CONTINUOUS MODULATION

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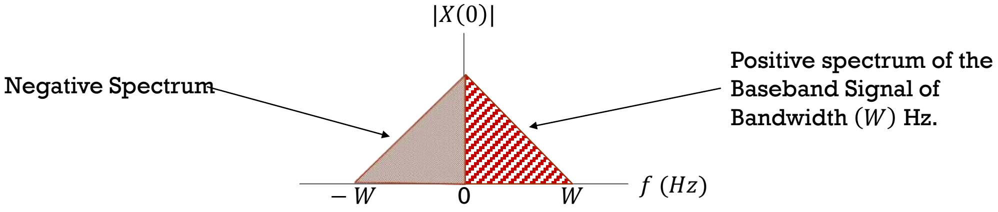
LECTURE OUTLINES

- 2.1 Why Modulate and Frequency Shifting
- 2.2 Linear Modulation
- 2.3 Double Sideband – Large Carrier (DSB-LC)
- 2.4 Double Sideband – Suppressed Carrier (DSB-SC)
- 2.5 Single Sideband Modulation (SSB)
- 2.6 Vestigial Sideband Modulation (VSB)

WHY WE NEED TO MODULATE

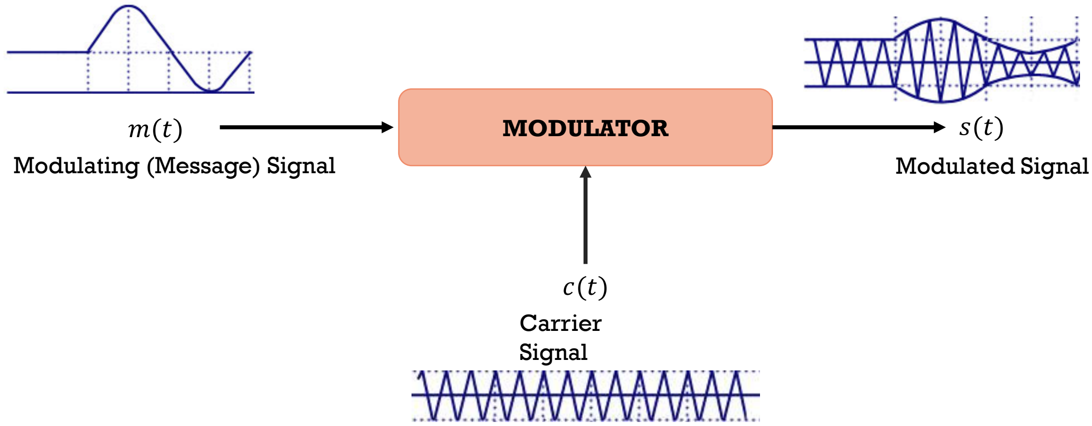


- The Information signal is always represented by Baseband signals.
- Baseband spectrum extends from ZERO to some MAX frequencies as shown in figure above.
- Transmission of lower frequencies (Baseband) is not proper for communication applications.
- Modulation helps to *Reduce Antenna Size, Extends the Transmission Distance, Enhance Multiplexing Theory, Avoid Interference, Improve Quality of Signal reception, and Robustness for Additive Channel Noise.*

WHY WE NEED TO MODULATE

- To make the signal more suitable for transmission through any channel (Free – Space for instance), we need to shift baseband (low frequencies) to higher order of frequencies based on the application (e.g. TV – Transmission).
- The process of shifting baseband to high frequency spectrum is done through the Modulation process.
- The modulation process is defined as the process by which some characteristic of a carrier is varied in according with modulating wave (Baseband Signal).
- Modulation Types:
  - Linear Modulation (Amplitude Modulation).
  - Angle Modulation (Frequency and Phase Modulation).

