Unit 2: Decoder and Priority Encoder

UNIT OBJECTIVE

At the completion of this unit, you will be able to locate, operate, and control a decoder and encoder circuit combination.

UNIT FUNDAMENTALS

A binary coded decimal (BCD) decoder detects and indicates unique 8-4-2-1 bit combinations between 0 and 9 decimal, or base 10 (indicated by 9_{10}).

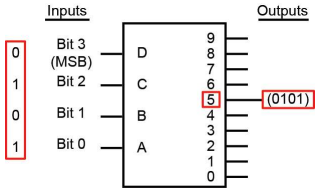
BCD information ranges between 0 and 9. Codes above 9 (10 through 15 for a 4-bit word) are invalid. These bit patterns are usually not decoded but generate some form of "out of limit" indication.

BCD bit code	Decimal value
1111 through 1010	Invalid codes in BCD format
1001	9
1000	8
0111	7
0110	6
0101	5
0100	4
0011	3
0010	2
0001	1
0000	0

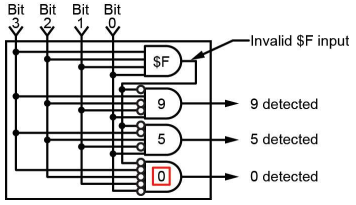
This table shows the relationship between BCD bit codes and their equivalent decimal value.

In the BCD decoder, only one output is active for a given input bit group. The active state can be high or low depending on the type of IC selected.

A 4-bit BCD input activates one of the outputs (0101 activates 5, for example).

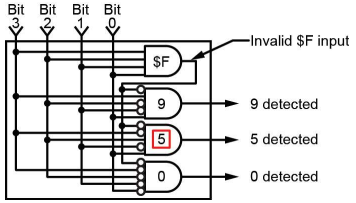


Each decoder section detects a specific input bit code.

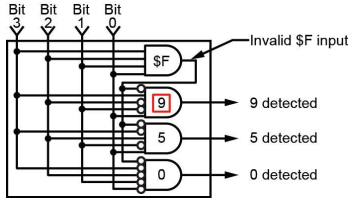


In this example, section 0 detects a 0000 input.

Section 5 detects a 0101 input.



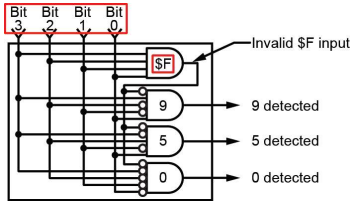
Section 9 detects a 1001 input.



Based on the circuit shown, what is the response to an input BCD code of 1111?

Note: Determine if the input disables or enables gate $F.

a. Gate $F generates an inactive output.
b. Gate $F disables the other gates, and all outputs are inactive.
c. All the gates are disabled.



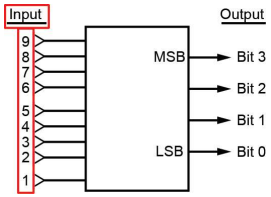
A binary-coded decimal encoder reverses the process of the BCD decoder. The encoder detects inputs between 9_{10} and 0 and generates unique 4-bit BCD codes.

Because the encoder outputs represent BCD equivalents, more than one output at a time may be active.

BCD bit code	Decimal value
1111 through 1010	Invalid codes in BCD format
1001	9
1000	8
0111	7
0110	6
0101	5
0100	4
0011	3
0010	2
0001	1
0000	0

This table shows the relationship between BCD bit codes and their equivalent decimal value.

A BCD encoder has nine possible active inputs, 1 through 9.



A 0 input is not required because inactive inputs generate inactive outputs.

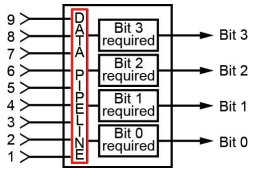
BCD bit code	Decimal value
1111 through 1010	Invalid codes in BCD format
1001	9
1000	8
0111	7
0110	6
0101	5
0100	4
0011	3
0010	2
0001	1
0000	0

This table shows the relationship between BCD bit codes and their equivalent decimal value.

The inputs and outputs of a BCD encoder are active high. Which output is generated if all inputs are low?

a. 1111
b. 1001
c. 0110
d. 0000

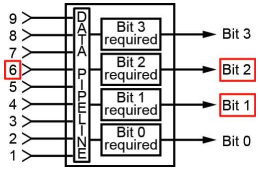
Each bit section of an encoder is connected to a data pipeline, which distributes the input data.



