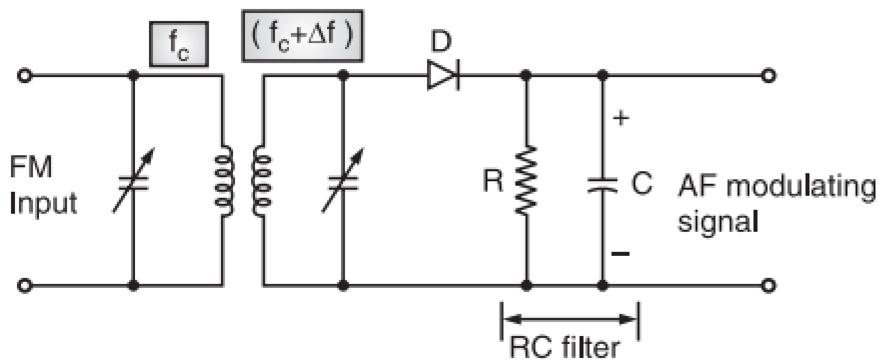
FM DEMODULATORS

The following two methods demodulate FM wave.

(1) Frequency discrimination method (Balanced FM Slope Detector (Balanced Frequency Discriminator)
(2) Phase discrimination method (Foster Seeley FM Demodulator)

FM Slope Detector / Simple FM Slope Detector (Frequency Discriminator)

The circuit diagram of a simple slope detector is as shown in figure 2.5.1,



Simple Slope Detector

Figure 2.5.1 Simple slope Detector

Diagram Source Electronics Post

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

- To overcome the drawbacks of the simple slope detector, a Balanced slope detector is used.

Balanced FM Slope Detector (Balanced Frequency Discriminator)

- The circuit diagram of the balanced slope detector is shown in Figure 2.5.2.

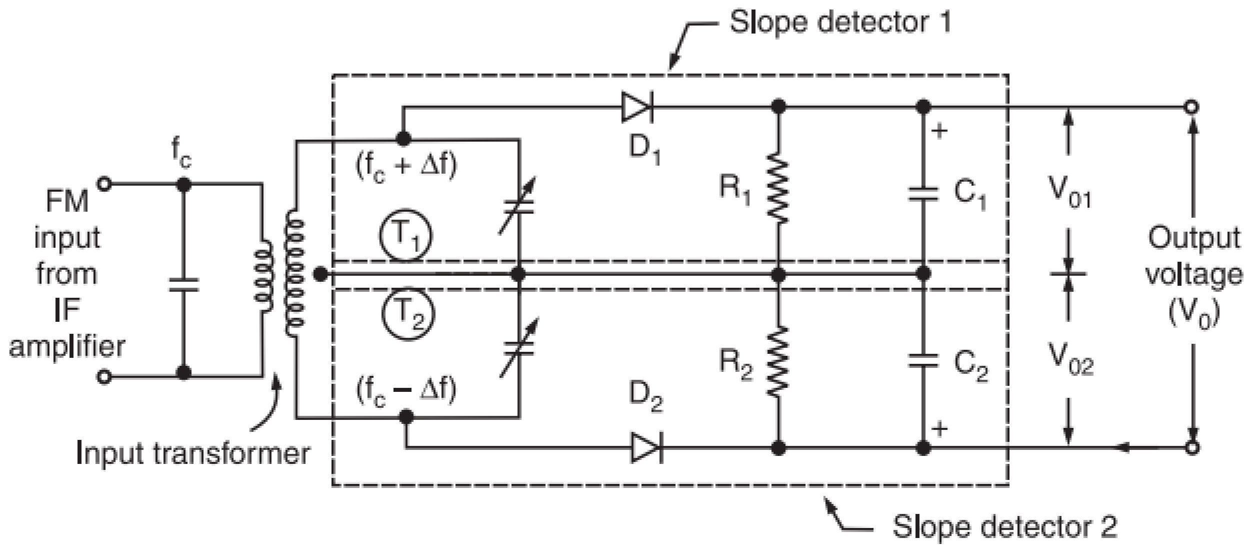


Figure 2.5.2 Balanced slope Detector

Diagram Source Electronics Post

As shown in the circuit diagram, the balanced slope detector consists of two slope detector circuits.

