2. RC Filters and Diodes

Learning Objectives

Design, build, and characterize the first-order RC filters. Learn characteristics of diodes. Practice how to use instruments to measure frequency dependence, transient response, and how to perform data analysis and curve fitting.

Assignments Before the Laboratory Session

Following components are needed for this experiment:

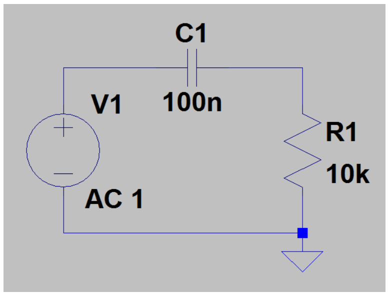
1. A collection of capacitors from a few hundred pF to 100 μF.
2. A collection of resistors from 1 kΩ to 1 MΩ.
3. A 1N4001 rectifying diode.

Print out the cover and score sheet. Bring it to the laboratory session. Fill in your name. Get the signature of teaching assistant when you complete the experiment as attendance record. Do the same for all experiments.

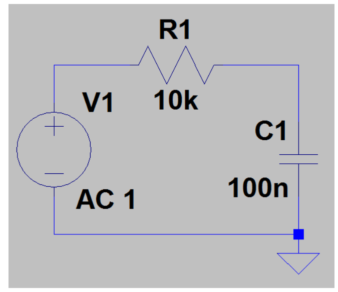
Passive components are basic to electronic circuits. Resistors control current, capacitors store charge, and inductors interact with time-varying magnetic field. An ideal resistor operates in dc and ac. Its resistance is independent of frequency. On the other hand, both capacitor and inductor have frequency-dependent impedances. A capacitor is an open circuit, i.e., infinite impedance, while an inductor is a short circuit, i.e., zero impedance, at dc. At very high frequency, the impedance of a capacitor approaches zero. How about inductor? The frequency dependence enables circuit designers to build circuits with a desired frequency response using R, L, and C. In this experiment, students use resistor and capacitor to build the first-order filters. Why do we need filters? Filters can select the signal within the information band and suppress the noise outside.

Inductors are used in power and radio frequency circuits. Transformer is formed by coupling two inductors through a common magnetic core. An ac input voltage can be transformed to a higher or lower output voltage according to the ratio of turns in the primary and secondary windings. Transformers are widely used in power circuits and for impedance matching.

As shown in Fig. 1, there are two basic RC filters, high pass filter and low pass filter, each consisting of a resistor and a capacitor. The high pass filter has the output signal across the resistor. It attenuates the low frequency while passing through the high frequency. The low pass filter has the output across the capacitor. It passes the low frequency while attenuating the high frequency. Together they can form a band pass filter allowing mid-frequency signal to pass through without much attenuation while low and high frequency signals are attenuated. They can also form equalizers. Search the web and learn what an equalizer is and where it is used. Filters have broad applications in tuning and in noise suppression. One can also use the RC circuit to control timing.



(a)



(b)

Fig. 1. (a) The high pass R·C filter circuit, (b) The low pass R·C filter circuit. The –3dB frequency of both filters is 158 Hz.

For sinusoidal ac signals, the amplitude attenuation and the phase shift of R·C filters can be modeled in the frequency domain by using the complex impedance of capacitor:

$$Z_C = \frac{1}{j\omega C} \tag{1}$$

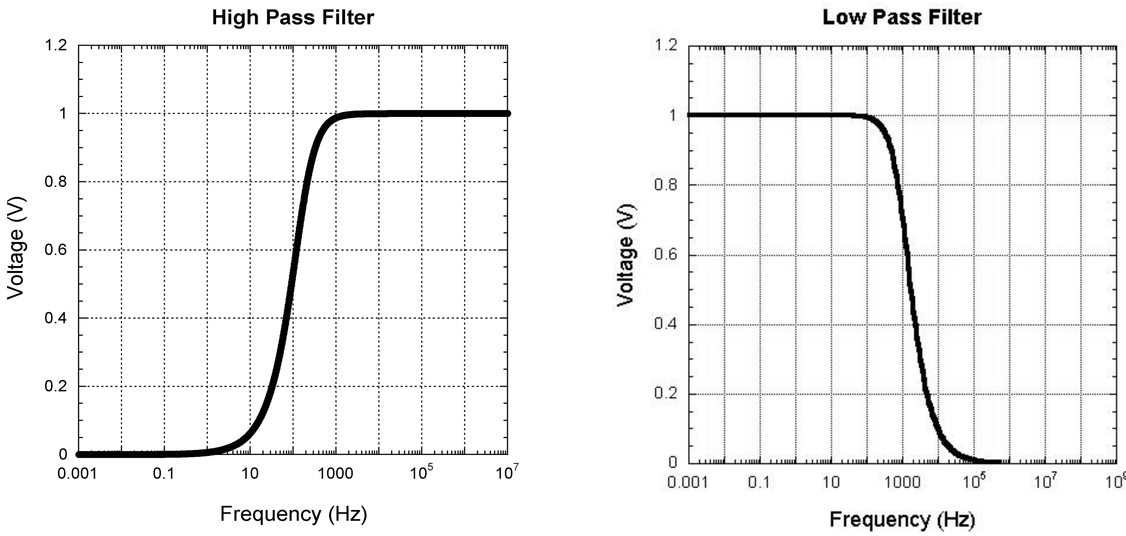
where $j = \sqrt{-1}$. R·C filters can be treated as voltage dividers. For example, the low pass filter has

