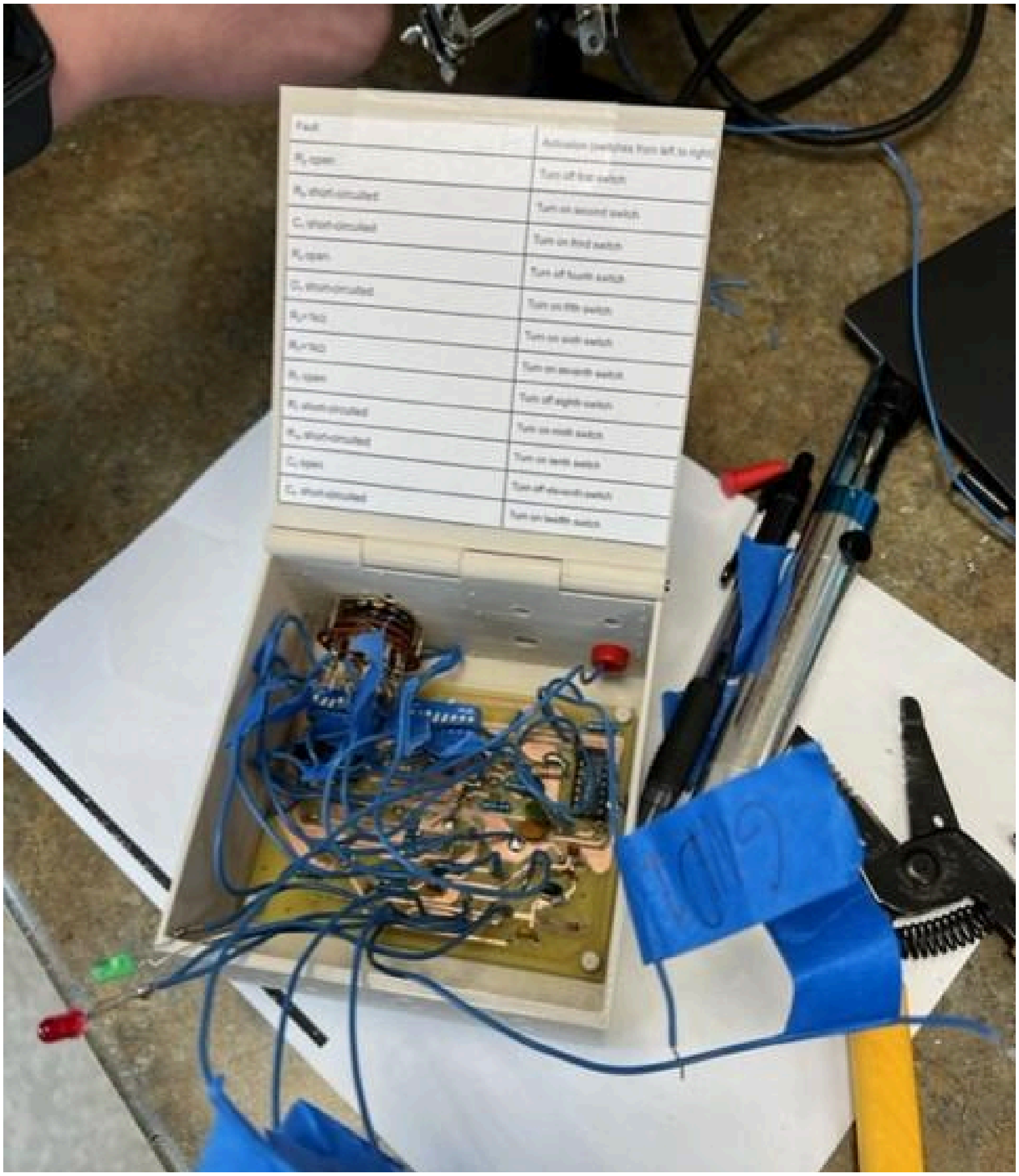
Junior Final Project- OP Amp Troubleshooting



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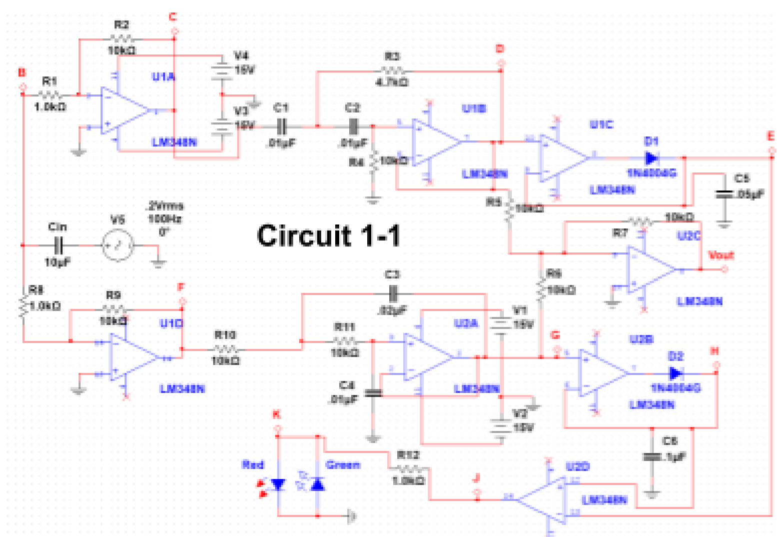
Objectives:
- Build and Test a complex op amp circuit.

Materials Required:
- Oscilloscope
- Multisim
- Dual power supply
- Sine-wave generator
- Digital multimeter
- Two LM348N Op amps (Substitutes for Eight 741C op amps)
- Three 0.01-uF disk capacitors
- One 0.02-uF disk capacitor
- One 0.05-uF disk capacitor
- One 10 uF 50-V electrolytic capacitor
- Two 1N4148 rectifier diodes (Substitutes for 1N4004 rectifier diodes)
- One red LED
- One green LED
- Four 1-kΩ resistors
- One 4.7-kΩ resistor
- Eight 10-kΩ resistors
- Ultiboard
- Inventor
- PCB
- Rotary Switch
- 8 Banana Jacks
- PLA

Procedure:.

1. We first created circuit 1-1 as our complex op-amp circuit in which we could troubleshoot.We then calculated the gain of A_1 and A_4 using the equation $A= -R_f/R_{IN}$ and recorded them in table 1-1.



2. We then applied a 400 mV sine wave at 1000 Hz at V_{IN}.

3. We measured and recorded the signals at points B, C, and F in table 1-1. On the basis of our measurements the gain of A_1 is still -10 when we measured and -10 when we measured A_4. These are almost the same values as our calculations so our calculations must be correct. We also measured V_{IN} and points C and F to see that there is phase inversion between V_{IN} and points C and F by 180 degrees.
4. We then connected the scope to point D and varied the frequency until the signal voltage was at 2.83V (0.707 * 4 volts) and we recorded this data in table 1-1. For this filter which is a high pass, the frequency we measured is its minimum frequency.
5. We then moved the scope to point G and varied the frequency until the signal voltage was at 2.83V again and it illuminated the Green LED when we did step 4 which was a higher frequency at 2.25kHz and the Red LED on step 5 when the frequency was lower at 1.1kHz.
6. We then observed the signals at points E and H while varying the sine-wave frequency which showed that DC voltage is present. We also observed that as the frequency gets higher the maximum amplitude of these waves gets lower.
7. We then moved the scope to point J and varied the sine-wave frequency. We noticed that the output switches at 1.63 kHz for the multisim and 12 kHz for the physical because the LED switched at this frequency.
8. We then moved the scope to point I and noticed that the wave is a normal sine wave that has a peak-to-peak voltage of 2.6 V_{P-P}, is not exactly in phase with the input due to the capacitors but it is not a full 180 out of phase and has a gain of 6.6, also the sine wave takes a very high frequency for clipping to start which seemed to be around 50 kHz. The output sine wave can be seen in figure 1-1.

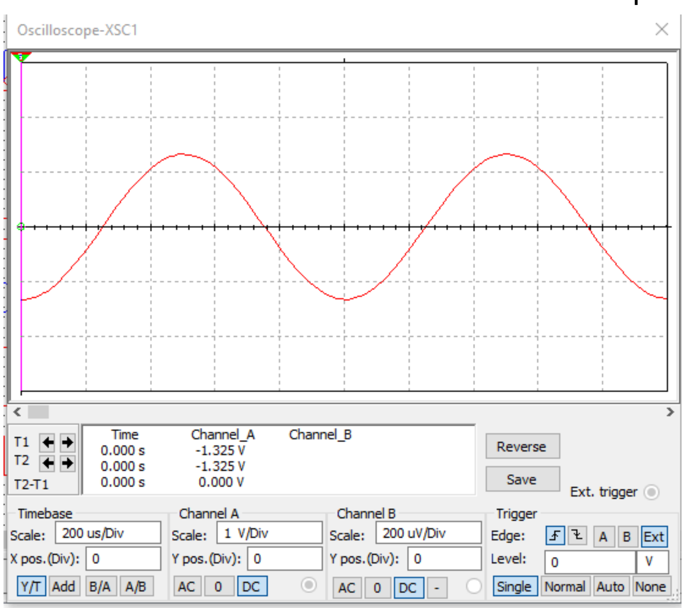


Figure 1-1M

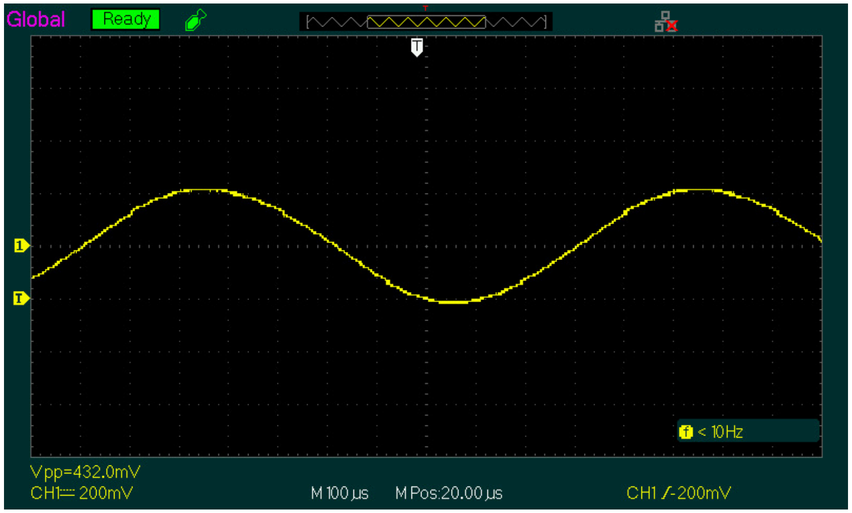


Figure 1-1B

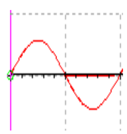
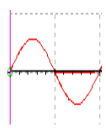
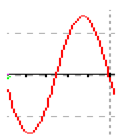
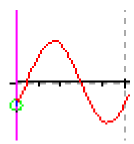
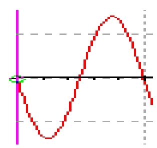
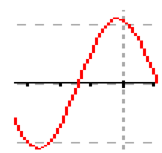
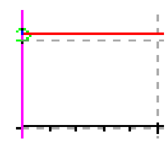
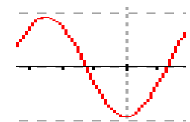
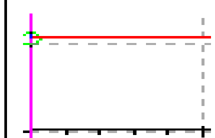
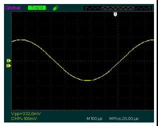
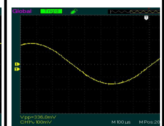
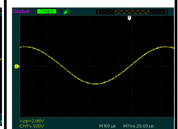
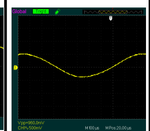
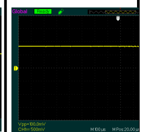
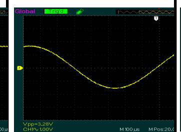
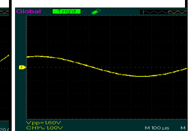
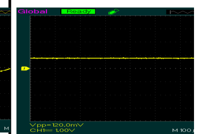
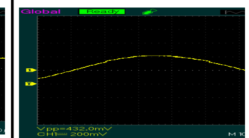
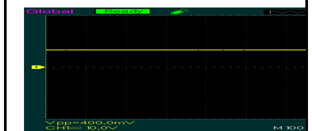
Table 1-1M Test Point	V_{IN}	B	C	D	E	F	G	H	I (V_{Out})	J
Waveform type										
Peak-peak or DC voltage (V)	0.40	0.40	4.00	0.74	0.36	4.00	3.12	2.21	2.59	11.40
Frequency, Hz min or max, kHz	X	X	X	2.25 Min	2.35 Min	X	1.10 Max	1.06 Max	X	1.64 Switch
Calculated Gain	X	X	-10	X	X	-10	X	X	X	X
Measured Gain	X	X	-10	X	X	-10	X	X	X	X

