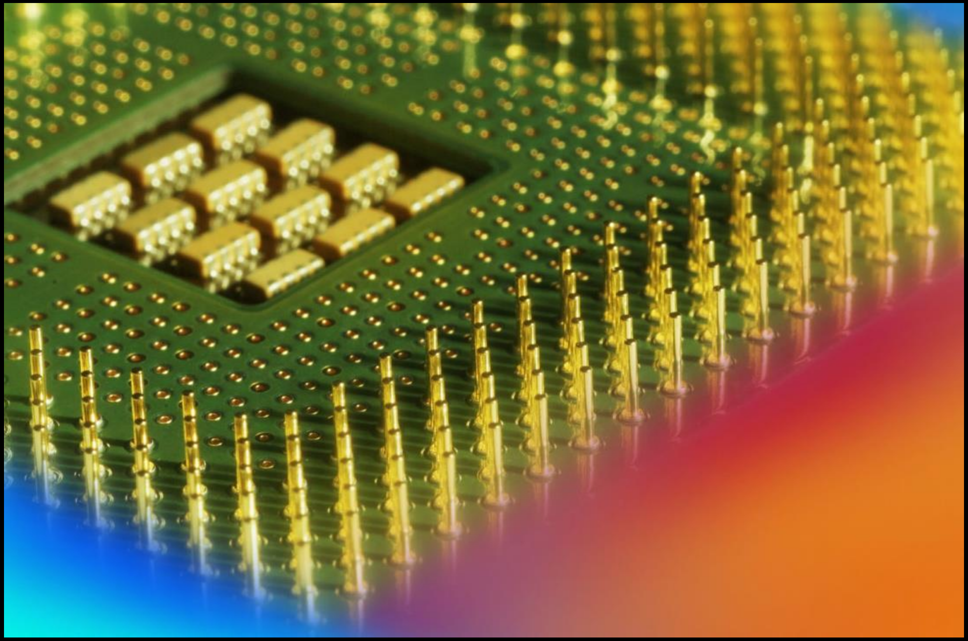
Digital Fundamentals

Tenth Edition

Floyd



Summary

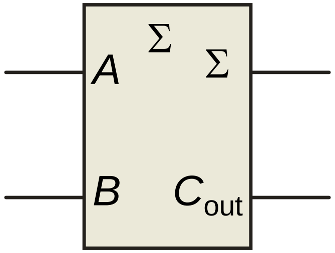
Half-Adder

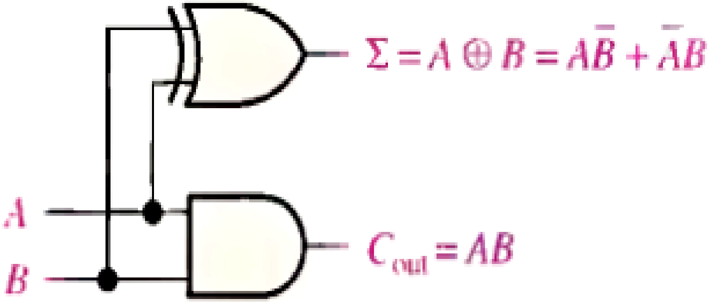
Basic rules of binary addition are performed by a **half adder**, which has two binary inputs (*A* and *B*) and two binary outputs (Carry out and Sum).

The inputs and outputs can be summarized on a truth table.

Inputs		Outputs	
A	B	C_{out}	Σ
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

The logic symbol and equivalent circuit are:





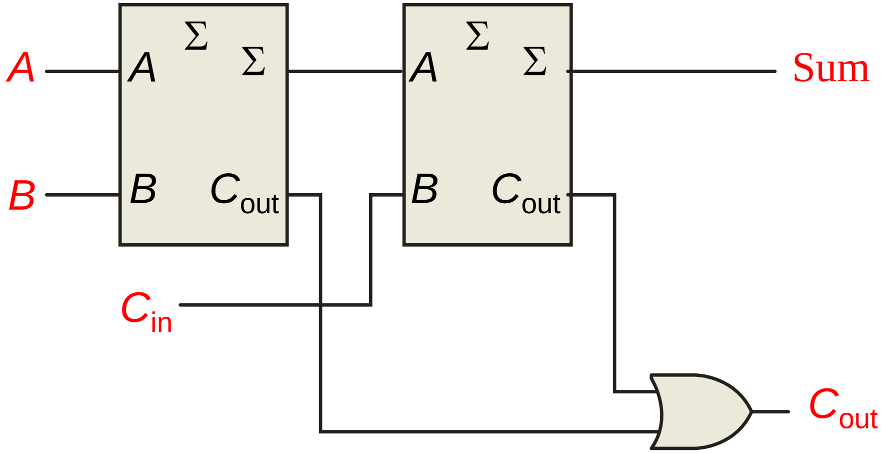
Summary

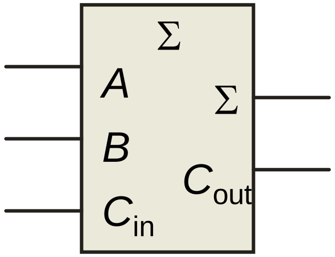
Full-Adder

By contrast, a **full adder** has three binary inputs (*A*, *B*, and Carry in) and two binary outputs (Carry out and Sum). The truth table summarizes the operation.

A full-adder can be constructed from two half adders as shown:

Inputs			Outputs	
A	B	C_{in}	C_{out}	Σ
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1



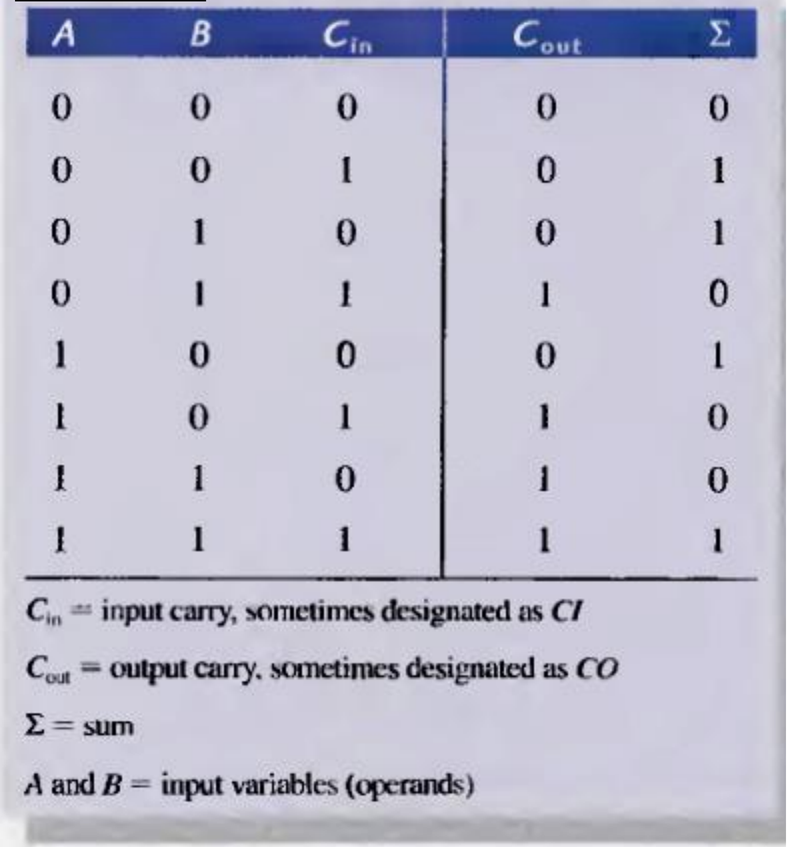


Symbol

Summary

Full-Adder

Truth Table



A	B	C_{in}	C_{out}	Σ
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

C_{in} = input carry, sometimes designated as CI

C_{out} = output carry, sometimes designated as CO

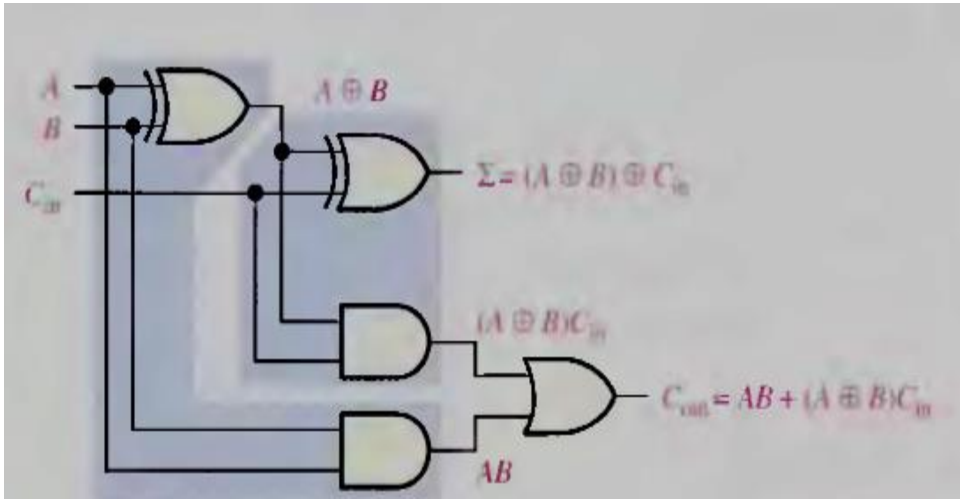
Σ = sum

A and B = input variables (operands)

Equation

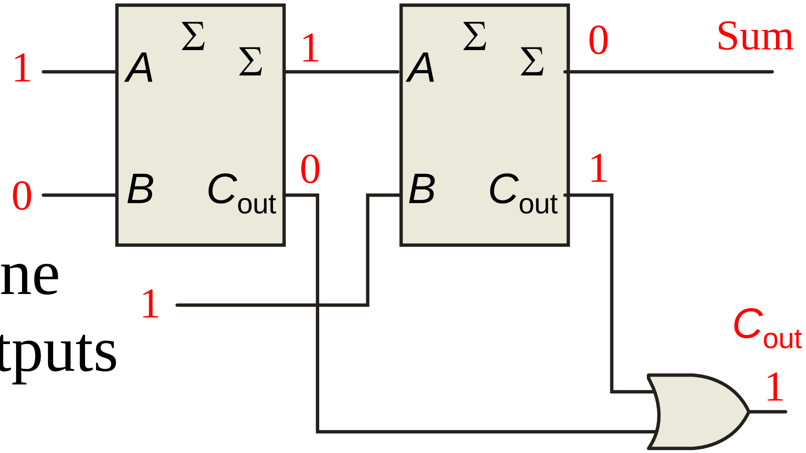
$$\Sigma = (A \oplus B) \oplus C_{in}$$

$$C_{out} = AB + (A \oplus B)C_{in}$$


A
B
C_{in}
$A \oplus B$
$\Sigma = (A \oplus B) \oplus C_{in}$
$(A \oplus B)C_{in}$
$C_{out} = AB + (A \oplus B)C_{in}$
AB

Summary

Full-Adder



Example

For the given inputs, determine the intermediate and final outputs of the full adder.

Solution

The first half-adder has inputs of 1 and 0; therefore the Sum =1 and the Carry out = 0.

The second half-adder has inputs of 1 and 1; therefore the Sum = 0 and the Carry out = 1.

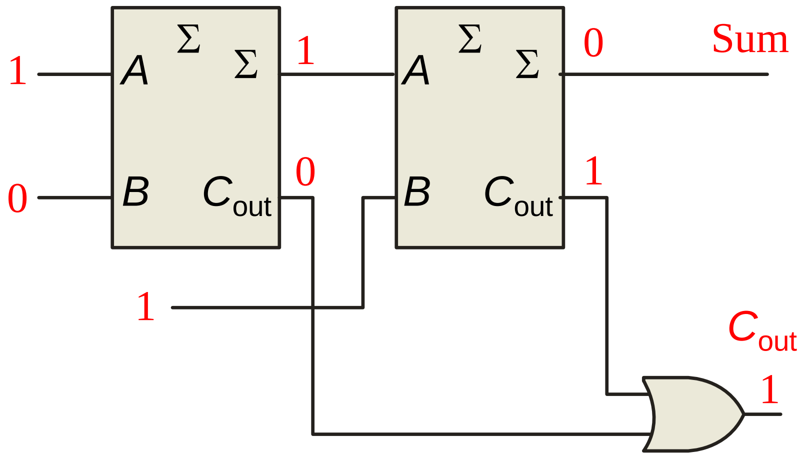
The OR gate has inputs of 1 and 0, therefore the final carry out = 1.

Summary

Full-Adder

Notice that the result from the previous example can be read directly on the truth table for a full adder.

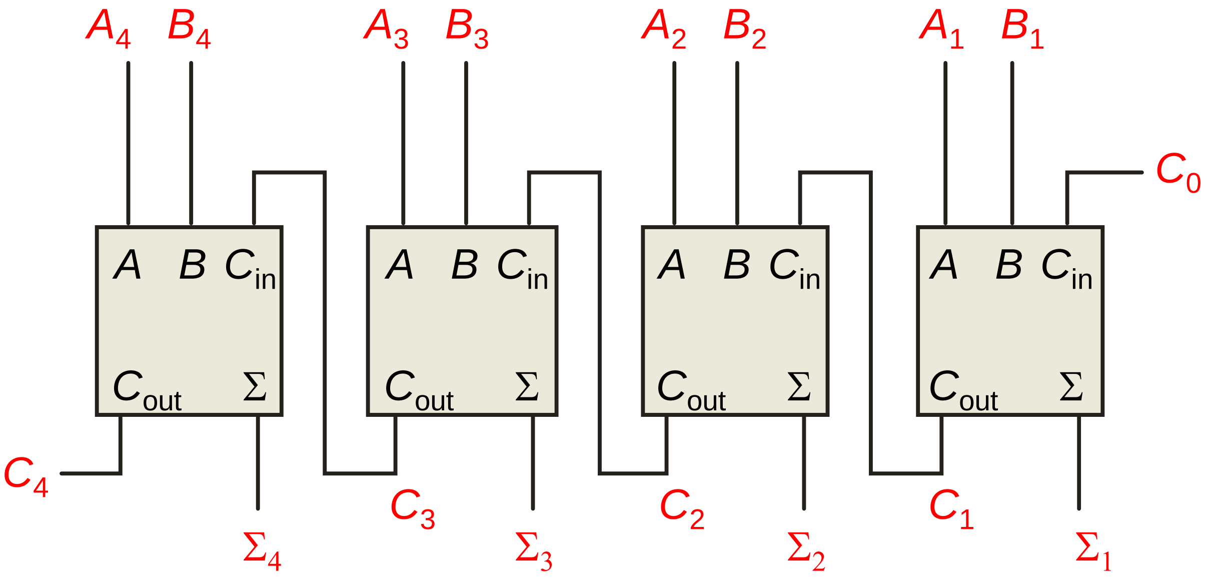
Inputs			Outputs	
A	B	C_{in}	C_{out}	Σ
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1



Summary

Parallel Adders

Full adders are combined into parallel adders that can add binary numbers with multiple bits. A 4-bit adder is shown.

