Real Time Clocks (RTC)

- Basically, it is the systems wrist-watch
- Typically, the keep seconds, minutes, hours, days, months, years, and some times centuries.
- Should account for leap-years.
- Most of the time, the system communicates with the RTC on a serial bus. Either setting the time, or requesting the time.
- Naturally, it is going to need some sort of battery back-up, or get set every time it powers up.

Review of Chapter 4…

- There are lots of Standard Single Purpose Processors for all kinds of applications
- We covered a few of the basic ones
- Important points include:
  - Functions of each peripheral we covered
  - Resolution and range calculations
  - A/D and D/A conversion calculations

Outline

Chapter 5 Memory

Outline

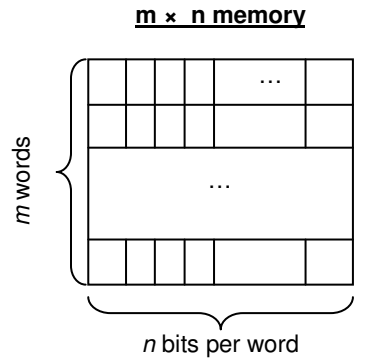
- Memory Write Ability and Storage Permanence
- Common Memory Types
- Composing Memory
- Memory Hierarchy and Cache
- Advanced RAM

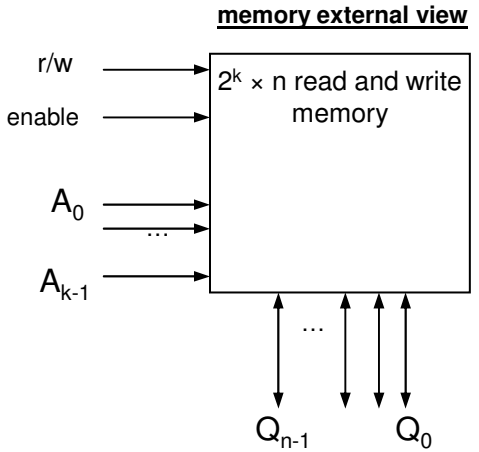
Introduction

- Embedded system's functionality aspects
  - Processing
    - processors
    - transformation of data
  - Storage
    - memory
    - retention of data
  - Communication
    - buses
    - transfer of data

Memory: basic concepts

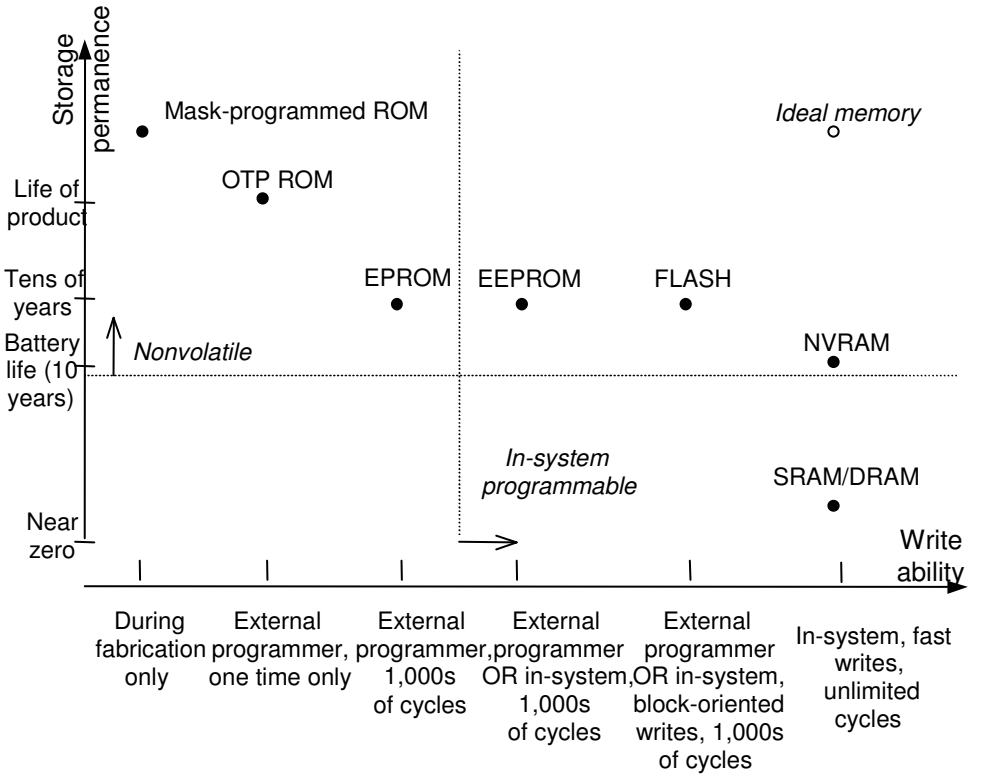
- Stores large number of bits
  - *m* x *n*: *m* words of *n* bits each
  - k = $Log_2(m)$ address input signals
  - or *m* = 2^k words
  - e.g., 4,096 x 8 memory:
    - 32,768 bits
    - 12 address input signals
    - 8 input/output data signals
- Memory access
  - r/w: selects read or write
  - enable: read or write only when asserted
  - multiport: multiple accesses to different locations simultaneously