Each section decides if its bit is required to represent part of the 4-bit BCD code.

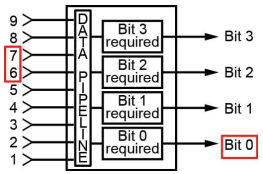
If a specific bit is needed, that section activates its output. If a specific bit is not needed, that section deactivates its output.

For example, an input of 6 requires a BCD output of 0110; therefore, sections BIT2 and BIT1 are active, and sections BIT3 and BIT0 are inactive.

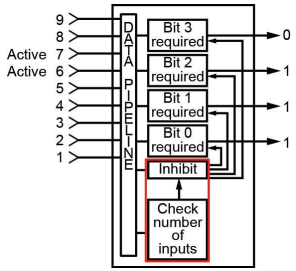


Each encoder input represents a unique BCD code; therefore, two or more active inputs should cause an output error.

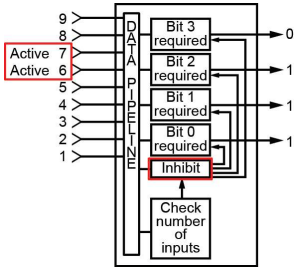
If inputs 6 (0110) and 7 (0111) are both active, BIT0 cannot be inactive (xxx0) and active (xxx1) simultaneously.



Encoders use another operating section to determine input priority (called priority detection).



Detecting more than one input activates the INHIBIT section. This section ensures that only output bits associated with the higher input value are encoded. Lower input values are locked out.



NEW TERMS AND WORDS

***binary coded decimal* (BCD) –** a form of 4-bit coding representing decimal number between 0 and 9.

***decoder* –** a circuit that generates one unique output in response to a set of input bit patterns.

***base* –** indicates the numbering system; base 10 indicates decimal, base 2 indicates binary, and base 16 indicates hexadecimal.

***disables* –** turns off, deactivates, inhibits, or makes nonresponsive.

***enables* –** turns on, activates, or makes responsive.

***encoder* –** a circuit that generates unique output bit patterns in response to a specific input.

***data pipeline* –** a common data path used to distribute information throughout a circuit.

EQUIPMENT REQUIRED

FACET® base unit
DIGITAL CIRCUIT FUNDAMENTALS 2 circuit board
Multimeter
Oscilloscope, dual trace
Two-post connectors
Terminal posts

Exercise 1: BCD Decoder Operation

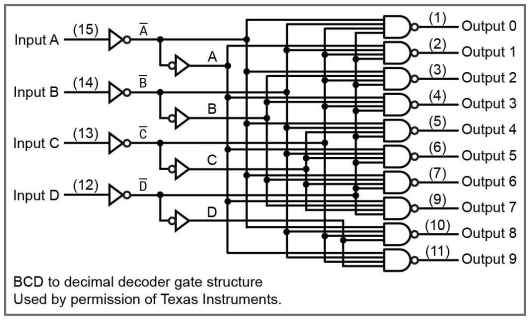
EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to operate a BCD to decimal decoder. You will verify your results by decoding 4-bit word inputs.

DISCUSSION

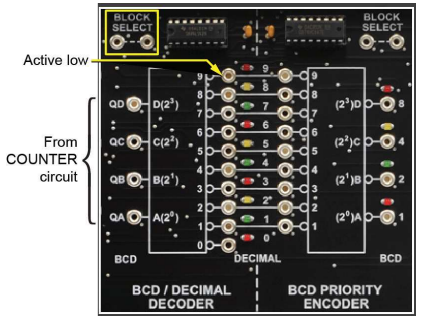
The 74LS42 BCD to decimal decoder consists of inverters and four input NAND gates. It is an MSI (medium scale integration) device and has a complexity of 18 equivalent gates.

Full decoding of all input bit pair combinations ensures that all outputs remain off for all invalid input conditions.