The input transformer has a center tapped secondary. Hence, the input voltages to the two slope detectors are 180° out of phase. There are three tuned circuits,Out of them, the primary is tuned to IF i.e., fc .

The upper tuned circuit of the secondary (T1) is tuned above fc by Δf i.e., its resonant frequency is (fc+ Δf). The lower tuned circuit of the secondary is tuned below fc by Δf i.e., at (fc – Δf). R1C1 and R2C2 are the filters used to bypass the RF ripple. Vo1 and Vo2 are the output voltages of the two slope detectors. The final output voltage Vo is obtained by taking the subtraction of the individual output voltages, Vo1 and Vo2, i.e.,

$$V_0 = V_{01} - V_{02} \quad (1)$$

We know that the equation of FM wave is

$$s(t)=A_c\cos(2\pi f_c t+2\pi k_f\int m(t)dt) \quad (2)$$

Differentiate the above equation with respect to 't'.

$$ds(t)/dt=-A_c(2\pi f_c+2\pi k_f m(t))\sin(2\pi f_c t+2\pi k_f\int m(t)dt) \quad (3)$$

We can write, $-\sin\theta$ as $\sin(\theta - 180^0)$

$$ds(t)/dt = A_c(2\pi f_c + 2\pi k_f m(t))\sin(2\pi f_c t + 2\pi k_f \int m(t)dt - 180^0$$

- In the above equation, the amplitude term resembles the envelope of AM wave and the angle term resembles the angle of FM wave. Here, our requirement is the modulating signal m(t)m(t). Hence, we can recover it from the envelope of AM wave.
- The following figure 2.5.3 shows the block diagram of FM demodulator using frequency discrimination method.

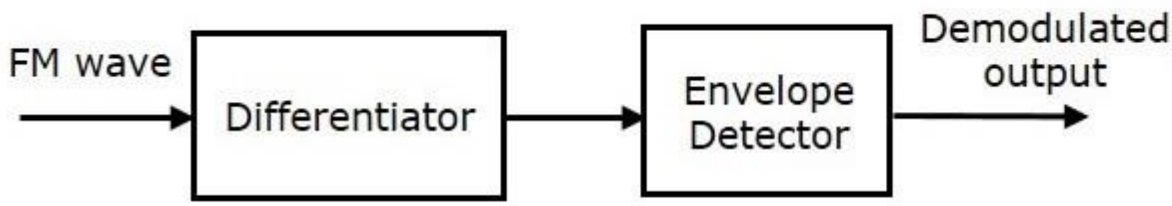


Figure 2.5.3 FM Demodulator using Frequency Discrimination method
Diagram Source Brain Kart

This block diagram consists of the differentiator and the envelope detector. Differentiator is used to convert the FM wave into a combination of AM wave and FM wave. This means, it converts the frequency variations of FM wave into the corresponding voltage (amplitude) variations of AM wave. We know the operation of the envelope detector. It produces the demodulated output of AM wave, which is nothing but the modulating signal.

Working Operation of the Circuit

The circuit operation can be explained by dividing the input frequency into three ranges as follows:

(i) **fin = fc:** When the input frequency is instantaneously equal to fc, the induced voltage in the T1 winding of secondary is exactly equal to that induced in the winding T2.

Thus, the input voltages to both the diodes D1 and D2 will be the same.

Therefore, their dc output voltages Vo1 and Vo2 will also be identical but they have opposite polarities. Hence, the net output voltage Vo = 0.

(ii) **fc < fin < (fc + Δf):** In this range of input frequency, the induced voltage in the winding T1 is higher than that induced in T2.

Therefore, the input to D1 is higher than D2. Hence, the positive output Vo1 of D1 is higher than the negative output Vo2 of D2. Therefore, the output voltage Vo is positive. As the input frequency increases towards (**fc + Δf**), the positive output voltage increases as shown below Figure. 2.5.4 .