Table 1-1B Test Point	V_{IN}	B	C	D	E	F	G	H	I (V_{Out})	J
Waveform type										
Peak-peak or DC voltage (V)	0.38	0.38	3.8	0.9	0.02	3.4	2	1	0.5	12
Frequency, Hz min or max (kHz)	X	X	X	2, min	2.4, min	X	1.3, max	1, max	X	12
Calculated Gain	X	X	-10	X	X	-10	X	X	X	X
Measured Gain	X	X	-10	X	X	-10	X	X	X	X

9. We then made multiple faults/changes to our circuit and listed the measurement values in table 1-2. We did this for every fault that is listed in table 1-2.

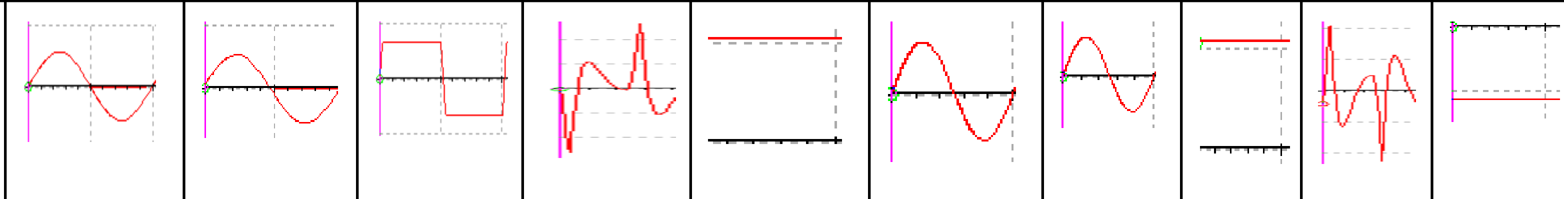
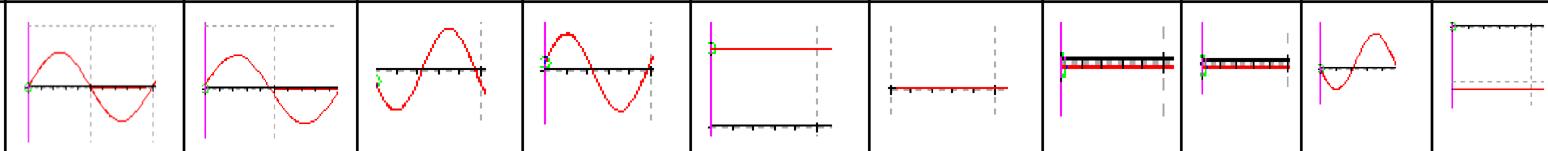
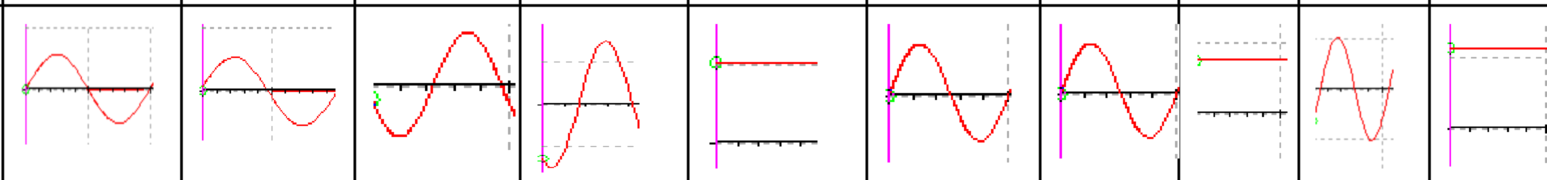
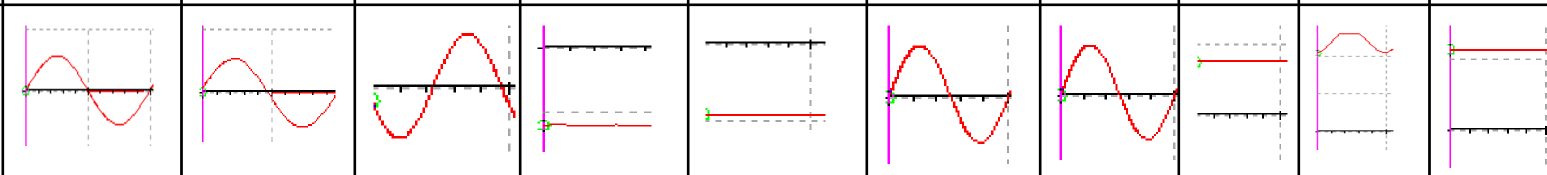
Table 1-2M Test Point	X	V_{IN}	B	C	D	E	F	G	H	I (V_{Out})	J	LEDs
R_2 Open	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.4	0.4	26.7	22.3	10.1	4.0	3.1	2.2	5.7	-11.4	-2.1
R_9 short circuited	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.5	0.0	0.0	0.0	0.7	-11.4	-2.1
C_1 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	2.1	1.1	4.0	3.1	1.5	2.1	11.4	1.8
R_4 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	-12.1	-9.6	4.0	3.1	1.5	2.5/ 12.0	11.4	1.8

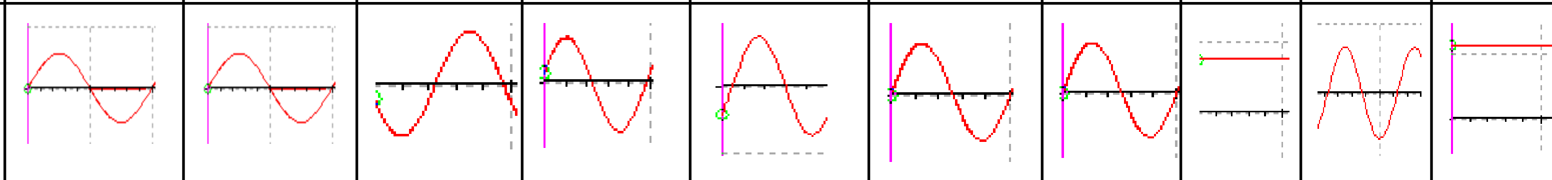
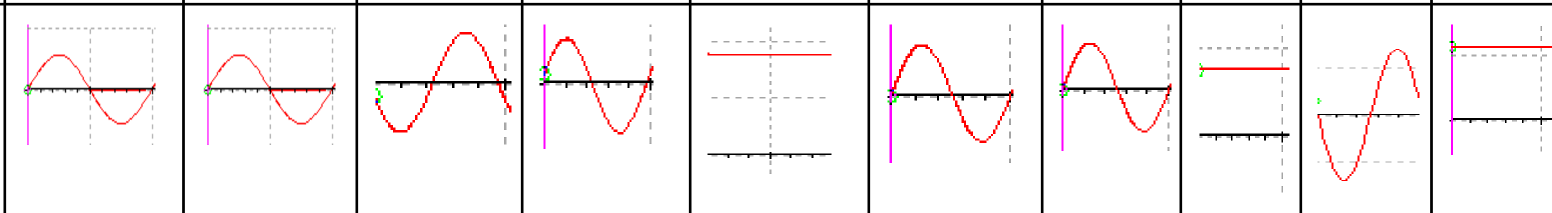
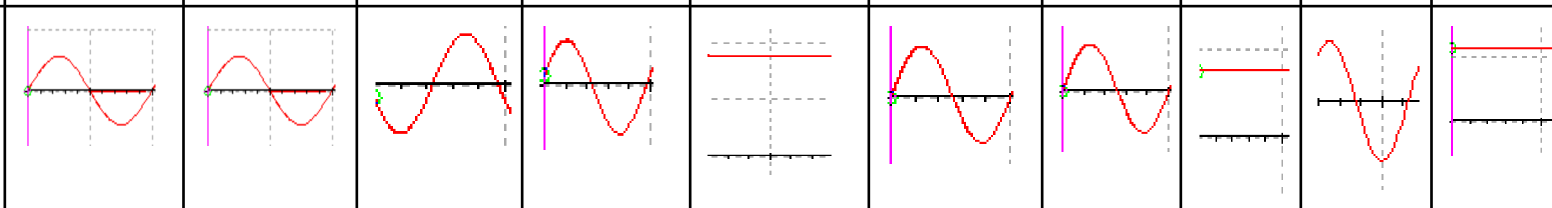
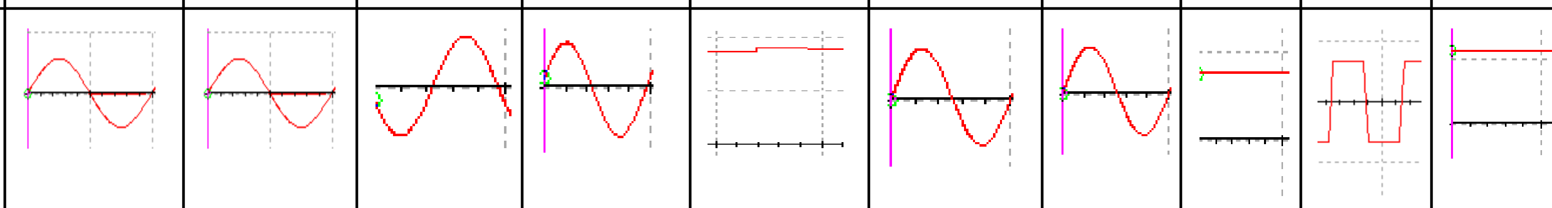
Table 1-2M Test Point	X	V_{IN}	B	C	D	E	F	G	H	I (V_{Out})	J	LEDs
D_1 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.7	4.0	3.1	1.5	2.6	11.4	1.8
R_5=1kΩ	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.1	1.5	5.7	11.4	1.8
R_7=1kΩ	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.1	1.5	0.4	11.4	1.8
R_7 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.1	1.5	26.6	11.4	1.8

