AM Modulators

Introduction

In the last study material we discussed various scheme of Amplitude Modulation. In this study material 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 study material is:

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

Basic Principle

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

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

In the above equation, the first term is the sine wave carrier and the second term is theproduct 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

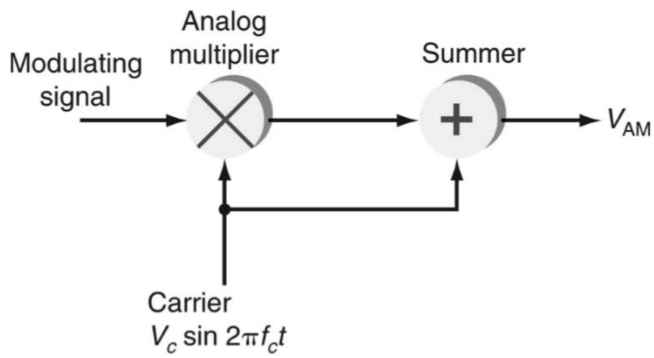


Fig 7-1 Block diagram realization of AM signal

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

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

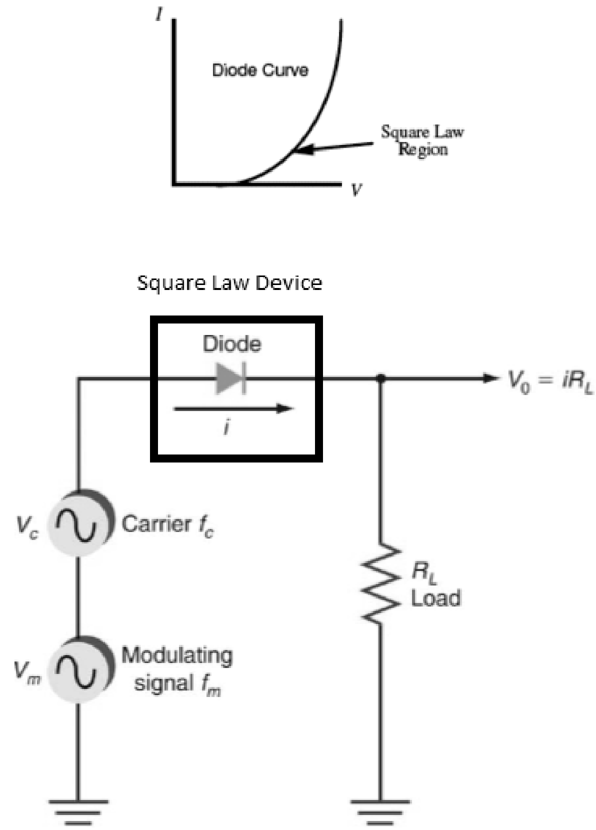


Fig 7-2 A Diode Square-Law Modulator

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

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.

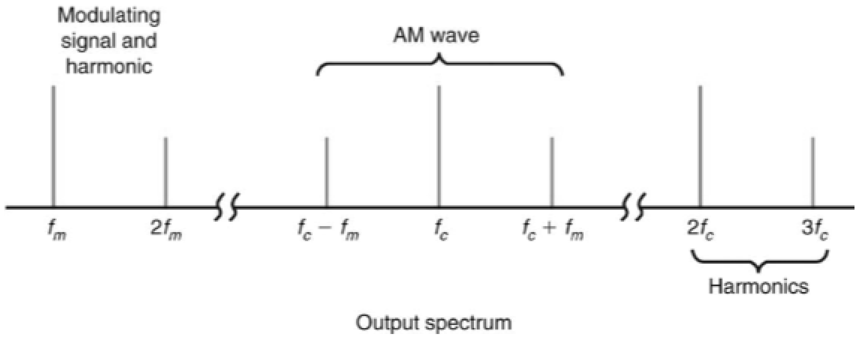


Fig 7-3 Frequency component present at the output of diode

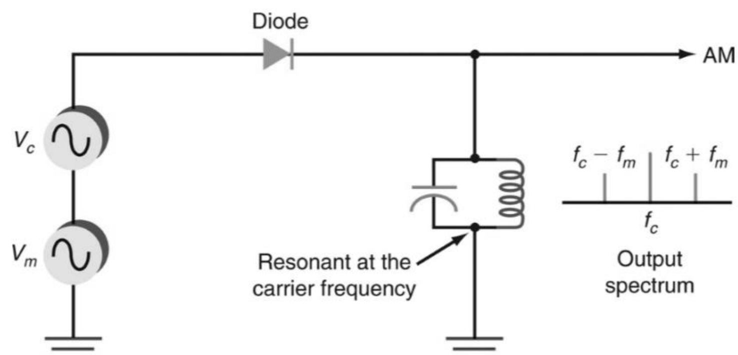


Fig 7-4 Modulated signal at the output of tank circuit

Therefore,

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

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

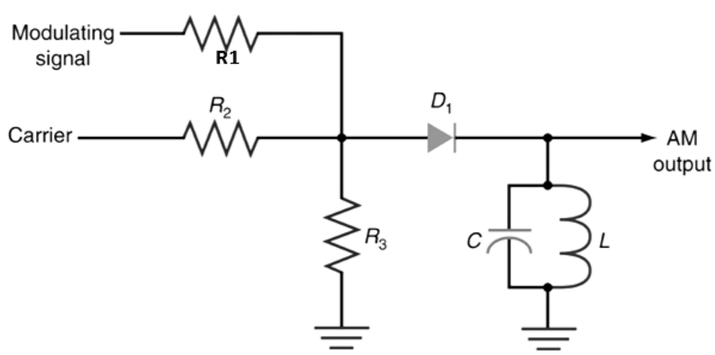


Fig 7-5 Low level diode modulator.

The abovementioned operation requires the amplitude of the carrier to be much greater than that of the modulating signal, i.e. , $V_c \gg V_m$. 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,

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

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

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

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

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

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

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

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 ω_c. Therefore,

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

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

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

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

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

Transistor Modulator (Basic Principle)

To perform modulation, we use non linear circuits. These circuits can be passive or active. Besides providing modulation active circuits also gives power gain. Transistor is an active device, whereas diode is passive. In practice, Transistor modulator is preferred over diode modulator. Transistor modulation consists of a resistive mixing network, a transistor, and an LC tuned circuit as shown in Fig (7-6). The emitter-base junction of the transistor serves as a diode and nonlinear device. Modulation and amplification occur as base current controls a larger collector current. The LC tuned circuit oscillates (rings) to generate the missing half cycle.

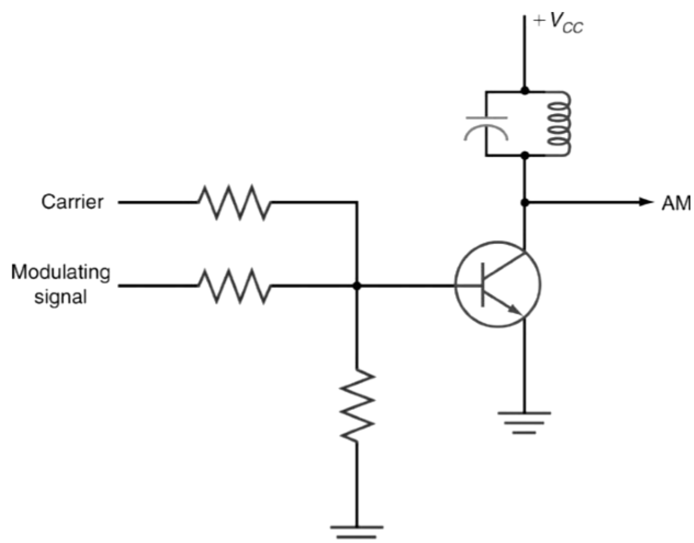


Fig (7-6) A Basic Transistor modulator

Emitter Modulator

The emitter modulator is basically a small signal amplifier, and is shown by Fig (7-7)

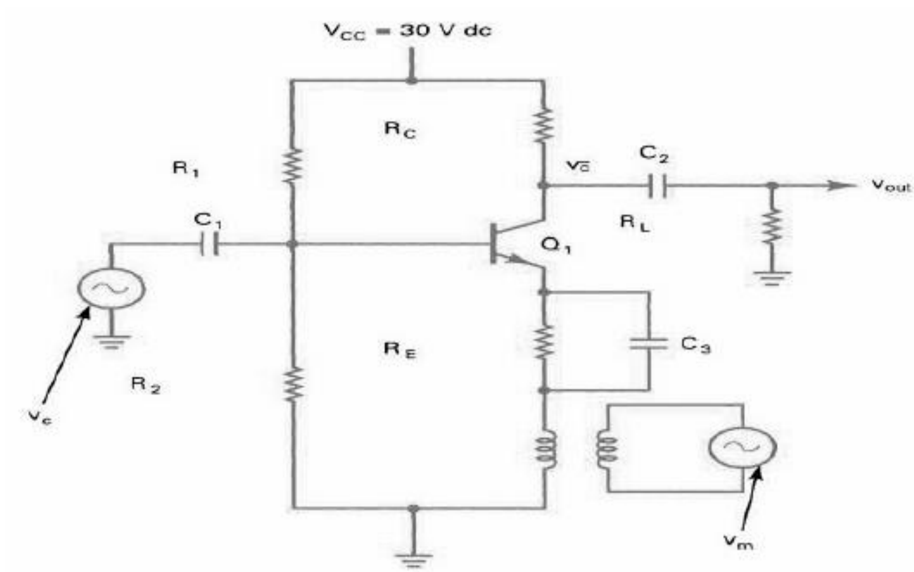


Fig (7-7) Single Transistor AM Modulator

When no modulating signal is present, the circuit operates as a linear amplifier. The output is simply the carrier amplified by the quiescent voltage gain. When a modulating signal is applied, the amplifier operates nonlinearly, and signal multiplication occurs. The modulating signal varies the gain of the amplifier at a sinusoidal rate equal to the frequency of the modulating signal and can be expressed as:

$$Av = Aq\,[1 + m \cos(\omega_m t)]$$

where Av = amplifier voltage gain with modulation

Aq = amplifier quiescent (without modulation) voltage gain

As cosine function goes from a maximum of +1 to a minimum of -1, above equation can be reduced to

$$Av = Aq\ (1 \pm m)$$

At 100% modulation,

$$Av_{(max)} = 2\ Aq, \text{ and}$$

$$Av_{\ (min)} = 0$$

Operation of the modulator is briefly described below:

Modulating signal is applied through isolation transformer to the emitter of transistor and the carrier is applied directly to the base. The modulating signal drives the circuit into both saturation and cut-off states, producing the nonlinear amplification necessary for modulation to occur. The collector waveform includes the carrier, upper and lower side frequencies as well as a component at the modulating frequency. Coupling capacitor C_2 removes the modulating signal frequency from the waveform, producing a symmetrical AM envelope at V_{out}.