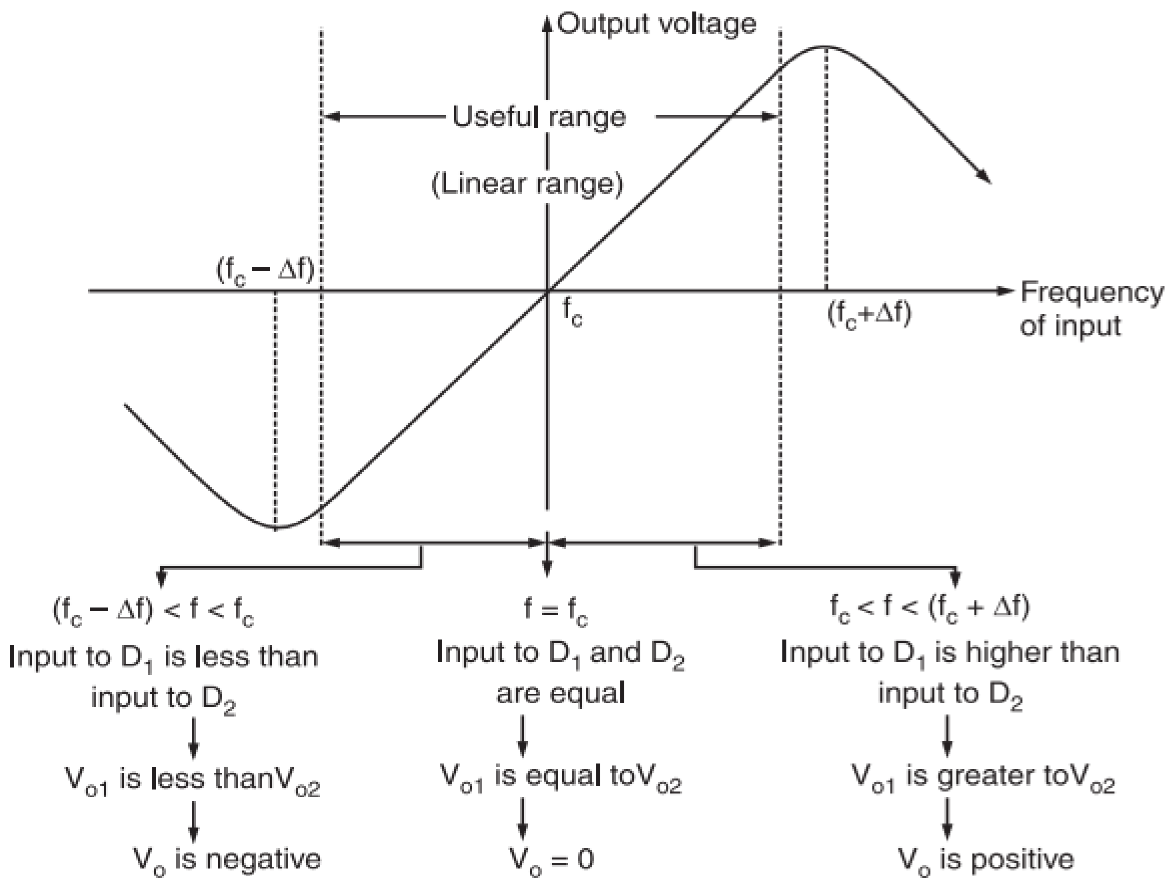


Fig. 2.5.4 Characteristics of the balanced slope detector

Diagram Source Electronics Post

If the output frequency goes outside the range of ($f_c - \Delta f$) to ($f_c + \Delta f$), the output voltage will fall due to the reduction in tuned circuit response.

Drawbacks of Slope Detector

- (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 winding of the transformer must be tuned to slightly different frequencies.

Advantages of Slope Detector

- The only advantages of the basic slope detector circuit is its simplicity.