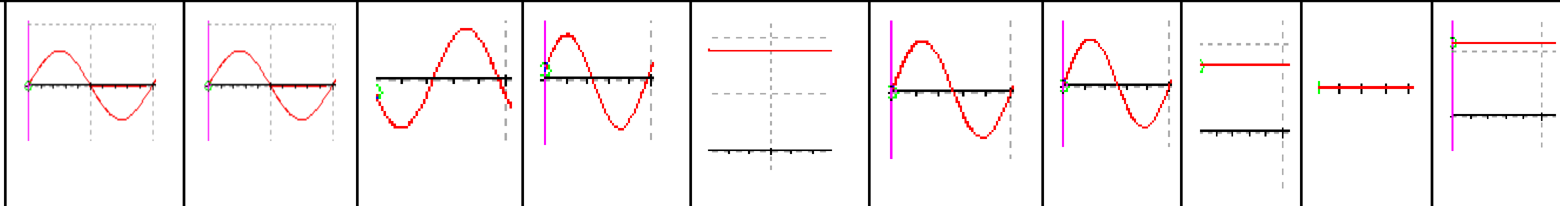
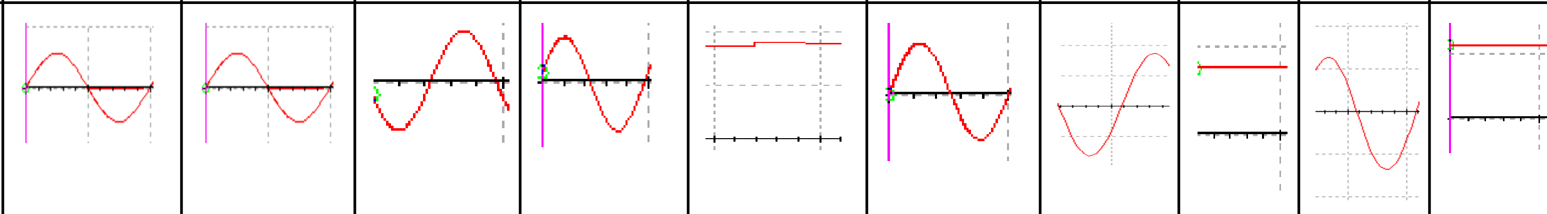
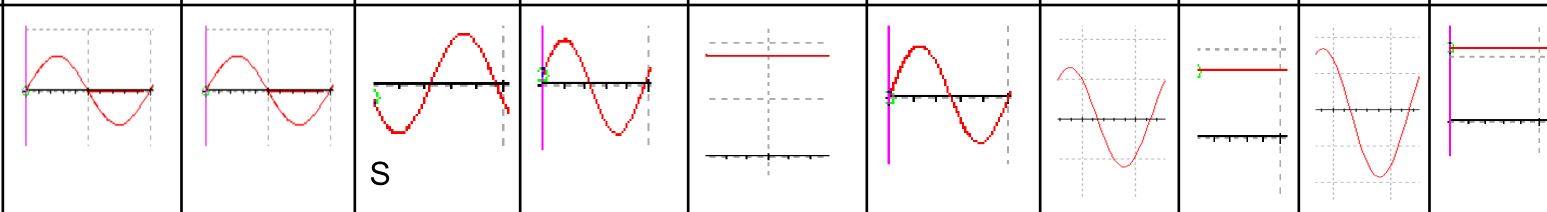
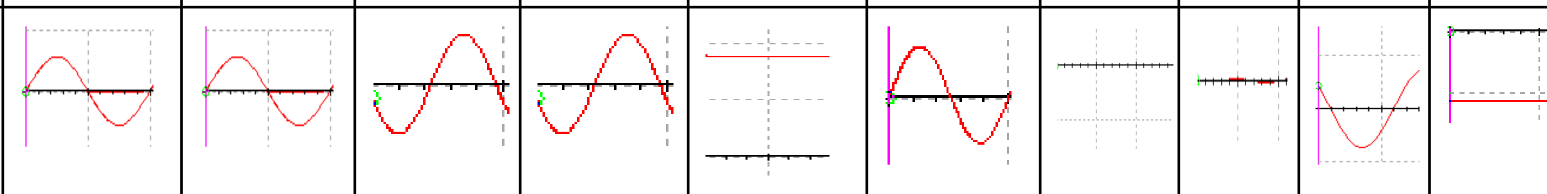
Table 1-2M Test Point	X	V_{IN}	B	C	D	E	F	G	H	I (V_{Out})	J	LEDs
R_7 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.1	1.5	0.0	11.4	1.8
R_{10} short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.5	1.75	2.4	11.4	1.8
C_3 open	Wave			S								**RED**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.4	0.4	4.0	2.4	1.3	1.5	11.4	1.8
C_4 short-circuited	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.4	0.4	4.0	0.4	0.4	4.0	0.0	0.0	0.8	-11.4	-2.1

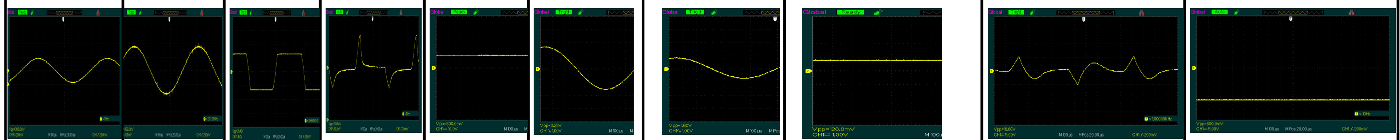
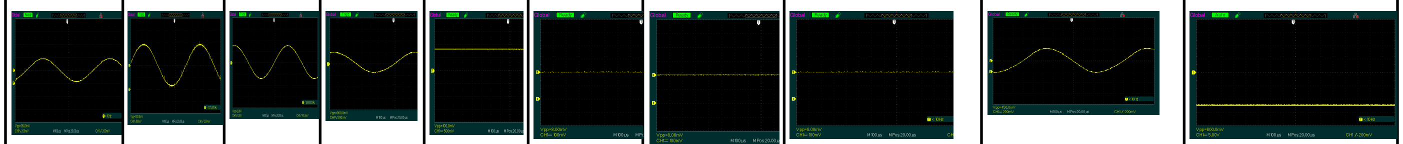
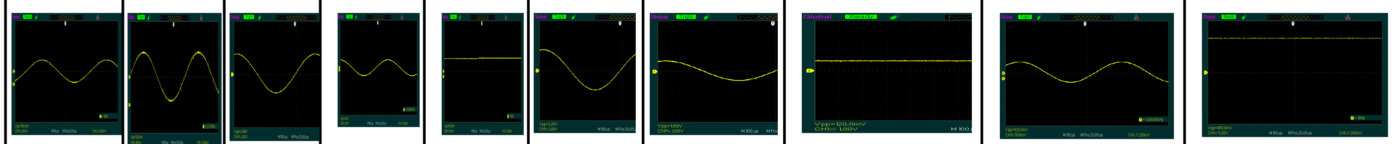
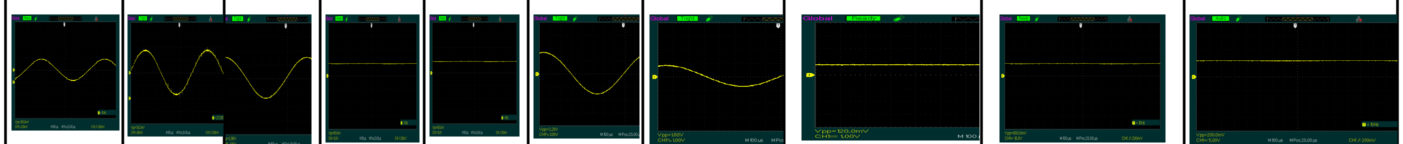
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_2 Open	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	26.00	0.25	10.00	4.00	3.10	2.20	10	-12	-2
R_9 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.8	0.9	0.02	0.0	0	0	0.4	-12	-2
C_1 short-circuited	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.8	1.2	0.5	3.4	2	1	0.8	12	2
R_4 open	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.8	10	10	3.4	2	1	10	6	2

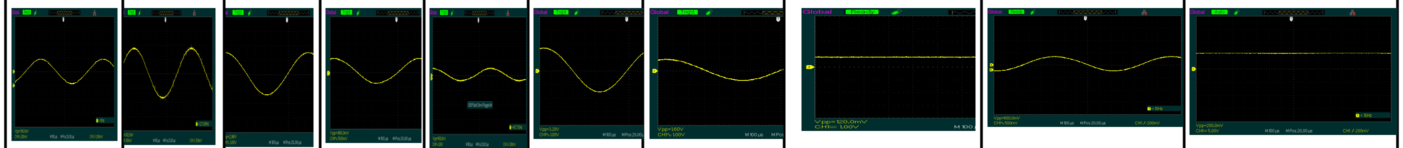
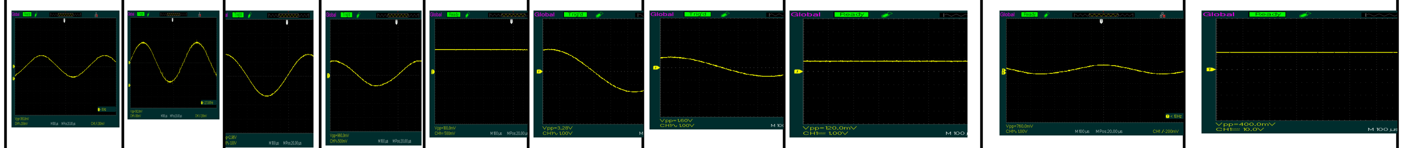
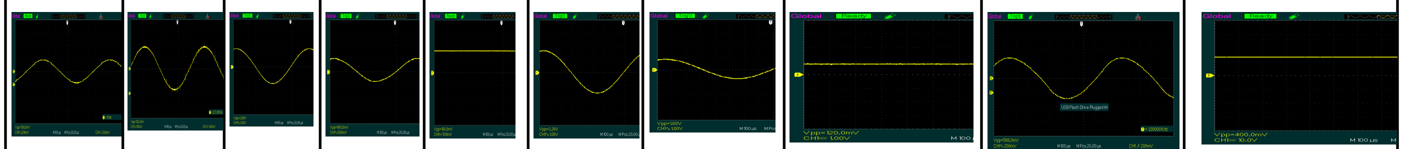
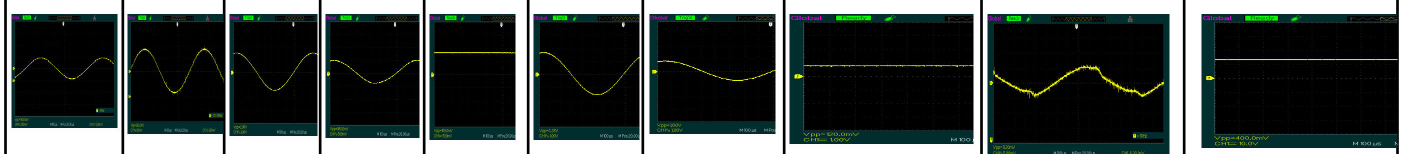
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
D_1 short-circuited	Wave											**RED**
(V)	2	1	0.40	3.80	0.90	0.90	3.40	2.00	1.00	0.62	12.00	2
R_5=1kΩ	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.80	0.90	0.02	3.4	2	1	0.76	12	2
R_7=1kΩ	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.57	12	2
R_7 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.01	12	2

