The synchronization is achieved in differt ways:

a- It can be achieved by transmitting a sinusoidal signal without any information with $x_c(t)$. This signal is called "Pilot Signal". It is just transmitted to give information about the frequency and the phase of the carrier signal to set the frequency and the phase of the local oscillator according to it.

b- By adding a synchronization circuit at the receiver to derive a local oscillator signal from the received bandpass signal.

* Both solutions require more complicated receiver than that required for non-synchronus detectors although the synchronus detector provides more signal quality. For this reason, some applications such as radio broad-casting, TV, and GSM mobile systems avoid using modulations with synchronus detection because they require more complex receivers which results in high cost devices.

* Note that, the bandwidth of the bandpass signal of AM and DSB-SC is:

$$BW = 2f_m \quad , \quad BW_{baseband} = f_m$$

$$\therefore \boxed{BW_{DSB} = BW_{AM} = 2\,BW_{baseband}}$$

C Single Side Band (SSB) Modulation:

This modulation transmits only only one side band of $x_c(t)$ (either USB or LSB). Each side band contains complete information about the message $m(t)$. Therefore,

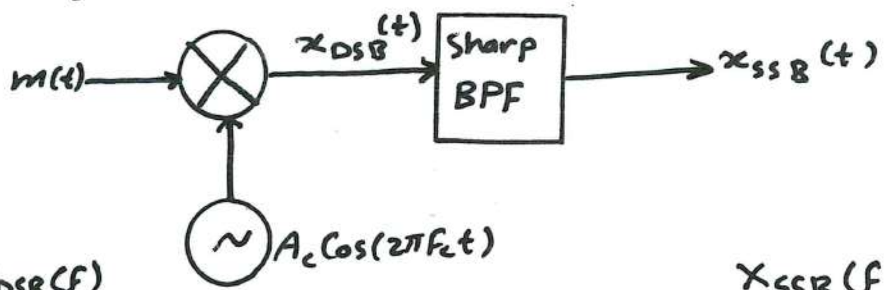
$$BW_{SSB} = \frac{1}{2} BW_{DSB} = BW_{baseband}$$

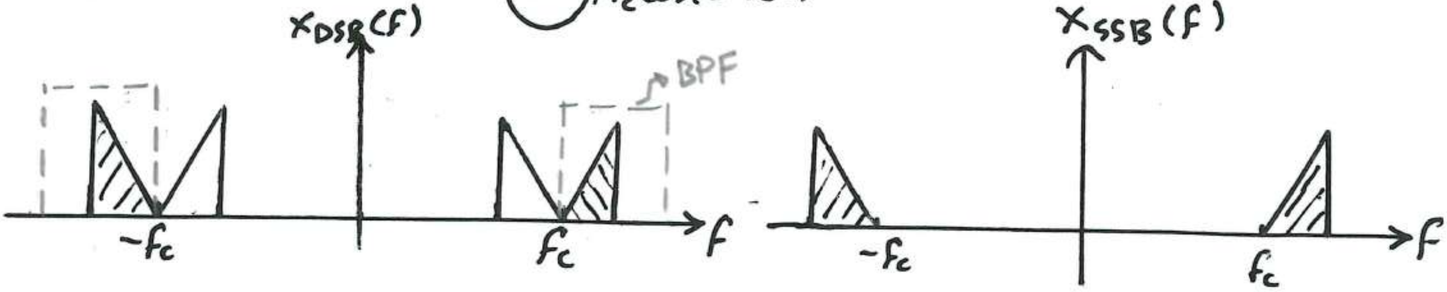
- Generation of SSB:

There are two methods to generate SSB signal.

