EE315 - Electronics Laboratory

Experiment - 1
AC Signal Measurement and Half-Wave Rectifiers

Objectives

1. Review AC signal parameters.
2. Review diode response.
4. Analyze single diode rectifier circuits.

Background

You must read the section titled ***Grounding of Test Equipment*** in the ***Electronics Laboratory Beginner's Guide*** before you start the experimental procedure. The voltage measurements in this experiment require the scope setup for differential voltage measurements using two scope probes.

1. AC Signals

Nonsinusoidal signals are an important class of signals, and are found in a wide variety of situations. There are many different ways to characterize these signals. This experiment focuses on a number of these.

Peak-to-peak amplitude of a periodic waveform is the difference between the lowest and highest amplitudes in the waveform.

Peak value of a waveform is the magnitude of the highest (or lowest) point of the waveform with respect to a reference or ground level. If the waveform is symmetric above and below the reference level, then a single peak value is specified. In case a waveform is not symmetric around the reference level, the positive and negative peak values should be measured and specified separately.

DC (average) value of a periodic signal is the average value over the period.

RMS (root-mean-square) value of a periodic waveform is defined as:

$$V_{rms} = \sqrt{\frac{1}{T}\int_{t=0}^{T} v^2(t)\, dt}$$

where, **square** of the signal is integrated over the waveform period, **T**, and then square **root** of the **mean** value is calculated. RMS value of a signal is useful in power calculations. Power dissipation **P** on a resistor can be calculated in terms of the RMS values

$$P = \frac{V_{rms}^2}{R} = I_{rms}^2 R$$

where, $\mathbf{V_{rms}}$ is the RMS voltage across **R**, and $\mathbf{I_{rms}}$ is the RMS current through **R**. Resistive power calculation based on RMS values will be correct for all AC waveform types combined with any DC level.

Pulse Waveform Parameters

Pulse waveforms appear in a variety of shapes in common application areas, such as logic circuits, digital communications, and switching power control. Description of pulse waveforms require additional timing parameters:

On time (T_{on}) or high time (T_{high}): Time duration where the signal is at **active level** (mostly with a high amplitude) in a pulse waveform.

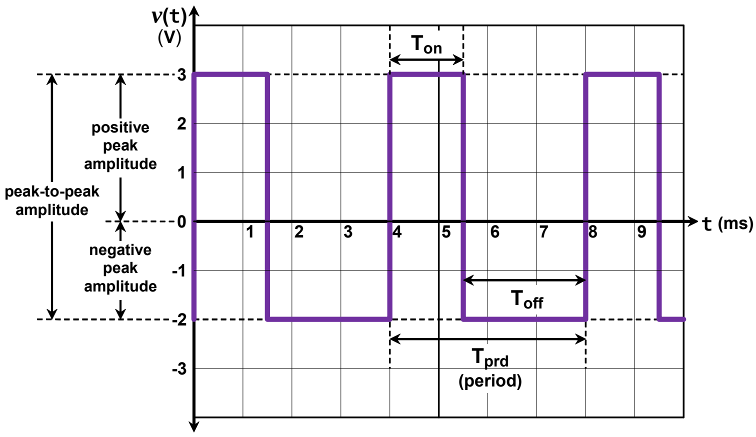
Off time (T_{off}) or low time (T_{low}): Time duration where the signal remains idle at reference level (mostly with a low amplitude) in a pulse waveform.

Duty cycle (DC): Ratio of on time to period of a pulse waveform. Duty cycle is usually expressed as a percentage:

$$\textbf{Duty cycle} = \frac{T_{on}}{T_{on} + T_{off}} \times 100\ \% = \frac{T_{on}}{T_{prd}} \times 100\ \%$$

As shown in the following example, if $\mathbf{T_{prd} = 4.0}$ **ms** and $\mathbf{T_{on} = 1.5}$ **ms** for a pulse waveform, then its duty cycle is

$$\textbf{Duty cycle} = \frac{1.5}{4.0} \times 100\ \% = 37.5\ \%.$$



2. Diode Circuits

A semiconductor diode is a non-linear device that changes its conductivity depending on the voltage polarity accross its terminals. A diode acts like a good conductor when it is forward biased and it has a large resistance when the voltage polarity is reversed. V-I characteristics (current versus voltage graph) of a diode is given below. A piecewise linear circuit model of the diode is obtained by linearizing the V-I characteristics.

