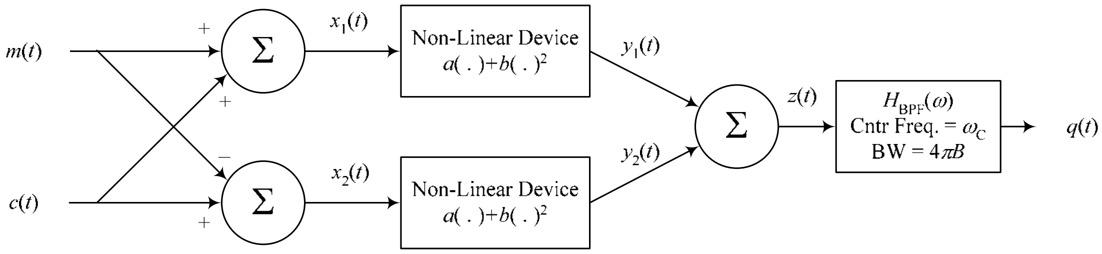
Double Sideband Suppressed Carrier (DSBSC) (Continuation)

The modulation and demodulation technique discussed last lecture require the existence of high quality multipliers (usually called mixers in communication applications). The use of multipliers is generally undesirable for reasons that are beyond the scope of this course. 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.

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

$$\begin{aligned} x_1(t) &= c(t) + m(t) = \cos(\omega_C t) + m(t) \\ x_1(t) &= c(t) - m(t) = \cos(\omega_C t) - m(t) \end{aligned}.$$

These signals are passed through two exactly similar non–linear devices that have scale there 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,

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

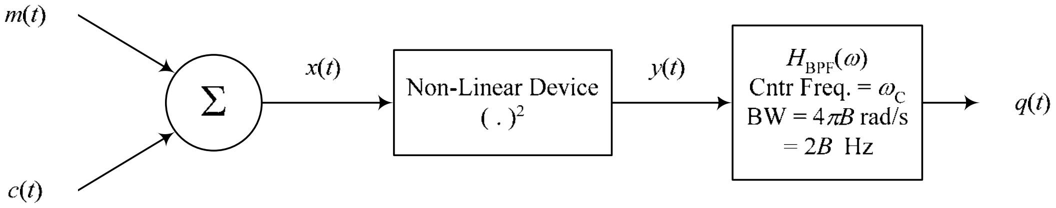
The sum (or actually the different) of the outputs of the two non–linear devices contains two terms that can be described as follows:

$2am(t)$	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:

- 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

Amplitude Modulation (AM)

The DSBSC modulation is one type of modulation in which the information (or message) is carried on the amplitude of a sinusoidal signal. Another type of this modulation is what we can call Double Side Band Including Carrier or Full AM (or simply AM).

Problem 1: The problem with DSBSC modulation is that its demodulation ALWAYS requires the availability of the carrier signal in the demodulator. This was assumed in our previous discussion without giving any method for obtaining this carrier from the received signal at the demodulator. Notice that the carrier at the demodulator must have the same frequency and phase of the carrier at the transmitter or some parts of the message signal will be lost (try the Matlab program named "DSBSC" on WebCT). In fact, the generation of the carrier signal at EXACTLY the same frequency and phase of the carrier at the modulation is relatively expensive and may drive the cost of the demodulator to be higher (you will study later in the course methods for obtaining the carrier frequency from a received signal).

Conclusion: For applications where ONLY ONE modulator but MANY demodulators are required, as it is the case for radio broadcasting, use any method for modulation even if it relatively expensive if it will reduce the cost of the demodulator. This will save a lot of money for many people at the expense of increasing the cost for the broadcasting entity.

Solution 1: The cost of the demodulator can be significantly reduced by using a modulator that DOES NOT require the generation of the carrier at the demodulator but uses what is called an ENVELOPE DETECTOR method to demodulate the amplitude modulated signal.

Problem 2: An envelope detector is a device that tracks the envelope (the upper of lower cover) of a modulated signal. Since most message signals are bipolar in nature (their amplitude ranges from a negative value –A to a positive value +A), therefore, when the modulated signal is a DSBSC, where the envelope of that signal sometimes touches zero, the envelope detector does not follow the message signal $m(t)$, but follows either $|m(t)|$ or $-|m(t)|$. So, the DSBSC modulation method is not suitable when we want to use envelope detectors to do the demodulation.