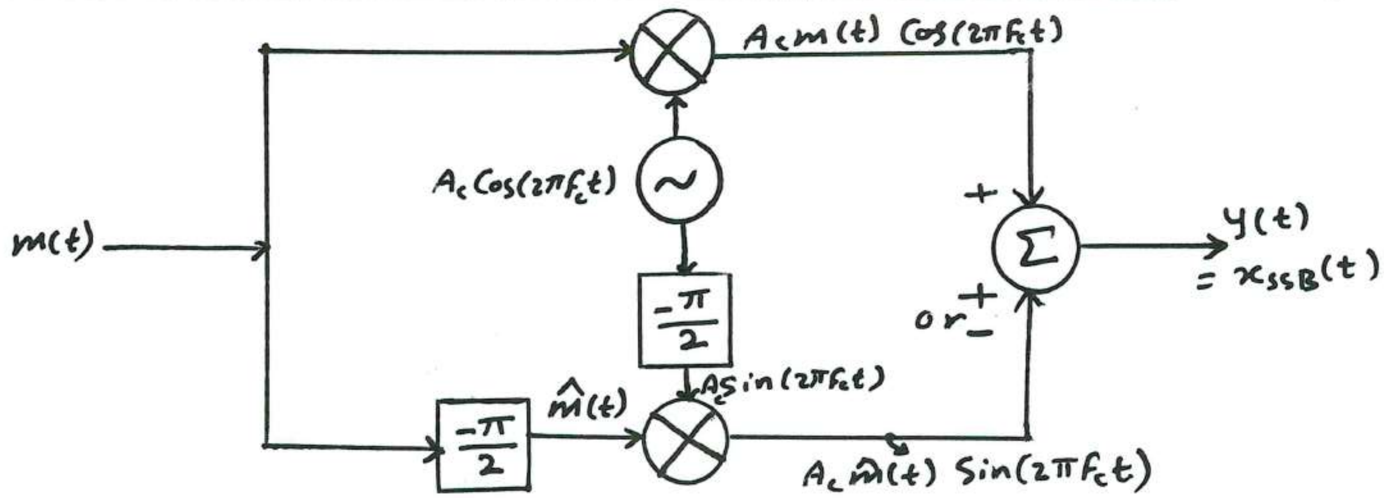
a) Selective - Filtering Method:

In this method, a DSB-SC signal is firstly generated, then passed through a sharp cutoff filter to suppress one of the bands.





b) Hilbert Transform Method (Phase Shift Method):



$$x_{SSB}(t) = A_c\, m(t) \cos(2\pi f_c t) \mp A_c\, \hat{m}(t) \sin(2\pi f_c t)$$

($-$ for USB, $+$ for LSB)

The difference will produce the USB, and the sum will produce the LSB. Let's verify the USB as follows:

$$x_{USB}(t) = A_c\, m(t) \cos(2\pi f_c t) - A_c\, \hat{m}(t) \sin(2\pi f_c t)$$

$$X_{USB}(f) = F.T\left[A_c\, m(t) \cos(2\pi f_c t)\right] - F.T\left[A_c\, \hat{m}(t) \sin(2\pi f_c t)\right]$$

$$F.T\left[A_c\, m(t) \cos(2\pi f_c t)\right] = \frac{A_c}{2}\left[M(f - f_c) + M(f + f_c)\right]$$

$$F.T\left[A_c\, \hat{m}(t) \sin(2\pi f_c t)\right] = \frac{A_c}{j2}\left[\hat{M}(f - f_c) - \hat{M}(f + f_c)\right]$$

$$\hat{M}(f - f_c) = -j\, \mathrm{sgn}(f - f_c)\, M(f - f_c)$$

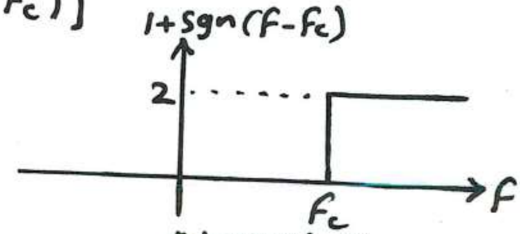
$$\hat{M}(f + f_c) = -j\, \mathrm{sgn}(f + f_c)\, M(f + f_c)$$

$$\therefore X_{USB}(f) = \frac{A_c}{2} M(f - f_c) + \frac{1}{2} M(f + f_c) - \frac{A_c}{j2}\Big(-j\, \mathrm{sgn}(f - f_c)\, M(f - f_c) - \big(-j\, \mathrm{sgn}(f + f_c)\, M(f + f_c)\big)\Big)$$

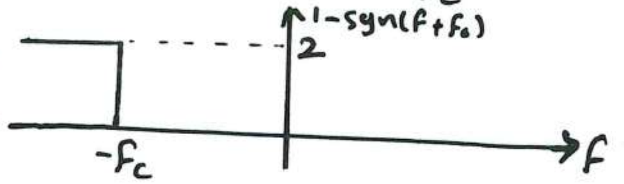
$$X_{USB}(f) = \frac{A_c}{2} M(f - f_c) + \frac{1}{2} M(f + f_c) + \frac{A_c}{2}\left[\mathrm{sgn}(f - f_c)\, M(f - f_c) - \mathrm{sgn}(f + f_c)\, M(f + f_c)\right]$$

$$X_{USB}(f) = \frac{A_c}{2} M(f - f_c)\left[1 + \mathrm{sgn}(f - f_c)\right] + \frac{A_c}{2} M(f + f_c)\left[1 - \mathrm{sgn}(f + f_c)\right]$$

$$1 + \mathrm{sgn}(f - f_c) = \begin{cases} 2 & \rightarrow f > f_c \\ 0 & \rightarrow f < f_c \end{cases}$$



$$1 - \mathrm{sgn}(f + f_c) = \begin{cases} 0 & \rightarrow f > -f_c \\ 2 & \rightarrow f < -f_c \end{cases}$$