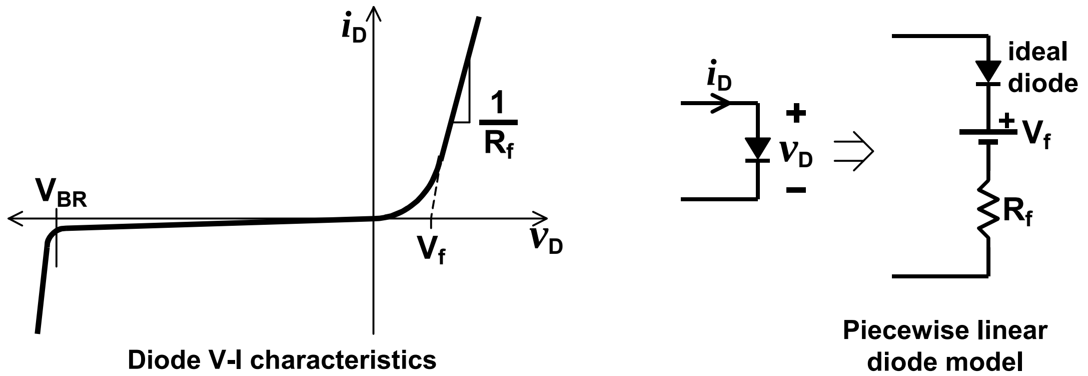


Figure 2. Diode current versus voltage characteristic curve and piecewise linear model under forward bias.

Diodes are used in various rectifier and wave shaping circuits. Conventional diodes can be divided into two groups as follows:

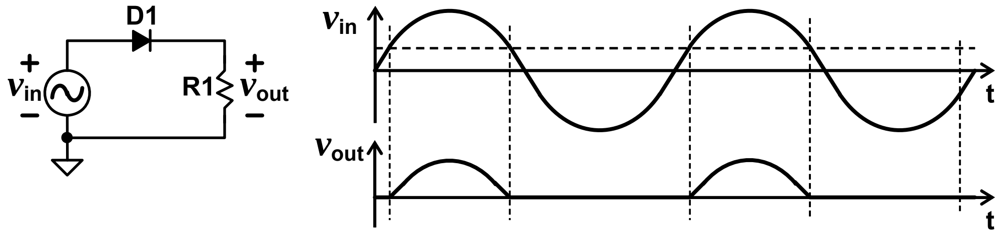
1. Signal diodes
2. Power diodes

Signal diodes are generally used in low-voltage and low-current applications where ON/OFF switching speed and a large reverse-to-forward resistance ratio are important. Signal diodes are mostly packaged in small cases, since power dissipation in typical waveshaping circuits is not critical.

Power diode applications are generally limited to the various rectifier circuits that convert AC power to DC power. Important characteristics of the power diodes are their ability to dissipate power and withstand large forward currents and large reverse voltages. Package size of power diodes varies dramatically with the current carrying and power dissipation capability.

Half-Wave Rectifier Circuits

Electrical power in buildings is available in AC because of better transmission and distribution efficiency compared to DC power. All electronic equipment working on DC power require some kind of rectifier to convert AC voltage to DC voltage. The basic half-wave rectifier circuit is shown below. The input signal v_{in}, is assumed to be purely sinusoidal AC signal with a time-average value of zero. The output signal v_{out}, across the load resistor **R1** will be as shown in the figure, since the diode conducts a significant current only during the positive cycles of the input waveform. The half-wave rectifier circuit produces an output signal that has a fundamental frequency same as the input AC freuency.



In case of an ideal diode, v_{out} does not depend on the load resistor and obviously it is exactly the positive half of v_{in}. The rectified output is now a combination of an AC signal and a DC component. Generally, it is the DC part of the rectified signal that is of interest, and the undesired AC component is described as ripple. Furthermore, the pulsating DC output signal can be made steady by means of a smoothing circuit. The quality of a rectifier circuit is measured by its ***ripple factor***, which is defined as

$$\textbf{Ripple factor} = \frac{\textbf{RMS value of AC output}}{\textbf{DC level of output}}$$

Preliminary Work

1. Show that the RMS value $\mathbf{V_{rms}}$ of a sinusoidal voltage waveform $\boldsymbol{v}\mathbf{(t) = V_p}\ sin\mathbf{(\omega t)}$ is given by

$$\mathbf{V_{rms}} = \frac{\mathbf{V_p}}{\sqrt{\mathbf{2}}}$$

where, $\mathbf{V_p}$ is the peak value of the voltage waveform.

Hint: Calculate the RMS value as it is defined:

$$\mathbf{V_{rms}} = \sqrt{\frac{\mathbf{2}}{\mathbf{T}}\int_{\mathbf{t=0}}^{\mathbf{T/2}} \mathbf{V_p^2}\, sin^{\mathbf{2}}\mathbf{(\omega t)\, dt}} \quad \text{by using} \quad sin^{\mathbf{2}}\mathbf{(\omega t)} = \frac{\mathbf{1} - cos\mathbf{(2\omega t)}}{\mathbf{2}}$$

2. Show that the total RMS value $\mathbf{V_{\Sigma rms}}$ of a voltage waveform $\boldsymbol{v}\mathbf{(t) = V_{DC}} + \boldsymbol{v}_{AC}\mathbf{(t)}$ is given by

$$\mathbf{V_{\Sigma rms}} = \sqrt{\mathbf{V_{DC}^2 + V_{ACrms}^2}}$$

where, $\mathbf{V_{ACrms}}$ is the RMS value of the pure AC component $\boldsymbol{v}_{AC}\mathbf{(t)}$.