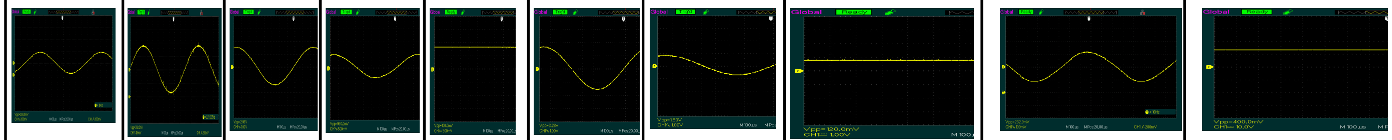
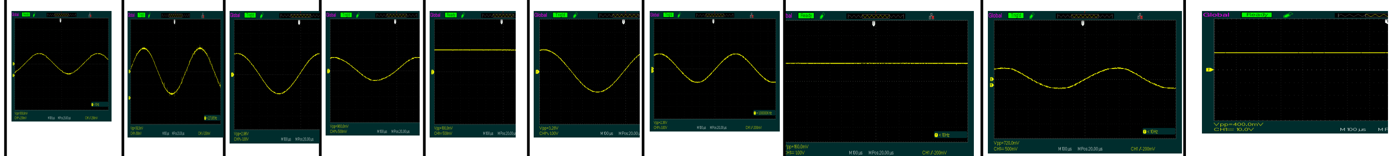
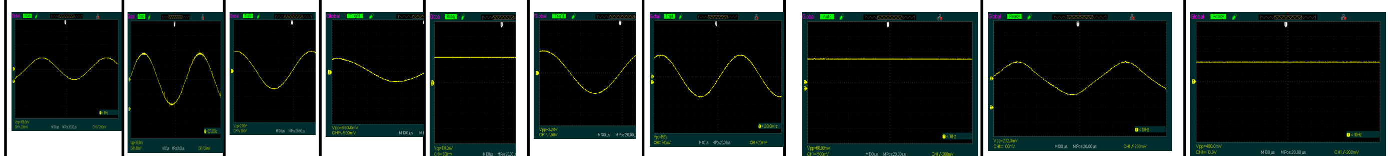
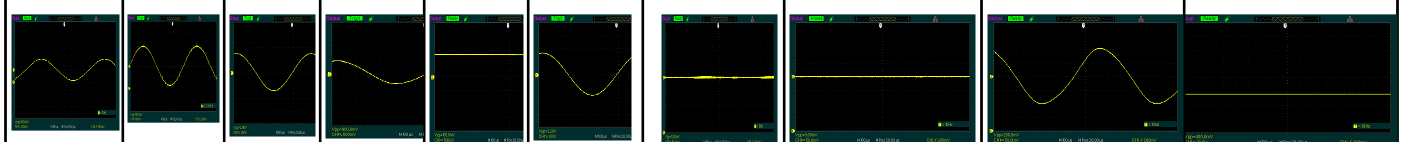
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_7 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.23	12	2
R_{10} short-circuited	Wave											**RED**
	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2.3	1.2	0.57	12	2
C_3 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	1.5	0.75	0.23	12	2
C_4 short-circuited	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	0.01	0.01	0.2	-12	-1.9

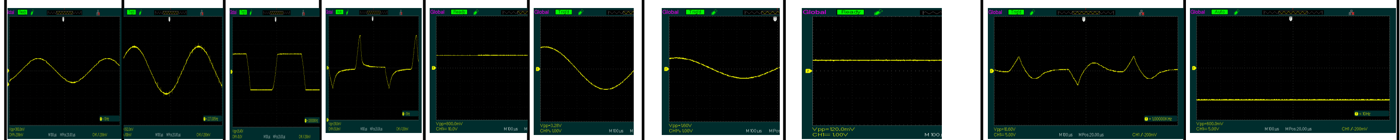
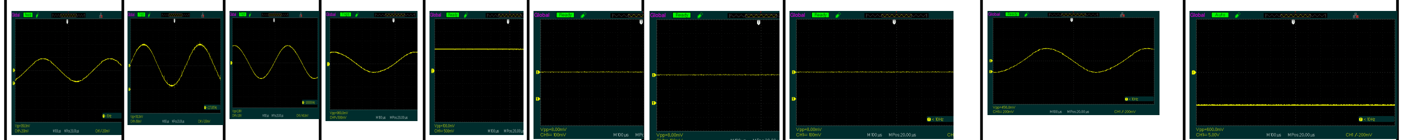
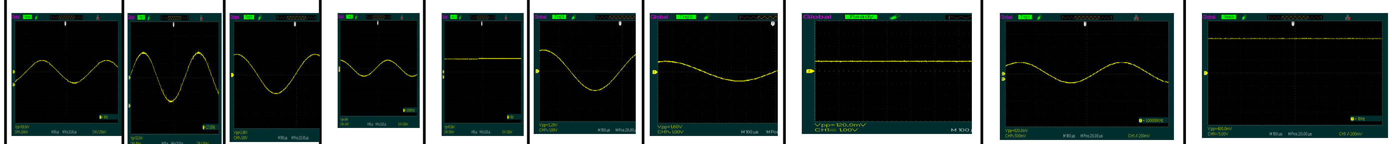
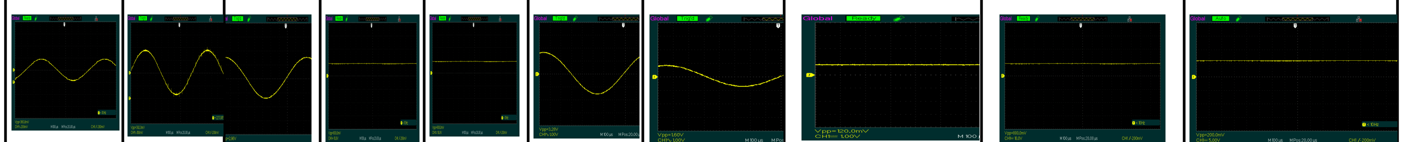
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_2 Open	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.40	0.40	26.00	0.25	10.00	4.00	3.10	2.20	10	-12	-2
R_9 short-circuited	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	0.0	0	0	0.4	-12	-2
C_1 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	1.2	0.5	3.4	2	1	0.8	12	2
R_4 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	10	10	3.4	2	1	10	6	2

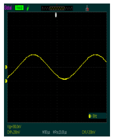
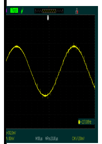
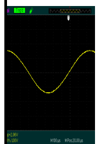
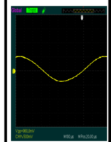
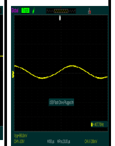
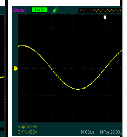
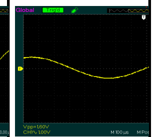
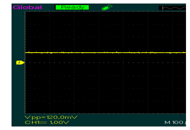
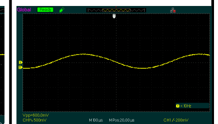
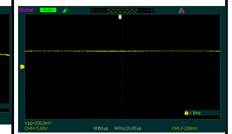
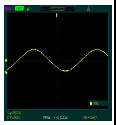
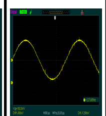
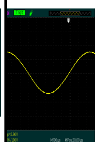
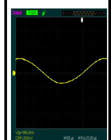
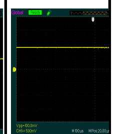
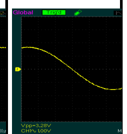
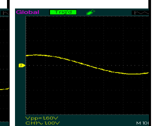
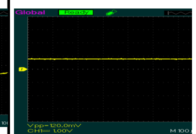
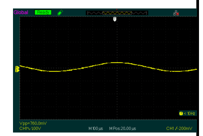
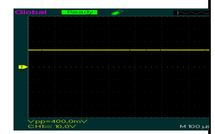
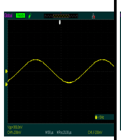
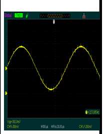
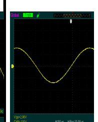
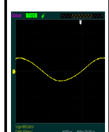
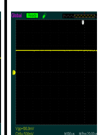
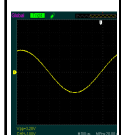
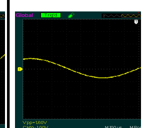
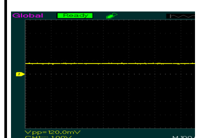
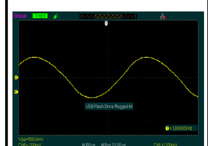
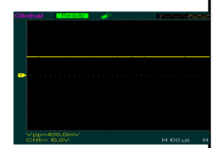
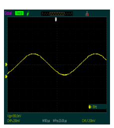
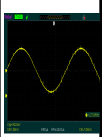
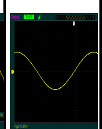
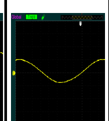
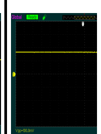
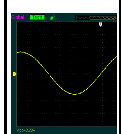
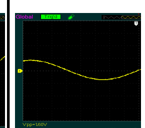
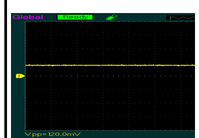
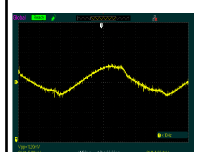
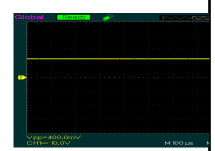
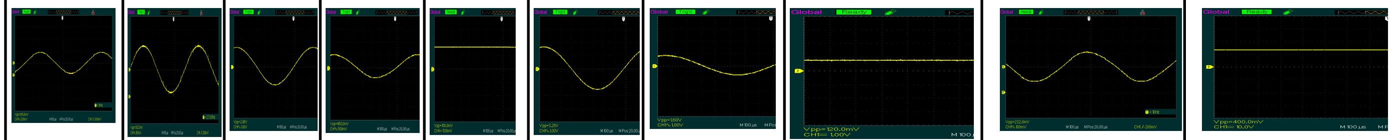
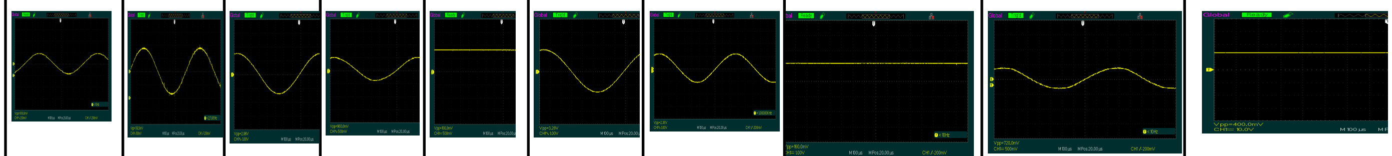
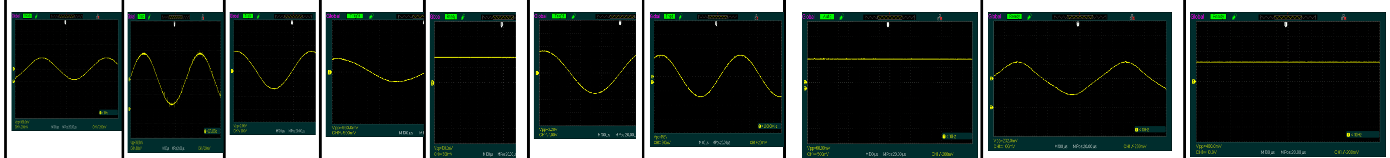
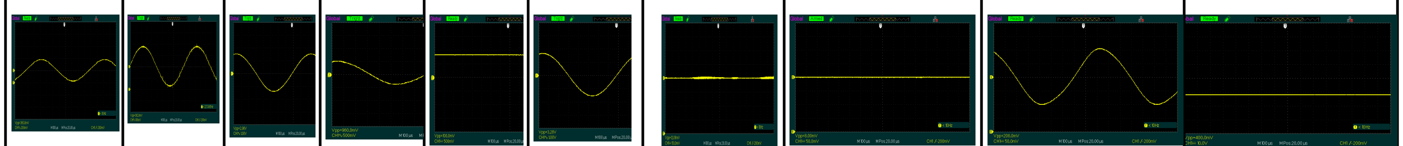
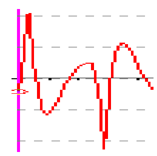
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
D_1 short-circuited	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	1	0.40	3.80	0.90	0.90	3.40	2.00	1.00	0.62	12.00	2
R_5=1kΩ	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.80	0.90	0.02	3.4	2	1	0.76	12	2
R_7=1kΩ	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.57	12	2
R_7 open	Wave											**RED**
(V)	$V_{P\text{-}P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.01	12	2