$$\frac{v_o}{v_{in}} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega/\omega_0} = \sqrt{\frac{1}{1+\omega^2/\omega_0^2}} \cdot e^{-j\tan^{-1}\frac{\omega}{\omega_0}} \tag{2}$$

where ω_0=1/(R·C). It is the angular frequency, $2\pi f_0$, at which the amplitude of the output voltage is reduced by a factor of 1/√2 or 70.7%. Since the power is proportional to voltage square, the power is reduced to 1/2 or 50%. For signal throughput, we often use the log scale. Decibel or dB is defined as 10 x log (P_{out}/P_{in}). When the throughput drops to 50%, it is -3 dB from its maximum. Therefore, f_0 is called the -3 dB cutoff point of the low pass filter. The cutoff frequency of a low pass filter usually occurs at high frequency. Likewise, for the high pass filter we have

$$\frac{v_o}{v_{in}} = \frac{R}{R + 1/j\omega C} = \frac{1}{1 - j\omega_0/\omega} = \sqrt{\frac{1}{1+\omega_0^2/\omega^2}} \cdot e^{j\tan^{-1}\frac{\omega_0}{\omega}} \tag{3}$$

Again, ω_0 equals 1/(R·C). It is the angular frequency at which the output voltage is reduced to 70.7%. The cutoff frequency of a high pass filter usually occurs at low frequency. The frequency response of low pass and high pass filters are shown in Fig. 2. There is a roll off at high frequency for the low pass filter and a roll off at low frequency for the high pass filters, respectively.



(a) (b)

Fig. 2. (a) The frequency response of the high pass filter, (b) The frequency response of the low pass filter. The plots are semi-log with the frequency in log scale and voltage in linear scale.

The presence of the complex number indicates that there is a frequency-dependent phase shift. What is the phase shift at the -3dB frequency? You can easily figure it out. It is $\pi/4$ or 45^o. The phase shift can be measured by displaying both the sinusoidal input signal and the output signal using a dual trace oscilloscope. Measure the period of the waveform, T_0. Measure the relative timing between two waveforms, ΔT. The phase difference can be calculated as $\theta = \Delta T / T_0 \cdot 2\pi$. An example recorded from an amplifier circuit is shown in Fig. 3.

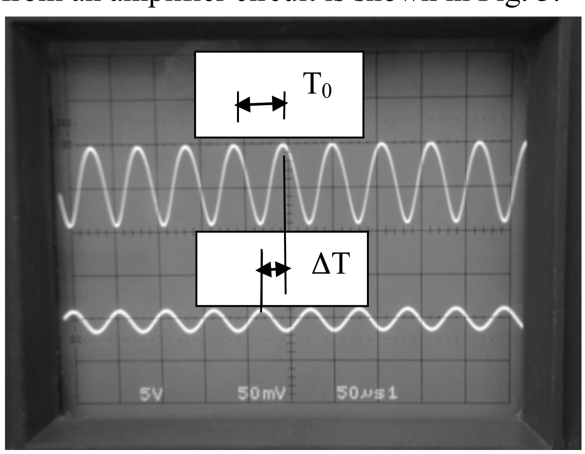
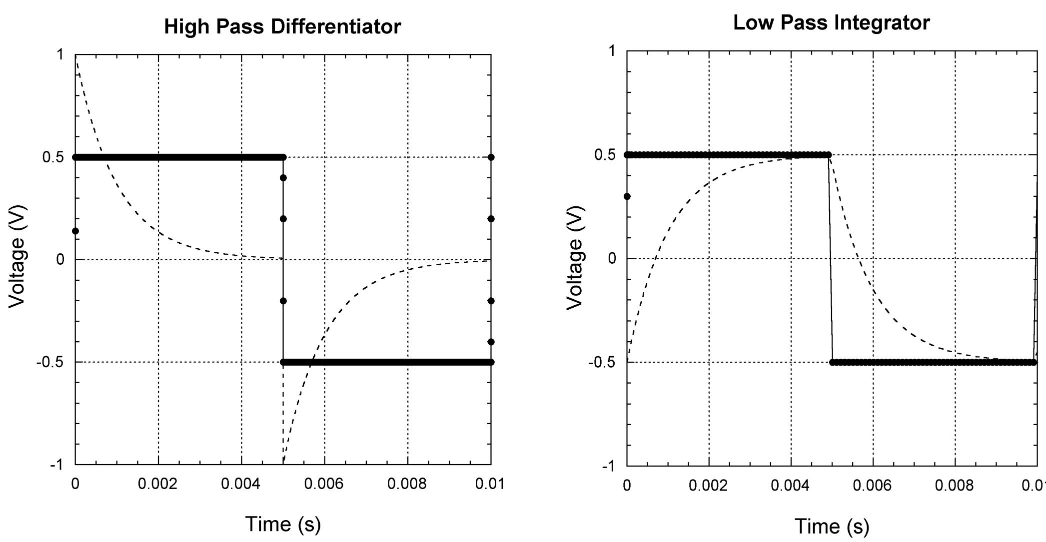