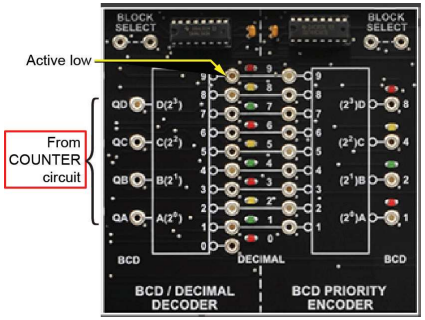


BCD to decimal decoder gate structure
Used by permission of Texas Instruments.

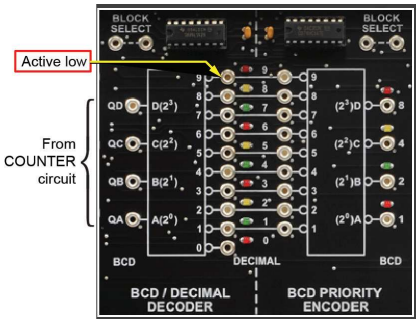
BLOCK SELECT, activated with a two-post connector, applies power to the LEDs.

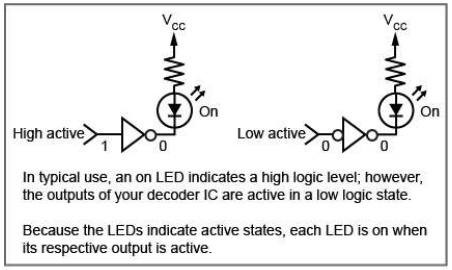


BCD circuit inputs QD through QA are generated from the COUNTER circuit and hard wired to the decoder.



Decoder outputs are active low (note the bubble at each output) and drive their respective LEDs. On your decoder circuit, an LED turns on to indicate an active low output.





In typical use, an on LED indicates a high logic level; however, the outputs of your decoder IC are active in a low logic state.

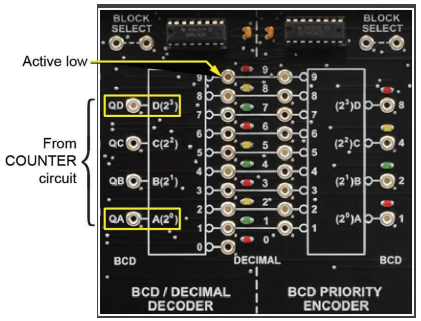
Because the LEDs indicate active states, each LED is on when its respective output is active.

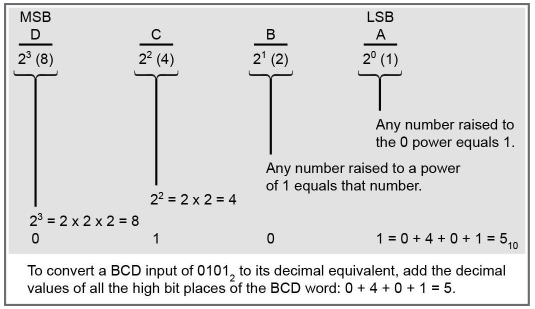
The LS42 is a BCD decoder. A 4-bit input word (QD through QA) has an equivalent decimal value between 9 and 0. Values greater than 9 are invalid and do not generate an output.

BCD bit code	Decimal value
1111 through 1010	Invalid codes in BCD format
1001	9
1000	8
0111	7
0110	6
0101	5
0100	4
0011	3
0010	2
0001	1
0000	0

This table shows the relationship between BCD bit codes and their equivalent decimal value.

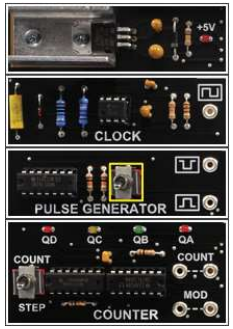
QD is the MSB and has a weight of 8_{10}. QA is the LSB and has a weight of 1_{10}.



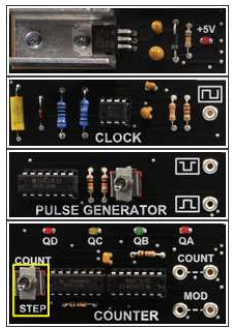


PROCEDURE

☐ 1. Place the toggle switch of the PULSE GENERATOR circuit in the DOWN position.

