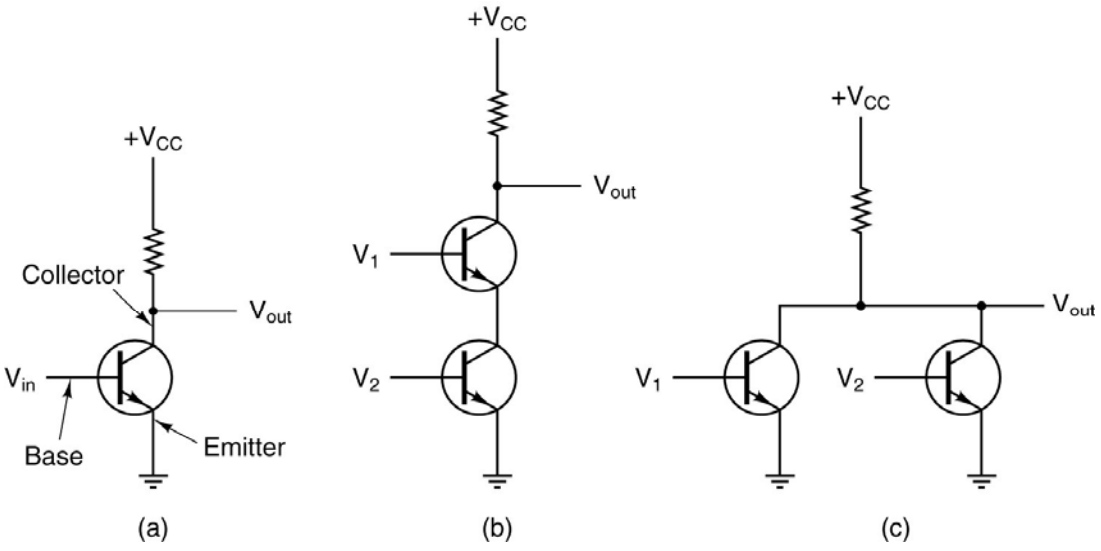
The Digital Logic Level

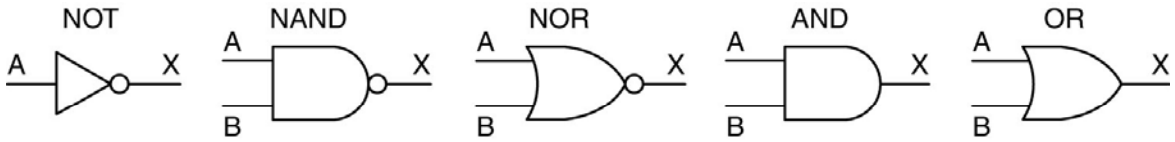
Chapter 3

Gates and Boolean Algebra (1)



(a) A transistor inverter.
(b) A NAND gate.
(c) A NOR gate.

Gates and Boolean Algebra (2)



A	X
0	1
1	0

(a)

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

(b)

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

(c)

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

(d)

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

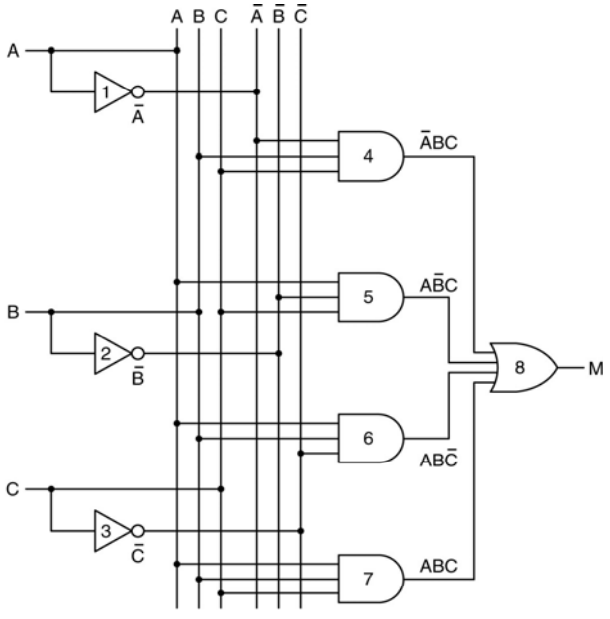
(e)

The symbols and functional behavior for the five basic gates.

Boolean Algebra

A	B	C	M
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

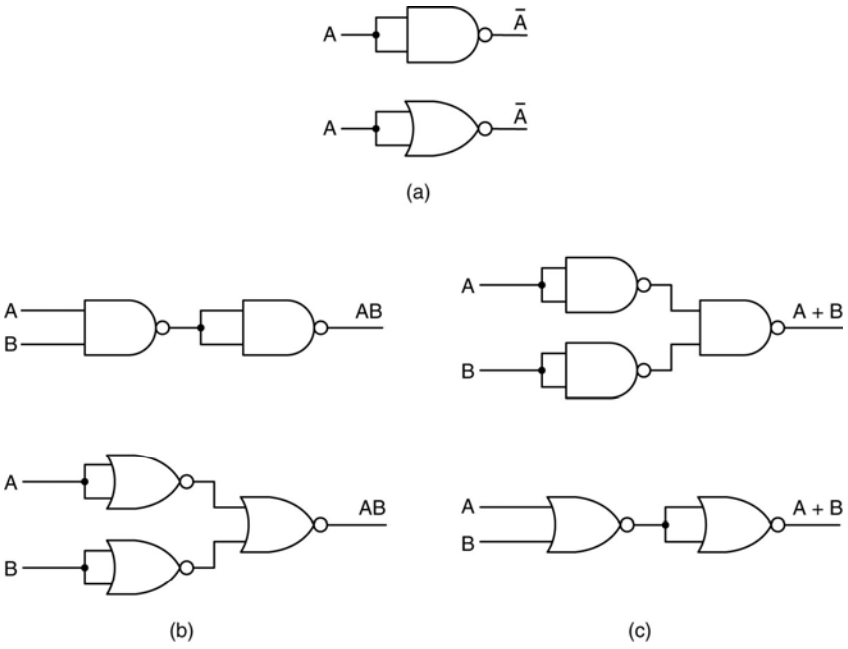
(a)



(b)

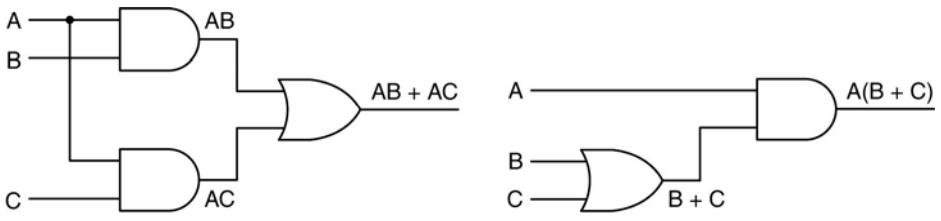
(a) Truth table for majority function of three variables.
(b) A circuit for (a).

Circuit Equivalence (1)



Construction of (a) NOT, (b) AND, and (c) OR gates using only NAND gates or only NOR gates.

Circuit Equivalence (2)



A	B	C	AB	AC	AB + AC
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

(a)

A	B	C	A	B + C	A(B + C)
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	1	0
0	1	1	0	1	0
1	0	0	1	0	0
1	0	1	1	1	1
1	1	0	1	1	1
1	1	1	1	1	1

(b)

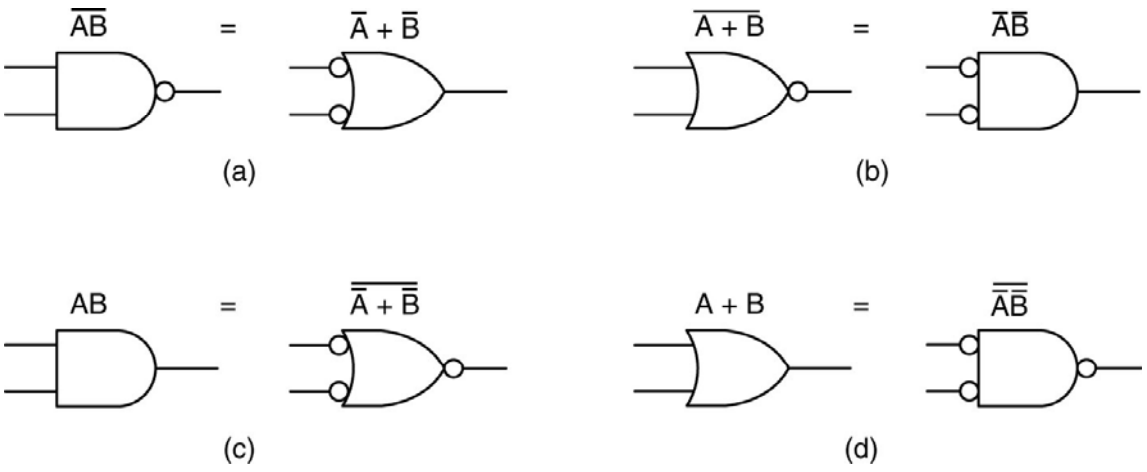
Two equivalent functions (a) AB + AC, (b) A(B + C).

Circuit Equivalence (3)

Name	AND form	OR form
Identity law	$1A = A$	$0 + A = A$
Null law	$0A = 0$	$1 + A = 1$
Idempotent law	$AA = A$	$A + A = A$
Inverse law	$A\overline{A} = 0$	$A + \overline{A} = 1$
Commutative law	$AB = BA$	$A + B = B + A$
Associative law	$(AB)C = A(BC)$	$(A + B) + C = A + (B + C)$
Distributive law	$A + BC = (A + B)(A + C)$	$A(B + C) = AB + AC$
Absorption law	$A(A + B) = A$	$A + AB = A$
De Morgan's law	$\overline{AB} = \overline{A} + \overline{B}$	$\overline{A + B} = \overline{A}\,\overline{B}$

Some identities of Boolean algebra.

Circuit Equivalence (4)

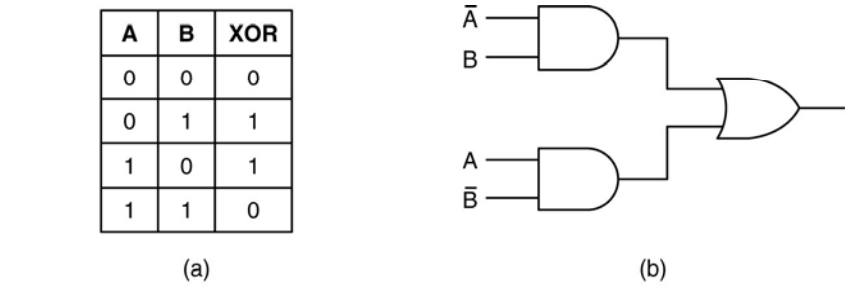


Alternative symbols for some gates:
(a) NAND, (b) NOR, (c) AND, (d) OR

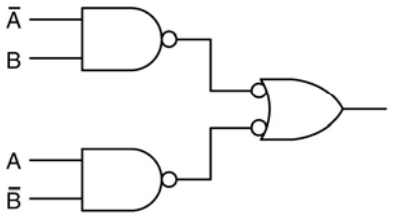
Circuit Equivalence (5)

A	B	XOR
0	0	0
0	1	1
1	0	1
1	1	0

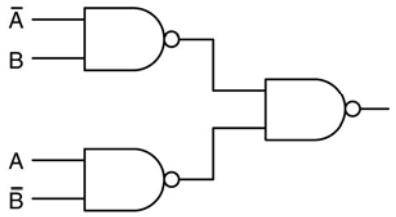
(a)



(b)



(c)



(d)

(a) The truth table for the XOR function.
(b-d) Three circuits for computing it.

