

William Stallings
Computer Organization
and Architecture
8th Edition

Chapter 5
Internal Memory

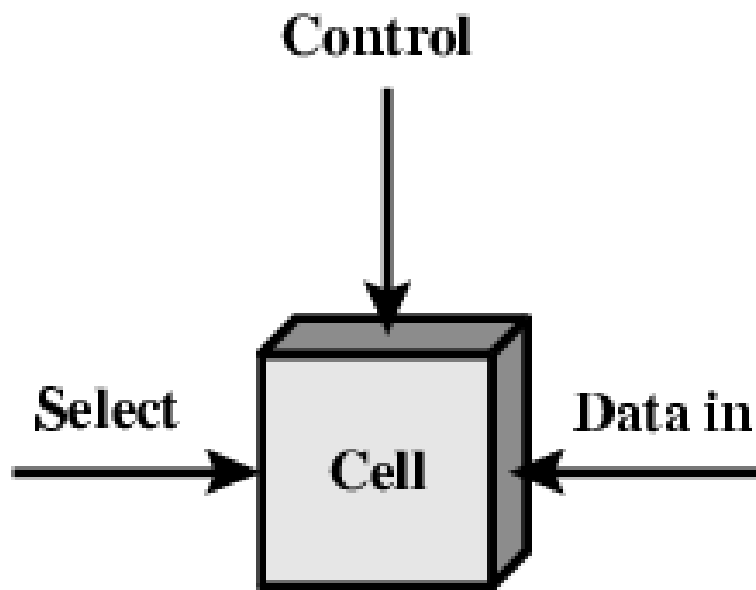
Semiconductor Memory Types

Memory Type	Category	Erase	Write Mechanism	Volatility
Random-access memory (RAM)	Read-write memory	Electrically, byte-level	Electrically	Volatile
Read-only memory (ROM)	Read-only memory	Not possible	Masks	Nonvolatile
Programmable ROM (PROM)			Electrically	
Erasable PROM (EPROM)	Read-mostly memory	UV light, chip-level	Electrically	
Electrically Erasable PROM (EEPROM)		Electrically, byte-level		
Flash memory		Electrically, block-level		

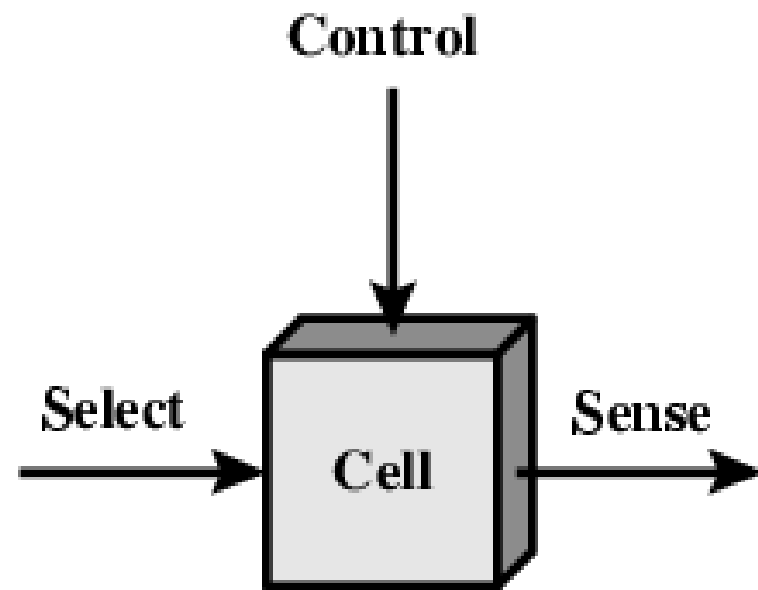
Semiconductor Memory

- RAM
 - Misnamed as all semiconductor memory is random access
 - Read/Write
 - Volatile
 - Temporary storage
 - Static or dynamic