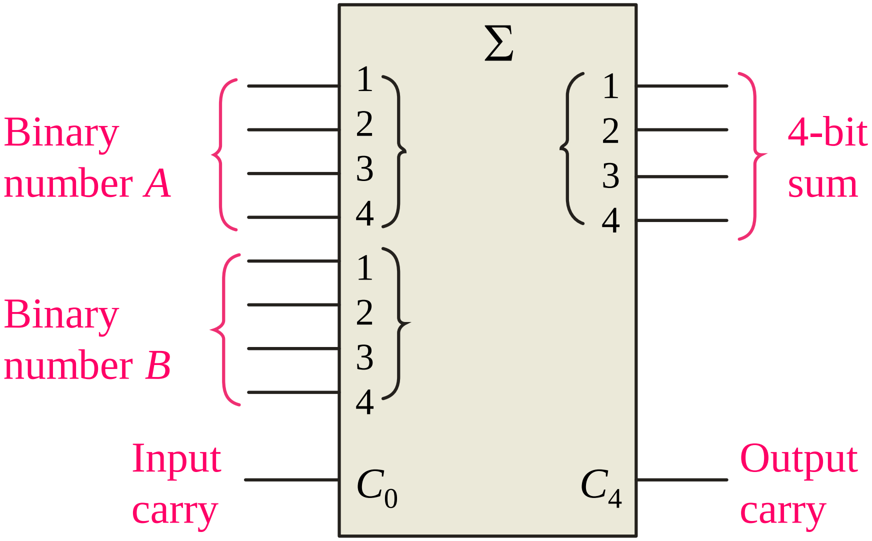


The output carry (C_4) is not ready until it propagates through all of the full adders. This is called *ripple carry*, delaying the addition process.

Summary

Parallel Adders

The logic symbol for a 4-bit parallel adder is shown. This 4-bit adder includes a carry in (labeled (C_0) and a Carry out (labeled C_4).

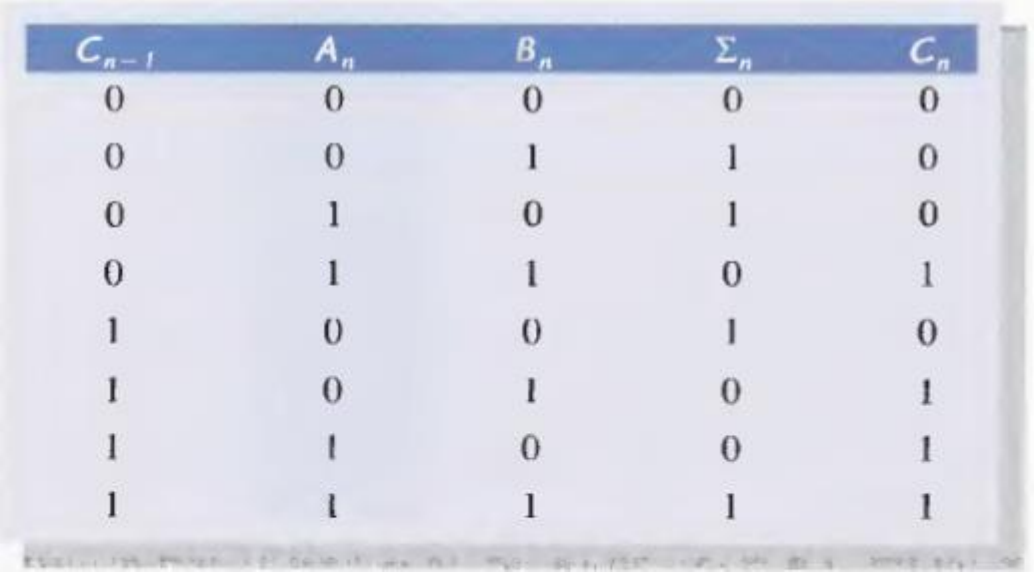


The 74LS283 is an example. It features *look-ahead carry*, which adds logic to minimize the output carry delay. For the 74LS283, the maximum delay to the output carry is 17 ns.

Summary

Parallel Adders

Truth Table for a 4-Bit Parallel Adder

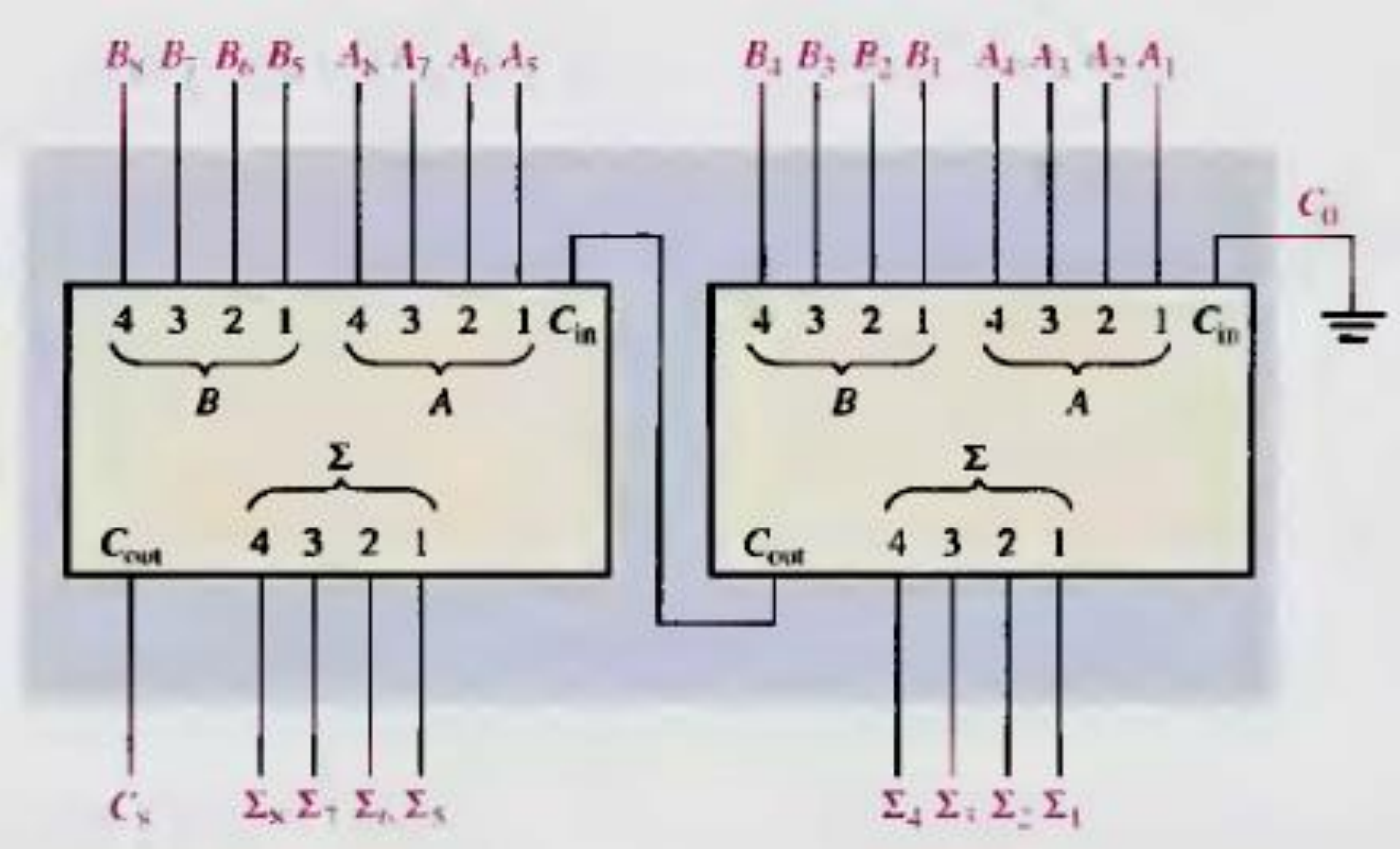


C_{n-1}	A_n	B_n	Σ_n	C_n
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Summary

Parallel Adders

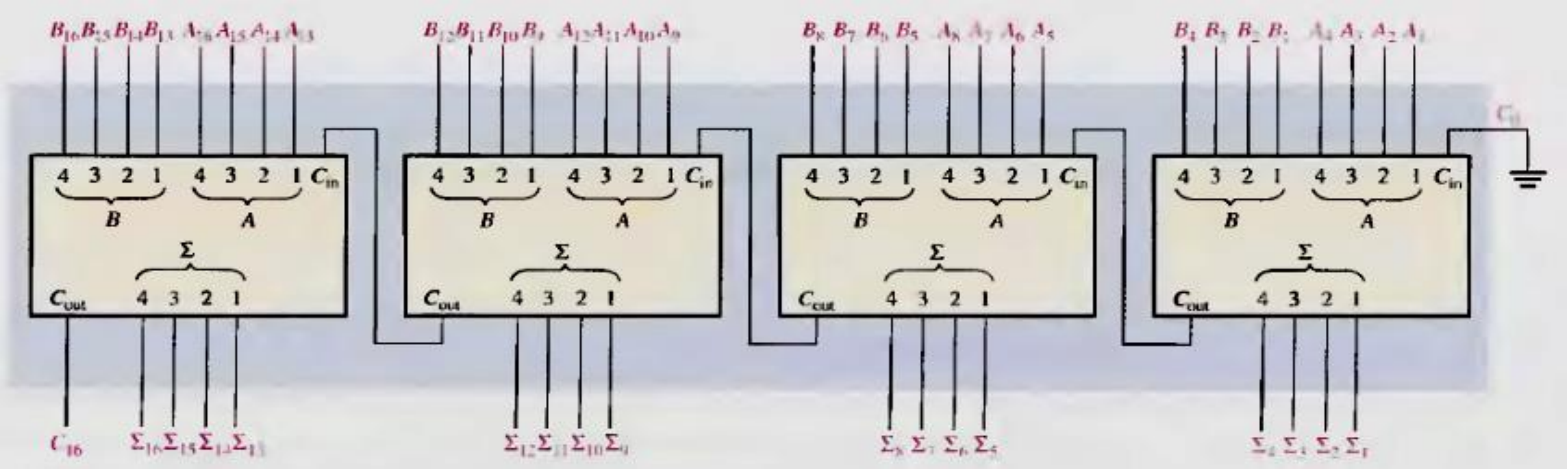
Cascading of two 4-bit adders to form an 8-bit adder


B_8 B_7 B_6 B_5 A_8 A_7 A_6 A_5
B_4 B_3 B_2 B_1 A_4 A_3 A_2 A_1
C_0
4 3 2 1 4 3 2 1 C_{in}
B
A
Σ
C_{out}
4 3 2 1
C_8
Σ_8 Σ_7 Σ_6 Σ_5
Σ_4 Σ_3 Σ_2 Σ_1

Summary

Parallel Adders

Cascading of four 4-bit adders to form a 16-bit adder


B_{16} B_{15} B_{14} B_{13} A_{16} A_{15} A_{14} A_{13}
B_{12} B_{11} B_{10} B_9 A_{12} A_{11} A_{10} A_9
B_8 B_7 B_6 B_5 A_8 A_7 A_6 A_5
B_4 B_3 B_2 B_1 A_4 A_3 A_2 A_1
C_0
4 3 2 1 4 3 2 1 C_{in}
B A
Σ
C_{out} 4 3 2 1
C_{16} Σ_{16} Σ_{15} Σ_{14} Σ_{13}
Σ_{12} Σ_{11} Σ_{10} Σ_9
Σ_8 Σ_7 Σ_6 Σ_5
Σ_4 Σ_3 Σ_2 Σ_1

EXAMPLE 6–4

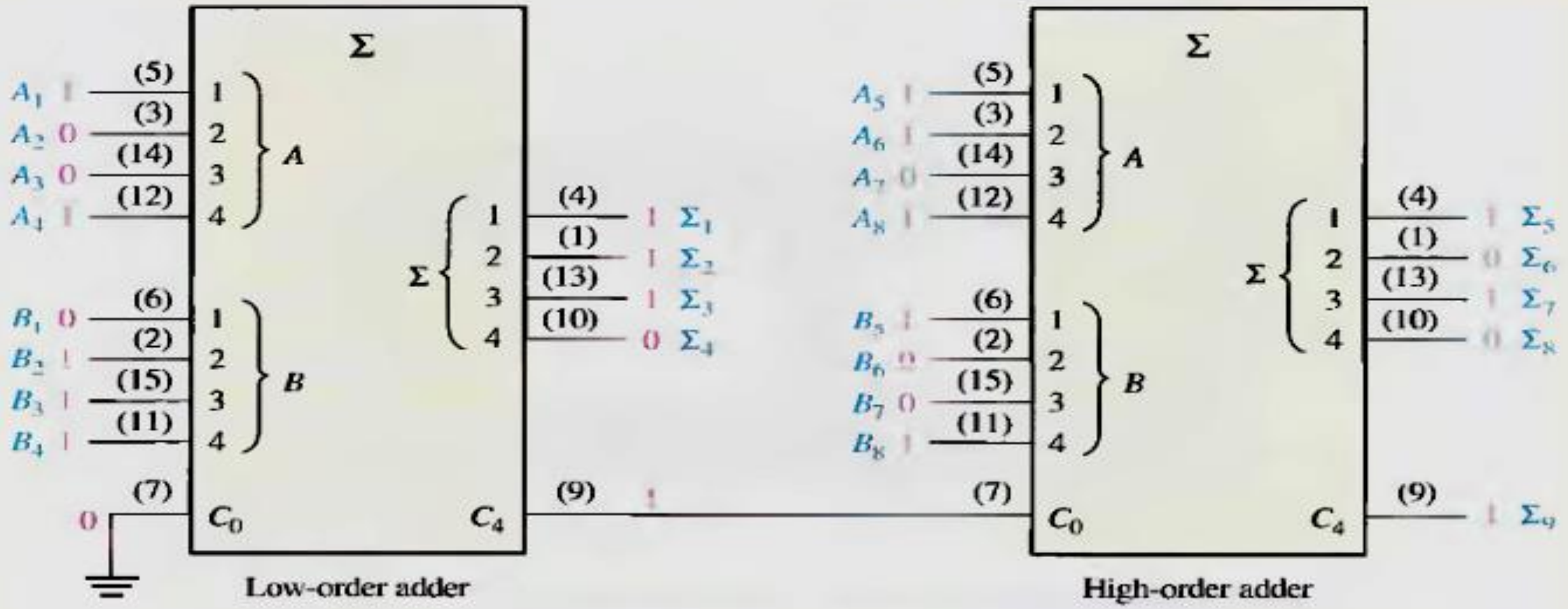
Show how two 74LS283 adders can be connected to form an 8-bit parallel adder. Show output bits for the following 8-bit input numbers:

$$A_8A_7A_6A_5A_4A_3A_2A_1 = 10111001 \quad \text{and} \quad B_8B_7B_6B_5B_4B_3B_2B_1 = 10011110$$

Solution Two 74LS283 4-bit parallel adders are used to implement the 8-bit adder. The only connection between the two 74LS283s is the carry output (pin 9) of the low-order adder to the carry input (pin 7) of the high-order adder, as shown in Figure 6–13. Pin 7 of the low-order adder is grounded (no carry input).