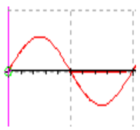
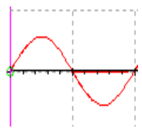
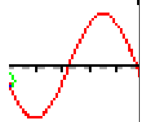
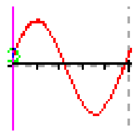
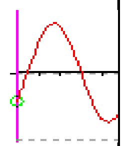
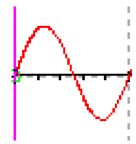
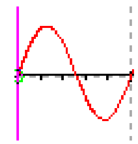
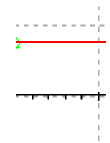
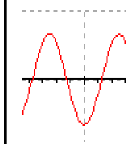
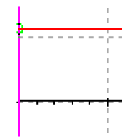
Table 1-2B Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_7 short-circuited	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2	1	0.23	12	2
R_{10} short-circuited	Wave											**RED**
	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	2.3	1.2	0.57	12	2
C_3 open	Wave											**RED**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	1.5	0.75	0.23	12	2
C_4 short-circuited	Wave											**GREEN**
(V)	$V_{P-P/DC}$	0.40	0.40	3.8	0.9	0.02	3.4	0.01	0.01	0.2	-12	-1.9

10. We then created a table to show the obvious indicators for each troubleshoot when compared to our normal set of readings which can be shown in table 1-3.

Table 1-3 *Faults*	*Indicator*
R_2 open	 as the output
R_9 short-circuited	0 volts are shown on points F, G, and H
C_1 short-circuited	Point D being way higher than its normal 0.7 volts at about ~2.1 volts
R_4 open	Points D and E becoming negative DC voltage
D_1 short-circuited	Point E being a sine wave at ~0.7 volts
R_5=1kΩ	The output being a way higher voltage at ~5.7 volts
R_7=1kΩ	The output being a way lower voltage at ~0.4 volts
R_7 open	The output being a square wave with a huge increase of voltage at ~26.6 volts
R_7 short-circuited	The output being 0 volts
R_{10} short-circuited	Points G and H being a little higher voltage at ~3.5 volts for point G and ~1.75 volts for point H
C_3 open	Points G and H being a lower voltage at ~2.4 volts for point G and ~1.3 volts for points H
C_4 short-circuited	Points G and H have no voltage

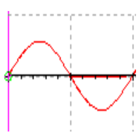
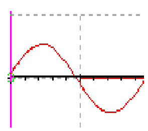
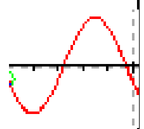
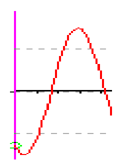
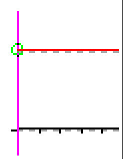
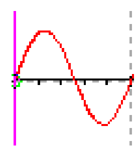
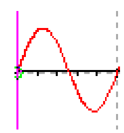
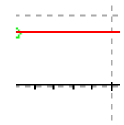
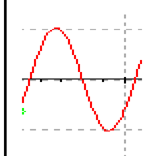
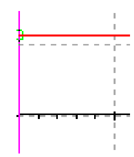
11. After this we had an assistant introduce a problem into the circuit and one of us had to troubleshoot and fix the problem which can be shown for each group member in table 1-4.

Henry:

Table 1-4H Test Point	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
Waveform											**RED**
$V_{P-P/DC}$	0.4	0.4	4.0	0.7	0.7	4.0	3.1	1.5	2.6	11.4	1.8

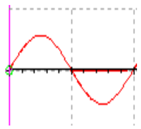
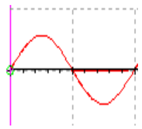
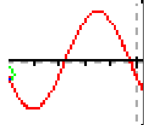
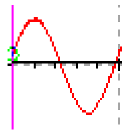
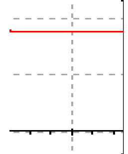
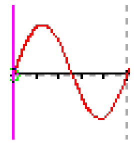
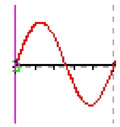
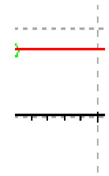
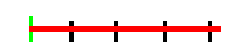
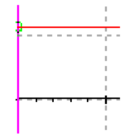
Trouble: I first checked which LED was on and saw that the red LED was on so I knew it had to be a fault on the chart that involved red LEDs. I then checked each point and everything seemed fine up until point E. At point E I saw that the waveform was a sine wave instead of the normal DC wave created by the diode in this circuit. With this information I knew that D_1 had to be short-circuited.

Colin:

Table 1-4C Test Point	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
Wave											**RED**
$V_{P-P/DC}$	0.4	0.4	4.0	2.1	1.1	4.0	3.1	1.5	2.1	11.4	1.8

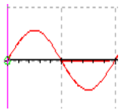
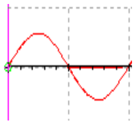
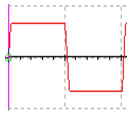
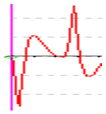
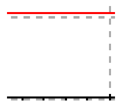
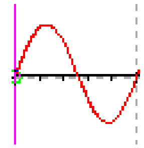
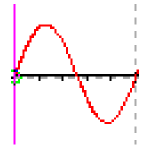
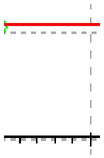
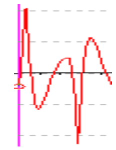
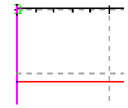
Trouble: I first checked the LED and saw that it was RED so it couldn't be a fault that had the light turn green. I then went through testing all the points for discrepancies and once I measured point D I saw that it was a lot higher than it was supposed to be. Based on the chart and data for the fault I knew that it had to be C_1 short circuiting due to the big increase in voltage for point D when compared to the working circuit values.

Jason:

Table 1-4J Test Point	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
Wave											**RED**
$V_{P\text{-}P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.1	1.5	0.0	11.4	1.8

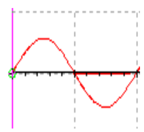
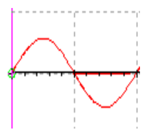
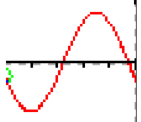
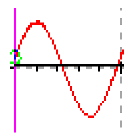
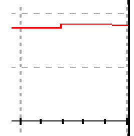
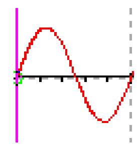
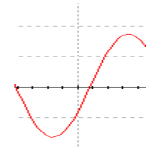
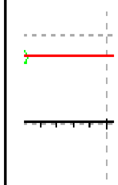
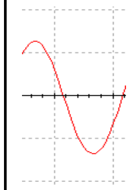
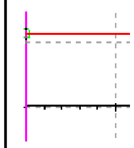
Trouble: I activated the circuit and first observed that the red LED was on, meaning that the bottom had a greater voltage after the filter than the top. I then connected the oscilloscope to the output and got 0 volts, which meant that R_7 had to be shorted because that is the only listed fault that could cause the output to be 0 volts.

Sidney:

Table 1-4S Test Point	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
Waveform											**GREEN**
$V_{P\text{-}P/DC}$	0.4	0.4	26.7	22.3	10.1	4.0	3.1	2.2	5.7	-11.4	-2.1

Trouble: Turned on circuit and identified that the Green LED was turned on. With this information I went to the Lab charts and located point C as both Vin and point B don't get changed with the Green LED on. When point C was checked, the wave on the oscilloscope had cut off matching the pictures for R2 open. To finalize, I checked R2 for faults and it was open.

Aiden:

Table 1-4A Test Point	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
Wave											**RED**
$V_{P\text{-}P/DC}$	0.4	0.4	4.0	0.7	0.4	4.0	3.5	1.75	2.4	11.4	1.8

Trouble: I first measured the input waveform and saw that the wave amplitude matched what it should. I then measured the points B through F and saw that they matched the wave forms they were supposed to match. But when I got to point G, the waveform had a higher amplitude than expected. I then measured point H and noticed that the amplitude was larger than expected as well. I then realized that R_{10} was shorted because without that resistance the amplitude of the waves would increase.

12. After we measured all of this data for the breadboard and multisim we started to create our ultiboard and enclosure for our physical troubleshooting box.

Ultiboard:

1. We had to create a circuit that was the complex op amp circuit we measured, but also to have multiple switches where we could create a fault and the ultiboard for our final circuit that we created can be shown in figure 1-2 where the blue represents the copper top and the purple represents the copper bottom and this circuit has the dimensions 4″ x 3″.