Write ability/ storage permanence

- Traditional ROM/RAM distinctions
  - ROM
    - read only, bits stored without power
  - RAM
    - read and write, lose stored bits without power
- Traditional distinctions blurred
  - Advanced ROMs can be written to
    - e.g., EEPROM
  - Advanced RAMs can hold bits without power
    - e.g., NVRAM
- Write ability
  - Manner and speed a memory can be written
- Storage permanence
  - ability of memory to hold stored bits after they are written



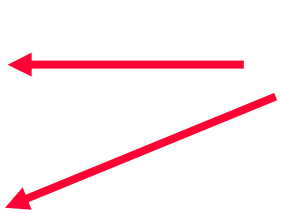
Write ability and storage permanence of memories, showing relative degrees along each axis (not to scale).

Write ability

- Ranges of write ability
  - High end
    - processor writes to memory simply and quickly
    - e.g., RAM
  - Middle range
    - processor writes to memory, but slower
    - e.g., FLASH, EEPROM
  - Lower range
    - special equipment, “programmer”, must be used to write to memory
    - e.g., EPROM, OTP ROM
  - Low end
    - bits stored only during fabrication
    - e.g., Mask-programmed ROM
- In-system programmable memory
  - Can be written to by a processor in the embedded system using the memory
  - Memories in high end and middle range of write ability

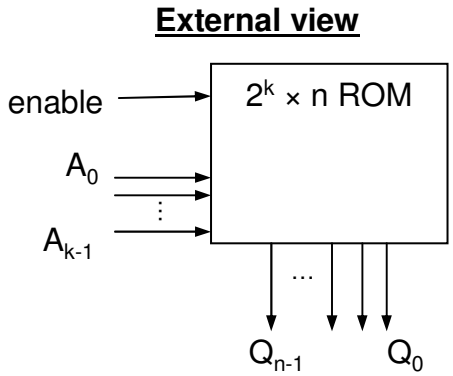
Storage PERMANENCE

- Range of storage permanence
  - High end
    - essentially never loses bits
    - e.g., mask-programmed ROM
  - Middle range
    - holds bits days, months, or years after memory's power source turned off
    - e.g., NVRAM, EEPROM, FLASH
  - Lower range
    - holds bits as long as power supplied to memory
    - e.g., SRAM
  - Low end
    - begins to lose bits almost immediately after written
    - e.g., DRAM