Circuit Equivalence (6)

A	B	F
0^V	0^V	0^V
0^V	5^V	0^V
5^V	0^V	0^V
5^V	5^V	5^V

(a)

A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

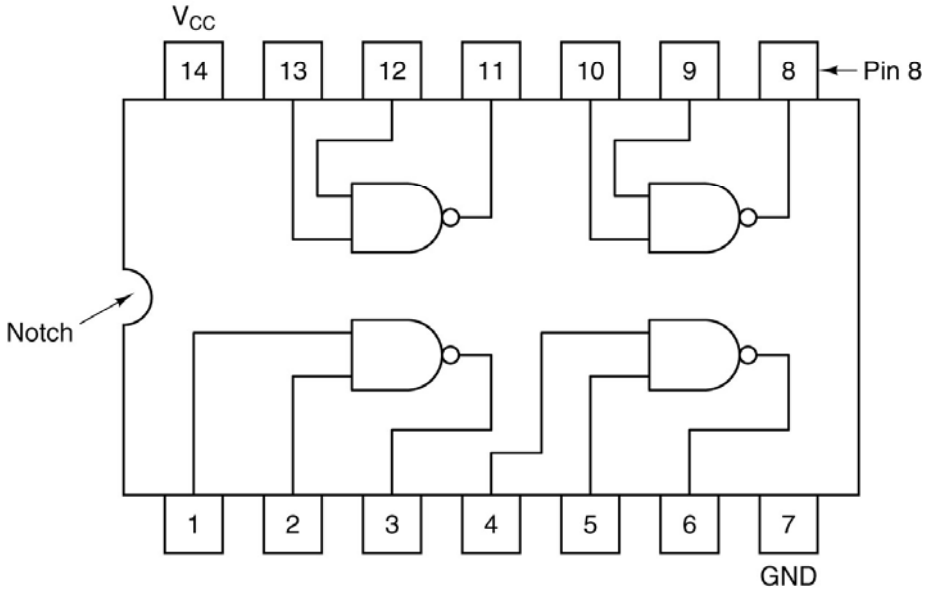
(b)

A	B	F
1	1	1
1	0	1
0	1	1
0	0	0

(c)

(a) Electrical characteristics of a device.
(b) Positive logic.
(c) Negative logic.

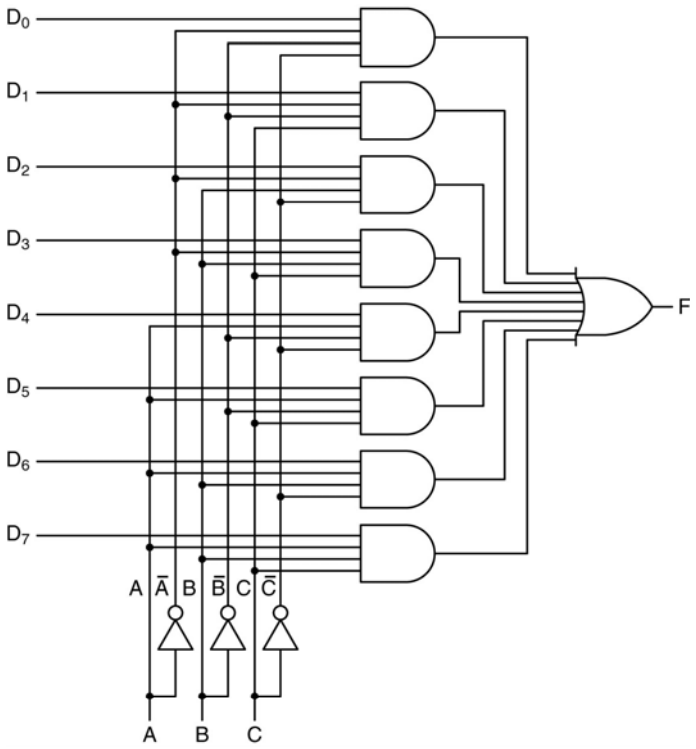
Integrated Circuits



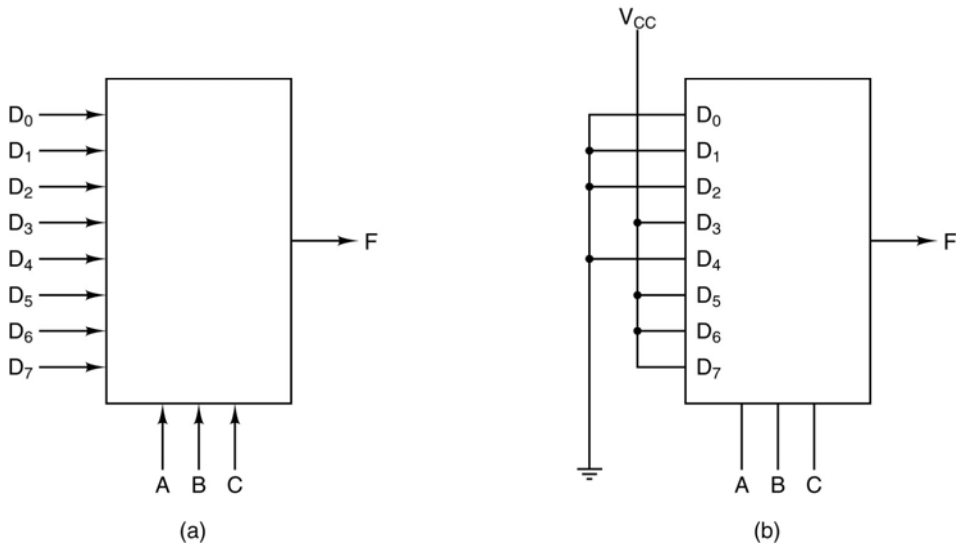
An SSI chip containing four gates.

Multiplexers (1)

An eight-input multiplexer circuit.



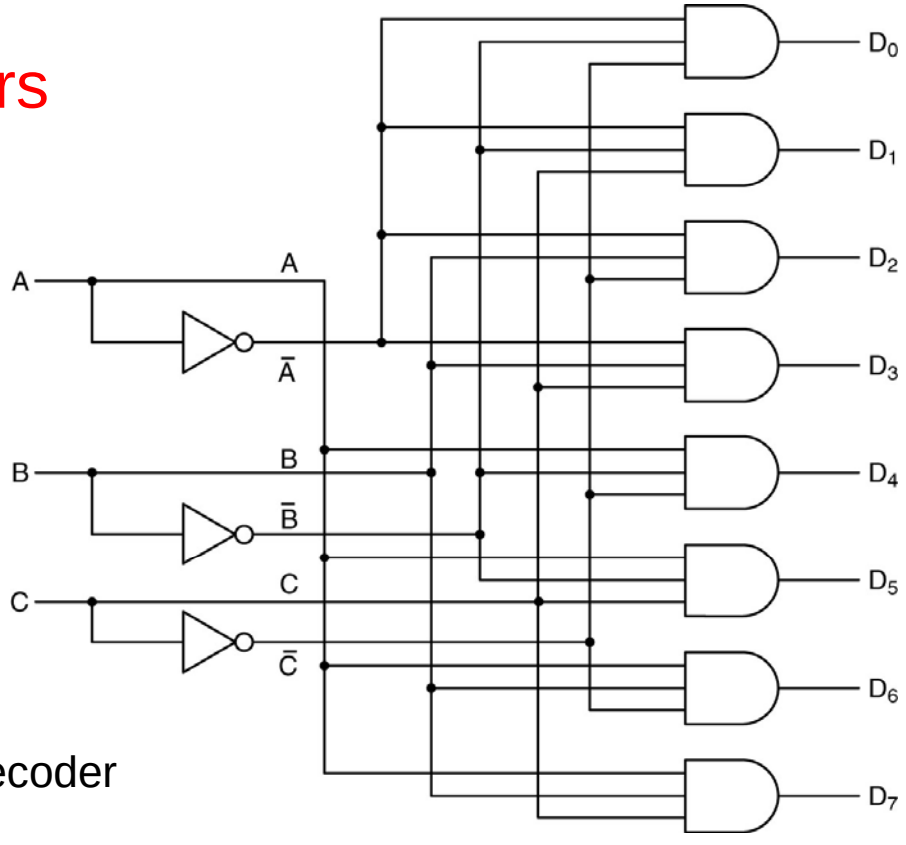
Multiplexers (2)



(a) An MSI multiplexer.

(b) The same multiplexer wired to compute the majority function.

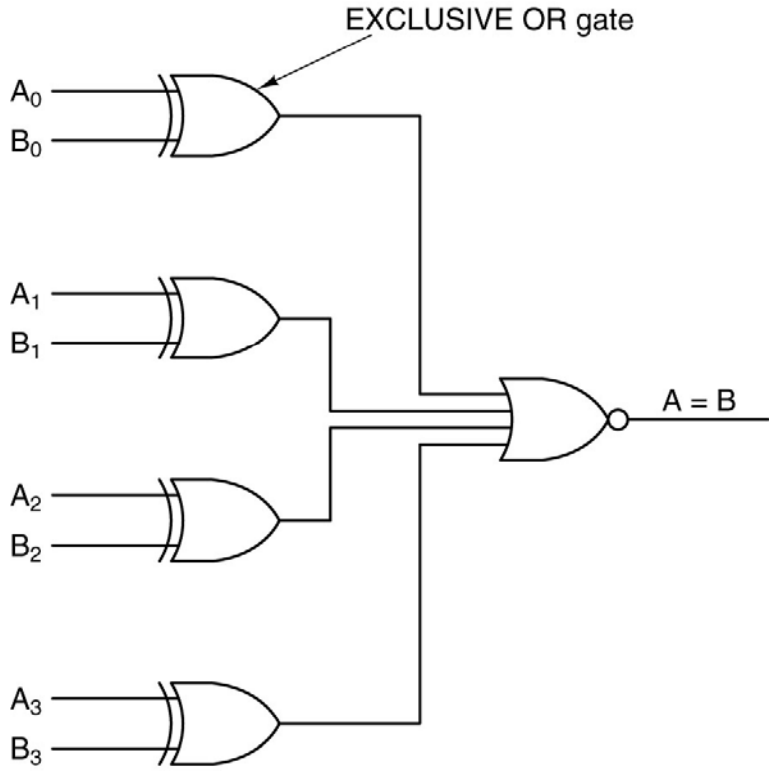
Decoders



A 3-to-8 decoder circuit.

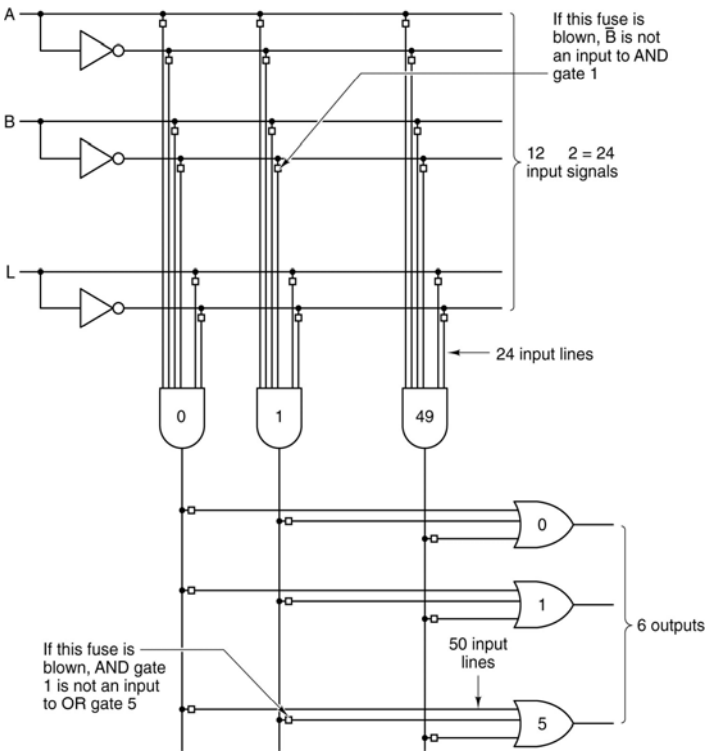
Comparators

A simple 4-bit comparator.

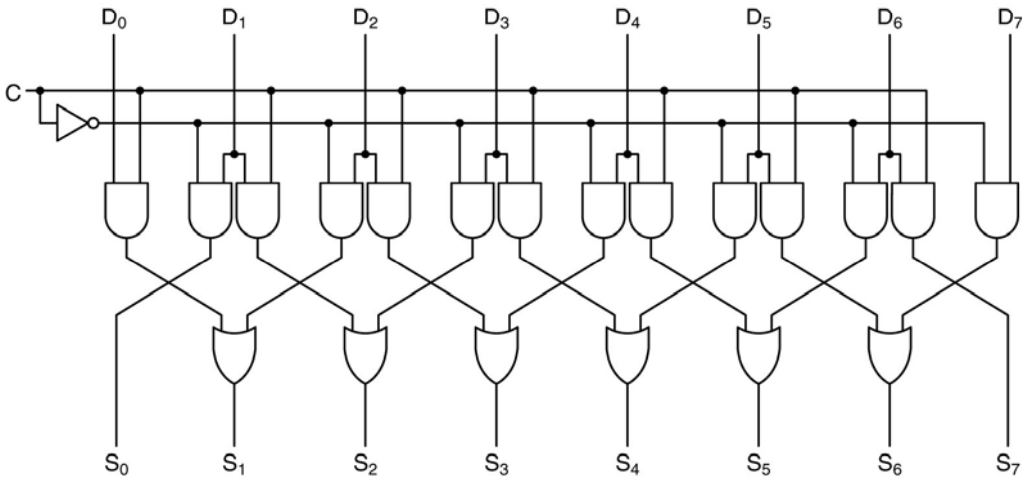


Programmable Logic Arrays

A 12-input, 6-output programmable logic array. The little squares represent fuses that can be burned out.