Fig. 3. Measuring the phase difference using a dual trace oscilloscope. T_0 is the period of the sinusoidal wave. The time delay between the peak of the input and the peak of the output is ΔT. In this example, the phase difference is π or 180^o.

The transient (time) responses of low pass and high pass filters to a 1-V peak-to-peak square waveform (-0.5 V to 0.5 V) are shown in Fig. 4. The high pass filter responses quickly to the rising or trailing edge and suppresses any non-zero steady voltage similar to a differentiator. The low pass filter can't track fast transitions. It gradually rises or decays to reach the steady waveform like an integrator. Time domain analysis can be performed by solving the differential equation with boundary conditions at time zero and infinity.

Filter design is quite simple. Consider a low pass filter with f_0 = 20 kHz. There are two components, R and C. To prevent excessive loading to the signal source, you should keep in mind that the resistance should be in the kΩ range. A specific value of capacitance in the right order of magnitude can be chosen according to the collection of capacitors available on hand, e.g., C = 2.2 nF. Since $2\pi f_0 = 1/RC = 1.25\text{x}10^5$, R = 3.6 kΩ. In putting the circuit together, you can use a standard resistor with a resistance of 3.1 kΩ which is a reasonably close match. You can add a 470 Ω resistor in series. Or, you can use a 10-kΩ potentiometer and adjust it to get the exact resistance. Of course, there are many combinations of R and C to accomplish the design goal. Use resistors in the kΩ range so that you won't load down the output of the function generator.



(a) (b)

Fig. 4. (a) The transient response of a high pass filter to a square input waveform, (b) The transient response of a low pass filter to a square input waveform. The output waveforms are shown as dotted curves.

There are many other filters with different frequency characteristics. For example, one can build a bandpass filter which has a high throughput within the filter band by cascading a high pass filter and a low pass filter. A notch filter, on the other hand, has a high throughput outside the filter band.

In the second half of the experiment, we will study and characterize a semiconductor pn junction diode. The entire electronics industry is based mostly on semiconductors. In a semiconductor, the difference between the energy of localized electrons and that of mobile electrons is relatively small. Therefore, the electronic properties of semiconductors can be easily modulated by a moderate voltage. Doping with impurity is a convenient way to control the conductivity of semiconductors. By introducing donors of electrons, the n-type semiconductor is realized while acceptors lead to the p-type semiconductor. A pn junction diode is formed with donors on one side and acceptors on the other side of the junction. Current flows from the anode p-side to the cathode n-side. The current flowing through a diode can be controlled by the voltage. Junctions with controllable electronic properties are fundamental to semiconductor electronics. Experimenting with pn junction diodes provides an opportunity to understand semiconductor physics.

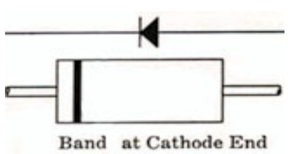


Fig. 5. Diagram of a diode.

The flow of current in a diode is controlled by the physics of pn junction. On the n-side, there are donors which provide electrons as carriers in the conduction band. On the p-side, there are acceptors which provide holes in the valance band. Electrons diffuse from the n-side to the p-side, likewise, holes from p-side to n-side. As a result, a depletion layer is formed at the junction by the immobile acceptor and donor atoms. The region is positively charged on the n-side and negatively charged on the p-side. The space charge creates an electric field. Carriers drift in the electric field, opposite to diffusion, creating a balance. The current versus voltage (I-V) characteristics of the junction can be described as:

$$I = I_s(e^{v/\eta V_T} - 1) \tag{4}$$

where I_s, the reverse saturation current, and η, the ideality factor, are device constants and V_T = kT/e. It carries a unit of voltage and is related to temperature. At room temperature, the value is 0.026 V. I_s is in the nA range and η is of the order of 2. The I-V relation is exponential. Since the exponential function approaches zero as its argument becomes negative, a diode with a negative bias, i.e., a reverse biased pn junction, has a very small reverse saturation current, I_s. As the bias becomes increasingly positive, the current increases exponentially. In other words, a diode is intrinsically a nonlinear device. The typical I-V plot of a diode is shown in Fig. 6.

