ELTR 145 (Digital 2), section 3

Recommended schedule

<u>Day 1</u>
   Topics: *Encoders and decoders*
   Questions: *1 through 10*
   Lab Exercise: *4-line to 16-line decoder (question 41)*

<u>Day 2</u>
   Topics: *Multiplexers and demultiplexers*
   Questions: *11 through 20*
   Lab Exercise: *Arbitrary logic function with multiplexer (question 42)*

<u>Day 3</u>
   Topics: *Display decoder/driver circuits*
   Questions: *21 through 30*
   Lab Exercise: *7-segment display circuit (question 43)*

<u>Day 4</u>
   Topics: *Programmable logic technology*
   Questions: *31 through 40*
   Lab Exercise: *Troubleshooting practice (decade counter circuit – question 44)*

<u>Day 5</u>
   Exam 3: *includes Arbitrary logic function performance assessment*
   Troubleshooting Assessment due: *Decade counter circuit*
   Question 45: Troubleshooting log
   Question 46: Sample troubleshooting assessment grading criteria

<u>Troubleshooting practice problems</u>
   Questions: *47 through 56*

<u>DC/AC/Semiconductor/Opamp review problems</u>
   Questions: *57 through 76*

<u>General concept practice and challenge problems</u>
   Questions: *77 through the end of the worksheet*

ELTR 145 (Digital 2), section 3

Skill standards addressed by this course section

EIA *Raising the Standard; Electronics Technician Skills for Today and Tomorrow,* June 1994

F Technical Skills – Digital Circuits
F.22 Understand principles and operations of types of multiplexer and demultiplexer circuits.
F.23 Troubleshoot and repair types of multiplexer and demultiplexer circuits.
F.26 Understand principles and operations of types of digital display circuits.
F.27 Troubleshoot and repair types of digital display circuits.
F.30 Understand principles and operations of types of digital encoders and decoders.
F.31 Troubleshoot and repair types of digital encoders and decoders.
F.32 Understand principles and operations of types of digital display devices.
F.33 Troubleshoot and repair types of digital display devices.

B Basic and Practical Skills – Communicating on the Job
B.01 Use effective written and other communication skills. *Met by group discussion and completion of labwork.*
B.03 Employ appropriate skills for gathering and retaining information. *Met by research and preparation prior to group discussion.*
B.04 Interpret written, graphic, and oral instructions. *Met by completion of labwork.*
B.06 Use language appropriate to the situation. *Met by group discussion and in explaining completed labwork.*
B.07 Participate in meetings in a positive and constructive manner. *Met by group discussion.*
B.08 Use job-related terminology. *Met by group discussion and in explaining completed labwork.*
B.10 Document work projects, procedures, tests, and equipment failures. *Met by project construction and/or troubleshooting assessments.*
C Basic and Practical Skills – Solving Problems and Critical Thinking
C.01 Identify the problem. *Met by research and preparation prior to group discussion.*
C.03 Identify available solutions and their impact including evaluating credibility of information, and locating information. *Met by research and preparation prior to group discussion.*
C.07 Organize personal workloads. *Met by daily labwork, preparatory research, and project management.*
C.08 Participate in brainstorming sessions to generate new ideas and solve problems. *Met by group discussion.*
D Basic and Practical Skills – Reading
D.01 Read and apply various sources of technical information (e.g. manufacturer literature, codes, and regulations). *Met by research and preparation prior to group discussion.*
E Basic and Practical Skills – Proficiency in Mathematics
E.01 Determine if a solution is reasonable.
E.02 Demonstrate ability to use a simple electronic calculator.
E.06 Translate written and/or verbal statements into mathematical expressions.
E.07 Compare, compute, and solve problems involving binary, octal, decimal, and hexadecimal numbering systems.
E.12 Interpret and use tables, charts, maps, and/or graphs.
E.13 Identify patterns, note trends, and/or draw conclusions from tables, charts, maps, and/or graphs.
E.15 Simplify and solve algebraic expressions and formulas.
E.16 Select and use formulas appropriately.

Common areas of confusion for students

Common mistake: *Confusing encoders, decoders, multiplexers, and demultiplexers.*

Students often mix up the identities of encoders, decoders, multiplexers, and demultiplexers. It is important for them to realize that while multiplexers and demultiplexers *contain* decoders, they are not the same as decoders (or encoders). In essence, muxes and demuxes "steer" signals to/from different locations, while encoders and decoders convert data from one format to another.

Questions

Question 1

What does it mean, in general terms, to *encode* something? Conversely, what does it mean to *decode* something? Perhaps the most common context for these terms to be used is cryptography (code-making and code-breaking), but they also find application in common digital circuits.

file 01407

Question 2

The simple switch-and-diode circuit shown here is an example of a digital *encoder*. Explain what this circuit does, as the switch is moved from position to position:
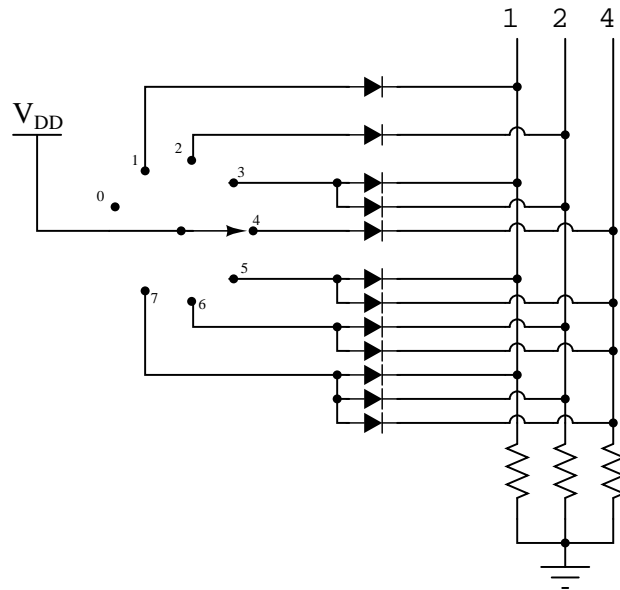
file 01408

Question 3

Having learned how to build simple encoder circuits using diode networks, you set out to form your own encoder manufacturing company: *Encoders, Inc.* After agreeing on a policy of truth in advertising, your board of directors drafts this slogan:

"Our encoder circuits are more reliable because there's less to break."

After months of hard work, you unveil your latest masterpiece, the 16-line to 4-line encoder:
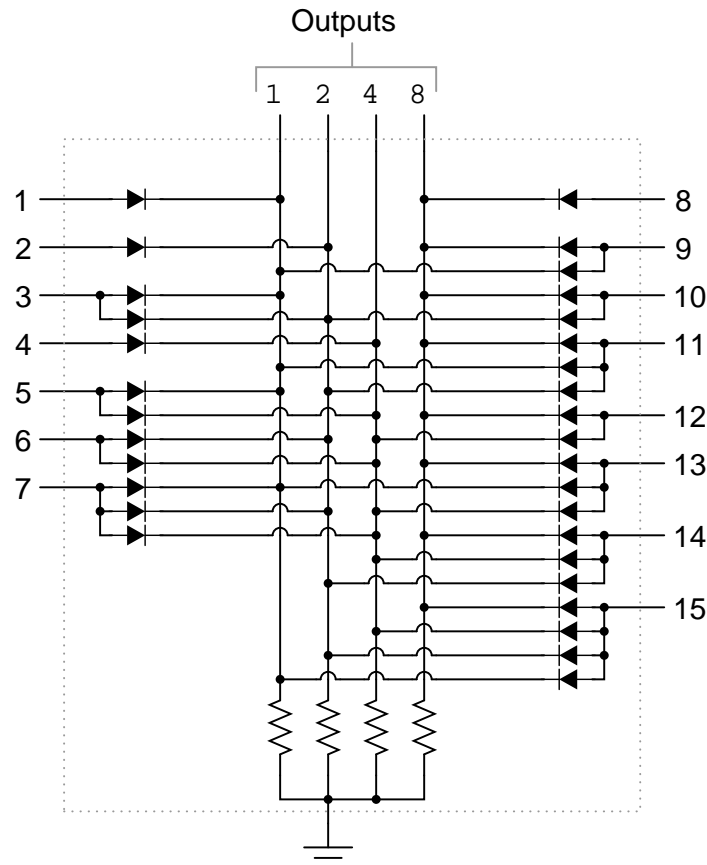
However, your first customer has a complaint with your encoder circuit. He claims it often outputs false codes. After sending it back to your workshop for warranty repair, you determine there is nothing wrong with the encoder circuit itself: it always outputs the correct codes when you energize the appropriate inputs. Perhaps the problem is in how the customer is using it.

You then telephone the customer and ask him how he is using the encoder. He tells you it is used as part of a fault diagnostic circuit for an important piece of machinery. Each input of the encoder is connected to a different sensor on the machine (low oil pressure switch, high temperature switch, out-of-limit travel switches, etc.), and then the encoder outputs drive a four-LED display for maintenance technicians to view. They would have rather used a separate LED for each "trouble" sensor, but the display panel was too small to accommodate fifteen LEDs, so they decided to use four LEDs and an encoder, having their technicians interpret a binary code to determine which of the fifteen sensors is activating.

To the best of your ability, determine why your company's flagship encoder circuit sometimes produces false codes in this application. Then, recommend a solution for your customer.
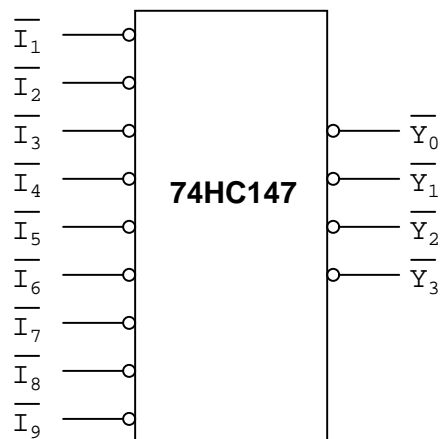
file 01409

5

Question 4

Explain how the following decimal-to-BCD encoder circuit works:
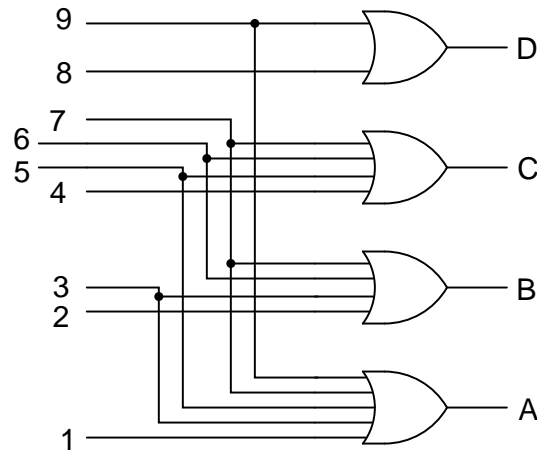
Also, determine which output (D or A) is the *most significant bit* of the BCD output.

file 03003

Question 5

Here is the block symbol for the 74HC147 decimal-to-BCD encoder:

Describe what sort of input conditions would be required to make it generate the code for the number 7, and how that numerical quantity would be represented on the output (Y) lines.
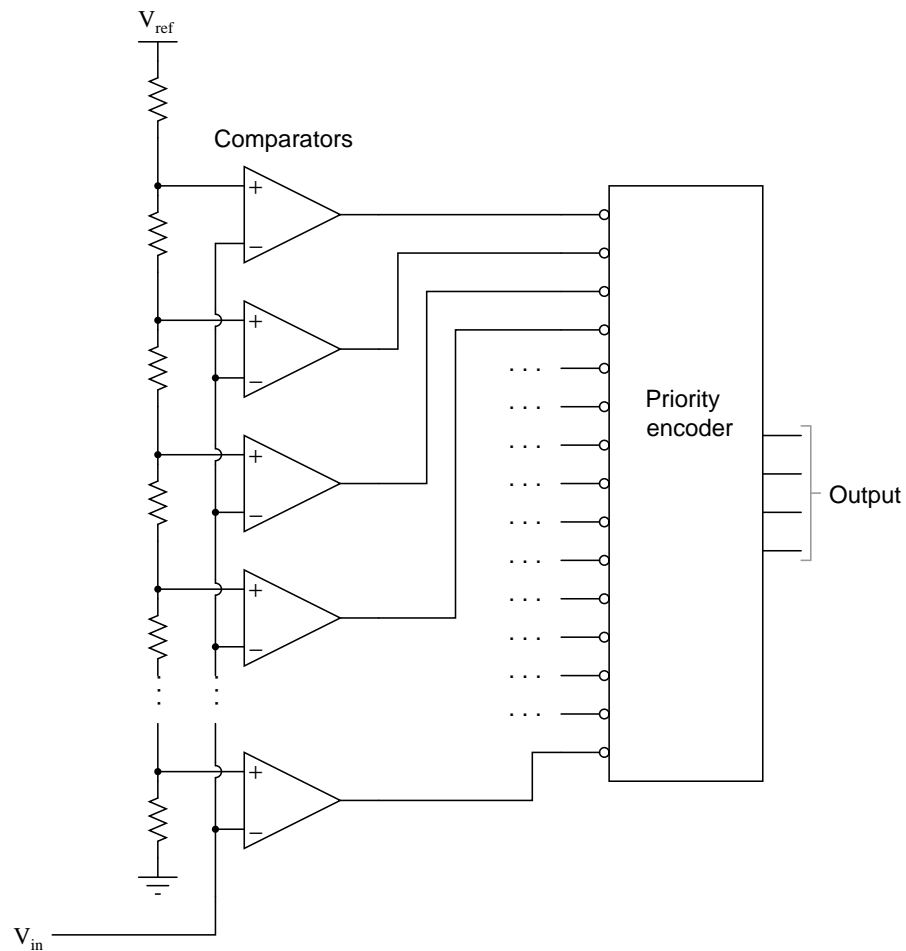
file 03004

Question 6

What is a *priority* encoder circuit, and how does it differ from a regular encoder? Find a datasheet for a priority encoder, and explain how the encoder circuit works.

file 01412

Question 7

The circuit shown here is a four-bit analog-to-digital converter (ADC). Specifically, it is a *flash* converter, so named because of its high speed:

Explain why we must use a *priority* encoder to encode the comparator outputs into a four-bit binary code, and not a regular encoder. What problem(s) would we have if we were to use a non-priority encoder in this ADC circuit?

file 01413

The truth table shown here is for a 4-line to 16-line *binary decoder* circuit:

D	C	B	A	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

For each of the sixteen output lines, there is a Boolean SOP expression describing its function. Just for example, write the Boolean expressions for output lines 5, 8, and 13.
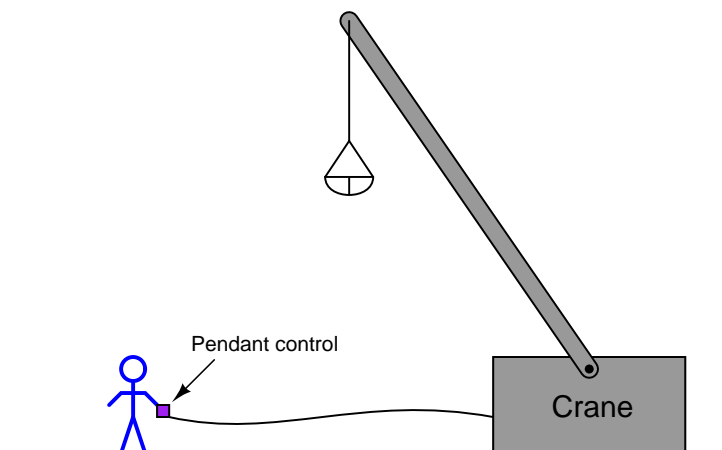
file 01414

Question 9

Suppose a crane has fifteen hydraulic solenoid valves controlling its motion:

- Tilt up (fast)
- Tilt down (fast)
- Tilt up (slow)
- Tilt down (slow)
- Turn left (fast)
- Turn right (fast)
- Turn left (slow)
- Turn right (slow)
- Cable up (fast)
- Cable down (fast)
- Cable up (slow)
- Cable down (slow)
- Bucket open (fast)
- Bucket open (slow)
- Bucket close (slow)

You are part of a team building a remote "pendant" control for this crane with fifteen buttons on it for controlling each of the fifteen solenoid valves. This control pendant connects to the main system by a multiconductor cable, but you really want to limit the number of conductors in this cable to keep it as light-weight as possible:

Draw a simple schematic diagram showing how a digital encoder and decoder circuit pair could be used to relay the same fifteen commands across fewer cable conductors, compared to if we used one conductor per pushbutton switch.

file 01415

Question 10

The type 74HC154 integrated circuit is a standard TTL decoder, 4-line to 16-line. Its block symbol looks like this:
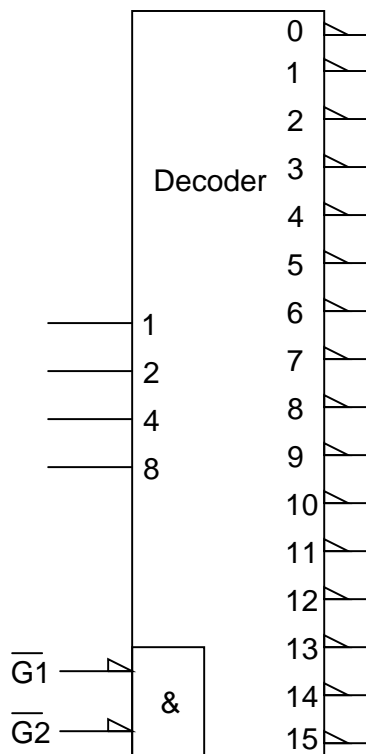

What do the "wedge" symbols next to the output lines represent? Also, what purpose do the $\overline{G1}$ and $\overline{G2}$ inputs serve, and why is there an ampersand character (&) next to them?

<u>file 01416</u>

Question 11

Imagine a telephone system with only one pair of wires stretching between phone units. For the sake of simplicity, let's consider each telephone to be a sound-powered (unamplified) unit, where the voltage produced directly by the microphone drives the speaker on the other end:
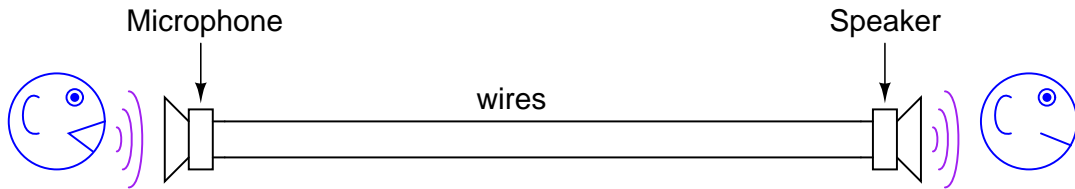
If we were to install a second telephone line to accommodate another pair of people talking to each other, it certainly would work, but it might be expensive to do so because of the cost of wire over the long distance:
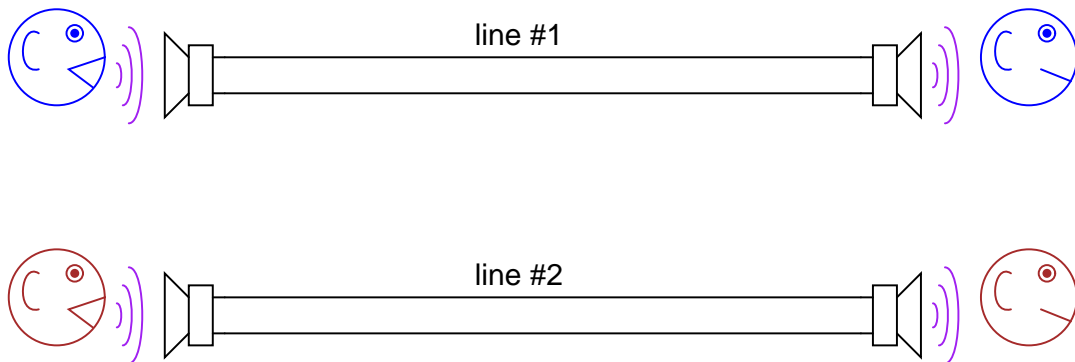
Suppose, though, we installed a set of DPDT switches that switched the two telephone conversations along the same pair of wires (only 1 telephone "line"). This general technique is known as *multiplexing*. The switches would be synchronized according to clocks at either end of the line, and cycled back and forth repeatedly:
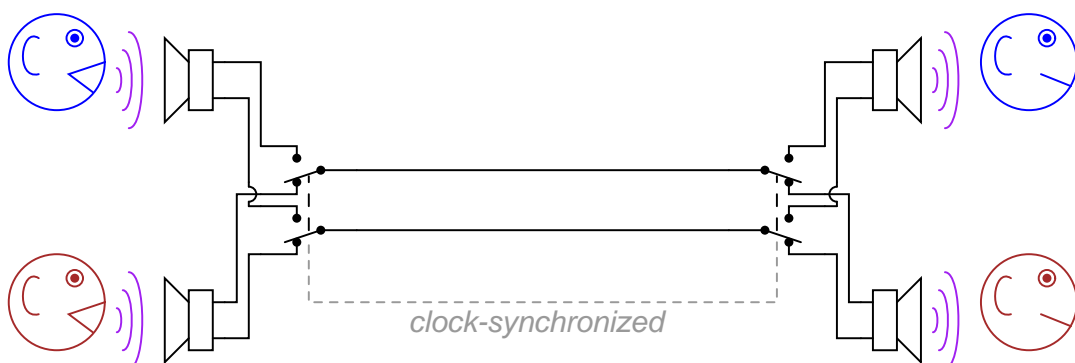
What would the conversation sound like to either of the listeners if the switch frequency was 1 Hz? What if it was 10 Hz? What if it was 40 kHz?

file 01343

Question 12

Most modern analog oscilloscopes have the ability to display multiple traces on their screens (dual-trace is the standard), even though the CRT itself used by the 'scope may only have one electron gun, and thus only be able to "paint" one flying dot on the screen at a time.

Oscilloscopes with single-gun display tubes achieve dual-trace capability by way of *multiplexing* the two input channels to the same CRT. There are usually two different modes for this multiplexing, though: **alternate** and **chop**.

Explain how these multiplexing techniques work, and what conditions would prompt you to use the two different multiplexing modes. I *strongly* encourage you to experiment with displaying two different signals on one of these oscilloscopes as your research. You will likely learn far more from a hands-on exercise than if you were to read about it in a book!

file 01344

A variety of practical electronic applications require *multiplexing*, where several input signals are individually selected, one at a time but very rapidly, to be communicated through a single channel. Telephony systems use this technique to "concentrate" multiple voice conversations over a single wire pair, and most analog dual-trace oscilloscopes use this technique to allow a single-gun CRT to display more than one signal trace on the screen at a time.

