IAT 2 – 5th Sem – Principles of Communication System – Questions with Solutions

Internal Assessment Test 2 – December 2022										
Sub:	**Principles of Communication Systems**					Sub Code:	18EC53	Branch:	ECE	
Date:	02-12-2022	Duration:	90 Minutes	Max Marks:	50	Sem / Sec:	**4/A, B, C, D**		**OBE**	

	Answer any FIVE FULL Questions	MARKS	CO	RBT
1	Explain the scheme of generation and demodulation of VSB modulated wave with relevant spectrum of signals and mathematical expressions	[10]	CO1	L2
2	With a neat block diagram, explain the working of a FDM transmitter and receiver	[10]	CO1	L2
3	Write the basic block diagram of PLL? Derive the expression for nonlinear model of PLL.	[10]	CO2	L2
4	a. A single tone FM signal is given by, V= 10 sin ($16\pi\times10^8$t + 3sin $2\pi\times10^3$t). Find the modulation index, deviation, carrier frequency, modulating frequency, and power of the FM signal	[5]	CO2	L3
	b. What is the bandwidth required for a FM signal if the modulating frequency is 1KHz and the maximum deviation is 10KHz. Also find the bandwidth required for AM signal and compare the both.	[5]	CO2	L3
5	Derive the expression for WBFM, show that the spectrum of WBFM wave contains infinite number of sidebands. Write the expression of theoretical bandwidth for WBFM	[10]	CO2	L3
6	With relevant equations and diagram explain the direct method generation FM using Hartley Oscillator	[10]	CO2	L2

1.11

* VESTIGIAL SIDEBAND MODULATION (VSB):-

Necessity (or) Need for VSB-Modulation:

↳ The SSB modulation is not appropriate way of modulation. Because the upper side band and lower side band meet at the carrier frequency 'f_c' and it is very difficut to isolate one side band. Therefore generating SSB-signal is challenging.

↳ To overcome this difficulty, the modulation technique known as "Vestigial side Band (VSB) - Modulation" is used.

↳ Vestigial sideband Modulated signal (VSB-signal) consists of

- Almost one complete side band and
- Vestige (or) Trace (or) part of the other side band.

* Generation of VSB Modulated Wave:

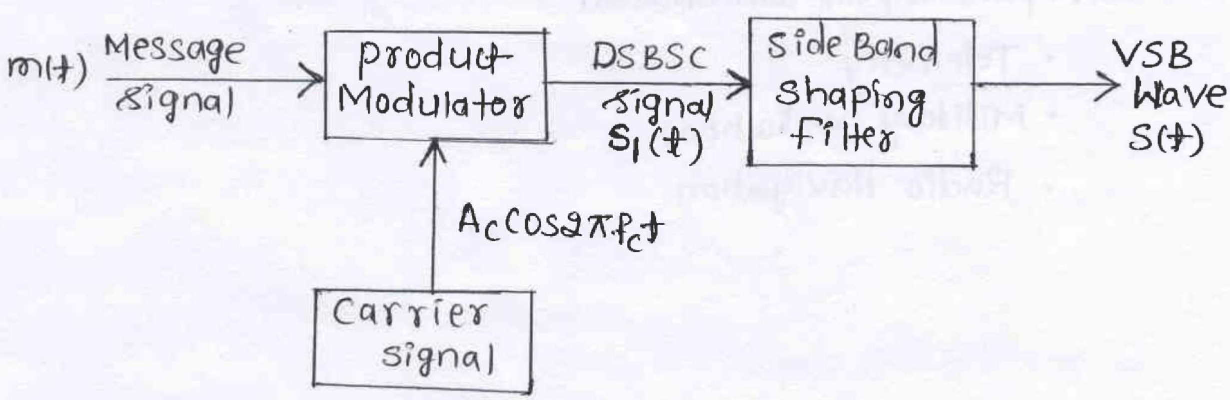


Figure 1: VSB Generator

- VSB signal generator consists of a product Modulator and a sideband shaping filter as shown in figure 1.
- product Modulator generates a DSBSC signal and then pass it through a side band shaping filter.
- Let H(f) be the transfer function of side band shaping filter. This filter will pass one complete sideband along with a vestige (or) trace (or) a part of unwanted (other) side band.

↳ The relation between the transfer function $H(f)$ of the filter and the spectrum $S(f)$ of the VSB-Modulated wave $s(t)$ is defined by, $S(f) = S_1(f) \times H(f)$.

