Amplitude Modulation and Demodulation

1) Objectives

Part A – Modulation

To produce a DSB–FC–AM (Double Sideband–Full Carrier–Amplitude Modulated) signal

Part B – Demodulation

To demodulate a DSB–FC–AM (Double Sideband–Full Carrier–Amplitude Modulated) signal and extract the message (modulating) signal

2) Equipment Required

1) ED – 2900: Power Supply Module
2) ED – 2950 A: Signal Source Module
3) ED – 2950 D: Balanced Modulator Module
4) ED – 2950 C: Detector Module
5) Oscilloscope
6) Signal (Function) Generator

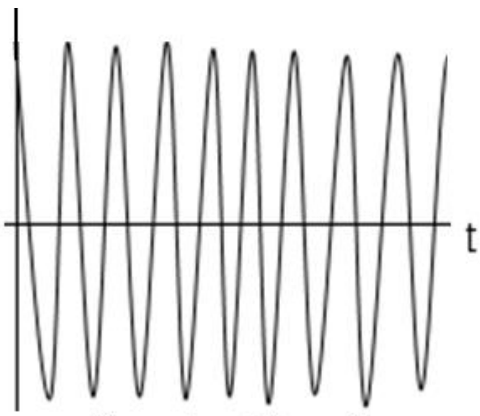
3) Theory

Part A – Modulation

An A.C. or D.C. signal does not contain any information. In order to convey information, it is necessary to change one or more of the parameters (amplitude, frequency, or phase) of a high frequency signal. The high frequency signal is called the carrier signal, and the low frequency signal, which contains the important information, is called the message (modulating) signal. The carrier signal whose one or more parameters are changed according to the message (modulating) signal is called the modulated signal. In the case of amplitude modulation (AM), the amplitude of the carrier signal is varied according to the message (modulating) signal.

The carrier signal is represented by:

$$x_c(t) = V_c\ Sin(\omega_c t)$$

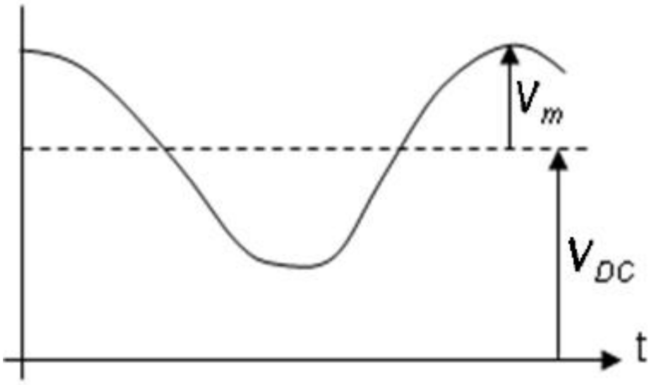


Carrier Signal

Amplitude Modulation and Demodulation

The message (modulating) signal is represented by:

$$x_m(t) = V_{DC} + V_m\, Sin(\omega_m t)$$



Message (modulating) Signal + D.C.

If these two signals are multiplied the output is given by:

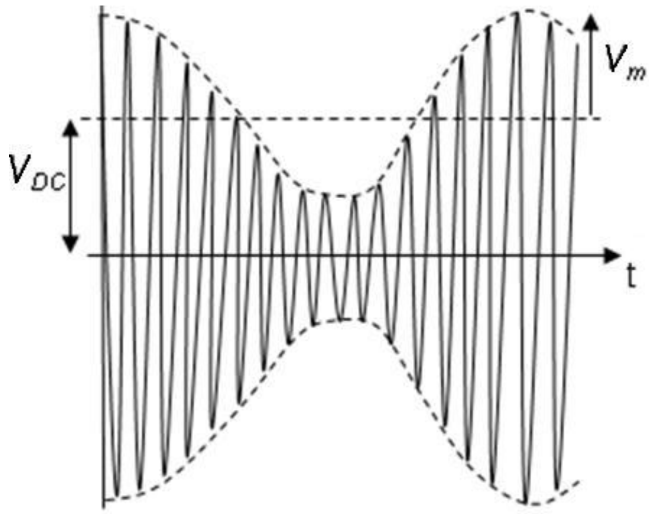
$$x(t) = x_m(t) \times x_c(t) = \{V_{DC} + V_m\, Sin(\omega_m t)\} \times \{V_c\, Sin(\omega_c t)\}$$

$$x(t) = V_{DC} V_c\, Sin(\omega_c t) + V_m V_c\, Sin(\omega_m t)\, Sin(\omega_c t)$$

