Name ________________________________

Part A (25 Points) ***Complete on Blackboard***

A. (25 Pts) _________

Part B (75 Points)

1. (12 Pts) _________
2. (12 Pts) _________
3. (10 Pts) _________
4. (8 Pts) _________
5. (11 Pts) _________
6. (6 Pts) _________
7. (13 Pts) _________
8. (3 Pts)__________

Total __________________

Annotate the circuit diagrams with information to help you find the answers to questions..

Show all of your work and write/draw neatly so the grader can figure out what you did.

At least skim through the entire quiz before you begin and then start with the problems you know best.

Note that some questions involve using things you have learned in new ways and some involve some minor new information. Focusing on what you know will make the problems easier to solve.

The proctor will only answer clarification questions where wording is unclear or where there may be errors/typos. No other questions will be responded to.

You have until the end of class to complete the quiz. If you are unable to complete it, make sure you have solved all problems you know how to do. Again, I am trying another approach to constructing this quiz. I will adjust the grades if less than half of the class is able to finish.

May Day in Ireland (TimeandDate.com)

May Day (Lá Bealtaine), or Labour Day (Lá an Lucht Oibre), is the first Monday of May. It is a public holiday in the Republic of Ireland. It is a traditional Celtic festival and a time to campaign for workers' rights.

The maypole dance is a fading tradition associated with May Day in Ireland. ©iStockphoto.com/Thomas Sarradet

What Do People Do?

Fairs or communal meals are held in some villages. Some people attend Labour Day parades, demonstrations and celebrations in large cities. These often attract contingents from trade unions, political parties and groups campaigning for social justice from the Republic of Ireland and Northern Ireland. These events may be on the first Monday of May or a Saturday close to this date.

Public Life

Banks, post offices and many other businesses and organizations are closed on the first Monday of May. However, stores and pubs are generally open, although they may open later and close earlier than usual. Public transport service schedules vary depending on where one lives and intends to travel. There may be some local disruption to traffic due to parades.

Background

The beginning of May is associated with the Celtic festival *Lá Bealtaine*. This marked the start of the season of blossoming flowers and fruit trees. Traditionally, belfires are lit on the evening before May Day. Belfires are large bonfires burning wood from a range of types of trees. The different types of wood had different spiritual meanings and were thought to play an important role in the fertility of the land and cattle in the coming year.

The first Monday of May became a public holiday following the *Public Holiday Regulations 1993 Act*. The holiday was first observed in 1994.

Symbols

The maypole is a traditional symbol of May Day and fertility in the Republic of Ireland. A maypole is generally three or more meters (ten or more feet) tall and is decorated with colorful ribbons. Children and young people traditionally dance around the maypole on May Day, although this custom is fading. Each person holds one or more ribbons during the dancing. After the dances are completed, the ribbons are arranged to make a decorative pattern on the pole. The May Day dances traditionally signified the beginning of the courting season for young people.

Op-Amp Specs (Excerpts)

ANALOG DEVICES

Low Noise, Precision Operational Amplifier

Data Sheet **OP27**

FEATURES

Low noise: 80 nV p-p (0.1 Hz to 10 Hz), 3 nV/√Hz
Low drift: 0.2 μV/°C
High speed: 2.8 V/μs slew rate, 8 MHz gain bandwidth
Low V_{OS}: 10 μV
CMRR: 126 dB at VCM of ±11 V
High open-loop gain: 1.8 million
Available in die form

GENERAL DESCRIPTION

The OP27 precision operational amplifier combines the low offset and drift of the OP07 with both high speed and low noise. Offsets down to 25 μV and maximum drift of 0.6 μV/°C make the OP27 ideal for precision instrumentation applications. Low noise, e_n = 3.5 nV/√Hz, at 10 Hz, a low 1/f noise corner frequency of 2.7 Hz, and high gain (1.8 million), allow accurate high-gain amplification of low-level signals. A gain bandwidth product of 8 MHz and a 2.8 V/μs slew rate provide excellent dynamic accuracy in high speed, data-acquisition systems.

A low input bias current of ±10 nA is achieved by use of a bias current cancellation circuit. Over the military temperature range, this circuit typically holds I_B and I_{OS} to ±20 nA and 15 nA, respectively.