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

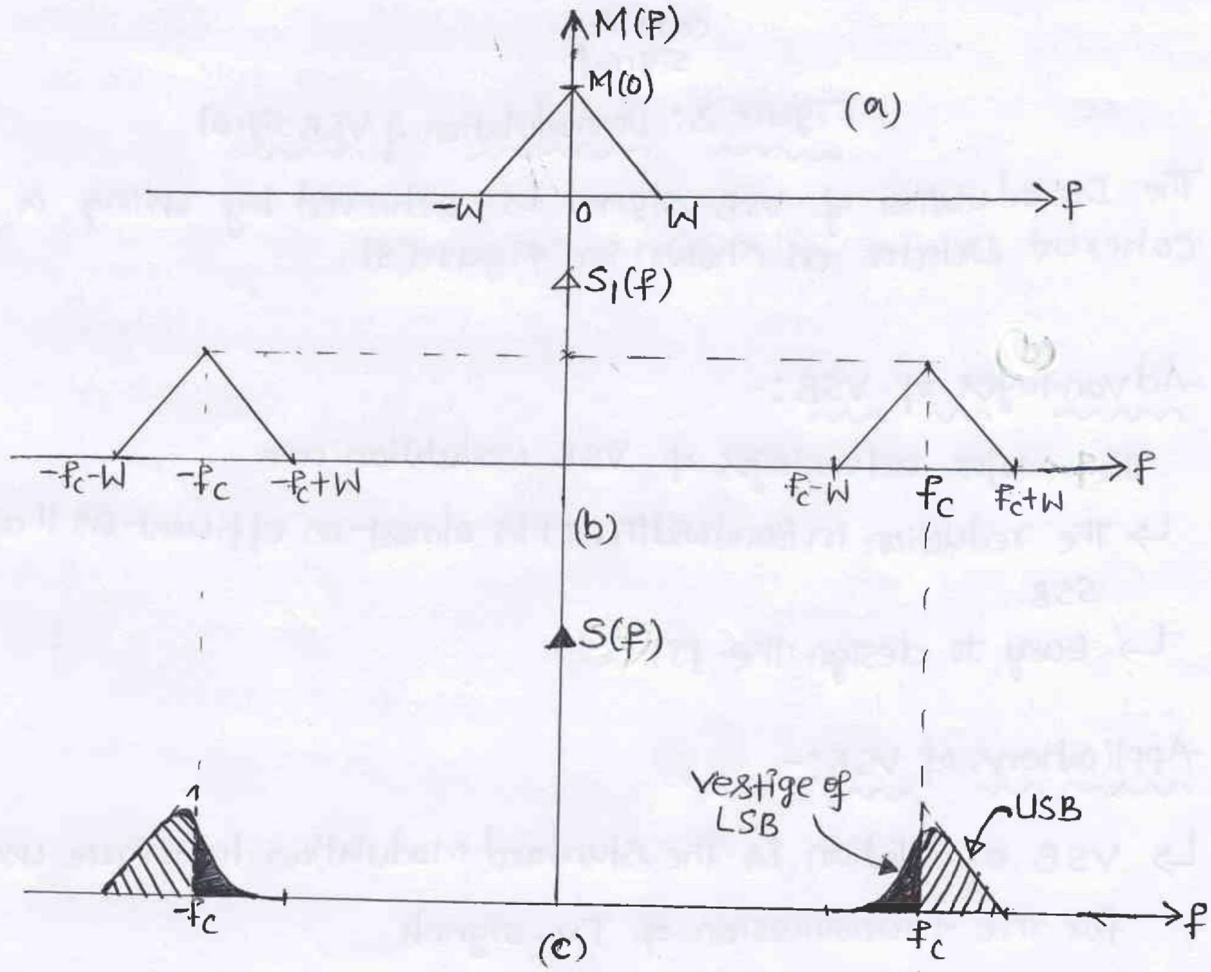


Figure 2: (a) Spectrum of $m(t)$ (b) Spectrum of DSBSC signal $s_1(t)$ (c) Spectrum of VSB-Modulated Signal $s(t)$

Frequency domain description of VSB modulated wave is shown in figure 2. Figure 2(b) is the spectrum of DSBSC signal produced at the output of product Modulator. Figure 2(c) shows the spectrum of VSB-modulated signal $s(t)$.

From figure 2(c) it is evident that the Total transmission Bandwidth of VSB-Modulated signal is higher than that of SSB and Lower than that of DSBSC-signal.