Phase Discrimination Method (Foster Seeley FM Demodulator)

The following figure 2.5.5 shows the block diagram of FM demodulator using phase discrimination method.

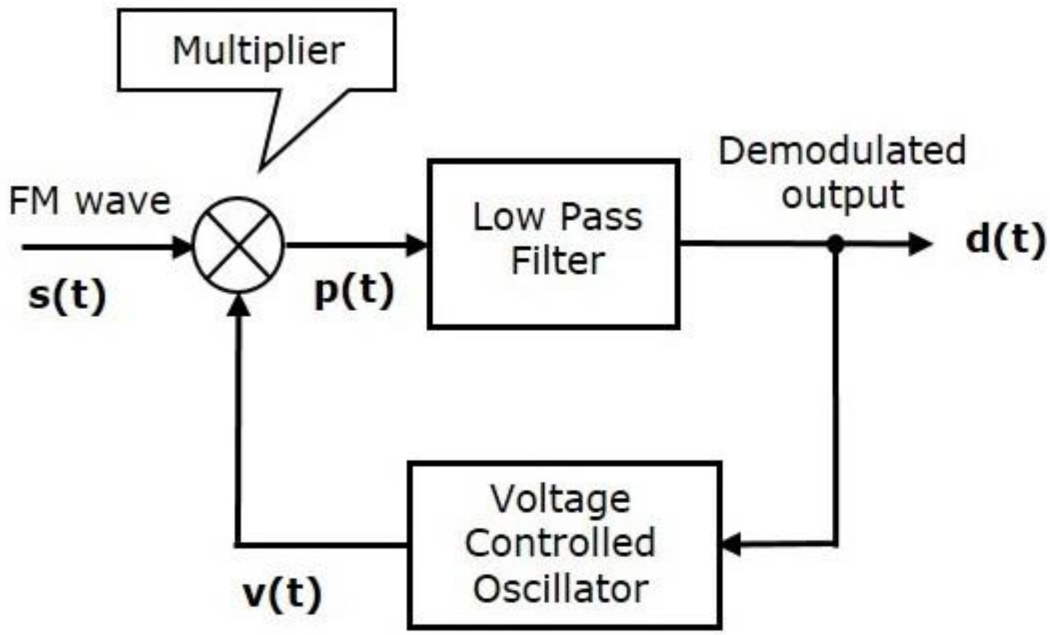


Figure 2.5.5 FM Demodulator using phase Discrimination method

Diagram Source Brain Kart

This block diagram consists of the multiplier, the low pass filter, and the Voltage Controlled Oscillator (VCO). VCO produces an output signal v(t)v(t), whose frequency is proportional to the input signal voltage d(t)d(t). Initially, when the signal d(t)d(t) is zero, adjust the VCO to produce an output signal v(t)v(t), having a carrier frequency and -90^{0}phase shift with respect to the carrier signal.

FM wave s(t)s(t) and the VCO output v(t)v(t) are applied as inputs of the multiplier. The multiplier produces an output, having a high frequency component and a low frequency component. Low pass filter eliminates the high frequency component and produces only the low frequency component as its output.

This low frequency component contains only the term-related phase difference. Hence, we get the modulating signal m(t) from this output of the low pass filter.

he Foster Seeley circuit is probably most commonly called the Foster Seeley discriminator. This is really a hang-over from early days of FM, and today the terms detector or probably better demodulator would probably be used.

The Foster Seeley discriminator circuit is characterised by the transformer, choke and diodes used within the circuit that forms the basis of its operation.

This FM demodulator circuit was invented by Dudley E. Foster and Stuart William Seeley in 1936. Although it was originally intended as a circuit to provide automatic frequency control, it was more widely used as an FM demodulator, whilst also being able to provide a voltage for automatic frequency control.

The Foster Seeley circuit was widely used until the 1970s when ICs using other techniques that were more easily integrated became widely available.

The circuit was widely used for all forms of radio communications applications from broadcasting to two way radio communications.

