**Angle modulation**

As previously stated, there are three properties of an analog signal that can be varied (modulated) by the information signal. Those properties are amplitude, frequency, and phase**.** The carrier wave is given by:

(1)

We already know that, when, the amplitude of the carrier, is varied in accordance with the modulating wave, it is called amplitude modulation (AM).

When, the carrier frequency ) is varied in accordance with the modulating wave, it is called frequency modulation (FM). When, the phase angle () of the carrier, is varied in accordance with the modulating wave, it is called phase modulation (PM). The phase term and the frequency term () are part of the angular term of the carrier wave, the PM and FM are together called **Angle modulation.**

**Basic Principles of Frequency Modulation (FM):**

In FM, the carrier amplitude remains constant and the carrier frequency is changed by the modulating signal. As the amplitude of the information signal varies, the carrier frequency shifts proportionately. As the modulating signal amplitude increases, the carrier frequency increases. If the amplitude of the modulating signal decreases, the carrier frequency decreases.

[The reverse relationship can also be implemented. A decreasing modulating signal increases the carrier frequency above its center value, whereas an increasing modulating signal decreases the carrier frequency below its center value].

As the modulating signal amplitude varies, the carrier frequency varies above and below its normal center, or *resting,* frequency with no modulation. The amount of change in carrier frequency produced by the modulating signal is known as the *frequency deviation fd*. Maximum frequency deviation occurs at the maximum amplitude of the modulating signal. The frequency of the modulating signal equals the frequency deviation rate.

If the modulating signal is a 500-Hz sine wave, the carrier frequency shifts above and below the center frequency 500 times per second.

Assume a carrier frequency of 150 MHz. If the peak amplitude of the modulating signal causes a maximum frequency shift of 30 kHz, the carrier frequency will deviate up to 150.03 MHz and down to 149.97 MHz. The total frequency deviation is 150.03 − 149.97 5 0.06 MHz 5 60 kHz. In practice, however, the frequency deviation is expressed as the amount of frequency shift of the carrier above or below the center frequency. Thus, the frequency deviation for the 150-MHz carrier frequency is represented as 630 kHz. This means that the modulating signal varies the carrier above and below its center frequency by 30 kHz. Note that the frequency of the modulating signal has no effect on the *amount* of deviation, which is strictly a function of the amplitude of the modulating signal.

|  |
| --- |
|  |
| **Fig-1a: modulating sigmal (information)** |
|  |
| **Fig-1b: Carrier wave** |
|  |
| **Fig-1c : frequency modulated wave** |

The fig.1 shows the modulating signal, the carrier and the frequency modulated wave.

**THEORY of Frequency Modulation: (ref: Kennedy)**

*Frequency modulation* is a system in which the amplitude of the modulated carrier is kept constant, while its frequency and rate of change are varied by the modulating signal. Let the message signal be given by:

(1)

The general equation of an unmodulated carrier may be written as . (2)

where instantaneous value (of voltage or current)

(maximum) amplitude

angular velocity, radians per second (rad/s)

phase angle, rad

Note that represents an angle in radians.

By the definition, of frequency modulation., the amount by which the carrier frequency is varied from its unmodulated value, called *the frequency deviation,* is made *proportional to the instantaneous amplitude of the modulating voltage.* The rate at which this frequency variation takes place is equal to the modulating frequency. *The amplitude of the.frequency modulated wave remains constant at all times.* This is the greatest advantage of FM.

***Mathematical Representation of FM.***

The instantaneous frequency /of the frequency modulated wave is given by: (3)

Where, ( is unmodulated carrier frequency, is proportionality constant expressed in Hz/volt and instantaneous modulating voltage.

The maximum deviation for this signal will occur when the sine term, has its maximum value, ± I. Under these conditions, the instantaneous frequency will be . (4)

so that the maximum deviation will be given by : (5)

The instantaneous amplitude of the FM signal will be given by a formula of the form:

(6)

Where, is some function of the carrier and modulating frequencies. This function represents an angle and will be called for convenience. The problem now is to determine the instantaneous value (i.e., formula) for this angle.