The output stage has good load driving capability. A guaranteed swing of ±10 V into 600 Ω and low output distortion make the OP27 an excellent choice for professional audio applications.

(Continued from Page 1)

PSRR and CMRR exceed 120 dB. These characteristics, coupled with long-term drift of 0.2 μV/month, allow the circuit designer to achieve performance levels previously attained only by discrete designs.

Low cost, high volume production of OP27 is achieved by using an on-chip Zener zap-trimming network. This reliable and stable offset trimming scheme has proven its effectiveness over many years of production history.

The OP27 provides excellent performance in low noise, high accuracy amplification of low level signals. Applications include stable integrators, precision summing amplifiers, precision voltage threshold detectors, comparators, and professional audio circuits such as tape heads and microphone preamplifiers.

PIN CONFIGURATIONS

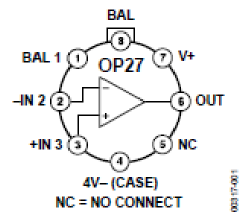


Figure 1. 8-Lead TO-99 (J-Suffix)

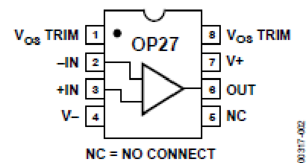


Figure 2. 8-Lead CERDIP – Glass Hermetic Seal (Z-Suffix), 8-Lead PDIP (P-Suffix), and 8-Lead SOIC (S-Suffix)

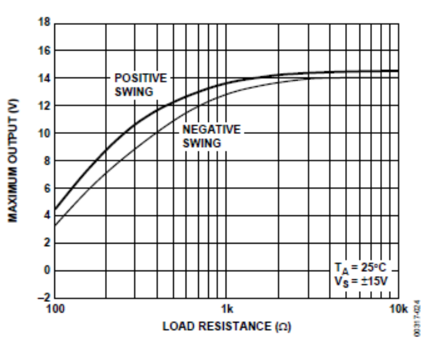


Figure 24. Maximum Output Voltage vs. Load Resistance

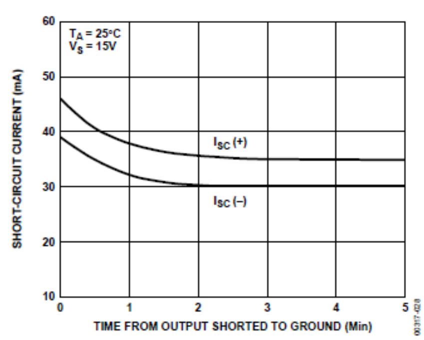


Figure 28. Short-Circuit Current vs. Time

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

$V_S = \pm15$ V, $T_A = 25°C$, unless otherwise noted.

Table 1.

Parameter	Symbol	Test Conditions	OP27A/OP27E Min	Typ	Max	OP27G Min	Typ	Max	Unit
INPUT OFFSET VOLTAGE[1]	V_{OS}			10	25		30	100	µV
LONG-TERM V_{OS} STABILITY[2, 3]	V_{OS}/Time			0.2	1.0		0.4	2.0	µV/Mo
INPUT OFFSET CURRENT	I_{OS}			7	35		12	75	nA
INPUT BIAS CURRENT	I_B			±10	±40		±15	±80	nA
INPUT NOISE VOLTAGE[3, 4]	$e_{n\ p\text{-}p}$	0.1 Hz to 10 Hz		0.08	0.18		0.09	0.25	µV p-p
INPUT NOISE Voltage Density[3]	e_n	f_O = 10 Hz		3.5	5.5		3.8	8.0	nV/√Hz
		f_O = 30 Hz		3.1	4.5		3.3	5.6	nV/√Hz
		f_O = 1000 Hz		3.0	3.8		3.2	4.5	nV/√Hz
INPUT NOISE Current Density[3]	i_n	f_O = 10 Hz		1.7	4.0		1.7		pA/√Hz
		f_O = 30 Hz		1.0	2.3		1.0		pA/√Hz
		f_O = 1000 Hz		0.4	0.6		0.4	0.6	pA/√Hz
INPUT RESISTANCE									
Differential Mode[5]	R_{IN}		1.3	6		0.7	4		MΩ
Common Mode	R_{INCM}			3			2		GΩ
INPUT VOLTAGE RANGE	IVR		±11.0	±12.3		±11.0	±12.3		V
COMMON-MODE REJECTION RATIO	CMRR	V_{CM} = ±11 V	114	126		100	120		dB
POWER SUPPLY REJECTION RATIO	PSRR	V_S = ±4 V to ±18 V		1	10		2	20	µV/V
LARGE SIGNAL VOLTAGE GAIN	A_{VO}	$R_L \ge 2$ kΩ, V_O = ±10 V	1000	1800		700	1500		V/mV
		$R_L \ge 600$ Ω, V_O = ±10 V	800	1500		600	1500		V/mV
OUTPUT VOLTAGE SWING	V_O	$R_L \ge 2$ kΩ	±12.0	±13.8		±11.5	±13.5		V
		$R_L \ge 600$ Ω	±10.0	±11.5		±10.0	±11.5		V
SLEW RATE[6]	SR	$R_L \ge 2$ kΩ	1.7	2.8		1.7	2.8		V/µs
GAIN BANDWIDTH PRODUCT[6]	GBW		5.0	8.0		5.0	8.0		MHz
OPEN-LOOP OUTPUT RESISTANCE	R_O	V_O = 0, I_O = 0		70			70		Ω
POWER CONSUMPTION	P_d	V_O		90	140		100	170	mW
OFFSET ADJUSTMENT RANGE		R_P = 10 kΩ		±4.0			±4.0		mV