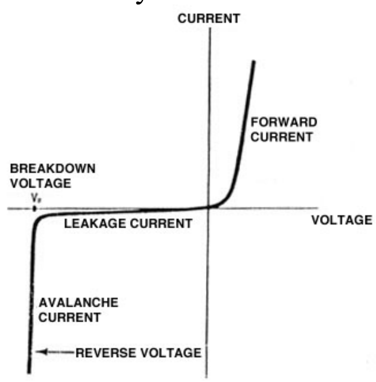


Fig. 6. Typical I-V characteristics of a diode. The rectifying diodes usually have a very large reverse breakdown voltage. They only conduct with a forward bias. Zener diodes, however, operate with reverse breakdown voltages which remain almost constant over a large swing in current. They are used as voltage references under reverse bias.

A rectifying diode behaves like an insulator with a very large resistance when the bias is negative. When it is biased above the turn on voltage, it behaves like a conductor with a very small resistance. In the case of a Si diode, the turn on voltage is approximately 0.6 V. Such a rectifying behavior makes diodes very useful in voltage limiting circuits. The resistance, r_d, above the turn on voltage can be calculated as:

$$\frac{1}{r_d} = \frac{dI}{dv} = \frac{I_s}{\eta V_T} e^{v/\eta V_T} \approx \frac{I}{\eta V_T} \tag{5}$$

The resistance is bias or current dependent. The larger the positive bias or current, the smaller is the resistance. Of course, one cannot bias the diode at an arbitrarily high voltage because the power dissipation may become excessive causing the diode to burn or fail.

To characterize the I-V curve of a diode, the following simple circuit is used:

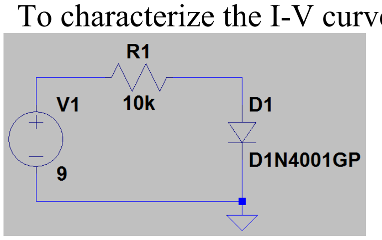


Fig. 7. Circuit to measure the dc characteristics of a diode. R1 can be as low as 100 Ω.

In manual measurements, a dc power supply is connected through a resistor to a diode. For a rectifying diode, the n-side, i.e., the side with a black band on the device or a bar in the symbol, is connected to the negative voltage or ground. Zener diode, on the other hand, requires a reverse bias voltage to operate. Note that the Zener diode has a symbol slightly different from that of a rectifying diode. Start with a 100-kΩ resistor. Confirm its resistance by reading the color bands one more time before connecting it to the circuit. Use the multimeter in dc voltage mode to measure the voltage across the resistor in the circuit. Then, measure the voltage across the diode. From the voltage across the resistor and its resistance, one can calculate the current. Replace the resistor with a smaller value and repeat the measurements. Reduce the resistance until it is 100 Ω (1 W).

From the data, one can plot the I-V curve. Manual measurements can be tedious. Alternatively, you can rely on the function generator, which replaces the power supply, and the dual trace oscilloscope, which replaces the multimeter, to measure I-V characteristics. Details of automatic measurement will be discussed in the lecture.

Since there is a charge buildup near the junction region, the transient response of a pn junction diode is determined by the charging and discharging of the junction capacitance. Under a reverse bias, the junction capacitance is determined by the length of the depletion region and by the dopant concentration. It is quite small, i.e., in the pF region. Under a forward bias, there is an additional capacitance due to excess minority carriers introduced by the current flow. During the transient switching, the voltage across the junction diode doesn't respond to the applied voltage instantaneously. There is a finite RC charging time along with, possibly, a delay. The transient response of 1N4001 to a square input signal is shown in Fig. 8.

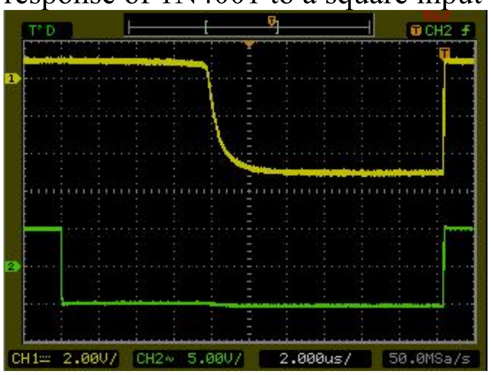


Fig. 8. Transient response of 1N4001 (yellow) to a ±10 V, square, input signal (green). In the on state, the diode junction voltage is small, e.g., 0.7 V. During the on to off switching, there is a delay of 8 μsec. The off to on transition is fast, i.e., nearly instantaneous.