Foster-Seeley FM discriminator basics

The Foster Seeley detector or as it is sometimes described the Foster Seeley discriminator is quite similar to the ratio detector at a first look. It has an RF transformer and a pair of diodes, but there is no third winding - instead a choke is used.

FM Foster Seeley discriminator / detector circuit

In many respects the Foster Seeley FM demodulator resembles the circuit of a full wave bridge rectifier - the format that uses a centre tapped transformer, but additional components are added to give it a frequency sensitive aspect.

The basic operation of the circuit can be explained by looking at the instances when the instantaneous input equals the carrier frequency, the two halves of the tuned transformer circuit produce the same rectified voltage and the output is zero. If the frequency of the input changes, the balance between the two halves of the transformer secondary changes, and the result is a voltage proportional to the frequency deviation of the carrier.

Looking in more detail at the circuit, the Foster-Seeley circuit operates using a phase difference between signals. To obtain the different phased signals a connection is made to the primary side of the transformer using a capacitor, and this is taken to the centre tap of the transformer. This gives a signal that is 90° out of phase.

When an un-modulated carrier is applied at the centre frequency, both diodes conduct, to produce equal and opposite voltages across their respective load resistors. These voltages cancel each one another out at the output so that no voltage is present. As the carrier moves off to one side of the centre frequency the balance condition is destroyed, and one diode conducts more than the other. This results in the voltage across one of the resistors being larger than the other, and a resulting voltage at the output corresponding to the modulation on the incoming signal.

The choke is required in the circuit to ensure that no RF signals appear at the output. The capacitors C1 and C2 provide a similar filtering function.

Both the ratio detector and Foster-Seeley detectors are expensive to manufacture. Any wound components like the RF transformers are expensive to manufacture when compared with integrated circuits produced in vast numbers. As a result the Foster Seeley discriminator as well as the ratio detector circuits are rarely used in modern radio receivers as FM demodulators.

Foster Seeley circuit for frequency control

Prior to the introduction of very stable local oscillators within superhet radios - the universal format for radios receiving FM, local oscillators had a tendency to drift. Drift was a major factor in domestic radio receivers, although it was present in all radios.

When receiving FM signals the drift meant that the incoming FM signal might drift away from being at the centre of the FM detector slope onto the non-linear portions. This meant that the signal would become distorted.

To overcome this, radio receivers would incorporate a facility known as automatic frequency control was implemented. Using this, the DC offset from the FM demodulator is used to tune the receiver local oscillator to bring it back on frequency.

FM demodulator curve produces

A DC offset is produced when the centre frequency of the carrier is not on the centre of the demodulator curve. By filtering off the audio, only a DC component remains. Typically a long time constant RC combination is used to achieve this was shown in the figure 2.5.6. The time constant of this RC network can be quite long as the drift of the oscillator occurs gradually over a period of seconds, and it must also be longer than that of the lowest frequency of the audio.

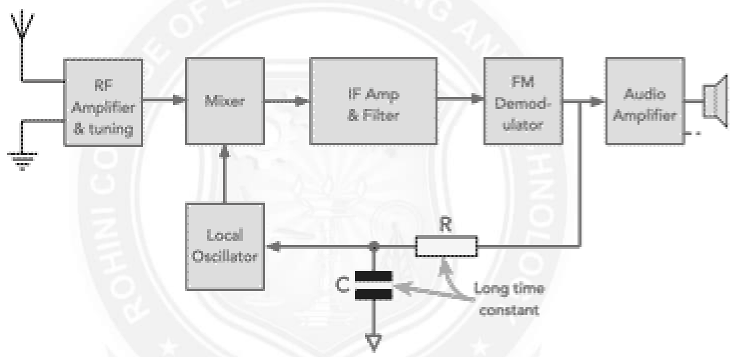


Fig 2.5.6 AFC circuitry for a super heterodyne radio receiver

Diagram Source Electronics Post

The filtered voltage is applied to a varactor diode within the local oscillator such that it causes the local oscillator to remain on tune for the FM signal being received. In this way the receiver can operate so that the signal being received is demodulated within the linear region of the FM demodulator.