Using trigonometric identities, the output can be expressed by:

$$x(t) = V_{DC} V_c\, Sin(\omega_c t) + \frac{V_m V_c}{2}\, [cos\{(\omega_c - \omega_m)t\} - cos\{(\omega_c + \omega_m)t\}]$$

$$x(t) = V_{DC} V_c\, Sin(2\pi f_c t) + \frac{V_m V_c}{2}\, [cos\{2\pi(f_c - f_m)t\} - cos\{2\pi(f_c + f_m)t\}]$$



Modulated Signal

Amplitude Modulation and Demodulation

From the above expression it can be seen that the output consists of three components:

a) The carrier component with amplitude $V_{DC}V_c$
b) The upper sideband component with amplitude $(V_mV_c)/2$
c) The lower sideband component with amplitude $(V_mV_c)/2$

The output can also be written as follows:

$$x(t) = V_{DC}V_c\left[Sin(2\pi f_c t) + \left(\frac{1}{2}\right)\left(\frac{V_m}{V_{DC}}\right)[cos\{2\pi(f_c - f_m)t\} - cos\{2\pi(f_c + f_m)t\}]\right]$$

The degree of modulation (modulation depth) is measured by the modulation index (m) and is defined as:

$$m = \left(\frac{V_m}{V_{DC}}\right)$$

In the above expression, V_m is the amplitude of the message (modulating) signal and V_{DC} is the value of the DC bias.

The output can be written in terms of the modulation depth (m) as follows:

$$x(t) = V_{DC}V_c\left[Sin(2\pi f_c t) + \left(\frac{1}{2}\right)m\,[cos\{2\pi(f_c - f_m)t\} - cos\{2\pi(f_c + f_m)t\}]\right]$$

The modulation depth can also be defined as follows:

$$m = \left(\frac{V_m}{V_c}\right)$$

In the above expression, V_m is the amplitude of the message (modulating) signal and V_c is the amplitude of the carrier signal.

An alternate way of defining the modulation depth is as follows:

$$m = \left(\frac{V_{max} - V_{min}}{V_{max} + V_{min}}\right)$$

In the above expression, V_{max} is the maximum value of the DSB–FC–AM signal, and V_{min} is the minimum value of the DSB–FC–AM signal.

The modulation index can also be expressed in percent form as:

$$m = \left(\frac{V_{max} - V_{min}}{V_{max} + V_{min}}\right) \times 100\%$$

Let,

$$V = V_cV_{DC}$$

Then,

$$x(t) = V\left[Sin(2\pi f_c t) + \left(\frac{1}{2}\right)m\,[cos\{2\pi(f_c - f_m)t\} - cos\{2\pi(f_c + f_m)t\}]\right]$$

Amplitude Modulation and Demodulation

$$x(t) = V\ Sin(2\pi f_c t) + \left(\frac{V}{2}\right) m\ [cos\{2\pi(f_c - f_m)t\} - cos\{2\pi(f_c + f_m)t\}]$$

From the above expression, it can be seen that the message signal is contained within the upper and lower sidebands. This implies that greater the amplitude of the sidebands, the better the transmitting efficiency.

Thus, greater the modulation index, greater the amplitude of the sideband signals and better the transmitting efficiency.

In practice, the modulation index is usually:

$$0 < m \leq 1$$

Note: If the modulation index is greater than 1 (i.e. m > 1), it is called over-modulation and this causes distortion.

The bandwidth requirement for DSB–FC–AM signal can be calculated as follows:

The upper frequency component is given by:

$$f_{USB} = f_c + f_m$$

The lower frequency component is given by:

$$f_{LSB} = f_c - f_m$$

The bandwidth required for a DSB–FC–AM signal is:

$$BW = f_{USB} - f_{LSB} = 2f_m$$

The power required for the transmission of a DSB–FC–AM signal can be calculated as follows:

$$P_{SB} \propto \left(\frac{Vm}{2}\right)^2 = \frac{V^2m^2}{4}$$

$$P_C \propto (V)^2 = V^2$$

$$P_T \propto \frac{V^2m^2}{4} + V^2 + \frac{V^2m^2}{4} = V^2\left(1 + \frac{1}{2}m^2\right)$$

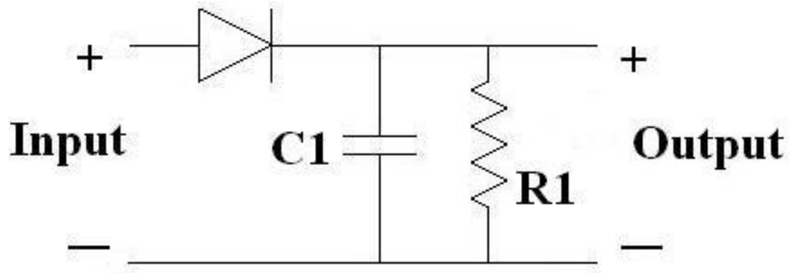
The modulation efficiency for a DSB–FC–AM signal can be calculated as follows:

$$\eta = \frac{\frac{V^2m^2}{4} + \frac{V^2m^2}{4}}{V^2\left(1 + \frac{1}{2}m^2\right)} = \frac{\frac{m^2}{2}}{1 + \frac{1}{2}m^2} = \frac{m^2}{2 + m^2}$$

