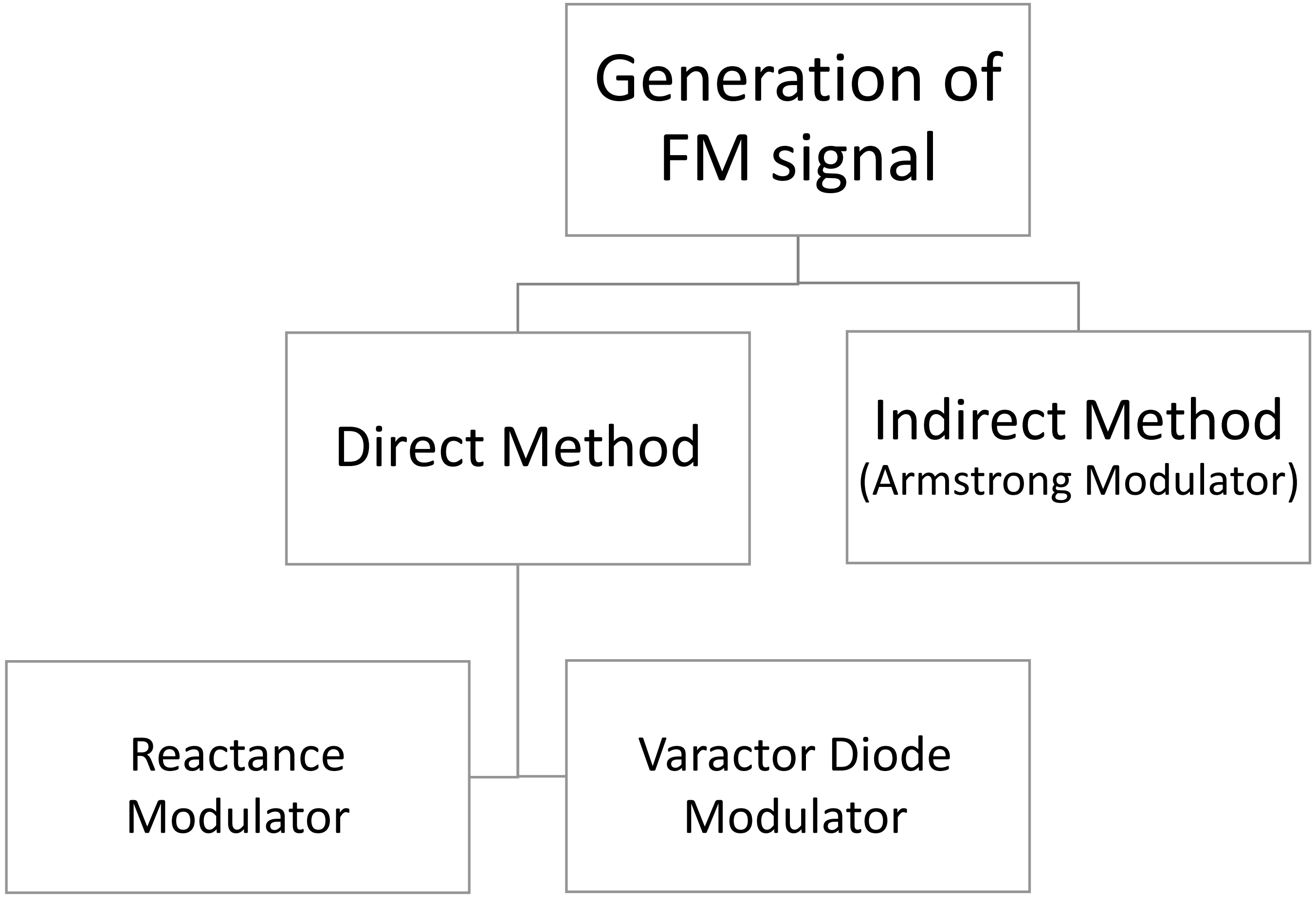
Communication Systems
EE-351

Lectures 20 and 21

Generation of FM signal:



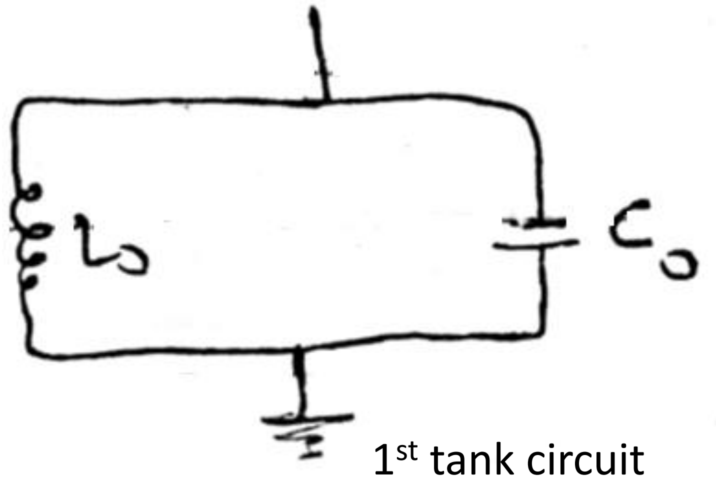
Direct Method:

- The direct method is straightforward to implement where the baseband or **modulating signal directly modulates the carrier.**
- How to generate carrier signal?
  - Using an oscillator circuit.
- This method is capable of providing large frequency deviations.

Direct Method:

- **Generation of carrier**: An oscillator with the help of tank circuit generates a carrier signal.

