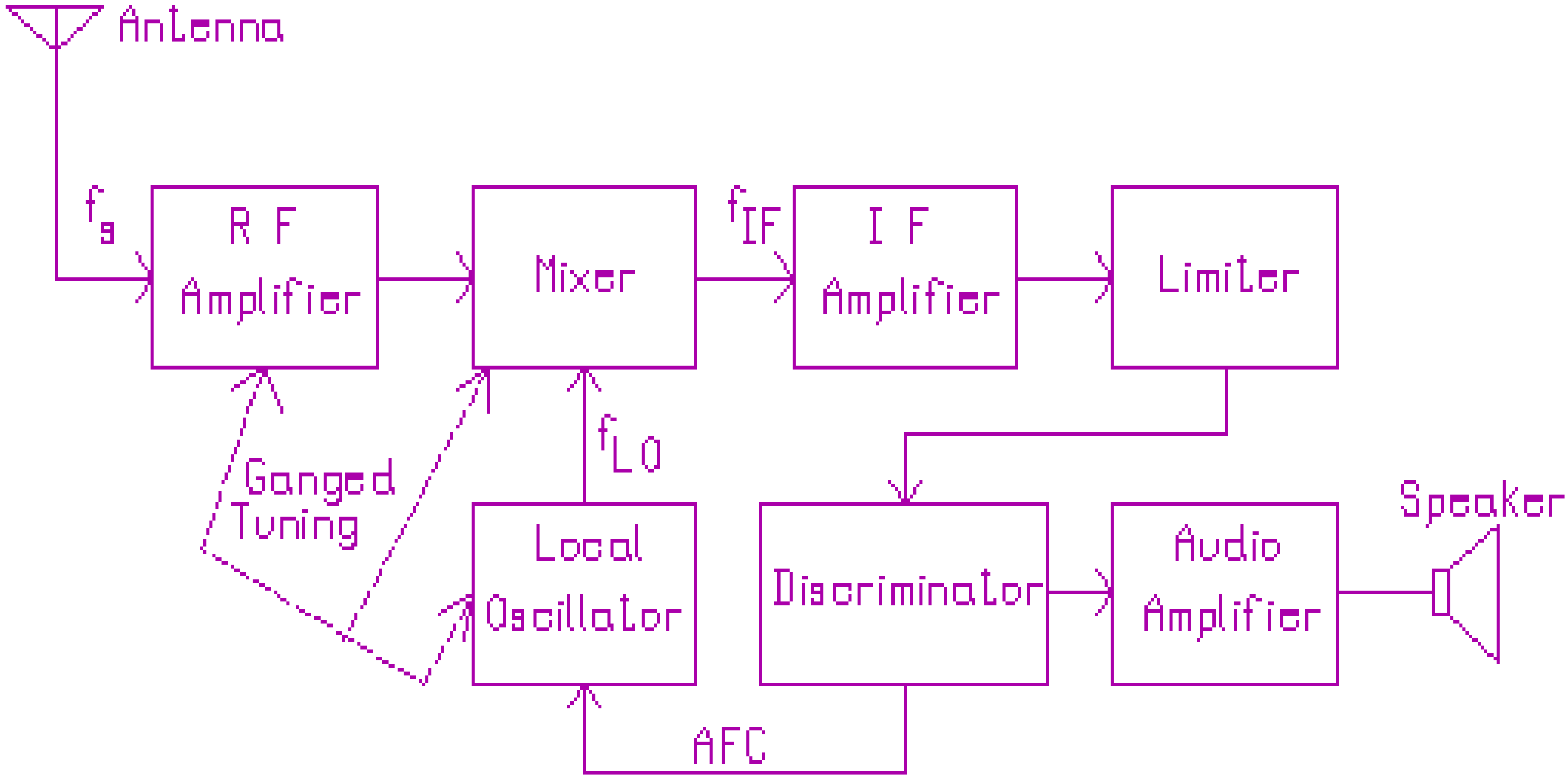
FM Receivers

- **FM receivers, like AM receivers, utilize the superheterodyne principle, but they operate at much higher frequencies (88 - 108 MHz).**
- **A *limiter* is often used to ensure the received signal is constant in amplitude before it enters the *discriminator* or *detector*.**

