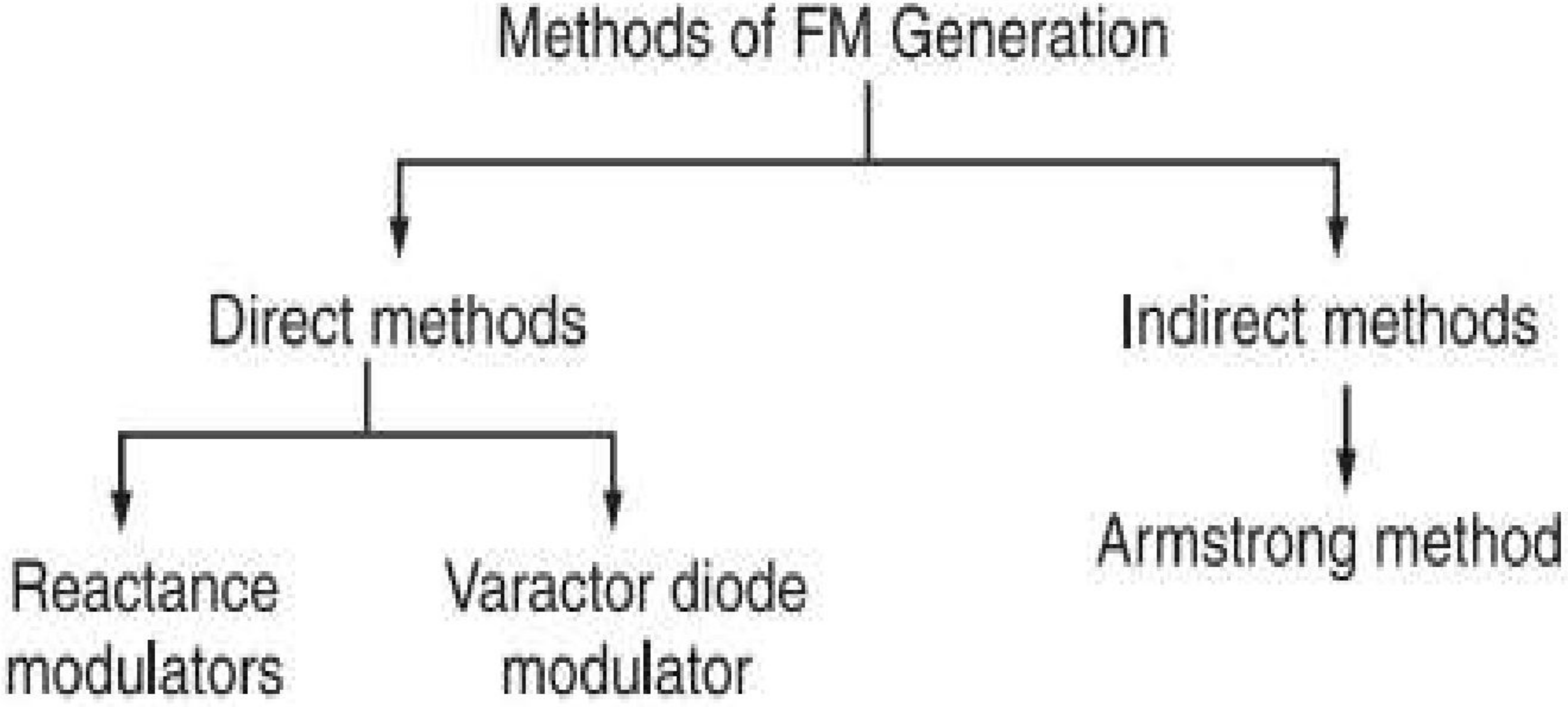
FM Generation

There are two methods for generation of FM wave.



- TWO types of FM Modulators –
- 1. Indirect FM – Modulation is obtained by phase modulation of the carrier.
  An instantaneous phase of the carrier is directly proportional to the amplitude of the modulating signal.
- 2. Direct FM- The frequency of carrier is varied directly by modulating signal.
  An instantaneous frequency variation is directly proportional to the amplitude of the modulating signal.

4.7 : FM/PM Modulators

- a phase modulator is a circuit in which the carrier instantaneous phase is proportional to the modulating signal.
- a frequency modulator is a circuit in which the carrier instantaneous phase is proportional to the integral of the modulating signal.

$$\text{PM modulator : } \quad \theta(t) \propto v(t)$$

$$\text{FM modulator : } \quad \theta(t) \propto \int v(t)$$

- considering the FM modulator, if the modulating signal is *v(t)* is differentiate before being applied to the FM modulator, the instantaneous phase is now proportional to the modulating signal (i.e. PM modulator).

$$\textbf{Differentiator + FM modulator} \quad = \theta(t) \propto \int \frac{dv(t)}{dt} = \theta(t) \propto v(t) = \textbf{PM modulator}$$