i.e., $\quad W < BW_{T(VSB)} < 2W$

* Demodulation of VSB-Modulated Wave:-

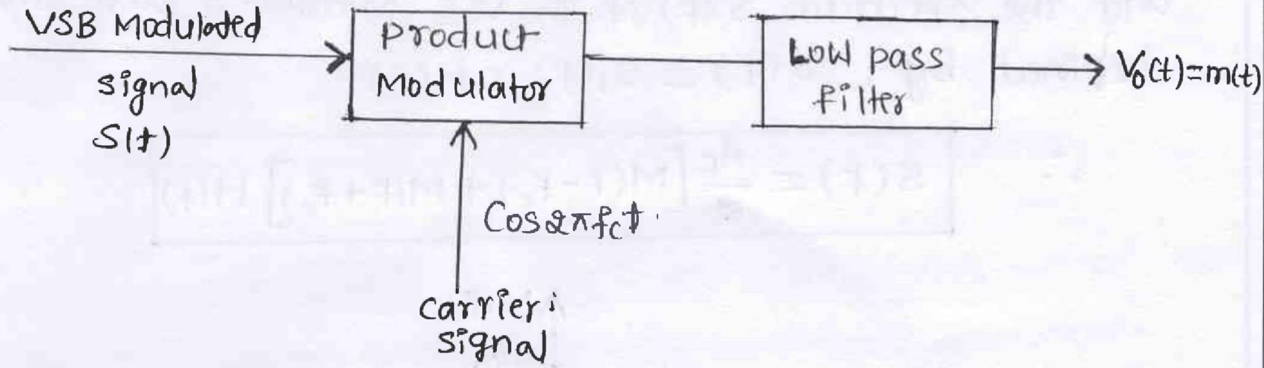


Figure 3: Demodulation of VSB signal

The Demodulation of VSB-signal is achieved by using a coherent Detector as shown in figure(3).

-Advantages of VSB:-

The Major advantages of VSB Modulation are

- The reduction in Bandwidth. It is almost as efficient as that of SSB.
- Easy to design the filter.

Applications of VSB:-

- VSB modulation is the standard Modulation technique used for the transmission of TV-signals.

1.13 * Frequency Division Multiplexing <FDM>

↳ Multiplexing is a process of combining N-independent message signals into a composite signal suitable for transmission over a common channel

↳ Multiplexing is accomplished by seperating the signals either in frequency or time.

↳ The technique of separating the signals in frequency domain is referred to as "Frequency Division Multiplexing" (FDM)