Essentially the effect of the AFC circuitry is to create a form of negative feedback loop that seeks to keep the centre of the FM signal at the centre of the FM demodulation S curve. It is essentially a frequency locked loop.

Most radios used for FM reception that have free running local oscillators incorporate an automatic frequency control, AFC circuit. It uses only a few components and it provides for a significant improvement in the performance of the receiver, enabling the FM signal to be demodulated with minimum distortion despite the drift of the local oscillator signal.

Prior to the widespread introduction of frequency synthesizers, AFC was not always used in radios such as walkie talkies and handhelds radios aimed at for two way radio communications applications as they tended to use crystal controlled oscillators and these did not drift to any major degree. Hence there was less requirement for an AFC. It uses a double-tuned RF transformer to convert frequency variations in the received fm signal to amplitude variations. These amplitude variations are then rectified and filtered to provide a dc output voltage. This voltage varies in both amplitude and polarity as the input signal varies in frequency.

The output voltage is 0 when the input frequency is equal to the carrier frequency (FR). When the input frequency rises above the center frequency, the output increases in the positive direction. When the input frequency drops below the center frequency, the output increases in the negative direction. The output of the Foster-Seeley discriminator is affected not only by the input frequency, but also to a certain extent by the input amplitude. Therefore, using limiter stages before the detector is necessary.

