Module 2.2 and 2.3
FM generation and detection

Mainly, there are two ways in which an FM wave can be generated.

FM Generation

- Direct Method
  - Reactance Modulator
  - Varactor Diode Modulator
- Indirect Method
  - Armstrong Method

[1] Direct Method

Principle : We know that the output frequency of any tank circuit depends on the value of L and C. Thus, if the value of L and C is varied then the output frequency will also vary and an FM wave will be generated.

There are two methods :

- Reactance modulator (Basic FET reactance modulator).
- Varactor diode modulator.

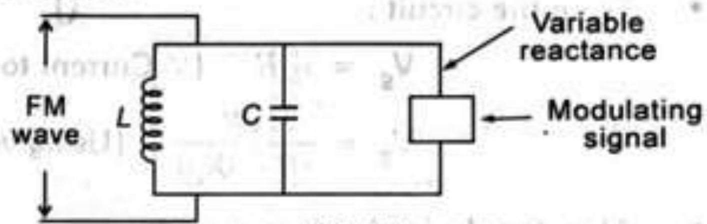
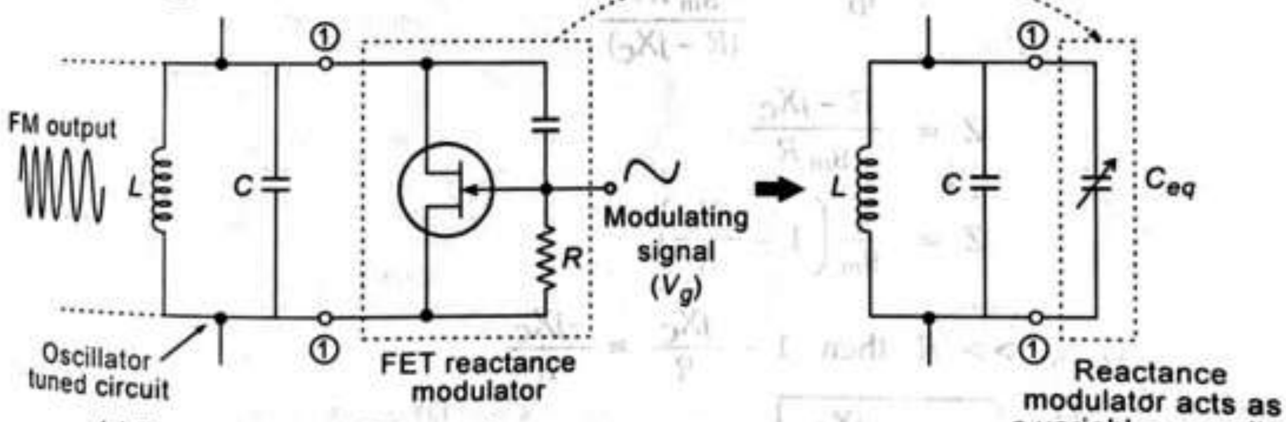


Fig. 5.8

> **Note :** *Each of the above circuits is explained in two steps.*
> *Step (i) : How the reactance of circuit varies with the modulating signal.*
> *Step (ii) : Working.*

5.7.1 Reactance Modulator

Circuit Diagram



(a) Frequency modulation using

(b) Equival

Step (i) : How the reactance of circuit varies with the modulating signal.

Consider the part of the circuit which acts as variable reactance modulator.

$X_C >> R$

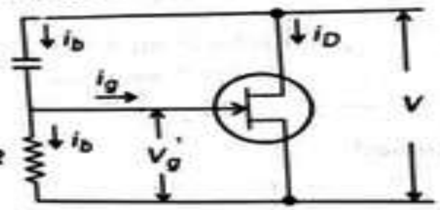


Fig. 5.10

FET is voltage control current source

g_m = amplification factor $= \frac{i_D}{V_{gs}}$

Assumptions

(i) $i_b << i_D$

(ii) $X_C >> R$

Mathematical Explanation

- From the circuit :

$$V_g = i_b R \quad \{\because \text{Current to the gate of FET is very low } (i_g \approx 0)\}$$

$$V_g = \frac{VR}{(R - jX_C)} \quad \{\text{Using voltage divider law}\}$$

- Also, the drain circuit is given by

$$i_D = g_m \times V_g \quad \text{where } g_m \text{ is the transconductance}$$

$$i_D = \frac{g_m \times RV}{(R - jX_C)}$$

- Now the overall impedance of circuit is

$$Z = \frac{V}{i_D} = \frac{V}{\frac{g_m RV}{(R - jX_C)}}$$

$$Z = \frac{R - jX_C}{g_m R}$$

$$Z = \frac{1}{g_m}\left(1 - \frac{jX_C}{R}\right)$$

as $X_C >> R$ then $1 - \frac{jX_C}{R} \approx \frac{-jX_C}{R}$

$$\therefore \boxed{Z = \frac{-jX_C}{g_m R}}$$

Now from above equation, Z depends on g_m and also g_m depends on the gate voltage applied

$$\left(\because\ g_m = \frac{i_D}{V_g}\right)$$

Thus the reactance of the circuit can be changed by varying the gate voltage. Hence, modulating signal is applied at the gate.

> **Note :** *In the above circuit the overall impedance of the circuit behaves almost like a capacitive reactance where equivalent capacitive reactance is*
>
> $$X_{eq} = \frac{X_C}{g_m R} \qquad 2\pi f C$$

Step (ii) : Working

Case (i) : When V_g Increases

When V_g increases

↓

g_m decreases $\left(\because\ g_m = \frac{i_n}{V_g}\right)$

↓

X_{eq} increases $\left(X_{eq} = \frac{X_C}{g_m R}\right)$

↓

Frequency increases

Case (ii) : When V_g Decreases

As V_g decreases

↓

g_m increases

↓

X_{eq} decreases

↓

Frequency decreases

5.7.2 Varactor Diode Modulator

applied voltage when it is R.B

Q. *With a neat circuit diagram, explain varactor diode FM modulator.*

Circuit Diagram

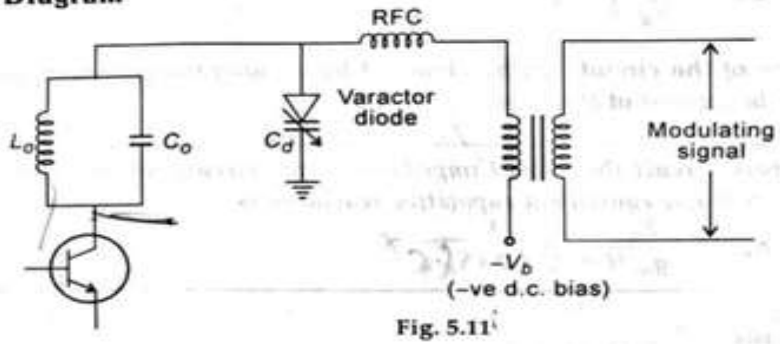


Fig. 5.11

Step (i) : How does the reactance of circuit change w.r.t. modulating signal

Note : *Please first read what is a varactor diode and how does it work in section 5.9.*

- We know that varactor diode can act as a capacitor if operated in reversed bias mode.
- Now, since the overall capacitance is the parallel combination of C_o and C_d, then $C_{eq} = C_o + C_d$.
- Also, C_d depends on the negative voltage applied and this voltage applied is proportional to the modulating voltage.

$$\therefore \boxed{C_d \propto V_m}$$

- Thus, the reactance of circuit can be changed by varying the voltage applied to the varactor diode.

Step (ii) : Working :

Case (i) : When Modulating Signal Increases

As V_m increases
↓
C_d decreases
↓
C_{eq} decreases
↓
Output frequency increases $\left(\because f \propto \frac{1}{C_{eq}}\right)$

Note : *RFC in the figure 5.11 is a radia frequency coil. It is used for noise reduction.*

Case (ii) : When Modulating Signal Decreases

As V_m decreases

$\downarrow$

C_d increases

$\downarrow$

C_{eq} increases

$\downarrow$

Output frequency decreases

Advantages of Direct Method

- Simple to design.

Disadvantages of Direct Method

- Since frequency of LC oscillator keeps on drifting, some additional circuits like AFC are required to maintain the consistency.

[2] Indirect Method

Q. ***With a neat block diagram, explain the principle and generation of indirect method of FM generation.***

Principle : The indirect method of FM generation generates FM through PM.