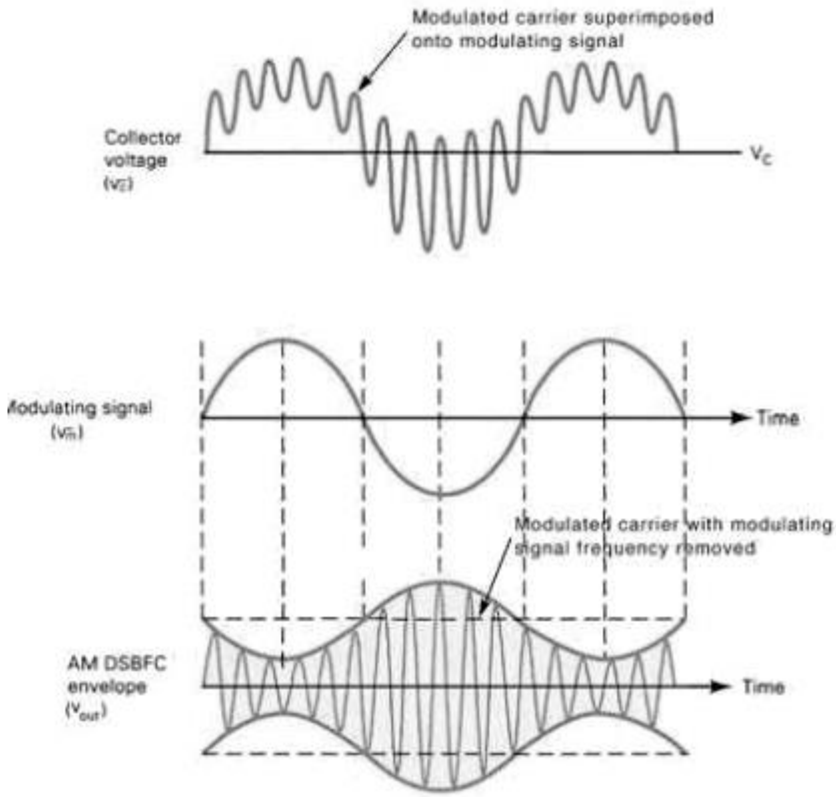


Fig 7-8 Emitter AM Modulator waveforms.

Following characteristics is to be noted with the operation of this circuit.

1. Amplitude of the output signal depends on the amplitude of input carrier and the voltage gain of amplifier
2. Coefficient of modulation depends entirely on the amplitude of modulating signal
3. Simple but incapable of producing high-power output waveforms

Collector Modulator

Similar to emitter modulator, the collector modulator is practically a transistor amplifier with the modulating signal is applied to the collector. The schematic diagram for the collector modulator is shown in Fig (7-9).

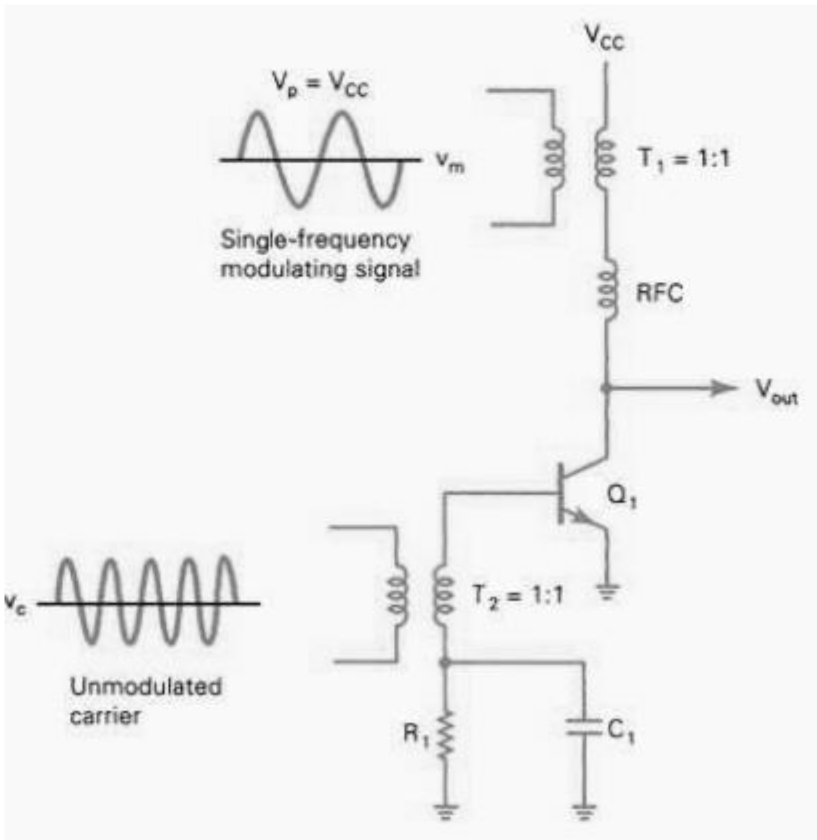


Fig (7-9) A simplified collector modulator

The RFC is a radio-frequency choke that acts as a short to DC and an open to high frequencies. Therefore, it isolates the DC power supply from high-frequency carrier and side frequencies while allowing low-frequency modulating signal to modulate the collector of the transistor

Operation of the circuit:

1. Without an applied modulating signal

- When the amplitude of carrier exceeds the barrier potential of the base-emitter junction (approximately 0.7V), the transistor turns on and the collector current flows.
- Similarly, when the amplitude drops below 0.7V, the transistor turns off and the collector current ceases. I.e. the transistor switches between saturation and cut-off controlled by the carrier signal.
- During each time where the transistor is on, the negative going waveform is produced at the collector. The waveform resembles a repetitive half-wave rectified signal with a fundamental frequency equal to fc.

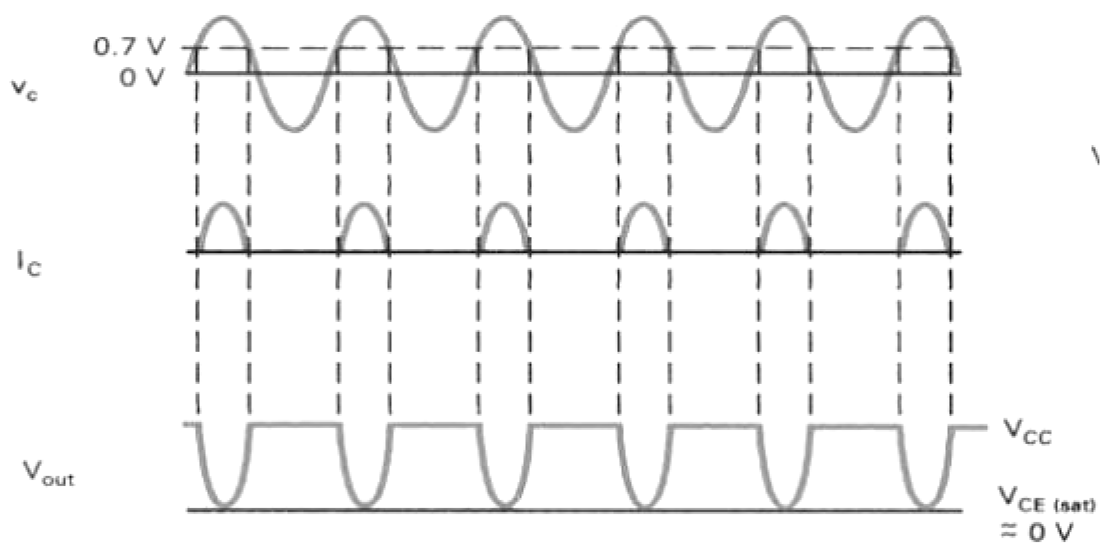


Fig (7-10) Collector waveform with no modulating signal.

2. with an applied modulating signal

- The modulating signal adds to and subtracts from the DC supply V_{CC} and the output voltage waveform swings from a maximum value ($2V_{CC}$) to a minimum value $V_{CE(sat)} \approx 0$).

- The circuit operates as before and the waveform produced again resembles a half-wave rectified carrier superimposed onto a low-frequency AC information signal.

Since the transistor operates nonlinearly, the collector waveform contains the two original input frequencies (f_c and f_m), the sum and difference frequencies ($f_c \pm f_m$) as well as the higher-order harmonics and inter-modulation components, it must be band-limited (filtered) to $f_c \pm f_m$ before being transmitted.

A much more practical collector modulator circuit for producing a medium-power AM DSBFC signal is discussed in the next section

High-Level AM: Collector Modulator

The collector modulator is a linear power amplifier that takes the low-level modulating signals and amplifies them to a high-power level. The operation of collector modulator is similar to that of the plate modulator. The circuit configuration most often employed for a collector modulator is the common-emitter amplifier .The transistor is biased in class C mode. A modulating output signal is coupled through a modulation transformer to a class C amplifier. The secondary winding of the modulation transformer is

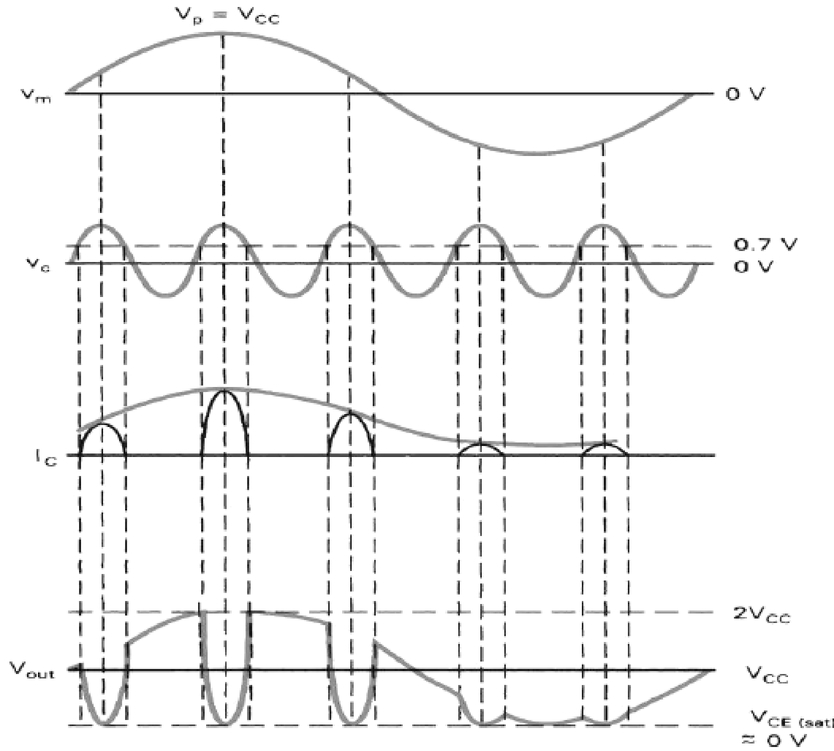


Fig (7-11) Collector waveform with an applied modulating signal

connected in series with the collector supply voltage of the class C amplifier. A circuit of a collector modulator is shown in Fig (7-12).

