Single tone phase modulation and Bandwidth of PM :- (11)

We know that for PM,

$$s(t) = V_c \cos[2\pi f_c t + k_p\, m(t)] \rightarrow ①$$

For single-tone $m(t) = V_m \cos 2\pi f_m t$

$$\therefore s(t) = V_c \cos[2\pi f_c t + k_p V_m \cos 2\pi f_m t]$$

$$\therefore s(t) = V_c \cos[2\pi f_c t + \Delta\theta \cos 2\pi f_m t]$$

where $\Delta\theta = k_p V_m$

$$\Rightarrow \boxed{\text{Bandwidth} = 2\Delta\theta = 2k_p V_m}$$

PM & FM are closely related.

$$\text{Modulation index} = \mu_p = \frac{\Delta f}{f_m} = \phi_m$$

where $\phi_m = \mu_p$ = modulation index of PM wave.

Generation of FM waves:-

There are two basic methods to generate FM waves

(1) Indirect FM (or) Armstrong method

(2) Direct FM.

Indirect FM:- In this method, the modulating wave is first used to produce a narrow-band FM signal, and frequency multiplication is next used to increase the frequency deviation to the desired level

Direct FM:- In this method, the carrier frequency is directly varied in accordance with the input baseband signal.

(1) **Indirect FM:-** A simplified block diagram of an indirect FM system is shown in Fig②. The message signal (i.e Base band signal) $m(t)$ is first integrated and then used to phase-modulate a crystal-controlled oscillator, the use of crystal control provides frequency stability. In order to minimize the distortion inherent in phase modulator, the maximum modulation index β is kept small (i.e $\beta \le 0.3$)

there by resulting in a narrow-band FM signal.
For the implementation of the narrow-band phase modulator, we may use the arrangement described in Narrow-band FM generation. The narrow band FM signal is next multiplied in frequency by means of a frequency multiplier so as to produce the desired wide-band FM signal.

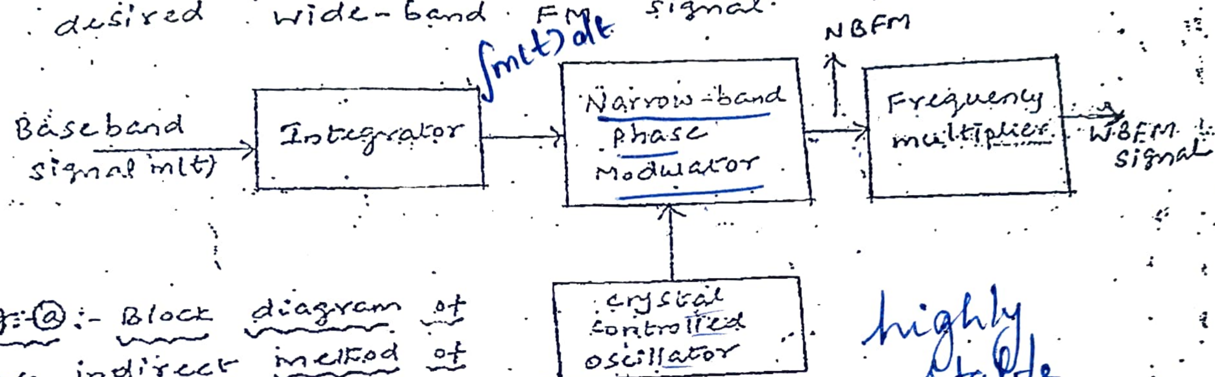
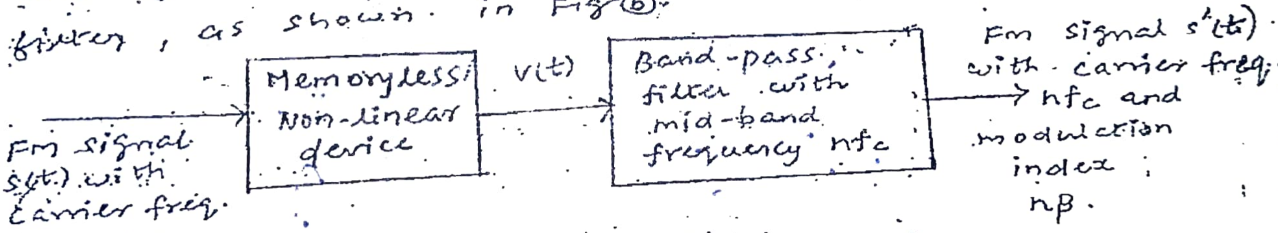


Fig:(a) :- Block diagram of the indirect method of generating WBFM signal.

highly Stable nature

A Frequency multiplier consists of a memoryless non linear device followed by a Bandpass filter, as shown in Fig (b).



Fig(b) :- Block diagram of Frequency multiplier.

The input-output relation of such a non-linear device may be expressed in the general form.

$$v(t) = a_1 s(t) + a_2 s^2(t) + \cdots + a_n s^n(t) \rightarrow (1)$$

where $a_1, a_2, \ldots a_n$ are the coefficients determined by the operating point of the device, and n is the highest order of the nonlinearity.
In other words, the memoryless non-linear device is an nth power-law device.

The input $s(t)$ is an FM signal defined by,

$$s(t) = V_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(t)\,dt\right] \rightarrow (2)$$

whose instantaneous frequency is

$$f_i(t) = f_c + k_f\, m(t) \longrightarrow ③$$

The mid-frequency of the band-pass filter in Fig ⑤ is set equal to nf_c, where f_c is the carrier frequency of the incomming FM signal $s(t)$.

In Fig ⑤; the output of the non-linear device $v(t)$ is applied to the Band pass Filter. After band-pass filtering of the non-linear device's output $v(t)$, we have a new FM signal defined by,

$$s'(t) = V_c' \cos\left[2\pi n f_c t + 2\pi n k_f \int_0^t m(t)\, dt\right] \rightarrow ④$$

whose instantaneous frequency is,

$$f_i'(t) = nf_c + nk_f\, m(t) \longrightarrow ⑤$$

Thus comparing eqs ③ and ⑤, we see that the non-linear processing circuit of Fig ⑤ acts as a frequency multiplier.

2) Direct FM:- In direct FM system, the instantaneous frequency of the carrier wave is varied directly in accordance with the message signal by means of a device known as voltage-controlled oscillator.

One way of implementing such a device is to use a sinusoidal oscillator having a highly selective frequency-determining resonant network and to control the oscillator by symmetrical incremental variation of the reactive components of this network. An example of such a scheme is shown in Fig ⑥, which is Hartley oscillator.

Assume that the capacitive component of the frequency-determining network in the oscillator consists of a fixed capacitor shunted by a voltage variable capacitor. The resultant

Capacitance is represented by $c(t)$, in Fig (1). A voltage-variable capacitor, commonly called varactor (or) varicap, is one whose capacitance depends on the voltage applied across its electrodes. [The voltage-variable capacitance may be obtained, for example, by using a p-n junction diode that is biased in the reverse direction; the larger the reverse voltage applied to a such a diode, the smaller the transition capacitance of the diode; because $C = \frac{\varepsilon A}{d}$ where $d \rightarrow$ width of the depletion region] 4

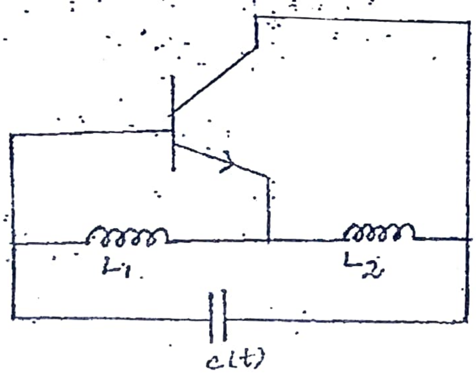


Fig (1):- Hartley oscillator.

The frequency of oscillation of the Hartley oscillator of fig (1) is given by,

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)\,c(t)}} \longrightarrow ①$$

where $c(t) \rightarrow$ is the total capacitance of the fixed capacitor and the variable-voltage capacitor, and L_1 and L_2 are the two inductances in the frequency-determining network of the oscillator.

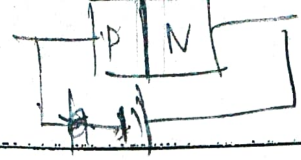
Assume that for a sinusoidal modulating wave of frequency f_m, the capacitance $c(t)$ is expressed as,

$$c(t) = C_0 + \Delta c \cos(2\pi f_m t) \longrightarrow ②$$

where $C_0 \rightarrow$ total capacitance in the absence of modulation and Δc is the maximum change in capacitance.