[1] Input offset voltage measurements are performed approximately 0.5 seconds after application of power. A/E grades guaranteed fully warmed up.
[2] Long-term input offset voltage stability refers to the average trend line of V_{OS} vs. time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 days are typically 2.5 µV. Refer to the Typical Performance Characteristics section.
[3] Sample tested.
[4] See voltage noise test circuit (Figure 31).
[5] Guaranteed by input bias current.
[6] Guaranteed by design.

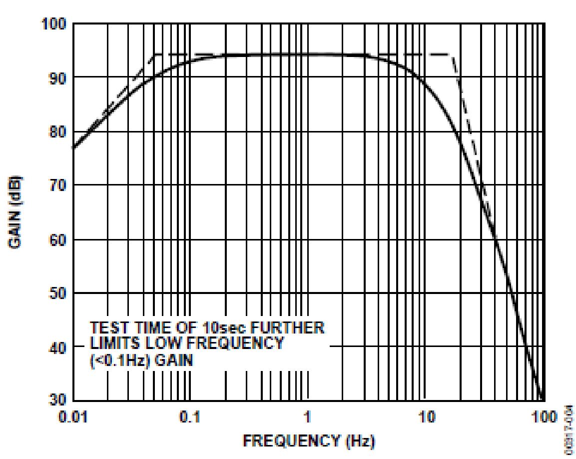


Figure 4. 0.1 Hz to 10 Hz p-p Noise Tester Frequency Response

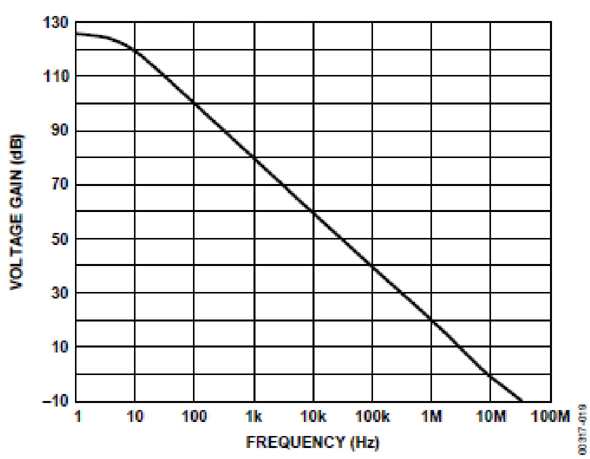


Figure 19. Open-Loop Gain vs. Frequency

ABSOLUTE MAXIMUM RATINGS

Table 5.