Amplitude Modulation and Demodulation

Part B – Demodulation

The most common circuit to perform the demodulation is diode detection. In this circuit, the diode rectifies the signal, allowing only half of the alternating waveform through. The capacitor is used to store the charge and provide a smoothed output from the detector, and also to remove any unwanted carrier frequency components. The resistor is used to enable the capacitor to discharge. If it were not there and no other load was present, then the charge on the capacitor would not leak away, and the circuit would reach a peak and remain there.



Envelop Detector

The detector efficiency is calculated as follows:

$$\eta = \frac{V_0}{V_i} \times 100\%$$

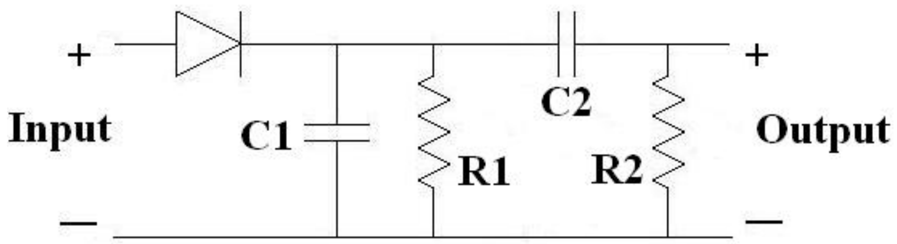
Where V_i is the peak-to-peak value of the message (modulating) signal and V_o is the peak-to-peak voltage at the output of the envelop detector circuit.

The values of the resistor and capacitor are important. If the time constant (product of (R_1) and (C_1)) is too small the detector tends to follow the peaks of the carrier signal. This causes distortion in the output called ripple effect. If the time constant is too large, the detector cannot follow the message (modulating) signal; and this causes distortion in the output called diagonal peak clipping.

To minimize the ripple effect we should have the time constant (R_1C_1) > T_c, where T_c is the period of the carrier. To avoid diagonal clipping we should have the time constant (R_1C_1) < T_m, where T_m is the period of the message (modulating) signal.

$$T_c < R_1C_1 < T_m$$

The output of the envelop detector still contains the D.C. bias term. To filter out the D.C. term the following circuit is used:



Envelop Detector + D.C. Blocking

Amplitude Modulation and Demodulation

The capacitor C_2 blocks the D.C. component (low frequency component) of the message (modulating) signal.

After the D.C. component has been removed, the output wave might have its negative voltage peaks clipped. This effect is called negative peak clipping. To avoid the effect of negative peak clipping at the output, the following equality must be met:

$$m \leq \frac{R_1}{R_1 + R_2}$$

Disadvantages of DSB–FC–AM Signals:

- The carrier contains two-thirds of the total transmitted power. This is a major drawback because the carrier contains no information.
- DSB–FC–AM systems utilize twice as much bandwidth as need with single-sideband systems.
- In DSB–FC–AM systems, the information contained in the upper sideband is identical to the information contained in the lower sideband. Therefore transmitting both sidebands is redundant.

Advantages of DSB–FC–AM Signals:

- The detector can be very simple and cheap. It only involves a diode rectifier followed by an RC circuit.

4) Procedure

Part A - Modulation

1) Connect the modules ED-2950 A and ED-2950 D to the power supply module ED 2900.

2) Turn on the power supply module ED 2900.

3) Turn both knobs (A) and (B) on the module ED-2950 A to zero.

4) Set the variable attenuation value (output dB) of the VCO on the module ED-2950 A to – 4dB.

5) The output of the VCO is taken from the "0 fixed attenuator socket" (i.e. the top right corner socket).

6) Ground the "ground socket" of the module ED-2950 A.

7) Adjust the value of the knob (C) on the module ED-2950 A so that the VCO produces an output wave having a frequency of 465 kHz. Check the output of the VCO on the oscilloscope and make sure that the frequency of the wave is 465 kHz. Measure the peak-to-peak amplitude of this wave and note its value in your notebook.
(This will form the carrier wave)

8) Set the signal generator to produce a Sine wave of 300 Hz having peak-to-peak amplitude of 1 volt. Check the output of the signal generator on the oscilloscope and make sure that the frequency of the Sine wave is 300 Hz and that its peak-to-peak amplitude is 1 volt.
(This will form the message (modulating) signal)

Amplitude Modulation and Demodulation

9) Connect the signal generator output to the input (a) of the module ED-2950 D.

10) Connect the output of the VCO from module ED-2950 A to the input (b) of the module ED-2950 D.