Shifters

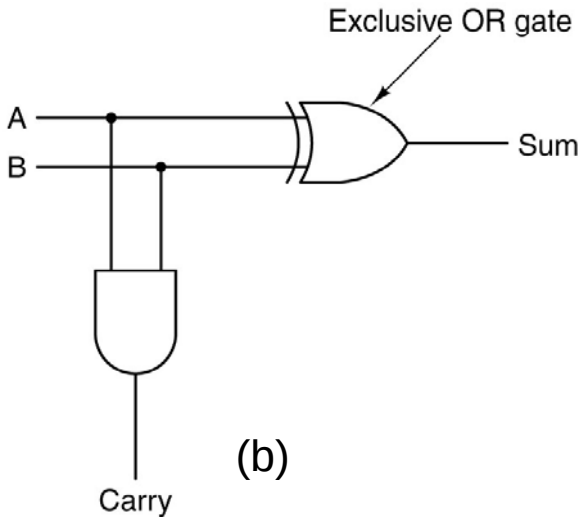


A 1-bit left/right shifter.

Adders (1)

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

(a)



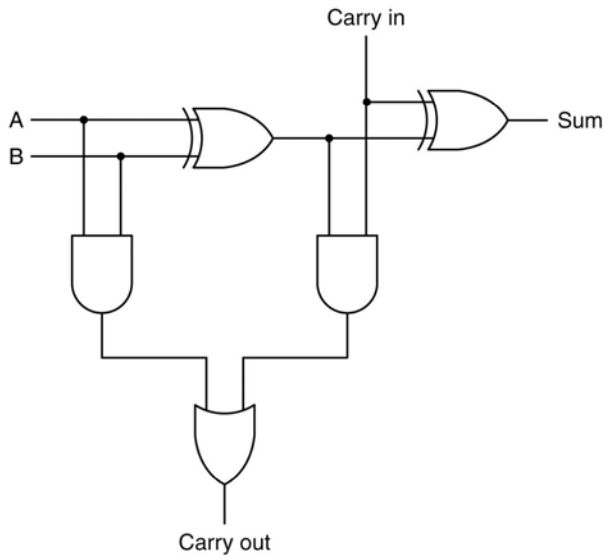
(b)

(a) A truth table for 1-bit addition.
(b) A circuit for a half adder.

Adders (2)

A	B	Carry in	Sum	Carry out
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

(a)

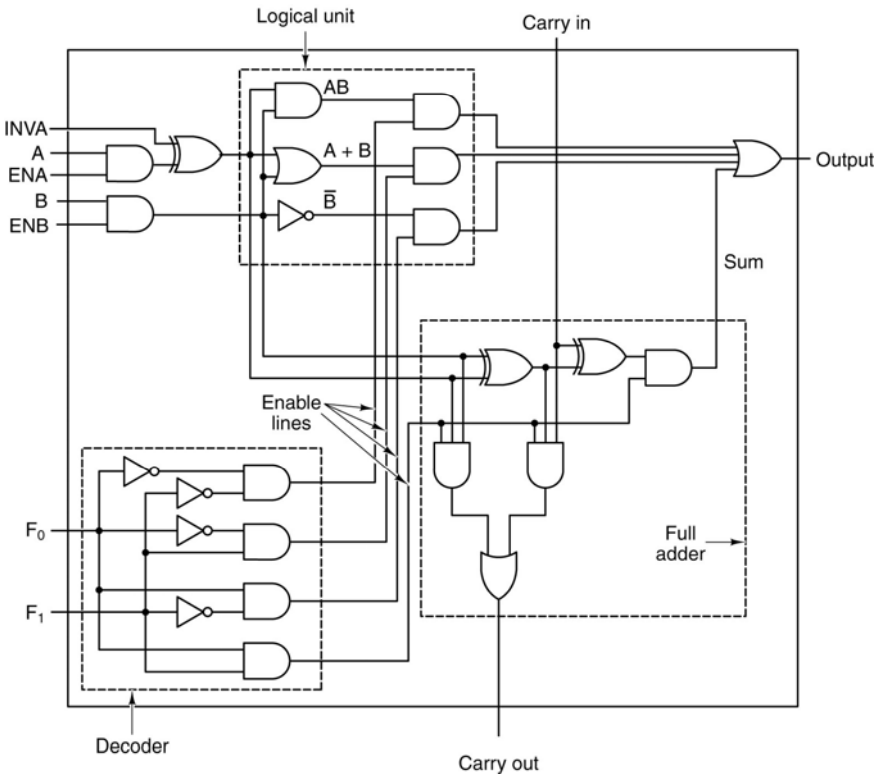


(b)

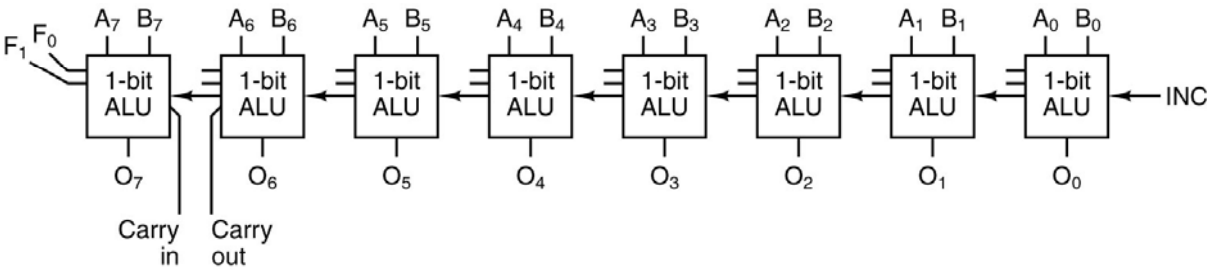
(a) Truth table for a full adder.
(b) Circuit for a full adder.

Arithmetic Logic Units (1)

A 1-bit ALU.

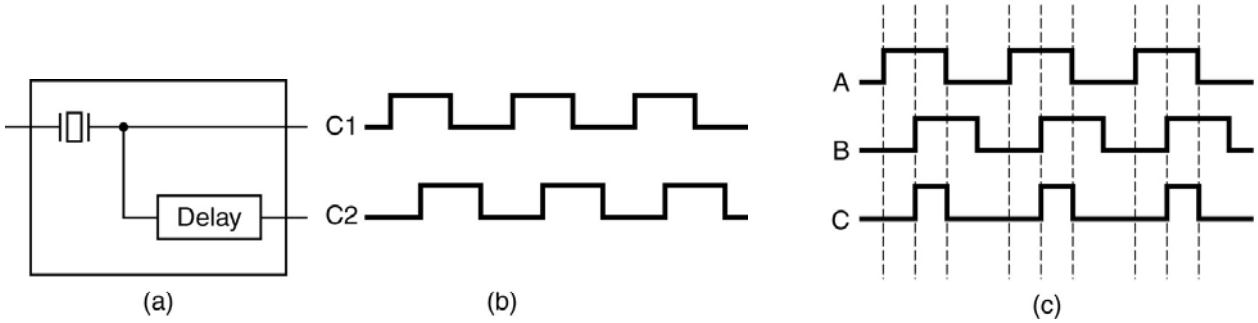


Arithmetic Logic Units (2)



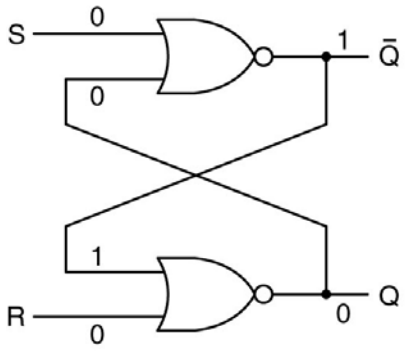
Eight 1-bit ALU slices connected to make an 8-bit ALU.
The enables and invert signals are not shown for simplicity.

Clocks

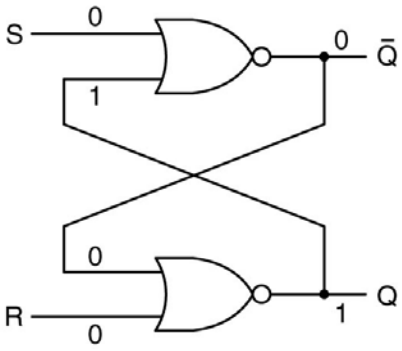


(a) A clock.
(b) The timing diagram for the clock.
(c) Generation of an asymmetric clock.

Latches (1)



(a)



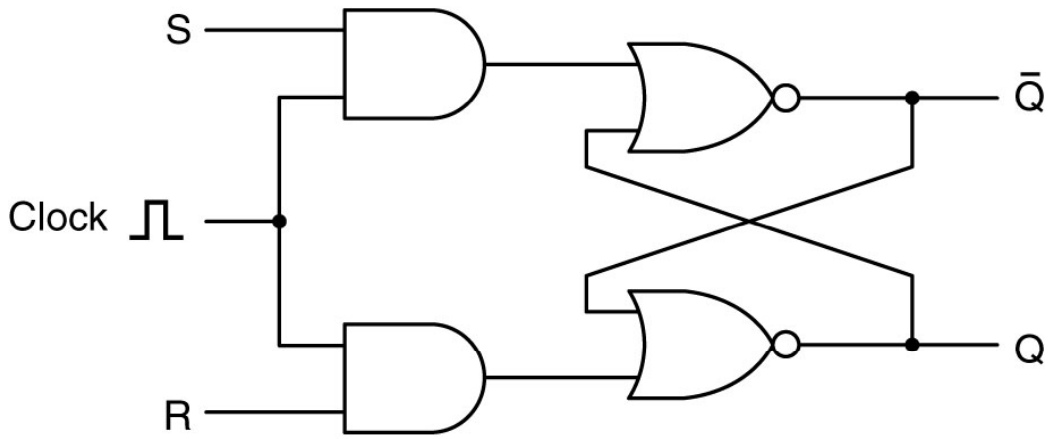
(b)

A	B	NOR
0	0	1
0	1	0
1	0	0
1	1	0

(c)

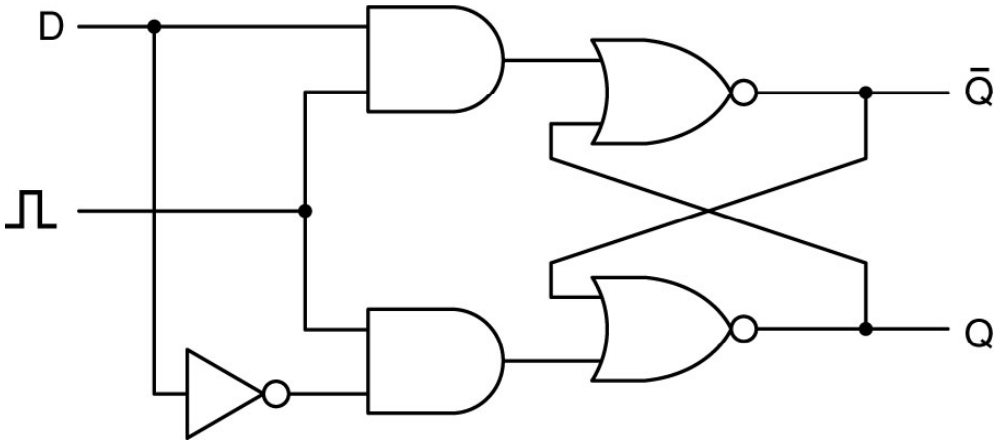
(a) NOR latch in state 0.
(b) NOR latch in state 1.
(c) Truth table for NOR.

Latches (2)



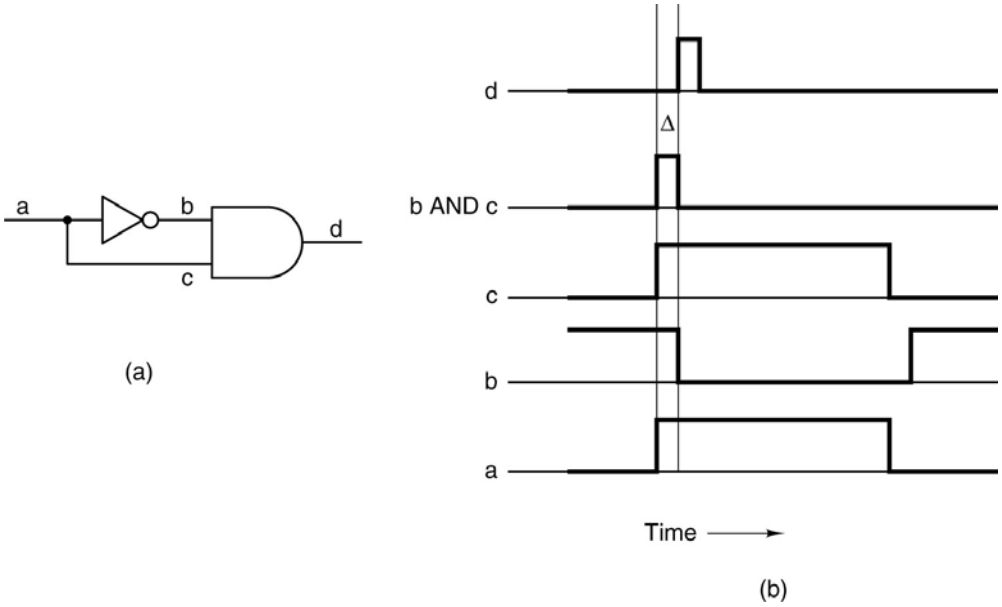
A clocked SR latch.