In order to rapidly select (or switch) analog signals in these multiplexing applications, we need some form of semiconductor on/off switch capable of fast switching time, low pass-through ("on" state) impedance, and high blocking ("off" state) impedance. Thankfully, there is such a device commonly and inexpensively produced, called a *CMOS bilateral switch*:

4066 CMOS quad bilateral switch IC
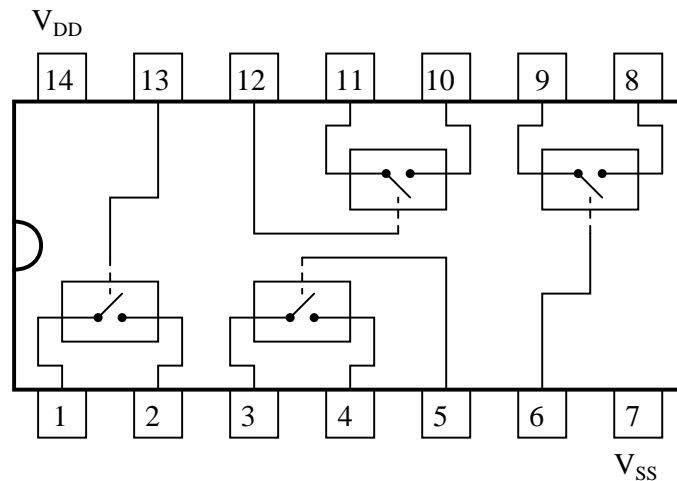
This hybrid analog/digital device uses digital logic signals (high/low) to activate the gates of CMOS transistor assemblies to switch analog signals on and off. It is like having four low-current solid-state relays in a single integrated circuit. When the control line is made "high" (standard CMOS logic level), the respective switch goes into its conductive ("on") state. When the control line is made "low," the switch turns off. Because it is MOSFETs we are turning on and off, the control lines draw negligible current (just like CMOS logic gate inputs).

If we are to use such bilateral switches to multiplex analog signals along a common signal line, though, we must add some accessory components to control which switch (out of the four) is active at any given time. Take for instance this circuit where we use four bilateral switches to multiplex the voltage signals from four accelerometers (measuring acceleration on a vibration-testing jig):

Four-channel analog multiplexer circuit
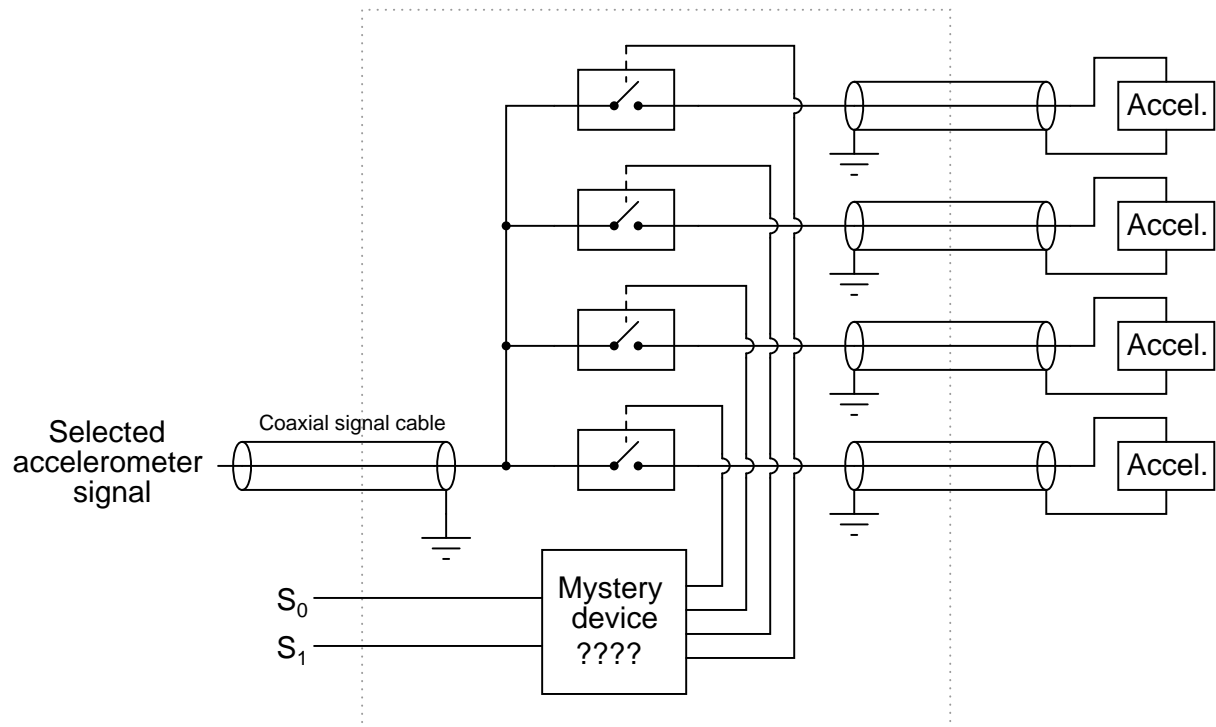
Identify the necessary "mystery device" shown in the schematic, which allows a binary input (S_0 and S_1 with four combinations of high/low states: 00, 01, 10, and 11) to activate just *one* bilateral switch at a time.

file 03006

Question 14

Multiplexers and *demultiplexers* are often confused with one another by students first learning about them. Although they appear similar, they certainly perform different functions. Shown here is a multiplexer and a demultiplexer, each using a multiple-position switch symbol to indicate the selection functions inside the respective circuits:

Mux or Demux?

Mux or Demux?
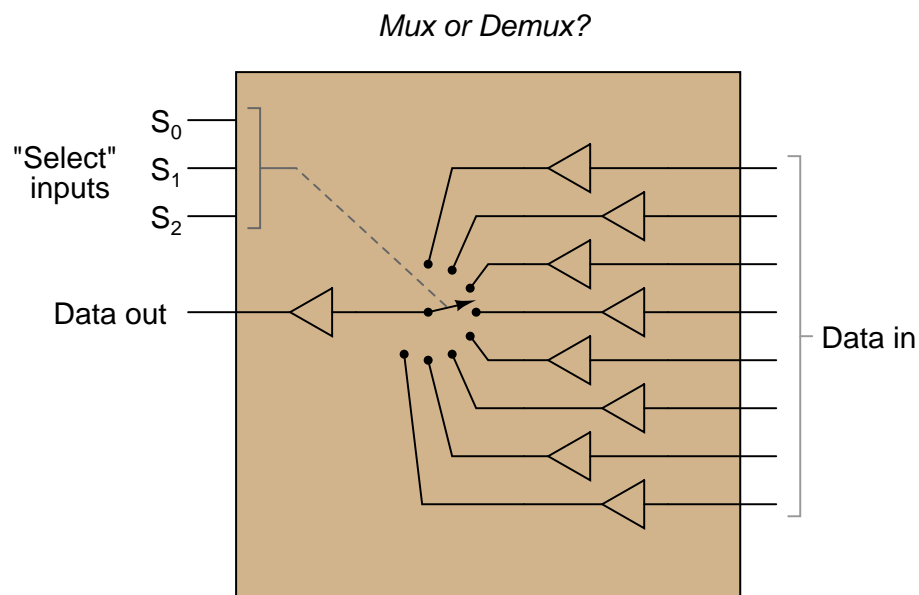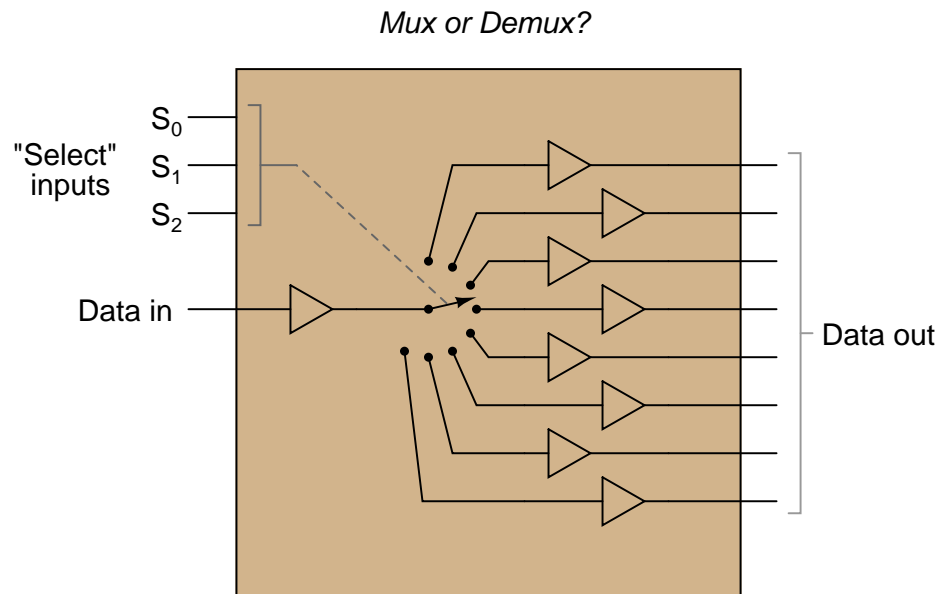
After identifying which is which, provide definitions for "multiplexer" and "demultiplexer" in your own words.

file 03005

Question 15

The 74HC150 is a high-speed CMOS (TTL-compatible) integrated circuit multiplexer, also known as a *data selector*. It is commonly available as a 24 pin DIP "chip." Identify the terminals of a 74HC150, and label them here:
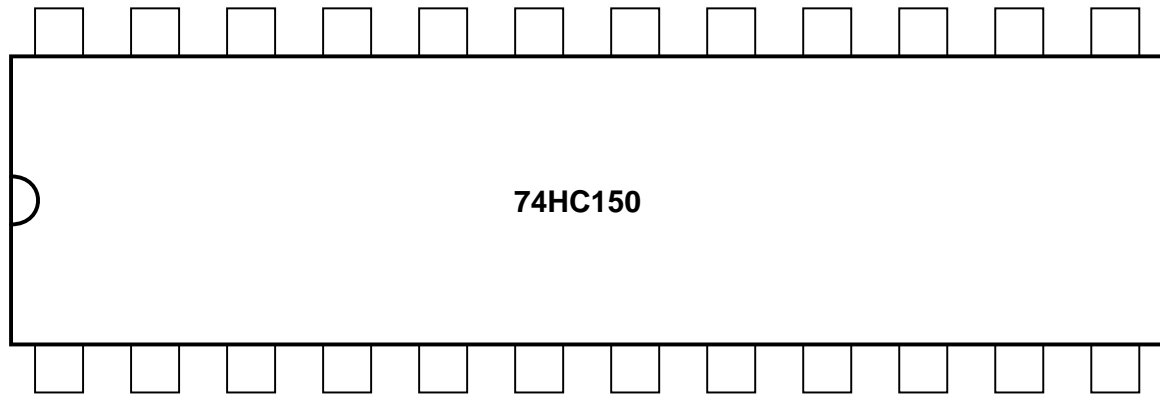

In particular, note the locations of the four "select" terminals, as well as the single output terminal.

What types of electrical "data" may be "selected" by this particular integrated circuit? For example, can it select an analog waveform, such as human speech from a microphone? Is it limited to discrete TTL signals (low and high, 0 volts and 5 volts DC)? How can you tell?

file 01438

Question 16

Multiplexers, or data selectors, may be used to generate arbitrary truth table functions. Take for example this Boolean SOP expression, shown beside a symbol for a 16-channel multiplexer:
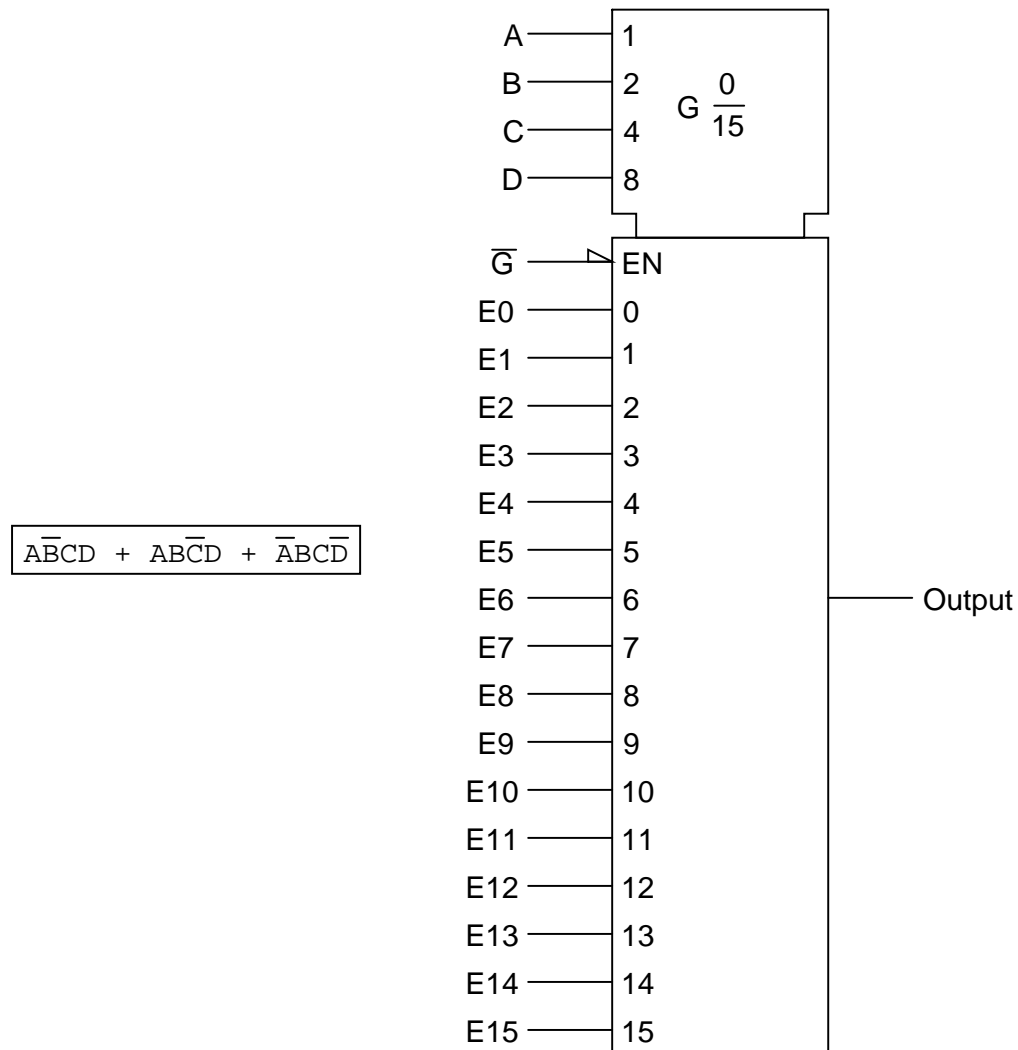
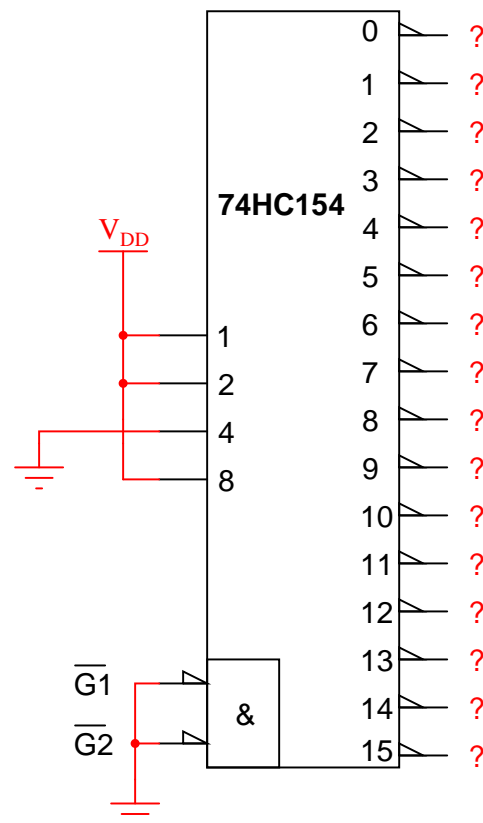$A\overline{B}CD + AB\overline{C}D + \overline{A}BC\overline{D}$

Show the wire connections necessary to make the multiplexer output the specified logic states in response to the data select (A, B, C, and D) inputs.
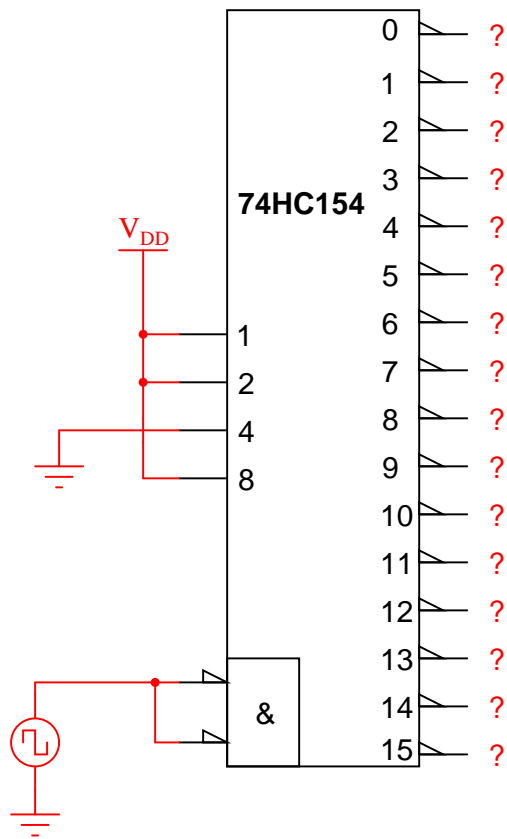
file 03011

The 74HC154 is a high-speed CMOS (TTL-compatible) integrated circuit decoder with four input lines and sixteen output lines:

Identify the logic states of all output terminals given the input conditions shown.
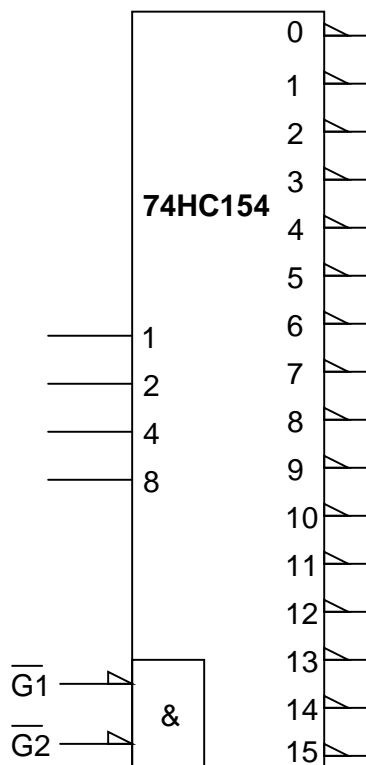
Now, identify the logic states for the same circuit, this time with a square wave (on/off pulse) logic signal applied to the enable terminals:

74HC154

V_{DD}

| 1 |
| 2 |
| 4 |
| 8 |

&

0	?
1	?
2	?
3	?
4	?
5	?
6	?
7	?
8	?
9	?
10	?
11	?
12	?
13	?
14	?
15	?

file 03012

19

The 74HC154 is a high-speed CMOS (TTL-compatible) integrated circuit decoder, which may also be used as a demultiplexer:

What terminal(s) do we use for the signal input, if using this chip as a *demultiplexer* and not just a decoder?

file 01437

Question 19

The 74HC137 and 74HC237 decoder/demultiplexer integrated circuits have a feature that some other decoder/demultiplexers do not: *address latching*. Explain what this additional feature is, how it works, and how you would disable the feature if you needed to use one of these integrated circuits in an application not requiring address latching.

file 03013

Question 20

When first learning about encoders, decoders, multiplexers, and demultiplexers, students often get them confused with one another. Write succinct definitions (complete with illustrations) for each of these four digital functions, based on your own research and written using your own words. Also, identify which two of these digital functions are usually performed by the same integrated circuit.
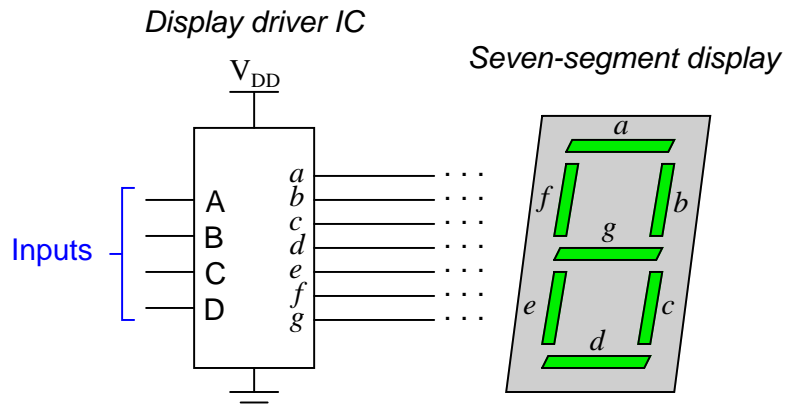
file 03179

Question 21

What is the purpose of a *seven-segment decoder* circuit? What is a "seven-segment" display, and why do we need a decoder circuit to drive it? Research the part number for a typical seven-segment decoder circuit (either CMOS or TTL).

file 01417

Question 22

A *seven segment decoder* is a digital circuit designed to drive a very common type of digital display device: a set of LED (or LCD) segments that render numerals 0 through 9 at the command of a four-bit code:

The behavior of the display driver IC may be represented by a truth table with seven outputs: one for each segment of the seven-segment display (a through g). In the following table, a ”1” output represents an active display segment, while a ”0” output represents an inactive segment:
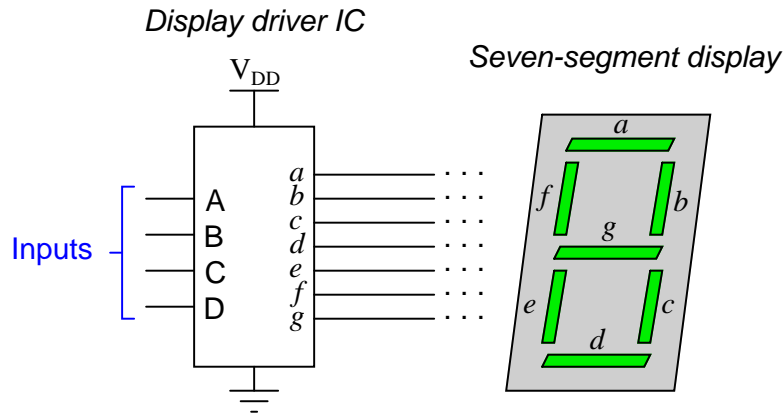
D	C	B	A	a	b	c	d	e	f	g	Display
0	0	0	0	1	1	1	1	1	1	0	”0”
0	0	0	1	0	1	1	0	0	0	0	”1”
0	0	1	0	1	1	0	1	1	0	1	”2”
0	0	1	1	1	1	1	1	0	0	1	”3”
0	1	0	0	0	1	1	0	0	1	1	”4”
0	1	0	1	1	0	1	1	0	1	1	”5”
0	1	1	0	1	0	1	1	1	1	1	”6”
0	1	1	1	1	1	1	0	0	0	0	”7”
1	0	0	0	1	1	1	1	1	1	1	”8”
1	0	0	1	1	1	1	1	0	1	1	”9”

Write the unsimplified SOP or POS expressions (choose the most appropriate form) for outputs a, b, c, and e.

file 02824

Question 23

A *seven segment decoder* is a digital circuit designed to drive a very common type of digital display device: a set of LED (or LCD) segments that render numerals 0 through 9 at the command of a four-bit code:

The behavior of the display driver IC may be represented by a truth table with seven outputs: one for each segment of the seven-segment display (*a* through *g*). In the following table, a "1" output represents an active display segment, while a "0" output represents an inactive segment:

D	C	B	A	a	b	c	d	e	f	g	Display
0	0	0	0	1	1	1	1	1	1	0	"0"
0	0	0	1	0	1	1	0	0	0	0	"1"
0	0	1	0	1	1	0	1	1	0	1	"2"
0	0	1	1	1	1	1	1	0	0	1	"3"
0	1	0	0	0	1	1	0	0	1	1	"4"
0	1	0	1	1	0	1	1	0	1	1	"5"
0	1	1	0	1	0	1	1	1	1	1	"6"
0	1	1	1	1	1	1	0	0	0	0	"7"
1	0	0	0	1	1	1	1	1	1	1	"8"
1	0	0	1	1	1	1	1	0	1	1	"9"

A real-life example such as this provides an excellent showcase for techniques such as Karnaugh mapping. Let's take output *a* for example, showing it without all the other outputs included in the truth table:

D	C	B	A	a
0	0	0	0	1
0	0	0	1	0
0	0	1	0	1
0	0	1	1	1
0	1	0	0	0
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1

Plotting a Karnaugh map for output *a*, we get this result:

23

```
 BA
DC\  00  01  11  10
  00 | 1 | 0 | 1 | 1 |
  01 | 0 | 1 | 1 | 1 |
  11 |   |   |   |   |
  10 | 1 | 1 |   |   |
```

Identify adjacent groups of 1's in this Karnaugh map, and generate a minimal SOP expression from those groupings.