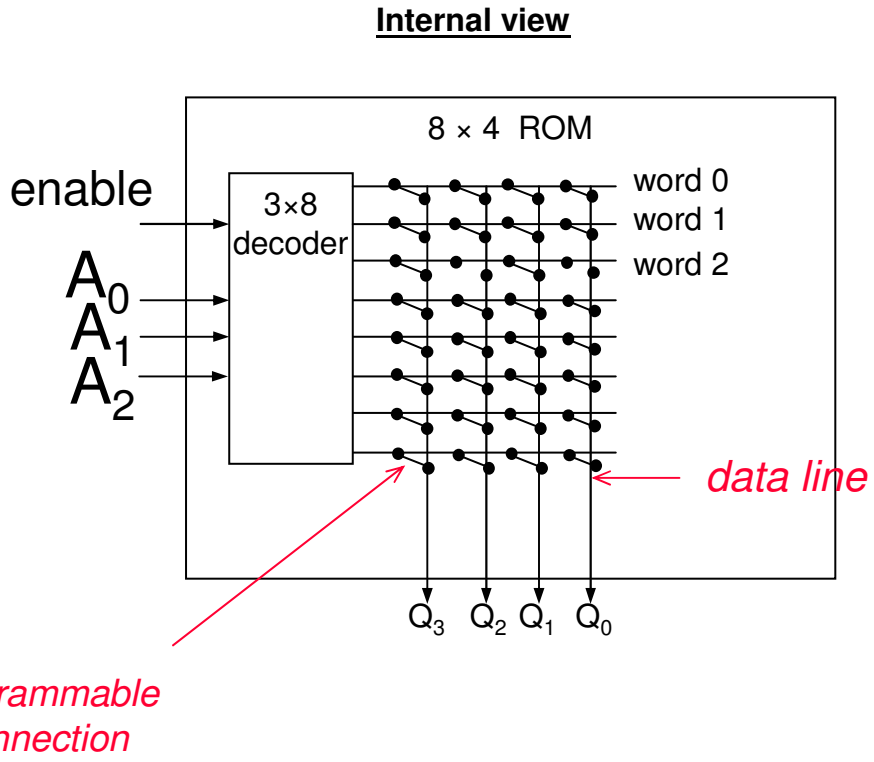
ROM: “Read-Only” Memory

- Nonvolatile memory
- Can be read from but not written to, by a processor in an embedded system
- Traditionally written to, “programmed”, before inserting to embedded system
- Uses
  - Store software program for general-purpose processor
    - program instructions can be one or more ROM words
  - Store constant data needed by system
  - Implement combinational circuit



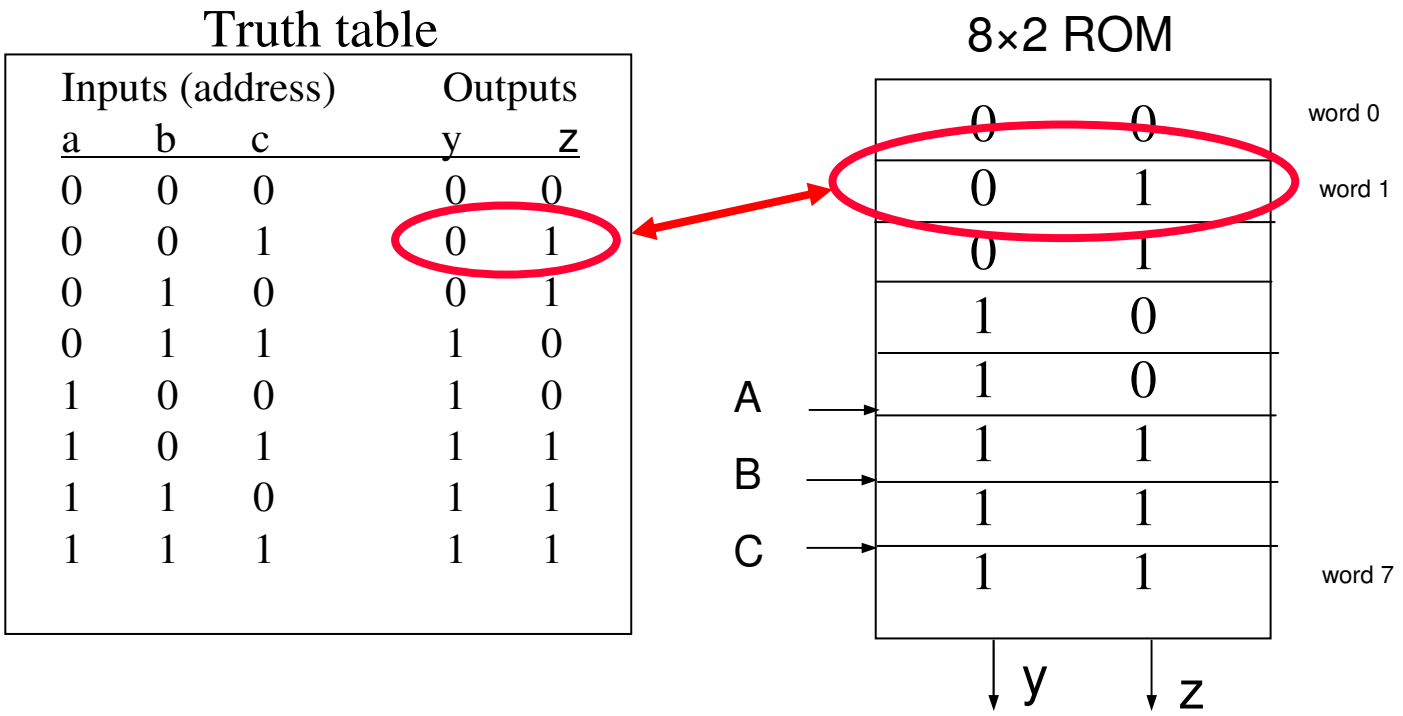
Example: 8 x 4 ROM

- Horizontal lines = words
- Vertical lines = data
- Lines connected only at circles
- Decoder sets word 2's line to 1 if address input is 010
- Data lines Q3 and Q1 are set to 1 because there is a "programmed" connection with word 2's line
- Word 2 is not connected with data lines Q2 and Q0
- Output is 1010