The sum of the two 8-bit numbers is

$$\Sigma_9\Sigma_8\Sigma_7\Sigma_6\Sigma_5\Sigma_4\Sigma_3\Sigma_2\Sigma_1 = 101010111$$



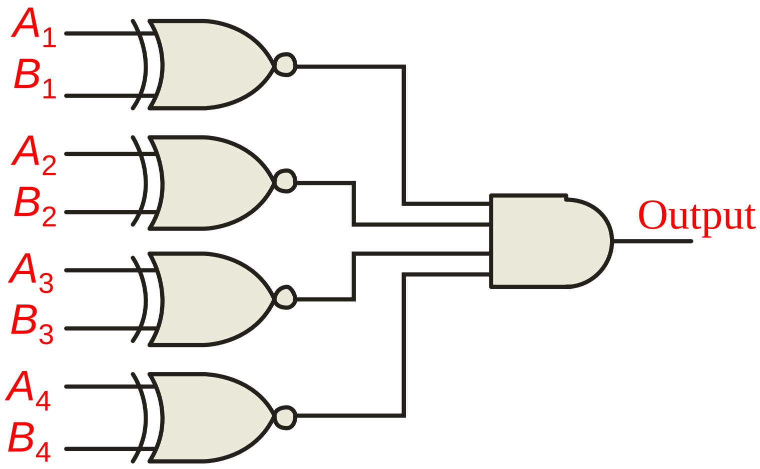
Summary

Comparators

The function of a comparator is to compare the magnitudes of two binary numbers to determine the relationship between them. In the simplest form, a comparator can test for equality using XNOR gates.

Example How could you test two 4-bit numbers for equality?

Solution AND the outputs of four XNOR gates.

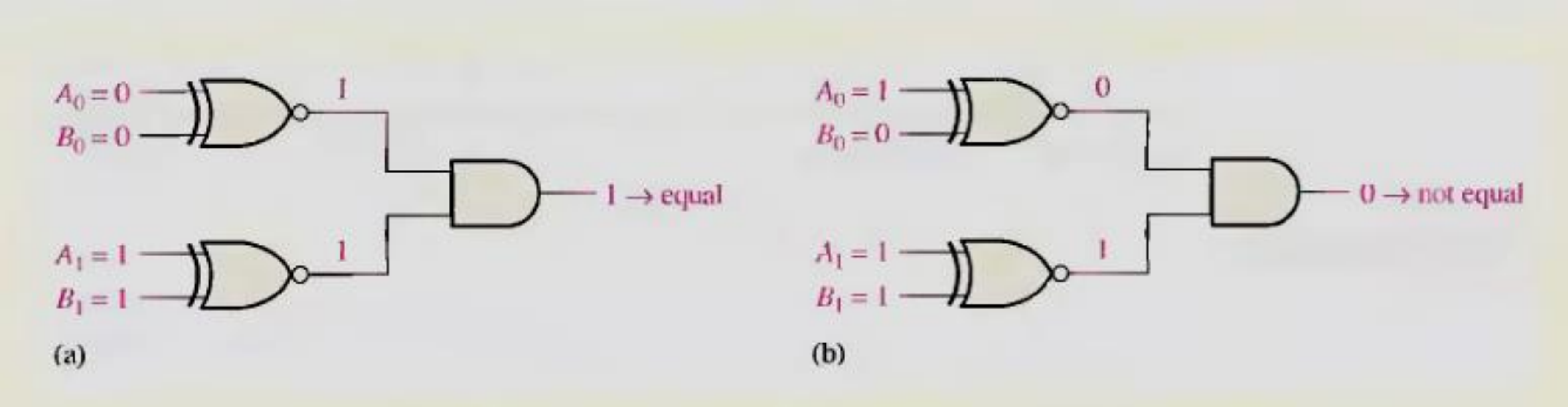


Comparators

EXAMPLE

Apply each of the following sets of binary numbers to the comparator inputs in Figure 6–21, and determine the output by following the logic levels through the circuit.

(a) 10 and 10 (b) 11 and 10



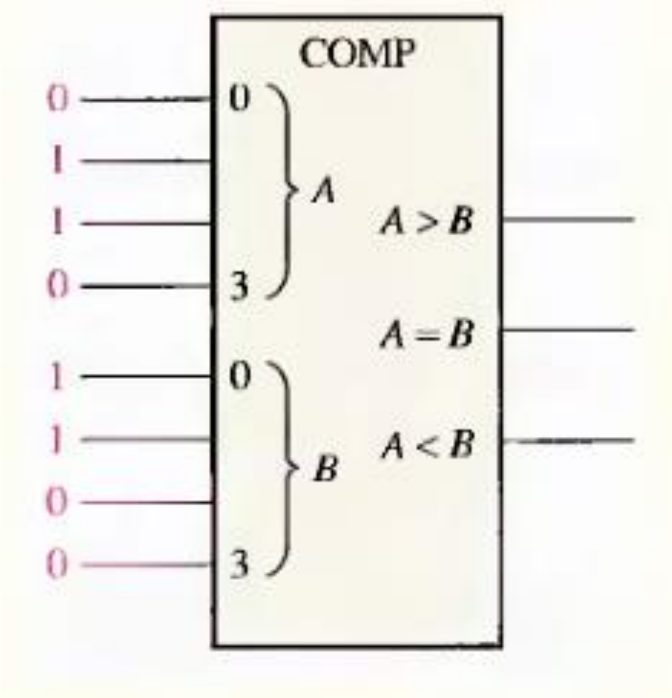
Solution (a) The output is 1 for inputs 10 and 10, as shown in

(b) The output is 0 for inputs 11 and 10, as shown in

Comparators

EXAMPLE

Determine the $A = B$, $A > B$, and $A < B$ outputs for the input numbers shown on the comparator in Figure



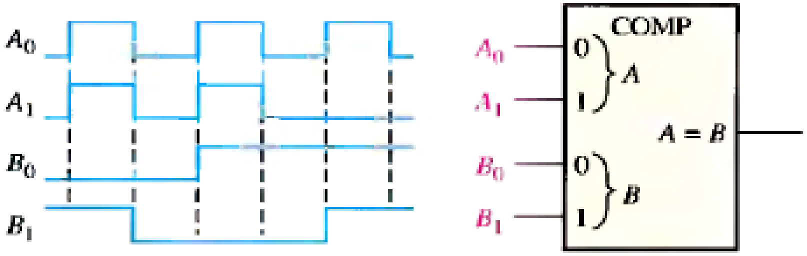
Solution The number on the A inputs is 0110 and the number on the B inputs is 0011. The **$A > B$ output is HIGH and the other outputs are LOW.**

Comparators

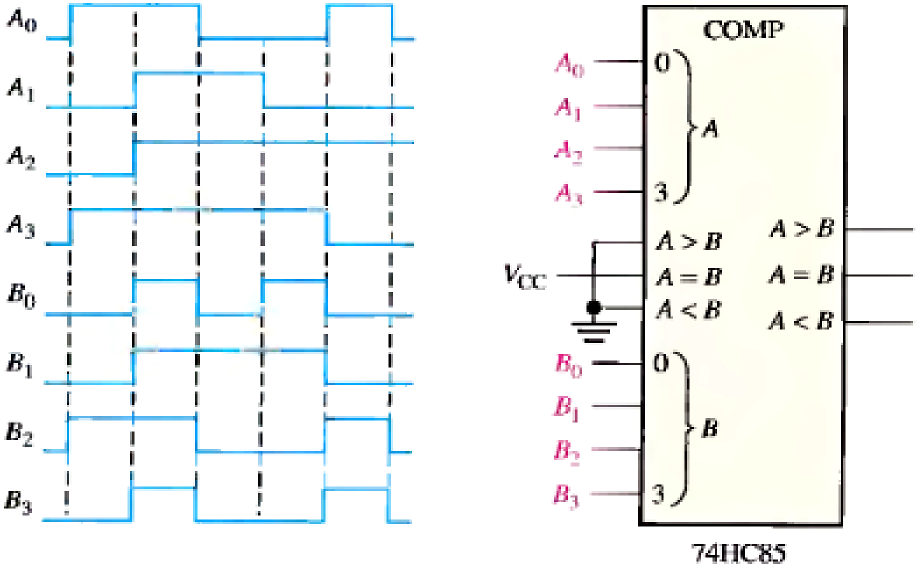
EXAMPLE

Comparators

11. The waveforms in Figure 6–79 are applied to the comparator as shown. Determine the output ($A = B$) waveform.



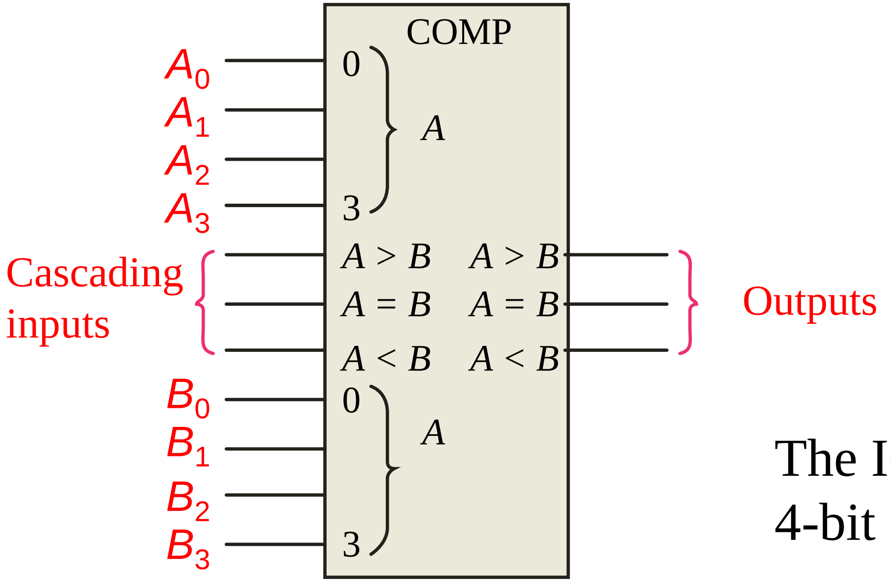
12. For the 4-bit comparator in Figure 6–80, plot each output waveform for the inputs shown. The outputs are active-HIGH.



Summary

Comparators

IC comparators provide outputs to indicate which of the numbers is larger or if they are equal. The bits are numbered starting at 0, rather than 1 as in the case of adders. Cascading inputs are provided to expand the comparator to larger numbers.

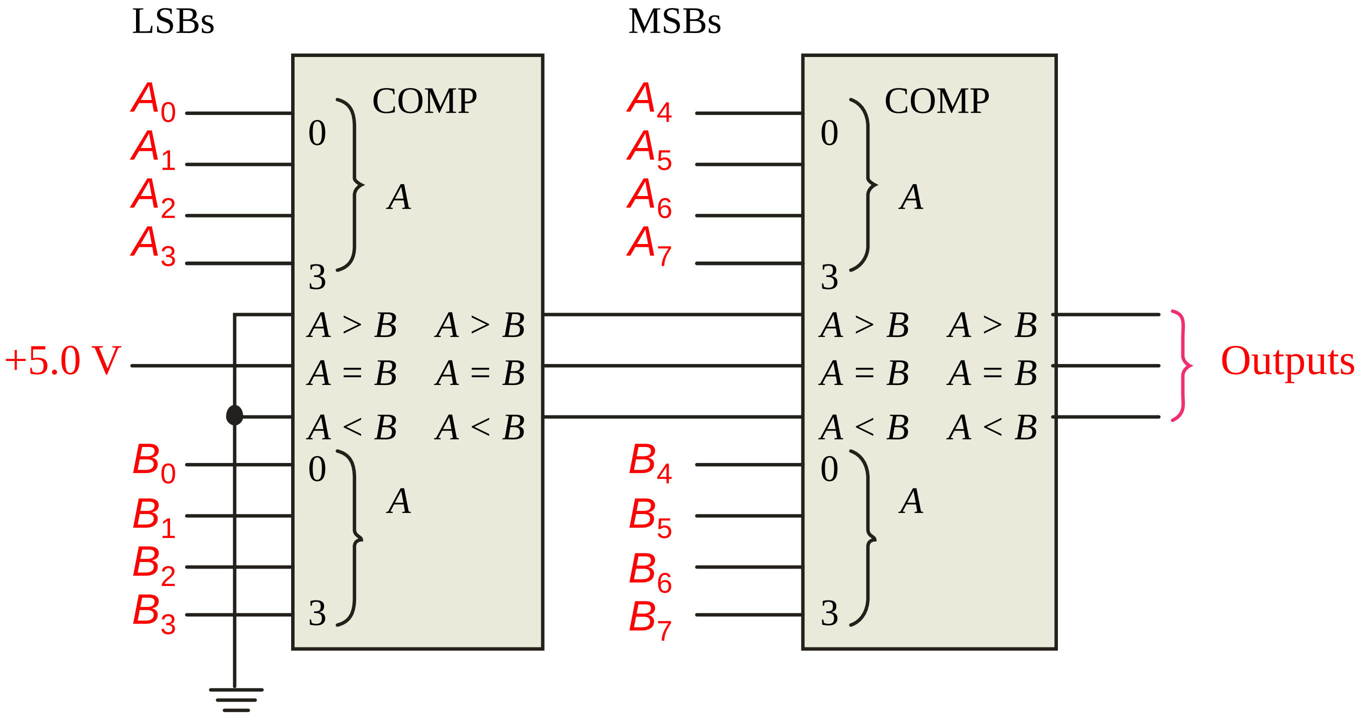


The IC shown is the 4-bit 74LS85.