As Fig. 2 shows, is the angle traced by the vector in time t. If *,* were rotating with a constant angular velocity, for example*,* this angle would be given by (in radians). In this instance. the angular velocity is anything but constant. It is governed by the formula for m obtained from Equation (3), that is, Formula) for this angle : (7)

|  |  |
| --- | --- |
| FIG-2 | In order to find must be integrated with respect to time. Thus,      Put,  (8) |

Therefore, using eqn. (6) and (8) we get,

(9)

The modulation index for FM, is defined as: (10)

Substituting Equation ( 4.10) into ( 4.9), we obtain, (11)

It is interesting to note that as the modulating frequency decreases and the modulating voltage amplitude remains constant, the modulation index increases. It will be the basis for distinguishing frequency modulation from phase modulation. Note that  *,* which is the ratio of two frequencies, is a dimensionless quantity in case of FM.

**Principles of Phase Modulation**

*Phase modulation* is a system in which the amplitude of the modulated carrier is kept constant, while its phase and rate of phase change are varied by the modulating signal. By the definition of phase modulation, the amount by which the carrier phase is varied from its unmodulated value, called the *phase deviation,* is made *proportional* to the *instantaneous amplitude* of the *modulating voltage.* The rate at which this phase variation changes is equal to the modulating frequency. The situation is illustrated in Fig. 3, which shows the modulating voltage and the resulting phase modulated wave. The figure also shows the phase variation with time, which can be seen to be the phase shifted version of the variation with time of the modulating voltage. The result of using that modulating voltage to produce FM is also shown for comparison. In PM, all components of the modulating signal having the same amplitude will deviate the carrier phase by the same amount. Similarly, all components of the modulating signal of the same frequency, will deviate the carrier phase at the same rate per second, no matter what their individual amplitudes. *As in the case of FM, the amplitude of the phase modulated wave remains constant at all times.*

|  |
| --- |
| FIG-3a : message |
| FIG-3b : carrier carrier |
| FIG-3c : FM |
| FIG-3c : PM |
|  |

FIG-3: *PM and FM Signals. (a) Message, (b) Carrier, (c) PM and (d) FM (e) Phase deviation*

*It can also be observed from the figure that, if only either FM or PM waves are given without reference* message signal, then it is not possible to distinguish between the two. This is the close proximity between the two forms of angle modulation. Hence in all further studies only FM will be dealt in detail. The observations can be easily mapped to PM.

***Mathematical Representation of PM.***

From the definition of Phase modulation, let us assume that, a phase shifter can be built that will cause the amount of phase shift to vary with the amplitude of the modulating signal. The greater the amplitude of the modulating signal, the greater the phase shift. Assumed further that positive alternations of the modulating signal produce a lagging phase shift and negative signals produce a leading phase shift.

So, we can write that the instantaneous phase of the phase modulated wave is given by:

. (12)

Where, is unmodulated (or average) carrier phase, proportional constant expressed in radians/volt and is the phase shifted version of instantaneous modulating voltage. The maximum deviation for this signal will occur when the cosine term has its maximum value, i.e Under these conditions, the instantaneous phase will be: (13)

so the maximum deviation of phase, will be given by : (14)

The instantaneous amplitude of the PM signal will be given by a formula of the form:

(15)

Where, is some function of the carrier and modulating phase values. This function along with represents an angle and will be called for convenience. The problem now is to determine the instantaneous value (i.e., formula) for this angle. It is governed by the formula for obtained from Equation (12) and can be directly written.

Therefore is given by: (16)

The modulation index for PM, is defined as : (17)

Note that the modulation index of PM is expressed in radians. Substituting Equation ( 17) into (16), we

obtain (18)

It is interesting to note that the modulation index of PM depends only on the modulating voltage and

independent of the modulating frequency. Hence the basis for distinguishing phase modulation from frequency modulation. Note that is measured in radians.