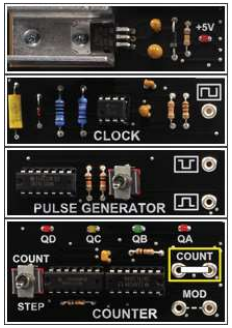


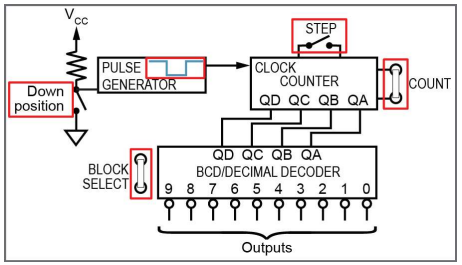
☐ 2. Place the toggle switch of the COUNTER circuit in the STEP position.



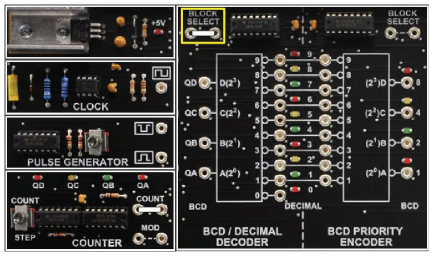
3. Activate the COUNTER circuit by placing a two-post connector into the COUNT terminals.

NOTE: The PULSE GENERATOR circuit's output clocks the COUNTER circuit. The COUNTER circuit's outputs drive inputs QD through QA of the BCD/DECIMAL DECODER circuit block.





4. Enable the BLOCK SELECT function of the BCD/DECIMAL DECODER circuit block.



5. Based on your COUNTER circuit LEDs, what is the binary value of the COUNTER output?

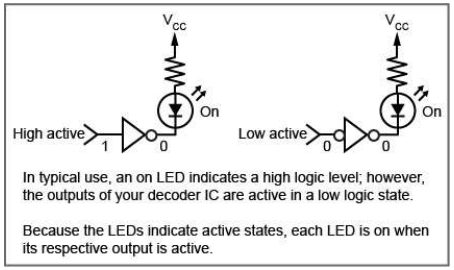
binary value =_____ (*Recall Value 1*)

6. Based on the decoder output indications, what is the binary value of the decoder input?

binary decoder input =_____ (*Recall Value 2*)

7. Use your voltmeter or oscilloscope to scan each output of your decoder circuit (the 0 through 9 test points). Which output indicates the active decoder output?

   a. outputs 1 through 9 and their respective LEDs
   b. output 0 and its LED



8. Why are decoder outputs 1 through 9 high (the respective circuit LEDs should be off)?

   a. These outputs are active, or enabled, by the decoding process of the IC.
   b. These outputs are active, or disabled, by the decoding process of the IC.
   c. These outputs are inactive, or disabled, by the decoding process of the IC.

9. Do your observations support the “bubble” output indicators placed at the outputs of the decoder IC?

   a. yes
   b. no

10. Use your circuit to verify the data in the table.

NOTE: You must cycle the PULSE GENERATOR toggle switch up then down to increment the COUNTER output by 1.

QD	QC	QB	QA	Decimal output
1	0	1	0	Invalid
1	0	0	1	9
1	0	0	0	8
0	1	1	1	7
0	1	1	0	6
0	1	0	1	5
0	1	0	0	4
0	0	1	1	3
0	0	1	0	2
0	0	0	1	1
0	0	0	0	0

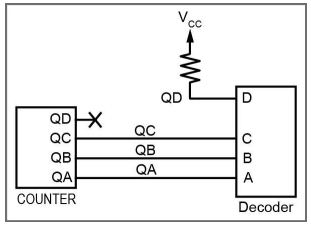
11. Based on your observations, which decoder output indicates a BCD value greater than 9?

   a. output 9
   b. output 0
   c. none of the outputs

12. Based on your circuit operation, how many decoder outputs are active for a given valid input?

    a. all
    b. 2 or more
    c. 1
    d. none

13. Place CM switch 8 in the ON position to force the COUNTER QD input to V_{CC}. Cycle your COUNTER output between 0 and 7 (QD LED on the COUNTER), and observe the decoder outputs.



14. Based on your observations, what is the output decimal count range of your decoder?

    a. 9 through 15
    b. 8 and 9
    c. 0 through 9
    d. 0 through 7

15. Why doesn't your decoder generate outputs of 0 through 7?

    a. QD pulled high sets the minimum decoder output at 8_{10}.
    b. The decoder inputs can only add to the minimum input value established by input QD.
    c. Both of the above

16. Your BCD decoder can indicate values between 0 and 9. Why are 4 inputs (QD through QA) required if values between 10 and 15 cannot be decoded?

    a. 4 inputs are not required and are used for instructional purposes only.
    b. 4 inputs are required because the MSB (QD) has a weight of 8_{10}.
    c. 4 inputs are required because the lower bits (QC through QA) have a maximum value of 7_{10}.
    d. Both statements b. and c.

CONCLUSION

- Your BCD decoder can indicate values between 0 and 9.
- Only one output at a time is active.
- Invalid inputs to a BCD decoder result in inactive outputs.
- The 74LS42 decoder has low active outputs.

REVIEW QUESTIONS

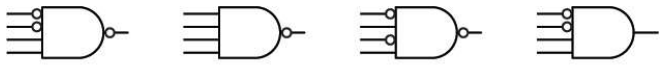
1. Your 74LS42 is called a BCD to decimal decoder. This means that an input of 1100_2
   a. generates a valid 4 output indication because the MSB is ignored.
   b. generates an output of 8 and 4 because the IC circuits split the input into 1xxx and x100.
   c. is invalid because 1100 falls outside of a BCD-coded value.
   d. sets all outputs high, the active output state of your decoder.

2. The bubbles at the output terminals of the 74LS42 decoder indicate
   a. active high outputs.
   b. active low outputs.
   c. tristate capability.
   d. an uncertain state for invalid BCD inputs.

3. What is the weight of a bit position based on the notation 2^3?
   a. 8
   b. 4
   c. 2
   d. 0

4. The binary range of inputs that generates a low active output for each specific input of the range is
   a. 0000 through 1111.
   b. 1010 through 1111.
   c. All of the above
   d. None of the above

5. The input 4-bit code to your decoder is 0011. Which gate generates an active low output?
   a. A
   b. B
   c. C
   d. D



Exercise 2: Priority Encoder Operation

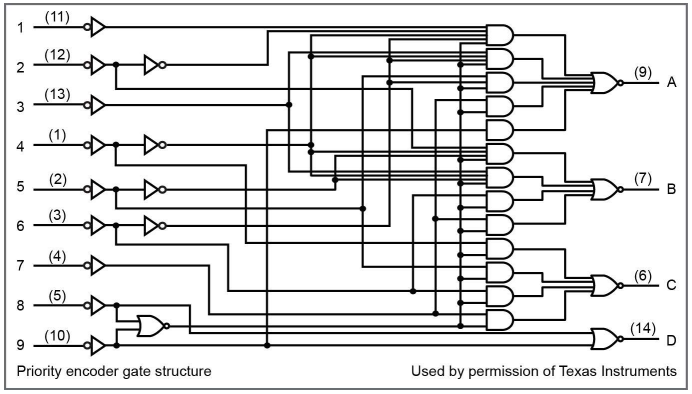
EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to operate a decimal input priority encoder. You will verify your results by encoding decimal inputs.

DISCUSSION

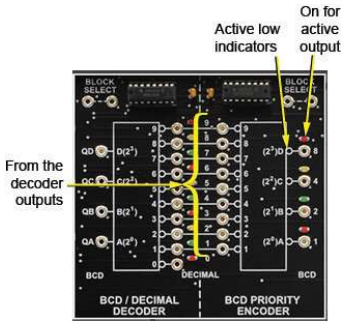
The 74LS147 MSI 9-line-to-4-line priority encoder consists of NOR, AND, and NOT gates. It is an MSI device and has a complexity of 31 equivalent gates.

Your decoder features internal priority decoding to ensure that only the highest value input is encoded.

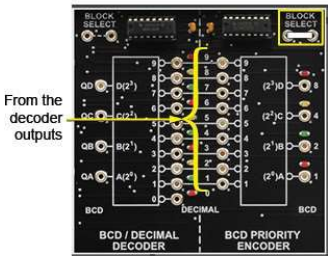


Priority encoder gate structure — Used by permission of Texas Instruments

The 74LS147 encodes 9 data lines to a 4-line BCD (8-4-2-1) code. Encoder inputs and outputs are active low (LEDs on).



BLOCK SELECT, enabled with a two-post connector, applies power to the LEDs.