Latches (3)



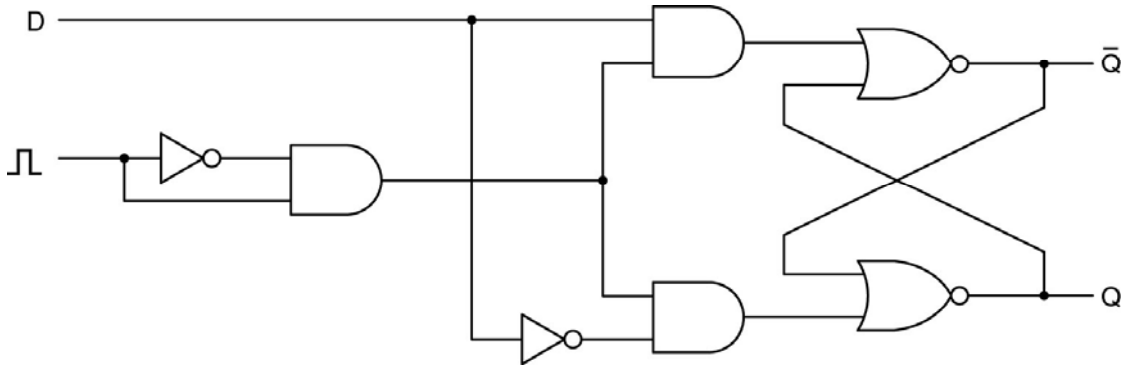
A clocked D latch.

Flip-Flops (1)



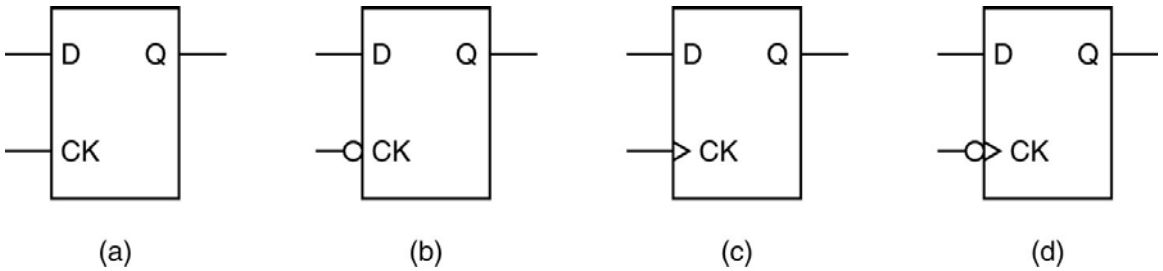
(a) A pulse generator.
(b) Timing at four points in the circuit.

Flip-Flops (2)



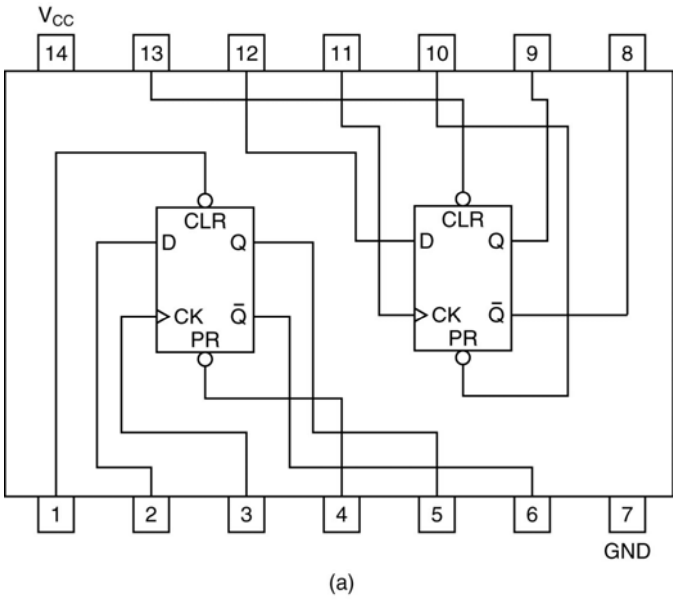
A D flip-flop.

Flip-Flops (3)



D latches and flip-flops.

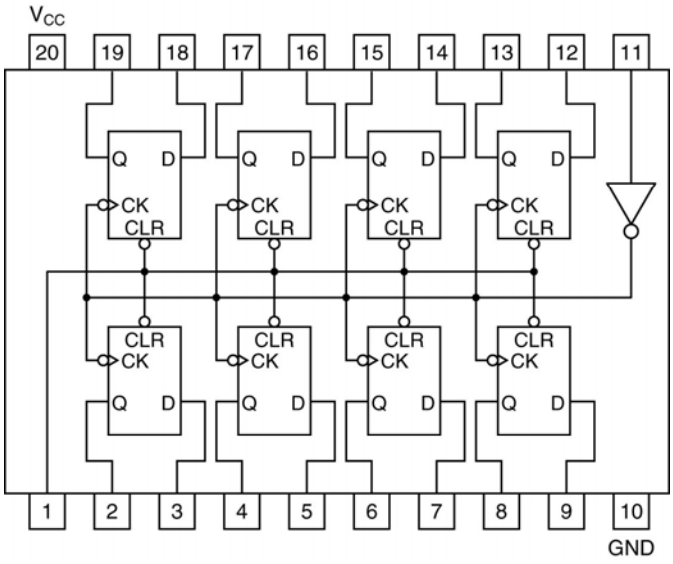
Flip-Flops (4)



(a)

Dual D flip-flop.

Flip-Flops (5)



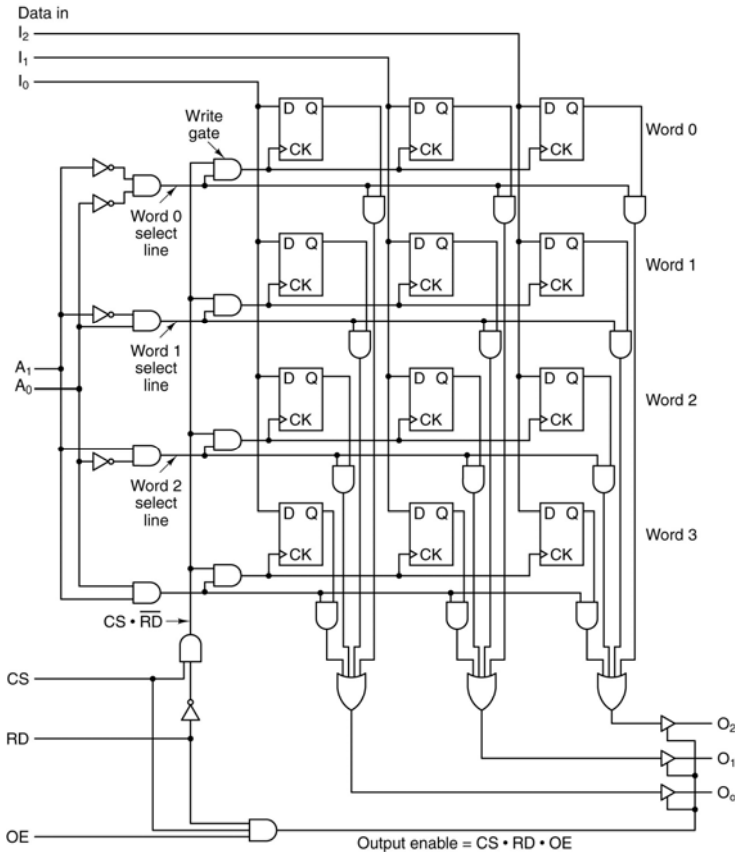
(b)

Octal flip-flop.

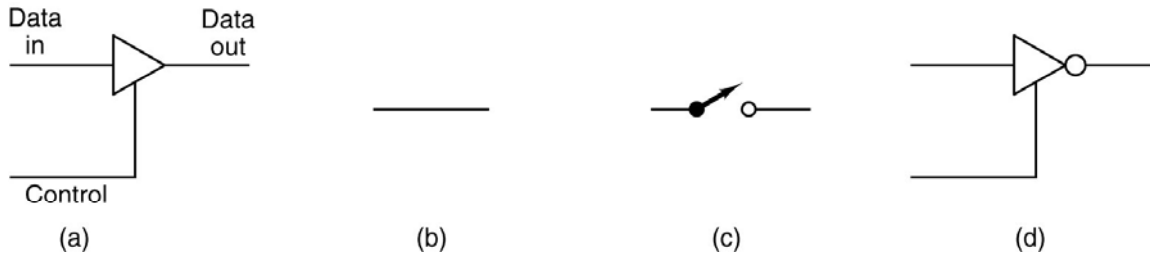
Memory Organization (1)

Logic diagram for a 4 x 3 memory.

Each row is one of the four 3-bit words.

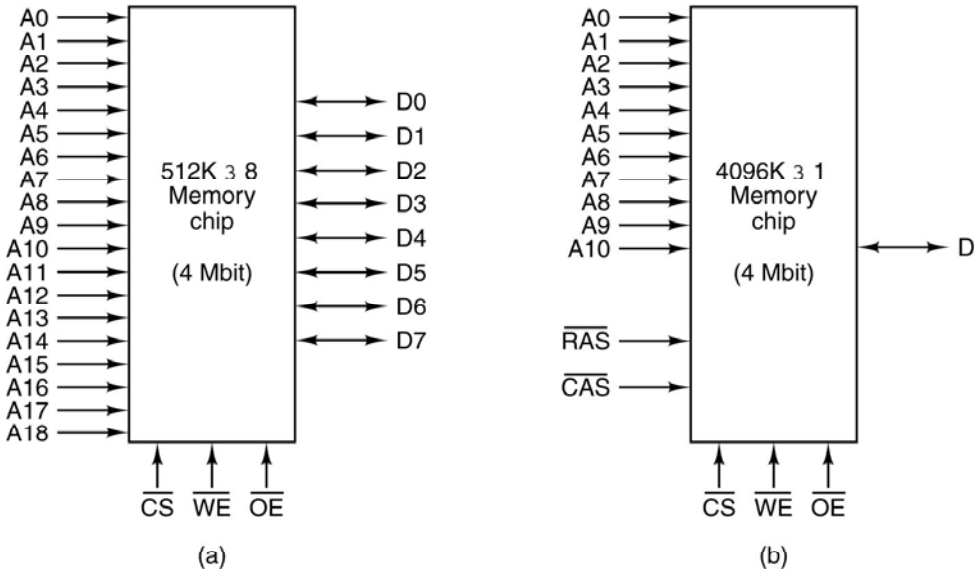


Memory Organization (2)



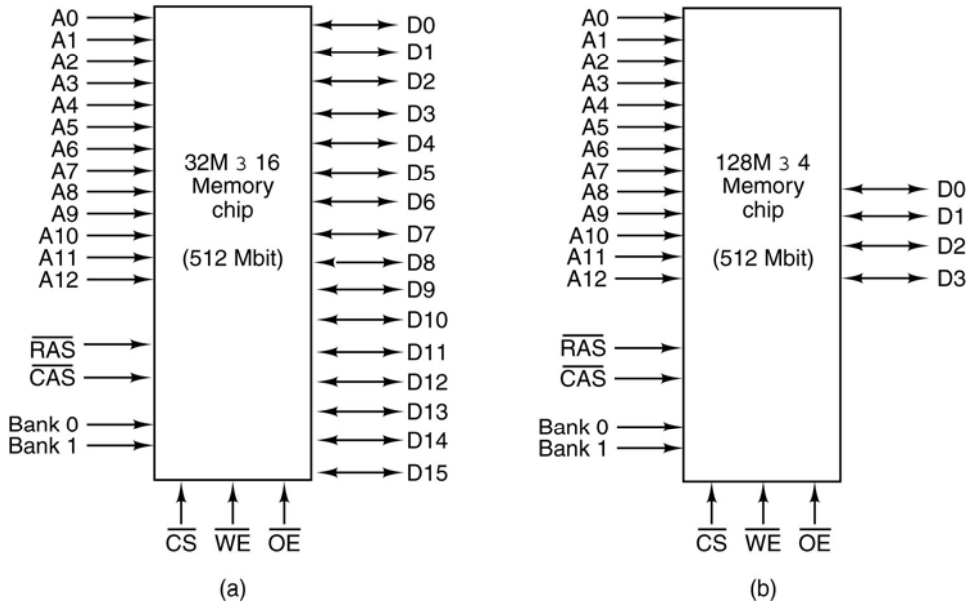
(a) A noninverting buffer.
(b) Effect of (a) when control is high.
(c) Effect of (a) when control is low.
(d) An inverting buffer.

Memory Chips (1)



Two ways of organizing a 4-Mbit memory chip.

Memory Chips (2)



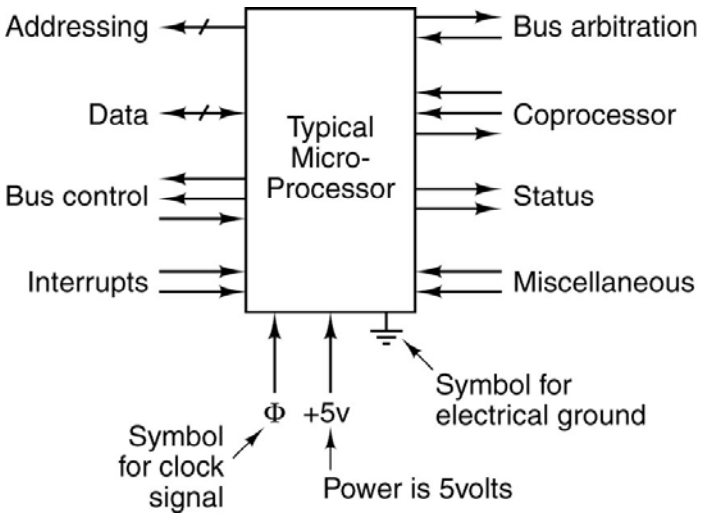
Two ways of organizing a 512 Mbit memory chip.

Nonvolatile Memory Chips

Type	Category	Erasure	Byte alterable	Volatile	Typical use
SRAM	Read/write	Electrical	Yes	Yes	Level 2 cache
DRAM	Read/write	Electrical	Yes	Yes	Main memory (old)
SDRAM	Read/write	Electrical	Yes	Yes	Main memory (new)
ROM	Read-only	Not possible	No	No	Large volume appliances
PROM	Read-only	Not possible	No	No	Small volume equipment
EPROM	Read-mostly	UV light	No	No	Device prototyping
EEPROM	Read-mostly	Electrical	Yes	No	Device prototyping
Flash	Read/write	Electrical	No	No	Film for digital camera

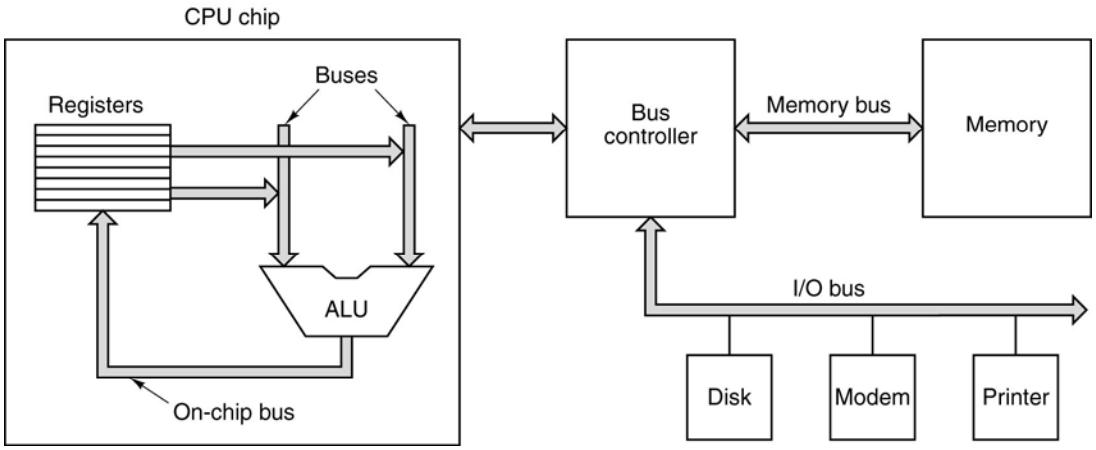
A comparison of various memory types.

CPU Chips



The logical pinout of a generic CPU. The arrows indicate input signals and output signals. The short diagonal lines indicate that multiple pins are used. For a specific CPU, a number will be given to tell how many.

Computer Buses (1)



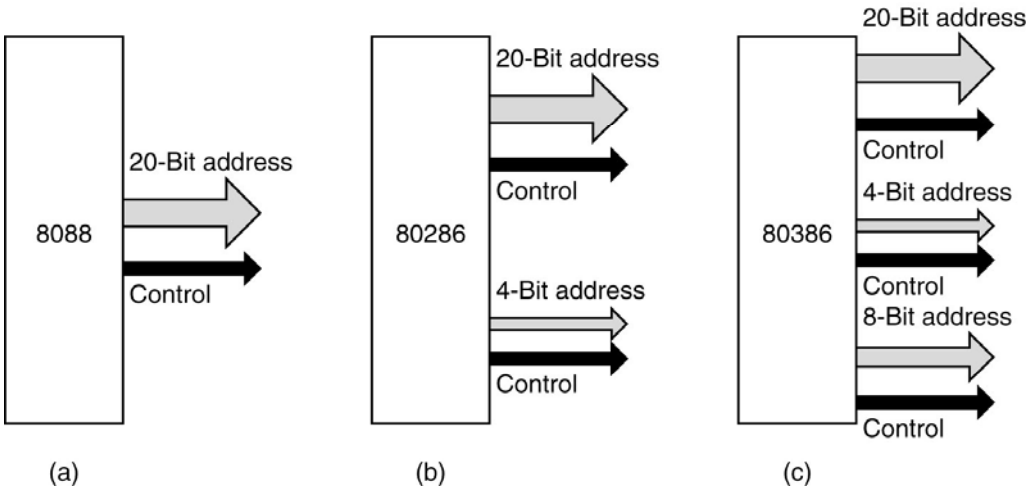
A computer system with multiple buses.

Computer Buses (2)

Master	Slave	Example
CPU	Memory	Fetching instructions and data
CPU	I/O device	Initiating data transfer
CPU	Coprocessor	CPU handing instruction off to coprocessor
I/O	Memory	DMA (Direct Memory Access)
Coprocessor	CPU	Coprocessor fetching operands from CPU

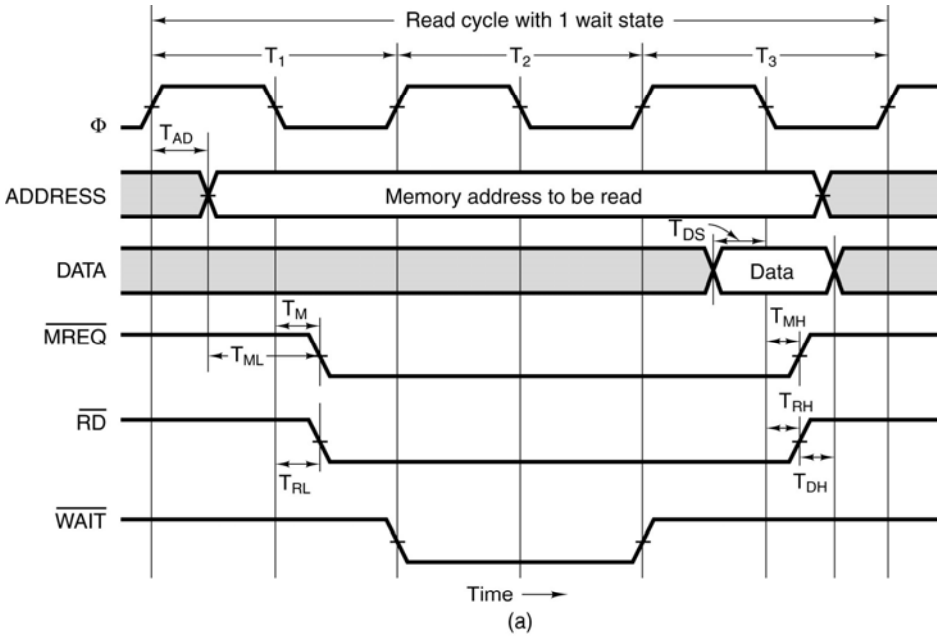
Examples of bus masters and slaves.

Bus Width



Growth of an Address bus over time.

Bus Clocking (1)



Read timing on a synchronous bus.

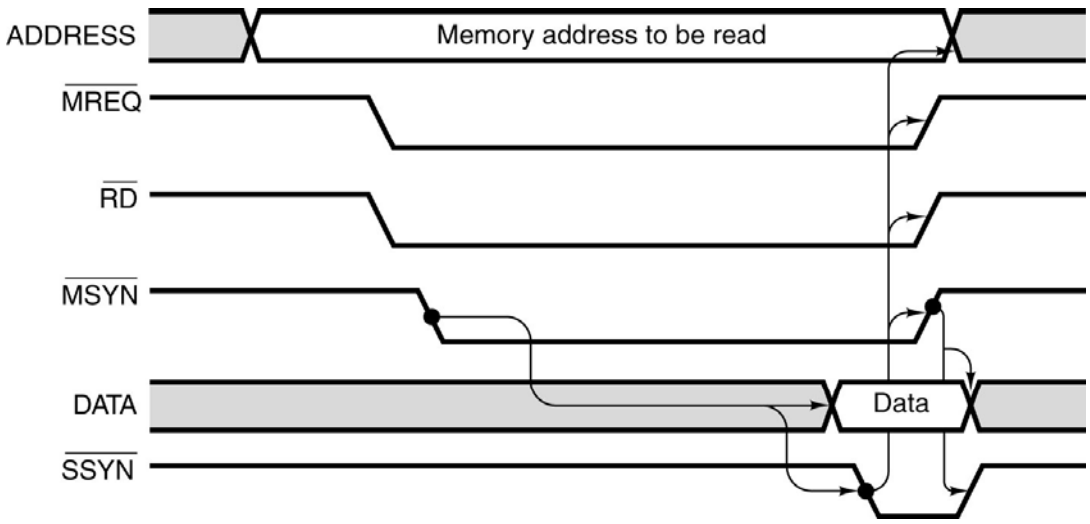
Bus Clocking (2)

Symbol	Parameter	Min	Max	Unit
T_{AD}	Address output delay		4	nsec
T_{ML}	Address stable prior to $\overline{MREQ}$	2		nsec
T_M	$\overline{MREQ}$ delay from falling edge of Φ in T_1		3	nsec
T_{RL}	RD delay from falling edge of Φ in T_1		3	nsec
T_{DS}	Data setup time prior to falling edge of Φ	2		nsec
T_{MH}	$\overline{MREQ}$ delay from falling edge of Φ in T_3		3	nsec
T_{RH}	$\overline{RD}$ delay from falling edge of Φ in T_3		3	nsec
T_{DH}	Data hold time from negation of $\overline{RD}$	0		nsec

(b)

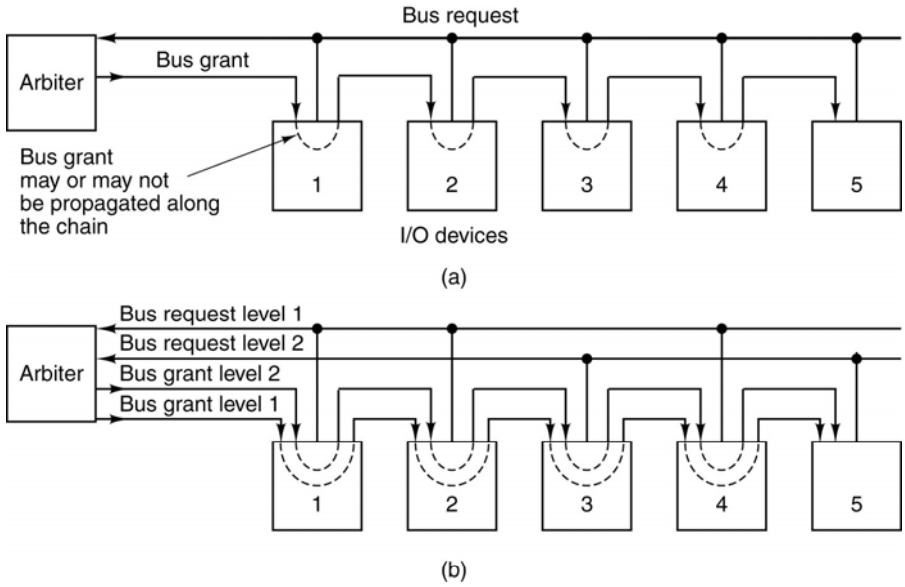
Specification of some critical times.