**Comparison of Frequency and Phase Modulation:**

From the purely theoretical point of view, the difference between FM and PM is quite simple. The modulation index is defined differently in each system. However, this is not nearly as obvious as the difference between AM and FM, and it must be developed further. First, the similarity will be stressed.

**SIMILARITIES:**

In phase modulation, the phase deviation is proportional to the amplitude of the modulating signal and therefore independent of its frequency. Also, since the phase-modulated vector sometimes leads and sometime lags the reference carrier vector, its instantaneous angular velocity must be continually changing between the limits imposed by *;* thus some form of frequency change must be taking place. In frequency modulation, the frequency deviation is proportional to the amplitude of the modulating voltage. Also, if we take a reference vector, rotating with a constant angular velocity which corresponds to the carrier frequency, then the FM vector will have a phase lead or lag with respect to the reference, since its frequency oscillates between Therefore FM must be a form of PM. With this close similarity of the two forms of angle modulation established, it now remains to explain the difference.

**DIFFERENCES**

lf we consider FM as a form of phase modulation, we must determine what causes the phase change in FM. The larger the frequency deviation, the larger the phase deviation, so that the latter depends at least to a certain extent on the amplitude of the modulation, just as in PM. The difference is shown by comparing the definition of PM, which states in part that the modulation index is proportional to the modulating voltage only, with that of the FM, which states that the modulation index is also inversely proportional to the modulation frequency. This means that under identical conditions FM and PM are indistinguishable for a single modulating frequency. This is because, under constant modulating frequency, both frequency and phase deviations are only dependent on modulating voltage. When the modulating frequency is changed the PM modulation index will remain constant, whereas the FM modulation index will increase as modulation frequency is reduced and vice versa.

As a final point, except for the way of defining modulation index, there is no difference between FM and PM.

**PERCENT MODULATION**

The percent modulation for an angle-modulated wave is determined in a different manner than it was with an amplitude-modulated wave. With angle modulation, percent modulation is simply the ratio of the frequency deviation actually produced to the maximum frequency deviation allowed by law stated in percent form. Mathematically, percent modulation is

(19)

**Example**, in the United States, the Federal Communications Commission (FCC) limits the frequency deviation for commercial FM broadcast-band transmitters to ±75 kHz. If a given modulating signal produces 50-kHz frequency deviation, the percent modulation is:

**Frequency Spectrum of the FM Wave**

In AM theory, we have the expression of instantaneous voltage of AM signal. From this it was possible to tell at a glance which frequencies were present in the modulated wave.

Unfortunately, the situation is far more complex, mathematically speaking, for FM. Since the instantaneous voltage of FM signal is the sine of cosine given by equation (18) ,

. (18)

From Equation (18), the individual frequency components that make up the modulated wave are not obvious. However, *Bessel function identities* are available that may **be** applied directly. One such identity is: (20)

Using these, it may then be shown that the instantaneous voltage expression of FM signal may be

expanded to yield:

(21)

It can be shown that the output consists of a carrier and an apparently infinite number of pairs of sidebands, each preceded by *J* coefficients. These are Bessel functions. In order to evaluate the value of a given pair of sidebands or the value of the carrier, it is necessary to know the value of the corresponding Bessel function. Separate calculation from above equation is not required since information of this type is freely available in table form, as in Table-1, or graphical form, as in Fig. 4.



TABLE-1



Fig-4

**Observations:**

The mathematics of the previous discussion may be reviewed in a series of observations as follows:

I. Unlike AM, where there are only three frequencies (the carrier and the first two sidebands), *FM has an infinite number of sidebands,* as well as the carrier. They are separated from the carrier by *.* and thus have a recurrence frequency of

2. The *J* coefficients eventually decrease in value as n increases, but not in any simple manner. As seen in fig. 4, the value fluctuates on either side zero, gradually diminishing. Since each *J* coefficient represents the amplitude of a particular pair of sidebands, these also eventually decrease, but only past a certain value *n. The modulation index determines how many sideband components have significant amplitudes.*

3. The sidebands at equal distances from have equal amplitudes, so that the sideband distribution is symmetrical about the carrier frequency. The *J* coefficient occasionally have negative values, signifying a 180° phase change for that particular pair of sidebands.