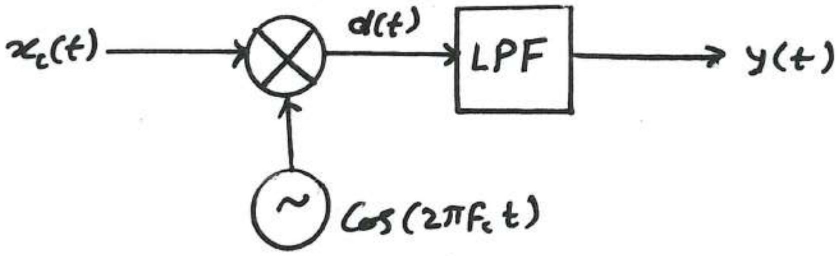
So,

$$X_{USB}(f) = \begin{cases} A_c M(f - f_c) & \rightarrow f > f_c \\ A_c M(f + f_c) & \rightarrow f < -f_c \\ 0 & \rightarrow |f| \leq f_c \end{cases}$$

which is exactly the USB of the transmitted signal.

- Demodulation (Detection) of SSB

a) Synchronus Detection:



$$d(t) = [m(t) A_c \cos(2\pi f_c t) \mp A_c \hat{m}(t) \sin(2\pi f_c t)] \cos(2\pi f_c t)$$

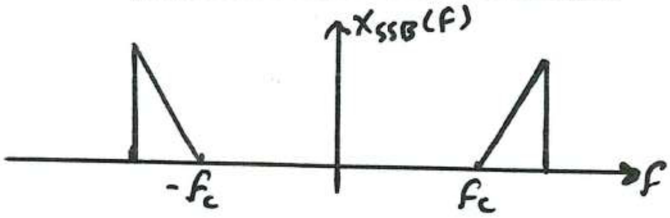
$$d(t) = A_c m(t) \cos^2(2\pi f_c t) \mp A_c \hat{m}(t) \sin(2\pi f_c t) \cos(2\pi f_c t)$$

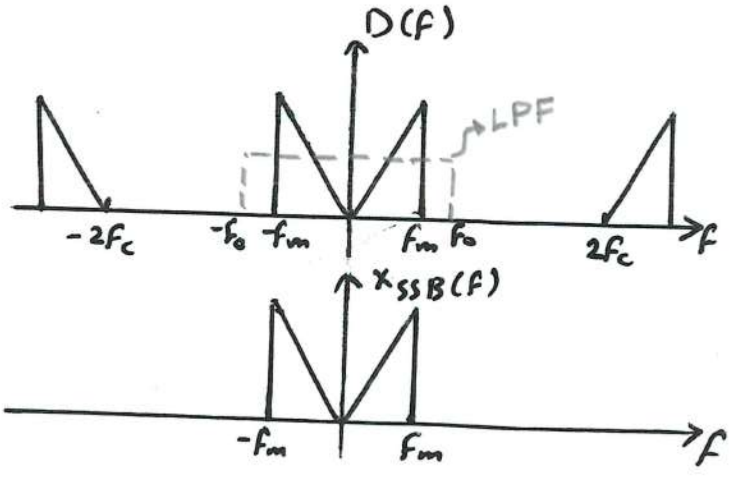
$$d(t) = \frac{A_c}{2} m(t) [1 + \cos(2\pi (2f_c) t)] \mp \frac{A_c}{2} \hat{m}(t) \sin(2\pi (2f_c) t)$$

$$d(t) = \frac{A_c}{2} m(t) + \frac{A_c}{2} m(t) \cos(2\pi (2f_c) t) \mp \frac{A_c}{2} \hat{m}(t) \sin(2\pi(2f_c) t)$$