We know that

$$\text{if} \quad v_c = V_c \sin \omega_c t$$

$$\text{and} \quad v_m = V_m \cos \omega_m t$$

> *Note : $v_m = V_m \sin w_m t$ and $v_m = V_m \cos w_m t$ are the same signal. just have a 90° phase difference. But in real world that doesn't make any difference.*

Now, equation of FM wave with $v_c = V_c \sin \omega_c t$ and $v_m = V_m \sin \omega_m t$ is

$$v_{FM} = V_c \sin (\omega_c t + m_f \sin \omega_m t)$$

$$m_f = \frac{k V_m f_c}{\omega_m} \quad \text{Let } k_f = k f_c$$

$$\boxed{\therefore \; v_{FM} = V_c \sin\left[\omega_c t + \frac{k_f V_m}{\omega_m} \sin \omega_m t\right]} \quad \ldots\ldots (1)$$

Now, equation of a PM wave with $v_c = V_c \sin \omega_c t$ as carrier and $v_m = V_m \cos \omega_m t$ as modulating signal is

$$v_{PM} = V_c \sin (\omega_c t + m_p \cos \omega_m t)$$

$$m_p = k V_m$$

$$\therefore \boxed{v_{PM} = V_c \sin\left[\omega_c t + k V_m \cos \omega_m t\right]} \quad \text{..... (2)}$$

Comparing the two equations we can conclude that : *if the modulating signal is integrated and then applied to a phase modulator then we can generate FM from PM* (Assuming $k = k_f$). The block diagram is as shown in *figure 5.12*.

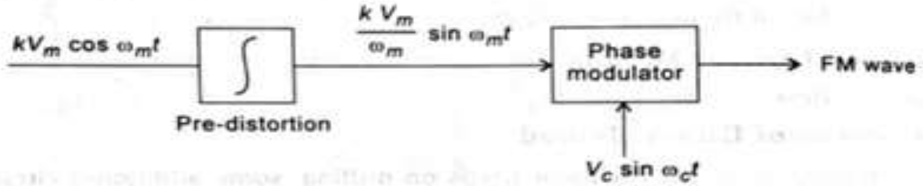


Fig. 5.12

5.8 Armstrong Method of FM Generation

Q. ***Draw block diagram of Armstrong frequency modulation and explain the functions of mixer and multiplier.***

- This method normally develops narrow band FM.
- To get wide band FM, some multipliers are used.

Prerequisites (for Understanding the Circuit)

We know that equation of a Narrowband FM signal with carrier suppressed is

$$v_{NBFM} = \frac{1}{2} \sin (\omega_c + \omega_m)t - \frac{1}{2} \sin (\omega_c - \omega_m)t \quad \text{..... (1)}$$

Also equation of a DSB-SC wave is

$$v_{DSB\text{-}SC} = \frac{-m_a V_c}{2} \cos (\omega_c + \omega_m)t + \frac{m_a V_c}{2} \cos (\omega_c - \omega_m)t$$

$$= \frac{m_a V_c}{2} \sin (\omega_c + \omega_m + 90°)t - \frac{m_a V_c}{2} \sin (\omega_c - \omega_m + 90°)t \quad \text{..... (2)}$$

Thus by comparing equations (1) and (2) we can conclude that the narrowband and DSB-SC wave have a phase difference of 90°. Also in both the cases *modulating signal should be a sine wave*. (Assuming $m_a = 1$ and $V_c = 1$ V)

Ans. **Advantages :**

- FM is more immune to noise.
- Amplitude limiters used in FM receivers improve the SNR of the received wave.
- FM has more number of side bands compared to AM.
- Bandwidth is more compared to AM.

Disadvantages :

- It is very complex.
- Due to line of sight communication, area covered is less.
- Noise induced depends on frequency of incoming signal, whereas in AM it is independent of frequency.
- Pre-emphasis and De-emphasis circuits are required.

Indirect Method of FM Generation

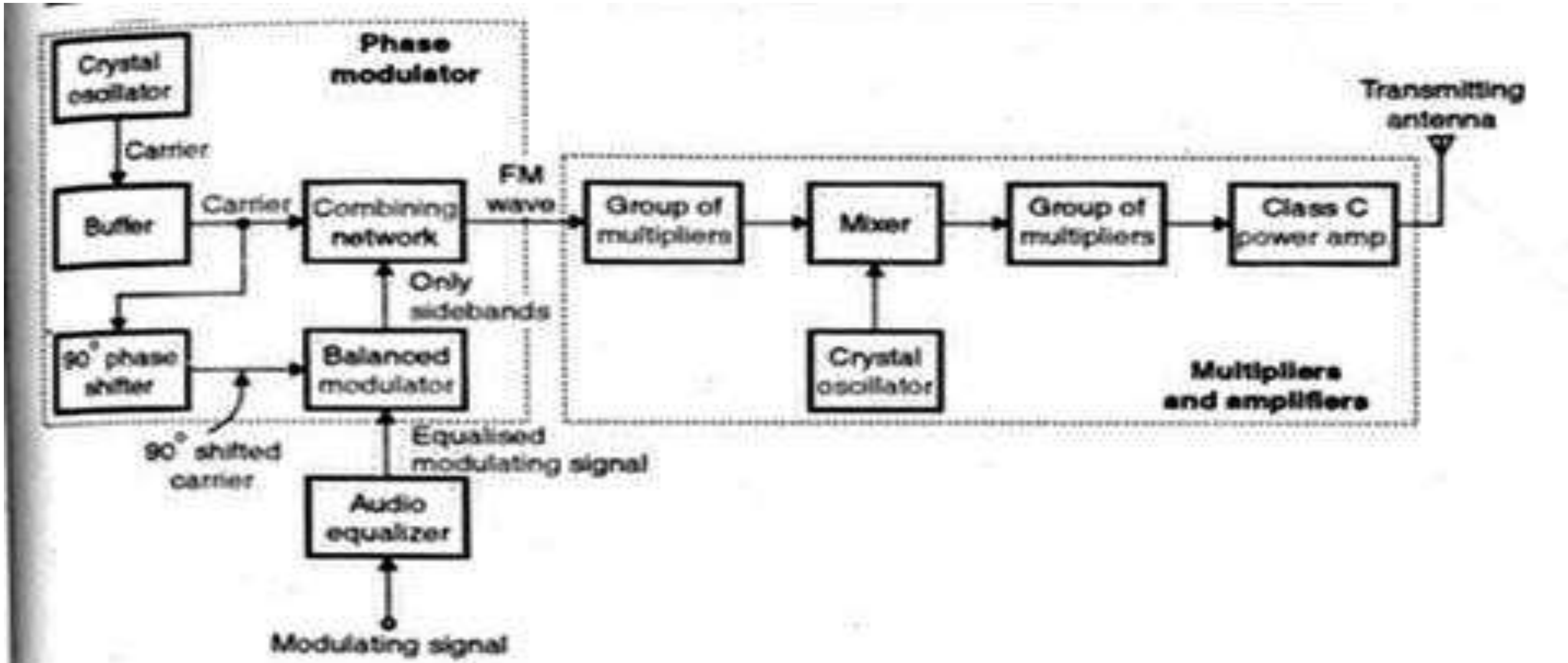


Fig. 6.9.1 : Indirect method [Armstrong method] of FM generation

$$e_{PM} = A \sin [\omega_c t + m_p \sin \omega_m t] \quad ...(6.9.1)$$

The Armstrong method uses the phase modulation to generate frequency modulation. This method can be understood by dividing it into four parts as follows :

Part I	:	How to obtain FM from phase modulator ?
Part II	:	Implementation of phase modulator.
Part III	:	Combining parts I and II to obtain the FM.
Part IV	:	Use of frequency multipliers and amplifiers.

Part I : How to generate FM from PM ?

1. In PM along with the phase variation, some frequency variation also takes place. Higher modulating voltages produce greater phase shift- which in turn produces greater frequency deviation.
2. And higher modulating frequencies produce a faster rate of change of modulating voltage hence they also produce greater frequency deviation.
3. **Thus in PM the carrier frequency deviation is proportional to modulating voltage as well as the modulating frequency.**
4. But in FM the frequency deviation is only proportional to the modulating voltage regardless of its frequency.
5. To correct this problem the modulating signal is passed through a low pass RC filter as shown in Fig. 6.9.2. Due to this the high frequency modulating signals are attenuated but there is no change in the amplitudes of low frequency modulating signals.
6. The filter output is then applied to a phase modulator alongwith the carrier as shown in Fig. 6.9.2.

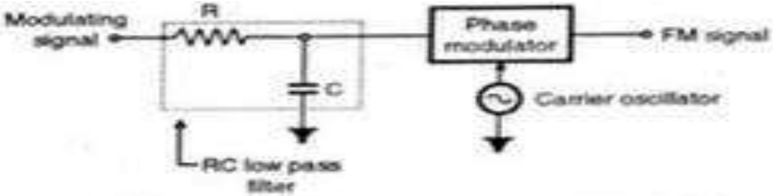


Fig. 6.9.2 : Generation of FM using phase modulation

Due to this arrangement the frequency deviation at the output of phase modulator corresponding to higher modulating frequencies is reduced. The result is FM produced by a phase modulator.