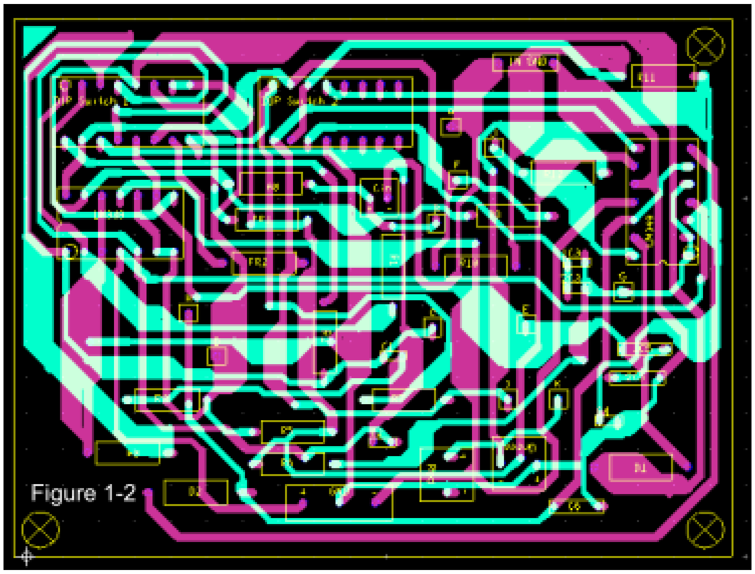


Figure 1-2

2. We then printed the circuit and the top can be shown in figure 1-3 and the bottom can be shown in figure 1-4.

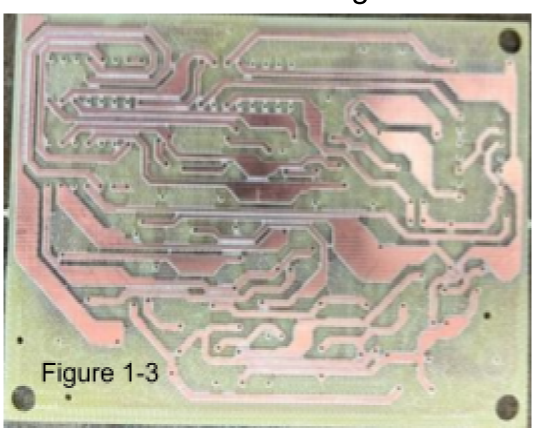


Figure 1-3

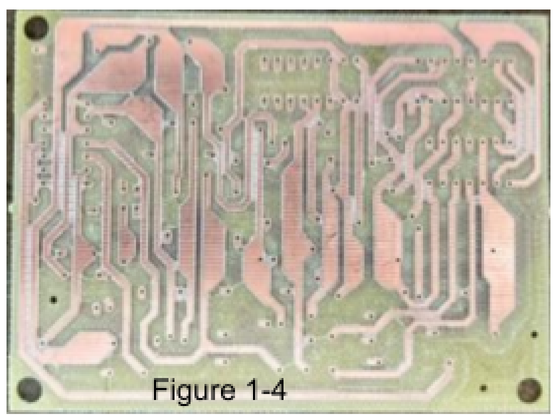
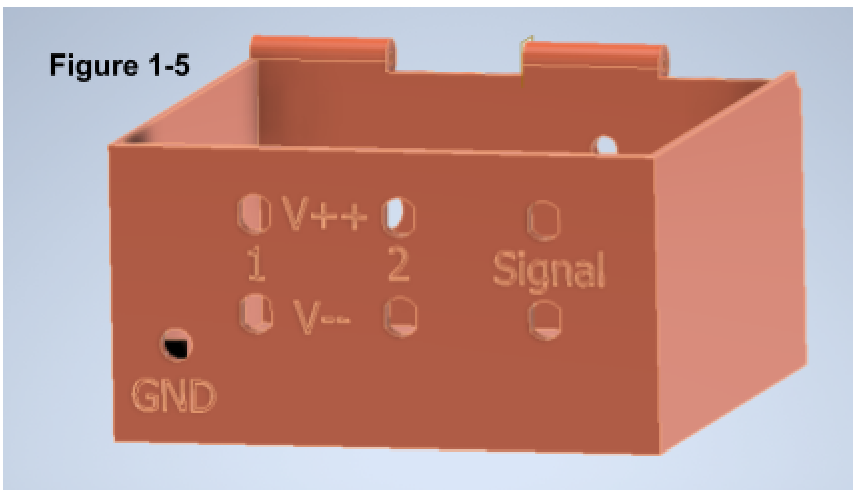


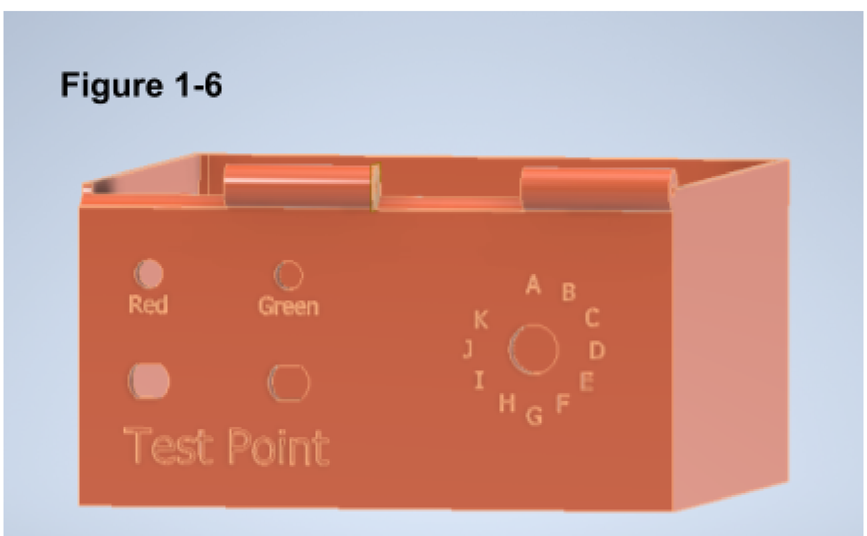
Figure 1-4

3. The ultiboard file where it can be downloaded and where each part is listed in each place can be used with this link: https://drive.google.com/file/d/1Sxwphx_LRRqJ1yRWuyWpFC0MeOHhCPbb/view?usp=sharing

Enclosure:

1. To have a circuit where one person could create a fault while the other couldn't see, we had to create a box like design that was 4.125″x 4.125″x 2″ where one side was where the person could change the faults and the other side had the test points where the other person could test to see where the fault is.
2. We decided to use a hinge to have the instructions on each of the changing faults so it could obscure the person trying to troubleshoot while the person that was making the fault could easily open the box, read the instructions, and change the circuit to a certain fault.
3. We also had the side with the faults have all the power inputs and signal generator so the person on the other side only had to worry about the test points and LED outputs when troubleshooting. The side of the box with the inputs and where one person would create a fault can be shown in figure 1-5 while the other side with just the test points can be shown in figure 1-6.





4. We had to measure each of the holes so that it fit the same dimensions as our banana jacks, rotary switch, and LEDs. Each Banana jack had a diameter of 0.295″, the LEDs had a diameter of 0.2″, and the rotary switch had a diameter of 0.35″.
5. We then had to create three pegs to be able to hold our printed circuit board that has the dimensions 4” x 3″ and they had a diameter of 0.2″ and a height of 0.4″, the top of the box with the pegs shown can be seen in figure 1-7.

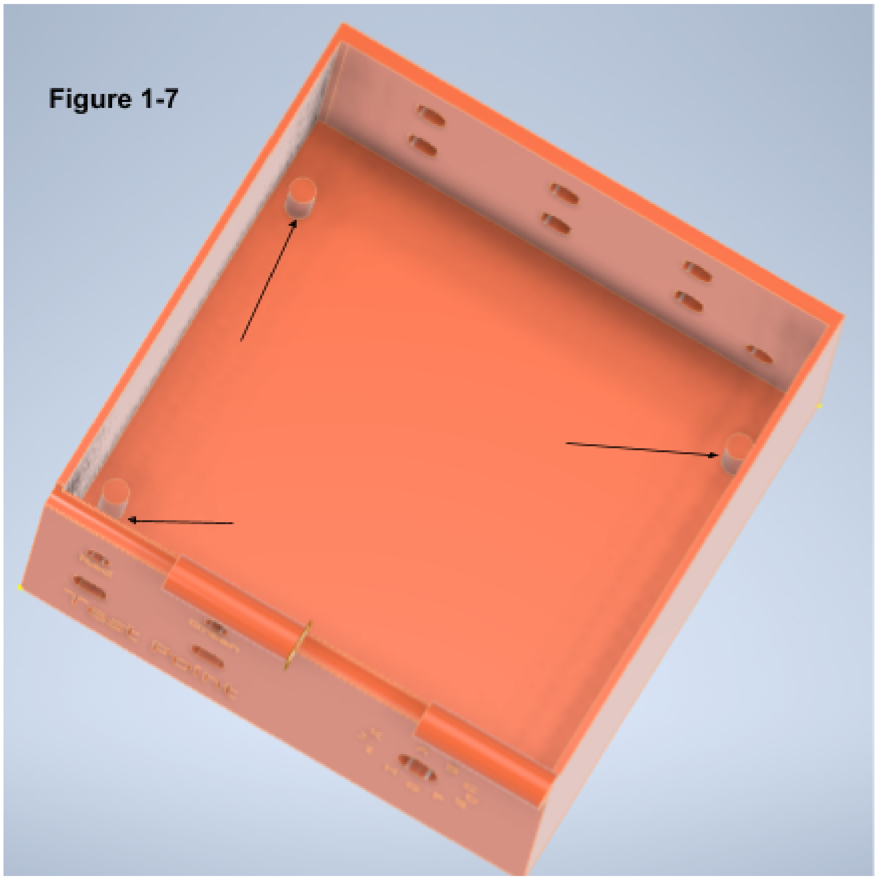


Figure 1-7

6. We then created a 4.125”x 4.125″x 0.175″ lid for the box that had the hinge so the box could easily open and close to access the circuit. This can be shown in figure 1-8.

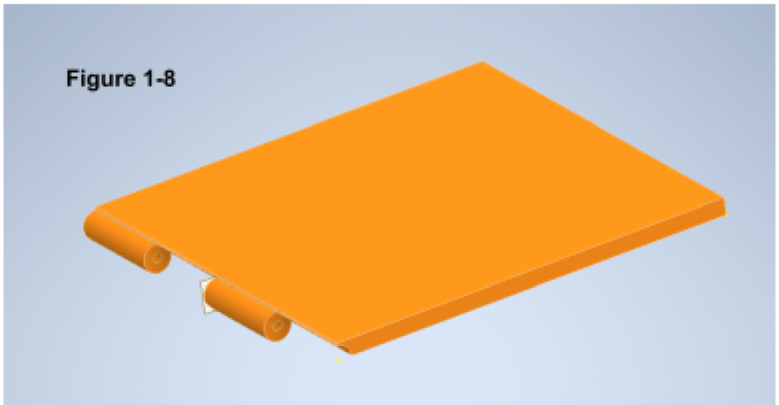


Figure 1-8

7. Once we had both the lid and the box ready we were ready to print it and figure 1-9 can show what the final product looks like with the lid on the box and figure 1-10 shows the box with the lid open.

