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Generation of FM signals

There are essentially two basic methods of generating frequency –modulated signals namely,

- **Direct FM**

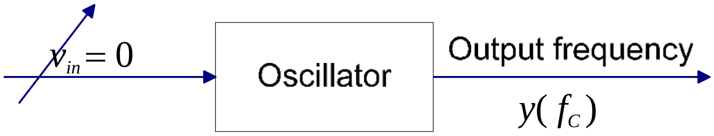
  (Carrier frequency is directly varied in accordance with the input base band signal, which is readily, accomplished using a voltage controlled oscillator (VCO).

- **Indirect FM**

  (The modulating signal is first used to produce a narrowband FM signal and frequency multiplication is next used to increase the frequency deviation to the desired level).

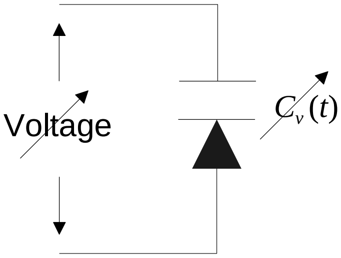
One method for generating an FM signal directly is to design an oscillator whose Frequency changes with the input voltage.

When the input voltage is zero, the oscillator generating a sinusoid with frequency f_C and when the input voltage changes, this frequency changes accordingly.



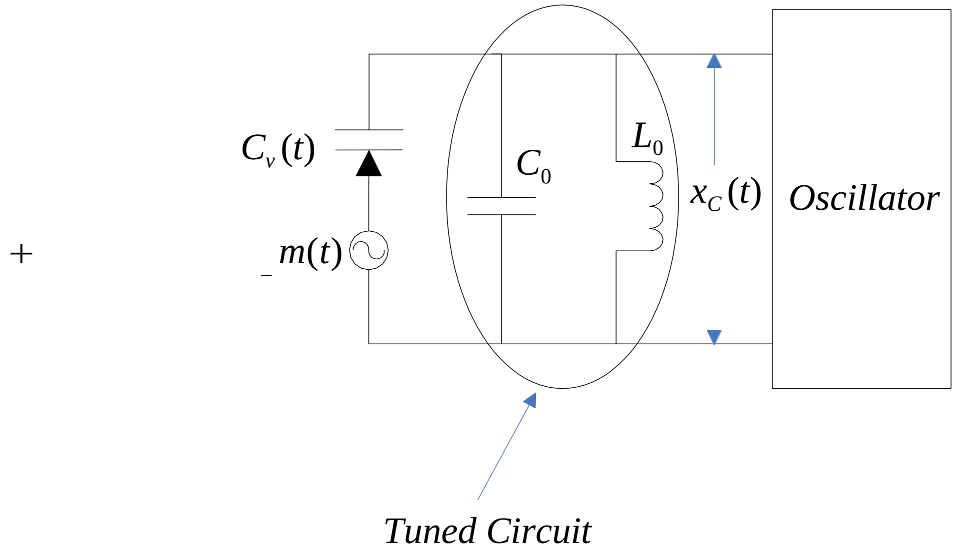
Voltage Controlled Oscillator (VCO)

In this approach a “Varactor diode” is used. A Varactor diode is a capacitor whose capacitance changes with the applied voltage.



Varactor diode

Therefore , if this capacitor is used in a tuned circuit of the oscillator and the message signal is applied to it, the frequency of the tuned circuit ,and the oscillator will change in accordance with the message signal(see diagram below).



