JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY KAKINADA
KAKINADA – 533 001 , ANDHRA PRADESH
GATE Coaching Classes as per the Direction of
Ministry of Education
GOVERNMENT OF ANDHRA PRADESH

Analog Communication

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Presentation Outline

Supressed carrier AM Schemes:

- DSB-SC AM Modulation and detection
- SSB Modulation and detection
- VSB Modulation and detection
- QAM
- Frequency Division Multiplexing
- Applications and Summary
- Problems

Learning Outcomes

- At the end of this Session, Student will be able to:
- LO 1 : Demonstrate fundamental concepts of suppressed carrier AM systems as well as their generation and demodulation
- LO 2 : Compare Full Carrier AM with other linear modulation techniques based on bandwidth, power and applications
- LO3 : Need for multiplexing and Frequency Division Multiplexing (FDM)

AM Power Distribution

- For a single-tone sinusoidal modulating signal, the AM signal consists of three frequency components – the carrier signal and the two sidebands: upper sideband and lower sideband. The easiest way to compute the total average power in an AM signal is to add the individual average power contents in each of three frequency components. That is,
- Total power in AM signal = Carrier power + Lower sideband power + Upper sideband power

$$P_{AM} = P_C + P_{LSB} + P_{USB}$$

Total AM Power

In general, the power of a signal is given as the ratio of square of RMS value of signal voltage and the load resistance. That is,

Signal Power = (RMS value of carrier signal voltage) ² / Load Resistance

Carrier Signal Power

The peak amplitude of the carrier term in AM signal is the same as that of unmodulated carrier signal. Therefore, the carrier power is given as

Carrier Power, $P_C = (A_C / \sqrt{2})^2 / R_L = A_C{}^2 / 2R_L = A_C{}^2 / 2$ (If R_L =1 Ohm)

Total Sideband Power , $P_{SB} = P_{LSB} + P_{USB} = \frac{1}{4}\mu^2 P_c + \frac{1}{4}\mu^2 P_c = \frac{1}{2}\mu^2 P_c$

Total AM Power, $P_{AM} = P_C + P_{LSB} + P_{USB} = P_C\left(1 + \frac{\mu^2}{2}\right)$

Total Power and Total Current in AM Wave

- $Pt=P_C\ (1+\frac{\mu^2}{2})$ Where, Pt is the Power of the AM wave after modulation.

  Pc is the Power of the carrier before modulation.

  Now,

$P_t = P_C + P_C\frac{\mu^2}{2} = P_C + P_{SB}$, *current in AM wave* $I_t = I_c\sqrt{1+\mu^2/2}$

Where $P_{SB} = P_C\frac{\mu^2}{2}$; $P_{USB} = P_{LSB} = P_C\frac{\mu^2}{2}$

- The power of the carrier is independent of μ
- The side band power depends on μ, and as the ‘μ’is increased ,the P_{SB} also increases.

Transmission Efficiency of AM Signal

Transmission efficiency of AM signal is defined as the percentage of total AM power contained in the sidebands. Mathematically,

$$\text{Transmission efficiency of AM signal, } \eta_{AM} = \frac{P_{AM}}{P_{SB}}$$

Note:

- In the efficient power distribution case ,i.e μ=1
- Still 66.66% of Pt is wasted in the form of transmission of additional carrier. This is the biggest drawback of AM.

Conclusion:

If μ=0 then P_C = 100% of P_t and P_{SB} = 0% of P_t

If μ=1 then P_C = 66.66% of P_t and P_{SB} = 33.33% of P_t

Note:

In the efficient power distribution case , i.e μ=1 ,still 66.66% of P_t; is wasted in the form of transmission of additional carrier. This is the biggest drawback of AM.

Modulation Efficiency(Ƞ):

It specifies share of sideband power in total power

Eg: if Ƞ=0.1, then 10% of P_{SB} in P_t;

if Ƞ=0.3, then 30% of P_{SB} in P_t.

Mathematically ;

$$\eta = \frac{P_{SB}}{P_t}$$

So,

$$\eta = \frac{\frac{P_c \mu^2}{2}}{P_c\left\{1+\frac{\mu^2}{2}\right\}}$$

$$\boxed{\eta = \frac{\mu^2}{2+\mu^2}}$$

Transmission Efficiency of AM Signal

- The carrier *c(t)* is completely independent of the information bearing or baseband signal *m(t)*, therefore transmission of carrier wave in s*(t)* represents a waste of power: major drawback with AM-FC
- Only a fraction of the total transmitted power is affected by *m(t)*

- Low transmitted power efficiency
- Poor reception quality
- Noisy signal reception
- Limited operating radio range

Supressed Carrier AM Schemes

- DSB SC – Double sideband supressed carrier AM
- SSB - Single sideband supressed carrier AM
- VSB - Vestigial sideband supressed carrier AM

Double Sideband Supressed Carrier AM

- This form of linear modulation is generated by using a Product Modulator that simply multiplies the message m(t) by the carrier c(t)
- Two forms of Product modulator :

1. Balanced modulator
2. Ring modulator

- Consider a sinusoidal carrier wave c(t) defined by

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

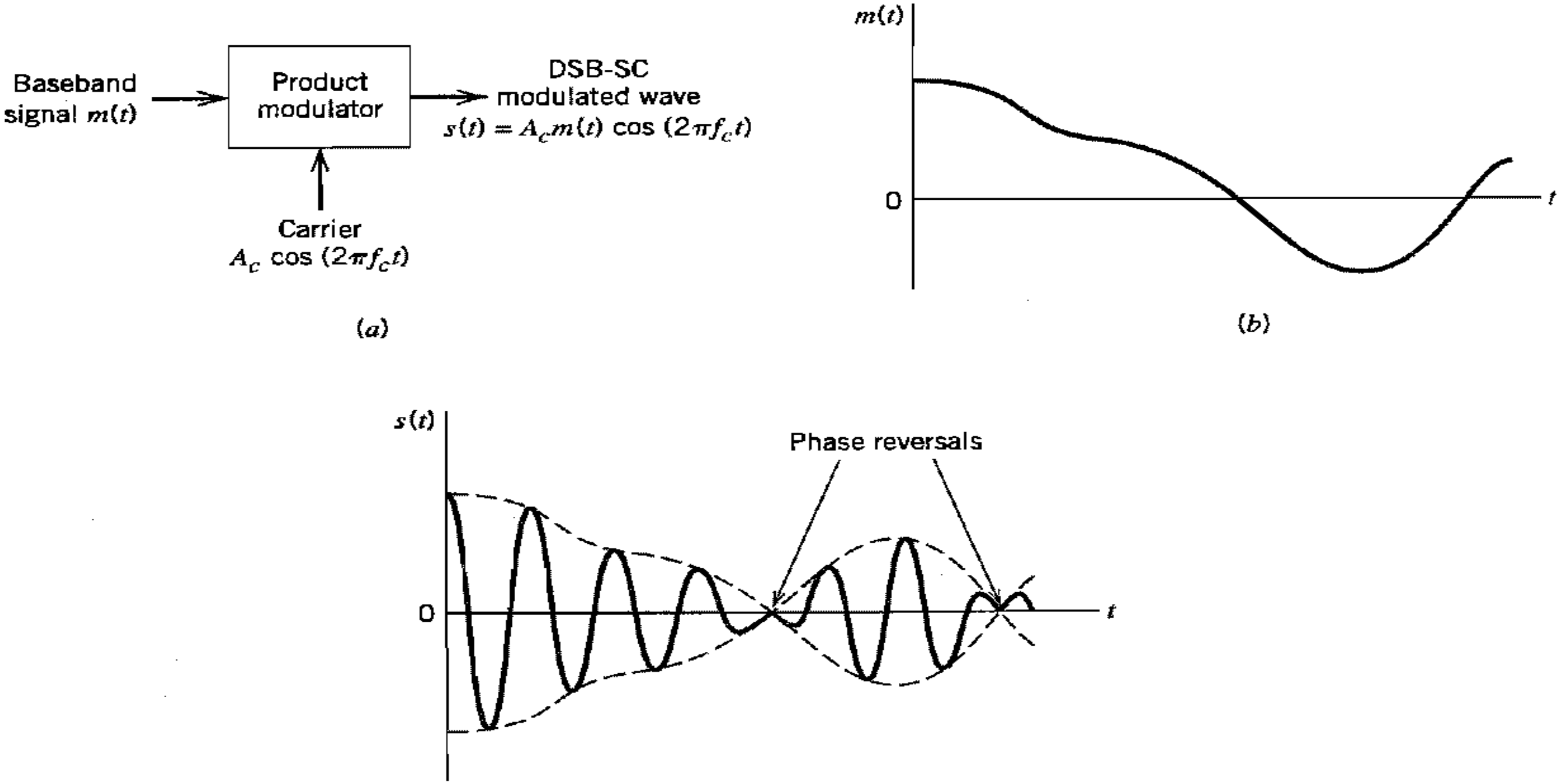
Where , A_c - Carrier amplitude, f_c - Carrier frequency

Let m(t) - Baseband signal , $c(t)$ is independent of m(t)

➢The resultant DSB-SC AM wave can be expressed as

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

DSB-SC AM



(a) Block diagram of Product Modulator (b) Baseband signal (c) DSB-SC modulated wave

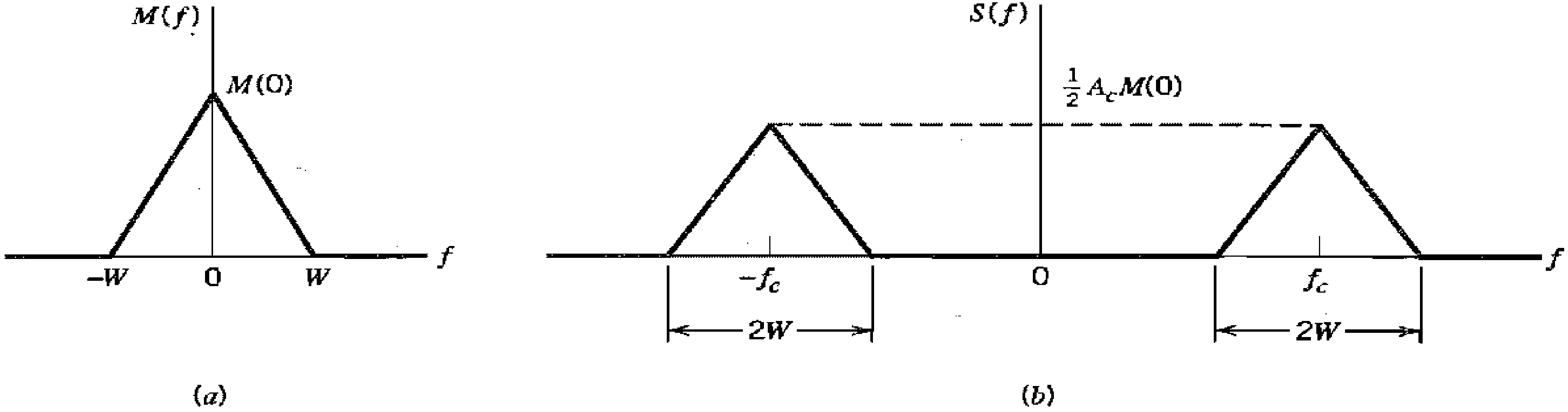
Spectrum of DSB-SC AM Wave

The Fourier transform of $s(t)$ is obtained as

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

where, m(t) is limited to the interval $-W \le f \le W$,

- *The modulation process simply translates the spectrum of the baseband signal by* $\pm f_c$.
- *The translation BW required for DSB-SC wave is 2 W*

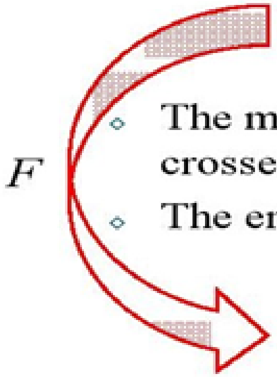


(a) Spectrum of Baseband signal (c) Spectrum of DSB-SC modulated wave

DSB-SC AM

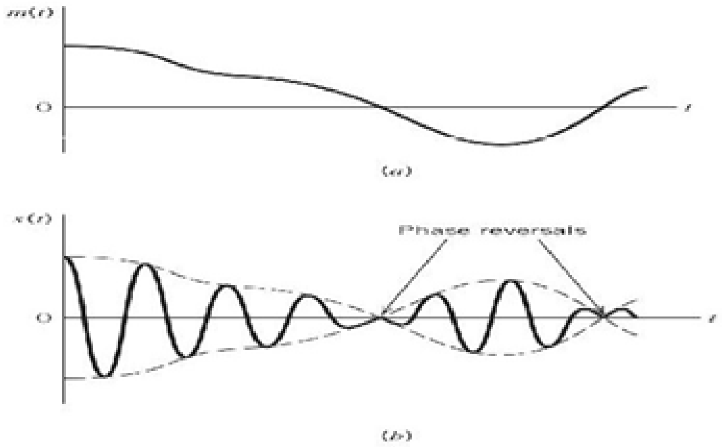
- *Double sideband-suppressed carrier (DSB-SC) modulation.*
  - Product of the message signal $m(t)$ and the carrier wave $c(t)$:

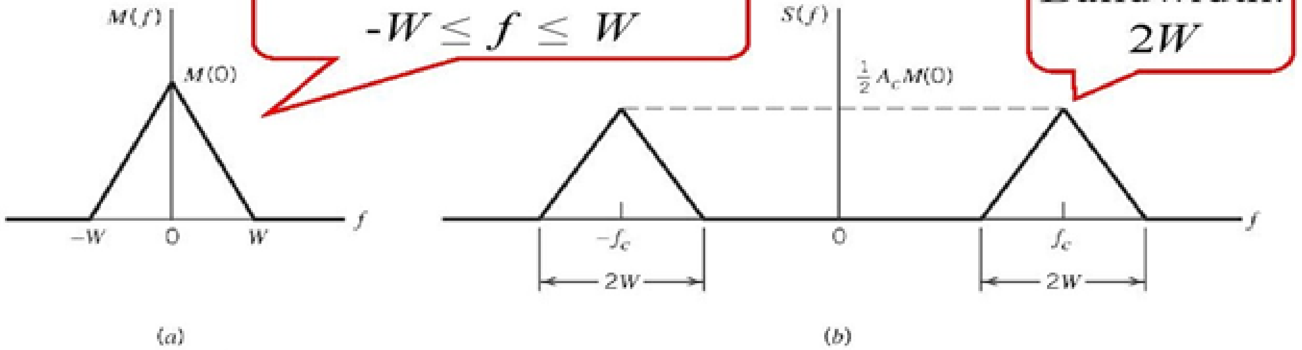
$$s(t) = c(t)m(t) = A_c \cos(2\pi f_c t)m(t)$$



  - 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.

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





limited to the interval $-W \le f \le W$

Bandwidth: $2W$

DSBSC Modulation Technique

- Double-sideband suppressed carrier (DSBSC) modulation technique is a modified form of amplitude modulation technique in which the carrier signal is completely suppressed from amplitude-modulated signal.
- The DSBSC frequency spectrum extends from lower sideband frequency $(f_c - f_m)$ to upper sideband frequency $(f_c + f_m)$, where f_c is the carrier signal frequency, and f_m is the maximum modulating signal frequency.

$$B_{DSBSC} = (f_c + f_m) - (f_c - f_m)$$

$$B_{DSBSC} = 2\, f_m$$

- Where f_m is highest modulating frequency in Hz of the modulating signal.

Power Gain in DSBSC Signal

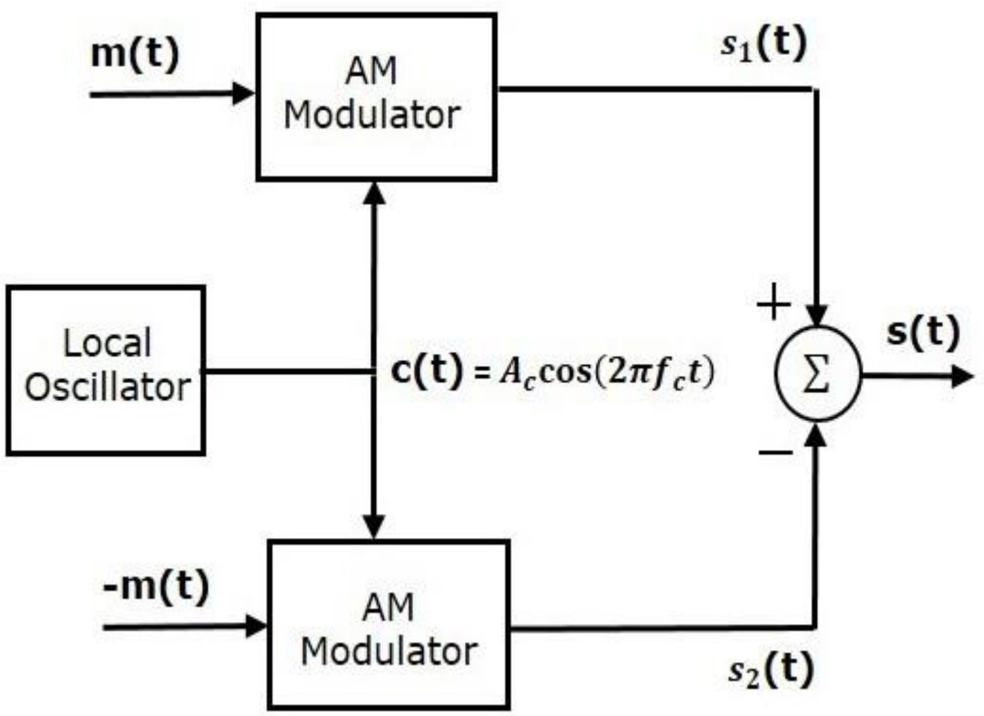
- We know that the power contained in DSBSC signal is only one-third that of total power transmitted in AM signal for $\mu = 1$.
- This also means that the minimum power increase in the sidebands by suppressing the carrier signal will be 3 times or $10 \log 3 \approx 4.77$ dB.
- It is quite substantial since a practical AM system generally operates at less than 100 % modulation index.
- So there is substantial power gain in DSBSC signal.
- “*The main disadvantage of DSBSC signal is that the resultant envelope is not a faithful representation of the modulating signal. It is merely the sum of the lower sideband and upper sideband signals. The frequency of its envelope is twice the modulating frequency*”.

DSBSC Generation

- This form of linear modulation is generated by using a Product Modulator that simply multiplies the message m(t) by the carrier c(t)
- Two forms of Product modulators :

1. Balanced modulator
2. Ring modulator

Balanced Modulator



Output of the upper AM modulator is

$$s_1(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t)$$

Output of the lower AM modulator is

$$s_2(t) = A_c[1 - k_a m(t)]\cos(2\pi f_c t)$$

the difference of $s_1(t)$ and $s_2(t)$.

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

$$\Rightarrow s(t) = A_c\cos(2\pi f_c t) + A_c k_a m(t)\cos(2\pi f_c t) - A_c\cos(2\pi f_c t) +$$

$$A_c k_a m(t)\cos(2\pi f_c t)$$

$$\Rightarrow s(t) = 2A_c k_a m(t)\cos(2\pi f_c t)$$

We know the standard equation of DSBSC wave is

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

Ring Modulator

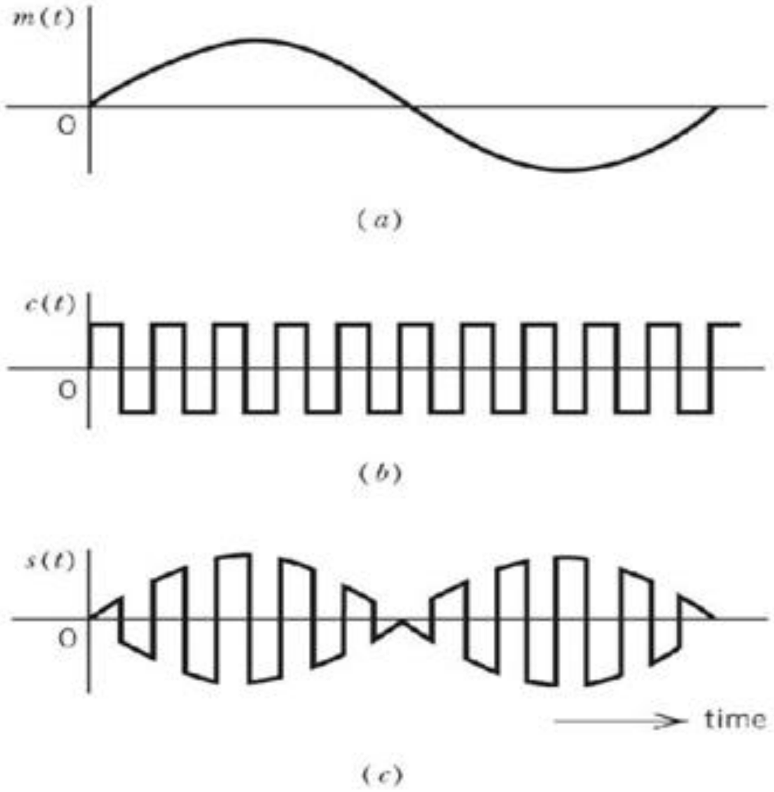
Ring modulator is one of the most useful product modulator, well suited for generating a DSB-SC wave.

- The diodes are controlled by square-wave carrier *c(t)* 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.

<u>The operation of the circuit.</u>

- Assuming 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 c(t) goes through zero.
- On one half-cycle of the carrier, the outer diodes are switched to their forward resistance r_f and the inner diodes are switched to their backward resistance $r_{b.}$ On the other half-cycle of the carrier wave, the diodes operate in the opposite condition.

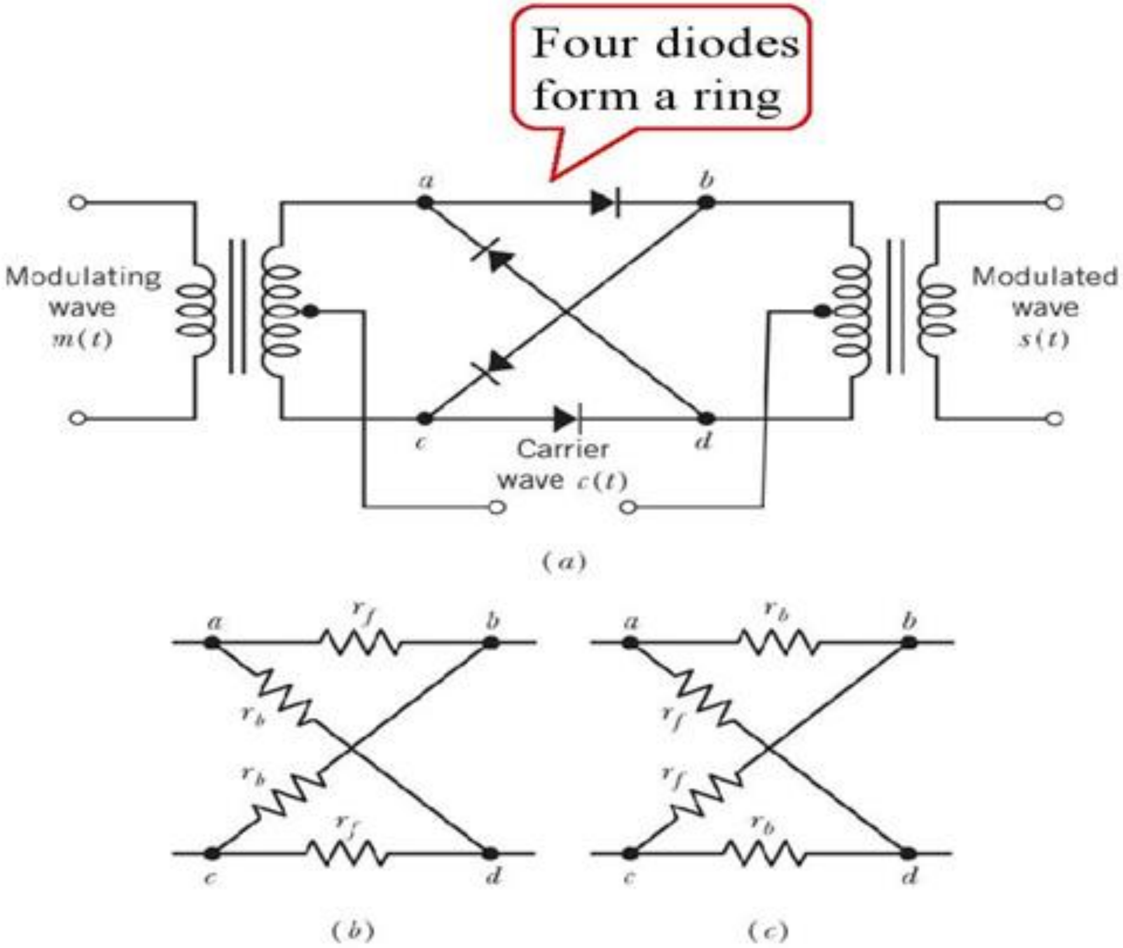
Ring Modulator



(a)

(b)

(c)


Four diodes form a ring

(a)

(b)

(c)

Ring modulator

  - The output voltage has the same magnitude as the output voltage, but they have opposite polarity.
  - In fact, the ring modulator acts as a *commutator.*
- Square-wave carrier *c(t)* can be represented by a Fourier series:

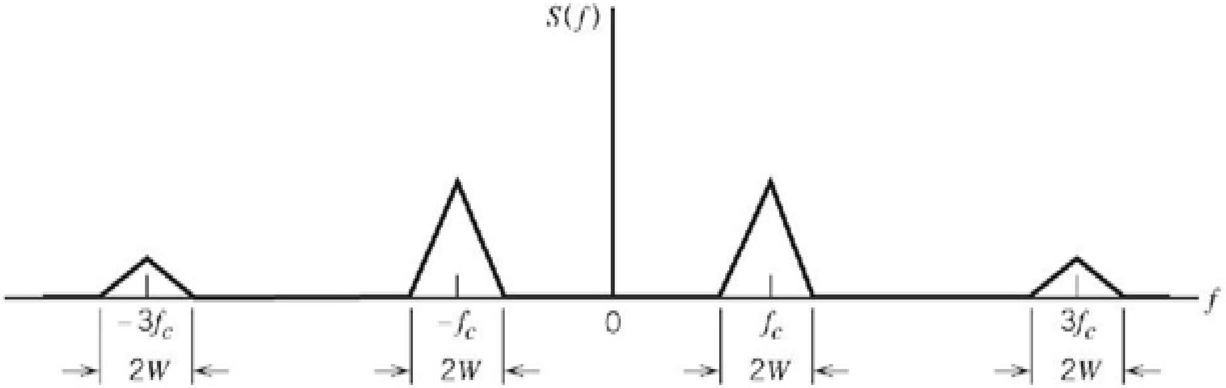
$$c(t) = \frac{4}{\pi} + \sum_{\mathrm{n}=1}^{\infty} \frac{(-1)^{\mathrm{n}-1}}{2\mathrm{n}-1} \cos[2\pi f_c t(2n-1)]$$

- The ring modulator output is therefore

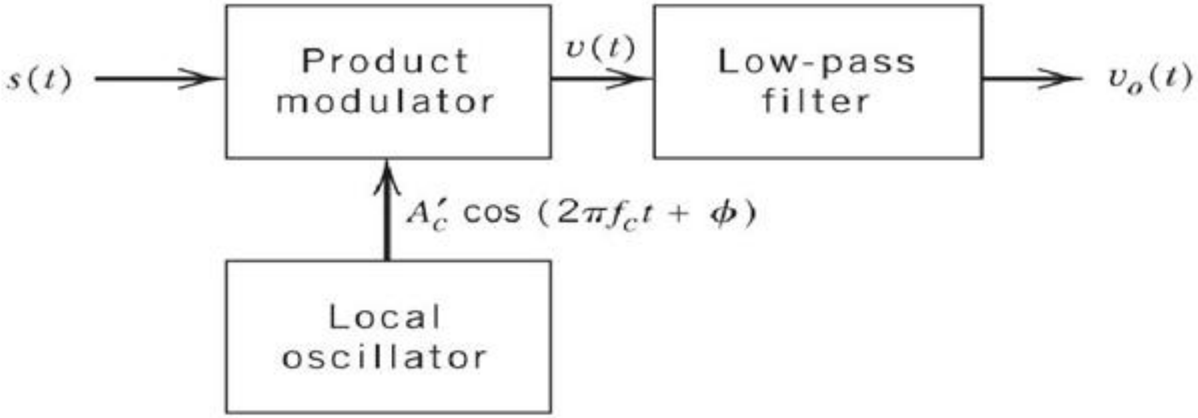
$$s(t) = c(t)m(t) = \frac{4}{\pi} + \sum_{\mathrm{n}=1}^{\infty} \frac{(-1)^{\mathrm{n}-1}}{2\mathrm{n}-1} \cos[2\pi f_c t(2n-1)]m(t)$$

- It is sometimes referred to as a *double-balanced modulator,* because it is balanced with respect to both the baseband signal and the square-wave carrier.

- Assuming that *m(t)* is limited to the frequency band $-W \leq f \leq W$, the spectrum of the modulator output consists of sidebands around each of the odd harmonics of the square-wave carrier *m(t)*.
- To prevent sideband overlap → $f_c > W$.
- we can use a band-pass filter of mid-band frequency f_c and bandwidth $2W$ to select the desired pair of sidebands around the carrier frequency f_c.
  - The circuitry needed for the generation of DSB-SC modulated wave consists of a ring modulator followed by a band-pass filter.



Coherent Detection of DSBSC waves

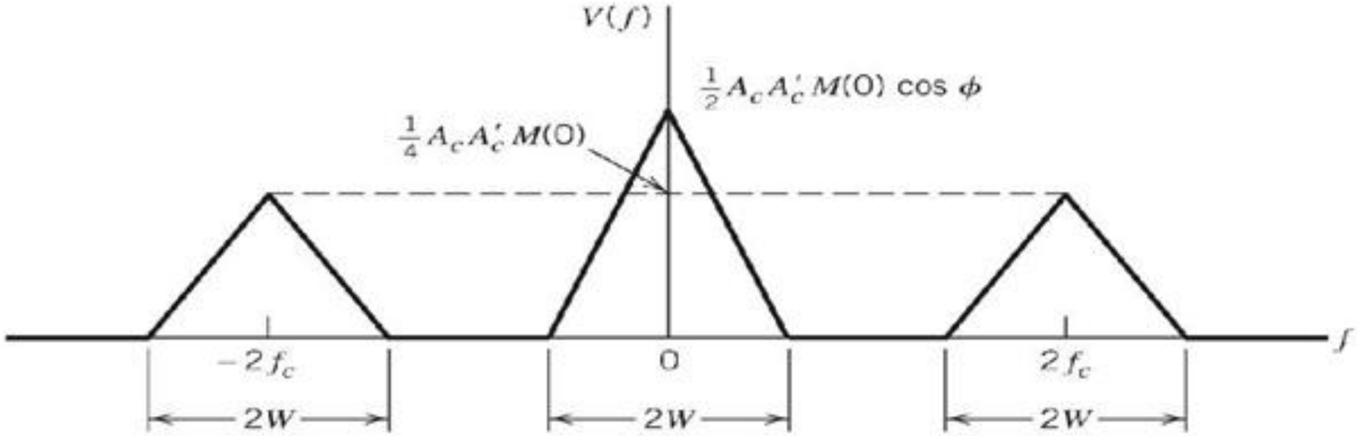


- It is assumed that the local oscillator signal is exactly coherent or synchronized, in both *frequency and phase*, with carrier wave *c(t)* used in the product modulator to generate *s(t)*. This method of demodulation is known as *coherent detection* or *synchronous demodulation*.

For a more general demodulation process, we assume ϕ is a arbitrary phase difference.

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

$$\begin{aligned} \upsilon(t) &= A_c' \cos(2\pi f_c t + \phi) s(t) \\ &= A_c A_c' \cos(2\pi f_c t) \cos(2\pi f_c t + \phi) m(t) \\ &= \frac{1}{2} A_c A_c' \cos(4\pi f_c t + \phi) m(t) + \frac{1}{2} A_c A_c' \cos\phi\, m(t) \end{aligned}$$



- The first term in Eq. is removed by low-pass filter, provided that the cut-off frequency of this filter is greater than W but less than $2f_c$ - W. This is satisfied by choosing $f_c > W$.

  Therefore:

$$v_o(t) = \frac{1}{2} A_c A'_c cos\emptyset m(t)$$

  - $v_o(t)$ is proportional to *m(t)* when the phase error $\emptyset$ is a constant. Attenuated by a factor equal to $cos\emptyset$.

$$\begin{cases} v_{o\_max} = \frac{1}{2} A_c A'_c m(t), & \text{when } \emptyset = 0 \\ v_{o\_\min} = 0, & \text{when } \emptyset = \pm\frac{\pi}{2} \quad \text{(quadrature null effect)} \end{cases}$$

  - When the phase error $\emptyset$ is constant , the detector provides an undistorted version of the original baseband signal *m(t).*

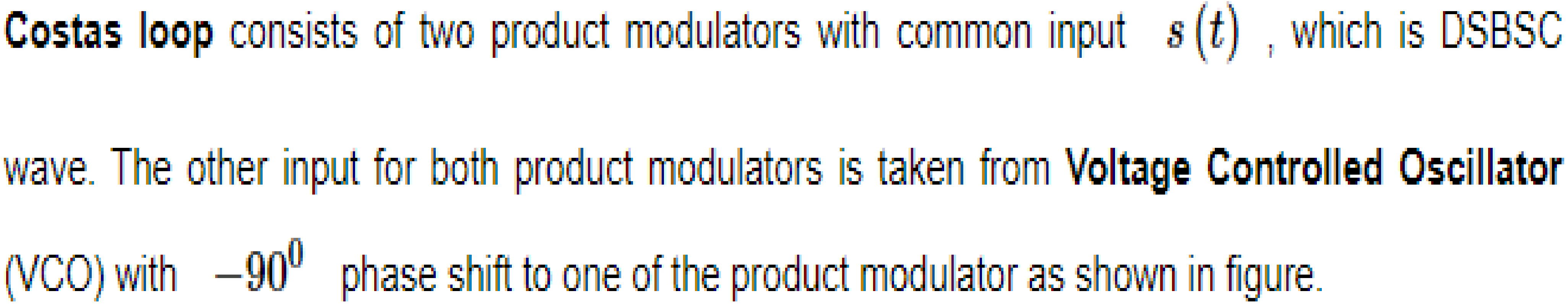
- In practice, we usually find that the phase error $\emptyset$ varies randomly with time, due to random variations in communication channel. The result is that at the detector output, the multiplying factor cos $\emptyset$ also varies randomly with time, which is obviously undesired.

- Provision must be made in the system to maintain the local oscillator in the receiver in *perfect synchronism,* in both frequency and phase, with the carrier wave used to generate the DSB-SC modulated signal in the transmitter.

- The resulting system complexity is the price that must be paid for suppressing the carrier wave to save transmitter power.

Handling Quadrature Null effect

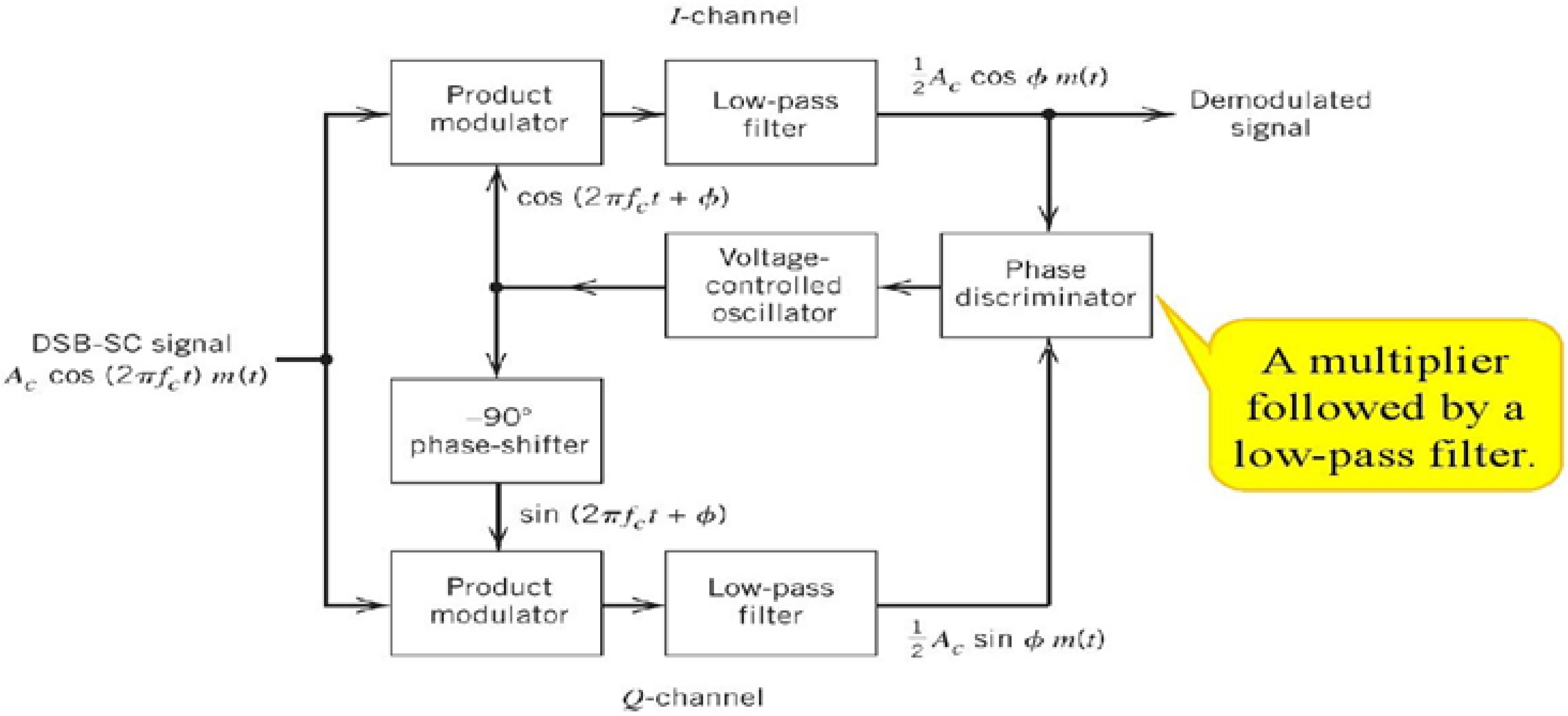
- Costas Receiver



Costas loop consists of two product modulators with common input $s(t)$, which is DSBSC wave. The other input for both product modulators is taken from **Voltage Controlled Oscillator** (VCO) with -90^0 phase shift to one of the product modulator as shown in figure.