Oscillator:

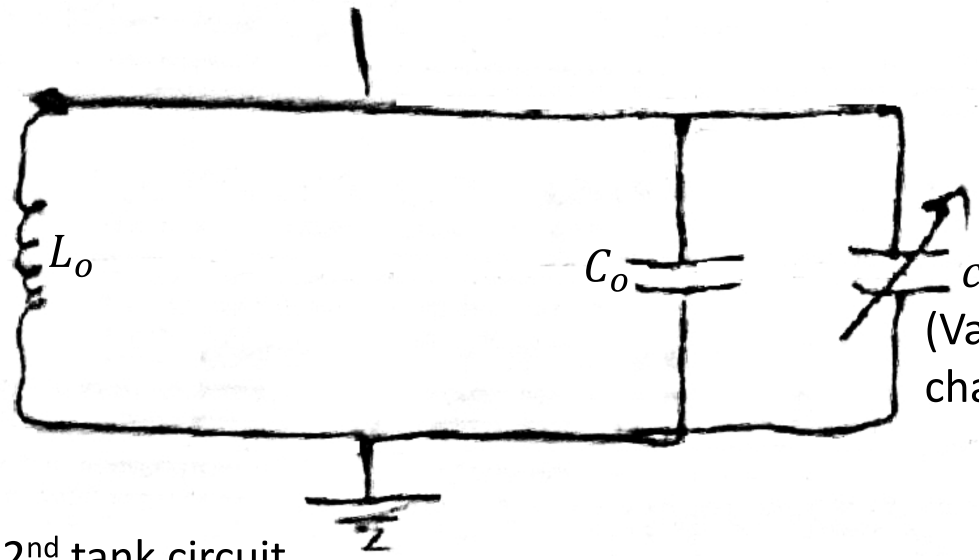


1st tank circuit

$f_o = \frac{1}{2\pi\sqrt{L_o C_o}}$ (both L_o and C_o are constants, we get a constant freq.)

Direct Method:

$$f' = \frac{1}{2\pi\sqrt{L_o(C_o + c(t))}}$$



(Variable capacitance)
change w.r.t m(t)

2nd tank circuit

Direct Method:

- Various devices used to generate variable capacitance or inductance:
  - **<u>Varactor diode or varicap (Reverse biased diode—voltage variable capacitor)</u>**
  - BJT or FET (capacitance is varied by Miller's effect)
  - Electron tube (Reactance tube (variable reactance proportional to m(t))
  - Klystron Oscillator (voltage controlled device)
  - Multivibrator (voltage controlled device)

Direct Method (Principle of VCO):

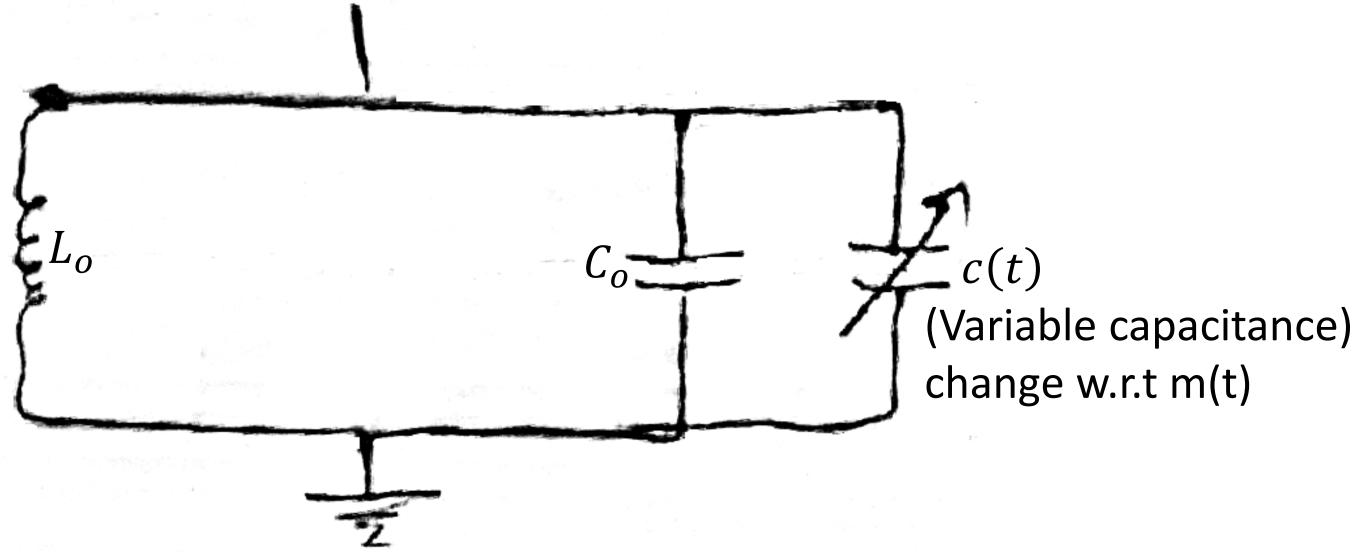
- An oscillator circuit whose freq. is controlled by a modulating voltage is called **VCO**.

- Freq. of the oscillator is varied in accordance to the input voltage.

- With the help of second tank circuit, we can generate a VCO which <u>generates output freq. that changes in accordance to m(t).</u>

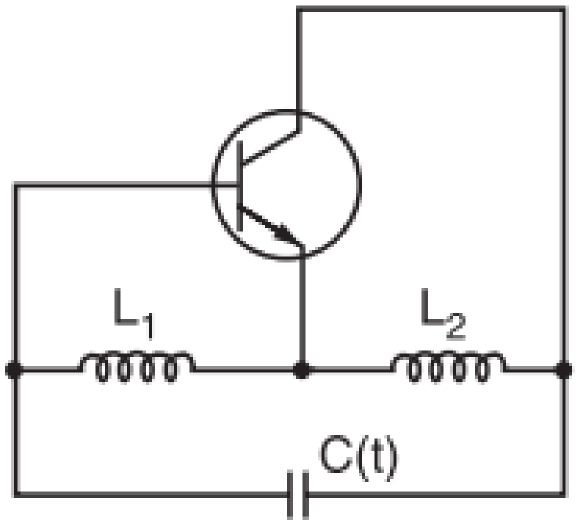
Direct Method (Principle of VCO):

- 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.**



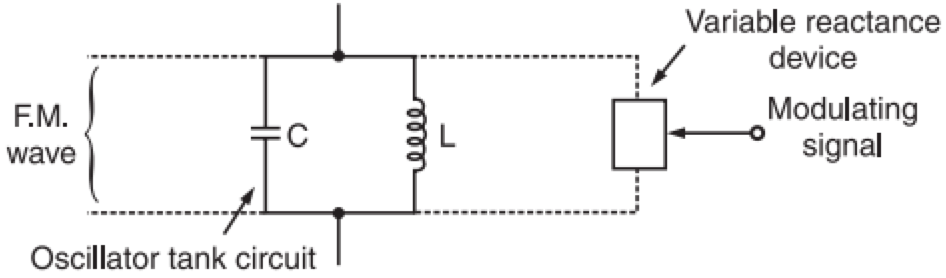
Varactor Diode:

- The **varactor diode is reverse biased**. Its capacitance is dependent on the reverse voltage applied across it. This capacitance is shown by the capacitor C(t) in figure below.