Solution 2: To avoid the crossing or touching of the upper and lower envelopes of the modulated signal, the signal that multiplies the carrier must always be positive or negative but not positive sometimes and negative sometimes. This can be achieved by adding a constant to the original message signal to lift it up so that the sum of the constant and the message signal is always positive (or always negative).

Assume we have a message signal $m(t)$ such that $-A < m(t) < A$, where A is a positive constant. Therefore,

$$q(t) = A + m(t) > 0$$

The AM signal is obtained by using the same modulation process of the DSBSC where a carrier signal $c(t) = \cos(\omega_C t)$ is multiplied by the signal $q(t)$ shown above to give

$$g_{AM}(t) = q(t).c(t) = [A + m(t)]\cos(\omega_C t) = A\cos(\omega_C t) + m(t)\cos(\omega_C t).$$

Notice that $g_{AM}(t)$ contains a DSBSC signal ($m(t)\cos(\omega_C t)$) and a scaled carrier term ($A\cos(\omega_C t)$). The carrier term CARRIER NO INFORMATION at all. It is there to make sure that the upper and lower envelopes do not touch each other. This is the reasoning for naming this type of modulation FULL AM, while naming the DSBSC as such (because it is similar to Full AM but after suppressing (removing) the carrier term).

The FT of the AM signal becomes

$$g_{AM}(t) \Leftrightarrow \pi A\left[\delta(\omega - \omega_C) + \delta(\omega + \omega_C)\right] + \frac{1}{2}\left[M(\omega - \omega_C) + M(\omega + \omega_C)\right].$$

Notice that the two delta functions centered at $\pm\omega_C$ represent the added carrier.

So, this signal can be demodulated using an envelope detector, which is extremely simple and is very cheap. As it is almost always the case, you cannot get something for free. So, where is the cost for this convenience? The cost for this convenience is that part of the power of the modulated signal carries no information (in fact most of the power of the modulated signal carries no information). A transmitted signal that carries no information to some degree may be considered as wasted.

To find the efficiency of the AM transmission, we need to find the ratio of the power of the signal that carries the information to the total power in the AM modulated signal. Assume that the message signal is $\cos(\omega_m t)$ (what is called a single–tone signal) with amplitude $A\mu$ where $0 \le \mu \le 1$ (i.e., a fraction μ of the amplitude of the carrier component in the AM (*μ is called the modulation index)*), or

$$\begin{aligned} z(t) &= A\mu\cos(\omega_m t)\cos(\omega_C t) \\ &= \frac{A\mu}{2}\left[\cos\{(\omega_C - \omega_m)t\} + \cos\{(\omega_C + \omega_m)t\}\right] \\ &= \frac{A\mu}{2}\cos\{(\omega_C - \omega_m)t\} + \frac{A\mu}{2}\cos\{(\omega_C + \omega_m)t\} \end{aligned}$$

The power of this signal is the sum of the two powers of the two sinusoids (because they have different frequencies (refer to page 39 of your textbook "Parseval's Theorem")

$$P_z = \frac{\left(\frac{A\mu}{2}\right)^2}{2} + \frac{\left(\frac{A\mu}{2}\right)^2}{2} = \left(\frac{A\mu}{2}\right)^2.$$

The power of the carrier term in the modulated signal is

$$w(t) = A\cos(\omega_C t), \qquad P_w = \frac{A^2}{2}$$

Therefore, the efficiency η of the AM transmission becomes

$$\eta = \frac{P_z}{P_z + P_w} = \frac{\left(\frac{A\mu}{2}\right)^2}{\left(\frac{A\mu}{2}\right)^2 + \frac{A^2}{2}} = \frac{\mu^2}{\mu^2 + 2}.$$

Since $0 \le \mu \le 1$ to avoid the touching of the upper and lower envelopes of the modulated signal, the MAXIMUM efficiency of the AM signal is

$$\eta_{\max} = \frac{1}{1+2} = 0.333 = 33.3\% \ .$$

So, no matter what we do, we cannot bring the efficiency of AM modulation to more than one third, or stated in other words, at least 2/3 of the power of the AM signal is wasted.

Generation of AM Signals

Since, AM signals are simply similar to DSBSC modulation but the information signal is shifted by a constant first and then modulated by the carrier, the generation of AM signals can be performed using ANY DSBSC modulation technique. Also, the demodulation of AM signals can be performed using ANY DSBSC demodulation technique. However, the opposite is not always true. So, not all AM modulation and demodulation techniques will work for DSBSC modulation and demodulation.