Parameter	Rating
Supply Voltage	±22 V
Input Voltage[1]	±22 V
Output Short-Circuit Duration	Indefinite
Differential Input Voltage[2]	±0.7 V
Differential Input Current[2]	±25 mA
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	
OP27A (J, Z)	−55°C to +125°C
OP27E (Z)	−25°C to +85°C
OP27E (P)	0°C to 70°C
OP27G (P, S, J, Z)	−40°C to +85°C
Lead Temperature Range (Soldering, 60 sec)	300°C
Junction Temperature	−65°C to +150°C

[1] For supply voltages less than ±22 V, the absolute maximum input voltage is equal to the supply voltage.
[2] The inputs of the OP27 are protected by back-to-back diodes. Current limiting resistors are not used in order to achieve low noise. If differential input voltage exceeds ±0.7 V, the input current should be limited to 25 mA.

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, θ_{JA} is specified for device in socket for TO-99, CERDIP, and PDIP packages; θ_{JA} is specified for device soldered to printed circuit board for SOIC package.

Absolute maximum ratings apply to both dice and packaged parts, unless otherwise noted.

Table 6.

Package Type	θ_{JA}	θ_{JC}	Unit
8-Lead Metal Can (TO-99) (J)	150	18	°C/W
8-Lead CERDIP (Z)	148	16	°C/W
8-Lead PDIP (P)	103	43	°C/W
8-Lead SOIC_N (S)	158	43	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

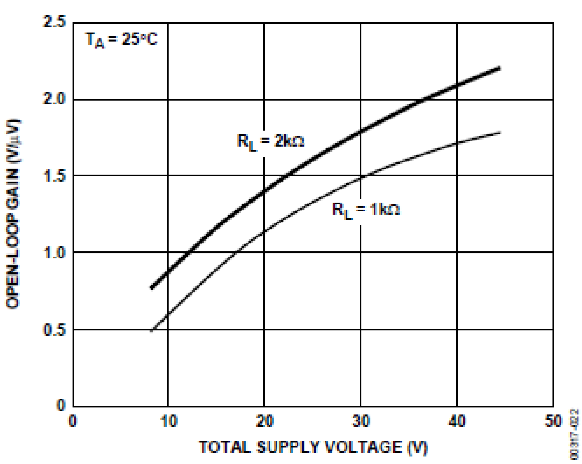


Figure 22. Open-Loop Voltage Gain vs. Supply Voltage

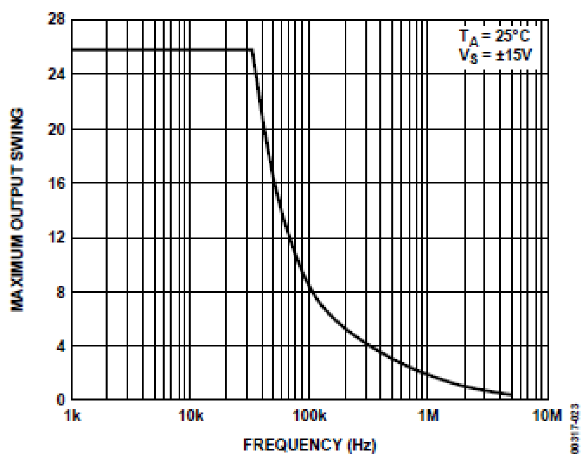


Figure 23. Maximum Output Swing vs. Frequency

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Part B (75 Points)

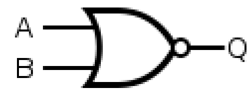
Problem 1 (12 Points) – System Design: Devices and Functions
This problem helps to define the context for the remaining questions. Identify at least 4 devices and functions located in the same cell in each table by circling the cells and numbering them from 2 to 5. An example is shown for the NOT GATE in column 2, row 6 as is its function 'Change True to False or False to True' and it is numbered 1.