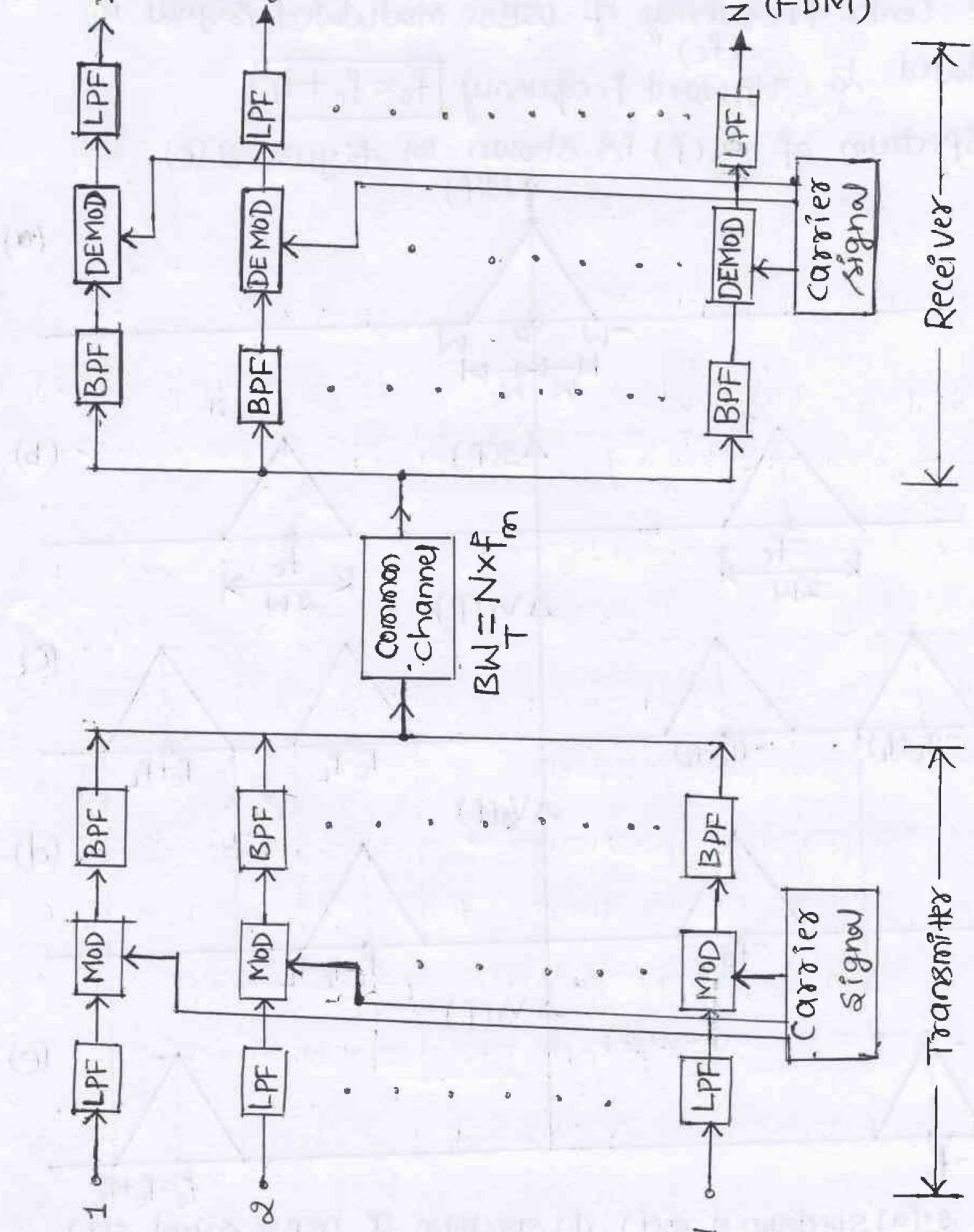


Figure 1: Block diagram of FDM system

The block diagram of FDM-system is shown in figure 1.

↳ N-Incoming independent message signals are modulated by mutually Exclusive carriers supplied from carrier source at each modulator. The Modulated signals are passed through the BPF to select any one side band. Therefore BPF's produces SSB-signals and are separated in frequency and combined into a composite signal. and this process is called Frequency division multiplexing.

↳ Multiplexed signal is transmitted over the Communication channel.

↳ Total Bandwidth required to N-SSB Modulated signals without any Guard band is

$$BW_T = N \times f_m \; ; \; N = \text{number of Input signals}$$

↳ At the receiver side N-independent message signals are recovered by passing the composite signal through the BPF followed by Demodulator and LPF.

Advantages of FDM:-

1. A Large Number of signals can be transmitted simultaneously.
2. FDM does not requires synchronization between Transmitter & receiver.
3. Demodulation of FDM is easy

Dis advantages of FDM:-

1. Communication channel must have Large Bandwidth i.e., $BW_T = N \times f_m$
2. Large Numbers of Modulators & Filters are required.
3. Cross talk occurs in FDM

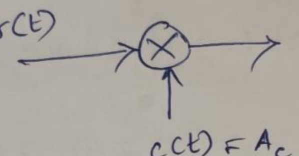
Phase Locked Loop (PLL):-

It is a non-linear device that tracks the phase of i/p signal & minimized phase error at the local oscillator.

why?

(In coherent demodulation, PLL is used to remove phase error)

(In general demodulation)

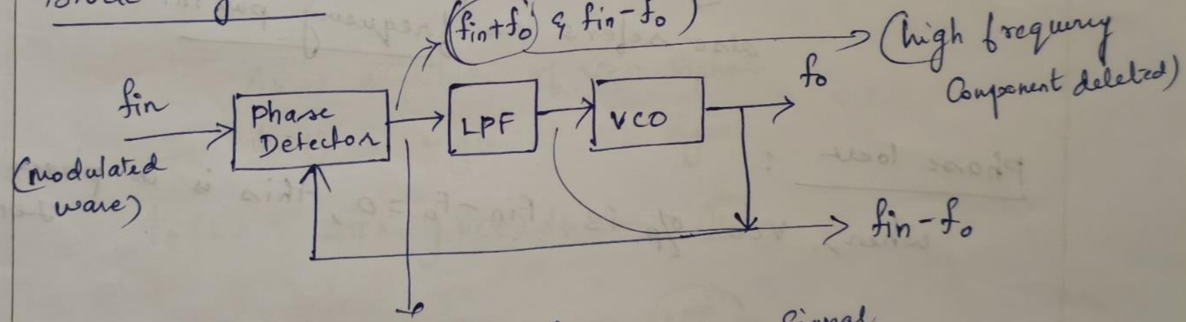


O/p (In o/p there will some distortion)

$c(t) = A_c \sin(\omega_c t + \phi)$ → phase error

[This phase error is eliminated using PLL].

Block diagram :-



($e = f_{in} - f_o$) ⇒ error signal

O/p of LPF → minimum frequency signal.

VCO o/p → f_o is directly proportional to the amplitude of the VCO's i/p

if VCO's i/p (amplitude) ↑ → f_o ↑

O/p → $\boxed{f_o = f + K\omega_n}$ (It is based on V_p voltage)

Operations of PLL :- (3 states)

1.) Free running state
2.) Capture
3.) Phase Lock

Free running : → if V_p is zero, PLL will be in free running state.

So, $f_o = f + \underbrace{K}_{\text{zero}} \omega_n$

$$\boxed{f_o = f}$$

Capture:

If V_p is applied, vco frequency starts to change and PLL is said to be in capture range.

⇓

also refers as "frequency pull in."