HOW TO MODULATE



$m(t)$ → **MODULATOR** → $s(t)$

Modulating (Message) Signal

Modulated Signal

$c(t)$

Carrier Signal

LINEAR MODULATION (AM)

- Is the process of changing the characteristics of carrier amplitude in correspondence with the amplitude of the modulating (message) signal.
- Suppose:

$$m(t) = A_m \cos(2\pi f_m t)$$

Amplitude of Modulating (Baseband) Wave

Modulating Frequency

$$c(t) = A_c \cos(2\pi f_c t)$$

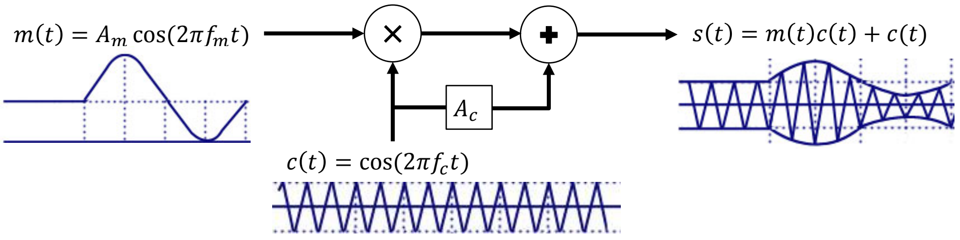
Amplitude of Modulating (Baseband) Wave

Carrier Frequency

$$A_c > A_m \;\&\; f_m << f_c$$

$$s(t) = m(t)c(t)$$

DSB - AM



$m(t) = A_m \cos(2\pi f_m t)$

$s(t) = m(t)c(t) + c(t)$

A_c

$c(t) = \cos(2\pi f_c t)$

$$s(t) = A_m \cos(2\pi f_m t)\cos(2\pi f_c t) + A_c \cos(2\pi f_c t)$$

$$s(t) = A_c[1 + \frac{A_m}{A_c}\cos(2\pi f_m t)]\cos(2\pi f_c t)$$

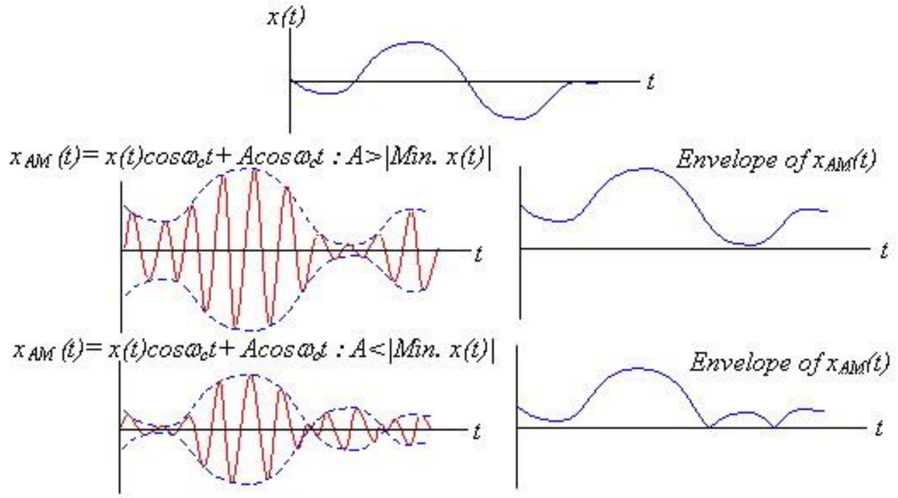
Amplitude Sensitivity $[volts^{-1}]$

$$s(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t) = A_c[1 + \mu\, m(t)]\cos(2\pi f_c t)$$

DSB - AM

- The envelope of $s(t)$ has essentially the same shape of as the baseband signal $m(t)$ provided two important requirements which they are:
  - The amplitude of $k_a m(t)$ is always less than unity $|k_a m(t)| < 1$. This is to ensure that the function of $1 + k_a m(t)$ is always positive. If $|k_a m(t)| > 1$, the carrier wave becomes *over-modulated* resulting in carrier phase reversal problem whenever the factor $1 + k_a m(t)$ crossing zero (Envelope distortion).
  - The carrier frequency must be much greater than the higher frequency of the modulating signal (W).
  - The carrier power is $= \frac{1}{2} A_c^2$
  - Upper SB power = Lower SB power = $= \frac{1}{8}\mu^2 A_c^2$