DEVICE		
VOLTAGE DIVIDER	HIGH-PASS FILTER	INVERTING AMPLIFIER
DC VOLTAGE SOURCE	NON-INVERTING AMPLIFIER	CAPACITOR
FUNCTION GENERATOR	BAND-PASS FILTER	INDUCTOR
RESISTOR	OP-AMP	OR GATE
PHOTOTRANSISTOR	FULL-WAVE RECTIFIER	555 TIMER
BAND REJECT FILTER	NOT GATE 1	AND GATE
NAND GATE	TRANSFORMER	NOR GATE
TRANSFORMER	OSCILLOSCOPE	LOW-PASS FILTER
DIODE	TRANSISTOR SWITCH	HALF-WAVE RECTIFIER
PHOTODIODE	LED	PHOTOCELL

Function		
Make Voltage Smaller	Convert AC Voltages to DC Voltages	Match Impedance
Block Current in One Direction Only	Store Energy	Block DC with a Single Component
Output an Electrical Signal	ON-OFF Switch	Store Energy
Increase Voltage, Power and Current while reversing Polarities	Deciding a Process is True if Any Monitored Conditions are False	Block a Small Range of Frequencies but Pass Others
Increase Voltage without an External Power Supply	Convert Light Energy into Electrical Energy	Block High Frequencies with a Single Components
Deciding a Process is True Only if All Monitored Conditions are True	Change True to False or False to True 1	Deciding a Process is True if Any Monitored Conditions are False
Pass a Small Range of Frequencies but Block Others	Increase Voltage, Power and Current while keeping Polarities the Same	Deciding a Process is True if Any Monitored Conditions are True
Increase Current Without an External Power Supply	Measure Voltage vs Time	Convert Electrical Energy into Heat
Produce an Output Voltage at least Thousands of Time Larger than the Difference between Two Inputs	Produce a Sequence of Square Voltage Pulses	Make the Output Voltage Larger than the Input Voltage
Produce a Single Square Pulse	Convert Electrical Energy into Light	Convert Light Energy into Electrical Energy

Problem 2 (12 Points) – Logic Gates

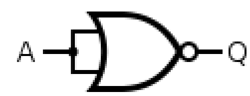
This problem addresses building logic devices from a single type of device, which is shown at the right.



a. (3 Pts) What kind of a logic gate is this and what is its truth table? Name the device and fill out the table below.

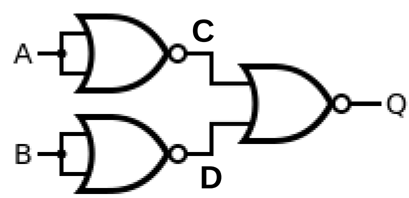
Input A	Input B	Output Q
0	0	
0	1	
1	0	
1	1	

b. (3 Pts) Assume that the two inputs are tied together to create a single input device, as shown. Name the device and fill out its truth table below.



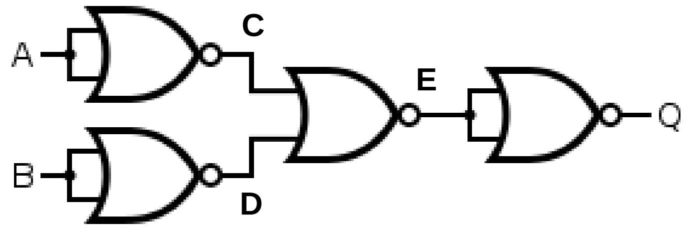
Input A	Output Q
0	
1	

c. (3 Pts) Assume that two of the configurations from part b are combined with the device from part a, as shown. Name the device that matches the functionality of this combination and fill out its truth table below. Note that, unlike parts a and b, you are asked to find the values at the intermediate points, not just the inputs and output.



Input A	Input B	C	D	Output Q
0	0			
0	1			
1	0			
1	1			

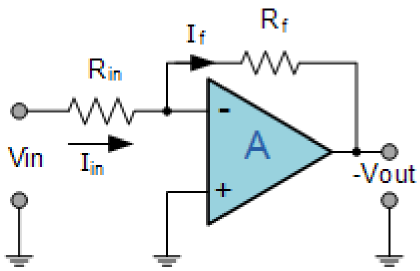
d. (3 Pts) Finally, add one more configuration from part b. Name the device this combination produces and fill out its truth table. Again, you must find the values at intermediate points, not just the inputs and output.