Costas Receiver

One method of obtaining a practical synchronous receiver system , suitable for demodulating DSB-SC waves



A multiplier followed by a low-pass filter.

- The frequency of the local oscillator is adjusted to be the same as the carrier frequency f_c, which is assumed known *a prior.*
- In the upper path is referred to as the *in-phase coherent detector* or *I-channel,* and that in the lower path is referred to as the quadrature-phase coherent detector or *Q-channel.*
- These two detectors are coupled together to from a negative feedback system designed in such a way as to maintain the local oscillator synchronous with the carrier-wave.
- By combining the *I*- and *Q*-channel outputs in *phase discriminator* (which consists of a *multiplier* followed by a *low-pass filter*), a dc control signal is obtained that automatically corrects for local phase errors in the *voltage-controlled oscillator* (VCO).

- Outputs of Product Modulator
  - I-Channel $A_c \cos(2\pi f_c t) m(t) \cos(2\pi f_c t + \phi) = \frac{1}{2} A_c m(t) \{\cos(4\pi f_c t + \phi) + \cos\phi\}$
  - Q-Channel $A_c \cos(2\pi f_c t) m(t) \sin(2\pi f_c t + \phi) = \frac{1}{2} A_c m(t) \{\sin(4\pi f_c t + \phi) + \sin\phi\}$
- Outputs of Low-Pass Filter
  - I-Channel $\frac{1}{2} A_c m(t) \cos\phi$
  - Q-Channel $\frac{1}{2} A_c m(t) \sin\phi$
- Output of Multiplier

$$\left\{\frac{1}{2} A_c m(t) \cos\phi\right\} \cdot \left\{\frac{1}{2} A_c m(t) \sin\phi\right\} = \frac{1}{8} A_c^2 \left[m(t)\right]^2 \sin 2\phi$$

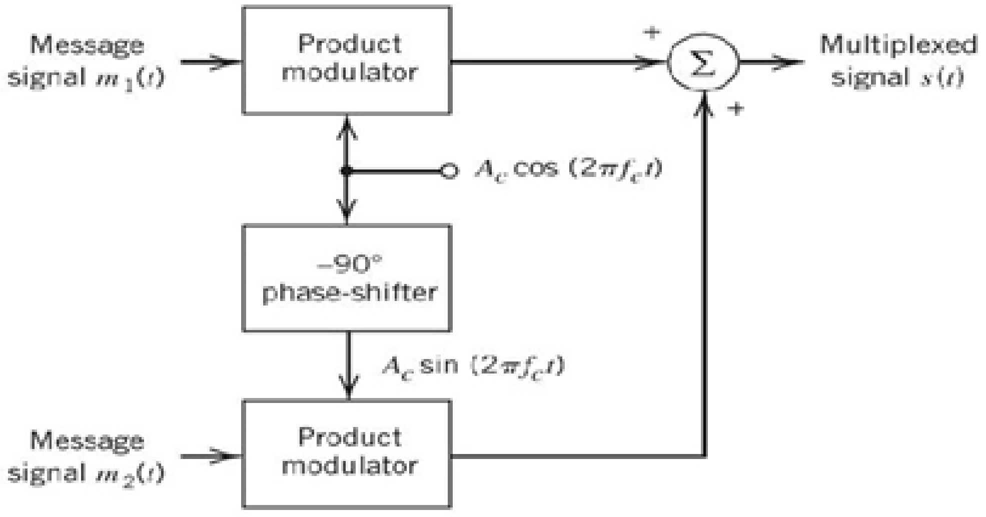
QAM- Quadrature Amplitude Modulation

The quadrature null effect of the coherent detector may also be put to good use in the construction of the so-called *quadrature-carrier multiplexing* or *quadrature-amplitude* Modulation , QAM is similar to DSB-SC but sends two message signals over the same spectrum. One of the message signal is sent in phase and the other is sent in quadrature. Finally, both are added to get QAM signal.

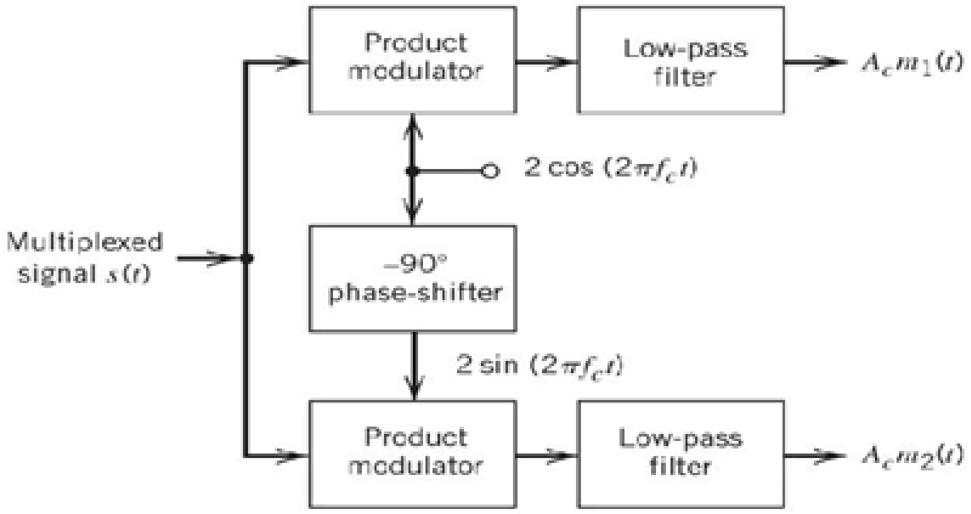
- There could be a serious problem with QAM demodulation if the local carrier has some phase error. This results in *co-channel interference*
- *It is used in color TV*

Enable two DSB-SC modulated waves to occupy the same channel bandwidth. It is a bandwidth-conservation scheme.

$$s(t) = \underset{\text{in-phase component}}{\underline{A_c m_1(t)}}\cos(2\pi f_c t) + \underset{\text{quadrature-phase component}}{\underline{A_c m_2(t)}}\sin(2\pi f_c t)$$



(a)



(b)

- With double-sideband modulation, we are transmitting only one such signal and the question that comes to mind is whether the band-pass bandwidth of $2W$ is actually required.
- In actual fact, it can be shown that due to the symmetry of the DSB signal about the carrier frequency, the same information is transmitted in the *upper* and *lower sidebands*, and only one of the sidebands needs to be transmitted.

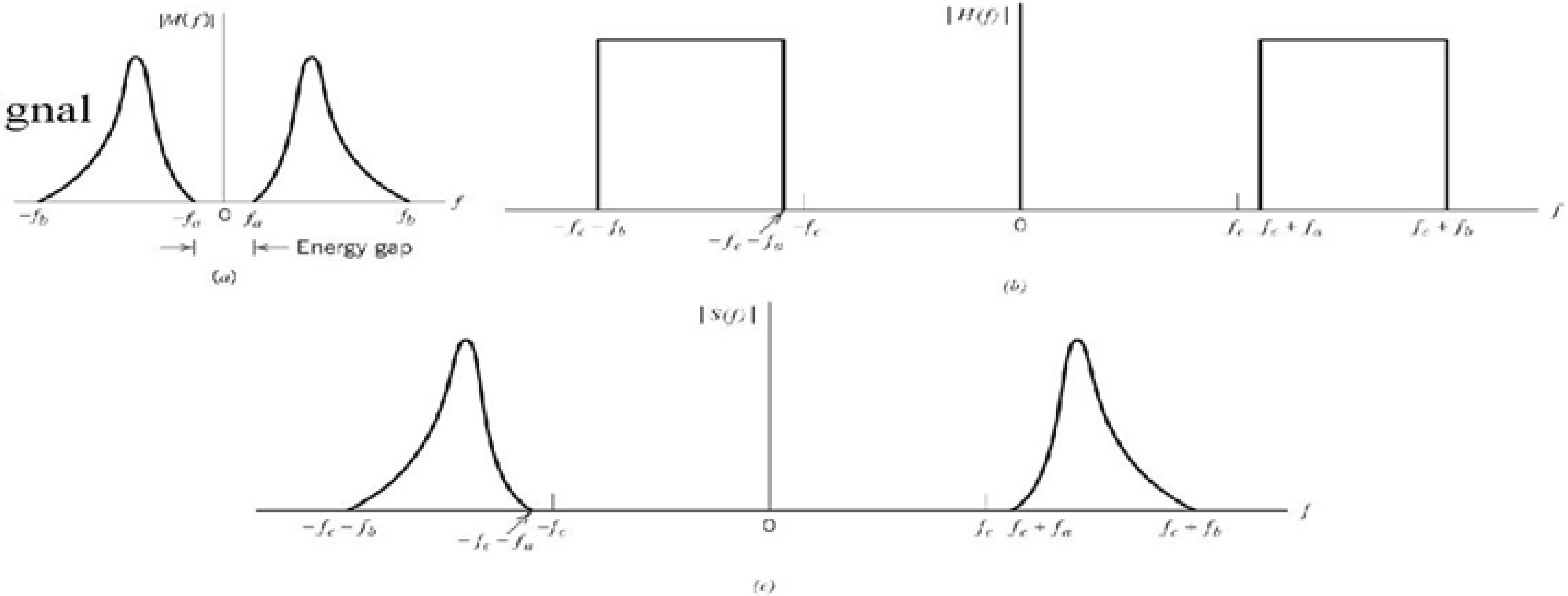
- There are two bandwidth conservation methods:
  - *Single-sideband* (SSB) modulation.
  - *Vestigial sideband* (VSB) modulation.

SSB Modulation

- Single-sideband suppressed carrier (SSBSC) or simply known as single-sideband (SSB) is a form of amplitude modulation in which the carrier is fully suppressed and one of the sidebands (lower or upper) is also suppressed
- With double-sideband transmission, the information contained in the lower sideband is identical to the information contained in the upper sideband.
- Therefore, transmitting both sidebands at the same time is <u>not</u> essential at all.
- In fact, the two sidebands of an AM signal are mirror images of each other, since one consists of the difference of the carrier and modulating frequencies and the other is the sum of the carrier and modulating frequencies.
- The two sidebands are uniquely related to each other because they are symmetrical about the carrier frequency.

SSB

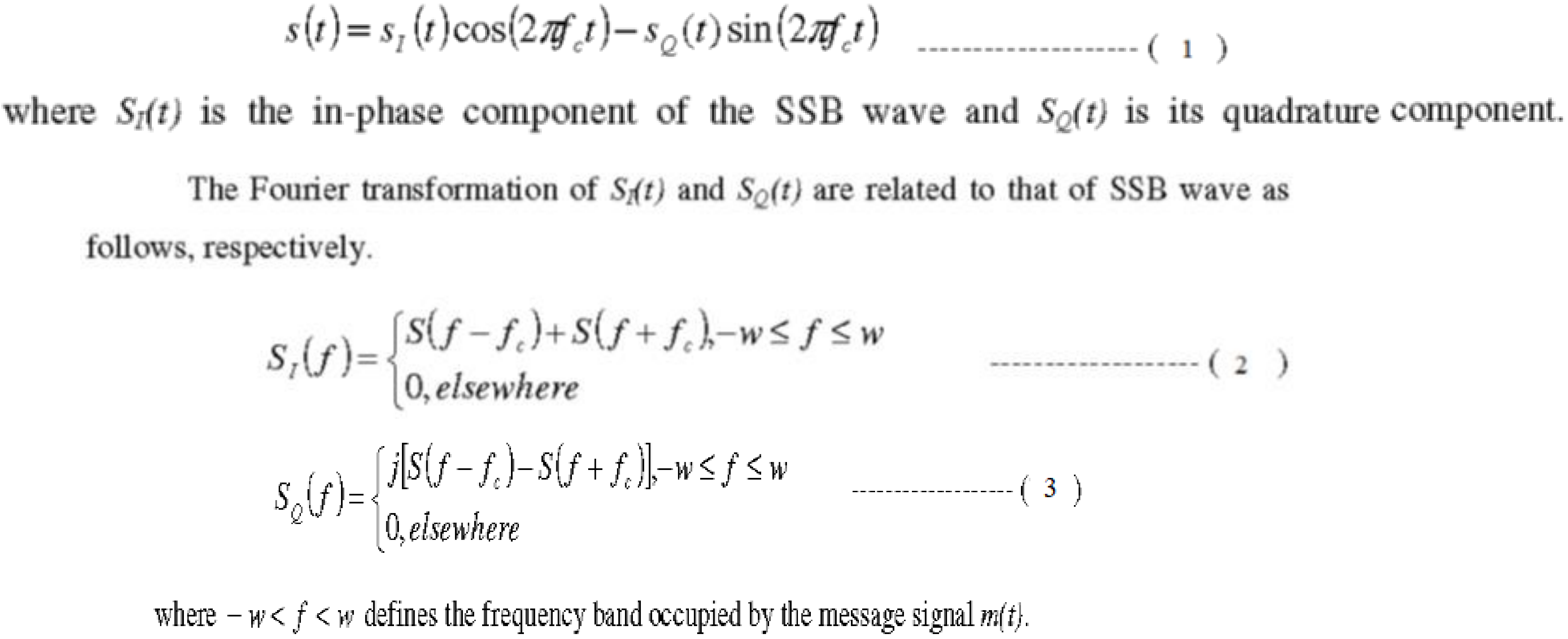
- The generation of a SSB signal is straightforward.
  - First, generate a double-sideband signal
  - Then apply an ideal pass-band filter to the result with cutoff frequencies of f_c and $f_c + W$ (or $f_c - W$) for the upper sideband (or lower sideband).
  - Practically, the approximate construction of an ideal filter is very difficult.