Block Diagram of FM Receiver



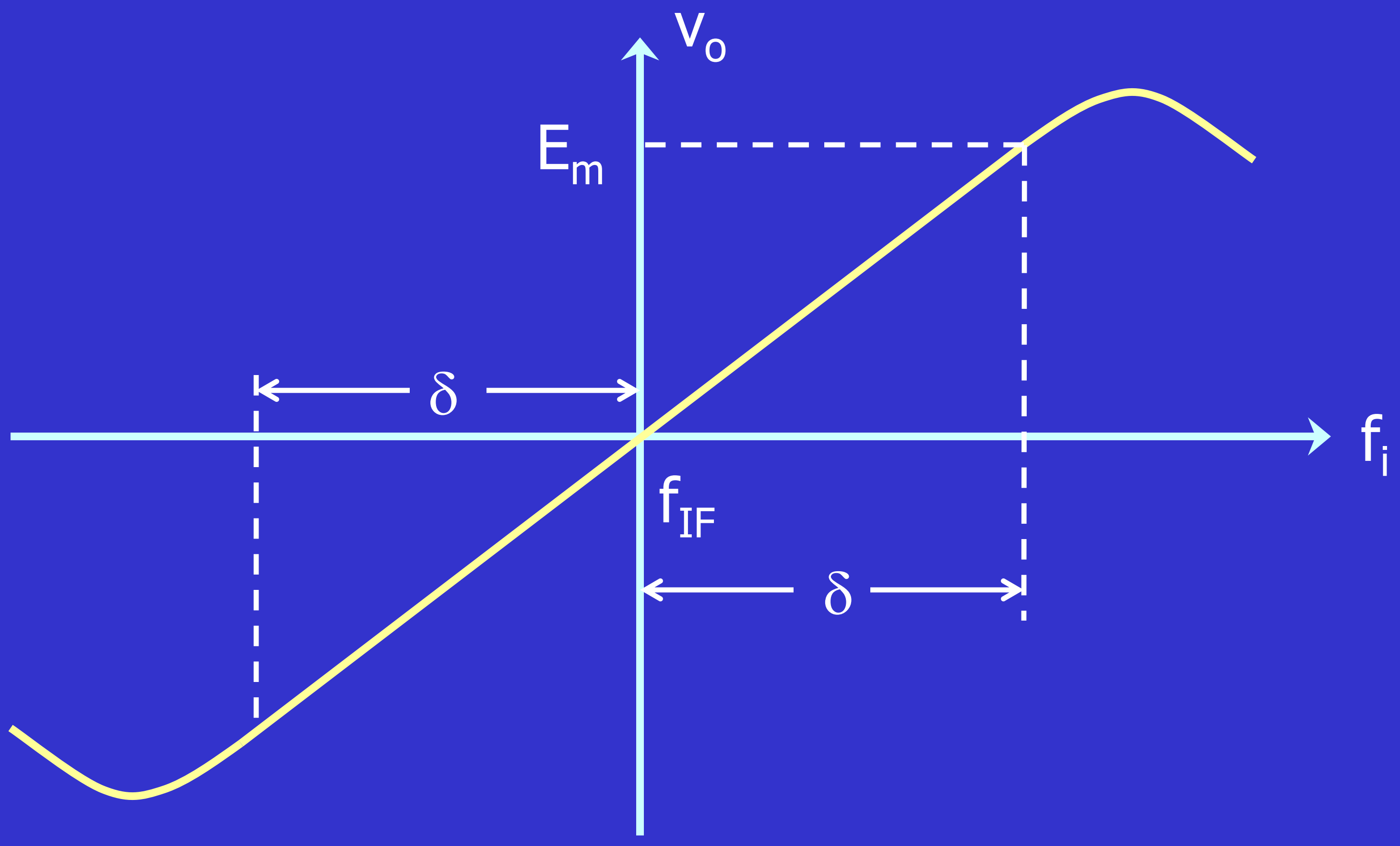
FM Demodulators

- **The FM demodulators must convert frequency variations of the input signal into amplitude variations at the output.**
- ***The Foster-Seeley discriminator* and its variant, the *ratio detector* are commonly found in older receivers. They are based on the principle of *slope detection* using resonant circuits.**