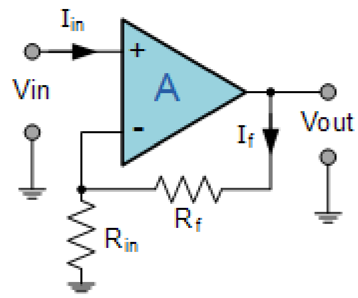


Input A	Input B	C	D	E	Output Q
0	0				
0	1				
1	0				
1	1				

Problem 3 (10 Points) – Operational Amplifiers

The two amplifier circuits below are configured with the same op-amp and resistors. Identify which type of amplifier each is and its gain $G = \frac{V_{out}}{V_{in}}$. For your calculations, assume that R_{in}= *11kΩ and Rf= 33kΩ.*





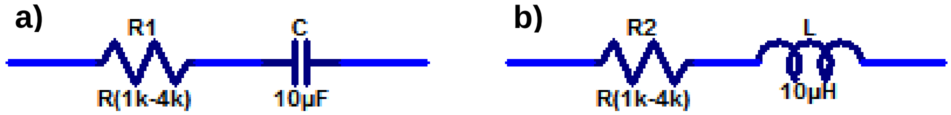
a. (3 Pts) The circuit at the left:

b. (3 Pts) The circuit at the right:

c. (2 Pts) If the op-amp is powered with two 9V batteries, which of the following input voltages listed below will the amplifier on the left be able to amplify without distortion? Circle all correct answers. *Hint: Assume the op-amp output voltage can swing to ±9V.*
   a. 1V
   b. 2V
   c. 3V
   d. 4V
   e. 5V

d. (2 Pts) If the op-amp is powered with two 9V batteries, which of the following input voltages listed below will the amplifier on the right be able to amplify without distortion? Circle all correct answers. *Hint: Assume the op-amp output voltage can swing to ±9V.*
   a. 1V
   b. 2V
   c. 3V
   d. 4V
   e. 5V

Problem 4 (8 Points) – Complex Impedance



Note that a range is given for the resistance value. That is because it will represent the net resistance from a voltage divider in which one resistor is a photocell (light dependent resistor).

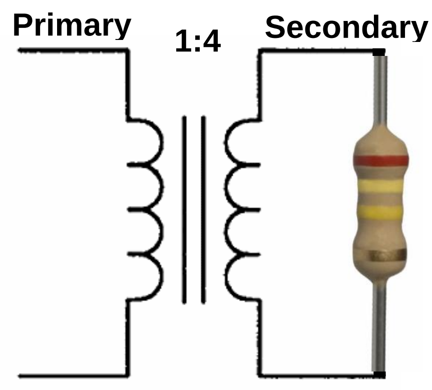
Earlier this semester, we analyzed circuits using complex impedances, where the impedance of resistors is real and the impedances of inductors and capacitors are imaginary. The ability to analyze circuits like the ones shown above may be useful in a following problem. To be prepared for the problem, you are to evaluate the net impedance of the two circuits at the bottom end (300Hz) and the top end (3.3kHz) of a practical audio range of frequencies. This is the historical audio range covered by traditional telephone services called POTS for Plain Old Telephone Service. (Really … that is what it is called!) This was the standard from 1876 – 1988 and still dominates thinking about what is good sound for a telephone.

a. (4 Pts) Evaluate the impedances for both L and C at these two frequencies and fill in the table below. That is, find Z_C and Z_L. *Be sure to show the full expression including j or i.*

Frequency	300Hz	3.3kHz
Z_C		
Z_L		

b. (4 Pts) If the magnitude of the capacitive or inductive impedance is less than 20% of the smallest resistance (remember there is a range specified), we will be able to be able to neglect it when we do simple analysis of a circuit in which this combination of components is found. For which of the four possible conditions in the table (two frequencies, Z_C and Z_L) can we neglect the imaginary impedance of Z_C or Z_L?

Problem 5 (11 Points) – Transformers



Transformers sometimes also play a role in practical audio circuits. Shown at the right is the symbol for an iron core transformer, like the one you built by winding magnet wires on a toroidal ferrite core. Unlike the one you made, this transformer does not have the same number of turns on the primary and the secondary. Rather it has 4 times as many secondary turns than primary. Assume that the transformer has the load resistor shown (colors are red-yellow-yellow).

a. (1 Pt) What is the value of the load resistor?

b. (2 Pts) What is the ratio of $\frac{V_{out}}{V_{in}}$?