4. Looking down Table.1 , as , increases, so does the value of a particular *J* coefficient, such as . Bearing in mind that is inversely proportional to the modulating frequency, we see that the relative amplitude of distant sidebands increases when the modulation frequency is lowered, The previous statement assumes that deviation (i.e., the modulating voltage) has remained constant.

5. In AM. increased depth of modulation increases the sideband power and therefore the total transmitted power. In FM, the total transmitted power always remains constant, but with increased depth of modulation the required bandwidth is increased. To be quite specific, what increases is the bandwidth required to transmit a relatively undistorted signal. This is true because increased depth of modulation means increased deviation, and therefore an increased modulation index, so that more distant sidebands acquire significant amplitudes.

6. As evidenced by Equation (20), the theoretical bandwidth required in FM is infinite. In practice , the bandwidth used is one that has been calculated to allow for all significant amplitudes of the sideband components under the most exacting conditions. This really means ensuring that, with maximum deviation by the highest modulating frequency, no significant sideband components are lopped off.

7. In FM, unlike in AM, the amplitude of the carrier component does not remain constant. Its J coefficient

Is which is a function of . This may sound somewhat confusing but keeping the overall amplitude

of the FM wave constant would be very difficult if the amplitude of the carrier wave were not reduced

when the amplitude of the various sidebands increased.

8. It is possible for the carrier component of the FM wave to disappear completely. This happens for certain

values of modulation index, called *eigenvalues.* Figure 4 shows that these are approximately 2.4, 5.5, 8.6, 11.8, and so on. These disappearances of the carrier for specific value a handy basis for measuring deviation.

***Bandwidth and Required Spectra***

Using Table 1 , it is possible to evaluate the size of the carrier and each sideband for each specific value of the modulation index. When this is done, the frequency spectrum of the FM wave for that particular value of may be plotted. This is done i n Fig. 5, which shows these spectrograms first for increasing deviation constant), and then for decreasing modulating frequency (). Both the table and the spectrogram illustrate the observations, especially points 2, 3, 4 and 5. It can be seen that as modulation depth increases, so does bandwidth (Fig. *5a).* and also that reduction in modulation frequency increases the number of sidebands, though not necessarily the bandwidth (Fig. 5b). Another point shown very clearly is that although the number of sideband components is theoretically infinite, in practice a lot of the higher sidebands have insignificant relative amplitudes, and this is why they are not shown in the spectrogram. Their exclusion in a practical system will not distort the modulated wave unduly.



FIG-5.

**Example:**

What is the bandwidth required for an FM signal in which the modulating frequency is 2 kHz and the maximum deviation is 10 kHz?

**Solution**

From Table 1 , it is seen that the highest *J* coefficient included for this value of is  *.* This means that

ail higher values of Bessel functions for that modulation index have values less than 0.01 and may therefore be ignored. *The eighth pair of sidebands is the furthest from the carrier to be included in this instance.* This gives

highest needed sideband x 2

.. 2 kHz X 8 X 2 = 32 kHz.

[A rule of thumb (Carson's rule) states that (as a good approximation) the bandwidth required to pass an

FM wave is twice the sum of the deviation and the highest modulating frequency, but it must be remembered that this is only an approximation. Actually, it does give a fairly accurate result if the modulation index is in excess of about 6.