Implementing combinational function

- Any combinational circuit of *n* functions of same *k* variables can be done with 2^*k* x *n* ROM



Mask-programmed ROM

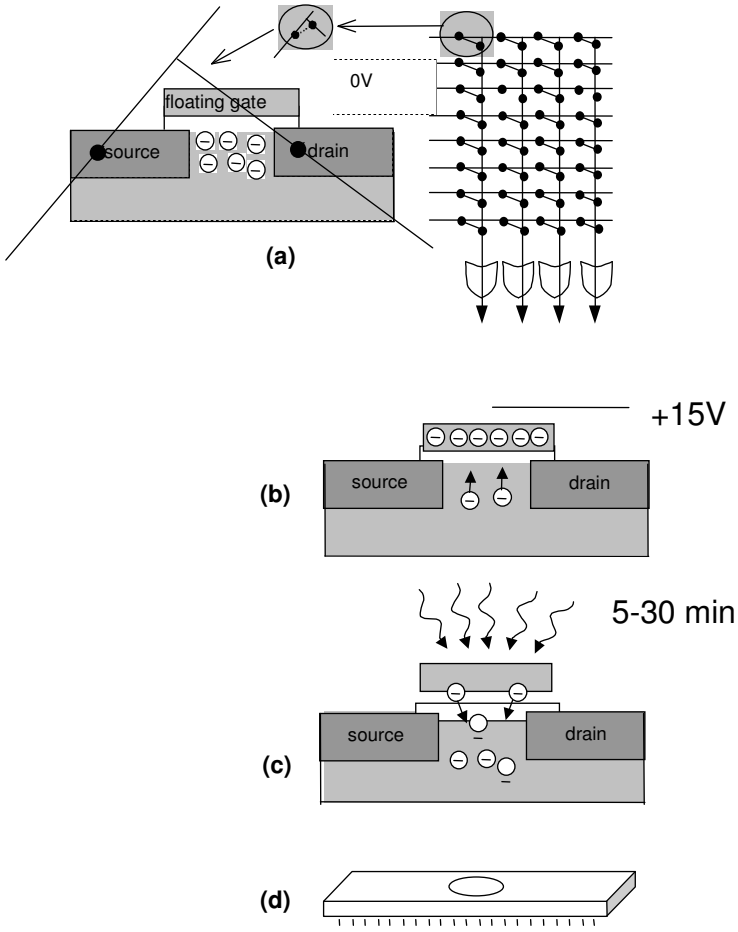
- Connections “programmed” at fabrication
  - set of masks
- Lowest write ability
  - only once
- Highest storage permanence
  - bits never change unless damaged
- Typically used for final design of high-volume systems
  - spread out NRE cost for a low unit cost

OTP ROM: One-time programmable ROM

- Connections “programmed” after manufacture by user
  - user provides file of desired contents of ROM
  - file input to machine called ROM programmer
  - each programmable connection is a fuse
  - ROM programmer blows fuses where connections should not exist
- Very low write ability
  - typically written only once and requires ROM programmer device
- Very high storage permanence
  - bits don’t change unless reconnected to programmer and more fuses blown
- Commonly used in final products
  - cheaper, harder to inadvertently modify

EPROM: Erasable programmable ROM

- **Programmable component is a MOS transistor**
  - Transistor has “floating” gate surrounded by an insulator
  - **(a)** Negative charges form a channel between source and drain storing a logic 1
  - **(b)** Large positive voltage at gate causes negative charges to move out of channel and get trapped in floating gate storing a logic 0
  - **(c)** (Erase) Shining UV rays on surface of floating-gate causes negative charges to return to channel from floating gate restoring the logic 1
  - **(d)** An EPROM package showing quartz window through which UV light can pass
- **Better write ability**
  - can be erased and reprogrammed thousands of times
- **Reduced storage permanence**
  - program lasts about 10 years but is susceptible to radiation and electric noise
- **Typically used during design development**