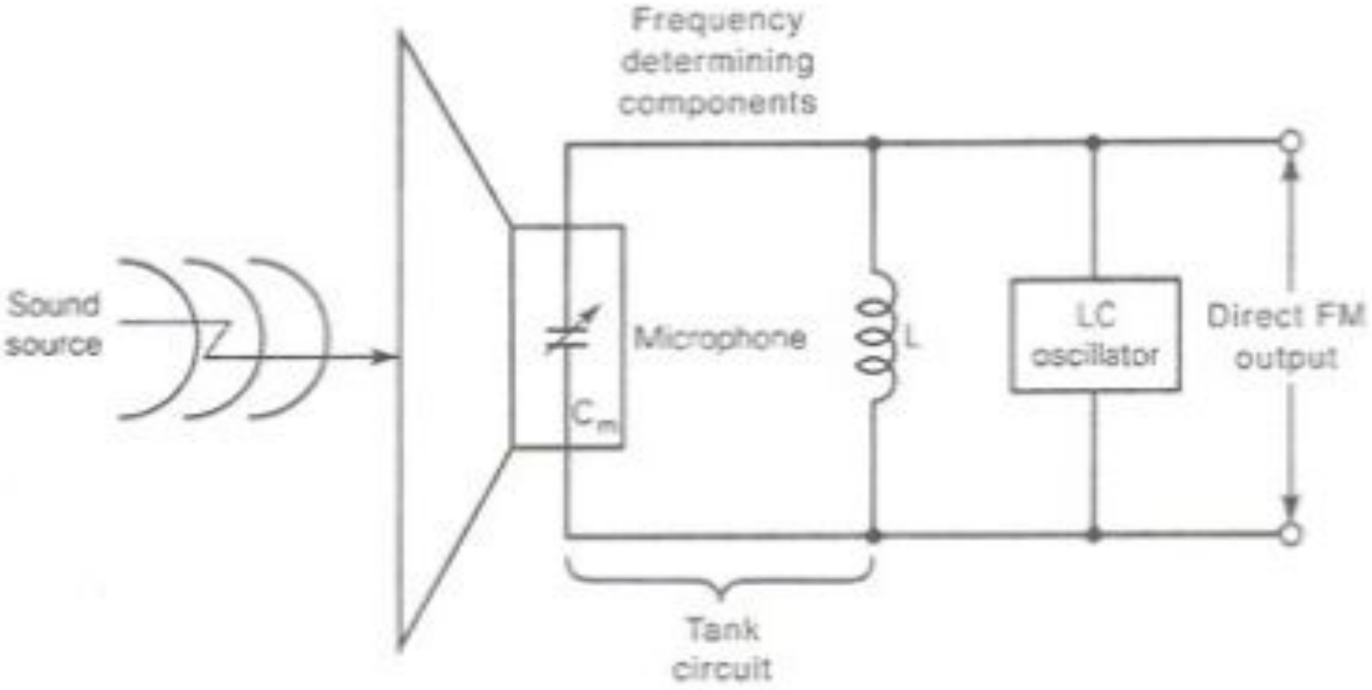
4.7 : FM/PM Modulators

- Meanwhile, if the modulating signal is integrated before being applied to the PM modulator, the instantaneous phase is now proportional to the integral of the modulating signal (i.e. FM modulator).

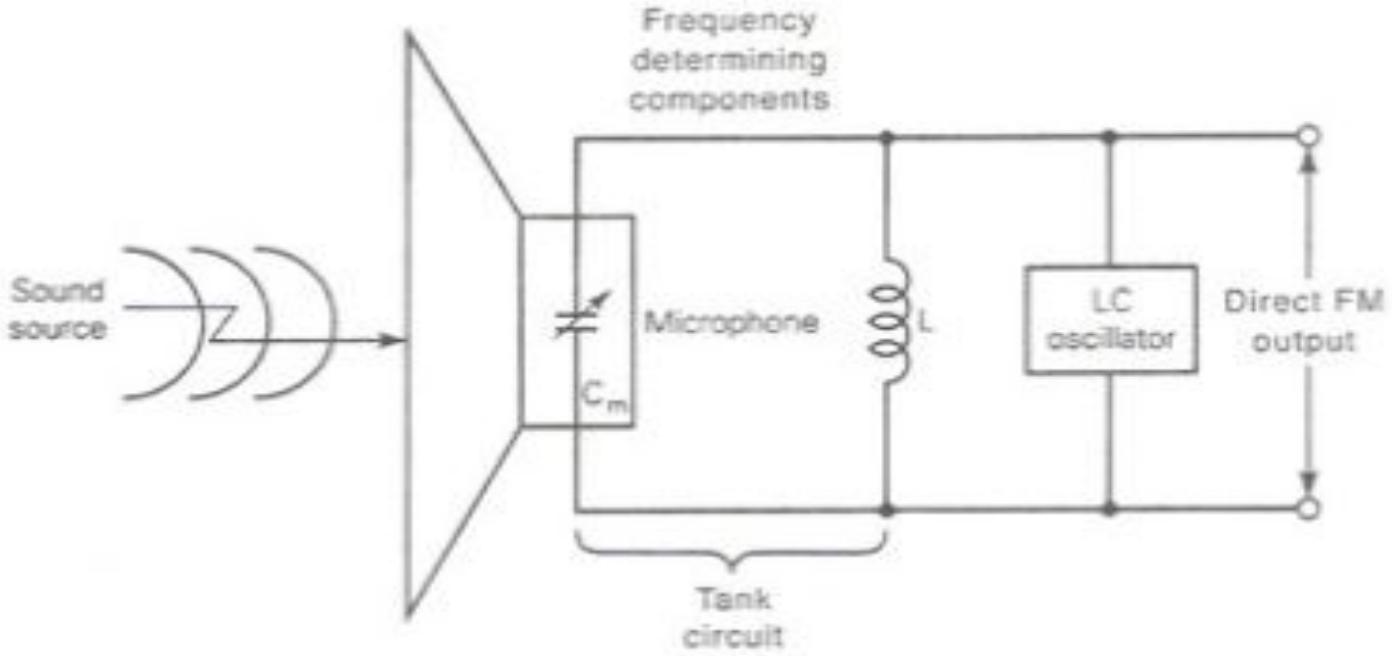
$$\textbf{Integrator + PM modulator} \quad = \quad \theta(t) \propto \int v(t) \ = \textbf{FM modulator}$$

4.7.1 : Direct FM Modulators

- with direct FM, the instantaneous frequency deviation is directly proportional to the amplitude of the modulating signal.
- schematic diagram of a simple direct FM generator :