Summary

Comparators

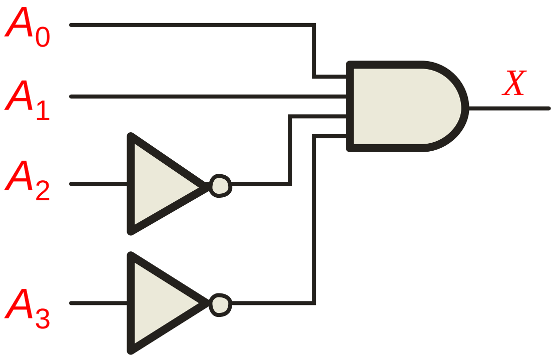
IC comparators can be expanded using the cascading inputs as shown. The lowest order comparator has a HIGH on the *A* = *B* input.



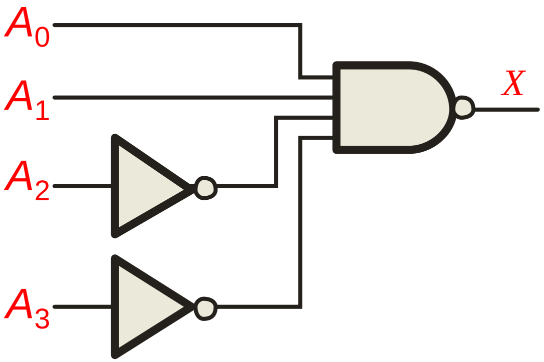
Summary

Decoders

A **decoder** is a logic circuit that detects the presence of a specific combination of bits at its input. Two simple decoders that detect the presence of the binary code 0011 are shown. The first has an active HIGH output; the second has an active LOW output.



Active HIGH decoder for 0011



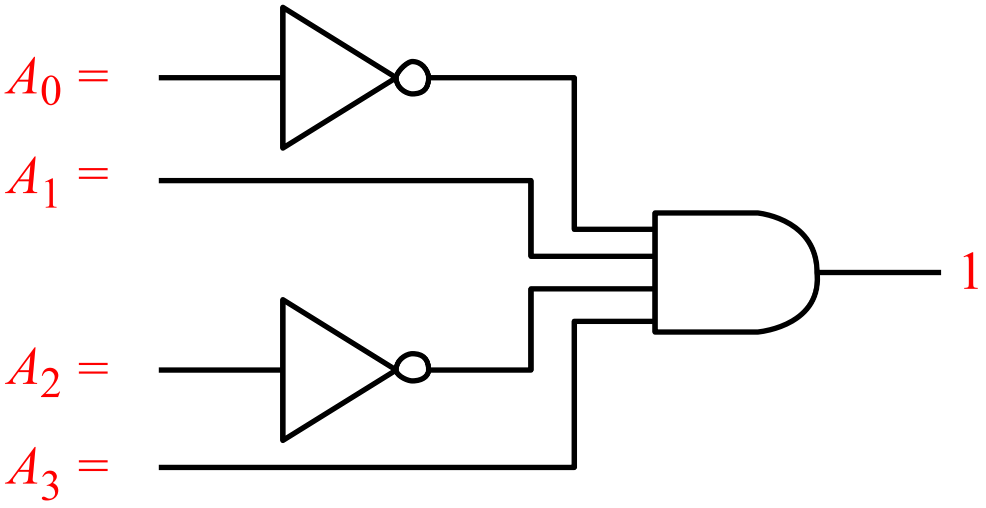
Active LOW decoder for 0011

Summary

Decoders

Question

Assume the output of the decoder shown is a logic 1. What are the inputs to the decoder?



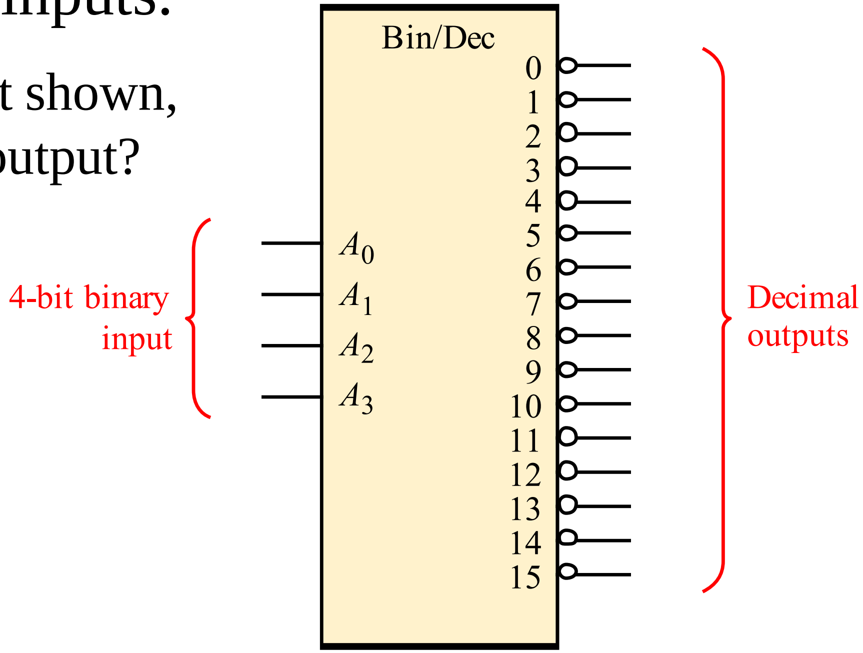
Summary

Decoders

IC decoders have multiple outputs to decode any combination of inputs. For example the binary-to-decimal decoder shown here has 16 outputs – one for each combination of binary inputs.

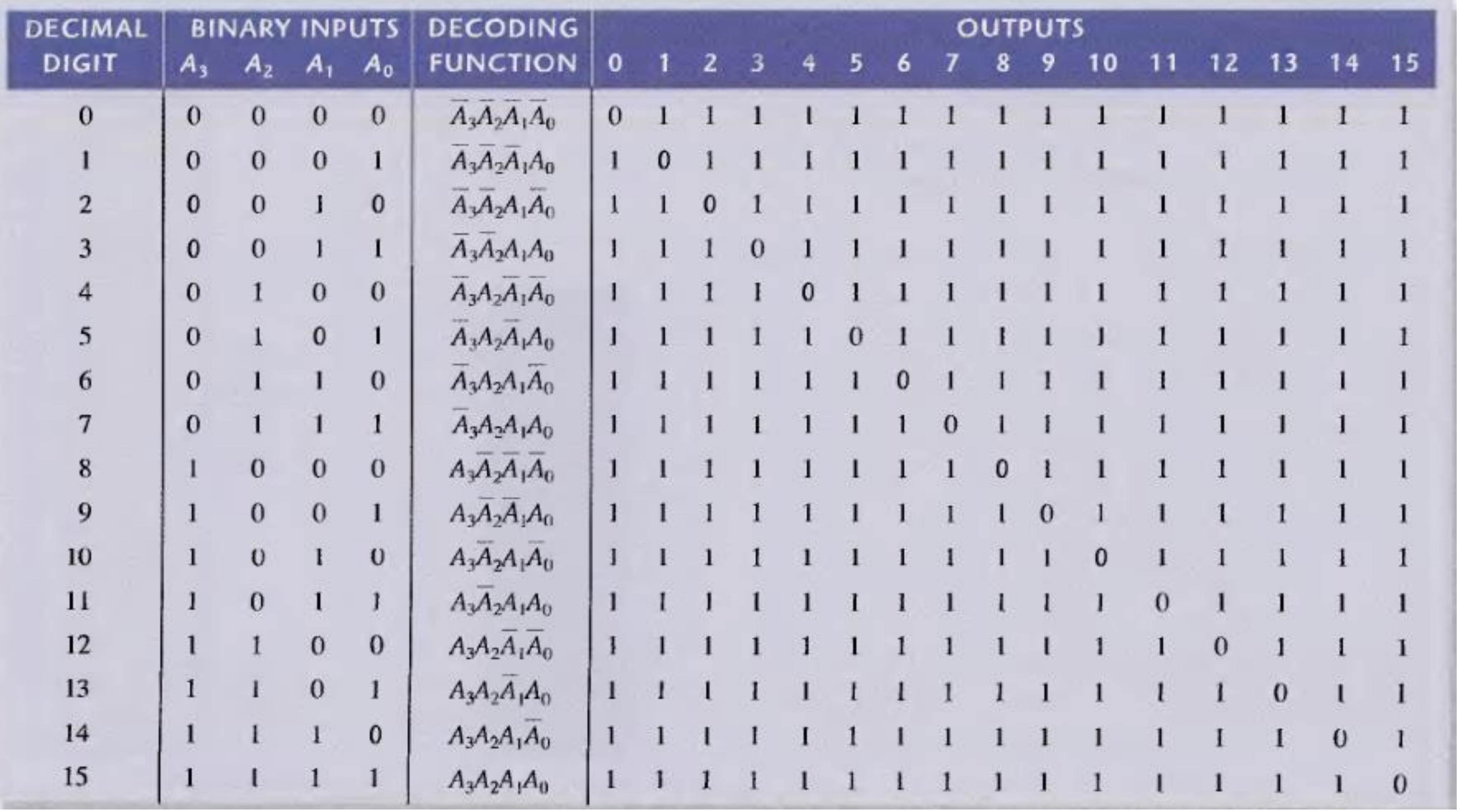
Question

For the input shown, what is the output?



Decoders

Decoding functions and truth table for a 4-line-to-16-line (1-of-16) decoder with active-LOW outputs.

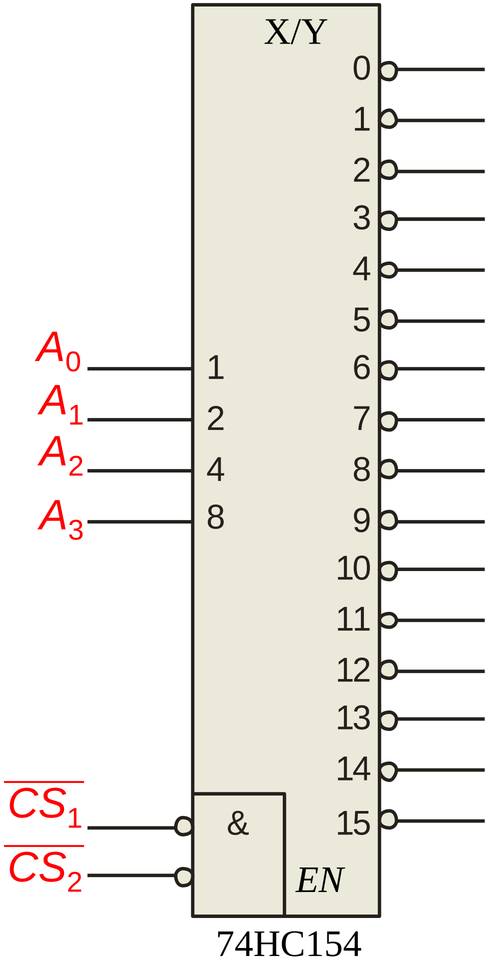


DECIMAL DIGIT	BINARY INPUTS				DECODING FUNCTION	OUTPUTS															
	A_3	A_2	A_1	A_0		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	$\overline{A}_3\overline{A}_2\overline{A}_1\overline{A}_0$	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	1	$\overline{A}_3\overline{A}_2\overline{A}_1A_0$	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	0	1	0	$\overline{A}_3\overline{A}_2A_1\overline{A}_0$	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	1	1	$\overline{A}_3\overline{A}_2A_1A_0$	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
4	0	1	0	0	$\overline{A}_3A_2\overline{A}_1\overline{A}_0$	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
5	0	1	0	1	$\overline{A}_3A_2\overline{A}_1A_0$	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
6	0	1	1	0	$\overline{A}_3A_2A_1\overline{A}_0$	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
7	0	1	1	1	$\overline{A}_3A_2A_1A_0$	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
8	1	0	0	0	$A_3\overline{A}_2\overline{A}_1\overline{A}_0$	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
9	1	0	0	1	$A_3\overline{A}_2\overline{A}_1A_0$	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
10	1	0	1	0	$A_3\overline{A}_2A_1\overline{A}_0$	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
11	1	0	1	1	$A_3\overline{A}_2A_1A_0$	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
12	1	1	0	0	$A_3A_2\overline{A}_1\overline{A}_0$	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
13	1	1	0	1	$A_3A_2\overline{A}_1A_0$	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
14	1	1	1	0	$A_3A_2A_1\overline{A}_0$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
15	1	1	1	1	$A_3A_2A_1A_0$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

Summary

Decoders

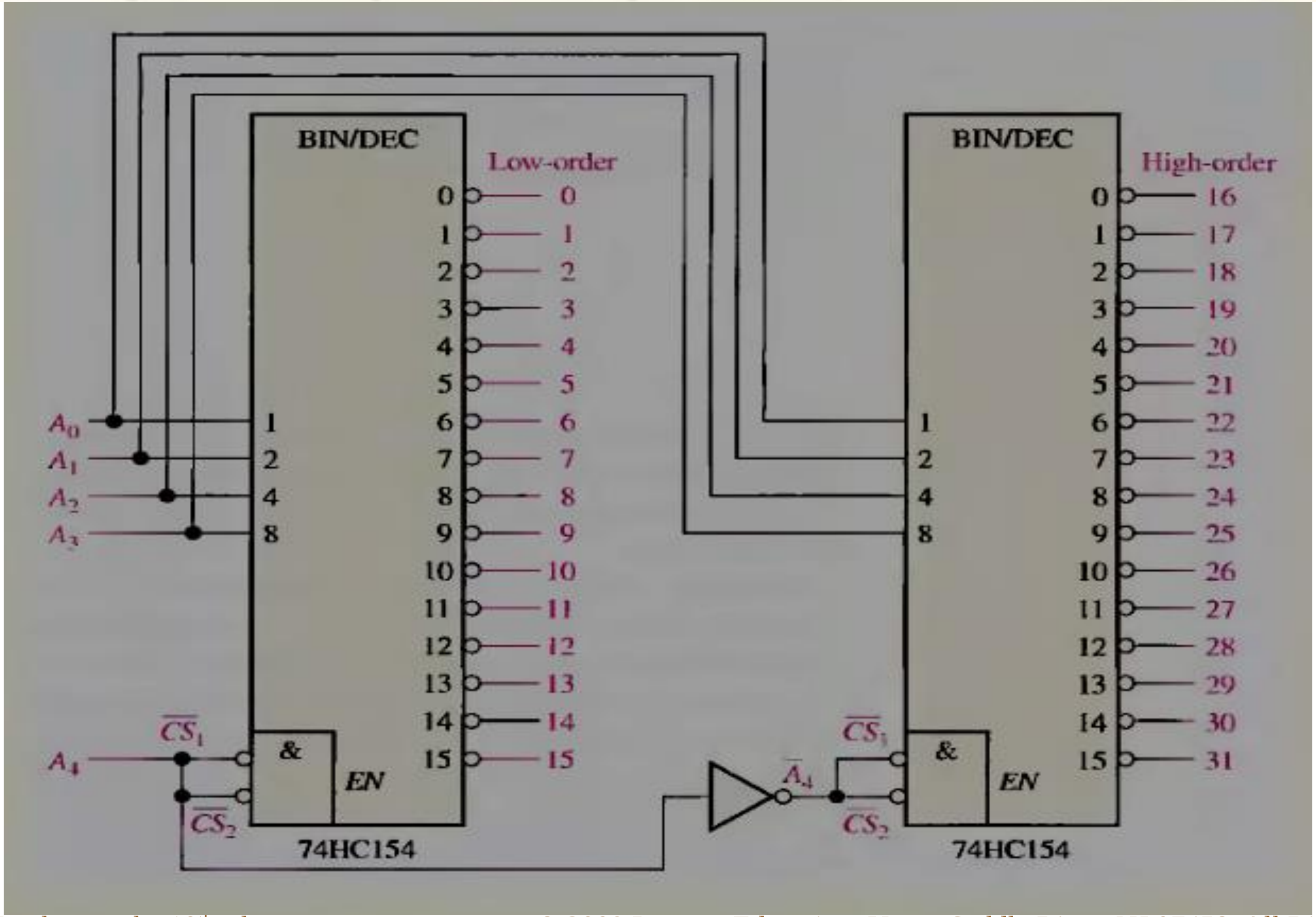
A specific integrated circuit decoder is the 74HC154 (shown as a 4-to-16 decoder). It includes two active LOW chip select lines which must be at the active level to enable the outputs. These lines can be used to expand the decoder to larger inputs.



Decoders

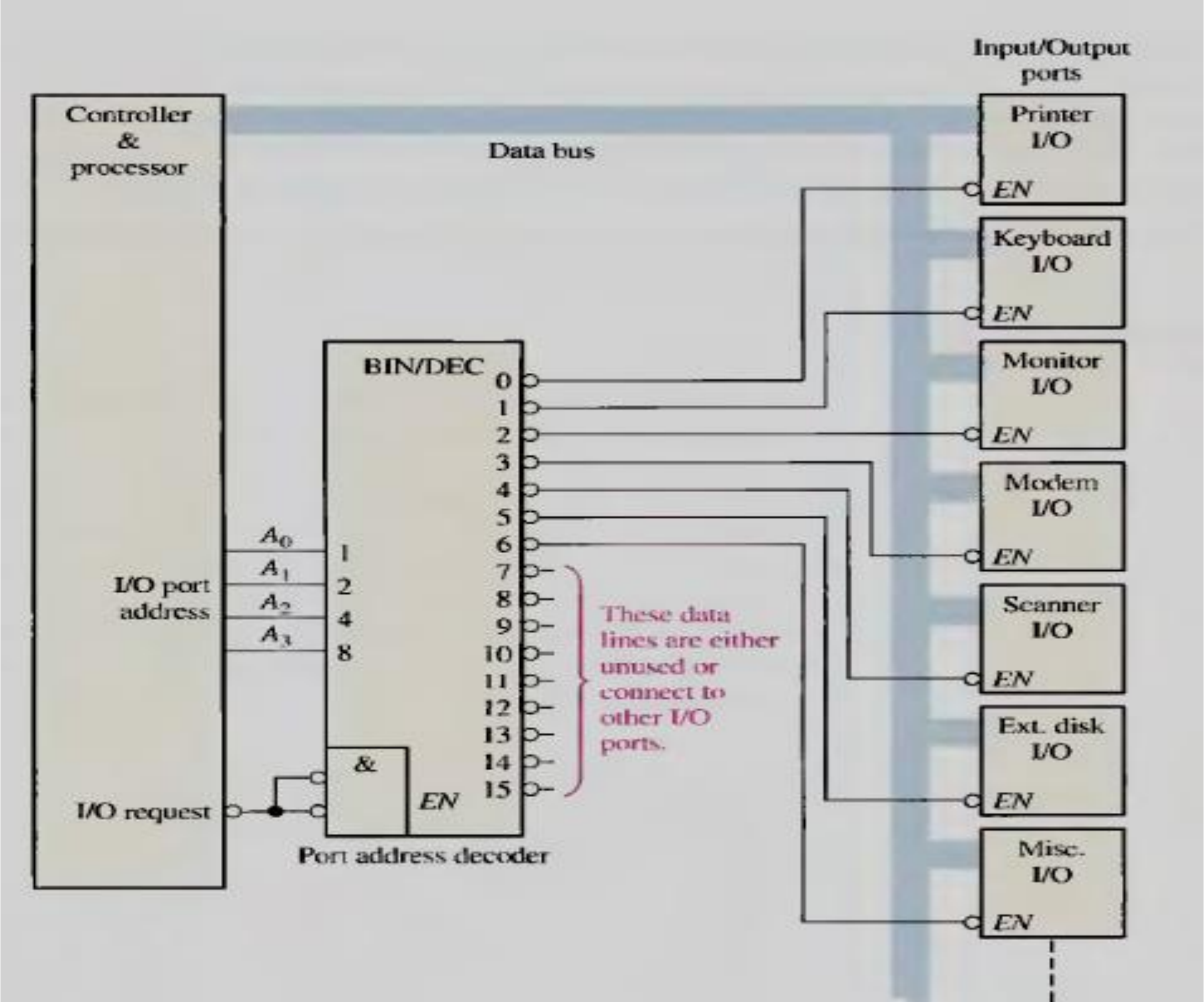
Question

A certain application requires that a 5-bit number be decoded. Use 74HC154 decoders to implement the logic. The binary number is represented by the format $A_4A_3A_2A_1A_0$.



Decoders

EXAMPLE



These data lines are either unused or connect to other I/O ports.

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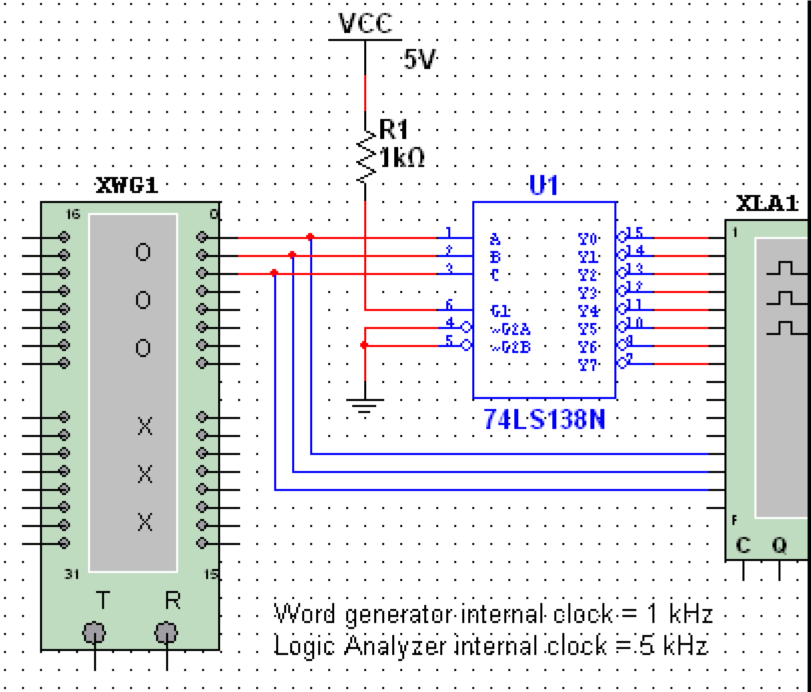
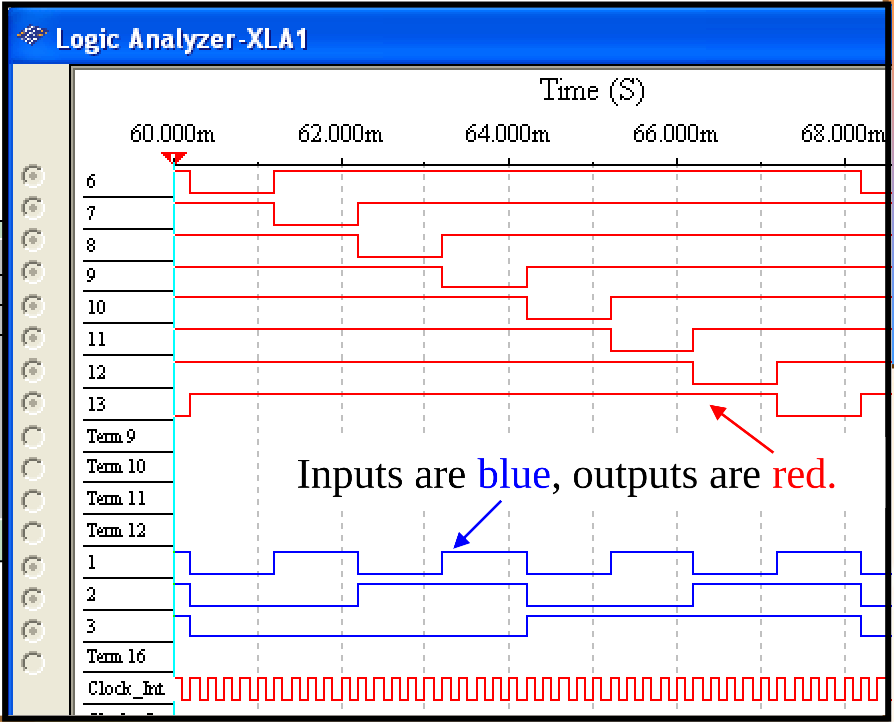
Summary

Decoders

The 74LS138 is a 3-to-8 decoder with three chip select inputs (two active LOW, one active HIGH). In this Multisim circuit, the word generator (XWG1) is set up as an up counter. The logic analyzer (XLA1) compares the input and outputs of the decoder.



Word generator internal clock = 1 kHz
Logic Analyzer internal clock = 5 kHz

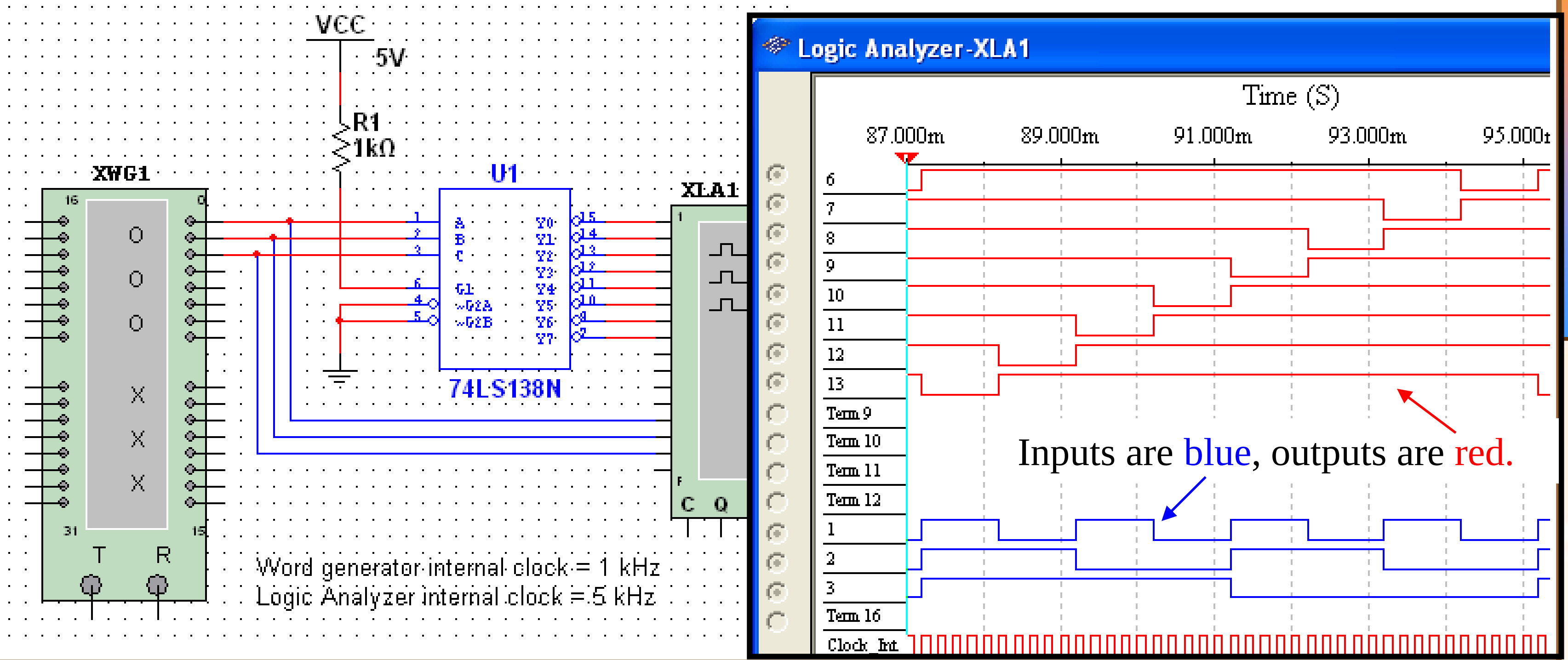


Inputs are blue, outputs are red.

Summary

Decoders

Question How will the waveforms change if the word generator is configured as a down counter instead of an up counter?