Voice Signal

Problem

- 1.Find the Hilbert transform of x(t)=$\delta(t)$
- Solution:
- H.T(x(t))= $\int_{-\infty}^{\infty} \frac{x(\tau)}{\pi(t-\tau)} d\tau$ $= \int_{-\infty}^{\infty} \frac{\delta(\tau)}{\pi(t-\tau)} d\tau$
- $= \int_{-\infty}^{\infty} \frac{\delta(\tau)}{\pi(t)} d\tau$
- $= \frac{1}{\pi t} \int_{-\infty}^{\infty} \delta(t) d\tau$
- Since area under unit impulse is 1
- $= \frac{1}{\pi t}$ (solution)

SSB Generation



$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t) \quad \text{------------------} (1)$$

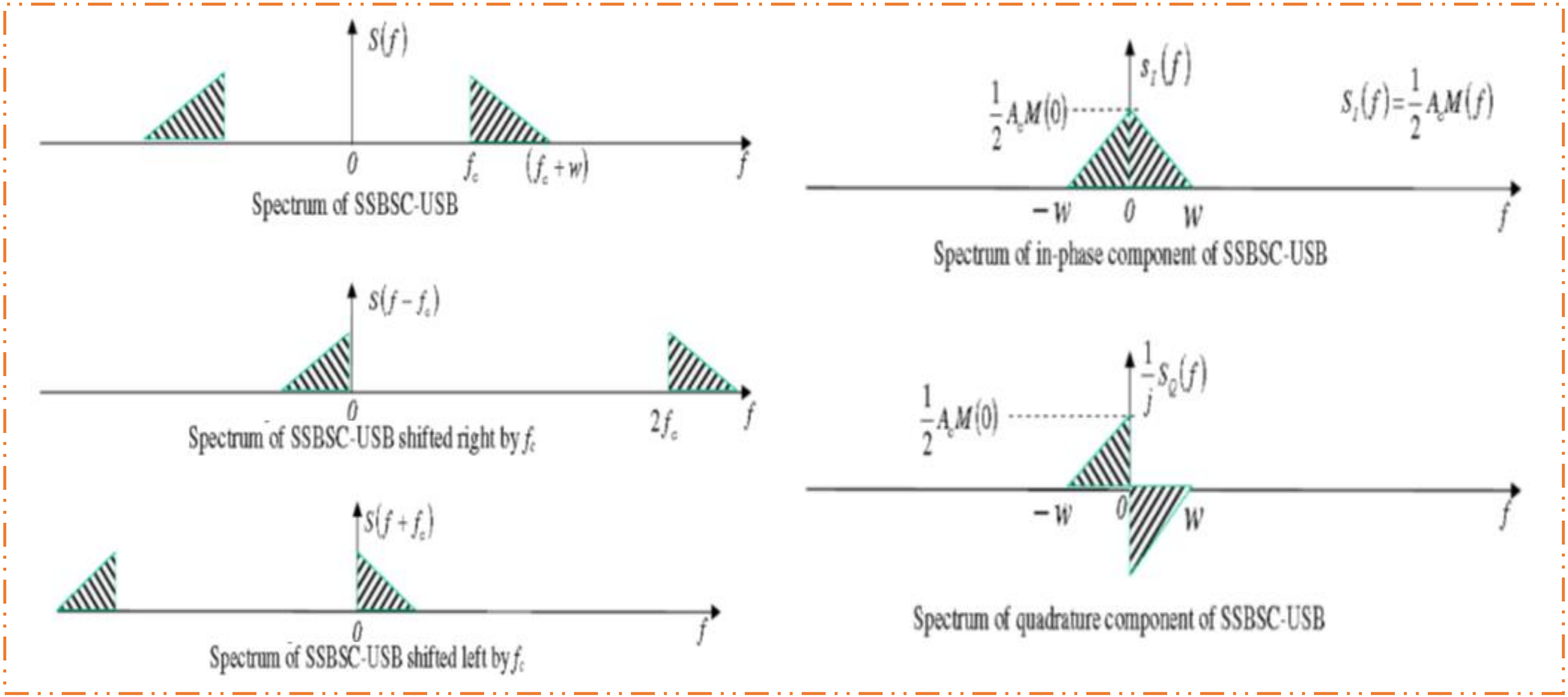
where $S_I(t)$ is the in-phase component of the SSB wave and $S_Q(t)$ is its quadrature component.

The Fourier transformation of $S_I(t)$ and $S_Q(t)$ are related to that of SSB wave as follows, respectively.

$$S_I(f) = \begin{cases} S(f-f_c)+S(f+f_c), -w \le f \le w \\ 0, elsewhere \end{cases} \quad \text{------------------} (2)$$

$$S_Q(f) = \begin{cases} j[S(f-f_c)-S(f+f_c)], -w \le f \le w \\ 0, elsewhere \end{cases} \quad \text{------------------} (3)$$

where $-w < f < w$ defines the frequency band occupied by the message signal $m(t)$.



Spectrum of SSBSC-USB

Spectrum of SSBSC-USB shifted right by f_c

Spectrum of SSBSC-USB shifted left by f_c

Spectrum of in-phase component of SSBSC-USB

Spectrum of quadrature component of SSBSC-USB

Where M(f) is the Fourier transform of the message signal m(t).

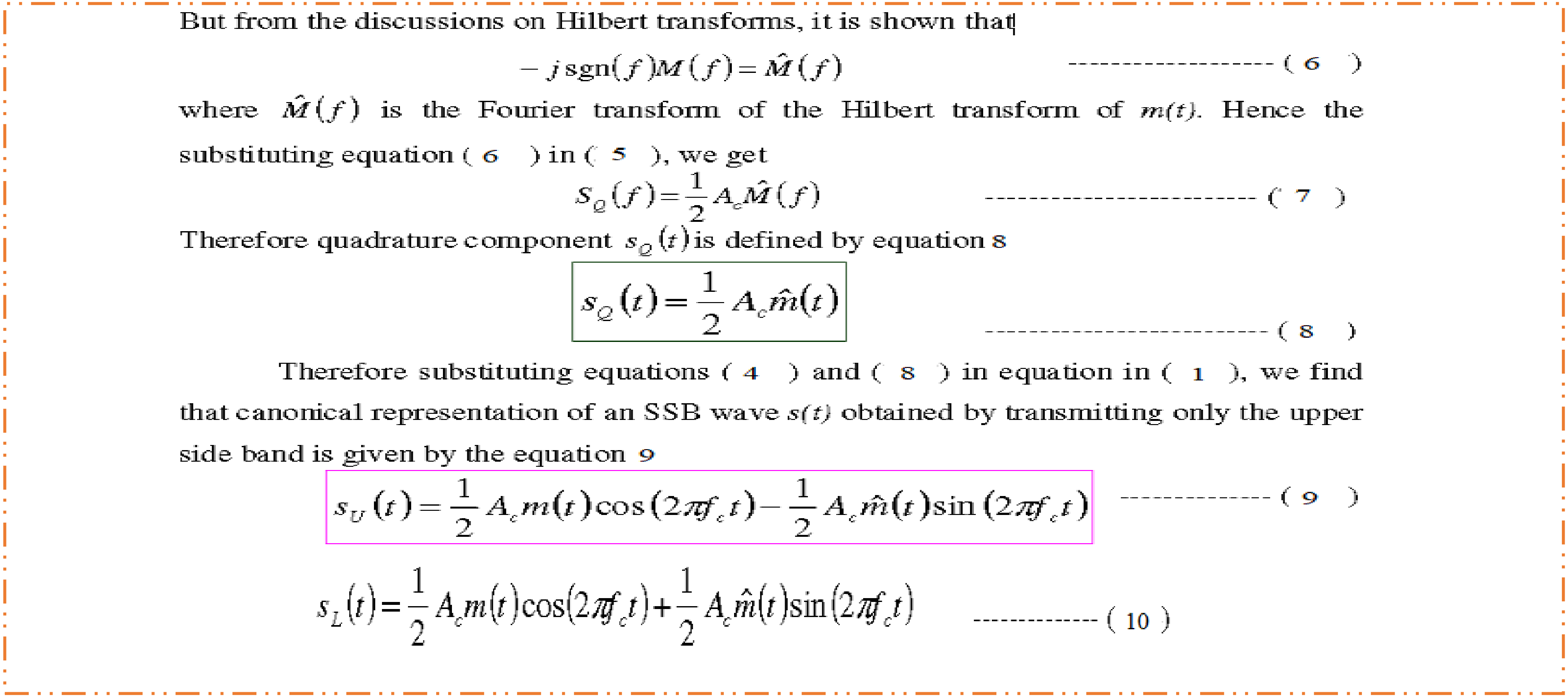
Accordingly in-phase component $S_I(t)$ defined by following equation .

$$\boxed{s_I(t)=\frac{1}{2}A_c m(t)} \qquad \text{------------------}(\ 4\ )$$

$$S_Q(f)=\begin{cases}\frac{-j}{2}A_c M(f), f>0\\ 0, f=0\\ \frac{j}{2}A_c M(f), f<0\end{cases}$$

$$S_Q(f)=\frac{-j}{2}A_c\,\mathrm{sgn}(f)M(f) \qquad \text{------------------}(\ 5\ )$$

where $\mathrm{sgn}(f)$ is the Signum function.



But from the discussions on Hilbert transforms, it is shown that

$$-j\,\mathrm{sgn}(f)M(f)=\hat{M}(f) \qquad \text{--------------------} \ (\ 6\ )$$

where $\hat{M}(f)$ is the Fourier transform of the Hilbert transform of $m(t)$. Hence the substituting equation (6) in (5), we get

$$S_Q(f)=\frac{1}{2}A_c\hat{M}(f) \qquad \text{--------------------------} \ (\ 7\ )$$

Therefore quadrature component $s_Q(t)$ is defined by equation 8

$$\boxed{s_Q(t)=\frac{1}{2}A_c\hat{m}(t)} \qquad \text{---------------------------} \ (\ 8\ )$$

Therefore substituting equations (4) and (8) in equation in (1), we find that canonical representation of an SSB wave $s(t)$ obtained by transmitting only the upper side band is given by the equation 9

$$\boxed{s_U(t)=\frac{1}{2}A_c m(t)\cos(2\pi f_c t)-\frac{1}{2}A_c\hat{m}(t)\sin(2\pi f_c t)} \qquad \text{--------------} \ (\ 9\ )$$

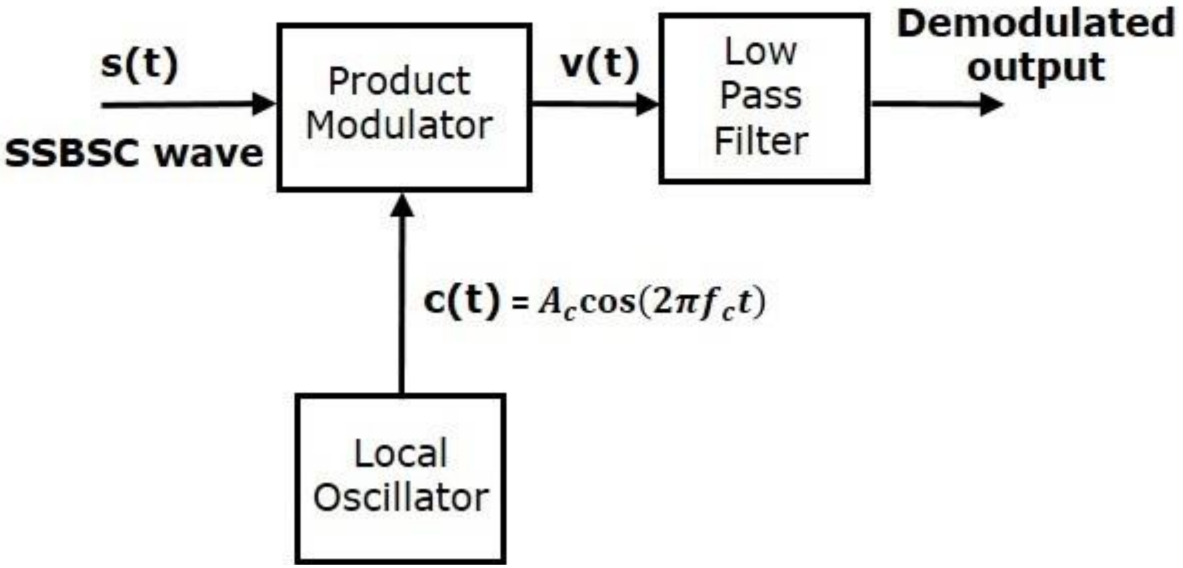
$$s_L(t)=\frac{1}{2}A_c m(t)\cos(2\pi f_c t)+\frac{1}{2}A_c\hat{m}(t)\sin(2\pi f_c t) \qquad \text{-------------} \ (\ 10\ )$$

Transmission bandwidth of SSB signal

- Since only one sideband is transmitted in SSB signal, transmission bandwidth is equal to the maximum frequency of the modulating signal. That is,
- $BW_{SSB} = f_m$
- We know that the transmission bandwidth of AM signal or DSBSC signal is twice the maximum frequency of the modulating signal. Therefore, SSB signal requires half as much bandwidth as conventional AM (DSBFC) or even double-sideband suppressed carrier (DSBSC) AM. That is,
- $BW_{SSB} = ½.\, BW_{AM} = ½.\, BW_{DSBSC} = f_m$

Demodulation of SSBSC Waves

Coherent Detector



In this process, the message signal can be extracted from SSBSC wave by multiplying it with a carrier, having the same frequency and the phase of the carrier used in SSBSC modulation. The resulting signal is then passed through a Low Pass Filter. The output of this filter is the desired message signal.

Advantages of SSB

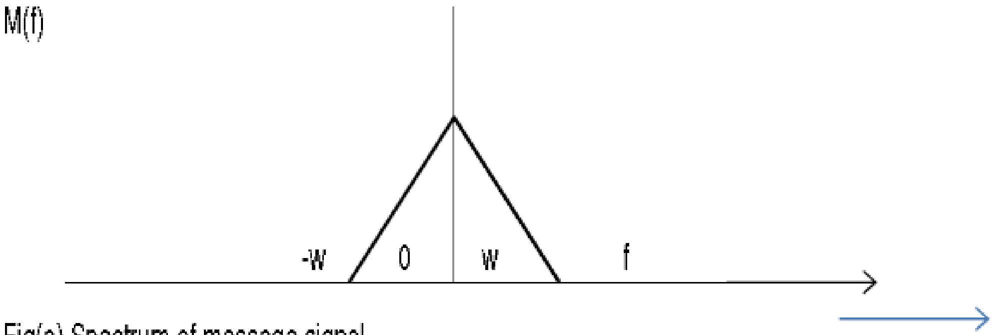
1. Transmit power efficiency
2. Bandwidth efficiency
3. Improvement in SNR
4. Reduction in noise
5. Reduction in distortion

Disadvantages of SSB

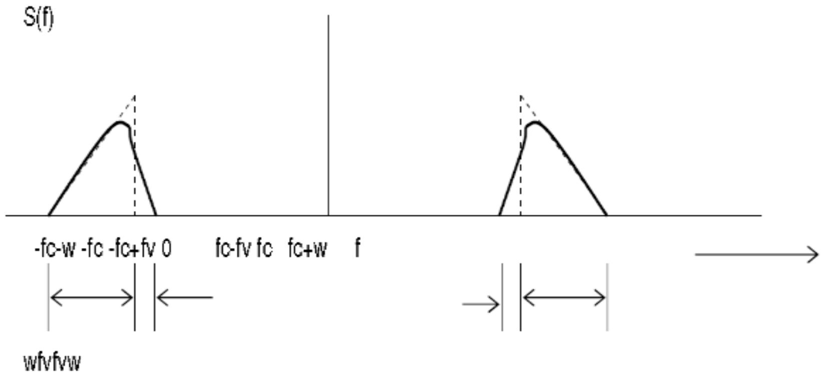
1. Difficulty in alignment and tuning
2. Complex

Vestigial Sideband Modulation

- The vestigial-sideband (VSB) modulation is another form of an amplitude-modulated signal (that is, the carrier signal plus double sideband) in which a part of the unwanted sideband (called as vestige, and hence the name vestigial sideband) is allowed to appear at the output of VSB transmission system.
- The AM signal is passed through a sideband filter before transmission of SSB signal. The design of sideband filter can be simplified to a greater extent if a part of the other sideband is also passed through it. However, in this process the bandwidth of VSB system is slightly increased.

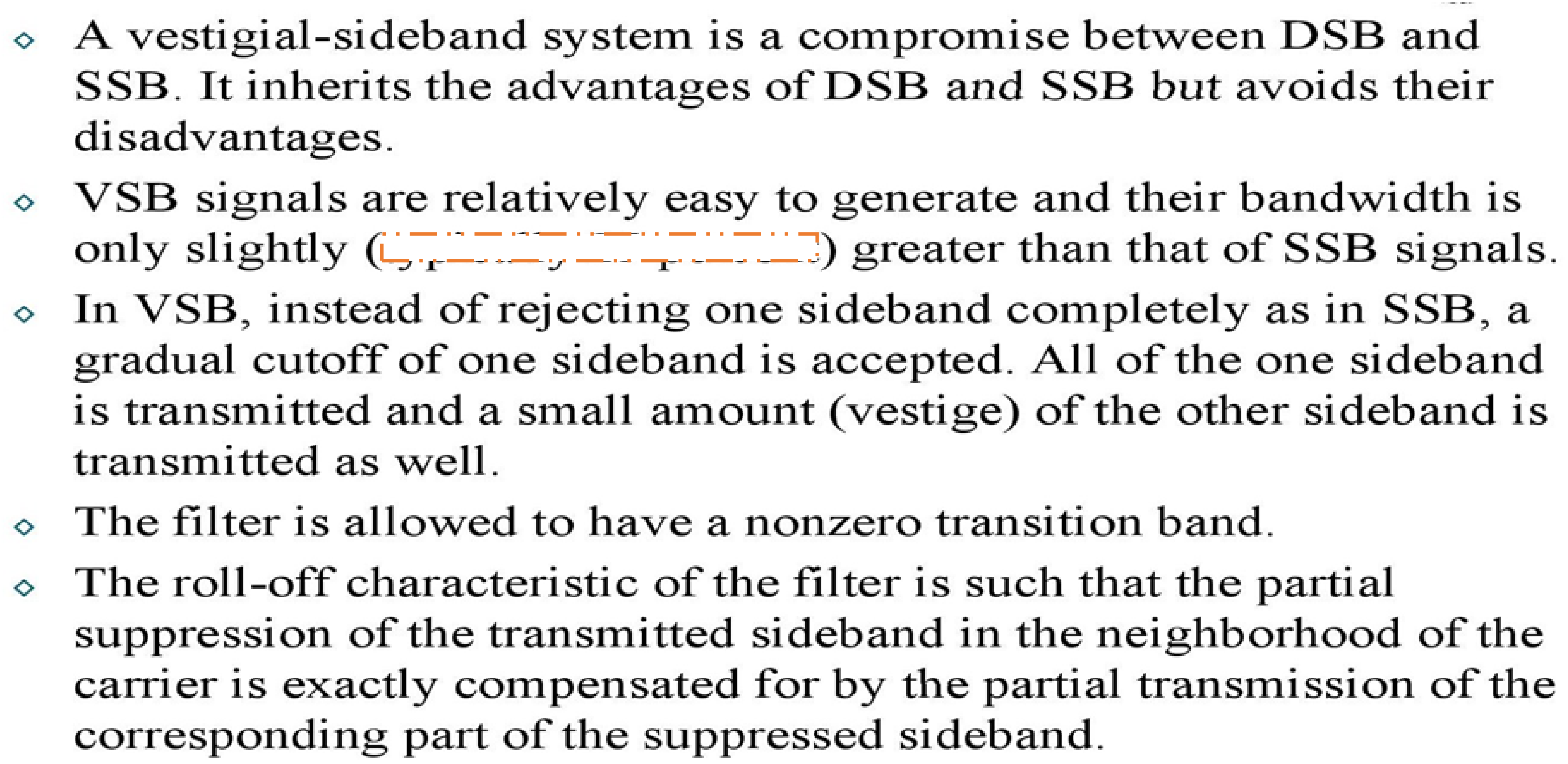


Fig(a) Spectrum of message signal



Fig(b) Spectrum of VSB wave containing vestige of the Lower side band

VSB



- A vestigial-sideband system is a compromise between DSB and SSB. It inherits the advantages of DSB and SSB but avoids their disadvantages.
- VSB signals are relatively easy to generate and their bandwidth is only slightly ([redacted]) greater than that of SSB signals.
- In VSB, instead of rejecting one sideband completely as in SSB, a gradual cutoff of one sideband is accepted. All of the one sideband is transmitted and a small amount (vestige) of the other sideband is transmitted as well.
- The filter is allowed to have a nonzero transition band.
- The roll-off characteristic of the filter is such that the partial suppression of the transmitted sideband in the neighborhood of the carrier is exactly compensated for by the partial transmission of the corresponding part of the suppressed sideband.

VSB

- Our goal is to determine the particular $H(f)$ required to produce a modulated signal $s(t)$ with desired spectral characteristics, such that the original baseband signal $m(t)$ may be recovered from $s(t)$ by coherent detection.

$$S(f) = U(f)H(f)$$

$$= \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right]H(f) \qquad (1)$$

- $m(t) \xrightarrow{F} M(f)$, $u(t) \xrightarrow{F} U(f)$

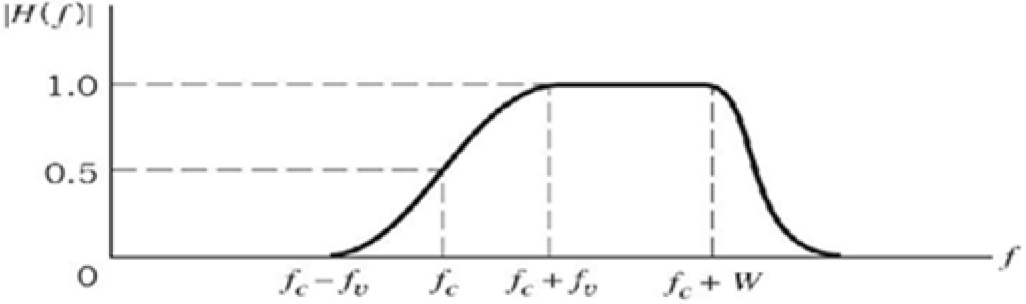
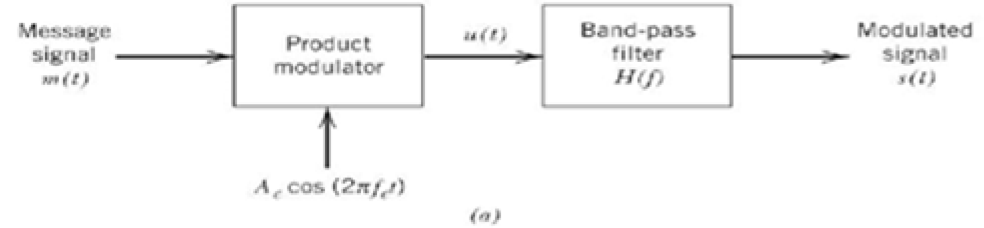
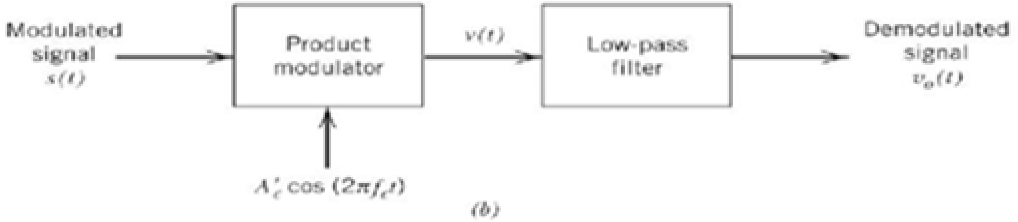
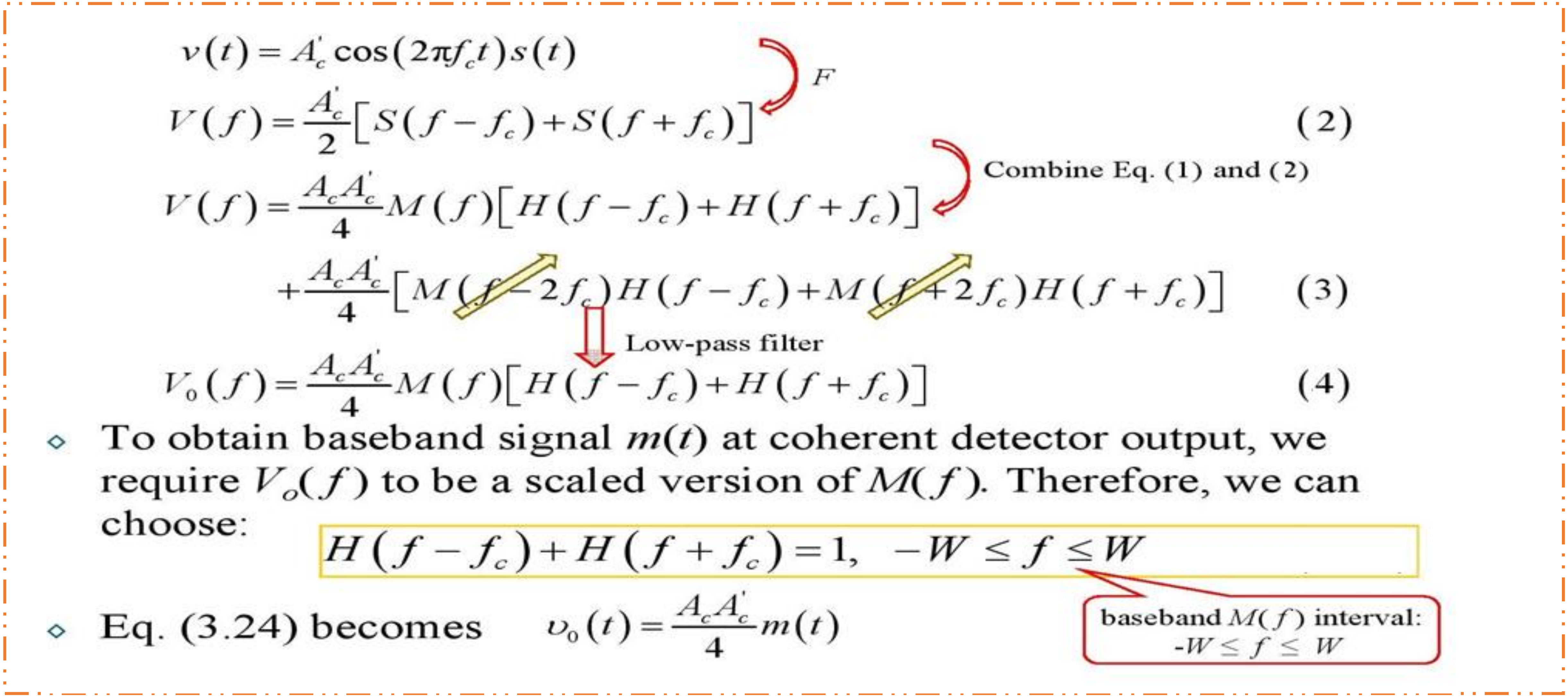


Figure :Amplitude response of VSB filter; only positive-frequency portion is shown.
f_v: the width of the vestigial sideband


Message signal $m(t)$
Product modulator
$u(t)$
Band-pass filter $H(f)$
Modulated signal $s(t)$
$A_c \cos(2\pi f_c t)$
(a)


Modulated signal $s(t)$
Product modulator
$v(t)$
Low-pass filter
Demodulated signal $v_o(t)$
$A_c' \cos(2\pi f_c t)$
(b)

VSB



$$v(t) = A_c' \cos(2\pi f_c t)\, s(t)$$

F

$$V(f) = \frac{A_c'}{2}\left[S(f-f_c) + S(f+f_c)\right] \qquad (2)$$

Combine Eq. (1) and (2)

$$V(f) = \frac{A_c A_c'}{4} M(f)\left[H(f-f_c) + H(f+f_c)\right]$$

$$+\frac{A_c A_c'}{4}\left[M(f-2f_c)H(f-f_c) + M(f+2f_c)H(f+f_c)\right] \qquad (3)$$

Low-pass filter

$$V_0(f) = \frac{A_c A_c'}{4} M(f)\left[H(f-f_c) + H(f+f_c)\right] \qquad (4)$$

- To obtain baseband signal $m(t)$ at coherent detector output, we require $V_o(f)$ to be a scaled version of $M(f)$. Therefore, we can choose:

$$\boxed{H(f-f_c) + H(f+f_c) = 1, \quad -W \le f \le W}$$

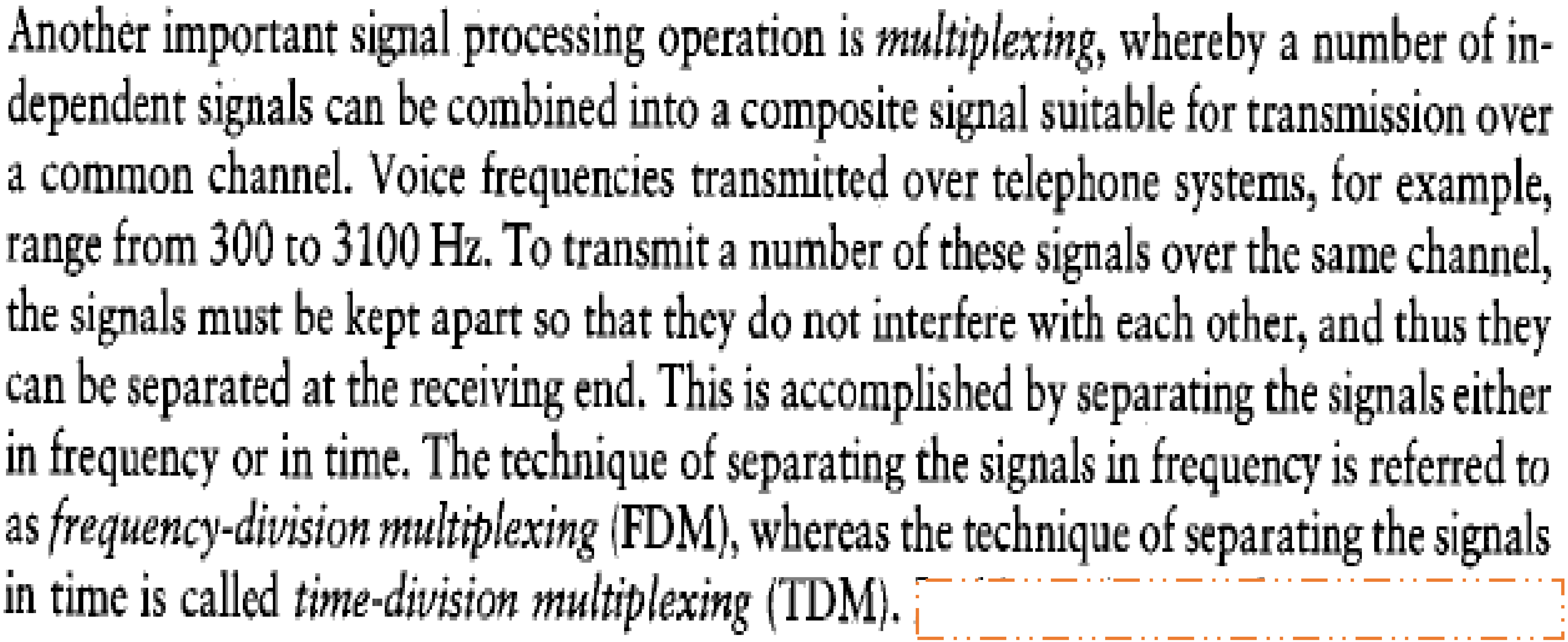
baseband $M(f)$ interval:
$-W \le f \le W$

- Eq. (3.24) becomes $\upsilon_0(t) = \frac{A_c A_c'}{4} m(t)$

Advantages of VSB Modulation

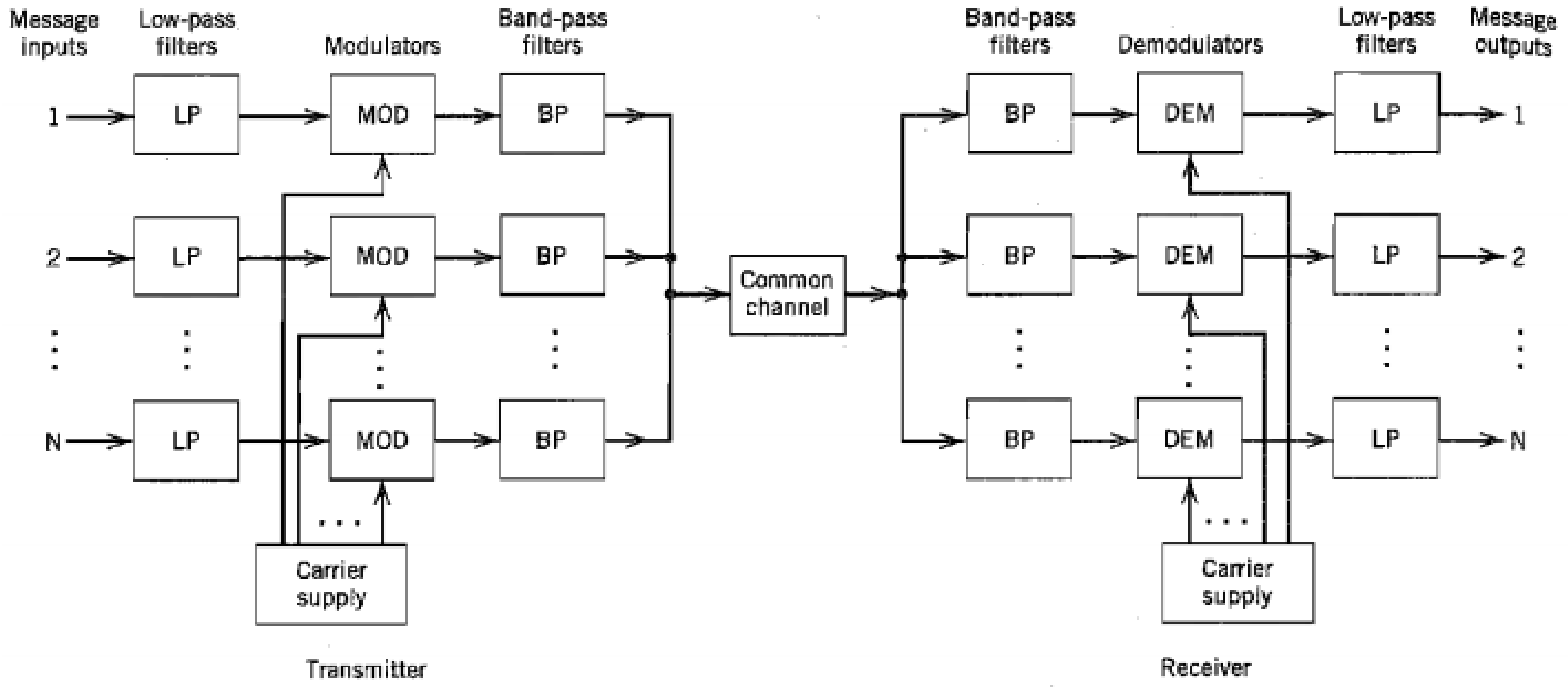
1. Use of simple filter design.
2. Less bandwidth as compared to that of DSBSC signal.
3. As efficient as SSB.
4. Possibility of transmission of low frequency components of modulating signals.

FDM- Frequency Division Multiplexing



Another important signal processing operation is *multiplexing*, whereby a number of independent signals can be combined into a composite signal suitable for transmission over a common channel. Voice frequencies transmitted over telephone systems, for example, range from 300 to 3100 Hz. To transmit a number of these signals over the same channel, the signals must be kept apart so that they do not interfere with each other, and thus they can be separated at the receiving end. This is accomplished by separating the signals either in frequency or in time. The technique of separating the signals in frequency is referred to as *frequency-division multiplexing* (FDM), whereas the technique of separating the signals in time is called *time-division multiplexing* (TDM).