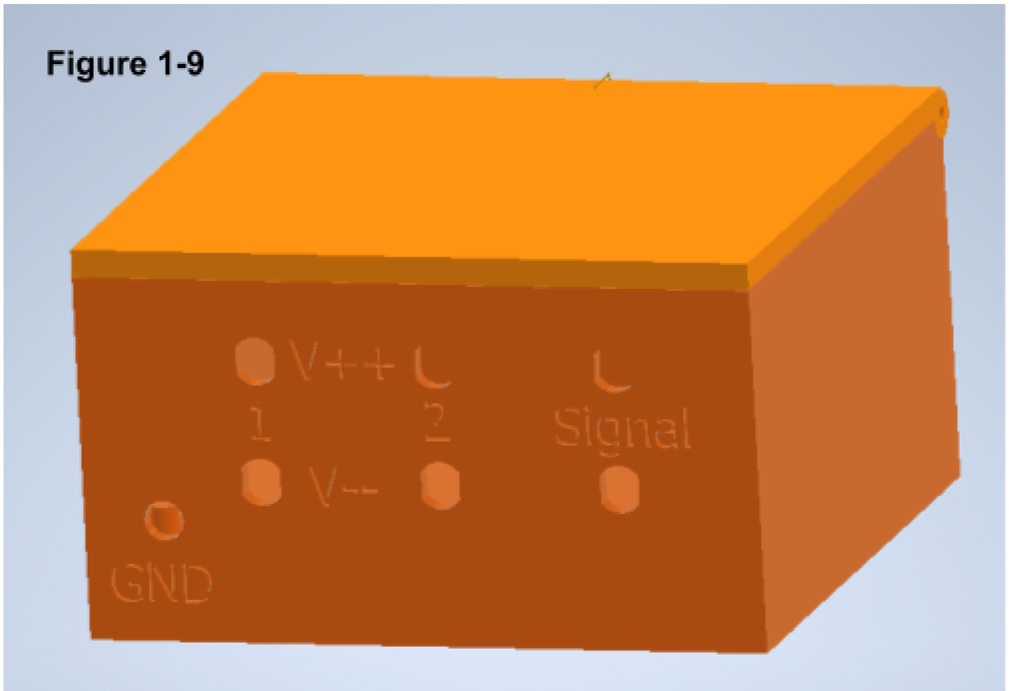


Figure 1-9

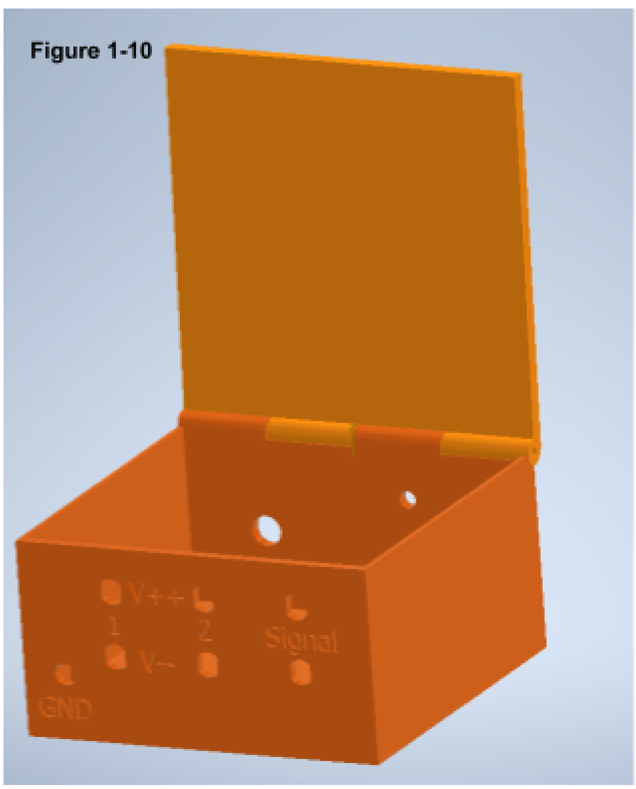


Figure 1-10

Final Product:

1. We first took the circuit and ultiboard from above and created this table for activating each fault we installed which is table 1-5.

Table 1-5 Fault	Activation (switches from left to right)
R_2 open	Turn off first switch
R_9 short-circuited	Turn on second switch
C_1 short-circuited	Turn on third switch
R_4 open	Turn off fourth switch
D_1 short-circuited	Turn on fifth switch
R_5=1kΩ	Turn on sixth switch
R_7=1kΩ	Turn on seventh switch
R_7 open	Turn off eighth switch
R_7 short-circuited	Turn on ninth switch
R_{10} short-circuited	Turn on tenth switch
C_3 open	Turn off eleventh switch
C_4 short-circuited	Turn on twelfth switch

2. We then printed this table out and taped it to the inside lid of the enclosure.
3. In the meantime, other groupmates began to solder together the final PCB board and once they did that we measured our final product fault data in table 1-6. The test side of the final product can be shown in figure 1-11 and the fault side can be shown in figure 1-12.

Figure 1-11

Figure 1-12

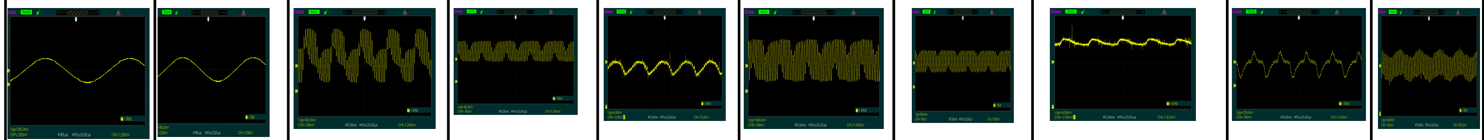
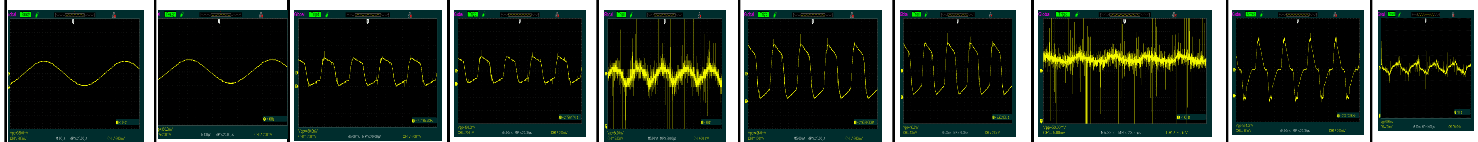
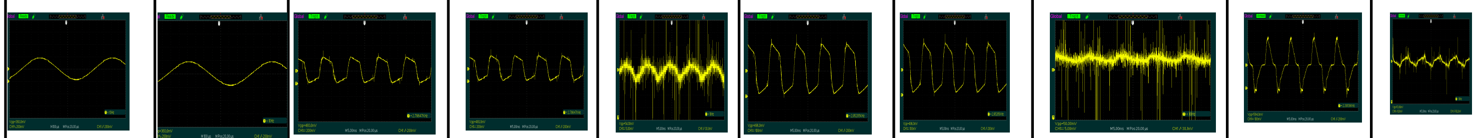
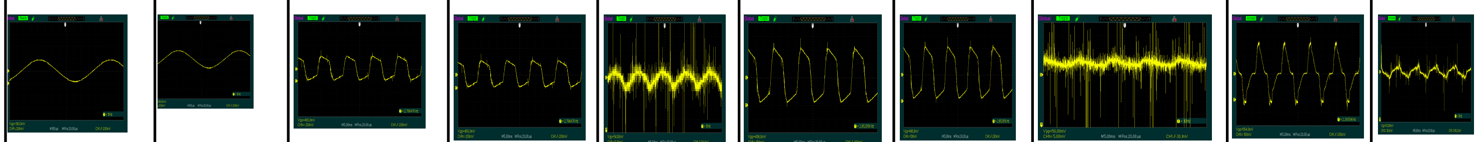
Table 1-6 Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_2 Open	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.400	0.400	0.400	0.200	0.002	0.340	0.200	0.003	0.230	0.028	0.028
R_9 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
C_1 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.008	0.380	0.360	0.007	0.400	0.015	0.028
R_4 open	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028

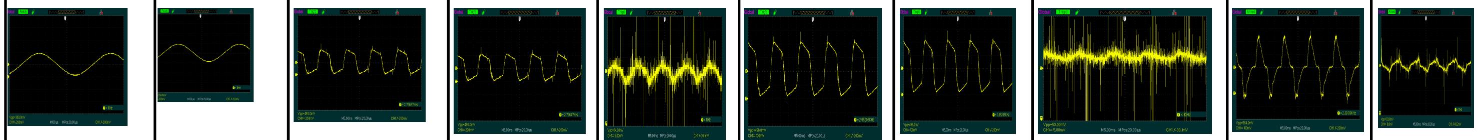
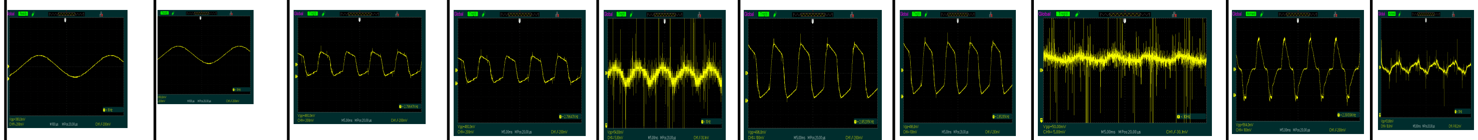
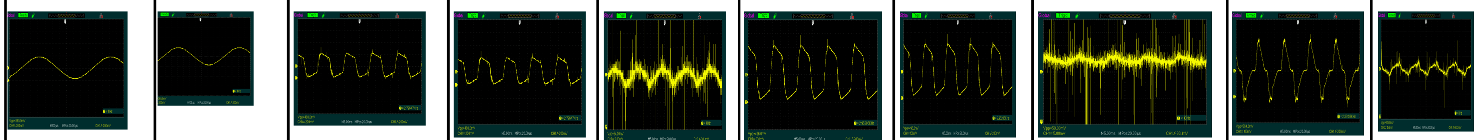
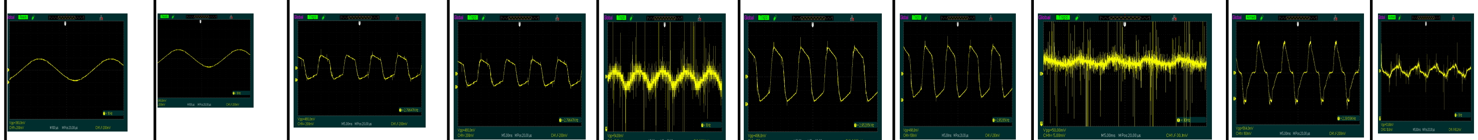
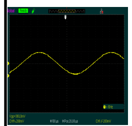
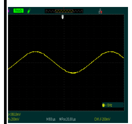
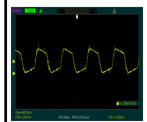
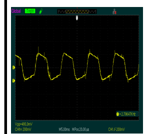
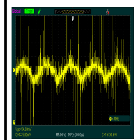
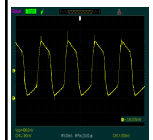
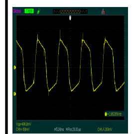
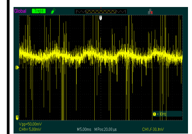
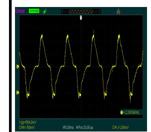
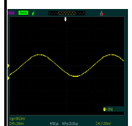
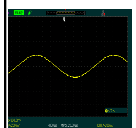
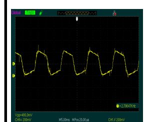
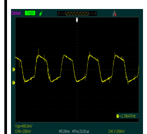
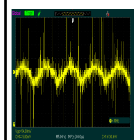
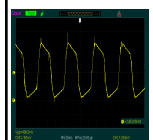
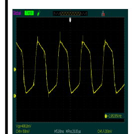
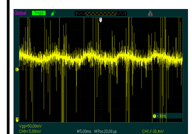
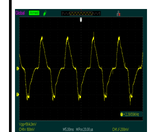
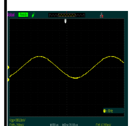
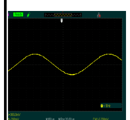
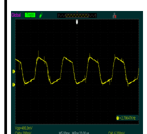
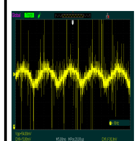
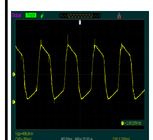
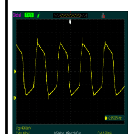
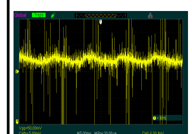
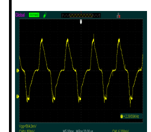
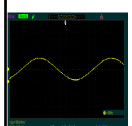
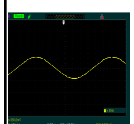
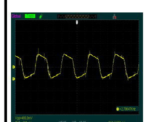
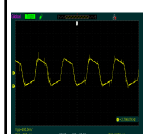
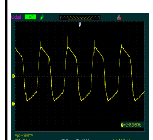
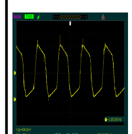
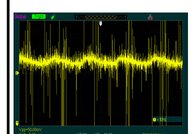
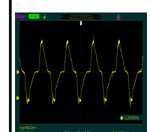
Table 1-6 Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
D_1 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
R_5=1kΩ	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
R_7=1kΩ	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
R_7 open	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028

Table 1-6 Test Point	X	V_{IN}	B	C	D	E	F	G	H	I	J	LEDs
R_7 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
R_{10} short-circuited	Wave											**GREEN**
	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
C_3 open	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028
C_4 short-circuited	Wave											**GREEN**
(V)	$V_{P\text{-}P/DC}$	0.4	0.4	0.400	0.400	0.010	0.312	1.300	0.080	0.525	0.010	0.028

Discussion:

Problem: Our 3D printed enclosure didn't quite fit together right off the printer
Troubleshooting: We thought about how to fix this problem and what could have caused the issue in the first place
Solution: We realized that our issue was due to the fact that we didn't include tolerance in our measurements and sanded our parts down until they fit

Problem: The holes on our PCB were too small for some components to fit through
Troubleshooting: We thought about ways to fix this without needing to reprint our board
Solution: We got a drill bit and widened every hole before trying to solder the component in.