Substituting eqn ② in eqn ① we get,

$C = \frac{\epsilon_0 \epsilon_r A}{d}$



rev. bia - depletion region width ↑ C↓ f↑

- msg

fwd bi - dep reg width ↓ C↑ f↓

+msg

- msg

(13)

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)(C_0+\Delta C\cos 2\pi f_m t)}}$$

$$= \frac{1}{2\pi\sqrt{(L_1+L_2)\,C_0\left(1+\frac{\Delta C}{C_0}\cos 2\pi f_m t\right)}}$$

$$= \frac{1}{2\pi\sqrt{(L_1+L_2)C_0}}\left(1+\frac{\Delta C}{C_0}\cos 2\pi f_m t\right)^{-1/2}$$

$$f_i(t) = f_0\left(1+\frac{\Delta C}{C_0}\cos 2\pi f_m t\right)^{-1/2} \longrightarrow (3)$$

$X_C = \frac{1}{2\pi f C}$

$f = \frac{1}{2\pi X_C}$

where $f_0 = \frac{1}{2\pi\sqrt{(L_1+L_2)C_0}}$ → unmodulated frequency of oscillation.

Provided that ΔC is small compared with C_0, we may approximate Eqn (3) as:

$$\therefore f_i(t) = f_0\left(1-\frac{\Delta C}{2C_0}\cos 2\pi f_m t\right)$$

Let $-\frac{\Delta C}{2C_0} = \frac{\Delta f}{f_0}$

$$(1+x)^{-n} = 1 - nx + \frac{n(n+1)}{2!}x^2 - \frac{n(n+1)(n+2)}{3!}x^3 + \cdots$$

$$f_i(t) = f_0\left(1+\frac{\Delta f}{f_0}\cos 2\pi f_m t\right)$$

$$\boxed{f_i(t) = f_0 + \Delta f\cos(2\pi f_m t)} \longrightarrow (4)$$

Eqn (4) is the desired relation for the instantaneous frequency of an FM wave, assuming sinusoidal modulation.

In order to generate a wide band FM with the required frequency deviation, we may use the configuration shown in Fig (ii), consisting of a voltage controlled oscillator, followed by a series of frequency multipliers and mixers.

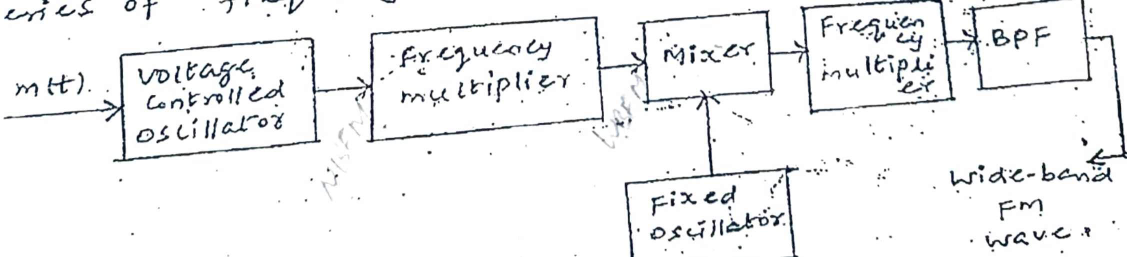


Fig (ii) Block diagram of wideband FM using a voltage-controlled oscillator.

PM → FM

VCO

Advantages of above configuration :-

i) Good oscillator stability.

ii) Constant proportionality between output frequency change and input voltage change and

iii) provides necessary frequency deviation to achieve WBFM.

Disadvantages –

(i) The carrier frequency is not obtained from a highly stable oscillator and

(ii) VCO is not corrected to the centre frequency (f_c).

To overcome the above disadvantage, feedback scheme is used.

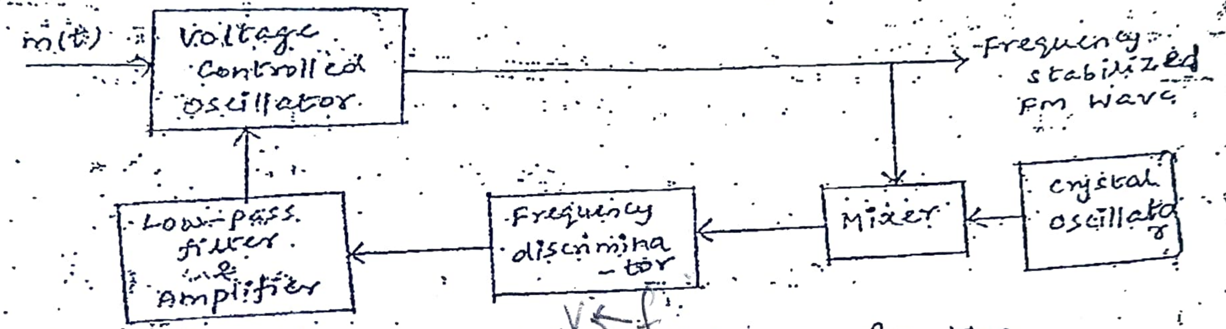


Fig (iii) – A feedback scheme for the frequency stabilization of a frequency modulator.

The output of the FM generator is applied to a mixer together with a output of a crystal oscillator, and the difference freq. is extracted.

The mixer output is next applied to a frequency discriminator and then low-pass filtered.

A frequency discriminator is a device whose output voltage has an instantaneous amplitude that is proportional to the instantaneous frequency of the FM wave applied to its input.

This dc voltage after suitable amplification, is applied to vco, used to modify the frequency of the oscillator to its correct value.

x

Note :- when the mixer o/p is zero, then freq. discriminator o/p will be zero. That shows the oscillator freq. is exactly at centre value.

Direct FM modulators:-

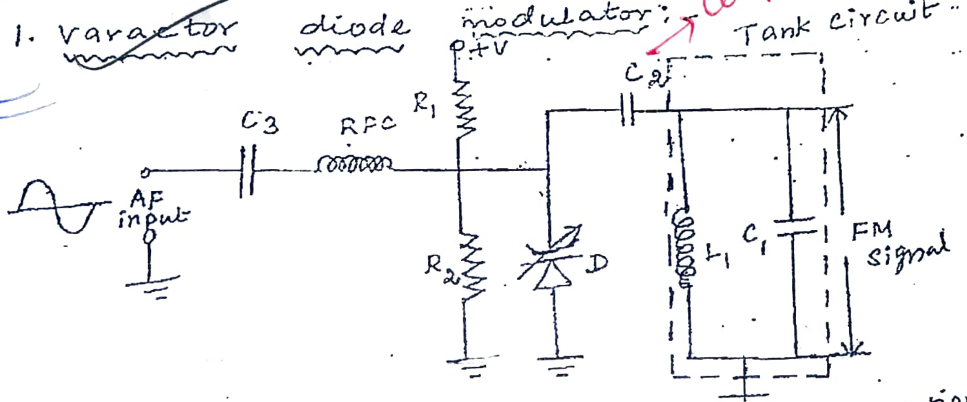
In this modulators, the frequency of the carrier wave will be varied directly inaccordance with the modulating signal.

Based on this principle two modulators are available. They are,

1. varactor diode modulator and
2. Reactance modulator.

coupling capacitance (large) (isolates varactor diode from tank ckt)

1. varactor diode modulator:



Cap → change as R.B is varied

Fig ①: varactor diode FM generation

varactor diode - variable capacitor diode. is a specially fabricated PN junction diode which is used as a variable capacitor in the reverse biased condition. The junction capacitance of the varactor diode changes as the reverse bias across it is varied. L_1C_1 forms the resonant circuit of the carrier oscillator. The varactor diode is connected across the resonant circuit through the coupling capaci-tor C_2 of relatively large value. This capacitor isolates the varactor diode from the oscillator circuit.

The modulating signal is fed in series with the regulated power supply. Therefore effective bias of the varactor diode is equal to the algebraic sum of the dc bias voltage and the instantaneous value of the modulating signal. The capacitance changes with the amplitu-de of the modulating signal resulting in frequency modulation of the oscillator circuit. At positive going modulating signal ~~de~~increases the reverse bias on the varactor diode there by it ~~its~~ decreases its capacitance (since $C_T \propto \frac{1}{W (or) d}$ where W (or) d is the width of the depletion layer) and increases the carrier frequency. A negative going modulating signal ~~in~~decreases the reverse bias on the varactor diode thereby it increases its capacitance and decreases the carrier frequency.

The radio frequency choke (RFC) has high reactance at the carrier frequency to prevent carrier signal from getting into the modulating signal.