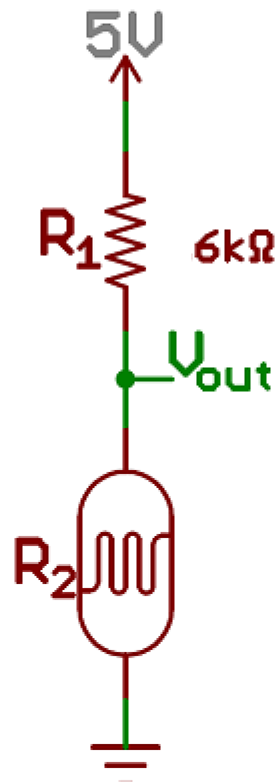
c. (2 Pts) What is the ratio of $\frac{I_{out}}{I_{in}}$?

d. (3 Pts) What is the input impedance of the loaded transformer Z_{in}? That is, what is $\frac{V_{in}}{I_{in}}$?

e. (3 Pts) If the RMS sinusoidal input voltage is 1V, how much power is delivered to the load resistor?

Problem 6 (6 Points) – Photocell Voltage Divider

A photocell, like the one we have used in class, is part of a simple voltage divider, as shown in the figure. The divider is connected to a 5V DC power supply. The upper resistor, $R_1 = 6k\Omega$, while the photocell varies between $1.5k\Omega$ and $9k\Omega$ for the range of light levels it experiences.

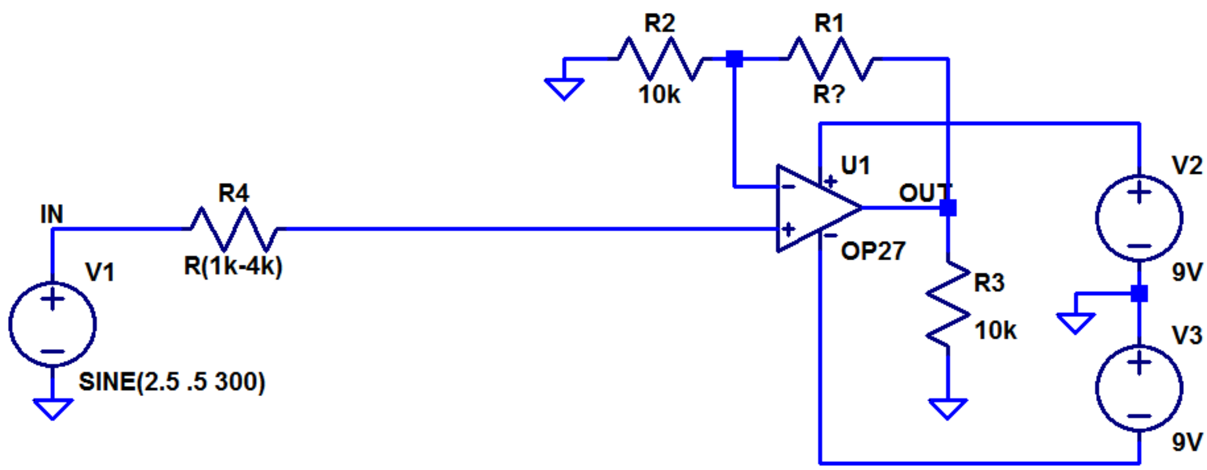


a. (3 Pts) Determine the minimum value of V_{out}.

b. (3 Pts) Determine the maximum value of V_{out}.

c. (4 Pts Extra Credit) Determine the Thevenin Equivalent voltage and resistance for both cases.