Phase lock :

when, vco o/p is $F_{in} - F_o = 0$, this is in phase lock zone.

$$(F_{in} - F_o) \rightarrow \boxed{VCO} \rightarrow F_{in} - F_o = 0$$

"(error = 0)"

PLL → Non-linear & linear model of PLL :-

Non-linear Model of PLL :

let the i/p Signal to PLL is $s(t)$

$$s(t) = A_c \sin[2\pi f_c t + \phi_1(t)] \longrightarrow (1)$$

$\phi_1(t) \rightarrow$ angle of modulated Signal.

$$\phi_1(t) = 2\pi K_f \int_0^t m(\tau)\, d\tau \longrightarrow (2)$$

Consider the vco o/p is,

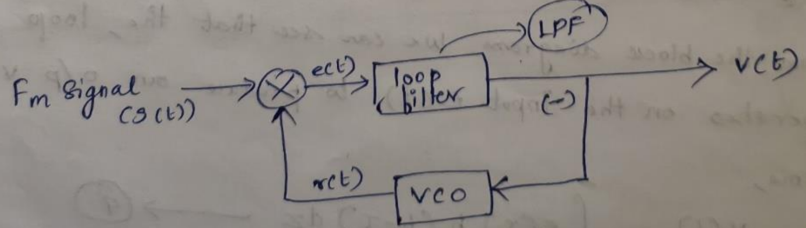
$$\phi_1(t) = 2\pi K_f \int_0^t m(\tau)\, d\tau$$

$$v(t) = A_v \cos(2\pi f_c t + \phi_2(t)) \longrightarrow (3)$$

$A_v \rightarrow$ amplitude of vco Signal

$\phi_2(t) \rightarrow$ angle of vco Signal

$$\phi_2(t) = 2\pi K_v \int v(t)\, dt \longrightarrow (4)$$



The non-linearity term we get is, (frequency Component & low frequency Component)

Frequency Component

$$\Rightarrow K_m A_c A_v \sin(2\pi f_c t + \phi_1(t) + \phi_2(t)) \longrightarrow (5)$$

low frequency Component :

$$\Rightarrow k_m A_c A_v \sin(\phi_1(t) - \phi_2(t)) \longrightarrow (6)$$

In LPF → high frequency Component is neglected,

Now,

I/p to the LPF is reduced to,

$$e(t) = k_m A_c A_v \sin(\phi_e(t)) \longrightarrow (7)$$

where,

$\phi_e(t)$ = phase error

$$\boxed{\phi_e(t) = \phi_1(t) - \phi_2(t)}$$

We know,

$$\left[\phi_2(t) = 2\pi K_v \int_0^t v(t)\, dt\right]$$

Now,

$$\phi_e(t) = \phi_1(t) - 2\pi K_v \int_0^t v(t)\, dt \longrightarrow (8)$$

From the block diagram, we can see that the, loop filter operates on the input $e(t)$, to produce an o/p $v(t)$

Now,

$$v(t) = \int_{-\infty}^{\infty} e(\tau)\, h(t-\tau)\, d\tau \longrightarrow (9)$$

Now,

We need to obtain error signal;

$\phi_e(t)$ ✓

impulse respons of $v(t)$

Substitute $v(t)$ in equation (8)

$$\phi_e(t) = \phi_1(t) - 2\pi K_v \int_{-\infty}^{\infty} e(\tau)\, h(t-\tau)\, d\tau \longrightarrow (10)$$

differentiate the equation (10), we get

$$\boxed{\frac{d\phi_e(t)}{dt} = \frac{d}{dt}\phi_1(t) - (2\pi K_v)\int_{-\infty}^{\infty} e(\tau)\, h(t-\tau)\, d\tau} \longrightarrow (11)$$

d/dt

(Loop gain parameter)

($e(\tau)$ → contains sin term)

By having this terms, it produces difficulties while analysing the PLL. (Produces some non-linearity w.r.t to the input).

So, it is called Non-linear model of PLL.

(that is most non-linear term)

(6.) A Single tone FM Signal is given by,

$$V = 10 \sin(16\pi \times 10^8 t + 3 \sin 2\pi \times 10^3 t) \text{ volt}$$

Find the modulation index, modulating frequency, deviation, carrier frequency and power of the FM signal.