Note that six of the cells are blank because the truth table does not list all the possible input combinations with four variables (A, B, C, and D). With these large gaps in the Karnaugh map, it is difficult to form large groupings of 1's, and thus the resulting "minimal" SOP expression has several terms.

However, if we do not care about output a's state in the six non-specified truth table rows, we can fill in the remaining cells of the Karnaugh map with "don't care" symbols (usually the letter X) and use those cells as "wildcards" in determining groupings:

```
 BA
DC\  00  01  11  10
  00 | 1 | 0 | 1 | 1 |
  01 | 0 | 1 | 1 | 1 |
  11 | X | X | X | X |
  10 | 1 | 1 | X | X |
```

With this new Karnaugh map, identify adjacent groups of 1's, and generate a minimal SOP expression from those groupings.

file 02838

Question 24

Examine the datasheet for a 7447 BCD-to-7-segment decoder/driver IC, and identify what input conditions need to be met in order to cause it to display any decimal digit from 0 to 9.

file 03039

Question 25

Liquid crystal display (LCD) elements require the application of *AC* voltage rather than *DC* voltage to prevent certain undesirable effects. Since logic circuits typically operate on DC power (V_{CC} or V_{DD} and Ground), there must be some clever way of generating the necessary AC from DC logic power in order to drive these power-thrifty display devices. Indeed, it just so happens that Exclusive-OR gates do the trick quite nicely:
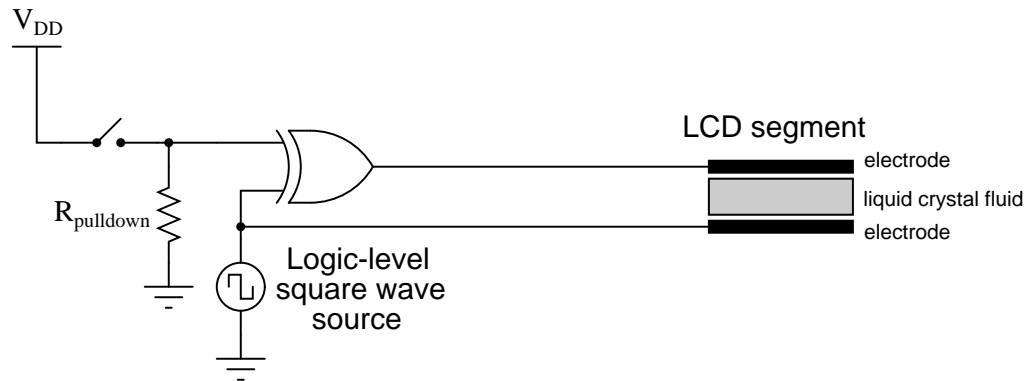
Consider the square wave voltage source in this schematic as a source of alternating "high" and "low" logic states, 5 volts and 0 volts respectively. Determine what sort of voltage exists across the liquid crystal fluid with the switch in the open position as well as the closed position, and from this determine which switch position results in a *darkened* LCD versus a *transparent* LCD.

file 03014

Question 26

A feature found on most 7-segment decoder/driver ICs is called *ripple blanking*. Describe what this feature is, and why it is used. Hint: a good source of information on this subject is a datasheet for a 7-segment decoder/driver IC.

file 03036

It is usually necessary to have more than one display digit for a digital system. The most obvious and direct way of driving multiple 7-segment display units is to use an equal number of BCD-to-7-segment decoders like this:
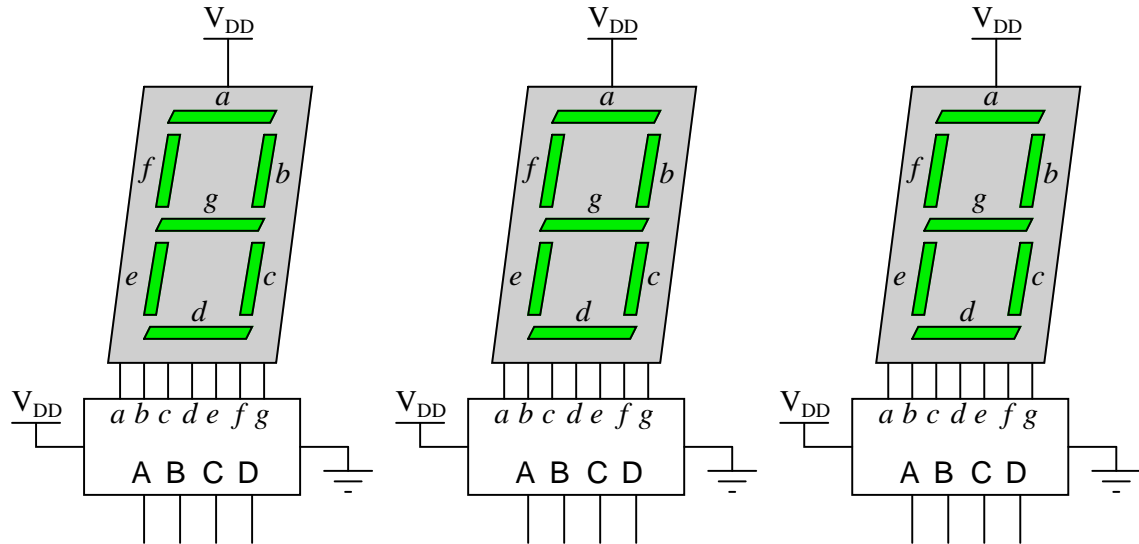

If we are driving the decoder ICs with a microprocessor or microcontroller, this direct technique unfortunately uses a lot of I/O pins. In this particular case, with three 7-segment displays, we would need to use *twelve* output pins on the microcontroller for the three BCD numbers:
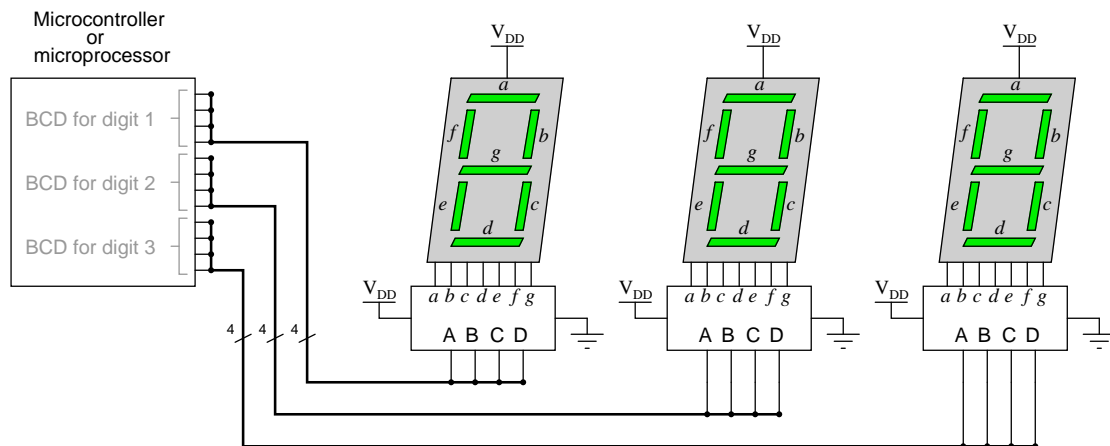
Due to limited pin count on most MPU and MCU chips, I/O lines are precious. It would be a shame to waste so many on a simple function such as driving display digits when we could use them for other tasks such as interfacing with memory devices, receiving real-world data from sensors, driving discrete control devices such as lights and solenoids, or communicating with other MPU/MCU systems. But if each digit requires four output lines for the BCD number, how can we possibly use less than twelve output lines on the processor?

One clever way to do just this exploits *persistence of human vision*, by driving only one digit at a time. Examine the following circuit, then explain how this "multiplexed" display system works with so few output

lines. Also identify what steps the MCU/MPU must take to successfully drive all three digits so the display looks continuous:
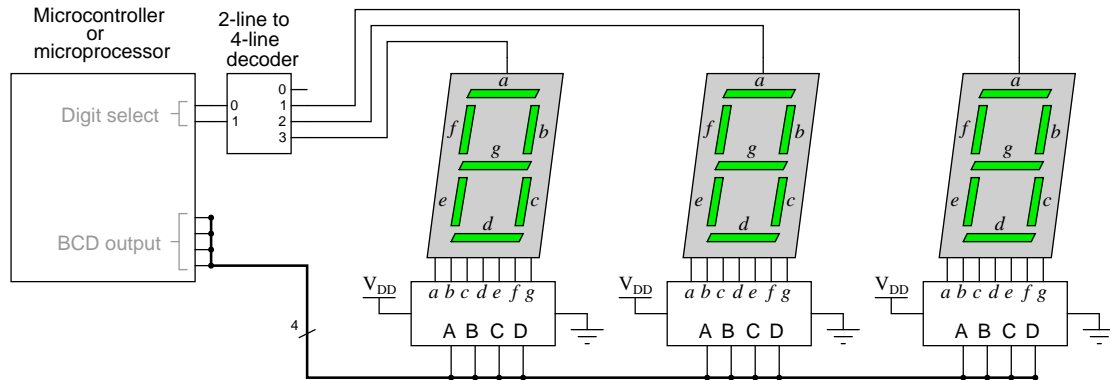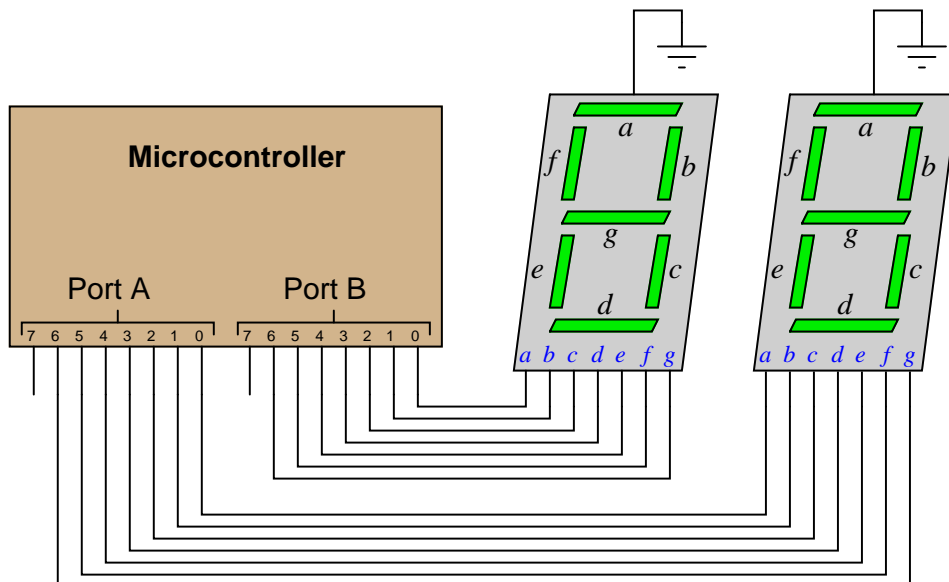

file 03035

Question 28

Digital computers communicate with external devices through *ports*: sets of terminals usually arranged in groups of 4, 8, 16, or more. These terminals may be set to high or low logic states by writing a program for the computer that sends a numerical value to the port. For example, here is an illustration of a microcontroller being instructed to send the hexadecimal number 2B to port A and A9 to port B:
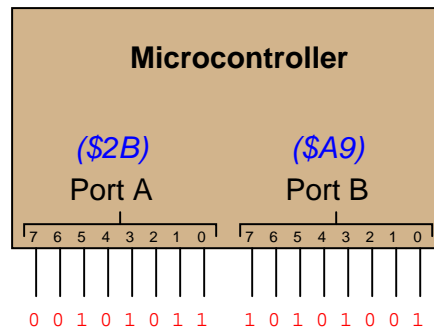
Suppose we wished to use the first seven bits of each port (pins 0 through 6) to drive two 7-segment, common-cathode displays, rather than use BCD-to-7-segment decoder ICs:

Write the necessary hexadecimal values to be output at ports A and B to generate the display "42" at the two 7-segment display units.

<u>file 03042</u>

Question 29

The MM58342 high-voltage display driver IC from National Semiconductor serves as an interface between either a microprocessor or microcontroller and a high-voltage vacuum fluorescent (VF) display panel. The IC reads and conditions 20 bits of data to drive 20 "grids" in such a display. When combined with a similar driver driving the anodes of the same VF display, individual pixels (or combinations of pixels) may be controlled (lit).

An interesting feature of this IC is that it receives the 20 bits of data serially (one at a time), through a single input pin:
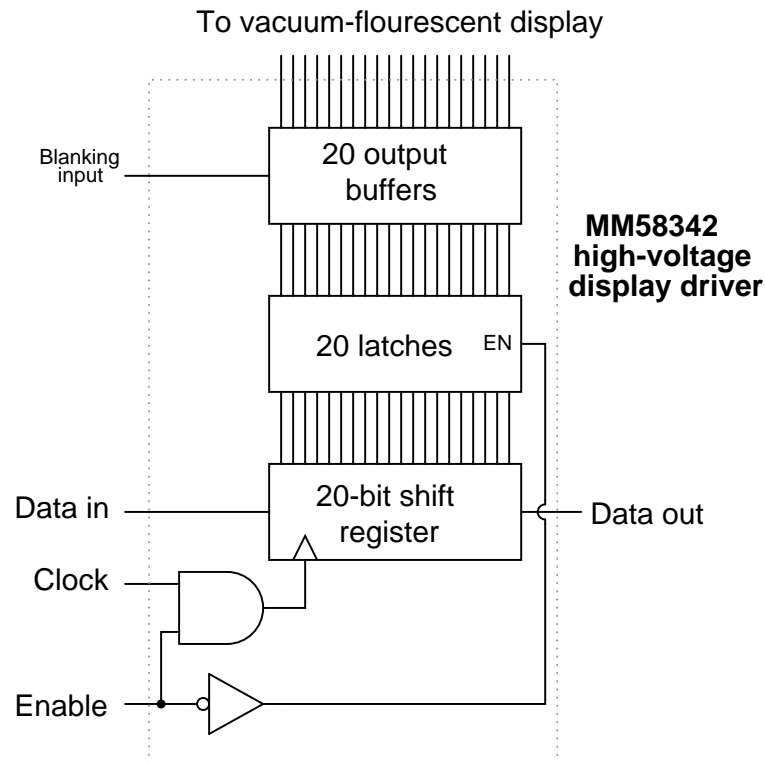
Read the datasheet for this device, then comment on why you think a serial (rather than parallel) data input format was chosen. Also describe the sequence of operation for loading data into this IC and outputting that data to the 20 output lines.

file 03040

Question 30

One new technology entering the market is *organic light-emitting diodes*, or OLEDs. Describe what these are, and why they hold so much promise for electronic display device elements.

file 03037

Question 31

Define the following acronyms as they apply to digital logic circuits:

- ASIC
- PAL
- PLA
- PLD
- CPLD
- FPGA

file 03041

Question 32

Why would anyone use programmable logic devices (PLD, PAL, PLA, CPLD, FPGA, etc.) in place of traditional "hard-wired" logic such as NAND, NOR, AND, and OR gates? Are there any applications where hard-wired logic would do a better job than a programmable device?
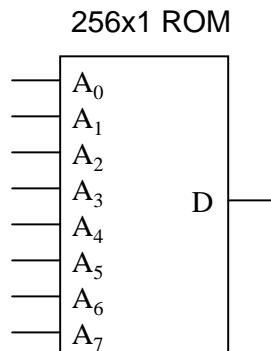
file 03048

Question 33

An important use for read-only semiconductor memories is as *look-up tables*. Describe what a "look-up table" is, and what one might be used for.
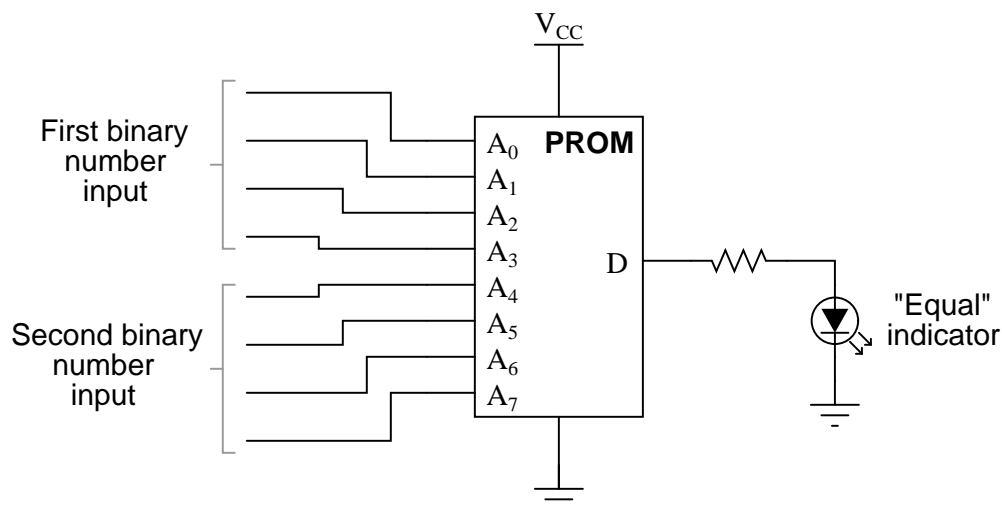
file 01477

Question 34

Perhaps the simplest form of programmable logic is a PROM integrated circuit, programmed with a specific truth table. Take for instance this example of a 256×1 PROM:

256x1 ROM

Suppose we wished to program this memory IC to act as a digital comparator, outputting a logical "high" state only when two four-bit binary numbers are equal:

Describe what the truth table would look like for the data we must program into this memory chip. How many rows would the truth table have? Could you briefly describe the content pattern of the data without having to complete the entire truth table?

file 03043

Question 35

Microcontrollers are single-chip microcomputers, containing a microprocessor core, memory, I/O control, and other associated components necessary to make the system self-contained. Simply put, a microcontroller follows sequential instructions that someone enters into its memory.

Programmable logic devices, however, are fundamentally different from microcontrollers both in how they are programmed and how they function after being programmed. Explain what some of these differences are.

file 03044

Question 36

The simplest types of programmable logic ICs are called PLDs (Programmable Logic Devices), PALs (Programmable Array Logic), PLAs (Programmable Logic Array), and GALs (Generic Array Logic). While each acronym represents a slightly different internal design architecture, these devices share a common feature of using inverters, AND gates, and OR gates to implement any desired combinational logic function.

Explain how it is possible to generate any arbitrary logic function with just these gate types (inverter, AND, OR), without any others. What principle or convention of Boolean algebra is used by these devices to do this?

file 03049

Question 37

Some programmable logic devices (and PROM memory devices as well) use tiny fuses which are intentionally "blown" in specific patterns to represent the desired program. Programming a device by blowing tiny fuses inside of it carries certain advantages and disadvantages – describe what some of these are.

file 03050

Question 38

A common term used to describe the internal workings of a programmable logic device is a *macrocell*. What, exactly, is a macrocell?

file 03051

Question 39

Most microcomputers can only perform one task (operation) at a time. They achieve the illusion of "multi-tasking" by alternately devoting time to one of several tasks in a rapid fashion – a sort of multiplexed computation. Most programmable logic devices, on the other hand, are easily able to perform multiple logic operations in a truly simultaneous manner. Explain how this is possible, whereas a microprocessor can only do one thing at a time.

file 03046

Question 40

Verilog and *VHDL* are two popular examples of a *hardware description language*, used when working with programmable logic. Explain the purpose of such a "language." What does it mean for a technician or engineer to "speak" this language, and how is it "spoken" to an actual programmable chip?

file 03047

Question 41

Competency: **4-line to 16-line decoder IC**   Version:

Truth table

D	C	B	A	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0																
0	0	0	1																
0	0	1	0																
0	0	1	1																
0	1	0	0																
0	1	0	1																
0	1	1	0																
0	1	1	1																
1	0	0	0																
1	0	0	1																
1	0	1	0																
1	0	1	1																
1	1	0	0																
1	1	0	1																
1	1	1	0																
1	1	1	1																
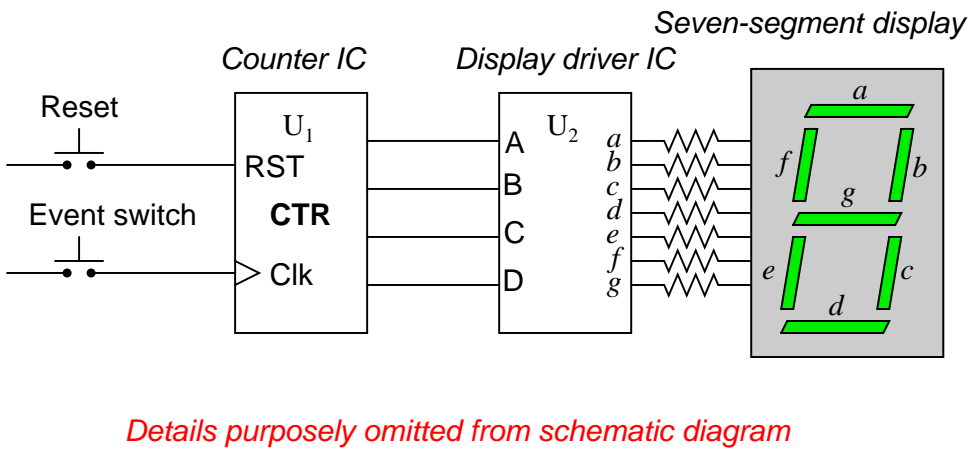
Schematic

file 03009

33

Question 42

Competency: **Arbitrary logic function using mux**   Version:

Truth table

Given

C	B	A	Output
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

Actual

C	B	A	Output
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

Schematic   *You draw it, in its entirety!*

Competency: **BCD to 7-segment decoder/driver IC**   Version:

Schematic

V_{DD}

V_{DD}

Seven-segment display

A
B
C
D

$R_{pulldown}$

A
B
C
D

a
b
c
d
e
f
g

V_{DD}

Seven-segment display

a
f   b
g
e   c
d

Parameters

All numerals (0 through 9) demonstrated ☐

Fault analysis

Suppose component ☐ fails   ☐ open   ☐ other _____

☐ shorted

What will happen in the circuit?

file 03010

Competency: **Decade counter circuit**   Version:

Schematic

Seven-segment display

Counter IC   *Display driver IC*

Reset

U_1

RST

CTR

Clk

A U_2

B

C

D

a
b
c
d
e
f
g

f *g* *b*

a

e *d* *c*

Details purposely omitted from schematic diagram

Given conditions

$U_1 =$ $U_2 =$

Parameters

Counter increments with each physical event,
counting from 0 to 9 and then resetting back
to 0 again. Count sequence exhibits no skipped
counts and no missed events.