Direct Method (Hartley Oscillator or Colpitt Oscillator):

- A two or three terminal device is placed across the tuned circuit. The **reactance of the device is varied proportional to modulating signal voltage**. This will vary the frequency of the oscillator to produce FM. **The devices used are FET, transistor or varactor diode.**
- An example of direct FM generation is shown in figure which uses a Hartley oscillator along with a varactor diode.



Direct Method (Hartley Oscillator or Colpitt Oscillator):

$$c(t) = C - km(t)$$

Generalized eq. used for any of the devices

K = constant of sensitivity of varactor diode

- When C is constant,

$$f_o = \frac{1}{2\pi\sqrt{L_o C}}$$

$$f = \frac{1}{2\pi\sqrt{L_o c(t)}} = \frac{1}{2\pi\sqrt{L_o (C - km(t)\,)}} = \frac{1}{2\pi\sqrt{L_o C(1 - \frac{k}{C} m(t)\,)}}$$

Direct Method (Hartley Oscillator or Colpitt Oscillator):

$$f = \frac{1}{2\pi\sqrt{L_o C}} \cdot \frac{1}{\sqrt{1 - \frac{k}{C} m(t)}}$$

$$= f_o [1 - \frac{k}{C} m(t)]^{-1/2}$$

$$\approx f_o [1 + \frac{k}{2C} m(t)]$$

$$f = f_o + k_f m(t)$$

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

$$k_f = \frac{f_o k}{2C}$$

Binomial approximation: $(1+x)^n \approx 1 + nx$ for $|x| \ll 1$, $(\frac{k}{C} m(t) \ll 1)$

Direct Method (limitation):

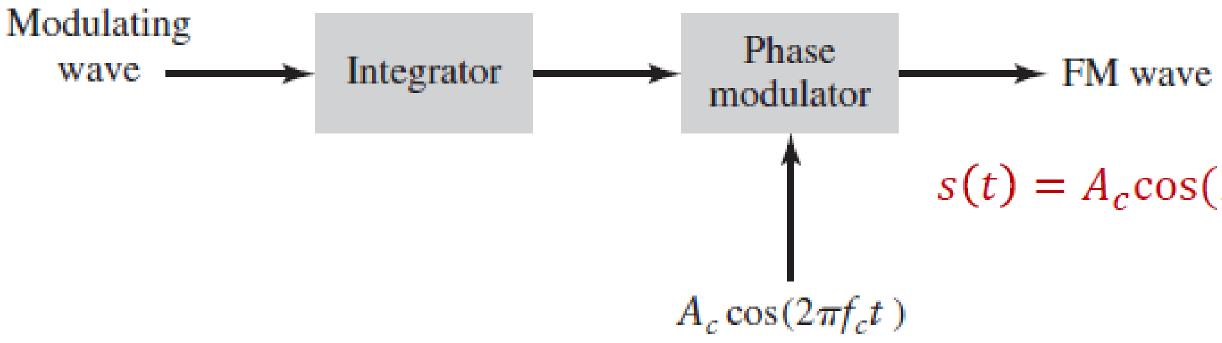
- A serious limitation of the direct method is the **tendency for the carrier frequency to drift**, which is usually unacceptable for commercial radio applications.
- To overcome this limitation, **frequency stabilization** of the FM generator is required, which is realized through the use of feedback around the oscillator.
- Although the oscillator may itself be simple to build, the use of frequency stabilization **adds system complexity to the design** of the frequency modulator.

Direct Method – Limitations:

- Stability
  - LC oscillator is not stable.
    - FM broadcasting cannot be done with the help of direct method.
- Distortion is generated in FM signal due to non-linear device (e.g., varactor diode)
- Used in high power FM transmissions.

Indirect Method:

Frequency modulation
$2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau$
$f_c + k_f m(t)$
$A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right]$



$$s(t) = A_c \cos(2\pi f_c t + 2\pi k_f \int_0^t m(t) dt)$$

$$s(t) = A_c \cos(2\pi F_c t) - A_c \sin(2\pi F_c t)\, \beta \sin(2\pi F_m t)$$

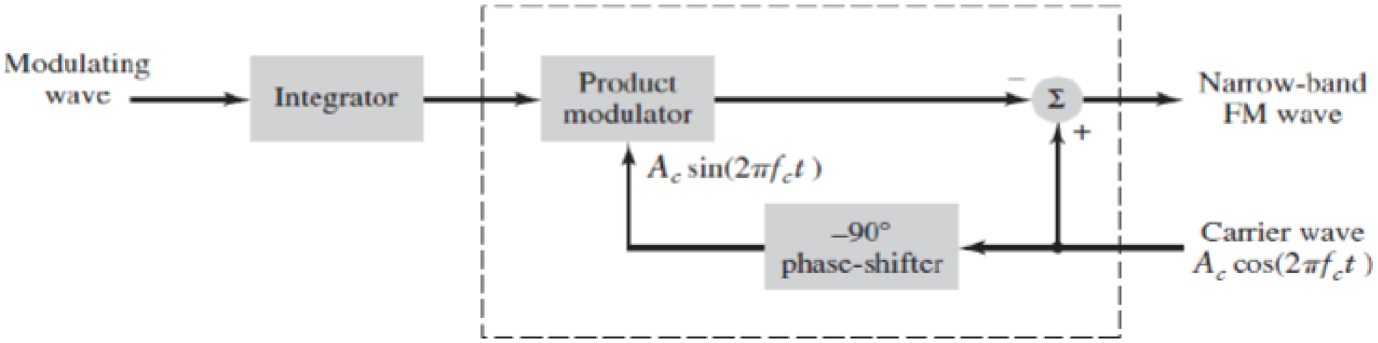


FIGURE 4.4 Block diagram of an indirect method for generating a narrow-band FM wave.