EEPROM: Electrically erasable programmable ROM

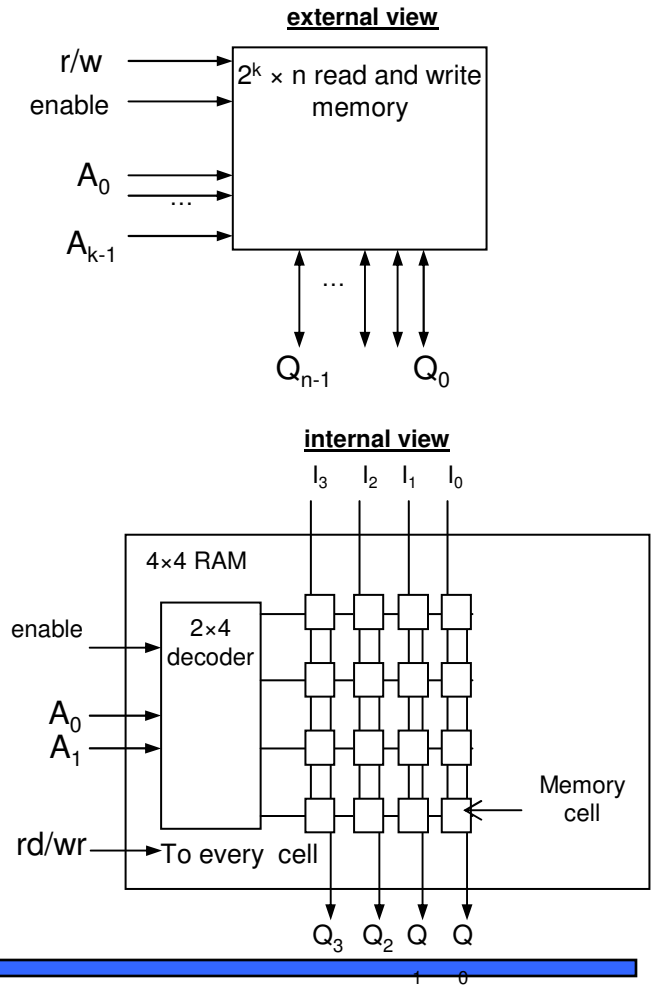
- Programmed and erased electronically
  - typically by using higher than normal voltage
  - can program and erase individual words
- Better write ability
  - can be in-system programmable with built-in circuit to provide higher than normal voltage
    - built-in memory controller commonly used to hide details from memory user
  - writes very slow due to erasing and programming
    - “busy” pin indicates to processor EEPROM still writing
  - can be erased and programmed tens of thousands of times
- Similar storage permanence to EPROM (about 10 years)
- Far more convenient than EPROMs, but more expensive

Flash Memory

- Extension of EEPROM
  - Same floating gate principle
  - Same write ability and storage permanence
- Fast erase
  - Large blocks of memory erased at once, rather than one word at a time
  - Blocks typically several thousand bytes large
- Writes to single words may be slower
  - Entire block must be read, word updated, then entire block written back
- Used with embedded systems storing large data items in nonvolatile memory
  - e.g., digital cameras, TV set-top boxes, cell phones

RAM: “Random-access” memory

- **Typically volatile memory**
  - bits are not held without power supply
- **Read and written to easily by embedded system during execution**
- **Internal structure more complex than ROM**
  - a word consists of several memory cells, each storing 1 bit
  - each input and output data line connects to each cell in its column
  - rd/wr connected to every cell
  - when row is enabled by decoder, each cell has logic that stores input data bit when rd/wr indicates write or outputs stored bit when rd/wr indicates read

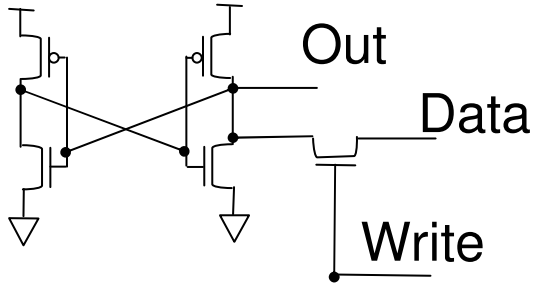


Basic types of RAM

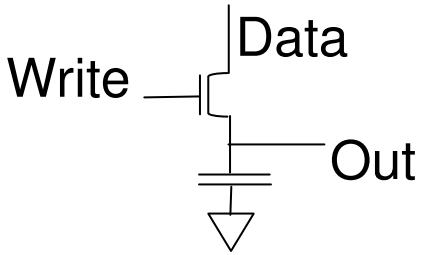
- SRAM: Static RAM
  - Memory cell uses flip-flop to store bit
  - Requires 6 transistors
  - Holds data as long as power supplied
- DRAM: Dynamic RAM
  - Memory cell uses MOS transistor and capacitor to store bit
  - More compact than SRAM
  - "Refresh" required due to capacitor leak
    - word's cells refreshed when read
  - Typical refresh rate 15.625 microsec.
  - Slower to access than SRAM

memory cell internals

SRAM



DRAM



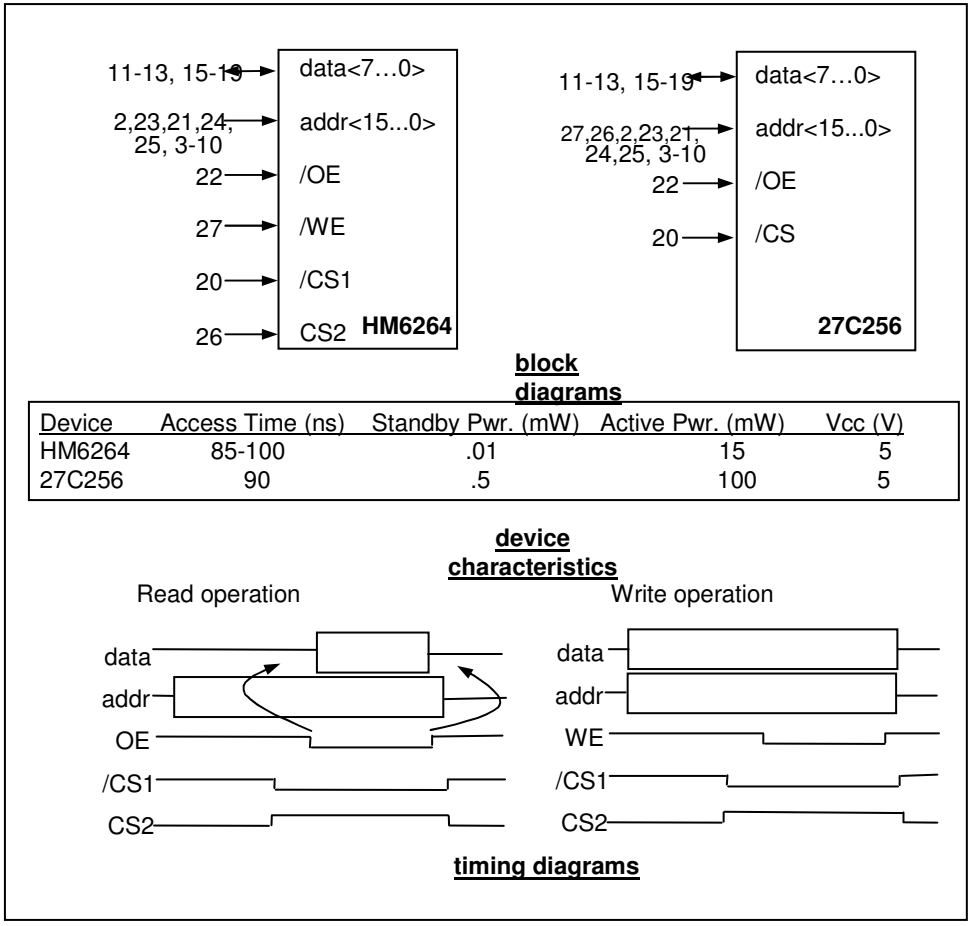
Ram variations

NVRAM: Nonvolatile RAM

- Holds data after external power removed
- Battery-backed RAM
  - SRAM with own permanently connected battery
  - writes as fast as reads
  - no limit on number of writes unlike nonvolatile ROM-based memory
- SRAM with EEPROM or flash
  - stores complete RAM contents on EEPROM or flash before power turned off