After LPF with $f_m < f_o << f_c$

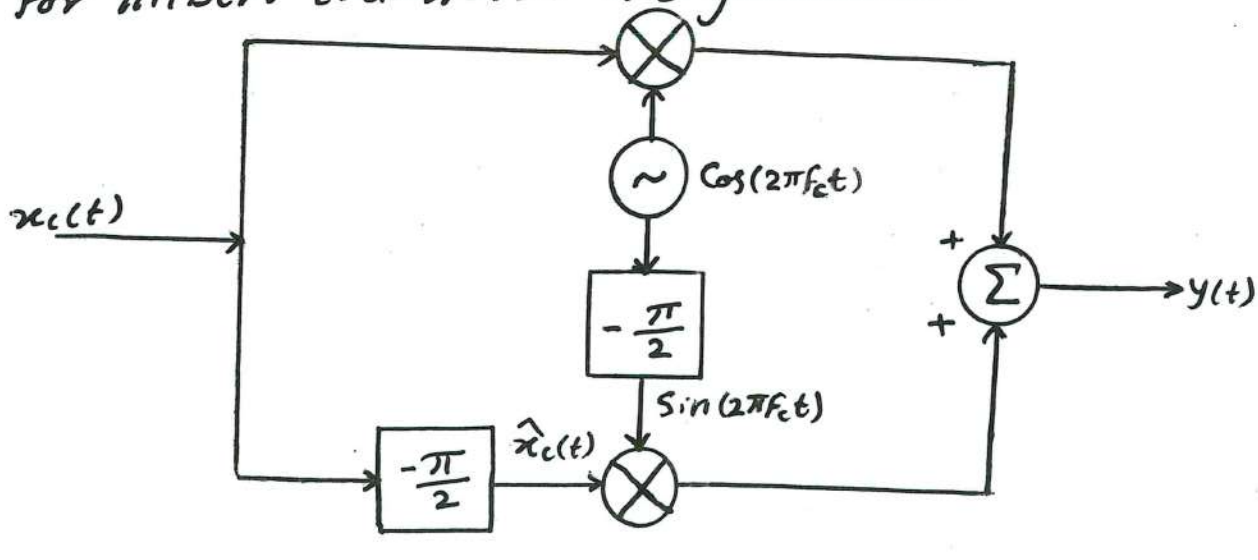
$$\boxed{y(t) = \frac{A_c}{2} m(t)}$$





b) Phase Shift Detection:

This method uses exactly the same system as that used for Hilbert transform SSB generation.



Suppose that the received signal is USB :

$$x_c(t) = A_c m(t) \cos(2\pi f_c t) - A_c \hat{m}(t) \sin(2\pi f_c t)$$

$$\hat{x}_c(t) = \{A_c \widehat{m(t) \cos(2\pi f_c t)}\} - \{\widehat{\hat{m}(t) \sin(2\pi f_c t)}\}$$

We previously deduce that:

if $x(t) = F(t) \cos(w_c t) \Rightarrow \hat{x}(t) = F(t) \sin(w_c t)$

Thus,

$$\hat{x}_c(t) = A_c m(t) \sin(2\pi f_c t) + A_c \hat{m}(t) \cos(2\pi f_c t)$$

$$y(t) = x_c(t) \cos(2\pi f_c t) + \hat{x}_c(t) \sin(2\pi f_c t)$$

$$y(t) = [A_c m(t) \cos^2(2\pi f_c t) - A_c \hat{m}(t) \sin(2\pi f_c t) \cos(2\pi f_c t)] + [A_c m(t) \sin^2(2\pi f_c t) + A_c \hat{m}(t) \sin(2\pi f_c t) \cos(2\pi f_c t)]$$

$$y(t) = A_c m(t) [\cos^2(2\pi f_c t) + \sin^2(2\pi f_c t)]$$

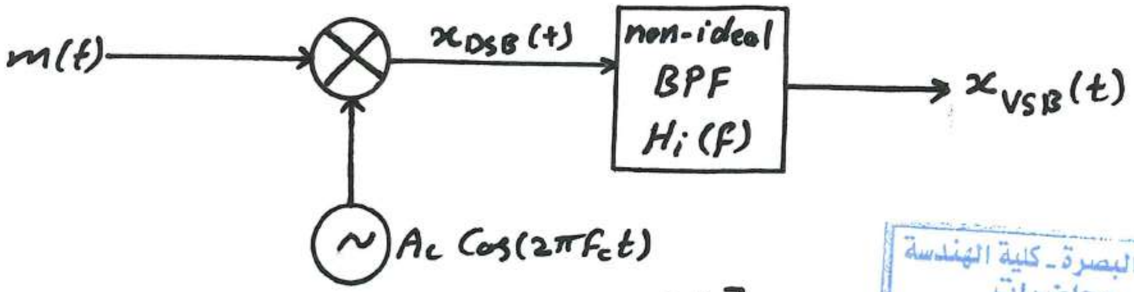
$$\therefore \quad \boxed{y(t) = A_c m(t)}$$

D Vestigial - Sideband (VSB) Modulation:

* VSB modulation represents a compromise between DSB-SC and SSB.
  - SSB → complex structure but small BW.
  - DSB → simple structure but twice the baseband signal BW
* VSB modulation takes the advantages of DSB-SC and the SSB and avoids their disadvantages with small tolerations.
* In VSB, one sideband is passed almost completely, while just a trace or vestige of the other sideband is kept.
* The typical bandwidth required to transmit a VSB is 1.25 that of SSB. The old analog commercial TV uses VSB in video signal transmission.

- Generation of VSB:

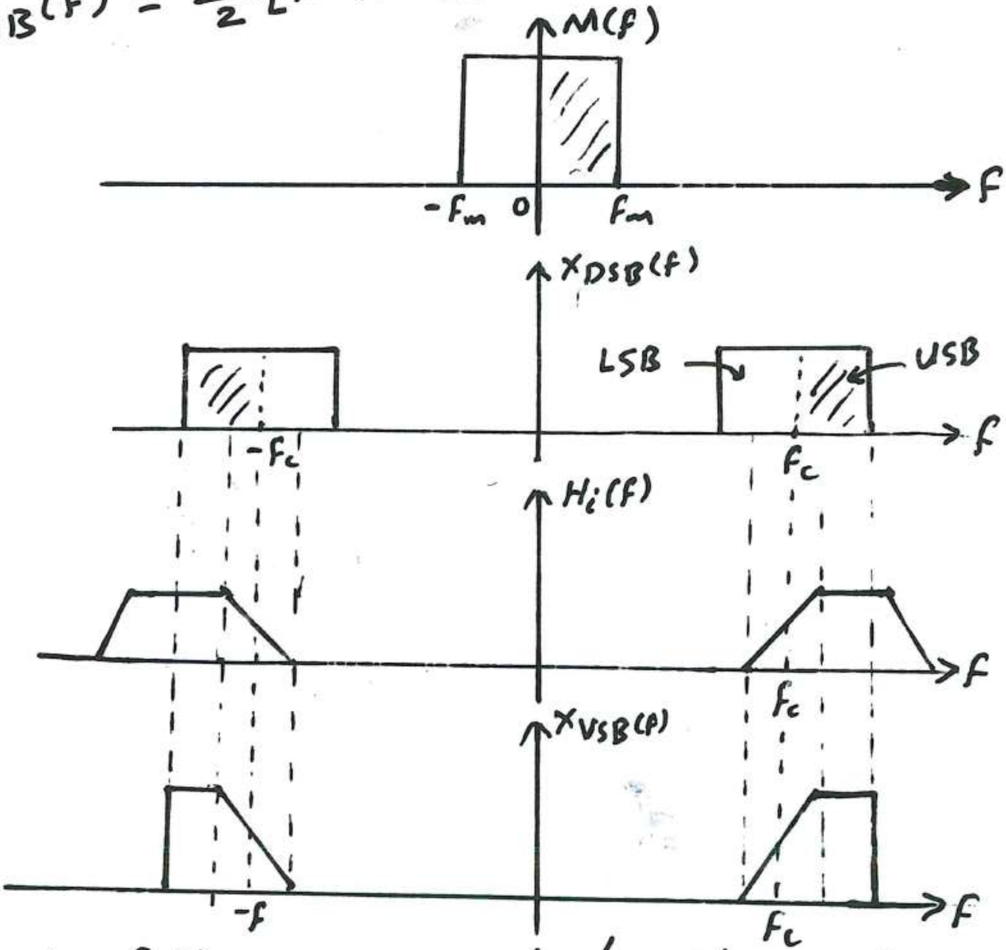
It can be generated by passing a DSB-SC signal through a non-ideal filter called vestigial filter as shown:



$$X_{DSB}(f) = \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right]$$

$$X_{VSB}(f) = X_{DSB}(f)\ H_i(f)$$

$$X_{VSB}(f) = \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right] H_i(f)$$