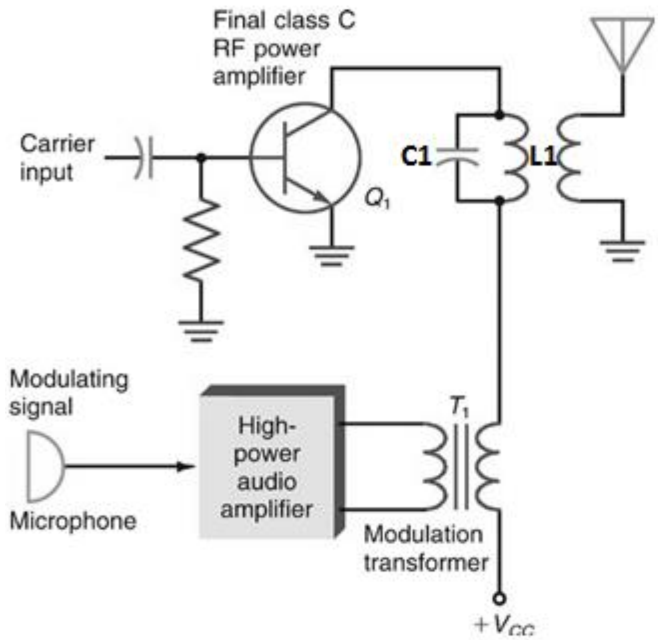


Fig (7-12) Collector Class C Modulator

The operation of this circuit is almost identical to the previous circuit except the addition of a tank circuit in the collector of the transistor. The waveforms of the circuit are shown below:

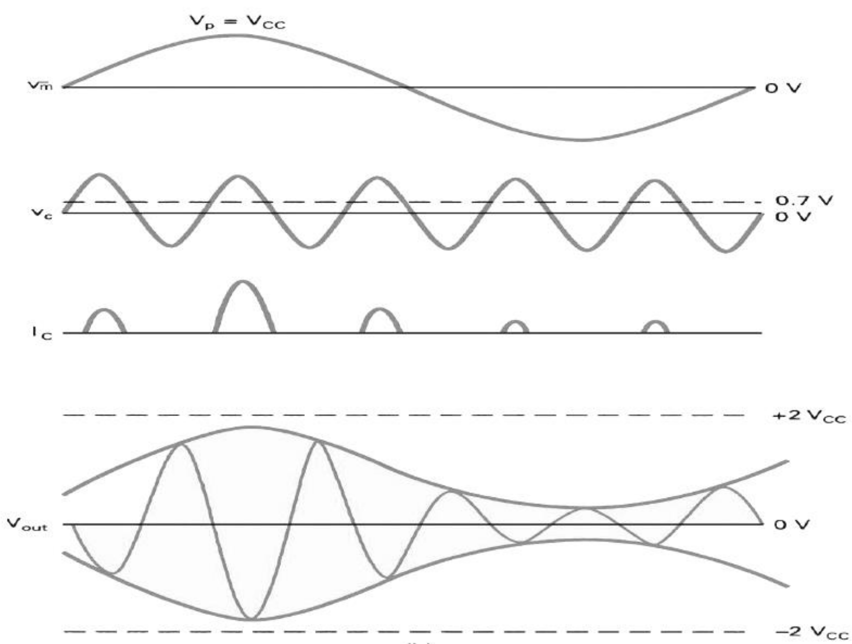


Fig (7-12) Waveform of collector modulator

The waveforms for the modulating signal, carrier and collector current are identical as before and the output is symmetrical AM DSBFC signal The positive half-cycle of the envelope is produced in the tank circuit by the flywheel action. As the transistor is conducting, capacitor C1 charges to $V_{CC} + V_m = 2V_{CC}$. When the transistor is off, C1 discharges through L1 . When L1 discharges, C1 charges to a minimum value of $-2V_{cc}$. The resonant frequency of the tank circuit is equal to f_c , and the bandwidth extends from $f_c - f_m$ to $f_c + f_m$. Consequently, the modulating signal, the harmonics and all the higher-order cross products are removed leaving a symmetrical AM DSBFC wave.

Comparisons between emitter modulator and collector modulator

Emitter Modulator	Collector Modulator
1. Less symmetrical envelope 2. Less power efficienc 3. Low output power 4. Require only small modulating signal drive power 5. Simpler circuit	1. More symmetrical envelope 2. Higher power efficiency 3. Higher output power 4.Need higher amplitude modulating signal 5. Complex circuit

Vander Bijl Modulator (Emitter Injection Modulator)

Hendrik van der Bijl

This is the transistor equivalent of the cathode modulator. The EMITTER-INJECTION MODULATOR has the same characteristics as the base-injection modulator discussed earlier. It is an extremely low-level modulator that is useful in portable equipment. In emitter-injection modulation, the gain of the RF amplifier is varied by the changing voltage on the emitter. The changing voltage is caused by the injection of the modulating signal into the emitter circuitry of Q1, as shown in figure 7-13. Here the modulating voltage adds to or subtracts from transistor biasing. The change in bias causes a change in collector current and results in a heterodyning action. The modulation envelope is developed across the collector-tank circuit.

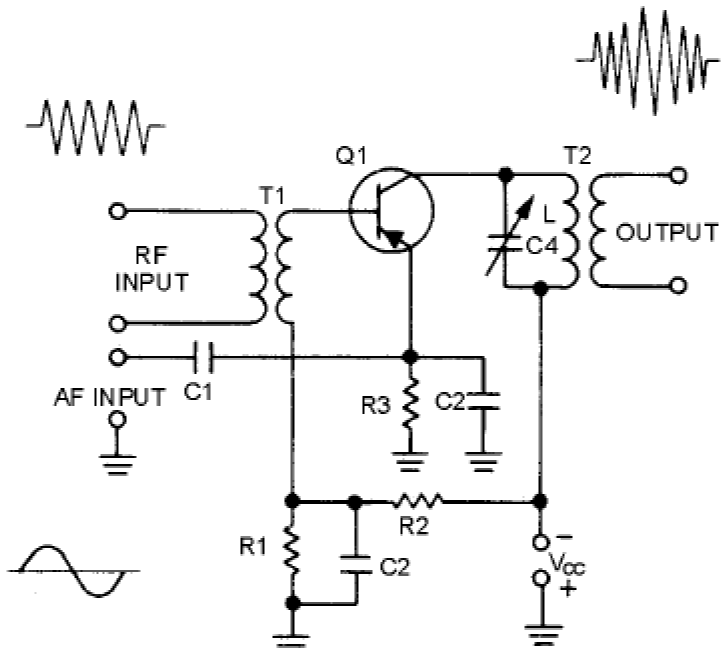


Figure 7-13 Emitter-injection modulator.

AM Transmitter

Low-Level Transmitters

Figure 7.14 shows a block diagram for a low-level AM DSBFC transmitter

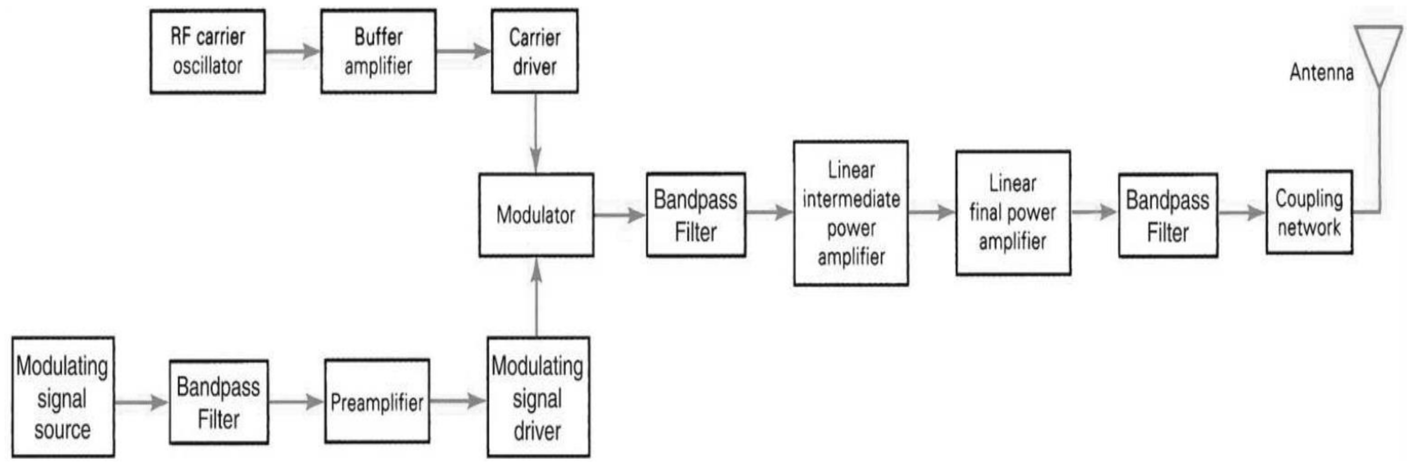


Fig 7-14 low-level AM DSBFC transmitter

Function of different blocks is given below:

The function of ***preamplifier*** (linear voltage amplifier with high input impedance) is to raise source signal amplitude to a usable level with minimum nonlinear distortion and as little thermal noise as possible.

Modulating signal driver (linear amplifier) amplifies the information signal to an adequate level to sufficiently drive the modulator.

RF carrier oscillator is used to generate the carrier signal, for this purpose usually crystal-controlled oscillators are used.

The *buffer amplifier* (low-gain, high-input impedance linear amplifier) is used to isolate the oscillator from the high-power amplifiers.