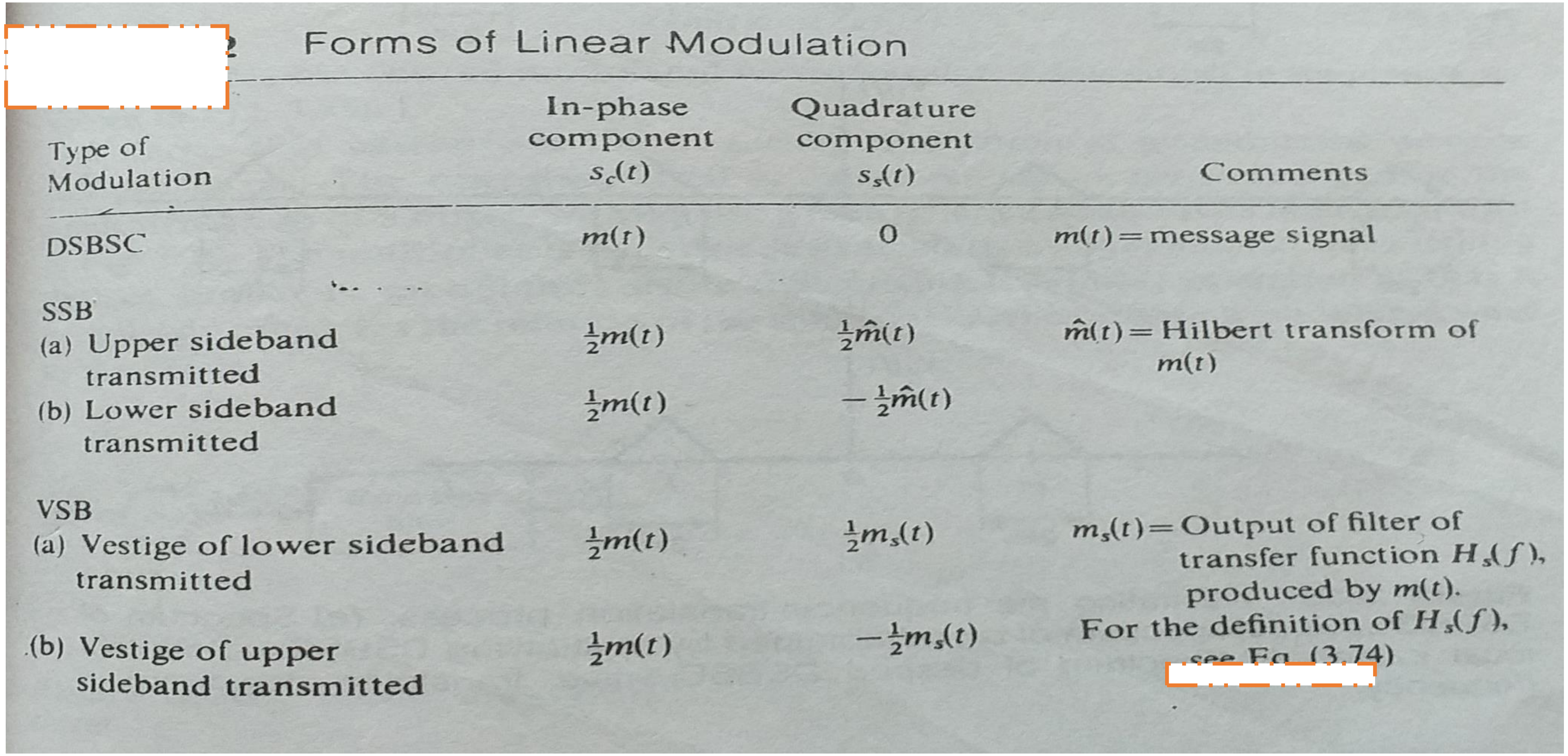
FDM- Frequency Division Multiplexing



Summary & Applications of AM

1. AM with Full carrier - is widely used in commercial AM Radio broadcast systems in which one Transmitter and numerous no. of receivers are present. Reception is simple
2. Suppressed carrier systems need less power when compared to full carrier AM to transmit the same amount of information so, the Transmission is less expensive. They are used for point to point communication where, one Tx. and one Rx. Are present, justifies the use of increased Rx. Complexity
3. SSB: Minimum Power and Minimum Bandwidth, preferred for long distance transmission of voice signals over metallic circuits., which permits longer spacing between Repeaters
4. Vestigial side band (VSB) is used for video transmission in colour television broadcast and wideband applications.
5. Linear Vs. Non-linear modulation

Linear Modulation



[redacted] Forms of Linear Modulation

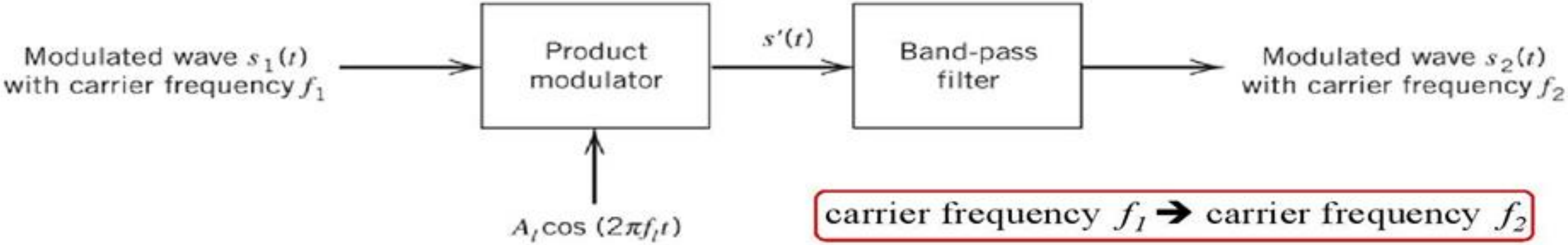
Type of Modulation	In-phase component $s_c(t)$	Quadrature component $s_s(t)$	Comments
DSBSC	$m(t)$	0	$m(t) =$ message signal
SSB			
(a) Upper sideband transmitted	$\frac{1}{2}m(t)$	$\frac{1}{2}\hat{m}(t)$	$\hat{m}(t) =$ Hilbert transform of $m(t)$
(b) Lower sideband transmitted	$\frac{1}{2}m(t)$	$-\frac{1}{2}\hat{m}(t)$	
VSB			
(a) Vestige of lower sideband transmitted	$\frac{1}{2}m(t)$	$\frac{1}{2}m_s(t)$	$m_s(t) =$ Output of filter of transfer function $H_s(f)$, produced by $m(t)$. For the definition of $H_s(f)$, see Eq. (3.74) [redacted]
(b) Vestige of upper sideband transmitted	$\frac{1}{2}m(t)$	$-\frac{1}{2}m_s(t)$	

Comparison of AM Techniques

S.No	Parameter	Standard AM	SSB	DSBSC	VSB
1	Power	High	Less	Medium	Less than DSBSC but greater than SSB
2	Bandwidth	2fm	fm	2fm	fm< Bw<2fm
3	Carrier Supression	No	Yes	Yes	No
4	Receiver Complexity	Simple	Complex	Complex	Simple
5	Application	Radio Communication	Point to Point communication preferred for long distance communication	Point to Point communication	Television broadcasting
6	Modulation type	Non Linear	Linear	Linear	Linear
7	Sideband Suppression	No	One side band completely	No	One side band suppressed Partially
8	Transmission Efficiency	Minimum	Maximum	Moderate	Moderate

Frequency Translation

- The basic operation involved in single-sideband modulation is in fact a form of *frequency translation*.
  - SSB modulation is sometimes referred to as *frequency changing*, *mixing*, or *heterodyning*.
- The *mixer* consists a product modulator followed by a band-pass filter.
  - Band-pass filter bandwidth: equal to that of the modulated signal $s_1(t)$ used as input.



carrier frequency f_1 ➔ carrier frequency f_2

Frequency Translation

- Due to frequency translation performed by the *mixer* : We may set

$$\begin{cases} f_2 = f_1 + f_l \\ f_l = f_2 - f_1 \end{cases}$$

assume $f_2 > f_1$
translated *upward*

or
$$\begin{cases} f_2 = f_1 - f_l \\ f_l = f_1 - f_2 \end{cases}$$

assume $f_1 > f_2$
translated *downward*

$$s_1(t) \times A_l \cos(2\pi f_l t) = m(t)\cos(2\pi f_1 t) \times A_l \cos(2\pi f_l t)$$

$$= \frac{1}{2} A_l m(t)\left[\cos\left(2\pi(f_1 + f_l)t\right) + \cos\left(2\pi(f_1 - f_l)t\right)\right]$$

  - The band-pass filter rejects the unwanted frequency and keeps the desired one.
- Mixing is a linear operation.

Problems

1.In a double side-band (DSB) full carrier AM transmission system, if the modulation index is doubled, then the ratio of total sideband power to the carrier power increases by a factor of ______________.

[GATE 2014: 1 Mark]

Solution:

The AM system is Double side band (DSB) with full carrier. The expression for total power in such modulation signal is

$$P_t = \frac{E_{c^2}}{2R} + \frac{\mu^2}{4}\frac{E_{c^2}}{2R} + \frac{\mu^2}{4}\frac{E_{c^2}}{2R} \qquad or, P_t = P_C + \frac{\mu^2}{2}P_C$$

The second term on the right hand side is side band power.

$$so, \qquad P_{SB} = \frac{\mu^2}{2}P_C \quad or, \qquad \frac{P_{SB}}{P_C} = \frac{\mu^2}{2}$$

Now if µ (modulation index) is doubled then $PSBPC$will be 4 times

So, it is factor of 4 Answer is a factor of 4

2. In commercial TV transmission in India, picture and speech signals are modulated respectively

(Picture) (Speech)

(a) VSB and VSB
(b) VSB and SSB
(c) VSB and FM
(d) FM and VSB

[GATE 1990: 2 Marks]

Solution:

Note that VSB modulation is the clever compromise between SSB and DSB. Since TV bandwidth is large so VSB is used for picture transmission. Also, FM is the best option for speech because of better noise immunity

Option (c)

3.Which of the following analog modulation scheme requires the minimum transmitted power and minimum channel bandwidth?

(a) VSB

(b) DSB-SC

(c) AM

(d) SSB

[GATE: 2005 1 Mark]

Solution:

Modulation type	BW	Power
Conventional AM	2 fm	Maximum power
DSB SC	2 fm	(Less power)
VSB	fm + vestige	Less than DSBSC but greater than SSB
SSB	fm	Less & power

So, SSB least power & bandwidth

Option (d)

4. A DSB-SC signal is generated using the carrier cos($\omega_c t+\theta$) and modulating signal x(t). The envelop of the DSB-SC signal is

(a) $x(t)$

(b) $|x(t)|$

(c) Only positive portion of x(t)

(d) $x(t)\cos\theta$

[GATE 1998: 1 Mark]

Solution:

Given

Carrier $\boldsymbol{c(t)=\cos(\omega ct+\theta)}$

Modulating signal $\boldsymbol{m(t)=x(t)}$

DSB SC modulated signal is given by

$$\boldsymbol{c(t).m(t)=s(t) =x(t)\cos(\omega ct+\theta)}$$

$$\boldsymbol{=x(t)\{\cos\theta.\cos\omega ct-\sin\theta\sin\omega ct\}}$$

$$\boldsymbol{=x(t)\cos\theta\ .\cos\omega ct-x(t).\sin\theta\sin\omega ct}$$

Envelope of $\boldsymbol{s(t)=\sqrt{}[x(t)\cos\theta]^2+[x(t)\sin\theta]^2}$

$$\boldsymbol{=\sqrt{}x^2(t)(cos^2\theta+sin^2\theta)}$$

$$\boldsymbol{=x(t)}$$

Option (b)

5. A 4 GHz carrier is DSB-SC modulated by a low-pass message signal with maximum frequency of 2 MHz. The resultant signal is to be ideally sampled. The minimum frequency of the sampling impulse train should be

(a) 4 MHz
(b) 8 MHz
(c) 8 GHz
(d) 8.004 GHz
[GATE: 1990 2 Mark]

Solution:

Given
$\boldsymbol{fc = 4\ GHz = 4000\ MHz}$
$\boldsymbol{fm = 2\ MHz\ (low\ pass\ message\ signal)}$
Such a signal is amplitude modulated (DSB-SC)
i.e. two side bands $(\boldsymbol{fc + fm})\&(\boldsymbol{fc - fm})$
i.e. 4002 & 3998 or 4 MHz = BW
so, min. sampling frequency should be (Nyquist Rate)
$\boldsymbol{fs(min) = 2 \times 4 = 8\ MHz}$

Option (b)

References

- Communication Systems by Simon Haykin, Wiley, 2nd Edition.
- Principle of Communication System by Taub ,Schilling & Saha, TMH.
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- Electronic Communication Systems by Kennedy and Davis, TMH.
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THANK YOU