Example: HM6264 & 27C256 RAM/ROM devices

- Low-cost low-capacity memory devices
- Commonly used in 8-bit microcontroller-based embedded systems
- First two numeric digits indicate device type
  - RAM: 62
  - ROM: 27
- Subsequent digits indicate capacity in kilobits



block diagrams

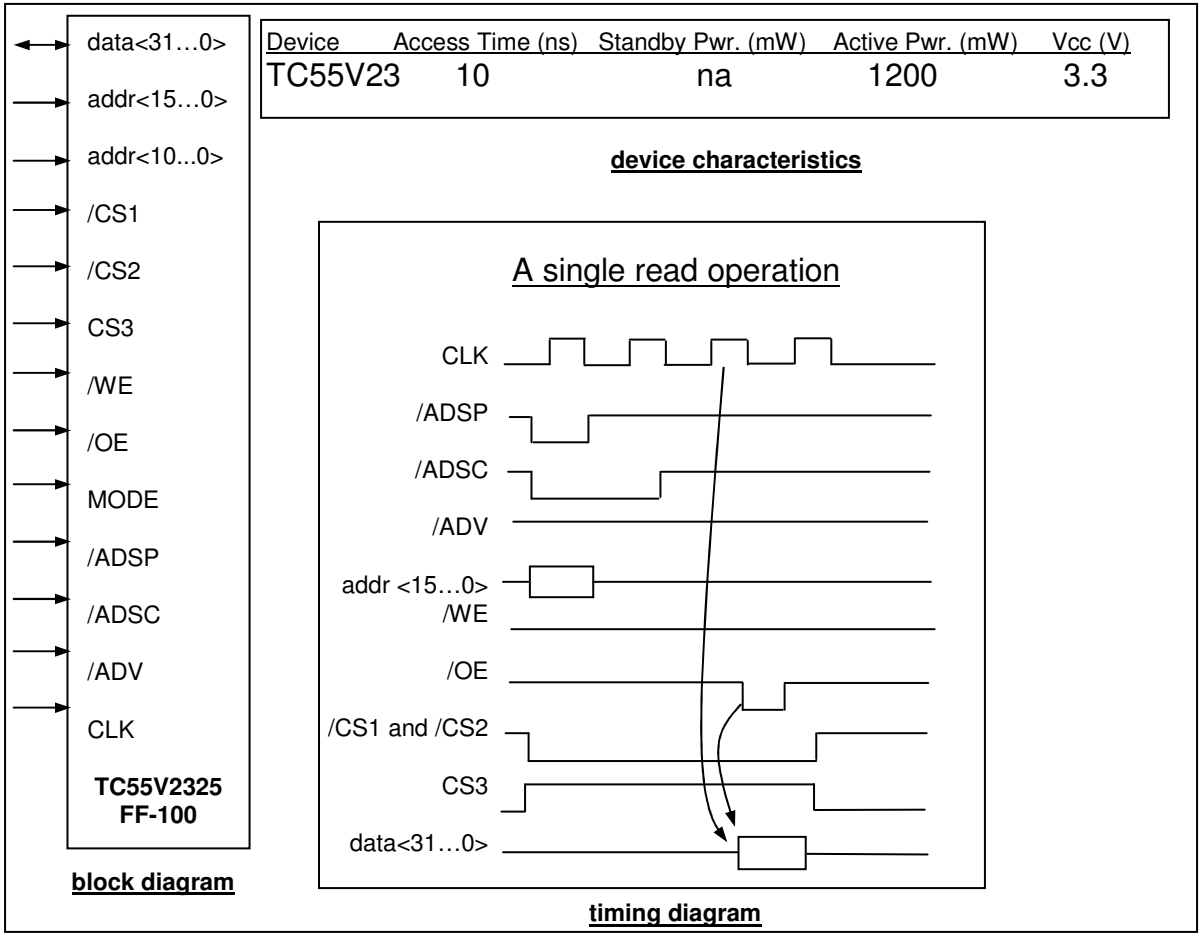
Device	Access Time (ns)	Standby Pwr. (mW)	Active Pwr. (mW)	Vcc (V)
HM6264	85-100	.01	15	5
27C256	90	.5	100	5