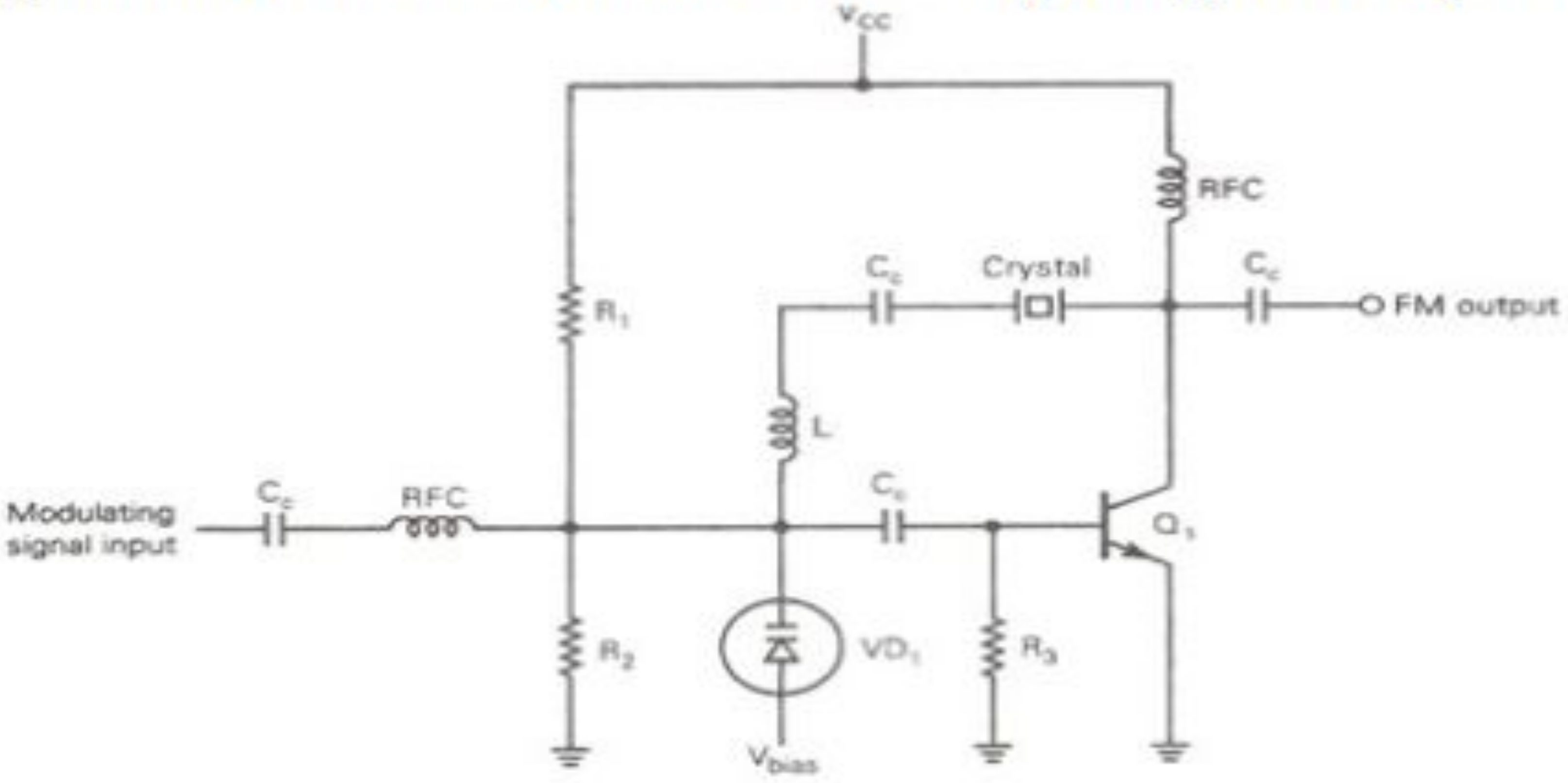
4.7.1 : Direct FM Modulators



- the tank circuit (L and C_m) is the frequency determining section for a standard LC oscillator.
- C_m is a capacitor microphone that converts the acoustical energy into a mechanical energy, which is used to vary the distance between the plates of C_m and consequently change its capacitance.
- as C_m is varied, the resonant frequency is varied. I.e. the oscillator output frequency varies directly with the external sound forces (i.e. direct FM).

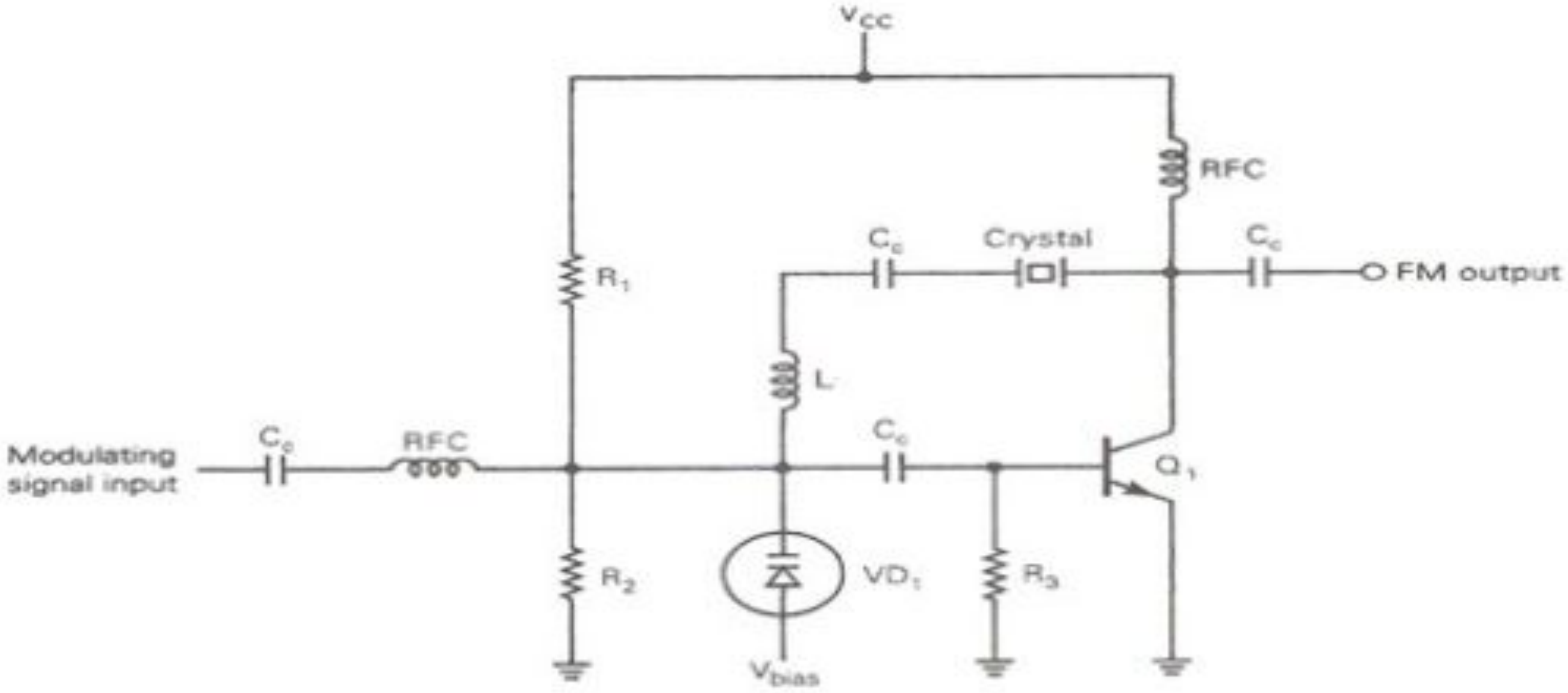
4.7.1.1 : Varactor diode modulator

- Direct FM generator using varactor diode to deviate the frequency of a crystal oscillator :