Asynchronous Buses



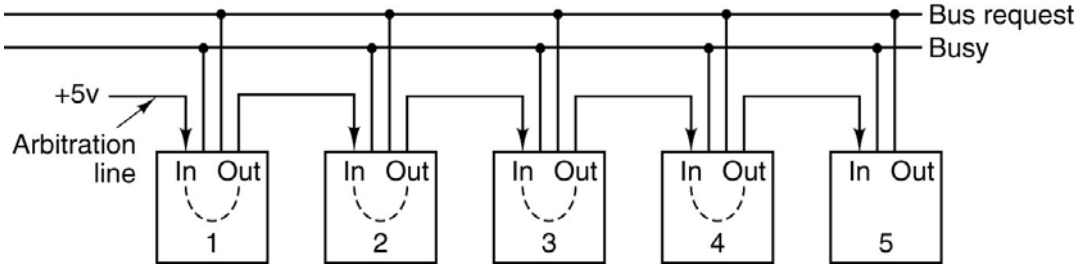
Operation of an asynchronous bus.

Bus Arbitration (1)



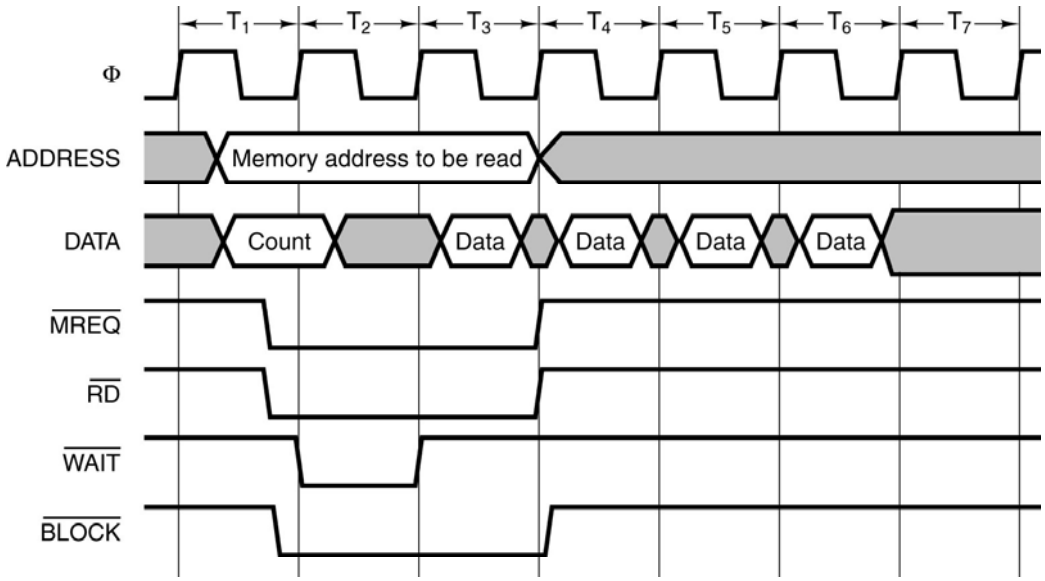
(a) A centralized one-level bus arbiter using daisy chaining.
(b) The same arbiter, but with two levels.

Bus Arbitration (2)



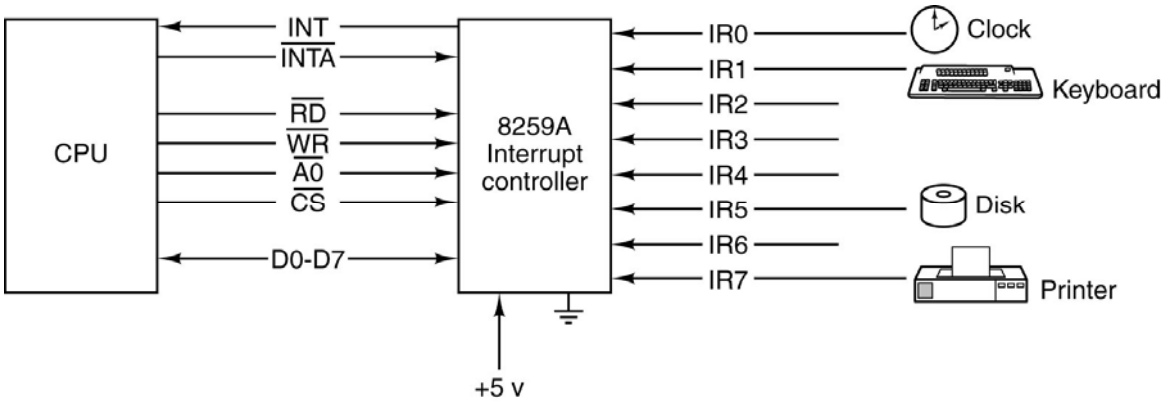
Decentralized bus arbitration.

Bus Operations (1)



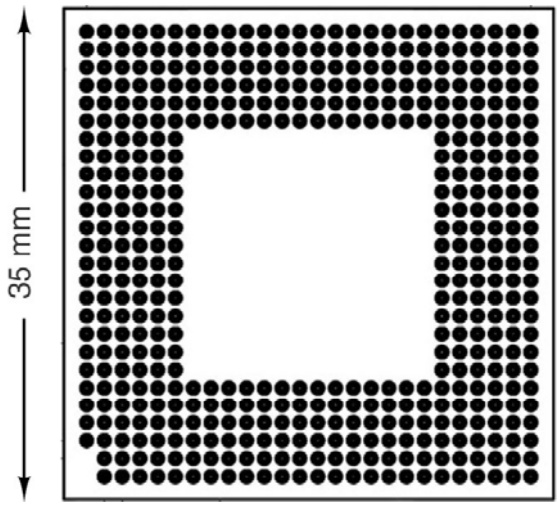
A block transfer.

Bus Operations (2)



Use of the 8259A interrupt controller.

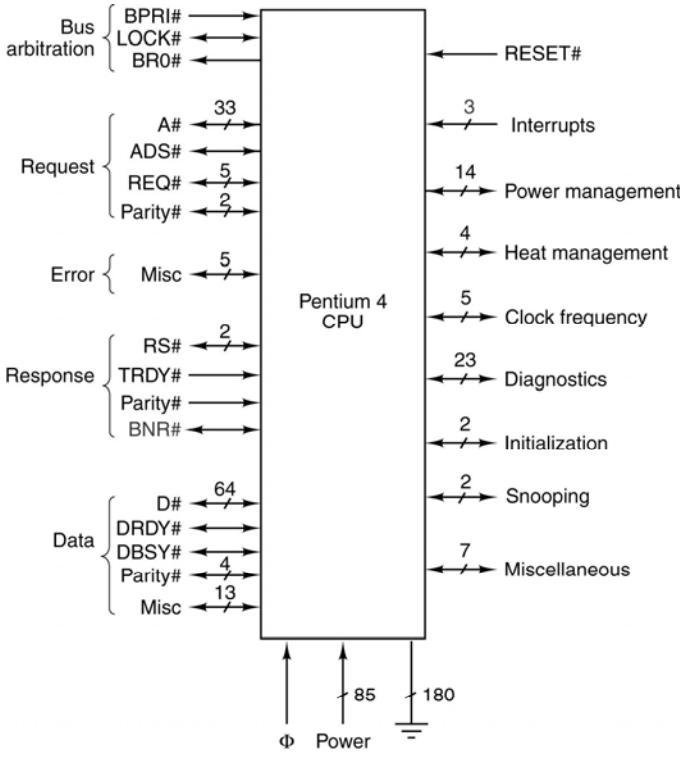
The Pentium 4



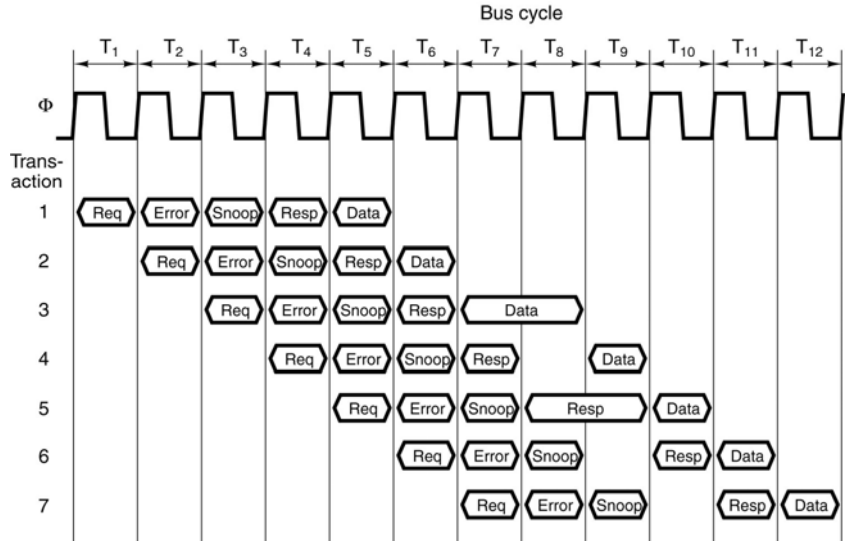
The Pentium 4 physical pinout.

The Pentium 4's Logical Pinout

Logical pinout of the Pentium 4. Names in upper case are the office are the official Intel names for individual signals. Names in mixed case are groups of related signals or signal descriptions.

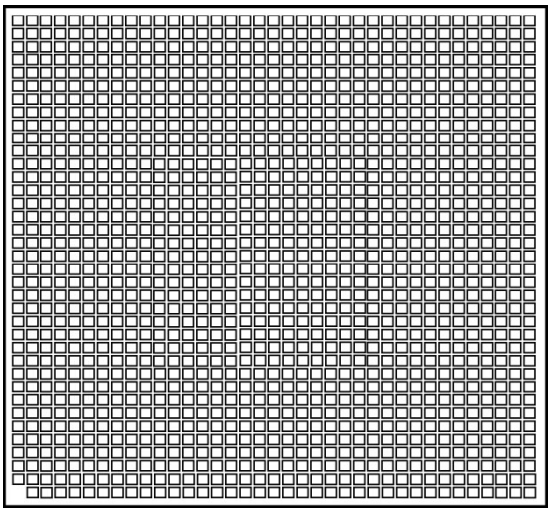


Pipelining on the Pentium 4's Memory Bus



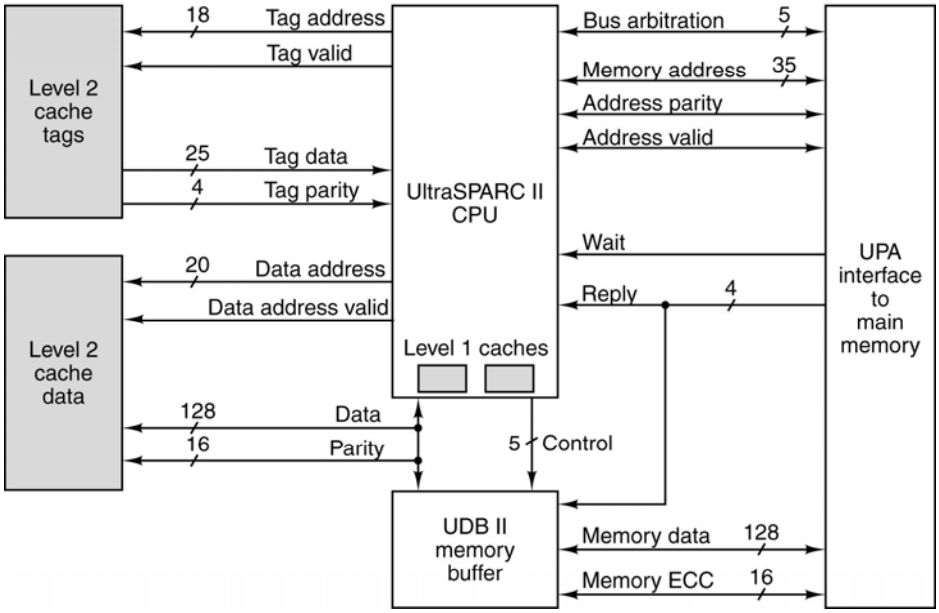
Pipelining requests on the Pentium 4's memory bus.