Let the indicator in the tuned circuit be L_0 and the capacitance of the varactor diode is given by

$$c(t) = c_0 + k_0 m(t) \qquad (2.18)$$

When m (t) =0, the frequency of the tuned circuit is given by:

$$f_c = \frac{1}{2\pi\sqrt{L_0 C_0}}$$

In general if m (t) ≠ 0, we have

$$f_i(t) = \frac{1}{2\pi\sqrt{L_0(c_0 + k_0 m(t))}}$$

c(t) (2.8)

$$\therefore f_i(t) = \frac{1}{2\pi\sqrt{L_0 C_0}} \cdot \frac{1}{\sqrt{1 + \frac{h_0}{C_0} m(t)}} = f_c \cdot \frac{1}{\sqrt{1 + \frac{k_0}{C_0} m(t)}}$$

Assuming that $\in = \frac{h_0}{c_0} m(t) << 1$

and using the approximations

$$\boxed{\begin{array}{l} \sqrt{1+\varepsilon} = (1+\varepsilon)^{\frac{1}{2}} \approx 1 + \frac{\varepsilon}{2} \\ \frac{1}{1+\varepsilon} \approx 1 - \varepsilon \end{array}} \quad \boxed{\varepsilon < 1}$$

We obtain

$$f_i(t) = f_c\left(1 - \frac{k_0}{2c_0} m(t)\right) \qquad (2.19)$$

This is the relation for a frequency modulated signal.

$$x_c(t) = A_c \cos\theta_i(t) = A_c \cos(2\pi f_i(t))$$

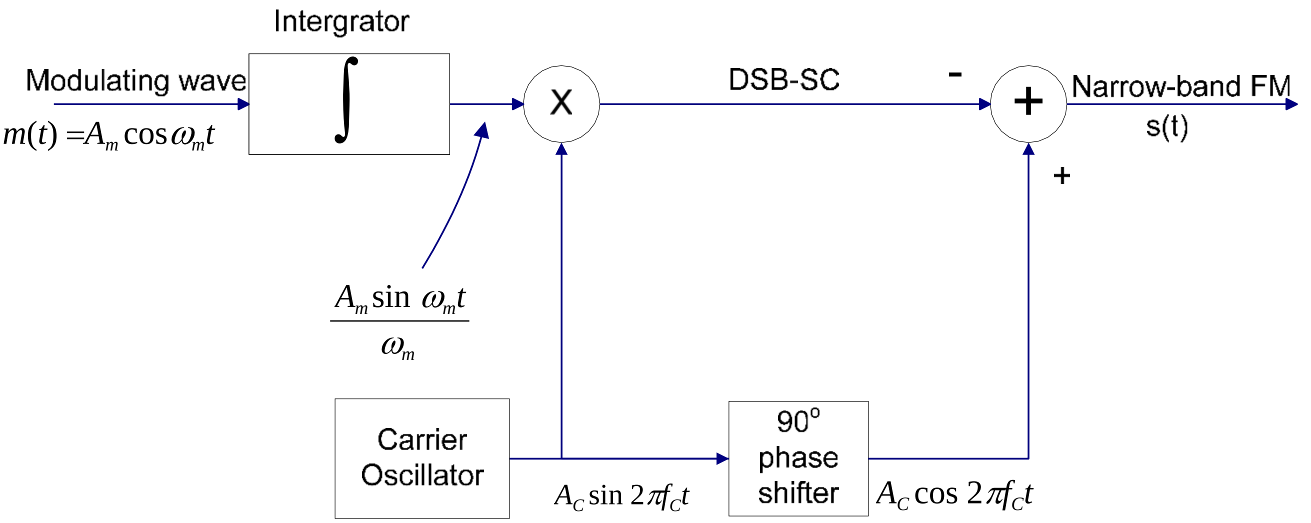
where $f_i(t) = f_c\left(1 - \frac{k_0}{2c_0} m(t)\right)$