- R_1 and R_2 develop a DC voltage that reverse bias the varactor diode VD_1 and determine the resonant frequency of the oscillator.
- external modulating signal voltage added or subtracted from the DC bias, which changes the capacitance of the diode and consequently changes the frequency of the oscillation.

4.7.1.1 : Varactor diode modulator



- positive alternations of the modulating signal increase the reverse bias of VD_1, which decrease its capacitance and increase the frequency of the oscillation.
- negative alternations of the modulating signal decrease the reverse bias of VD_1, which increase its capacitance and decrease the frequency of the oscillation.
- simple to use, stable and reliable but limited peak frequency deviation thus limited use to the low index applications.

Basic FM reactance Modulator

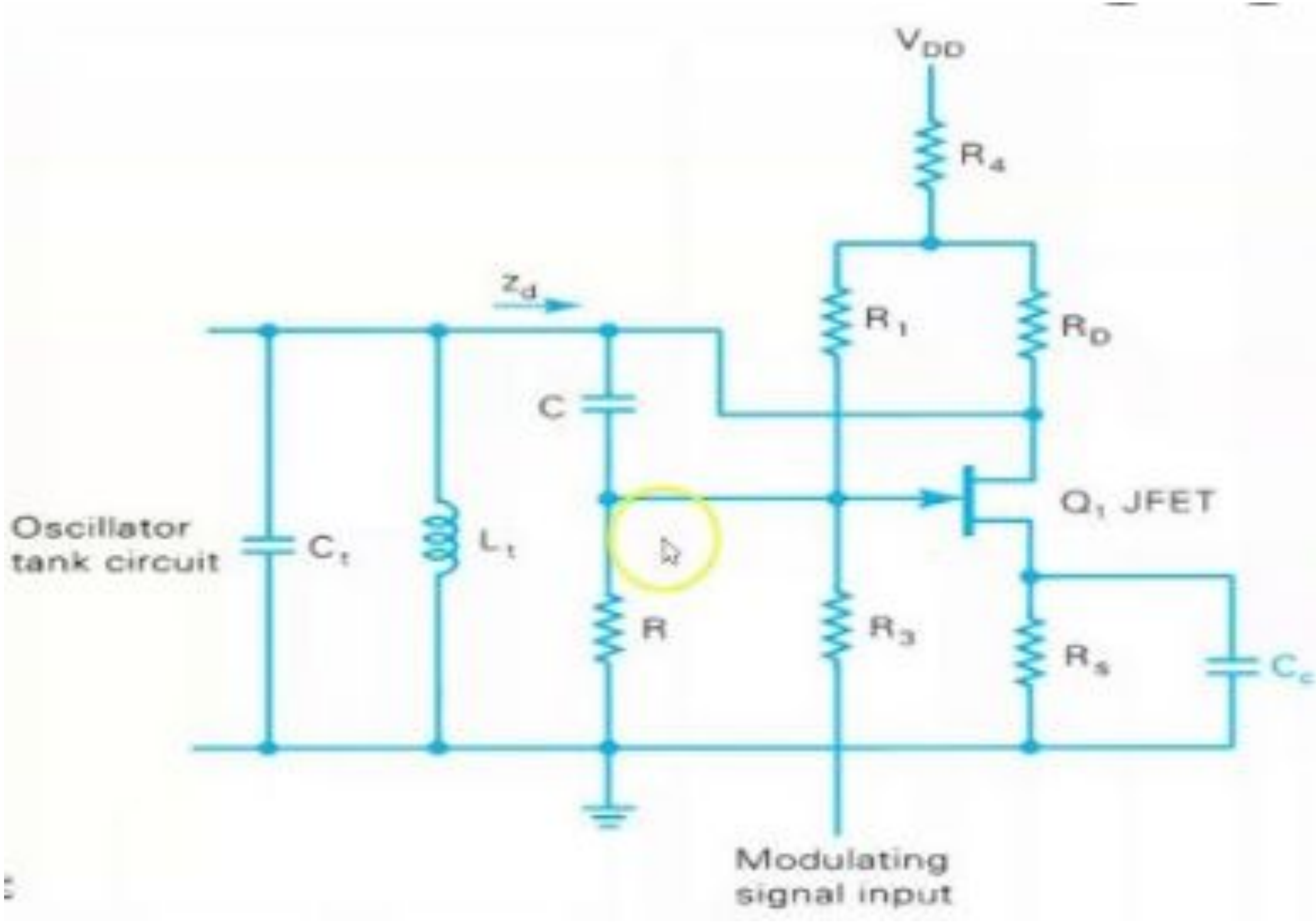


Fig a) Schematic Diagram of JFET reactance modulator

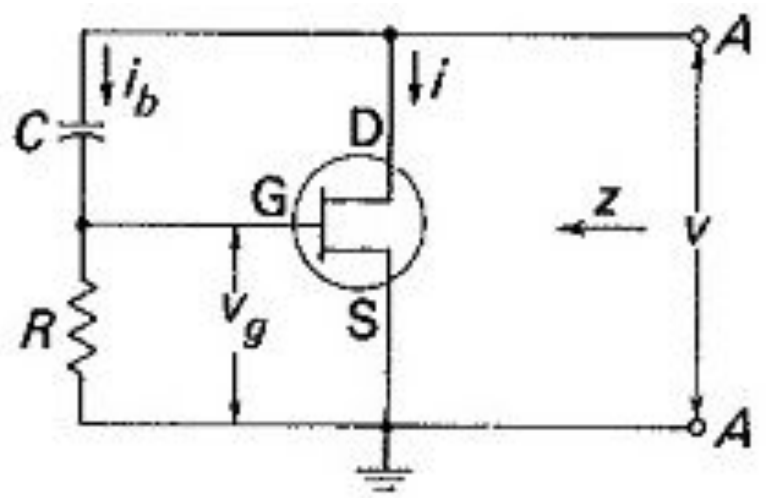


Figure b) AC equivalent Circuit

- The Circuit shown in figure b is the basic circuit of a FET reactance modulator which behaves as a three terminal reactance that may be connected across the tank circuit of the oscillator to be frequency modulated.