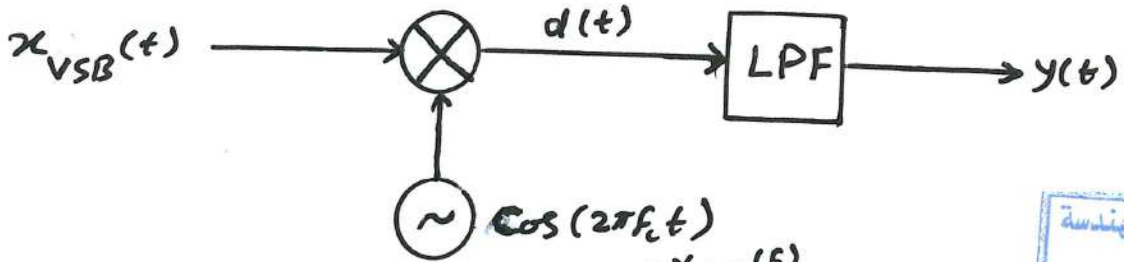


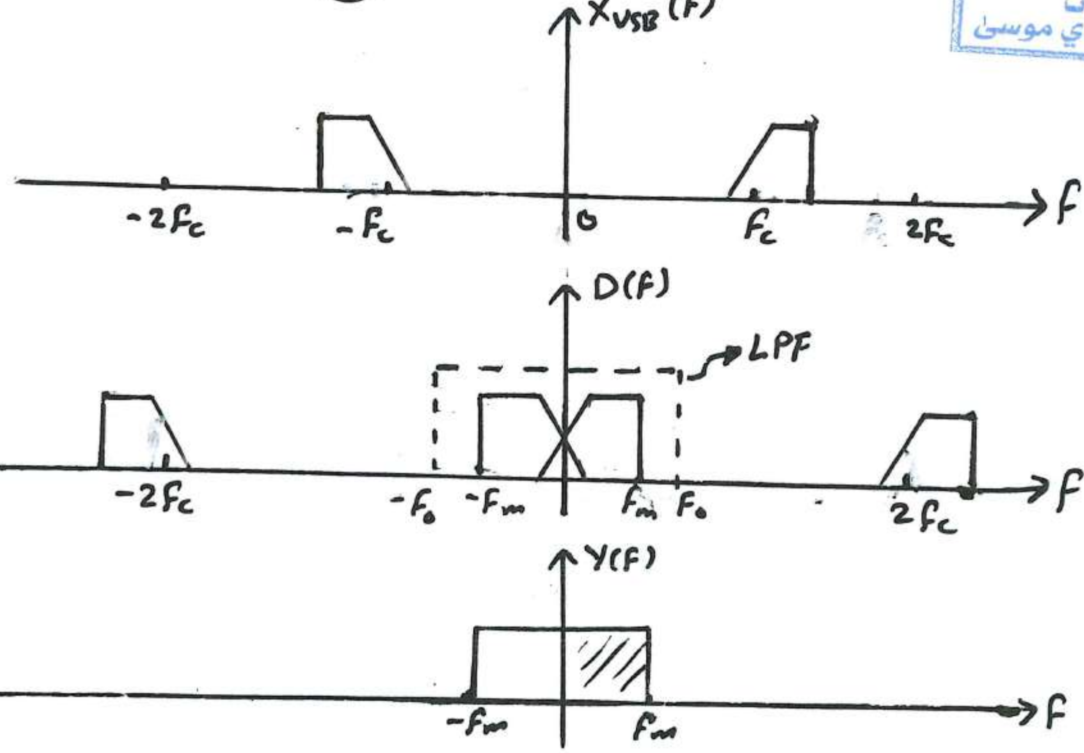
* Since the filter is non-ideal, the VSB modulation is more realizable than the SSB.

* It is also noticeable that the modulator of VSB is much simpler than the phase shift modulator of SSB.

- Demodulation (Detection) of VSB:

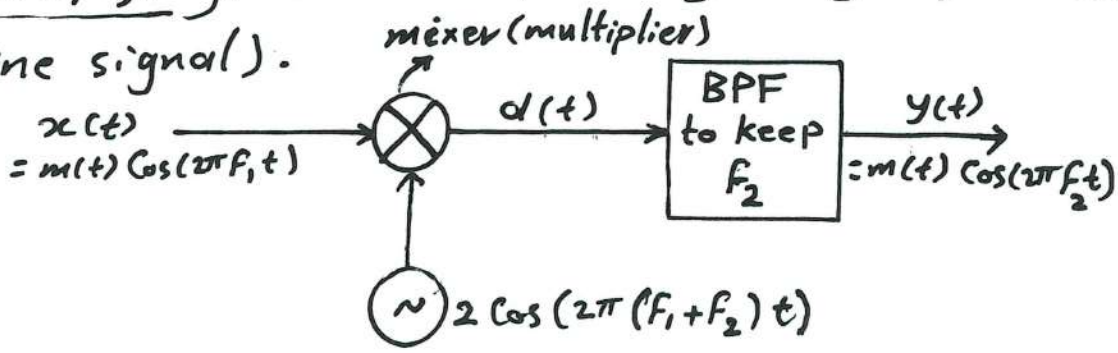
The synchronous (coherent) detection can be utilized to demodulate VSB Signal.