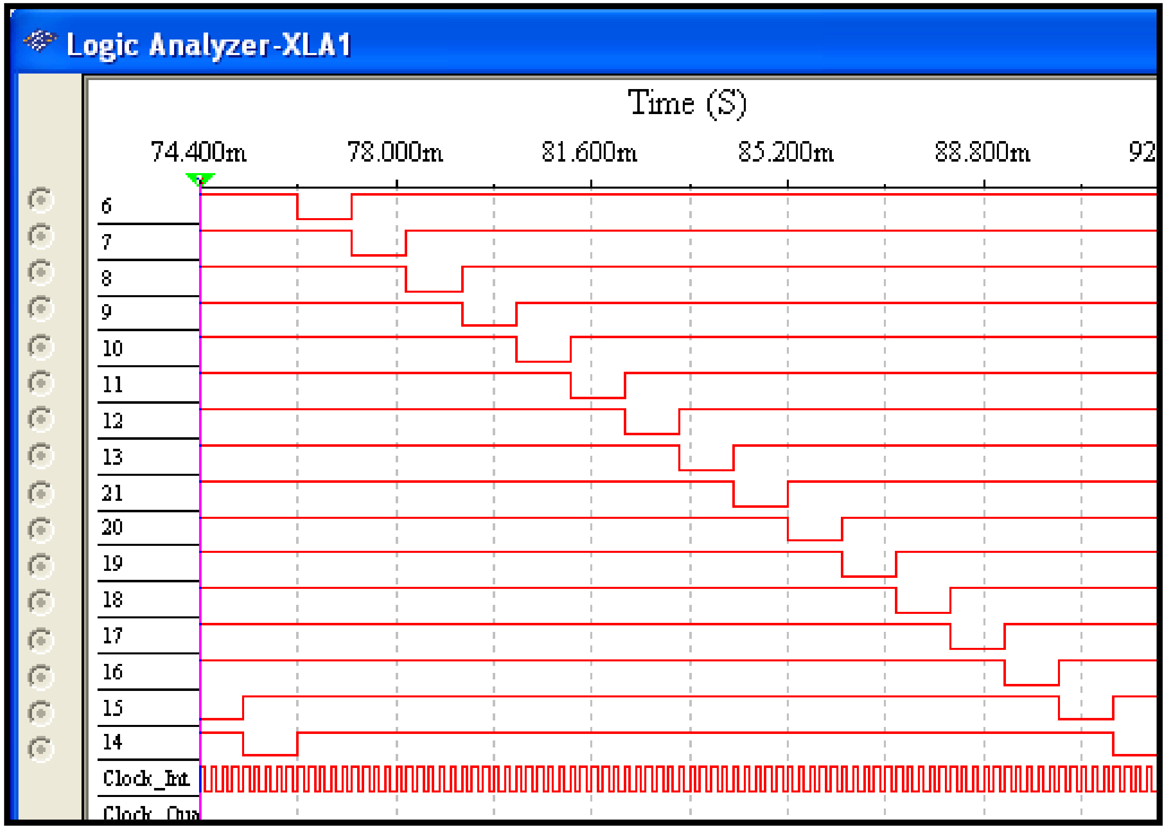


Word generator internal clock = 1 kHz
Logic Analyzer internal clock = 5 kHz

Inputs are blue, outputs are red.

Summary

Decoders



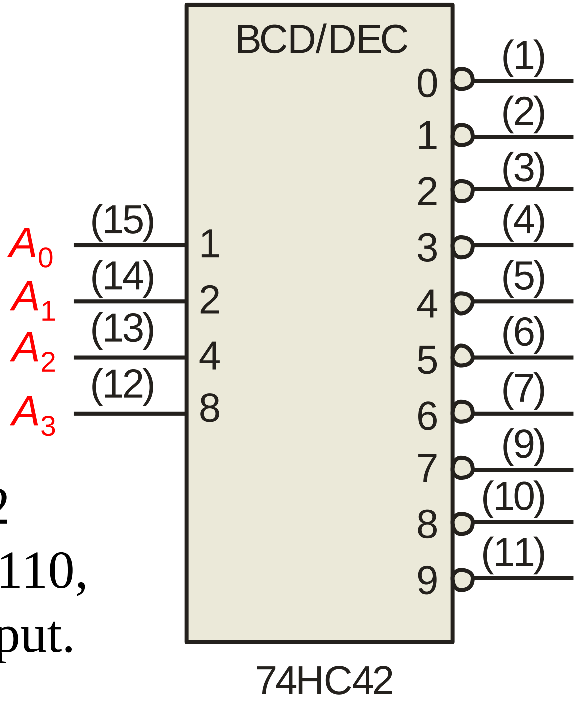
Question

Is the word generator set as an up counter or a down counter? (The least significant decoder output at the top). It is an up counter.

Summary

Decoders

BCD-to-decimal decoders accept a binary coded decimal input and activate one of ten possible decimal digit indications.



Example Assume the inputs to the 74HC42 decoder are the sequence 0101, 0110, 0011, and 0010. Describe the output.

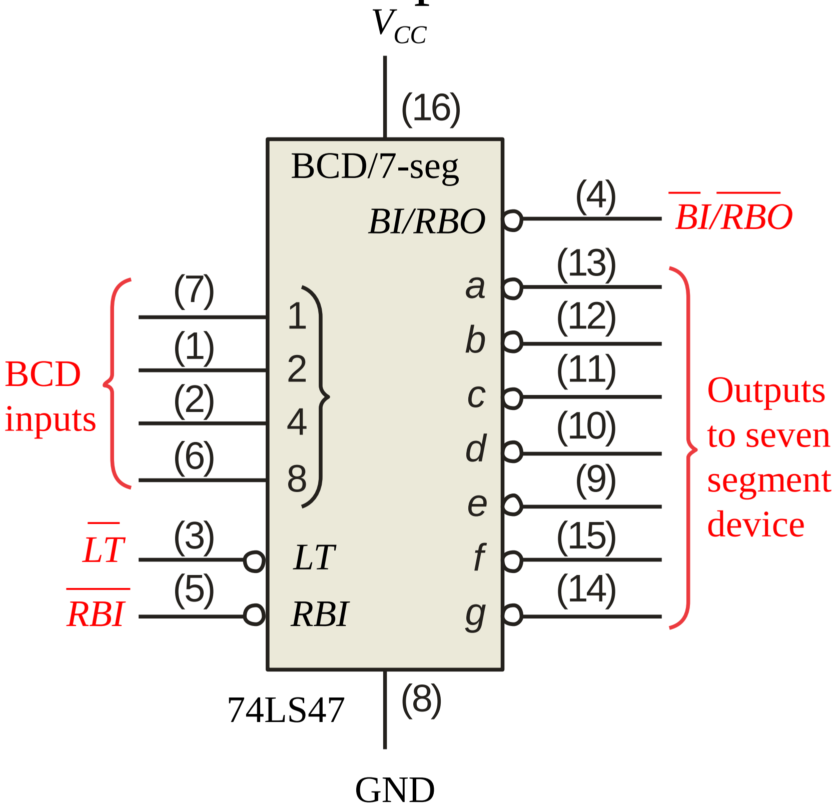
Solution All lines are HIGH except for one active output, which is LOW. The active outputs are 5, 6, 3, and 2 in that order.

Summary

BCD Decoder/Driver

Another useful decoder is the 74LS47. This is a BCD-to-seven segment display with active LOW outputs.

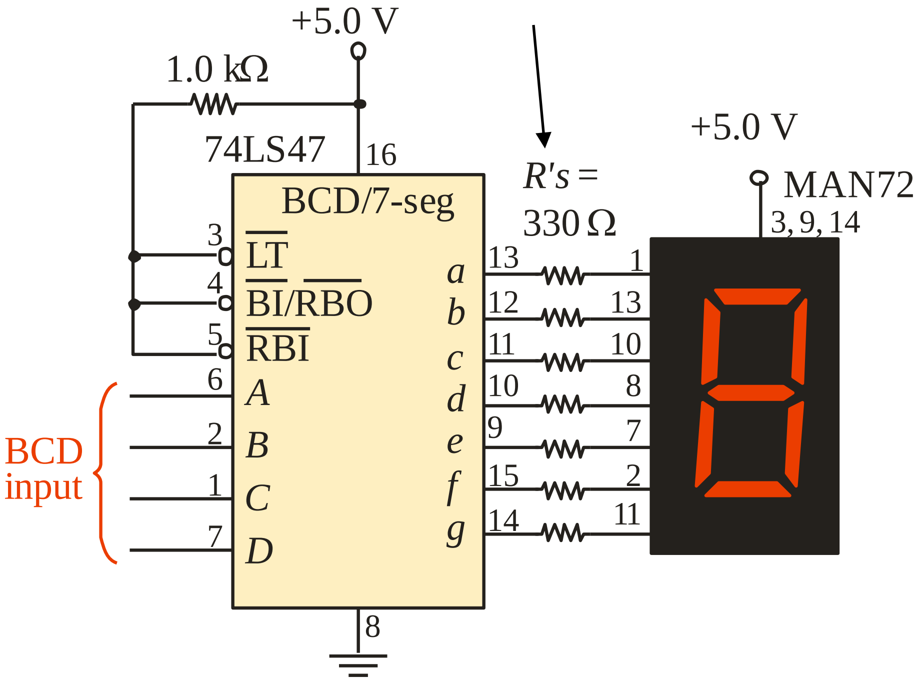
The *a*-*g* outputs are designed for much higher current than most devices (hence the word driver in the name).



Summary

BCD Decoder/Driver

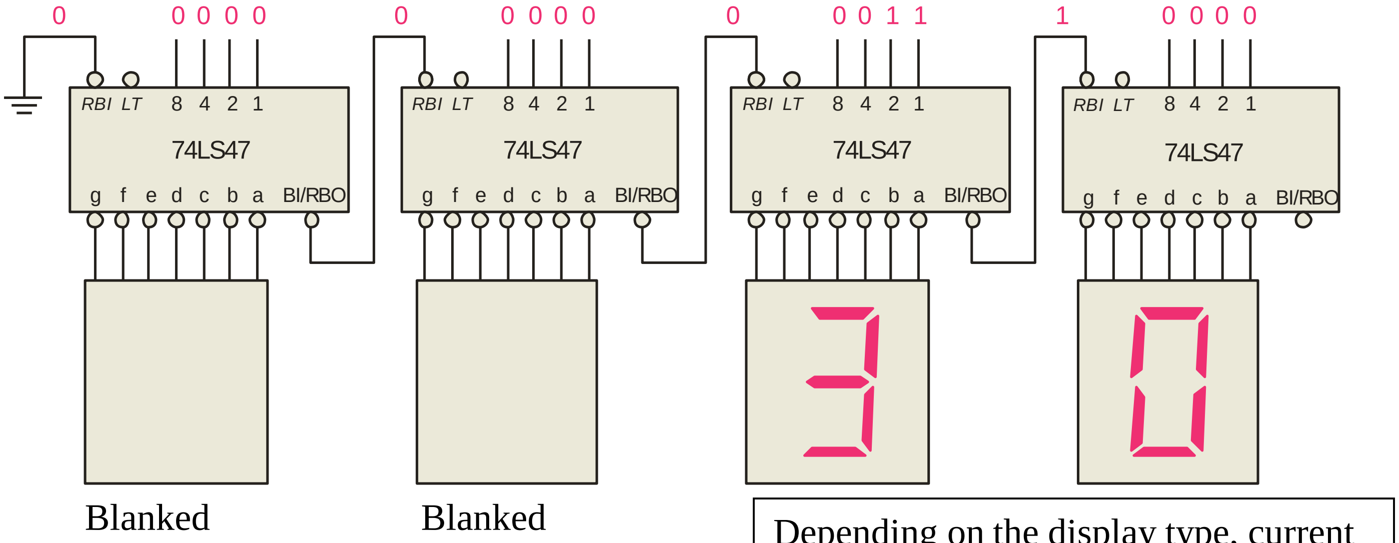
Here the 7447A is an connected to an LED seven segment display. Notice the current limiting resistors, required to prevent overdriving the LED display.



Summary

BCD Decoder/Driver

The 74LS47 features leading zero suppression, which blanks unnecessary leading zeros but keeps significant zeros as illustrated here. The $\overline{BI}/\overline{RBO}$ output is connected to the $\overline{RBI}$ input of the next decoder.

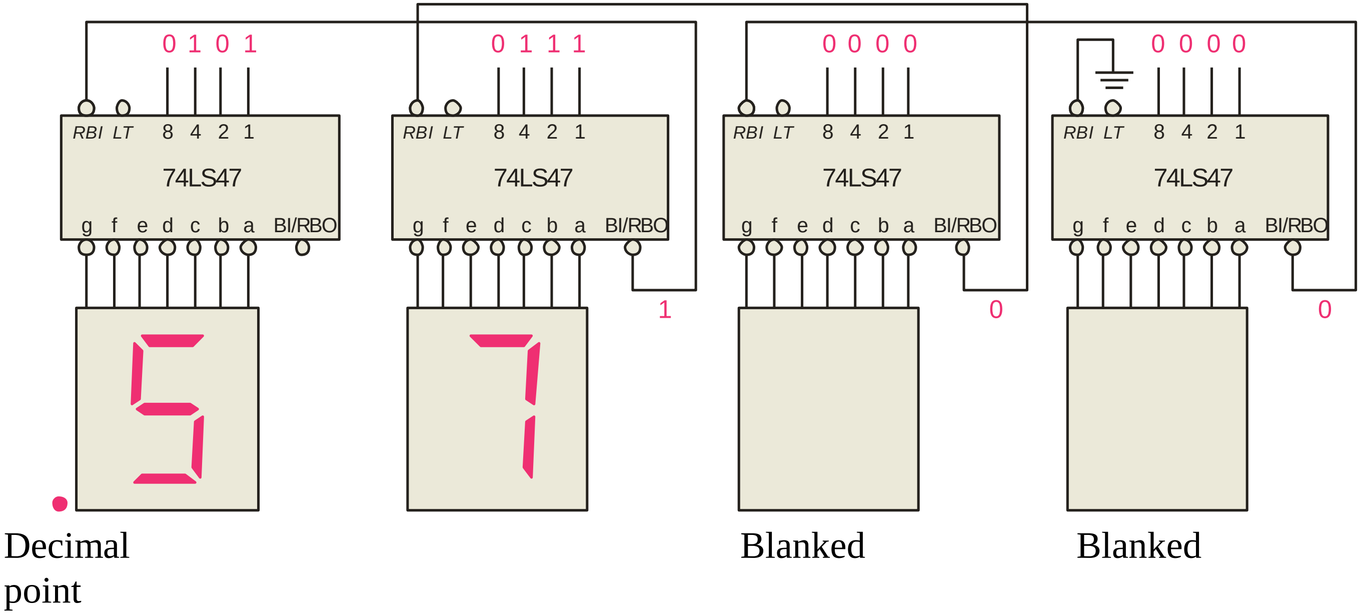


Depending on the display type, current limiting resistors may be required.

Summary

BCD Decoder/Driver

Trailing zero suppression blanks unnecessary trailing zeros to the right of the decimal point as illustrated here. The $\overline{RBI}$ input is connected to the $\overline{BI}/\overline{RBO}$ output of the following decoder.