☐ YES

☐ NO

Question 45

Troubleshooting log

Actions / Measurements / Observations (i.e. *What I did and/or noticed . . .*)	Conclusions (i.e. *What this tells me . . .*)

file 03933

Question 46

NAME: _____   **Troubleshooting Grading Criteria**
You will receive the highest score for which *all* criteria are met.

100 % *(Must meet or exceed all criteria listed)*
  A. Absolutely flawless procedure
  B. No unnecessary actions or measurements taken

90 % *(Must meet or exceed these criteria in addition to all criteria for 85% and below)*
  A. No reversals in procedure (i.e. changing mind without sufficient evidence)
  B. Every single action, measurement, and relevant observation properly documented

80 % *(Must meet or exceed these criteria in addition to all criteria for 75% and below)*
  A. No more than one unnecessary action or measurement
  B. No false conclusions or conceptual errors
  C. No missing conclusions (i.e. at least one documented conclusion for action / measurement / observation)

70 % *(Must meet or exceed these criteria in addition to all criteria for 65%)*
  A. No more than one false conclusion or conceptual error
  B. No more than one conclusion missing (i.e. an action, measurement, or relevant observation without a corresponding conclusion)

65 % *(Must meet or exceed these criteria in addition to all criteria for 60%)*
  A. No more than two false conclusions or conceptual errors
  B. No more than two unnecessary actions or measurements
  C. No more than one undocumented action, measurement, or relevant observation
  D. Proper use of all test equipment

60 % *(Must meet or exceed these criteria)*
  A. Fault accurately identified
  B. Safe procedures used at all times

50 % *(Only applicable where students performed significant development/design work – i.e. not a proven circuit provided with all component values)*
  A. Working prototype circuit built and demonstrated

0 % *(If any of the following conditions are true)*
  A. Unsafe procedure(s) used at any point

file 03932

Question 47

Identify which diode is failed in this circuit, given the following truth table (showing the actual operation of the encoder circuit, not what it *should* do):
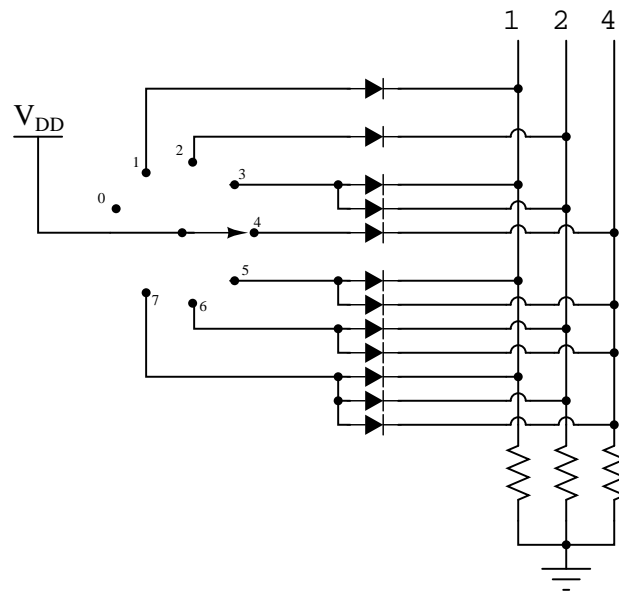
Switch position	Output code
0	000
1	001
2	010
3	011
4	100
5	001
6	110
7	111

Be sure to specify whether you think the failed diode is *open* or *shorted*.
<u>file 03909</u>

Identify which diode is failed in this circuit, given the following truth table (showing the actual operation of the encoder circuit, not what it *should* do):

Switch position	Output code
0	000
1	111
2	010
3	111
4	100
5	111
6	110
7	111

Be sure to specify whether you think the failed diode is *open* or *shorted*.
<u>file 03911</u>

Identify which diode is failed in this circuit, given the following truth table (showing the actual operation of the encoder circuit, not what it *should* do):
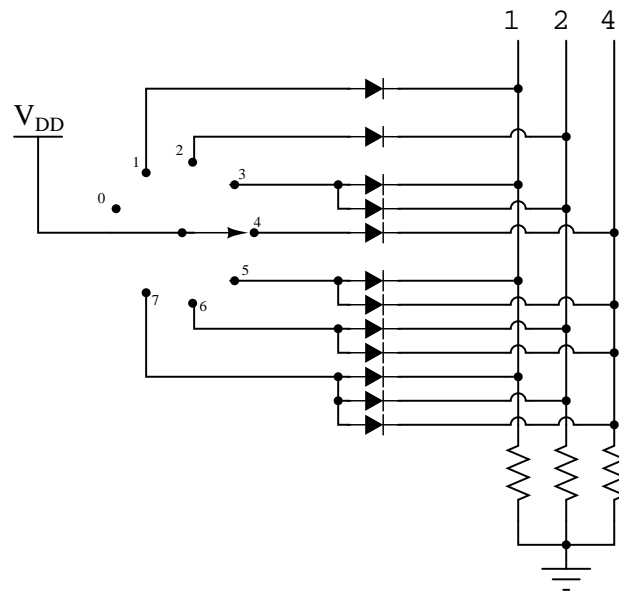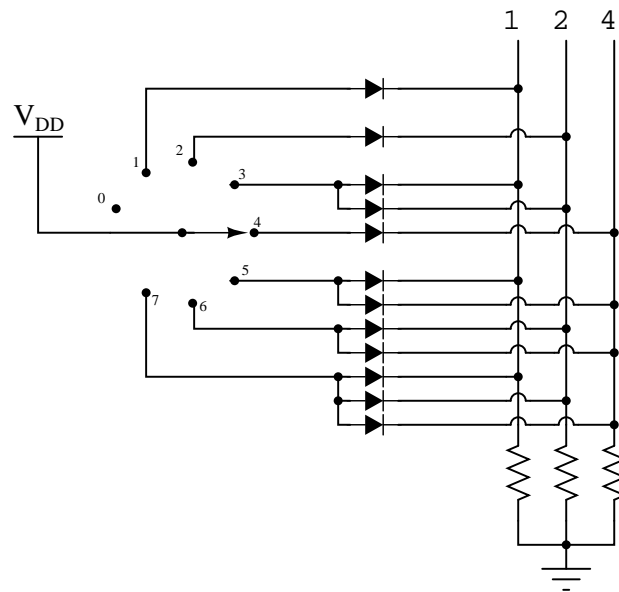

Switch position	Output code
0	000
1	001
2	110
3	111
4	100
5	101
6	110
7	111

Be sure to specify whether you think the failed diode is *open* or *shorted*.
file 03910

Question 50

Suppose OR gate U_3 were to fail with the output terminal always high. Which output codes would be affected by this fault?
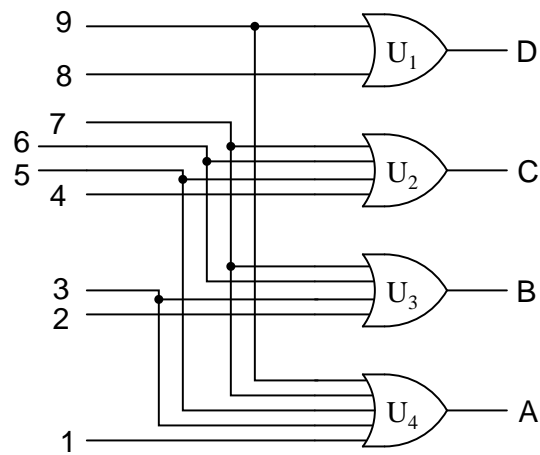
Question 51

Predict how the operation of this "flash" analog-to-digital converter (ADC) circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):
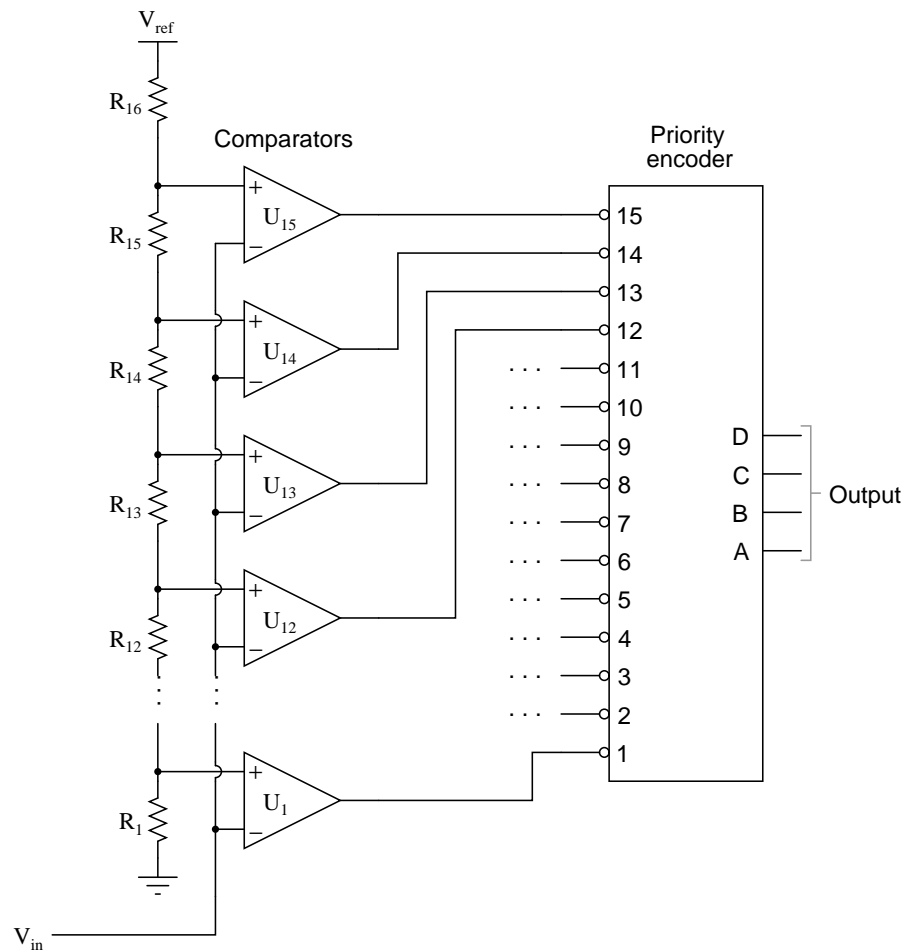
- Resistor R_{16} fails open:

- Resistor R_1 fails open:

- Comparator U_{13} output fails low:

- Solder bridge (short) across resistor R_{14}:

    For each of these conditions, explain *why* the resulting effects will occur.
    file 03912

43

Question 52

This "flash" ADC circuit has a problem. The output code jumps from 0000 to 1111 with just the slightest amount of input voltage (V_{in}). In fact, the only time it outputs 0000 is when the input terminal is slightly negative with reference to ground:
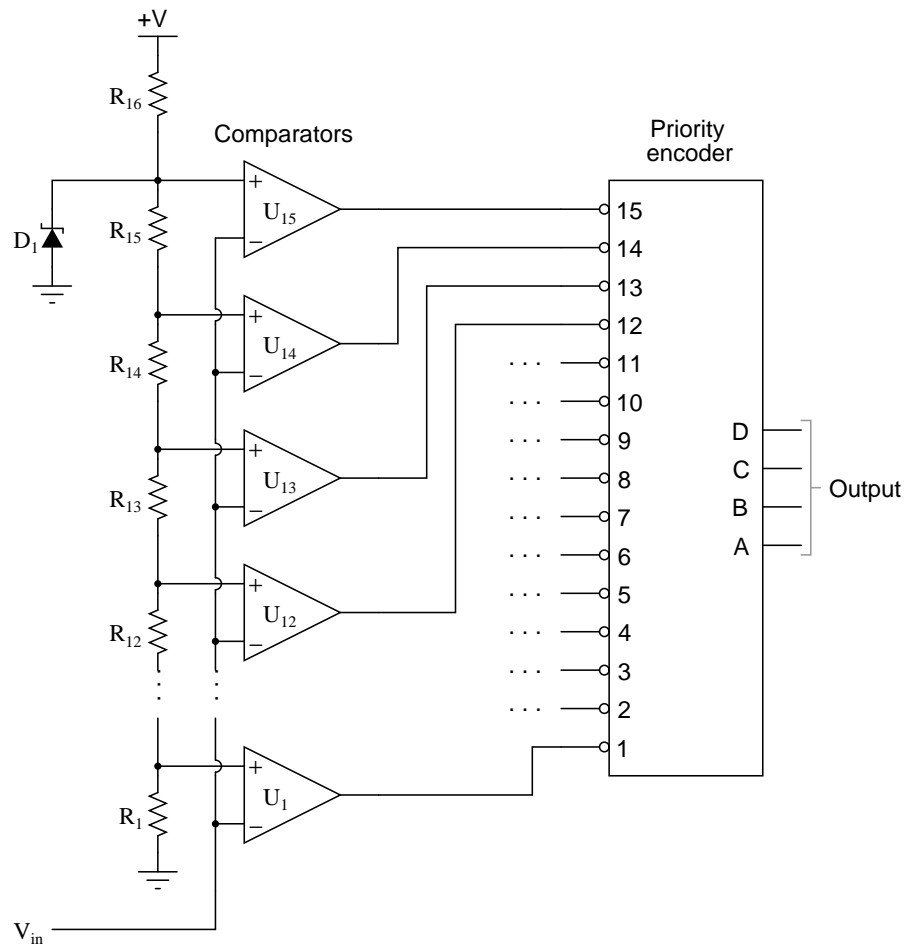
Identify at least two possible component faults that could cause this problem, and explain your reasoning in how you made the identifications.

file 03913

Question 53

The following schematic diagram shows an eight-step arbitrary waveform generator. The analog multiplexer selects one of the eight potentiometer signals at a time, stepping from one to the next at the pace of the clock pulse:
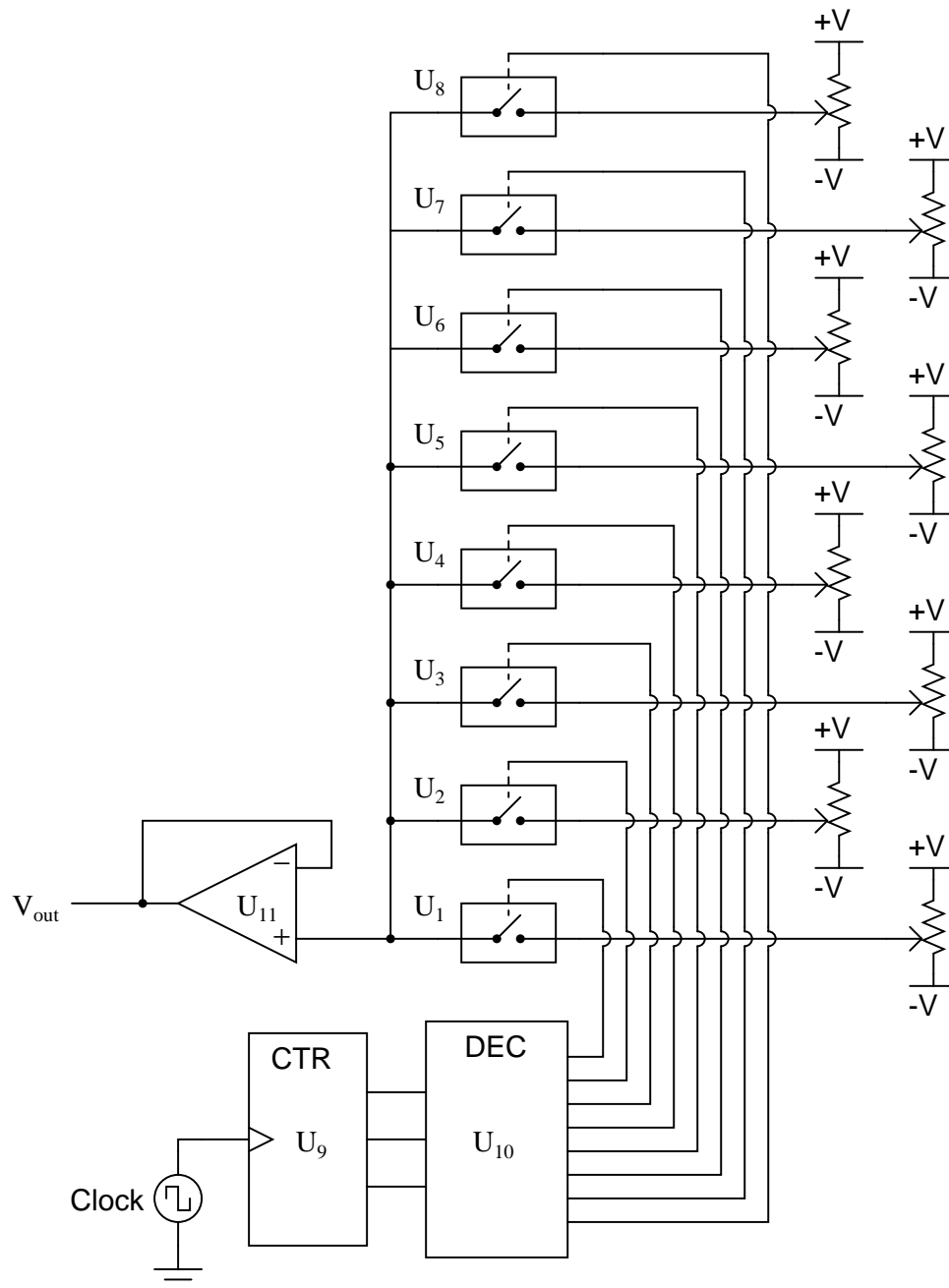
Explain what effect a *shorted* bilateral switch would have on the output waveform. Be as specific as possible.

<u>file 03915</u>

Question 54

Predict how the operation of this "concentrator" circuit (which takes eight digital inputs and "concentrates" them into a single, multiplexed, communication line to be expanded into eight outputs at the receiving end) will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):
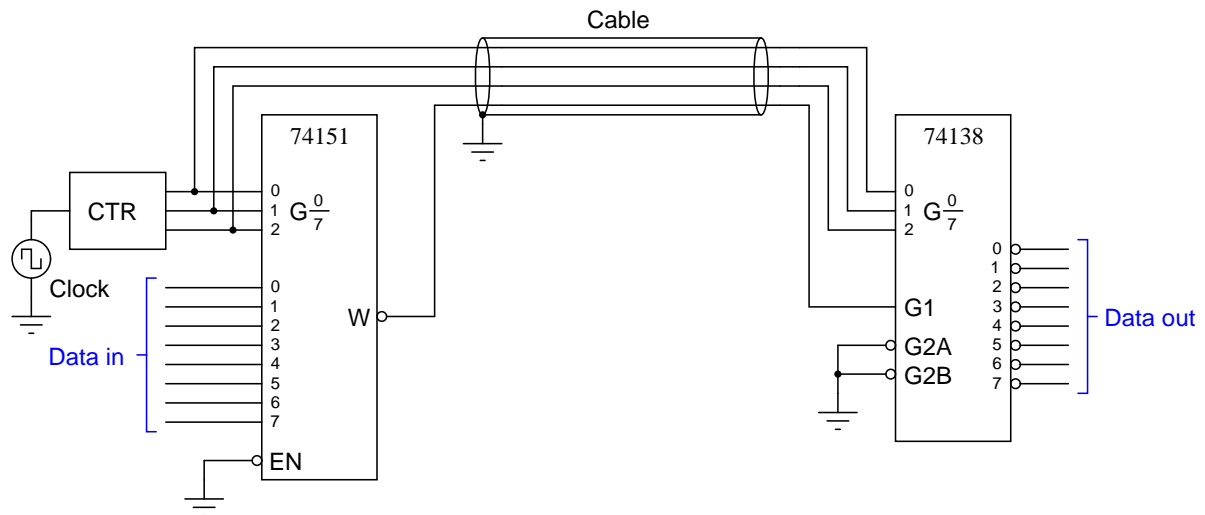
- Clock pulse generator stops pulsing:

- Pin breaks on the W output of 74151 chip, leaving that wire floating:

- Pin breaks on G2A input of 74138 chip, leaving it floating:

- Enable pin breaks on 74151 chip, leaving it floating:

  For each of these conditions, explain *why* the resulting effects will occur.
  file 03918

46

Question 55

Two electronics students attempt to build 7-segment display circuits, one using a 7447 decoder/driver IC and the other using a 7448. Both students connect their ICs to common-cathode 7-segment displays as such:
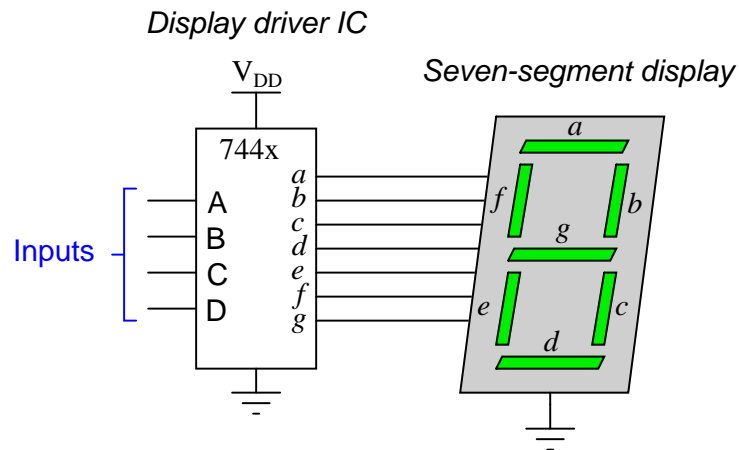
The student using the 7448 notices the LED segments glowing faintly, but the patterns are not correct for the digits that are supposed to be displayed. The student using the 7447 has an even worse problem: no light at all! Both have checked and re-checked their wiring, to no avail. It seems as though all the connections are in the right place.