Indirect method for generating of FM

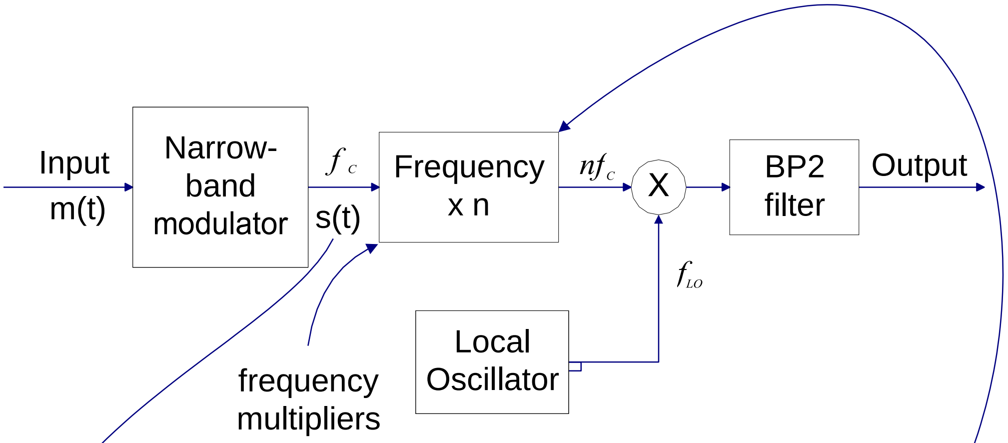
Another approach for generating an angle modulation signal is to first generate a **narrowband** angle –modulated signal, and then change it to a wideband signal. Due to the similarity of conventional AM signals, generation of narrowband angle modulated signals is straightforward.

Generation of narrow-band angle modulated signal

2.19

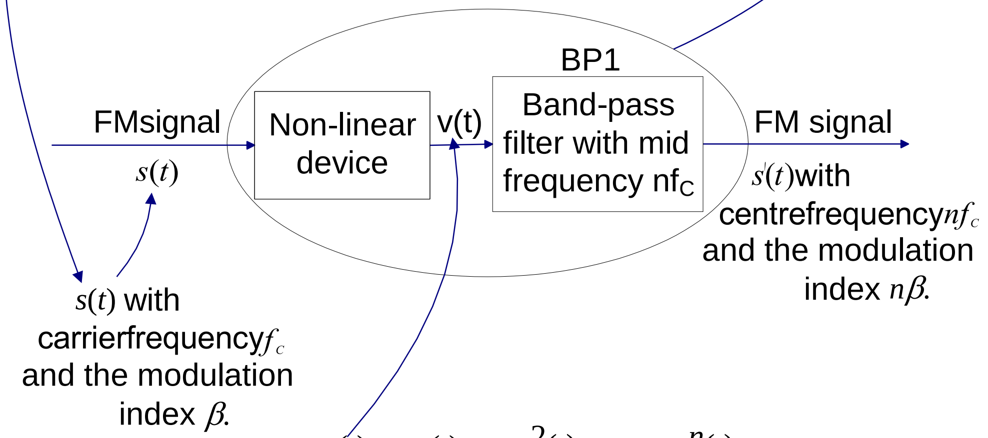


The next step is to use the narrowband angle modulated signals to generate a wideband modulated signals (see diagram below).



The narrow-band angle modulated signal enters a frequency multiplier that multiplies the instantaneous frequency of the input by some constant n.

The frequency multiplier consists of a nonlinear device followed by a band pass filter (see below).



$$v(t) = a_1 s(t) + a_2 s^2(t) + \ldots + a_n s^n(t)$$

Where $a_1, a_2, a_{3,\ldots\ldots\ldots}, a_n$ coefficient and n are is the highest order of nonlinearity.
The input signal (FM) is defined by

$$s(t) = A\cos(2\pi f_C t + 2\pi k_f \int_0^t m(\tau)\,d\tau)$$

Whose instantaneous frequency is:

$$f_i(t) = f_C + k_f m(t)$$

The mid-band frequency of the band-pass filter is set to nf_C where f_C is carrier frequency of the incoming FM single s(t).

The band-pass filter is designed to have a bandwidth equal to n times the transmission bandwidth of s(t).
After band-pass filtering the nonlinear devices output v(t), we have a new FM signal defined by

$$s'(t) = A'_C \cos\left(2\pi n f_C t + 2\pi n k_f \int_0^t m(\tau)\,d\tau\right)$$

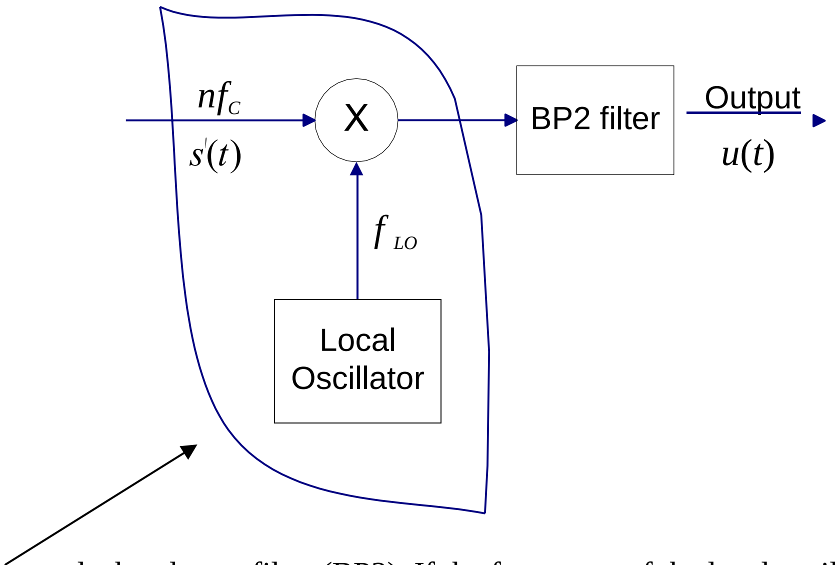
Whose instantaneous frequency is:

$$f'_i(t) = n f_C + n k_f m(t) \qquad (2.20)$$

Comparing $f_i(t) = f_c + k_f m(t)$ and $f'_i(t) = n f_C + k_f n m(t)$,
we see that nonlinear processing circuit in page … acts as a frequency multiplier.
The frequency multiplication ratio is determined by the highest power n in the equation

$$v(t) = a_1 s(t) + a_2 s^2(t) + \ldots\ldots + a_n s^n(t)$$

Note: see the top diagram in page … after the above described process , there is no guarantee that the carrier frequency of this signal n f_C will be the desired carrier frequency, we may perform an up or down conversion to shift the modulated signal to the desired center frequency, (see page…). This stage consists



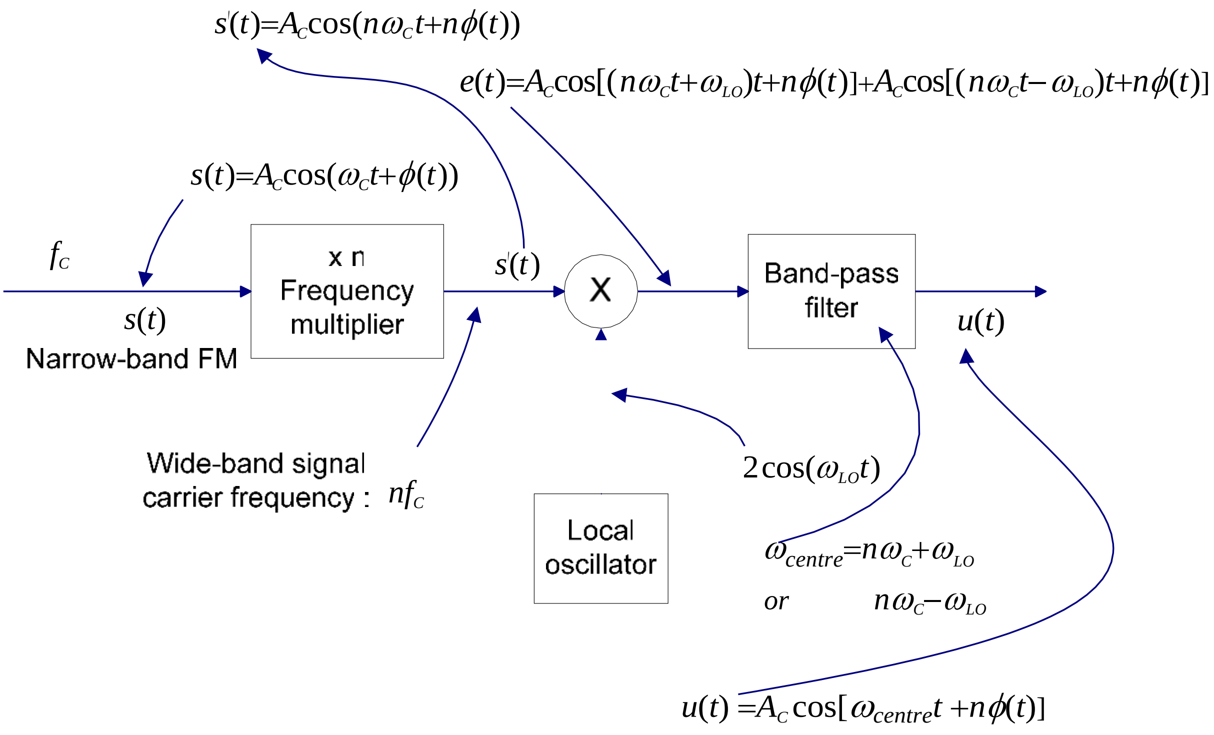
of a mixer and a band-pass filter (BP2). If the frequency of the local oscillator of the mixer is f_{LO} and we are using a down converter, the final wideband FM signal is given by