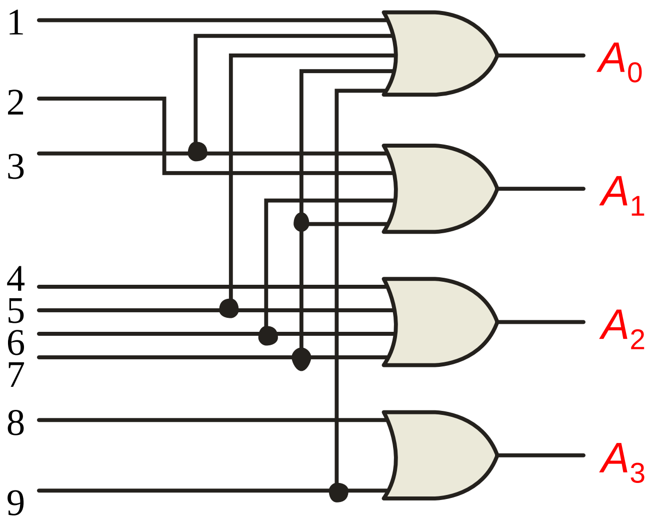


Summary

Encoders

An **encoder** accepts an active logic level on one of its inputs and converts it to a coded output, such as BCD or binary.

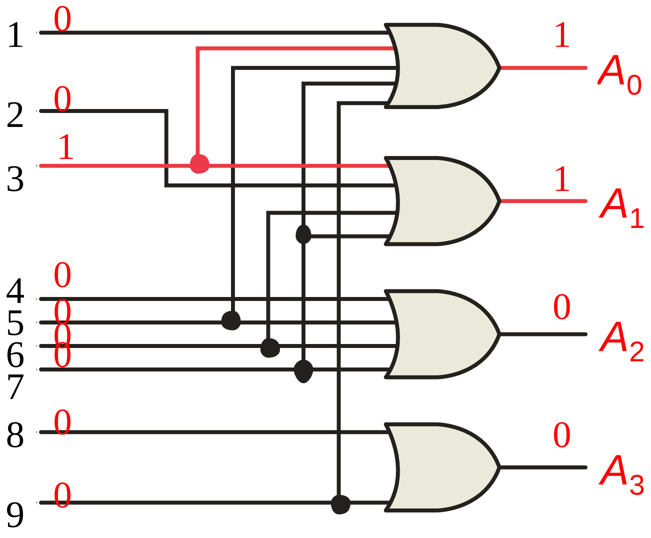
The decimal to BCD is an encoder with an input for each of the ten decimal digits and four outputs that represent the BCD code for the active digit. The basic logic diagram is shown. There is no zero input because the outputs are all LOW when the input is zero.



Encoders

Example Show how the decimal-to-BCD encoder converts the decimal number 3 into a BCD 0011.

Solution The top two OR gates have ones as indicated with the red lines. Thus the output is 0111.

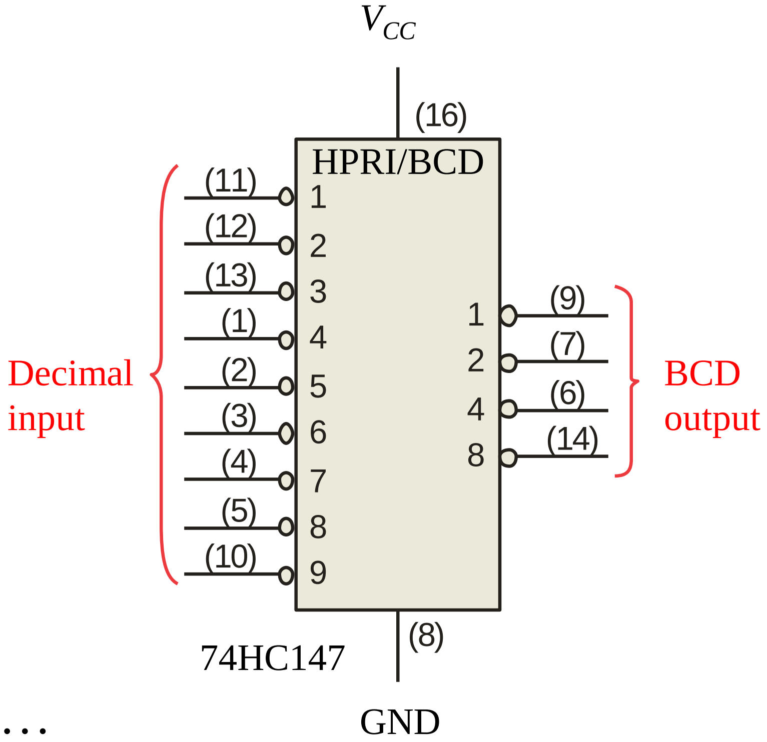


Summary

Encoders

The 74HC147 is an example of an IC encoder. It is has ten active-LOW inputs and converts the active input to an active-LOW BCD output.

This device is offers additional flexibility in that it is a **priority encoder**. This means that if more than one input is active, the one with the highest order decimal digit will be active.

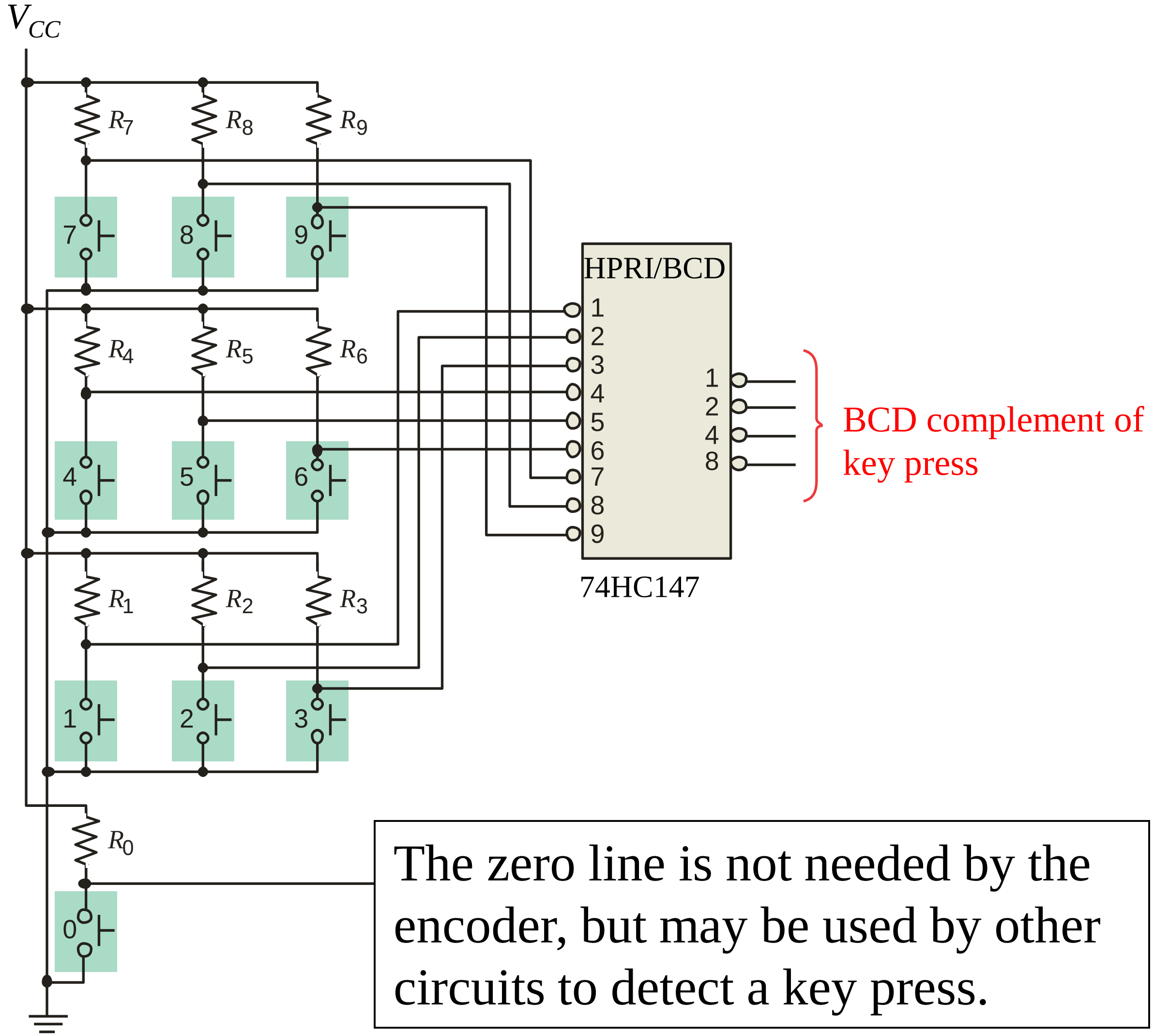


The next slide shows an application …

Summary

Encoders

Keyboard encoder



BCD complement of key press

The zero line is not needed by the encoder, but may be used by other circuits to detect a key press.

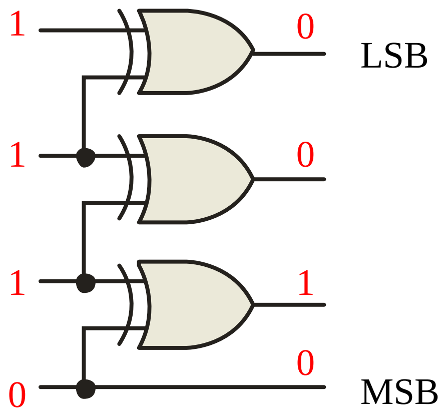
Summary

Code converters

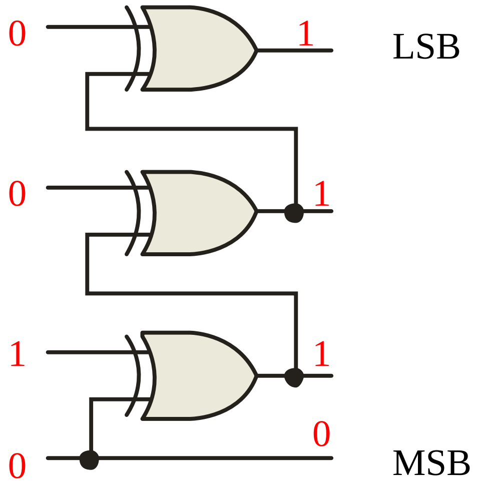
There are various code converters that change one code to another. Two examples are the four bit binary-to-Gray converter and the Gray-to-binary converter.

Example Show the conversion of binary 0111 to Gray and back.

Solution



Binary-to-Gray



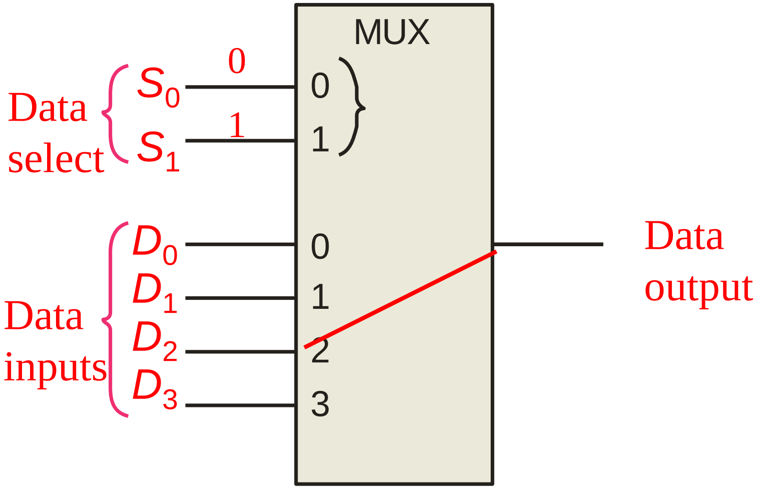
Gray-to-Binary

Summary

Multiplexers

A multiplexer (MUX) selects one data line from two or more input lines and routes data from the selected line to the output. The particular data line that is selected is determined by the select inputs.

Two select lines are shown here to choose any of the four data inputs.



Question

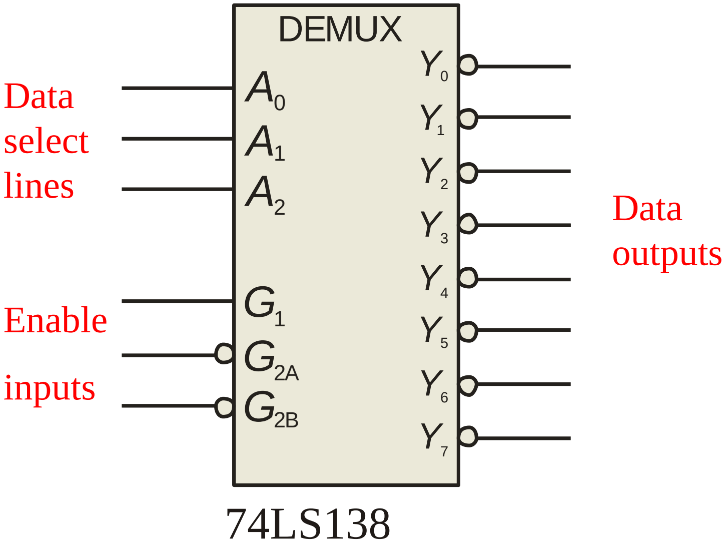
Which data line is selected if $S_1S_0 = 10$? D_2

Summary

Demultiplexers

A demultiplexer (DEMUX) performs the opposite function from a MUX. It switches data from one input line to two or more data lines depending on the select inputs.