Instantaneous frequency of oscillations of the tank circuit is given by,

$$f_i(t) = \frac{1}{2\pi\sqrt{L_1 c(t)}} \rightarrow ①$$

where $C(t) = C_0 + \Delta C \; V_m \cos 2\pi f_m t \rightarrow ②$

$C_0 \rightarrow$ Total capacitance in the absence of modulation.

$\Delta C \rightarrow$ Maximum change in capacitance in the presence of modulation.

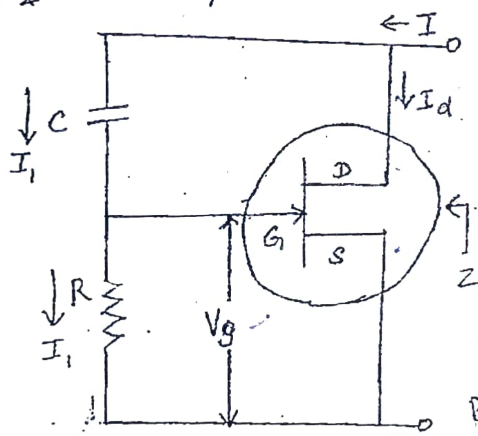
$V_m \cos 2\pi f_m t \rightarrow$ modulating signal.

2. Reactance modulator:-

Fig ⓐ shows the basic circuit of FET reactance modulator which behaves as a 3 terminal reactance circuit that is connected across the tank circuit of oscillator to be frequency modulated.

The reactance appearing between the terminals A and B is the reactance between the drain and source which is controlled by the signal at the gate terminal. The value of the reactance varies with respect to the transconductance g_m of the FET which in turn depends on the Gate bias.

To determine the reactance Z, the varying voltage V is applied to the terminals A-B and the current I_d is measured. Neglecting the gate current, let the current through C & R be I_1.



Vge is applied

Z → gm (varied)

Z → Reactance

$g_m \rightarrow \frac{1}{R}$

Fig ①: FET reactance modulator

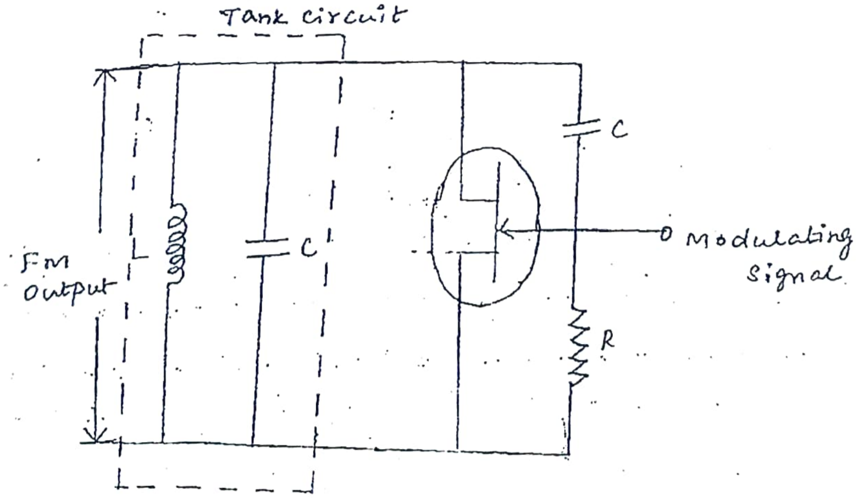


Fig ②: FET Reactance modulator as FM generator

At the carrier frequency, the reactance of C is much larger than R

$$I_1 = \frac{V}{R + \frac{1}{j\omega C}} \rightarrow (1)$$

Since $X_C >> R$ the above equation can be written as,

$$I_1 = \frac{V}{\frac{1}{j\omega C}} = j\omega C V \rightarrow (2)$$

From the circuit we have,

$$V_g = I_1 R = j\omega C R V \rightarrow (3)$$

For the FET,

$$I_d = g_m V_{gs} = g_m V_g \rightarrow (4)$$

since $V_{gs} = V_g$

where $g_m \rightarrow$ Transconductance

Using eqn (3) in eqn (4) we get,

$$I_d = g_m \cdot j\omega C R V \rightarrow (5)$$

The circuit impedance of the FET is given by,

$$Z = \frac{V}{I_d} = \frac{\cancel{V}}{j\omega g_m R C \cancel{V}} = \frac{1}{j\omega [g_m R C]} = \frac{1}{j\omega C_{eq}} \rightarrow (6)$$

where $C_{eq} = g_m R C \rightarrow (7)$

From the equation (7), we can observe that C_{eq} is directly proportional to g_m. g_m varies with the applied modulating voltage across the FET, which in turn varies the capacitance and reactance. This change in capacitance varies the frequency of the oscillator. If inductor is connected instead of capacitor, the FET impedance will be inductive.

Note:- The non-resistive component of impedance in an AC circuit, arising from the effect of inductance or capacitance or both called reactance.

Demodulation (or) Detection of FM

The process of extracting modulating signal from a frequency modulated wave is known as Frequency demodulation (or) detection. The electronic circuit that perform the demodulation process is called FM demodulator (or) detector.

Principle of FM detection:-

The FM detectors perform the detection in two steps.

i) It converts the frequency modulated signal into its corresponding amplitude modulated (AM) signal by using frequency discriminators. (whose o/p voltage depends on input frequency from which original modulating signal is detected.)

ii) The original modulating signal is recovered from this AM signal by using a Envelope detector.

* The FM discriminators are obtained by using simple RC (or) LC combination

Types of FM detectors:-

FM detectors (or) discriminators can be divided into two types.

(1) Slope detectors (or) Frequency discriminators: The principle of operation depends on the slope of the frequency response characteristics of a frequency selective network. Two main FM detectors (which use detuned resonant circuits) comes under this category are.

i) single tuned discriminator (or) slope detector

ii) stagger tuned discriminator (or) Balanced slope detector (or) Round-Travis detector

Phase discriminators:-

There are two types of phase discriminators which are used to extract the modulating signal from frequency modulated wave. They are,

(i) Foster - seeley discriminator

and

(ii) Ratio detector:

Slope detector (or) single tuned discriminator:-

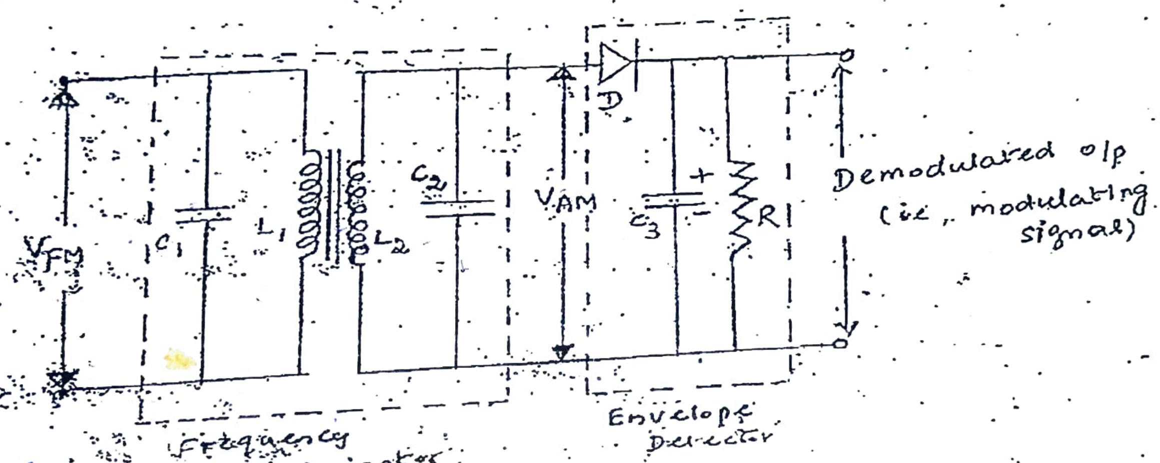


Fig (a):- Slope Detector.