device characteristics

timing diagrams

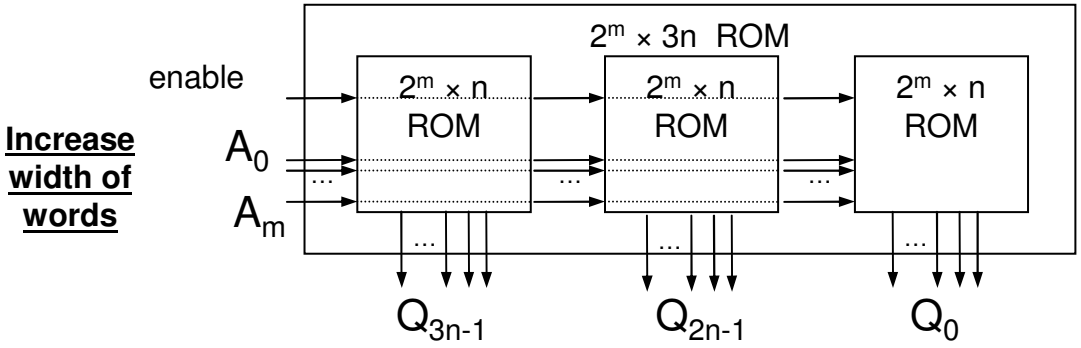
Example: TC55V2325FF-100 memory device

- 2-megabit synchronous pipelined burst SRAM memory device
- Designed to be interfaced with 32-bit processors
- Capable of fast sequential reads and writes as well as single byte I/O



Composing memory

- Memory size needed often differs from size of readily available memories
- When available memory is larger, simply ignore unneeded high-order address bits and higher data lines
- When available memory is smaller, compose several smaller memories into one larger memory
  - Connect side-by-side to increase width of words



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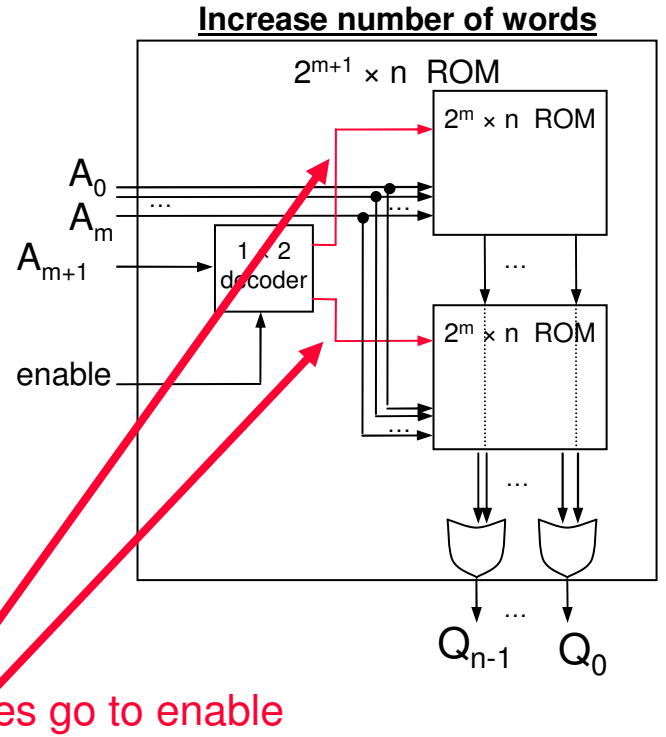
  - Connect top to bottom to increase number of words
    - added high-order address line selects smaller memory containing desired word using a decoder



Composing memory

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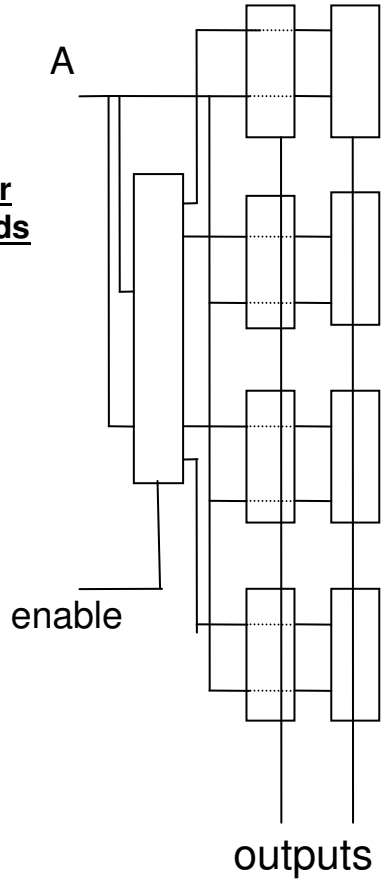
- When available memory is smaller, compose several smaller memories into one larger memory
  - Connect side-by-side to increase width of words
  - Connect top to bottom to increase number of words
    - added high-order address line selects smaller memory containing desired word using a decoder
  - Combine techniques to increase number and width of words

Increase number and width of words



Things To Do Before Next Tuesday

- Finish Reading Chapter 5 (page 136)
- Prepare for 15 minute quiz on Tuesday at the beginning of class.
- It will cover:
  - A/D and D/A conversions
  - Functions of some of the standard single purpose processors we covered.