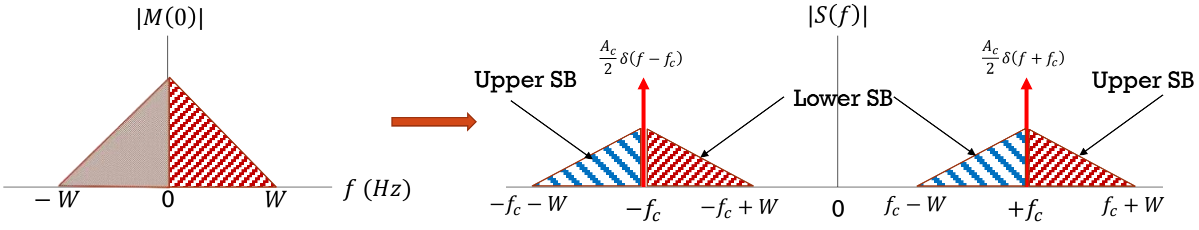
DSB - AM



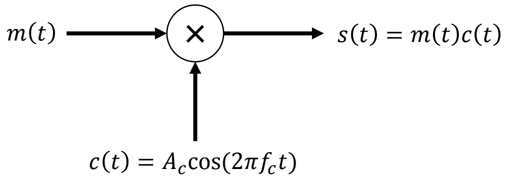
DSB – AM SPECTRUM

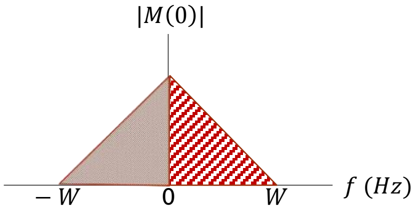
- Applying Fourier Transform we find that:

$$S(f) = \frac{A_c}{2}[\delta(f-f_c)+\delta(f+f_c)] + \frac{k_a A_c}{2}[M(f-f_c)+M(f+f_c)]$$



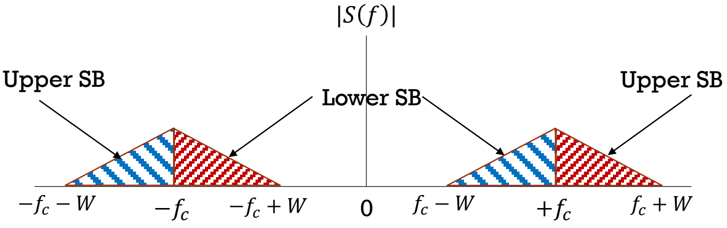
DSB - SC





$$s(t) = A_m m(t)\cos(2\pi f_c t)$$

$$S(f) = \frac{1}{2}A_c[M(f - f_c) + M(f + f_c)]$$



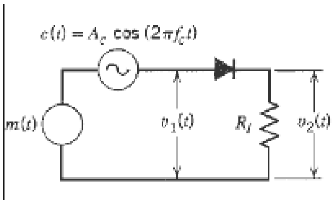
GENERATION OF DSB - AM SIGNAL

- **Switching Modulator:**

$$v_1(t) = A_c\cos(2\pi f_c t) + m(t)$$

- Be aware that $|m(t)| \ll A_c$.

$$v_2(t) = \begin{cases} v_1(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases}$$



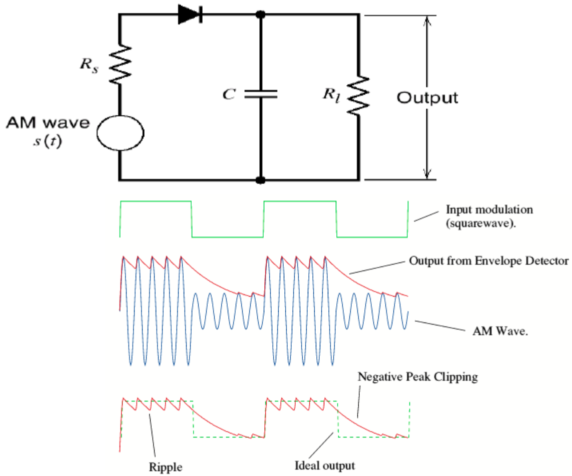
$$v_2(t) = [A_c\cos(2\pi f_c t) + m(t) + m(t)]\,g(t)$$

$$g(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos[2\pi f_c t(2n-1)] = \frac{A_c}{2}\left[1 + \frac{4}{\pi A_c}m(t)\right]\cos(2\pi f_c t)$$