11) Connect the +1 volt output on the module ED-2950 D to the input (ā) of the module ED-2950 D. (This will provide the D.C. bias to the message (modulating) signal)

12) Ground the "ground socket" of the module ED-2950 D.

13) Connect the output (c) of the module ED-2950 D to the oscilloscope and observe the DSB-FC-AM signal.

14) Adjust the amplitude of the message (modulating) signal to change the modulation index. Produce DSB-FC-AM signals having modulation depth (m) = 25%, 50%, 75% and 100%. Measure V_{max} and V_{min} accurately and tabulate your results. Show your calculations for the modulation depth (m) and the modulation efficiency. Sketch the DSB-FC-AM signal that you observe on the oscilloscope for each case in your notebook.

15) Increase the amplitude of the message (modulating) signal to produce a modulation depth (m) = 125%. Show your calculation for the modulation depth. Sketch the DSB-FC-AM signal that you observe in your notebook.

16) Increase the amplitude of the message (modulating) signal to produce a modulation depth (m) = 150%. Show your calculation for the modulation depth. Sketch the DSB-FC-AM signal that you observe on the oscilloscope in your notebook.

17) Adjust the amplitude of the message (modulating) signal to produce a modulation depth of 50%. Show your calculation for the modulation depth. Change the message (modulating) signal form to square waveform. Sketch the DSB-FC-AM signal that you observe on the oscilloscope in your notebook.

18) Adjust the amplitude of the message (modulating) signal to produce a modulation depth of 50%. Show your calculation for the modulation depth. Change the message (modulating) signal form to triangular waveform. Sketch the DSB-FC-AM signal that you observe on the oscilloscope in your notebook.

19) Prove the following relations:

$$m = \left(\frac{V_m}{V_{DC}}\right) = \left(\frac{V_m}{V_c}\right) = \left(\frac{V_{max} - V_{min}}{V_{max} + V_{min}}\right)$$

20) Prove the criteria for preventing negative peak clipping:

$$m \leq \frac{R_1}{R_1 + R_2}$$

Amplitude Modulation and Demodulation

Part B – Demodulation

1) Set the signal generator to produce a Sine wave of frequency 300 Hz. Adjust the amplitude of the message (modulating) signal to produce a modulation depth of 85 %. Show your calculation for the modulation depth. Sketch the DSB-FC-AM signal that you observe on the oscilloscope in your notebook.

1) Connect the module 2950 C to the power supply unit ED 2900.

2) Ground the "ground socket" of the module ED-2950 C.

3) Connect the output (c) of the module ED-2950 D to the input of diode (D_1) on the module 2950 C.

4) Measure the output across the following component permutations. Sketch the output that you see on the oscilloscope in your notebook and comment on your results. For each of the following cases calculate the detector efficiency. Make sure that the frequency of the message (modulating) signal is still 300 Hz.

   (a) R_1
   (b) $R_1 \| R_3$
   (c) $R_1 \| C_1$ Also calculate time constant i.e. RC product
   (d) $R_1 \| C_2$ Also calculate time constant i.e. RC product
   (e) $R_1 \| C_3$ Also calculate time constant i.e. RC product
   (f) $R_1 \| R_3 \| C_1$ Also calculate time constant i.e. RC product
   (g) $R_1 \| R_3 \| C_2$ Also calculate time constant i.e. RC product
   (h) $R_1 \| R_3 \| C_3$ Also calculate time constant i.e. RC product
   (i) $R_1 \| R_3 \| C_1 \| C_2$ Also calculate time constant i.e. RC product
   (j) $R_1 \| R_3 \| C_1 \| C_3$ Also calculate time constant i.e. RC product
   (k) $R_1 \| R_3 \| C_2 \| C_3$ Also calculate time constant i.e. RC product
   (l) $R_1 \| R_3 \| C_1 \| C_2 \| C_3$ Also calculate time constant i.e. RC product

5) Set the signal generator to produce a Sine wave of frequency 300 Hz. Adjust the amplitude of the message (modulating) signal to produce a modulation depth of 100 %. Show your calculation for the modulation depth. Sketch the DSB-FC-AM signal that you observe on the oscilloscope in your notebook. Use the values $R_1 \| C_3$. Connect the output of capacitor C_3 to the input of capacitor C_6. Connect the output of the audio amplifier to the oscilloscope. Adjust the audio amplifier control knob to increase the output amplitude. Sketch the output waveform that you observe on the oscilloscope. Note: you will observe the effect of negative peak clipping clearly.

6) Reduce the message (modulating) signal amplitude slowly till the negative peak clipping just disappears. Record the amplitude of the message (modulating) signal when the negative peak clipping just disappears. Calculate the modulation depth (m) when the negative peak clipping just disappears.