7. This can be proved mathematically as follows :

Consider the expression for a PM wave,

$$e_{PM} = A \sin [\omega_c t + m_p \sin \omega_m t] \quad ...(6.9.2)$$

Let $$e_{PM} = A \sin \theta \text{ where } \theta = [\omega_c t + m_p \sin \omega_m t] \quad ...(6.9.3)$$

The instantaneous angular frequency of the PM wave is defined as,

$$\omega_i = \frac{d\theta}{dt} = \frac{d}{dt}[\omega_c t + m_p \sin \omega_m t]$$

$$= \omega_c + m_p \cos \omega_m t \times \omega_m$$

$$\therefore \quad f_i = f_c + m_p f_m \cos \omega_m t \quad ...(6.9.4)$$

The second term in the RHS of Equation (6.9.4) is the frequency deviation. The maximum deviation is given by

$$\delta_{max} = f_m m_p \quad ...(6.9.5)$$

As m_p is proportional to the modulating voltage, the frequency f_i in the Equation (6.9.4) will vary in proportion with the modulating voltage. Thus frequency modulation can be obtained using PM. Now let us see how to implement the phase modulator.

Part II : Implementation of the phase modulator :

The block diagram of phase modulator circuit is shown in Fig. 6.9.3.

1. The crystal oscillator produces a stable unmodulated carrier which is applied to the "90° phase shifter" as well as the "combining network" through a buffer.
2. The 90° phase shifter produces a 90° phase shifted carrier. It is applied to the balanced modulator alongwith the modulating signal. Thus the carrier used for modulation is 90° shifted with respect to the original carrier.
3. At the output of the balanced modulator we get DSBSC signal i.e. A.M. signal without carrier. This signal consists of only two sidebands with their resultant in phase with the 90° shifted carrier as shown in Fig. 6.9.4.

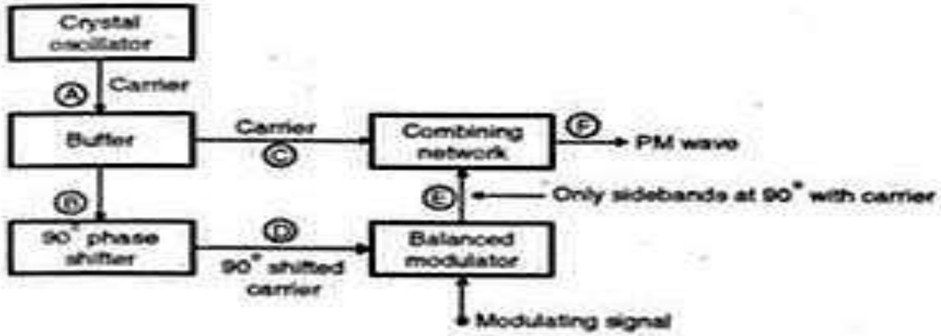


Fig. 6.9.3 : Phase modulator circuit

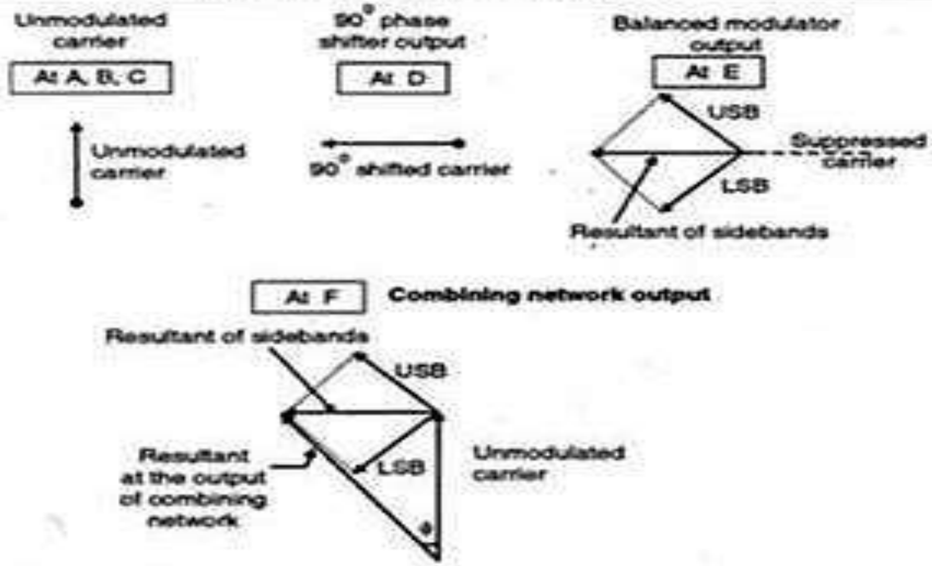


Fig. 6.9.4 : Phasors explaining the generation of P.M.

he two sidebands and the original carrier without any phase shift are applied to a combining etwork. At the output of the combining network we get the resultant of vector addition of he carrier and two sidebands as shown in Fig. 6.9.4.

low as the modulation index is increased, the amplitude of sidebands will also increase. Hence the amplitude of their resultant increases. This will increase the angle "ϕ" made by the esultant with unmodulated carrier. The angle "ϕ" decreases with reduction in modulation ndex as shown in Fig. 6.9.5. **Thus the resultant at the output of the combining network s phase modulated.** Hence the block diagram of Fig. 6.9.5 operates as a phase modulator.

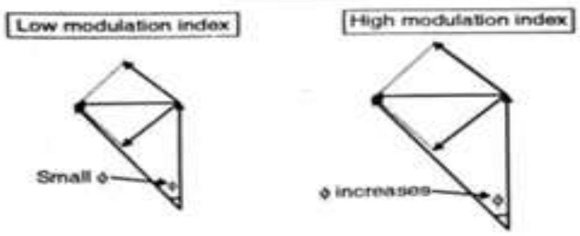


Fig. 6.9.5 : Effect of modulation index on ϕ

Part III : Combine parts I and II to generate FM :

Combining parts I and II we get the block diagram of the Armstrong method of FM generation as shown in Fig. 6.9.6.

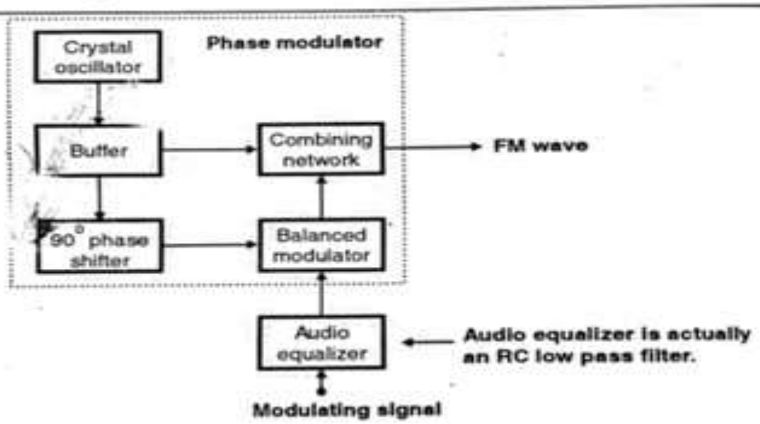


Fig. 6.9.6 : Block diagram of indirect method

1. The audio equalizer block shown in Fig. 6.9.6 is nothing but an RC low pass filter. The role of RC filter has already been discussed in part - I.
2. The modulating signal is passed through the audio equalizing circuit and applied to the phase modulator circuit.
3. We get the FM wave at the output of the combining network. Thus in the indirect method of FM generation we use phase modulation to obtain FM.

Part IV : Use of Frequency Multipliers Mixer and Amplifier :

The FM signal produced at the output of phase modulator has a low carrier frequency and low modulation index. They are increased to an adequately high value with the help of frequency multipliers and mixer. The power level is raised to the desired level by the amplifier.

Summary of operation of the Armstrong Method :

Now refer to Fig. 6.9.6. The operation of the Armstrong method is as follows :

(i) The crystal oscillator generates the carrier at low frequency typically at 1 MHz. This is applied to the combining network and a 90° phase shifter.

(ii) The modulating signal is passed through an audio equalizer to boost the low modulating frequencies, for the reason discussed earlier. The modulating signal is then applied to a balanced modulator.

(iii) The balanced modulator produces two sidebands such that their resultant is 90° phase shifted with respect to the unmodulated carrier.

(iv) The unmodulated carrier and 90° shifted sidebands are added in the combining network.

(v) As discussed earlier, at the output of the combining network we get FM wave. This FM wave has a low carrier frequency f_c and low value of the modulation index m_f.

(vi) The carrier frequency and the modulation index are then raised by passing the FM wave through the first group of multipliers. The carrier frequency is then raised by using a mixer and then the f_c and m_f both are raised to required high values using the second group of multipliers. The effect of multiplication and mixing is as discussed earlier.

(vii) The FM signal with high f_c and high m_f is then passed through a class C power amplifier to raise the power level of the FM signal.