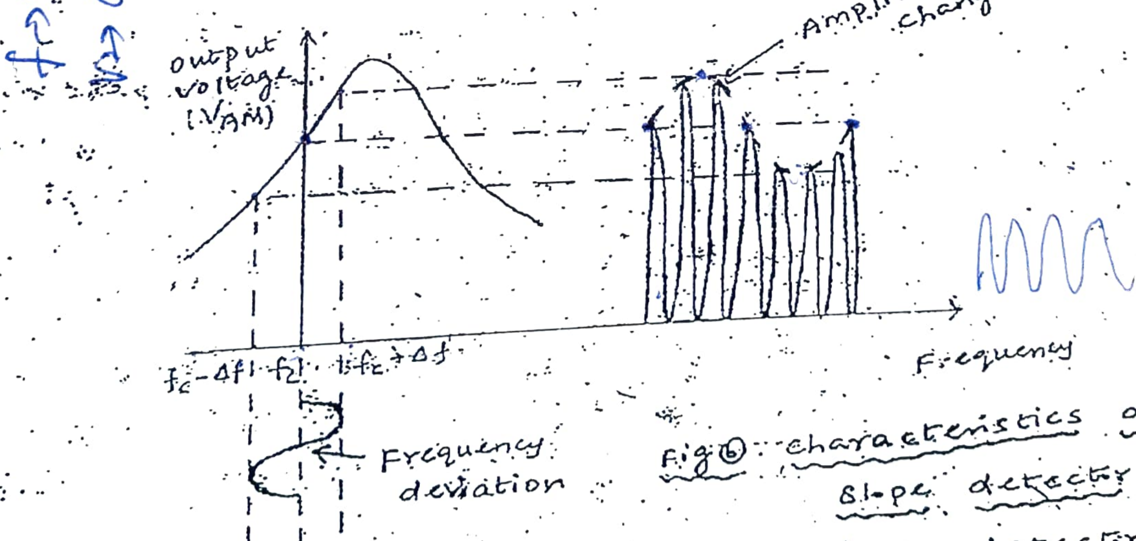


Fig (b): characteristics of slope detector

Fig (a) shows the circuit of slope detector. It consists of a parallel LC tuned circuit which acts as a frequency discriminator and Envelope detector.

When the frequency discriminator is slightly detuned from the carrier frequency f_c, a low frequency deviation produces small amplitude variation, while high frequency deviation produces large amplitude variation. Through this action the FM signal is changed to AM signal. Thus the AM signal is detected by a Envelope detector followed by Frequency discriminator circuit.

The frequency response of this detuned input is shown in Fig (b).

The slope of the characteristic curve is given by $\frac{dV_{AM}}{dw}$

Advantages:-

Simplicity in construction & very cheap.

Disadvantages:-

i) The non-linear characteristics of the circuit causes a harmonic distortion. The non-linearity is obvious from the fact that the slope is not the same at every point of the characteristics.

ii) It does not eliminate the amplitude variations and the output is sensitive to any amplitude variation in the input FM signal, which is not a desirable feature. A good discriminator circuit should respond only to frequency variations and not to amplitude variations.

The first limitation (non-linearity) is removed by using stagger-tuned ~~frequency~~ discriminator (or) Balanced slope detector.

Balanced-slope detector:- (or) Round-Travis Detector:-

The circuit uses two identical slope detectors. They are connected back to back, to the opposite ends of a centre tapped transformer and hence fed 180° out of phase.

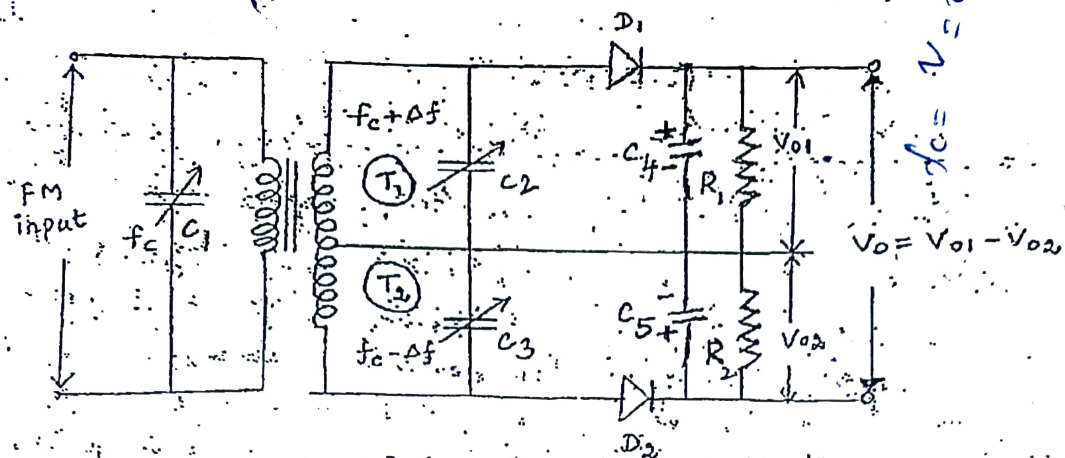


Fig (c) Balanced slope detector

Let $f_c + \Delta f$ & $f_c - \Delta f$ be the resonant frequency (tuned freq) of the upper secondary circuit (T_1) & lower secondary circuit (T_2). The input of FM signal is coupled to T_1 and T_2 180° out of phase.

The secondary side tuned circuits (T_1 & T_2) are connected to diodes D_1 and D_2 with RC loads. The total output (V_0) is equal to difference between V_{01} and V_{02} (i.e, $V_0 = V_{01} - V_{02}$).

Fig (d) shows the characteristic of the balanced slope detector. It shows V_0 with respect to input frequency.

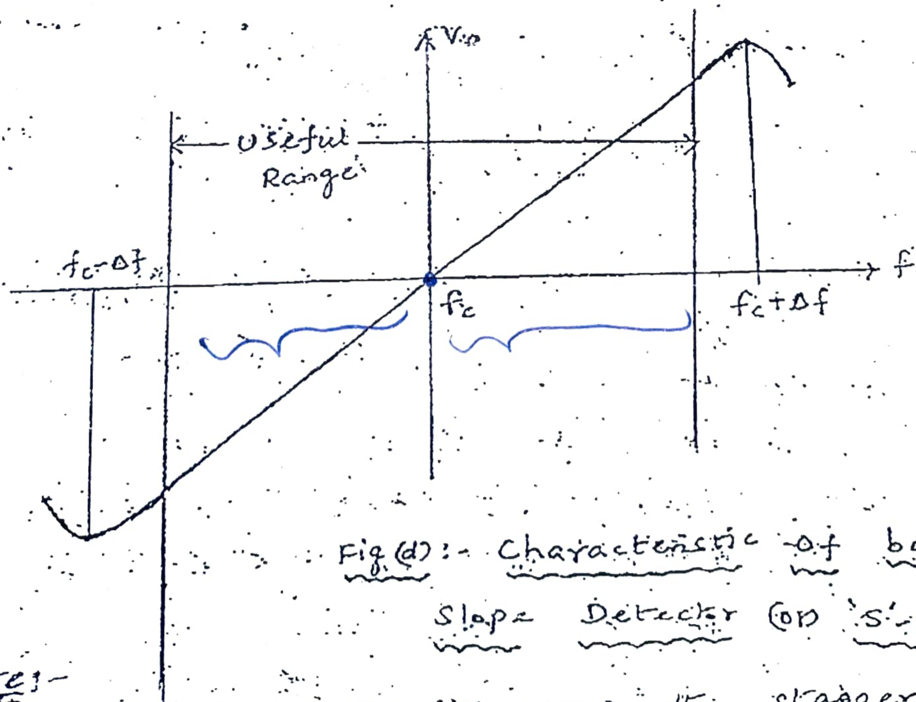


Fig (d) :- Characteristic of balanced Slope Detector (or) 'S'-curve.

Note:- Two tuned circuits are in the stagger tuned mode, i.e, one is tuned above carrier freq. f_c and other is tuned below f_c.

Circuit Operation:-

When the input freq. is equal to f_c, (f_c lies in a position which is in equi distant from $f_c+\Delta f$ and $f_c-\Delta f$) the voltage applied to the diodes will be identical. Thus the detector output (V_o) is zero. [Because $V_{o1}=V_{o2}$].

When the input freq. is $f_c+\Delta f$, the upper circuit T_1 produces maximum voltage since it is tuned to this frequency (i.e $f_c+\Delta f$). whereas lower circuit T_2 is tuned to $f_c-\Delta f$, which is quite away from $f_c+\Delta f$. Hence T_2 produces minimum voltage. Hence the output V_{o1} is maximum where V_{o2} is minimum. Therefore $V_o=V_{o1}-V_{o2}$ is maximum positive for $f_c+\Delta f$.

When input freq. is $f_c-\Delta f$, the lower circuit T_2 produces maximum signal since it is tuned to it. But upper circuit T_1 produces minimum signal. Hence rectified output V_{o2} is maximum and V_{o1} is minimum. Therefore $V_o=V_{o1}-V_{o2}$ is maximum negative for $f_c-\Delta f$. This is shown in Fig (d).

If the input freq. lies between these two extremes, the o/p will have some intermediate value. o/p is either +ve (or) -ve voltage depending upon the input freq. For example if the input freq. tries to increase above f_c, then V_{o1} will be grater than V_{o2} and net output V_o will be positive. On the other hand if the input freq. tries to fall below f_c then V_{o2} will be grater value than V_{o1} and net output V_o will be negative.