It can be made inductive or capacitive by a simple component change. The value of this reactance is proportional to the transconductance of the device, which can be made to depend on the gate bias and its variations. Note that an FET is used in the explanation here for simplicity only. Identical reasoning would apply to a bipolar transistor or a vacuum tube, or indeed to any other amplifying device.

Theory of reactance modulators: In order to determine z, a voltage v is applied to the terminals A – A between which the impedance is to be measured, and the resulting current i is calculated. The applied voltage is then divided by this current, giving the impedance seen when looking into the terminals. In order for this impedance to be a pure reactance (it is capacitive here), two requirements must be fulfilled. The first is that the bias network current i_b must be negligible compared to the drain current. The impedance of the bias network must be large enough to be ignored. The second requirement is that the drain-to-gate impedance (X_C here) must be greater than the gate-to-source impedance (R in this case), preferably by more than 5:1. The following analysis may then be applied:

$$v_g = i_b R = \frac{Rv}{R - jX_C} \tag{5-15}$$

The FET drain current is

$$i = g_m v_g = \frac{g_m R v}{R - jX_C} \tag{5-16}$$

Therefore, the impedance seen at the terminals A – A is

$$z = \frac{v}{i} = v \div \frac{g_m R v}{R - jX_C} = \frac{R - jX_C}{g_m R} = \frac{1}{g_m}\left(1 - \frac{jX_C}{R}\right) \tag{5-17}$$

If $X_C \gg R$ in Equation (5-17), the equation will reduce to

$$z = -j\,\frac{X_C}{g_m R} \tag{5-18}$$

This impedance is quite clearly a capacitive reactance, which may be written as

$$X_{eq} = \frac{X_C}{g_m R} = \frac{1}{2\pi f g_m R C} = \frac{1}{2\pi f C_{eq}} \tag{5-19}$$

From Equation (5-19) it is seen that under such conditions the input impedance of the device at A – A is a pure reactance and is given by

$$C_{eq} = g_m R C \tag{5-20}$$

The following should be noted from Equation (5-20):

1. **This equivalent capacitance depends on the device transconductance and can therefore be varied with bias voltage.**
2. **The capacitance can be originally adjusted to any value, within reason, by varying the components R and C.**
3. **The expression $g_m RC$ has the correct dimensions of capacitance; R, measured in ohms, and g_m, measured in siemens (s), cancel each other's dimensions, leaving C as required.**
4. **It was stated earlier that the gate-to-drain impedance must be much larger than the gate-to-source impedance. This is illustrated by Equation (5-17). If X_C/R had not been much greater than unity, z would have had a resistive component as well.**

If R is not much less than X_C (in the particular reactance modulator treated), the gate voltage will no longer be exactly 90° out of phase with the applied voltage v, nor will the drain current i. Thus, the input impedance will no longer be purely reactive. As shown in Equation (5-17), the resistive component for this particular FET reactance modulator will be $1/g_{m.}$ This component contains g_m it will vary with the applied modulating voltage. This variable resistance (like the variable reactance) will appear directly across the tank circuit of the master oscillator, varying its Q and therefore its Output voltage. A certain amount of amplitude modulation will be created. This applies to all the forms of reactance modulator. If the situation is unavoidable, the oscillator being modulated must be followed by an amplitude limiter.

The gate-to-drain impedance is, in practice, made five to ten times the gate-to-source impedance. Let X_C = nR (at the carrier frequency) in the capacitive RC reactance FET so far discussed. Then

$$X_C = \frac{1}{\omega C} = nR$$

$$C = \frac{1}{\omega nR} = \frac{1}{2\pi fnR} \tag{5-21}$$

Substituting Equation (5-21) into (5-20) gives

$$C_{eq} = g_m RC = \frac{g_m R}{2\pi fnR}$$

$$C_{eq} = \frac{g_m}{2\pi fn} \tag{5-22}$$

Equation (5-22) is a very useful formula. In practical situations the frequency of operation and the ratio of X_C to R are the usual starting data from which other calculations are made.