The decimal (9 through 1) inputs of the encoder are hardwired to the outputs of the decoder.

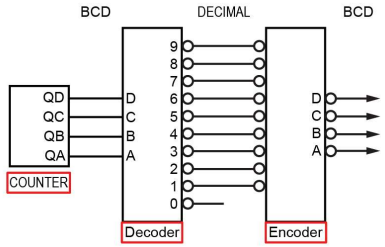
The 74LS147 is a priority BCD encoder. A valid 1 through 9 decimal input is converted to an equivalent 4-bit BCD code. A 0 input does not generate an output.

Priority encoding means that only the greatest decimal input value generates an output.

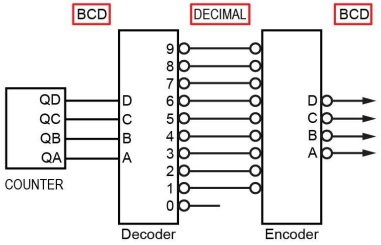
Decimal number	MSB → BCD → LSB 2^3 (8)	2^2 (4)	2^1 (2)	2^0 (1)
9	1	0	0	1
8	1	0	0	0
7	0	1	1	1
6	0	1	1	0
5	0	1	0	1
4	0	1	0	0
3	0	0	1	1
2	0	0	1	0
1	0	0	0	1
0	0	0	0	0

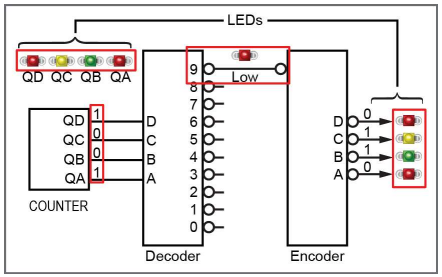
2^3 represents the MSB of the BCD 4-bit code. BCD is an 8-4-2-1 code; therefore, a decimal number comprises combinations of binary bits. For example, the decimal number 6 comprises bits $2^2(4) + 2^1(2)$. Although you may convert numbers greater than 9, your encoder operates in BCD format and is limited to numbers 1 through 9.

On your circuit board, the COUNTER circuit's output drives the decoder. In turn, the decoder's output drives the encoder's input.



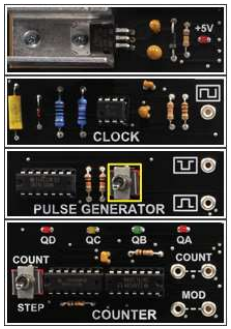
The BCD-to-decimal-to-BCD conversion process makes the encoder's output LED pattern identical to the counter's output.



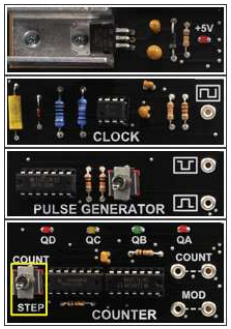


PROCEDURE

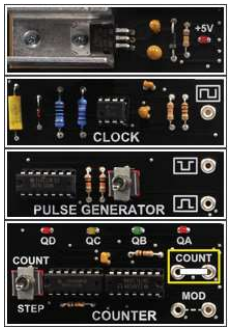
☐ 1. Place the toggle switch of the PULSE GENERATOR circuit in the DOWN position.



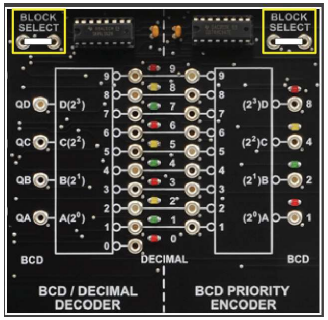
☐ 2. Place the toggle switch of the COUNTER circuit in the STEP position.



3. Enable the COUNTER circuit by placing a two-post connector into the COUNT terminals.



4. Place two-post connectors in the BLOCK SELECT terminals of the BCD/DECIMAL DECODER and the BCD PRIORITY ENCODER circuit blocks.