It is desirable that the characteristic shown in Fig (d), should be linear between $f_c+\Delta f$ and $f_c-\Delta f$, then only proper detection will take place. The Linearity of the characteristic depends upon alignment of tuning circuits and coupling characteristics of the tuned circuits.

If suppose the input freq. goes outside the range i.e, $f_c\pm\Delta f$, the output will fall because of the behaviour of the tuned circuit.

Advantages:-

Efficient & provides satisfactory operation.

Disadvantages:-

i) The linear characteristic is limited to a small freq. deviation (Δf).

ii) It is very difficult to align because of three different freq. to which various tuned circuits are to be tuned.

iii) The tuned circuit output is not purely bandlimited and, hence, the lowpass RC filter of the envelope detector introduces distortion.

Foster-seeley (centre-tuned) Discriminator:- This type of discriminator is very widely used. The circuit arrangement is shown in fig (e).

The FM signal is applied to the primary of the RF transformer T_1. The primary and secondary windings are resonated at the carrier frequency with C_1 and C_2. The parallel tuned circuit in the primary of T_1 is connected in the collector of a limiter amplifier Q_1 that removes amplitude variations from the FM signal.

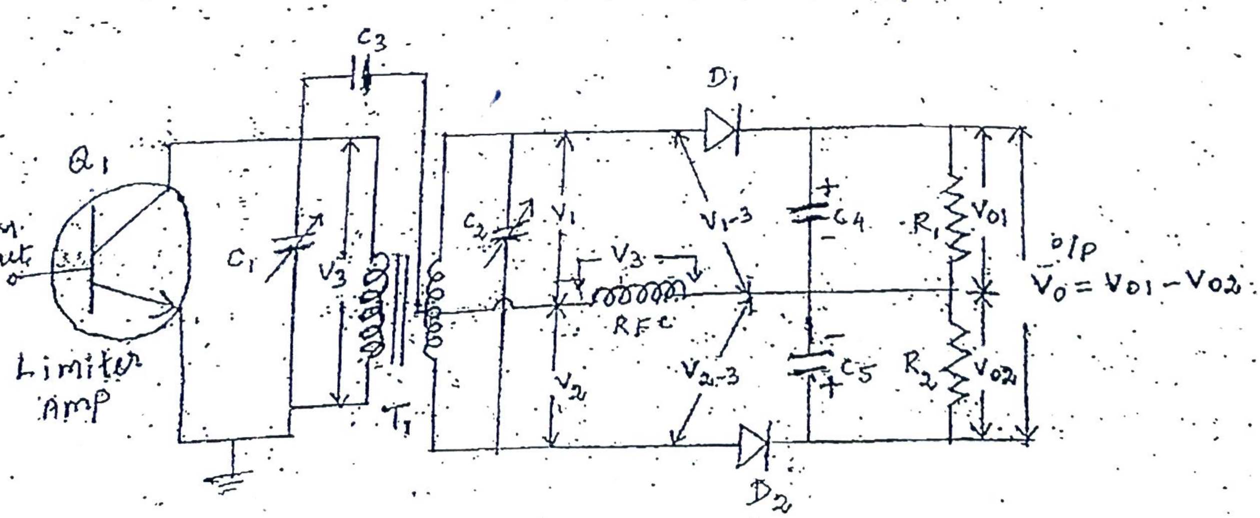
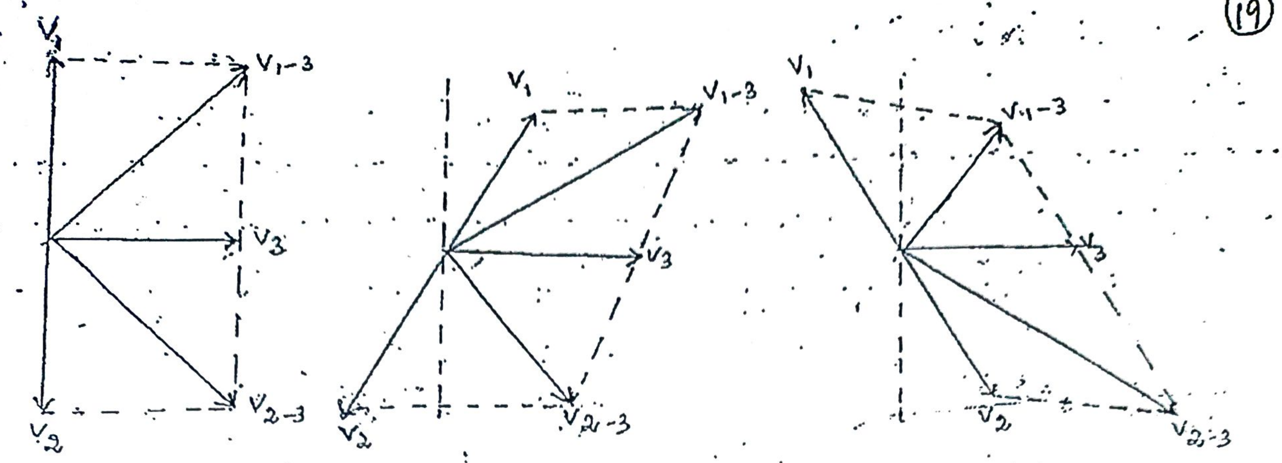


Fig:- The Foster-Seeley discriminator



(a) carrier frequency (b) Above carrier frequency (c) Below carrier frequency

Fig: vector diagrams of Foster-Seely method

The signal across the primary of T_1 is also passed through capacitor C_3 and appears directly across an RFC. The voltage appearing across RFC is exactly the same as that appearing across the primary winding. The voltage across RFC is designated as V_3.

The current flowing in the primary winding of T_1 introduces voltage in the secondary winding. Because the secondary winding is centre-tapped the voltage across the upper portion V_1 will be 180° out of phase with voltage across the lower portion V_2. The voltage induced into the secondary winding is 90° out of phase with the primary winding.

When both the primary and the secondary windings of an air-core transformer are tuned resonant circuits (i.e f_c), the phase relationship between the voltage across the primary and secondary will be 90°. This means that the voltage V_1 and V_2 will also be 90° out of phase with V_3, the voltage across RFC. This phase relationship is shown in the vector diagrams in Fig (a); the i/p is unmodulated carrier freq. (i.e f_c).

The remainder of the circuit consists of two diode detector circuits similar to those used for AM detection. The voltage V_{1-3} applied to D_1, R_1 and C_4 is the sum of voltages V_1 and V_3. The voltage V_{2-3} applied to D_2, R_2 and C_5 is the sum of voltages V_2 and V_3. Since the voltages V_1 and V_2 are out of phase with voltage V_3, the respective sums V_{1-3} and V_{2-3}, are vector sums, as illustrated in Fig (a).

On one half cycle of the primary voltage, D_1 conducts and current flows through R_1 and charges C_4. On the next half cycle, D_2 conducts and current flows through R_2 and charges C_5. The voltage across R_1 and R_2 designated V_{01} and V_{02} are identical because V_{1-3} and V_{2-3} are the same. Since two voltages are equal but of the opposite polarity the output voltage is zero. At the carrier centre frequency (i.e f_c) with no modulation, the modulator o/p is therefore zero.

When the i/p frequency increases (i.e $f_c+\Delta f$) the inductive reactance will be higher than the capacitive reactance, making this circuit inductive. This causes phase relationship between V_1 and V_2 to change with respect to V_3. If the i/p is above the resonant frequency, then V_1 will lead V_3 by a phase angle less than 90°. Since V_1 and V_2 remains 180° out of phase, V_2 will then lag V_3 by an angle of more than 90°. This change in phase relationship is shown in Fig (b). When the new vector sums of V_1 and V_3 and V_2 and V_3 are computed, it is found that the voltage V_{1-3} applied to D_1 is grater than the voltage V_{2-3} applied to D_2. Therefore the voltage across R_1 (i.e V_{01}) will be greater than the voltage across R_2 (i.e V_{02}) and net output voltage will be positive.

If the frequency deviation lower than the centre frequency (i.e $f_c-\Delta f$), voltage V_1 will lead by an angle of more than 90° while voltage V_2 will lag by an angle less than 90°. The resulting vector additions of V_1 and V_3 and V_2 and V_3 are shown in Fig (c). This time V_{2-3} is greater than V_{1-3}. As a result, the voltage across R_2 (i.e. V_{02}) will be greater than the voltage across R_1 (i.e. V_{01}) and the net output voltage will be negative. (20)

As the frequency deviates above and below the centre frequency, the output voltage increases or decreases, and therefore, the original modulating signal is recovered.