Memory Cell Operation



(a) Write

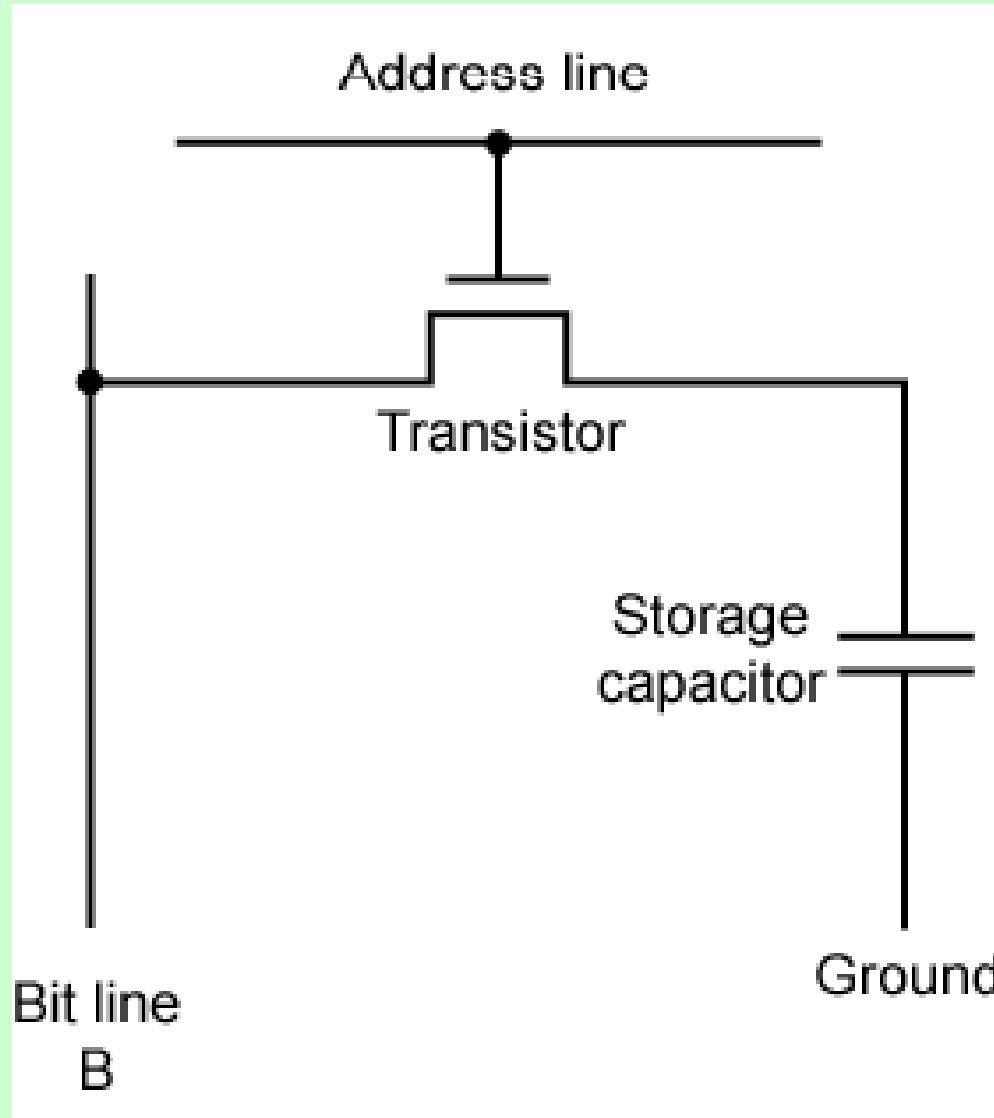


(b) Read

Dynamic RAM

- Bits stored as charge in capacitors
- Charges leak
- Need refreshing even when powered
- Simpler construction
- Smaller per bit
- Less expensive
- Need refresh circuits
- Slower
- Main memory
- Essentially analogue
 - Level of charge determines value

Dynamic RAM Structure



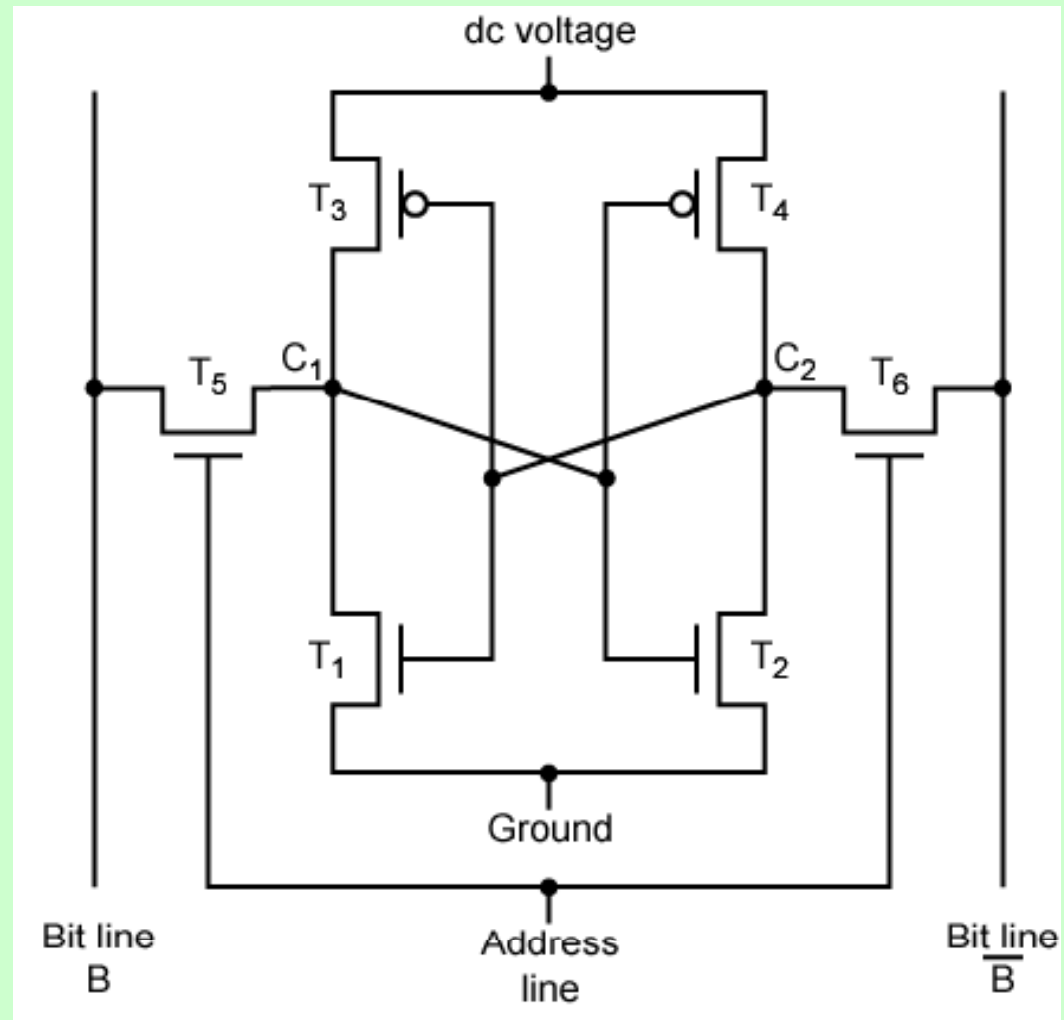
DRAM Operation

- Address line active when bit read or written
 - Transistor switch closed (current flows)
- Write
 - Voltage to bit line
 - High for 1 low for 0
 - Then signal address line
 - Transfers charge to capacitor
- Read
 - Address line selected
 - transistor turns on
 - Charge from capacitor fed via bit line to sense amplifier
 - Compares with reference value to determine 0 or 1
 - Capacitor charge must be restored

Static RAM

- Bits stored as on/off switches
- No charges to leak
- No refreshing needed when powered
- More complex construction
- Larger per bit
- More expensive
- Does not need refresh circuits
- Faster
- Cache
- Digital
 - Uses flip-flops

Stating RAM Structure



Static RAM Operation

- Transistor arrangement gives stable logic state
- State 1
 - C_1 high, C_2 low
 - T_1 T_4 off, T_2 T_3 on
- State 0
 - C_2 high, C_1 low
 - T_2 T_3 off, T_1 T_4 on
- Address line transistors T_5 T_6 is switch
- Write – apply value to B & compliment to \bar{B}
- Read – value is on line B

SRAM v DRAM

- Both volatile
 - Power needed to preserve data
- Dynamic cell
 - Simpler to build, smaller
 - More dense
 - Less expensive
 - Needs refresh
 - Larger memory units
- Static
 - Faster
 - Cache

Read Only Memory (ROM)

- Permanent storage
 - Nonvolatile
- Microprogramming (see later)
- Library subroutines
- Systems programs (BIOS)
- Function tables

Types of ROM

- Written during manufacture
 - Very expensive for small runs
- Programmable (once)
 - PROM
 - Needs special equipment to program
- Read “mostly”
 - Erasable Programmable (EPROM)
 - Erased by UV
 - Electrically Erasable (EEPROM)
 - Takes much longer to write than read
 - Flash memory
 - Erase whole memory electrically

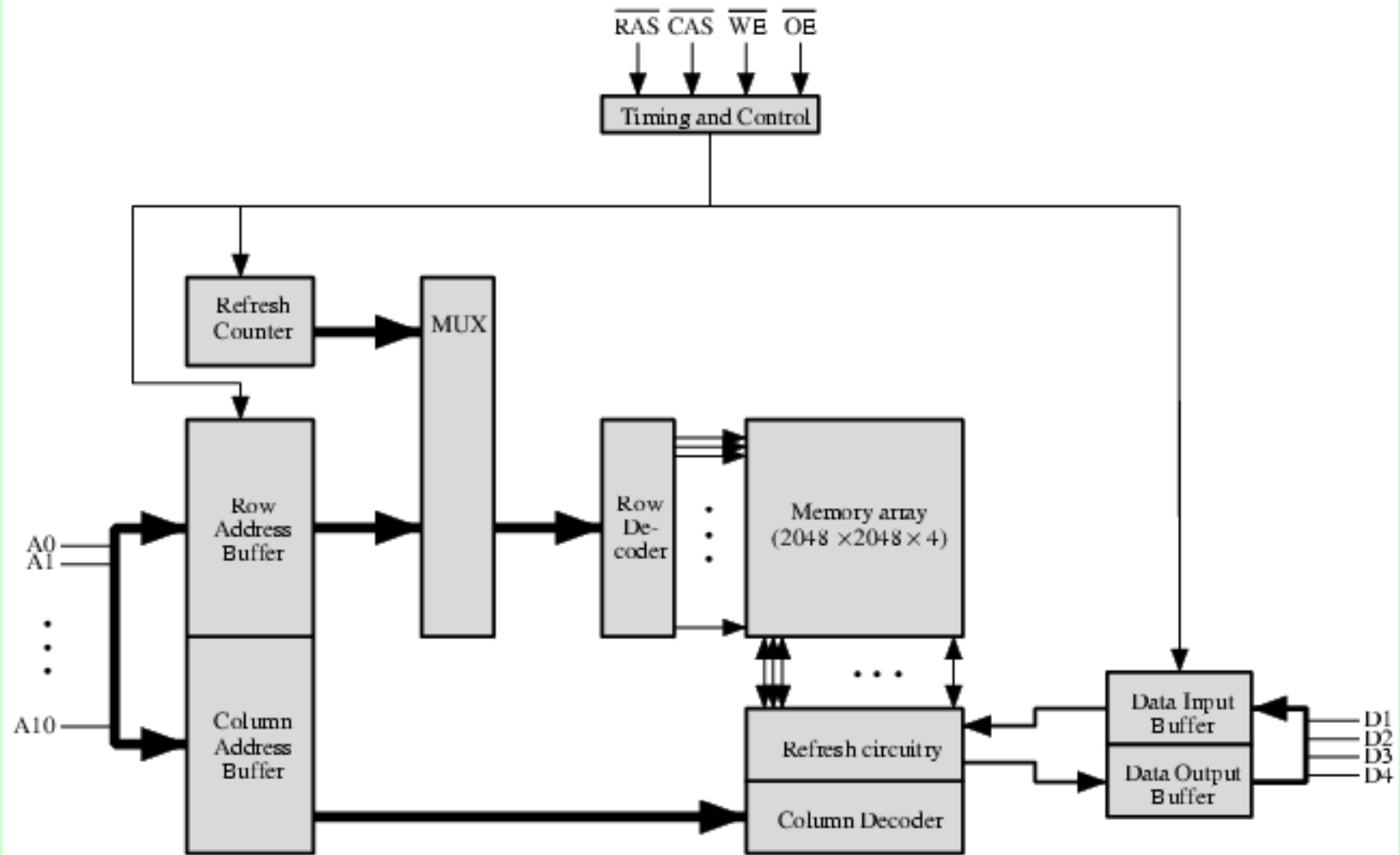
Organisation in detail

- A 16Mbit chip can be organised as 1M of 16 bit words
- A bit per chip system has 16 lots of 1Mbit chip with bit 1 of each word in chip 1 and so on
- A 16Mbit chip can be organised as a 2048 x 2048 x 4bit array
 - Reduces number of address pins
 - Multiplex row address and column address
 - 11 pins to address ($2^{11}=2048$)
 - Adding one more pin doubles range of values so x4 capacity

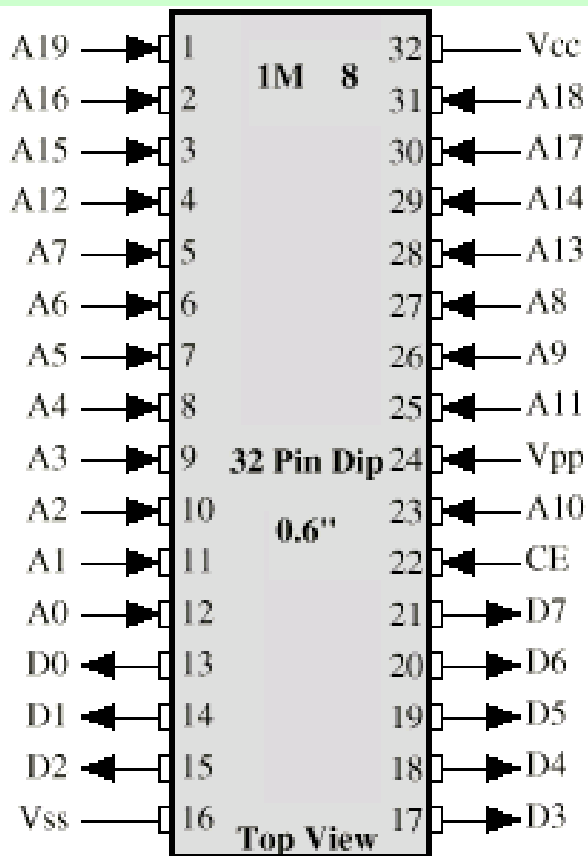
Refreshing

- Refresh circuit included on chip
- Disable chip
- Count through rows
- Read & Write back
- Takes time
- Slows down apparent performance

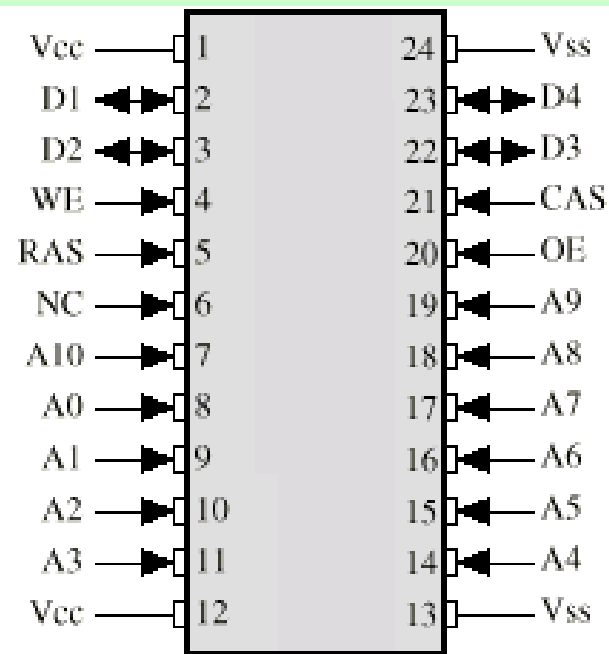
Typical 16 Mb DRAM (4M x 4)



Packaging

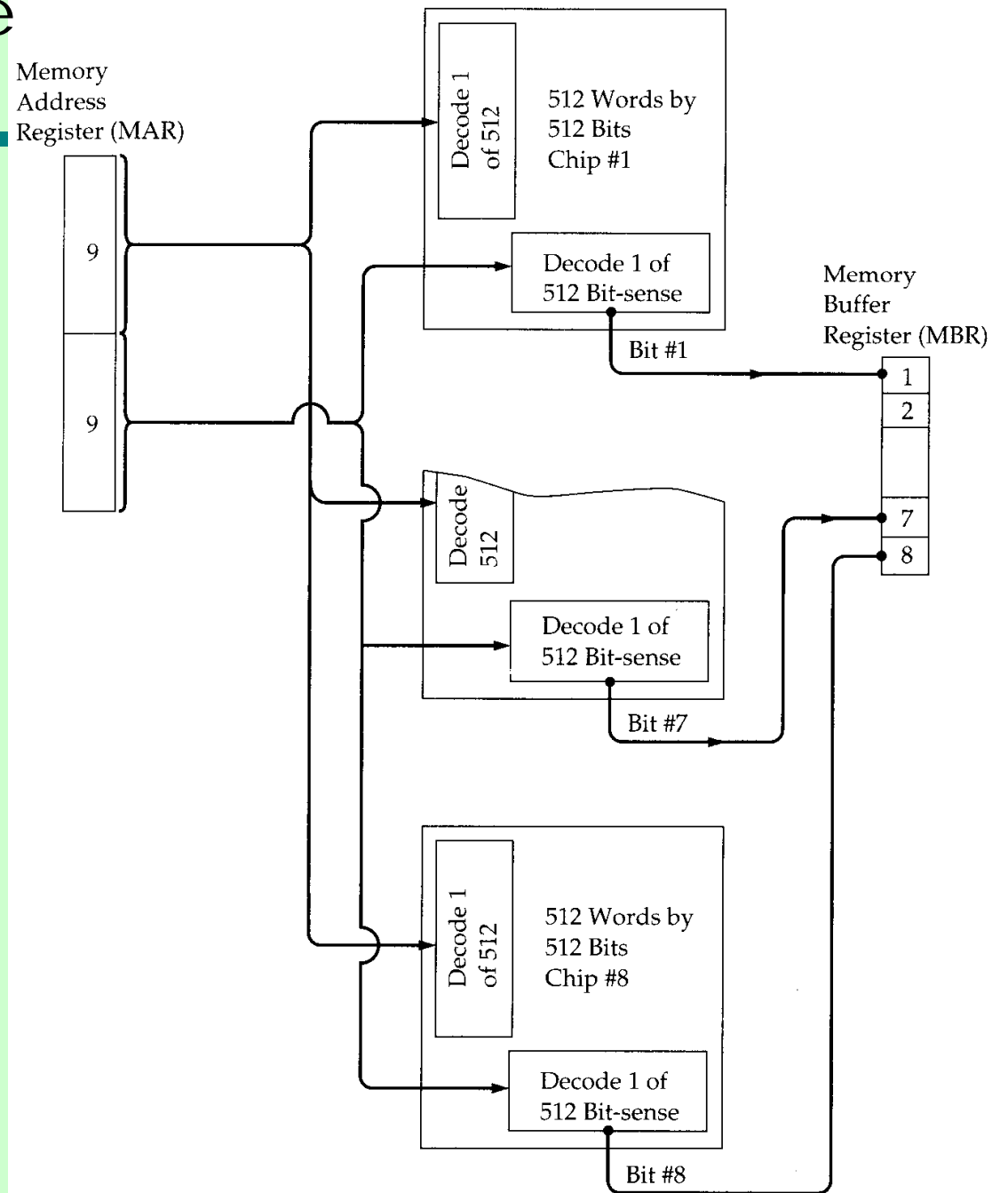


(a) 8 Mbit EPROM

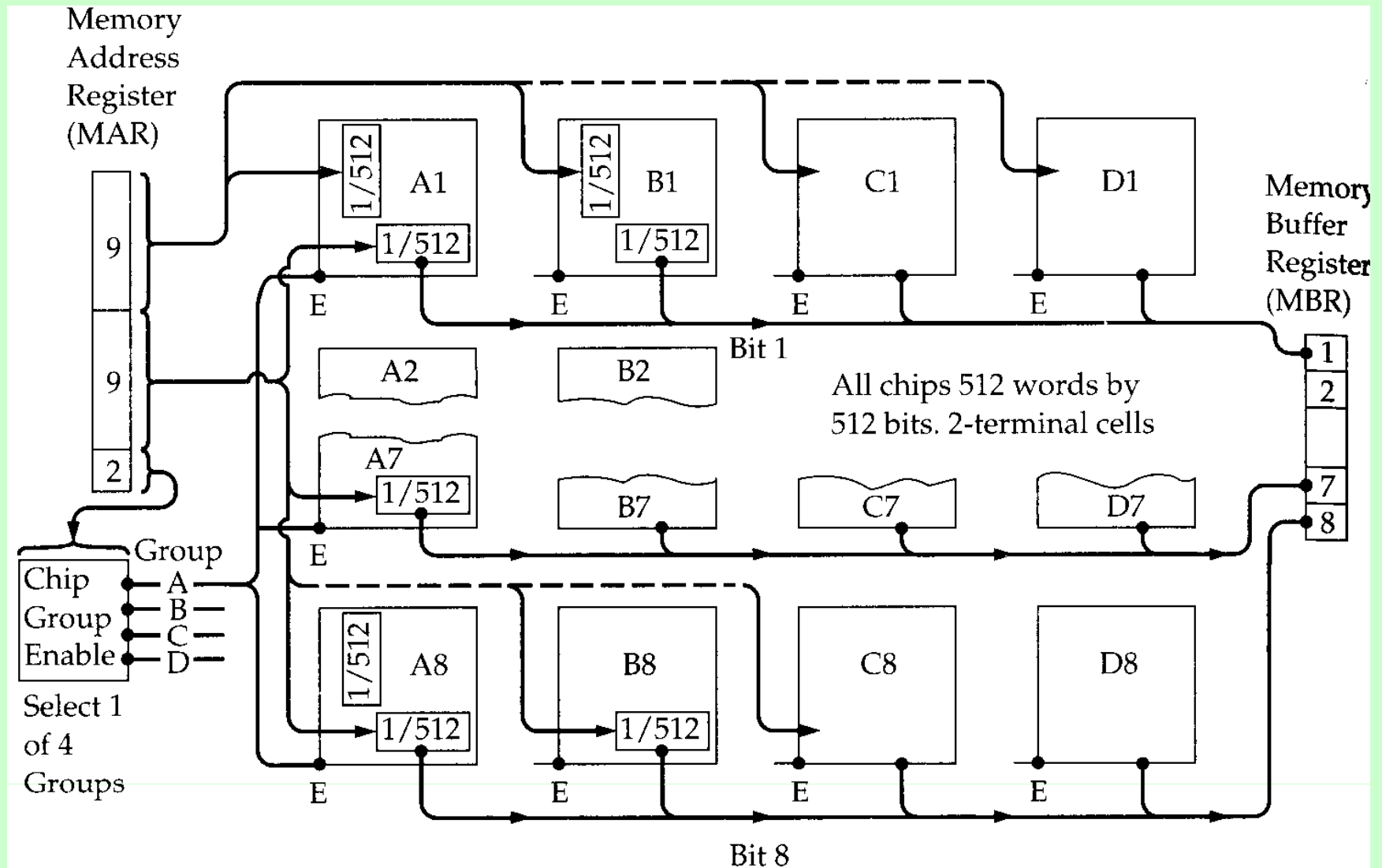


(b) 16 Mbit DRAM

256kByte Module Organisation



1MByte Module Organisation



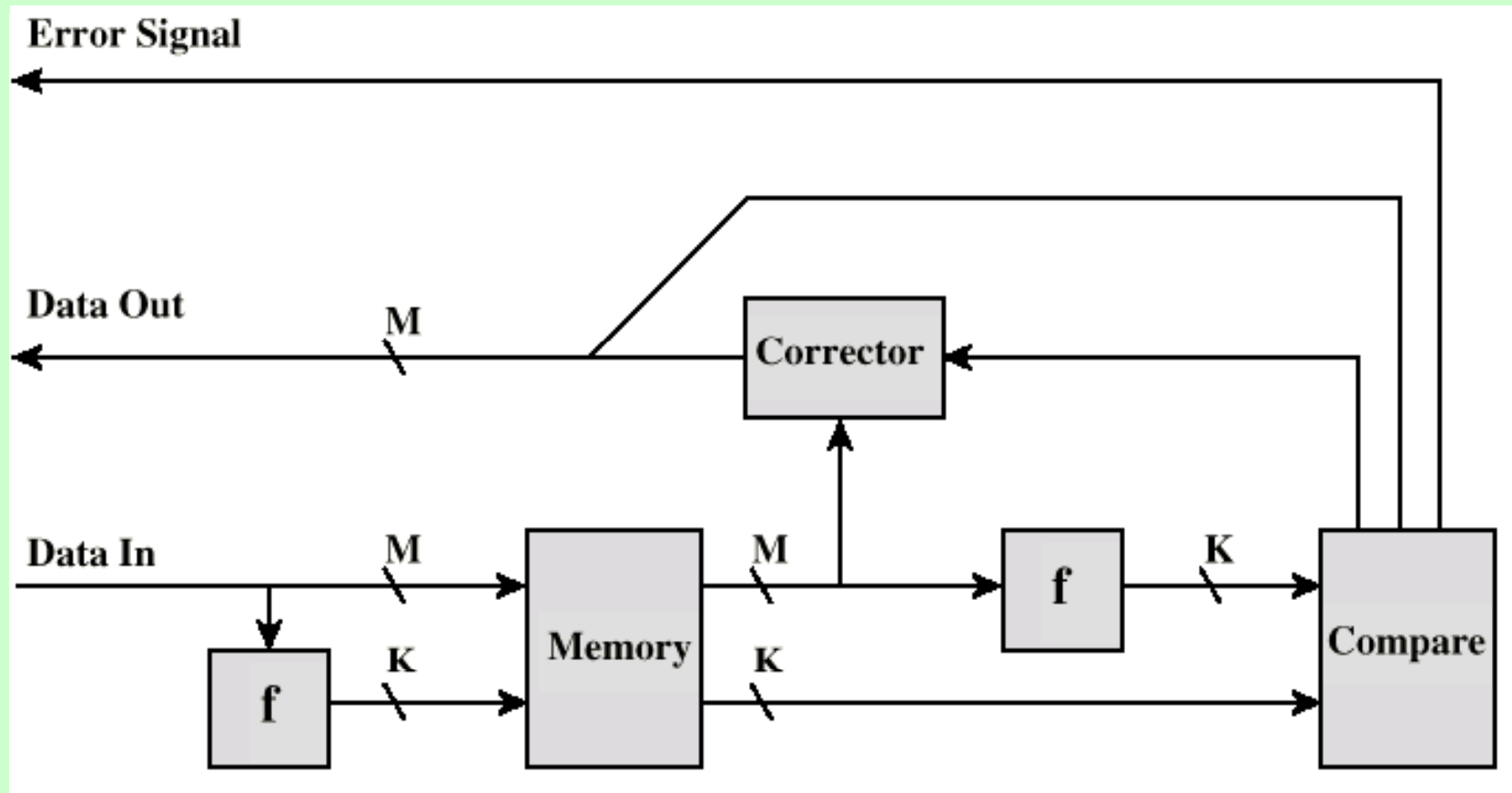
Interleaved Memory

- Collection of DRAM chips
- Grouped into memory bank
- Banks independently service read or write requests
- K banks can service k requests simultaneously