$$u(t) = A'_C \cos\left(2\pi(nf_C - f_{L0})t + 2\pi n k_f \int_0^t m(\tau)\,d\tau\right) =$$

$$A'_C \cos(2\pi(nf_C - f_{L0})t + n\phi(t))$$

Since we can freely chose n and f_{L0}, we can generate any modulation index at any desired carrier frequency by this method.

Example: a narrowband to wideband converter is implemented as follows.



The output of the narrowband frequency modulator is given by:

$$s(t) = A_c\cos(w_c t + \phi(t))$$

With $w_c = 2\pi\times10^5 Hz$, the peak frequency deviation of $\phi(t)$ is 50Hz and the bandwidth of $\phi(t)$ is 500Hz. The wideband output $u(t)$ is to have a carrier frequency of 85MHz and a deviation ratio of 5. Determine the frequency multiplier factor n. Also determine two possible local oscillator frequencies. Determine the centre frequency and the bandwidth of the band-pass filter.

Deviation ratio at the output of the narrowband FM (i.e. s (t)):

$$D = \frac{\otimes f}{W} = \frac{50Hz}{500Hz} = 0.1 \qquad \left.\begin{array}{l}\otimes f = 50Hz\\ W = 500Hz\end{array}\right\}\text{given}$$

The frequency multiplier n is:

$$\text{n=}\frac{D\text{at the output}}{\text{D}} = \frac{5}{0.1} = 50$$

Wideband carrier frequency =n. $w_c = 50\times10^5 = 5MHz$

We need a carrier of 85MHz

$\therefore w_{LO} = 85+5=90MHz$ or

$w_{\mathrm{LO}} = 85 - 5 = 80MHz$

Centre frequency of the BP filter must be equal to the desired carrier frequency of the wideband output .i.e85MHz.

The BW of the band pass filter is calculated using Carson’s rule.

$$B = 2\otimes f + 2w = 2w(\frac{\otimes f}{w} + 1) = 2 \times 500(5 + 1) = 6KHz$$

Demodulation of FM:

The demodulation of A FM signal requires a circuit that yields an output voltage that varies linearly proportional to the frequency deviation of the input.
Such circuits are known as **discriminators**.

There are many different circuit designed for frequency detection (by a frequency detector –known as a discriminator).

There are four operational categories:

- ✓ FM to AM conversion
- Phase shift discrimination
- Zero crossing detection
- ✓ Frequency feedback(PLL)