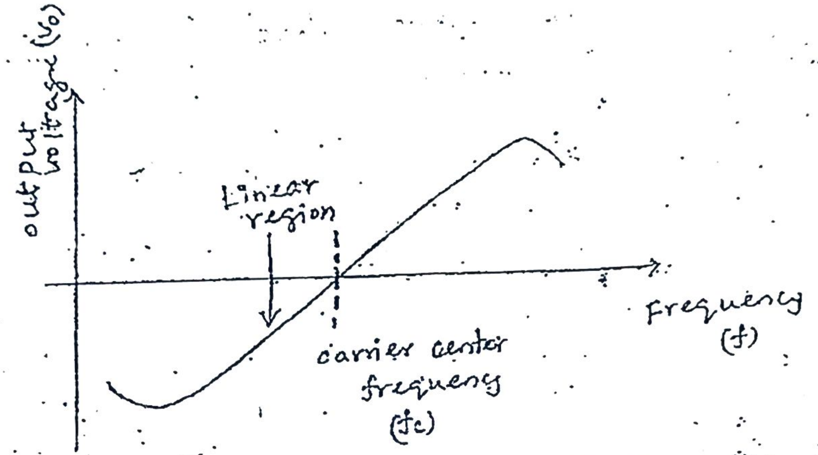


Fig (d):- output voltage of the discriminator

Advantages:-

i) The phase discriminator is much easier to align than the balanced slope detector.

ii) only two tuned circuits are necessary and both are tuned to same frequency

iii) Linearity is better.

Disadvantage:-

The only disadvantage of Foster Seely disciminator is, it needs a separate amplitude limiting circuit.

(To overcome the above disadvantage Ratio detector is used)

Ratio detector:-

Another widely used Fm demodulator is the ratio detector. It is similar in appearance to the Foster-seely discriminator but has ~~several~~ three important differences. is shown in Fig (d) They are,

i) one of the diode has been reversed.

ii) A large capacitor has been placed at the output.

iii) The output is taken in between resistor and capacitor network.

The FM signal is applied to the RF transformer T_1 with its center tapped secondary. This FM signal also passed through capacitor C_3 and applied across the RFC as in the Foster-Seely discriminator. The circuit uses two diodes, but not that the direction of D_2 is reversed from that in the discriminator. The voltages V_{1-3} and V_{2-3} applied to D_1 and D_2, respectively, are again a composite of V_1 and V_3 (V_{13}) and V_2 and V_3 (V_{2-3}) as before.

Another major difference in the ratio detector is the use of a very large capacitor C_6 connected across the output. The load resistors R_1 and R_2 are equal in value, and their common connection is at ground. The output is taken from between points C and D in the circuit.

Capacitors C_4 and C_5 and Resistors R_1 and R_2 form a bridge circuit. The voltage across capacitors C_4 and C_5 is the bridge input voltage, while the output is taken between points C and D.

With no modulation on the carrier (i.e f_c), the voltage V_{1-3} applied to D_1 is the same as voltage V_{2-3} applied to D_2. Therefore capacitors C_4 and C_5 charge to the same voltage with the polarity shown. Since C_6 is connected across these two capacitors, it will charge to the sum of their voltages. Because C_6 is a very large capacitor, usually tantalum (or) electrolytic, it takes several cycles of the input signal for the capacitor to charge fully. However, once charges, it will maintain a relatively constant voltage. Since R_1 and R_2 are equal, their voltage drops will be equal. Also, the voltage drop across C_4 and C_5 are equal. The bridge circuit, therefore, is balanced. Looking between points C and D, you will see 0V because the potential is the same.

Assume at the center carrier frequency (i.e. f_c), the voltage drop across C_4 and C_5 are each 2V. This means charge on C_6 is 4V. Then the voltages across R_1 and R_2 are each 2V.

If the frequency increases, the phase relationship in the circuit will change as described previously for the (Foster-Seely) discriminator circuit. This will cause the voltage across C_4 to be greater than the voltage across C_5. Assume that the voltage across C_4 is 3V and the voltage across C_5 is 1V. The voltage across R_1 and R_2 remains the same at 2V each because the charge on C_6 does not change. The bridge is now unbalanced, and an o/p voltage will appear between points C and D in the circuit. Using the point 'O' as a reference, the voltage across R_2 is 2V positive. Therefore o/p voltage at CD is +1V.

If the frequency decreases, then the phase relationship will be such that charge on C_5 will be greater than the charge on C_4. If the voltage across C_5 is +3V with respect to 'O' and the voltage across R_2 remains 2V, then the o/p voltage is -1V. The bridge is unbalanced, but in the opposite direction, and the output voltage is of the opposite polarity.

The above cases, shows that the output voltage follows deviation in frequency of the FM signal. Hence this circuit will translate the frequency modulated signal into original modulating signal in the same way as Foster-Seely discriminator.

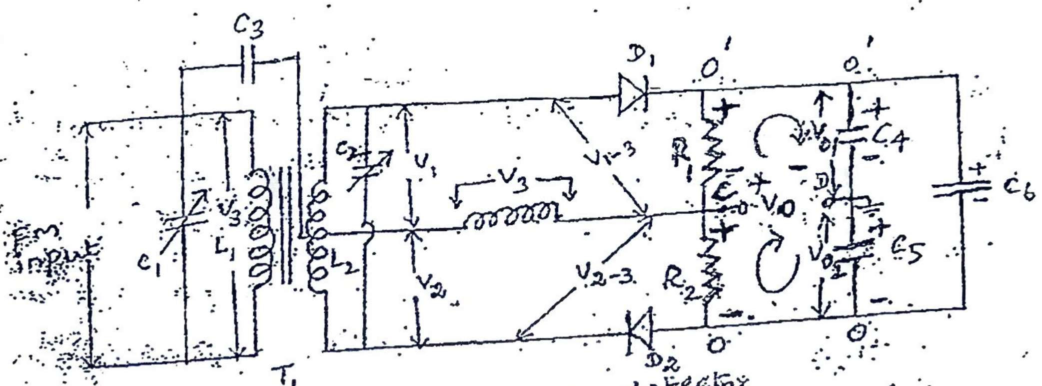


Fig ⓐ :- A Ratio detector

The primary advantage of the ratio detector over the Foster-Seely discriminator is that is essentially insensitive to noise and amplitude variation. The reason for this is the very large capacitor C_6. Since it takes a long time for this capacitor to charge or discharge, short noise pulses (or) minor amplitude variations are totally smoothed out.

The o/p voltage of Ratio detector is calculated as follows:

V_0 (due to D_1), $V_0 + \left(\frac{V_{01}+V_{02}}{2}\right) - V_{01} = 0 \Rightarrow V_0 = V_{01} - \left(\frac{V_{01}+V_{02}}{2}\right) \rightarrow (1)$

V_0 (due to D_2), $-V_{02} + \frac{V_{01}+V_{02}}{2} - V_0 = 0 \Rightarrow V_0 = -V_{02} + \left(\frac{V_{01}+V_{02}}{2}\right) \rightarrow (2)$

$(1)+(2) \Rightarrow 2V_0 = V_{01} - V_{02} \rightarrow (3)$

$\therefore V_0 = \frac{V_{01} - V_{02}}{2} \rightarrow (4)$ (which is half compared to Foster-Seely)

The ratio detector o/p is equal to half the difference between the o/p voltages from the individual diodes.

$\therefore$ Ratio detector o/p is half compared to that of Foster-Seely discriminator.

PLL as an FM demodulator:-

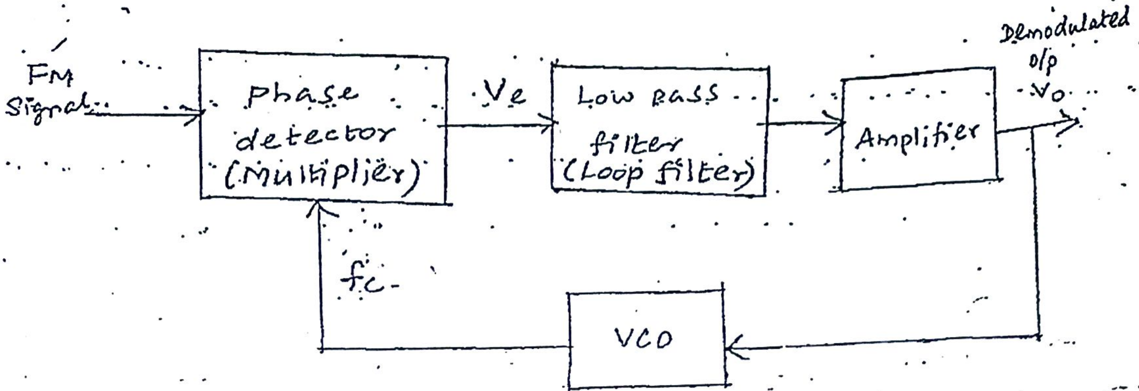


Fig ⓐ:- PLL FM demodulator

PLL is called phase locked loop. It consists of phase detector, low pass filter, Amplifier and VCO. It is used to lock the output frequency and phase to the frequency and phase of the input signal.