The UltraSPARC III (1)



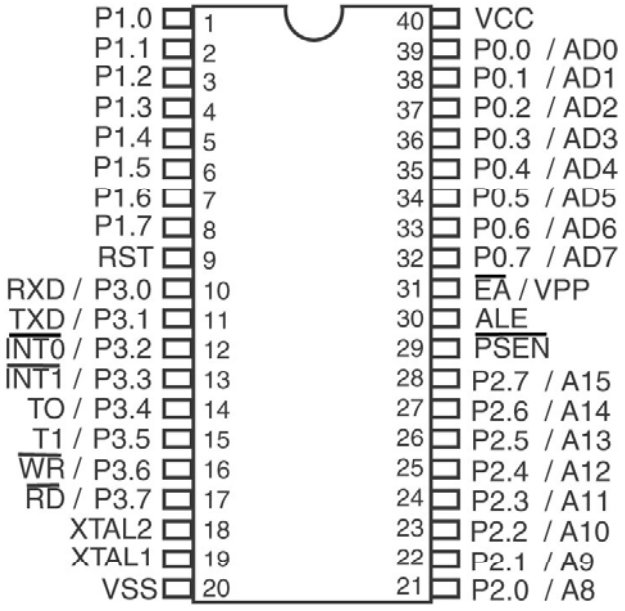
The UltraSPARC III CPU chip.

The UltraSPARC III (2)



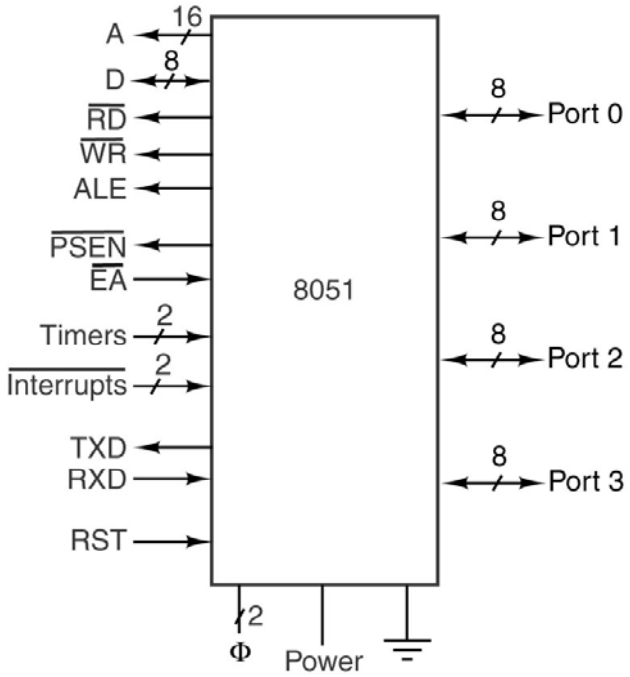
The main features of the core of an UltraSPARC III system.

The 8051 (1)



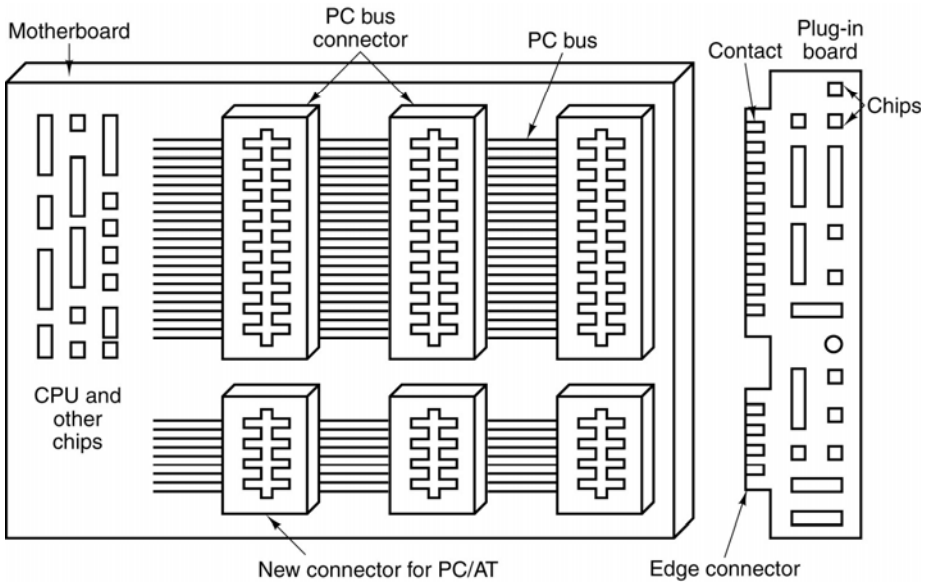
Physical pinout of the 8051.

The 8051 (2)



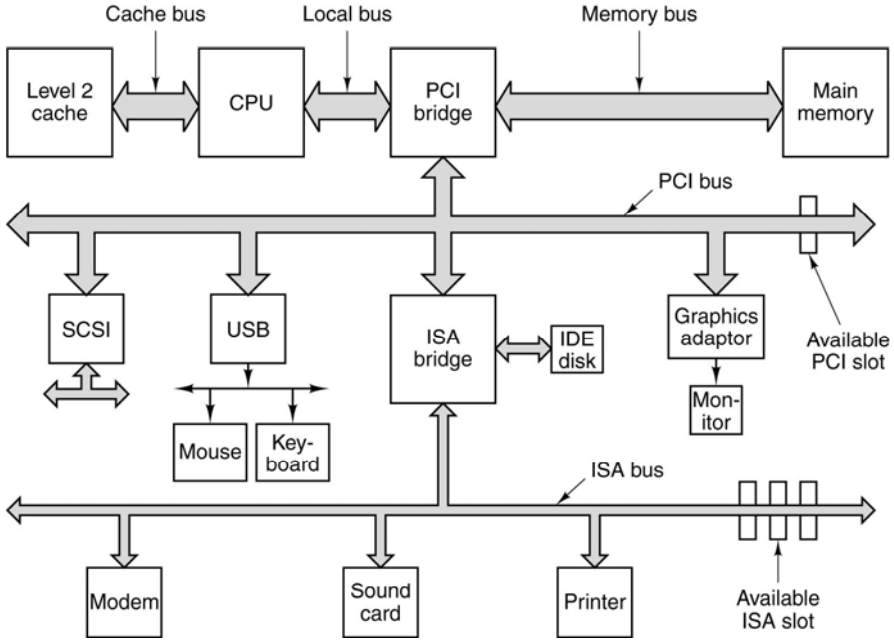
Logical pinout of the 8051.

The ISA Bus



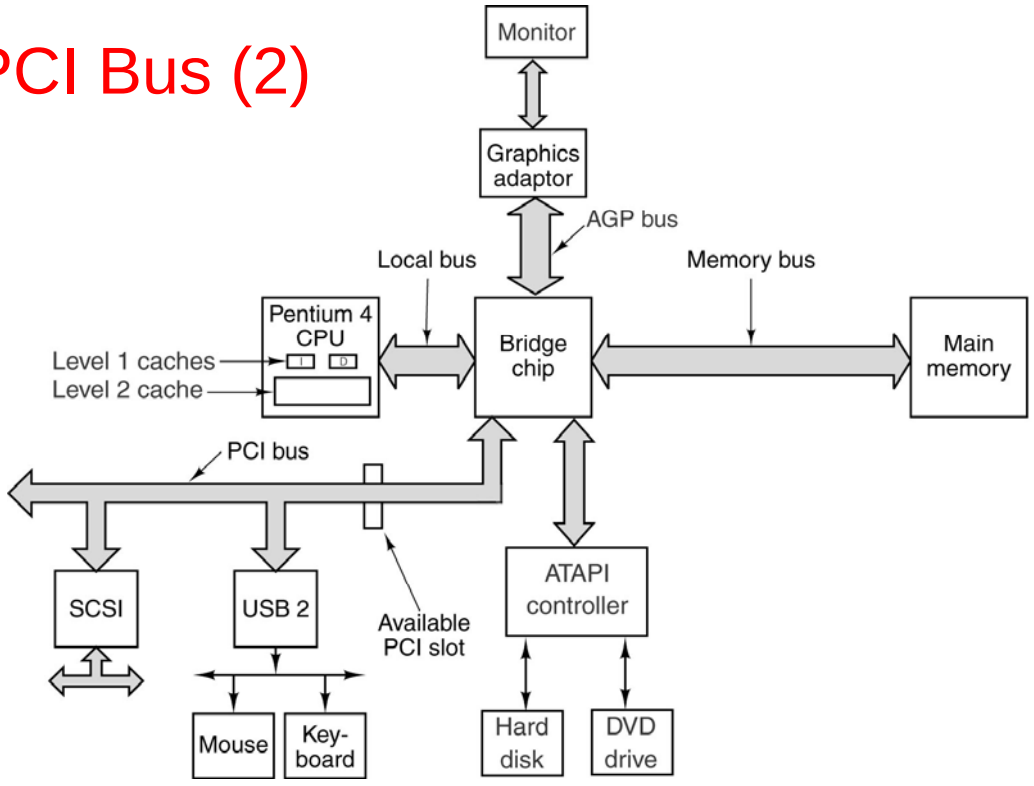
The PC/AT bus has two components, the original PC part and the new part.

The PCI Bus (1)



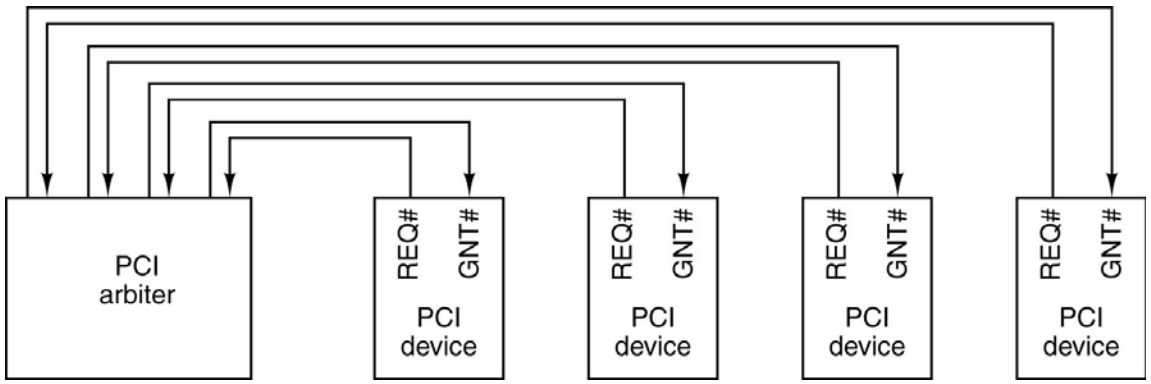
Architecture of an early Pentium system. The thicker buses have more bandwidth than the thinner ones but the figure is not to scale.

The PCI Bus (2)



The bus structure of a modern Pentium 4.

PCI Bus Arbitration



The PCI bus uses a centralized bus arbiter.

PCI Bus Signals(1)

Signal	Lines	Master	Slave	Description
CLK	1			Clock (33 MHz or 66 MHz)
AD	32	×	×	Multiplexed address and data lines
PAR	1	×		Address or data parity bit
C/BE	4	×		Bus command/bit map for bytes enabled
FRAME#	1	×		Indicates that AD and C/BE are asserted
IRDY#	1	×		Read: master will accept; write: data present
IDSEL	1	×		Select configuration space instead of memory
DEVSEL#	1		×	Slave has decoded its address and is listening
TRDY#	1		×	Read: data present; write: slave will accept
STOP#	1		×	Slave wants to stop transaction immediately
PERR#	1			Data parity error detected by receiver
SERR#	1			Address parity error or system error detected
REQ#	1			Bus arbitration: request for bus ownership
GNT#	1			Bus arbitration: grant of bus ownership
RST#	1			Reset the system and all devices

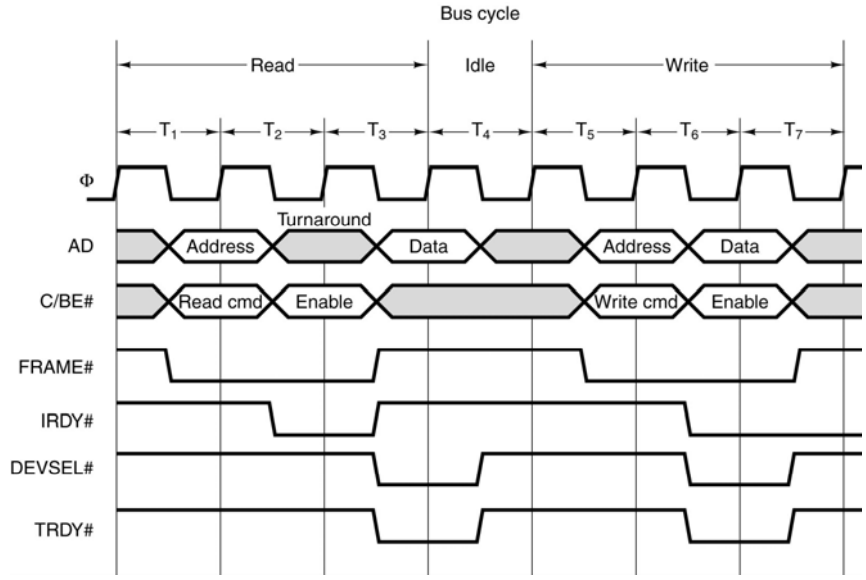
Mandatory PCI bus signals.