GENERATION OF DSB - AM SIGNAL

- **Envelop Detector:**

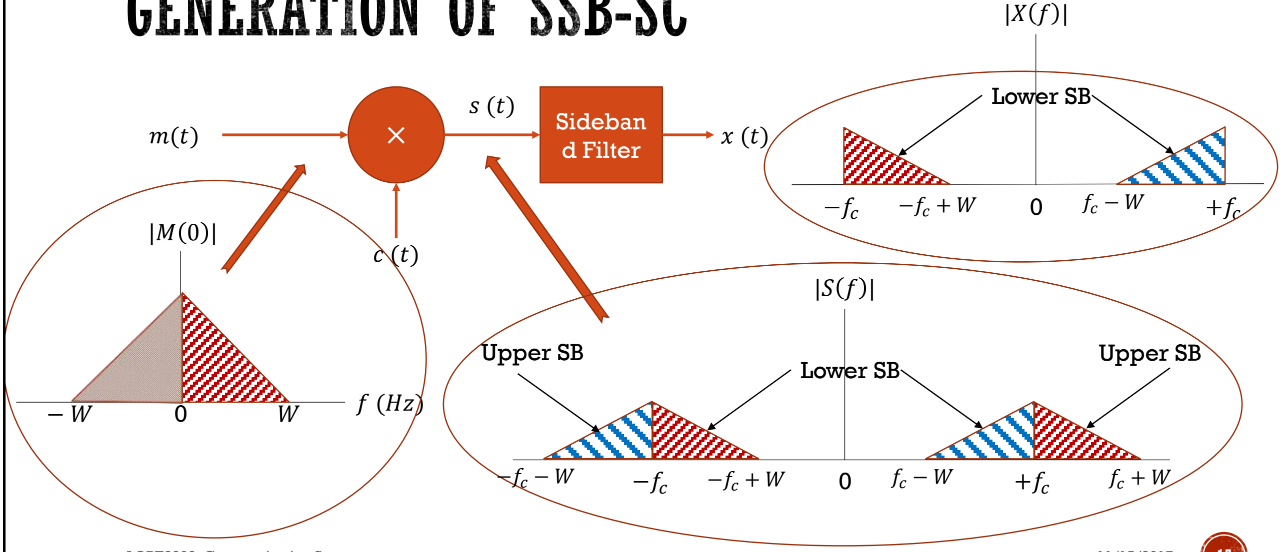
This is essentially just a half-wave rectifier which charges a capacitor to a voltage to the peak voltage of the incoming AM waveform, . When the input wave's amplitude increases, the capacitor voltage is increased via the rectifying diode. When the input's amplitude falls, the capacitor voltage is reduced by being discharged by a 'bleed' resistor, *R*. 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.



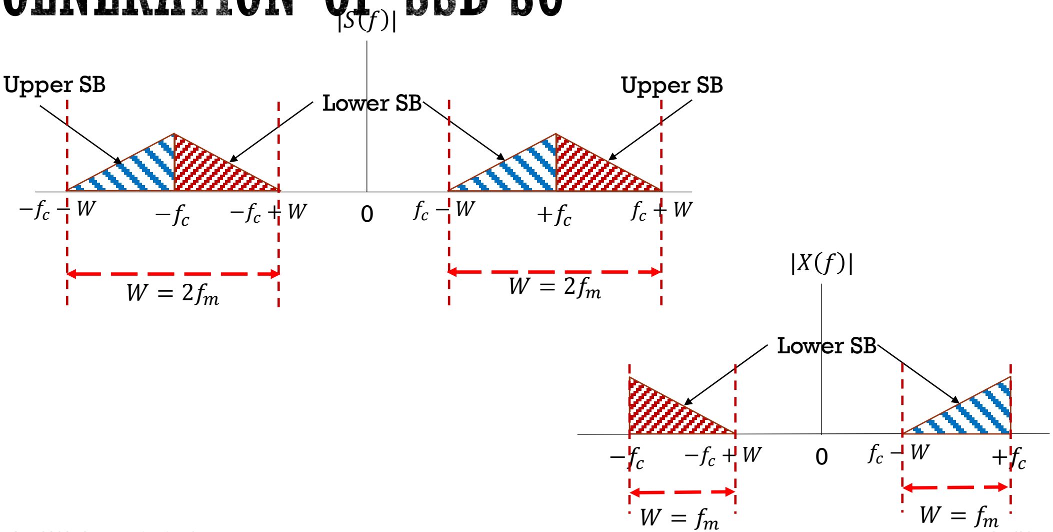
SINGLE SIDEBAND MODULATION (SSB)