Under a high reverse bias, a diode may operate in a different regime, namely, the avalanche breakdown regime. When carriers drift in a large electric field, their kinetic energy may reach a level which is large enough to generate new electron-hole pairs. As the number of carriers multiplies rapidly, an avalanche breakdown takes place. At the breakdown voltage, the current can abruptly increase. Diodes designed to operate in the avalanche breakdown regime are called Zener diodes. They operate under a reverse bias and can serve as voltage references. The Zener breakdown voltage is determined by the doping profile in the junction. It ranges from a few volts to few hundred volts.

In addition to rectifying current, there are other diode applications. For example, light emitting diodes (LED) are used as indicators, display matrix, and for lighting. Infrared, red, yellow, green, blue, and ultraviolet LEDs are readily available. Using phosphors, LEDs for lighting can produce white light. There is also infrared LED for remote control. Optoelectronic devices are made of compound semiconductors. For example, the blue LED is made of GaN.

The LED operates in a circuit just like a forward biased pn junction diode. By choosing the resistor in series, one can control the brightness of the LED. Typical current is 5-25 mA. The turn-on voltage, however, is color dependent. It could range from 1.5 to 4 V. The polarity of the LED is determined by comparing lengths of two leads. The long lead is the anode and the short lead is the cathode.

Activities During the Laboratory Session

Verify the integrity of the oscilloscope probe by connecting it to the internal square wave source. Verify the integrity of the multimeter test lead by measuring its resistance. By following procedures listed below, you will design, build, and characterize two RC filter, low pass and high pass, in terms of frequency responses the time domain waveforms. You will also obtain the current versus voltage curve of a diode.

1. Design a low pass RC filter circuit with a –3 dB frequency around 20 kHz. Pick a resistor in the 1 kΩ - 100 kΩ range first. Calculate the capacitance by using $f=1/(2\pi RC)$. Find a capacitor close to the calculated value. Use a potentiometer for fine tuning if you desire to do so.
2. Construct the circuit on the prototype circuit board.
3. Measure the frequency response and -3dB frequency. Adjust the output of the function generator to get a 1 kHz and 1 V peak-to-peak sinusoidal waveform as displayed by the oscilloscope. Connect the output of the function generator to the input node of the RC filter. Connect both the input and the output of RC filter to the dual trace oscilloscope. Trigger the oscilloscope with the input signal. Activate cursors of the oscilloscope for peak-to-peak voltage reading. Display both the input and the output sinusoidal waveforms.

   Scan the frequency of the function generator from low, e.g., 1 Hz, to high, e.g., 200 kHz, to identify the frequency at which the response rolls off by -3 dB. If the -3dB frequency is high, increase R; if low, decrease R. Resistance can be increased by adding a resistor in series. Resistance can be reduced by adding a resistor in parallel. The phase difference between the input and output becomes obvious when the frequency is around the -3dB point. Characterize the frequency response by recording the output voltage as a function of frequency from 1 Hz to 200 kHz. Observe the phase delay by digitizing input and output waveforms at the –3dB frequency. When the output signal becomes small, you need to increase the sensitivity of the oscilloscope. You also need to manually measure the peak-to-peak voltage by setting the cursor line at the mid-point of the noisy trace. Automatic readout is not accurate when noise is present. It measures the peak-to-peak voltage of noise, not the signal.

   It is quite flexible in selecting frequencies or frequency interval to record data. In the frequency range where there is little or no change in response, you only need two to three measurements. In the frequency range where there is strong frequency dependence, take eight to ten data points. The idea is to gather enough data so that the frequency response can be determined accurately via curve fitting. If you increase the frequency further, eventually, measurements will be limited either by the highest frequency that the function generator can produce or by the noise of the oscilloscope in measuring very small voltages.

