tr>
<tr>
<td>EEPROM</td>
<td>1000s, byte</td>
<td>10 years</td>
</tr>
<tr>
<td>NVRAM</td>
<td>∞</td>
<td>5 years</td>
</tr>
<tr>
<td>SRAM</td>
<td>∞</td>
<td>while powered</td>
</tr>
<tr>
<td>DRAM</td>
<td>∞</td>
<td>64 ms</td>
</tr>
</tbody>
</table>
ROMs

8 × 4 ROM

enable

3×8 decoder

A₀, A₁, A₂

word 0, word 1, word 2

word line

data line

programmable connection

wired-OR

Q₃, Q₂, Q₁, Q₀
EPROMs
EEPROM and FLASH

Slow write

Fowler-Nordheim Tunneling

EEPROM: bit at a time

FLASH: block at a time

Source: SST
Static RAM Cell

Word

Bit

Bit
Standard SRAM: 6264

- **8K \times 8**
- Can be very fast: Cypress sells a 55ns version
- Simple, asynchronous interface

### Address Space
- **Addr[12:0]**: 19–15, 13–11, 10–2, 25–23, 21

### Data Space
- **D[7:0]**
- **CS1**
- **CS2**
- **WE**
- **OE**
Standard SRAM: 6264

- CS1
- CS2
- WE
- OE
- Addr
- Data
Features

• 55, 70 ns access times
• CMOS for optimum speed/power
• Easy memory expansion with CE1, CE2, and OE features
• TTL-compatible inputs and outputs
• Automatic power-down when deselected

Functional Description

The CY6264 is a high-performance CMOS static RAM organized as 8192 words by 8 bits. Easy memory expansion is provided by an active LOW chip enable (CE1), an active HIGH chip enable (CE2), and active LOW output enable (OE) and three-state drivers. Both devices have an automatic power-down feature (CE1), reducing the power consumption by over 70% when deselected. The CY6264 is packaged in a 450-mil (300-mil body) SOIC.

An active LOW write enable signal (WE) controls the writing/reading operation of the memory. When CE1 and WE inputs are both LOW and CE2 is HIGH, data on the eight data input/output pins (I/O0 through I/O7) is written into the memory location addressed by the address present on the address pins (A0 through A12). Reading the device is accomplished by selecting the device and enabling the outputs, CE1 and OE active LOW, CE2 active HIGH, while WE remains inactive or HIGH. Under these conditions, the contents of the location addressed by the information on address pins is present on the eight data input/output pins.

The input/output pins remain in a high-impedance state unless the chip is selected, outputs are enabled, and write enable (WE) is HIGH. A die coat is used to insure alpha immunity.
Toshiba TC55V16256J 256K × 16

38–35, 32–29, 16–13, 10–7

D[15:0]
Addr[17:0]
UB
LB
OE
WE
CE

12 or 15 ns access time
Asynchronous interface
UB, LB select bytes
Toshiba TC55V16256J 256K × 16

Memory - p. 15
Dynamic RAM Cell

Basic problem: Leakage

Solution: Refresh
Ancient DRAM: 4164

64K × 1
Apple IIe vintage

9,13,10–12,6,7,5

Addr[7:0]
DIN DOUT
WE
CAS
RAS

2 3 15 4
Basic DRAM read and write cycles

- **RAS**
- **CAS**
- **Addr**
- **WE**
- **Din**
- **Dout**
Page mode read cycle

\[ \text{RAS} \]

\[ \text{CAS} \]

\[ \text{Addr} \]

\[ \text{WE} \]

\[ \text{Din} \]

\[ \text{Dout} \]
Samsung 8M × 16 SDRAM

21,20 → BA[1:0]
         Addr[11:0]
         DQ[15:0]
       39 → UDQM
       15 → LDQM
       3 → WE
       15 → CAS
       15 → RAS
       37 → CKE
       38 → CLK

Bank address
Address (multiplexed)
Data I/O
Upper byte enable
Lower byte enable
Write enable
Column Address Strobe
Row Address Strobe
Clock Enable
Clock

Synchronous interface
Designed for burst-mode operation
Four separate banks; pipelined operation
## SDRAM: Control Signals

<table>
<thead>
<tr>
<th>RAS</th>
<th>CAS</th>
<th>WE</th>
<th>action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NOP</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Load mode register</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Active (select row)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Read (select column, start burst)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Write (select column, start burst)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Terminate Burst</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>Precharge (deselect row)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>Auto Refresh</td>
</tr>
</tbody>
</table>

Mode register: selects 1/2/4/8-word bursts, CAS latency, burst on write
SDRAM: Timing with 2-word bursts

Clk

RAS

CAS

WE

Addr

BA

DQ

Load  Active  Write  Read  Refresh

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