Slope Detector

- La Ca produce an output voltage proportional to the input frequency.
- Center frequency is place at the center of the most linear portion of the voltage versus-frequency curve
- When IF deviates above or below fc , output voltage increases or decreases
- Tuned circuit converts frequency variation to voltage variation

S-curve Characteristics of FM Detectors



Balanced Slope Detector

- Two single-ended slope detectors connected in parallel and fed 180 o out of phase
- Phase inversion accomplished by center-tapping secondary winding
- Top tuned circuit is tuned to a frequency above the IF center frequency by approx. 1.33 X Δ f (1.33 X 75 k = 100kHz)
- Similarly, the lower to 100 kHz bellow the IF

- **At the IF center frequency, the output voltage from the two tuned circuits are equal in amplitude but opposite in polarity, v out = 0 V**
- **When IF deviate above resonance, top tuned circuit produces a higher output voltage than the lower circuit and voltage goes positive**
- **When IF deviate below resonance, lower tuned circuit produces higher output than upper, and output goes negative**

Foster-Seely Discriminator

- **Similar to balanced slope detector**
- **Output voltage versus frequency deviation is more linear**
- **Only one tuned circuit: easier to tune**
- **Slope-detector and Foster-Seely discriminator respond to amplitude variation as well as frequency deviation: must be preceded by a separate limiter circuit**

Ratio Detector

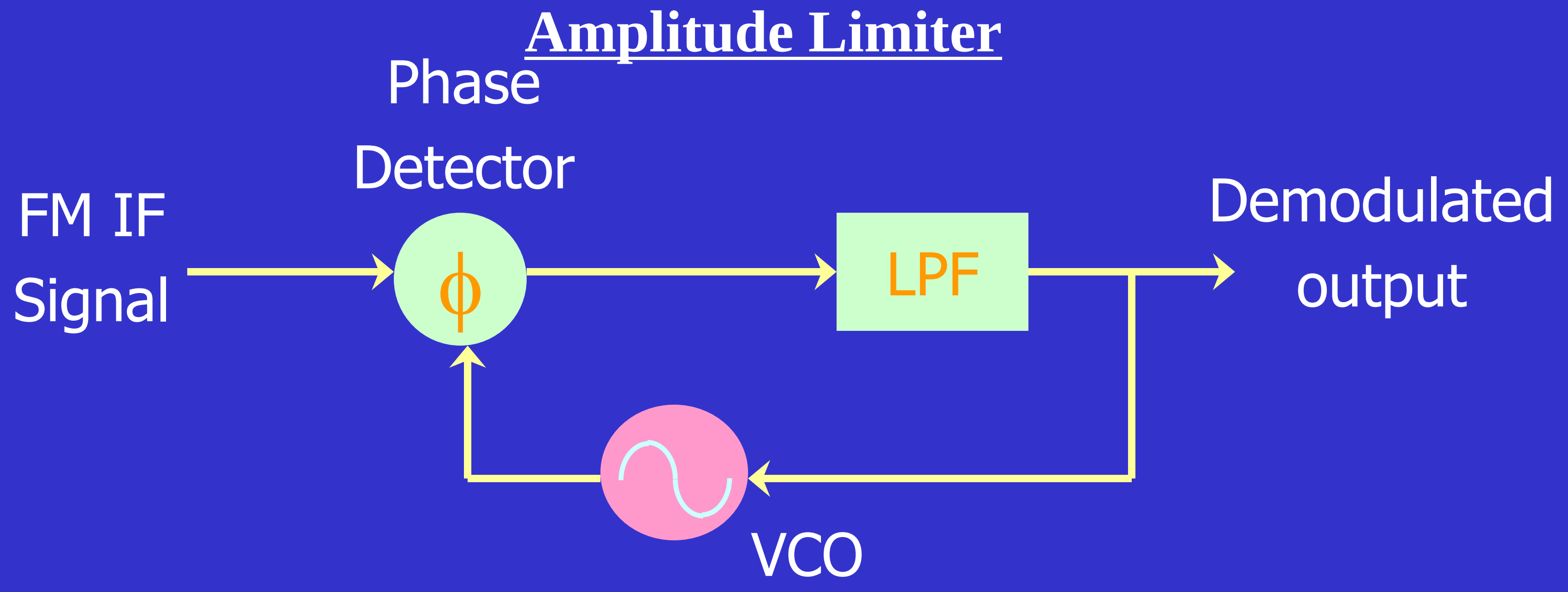
- **Advantages over slope detector & Foster-Seely: It is insensitive to amplitude variation in input signal**

