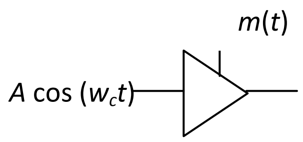
Modulator Circuits

Contents

The modulation and demodulation technique discussed last lecture require the existence of high quality multipliers (usually called mixers in communication applications).

1. Multiplier Modulators

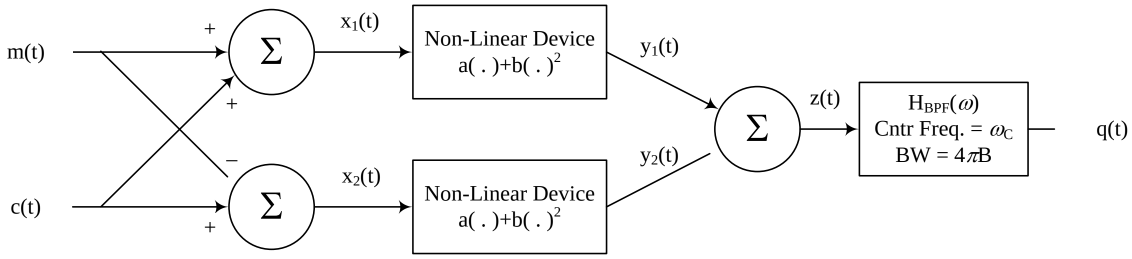


The use of multipliers is generally undesirable for two main reasons: expensive and have linearity problems. So, we need to find DSBSC modulation techniques that do not depend on multipliers.

To avoid the use of multipliers, several multiplier-less methods exist.

2. Non–Linear Modulators

In the following block diagram for DSBSC modulation, the message signal $m(t)$ with a BW of $2\pi B$ rad/s and the carrier signal $c(t) = \cos(\omega_c t)$ are not multiplied, but are added the upper path and subtracted in the lower path.



DSBSC modulation using non-linear device

The signals $x_1(t)$ and $x_2(t)$ therefore are

$$x_1(t) = c(t) + m(t) = \cos(\omega_C t) + m(t)$$
$$x_2(t) = c(t) - m(t) = \cos(\omega_C t) - m(t)$$

These signals are passed through two exactly similar non–linear devices that scale the input signals and add it to a scaled version of the square of their input signals.

$$\begin{aligned} y_1(t) &= a[\cos(\omega_C t) + m(t)] + b[\cos(\omega_C t) + m(t)]^2 \\ &= a\cos(\omega_C t) + am(t) + bm^2(t) + 2bm(t)\cdot\cos(\omega_C t) + b\cos^2(\omega_C t) \\ &= \underbrace{am(t)}_{Undesired} + \underbrace{bm^2(t)}_{Undesired} + \underbrace{2bm(t)\cdot\cos(\omega_C t)}_{Desired} + \underbrace{a\cos(\omega_C t)}_{Undesired} + \underbrace{\frac{b}{2}}_{Undesired} + \underbrace{\frac{b}{2}\cos(2\omega_C t)}_{Undesired} \end{aligned}$$

$$\begin{aligned} y_2(t) &= a[\cos(\omega_C t) - m(t)] + b[\cos(\omega_C t) - m(t)]^2 \\ &= a\cos(\omega_C t) - am(t) + bm^2(t) - 2bm(t)\cdot\cos(\omega_C t) + b\cos^2(\omega_C t) \\ &= \underbrace{-am(t)}_{Undesired} + \underbrace{bm^2(t)}_{Undesired} - \underbrace{2bm(t)\cdot\cos(\omega_C t)}_{Desired} + \underbrace{a\cos(\omega_C t)}_{Undesired} + \underbrace{\frac{b}{2}}_{Undesired} + \underbrace{\frac{b}{2}\cos(2\omega_C t)}_{Undesired} \end{aligned}$$

So,

$$\begin{aligned} z(t) &= y_1(t) - y_2(t) \\ &= \underbrace{2am(t)}_{Undesired} + \underbrace{4bm(t)\cdot\cos(\omega_C t)}_{Desired} \end{aligned}$$

The sum (or actually the different) of the outputs of the two non–linear devices contains two terms that can be described as follows:

$2am(t)$ is the original message signal. This is an UNDESIRED BASEBAND signal with bandwidth BW = $2\pi B$ rad/s.

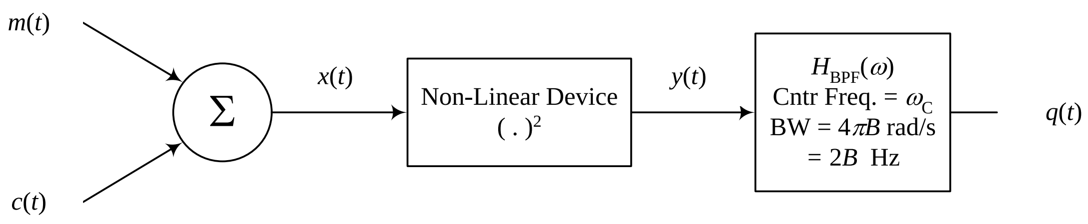
$4bm(t)\cdot\cos(\omega_C t)$ is the message signal multiplied by the carrier. This is the DESIRED signal with frequency centered around $\pm\omega_C$.

It is obvious that since the desired signal $2bm(t)\cdot\cos(\omega_C t)$ occurs around $\pm\omega_C$, we can use a BPF with a passband region centered around $\pm\omega_C$ and BW = $4\pi B$ rad/s (or $2B$ Hz) to allow this signal and reject the first component $2am(t)$.

Notes:

- The above circuit is single balanced modulator. It is balanced for the carrier as no carrier term appears at the input to the BPF. Double balanced modulator exist were only the product term appears at the input to the BPF.
- Many non–linear devices exist such as transistors and diodes. These devices operate non–linearly around their biasing regions. The non–linearity of these devices may be in the form of an exponential relationship that can be approximated as a square relation for signals with low amplitudes in specific operation regions of these devices.

- The modulation system shown above can be used for demodulation too. Just replace the BPF with a LPF of BW = $4\pi B$ rad/s and feed the carrier signal to one input and the DSBSC modulated signal to the other input. (Exercise: show that the output of that system is a scaled version of the message signal)
- The following block diagram is a simpler DSBSC modulator, where the non–linear device has $a = 0$ (Exercise: verify that this system is able to do DSBSC modulation). However, this system can be used for demodulation only if the magnitude of the message signal is significantly small such that the square of that signal is much lower (and therefore can be ignored) than the magnitude of the message signal.



Another DSBSC modulation using a non-linear device

3. Switching Modulators

Replacing multiplication by switching:

Another type of DSBSC modulator/demodulators is switching modulation. The idea of switching modulation is the other carriers such as "square waves" can be used instead of sinusoidal waves to modulate the message signal. Since a square wave can be represented in terms of a sum of sinusoids with fundamental frequency ω_o equal to the frequency of the square wave. So, if a message signal is modulated using a square wave with frequency equal to the desired carrier frequency ω_C and then this modulated signal is filtered using a BPF centered at ω_C with bandwidth twice the bandwidth of the message signal, the resulting signal is a DSBSC signal.

For periodic signals $\emptyset(t) = \sum_{n=0}^{\infty} c_n \cos(n\omega_c t + \theta_n)$

$$m(t)\emptyset(t) = \sum_{n=0}^{\infty} c_n m(t)\cos(n\omega_c t + \theta_n)$$

Spectrum of $M(\omega)$ is shifted to $0, \pm\omega_c, \pm 2\omega_c, \pm 3\omega_c, \ldots, , \pm n\omega_c$

We can use a BPF with bandwidth of $2B$ Hz , and center frequency $f_c = \omega_c$.

For the squared pulse train shown in Figure 4.4

$$w(t) = \frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 3\omega_c t - \cdots\right)$$

$$m(t) \times w(t) = m(t)\left[\frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \cdots\right)\right]$$

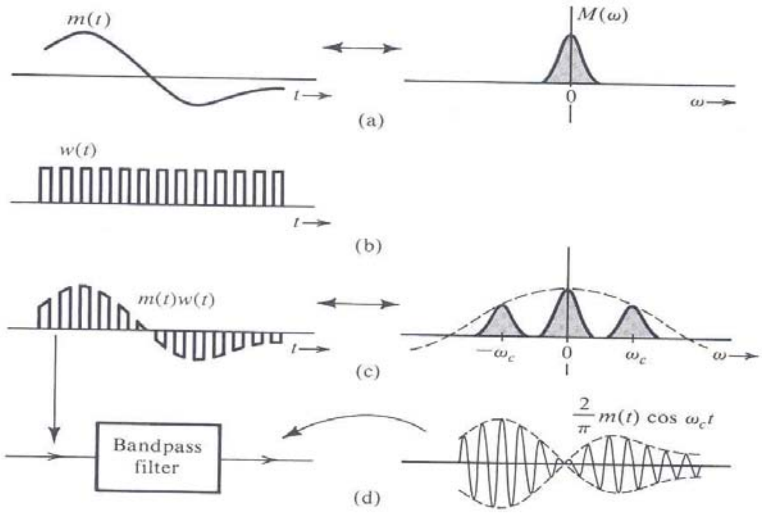
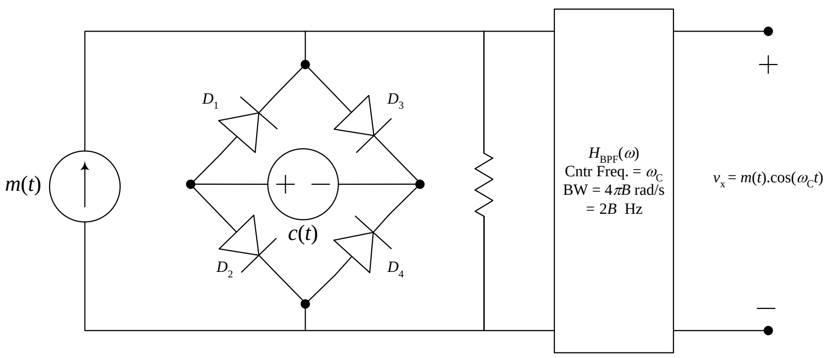


Figure 4.4 Switching modulator for DSB-SC.

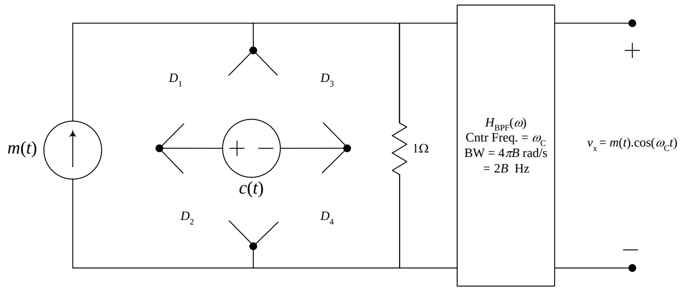
The square wave modulation can be performed using one of many configurations:

3.1 Diode–bridge

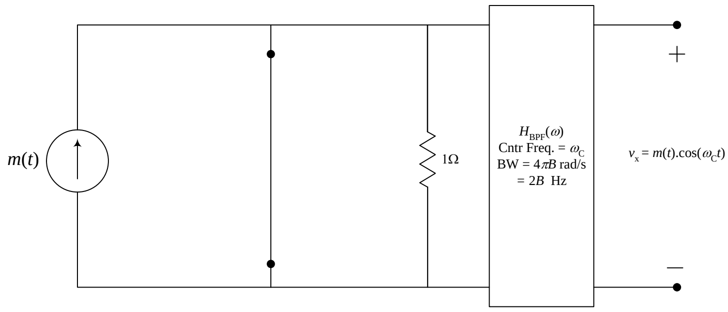
A typical configuration of diode–bridge modulator is shown below, where $c(t)$ = $\cos(\omega_C t)$.



When $c(t) < 0$, all diodes are turned off and therefore, the circuit simplifies to the following



Therefore, the current of the message source $m(t)$ passes through the 1 Ω resistor and creates a voltage across the resistor that is equal to $m(t)$ Volts. However, when $c(t) > 0$, all diodes become forward–biased (they become like conductors), and therefore the circuit simplifies to



So, all current of the message source passes through the short circuit and no current passes through the resistor. This leaves the voltage across the resistor to be zero. The switch can also be connected in series rather than in parallel.