The 74LS138 was introduced previously as a decoder but can also serve as a DEMUX. When connected as a DEMUX, data is applied to one of the enable inputs, and routed to the selected output line depending on the select variables. Note that the outputs are active-LOW as illustrated in the following example…



Summary

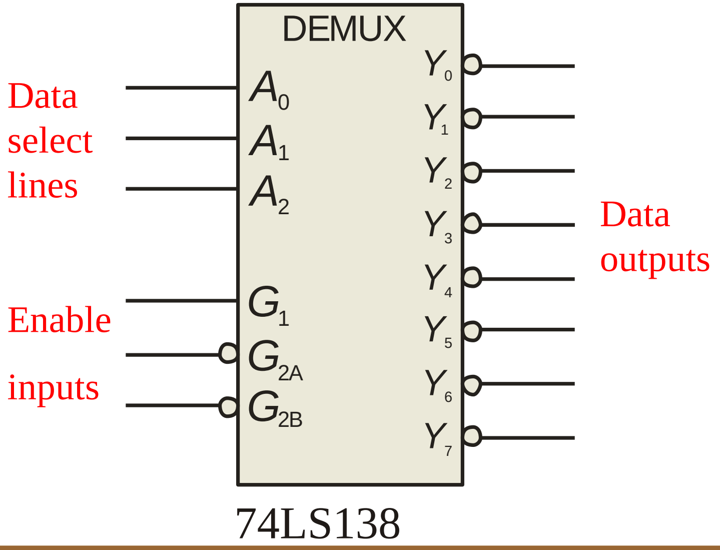
Demultiplexers

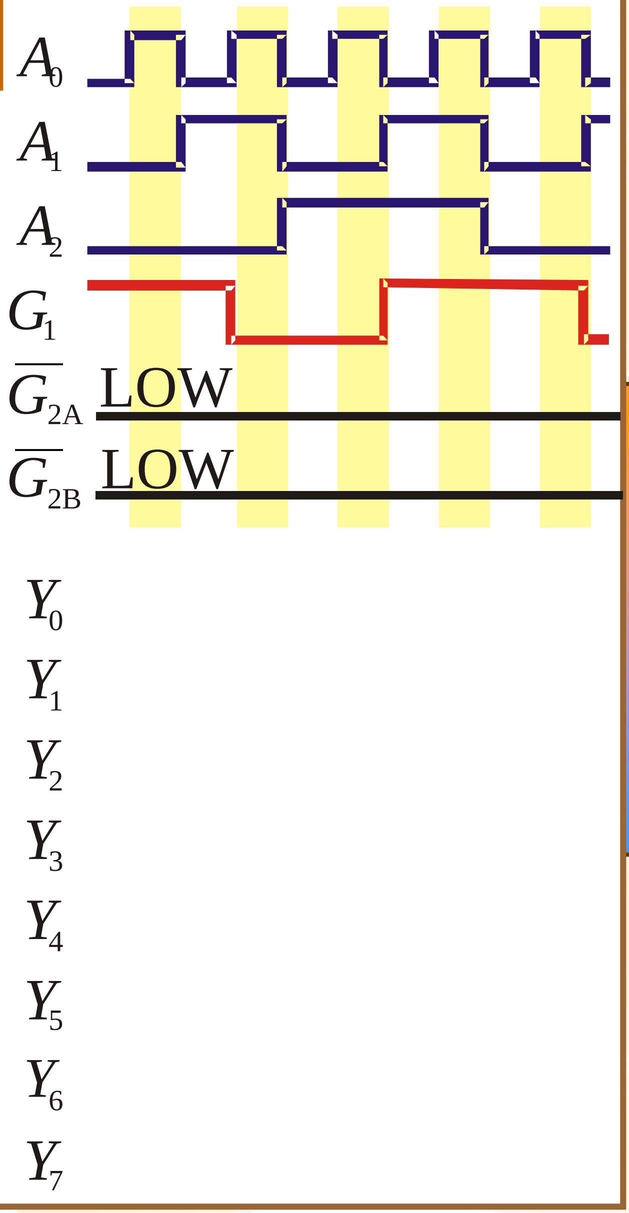
Example

Determine the outputs, given the inputs shown.

Solution

The output logic is opposite to the input because of the active-LOW convention. (Red shows the selected line).





Selected Key Terms

Full-adder A digital circuit that adds two bits and an input carry bit to produce a sum and an output carry.

Cascading Connecting two or more similar devices in a manner that expands the capability of one device.

Ripple carry A method of binary addition in which the output carry from each adder becomes the input carry of the next higher order adder.

Look-ahead carry A method of binary addition whereby carries from the preceding adder stages are anticipated, thus eliminating carry propagation delays.

Selected Key Terms

Decoder A digital circuit that converts coded information into a familiar or noncoded form.

Encoder A digital circuit that converts information into a coded form.

Priority encoder An encoder in which only the highest value input digit is encoded and any other active input is ignored.

Multiplexer (MUX) A circuit that switches digital data from several input lines onto a single output line in a specified time sequence.

Demultiplexer (DEMUX) A circuit that switches digital data from one input line onto a several output lines in a specified time sequence.

Quiz

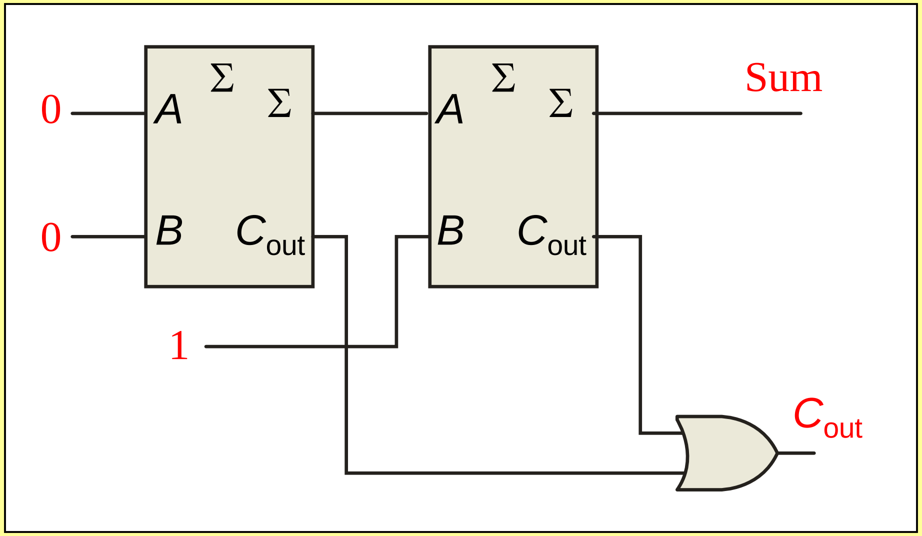
1. For the full-adder shown, assume the input bits are as shown with $A = 0$, $B = 0$, $C_{in} = 1$. The Sum and C_{out} will be

a. Sum = 0 $C_{out} = 0$

b. Sum = 0 $C_{out} = 1$

c. Sum = 1 $C_{out} = 0$

d. Sum = 1 $C_{out} = 1$



Quiz

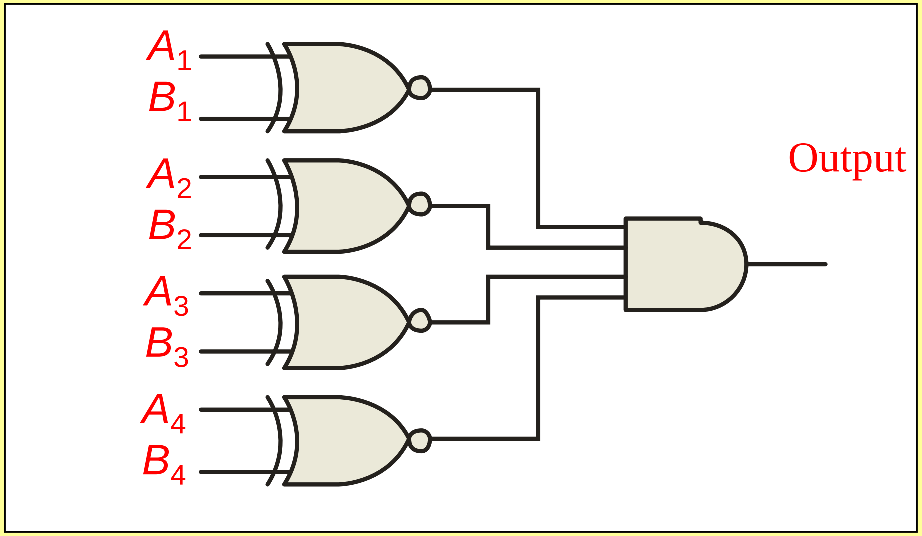
2. The output will be LOW if

a. $A < B$

b. $A > B$

c. both a and b are correct

d. $A = B$



Quiz

3. If you expand two 4-bit comparators to accept two 8-bit numbers, the output of the least significant comparator is

a. equal to the final output

b. connected to the cascading inputs of the most significant comparator

c. connected to the output of the most significant comparator

d. not used

Quiz

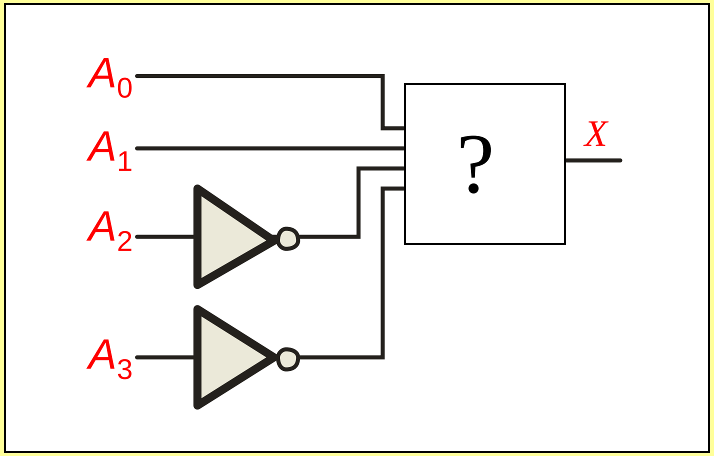
4. Assume you want to decode the binary number 0011 with an active-LOW decoder. The missing gate should be

a. an AND gate

b. an OR gate

c. a NAND gate

d. a NOR gate



Quiz

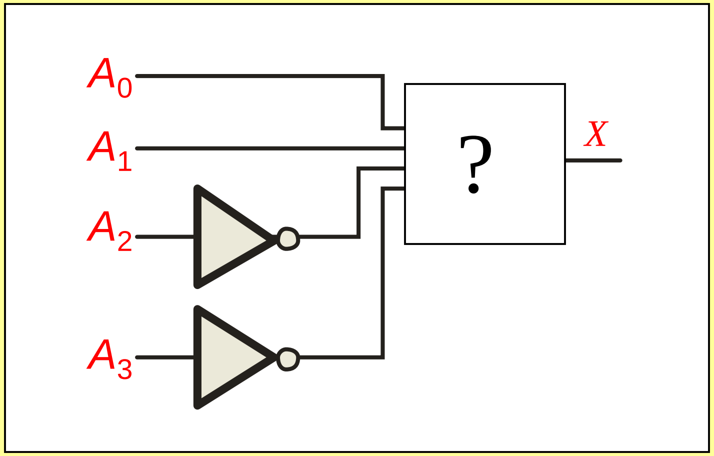
5. Assume you want to decode the binary number 0011 with an active-HIGH decoder. The missing gate should be

a. an AND gate

b. an OR gate

c. a NAND gate

d. a NOR gate



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Quiz

6. The 74138 is a 3-to-8 decoder. Together, two of these ICs can be used to form one 4-to-16 decoder. To do this, connect

a. one decoder to the LSBs of the input; the other decoder to the MSBs of the input

b. all chip select lines to ground

c. all chip select lines to their active levels

d. one chip select line on each decoder to the input MSB

Quiz

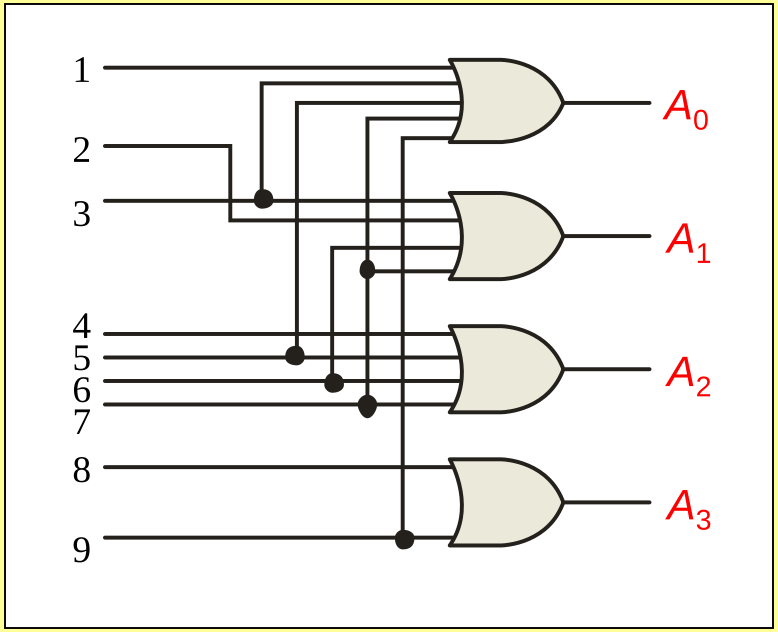
7. The decimal-to-binary encoder shown does not have a zero input. This is because

a. when zero is the input, all lines should be LOW

b. zero is not important

c. zero will produce illegal logic levels

d. another encoder is used for zero



Quiz

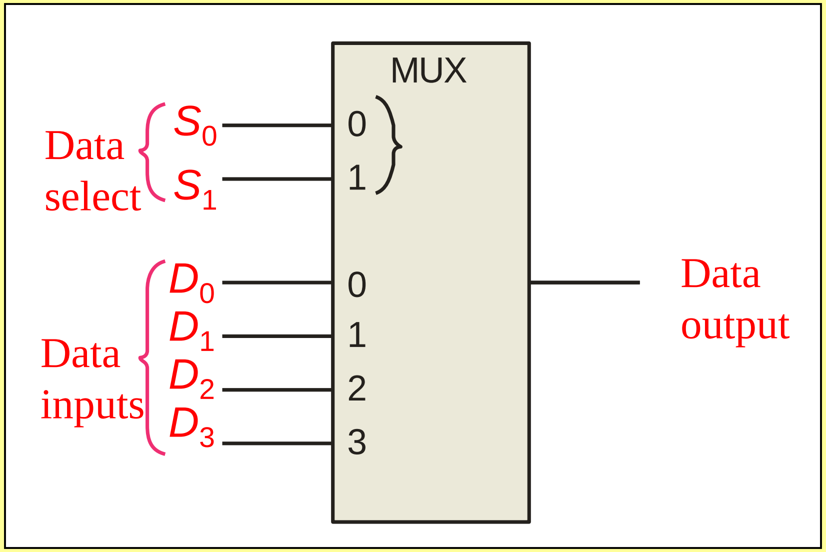
8. If the data select lines of the MUX are S_1S_0 = 11, the output will be

a. LOW

b. HIGH

c. equal to D_0

d. equal to D_3



Quiz

9. The 74138 decoder can also be used as

a. an encoder

b. a DEMUX

c. a MUX

d. none of the above

Quiz

10. The 74LS280 can generate even or odd parity. It can also be used as

a. an adder

b. a parity tester

c. a MUX

d. an encoder

Quiz

Answers:

1. c
2. c
3. b
4. c
5. a
6. d
7. a
8. d
9. b
10. b