Important Formulae

Sr. No.			Expressions
1.	Expression of an FM wave	:	$e_{FM} = A \sin [\omega_c t + m_f \sin \omega_m t]$
2.	Spectrum of FM	:	$e_{FM} = \{J_o (m_f) \sin \omega_c t + J_1 (m_f) [\sin (\omega_c + \omega_m) t - \sin (\omega_c - \omega_m) t + J_2 (m_f) [\sin (\omega_c + 2\omega_m) t + \sin (\omega_c - 2\omega_m) t + \ldots\}$
3.	Total power transmitted by FM wave	:	$P_t = A^2 / 2R$

Sr. No.			Expressions
4.	Ideal bandwidth of FM wave	:	$BW = \infty$
5.	Practical bandwidth of FM wave	:	$BW = 2[\delta + f_{m(max)}]$
6.	Deviation of FM wave	:	$\delta = k E_m f_c$
7.	Modulation index of FM wave	:	$m_f = \delta / f_m$
8.	Expression of a PM wave	:	$e_{PM} = A \sin[\omega_c t + m_p \sin \omega_m t]$
9.	Modulation index of a PM wave	:	$m_p = \phi_m$
10.	Percentage modulation	:	$\frac{\text{Actual frequency deviation}}{\text{Maximum allowed deviation}}$
11.	Equivalent capacitance for FET reactance modulator	:	$C_{eq} = g_m RC$ $C_{eq} = g_m / 2 \pi nf$
Effect of mixing on FM :			
1.	New center frequency	:	$(f_c + f_o)$
2.	New deviation	:	δ (remains same)
3.	New modulation index	:	m_f (remains same)
Effect of multiplication (Multiply by N)			
1.	New center frequency	:	$N f_c$
2.	New deviation	:	$N \delta$
3.	New modulation index	:	$N m_f$

Important Points to Remember

- In FM the frequency of the carrier is changed in accordance with the modulating voltage. The amplitude of FM wave is constant.
- Modulation index $m_f = \frac{\text{Deviation}(\delta)}{\text{Modulating frequency } f_m}$
- Mathematical expression for FM is $e_{FM} = A \sin[\omega_c t + m_f \sin \omega_m t]$
- The phase modulation (PM) is another type of angle modulation. The phase of carrier is changed in proportion with the modulating voltage.
- The FM and PM are closely related and interconvertable.
- FM has large BW, better noise immunity and constant transmitted power.
- Approximate FM bandwidth is $BW = 2[\delta + f_{m(max)}]$

- The preemphasis is used to artificially boost the higher modulating frequencies. It is a high pass filter. Preemphasis will improve the noise immunity at higher modulating frequencies.
- De-emphasis is used to reduce the amplitudes of artificially boosted higher modulating signals, to their original values.
- The FM wave can be generated by direct or indirect methods.
- Methods of direct generation of FM are :
  (i) FET reactance modulator
  (ii) Transistor reactance modulator
  (iii) Varactor diode reactance modulator.
- In the direct methods reactance of a two or three terminal device is changed in accordance with the modulating voltage. This is further used to change the oscillator frequency to generate FM.
- The indirect method of FM generation is called Armstrong method. Here the phase modulation is used to generate FM.
- Mixing is used to change the center frequency f_c in FM, it has no effect on the deviation and modulation index.
- Multiplication is used to multiply the frequency deviation, modulation index and the center frequency of FM wave.

Parameters	AM	FM	PM
(1) Formulae	$m_a = \frac{V_m}{V_c}$	$m_f = \frac{\delta}{f_m}$ where $\delta = kf_c v_m$, k = Constant	$m_p = kv_m$ where k = Constant
(2) Practically feasible value	Between 0 to 1	Greater than 0	Greater than 0
(3) Depends on modulating frequency	No	Yes	No
(4) Depends on carrier frequency	No	Yes	No
(5) Depends on carrier voltage	Yes	No	No

FM Demodulator

Requirements of FM Detector :

The FM demodulator must satisfy the following requirements :

(i) It must convert frequency variations into amplitude variations.

(ii) This conversion must be linear and efficient.

(iii) The demodulator circuit should be insensitive to amplitude changes. It should respond only to the frequency changes.

(iv) It should not be too critical in its adjustment and operation.

Now let us see how to convert the frequency changes to voltage variations.

7.2.1 Principle of Slope Detection :

Consider a tuned circuit shown in Fig. 7.2.1. A frequency modulated signal is applied to this tuned circuit. The center frequency of the FM signal is f_c and the frequency deviation is δ. The resonant frequency of the tuned circuit is deliberately adjusted to $(f_c + \Delta f)$ as shown in Fig. 7.2.2. As shown in the Fig. 7.2.2 the amplitude of the output voltage of the tank circuit depends on the frequency deviation of the input FM signal.

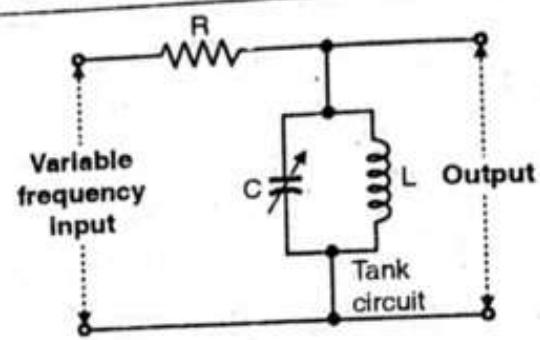


Fig. 7.2.1 : Tuned circuit

The output voltage of the tank circuit is then applied to a simple diode detector with an RC load with proper time constant. This detector is identical to the AM diode detector. Eventhough the slope detector circuit is simple it has the following disadvantages :

(i) It is inefficient.

(ii) It is linear only over a limited frequency range.

(iii) It is difficult to adjust as the primary and secondary windings of the transformer must tuned to slightly different frequencies.

The only advantage of the basic slope detector circuit is its simplicity. To overcome drawbacks of the simple slope detector, a "Balanced slope detector" is used.

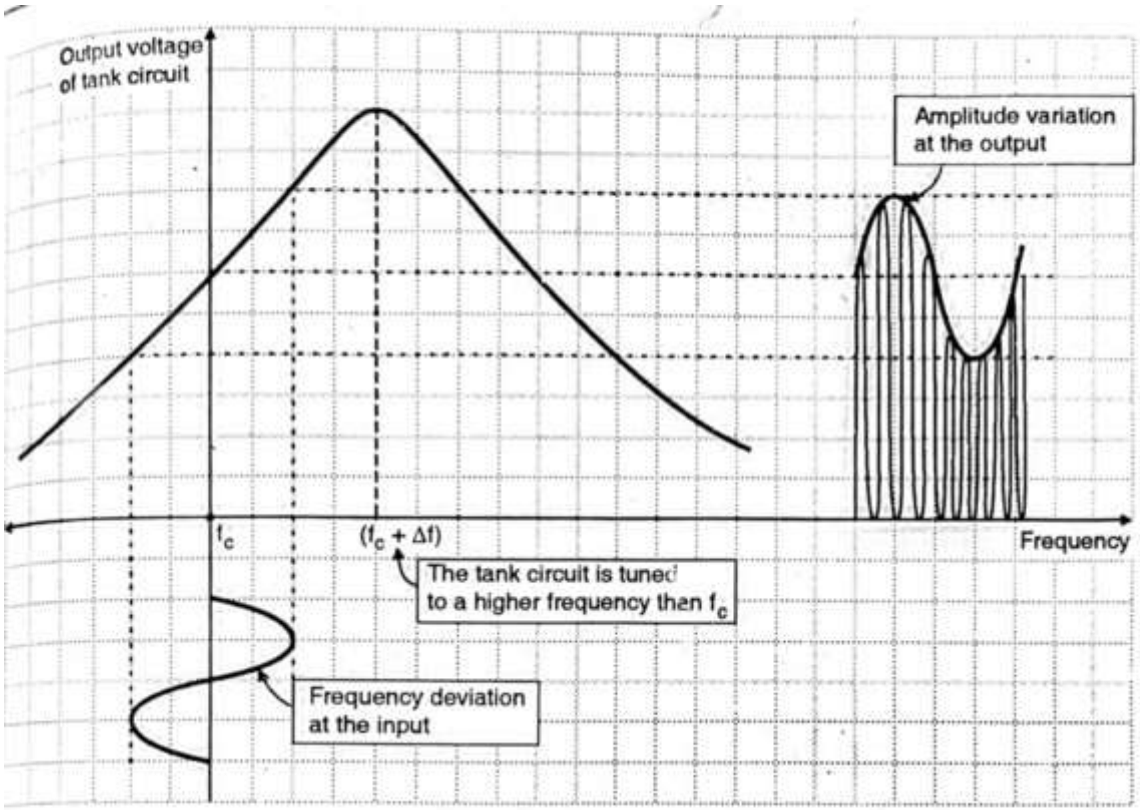
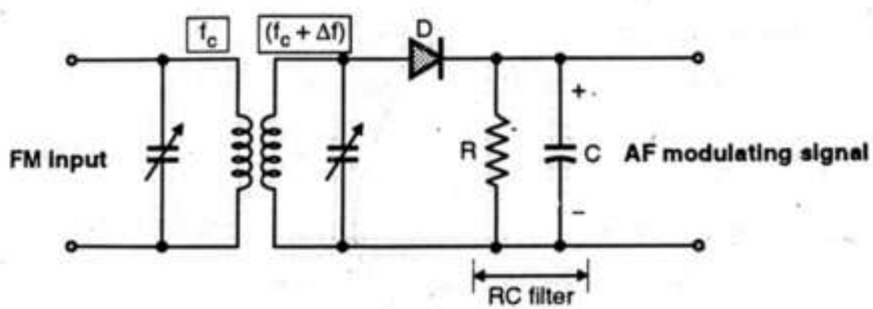


Fig. 7.2.2 : Characteristics of a slope detector



circuit of the secondary (T_1) is tuned above f_c by Δf i.e. its resonant frequency is ($f_c + \Delta f$). The lower tuned circuit of the secondary is tuned below f_c by Δf i.e. at ($f_c - \Delta f$).