- In AM, Two-Thirds of the transmitted power is in the carrier which is conveys no information.
- One sideband is fair to be transmitted as it contains all information of the original signal.
- There is no reason to transmit both sidebands as in DSB. One sideband can be suppresses and transmit either the upper or the lower sideband.
- SSB modulation scheme has benefits of:
  - Efficient Bandwidth: The primary benefit of an SSB signal is that the spectrum space it occupies is only one-half that of AM and DSB signals. This greatly conserves spectrum space and allows more signals to be transmitted in the same frequency range.
  - Efficient Power: All the power previously devoted to the carrier and the other sideband can be channeled into the single sideband, producing a stronger signal that should carry farther and be more reliably received at greater distances. Alternatively, SSB transmitters can be made smaller and lighter than an equivalent AM or DSB transmitter because less circuitry and power are used.
  - Lower Noise: Because SSB signals occupy a narrower bandwidth, the amount of noise in the signal is reduced.

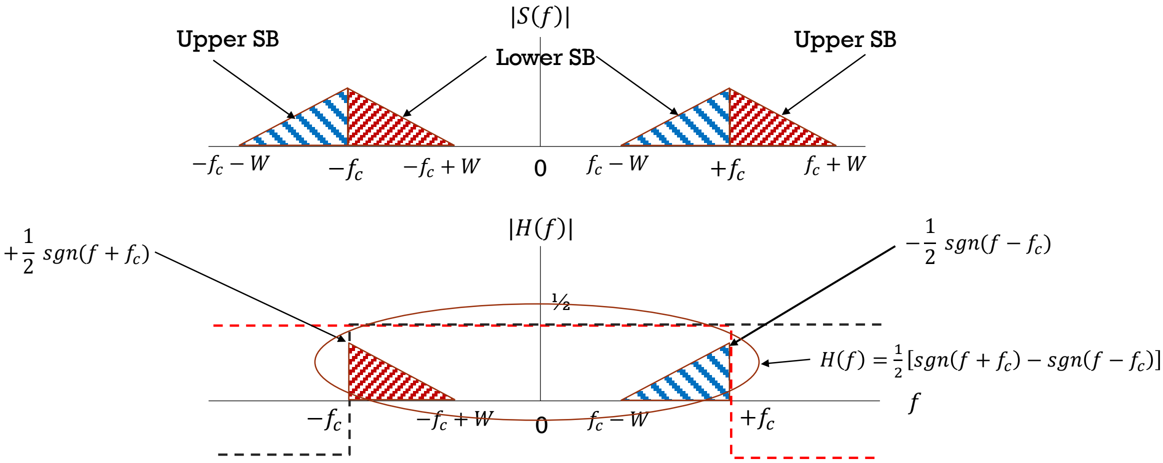
GENERATION OF SSB-SC



GENERATION OF SSB-SC



GENERATION OF SSB-SC



HILBERT TRANSFORM

- *The signum function definition:*

$$sgn(f) = \begin{cases} 1, & f > 0 \\ 0, & f = 0 \\ -1, & f < 0 \end{cases}$$

- Fourier transform of Hilbert Transform:

$$\frac{1}{\pi t} \rightleftharpoons -j\, sgn(f)$$

HILBERT TRANSFORM

- Back to FT pairs:

$$\boxed{m(t) \rightleftharpoons M(f) \qquad\qquad m(t)e^{\pm j2\pi f_c t} \rightleftharpoons M(f \mp f_c)}$$

$$\boxed{\hat{m}(t) \rightleftharpoons -j\,sgn(f)M(f) \qquad \hat{m}(t)e^{\pm j2\pi f_c t} \rightleftharpoons -j\,sgn(f \mp f_c)M(f \mp f_c)}$$