Error Correction

- Hard Failure
 - Permanent defect
- Soft Error
 - Random, non-destructive
 - No permanent damage to memory
- Detected using Hamming error correcting code

Error Correcting Code Function



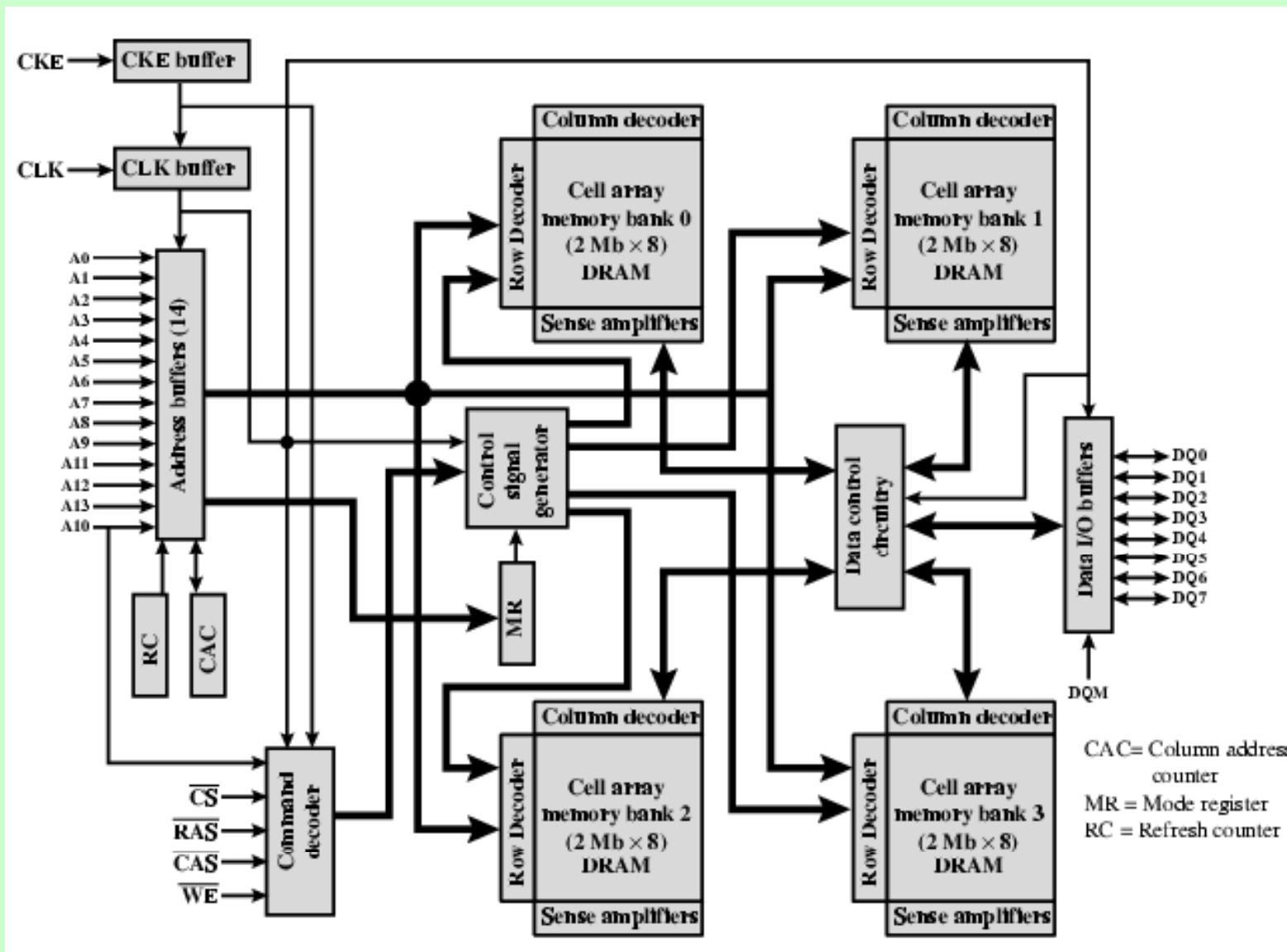
Advanced DRAM Organization

- Basic DRAM same since first RAM chips
- Enhanced DRAM
 - Contains small SRAM as well
 - SRAM holds last line read (c.f. Cache!)
- Cache DRAM
 - Larger SRAM component
 - Use as cache or serial buffer

Synchronous DRAM (SDRAM)

- Access is synchronized with an external clock
- Address is presented to RAM
- RAM finds data (CPU waits in conventional DRAM)
- Since SDRAM moves data in time with system clock, CPU knows when data will be ready
- CPU does not have to wait, it can do something else
- Burst mode allows SDRAM to set up stream of data and fire it out in block
- DDR-SDRAM sends data twice per clock cycle (leading & trailing edge)

SDRAM



SDRAM Read Timing

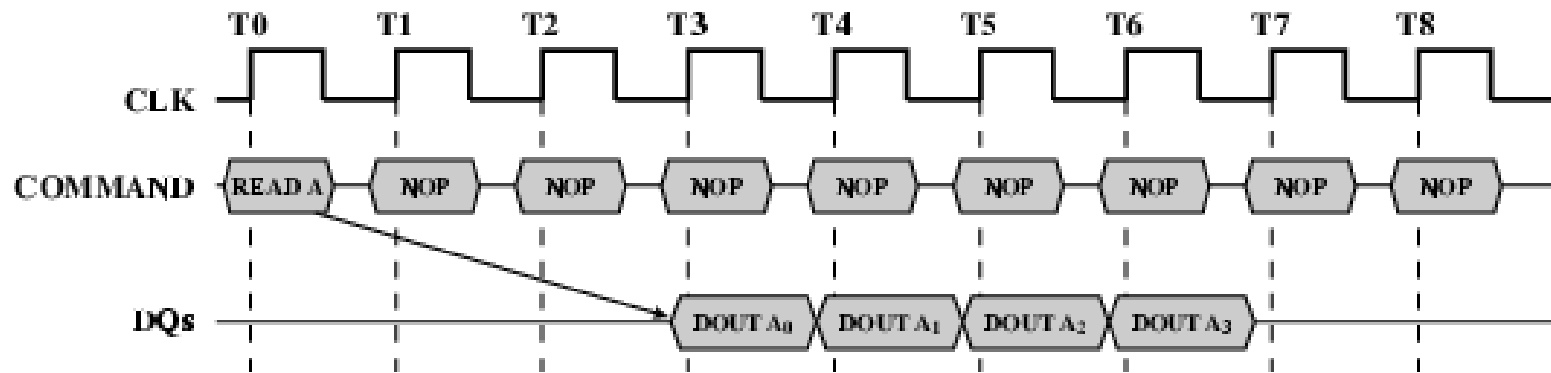
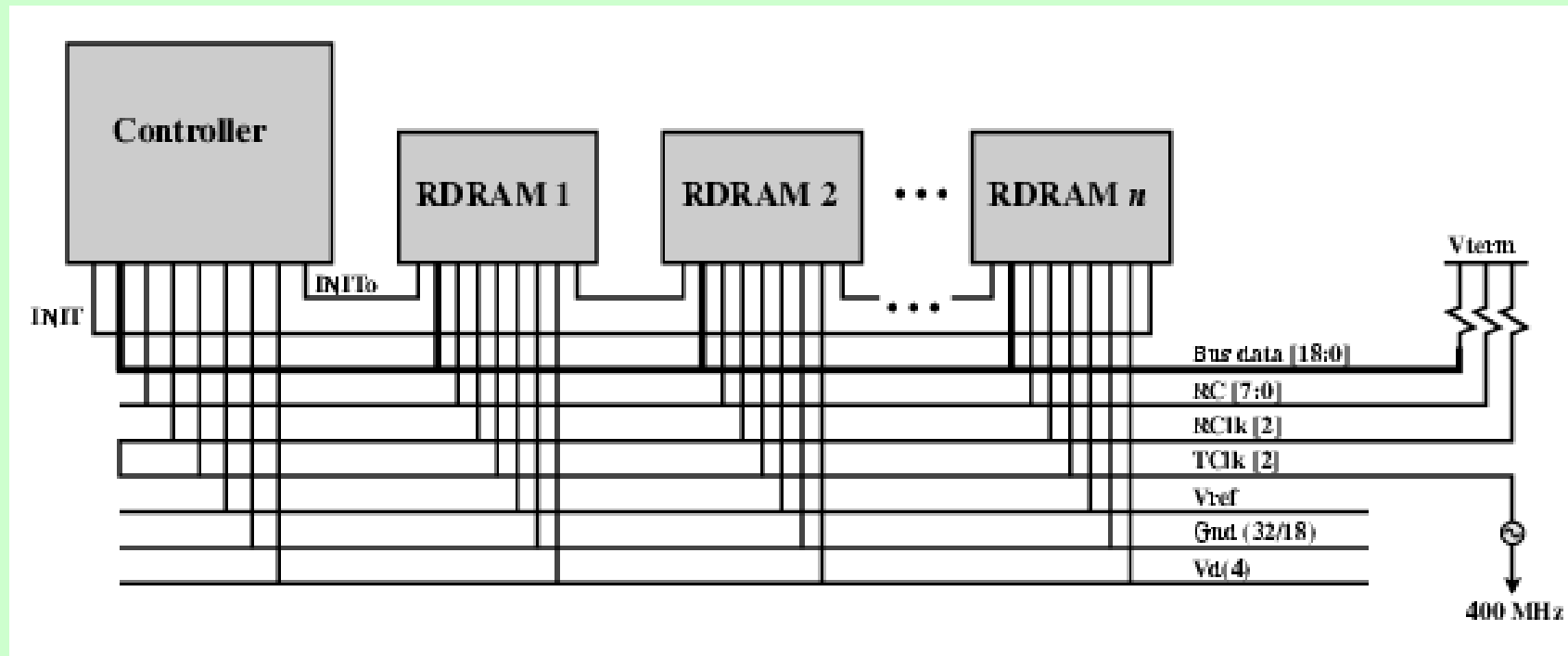


Figure 5.13 SDRAM Read Timing (Burst Length = 4, CAS latency = 2)

RAMBUS

- Adopted by Intel for Pentium & Itanium
- Main competitor to SDRAM
- Vertical package – all pins on one side
- Data exchange over 28 wires < cm long
- Bus addresses up to 320 RDRAM chips at 1.6Gbps
- Asynchronous block protocol
 - 480ns access time
 - Then 1.6 Gbps