Circuit Operation of a Foster-Seeley Discriminator

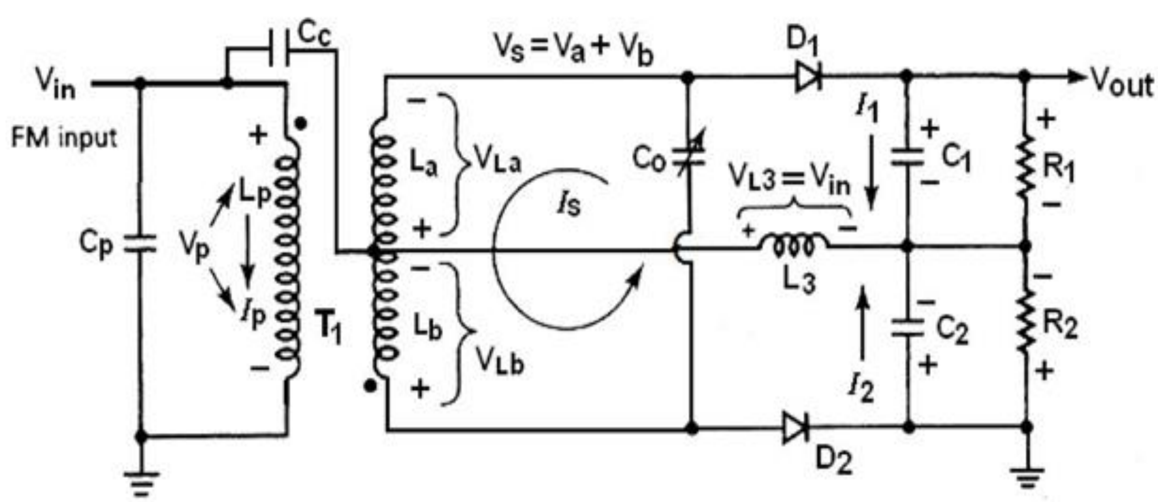


Fig 2.5.7 Circuit Operation of a Foster-Seeley Discriminator

Diagram Source Electronics Post

- Fig. shows a typical Foster-Seeley discriminator. The primary tank circuit consists of C1 and L1. C2 and L2 form the secondary tank circuit. Both tank circuits are tuned to the center frequency of the incoming fm signal.
- Choke L3 is the dc return path for diode rectifiers D1 and D2. Resistors R3 and R4 are the load resistors and are bypassed by C3 and C4 to remove rf.
- To obtain the different phased signals a connection is made to the primary side of the transformer using a capacitor, and this is taken to the centre tap of the transformer. This gives a signal that is 90° out of phase.
- When an un-modulated carrier is applied at the centre frequency, both diodes conduct, to produce equal and opposite voltages across their respective load resistors. These voltages cancel each one another out at the output so that no voltage is present.
- As the carrier moves off to one side of the centre frequency the balance condition is destroyed, and one diode conducts more than the other. This results in the voltage across one of the resistors being larger than the other, and a resulting voltage at the output corresponding to the modulation on the incoming signal.
- The choke is required in the circuit to ensure that no RF signals appear at the output. The capacitors C1 and C2 provide a similar filtering function.
- The operation of the Foster-Seeley discriminator can best be explained using vector diagrams fig. 3 that show phase relationships between the voltages and currents in the circuit. Let's look at the phase relationships when the input frequency is equal to the center frequency of the resonant tank circuit.

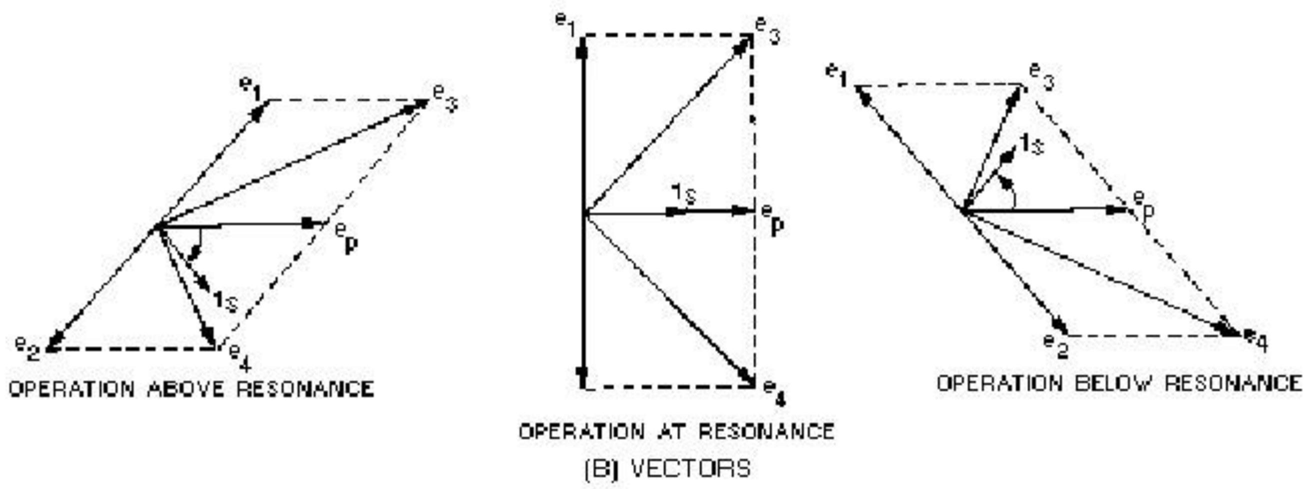


Fig.2.5.8 Phasor diagram of foaster seeley discriminator - Typical discriminator response
Diagram Source Electronics Post

Advantages of Foster-Seeley FM discriminator:

- Offers good level of performance and reasonable linearity.
- Simple to construct using discrete components.
- Provides higher output than the ratio detector
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- Simple to construct using discrete components.
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- This circuit is more efficient than simple slope detector.
- It has better linearity than the simple slope detector.

Disadvantages of Foster-Seeley FM discriminator:

- Does not easily lend itself to being incorporated within an integrated circuit.
- High cost of transformer.
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- Does not easily lend itself to being incorporated within an integrated circuit.
- High cost of transformer.

- Narrower bandwidth than the ratio detector
- The circuit is sensitive to both frequency and amplitude and therefore needs a limiter before it to remove amplitude variations and hence amplitude noise.
- (i) Even though linearity is good, it is not good enough.
- (ii) This circuit is difficult to tune since the three tuned circuits are to be tuned at different frequencies i.e., fc, (fc+Δf) and (fc – Δf).
- (iii) Amplitude limiting is not provided.