Conclusion

We built and tested a complex op amp circuit throughout the lab when we printed our own PCB and soldered the components to it. We had to make modifications from the original circuit to account for the faults we needed to install and add in rows of switches to control which faults are active at what times. We then tested this completed circuit in table 1-6 where we recorded waveforms and voltage readings at various test points. Unfortunately, our circuit did not work as expected and our data of our final project was very different from our protoboard.

Datasheet:

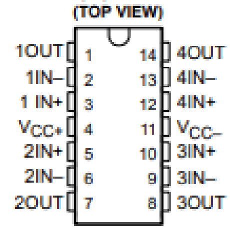
LM348:

LM148, LM248, LM348
QUADRUPLE OPERATIONAL AMPLIFIERS

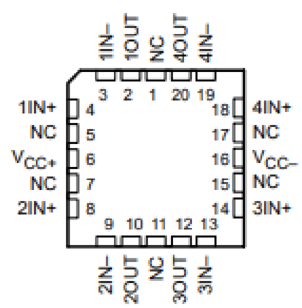
SLOS058C – OCTOBER 1979 – REVISED DECEMBER 2002

- **μA741 Operating Characteristics**
- **Low Supply-Current Drain . . . 0.6 mA Typ (per amplifier)**
- **Low Input Offset Voltage**
- **Low Input Offset Current**
- **Class AB Output Stage**
- **Input/Output Overload Protection**
- **Designed to Be Interchangeable With Industry Standard LM148, LM248, and LM348**

LM148 . . . J PACKAGE
LM248 . . . D OR N PACKAGE
LM348 . . . D, N, OR NS PACKAGE
(TOP VIEW)



LM148 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description/ordering information

The LM148, LM248, and LM348 are quadruple, independent, high-gain, internally compensated operational amplifiers designed to have operating characteristics similar to the μA741. These amplifiers exhibit low supply-current drain and input bias and offset currents that are much less than those of the μA741.

ORDERING INFORMATION

T_A	V_{IO}max AT 25°C	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	6 mV	PDIP (N)	Tube of 25	LM348N	LM348N
		SOIC (D)	Tube of 50	LM348D	LM348
			Reel of 2500	LM348DR	
		SOP (NS)	Reel of 2000	LM348NSR	LM348
–25°C to 85°C	6 mV	PDIP (N)	Tube of 25	LM248N	LM248N
		SOIC (D)	Tube of 50	LM248D	LM248
			Reel of 2500	LM248DR	
–55°C to 125°C	5 mV	CDIP (J)	Tube of 25	LM148J	LM148J
		LCCC (FK)	Tube of 50	LM148FK	LM148FK

† Package drawings, standard packing quantities, thermal data, symboliztion, and PCB design guidelines are available at www.ti.com/sc/package.

recommended operating conditions

	MIN	MAX	UNIT
Supply voltage, V_{CC+}	4	18	V
Supply voltage, V_{CC-}	–4	–18	V

electrical characteristics at specified free-air temperature, $V_{CC\pm}$ = ±15 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†		LM148			LM248			LM348			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0	25°C		1	5		1	6		1	6	mV
			Full range			6			7.5			7.5	
I_{IO}	Input offset current	V_O = 0	25°C		4	25		4	50		4	50	nA
			Full range			75			125			100	
I_{IB}	Input bias current	V_O = 0	25°C		30	100		30	200		30	200	nA
			Full range			325			500			400	
V_{ICR}	Common-mode input voltage range		Full range	±12			±12			±12			V
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	±12	±13		±12	±13		±12	±13		V
		R_L ≥ 10 kΩ	Full range	±12			±12			±12			
		R_L = 2 kΩ	25°C	±10	±12		±10	±12		±10	±12		
		R_L ≥ 2 kΩ	Full range	±10			±10			±10			
A_{VD}	Large-signal differential voltage amplification	V_O = ±10 V, R_L = ≥ 2 kΩ	25°C	50	160		25	160		25	160		V/mV
			Full range	25			15			15			
r_i	Input resistance‡		25°C	0.8	2.5		0.8	2.5		0.8	2.5		MΩ
B_1	Unity-gain bandwidth	A_{VD} = 1	25°C		1			1			1		MHz
ϕ_m	Phase margin	A_{VD} = 1	25°C		60°			60°			60°		
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min, V_O = 0	25°C	70	90		70	90		70	90		dB
			Full range	70			70			70			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	$V_{CC\pm}$ = ±9 V to ±15 V, V_O = 0	25°C	77	96		77	96		77	96		dB
			Full range	77			77			77			
I_{OS}	Short-circuit output current		25°C		±25			±25			±25		mA
I_{CC}	Supply current (four amplifiers)	No load, V_O = 0	25°C					2.4	4.5		2.4	4.5	mA
		No load, V_O = V_{OM}	25°C		2.4	3.6							
V_{O1}/V_{O2}	Crosstalk attenuation	f = 1 Hz to 20 kHz	25°C		120			120			120		dB

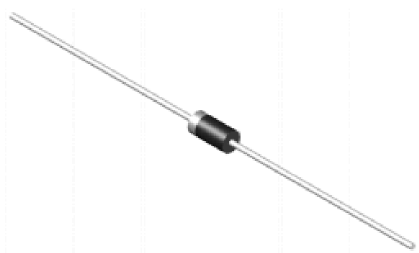
† All characteristics are measured under open-loop conditions with zero common-mode input voltage, unless otherwise specified. Full range for T_A is –55°C to 125°C for LM148, –25°C to 85°C for LM248, and 0°C to 70°C for LM348.
‡ This parameter is not production tested.

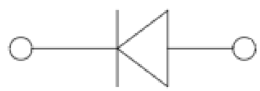
1N4004:

1N4001 THRU 1N4007

RoHS
COMPLIANT

General Purpose Rectifier





Features
- High efficiency
- High current capability
- High reliability
- High surge current capability
- Low power loss
- Solder dip 275 °C max. 7 s, per JESD 22-B106

Mechanical Data
- **Package**: DO-204AL(DO-41)
Molding compound meets UL 94 V-0 flammability rating, RoHS-compliant
- **Terminals**: Tin plated leads, solderable per J-STD-002 and JESD22-B102
- **Polarity:**Color band denotes cathode end

■Maximum Ratings (Ta=25℃ Unless otherwise specified)

PARAMETER	SYMBOL	UNIT	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007
Device marking code			1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007
Repetitive Peak Reverse Voltage	VRRM	V	50	100	200	400	600	800	1000
Average Forward Current @60Hz sine wave, Resistance load, Ta =50℃	$I_{F(AV)}$	A	1.0						
Surge(Non-repetitive)Forward Current @ 60Hz Half-sine wave,1 cycle, Ta=25℃	IFSM	A	30						
Storage Temperature	Tstg	℃	-55 ~+150						
Junction Temperature	Tj	℃	-55~+125						

■Electrical Characteristics (T$_a$=25℃ Unless otherwise specified)

PARAMETER	SYMBOL	UNIT	TEST CONDITIONS	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007
Maximum instantaneous forward voltage drop per diode	V_{FM}	V	IFM=1.0A	1.0						
Maximum DC reverse current at rated DC blocking voltage per diode	I_{RRM1}	μA	T$_a$=25℃	2.5						
	I_{RRM2}		T$_a$=100℃	50						
Typical junction capacitance	Cj	pF	Measured at 1MHZ and Applied Reverse Voltage of 4.0 V.D.C.	12						

■Thermal Characteristics (T$_a$=25℃ Unless otherwise specified)

PARAMETER	SYMBOL	UNIT	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007
Thermal Resistance(Typical)	$R_{θJ-A}$	℃/W	50						

■Ordering Information (Example)

PREFERED P/N	PACKAGE CODE	UNIT WEIGHT(g)	MINIMUM PACKAGE(pcs)	INNER BOX QUANTITY(pcs)	OUTER CARTON QUANTITY(pcs)	DELIVERY MODE
1N4001~1N4007	D1	Approximate 0.27	Approximate 5000	5000	50000	Tape
1N4001~1N4007	C1	Approximate 0.27	Approximate 1000	1000	50000	Bulk

1N4148:

1N4148

www.vishay.com

Vishay Semiconductors

Small Signal Fast Switching Diodes

FEATURES

- Silicon epitaxial planar diode
- Electrically equivalent diodes: 1N4148 - 1N914
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT
HALOGEN FREE

APPLICATIONS

- Extreme fast switches

DESIGN SUPPORT TOOLS click logo to get started

3D Models Available

MECHANICAL DATA

Case: DO-35 (DO-204AH)

Weight: approx. 105 mg

Cathode band color: black

Packaging codes / options:

TR/10K per 13" reel (52 mm tape), 50K/box

TAP/10K per ammopack (52 mm tape), 50K/box

PARTS TABLE

PART	ORDERING CODE	TYPE MARKING	CIRCUIT CONFIGURATION	REMARKS
1N4148	1N4148-TAP or 1N4148TR	V4148	Single	Tape and reel / ammopack

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Repetitive peak reverse voltage		V_{RRM}	100	V
Reverse voltage		V_R	75	V
Peak forward surge current	t_p = 1 µs	I_{FSM}	2	A
Repetitive peak forward current		I_{FRM}	500	mA
Forward continuous current		I_F	300	mA
Average forward current	$V_R = 0$	$I_{F(AV)}$	150	mA
Power dissipation	l = 4 mm, T_L = 45 °C	P_{tot}	440	mW
	l = 4 mm, $T_L \leq$ 25 °C	P_{tot}	500	mW

THERMAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Thermal resistance junction to ambient air	l = 4 mm, T_L = constant	R_{thJA}	350	K/W
Junction temperature		T_j	175	°C
Storage temperature range		T_{stg}	-65 to +150	°C