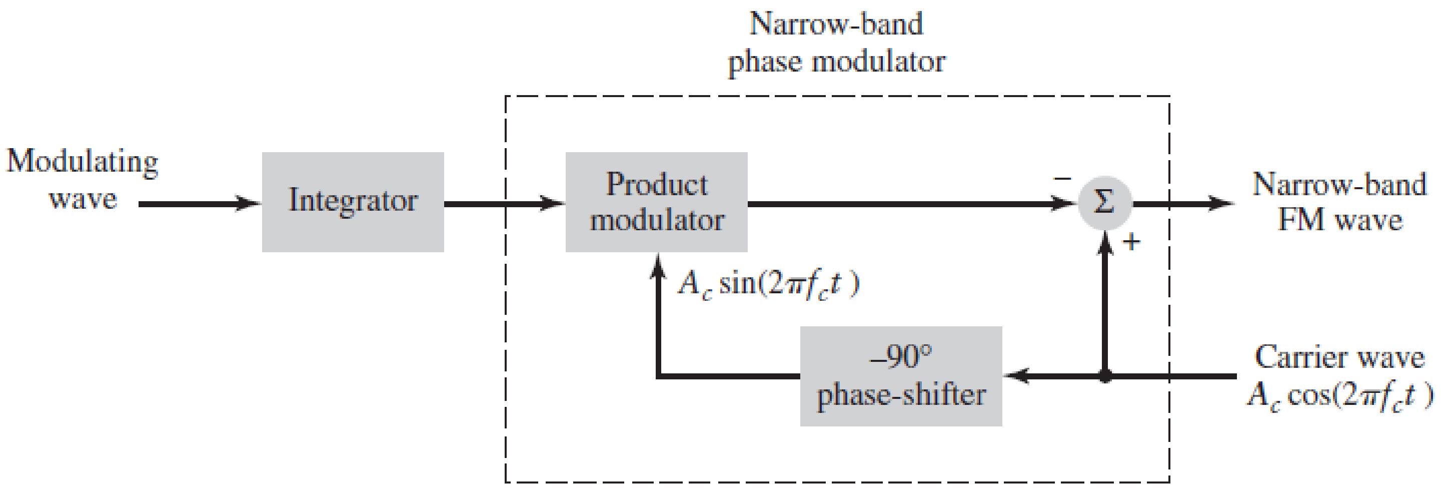


FIGURE 4.4 Block diagram of an indirect method for generating a narrow-band FM wave.

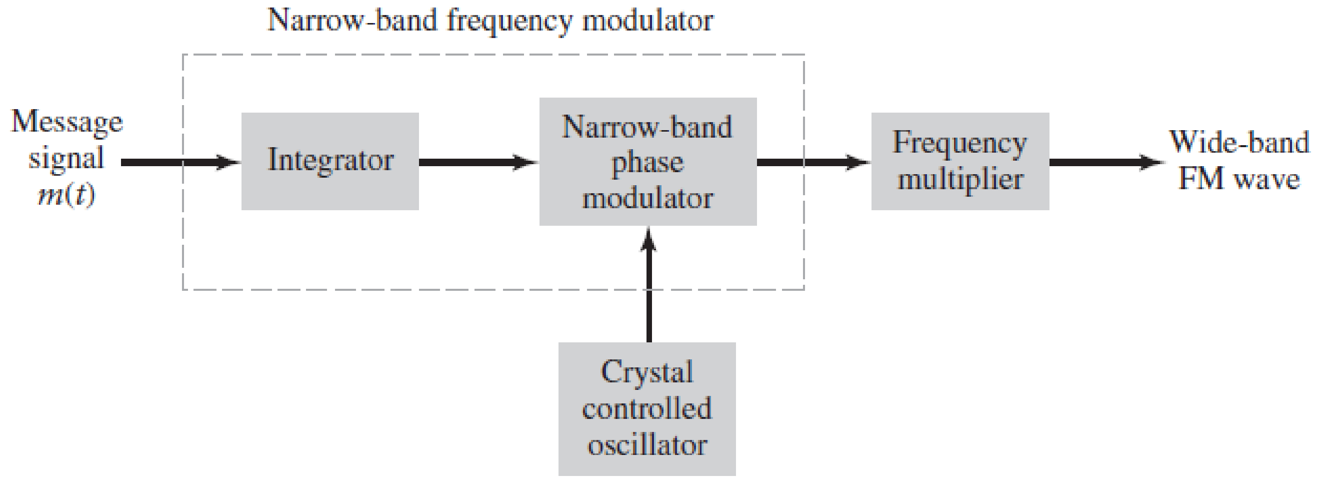
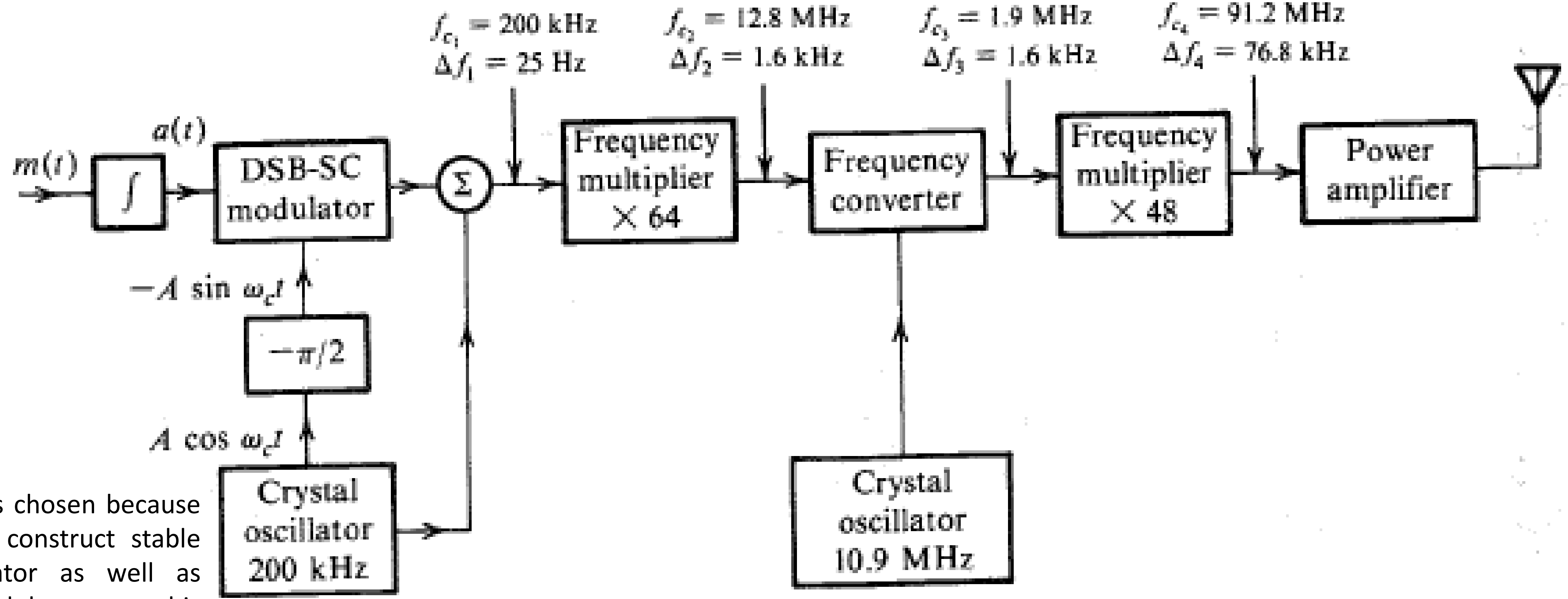