Sol:

$$V = 10 \sin(16\pi \times 10^8 t + 3 \sin 2\pi \times 10^3 t)$$

Standard form;

$$V = E_c \sin(\omega_c t + m_f \sin \omega_m t)$$

$E_c = 10$

$\omega_c = 16 \times \pi \times 10^8$

$m_f = 3$

$\omega_m = 2\pi \times 10^3$

$$f_c = \frac{\omega_c}{2\pi} = 8 \times 10^8 \text{ Hz}$$

$$f_m = \frac{\omega_m}{2\pi} = 10^3 \text{ Hz}$$

Modulation index $\rightarrow$ $m_f = \dfrac{\Delta f}{f_m}$

$$\Delta f = m_f \cdot f_m$$

$$\boxed{\Delta f = 3 \times 10^3} \text{ Hz}$$

Power: $P = \dfrac{E_c^2}{2R} = \dfrac{10^2}{2R} = \dfrac{50}{R}$

$$\therefore \boxed{P = \frac{50}{R}}$$

(8.) what is the bandwidth required for a FM Signal if the modulating frequency is 1 KHZ and the maximum deviation is 10 KHZ. what is BW required for a DSBFC (AM) transmission?

Sol:

$f_m = 1 KHZ$

$\Delta f = 10 KHZ$

$BW = 2(f_m + \Delta f)$

$= 2(1+10) = 22 KHZ$

$\boxed{BW = 22 KHZ}$

BW for AM transmission;

$BW = 2 \times f_m$

$= 2 \times 1 KHZ$

$\boxed{BW = 2 KHZ}$

We can observe that,

$\boxed{BW_{(fm)} >> BW_{(Am)}}$

(freq. modulation) (amplitude modulation)

Frequency Modulation

In **Frequency Modulation** the frequency of carrier signal is varied according to the instantaneous value of the modulating or baseband signal

- The general expression for **Frequency Modulated (FM) wave** is:

$$S(t) = A \cos\left[\omega_c t + k_f \int_0^t x(t).dt\right]$$

- Frequency deviation is given as:

$$\Delta\omega = |k_f \cdot x(t)|_{max} = k_f |x(t)|_{max}$$

Depending upon the **frequency sensitivity k_f**, FM may be divided as:

- **Narrowband FM:** k_f is small therefore bandwidth of FM is narrow
- **Wideband FM:** k_f is large therefore bandwidth of FM is wide

Wideband Frequency Modulation

- A **wideband FM** is the FM wave with a **large bandwidth,** it has infinite bandwidth and hence known as wideband FM
- The **modulation index m_f** of wideband FM is higher than 1

It is used in the entertainment broadcasting applications such as FM radio, TV etc.

- **We know that the bandwidth of FM signal depends upon** the frequency deviation ($\Delta\omega$)
- If frequency deviation is more, bandwidth will be large
- In case of **Wideband FM, k_f** is high therefore bandwidth of FM is wide

Wideband Frequency Modulation

- The expression for **Single Tone FM wave** is given as:

$$S(t) = A\cos(\omega_c t + m_f \sin \omega_m t) \quad -(1)$$

- This expression may be considered as a **real part** of the **exponential phasor** given by:

$$c_{FM} = A e^{j(\omega_c t + m_f \sin \omega_m t)}$$
$$= A e^{j\omega_c t} \cdot e^{j m_f \cdot \sin \omega_m t} \quad -(2)$$

- In above expression **2nd exponential** is a **periodic function** of period **$1/f_m$** and can be expanded in the form of complex Fourier series as:

$$e^{j m_f \cdot \sin \omega_m t} = \sum_{n=-\infty}^{\infty} C_n e^{jn\omega_m t}$$

$$\text{for } -\frac{1}{2f_m} \le t \le \frac{1}{2f_m}$$

- The **coefficient C_n** is given by:

$$C_n = f_m \int_{-\pi/\omega_m}^{\pi/\omega_m} e^{j(m_f \sin \omega_m t)} e^{-jn\omega_m t} \quad -(3)$$

- Substituting **$x = \omega_m t$**, we get

$$C_n = \frac{1}{2\pi} \int_{-\pi}^{\pi} e^{j(m_f \sin x - nx)} dx \quad -(4)$$

- In the above equation, **integral on the right hand side** is the **n^{th} order Bessel function** of the **first kind and argument m_f**
- This function is represented by **$J_n(m_f)$**

$$C_n = J_n(m_f)$$

$$e^{j m_f \cdot \sin \omega_m t} = \sum_{n=-\infty}^{\infty} J_n(m_f) e^{jn\omega_m t}$$

Wideband Frequency Modulation

Therefore,

$$c_{FM}(t) = A e^{j\omega_c t} \sum_{n=-\infty}^{\infty} J_n(m_f) e^{jn\omega_m t}$$
$$= A \sum_{n=-\infty}^{\infty} J_n(m_f) e^{j(\omega_c + n\omega_m)t} \quad -(6)$$

- In above expression, the **real part** of RHS provides the **expression for FM signal** i.e.:

$$S(t) = A \sum_{n=-\infty}^{\infty} J_n(m_f)(\cos \omega_c + n\omega_m)t \quad -(7)$$