What do you think the problem is? Hint: consult datasheets for both chips to find clues!

file 03916

Question 56

An obsolete display technology that still finds enthusiastic followers in the hobbyist world, called *Nixie tubes*, relies on a BCD-to-10 decoder to drive one of ten different metal cathodes inside a neon-filled glass bulb. For each BCD code, exactly one of the cathode figures inside the "Nixie tube" will glow, causing that numeral to shine with a pink-orange light. The tube receives power through a common anode (usually over 150 volts DC).

A friend of yours is trying to build his own Nixie tube display circuit, but is experiencing problems. He wants to use a 7442 BCD-to-10 decoder to drive ten discrete transistors, each one handling the current for a digit in the tube. Being cautious, your friend decides to connect just one of the Nixie tube digits to a transistor, and then to the 7442, to see if the idea works (before connecting all ten).
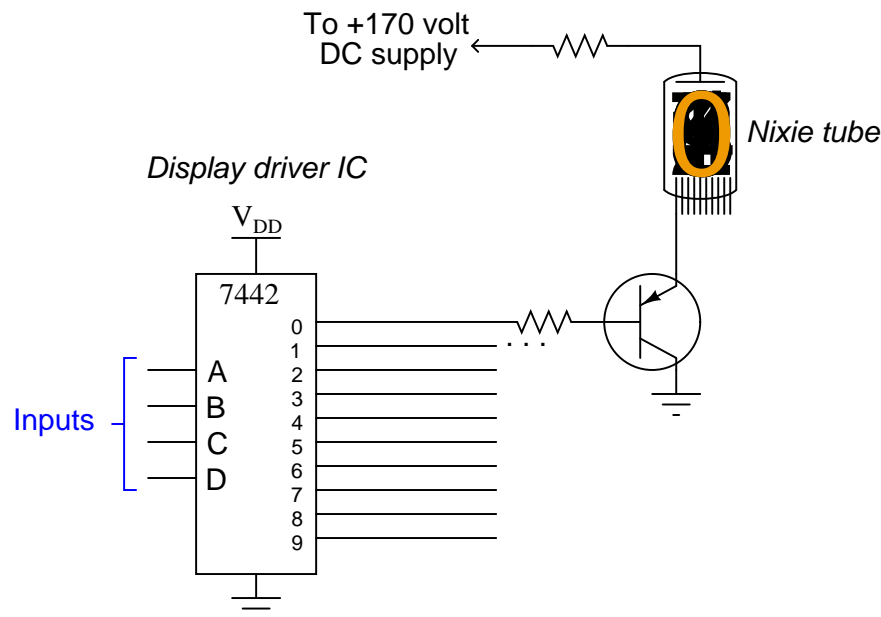
Unfortunately, that one digit begins to glow the moment the high-voltage DC supply is turned on, even before the 7442 chip receives power! And after that, the 7442 gets warm to the touch, which is not good.

Thinking he has damaged the 7442 IC, your friend turns to you for advice. Did he do anything wrong here? Explain what advice you would give to him.

file 03917

Question 57

How much voltage needs to be dropped across resistor R_1 in order to make voltage V_{AB} equal to zero?
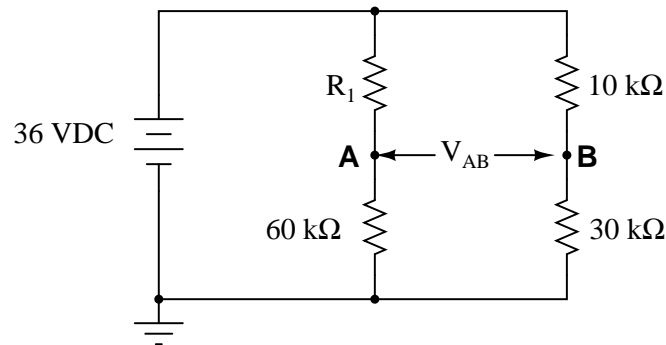
How much resistance must R_1 possess in order to drop that amount of voltage?
file 00543

Question 58

A *thermistor* is a special resistor that dramatically changes resistance with changes in temperature. Consider the circuit shown below, with two identical thermistors:
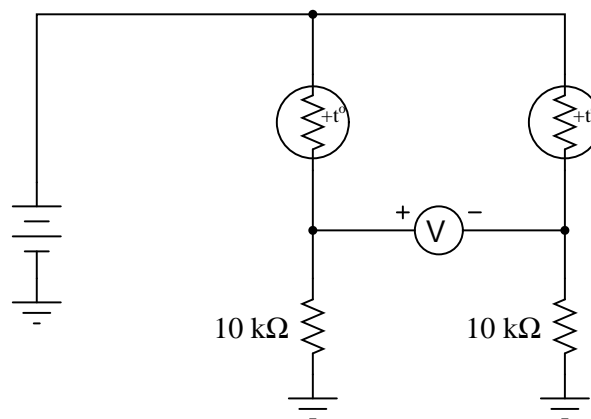
The "+t^o" label in each one shows that they both have positive α coefficients.

How much voltage would you expect the voltmeter to register when the two thermistors are at the exact same temperature? Which thermistor would have to become hotter in order to cause the voltmeter to read a significant *negative* voltage?
file 01751

Question 59

The following bridge circuit uses two strain gauges (one to measure strain, the other to compensate for temperature changes), the amount of strain indicated by the voltmeter in the center of the bridge. Unfortunately, though, it has a problem. Instead of registering a very small voltage as it normally does, the voltmeter shows a large voltage difference, with point **A** positive and point **B** negative:
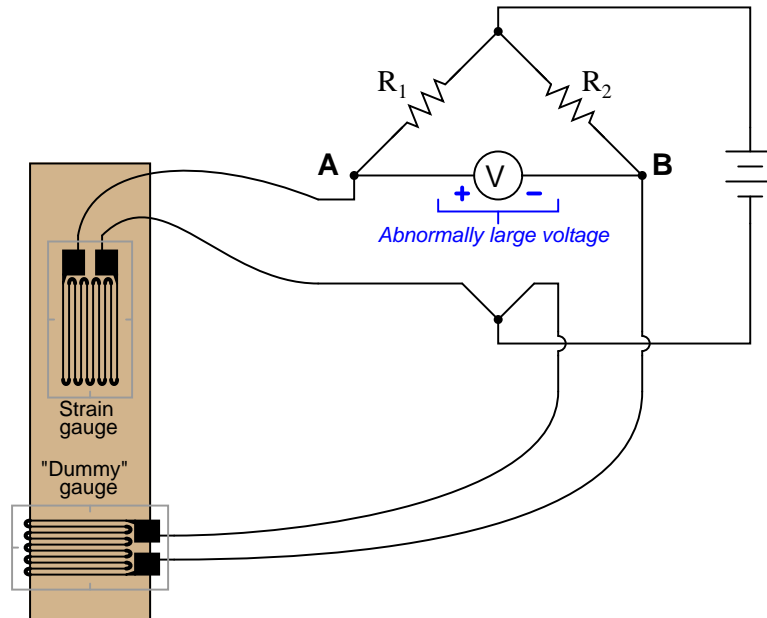
Something is wrong in the bridge circuit, because this voltage is present even when there is no physical stress on the specimen. Identify which of the following faults could cause the excessive voltage to appear across the voltmeter, and which could not. Consider only one of these faults at a time (no multiple, simultaneous faults):

- Resistor R_1 failed open
- Resistor R_1 failed shorted
- Resistor R_2 failed open
- Resistor R_2 failed shorted
- Strain gauge (measurement) failed open
- Strain gauge (measurement) failed shorted
- "Dummy" gauge (temperature compensation) failed open
- "Dummy" gauge (temperature compensation) failed shorted
- Voltage source is dead (no voltage output at all)

file 03331

Question 60

During the early development of telephone technology, a unit was invented for representing power gain (or loss) in an electrical system. It was called the *Bel*, in honor of Alexander Graham Bell, the telecommunications pioneer.

"Bels" relate to power gain ratios by the following equation:

$$A_{P(ratio)} = 10^{A_{P(Bels)}}$$

Given this mathematical relationship, translate these power gain figures given in units of Bels, into ratios:

- $A_P = 3$ B ; $A_P =$
- $A_P = 2$ B ; $A_P =$
- $A_P = 1$ B ; $A_P =$
- $A_P = 0$ B ; $A_P =$
- $A_P = -1$ B ; $A_P =$
- $A_P = -2$ B ; $A_P =$
- $A_P = -3$ B ; $A_P =$

file 00675

Question 61

Manipulate this equation algebraically, so that we can convert power gains expressed in units of Bels, into ratios.

$$A_{P(ratio)} = 10^{A_{P(Bels)}}$$

Then, convert the following power gains, expressed as ratios, into units of Bels:

- $A_P = 250$; $A_P =$
- $A_P = 1275$; $A_P =$
- $A_P = 10$; $A_P =$
- $A_P = 1$; $A_P =$
- $A_P = 0.1$; $A_P =$
- $A_P = 0.025$; $A_P =$
- $A_P = 0.00009$; $A_P =$

file 00676

Question 62

Convert the following amplifier gains (either power, voltage, or current gain ratios) into gains expressed in the unit of decibels (dB):

- $A_P = 25$; $A_{P(dB)} =$
- $A_V = 10$; $A_{V(dB)} =$
- $A_I = 37$; $A_{I(dB)} =$
- $A_P = 150$; $A_{P(dB)} =$
- $A_I = 41$; $A_{I(dB)} =$
- $A_V = 3.4$; $A_{V(dB)} =$
- $A_P = 18$; $A_{P(dB)} =$
- $A_V = 100$; $A_{V(dB)} =$

file 02447

Question 63

Convert the following amplifier gains expressed in the unit of decibels (dB), to gain figures expressed as unitless ratios:

- $A_P = 5$ dB ; $A_{P(ratio)} =$
- $A_V = 23$ dB ; $A_{V(ratio)} =$
- $A_I = 20$ dB ; $A_{I(ratio)} =$
- $A_P = 2.5$ dB ; $A_{P(ratio)} =$
- $A_I = 7.4$ dB ; $A_{I(ratio)} =$
- $A_V = 45$ dB ; $A_{V(ratio)} =$
- $A_P = 12.8$ dB ; $A_{P(ratio)} =$
- $A_V = 30$ dB ; $A_{V(ratio)} =$

file 02448

Question 64

Identify each of these filter types, and explain *how* you were able to positively identify their behaviors:

file 02098

53
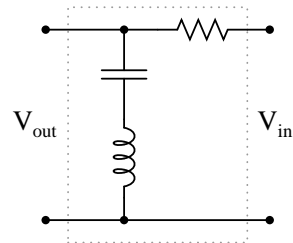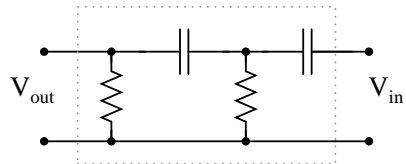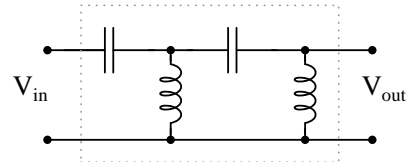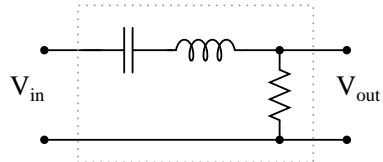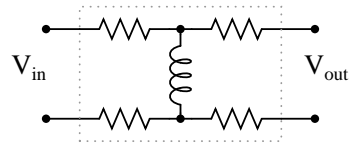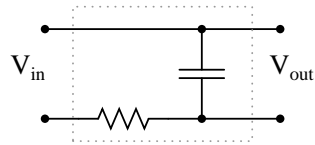
Question 65

Identify the following filter types, and be prepared to explain your answers:
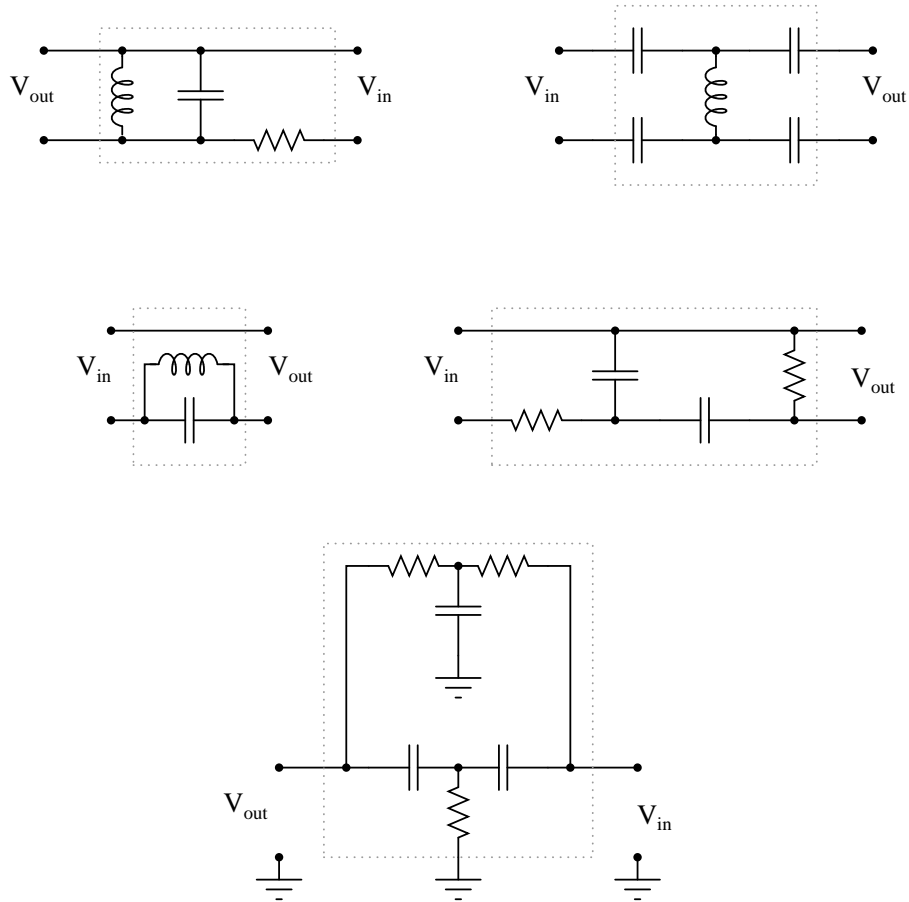
file 00620

Question 66

Identify what type of filter this circuit is, and calculate its cutoff frequency given a resistor value of 1 kΩ and a capacitor value of 0.22 μF:
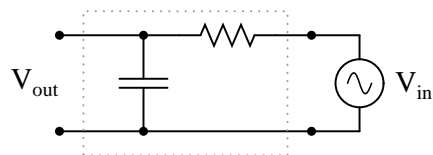
Calculate the impedance of both the resistor and the capacitor at this frequency. What do you notice about these two impedance values?

file 00617

Question 67

Identify what type of filter this circuit is, and calculate its cutoff frequency:
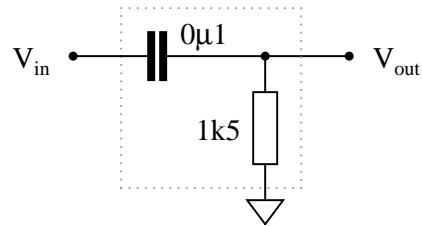
Question 68

Identify what type of filter this circuit is, and calculate its cutoff frequency:
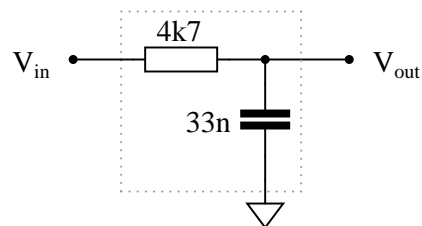
Question 69

Calculate the voltage output by the secondary winding of a transformer if the primary voltage is 35 volts, the secondary winding has 4500 turns, and the primary winding has 355 turns.

$V_{secondary} =$

Question 70

Calculate the load current and load voltage in this transformer circuit:
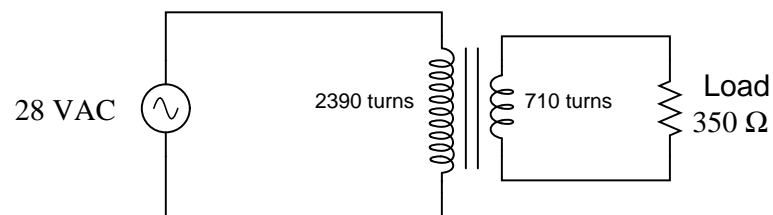
$I_{load} =$ $\qquad$ $V_{load} =$

Question 71

Calculate the number of turns needed in the secondary winding of a transformer to transform a primary voltage of 300 volts down to a secondary voltage of 180 volts, if the primary winding has 1150 turns of wire.

$N_{secondary} =$

file 02215

Question 72

Calculate all voltage drops and currents in this circuit, complete with arrows for current direction and polarity markings for voltage polarity. Then, calculate the overall voltage gain of this amplifier circuit (A_V), both as a ratio and as a figure in units of decibels (dB):
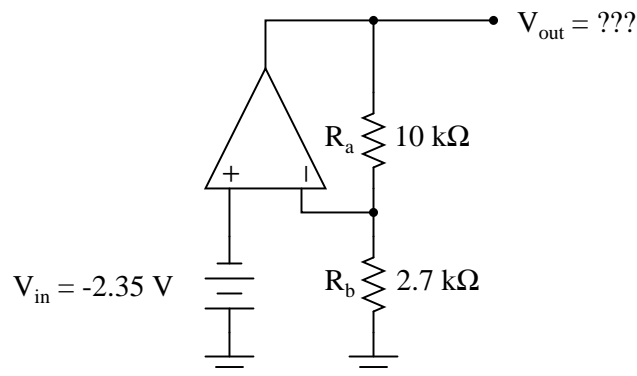
file 02460

Question 73

Determine all current magnitudes and directions, as well as voltage drops, in this circuit:
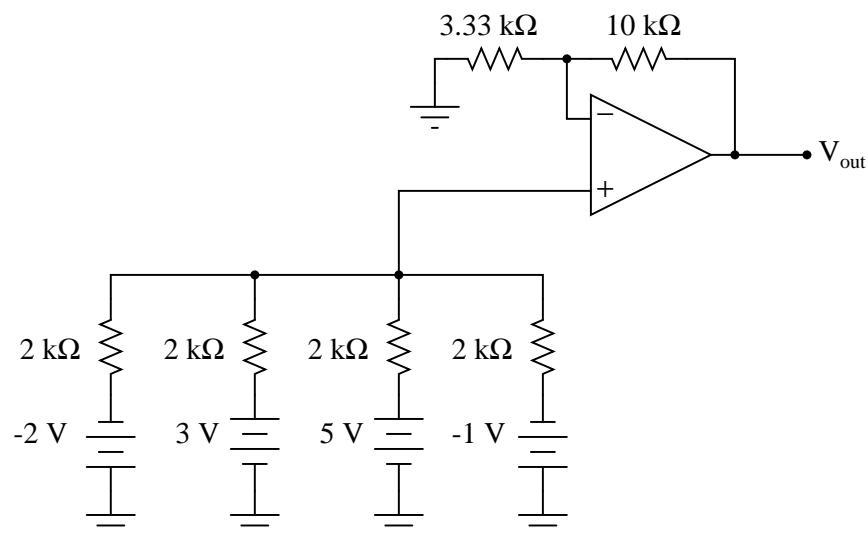
file 02523

Question 74

Calculate the necessary resistor value (R_1) in this circuit to give it a voltage gain of 10.5:
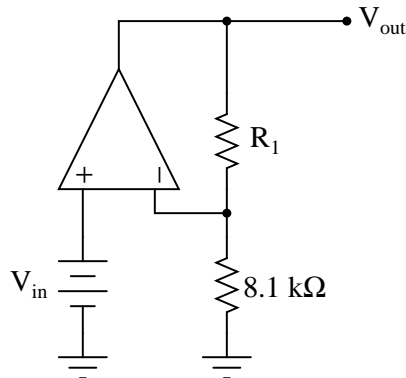
Question 75

Approximate the voltage gains of this *active filter* circuit at $f = 0$ and $f = \infty$ (assume ideal op-amp behavior):
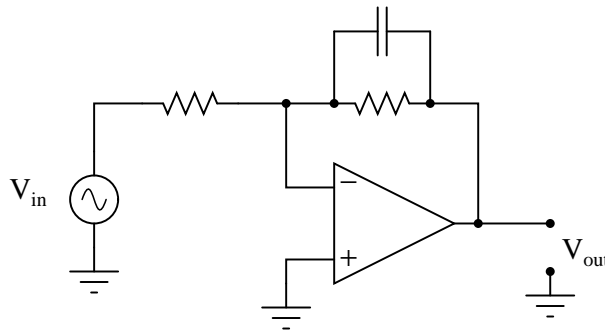
Approximate the voltage gains of this other "active filter" circuit at $f = 0$ and $f = \infty$ (assume ideal op-amp behavior):
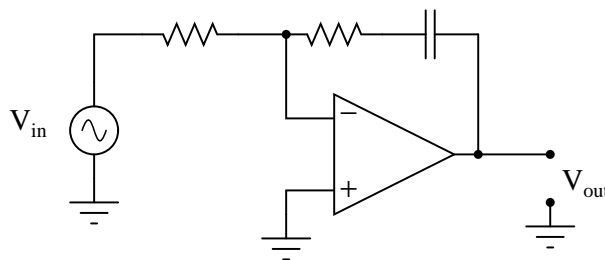
What type of filtering function (low pass, high pass, band pass, band stop) is provided by both these filter circuits? Comparing these two circuit designs, which one do you think is more practical? Explain your answer.