The PLL circuit is basically used for tracking a particular system. It synchronized the output with the input signal (reference signal) in terms of frequency and phase. This type of synchronization between input and output is called locked state. In this state the phase error between input and output is minimum. If error gets into the system then the PLL system will work automatically to minimize the phase and lock the phase of the output signal with that of the input signal.

The inputs to the phase detector are the input FM signal and voltage from VCO at carrier frequency f_c. When there are two signals having different frequencies, it is found that, the phase difference between the two signals is always varying. The phase detector detects the difference in phase between the two signals and produces the corresponding output voltage (which is proportional to the difference between FM input and VCO output). The output of the phase detector is V_e which is the error voltage.

The error voltage V_e applied to the LPF ~~which~~ removes high frequency noise presented in the phase detector and produces ripple free DC level.

The amplifier amplifies the signal to an adequate level and the output voltage proportional to the change in the frequency of FM signal to the centre carrier frequency f_c.

Differences between NBFM and WBFM

NBFM	WBFM
Modulation index (β) is smaller when compared to 1 radian i.e $\beta < 1$.	Modulation index (β) is larger when compared to 1 radian i.e $\beta > 1$.
It consists of one carrier component and two side bands.	It consists of one carrier component and infinite side bands.
Bandwidth required is $2f_m$.	Bandwidth required is $2N f_{m\,max}$ (or) $2(\Delta f + f_m)$
Frequency deviation is about 5 KHz.	Frequency deviation is 75 KHz
used in mobile communication.	used in radio broadcasting.

Problems:-

1) What is the bandwidth required for an FM wave in which the modulating signal is 2 KHZ and maximum frequency deviation is 12 KHZ? (use Carson's rule)

Soln:- $f_m = 2\ KHZ$, $\Delta f = 12\ KHZ$

According to Carson's rule

$$B\cdot W = 2(\Delta f + f_m) = 28\ KHZ$$

2) A 80 MHZ carrier is frequency modulated by a sinusoidal signal of 1 V amplitude and the frequency sensitivity is 100 HZ/V. Find the approximate bandwidth of the FM waveform, if the modulating signal has a frequency of 10 KHZ.

Soln:

Frequency sensitivity : $k_f = 100\ HZ/volt$

Amplitude of modulating signal $V_m = 1V$

Modulating signal freq. $f_m = 10\ KHZ$

WKT,

$$\Delta f = k_f V_m$$

$$\Delta f = 100\ HZ/V \times 1V$$

$$\therefore \Delta f = 100\ HZ$$

Freq. of modulating signal $f_m = 10\ KHZ$ [Given]

$$\therefore BW = 2(\Delta f + f_m) = 20.2\ KHZ$$

3) Obtain the bandwidth of the FM signal

$$c(t) = 10 \times \cos[2\times 10^7 \times \pi t + 8 \cos(1000 \times \pi t)]$$

Soln: Compare given FM signal with single tone FM signal

$$c(t) = V_c \cos[2\pi f_c t + \beta \cos 2\pi f_m t]$$

Hence $\beta = 8$, $f_m = 500\ HZ$

$$\therefore \Delta f = \beta \times f_m \qquad \therefore \frac{\Delta f}{f_m} = \beta$$

$$\therefore \Delta f = 8 \times 500 = 4000\ HZ$$

$$\therefore \Delta f = 4\ KHZ$$

By Carson's rule,

$$B\cdot W = 2(\Delta f + f_m) = 9\ KHZ$$

4) A carrier of frequency 100 MHz is frequency modulated by a signal $x(t) = 20 \sin(200\pi \times 10^3 t)$. What is the bandwidth of the FM signal if the frequency sensitivity of the modulator is 25 KHZ per volt?

Soln:

$x(t) = 20 \sin(200\pi \times 10^3 t)$

Comparing above eqn with $x(t) = V_m \sin(2\pi f_m t)$ we get,

$V_m = 20V, \quad f_m = 100\ KHZ$

Hence $\Delta f = K_f V_m$

$\Delta f = 20\cancel{V} \times 25\ KHZ/V$

$\therefore \Delta f = 500\ KHZ$

$\therefore$ By Carson's rule

$B.W = 2(\Delta f + f_m) = 2200\ KHZ = 2.2\ MHZ$

5) If the maximum phase deviation in a phase modulation system is 0.1 radian when a modulating Signal of 10 V is applied, determine the value of phase deviation constant.

Soln:- $\Delta\theta = 0.1$ radian

For PM,

$K_p = \text{phase deviation constant} = \dfrac{\Delta\theta}{V_m}$ $\qquad \therefore \Delta\theta = K_p V_m$

$\therefore K_p = \dfrac{\Delta\theta}{V_m} = \dfrac{0.1\ \text{radian}}{10\ V}$

$\therefore K_p = 0.01$ rad/volt

6) A carrier wave of frequency 100 MHZ is frequency modulated by a sinusoidal wave of amplitude 2 volts and frequency 100 KHZ. The frequency sensitivity of the modulator is 2.5 KHZ/volt. Determine the bandwidth of FM signal.

Soln:- $K_f = 2.5\,KHz/V$, $f_m = 100\,KHz$ & $V_m = 2V$

$\therefore$ Frequency deviation $\Delta f = 2 \times 2.5 \times 10^3$

$\therefore \Delta f = 5{,}000\,Hz$

By carson's rule,

$B.W = 2\,[\Delta f + f_m] = 210\,KHz$

7) When the modulating frequency in an FM system is 400 Hz and the modulating voltage is 2.4 V, the modulation index is 60. Calculate the maximum deviation. What is the modulating index when the modulating frequency is reduced to 250 Hz and the modulating voltage is simultaneously raised to 3.2 V?

Soln:

i) Maximum freq. deviation

$\beta_1 = 60$, $f_{m1} = 400\,Hz$

$\Delta f = \beta_1 \cdot f_{m1} = 60 \times 400 = 24000\,Hz = 24\,KHz$

ii) Modulation index for $f_{m2} = 250\,Hz$, $V_{m2} = 3.2\,V$

$$\beta = \frac{\Delta f}{f_m} = \frac{K_f V_m}{f_m}$$

$$\therefore \beta_1 = \frac{K_1 V_{m1}}{f_{m1}}$$

$$60 = \frac{K_1 \times 2.4}{400}$$

$\therefore K_1 = 10{,}000\,Hz/volt = 10\,KHz/volt$

Now,

$$\beta_2 = \frac{K_1 V_{m2}}{f_{m2}}$$ {Note that K_1 remains the same}

$$\therefore \beta_2 = \frac{10{,}000 \times 3.2}{250} = 128$$

8) An angle modulated wave is described by the equation $V(t) = 10 \cos(2\times10^6 \pi t + 10 \cos 2000\pi t)$.
Find
1) power of the modulated signal
2) maximum frequency deviation and
3) Bandwidth.

Soln:- The given angle modulated signal is

$$v(t) = 10 \cos(2\times10^6 \pi t + 10 \cos 2000\pi t)$$

comparing above equation with standard FM equation we get,

$$v(t) = V_c \cos(2\pi f_c t + \beta \cos 2\pi f_m t)$$

$$V_c = 10V, \quad f_m = 1000\,HZ \;\&\; \beta = 10$$

(1) power of the modulated signal is,

$$P_t = \frac{V_c^2}{2R} = \frac{10^2}{2\times1}$$ (Assume R=1 (Normalized load))

$$P_t = 50 \text{ Watts}$$

(2) Freq. deviation $\Delta f = \beta \cdot f_m$

$$\Delta f = 10\times1000 = 10000\,HZ = 10\,KHZ$$

(3) By Carson's rule

$$B.W = 2(\Delta f + f_m) = 22\,KHZ$$

9) Find the carrier, modulating frequency, modulation index and maximum deviation of the FM wave represented by the equation

$$e_{FM}(t) = 6 \sin(3\times10^8 t + 9 \sin 1000 t).$$

What power will the FM wave dissipate in a 10Ω resistor?