FIGURE 4.10 Block diagram of the indirect method of generating a wide-band FM wave.

Indirect Method (Armstrong Modulator):



This 200kHz is chosen because it is easy to construct stable crystal oscillator as well as balanced modulators at this freq.

Figure 5.10 Armstrong indirect FM transmitter.

Commercial FM transmitter

Indirect Method—Limitation:

- This method has an **advantage of frequency stability** but
- It suffers from **inherent noise** caused by excessive multiplication and distortion at lower modulating frequencies, where $\frac{\Delta f}{f_m}$ is not small enough.

Indirect Method:

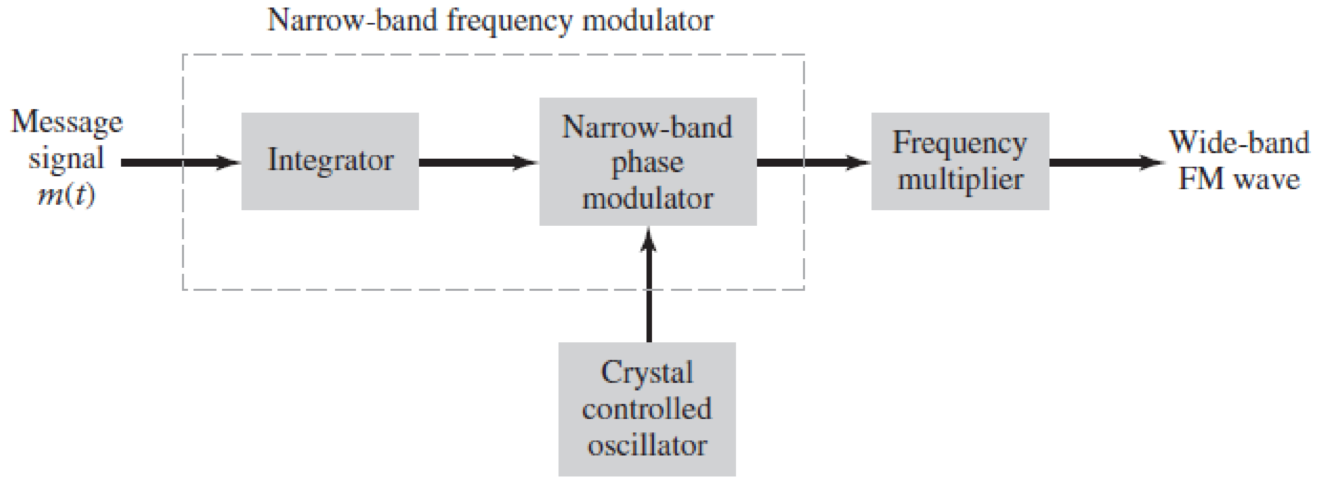


FIGURE 4.10 Block diagram of the indirect method of generating a wide-band FM wave.

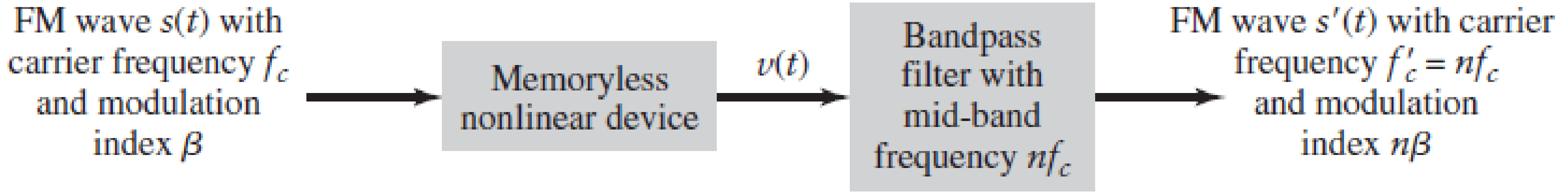


FIGURE 4.11 Block diagram of frequency multiplier.

The implication of the nonlinear device being memoryless is that it has no energy-storage elements.

- In other words, the memoryless nonlinear device is an nth power-law device.

Generation of Frequency Modulated Signal:

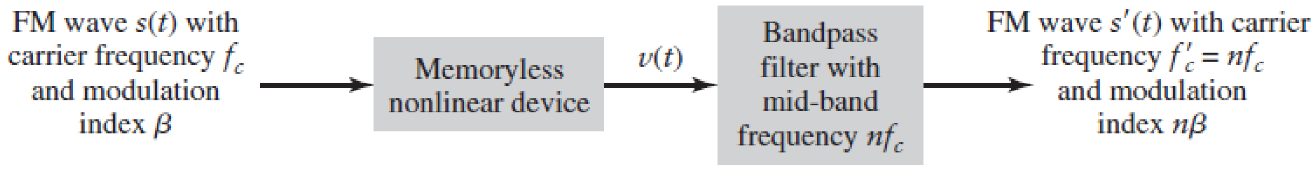
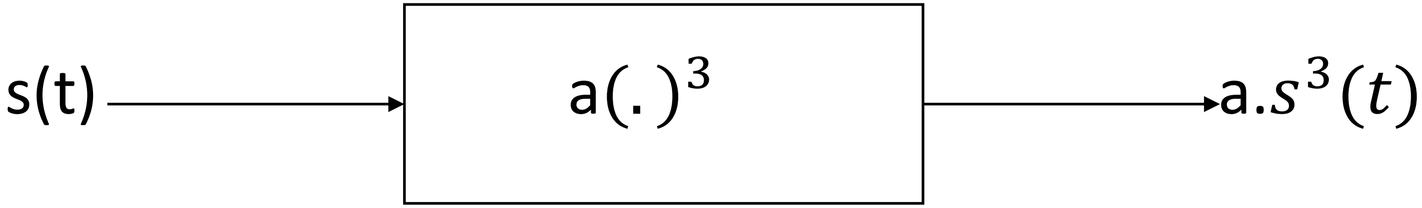


FIGURE 4.11 Block diagram of frequency multiplier.

Consider an example using the following non-linear device:



$$s(t) = A_c cos[(2\pi F_c t) + \beta \sin(2\pi F_m t)] = A_c cos\theta_i(t)$$

$$\tilde{s}(t) = a.(A_c cos\theta_i(t))^3 = a\, {A_c}^3\, cos^3(\theta_i(t))$$

$$= \frac{a{A_c}^3 cos3\theta_i(t) + 3cos\theta_i(t)}{4}$$

$$= \frac{a{A_c}^3 cos3((2\pi F_c t) + \beta \sin(2\pi F_m t)) + 3\cos((2\pi F_c t) + \beta \sin(2\pi F_m t))}{4}$$

Generation of Frequency Modulated Signal:

$$\frac{aA_c{}^3}{4}\cos((6\pi f_c t) + 3\beta\sin(2\pi f_m t)) + \frac{3aA_c{}^3}{4}\cos((2\pi f_c t) + \beta\sin(2\pi f_m t))$$

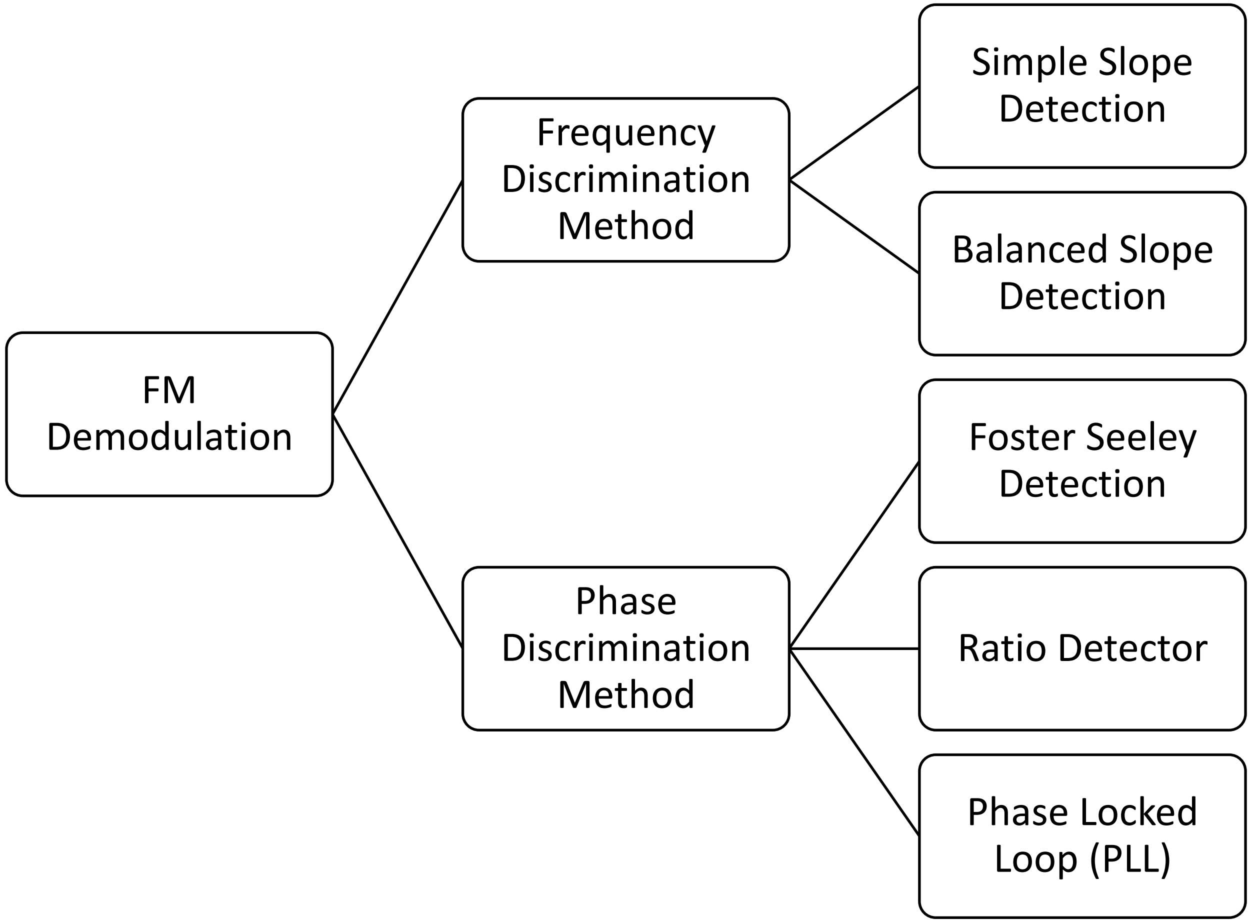
- Filter the components with filter centered at $3f_c$ and block components at f_c