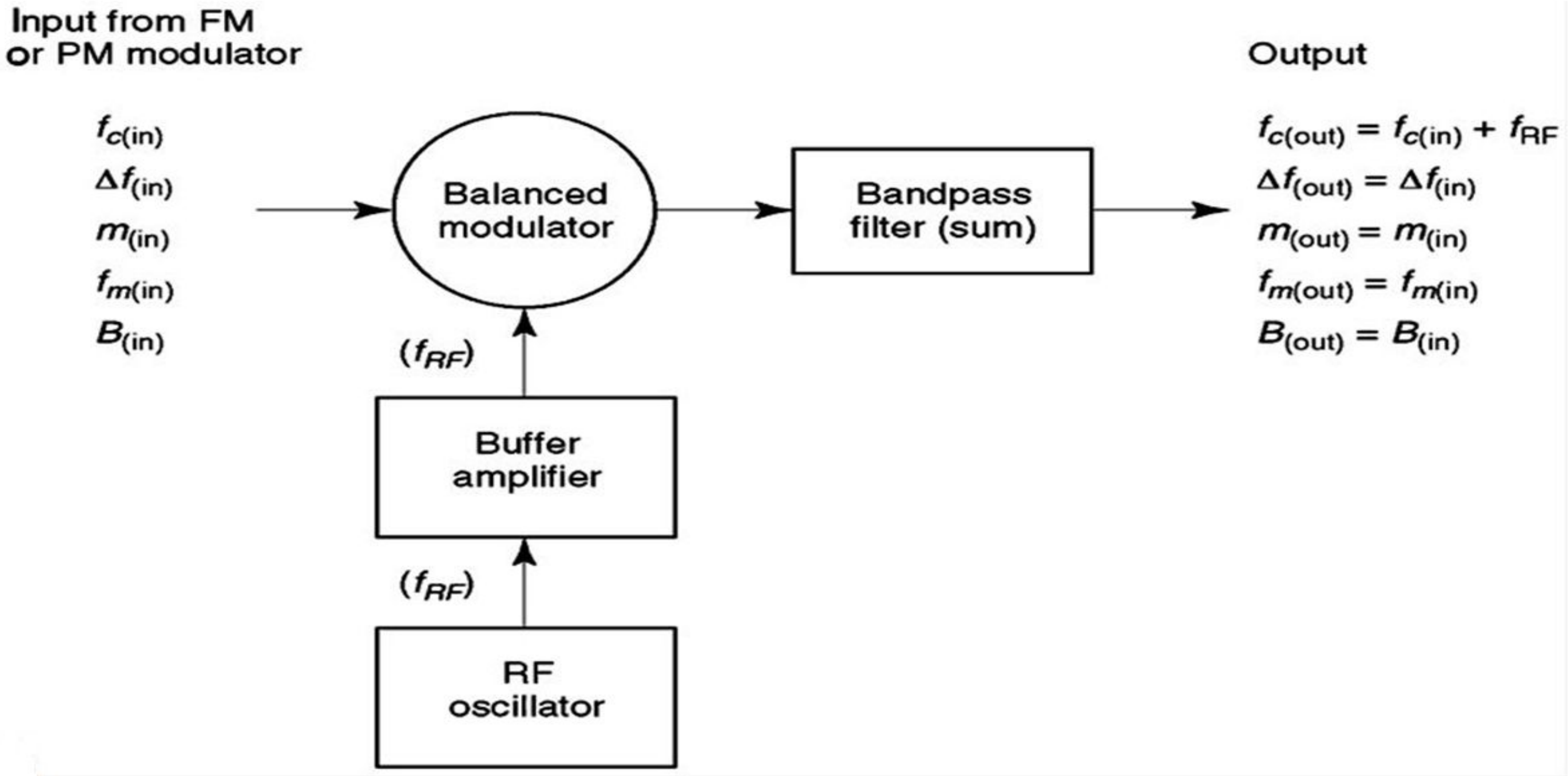
Frequency Up Conversion

- With FM and PM modulator, the carrier frequency at the output of the modulator is generally somewhat lower than the desired frequency of transmission.
- Therefore it is often necessary to up convert the frequency of the modulated carrier after modulation.

- There are two methods of performing frequency up conversion.

1) Heterodyne Method of frequency up conversion
2) Frequency Multiplier method of frequency up conversion

1. Heterodyne Method of frequency up conversion



1. Heterodyne Method of frequency up conversion

- A relatively low frequency, angle modulated carrier along with its side frequencies are applied to one input of a balanced modulator
- The second input is a relatively high frequency unmodulated RF carrier signal.
- In balance modulator two inputs mix nonlinearly and produces sum and difference frequencies at its output.
- Sum and difference frequencies are also produced between side frequencies of modulated signal and RF carrier.
- The bandpass filter (BPF) is tuned to the sum frequency with bandpass wide enough to pass the carrier plus the upper and lower side frequencies.
- Thus the BPF passes the sum of the modulated and the unmodulated carrier while the difference frequencies are blocked.
- The output of the bandpass filter is $f_{c(out)} = f_{c(in)} + f_{RF}$

Where $f_{c(out)}$ = up converted modulated signal

$f_{c(in)}$ = input modulated signal

f_{RF} = RF carrier

1. Heterodyne Method of frequency up conversion

- Since the side frequencies of the modulated carrier are unaffected by the heterodyning process, frequency deviation is also unaffected.
- Thus the output of the BPF contains the BPF contains the original frequency deviation (both its magnitude Δf and rate of change fm).
- The modulation Index, phase deviation and bandwidth are also unaffected by heterodyne process. Only the carrier frequency is affected.
- Therefore $\Delta\Theta_{(out)} = \Delta\Theta_{(in)}$

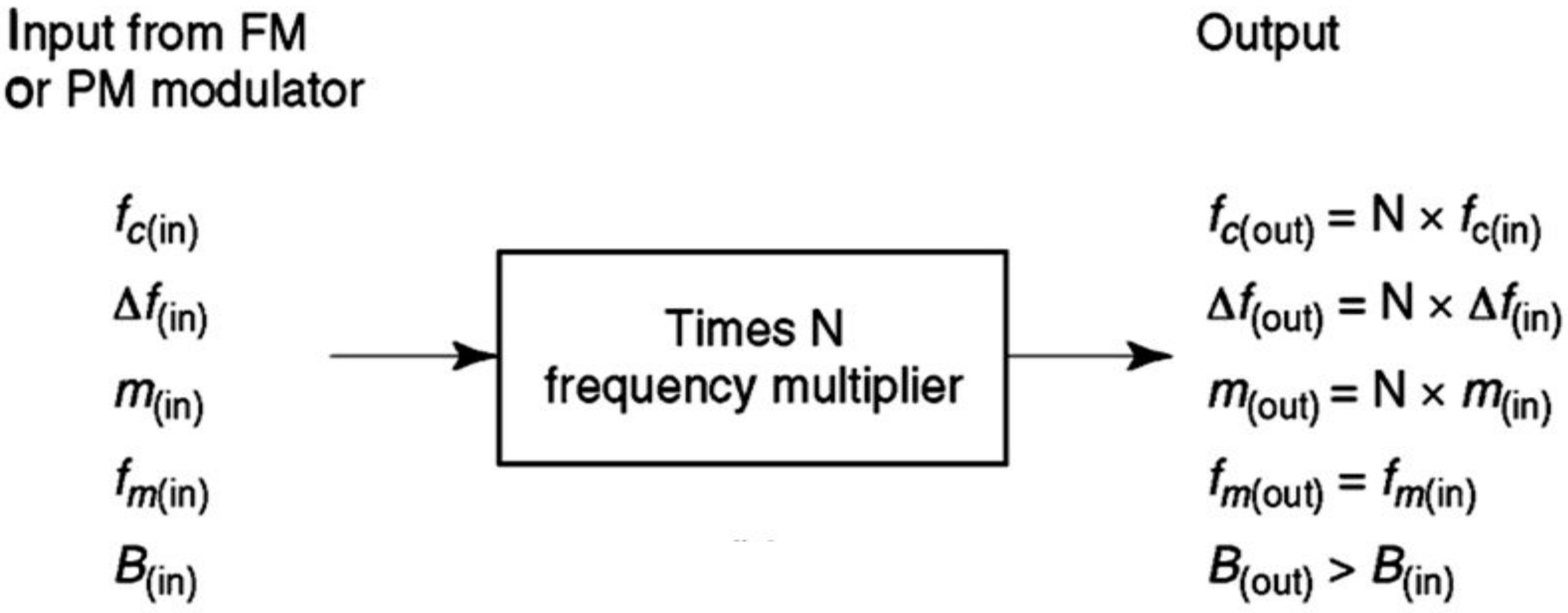
$$\Delta f_{(out)} = \Delta f_{(in)}$$

$$m_{(out)} = m_{(in)}$$

$$f_{m(out)} = f_{m(in)}$$

$$B_{(out)} = B_{(in)}$$

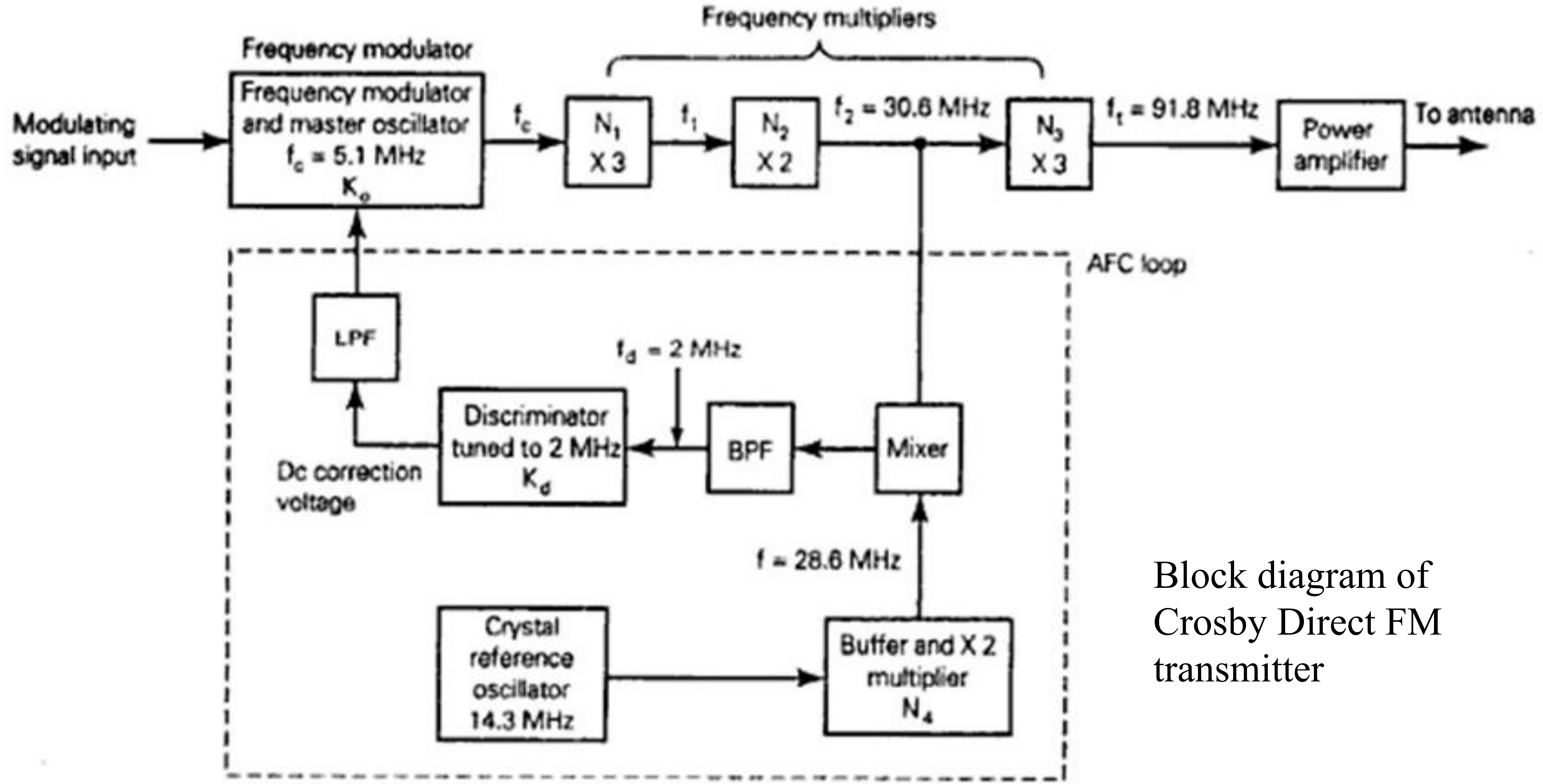
2. Multiplication Method of Up conversion



- with multiplication method, the frequency of the modulated carrier is multiplied by a factor of N in the frequency multiplier.
- frequency deviation, phase deviation and modulation index are also multiplied.
- However, the rate of the deviation is unaffected (i.e. the separation between adjacent side frequencies remains unchanged).
- as frequency deviation and modulation index are multiplied, the number of side frequency also increases. Thus, the bandwidth also increases.
- For modulation index higher than 10, Carson's Rule can be applied

$$B_{out} = N(2\Delta f) = NB_{in}$$

Direct FM Transmitter



Block diagram of Crosby Direct FM transmitter

- also known as *Crosby direct FM transmitter* (includes an automatic frequency control –AFC loop)
- the carrier frequency is basically the center frequency of the master oscillator f_c = 1.5 MHz, which is multiplied by 18 to produce a final transmission carrier frequency f_t = 98.1 MHz.