Phased Locked Loop (PLL)

- PLL initially locks to the IF frequency
- After locking, voltage controlled oscillator (VCO) would track frequency changes in the input signal by maintaining a phase error
- The PLL input is a deviated FM and the VCO natural frequency is equal to the IF center frequency
- The correction voltage produced at the output of the phase comparator is proportional to the frequency deviation that is equal to the demodulated information signal

PLL FM Detector

- ***PLL*** ***detectors*** **are commonly found in modern FM receivers.**



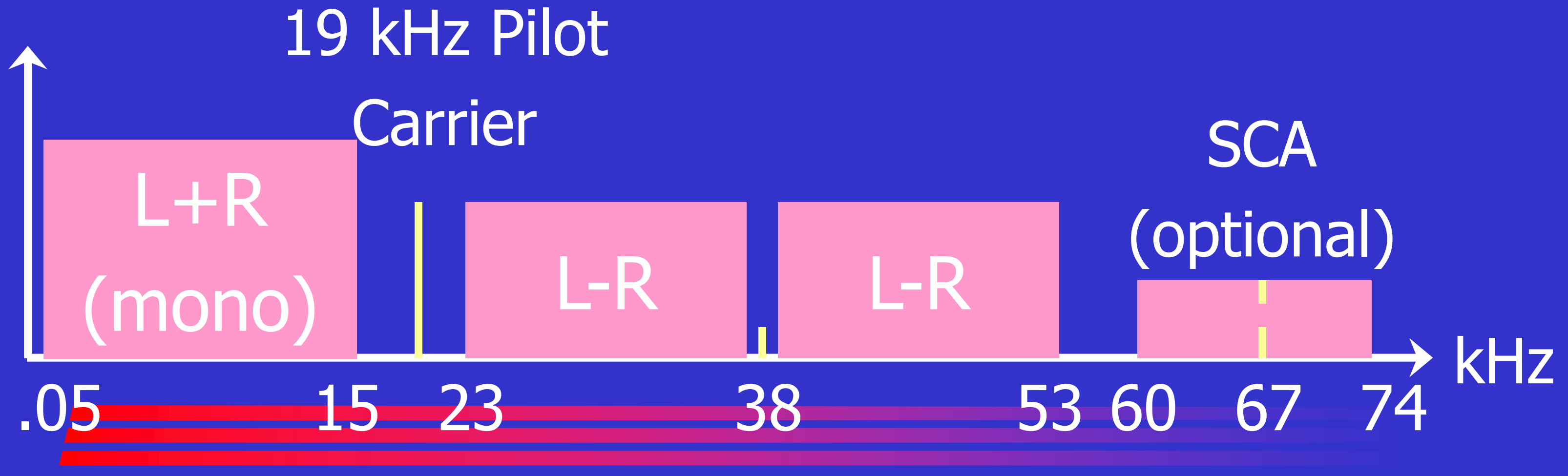
Amplitude Limiter

- **Most frequency discriminators use envelope detection to extract the intelligence from the FM wave form**
- **Envelope detection will demodulate incident amplitude variations as well as frequency variation**
- **Transmission noise and interference add to the signal to produce unwanted amplitude variations**

- **In the receiver, unwanted AM and random noise are demodulated along with the signal: unwanted distortion is produced**
- **A limiter circuit is used to produce a constant amplitude output for all input signal above a specified threshold level**

FM Stereo Broadcasting: Baseband Spectra

- **To maintain compatibility with mono system, FM stereo uses a form of FDM or frequency-division multiplexing to combine the left and right channel information:**