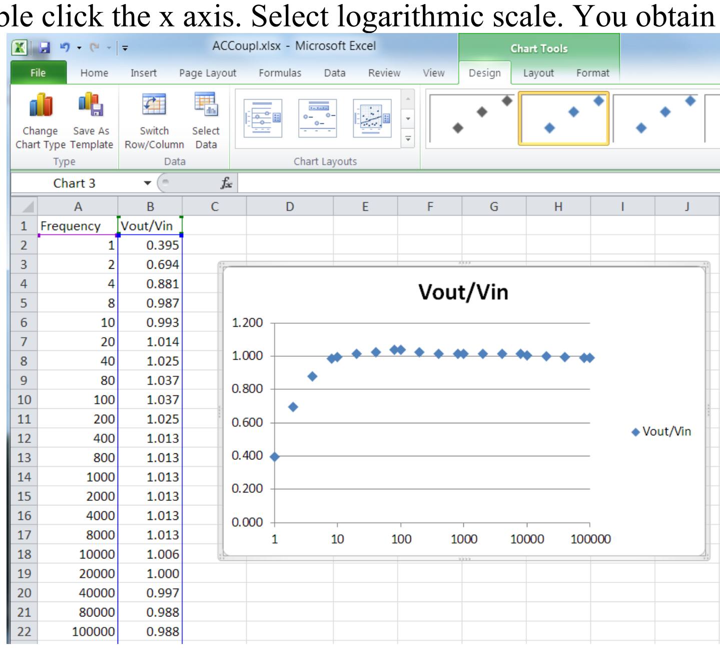
4. Take the resistor or potentiometer out of the circuit and measure its resistance with a multimeter in the resistance mode. From R·C value determined by the –3dB frequency, you can calculate the capacitance accurately. The labeled capacitance can be off by 20%. Put the resistor back into the circuit.
5. To study the transient response of the filter circuit, use the square wave as input. The waveforms should look similar to what are shown in Fig. 4. Digitize both the input and output waveforms at the –3dB frequency.
6. Design and build a high pass RC filter circuit with a –3 dB frequency around 20 Hz. Use a resistor in the 1 kΩ - 100 kΩ range. Repeat procedure 2-3. Measure the frequency response using the signal generator in the sinusoidal mode and the oscilloscope. Repeat procedure 5 to record the transient response using square wave. Digitize or capture waveforms.
7. Attach the input of the high pass filter to the output of the low pass filter. Connect the signal from the function generator to the input of the low pass filter, which is in the front. Monitor the signal of the output of the high pass filter, which is in the back. Scan the frequency of the function generator. Record the frequency response. What is the maximum throughput, i.e., output voltage divided by the input voltage? Why? What will you do if you want the throughput to be close to 100%?
8. Measure the resistance of a diode by using a multimeter in the resistance mode. First, connect the red lead to anode and black lead to cathode. Record the resistance. Then, connect the red lead to cathode and black lead to anode. Record the resistance. A good diode should have a measurable resistance with a forward bias and an extremely large or infinite resistance with a reverse bias.
9. Build the diode test circuit shown in Fig. 7 with a 1-W 100-Ω resistor. Put a rectifying diode, 1N4001, in the circuit. Apply a dc positive voltage. Vary the voltage from 0 V, 0.2 V, 0.4 V, 0.5 V, 0.6 V, 0.7 V, 0.8 V, 0.9 V; and 1 V to 10 V in 1-V steps. Measure the voltage across the resistor. Measure the voltage across the diode. Divide the voltage across the resistor by the resistance value to obtain the resistor current, which is also the diode current because they are in series. Record the diode current in mA unit and the diode voltage. Now, reverse the polarity of power supply and apply a negative voltage. Change the resistor to 100 kΩ. Record I and V for negative bias voltages from 0 to –10 V in 2-V steps. For 1N4001, there should be an extremely small leakage current under reverse bias.
10. Use the diode test circuit with 470-Ω resistor. Instead of the dc power supply, drive the circuit with a 10-V square wave generated by the function generator. Display the input signal and the

waveform at the anode of the diode by using the oscilloscope. Determine the delay in switching off as shown in Fig. 8. Increase the resistance to 4.7 kΩ. What is the delay?

Activities After the Laboratory Session

Data analysis is a vital skill for engineers. The goal of data analysis for RC filter is to determine accurately the value of ω or 1/(RC). This can be done by analyzing either the amplitude or the phase data. We will focus on the amplitude using a high pass filter as an example.

Start Excel. Click "File" and "Open". Enter the name of the spreadsheet in which you recorded the data. In the spreadsheet, you should have at least two columns of data corresponding to frequency and throughput, i.e., the ratio between the output peak-to-peak voltage to that of the input. If the input is set at 1 V, the throughput is simply the output voltage. You can highlight both columns by clicking column A, then column B with the shift key pressed. Click "Insert", "Scatter" chart. Choose the first format to show data only. The throughput versus frequency curve is plotted. Since the range of frequencies is broad, you need a semilog plot. To plot the frequency in log scale, double click the x axis. Select logarithmic scale. You obtain the Bode plot.



	A	B
1	Frequency	Vout/Vin
2	1	0.395
3	2	0.694
4	4	0.881
5	8	0.987
6	10	0.993
7	20	1.014
8	40	1.025
9	80	1.037
10	100	1.037
11	200	1.025
12	400	1.013
13	800	1.013
14	1000	1.013
15	2000	1.013
16	4000	1.013
17	8000	1.013
18	10000	1.006
19	20000	1.000
20	40000	0.997
21	80000	0.988
22	100000	0.988

To perform curve fitting, you need the product of RC according to values of components used and add a column to keep calculated results. Enter the value of 1/(2πRC) in cell E2. Enter the calculation formula in cell C2 as shown in the following figure. Copy and paste the formula to the remaining rows under column C.