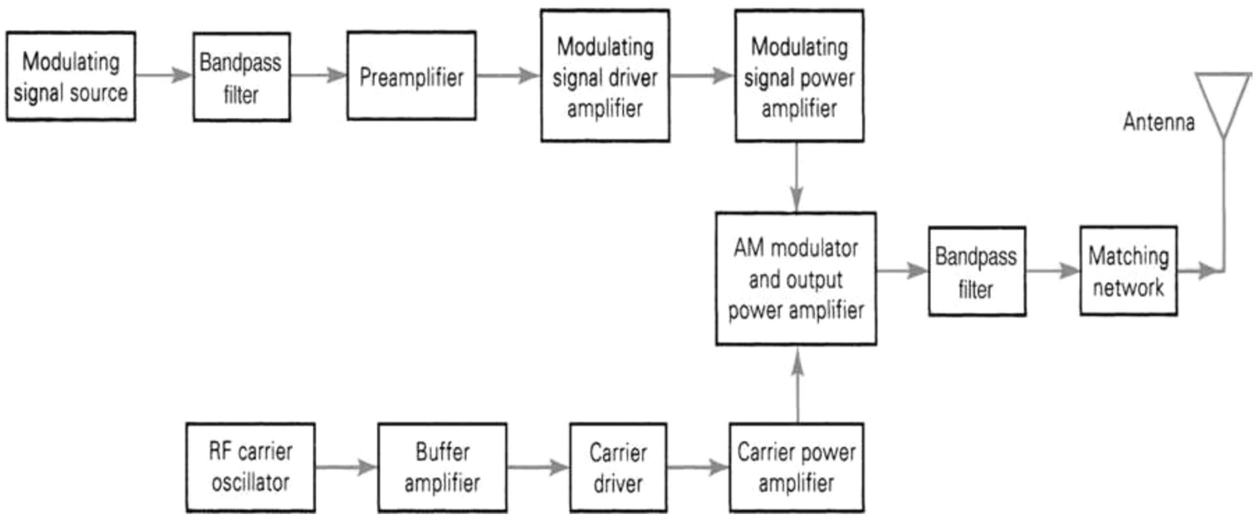
The ***modulator*** can use either emitter or collector modulation

The ***intermediate*** and ***final power amplifiers*** (push-pull modulators) are required with low-level transmitters to maintain symmetry in the AM envelope

The *coupling network m*atches output impedance of the final amplifier to the transmission line/antenna. Application of this transmission is in low-power, low-capacity systems: wireless intercoms, remote-control units, pagers and short-range walkie-talkie.

High-Level Transmitters

The block diagram for a high-level AM DSBFC transmitter:



Modulating signal is processed similarly as in low-level transmitter except for the addition of power amplifier to provide higher power modulating signal necessary to achieve 100% modulation (carrier power is maximum at the high-level modulation point). Same circuit as before, for carrier oscillator, buffer and driver but with addition of power amplifier is also applied here. The modulator circuit has three primary functions:

- Provide the circuitry necessary for modulation to occur
- It is the final power amplifier
- Frequency up-converter: translates low-frequency information signals to radio-frequency signals that can be efficiently radiated from an antenna and propagated through free space

You have studied six methods of amplitude modulation. These are not the only methods available, but they are the most common. All methods of AM modulation use the same theory of heterodyning across a nonlinear device. AM modulation is one of the easiest and least expensive types of modulation to achieve. The primary disadvantages of AM modulation are susceptibility to noise interference and the inefficiency of the transmitter. Power is wasted in the transmission of the carrier frequency because it contains no AM intelligence. Conventional AM DSB communication systems have two inherent disadvantages.

- First, with conventional AM, carrier power constitutes two thirds or more of the total transmitted power .This is a major drawback because the carrier contains no information.
- Conventional AM systems utilize twice as much bandwidth as needed with SSB systems. With SSB transmission, the information contained in the USB is identical the information contained in the LSB. Therefore, transmitting both sidebands is redundant.
- Consequently, Conventional AM is both power and bandwidth inefficient, which are the two predominant considerations when designing modern electronic communication systems.

In the next section, you will study other forms of modulation that have been developed to overcome these disadvantages.

DSB-SC Modulators

Double sideband-suppressed carrier (DSB-SC) is a type of modulation, in which the transmitted wave consists of only the upper and lower sidebands. Transmitted power is saved through the suppression of the carrier wave, but the channel bandwidth requirement is same as in AM (i.e. twice the bandwidth of the message signal).

Basically, double sideband-suppressed (DSB-SC) modulation consists of the product of both the message signal m (t) and the carrier signal, as follows:

- The modulated signal s (t) undergoes a phase reversal whenever the message signal m (t) crosses zero. The envelope of a DSB-SC modulated signal is different from the message signal.
- The transmission bandwidth required by DSB-SC modulation is the same as that for amplitude modulation which is twice the bandwidth of the message signal, $2\omega_m$.

There are three methods to generate DSB-SC waves. They are:

1. Product Modulator
2. Balanced modulator
3. Ring modulator

Product Modulator

A Product modulator is a circuit that generates a DSB-SC signal, suppressing the carrier and leaving only the sum and difference frequencies at the output. This modulation process does not introduce sinusoid at fc and as a result, it is called Double-sideband, suppressed-carrier (DSB-SC modulation). The output of a DSB-SC modulator can be further processed by filters or phase-shifting circuitry to eliminate one of the sidebands, resulting in a SSB signal.

In the time domain, for the baseband signal $m(t) = V_m \cos\omega_m t$, the DSB-SC signal

$$\mathcal{V}_{DSB}(t) = m(t) \times \cos\omega_c t$$

$$= V_m \cos\omega_m t \times V_c \cos\omega_c t$$

$$= \frac{VmVc}{2}[\cos(\omega_c - \omega_m) + \cos\ (\omega_c + \omega_m)]$$

When the baseband is a single sinusoid of frequency fm, the modulated signal consists of two sinusoids; the component of frequency $\omega_c+\omega_m$ (USB) and the component of frequency $\omega_c+\omega_m$ (LSB).

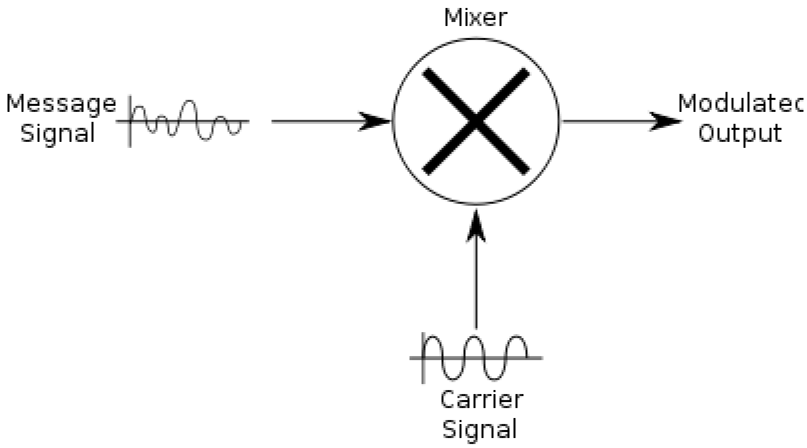


Fig 7-14 Product modulator to generate DSB-SC signal

Fig 7-14 shows the schematic diagram of product modulator for the realization of DSB-SC signal. This scheme is also known as heterodyning. The operation of frequency mixing/conversion is known as heterodyning. This is basically a shifting of spectra by an additional ωc. This is also equivalent to the operation of modulation with modulating carrier frequency that differs from incoming carrier frequency by ωm.

Balance Modulator

One possible scheme for generating a DSBSC wave is to use two AM modulators arranged in a balanced configuration so as to suppress the carrier wave, as shown in Fig. 7-14. Assume that two AM modulators are identical, except for the sign reversal of the modulating signal applied to the input of one of the modulators. Thus the outputs of the two AM modulators can be expressed as follows

$$S_1(t) = A_c\,[1+k_a m\,(t)]\cos\omega_c t$$

and

$$S_2(t) = A_c[1 - k_a m(t)] \cos \omega_c t$$

Subtracting $S_2(t)$ from $S_1(t)$, we obtain

$$S(t) = S_1(t) - S_2(t)$$

$$S(t) = 2A_c k_a m(t) \cos \omega_c t$$

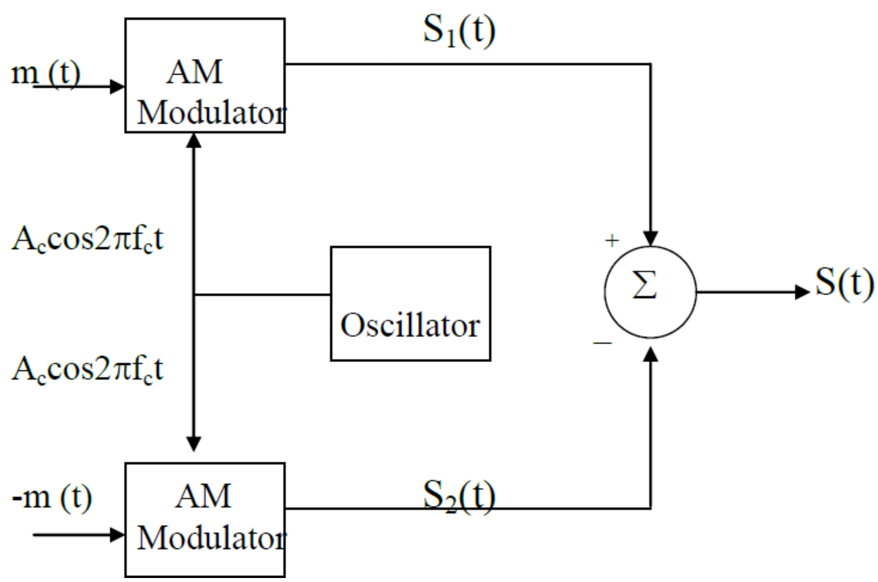


Fig 7-14 Balanced Modulator

Hence, except for the scaling factor 2ka the balanced modulator output is equal to product of the modulating signal and the carrier signal as in product modulator.

Ring Modulator

The DSB-SC can be generated using either the balanced modulator or and the 'ring-modulator'. The balanced modulator uses two identical AM generators along with an adder. The two amplitude modulators have a common carrier with one of them modulating the input message, and the other modulating the inverted message. Generation of AM is not simple, and to have two AM generators with identical operating conditions is extremely difficult. Hence, laboratory implementation of the DSB-SC is usually using the 'ring-modulator', shown in figure (7-15)

Ring modulator is one of the most useful product modulator, well suited for generating a DSB-SC wave. The diodes are controlled by a square-wave carrier of frequency f_c, which is applied longitudinally by means of two center-tapped transformers. If the transformers are perfectly balanced and the diodes are identical, there is *no* leakage of the modulation frequency into the modulation output . To understand the operation of the circuit, assume that the diodes have a constant forward resistance r_f when switched on and a constant backward resistance r_b when switched off; and they switch as the carrier wave crosses through zero axis. On one half-cycle of the carrier wave, the outer diodes (D1-D3) are switched to their forward resistance r_f and the inner diodes (D2-D4) are switched to their backward resistance r_b. On other half-cycle of the carrier wave, the diodes operate in the opposite condition

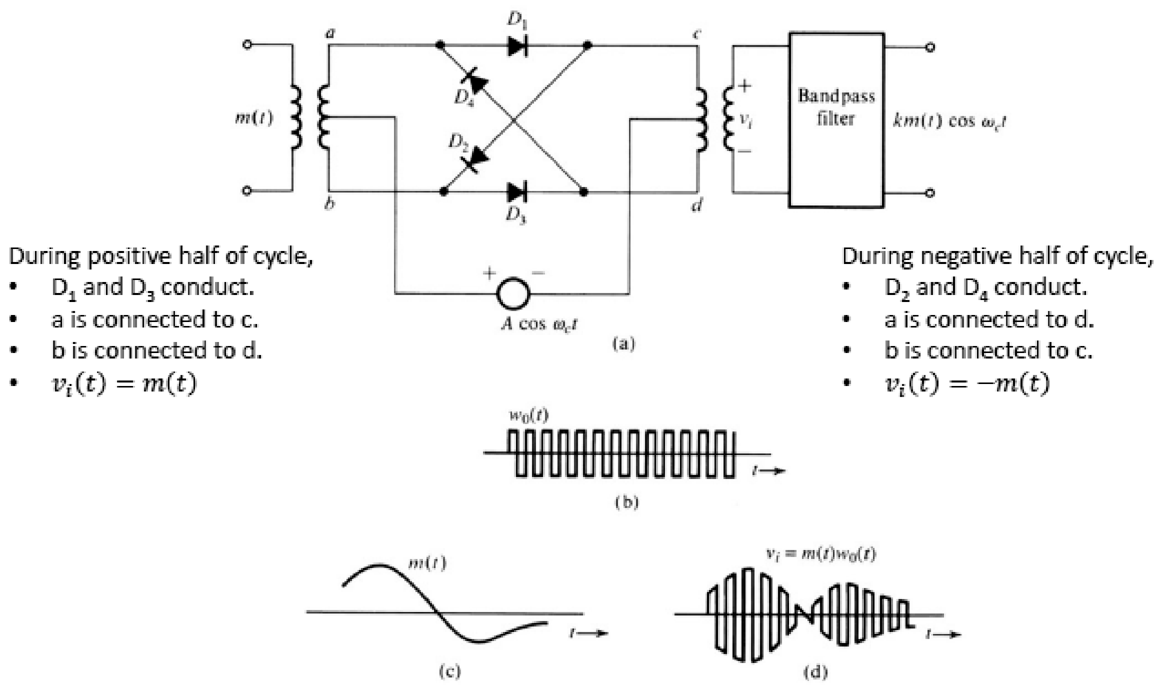


Fig (7-15) The ring modulator used for the generation of DSB-SC

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$$X(t) = \sum_{n=0}^{\infty} C_n \cos(n\omega_c t + \theta c)$$

$$W_0(t) = \frac{4}{\pi}\left(\cos \omega_c t - \frac{1}{3} \cos 3\omega_c t + \frac{1}{5} \cos 5\omega_c t - \cdots\right)$$

$$V_i(t) = m(t) \times w_0(t)$$

$$= \frac{4}{\pi}\left(m(t) \cos \omega_c t - \frac{1}{3}\, m(t) \cos 3\omega_c t + \frac{1}{5}\, m(t) \cos 5\omega_c t - \cdots\right)$$

The output of band-pass filter will be:

$$= \frac{4}{\pi} m(t) \cos \omega_c t$$

The modulator output consists of modulation products. The ring modulator is sometimes referred to as a double-balanced modulator, because it is balanced with respect to both the message signal and the square wave carrier signal.

Single-Sideband Suppressed Carrier (SSB-SC) Modulator

There are two methods used for SSB Transmission.

- Filter Method
- Phase Shift Method

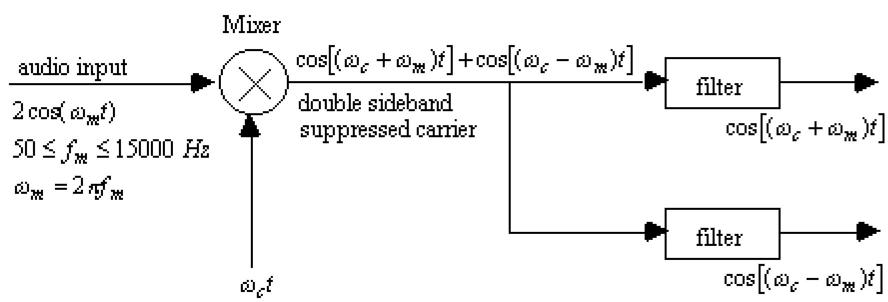
Filter Method

Conceptually, the generation of a SSB signal is straightforward. This can be generated with two easy steps:

– Generate a DSB signal.
– Apply an ideal band-pass filter.

The **filter method** is the simplest and most widely used method of generating SSB signals. The modulating signal is first applied to the audio amplifier. The amplifier's output is fed to one input of a balanced modulator. A crystal oscillator provides the carrier signal which is also applied to the balanced modulator. The output of the balanced modulator is a double- sideband (DSB) signal. An SSB signal is produced by passing the DSB signal through a highly selective band-pass filter. With the filter method, it is necessary to select either the upper or the lower sideband. Practically, the construction of ideal filter is very difficult. The modulating signal is assumed to be a single-frequency sine wave. The passband for the output filter is indicated on the diagram for the upper sideband. The lower sideband also could be selected, if desired, rather than the upper sideband. The sideband-suppression filter must have very sharp cutoff characteristics, and the IF must be quite low for most SSB applications.

In a typical example, the filter's response must change from near zero attenuation to near full (30 dB or more) attenuation over a range of only 600 Hz. To obtain a filter response curve with skirts as steep as those suggested, the Q of the filter (reactance/resistance) must be very high. Possible filter types include LC filters, crystal filters, ceramic filters, mechanical filters, and SAW filters. Because of Q limitations, LC filters cannot be used for IF values greater than about 100 kHz. Mechanical filters have been used at frequencies up to 500 kHz and crystal filters and ceramic filters up to about 30 MHz. SAW filters can be used up to 2 GHz.



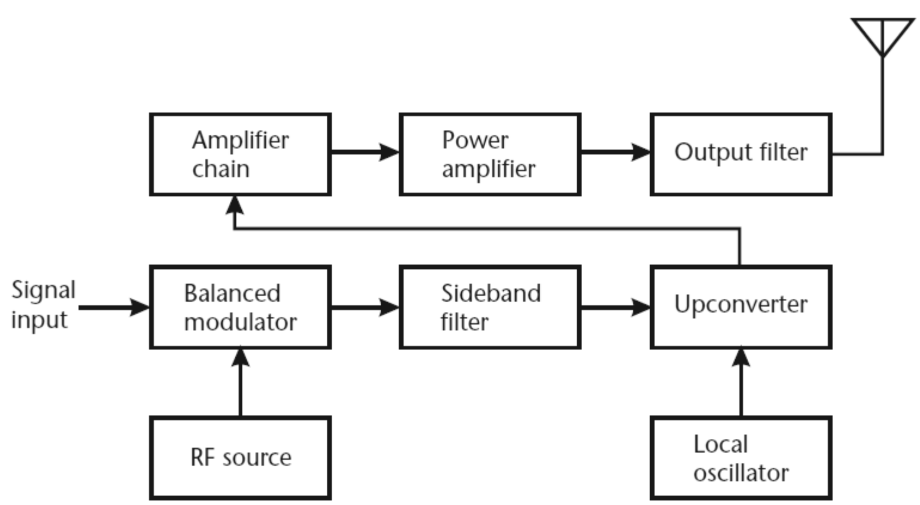
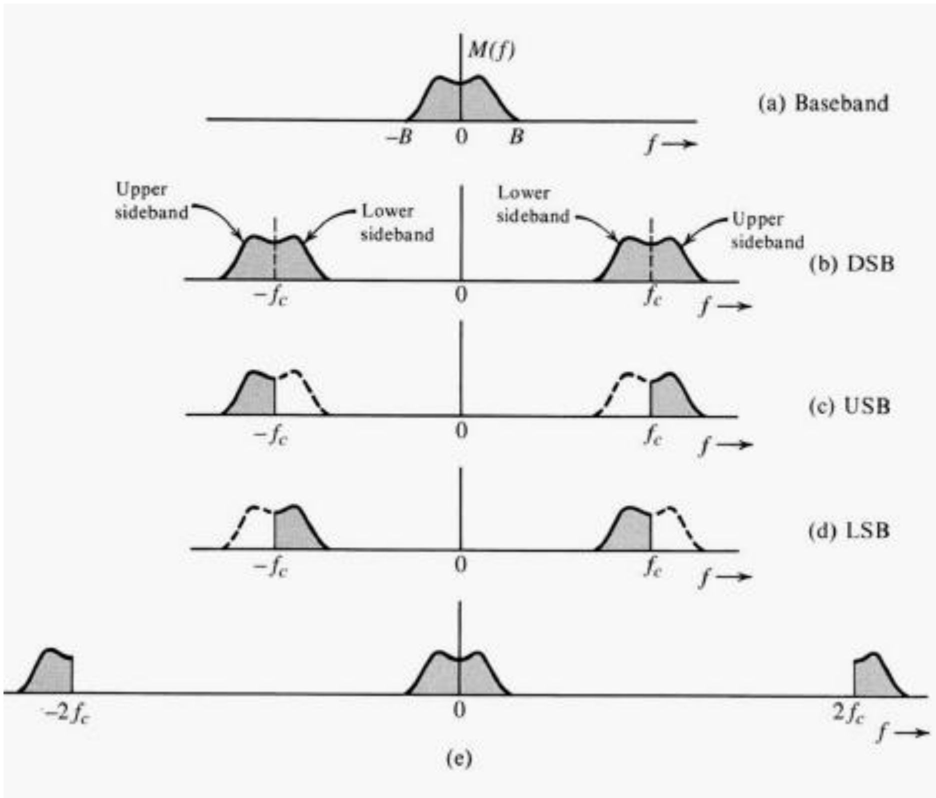


Fig 7-16 SSB Generation using Filter- Method



Phase-Shift Method

The phase-shift method of producing SSB suppressed-carrier signal is shown in Figure 7-16. This method avoids filters and some of their attendant disadvantages.

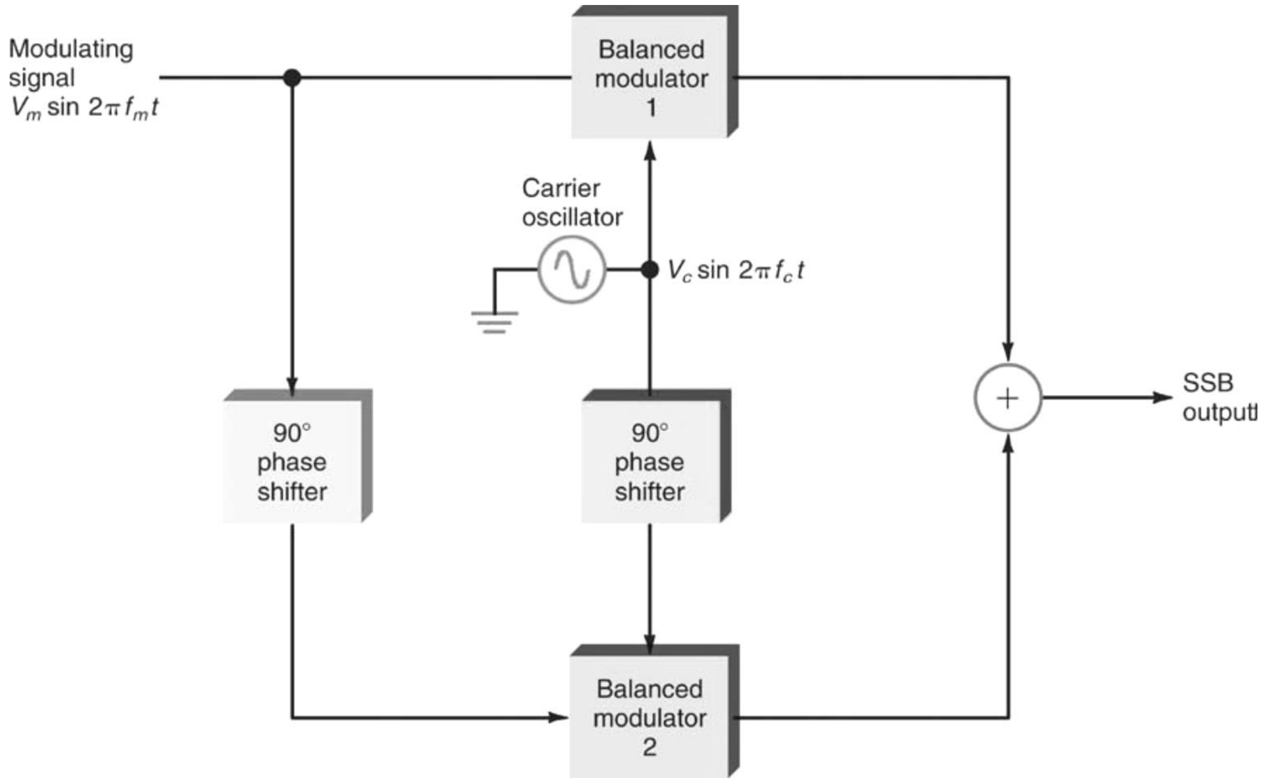


Fig 7-16 SSB-SC Generation using Phase Shift Method

The audio input signal is applied to two all-pass networks with phase shifts that differ by 90 degrees over the frequency range of interest. The signals are then applied to two balanced modulators along with in-phase and quadrature (90-degree out of phase) signals of the desired RF frequency. The in-phase and quadrature signals can be obtained by digital frequency division of the output of a variable-frequency oscillator operating at four times the output frequency. The outputs of the two balance modulators are summed and then amplified to the desired level. The operation of an SSB modulator that uses the phase shift method is demonstrated as follows:

The equation of a wave with the carrier removed is

$$V_{OBM1} = V_m \cos\omega_m t \times V_c \cos\omega_c t$$

$$= \frac{VmVc}{2}[\cos(\omega_c - \omega_m) + \cos\ (\omega_c + \omega_m)] \qquad (7.3)$$

This is the case for the output of the first modulator. When both modulating and carrier frequencies are shifted 90 degrees, as in the case of the second balanced modulator, the equation for a wave with the carrier removed is

$$V_{OBM2} = V_m \cos(\omega_m t + \pi/2) \times V_c \cos(\omega_c t + \pi/2)$$

$$= \frac{VmVc}{2}\left[\cos\left(\omega_c + \frac{\pi}{2} - \omega_m - \frac{\pi}{2}\right) + \cos\ \left(\omega_c + \frac{\pi}{2} + \omega_m + \frac{\pi}{2}\right)\right]$$

$$= \frac{VmVc}{2}[\cos(\omega_c - \omega_m) - \cos\ (\omega_c + \omega_m)] \qquad (7.4)$$

On the application of equation (7.3) and (7.4) to adder, the output of adder will be

$$V_{SSB}(t) = V_m V_c \cos(\omega_c - \omega_m) \qquad (7.5)$$

Output corresponds to the equation of the lower sideband. If the polarity of one of the modulating voltages or one of the RF voltages is reversed, the other sideband would appear at the output terminals. Possible variations of SSB are SSB with full carrier and SSB with reduced carrier. The carrier can be added after generation of the SSB signal. The advantages of single side band SSB transmission are as follows.

Advantages

- It allows better management of the frequency spectrum. More transmission can fit into a given frequency range than would be possible with double side band DSB signals.
- All of the transmitted power is message power none is dissipate as carrier power.

- The noise content of a signal is an exponential function of the bandwidth: the noise will decrease by 3dB when the bandwidth is reduced by half. There fore, single side band SSB signals have less noise contamination than DSB double side band.

Disadvantages

- The cost of a single side band SSB reciver is higher than the double side band DSB counterpart be a ratio of about 3:1.
- The average radio user wants only to flip a power switch and dial a station. Single side band SSB recievers require several precise frequency control settings to minimize distortion and may require continual readjustment during the use of the system.

AM Demodulation

So far, we have discussed various scheme of amplitude modulation. The basic process involved in any AM system is frequency shift of baseband signal around carrier signal. At the receiver end the modulated signal becomes meaningful for human use, if it is brought back, further, to its original position in frequency domain as it is shown in fig 7.17.

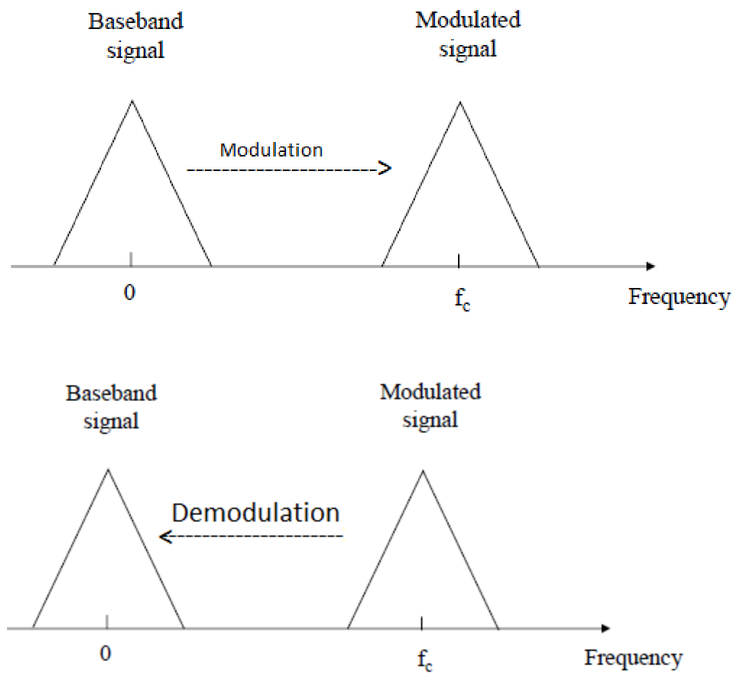


Fig 7.17 Pcocess involved in modulation and demodulation

Thus, Demodulation or detection is the process of recovering the intelligence contained in the modulated carrier. It is reverse of the modulation process. Both, modulation and demodulation involve frequency shifting, which requires the incorporation of nonlinear element.

Demodulators, or detectors, are circuits that accept modulated signals and recover the original modulating information. The circuit used for modulation and demodulation are quite similar. In demodulation as in modulation, it is necessary that detection process be linear. Any new terms appearing in the frequency spectrum of the detected signal produces distortion.

The difference between detection and demodulation is subtle, and virtually indicate the same process. If the recovery of information signal involves the reintroduction of the carrier, either internally as part of the applied modulated signal or externally as produced by a local oscillator, and through converter action sum and difference frequency terms are produced , then the process is technically demodulation.

DSB-SC and SSB-SC signal require a demodulation process. If frequency translation is not essential to the recovery of the information signal, the process technically is detection. The detector reproduces the signal frequency by producing a distortion of a desirable kind. When the output of the detector is impressed upon a low-pass filter, the radio frequencies are suppressed and only the low-frequency intelligence signal and dc components are left.

There are mainly three methods to demodulate AM signals, they are

- Square-Law Detection
- Envelope Detection
- Coherent Detection

Square-Law Detection (Non-Linear Demodulator)

A Square-law modulator requires nonlinear element and a low pass filter for extracting the desired message signal. Semi-conductor diodes and transistors are the most common nonlinear devices used for implementing square law modulators. The filtering requirement is usually satisfied by using a single or double tuned filters. When a nonlinear element such as a diode is suitably biased and operated in a restricted portion of its characteristic curve, that is ,the signal applied to the diode is relatively weak, we find that transfer characteristic of diode-load resistor combination can be represented closely by a square law. In the square law region, the output voltage Vo is proportional to the square of the input voltage Vi, thus Vo is proportional to the input power.