- Therefore **original single tone FM** expression is **converted** into **modified form** which consist of Bessel function
- The **Bessel function** is **expanded** in a **power series** given as:

$$J_n(m_f) = \sum_{m=0}^{\infty} \frac{(-1)^m \left(\frac{1}{2} m_f\right)^{n+2m}}{m!\,(n+m)!} \quad -(8)$$

- Few important properties of **Bessel function** may be summarized as:

1. $J_n(m_f) = J_{(-n)} m_f$, for even n

$J_n(m_f) = -J_{(-n)} m_f$, for odd n

2. $J_0(m_f) \simeq 1$

$J_1(m_f) \simeq m_f/2$

$J_n(m_f) \simeq 0$ for $n > 1$

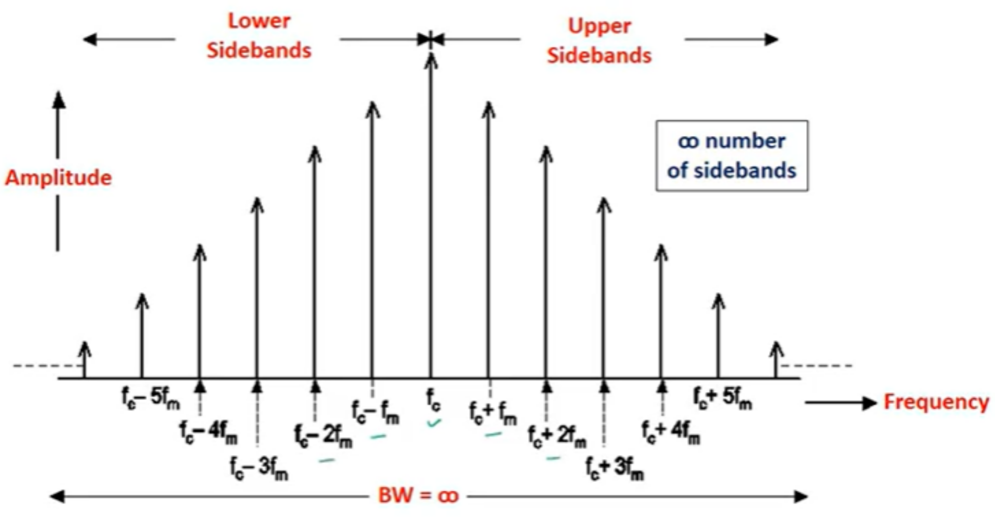
For small values of m_f

3. $\sum_{n=-\infty}^{\infty} J_n^2(m_f) = 1$

- By the use of **first property**, equation can be written as:

⇒ $s(t) = A\{J_0(m_f)\cos \omega_c t + J_1(m_f)[\cos(\omega_c + \omega_m)t - \cos(\omega_c - \omega_m)t] + J_2(m_f)[\cos(\omega_c + 2\omega_m)t + \cos(\omega_c - 2\omega_m)t] + J_3(m_f)[\cos(\omega_c + 3\omega_m)t - \cos(\omega_c - 3\omega_m)t] + J_4(m_f)[\cos(\omega_c + 4\omega_m)t + \cos(\omega_c - 4\omega_m)t] + \ldots\ldots\}$

Wideband Frequency Modulation



Ideal Frequency Spectrum of FM

Wideband Frequency Modulation

From the above equation some important points are summarized as:

- The FM wave consists of **carrier**, the **first term** represents the **carrier**
- The FM wave ideally consists of **infinite number of sidebands**, all the terms except the first one are sidebands
- The **amplitudes** of the **carrier** and **sidebands** is **dependent** on the **J coefficients**
- As the **values of J coefficients** are dependent on the **modulation index** m_f, the modulation index determines how many sideband components have significant amplitudes
- Some of the **J coefficients** can be **negative**, therefore, there is a 180° phase shift for that particular pair of sidebands
- The **carrier component does not remain constant** as $J_0(m_f)$ is varying the amplitude of the carrier will also vary, however, the amplitude of FM wave will remain constant
- For **certain values of modulation index**, the **carrier component will disappear** completely, these values are known as eigen values
- In case of **FM**, the **total transmitted power always remains constant**, it is not dependent on the modulation index

FM Generation

The **FM** modulator circuits are used for generating FM signals can be broadly divided into two categories

Methods of FM Generation

- **Direct Methods** — parameter method
  - varying the frequency of the carrier directly by the modulating input
  - **Reactance Modulators**
  - **Varactor Diode Modulator**
- **Indirect Methods**
  - directly altering the phase of the carrier based on the input (it is a form of direct phase modulation
  - **Armstrong Method**

Direct Method of FM Generation

- **Direct method** is also known as **parameter variation method**, where the baseband or modulating signal directly modulates the carrier
- The carrier signal is generated with the help of an **oscillator circuit**
- This **oscillator circuit** uses a parallel tuned **L-C circuit**