**4.2.2 Narrowband and Wideband FM**

Depending on the bandwidth occupied by the FM for practical transmission, FM is classified into *narrowband and wideband* cases. The bandwidth is also directly proportional to the modulation index value, Therefore by convention, wideband FM has been defined as that in which modulation index normally exceeds unity. Since the maximum pennissible deviation is 75 kHz and modulating frequencies range from 30 Hz to 15 kHz. The maximum modulation index ranges from S to 2500. The modulation index in narrowband FM is near unity, since the maximum modulating frequency there is usually 3 kHz, and the maximum deviation is typically *5* kHz.

The proper bandwidth to use in an FM system depends on the application. With a large deviation, noise willbe better supressed (as will other interference), but care must be taken to ensure that impulse noise peaks do not become excessive. On the other hand, the wideband system will occupy up to 15 times the bandwidth of the narrowband system. These considerations have resulted in wideband systems being used in entertainment broadcasting, while narrowband systems are employed for communications. Thus narrowband FM is used by the so called FM mobile communications services. These include police, ambulances, taxicabs, radio-controlled appliance repair services and short range VHF ship-to-shore services. The higher audio frequencies are attenuated, as indeed they are in most carrier (long distance) telephone systems, but the resulting speech quality is still perfectly adequate. Maximum deviation of *5* to IO kHz are pennitted, and the channel space is not much greater than for AM broadcasting, i.e., of the order of 15 to 30 kHz. Narrowband systems with even lower maximum deviations are envisaged

**GENERATION OF FREQUENCY MODULATION**

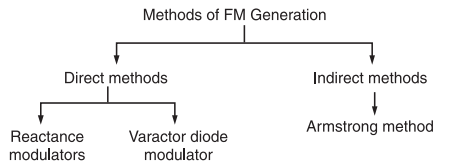
The prime requirement of a frequency modulation system is a variable output frequency, with the variation proportional to the instantaneous amplitude of the modulating voltage. The subsidiary requirements are that the unmodulated frequency should be constant, and the deviation independent of the modulating frequency.

The FM modulator circuits used for generating FM signals can be divided into two categories such as:

**(i) The direct method or parameter variation method**

**(ii) The Indirect method or the Armstrong method**

The classification of FM generation methods is shown below :



**The Direct Method or Parameter Variation Method**

In direct method or parameter variation method, the baseband or modulating signal directly modulates the carrier.

The carrier signal is generated with the help of an oscillator circuit.

This oscillator circuit uses a parallel tuned L-C circuit.

Thus the frequency of oscillation of the carrier generation is governed by the expression:

Now, we can make the carrier frequency ωc to vary in accordance with the baseband or modulating signal if L or C is varied according to .

An oscillator circuit whose frequency is controlled by a modulating voltage is called **voltage controlled oscillator** **(VCO)**.

The frequency of VCO is varied according to the modulating signal simply by putting a shunt voltage variable capacitor with its tuned circuit.

This voltage variable capacitor is called **varactor** or **varicap.**

This type of property is exhibited by reverse biased semiconductor diodes. Also the capacitance of bipolar junction transistors (BJT) and field-effect transistors (FET) is varied by the Miller-effect. This miller capacitance may be utilized for frequency modulation. In addition to this, the electron tubes may also provide variable reactance (either it is inductive or capacitive) which is proportional to modulating or baseband signal. This type of tubes are called reactance tubes and may be used for FM generation.

The inductance L of the tuned circuit may also be varied in accordance with the baseband or modulating signal .

The FM circuit using such inductors is called **saturable reactor modulator**.

Frequency modulation can also be achieved from voltage controlled devices such as P**IN diode, (**A **PIN diode** is a [diode](https://en.wikipedia.org/wiki/Diode) with a wide, undoped [intrinsic semiconductor](https://en.wikipedia.org/wiki/Intrinsic_semiconductor) region between a [p-type semiconductor](https://en.wikipedia.org/wiki/P-type_semiconductor) and an [n-type semiconductor](https://en.wikipedia.org/wiki/N-type_semiconductor) region. The p-type and n-type regions are typically heavily [doped](https://en.wikipedia.org/wiki/Doping_(semiconductor)) because they are used for [ohmic contacts](https://en.wikipedia.org/wiki/Ohmic_contact" \o "Ohmic contact).**),Klystron oscillators**and**multivibrators.**

**Transistor/FET reactance modulator:**

One method of FM generation suggests itself immediately. If either the capacitance or inductance of an. *LC* oscillator tank is varied, frequency modulation of some form will result. If this variation can be made directly proportional to the voltage supplied by the modulation circuits, the FM will be obtained.