3. Frequency Translation and Mixing:

* In the receiver side, it is desirable to translate (shift) the bandpass signal to a new center frequency.
* Frequency translation can be accomplished by Mixing (multiplying) the bandpass signal by a periodic signal (cosine signal).



$d(t) = x(t) \cdot 2\cos(2\pi(f_1+f_2)t)$

$d(t) = m(t) \cdot 2\cos(2\pi(f_1+f_2)t)\cos(2\pi f_1 t)$

$d(t) = m(t)\left[\cos(2\pi f_2 t) + \cos(2\pi(2f_1+f_2)t)\right]$

$d(t) = m(t)\cos(2\pi f_2 t) + m(t)\cos(2\pi(2f_1+f_2)t)$

After BPF centered at f_2.

$$y(t) = m(t)\cos(2\pi(f_2)t)$$

The center frequency is translated from f_1 to f_2.

* This process is called a frequency translating, frequency mexing, or frequency heterodyning.

Notes:

- In most commercial AM radio receivers, the received Radio Frequency (RF) signal is within the range: (540 kHz → 1600 kHz)
- This band is translated (shifted) to a fixed frequency of (455 kHz), which then can be easily amplified, filtered, and demodulated.
- 455 kHz is within the Intermediate Frequency (IF) range.

Translating from $f_{RF} = 540\,kHz \rightarrow 1600\,kHz$

to $f_{IF} = 455\,kHz$

- Another application about frequency translation is the "down converter" of the commercial satellite communication receiver. It also convert the:

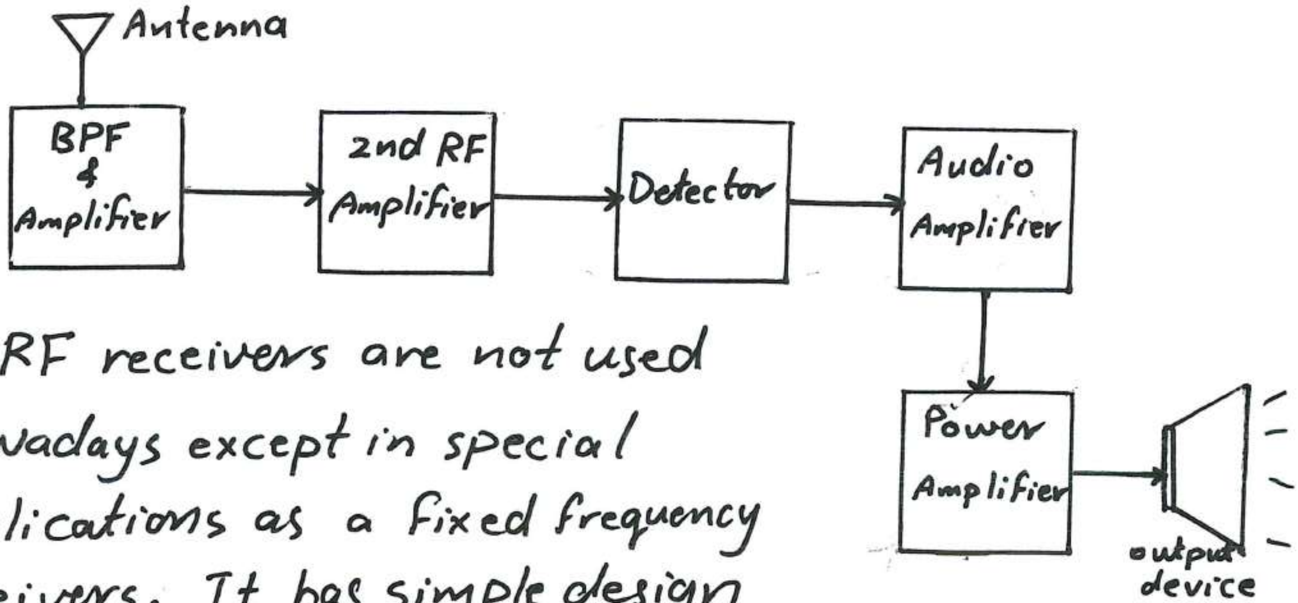
RF ⟶ IF

to simplify the electronic circuit and reduce its cost significantly.