5. Based on the circuit LEDs, what is the 4-bit BCD input (QD through QA) value of your decoder?

   a. 1111
   b. 1001
   c. 0110
   d. 0000

6. This exercise deals with the BCD PRIORITY ENCODER circuit block. Why are the decoder input and output of interest?

   a. The decoder's outputs drive the encoder's inputs.
   b. A relationship exists between the COUNTER circuit's output, the decoder conversion, and the encoder conversion.
   c. Both of the above

7. What is the 4-bit BCD measured output value of your encoder?

   NOTE: The encoder's outputs are active low (LEDs on).

   a. $F, or 1111
   b. 0, or 0000
   c. The outputs are not a valid BCD value.

8. Is the COUNTER circuit's output (QD through QA) identical to the output of your encoder (8-4-2-1)?

   NOTE: The encoder's outputs are active low (LEDs on). Compare the circuit LEDs.

   a. yes
   b. no

9. The 0 output of your decoder is active. The encoder does not have a 0 input. Why does the encoder generate a 1111 output?

   NOTE: Use your voltmeter or oscilloscope to verify the encoder outputs.

   a. The encoder's outputs are all active.
   b. The encoder's inputs are all inactive.
   c. The 0 input is missing, causing an encoding error.

10. Use your COUNTER circuit to generate a 1 through 9 decimal input to your encoder, and compare the encoder's output LEDs to the COUNTER circuit's output LEDs.

    NOTE: Use the PULSE GENERATOR circuit's toggle switch (up-down) to increment your COUNTER circuit.

Encoder decimal input	Encoder output 8	4	2	1
9	0	1	1	0
8	0	1	1	1
7	1	0	0	0
6	1	0	0	1
5	1	0	1	0
4	1	0	1	1
3	1	1	0	0
2	1	1	0	1
1	1	1	1	0
None	1	1	1	1

11. Based on your circuit observations, does the decoder/encoder combination maintain the BCD-to-decimal-to-BCD relationship?

    a. yes
    b. no

12. Based on your results, what is the primary function of your encoder circuit?

    a. to convert decimal inputs to equivalent BCD code
    b. to convert BCD code to equivalent decimal outputs

13. Set your COUNTER for a binary output 0011 (QD through QA). The decoder's output is 3_{10}, and the encoder's LEDs output display is 0011.

    NOTE: The short to common enables inputs 1 and 2 of the encoder. Input 3 is active due to the counter/decoder operation.

14. Observe the decoder's output display as you momentarily short inputs 1 and 2 of your encoder to any common point on your circuit board.

15. Why does the encoder's output display remain at 0011,(LEDs 1 and 2 on)?

    a. The encoder priority circuits ignore all decimal inputs less than 3 because input 3 is active low.
    b. Inputs 2 and 1 are active and have a sum of 3.
    c. The sum of inputs 2 and 1 equals the active input 3.

16. Observe encoder circuit operation as you momentarily connect inputs 4 through 9 to any common point on your circuit board.

17. Does the encoder priority scheme ensure that only the higher decimal value is encoded into a BCD value?

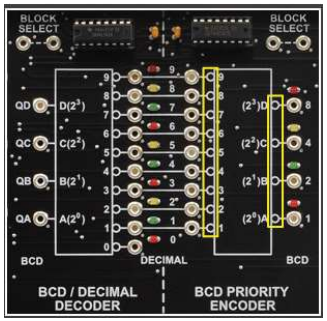
    a. yes
    b. no

CONCLUSION

- A BCD encoder converts decimal inputs into 4-bit BCD equivalent patterns.
- The 74LS147 encoder accepts decimal inputs of 1 through 9 and generates equivalent BCD outputs.
- The inputs and outputs of a 74LS147 encoder are active low.
- A BCD encoder has outputs in the 8-4-2-1 format.
- When the decimal input value of the encoder is less than 1 or greater than 9, the outputs are inactive and generate a 1111 code.
- A 74LS147 encoder has priority circuits that allow conversion of the highest valid decimal input.

REVIEW QUESTIONS

1. On the 74LS147 encoder, what do the input/output bubbles indicate?
   a. the input and output terminals of the device
   b. that the active state of the inputs and outputs is low
   c. that the active state of the inputs and outputs is high or low depending on the decimal value
   d. that the outputs are complements of the inputs



2. If the decimal input value of your encoder is less than 1, the outputs are
   a. inactive and generate a 1111 code.
   b. inactive and generate a 0000 code.
   c. active and generate a 1111 code.
   d. active and generate a 0000 code.