There are a number of devices whose reactance can be varied by the application of voltage. The three terminal ones include the-reactance field-effect transistor (FET), the bipolar transistor.

Of the various methods of providing a voltage-variable reactance which can be connected across the tank circuit of an oscillator, the most common are the reactance modulator.

**Generation of FM using VCO (voltage controlled oscillator):**

Oscillators whose frequencies are controlled by an external input voltage are generally referred to as *voltage-controlled oscillators (VCOs)*. *Voltage-controlled crystal oscillators* are generally referred to as *VXO*s. Although some VCOs are used primarily in FM, they are also used in other applications where voltage-to-frequency conversion is required. Although VCOs for VHF, UHF, and microwaves are still implemented with discrete components, more and more they are being integrated on a single chip of silicon along with other transmitter or receiver circuits. An example of such a VCO is shown

in Fig. 6 . This circuit uses silicon-germanium (Si-Ge) bipolar transistor to achieve an operating frequency centered near 10 GHz. The oscillator uses cross- coupled transistors *Q*1 and *Q*2 in a multivibrator or flip-flop type of design. The signal is a sine wave whose frequency is set by the collector inductances and varactor capacitances. The modulating voltage, usually a binary signal to produce FSK, is applied to the junction of *D*1 and *D*2.

|  |  |
| --- | --- |
|  | FIG-6 |

Two complementary outputs are available from the emitter followers *Q*3 and *Q*4. In this circuit, the inductors are actually tiny spirals of aluminum (or copper) inside the chip, with inductance in the 500- to 900-pH range. The varactors are reverse-biased diodes that function as variable capacitors. The tuning range is from 9.953 to 10.66 GHz.

There are also many different types of lower-frequency VCOs in common use, including IC VCOs using *RC* multivibrator-type oscillators whose frequency can be controlled over a wide range by an ac or dc input voltage. These VCOs typically have an operating range of less than 1 Hz to approximately 1 MHz. The output is either a square or a triangular wave rather than a sine wave. Fig. 6-9(*a*) is a block diagram of one widely used *IC VCO,* the popular *NE566.* External resistor *R*1 at pin 6 sets the value of current produced by the internal current sources. The current sources linearly charge and discharge external capacitor *C*1 at pin 7. An external voltage *VC* applied at pin 5 is used to vary the amount of current produced by the current sources. The *Schmitt trigger circuit* is a level detector that controls the

current source by switching between charging and discharging when the capacitor charges or discharges to a specific voltage level. A linear saw-tooth of voltage is developed across the capacitor by the current source. This is buffered by an amplifier and made available at pin 4. The Schmitt trigger output is a square wave at the same frequency available at pin 3. If a sine wave output is desired, the triangular wave is usually filtered with a tuned circuit resonant to the desired carrier frequency.

|  |  |
| --- | --- |
| FIG-(7a) | FIG-(7b) |

A complete frequency modulator circuit using the NE566 is shown in Fig. 7(*b*). The current sources are biased with a voltage divider made up of *R*2 and *R*3. The modulating signal is applied through *C*2 to the voltage divider at pin 5. The 0.001-*μ*F capacitor between pins 5 and 6 is used to prevent unwanted oscillations. The center carrier frequency of the circuit is set by the values of *R*1 and *C*1. Carrier frequencies up to 1 MHz may be used with this IC. If higher frequencies and deviations are necessary, the outputs can be filtered or used to drive other circuits, such as a frequency multiplier. The modulating signal can vary the carrier frequency over nearly a 10 :1 range, making very large deviations possible. The deviation is linear with respect to the input amplitude over the entire range.