$$\tilde{s}(t) = \frac{aA_c{}^3}{4}\cos((6\pi f_c t) + 3\beta\sin(2\pi f_m t))$$

Hence, freq. multiplication by a factor of 3, so modulation index = 3β

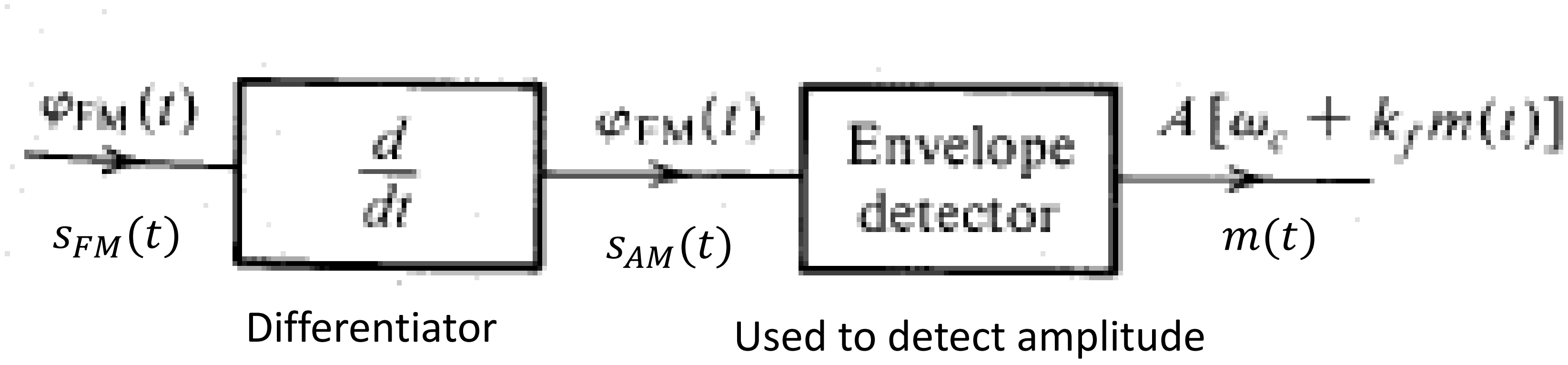
If consider n times multiplication, the output is multiplied by a factor of n, and modulation index becomes nβ

FM signal Demodulation:



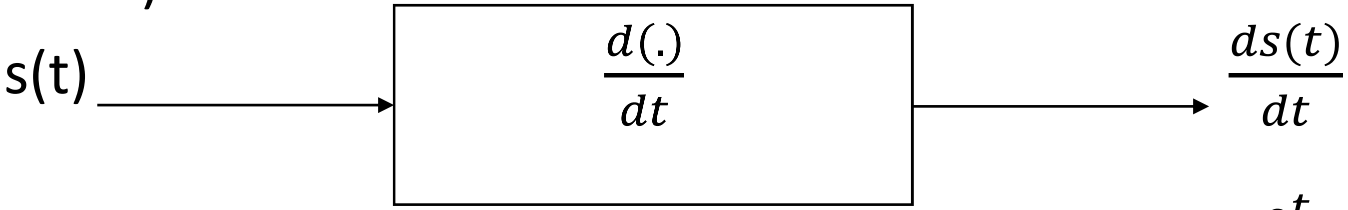
FM signal Demodulation:

- Generalized way to extract m(t):



FM signal Demodulation:

- FM signal can be demodulated using a differentiator (a linear time invariant circuit)



$$s(t) = A_c\cos(2\pi f_c\mathrm{t} + 2\pi k_f \int_0^t m(t)d\mathrm{t})$$

$$\frac{ds(t)}{dt} = -A_c\sin(2\pi f_c\mathrm{t} + 2\pi k_f \int_0^t m(t)d\mathrm{t}) \times \frac{d}{dt}\left(2\pi f_c t + 2\pi k_f \int_0^t m(t)dt\right)$$

$$= -A_c\sin(2\pi f_c\mathrm{t} + 2\pi k_f \int_0^t m(t)d\mathrm{t}) \times (2\pi f_c + 2\pi k_f m(t))$$

$$\frac{ds(t)}{dt} = -A_c\ (2\pi f_c + 2\pi k_f m(t)) \times \sin(2\pi f_c\mathrm{t} + 2\pi k_f \int_0^t m(t)d\mathrm{t})$$

Envelope of output of differentiator is $A_c\ (2\pi f_c + 2\pi k_f m(t))$

Optional:
- sign can be removed using $\sin(\theta + \pi)$

$$A_c\ (2\pi f_c + 2\pi k_f m(t)) \times \sin(2\pi f_c\mathrm{t} + 2\pi k_f \int_0^t m(\tau)d\tau + \pi)$$

FM signal Demodulation:

$$= 2\pi A_c \ (f_c + k_f m(t)) = 2\pi A_c \ f_c(1 + \frac{k_f m(t)}{f_c})$$

This can be used to recover original message signal $m(t)$

- For envelope detection, the signal should not be overmodulated. Since, overmodulation results in phase reversal.

$2\pi A_c(f_c + k_f m(t))$ the condition for No envelope distortion is

$$f_c \geq k_f max|m(t)|$$
$$f_i(t) = f_c + k_f m(t)$$
$$\Delta F = max|f_i(t) - f_c|$$
$$= max\left|k_f m(t)\right|$$

$\Delta F = k_f max \ |m(t)|$

Therefore, $f_c \geq \Delta F$ (condition for No envelope distortion)

FM signal Demodulation:

$$\frac{d}{dt}\left(s_{FM}(t)\right)$$
$$= A_c 2\pi f_c \left(1 + \frac{k_f}{f_c} m(t)\right) \sin(2\pi f_c t + 2\pi k_f \int m(t)\,dt + \pi)$$