Hint: DC (average) value of $\boldsymbol{v}_{AC}\mathbf{(t)}$ is zero by definition, and this implies

$$\frac{\mathbf{1}}{\mathbf{T}}\int_{\mathbf{t=0}}^{\mathbf{T}} \boldsymbol{v}_{AC}\mathbf{(t)\, dt = 0}$$

Procedure

Part 1. Voltage Measurements

Connect the function generator to a digital multimeter (DMM) and to the oscilloscope. Adjust the function generator to provide **1 kHz** sine wave, with an amplitude of **2 V**p-p (peak-to-peak).

1.a) Set up the oscilloscope and DMM to measure this signal. Use the measurement function on the oscilloscope to determine peak, peak-to-peak and DC values. Use the digital voltmeter to measure both DC and AC rms values.

1.b) Record the following for the sine wave:

Peak voltage: __________ Peak to-peak voltage: __________

Oscilloscope RMS voltage __________ DC voltage: __________

DVM AC RMS voltage __________ DVM DC voltage __________

1.c) Switch to the triangle wave keeping frequency and peak-to-peak amplitude the same. Measure and record:

Peak voltage: __________ Peak to-peak voltage: __________

Oscilloscope RMS voltage __________ DC voltage: __________

DVM AC RMS voltage __________ DVM DC voltage __________

1.d) Switch the function generator so that it provides a square wave signal. Verify on the oscilloscope that the frequency and peak value of the signal has not changed. Record the following:

Peak voltage: __________ Peak to-peak voltage: __________

Oscilloscope RMS voltage __________ DC voltage: __________

DVM AC RMS voltage __________ DVM DC voltage __________

1.e) Adjust the function generator offset setting to **1.0 V**. This should fully offset the square wave, so that the wave should have a minimum value of zero volts. Use the oscilloscope to verify that this is the case. Record the following voltages:

Peak voltage: __________ Peak to-peak voltage: __________

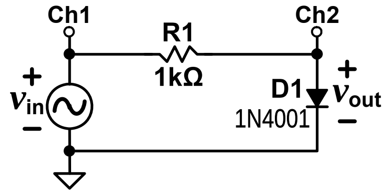
Oscilloscope RMS voltage __________ DC voltage: __________

DVM AC RMS voltage __________ DVM DC voltage __________

Use the AC RMS reading of the DVM and the DC voltage reading, calculate the total RMS value of this wave __________

Part 2. Diode Circuits

2. Test the diode before using it and be sure that it works. Build the following circuit, with a **1 kΩ** resistor and a **1N4001** or **1N4007** silicon diode. Set function generator to obtain a **1 kHz** triangular waveform with **5 V** peak amplitude.

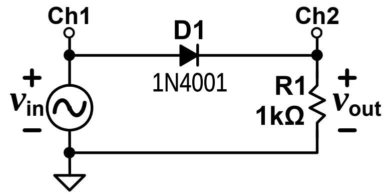


2.a) Describe a method to measure the current in this circuit using an oscilloscope.

Note that ground connectors of scope probes and function generator cable should be attached to the same reference node in the circuit. You should setup the scope for differential voltage measurements by using two probes.

2.b) Measure the circuit current using a multimeter and compare with the results you obtained on the oscilloscope.

3. Build the following circuit and use the same **1 kHz** triangular waveform as v_{in}.



3.a) Sketch the v_{in} and v_{out} waveforms observed in DC coupling mode.

3.b) Use the oscilloscope in X-Y mode (v_{in} on X axis, v_{out} on Y axis) to obtain the input-output transfer function. Sketch the transfer function and clearly describe function and scale of each axis on the plot.

3.c) Estimate turn on voltage of the diode on the transfer function.

4. Change input waveform to v_{in} **= 2V sin(2π 1000t)**.

4.a) Sketch v_{out} observed in DC coupling mode. What is the peak output voltage value measured?

4.b) Verify that the measured peak output voltage is correct with calculations.

4.c) Measure the frequency and period of v_{in} and v_{out}.

5. Change input waveform to square wave keeping frequency and amplitude settings the same.

5.a) Measure the peak voltage and DC component of v_{out}.

5.b) Calculate the expected average value of v_{out} based on the measurements on v_{in} signal and compare with the DC value measured before.

5.c) Measure the frequency and period of v_{in} and v_{out}.

Questions

Q1. What is the minimum possible value of the ratio $\mathbf{V}_{peak}/\mathbf{V}_{rms}$ for a waveform? Describe a waveform that has the minimum $\mathbf{V}_{peak}/\mathbf{V}_{rms}$ ratio.