The **frequency of oscillation** of the carrier generation is given by: $\omega_c = \frac{1}{\sqrt{LC}}$

ω_c
$x(t)$

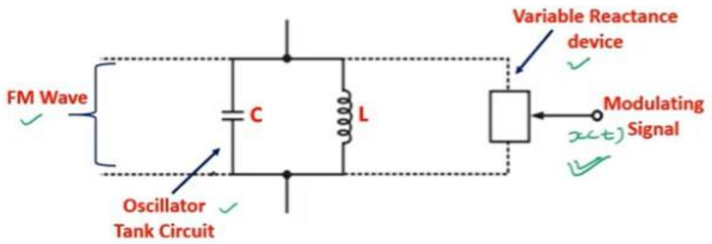
- The carrier frequency $\boldsymbol{\omega_c}$ **vary** in accordance with the baseband or modulating signal x(t) if L or C is varied according to x(t)
- An oscillator circuit whose frequency is controlled by a modulating voltage is known as **voltage controlled oscillator (VCO)**
- The **frequency of VCO** is **varied** according to the modulating signal just by putting a shunt voltage variable capacitor with its tuned circuit
- This voltage variable capacitor is known as **varactor** or **varicap**

- The **inductance L** of the tuned circuit may also be varied in accordance with the baseband or modulating signal x(t)
- The FM circuit using such inductors is called **saturable reactor modulator**

Frequency modulation can also be achieved from **voltage controlled devices** such as PIN diode, Klystron oscillators and multivibrators

Reactance Modulator

- In **direct FM generation**, the instantaneous frequency of the carrier is changed directly in proportion with the message signal
- A **reactance modulator** changes the frequency of tank circuit of oscillator by changing its **reactance**



- The **frequency** of this **oscillator** is **changed** by changing the reactive components involved in the tuned circuit
- If **L or C of a tuned circuit** of an oscillator is **changed** in accordance with the amplitude of modulating signal then FM can be obtained across the tuned circuit

- A **two** or **three** terminal device is placed across the tuned circuit
- The reactance of the device is varied proportional to modulating signal voltage
- It will vary the frequency of the oscillator to produce FM
- **The devices used are FET, transistor or varactor diode**

Reactance Modulator

Frequency of oscillations of the **Hartley oscillator** is:

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)C(t)}} \quad \text{—(1)}$$

where $C(t) = C + C_{varector}$

Let the relationship between the modulating voltage x(t) = 0 and the capacitance C(t) is written as:

$$C(t) = C - k_c\, x(t) \quad \text{—(2)}$$

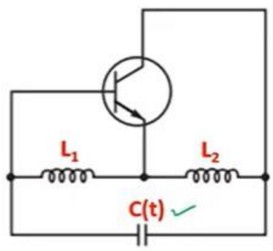
k_c is the sensitivity of the varactor capacitance

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)(C-k_c\,x(t))}} = \frac{1}{2\pi\left[\sqrt{(L_1+L_2)C-(L_1+L_2)k_c\,x(t)}\right]}$$

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)C}\left[1-\frac{k_c\,x(t)}{C}\right]^{1/2}} \quad \text{—(3)}$$

Let us say, $\frac{1}{2\pi\sqrt{(L_1+L_2)C}} = f_0,$

An **example of direct FM** is shown in figure, which uses Hartley oscillator along with a varactor diode



f_0 is the oscillator frequency in absence of the modulating signal [x(t) = 0]. Therefore,

$$\boxed{f_i(t) = f_0\left[1-\frac{k_c}{C}x(t)\right]^{-1/2}}$$

Reactance Modulator

If the **maximum change in the capacitance** corresponding to the **modulating wave** is assumed to be small as compared to the **unmodulated capacitance C,** then equation can be written as:

$$f_i(t) = f_0 \left[1 - \frac{k_c}{C} x(t)\right]^{-1/2}$$

$$f_i(t) = f_0 \left[1 + \frac{k_c}{2C} x(t)\right]$$

$$f_i(t) = f_0 + \frac{f_0 k_c}{2C} \cdot x(t) \quad \text{— 5}$$

let us define: $\frac{f_0 k_c}{2C} = k_f$

Therefore, we can write: $\boxed{f_i(t) = f_0 + k_f x(t)}$

Where,
k_f is known as the frequency sensitivity of the modulator

Limitations of Direct Method of FM Generation

- It is very difficult to get **high order stability** in **carrier frequency.** It is because in this method the basic oscillator is not a stable oscillator, as it is controlled by the modulating signal
- Due to the **non-linearity of the varactor diode**, **FM signal is distorted**. Varactor diode produces frequency variations are produced because of harmonics of the modulating or baseband signal