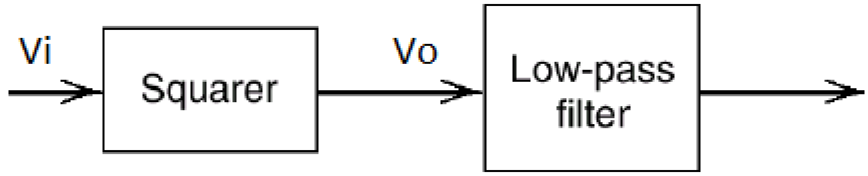


Fig 7.18 Block Diagram of Square-Law Detector

It utilizes the non-linear portion of the dynamic current-voltage characteristic of a diode. It differs from the linear diode detector is that in this case the applied input carrier voltage is of small magnitude and hence is restricted to the excessively non linear portion of the dynamic characteristic, whereas in linear diode detector, a large amplitude modulated carrier voltage is applied to the diode and most of the operation takes place over the linear region of the

The basic circuit of square law diode detector is shown in Fig 7.19. The diode is biased positively to shift the zero-signal operating point to the small current non linear region of the dynamic current-voltage characteristic. The capacitor-resistor combination constitutes the load. To study the operation of this detector, we may consider first only the resistor R to constitute the load impedance. Then the dynamic current-voltage characteristic ofthe diode. Superposition of modulated carrier voltage on the dynamic characteristic is also illustrated. This results in the output current waveform. Since the operation takes place over the non linear region of the characteristic the current waveform has its lower half compressed.

A square law device has the input- output characteristics of the form

$$V_o = a\,(V_i) + b(V_i)^2 \qquad (7.7)$$

Where, $$V_i = V_c\ [1 + m \cos \omega_m t] \cos \omega_c t \qquad (7.8)$$

The first term in equation (7.7) contains terms in frequency ω_c, $(\omega_c - \omega_m)$, $(\omega_c + \omega_m)$. Evidently, the second term in equation (7.7) gives terms in frequencies $2\omega_c$, $2(\omega_c - \omega_m)$, $2(\omega_c + \omega_m)$, ω_m and $2\omega_m$

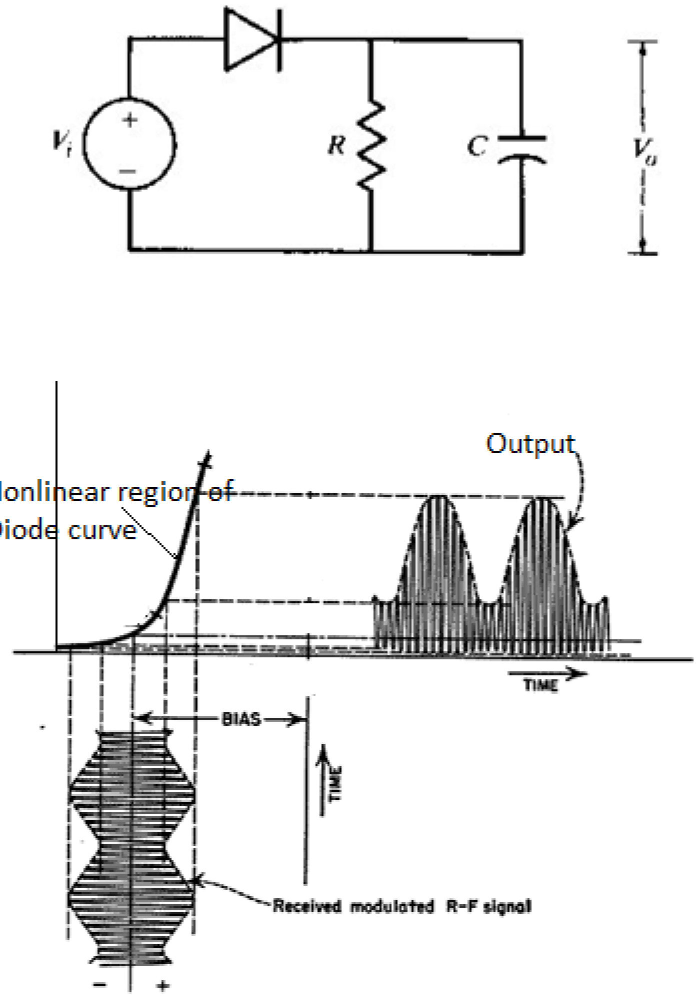


Fig7.19 Squarelaw diode detector and its input-outpur behavior with applied RF input

This average current consists of a steady or D C component and a time varying component at the modulation frequency. The shunt capacitor C bypasses all the radio frequency components like ω_c, $(\omega_c - \omega_m)$, $(\omega_c + \omega_m)$, $2\omega_c$, $2(\omega_c - \omega_m)$, $2(\omega_c + \omega_m)$ leaving only the average component like ω_m and $2\omega_m$ to flow through the load resistor R producing the detected output. The term in frequency ω_m constitute the desired output whereas the term in frequency $2\,\omega_m$ forms the distortion term.

Linear Diode Detector

There are various ways to *detect* the amplitude of a modulated waveform. Here we'll consider one of the simplest, used by most portable radios, etc, the *Envelope Detector.* Envelope detector is used to detect high level modulated levels, whereas square -law detector is used to detect low level modulated signals (i.e., below 1v). It is also based on the switching action or switching characteristics of a diode. It consists of a diode and a resistor-capacitor filter as shown in Fig 7.20.

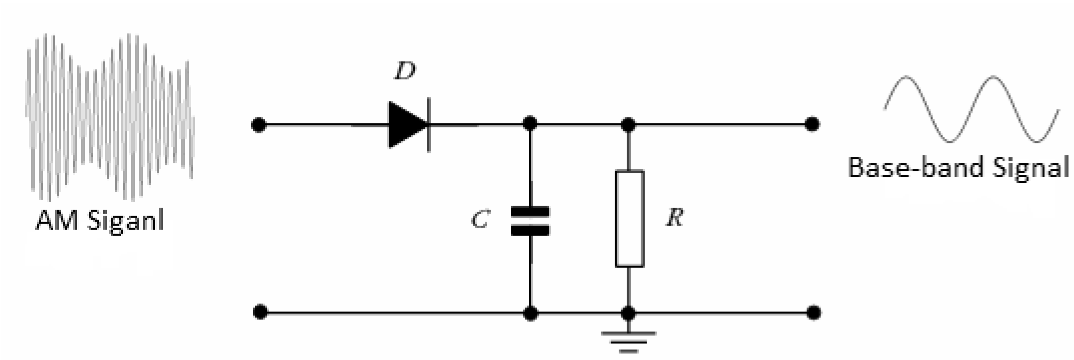


Fig 7.20 Envelope Detector

The operation of the envelope detector is as follows. On a positive half cycle of the input signal, the diode is forward biased and the capacitor C charges up rapidly to the peak value of the input signal. When the input signal falls below this value, the diode becomes reverse biased and the capacitor C discharges slowly through the 'bleed' resistor R. The discharging process continues until the next positive half cycle. When the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated. The main advantage of this form of AM Demodulator is that it is very simple and cheap! Just one diode, one capacitor, and one resistor. That's why it is used so often. However, it does suffer from some practical problems.

The circuit relies upon the behavior of the diode — allowing current through when the input is +ve with respect to the capacitor voltage, hence 'topping up' the capacitor voltage to the peak level, but blocking any current from flowing back out through the diode when the input voltage is below the capacitor voltage. Unfortunately, all real diodes are non-linear. The current they pass varies with the applied voltage. As a result, the demodulated output is slightly distorted in a way which depends upon the diode's *I/V characteristic*. For example, most AM transistor radios produce output signals like music with about 5-10% distortion. OK for casual listening, but hardly Hi-Fi! As a result, this simple type of AM demodulator isn't any good if we want the recovered waveform to be an accurate representation of the original modulating waveform. The circuit also suffers from the problems known as *Ripple* and *Negative Peak Clipping*. These effects are illustrated in figure (7.21). The ripple effect happens because the capacitor will be discharged a small amount in between successive peaks of the input AM wave.

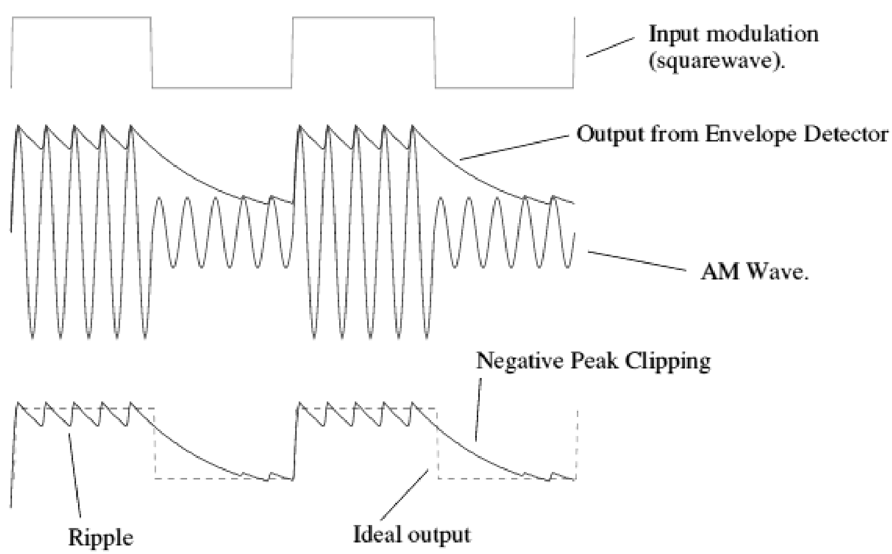


Fig 7.21 Ripple and Peak Clipping effect

The illustration shows what happens in the worst possible situation where the modulating signal is a square wave whose frequency isn't much lower than the carrier frequency. Similar, but less severe, problems can arise with other modulating signals.