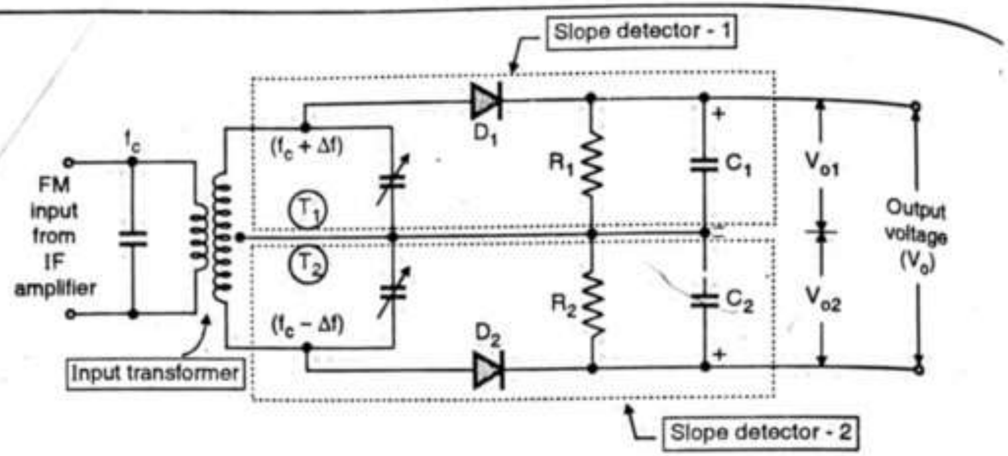


Fig. 7.2.4 : Balanced slope detector

4. $R_1 C_1$ and $R_2 C_2$ are the filters used to bypass the RF ripple. V_{o1} and V_{o2} are the output voltages of the two slope detectors. The final output voltage V_o is obtained by taking the subtraction of the individual output voltages, V_{o1} and V_{o2}.

$$\boxed{\therefore V_o = V_{o1} - V_{o2}} \quad ...(7.2.1)$$

Operation of the Circuit :

We can understand the circuit operation by dividing the input frequency into three ranges as follows :

(i) $f_{in} = f_c$:

When the input frequency is instantaneously equal to f_c, the induced voltage in the T_1 winding of secondary is exactly equal to that induced in the winding T_2. Thus the input voltages to both the diodes D_1 and D_2 will be the same. Therefore their dc output voltages V_{o1} and V_{o2} will also be identical but they have opposite polarities. Hence the net output voltage $V_o = 0$.

(ii) $f_c < f_{in} < (f_c + \Delta f)$:

In this range of input frequency, the induced voltage in the winding T_1 is higher than that induced in T_2. Therefore the input voltage to D_1 is higher than D_2. Hence the positive output V_{o1} of D_1 is higher than the negative output V_{o2} of D_2. Therefore the output voltage V_o is positive. As the input frequency increases towards $(f_c + \Delta f)$ the positive output voltage increases as shown in Fig. 7.2.5.

Disadvantages :

1. Eventhough linearity is good, it is not good enough.
2. This circuit is difficult to tune since the three tuned circuits are to be tuned at different frequencies, i.e. f_c, $(f_c + \Delta f)$ and $(f_c - \Delta f)$.
3. Amplitude limiting is not provided.

Phase Discriminator [Foster Seeley Discriminator

The phase discriminator or Foster Seeley discriminator is as shown in Fig. 7.2.6(a). If you compare this circuit with the balanced slope detector circuit then you will find that the diode and load arrangement is same in both the circuits. But the method of applying the input voltage to the diodes which is proportional to the frequency deviation, is entirely different. The Foster Seeley discriminator is thus derived from the balanced modulator.

However here the primary and the secondary windings both are tuned to the same center frequency "f_c" of the incoming signal. This simplifies the tuning process to a great extent and it will yield better linearity than the balanced slope detector.

Principle of Operation : Eventhough the primary and secondary tuned circuits are tuned to the same center frequency, the voltages applied to the two diodes D_1 and D_2 are not constant. They vary depending on the frequency of the input signal. This is due to the change in phase shift between the primary and secondary windings depending on the input frequency.

Due to this

(i) At $f_{in} = f_c$, the individual output voltages of the two diodes will be equal and opposite. The output voltage is zero as,

$$V_o = V_{o1} - V_{o2}$$

(ii) For $f_{in} > f_c$, the phase shift between the primary and secondary windings is such that the output of D_1 is higher than D_2. Hence the output voltage will be positive.

(iii) For $f_{in} < f_c$ the phase shift is such that output of D_2 is higher than that of D_1 making the output voltage negative.

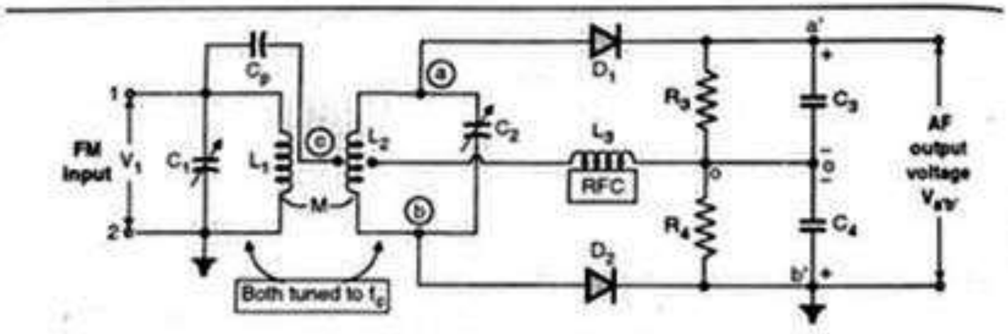


Fig. 7.2.6(a) : Phase discriminator

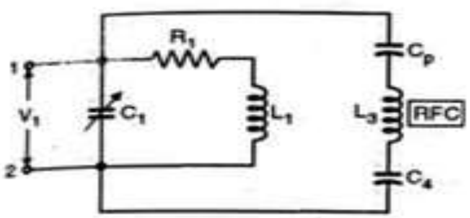
This is clear if you see the phasor diagrams of Figs. 7.2.6(e), (f) and (g). Because the output is dependent on the primary-secondary phase relationship this circuit is called as "phase discriminator".

Mathematical Analysis of Phase Discriminator :

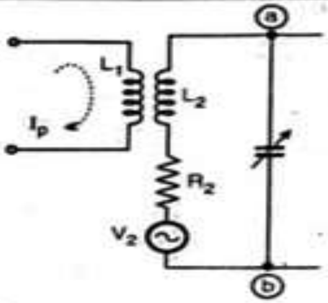
The mathematical analysis will be carried out in two parts.

Part I : To prove that voltage across RFC is equal to the primary voltage V_1.

(i) Carefully examine the circuit of Fig. 7.2.6(a). The load resistances R_3 and R_4 are much larger than capacitive reactances X_{C3} and X_{C4}, hence they are effectively bypassed. Therefore the series combination of L_3 i.e. RFC, C_p and C_4 appears across the primary winding. The equivalent circuit is as shown in Fig. 7.2.6(b).



(b) Equivalent circuit across primary



(c) Relation between primary and secondary

Fig. 7.2.6

(ii) Therefore the voltage across RFC L_3 is given by,

$$V_L = \frac{V_1 Z_{L3}}{Z_{Cp} + Z_{L3} + Z_{C4}} \qquad .....(7.2.2)$$

As C_p is a coupling capacitor and C_4 is a bypass capacitor, their reactance will be much less as compared to the reactance of RFC.

$$\therefore \quad \left[Z_{Cp} + Z_{L3} + Z_{C4}\right] \approx Z_{L3} \qquad .....(7.2.3)$$

Substitute this in Equation (7.2.2), to get,

$$V_L \approx V_1 \qquad .....(7.2.4)$$

Thus voltage across RFC is equal to the primary voltage V_1.

Part II : To find the input voltages to the diodes D_1 and D_2.

From equivalent circuit of Fig. 7.2.6(b) the expression for the primary current can be written as,

$$I_p = \frac{V_1}{j\omega L_1} \qquad \text{—(7.2.5)}$$

This is neglecting the primary resistance R_1 and the impedance coupled from the secondary side.