Problem 7 (13 Points) – Audio Frequency Light Sensor Amplifier

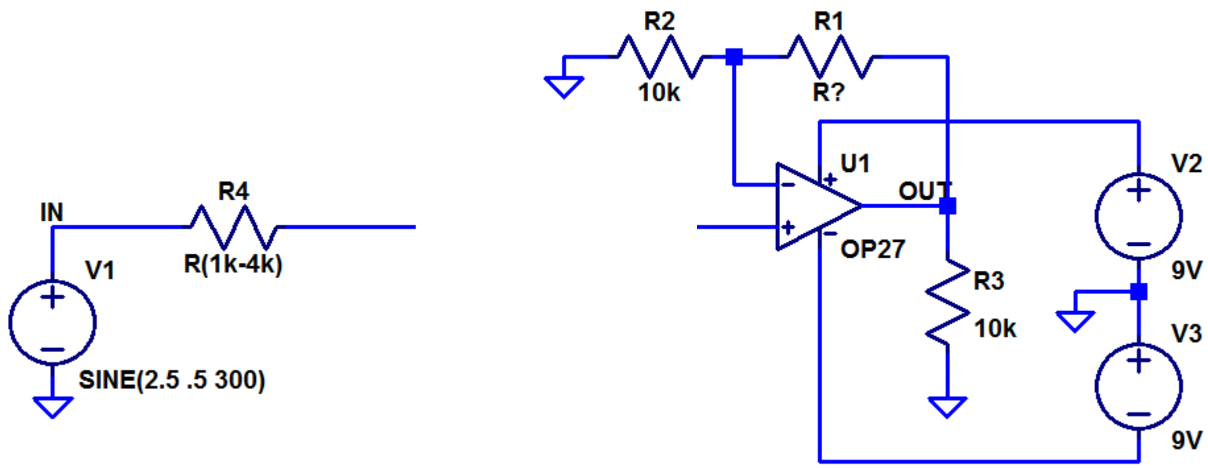


In the circuit above, the voltage source V1 and the resistor R4 represent the approximate range of the behavior of the voltage divider circuit from the previous problem. Not exactly, just similar. The frequency is 300Hz (bottom of the specified audio range) and the resistor varies from 1kΩ to 4kΩ. The source is sinusoidal with offset 2.5V and amplitude 0.5V. The op-amp is an OP27G. On the spec sheet found at the beginning of this quiz, you will find the Output Voltage Swing for the OP27G when it is powered by ±15V. Assume that the percentage output swing is the same for the ±9V used in the circuit above.

a. (2 Pts) What is the maximum possible voltage swing for the circuit above?

b. (2 Pts) What kind of an amplifier is this circuit?

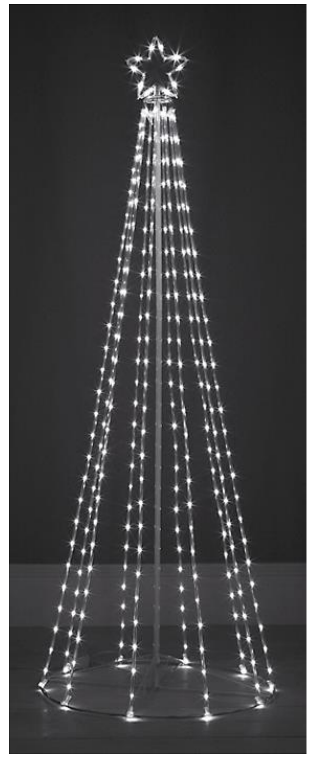
c. (3 Pts) Note that resistor R1 is unspecified. How large can it be if the output has to be less than the voltage swing you found in part a? Remember that you will need to include the offset in your calculation. First find the theoretical value and then find the largest possible standard value (see chart at the beginning of this quiz). *Hint: start by writing the general expression for the gain for this type of amplifier. Also think about how much current is going through R4… which you can figure out from one of the two conditions that op-amps must satisfy when they have negative feedback (found in the upper left-hand cell of the table on page 2 of the Quiz 3 formula sheet).*



d. (3 Pts) If we are interested in only amplifying the sinusoidal part of the input voltage and not the offset, we will need to add a component that blocks DC but passes higher frequencies. We know that capacitors and inductors are open circuits in some frequency ranges (either really large or really small) and, thus, one of them will block DC. Which one is it? Note that we use the other one to block high frequencies. Draw the additional component in the circuit above in the space between R4 and the + input to the op-amp. You will now have a combination with the resistor R4 that looks like either circuit a) or circuit b) in Problem 4. *Use the same value for C or L from problem 4 in the diagram.*

e. (3 Pts) Assume that the component you added in part d successfully blocks the DC offset voltage. Now how large can R be? Again, find the theoretical value and then the largest standard value.

Problem 8 (3 Points) – LED Maypole



Finally, we will have a problem based on the fact that it is Irish May Day today. Assume you make a ‘tree’ inspired by the maypole out of strings of LEDs connected in series. If the string is 50 LEDs, each of which has a forward voltage of 3.3V and an optimum operating current of 50mA, what resistor should you connect between the LEDs and a 180V DC power supply?