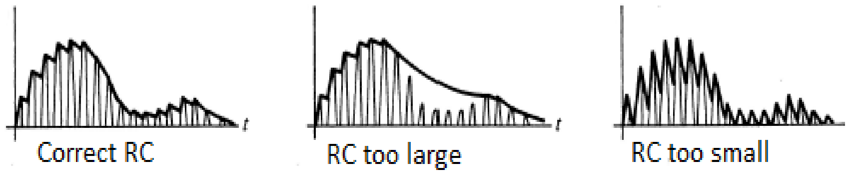


Fig 7.22 Different value of RC affecting output of envelope detector

Consider what happens when we have a carrier frequency, ω_c , and use an envelope detector whose *time constant*, τ = RC. The time between successive peaks of the carrier will be

$$T = \frac{1}{f_c}$$

Each peak will charge the capacitor to some voltage, V_{peak}, which is proportional to the modulated amplitude of the AM wave. Between each peak and the next the capacitor voltage will therefore be discharged to

$$V'_{peak} \approx V_{peak} \exp(-\frac{T}{\tau})$$

which, provided that $T \ll \tau$, is approximately the same as

$$V'_{peak} = V_{peak} \, [1 - \frac{T}{\tau}]$$

The peak-to-peak size of the ripple, ΔV, will therefore be

$$\Delta V = V_{peak} \frac{T}{\tau}$$

$$= \frac{V_{peak}}{\tau f_c}$$

A sudden, large reduction in the amplitude of the input AM wave means that capacitor charge isn't being 'topped up' by each cycle peak. The capacitor voltage therefore falls exponentially until it reaches the new, smaller, peak value. To assess this effect, consider what happens when the AM wave's amplitude suddenly reduces from V_{peak} to a much smaller value. The capacitor voltage then declines according to

$$V_{drop} = V_{peak}\ exp(-t/\tau)$$

This produces the negative peak clipping effect where any swift reductions in the AM wave's amplitude are 'rounded off' and the output is distorted. Here we've chosen the worst possible case of square wave modulation. In practice the modulating signal is normally restricted to a specific frequency range. This limits the maximum rate of fall of the AM wave's amplitude. We can therefore hope to avoid negative peak clipping by arranging that the detector's time constant $\tau \ll t_m$, where

$$t_m = \frac{1}{f_m}$$

Here, f_m is the highest modulation frequency used in a given situation.

The above implies that we can avoid negative peak clipping by choosing a small value of τ. However, to minimize ripple it is desired to make τ as large as possible. In practice we should therefore choose a value

$$\frac{1}{f_m} \gg \tau \gg \frac{1}{f_c}$$

Therefore, to minimize the signal distortion caused by these effects. This is possible only if the modulation frequency $f_m \ll f_c$. Envelope detectors only work satisfactorily when we ensure this inequality is true.

Advantages:

- It is very simple to design.
- It is inexpensive.
- Efficiency is very high when compared to Square Law detector.

Disadvantage:

- Due to large time constant, some distortion occurs which is known as diagonal clipping i.e., selection of time constant is somewhat difficult.

Application:

- It is most commonly used in almost all commercial AM Radio receivers.

Coherent Detector

The base band signal m (t) can be recovered from a DSB-SC wave by multiplying it with a locally generated sinusoidal signal and then low pass filtering the product. It is assumed that local oscillator signal is coherent or synchronized, in both frequency and phase ,with the carrier signal $V_c(t)$ used in the product modulator to generate DSB-SC. This method of demodulation is known as coherent detection or synchronous demodulation shown in Fig 7.22. For DSB-SC, we can no longer use the "envelope detector" (as used for DSB-FC), in which no local carrier is required for the receiver. The key to making the synchronous detector work is to ensure that the signal producing the switching action is perfectly in phase with the received AM carrier. An internally generated carrier signal from an oscillator will not work. **Synchronous detectors** use an internal clock signal at the carrier frequency in the receiver to switch the AM signal off and on, producing rectification similar to that in a standard diode detector.

Synchronous detectors or **coherent detectors** have less distortion and a better signal-to-noise ratio than standard diode detectors

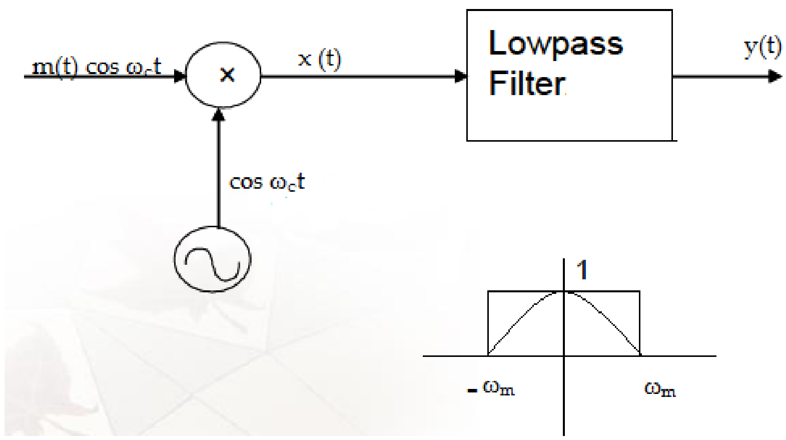


Fig 7.22 Coherent detector

The output of product modulator is

$$x(t) = m(t)cos^2\omega_c t$$

$$= \frac{m(t)}{2}[1 + \cos 2\omega_c t]$$

At the output of low pass filter

$$y(t) = \frac{m(t)}{2}$$

Which is the desired baseband signal.

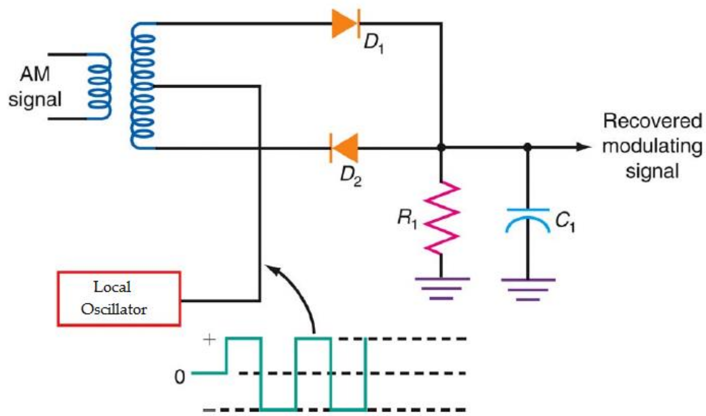


Fig 7- 23 A practical synchronous detector.

Points to Remember

- In commercial AM radio broadcast systems standard AM is used in preference to DSBSC or SSB modulation.
- Suppressed carrier modulation systems require the minimum transmitter power and minimum transmission bandwidth
- Suppressed carrier systems are well suited for point –to-point communications.
- SSB is the preferred method of modulation for long-distance transmission of voice signals over metallic circuits, because it permits longer spacing between the repeaters.
- VSB modulation requires a transmission bandwidth that is intermediate between that required for SSB or DSBSC.
- VSB modulation technique is used in TV transmission.
- DSBSC, SSB, and VSB are examples of linear modulation.
- In Commercial TV broadcasting, the VSB occupies a width of about 1.25MHz, or about one-quarter of a full sideband.

- The basic operation of SSB modulation is simply a special case of *frequency translation*. So SSB modulation is sometimes referred to as *frequency changing*, *mixing*, or *heterodyning*. The mixer is a device that consists of a product modulator followed by a band-pass filter, which is exactly what SSB modulation does.
- *Multiplexing* is a technique to combine a number of independent signals into a composite signal suitable for transmission.
- **Advantages of Amplitude modulation**
  - Generation and detection of AM signals are very easy
  - It is very cheap to build, due to this reason it I most commonly used in AM radio broad casting
- **Disadvantages of Amplitude of modulation:-**
  - Amplitude modulation is wasteful of power
  - Amplitude modulation is wasteful of band width

Questions

1. Explain Amplitude modulation with spectrum. Show that a nonlinear device can be used for generating AM signal. What are its limitations?
2. Explain the generation of AM wave using a) Square law modulator b) Switching modulator.
3. Explain the DSB-SC wave modulation with spectrum.
4. Explain the generation of DSB-SC wave using a) Balanced modulator b) Ring modulator.
5. Explain SSB Modulation with its Spectral characteristics? What are the Advantages of SSB systems?

6. How to Generate SSB using a) Filter method & b) Phase shift method?
7. Explain Demodulation of SSB wave using Coherent detection?
8. Compare different AM systems?
9. Explain VSB: generation, spectra and demodulation?
10. List Application of different AM systems?
11. What is Multiplexing? Explain FDM

Problems

1. The antenna current of an AM transmitter is 8A when only the carrier is sent, but it increases to 8.93A when the carrier is modulated by a sine wave .Find the percentage modulation. Determine the antenna current when the depth of modulation changes to 0.8?
2. A 360W carrier is simultaneously Amplitude modulated by two audio waves with modulation percentages of 55 and 65 respectively. What is the total sideband power radiated?
3. A transmitter supplies 8kw to the antenna when unmodulated. Determine the total power radiated when modulated to 30%? The rms value of the antenna current before modulation is 10A and after modulation is 12A. Calculate the percentage modulation employed assuming no distortion.
4. A Radio transmitter using AM has unmodulated carrier output power of 10kw and can be modulated to a maximum depth of 90% by a sinusoidal modulating voltage without causing overloading. find the value to which unmodulated carrier power may be increased without resulting in overloading if the maximum permitted modulation index is restricted to 40%?

5. A Certain AM transmitter is coupled to an antenna. The input power to the antenna is measured although monitoring of the input current , when there is no modulation ,the current is 10.8A.With modulation ,the current rises to 12.5A. Determine the depth of modulation?
6. A 1000 KHz carrier is simultaneously modulated with 300HZ audio sine wave. What will be the frequencies present in the output?
7. A broad cast AM transmitter radiates 50KW of carrier power. What will be the radiated power at 85% modulation?
8. When the modulation percentage is 75%, an AM transmitter produces 10KW. How much of this is carrier power?
9. When the modulation percentage is 75% an AM transmitter produces 10KW. What would be the percentage power saving if the carrier and one of the side bands were suppressed before the transmission took place?
10. A 360W carrier is simultaneously modulated by two audio waves with modulation percentage of 55 & 65 respectively. What is the total sideband power radiated?
11. When a broadcast AM transmitter is 50% modulated its antenna current is 12A. What will the current be when the modulation depth is increased to 0.9?
12. The output current of a 60% modulated AM Generator is 1.5A.To what value will this current rise if the generator is modulated additionally by another audio wave, whose modulation index is 0.7?
13. A message signal $m(t) = \cos 2000\pi t + 2\cos 4000\pi t$ modulates the carrier $c(t) = 100 \cos 2\pi f_c t$ where f_c=1MHz to produce the DSB signal $m(t)c(t)$.

a) Determine the expression for the upper sideband signal?

b) Determine and sketch the spectrum of the USB signal?

14. An AM signal has the form

$$u(t) = [20 + 2 \cos 3000\pi t + 10\cos 6000\pi t] \cos 2\pi f_c t$$

Where $f_c = 10^5$Hz.

a. Sketch the spectrum of u (t)?

b. Determine the power in each of the frequency components?

c. Determine the modulation index?

d. Determine the power in the sidebands, the total power, and the ratio of the sidebands power to the total power?