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C2 =1/SQRT(1+(E2/A2)^2)

	A	B	C	D	E
1	Frequency	Vout/Vin	Modeling	D^2	1/(2πRC)
2	1	0.142	0.138	1.96393E-05	7.2
3	2	0.274	0.268	4.04005E-05	
4	4	0.492	0.486	4.04123E-05	
5	8	0.740	0.743	1.08514E-05	
6	10	0.812	0.812	2.16838E-07	
7	20	0.936	0.941	2.38868E-05	
8	40	0.976	0.984	6.69668E-05	
9	80	0.992	0.996	1.57962E-05	
10	100	0.992	0.997	2.93551E-05	
11	200	0.996	0.999	1.12401E-05	
12	400	1.000	1.000	2.62313E-08	
13	800	1.000	1.000	1.64005E-09	
14	1000	1.000	1.000	6.71794E-10	
15	2000	1.000	1.000	4.19896E-11	
16	4000	1.000	1.000	2.62439E-12	
17	8000	1.000	1.000	1.64025E-13	
18	10000	1.000	1.000	6.71846E-14	
19	20000	1.000	1.000	4.19904E-15	
20	40000	1.000	1.000	2.6244E-16	
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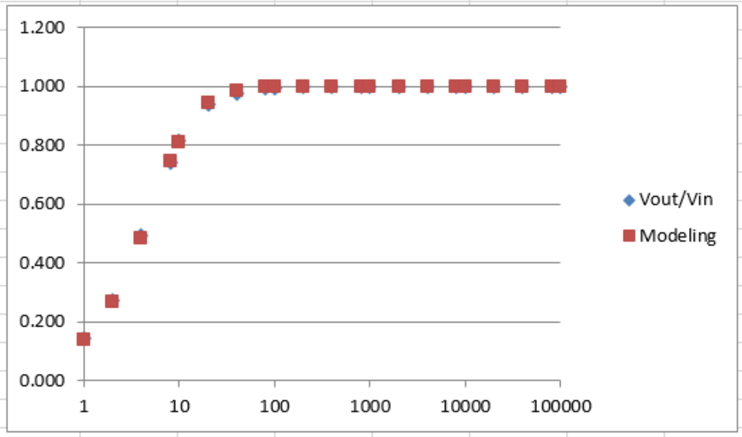
22	100000	1.000	1.000	6.71846E-18	
23				0.000258794	

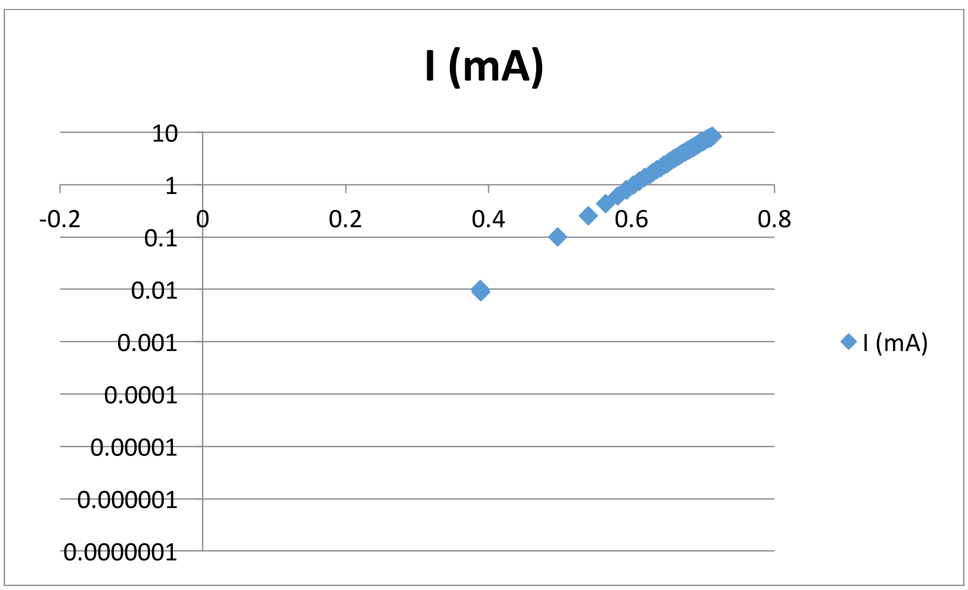


Highlight columns A, B, and C. Insert a scatter chart. Select log scale for the horizontal axis. You can see both measured and calculated results in one plot. Values of components are subject to manufacturing margins, i.e., 5% for resistors and 20% for capacitors. Calculated results may deviate from measured results substantially. To determine the true RC value, you need to perform curve fitting. You can do it manually by changing the RC value to find the best fit. You can use visual inspection for qualitative match. For quantitative match, you need to create the fourth column to track square deviations. Enter in cell D2 =(B2-C2)^2. Copy the formula to the remaining rows. At the bottom of the spreadsheet, enter =sum(d2:d22) in cell D23. This is the total sum of square deviations. By varying RC, you want to minimize the total square deviation.

Excel has a build-in feature, solver, to perform optimization. You need to have solver activated. Click “File”, “Options”, “Add-Ins”. Manage Excel Add-ins to activate “Analysis ToolPak” and “Solver Add-in”. Once you have the solver installed, click “Data”, “Solver”. “Set objective”: the cell containing the sum of square deviations; “To”: Min(imize); “By Changing Variable Cells”: E2; “Subject to the Constraints”: E2 <= 10, for example. Proceed by clicking “Solve”. Click “OK” to save the result of optimization. Go to the top of the spreadsheet to find the optimized value of RC. From the measured value of resistance, you can determine the capacitance very accurately.

Analyze diode characteristics to find values of I_s and η which provide the best fit to the experimental data. The easiest way to perform curve fitting is to plot the data using a semilog plot, namely, ln(I) versus V. Since log function is involved, remove data with a negative current if there is any. Sometimes, noise can turn a near zero reading into negative. When the diode is turned on, the first term of Eq. (6) is much larger than the second term, i.e., 1, therefore, the second term can be neglected. In the e-based semilog plot, Eq. (6) is a line. The slope of the line equals $1/\eta V_T$. Using the value of V_T at room temperature, namely, 0.026 eV, one can determine η. By extrapolation, the intersection of the line with the vertical axis yields $\ln(I_s)$. Whether you measure the current in mA or μA, since the reverse saturation current is smaller than μA, the intersection is always located along the negative y-axis.

Here is an example using data acquired from 1N4001 with positive voltage. You can highlight the junction voltage data and diode current data in two columns. Click "Insert", "Scatter" chart. I-V curve is plotted. To plot the data in log(I), double click the y axis. Select logarithmic scale. In this semi-log plot, the theoretical model is nearly a straight line. To find the intersection of the line with the y axis manually, you can double click the y axis. Change the axis minimum from auto to fixed, 1.0E-7. Here is what you will see:



By drawing a line through the data above 0.1 mA you can find that the intersection is somewhere around 0.0000001 (mA) or 0.1 nA. To find the intersection in linear scale, you need to covert the log scale by using a calculator. The intersection is approximately 2/10 of a log unit above 0.0000001. $10^{0.2}$ is approximately 2.7. Therefore I_S is around $2.7\text{x}10^{-7}$ mA. Double click the y axis. Change the logarithmic base from 10 to 2.7183, which is e. Excel will round it off to 2.7. To find the slope manually, you need $\Delta y/\Delta x$. Select two points along the x axis, e.g., 0.4 V and 0.6 V. The horizontal span is 0.2 V. The vertical span of I versus V curve covers approximately 4.2 units. Therefore, the slope is 4.2/0.2 or 21. The ideality factor is 1/(21*0.026)=1.83.

If you need additional information on diode curve fitting, please browse: http://www.ece.ucsb.edu/Faculty/rodwell/Classes/ece2c/labs/CurveFittinginExcel.pdf

Prepare and submit a summary with data, analysis, and interpretation of data or conclusion. Please include a photo or scanned image of the cover and score sheet with signature of teaching assistant in your summary.

Self-Study

1. What is the functionality of a filter? Where do we need one?
2. Explain the correlations among low-pass filter, high-pass filter, integrator, and differentiator. Draw the circuit diagram, time waveform, and frequency response of each filter qualitatively.
3. What effect does a filter have on the phase of a sinusoidal input waveform?
4. Can you cascade two filters to form a bandpass filter for the audio band?
5. Can you measure the capacitance using a multimeter? If not, how do you measure the capacitance accurately?
6. Can you draw the typical I-V curve of a pn junction diode?
7. At what voltage will a diode turn on or conduct?
8. Under the reverse bias, how does a diode behave?
9. Can a 1N4001 switch or rectify at very high frequencies?

Cover and Score Sheet

Experiment 2 - RC Filters and Diodes

Author:________________________________ Partner:___________________________

Score

Item	Credit	Score
Data	4	
Low Pass Filter		
Circuit Diagram With Values of Components		
Measured and Calculated Frequency Plot; -3dB Point		
Transient, Time Response		
High Pass Filter		
Circuit Diagram With Values of Components		
Measured and Calculated Frequency Plot; -3dB Point		
Transient, Time Response		
Diode		
IV Plot		
Curve Fitting; I_S, η		
Conclusion	1	
Total	**5**	

TA Signature: _________________________________ Date:____________________