4. Classification of Receivers:

The signal transmitted from a radio transmitter is picked up by radio receiver. However, the received signal is very weak. Therefore, any receiver should be begin with BPF to pick the desired signal up and amplifier to enhance the signal intensity.

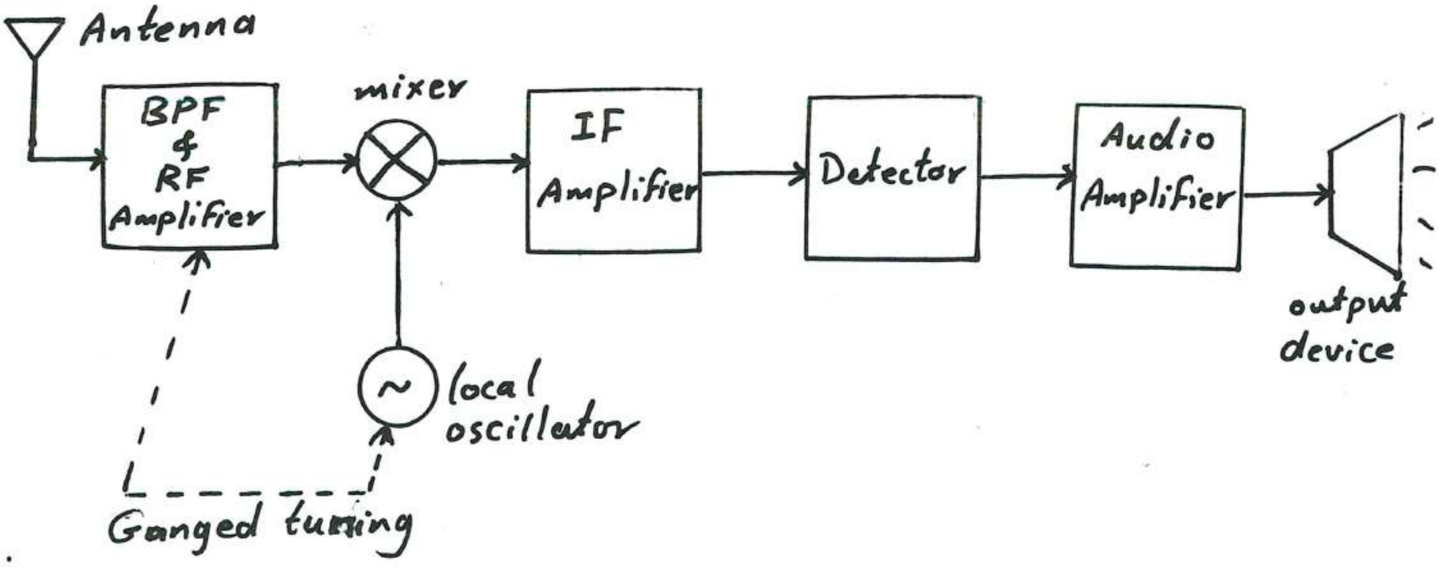
a) Tuned Radio Frequency (TRF) Receivers:



TRF receivers are not used nowadays except in special applications as a fixed frequency receivers. It has simple design but bad quality signal.

b) Superheterodyne Receivers:

Heterodyne means mixing.



BPF : is used to pick the desired signal up.

RF Amplifier: amplifies the received signal to a suitable high level.

Mixer: (down converter) to translate the RF signal down to IF frequency.

IF Amplifier: It is a cascade amplifier to amplify the IF signal to noticeably high level.

Detector: To perform demodulation process which recovers the orginal baseband signal.

Audio Amplifier: One stage amplifier for additional amplification.

5. Image Frequency Rejection:

In superheterodyne receivers, it is required to reduce the RF frequency down to a fixed IF frequency. The local oscillator frequency (f_{LO}) must continuously differ from (f_{RF}) by an amount of (f_{IF}),

$$f_{LO} = f_{RF} + f_{IF}$$

where f_{LO} : local oscillator frequency

f_{RF} : Radio Frequency

f_{IF} : Intermediate Frequency

The BPF of the receiver is not that sharp to perfectly filter all the received signal out, so some undesired signals may reach the mixer.