(ii) The voltage induced in the secondary winding due to this primary current is given as,

$$V_2 = \pm j\omega M I_p \qquad \text{—(7.2.6)}$$

Where M = Mutual inductance and the sign of V_2 depends on the direction of winding. It is convenient to take the negative sign

$$\therefore \quad V_2 = -j\omega M I_p \qquad \text{—(7.2.7)}$$

Substitute the value of I_p from Equation (7.2.5) to get

$$V_2 = -j\omega M \cdot \frac{V_1}{j\omega L_1} = \frac{-M}{L_1} \cdot V_1 \qquad \text{—(7.2.8)}$$

The secondary equivalent circuit is as shown in Fig. 7.2.6(d).

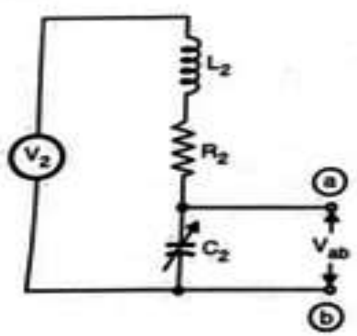
(iii) The secondary voltage V_{ab} can be calculated by referring to Fig. 7.2.6(d).

$$\therefore \quad V_{ab} = \frac{Z_{C2}}{Z_{L2} + R_2 + Z_{C2}} \times V_2 \qquad \text{—(7.2.9)}$$

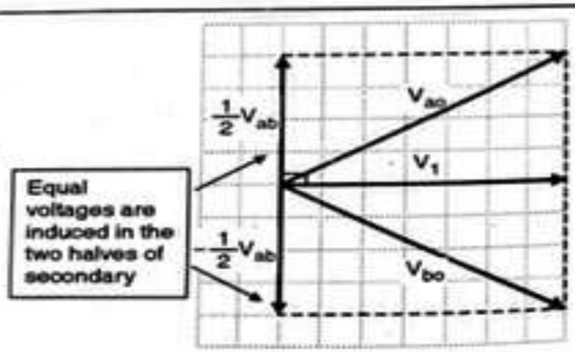
Substitute the value of V_2 from Equation (7.2.8) to get,

$$V_{ab} = \frac{-jX_{C2}(-V_1 M/L_1)}{R_2 + j(X_{L2} - X_{C2})}$$

$$= j\frac{M}{L_1}\frac{V_1 X_{C2}}{R_2 + jX_2} \qquad \text{—(7.2.10)}$$



(d) Secondary equivalent circuit



(e) Phasor diagram for $f_{in} = f_c$

Fig. 7.2.6

where $X_2 = X_{L2} - X_{C2}$ .....(7.2.11)

The voltage applied to D_1 is V_{ao} and that applied to D_2 is V_{bo}. So let us calculate them.

Input to D_1 : $V_{ao} = V_{ac} + V_L = \frac{1}{2} V_{ab} + V_1$ .....(7.2.12)

Input to D_2 : $V_{bo} = V_{bc} + V_L = -V_{ac} + V_L = -\frac{1}{2} V_{ab} + V_1$ .....(7.2.13)

This shows that the input to each diode is the sum of primary voltage and the corresponding half secondary voltage.

Output Voltage :

The output voltage is

$$V_{a'b'} = V_{a'o} - V_{b'o} \quad .....(7.2.14)$$

As the diode drops are not known, we cannot calculate the output exactly. But it is sure that the output will be proportional to the voltage applied at the diode inputs.

$$\therefore \quad V_{a'b'} \propto V_{ao} - V_{bo} \quad .....(7.2.15)$$

Output voltage for $f_{in} = f_c$:

Consider the equation $X_2 = X_{L2} - X_{C2}$

At $f_{in} = f_c$, $X_{L2} = X_{C2}$, $\therefore X_2 = 0$

Hence Equation (7.2.10) reduces to $V_{ab} = j\frac{M}{L_1}\frac{V_1 X_{C2}}{R_2}$

$$\therefore \quad V_{ab} = \frac{MV_1 X_{C2}}{L_1 R_2} \angle 90^\circ \quad .....(7.2.16)$$

This shows that V_{ab} leads V_1 by 90°. Hence $\frac{1}{2} V_{ab}$ will lead V_1 by 90° and $-\frac{1}{2} V_{ab}$ lags V_1 by 90°.

The input voltages to the diodes can be obtained vectorically as shown by the phasor diagram in Fig. 7.2.6(e). Looking at the figure it is clear that

$$V_{ao} = V_{bo} \quad .....(7.2.17)$$

i.e. input voltage to both the diodes will be the same.

$$\therefore \quad V_{a'o} = V_{b'o} \quad .....(7.2.18)$$

$$\therefore \quad V_o = V_{a'o} - V_{b'o} = 0$$

Output voltage at $f_{in} = f_c$ will be zero.

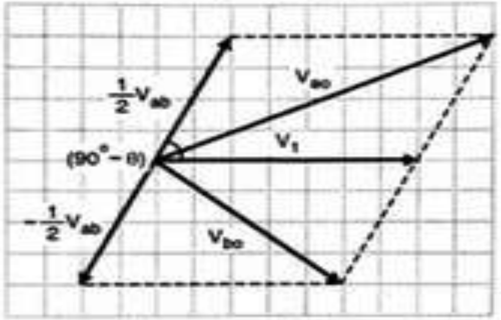
(ii) Output voltage for $f_{in} > f_c$:

$$X_2 = X_{L2} - X_{C2}$$

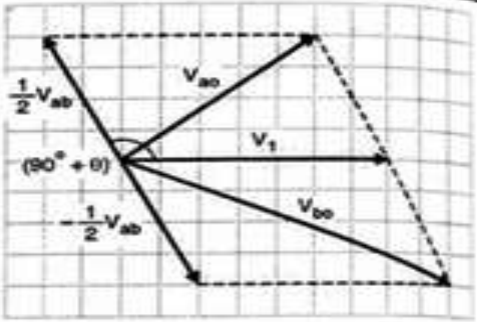
As $f_{in} > f_c$, $X_{L2} > X_{C2}$ $\therefore$ X_2 is positive.

$$\therefore \quad V_{ab} = j\frac{M}{L_1} \cdot \frac{V_1 X_{C2}}{R_2 + jX_2} = \frac{V_1 X_{C2} M}{L_1 |Z_2|} \frac{\angle 90^\circ}{\angle \theta}$$

$$= \frac{V_1 X_{C2} M}{L_1 |Z_2|} \angle 90^\circ - \theta \qquad \text{—(7.2.1}$$



(f) Phasor diagram for $f_{in} > f_c$



(g) Phasor diagram for $f_{in} < f_c$

Fig. 7.2.6

The Equation (7.2.19) shows that V_{ab} leads V_1 by less than 90°. Hence $\frac{1}{2}V_{ab}$ will lead V_1 less than 90° and $-\frac{1}{2}V_{ab}$ will lag behind V_1 by more than 90°. This is shown vectorically Fig. 7.2.6(f). The input voltage to D_1 i.e. V_{ao} is greater than the input to D_2 i.e. V_{bo}. Hence the output voltage V_o is positive.

(iii) Output voltage for $f_{in} < f_c$:

Similarly for $f_{in} < f_c$ it can be proved that V_{ab} leads V_1 by more than 90°. Hence $\frac{1}{2}V_{ab}$ leads V_1 by more than 90° and $-\frac{1}{2}V_{ab}$ lags V_1 by less than 90°. This is as shown in Fig. 7.2.6(g). The input voltage to diode D_1 i.e. V_{ao} is less than input to D_2 i.e. V_{bo}. Hence the output voltage is negative.

The discriminator response is as shown in Fig. 7.2.6(h).

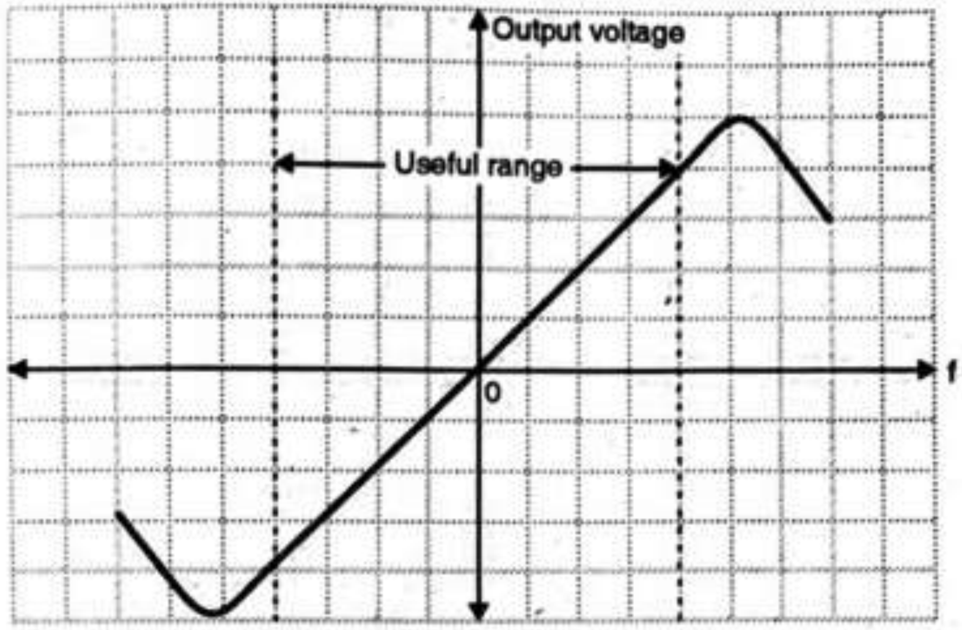


Fig. 7.2.6(h) : The discriminator response

Advantages of Phase Discriminator :

(i) It is more easy to align (tune) than the balanced slope detector as there are only two tuned circuits and both are to be tuned at the same frequency f_c.

(ii) Linearity is better. This is because the operation of the circuit is dependent more on the primary to secondary phase relationship which is very much linear.

Disadvantage :

It does not provide any amplitude limiting. So in the presence of noise or any other spurious amplitude variations, the demodulator output responds to them and produces errors.

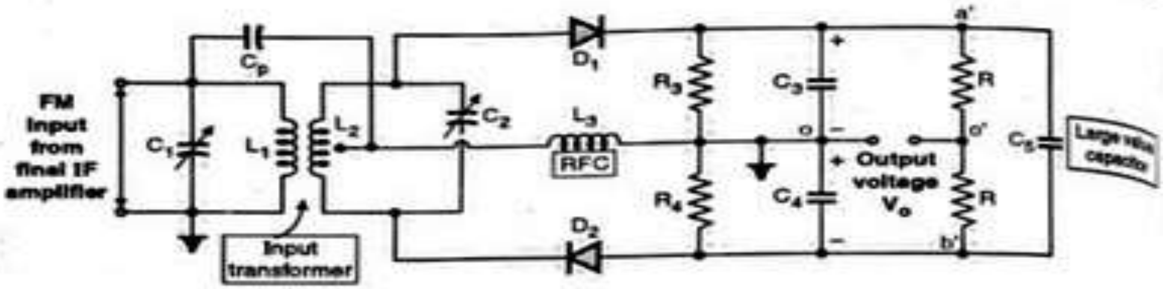


Fig. 7.2.7 : Ratio detector circuit

The additional feature of the ratio detector is the amplitude limiting action which is incorporated due to the large capacitor C_5. Due to this the amplitude limiter is not required prior to the ratio detector.

Amplitude Limiting using Ratio Detector :

Let us see now the reaction of the ratio detector circuit to the amplitude changes in the FM signal which is applied at its input.

(i) If the FM input V_1 tries to increase, the secondary voltage also increases. Due to this, extra diode current (through D_1 and D_2) will start flowing. Hence the load current increases.

(ii) But the voltage $V_{a'b'}$ i.e. voltage across the capacitor C_5 will not change instantaneously. It will increase very gradually.

(iii) Thus the load current has increased but the load voltage $V_{a'b'}$ is almost constant. Hence the load impedance is said to be decreased.

(iv) Due to this decreased load impedance, the secondary of the input transformer is heavily damped.

(v) Due to the damping, the Q decreases and therefore the gain of the amplifier driving the ratio detector will also decrease. This will counteract the increase in FM input voltage to the ratio detector.

Similarly if the amplitude of the FM input signal tries to decrease, the load impedance will now increase. The damping of the input transformer is reduced, Q increases increasing the gain of the driving amplifier to compensate for the reduction in amplitude. The ratio detector thus provides the amplitude limiting by means of the process called "Diode Variable Damping".

Advantages of Ratio Detector :

(i) Easy to align.
(ii) Very good linearity, due to linear phase relationship between primary and secondary.
(iii) Amplitude limiting is provided inherently. So additional limiter is not required.

7.2.5 Quadrature Detector :

The Foster Seeley and ratio detector circuits cannot be fabricated in the IC form as both these

Sum of V_{Ad} and V_{Bd}

To prove that the sum of V_{Ad} and V_{Bd} is always constant and independent of the incoming frequency, consider the three possible cases of incoming frequency, assuming V_{in} is constant.

Case (i) : $f_i = f_c$, V_{in} = Constant

It has already been explained that under this condition, the output voltages of the two diodes are equal, as shown in *figure 6.22(a)*. If the output of each diode is V volts, we have :

$$V_{AB} = V_{Ad} + V_{Bd} = V + V$$

$$V_{AB} = 2V$$

Case (ii) : $f_i > f_c$, V_{in} = Constant

It is observed from *figure 6.22(b)* that under this condition V_{D_1} is greater than V_{D2}. When f_i is equal to f_c, the two voltages are equal to V, as considered in case (i). However, V_{D_1} increases from V volts, and V_{D_2} decreases from its value of V volts in equal amounts. If the increase in V_{D_1} is ΔV volts, the voltage V_{D_1} will decrease from V volts by the same amount, ΔV.

The two voltages for this case are given as:

$$V_{D_1} = V + \Delta V$$

$$V_{D_2} = V - \Delta V$$

The sum of the two voltages is obtained as:

$$V_{AB} = V + \Delta V + V - \Delta V$$

$$V_{AB} = 2V$$

Case (iii) : $f_i < f_c$, V_{in} = Constant

Under this condition, V_{D_1} is less than V_{D_2}, as shown in *figure 6.22(c)*. With the same reasoning as in case (ii), the two voltages can be obtained as:

$$V_{D_1} = V - \Delta V$$

$$V_{D_2} = V + \Delta V$$

So that,

$$V_{AB} = V - \Delta V + V + \Delta V$$

$$V_{AB} = 2V$$

Conclusion

The sum of the output voltages of the diodes, which appears as V_{AB} in a ratio detector, is always constant at all frequencies, as obtained by equations (1), (2), and (3). Therefore, the voltage across the capacitor C_3 is independent of incoming frequency.

Action of C_3 to Limit Amplitude

Consider a situation in which the noise voltage alters the amplitude of the input FM signal, V_{in}. The capacitor comes into action when there is a change in V_{in}. The action of the capacitor can be explained by considering the three possible conditions of V_{in} :

- Case (i) : V_{in} remains constant
- Case (ii) : V_{in} increases
- Case (iii) : V_{in} reduces

Case (i) : V_{in} Remains Constant

This case is explained in the preceding section. It is proved that if V_{in} is constant, the voltage across A and B remains constant at all incoming frequencies.

If voltage V_{AB} remains constant, the capacitor charges to V_{AB}. Since it is a d.c. voltage, being constant at all times, it remains constant across the capacitor C_3. Beyond this point, there is no charging or discharging until V_{in} remains constant.

This situation indicates that the capacitor C_3 offers infinite impedance. Therefore, the total load of D_1 and D_2 is only due to R_1 and R_2 because C_5 acts as an open circuit, and R_3 and R_4 are very large as compared to R_1 and R_2. Therefore, when V_{in} is constant, capacitor C_3 does not take any action and is therefore constant.

Case (ii) : V_{in} Increases

When there is an increase in the amplitude of V_{in}, the secondary voltages V_{ac} and V_{bc} increase accordingly. This increases biasing of the diodes, and the output voltages of D_1 and D_2 increase in the same proportion. As a result, the total voltage, V_{AB}, across the points A and B increases. Due to the increase in V_{AB}, the capacitor C_3 starts charging through the excess current supplied by the two diodes. This increases the capacitor voltage in the same proportion as the increases in V_{in}. Therefore, under this condition, the voltages across R_2 (V_{BD}) and R_4 (V_{BD}) increases equally. The output voltage V_o is the difference of $V_{Bd'}$ and V_{Bd}. The increase in these two voltages cancel each other at the output terminals. As a result, the rise in V_{in} does not alter the modulating signal.

Case (iii) : V_{in} Decreases

When there is a decrease in the input FM voltage, V_{in}, the input diode voltages V_{D1} and V_{D2} decrease accordingly, and the diode currents are reduced. The voltage V_{AB} is also reduced, but this change does not happen instantaneously because of the presence of C_3, implying that even when there is a decrease in the diode currents, the voltage across A and B remains constant This situation indicates that the load impedance of the diodes has increased.

The output voltage will not be affected because V_{AB} remains constant even when V_{in} decreases. Therefore, the decrease in V_{in} is not reflected at the output of the ratio detector. The ratio detector takes care of any unwanted change in the amplitude of V_{in} due to the timely action of the capacitor C_3. The changes in V_{in} are not reflected at the output, and no additional amplitude limiter is required with a ratio detector.

6.3 Frequently Asked Questions

Q.1. How does a tank circuit work ?

circuits require a transformer. A quadrature detector and a phase locked loop detector can be fabricated in the IC form hence they are widely used in the modern receiver circuits.