- Starting from DSB-SC, we know that the FT of $s(t)$ for DSB-SC signal is giving by:

$$S(f) = \frac{1}{2}A_c[M(f+f_c) + M(f-f_c)]$$

BACK TO SSB-SC

- The DSB-SC signal is now passed through a BandPass Filter of a Transfer Function $H(f)$ given by Hilbert Transform.

$$S_{SSB}(f) = S(f)H(f)$$

$$S_{SSB}(f) = \frac{1}{2}A_c[M(f+f_c) + M(f-f_c)].\frac{1}{2}[sgn(f+f_c) - sgn(f-f_c)]$$

$$= \frac{1}{4}A_c\left[M(f+f_c)sgn(f+f_c) + M(f-f_c)sgn(f-f_c)\right] - \frac{1}{4}A_c[M(f+f_c)sgn(f-f_c) + M(f-f_c)sgn(f+f_c)\right]$$

$\frac{1}{2}A_c\cos(2\pi f_c t)$

$$S_{LSSB}(f) = \frac{1}{4}A_c\left[M(f+f_c) + M(f-f_c)\right] + \frac{1}{4}A_c[M(f+f_c)sgn(f+f_c) - M(f-f_c)sgn(f-f_c)]$$

BACK TO SSB-SC

$$j\,\frac{A_c}{4}\,\hat{m}(t)e^{-j2\pi f_c t} - j\,\frac{A_c}{4}\,\hat{m}(t)e^{+j2\pi f_c t} = \frac{\mathrm{j}}{2}\hat{m}(t)\sin(2\pi f_c t)$$

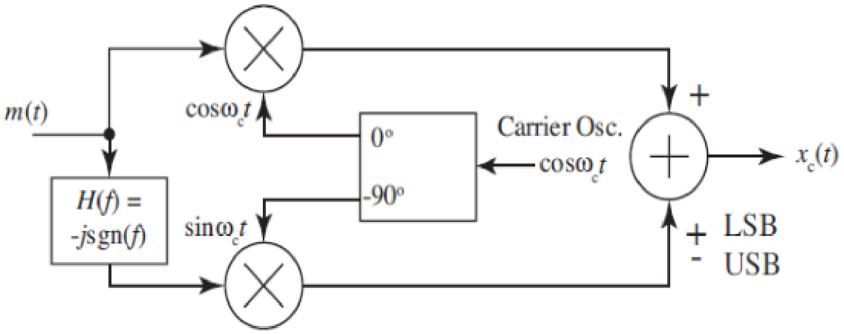
- The Lower SSB-SC signal is:

$$\boxed{S_{LSB}(f) = \frac{1}{2}A_c\cos(2\pi f_c t) + \frac{\mathrm{j}}{2}\hat{m}(t)\sin(2\pi f_c t)}$$

- The Upper SSB-SC signal is:

$$\boxed{S_{LSB}(f) = \frac{1}{2}A_c\cos(2\pi f_c t) - \frac{\mathrm{j}}{2}\hat{m}(t)\sin(2\pi f_c t)}$$

2.5 SSB-SC BLOCK DIAGRAM



VIRTUES OF SSB

- The SSB modulation as known is very difficult to generate because of it is either requires to have very sharp cut-off filter in the frequency domain also very difficult to realize the transfer function of the filter in term of Hilbert Transform.
- The amplitude characteristics, as known, is best at the middle of the band of any filter, as well as phase characteristics. But, the moment we deviate from the band, typical filter that will realize, synchronize or make will show a non-ideal characteristics, so around the edge of the band we will have both non-linear phase amplitude characteristics.
- If the basic message signal has a significant amount of low frequency contents, it will go around the carrier frequency.
- It means that a significant energy contents at low frequencies will translate to significant energy content around the carrier frequency. Thus, if the filter has a sharp cut-off factor at the carrier frequency, then, it will definitely distort the low frequency contents of the original message signal. Hence, using SSB method will create this issue for the signal.

VESTIGIAL SIDEBAND MODULATION