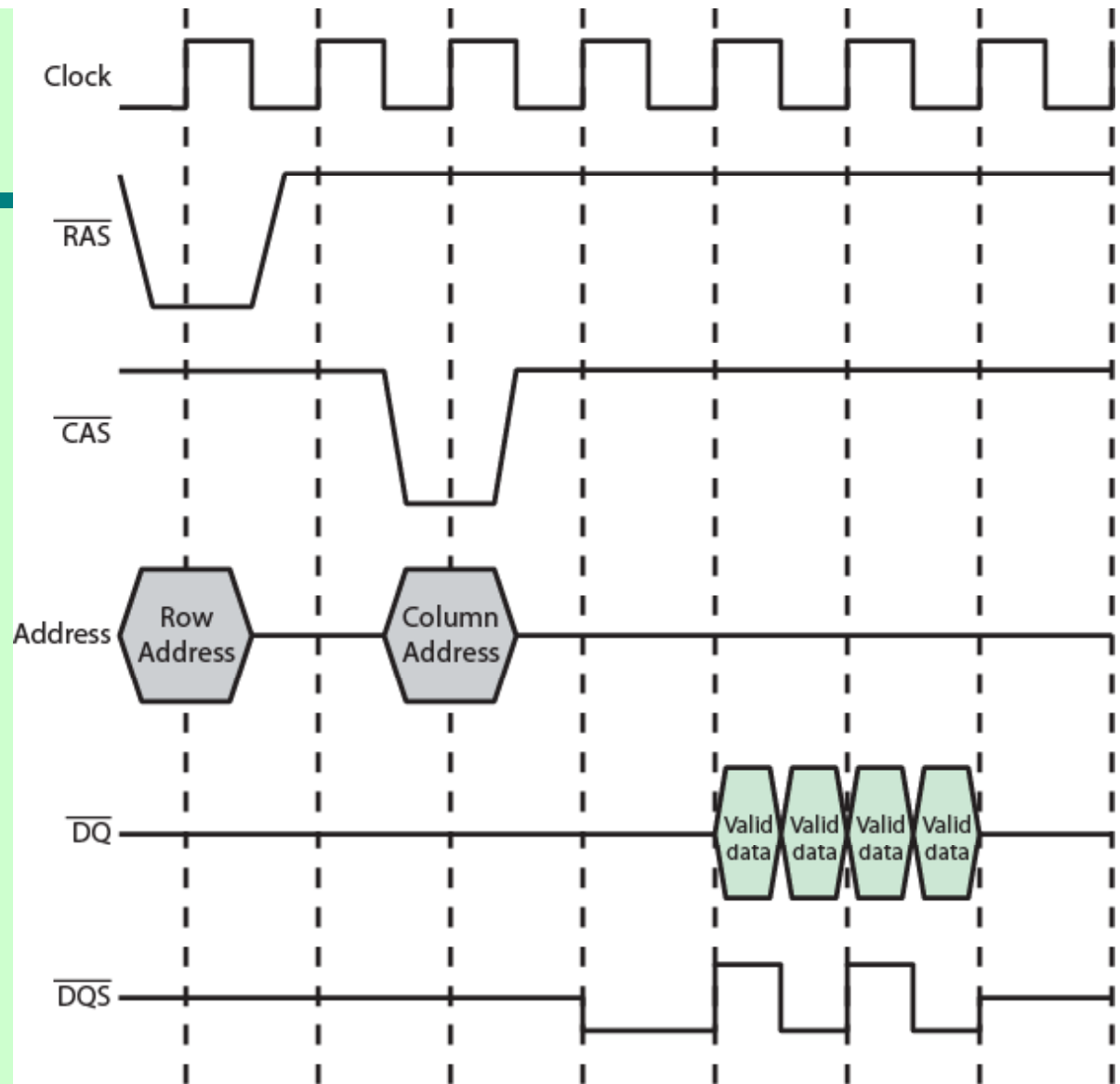
RAMBUS Diagram



DDR SDRAM

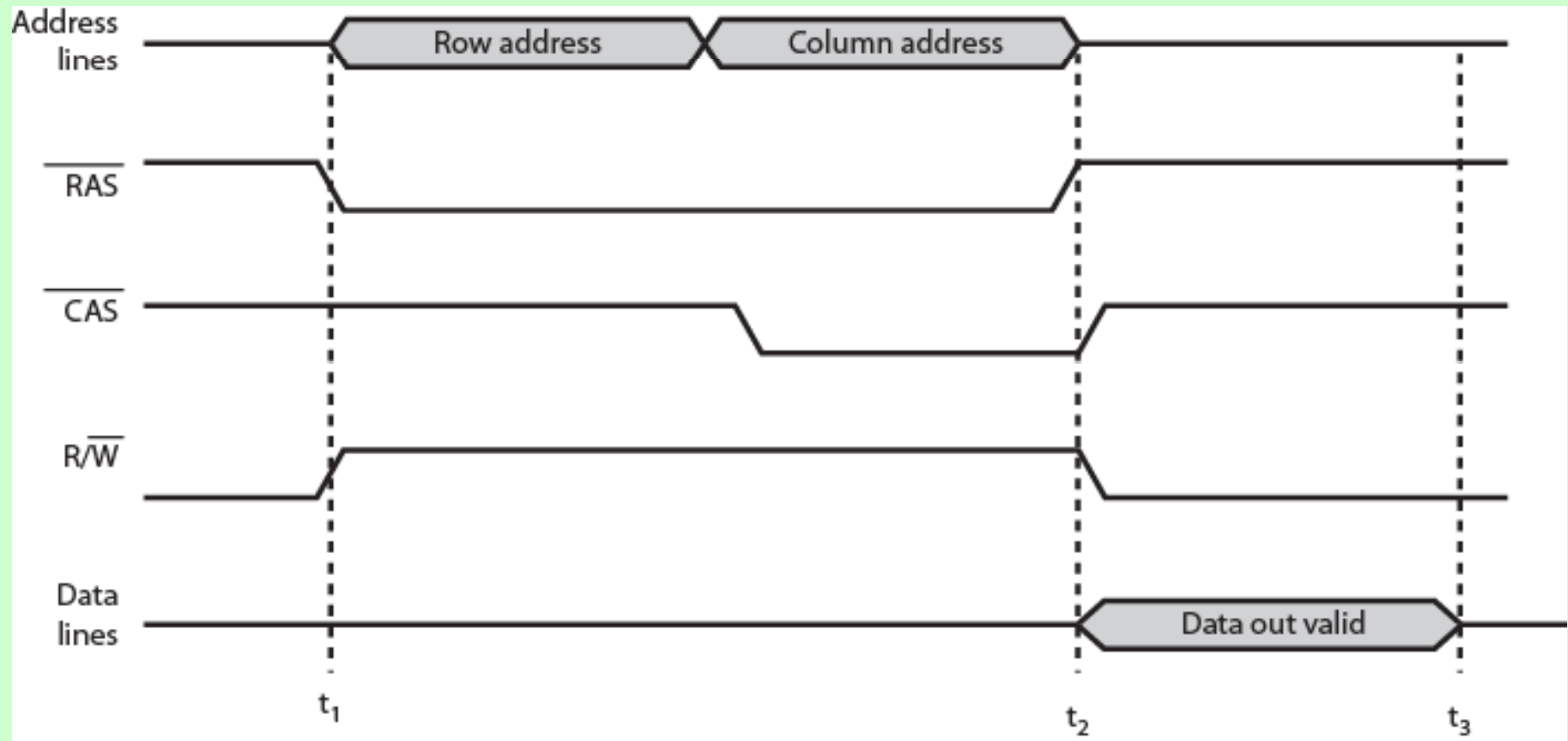
- SDRAM can only send data once per clock
- Double-data-rate SDRAM can send data twice per clock cycle
 - Rising edge and falling edge

DDR SDRAM Read Timing



RAS = row address select
CAS = column address select
DQ = data (in or out)
DQS = DQ select

Simplified DRAM Read Timing



Cache DRAM

- Mitsubishi
- Integrates small SRAM cache (16 kb) onto generic DRAM chip
- Used as true cache
 - 64-bit lines
 - Effective for ordinary random access
- To support serial access of block of data
 - E.g. refresh bit-mapped screen
 - CDRAM can prefetch data from DRAM into SRAM buffer
 - Subsequent accesses solely to SRAM

Reading

- The RAM Guide
- RDRAM