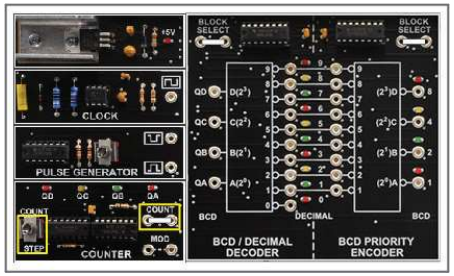
3. When several inputs of your encoder are enabled simultaneously, the encoder BCD output pattern
   a. represents the lower input value.
   b. is the sum of the digital input values.
   c. is the difference of the input values.
   d. represents the higher input value.

4. Valid inputs to the encoder are 1 through 9. Multiple inputs
   a. generate invalid outputs.
   b. generate valid outputs.
   c. set all outputs high.
   d. reset all outputs low.

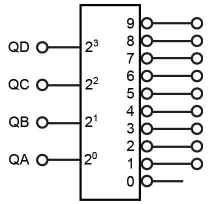
5. On your encoder, the description 9-line-to-4-line
   a. does not apply because your encoder is a BCD device.
   b. indicates that 9 input lines are reduced to 4 output lines.
   c. indicates that 4 input lines are expanded to 9 output lines.
   d. indicates that any combination of 9 lines can drive 4 lines.

UNIT TEST

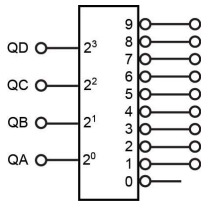
1. A BCD to decimal decoder converts
   a. binary inputs to hexadecimal outputs.
   b. decimal inputs to 8-4-2-1 BCD code.
   c. BCD, 8-4-2-1 inputs to decimal equivalent outputs.
   d. None of the above



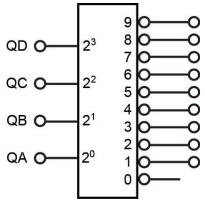
2. The outputs of this decoder are
   a. active high.
   b. active in a tristate mode.
   c. active low.
   d. all low with a 0000 input.



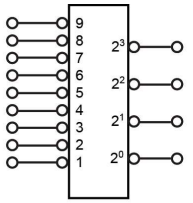
3. The expected range of valid inputs in this decoder is
   a. 0000 through 1001.
   b. 1111 through 0110.
   c. 0001 through 1001.
   d. None of the above



4. If the input to this decoder is 0110, then
   a. any outputs can be active when their value equals 6.
   b. all outputs not equal to 6 can be active.
   c. only one output is active, but it must not be output 6.
   d. only output 6 is active.

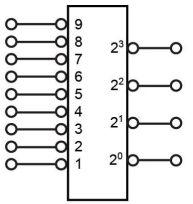


5. The maximum output BCD value of this encoder is
   a. 1111.
   b. 1010.
   c. 0110.
   d. 0000.



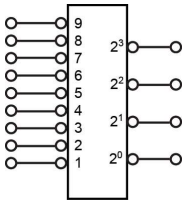
Note: Outputs are active low.

6. What is the correct 4-bit binary code for this encoder?
   a. 1111, 1110 through 0110
   b. 1111 through 0000
   c. 0000 through 1111
   d. 0001 through 1001

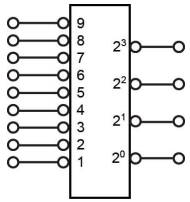


Note: Outputs are active low.

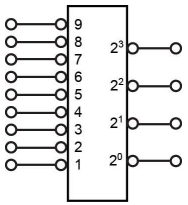
7. On this encoder,
   a. a BCD input is converted to an encoded decimal output.
   b. a decimal input is converted to a BCD equivalent output.
   c. multiple active inputs generate simultaneous switched outputs.
   d. if all inputs are low (simultaneously), all outputs are low.



8. On this encoder, what are the active levels of input and output?
   a. high
   b. tristate controlled
   c. low
   d. complementary



9. In this encoder, input 6 is low. As a result,
   a. no output is low.
   b. no output is high.
   c. the BCD output is 0110.
   d. the BCD output is 1001.



10. If the inputs of the encoder on your circuit board are all high, then the encoder's output is
    a. 1111.
    b. 0000, indicating decimal 0.
    c. unknown because a 0 output is not available.
    d. in a "maybe" state.