Soln: Comparing the above eqn with standard FM equation we get,

$$e_{FM}(t) = V_c \sin(2\pi f_c t + \beta \sin 2\pi f_m t)$$

$$V_c = 6V, \quad f_m = \frac{1000}{2\pi} = 159.15\,HZ \;\&\; \beta = 9$$

Power dissipated in 10Ω load will be,

$$P_t = V_c^2/2R = 1.8 \text{ watts}$$

10) Determine instantaneous frequency of a wave having a total phase angle given by (2.5)

$\phi(t) = 2000t + \sin 10t$.

Soln:

WKT,

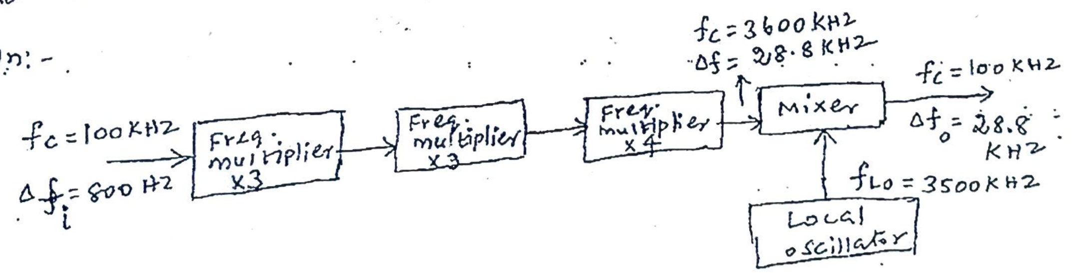
$$\omega_i(t) = \frac{d}{dt}[\phi(t)]$$

$$\therefore \omega_i(t) = \frac{d}{dt}[2000t + \sin 10t]$$

$$\therefore \omega_i(t) = 2000 + 10 \cos 10t$$

11) The 100 KHZ carrier is frequency modulated to produce a peak deviation of 800 HZ. This FM signal is passed through a 3x3x4 frequency multiplier chain. The output of this is mixed with an oscillator signal and difference frequency is taken as the new output. Determine the frequency of the oscillator required to produce a 100 KHZ carrier at the FM output and also determine the peak deviation at the output.

Soln:-



$$\Delta f_o = n \Delta f_i = 3 \times 3 \times 4 \times 800$$

$$\therefore \Delta f_o = 28.8 \text{ KHZ}$$

$$f_{LO} = 3600 \text{ KHZ} - 100 \text{ KHZ} = 3500 \text{ KHZ}$$

Deviation ratio: Deviation ratio is the ratio of the maximum carrier frequency deviation to the highest audio modulating frequency.

i.e Deviation ratio $(m) = \frac{\text{Max. freq. deviation}}{\text{Max. modulation freq}} = \frac{\max \Delta f}{\max f_m}$

Comparison between FM and AM

S. No	Amplitude Modulation (AM)	Frequency modulation (FM)
1.	Amplitude of the carrier is varied according to the amplitude of the modulating signal.	Frequency of the carrier is varied accordi-ng the amplitude of the modulating signal.
2.	AM has poor fidelity due to narrow bandwidth.	Since bandwidth is large, fidelity is better.
3.	Noise interference is more.	Noise interference is minimum.
4.	Adjacent channel interference is present.	Adjacent channel interference is avoided due to wide bandwidth.
5.	AM broadcast operates in MF & HF range.	FM broadcast operates VHF & UHF range.
6.	In AM only carrier and two sidebands are present.	Infinite number of sidebands and carrier are present.
7.	The transmission equipment is simple.	The transmission equipment is complex.
8.	Transmitted power varies according to the modulation index.	Transmitted power remains constant irrespec-tive of modulation index.
9.	Most of the power is in carrier hence less efficient	All the transmitted power is useful.
10.	Depth of modulation have limitation. It can not be increased above 1.	Depth of modulation have no limitation. It can be increased by increasing δf.

① Fig ① shows the block diagram of WBFM modulator used to transmit audio signals containing frequencies in the range 100 Hz to 15 KHz. The desired FM signal at the transmitter output is to have a carrier frequency of 100 MHz and a minimum frequency deviation of 75 KHz. Assume the modulation index $\beta = 0.2$ radians for NBFM. Find the frequency multiplier values N_1, N_2 and values of carrier frequency deviation at the various points in WBFM modulator.

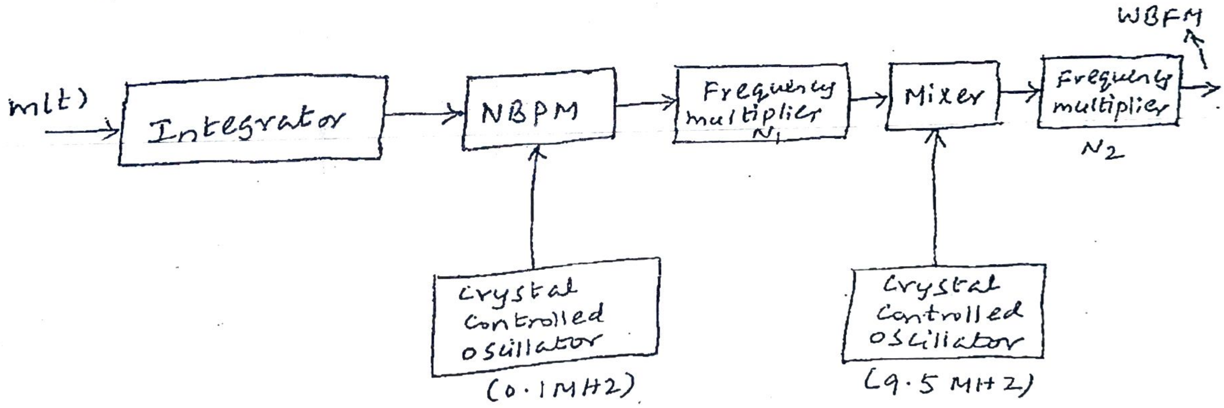


Fig ① Block diagram of WBFM modulator

Soln: ~~To produce an freq. deviation of Δf = 75 KHz at the transmitter output, the use of freq. multiplication is obviously required. Specifically, with Δf1 = 20 Hz and Δf = 75 KHz, we require a total freq. multiplication ratio of 3750.~~

$$f_1 = 0.1\,MHz, \quad f_2 = 9.5\,MHz, \quad \beta = 0.2 \text{ radians}$$

Baseband signal range = 100 Hz – 15 KHz

$\therefore$ Modulation index $\beta = \dfrac{\Delta f_i \text{ or } \delta_i}{f_m}$

Here δ_i is the freq. deviation before multiplication and f_m should be taken as lowest signal freq. for obtaining multiplication factor N_1 and N_2.

Hence taking $f_m = 100$ Hz & putting $\beta = 0.2$

$$0.2 = \frac{\delta_i}{100}$$

$$\therefore \delta_i = 20\,Hz$$

The output freq. deviation $\delta_o = 75\,KHz$

The input freq. deviation $\delta_i = 20\,Hz$

$$\therefore \text{Multiplication factor } (N_1 N_2) = \frac{\delta_o}{\delta_i} = \frac{75 \times 10^3}{20} = 3750$$

Hence $N_1 N_2 = 3750$

The carrier freq. $N_1 f_1$ at the first multiplier o/p is translated downward to $(f_2 - N_1 f_1)$ by mixing it with a sinusoidal wave of freq. $f_2 = 9.5\,MHz$, which is supplied by a second crystal-controlled oscillator. However the carrier freq. at the i/p of the second freq multiplier is required to equal f_c/N_2. Equating these two frequencies, we thus get,

$$f_2 - N_1 f_1 = \frac{f_c}{N_2} \rightarrow (1)$$

Hence with $f_1 = 0.1\,MHz$, $f_2 = 9.5\,MHz$ and $f_c = 100\,MHz$, we have

$$9.5 - 0.1\,N_1 = \frac{100}{N_2} \rightarrow (2)$$

Solving Eqs (1) and (2) for N_1 and N_2,

$N_1 = 75$

$N_2 = 50$

From eqn (2);

$9.5 N_2 - 0.1 N_1 N_2 = 100$

$9.5 N_2 - 0.1 \times 3750 = 100$

$N_2 = \frac{475}{9.5} = 50$

WKT,

$N_1 N_2 = 3750$

$N_1 = \frac{3750}{N_2} = 75$

Table 1: values of carrier freq & freq. deviation at varies points in WBFM modulator

	At the phase modulator o/p	At the first freq. multiplier o/p	At the mixer o/p	At the second freq. multiplier o/p
Carrier frequency	0.1 MHz	7.5 MHz	2.0 MHz	100 MHz
Frequency deviation	20 Hz	1.5 KHz	1.5 KHz	75 KHz