**Frequency Demodulators**

Any circuit that will convert a frequency variation in the carrier back to a proportional

voltage variation can be used to demodulate or detect FM signals. Circuits used to

recover the original modulating signal from an FM transmission are called demodulators,

detectors, or discriminators.

**Slope Detectors:**

The simplest frequency demodulator, the *slope detector,* makes use of a tuned circuit and

a diode detector to convert frequency variations to voltage variations. The basic circuit

is shown in Fig. 8(a). This has the same configuration as the basic AM diode detector.

although it is tuned differently. The FM signal is applied to transformer *T*1 made up of *L*1 and *L*2. Together *L*2 and *C*1 form a series resonant circuit. Remember that the signal voltage induced into *L*2 appears

in series with *L*2 and *C*1 and the output voltage is taken from across *C*1. The response

curve of this tuned circuit is shown in Fig. 8(*b*). Note that at the resonant frequency *fr*

the voltage across *C*1 peaks. At lower or higher frequencies, the voltage falls off.

To use the circuit to detect or recover FM, the circuit is tuned so that the center or

carrier frequency of the FM signals is approximately centered on the leading edge of the

response curve, as shown in Fig. 8(*b*). As the carrier frequency varies above and below

its center frequency, the tuned circuit responds as shown in the figure. If the frequency

goes lower than the carrier frequency, the output voltage across *C*1 decreases. If the

frequency goes higher, the output across *C*1 goes higher. Thus, the ac voltage across *C*1

is proportional to the frequency of the FM signal. The voltage across *C*1 is rectified into

dc pulses that appear across the load *R*1. These are filtered into a varying dc signal that

is an exact reproduction of the original modulating signal.

The main difficulty with slope detectors lies in tuning them so that the FM signal is correctly

centered on the leading edge of the tuned circuit. In addition, the tuned circuit does not

have a perfectly linear response. It is approximately linear over a narrow range, as Fig. 8(*b*)

shows, but for wide deviations, amplitude distortion occurs because of the nonlinearity.

|  |
| --- |
| FIG-8a |
| FIG-8b |

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.

**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.

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

### Balanced FM Slope Detector (Balanced Frequency Discriminator)

|  |  |
| --- | --- |
| https://electronicspost.com/wp-content/uploads/2020/06/3-3.png | Balanced Slope Detector  Fig-9 |

The circuit diagram of the balanced slope detector is shown in Figure. 9.

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.,

#### 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 Vo1and 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 Vo1of 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 in Fig-10.

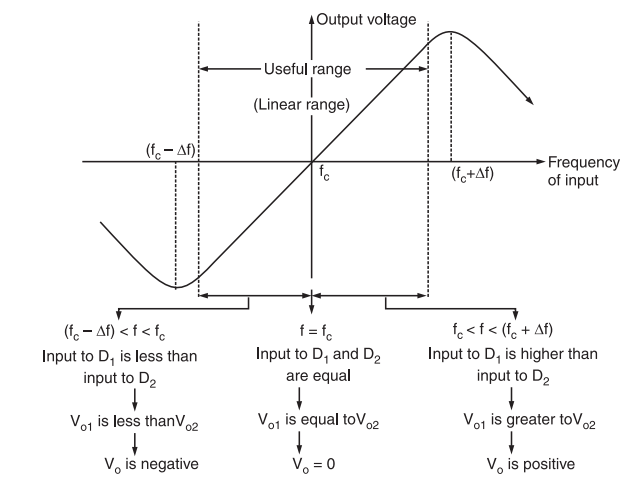


Fig -10: Characteristics of the balanced slope detector

If the output frequency goes outside the range of (fc – Δf) to (fc + Δf), the output voltage will fall due to the reduction in tuned circuit response.

#### Advantages

(i) This circuit is more efficient than simple slope detector.

(ii) It has better linearity than the simple slope detector.

#### Drawbacks

(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.