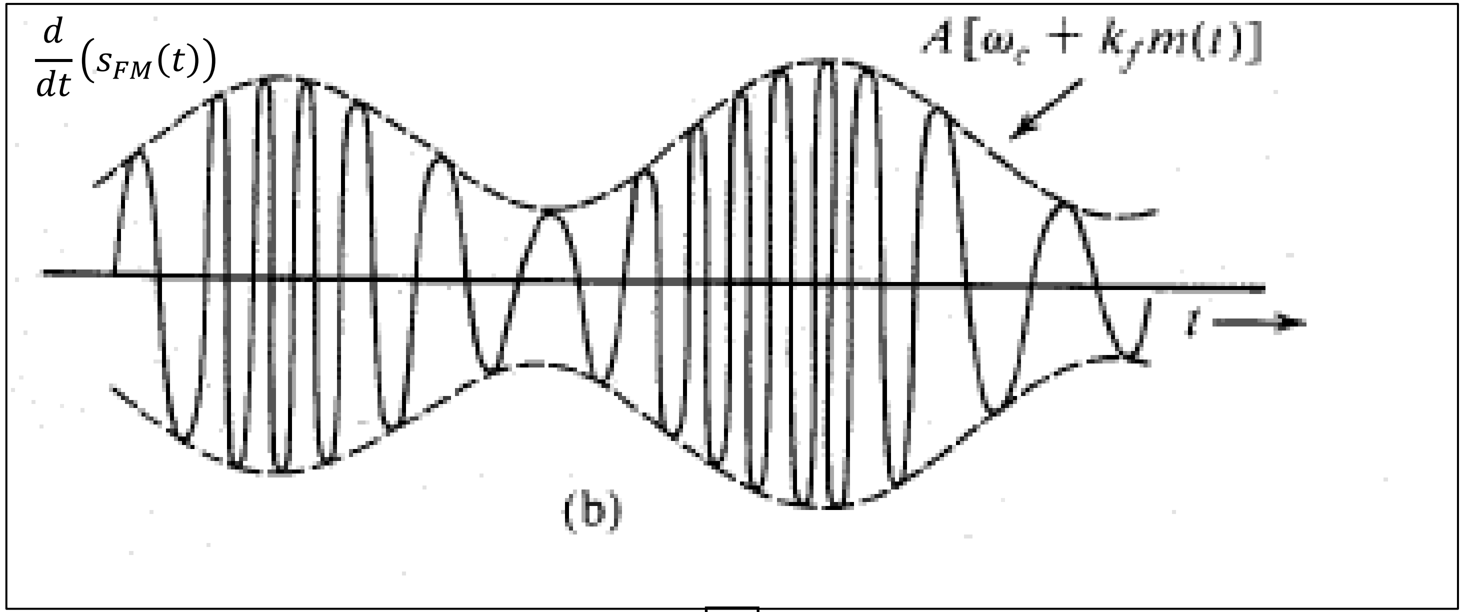
$$s_{AM}(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t)$$

Amplitude = $A_c 2\pi f_c + A_c 2\pi k_f m(t)$

DC term(bias) Amplitude modulation

Shifts the signal up/down

FM signal Demodulation:



Envelope Detector

$m(t)$

FM signal Demodulation (Limitations):

$$s_{FM}(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt\right)$$

$s'_{FM}(t)$ = noise affected FM signal

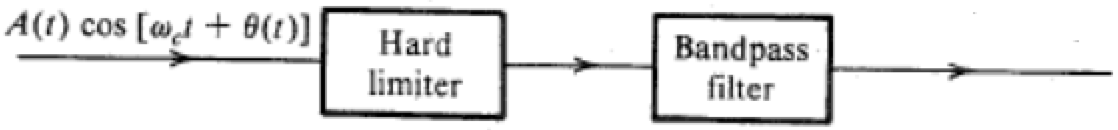
$$s'_{FM}(t) = A_c(t)\cos(2\pi f_c t + 2\pi k_f \int m(t)\, dt)$$

$$\frac{d}{dt}s'(t)$$
$$= A'_c(t)\cos\big(2\pi f_c t + \varphi(t)\big) + A_c(t)(-\sin(2\pi f_c t + \varphi(t)))(2\pi f_c t + 2\pi k_f m(t))$$

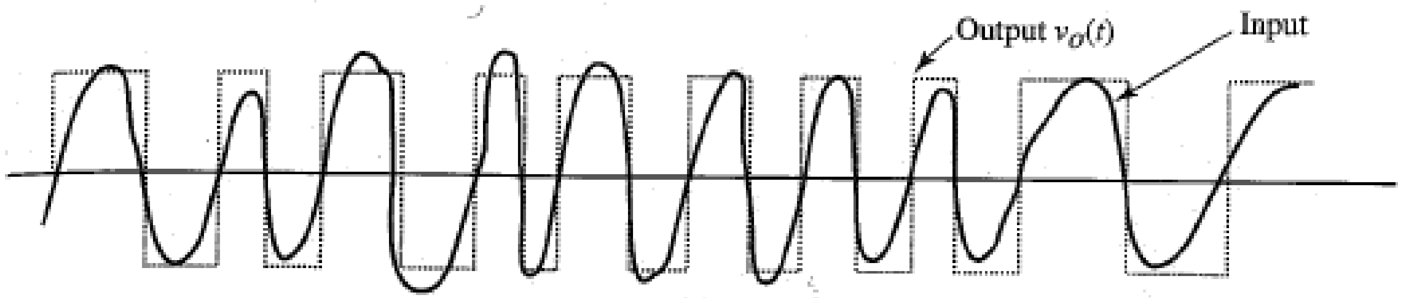
$A'_c(t)\cos\big(2\pi f_c t + \varphi(t)\big)$ cause of error at the receiver

FM signal Demodulation (Solution):

- Limiter: The amplitude variations of an angle-modulated carrier can be eliminated by what is known as a bandpass limiter.



(a)



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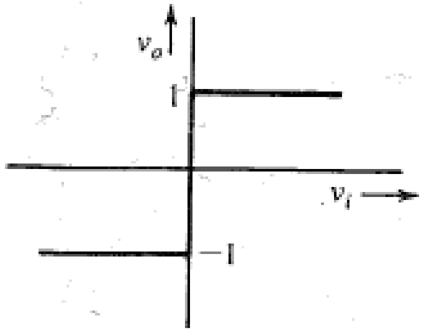

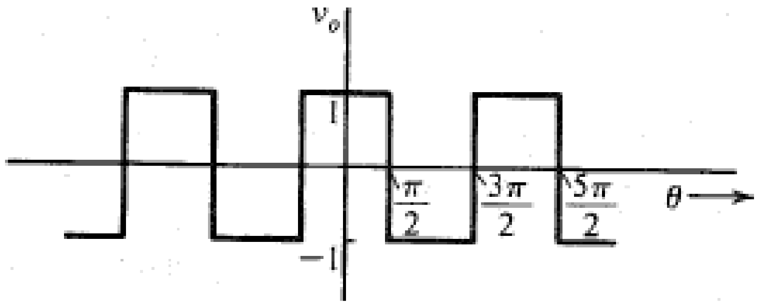

FM signal Demodulation: