Communication Electronics (Lecture 5)

AM Modulators

Introduction

In the last lectures we discussed various scheme of Amplitude Modulation. In the next few lectures we will discuss different modulator circuits to generate modulated output. Modulator circuits cause carrier amplitude to be varied in accordance with modulating signals. Modulator circuits produce AM, DSB, and SSB transmission methods. Step-by-step discussion covered in this chapter is:

- Basic Principles of Amplitude Modulation
- Amplitude Modulators
- Amplitude Demodulators
- Balanced Modulators
- SSB Circuits

Basic Principle

As it is seen in the last chapter that the basic equation for an AM signal is:

$$\nu_{AM}=V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t) \qquad (7.1)$$

In the above equation, the first term is the sine wave carrier and the second term is the product of the sine wave carrier and modulating signal. As it is apparent from Equ. (7.1) that amplitude modulation voltage can be produced by a circuit that can multiply the carrier by the modulating signal and then add the carrier. Block diagram realization of above equation is shown in Fig (7-1). The product of the carrier and modulating signal can be generated by applying both signals to a nonlinear component such as a diode. A square law device can be used to generate product term of the expression. A square-law function is one that varies in proportion to the square of the input signals. A diode gives a good approximation of a square-law response. Bipolar and field-effect transistors (FETs) can also be biased to give a square-law response. A square law device has the input- output characteristics of the form

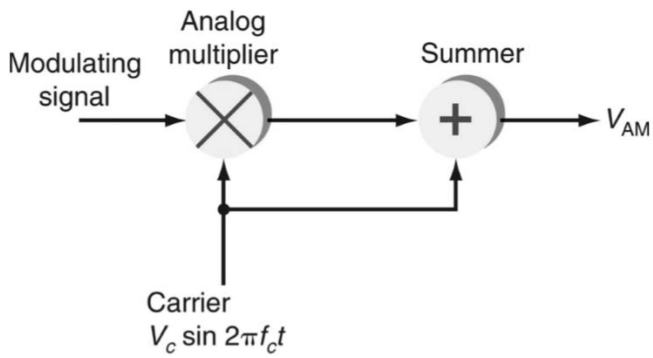

Fig 7-1 Block diagram realization of AM signal

$$V_o = a\,(V_i) + b(V_i)^2$$

Where, $V_i = (V_c \sin 2\pi f_c t + V_m \sin 2\pi f_m t)$.

Two conditions must be met in a circuit for heterodyning to occur. First, at least two different frequencies must be applied to the circuit. Second, these signals must be applied to a nonlinear impedance (Like transistor or diodes). These two conditions will result in new frequencies (sum and difference) being produced. Any one of the frequencies can be selected by placing a frequency-selective device (such as a tuned tank circuit) in series with the nonlinear impedance in the circuit.

The way in which this can be applied, is shown in Fig 7-2. The diode serves as the nonlinear impedance in the circuit. Generators Vc and Vm are signal sources of different frequencies. The primary of transformer, with its associated capacitance, serves as the frequency-selective device

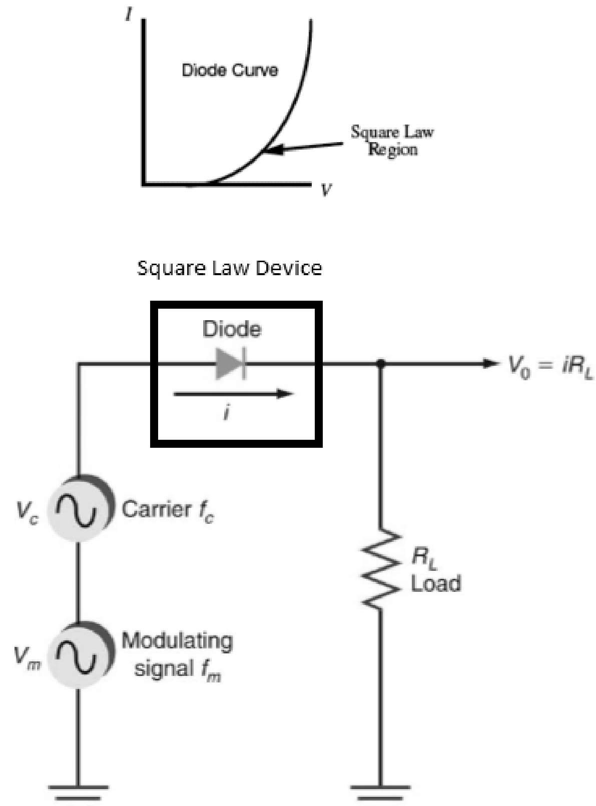

Fig 7-2 A Diode Square-Law Modulator

$= \mathbf{a\, V_c \sin 2\pi f_c t} + a\, V_m \sin 2\pi f_m t + bV_c^2 \sin^2 2\pi f_c t + bV_m^2 \sin^2 2\pi f_m t + \mathbf{2b\, V_c \sin 2\pi f_c t.\ V_m \sin 2\pi f_m t}$

Combining the terms in bold letter

$= \mathbf{a\, V_c \sin 2\pi f_c t + 2b\, V_c \sin 2\pi f_c t.\ V_m \sin 2\pi f_m t} + a\, V_m \sin 2\pi f_m t + bV_c^2 \sin^2 2\pi f_c t + bV_m^2 \sin^2 2\pi f_m t$

The output of square-law device contains frequency component at and around f_c, The other undesired harmonics as shown in Fig 7-3. The terms which are not bold in above expression, can be deselected using a tank circuit which is tuned at frequency f_C as shown in Fig 7-4.

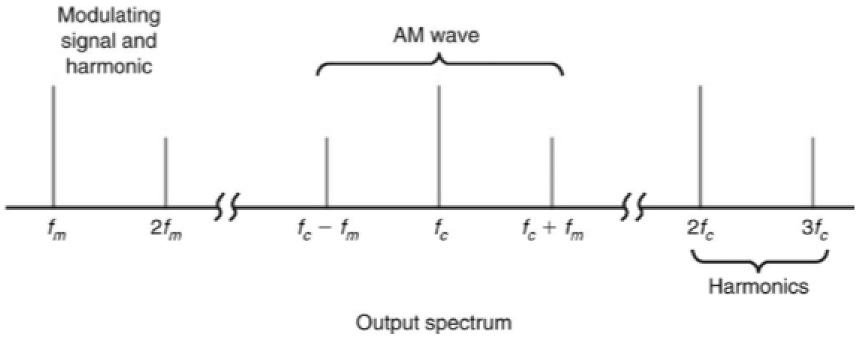

Fig 7-3 Frequency component present at the output of diode

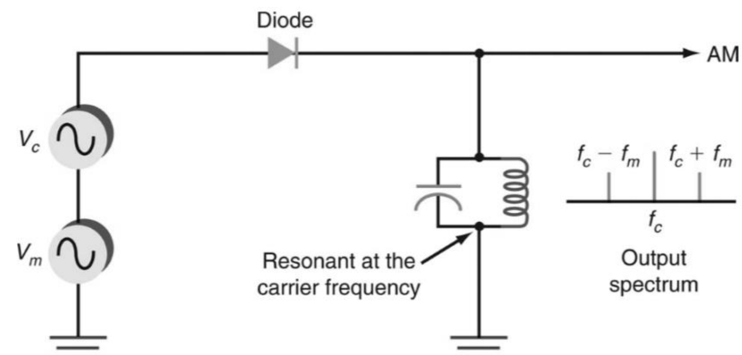

Fig 7-4 Modulated signal at the output of tank circuit

Therefore,

$$V_o = \boldsymbol{a}\left[\mathbf{1} + \left(\frac{2b}{a}\right) V_m \sin 2\pi f_m t\right] V_C \sin 2\pi f_c t \qquad (7.2)$$

Equation (7.2) is the desired expression of AM signal where modulation index m $=\left(\frac{2b}{a}\right) \boldsymbol{V_m}$. In order to avoid over modulation we make

$$\left(\frac{2b}{a}\right) V_m \leq 1.$$

Low Level and High Level Modulation

There are two levels of modulation: low-level modulation and high-level modulation. With low-level modulation, the modulation takes place prior to the output element of the final stage of transmitter. In high-level modulators, the modulation takes place in the final element of the final stage of transmitter.

Low-level versus high-level modulation:

- With low-level modulation, less modulating signal power is required to achieve a high percentage of modulation. For high-level modulation, the carrier signal is at its maximum amplitude at the final element, therefore much higher amplitude modulating signal is required to achieve high percent modulation
- However, low-level modulation is not suitable for high-power applications when all the amplifiers that follow the modulator stage must be linear

Low-Level AM: Diode Modulator

In low level modulator, little power is associated with either the carrier or the information signal; consequently the output power of modulator is low. As shown in Fig (7-5), diode modulation consists of a resistive mixing network, a diode rectifier, and an *LC* tuned circuit. The carrier is applied to one of the input resistor and the modulating signal to another input resistor. This resistive network causes the two signals to be linearly mixed (i.e. algebraically added). A diode passes half cycles when forward biased. The carrier amplitude controls the operating region of piecewise-linear device. The carrier, in fact, would control the conducting stage of the diode described as follows:

a) When the carrier is positive, the diode operates in the conducting region so that it has low forward resistance. It acts as low resistance to the incoming signal.

b) When the carrier is negative, diode offers high resistance to the incoming signal because of being reverse biased.

The coil and capacitor repeatedly exchange energy, causing an oscillation or ringing at the resonant frequency

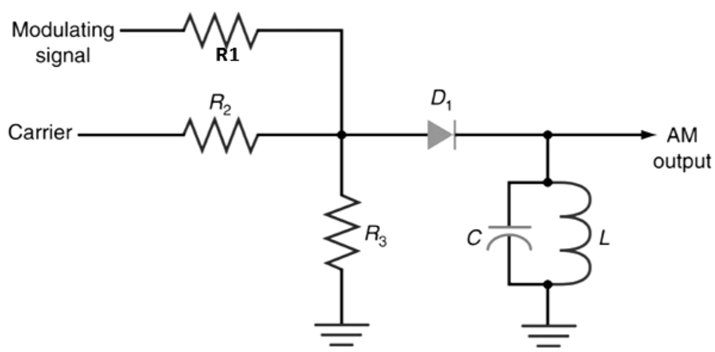

Fig 7-5 Low level diode modulator.

The abovementioned operation requires the amplitude of the carrier to be much greater than that of the modulating signal, i.e. , $V_c >> V_m$. Now, the input signal to the modulator is:

$$V_i(t) = (V_c \cos \omega_c t + V_m \cos\omega_m t)$$

Since V_c controls the ON and OFF state of the diode, it acts like a switch. Thus, the action of the carrier can be described by a switching function which can be written as

$$S(t) = \frac{1}{2} + \frac{2}{\pi}\cos \omega_C t + \frac{2}{3\pi}\cos 3\omega_C t + \cdots \ldots\ldots + \frac{2}{n\pi}\cos n\omega_C t.$$

Where, n = odd(1, 3, 5, 7………..)

The output signal would be the product of the input signal $V_i(t)$ and switching function S(t). Therefore,

$V_o(t) = V_i(t) \times S(t)$

$$= (V_c \cos \omega_c t + V_m \cos\omega_m t)\left(\frac{1}{2} + \frac{2}{\pi}\cos \omega_C\, t + \frac{2}{3\pi}\cos 3\omega_C t + \cdots \ldots . + \frac{2}{n\pi}\cos n\omega_C t\right)$$

$$= \frac{1}{2}(V_c \cos \omega_c t + V_m \cos\omega_m t) + \frac{2}{\pi}(V_c \cos \omega_c t + V_m \cos\omega_m t) \cos \omega_c t +$$

$$+ \frac{2}{3\pi}(V_c \cos \omega_c t + V_m \cos\omega_m t) \cos 3\omega_c t$$

$$+ \frac{2}{n\pi}(V_c \cos \omega_c t + V_m \cos\omega_m t) \cos n\omega_c t$$

$$= \boldsymbol{\frac{V_c}{2} \cos \omega_c t} + \boldsymbol{\frac{2Vm}{\pi} \cos\omega_m t \cos \omega_c t} + \frac{V_m}{2} \cos \omega_m t + \frac{2}{\pi} V_c \cos^2 \omega_c t + \frac{2}{3\pi} V_c \cos\omega_c t \cos 3\, \omega_c t$$

$$+ \frac{2}{3\pi} V_m \cos\omega_m t \cos 3\, \omega_c t + \ldots\ldots$$

The amplitude modulated output will be contributed by the bold written terms in the expression. Other terms will be blocked by an L-C tuned circuit which is tuned at frequency $\boldsymbol{\omega_c}$. Therefore,

$$V_{AM}(t) = \frac{V_c}{2} \cos \omega_c t + \frac{2Vm}{\pi} \cos\omega_m t \cos \omega_c t$$

$$= \frac{V_c}{2}\left(\cos \omega_c t + \frac{4Vm}{\pi Vc} \cos\omega_m t \cos \omega_c t\right)$$

$$= \frac{V_c}{2}\left(1 + \frac{4Vm}{\pi Vc} \cos\omega_m t\right) \cos \omega_c t$$

$$= \frac{V_c}{2}\left(1 + m \cos\omega_m t\right) \cos \omega_c t \qquad (7\text{-}5)$$

Where, $m = \frac{4Vm}{\pi Vc}$ is the modulation index. Equation (7-5) gives the desired output of AM.