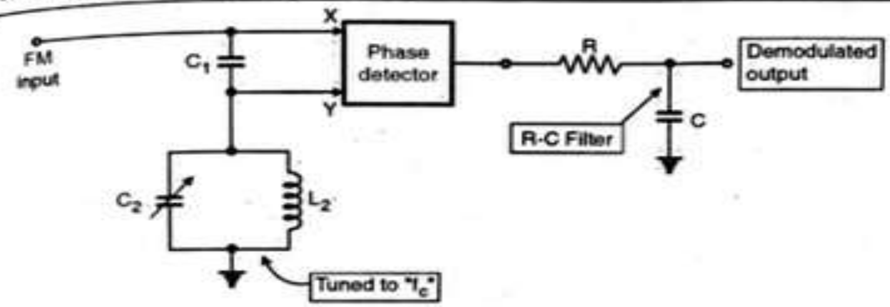


Fig. 7.2.8(a) : Quadrature detector

The block diagram of the quadrature detector is as shown in the Fig. 7.2.8(a). The capacitor "C_1" has a high reactance at the center frequency "f_c" of the FM input signal. The parallel resonant circuit has a resonant frequency equal to the center frequency "f_c" of FM input. The FM input is applied directly at "X" input of a phase detector and the voltage across the resonant circuit is applied to the "Y" input, as shown in Fig. 7.2.8(a).

Operation of the Circuit :

The operation of the circuit is frequency dependent.

(i) **When $f_{in} = f_c$:** When the instantaneous frequency at the input i.e. $f_{in} = f_c$, the reactance of C_1 is large and the tank circuit impedance is resistive. Due to this the voltage at point "Y" will lead the input voltage by 90° exactly. Thus the two input signals to the phase detector are 90° out of phase at the center frequency f_c.

(ii) **When $f_{in} < f_c$:** For the input frequencies less than f_c, the resonant circuit will have a inductive impedance. Thus the voltage across it will lead the FM input by more than 90°.

(iii) **When $f_{in} > f_c$:** For the input frequencies above f_c, the resonant circuit impedance will be capacitive. The voltage at input Y will lead the FM input by less than 90°.

(iv) The output of the phase detector is dependent on the amount of phase shift between its inputs X and Y. The output of the analog multiplier is averaged out by the RC filter at the output.

(v) Thus the amount of output voltage is proportional to the output of the detector which in turn depends on the phase shift between X and Y. And the phase shift depends on the frequency deviation of FM input. Thus the output voltage is proportional to the frequency deviation.

The operation will be clear by studying the waveforms of Fig. 7.2.8(b).

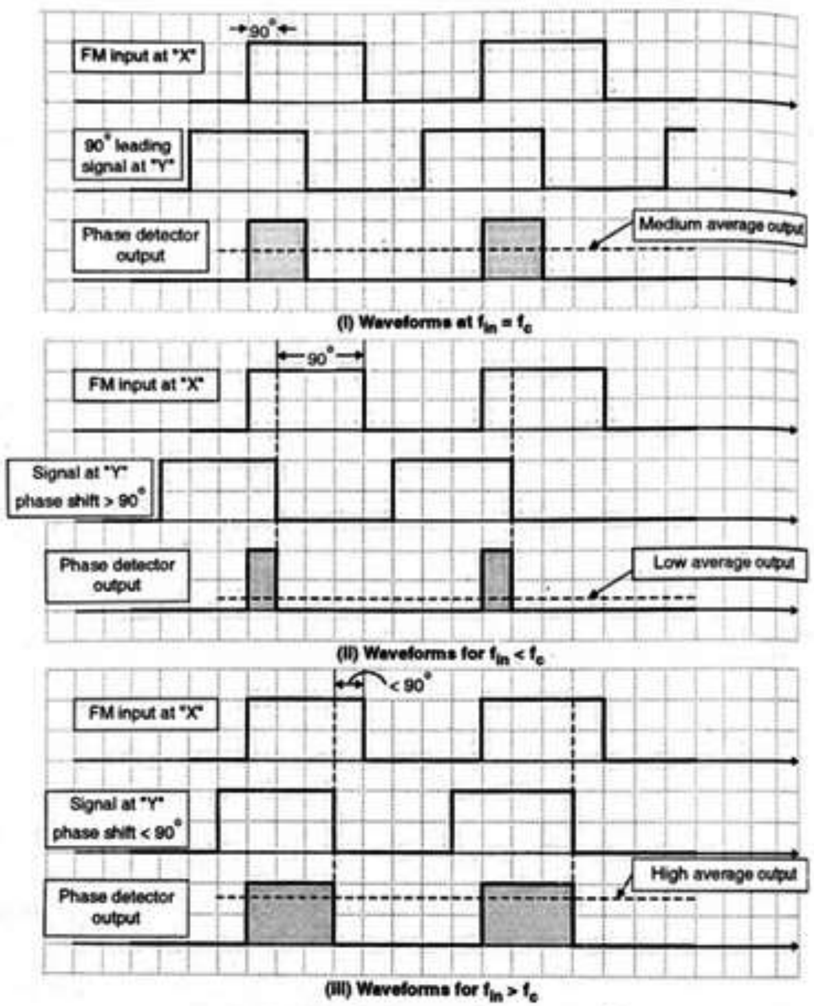


Fig. 7.2.8(b) : Quadrature detector waveforms

Advantages :

(i) It can operate with small amplitude signals (100 µ V or so).

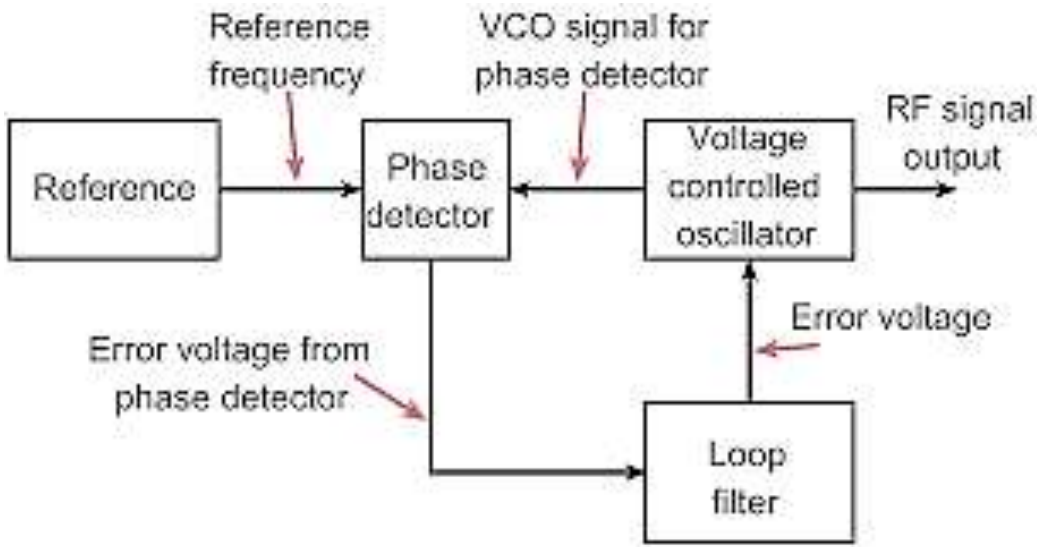
(ii) Alignment is easy as only one circuit is to be tuned.

(iii) Very good linearity and low distortion in the output.

7.2.6 Comparison of FM Demodulators :

Sr. No.	Parameter	Balanced slope detector	Phase discriminator	Ratio detector
(1)	Alignment/tuning	Critical as three circuits are to be tuned at different frequencies	Not critical	Not critical
(2)	Output characteristics depends on	Primary and secondary frequency relationship	Primary and secondary phase relation.	Primary and secondary phase relation.
(3)	Linearity of output characteristics	Poor	Very good	Good
(4)	Amplitude limiting	Not provided inherently	Not provided inherently	Provided by the ratio detector
(5)	Applications	Not used in practice	FM radio, satellite station receiver etc.	TV receiver sound section, narrow band FM receivers.

FM detection using Phase lock loop



- A Phase-Locked Loop (PLL) is basically a negative feedback system.
- A VCO is a sine wave generator whose frequency is determined by the voltage applied to it from an external source. It means that any frequency modulator can work as a VCO.
- A phase-locked loop (PLL) is primarily used in tracking the phase and frequency of the carrier component of an incoming FM signal.
- application in commercial FM receivers.

- **Working Operation**
- The operation of a PLL is similar to any other feedback system where the feedback signal tends to follow the input signal.
- If the signal fed back is not equal to the input signal, the error signal will change the value of the fed back signal until it is equal to the input signal.
- The difference signal between s(t) and b(t) is called an error signal.
- A PLL operates on a similar principle except for the fact that the quantity feedback is not the amplitude, but a generalized phase $\Phi(t)$.
- The error signal or difference signal e(t) is utilized to adjust the VCO frequency in such a way that the instantaneous phase angle comes close to the angle of the incoming signal s(t).
- At this point, the two signals s(t) and b(t) are synchronized and the PLL is locked to the incoming signal s(t).