- The frequency modulator can be either a reactance modulator or a voltage controlled oscillator.
- The carrier rest frequency is the unmodulated output frequency from the master oscillator (fc).
- There are 3 aspects of frequency conversion-

1. When the frequency of a frequency modulated carrier is multiplied, its frequency and phase deviations are multiplied as well
2. The rate at which the carrier is deviated (i.e the modulating signal frequency, fm) is unaffected by the multiplication process. Therefore the modulation index is also multiplied.
3. When an angel modulated carrier is heterodyne with another frequency in non linear mixer, the carrier can be either up or down converted, depending on the passband of the output filter.

However, the frequency deviation, phase deviation and rate of change are unaffected by the heterodyning process. Therefore the frequency and phase deviation at the output of the modulator are also multiplied by 18.

To achieve maximum deviation allowed for FM stations at antenna (75 kHz), the deviation at the output of the modulator is

$$\Delta f = \frac{75\,kHz}{N} = \frac{75000}{18} = 4166.7\,Hz$$

The modulation index at the output of the modulator, $m = \dfrac{4166.7}{f_m}$

For maximum modulating signal frequency allowed for FM (15 kHz)

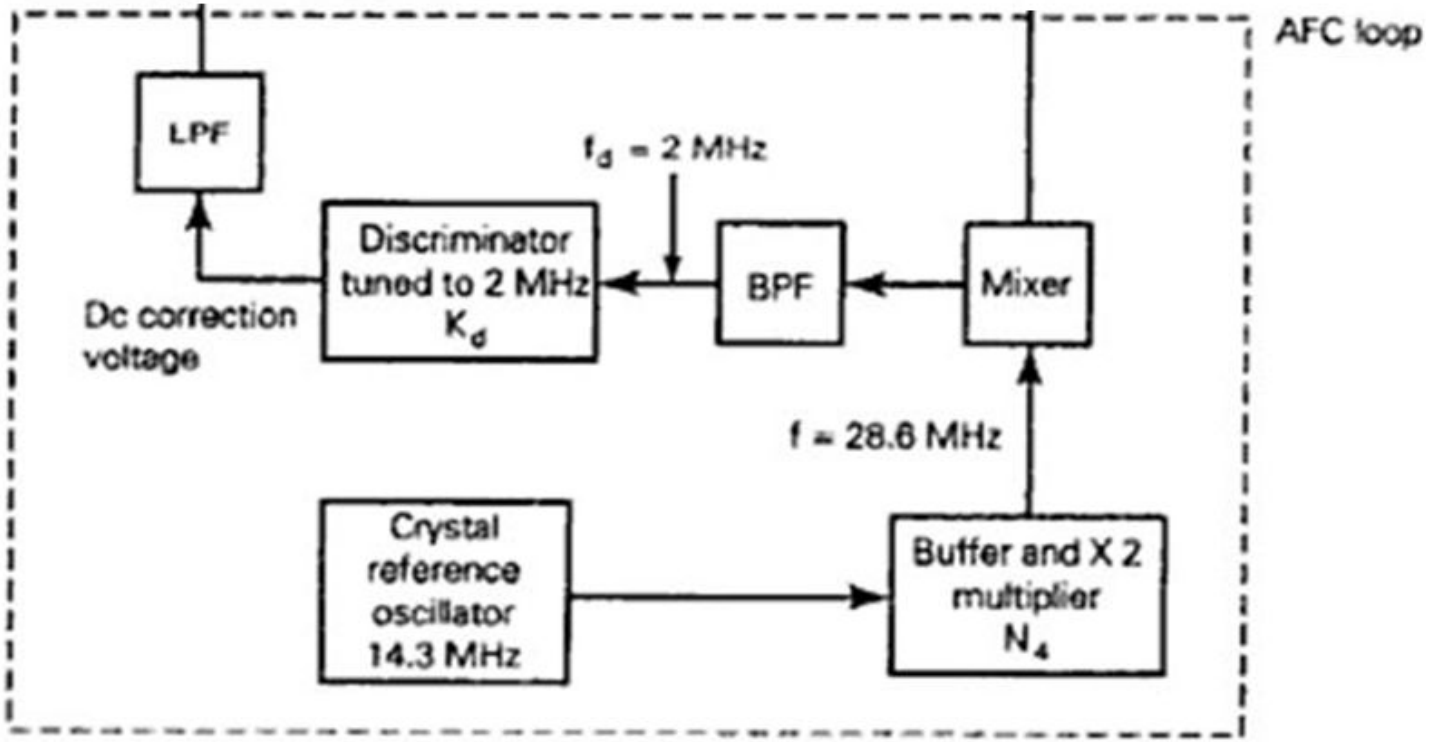
$$m = \frac{4166.7}{15000} = 0.2778$$

The modulating index at the antenna is m = 0.2778 * 18 = 5

AFC LOOP

- for medium and high index FM systems, the oscillator cannot be a crystal type because the frequency at which the crystal oscillates cannot be significantly deviated.
- as a result, the stability of the oscillator in the direct FM is low.
- to overcome this problem, AFC loop is used.
    - with AFC, the carrier signal is mixed in a nonlinear device with the signal from a crystal reference oscillator (the output is down-converted in frequency).
    - the output is then fed back to the input of a *frequency discriminator*. It is a frequency-selective device whose output voltage is proportional to the difference between the input frequency and its resonant frequency.

AFC LOOP



- If the discriminator responded to the frequency deviation, the feedback loop would cancel the deviation and thus remove the modulation from the FM wave (this effect is called wipe off).
- The dc correction voltage is added to the modulating signal to automatically adjust the master oscillator's center frequency to compensate for the low frequency drift.

- From the Crosby Direct FM transmitter block diagram, the output from the doubler f2= 30.6MHz, which is mixed with a crystal controlled reference frequency fr =28.6MHz to produce a difference frequency fd =2MHz
- The discriminator is a relatively high-Q (narrowband) tuned circuit that reacts only to frequencies near its center frequency (2MHz in this case)
- Therefore, the discriminator responds to long term, low frequency changes in the carrier frequency because of master oscillator frequency drift and because low pass filtering does not respond to the frequency deviation produced by the modulating signal.

Limitations of Direct Method of FM Generation

1. In this method, it is very difficult to get high order stability in carrier frequency because in this method the basic oscillator is not a stable oscillator, as it is controlled by the modulating signal.
2. Generally in this method we get distorted FM, due to non-linearity of the varactor diode.