PCI Bus Signals(2)

Signal	Lines	Master	Slave	Description
REQ64#	1	×		Request to run a 64-bit transaction
ACK64#	1		×	Permission is granted for a 64-bit transaction
AD	32	×		Additional 32 bits of address or data
PAR64	1	×		Parity for the extra 32 address/data bits
C/BE#	4	×		Additional 4 bits for byte enables
LOCK	1	×		Lock the bus to allow multiple transactions
SBO#	1			Hit on a remote cache (for a multiprocessor)
SDONE	1			Snooping done (for a multiprocessor)
INTx	4			Request an interrupt
JTAG	5			IEEE 1149.1 JTAG test signals
M66EN	1			Wired to power or ground (66 MHz or 33 MHz)

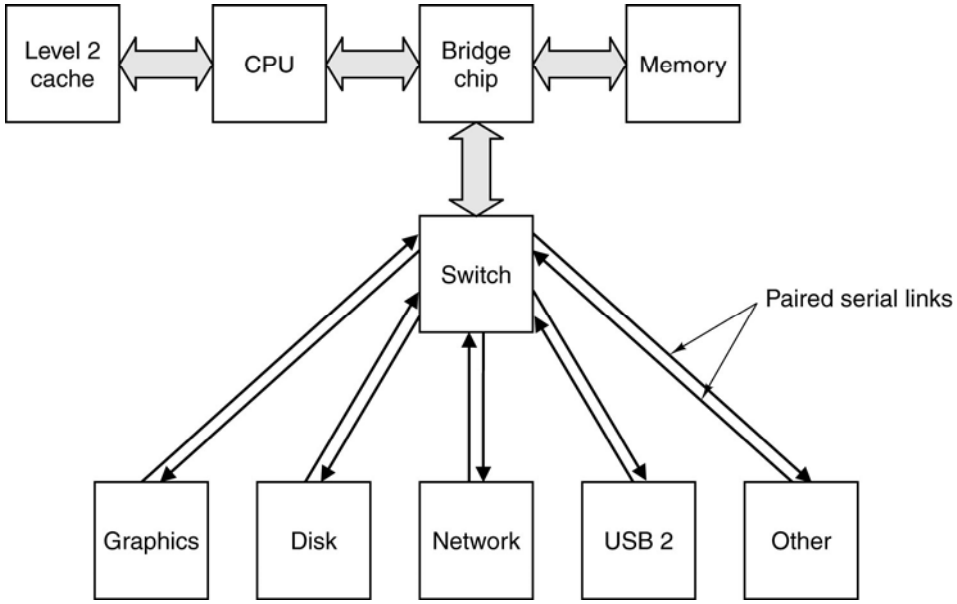
Optional PCI bus signals.

PCI Bus Transactions



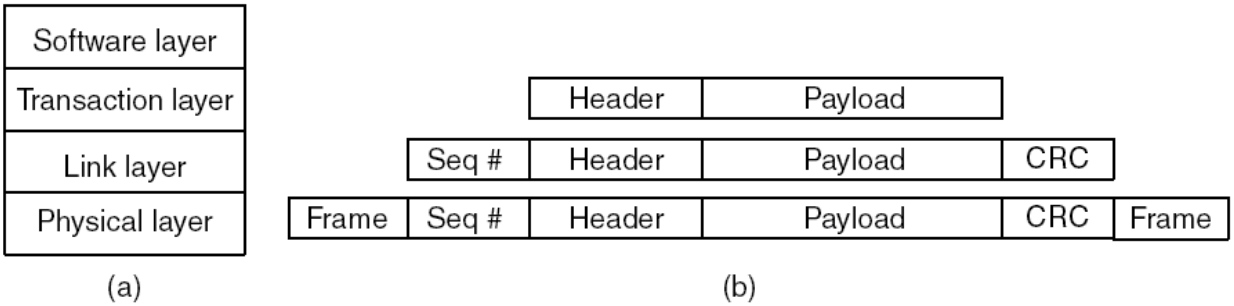
Examples of 32-bit PCI bus transactions. The first three cycles are used for a read operation, then an idle cycle, and then three cycles for a write operation.

PCI Express



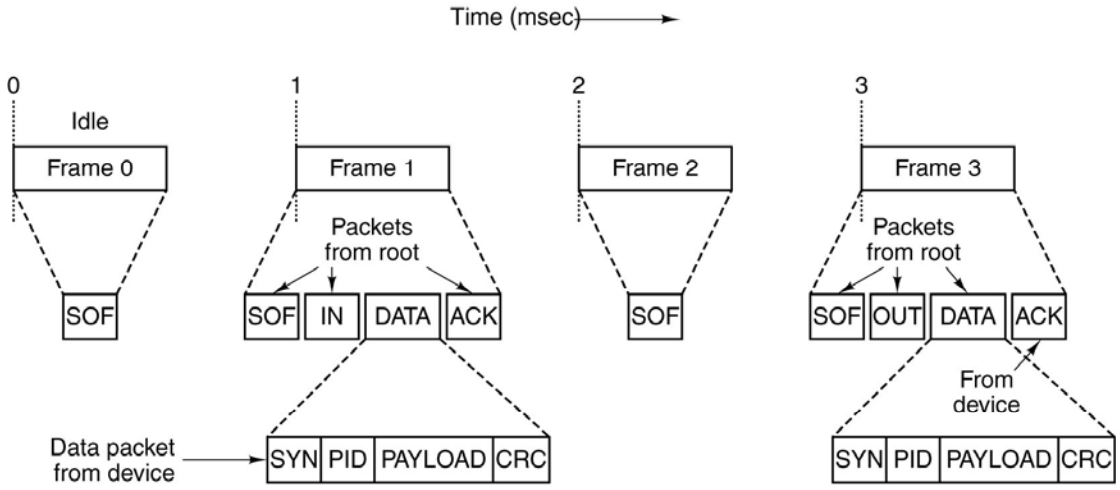
A typical PCI Express system.

PCI Express Protocol Stack



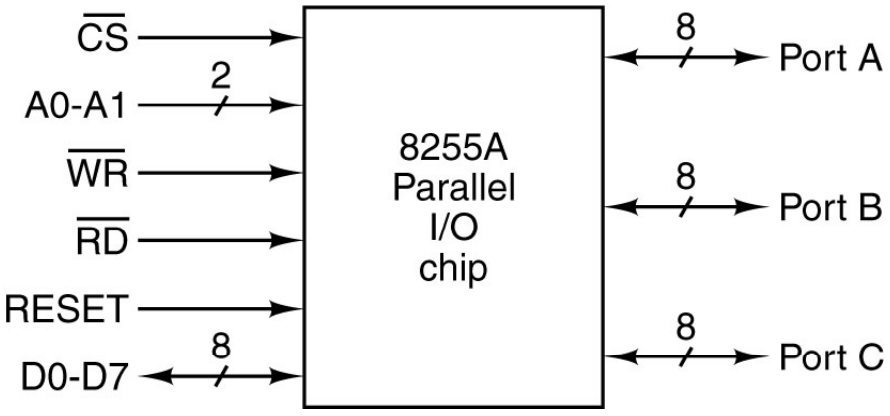
(a) The PCI Express protocol stack.
(b) The format of a packet.

The Universal Serial Bus



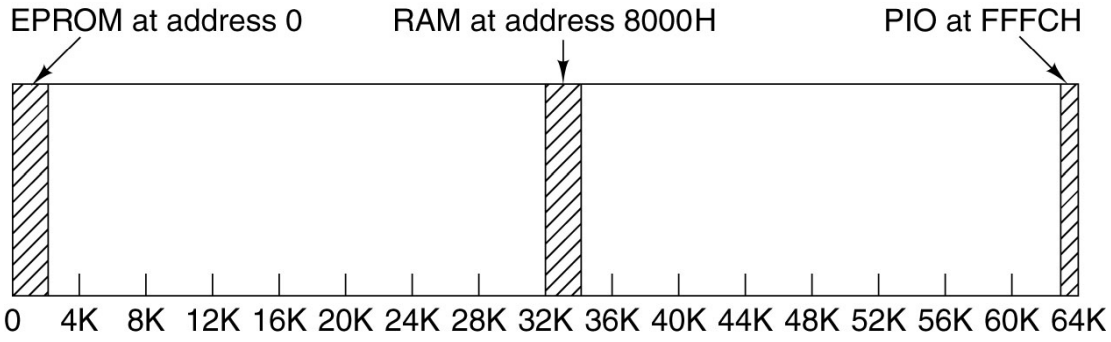
The USB root hub sends out frames every 1.00 ms.

PIO Chips



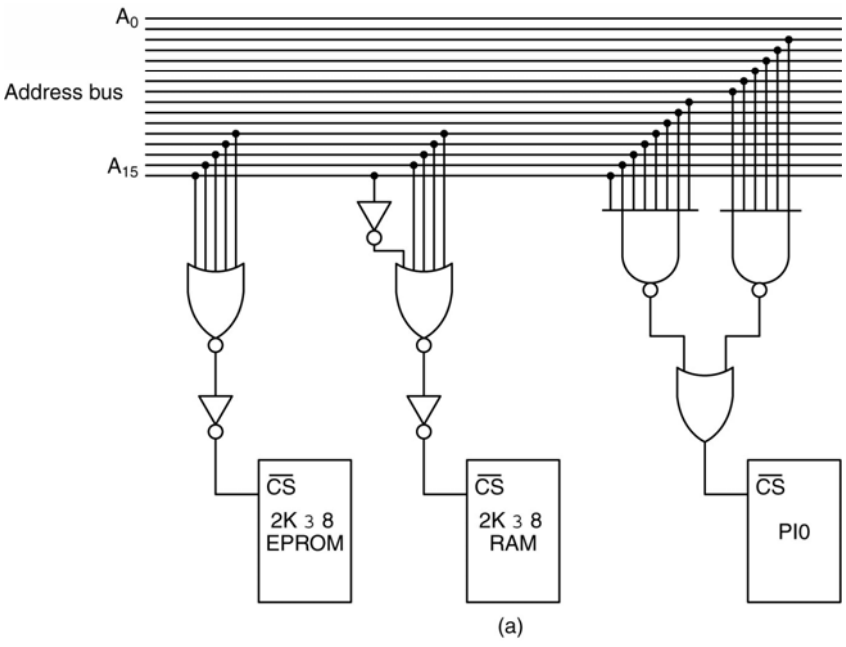
An 8255A PIO chip.

Address Decoding (1)



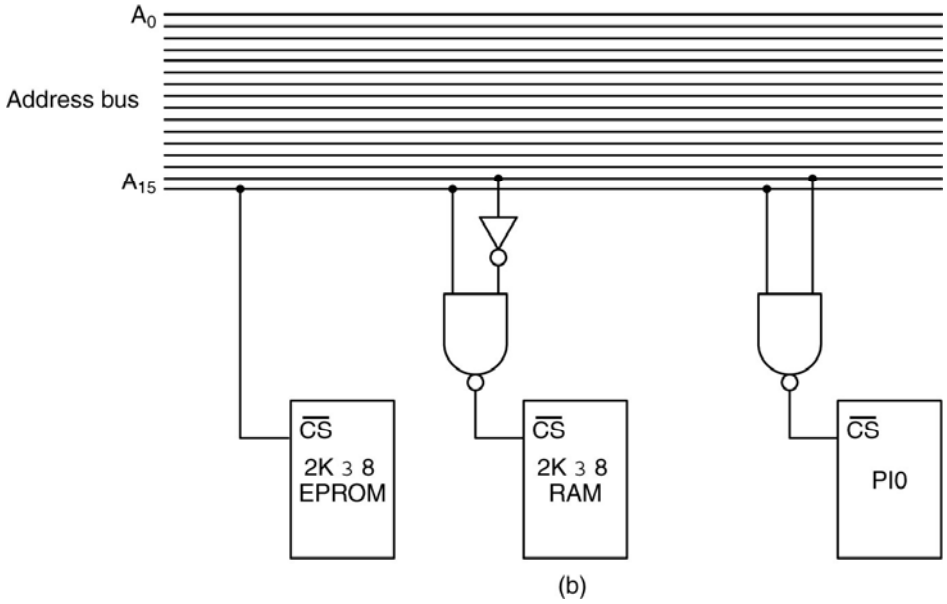
Location of the EPROM, RAM, and PIO in our 64 KB address space.

Address Decoding (2)



Full address decoding.

Address Decoding (3)



Partial address decoding.