Question 76

A very popular active filter topology is called the *Sallen-Key*. Two examples of Sallen-Key active filter circuits are shown here:
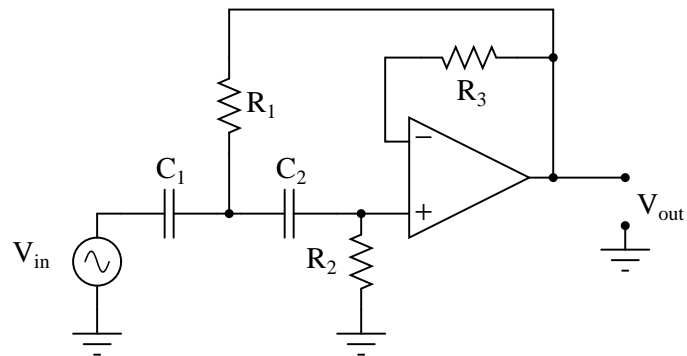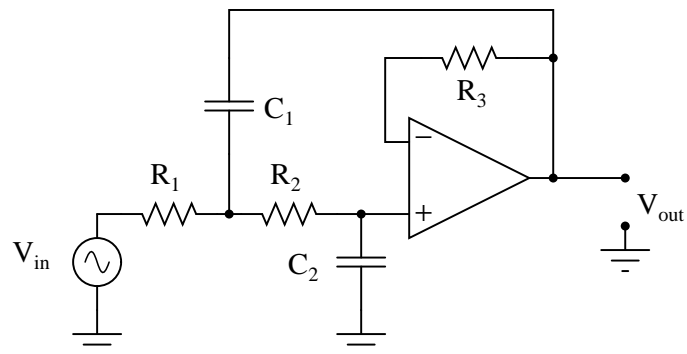
Determine which of these Sallen-Key filters is low pass, and which is high pass. Explain your answers.
file 00765

Question 77

Design a circuit to convert four-bit binary to four-bit Gray code. Hint: it uses Exclusive-OR gates.
file 01410

Question 78

Design a circuit to convert four-bit Gray code to four-bit binary. Hint: it uses Exclusive-OR gates.
file 01411

Question 79

Multiplexers, or data selectors, may be used to generate arbitrary truth table functions. Take for example this truth table, shown beside a symbol for a 16-channel multiplexer:

D	C	B	A	Out
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	1
1	1	0	0	1
1	1	0	1	0
1	1	1	0	0
1	1	1	1	1
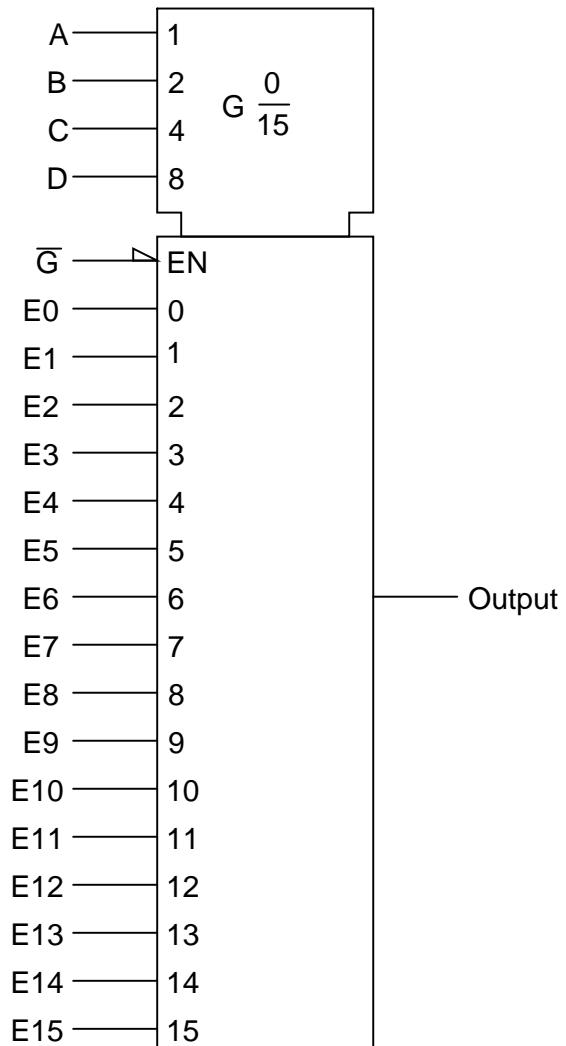
Show the wire connections necessary to make the multiplexer output the specified logic states in response to the data select (A, B, C, and D) inputs.

file 01476

Question 80

The truth table shown here is for a 4-line to 16-line *binary decoder* circuit:

D	C	B	A	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

For each of the sixteen output lines, there is a Boolean SOP expression describing its function. Just for example, write the Boolean expressions for output lines 2, 11, and 14.

file 04054

Question 81

Liquid crystal display (LCD) technology used to have very narrow viewing angles. Anyone who remembers the first LCD displays on portable personal computers will recall how you could only see the display if you viewed it perpendicular to the display surface, or at a very slight angle from perpendicular.

Modern LCD technology is much better, is still not as good as viewing printed paper, the "gold standard" for non-emissive display. One term frequently used to describe the quality of viewing with regard to angle is *Lambertian*. Define what "Lambertian" means with regard to display surfaces.

file 03038

Question 82

One method of driving pixels in a grid-based display is to organize the pixels into rows and columns, then select individual pixels for illumination by the intersection of a specific row line and a specific column line. In this example, we are controlling an 8 × 8 grid of LEDs with two 8-bit (1-byte) ports of a microcontroller:
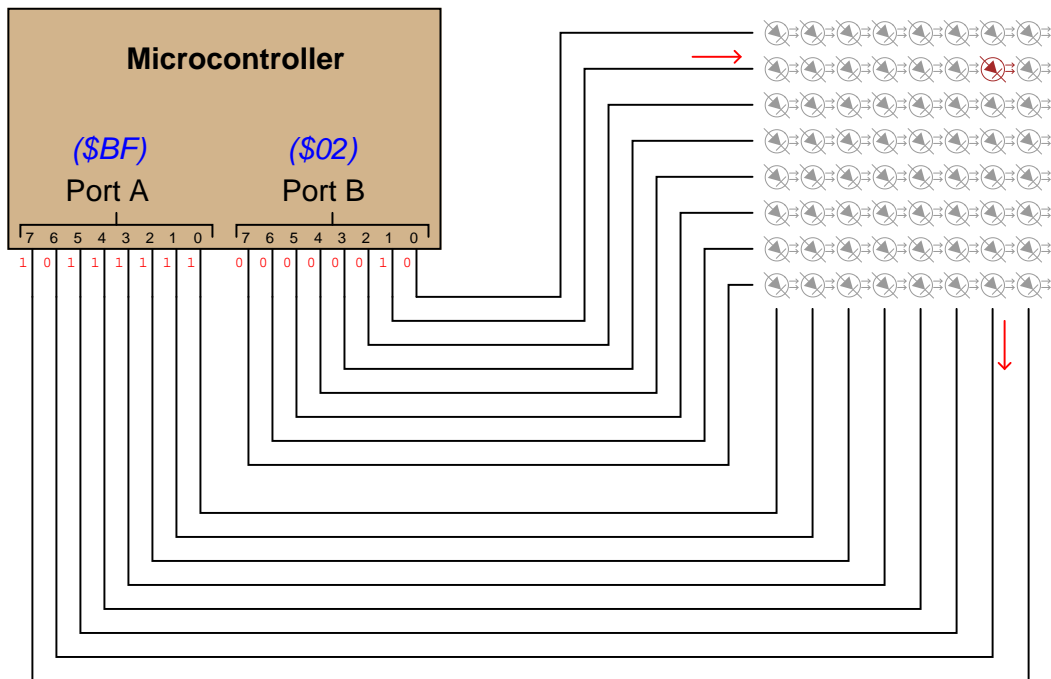
Note that a *high* state is required on one of port B's pins to activate a row, and a *low* state is required on one of port A's pins to activate a column, because the LED anodes connect to port A and the LED cathodes connect to port B.

Determine the hexadecimal codes we would need to output at ports A and B to energize the LED in the far lower-left corner of the 8 × 8 grid.

Port A =

Port B =

file 04053

Answers

To *encode* something is to convert an unambiguous piece of information into a form of code that is not so clearly understood. To *decode* is to perform the reverse operation: translating a code back into an unambiguous form.

Answer 2

This encoder generates a three-bit binary code corresponding to the switch position (one out of eight positions).

Follow-up question: trace the path of electron flow through the circuit with the switch in position #3.

Challenge question: are there other codes (besides binary) that could possibly be generated with a circuit of this general design?

Answer 3

I'll answer this question with another question: what if *two* failures occur on this machine at the same time?

Answer 4

I'll let you figure out the details of how this circuit functions, but I will tell you that D is the MSB.

Follow-up question: what would have to be modified in order to turn this into a hexadecimal-to-binary (16 line to 4 line) encoder? Would any additional OR gates have to be added to the circuit?

Answer 5

To encode the number 7, you would have to make the I_7 line low (connect it to ground). This would make the outputs assume the following states:

- $Y_0 = \text{low}$
- $Y_1 = \text{low}$
- $Y_2 = \text{low}$
- $Y_3 = \text{high}$

Answer 6

A *priority* encoder encodes only the highest-order active input, even if multiple inputs are activated.

Answer 7

I won't directly answer this question, but instead pose a "thought experiment." Suppose the analog input voltage (V_{in}) were slowly increased from 0 volts to the reference voltage (V_{ref}). What do the outputs of the comparators do, one at a time, as the analog input voltage increases? What input conditions does the encoder see? How would a primitive "diode network" type of encoder (which we know does *not* encode based on priority) interpret the comparator outputs?

Answer 8

Output line 5: $A\overline{B}C\overline{D}$
Output line 8: $\overline{A}\,\overline{B}\,\overline{C}D$
Output line 13: $A\overline{B}CD$

Follow-up question: based on what you see here, what kind of logic gate circuitry is a decoder such as this comprised of? You don't have to actually draw a schematic diagram, but just generally describe the circuitry necessary to implement sixteen different SOP expressions.

Answer 9

(Solenoid drive circuitry not shown):
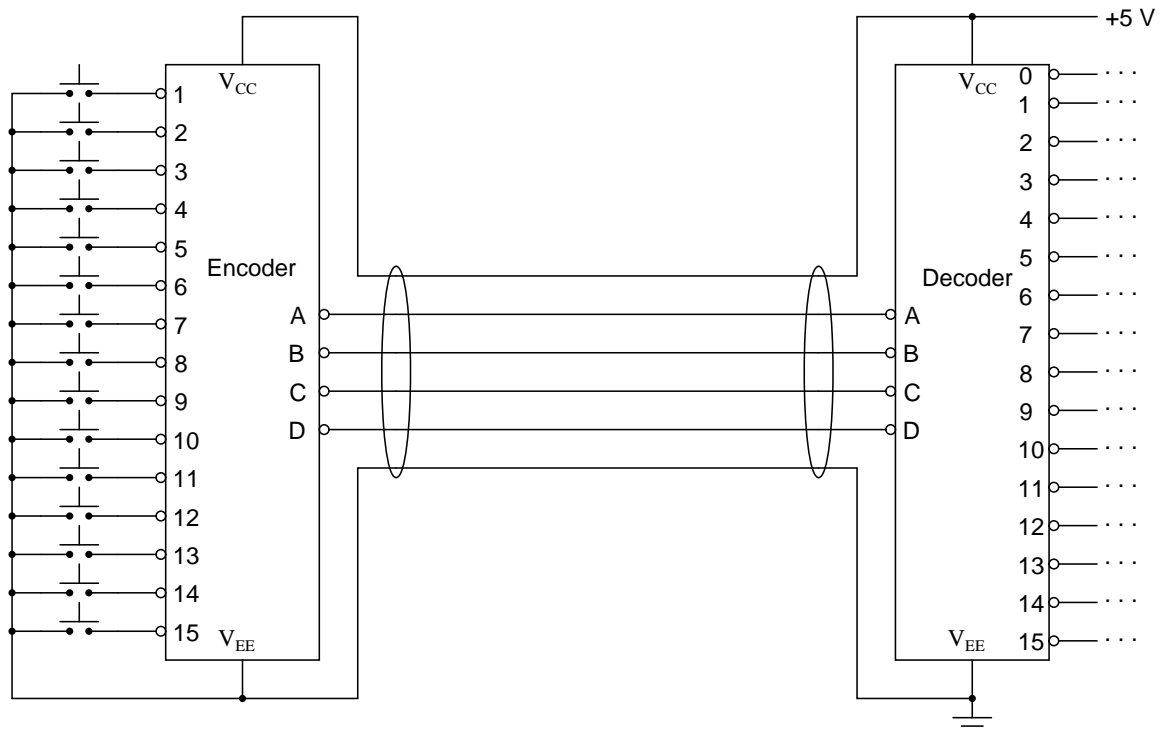
Follow-up question: can you think of any disadvantages to this crane control strategy, compared to using a thicker cable where each pushbutton has its own dedicated conductor?

Challenge question: my choice of active-low inputs and outputs was not arbitrary. Explain why.

Answer 10

The "wedge" symbols represent complementation in the IEEE/ANSI digital schematic convention, similar to "bubbles" placed near outputs or inputs of traditional logic gate symbols. Similarly, the ampersand character represents the AND function.

Perhaps the best way to determine what the $\overline{G1}$ and $\overline{G2}$ inputs do is to examine the truth table given in the datasheet for this integrated circuit.

Answer 11

At 1 Hz, a half-second of each conversation would be missing, every second. The result would be a very "choppy" stream of audio reaching each listener.

At 10 Hz, the "choppiness" would be reduced, with only 1/20 of a second's worth of conversation missing every 1/10 of a second from each conversation. It would still be very difficult to listen to, though.

At 40 kHz switching speed, both conversations would sound seamless.

Follow-up question: how can we multiplex more than two conversations along the same pair of telephone wires?

Challenge question: is there a limit as to how many conversations we can multiplex on the same wire pair? If so, what parameters would define this limit?

Answer 12

Chop is used to display two waveforms when the timebase is set to a slow (low-frequency) setting. *Alternate* is used to display two waveforms when the timebase is set to a fast (high-frequency) setting.

Answer 13

This "mystery device" is a 2-line to 4-line binary *decoder*.

Answer 14

I'll let you research the answer to this question on your own!

Answer 15

Did you really think I would just show you the pinout here, instead of having you consult a datasheet? This is a discrete-signal device, only. It cannot "select" analog signals such as those involved in telephony.

Challenge question: how could you build an analog signal multiplexer, using components you are familiar with? I recommend you start with something simple, such as a four-channel multiplexer, before attempting something with as many channels as the digital device shown here (74HC150).

Answer 16
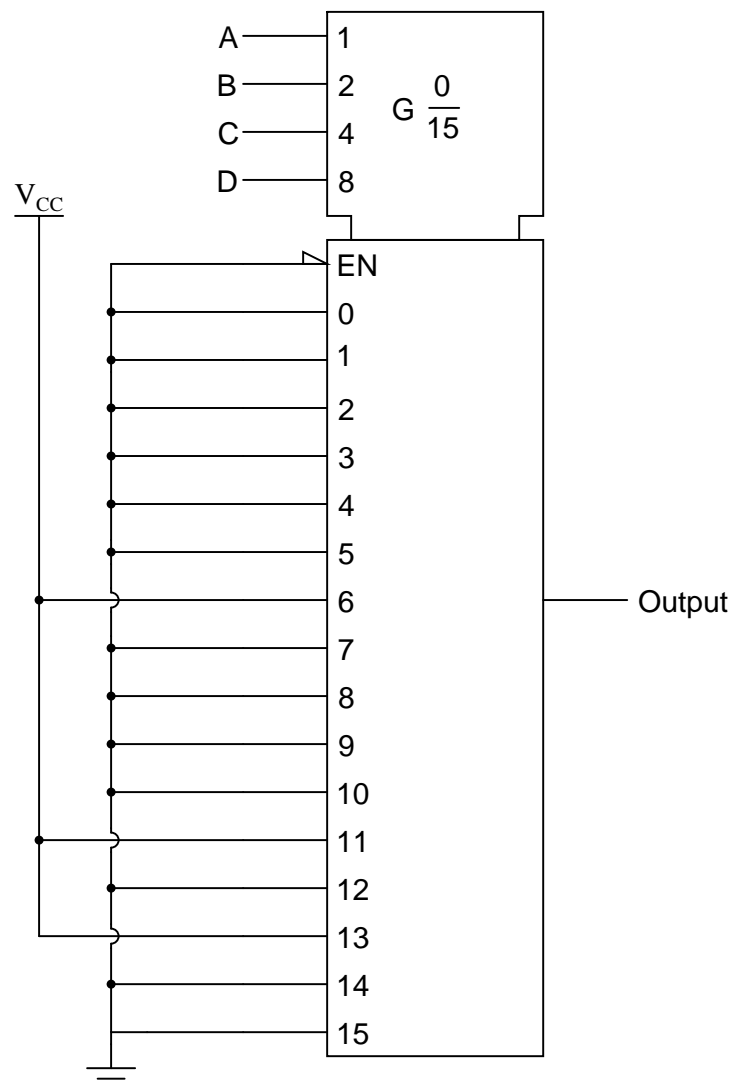
Answer 17

In the first scenario with the enable lines grounded, output #11 will be low, with all other outputs high. In the second scenario with a square wave signal input to the enable lines, output #11 will pulse while all other outputs remain in the high state.

Answer 18

Use the enable terminals (together) as one "input" terminal.

Answer 19

I'll let you figure out the answers to this question. The manufacturers' datasheet, of course, is probably your best source of information!

Follow-up question: what is the functional difference between the 74HC137 and the 74HC237? How would the respective schematic symbols for these two decoder/demux ICs differ?

Challenge question: think of a practical application where you might need the feature of address latching.

Answer 20

I'll let you figure out the first part of the answer (four succinct definitions, complete with illustrations)! Because it is so easy to get these four functions mixed up in your mind, it is important that you arrive at your own understanding of which is which, rather than have someone else (like me) provide ready-made definitions for you to memorize.

Decoding and *demultiplexing* are usually performed by the same integrated circuit device. A good example of this is the 74HC154.

Answer 21

Seven-segment displays are a very common numerical interface for digital electronic equipment:
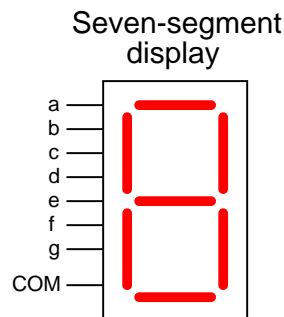
A special decoder circuit is needed to translate 4-bit BCD codes into the particular combinations of segment activations that represent decimal digits.

Follow-up question: what does the internal schematic of a typical seven-segment display look like? Is there just one type, or are there different types of seven-segment displays?

Answer 22

Raw (unsimplified) expressions:

$$a = (D + C + B + \overline{A})(D + \overline{C} + B + A)$$

$$b = (D + \overline{C} + B + \overline{A})(D + \overline{C} + \overline{B} + A)$$

$$c = D + C + \overline{B} + A$$

$$e = \overline{D}\,\overline{C}\,\overline{B}\,\overline{A} + \overline{D}\,\overline{C}B\overline{A} + \overline{D}CB\overline{A} + D\overline{C}\,\overline{B}\,\overline{A}$$

Challenge question: use the laws of Boolean algebra to simplify each of the above expressions into their simplest forms.

Answer 23

Karnaugh map groupings with strict "1" groups:

$$\overline{D}B + \overline{D}CA + D\overline{C}\,\overline{B} + \overline{C}\,\overline{B}\,\overline{A}$$

Karnaugh map groupings with "don't care" wildcards:

$$D + B + CA + \overline{C}\,\overline{A}$$

Follow-up question: this question and answer merely focused on the a output for the BCD-to-7-segment decoder circuit. Imagine if we were to approach all seven outputs of the decoder circuit in these two fashions, first developing SOP expressions using strict groupings of "1" outputs, and then using "don't care" wildcards. Which of these two approaches do you suppose would yield the simplest gate circuitry overall? What impact would the two different solutions have on the decoder circuit's behavior for the six unspecified input combinations 1010, 1011, 1100, 1101, 1110, and 1111?

Answer 24

I'll let you figure out these details by researching the datasheet yourself!

Follow-up question: what features differentiate the 7447 decoder/driver IC from the 7448 or 7449? How about the 74247, 74248, and 74249 decoder/driver circuits? Be prepared to show your sources when answering this question in class.

Answer 25

Closing the switch makes the LCD opaque; opening the switch makes the LCD transparent.

Answer 26

"Ripple blanking" is used in multi-digit displays to force leading or trailing zeroes to the off state.

Answer 27

MCU/MPU steps:

1. Select digit number 1
2. Output BCD code for digit number 1
3. Pause for very brief (milliseconds) amount of time
4. Select digit number 2
5. Output BCD code for digit number 2
6. Pause for very brief (milliseconds) amount of time
7. Select digit number 3
8. Output BCD code for digit number 3
9. Pause for very brief (milliseconds) amount of time
10. Repeat cycle

Follow-up question: what would have to be changed in this circuit to use common-cathode LED 7-segment displays instead of common-anode displays?

Answer 28

Port A = $5B_{16}$ Port B = 66_{16}

Note that the following answers are also valid:
Port A = DB_{16} Port B = $E6_{16}$

Follow-up question: write these same numerical values in decimal rather than hexadecimal.

Answer 29

If it were not for the serial input, this IC would have quite a few more pins! The timing diagram and description in the datasheet should provide plenty of information for determining how to send data to the display using this IC.

Answer 30

An "organic" LED is one made from organic (carbon-containing) molecules instead of crystalline silicon, gallium arsenide, or other more traditional semiconductor substances. One distinct advantage of these devices is their ease of manufacture, but I'll let you research exactly why (as well as other advantages of these devices).

Answer 31

- ASIC: *Application-Specific Integrated Circuit*
- PAL: *Programmable Array Logic*
- PLA: *Programmable Logic Array*
- PLD: *Programmable Logic Device*
- CPLD: *Complex Programmable Logic Device*
- FPGA: *Field-Programmable Gate Array*

Follow-up question: now, comment on what each of these acronyms actually means, going beyond a mere recitation of the definition.

Answer 32

I'll let you do the research on this one!

Answer 33

A *look-up table* is a set of data programmed into a memory device, used to map a function of some kind: for each unique input (address), there is an output (data) that means something to the system in which it is installed.

An example of a look-up table is an EBCDIC-to-ASCII code converter, where an EBCDIC code input to the address lines of a ROM chip "looks up" the equivalent ASCII character value from memory, and outputs it as the result through the ROM chip's data lines.

Answer 34

Here's a clue: the truth table would only have sixteen rows with a "1" output. All other rows will be programmed with "0" outputs!

Answer 35

Unlike microcontrollers, programmable logic devices are not (necessarily) sequential devices: the latter act as a collection of logic gates and other "primitive" logic elements to directly implement certain logic functions.

Answer 36

With a sufficient number of AND, OR, and inverter gates, any SOP or POS expression may be generated.

Answer 37

Certainly, the stored program will be nonvolatile, but it will also be read-only. This is why fuse-programmed devices are sometimes called "OTP". (I'll let you research what that acronym means.)

Answer 38

A macrocell is a collection of logic gates and a flip-flop, lumped together in one unit. PLDs usually have many macrocells, which may be interconnected to form a variety of synchronous logic functions.

Answer 39

The secret is in the programming: programmable logic devices are literally "wired" by the programs you write for them, with thousands of logic elements available to be connected in almost any way you desire. Microprocessors, on the other hand, have fixed wiring that responds to sequences of steps, the program merely specifying those sequence of those steps.

Answer 40

A hardware description language (HDL) is a textual convention for specifying the interconnections of a programmable logic device. Text files are written by a human programmer, then "compiled" into a form that the programmable logic device can directly accept and use.

Answer 41

Use circuit simulation software to verify your predicted and actual truth tables.

Answer 42

Use circuit simulation software to verify your predicted and actual truth tables.

Answer 43

Use circuit simulation software to verify your predicted and actual truth tables.