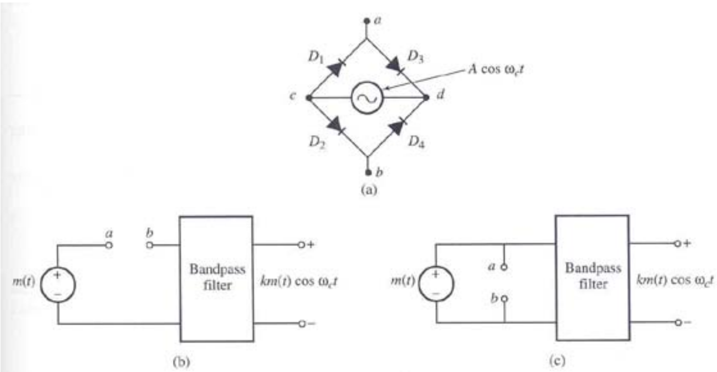


Figure 4.5 (a) Diode-bridge electronic switch. (b) Series-bridge diode modulator. (c) Shunt-bridge diode modulator.

Hence, the signal at the input of the BPF is equal to the message signal when the carrier is negative and equal to zero when the carrier is positive. This is simply like multiplying the message signal with a square wave that has a frequency equal to the carrier frequency. The BPF removes the DC term and all higher harmonics of this signal resulting in a DSBSC signal at its output.

This circuit can also be used for demodulating the DSBSC signal by feeding this signal in place of the message signal and replacing the BPF with a LPF.

3.2 Ring Modulator

The ring modulator works in a similar way except that it results in having a bipolar square wave multiplied by the message signal (see page 159 of your textbook for details).

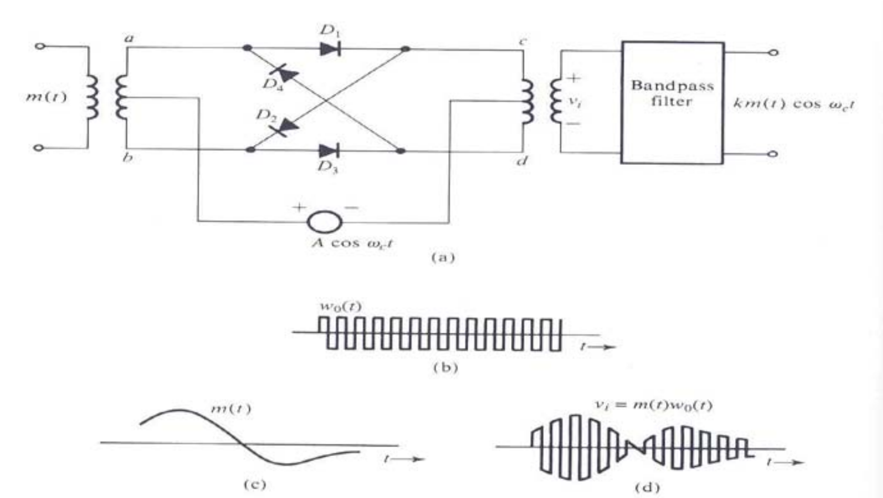


Figure 4.6 Ring modulator.

$$w_0(t) = \frac{4}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \cdots\right)$$

$$v_i\ (t) = m(t)w_0(t) = \frac{4}{\pi}\left(m(t)\cos\omega_c t - \frac{1}{3}m(t)\cos 3\omega_c t + \cdots\right)$$

See example 4.2 in the book

The above circuits can be use for demodulation also

Example 4.3

Analyze the bridge modulator as a demodulator

$$m(t)\cos\omega_c t \times w(t) = m(t)\cos\omega_c t\left[\frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \cdots\right)\right]$$

$$= \frac{2}{\pi}m(t)cos^2\ \omega_c t + \cdots$$

$$= \frac{1}{\pi}m(t) + \frac{1}{\pi}m(t)\cos(2\omega_c t) + \cdots$$

Using a LPF

$$= \frac{1}{\pi}m(t)$$