Answer 44

Use circuit simulation software to verify your predicted and measured parameter values.
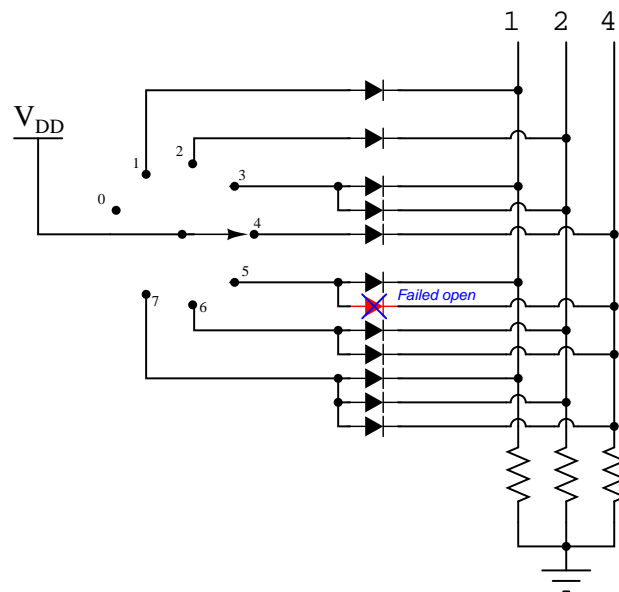
Answer 45

I do not provide a grading rubric here, but elsewhere.
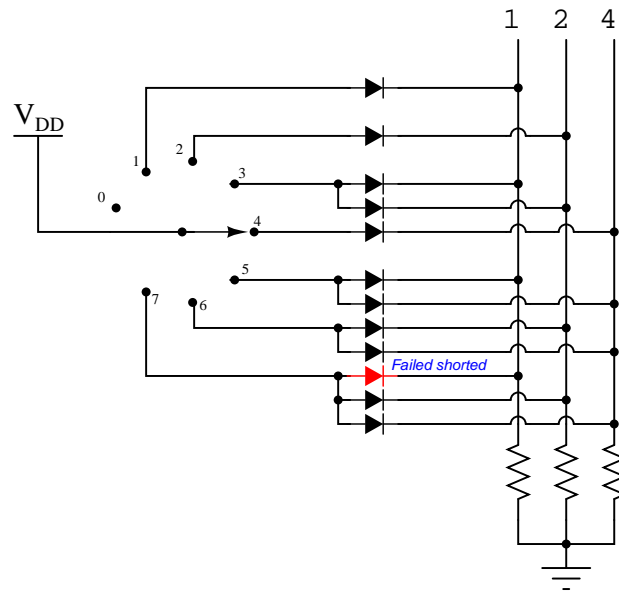
Answer 46

Be sure to document all steps taken and conclusions made in your troubleshooting!

Answer 47

Answer 48

Answer 49
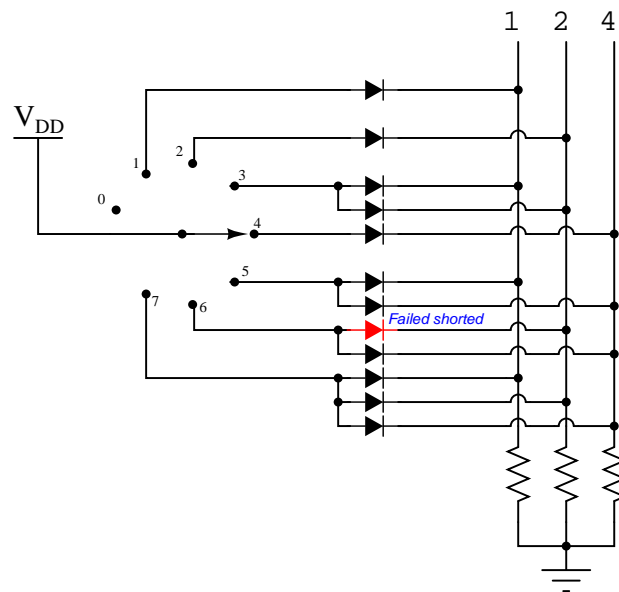
Answer 50

The following output codes would be adversely affected by this fault: 1, 4, 5, 8, and 9.

Answer 51

- Resistor R_{16} fails open: *Output code will be 15 (*1111*) all the time.*

- Resistor R_1 fails open: *If $V_{in} < V_{ref}$, output will be 0 (*0000*); if $V_{in} > V_{ref}$, output will be 15 (*1111*).*

- Comparator U_{13} output fails low: *Output will assume the "13" state (*1101*) unless V_{in} exceeds that analog value, then the ADC will register properly.*

- Solder bridge (short) across resistor R_{14}: *There will be no distinctive "13" state (*1101*), the analog values for all the other states adjusting slightly to fill the gap.*

Answer 52

One possible fault is that resistor R_{16} has failed open, but this is not the only possibility.

Answer 53

If one of the bilateral switches were to fail shorted, it would skew all the arbitrary waveform voltages "toward" the one with the failed switch, distorting the waveform from its original shape.

Answer 54

- Clock pulse generator stops pulsing: *Only one channel out of the eight will work, and it works all the time without interruption. Data cannot get through any of the other seven channels.*

- Pin breaks on the W output of 74151 chip, leaving that wire floating: *All selected outputs on the 74138 chip go low, instead of repeating the respective logic states input at the 74151 chip.*

- Pin breaks on G2A input of 74138 chip, leaving it floating: *All outputs on the 74138 chip go high, all the time.*

- Enable pin breaks on 74151 chip, leaving it floating: *All selected outputs on the 74138 chip go low, instead of repeating the respective logic states input at the 74151 chip.*

Answer 55

Neither the 7447 nor the 7448 are designed to *source* current to the LED segments, only *sink* current. I'll let you figure out why the 7448 chip has the ability to make any of the LED segments light up at all.

Follow-up question: trace the direction of electron flow through the wires between the decoder chip and the display.

Answer 56

The transistor is not correct. Your friend will have to have a different transistor output stage for his display circuit!

Follow-up question: comment on your friends' strategy to connect only one transistor to one Nixie tube cathode for a test. Was this a good idea? Why or why not? Did doing this save the 7442 from further damage?

Answer 57

$V_{R1} = 9$ V
$R_1 = 20$ kΩ

Follow-up question: what do you notice about the four resistors' values in this condition where $V_{AB} = 0$? Pair up these four resistors into two sets of two pairs, and calculate the ratios of those pairs. What do you notice about these ratios?

Answer 58

If the two thermistors are at equal temperature, the voltmeter should register 0 volts. To get the voltmeter to register negative, the left-hand thermistor would have to be warmer than the right-hand thermistor.

Answer 59

- Resistor R_1 failed open *Not possible*
- Resistor R_1 failed shorted *Possible*
- Resistor R_2 failed open *Possible*
- Resistor R_2 failed shorted *Not possible*
- Strain gauge (measurement) failed open *Possible*
- Strain gauge (measurement) failed shorted *Not possible*
- "Dummy" gauge (temperature compensation) failed open *Not possible*
- "Dummy" gauge (temperature compensation) failed shorted *Possible*
- Voltage source is dead (no voltage output at all) *Not possible*

Follow-up question: identify possible *wire* or *connection* failures in this circuit which could cause the same symptom to manifest.

Answer 60

- $A_P = 3$ B ; $A_P = 1000$
- $A_P = 2$ B ; $A_P = 100$
- $A_P = 1$ B ; $A_P = 10$
- $A_P = 0$ B ; $A_P = 1$
- $A_P = -1$ B ; $A_P = \frac{1}{10}$
- $A_P = -2$ B ; $A_P = \frac{1}{100}$
- $A_P = -3$ B ; $A_P = \frac{1}{1000}$

Follow-up question: a geologist, taking a class on electronics, sees this mathematical pattern and remarks, "This is just like the *Richter* scale!" Explain what the geologist means.

Answer 61

$$A_{P(Bels)} = \log A_{P(ratio)}$$

- $A_P = 250$; $A_P = 2.398$ B
- $A_P = 1275$; $A_P = 3.106$ B
- $A_P = 10$; $A_P = 1$ B
- $A_P = 1$; $A_P = 0$ B
- $A_P = 0.1$; $A_P = -1$ B
- $A_P = 0.025$; $A_P = -1.602$ B
- $A_P = 0.00009$; $A_P = -4.046$ B

Answer 62

- $A_P = 25$; $A_{P(dB)} = 13.98$ dB
- $A_V = 10$; $A_{V(dB)} = 20$ dB
- $A_I = 37$; $A_{I(dB)} = 31.36$ dB
- $A_P = 150$; $A_{P(dB)} = 21.76$ dB
- $A_I = 41$; $A_{I(dB)} = 32.26$ dB
- $A_V = 3.4$; $A_{V(dB)} = 10.63$ dB
- $A_P = 18$; $A_{P(dB)} = 12.55$ dB
- $A_V = 100$; $A_{V(dB)} = 40$ dB

Answer 63

- $A_P = 5$ dB ; $A_{P(ratio)} = 3.16$
- $A_V = 23$ dB ; $A_{V(ratio)} = 14.13$
- $A_I = 20$ dB ; $A_{I(ratio)} = 10$
- $A_P = 2.5$ dB ; $A_{P(ratio)} = 1.78$
- $A_I = 7.4$ dB ; $A_{I(ratio)} = 2.34$
- $A_V = 45$ dB ; $A_{V(ratio)} = 177.8$
- $A_P = 12.8$ dB ; $A_{P(ratio)} = 19.05$
- $A_V = 30$ dB ; $A_{V(ratio)} = 31.62$

Answer 64
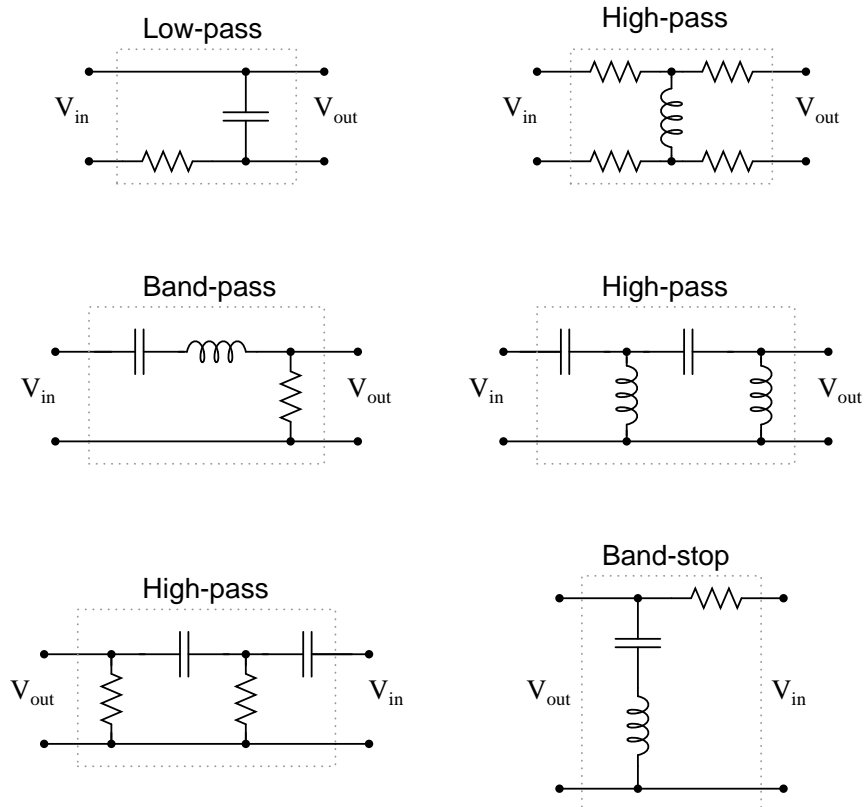
Follow-up question: in each of the circuits shown, identify at least one *single* component failure that has the ability to prevent any signal voltage from reaching the output terminals.

Answer 65
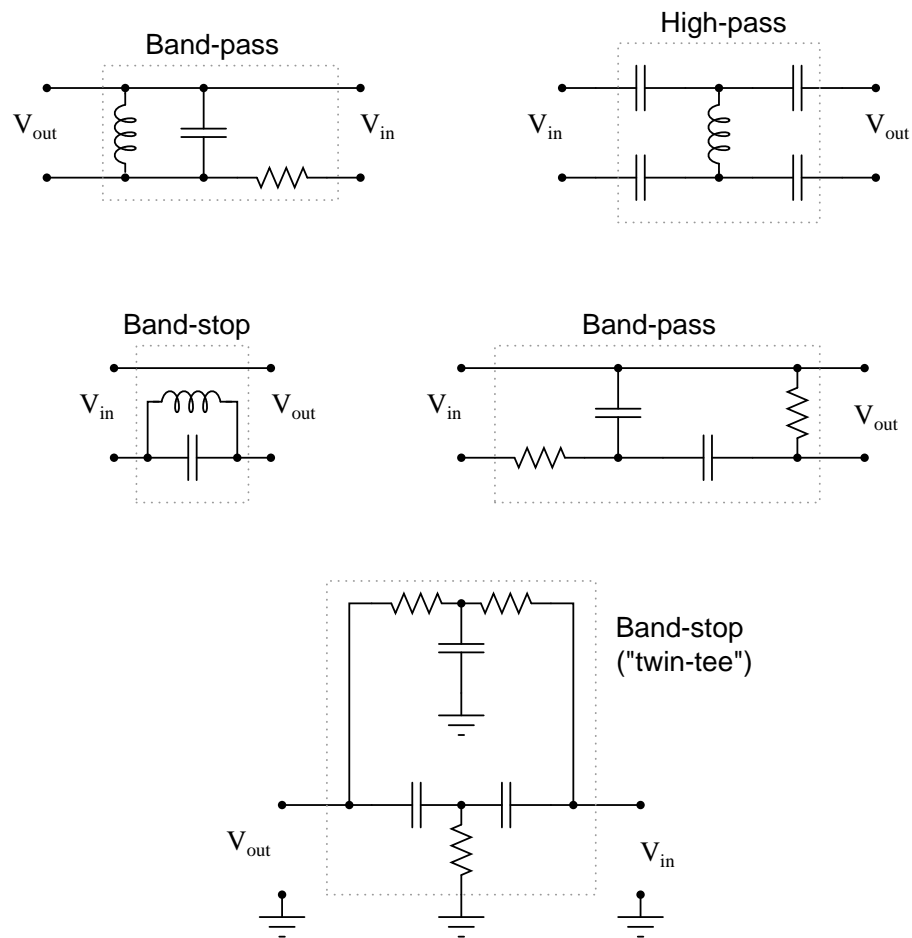
Answer 66

This is a *low-pass* filter.

$f_{cutoff} = 723.4$ Hz

Answer 67

This is a *high-pass* filter.

$f_{cutoff} = 1.061$ kHz

Answer 68

This is a *low-pass* filter.

$f_{cutoff} = 1.026$ kHz

Answer 69

$V_{secondary} = 443.7$ volts

Answer 70

$I_{load} = 23.77$ mA $V_{load} = 8.318$ V

Answer 71

$N_{secondary} = 690$ turns

Answer 72

Current arrows drawn in the direction of conventional flow

$V_{out} = -11.054$ V

$V_{Ra} = 8.704$ V
10 kΩ

$I_{Ra} = I_{Rb} = 870.4$ μA

$V_{in} = -2.35$ V

2.7 kΩ
$V_{Rb} = 2.35$ V
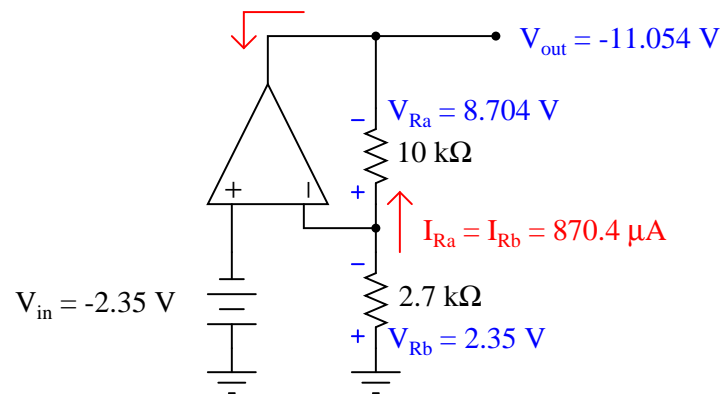
$A_V = 4.704 = 13.449$ dB

Follow-up question: how much input impedance does the -2.35 volt source "see" as it drives this amplifier circuit?

Answer 73

Conventional flow notation
used for all current arrows
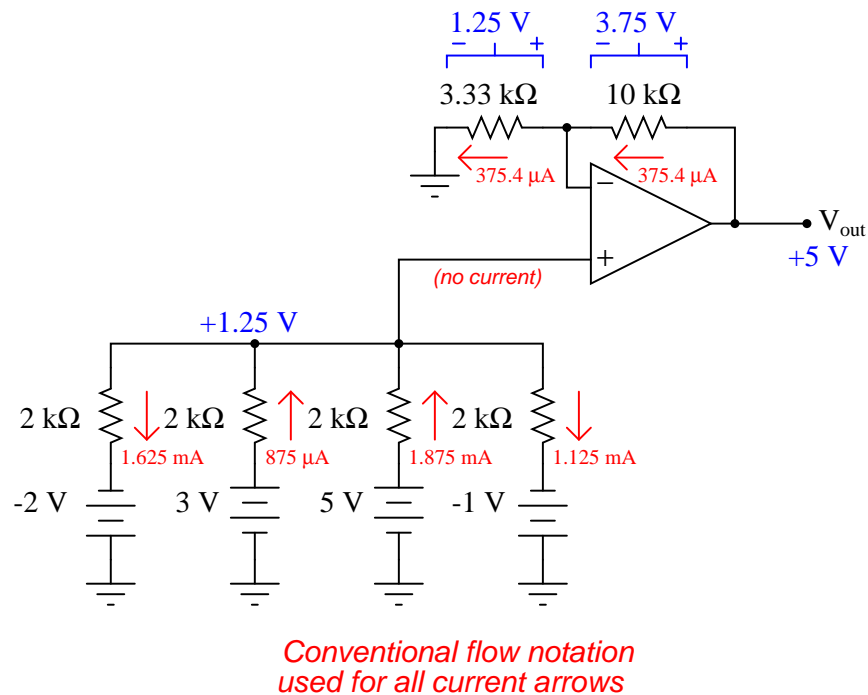
Follow-up question: what would be required to get this circuit to output the *exact* sum of the four input voltages?

Answer 74

$R_1 = 76.95$ kΩ

Answer 75

These are both low pass filters. The circuit with the shunt capacitor is the more practical one, because its voltage gain remains finite for all possible input signal frequencies:
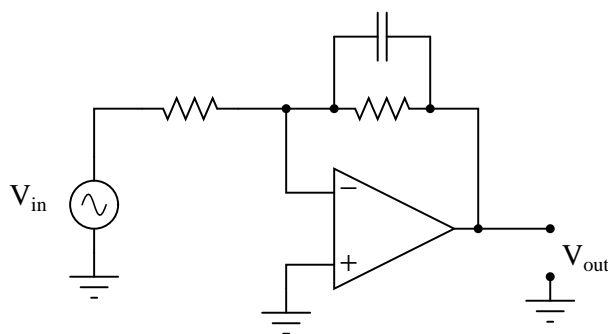
Answer 76

The first filter shown is low pass, while the second filter shown is high pass.

Challenge question: what is the purpose of resistor R_3 in each circuit?

Answer 77

Binary input

MSB — LSB

MSB — LSB

Gray code output

Answer 78

Gray code input

MSB — LSB

MSB — LSB

Binary output
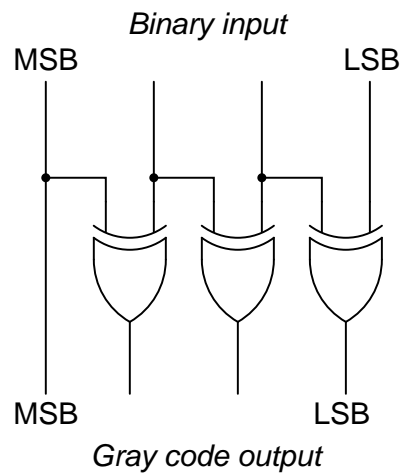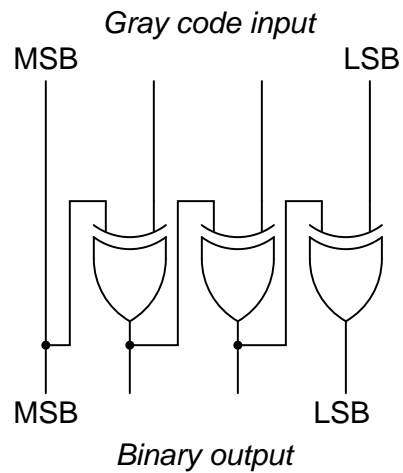
Challenge question: this circuit is not as suited to high-speed conversion as a binary-to-Gray converter, even though it uses the same quantity and same type of logic gate. Explain why problems may arise if this circuit is forced to convert Gray code inputs that are changing rapidly (for instance, translating the output of a Gray-code rotary encoder into binary, when the mechanical encoder is rotating at a very high speed).
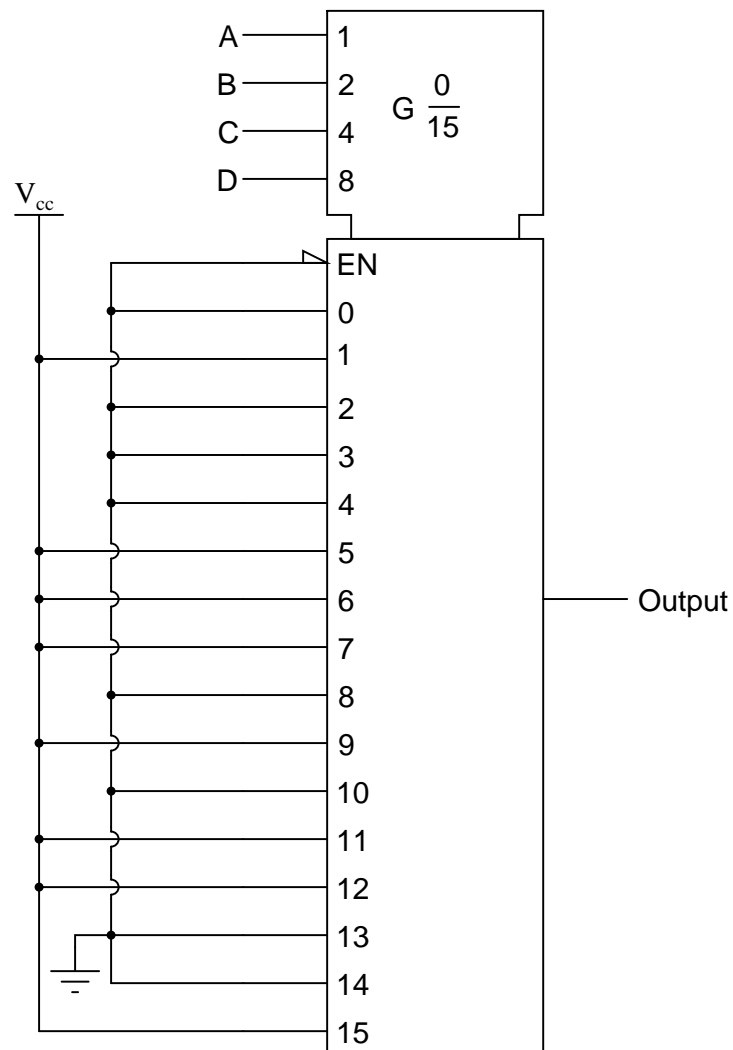
Answer 79

Follow-up question: what if this multiplexer had an active-low output, like the 74150? How would this change your design for implementing the truth table?

Answer 80

Output line 2: $\overline{A}B\overline{C}\,\overline{D}$
Output line 11: $AB\overline{C}D$
Output line 14: $\overline{A}BCD$

Follow-up question: based on what you see here, what kind of logic gate circuitry is a decoder such as this comprised of? You don't have to actually draw a schematic diagram, but just generally describe the circuitry necessary to implement sixteen different SOP expressions.

Answer 81

A "Lambertian" surface emits (or reflects) light with an intensity proportional to the cosine of the viewing angle (relative to perpendicular). Paper is Lambertian in its reflective characteristics, which is one of the reasons it is so easy to read compared to contemporary digital display technologies.

Answer 82

Port A = $FE

Port B = $80

Notes

Notes 1

This question gets students thinking about encoding and decoding in general terms – terms which they are probably already familiar with. This is a good first step in instruction, to identify a well-known context for a new subject, so students have an easier time relating to it.

Notes 2

Ask your students to explain how the term "encoder" applies to this simple circuit. What, exactly, is being encoded, and what form of code is the data being converted to?

Notes 3

Despite the overly simplistic nature of the company's product, this scenario accurately reflects the realistic nature of product development and customer application. Often, a company designs, builds, and markets a product, and the customers experience trouble because their applications are improper for that product, or the application reveals a deficiency in the product that wasn't detected during development.

As elegant as the "diode network" design of encoder is, it certainly has its limitations. Ask your students whether the output of this encoder circuit will *always* be incorrect if two inputs are simultaneously activated, or if only particular combinations of active inputs cause problems. Which condition would be easier to troubleshoot?

Discuss alternative solutions with your students, being sure to first define what the problem is so that all understand.

Notes 4

Non-priority encoder circuits such as this one are fairly simple to figure out, and so I do not provide an explanation for students in the "Answer" section.

Notes 5

This is a good review of active-low inputs, how they are drawn on schematics, and what they mean in practical digital circuits. A potentially confusing aspect of this question is the presence of active-low inputs *and* outputs, but it is well worth your time to review with students, because like it or not there are many ICs with active-low I/O lines.

Notes 6

Be sure to ask your students where and how they found their respective priority encoder datasheets.

Notes 7

Here, I show students a very practical application of a priority encoder, in which the necessity of priority encoding should be apparent after some analysis of the circuit.

Notes 8

Nothing really complex or tricky here. Just a straightforward application of Boolean SOP expressions.

Notes 9

If time permits, you might want to ask students to sketch a "typical" solenoid drive sub-circuit, interposing the decoder outputs to DC (or AC!) solenoid valve coils. Several options are possible here, each with their own merits and drawbacks.

The challenge question is a good one to discuss, even if most students were not able to answer it on their own. It is not good enough to merely have a system that works – we must also have a system that is *safe*.

Notes 10

Much may be learned from a good datasheet. This question, and others like it, prompts students to research manufacturer datasheets as a learning experience.

Note the truth table (likely) given in the datasheets your students collect. How are "irrelevant" states denoted in the truth tables? Ask your students what this means (especially with reference to the question regarding the strobe inputs).

Notes 11

Ask your students why this technique of switching conversations works. How is it possible for audio conversations to sound "seamless" when half the information is missing from each one (regardless of switching speed)?

Ask your students for answers to the challenge question. If no one has any, give them a hint: how does the *bandwidth* of the telephone lines impact multiplexing a large number of signals?

Notes 12

Don't simply tell your students how the *alternate* and *chop* facilities of their oscilloscopes work. Let them experience these two modes of multiplexing directly, with hands-on investigation. If nothing else, this will provide them with additional practice using oscilloscopes.

Notes 13

This question serves a few purposes: to introduce students to the 4066 quad bilateral switch, to showcase a practical application for analog multiplexing, and to review a previous subject (decoders).

Notes 14

This question forces students to directly face a point of confusion I have noticed over several years of teaching. Ask them where they were able to find definitions for each term.

Notes 15

Datasheets not only provide basic pinout information, but they also reveal important operational characteristics of integrated circuits. In many cases they also show typical applications, which have great educational value. Stress the importance of datasheets to your students with "look-up" exercises such as this, build their ability to interpret the information contained.

In regard to the challenge question, it is a common mistake for students to think they can build an analog signal multiplexer around a digital signal multiplexer. In actuality, they would need a completely different type of device!

Notes 16

Discuss with your students the significance of using a multiplexer in this fashion: to implement arbitrary logic functions. For those students who may not be familiar with the term, be sure to define the word "arbitrary." It may seem silly, but students often fail to ask for the definitions of words that are new to them, for fear of sounding dumb in front of their peers and in front of you. One more reason to model respect in your classroom, and also to create an atmosphere where students feel comfortable asking any question.

Notes 17

This question previews the use of a decoder as a demultiplexer.

Notes 18

Explain to your students that "decoder" and "demultiplexer" are really just two different words for the same device, seeing as how all real decoders come equipped with enable inputs.

Notes 19

The feature of address latching is not hard to understand if students have already studied D-type latches (and/or parallel-in/parallel-out shift registers).

Notes 20

Here is a good example of where students like to fall on rote memorization, and where such shallow learning strategies often fail. It is imperative that students do their own research and cast these functions into their own personal terms. This way, they will understand the differences rather than just memorize the differences.

Call on individual students to present their findings for this question, and let the classroom be a place where students share their understandings with one another. Let them know that this is important for them to grasp, but *do not* simply provide ready-made answers for them!

Notes 21

Be sure to ask your students to reveal the decoder datasheets they found. Once again, manufacturer datasheets contain a wealth of information, and your students will learn much by researching them.

Notes 22

This shows a very practical example of SOP and POS Boolean forms, and why simplification is necessary to reduce the number of required gates to a practical minimum.

Notes 23

One of the points of this question is for students to realize that bigger groups are better, in that they yield simpler SOP terms. Also, students should realize that the ability to use "don't care" states as "wildcard" placeholders in the Karnaugh map cells increases the chances of creating bigger groups.

Truth be known, I chose a pretty bad example to try to make an SOP expression from, since there are only two non-zero output conditions out of ten! Formulating a POS expression would have been easier, but that's a subject for another question!

Notes 24

Given that datasheets for this particular decoder/driver IC are easy to obtain and read, your students should have no trouble doing the research.

Notes 25

Note that I did not specify anywhere in the question or in the answer whether the application of voltage across an LCD segment darkened or lightened that segment. This is a detail I leave up to students to research!

The particular method of generating AC from DC using an XOR gate is quite clever. Essentially, we are using the XOR's ability as a controlled inverter/buffer to reverse "polarity" of the square wave signal. Be sure to have your students explain how AC is applied across the LCD in this circuit.

Notes 26

The answer I give here is purposefully vague, as usual. What I want students to do is research datasheets on their own and be able to show where they got their information.

Notes 27

Be sure to ask your students where they were able to research multiplexed 7-segment displays, and what they think about this particular technique of producing a "continuous" three-digit decimal display by flashing them very rapidly. Clever techniques such as this are often necessary to make the most of limited hardware.

By the way, I have omitted the customary LED current-limiting resistors from the schematic diagrams, for brevity's sake. See if any of your students are able to catch this omission!

Notes 28

The root of this question is little more than binary-to-hexadecimal conversion, but it also introduces students to the concept of controlling bit states in microcomputer ports by writing hex values. As such, this question is *very* practical! Although it is unlikely that someone would omit BCD-to-7-segment decoders when building a two-digit decimal display (because doing it this way uses so many more precious microcontroller I/O pins), it is certainly possible! There are many applications other than this where you need to get the microcontroller to output a certain combination of high and low states, and the fastest way to program this is to output hex values to the ports.

In case students ask, let them know that a dollar sign prefix is sometimes used to denote a hexadecimal number. Other times, the prefix 0x is used (e.g., $F3 and 0xF3 mean the same thing).

Notes 29

While this question introduces the concept of a vacuum-fluorescent (VF) display, it also serves as a review of shift register and latch technology. The block diagram should be informative enough for most students to be able to figure out at least an approximate procedure for loading and outputting data.

It is interesting to note (and discuss with your students) that this IC does not decode characters. It merely conditions and outputs bits of information to the grids of a VF display. Ask your students, then, where they think the patterns of "on" and "off" pixels must be generated to form specific characters on the display.

Notes 30

This question is destined for obsolescence, as organic LEDs will either become so popular as to lose their novelty ("new technology") or become supplanted by something even better. But for now (May 2005), they are worthy of their own question in the Socratic Electronics project!

Notes 31

There is a veritable "alphabet soup" of acronyms in the world of programmable digital logic, and these are just a few. Going into the precise meaning of each acronym may not be the best use of time in answering this question, as there is little context in which to understand the meanings. Please do not attempt to do what so many technical courses do, and that is stuff students' heads with acronym definitions to the neglect of actually *understanding* the various technologies. This question is intended only as an opening to an in-depth discussion of programmable logic, and not an end in itself!

Notes 32

Ask your students to share where they found their information on programmable devices, and how they determined the advantages and disadvantages of this technology compared to hard-wired logic.

Notes 33

The EBCDIC-to-ASCII code converter concept is not hypothetical! I actually designed and helped build such a circuit to allow standard personal computers to "talk" to an obsolete CNC machine tool control computer which didn't understand ASCII data, only EBCDIC. A look-up table implemented in a UVEPROM served as a neat way to implement this function, without a lot of complex circuitry.

Notes 34

This is an example of a *look-up table*, whereby arbitrary data programmed into a memory circuit fulfills a logic function. If time permits, discuss with your students what other sorts of useful logic functions might be programmed into a PROM chip such as this.

Notes 35

Discuss with your students how programmable logic devices are more primitive and direct devices than microcontrollers, which are more abstract by comparison. Perhaps the easiest distinction to understand is in terms of gate connections. In a microcontroller, the connections between its constituent gates are fixed; only the software (bits stored in memory) ever change. In a programmable logic device, it is as though you are directly forging connections between its constituent gates (as many or as few as needed), creating a hard-wired circuit by specifying connections in a "hardware description language" (HDL).

Notes 36

This question requires students to review the principles of how SOP and POS expressions relate to truth tables, and in doing so explain how any arbitrary truth table may be fulfilled.

Notes 37

It is interesting to mention that some programmable devices (Texas Instruments' TIBPAL series, for example) are built with a "security fuse" inside which prevents anyone from reverse-engineering a programmed chip!

Notes 38

Ask your students to show you where they found their information, and if they were able to determine how many macrocells are in a typical PLD.

Notes 39

Understanding the distinction between microcontrollers and programmable logic devices can be difficult, especially if one has limited experience with both (as most students do). The purpose of this question is to shed some more light on this often misunderstood subject, while simultaneously highlighting an important feature of programmable logic: true simultaneity.

The fundamental principle I want students to see from these analogies is that microcontrollers and microprocessors are re-programmed by changing a *sequence* of fixed operations, while programmable logic systems are re-programmed by changing *associations* between fixed elements.

Notes 40

If time permits, you may want to compare and contrast fully-featured languages such as Verilog and VHDL with more primitive hardware description languages such as ABEL. In either case, though, files written in an HDL are intended to describe the interconnections of available logic elements inside a programmable logic device.

Notes 41

It should be noted that the input states in this circuit are defined by the voltage levels, not by the contact status. In other words, a closed contact equals a "low" (0) logic state.

Here, the arrangement of the input letters D, C, B, and A is purposeful: D represents the most significant bit, while A represents the least significant bit, just like the IC datasheets typically order the input lines.

Normally, I draw LEDs in the schematic to give visual indication of output states. Here, due to the sheer number of required LEDs (16), I decided not to. However, students with access to lots of LEDs may choose to add them to their circuits, because visual indicators do make the circuit's function easier to understand.

If the decoder IC has enable inputs, the students must figure out what to do with them to make the circuit function!

Notes 42

The purpose of this exercise is for students to connect a multiplexer to fulfill an arbitrary logic function specified by the instructor, thus showing the flexibility of the technique.

Here, the arrangement of the input letters C, B, and A is purposeful: C represents the most significant bit, while A represents the least significant bit, just like the IC datasheets typically order the input lines.

Notes 43

Students are left on their own to figure out what they must do with the other inputs (lamp test, BI, RBI, etc.) to make the decoder/driver chip function properly.

Notes 44

I have purposely left the details of the schematic diagram vague, so that students must do a lot of datasheet research on their own to figure out how to make an event counter circuit. You may choose to give your students part numbers for the integrated circuits, or choose not to, depending on how capable your students are. The point is, they must figure out how to make the ICs work based on what they read from the manufacturer.

Something else students will probably have to do is de-bounce the event switch. Some event switches are inherently bounceless, while others are definitely not. Switch debouncing is something your students need to learn about and integrate into this circuit.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Notes 45

The idea of a troubleshooting log is three-fold. First, it gets students in the habit of documenting their troubleshooting procedure and thought process. This is a valuable habit to get into, as it translates to more efficient (and easier-followed) troubleshooting on the job. Second, it provides a way to document student steps for the assessment process, making your job as an instructor easier. Third, it reinforces the notion that each and every measurement or action should be followed by reflection (conclusion), making the troubleshooting process more efficient.

Notes 46

The purpose of this assessment rubric is to act as a sort of "contract" between you (the instructor) and your student. This way, the expectations are all clearly known in advance, which goes a long way toward disarming problems later when it is time to grade.

Notes 47

This question helps students understand the purpose of the diodes in this type of encoder circuit: to steer the power to the appropriate output lines, and *only* to those lines.

Notes 48

This question helps students understand the purpose of the diodes in this type of encoder circuit: to steer the power to the appropriate output lines, and *only* to those lines.

Notes 49

This question helps students understand the purpose of the diodes in this type of encoder circuit: to steer the power to the appropriate output lines, and *only* to those lines.

Notes 50

Ask your students to explain how they determined the affected codes. Although the question itself is relatively simple, there is room for creativity in the answers!

Notes 51

The purpose of this question is to approach the domain of circuit troubleshooting from a perspective of knowing what the fault is, rather than only knowing what the symptoms are. Although this is not necessarily a realistic perspective, it helps students build the foundational knowledge necessary to diagnose a faulted circuit from empirical data. Questions such as this should be followed (eventually) by other questions asking students to identify likely faults based on measurements.

Notes 52

Have your students explain their reasoning in class to you, so that you may observe their diagnostic thought processes.

Notes 53

A failed-shorted bilateral switch would create a sort of *passive averager* circuit between the shorted-switch pot and the selected-switch pot. If your students have difficulty figuring out the effects of this fault, remind them of what a passive averager is, and how it works.

Notes 54

The purpose of this question is to approach the domain of circuit troubleshooting from a perspective of knowing what the fault is, rather than only knowing what the symptoms are. Although this is not necessarily a realistic perspective, it helps students build the foundational knowledge necessary to diagnose a faulted circuit from empirical data. Questions such as this should be followed (eventually) by other questions asking students to identify likely faults based on measurements.

Notes 55

This question provides an excellent opportunity to discuss the difference between *sourcing* and *sinking* current, as well as the importance of knowing what the output stage of an IC looks like internally.

Notes 56

I have left the answer purposefully vague so that students will have to figure out how to properly use BJTs to drive the Nixie tube cathodes. This is a good opportunity for them to review BJT theory and switch application use, so don't spoil it by giving away the answer!

Notes 57

The follow-up question regarding ratios is a good introduction to the fundamental principle of balanced bridge circuits. Having students work through the calculations together is a good way for them to see the principle for themselves.

It is also important to note in this circuit which ratios are *not* in agreement with each other. You can't just divide these four resistors into any set of two pairs and expect the ratios to equal each other! It is very important for students to see this, as well.

Notes 58

This circuit may be viewed from the perspective of it being two voltage dividers, or from the perspective of being a current divider. Either way, it is a good exercise for you and your students to explore how it functions.

Notes 59

This question helps students build the skill of eliminating unlikely fault possibilities, allowing them to concentrate instead on what is more likely. An important skill in system troubleshooting is the ability to formulate probabilities for various fault scenarios. Without this skill, you will waste a lot of time looking for unlikely faults, thereby wasting time.

For each fault scenario it is important to ask your students *why* they think it is possible or not possible. It might be that some students get the right answer(s) for the wrong reasons, so it is good to explore the reasoning for each answer.

Notes 60

Ask your students how these two systems of power gain expression (Bels versus ratios) compare in terms of *range*. Which system of expression encompasses the greatest range of power gains or losses, with the smallest changes in numerical value?

Notes 61

Challenge your students to estimate the log values without using their calculators. For example, they should be able to estimate the log of 1275 as being between 3 and 4; the log of 0.025 as being between -1 and -2. Work together to devise a technique for doing this, where there will be no guessing.

Mathematical estimation is an important skill for technical people to possess. Not only is it useful in the event no calculator is readily available, but it also helps greatly in students being able check their (electronically) calculated work. I can't tell you how many times I've seen students blindly enter numbers into a calculator, only to arrive at an answer that is *grossly* in error, and not realize it at all because they cannot do the estimation mentally.

Notes 62

Nothing special here, just straightforward ratio-to-decibel calculations. Have your students share and discuss the steps necessary to do all these conversions.

Notes 63

Nothing special here, just straightforward decibel-to-ratio calculations. Have your students share and discuss the steps necessary to do all these conversions.

Notes 64

Some of these filter designs are resonant in nature, while others are not. Resonant circuits, especially when made with high-Q components, approach ideal band-pass (or -block) characteristics. Discuss with your students the different design strategies between resonant and non-resonant band filters.

The high-pass filter containing both inductors and capacitors may at first appear to be some form of resonant (i.e. band-pass or band-stop) filter. It actually *will* resonate at some frequency(ies), but its overall behavior is still high-pass. If students ask about this, you may best answer their queries by using computer simulation software to plot the behavior of a similar circuit (or by suggesting they do the simulation themselves).

Regarding the follow-up question, it would be a good exercise to discuss which suggested component failures are more likely than others, given the relatively likelihood for capacitors to fail shorted and inductors and resistors to fail open.

Notes 65

Some of these filter designs are resonant in nature, while others are not. Resonant circuits, especially when made with high-Q components, approach ideal band-pass (or -block) characteristics. Discuss with your students the different design strategies between resonant and non-resonant band filters.

Although resonant band filter designs have nearly ideal (theoretical) characteristics, band filters built with capacitors and resistors only are also popular. Ask your students why this might be. Is there any reason inductors might purposefully be avoided when designing filter circuits?

Notes 66

Be sure to ask students where they found the cutoff frequency formula for this filter circuit.

When students calculate the impedance of the resistor and the capacitor at the cutoff frequency, they should notice something unique. Ask your students why these values are what they are at the cutoff frequency. Is this just a coincidence, or does this tell us more about how the "cutoff frequency" is defined for an RC circuit?

Notes 67

Be sure to ask students where they found the cutoff frequency formula for this filter circuit.

Notes 68

Be sure to ask students where they found the cutoff frequency formula for this filter circuit.

Notes 69

Transformer winding calculations are simply an exercise in mathematical ratios. If your students are not strong in their ratio skills, this question provides an application to sharpen them!

Notes 70

Most transformer problems are nothing more than ratios, but some students find ratios difficult to handle. Questions such as this are great for having students come up to the board in the front of the classroom and demonstrating how they obtained the results.

Notes 71

Most transformer problems are nothing more than ratios, but some students find ratios difficult to handle. Questions such as this are great for having students come up to the board in the front of the classroom and demonstrating how they obtained the results.

Notes 72

Operational amplifier circuits provide a great opportunity to review basic concepts of DC circuits: voltage drops, polarity, current directions, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, etc. This circuit is no exception. Emphasize the fact that a great many opamp circuits may be comprehensively analyzed merely with knowledge of these fundamental principles and the characteristics of an ideal opamp (zero input current, infinite open-loop gain, unlimited output voltage swing, zero voltage between input terminals when negative feedback is in effect).

The follow-up question is important because it showcases one of the great advantages of using noninverting opamp amplifier circuits as voltage signal amplifiers: extremely high input impedance. This would be a good opportunity to review typical input impedance values for operational amplifiers, by showing datasheets for some typical opamps and for some non-typical (i.e. MOSFET input) opamps.

Notes 73

This question not only provides practice analyzing the behavior of a summer circuit, but also analyzing the behavior of a passive averager circuit. If your students need some refreshing on how to analyze the passive averager, you might want to review Millman's Theorem with them.

Notes 74

Ask your students how they solved this problem, especially since it is fairly safe to say that they didn't find the equation directly solving for R_1 in any book. Algebraic manipulation is necessary to take the standard voltage gain equation and put it into a form suitable for use answering this question.

Notes 75

Discuss with your students their methods of determining filter type. How did they approach this problem, to see what type of filter both these circuits were?

Also, discuss with your students the problem of having an amplifier circuit with an unchecked gain (approaching infinity). Ask them what is wrong with obtaining such high voltage gains from any amplifier. Have them describe to you the effect of a huge voltage gain on the integrity of the amplified signal.

Notes 76

The word "topology" may be strange to your students. If any of them ask you what it means, ask them if they own a dictionary!

Like all the other active filter circuits, the fundamental characteristic of each filter may be determined by qualitative analysis at $f = 0$ and $f = \infty$. This is a form of *thought experiment*: determining the characteristics of a circuit by imagining the effects of certain given conditions, following through by analysis based on "first principles" of circuits, rather than by researching what the circuit's intended function is.

Resistor R_3 is actually not essential to the circuit's operation, but is normally found in Sallen-Key filters anyway. If it makes the analysis of the circuit any simpler, tell your students they may replace that resistor with a straight wire in their schematic diagrams.

Notes 77

This circuit is very easy to design, if you remember the conversion process going from binary to Gray. There are many good references available for students to learn (or re-learn) this process from, so don't simply tell them how to do it! Let them research it on their own.

Notes 78

This circuit is very easy to design, if you remember the conversion process going from Gray to binary. There are many good references available for students to learn (or re-learn) this process from, so don't simply tell them how to do it! Let them research it on their own.

Notes 79

Discuss with your students the significance of using a multiplexer in this fashion: to implement arbitrary logic functions. For those students who may not be familiar with the term, be sure to define the word "arbitrary." It may seem silly, but students often fail to ask for the definitions of words that are new to them, for fear of sounding dumb in front of their peers and in front of you. One more reason to model respect in your classroom, and also to create an atmosphere where students feel comfortable asking any question.

Notes 80

Nothing really complex or tricky here. Just a straightforward application of Boolean SOP expressions.

Notes 81

This question is destined for obsolescence, as Lambertian displays will likely become a reality in the next several years. But for now (May 2005), it is a term worth defining in the introductory study of display technologies.

An example of an early attempt at full-Lambertian display is the *Gyricon* technology developed by Xerox. Research this and be prepared to discuss it with your students as an example of a novel approach for non-emissive electronic displays.