FM Stereo Broadcasting

- **To enable the L and R channels to be reproduced at the receiver, the L-R and L+R signals are required. These are sent as a DSBSC AM signal with a *suppressed subcarrier* at 38 kHz.**
- **The purpose of the 19 kHz *pilot* is for proper detection of the DSBSC AM signal.**
- **The optional *Subsidiary Carrier Authorization* (SCA) signal is normally used for services such as background music for stores and offices.**

Chapter 7: Angle Modulation Transmission

- What is Angle modulation
- What is the difference between frequency and phase modulation
- What is direct and indirect modulation
- Deviation sensitivity, phase deviation, modulation index
- Bandwidth of angle-modulated wave
- Bandwidth requirements
- Phasor representation of angle-modulated wave
- Frequency up-conversion
- FM transmitters
- Angle modulation versus AM

Angle modulation

$$v_{\text{anglemod}}(t) = V_c \cos\left(\theta_{inst}(t)\right)$$

$\theta_{inst}(t)$ = instantaneous phase (radians)

Question:

What is the instantaneous frequency?

Angle modulation

$$v_{\text{anglemod}}(t) = V_c \cos\left(\theta_{inst}(t)\right)$$

$$\omega_{inst}(t) = \frac{d\theta_{inst}(t)}{dt}$$

$$\theta_{inst}(t) = \int_0^t \omega_{inst}(t)\,dt$$

$v_{anglemod}(t)$	= angle modulated wave (Volt)
V_c	= peak carrier amplitude (Volt)
ω_{inst}	= instantaneous angular frequency (rad/sec)
θ_{inst}	= instantaneous phase (radians)

Phase modulation

The instantaneous phase of a harmonic carrier signal is varied in such a way that the instantaneous phase deviation i.e. the difference between the instantaneous phase and that of the carrier signal is linearly related to the size of the modulating signal at a given instant of time.

$$\theta_{inst}\left(t\right)=?$$

$$v_{PM}\left(t\right)=?$$

$$\omega_{inst}\left(t\right)=?$$

Phase modulation

The instantaneous phase of a harmonic carrier signal is varied in such a way that the instantaneous phase deviation i.e. the difference between the instantaneous phase and that of the carrier signal is linearly related to the size of the modulating signal at a given instant of time.

$$\theta_{inst}(t) = \omega_c t + K_p v_m(t)$$

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p v_m(t) + \cancel{\theta_c}\right)$$

$$\omega_{inst}(t) = \frac{d\theta_{inst}(t)}{dt} = \frac{d\left\{\omega_c t + K_p v_m(t)\right\}}{dt} = \omega_c + K_p \frac{dv_m(t)}{dt}$$

K_p is the phase deviation sensitivity (rad/Volt)

Frequency modulation

The frequency of a harmonic carrier signal is varied in such a way that the instantaneous frequency deviation i.e. the difference between the instantaneous frequency and the carrier frequency is linearly related to the size of the modulating signal at a given instant of time.

$$\omega_{inst}(t) = ?$$

$$\theta_{inst}(t) = ?$$

$$v_{FM}(t) = ?$$

Frequency modulation

The frequency of a harmonic carrier signal is varied in such a way that the instantaneous frequency deviation i.e. the difference between the instantaneous frequency and the carrier frequency is linearly related to the size of the modulating signal at a given instant of time.

$$\omega_{inst}(t) = \omega_c + K_f v_m(t)$$

$$\theta_{inst}(t) = \int_0^t \omega_{inst}(t)\,dt = \omega_c t + \int_0^t K_f v_m(t)\,dt$$

$$v_{FM}(t) = V_c \cos\left(\omega_c t + \int_0^t K_f v_m(t)\,dt + \cancel{\theta_c}\right)$$

K_f is the frequency deviation sensitivity $\left[\frac{rad/s}{Volt}\right]$

PM: $\theta_{inst}(t) = \omega_c t + K_p v_m(t)$ — K_p is the deviation sensitivity

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p v_m(t)\right)$$

$$\omega_{inst}(t) = \frac{d\theta_{inst}(t)}{dt} = \frac{d\left\{\omega_c t + K_p v_m(t)\right\}}{dt} = \omega_c + K_p \frac{dv_m(t)}{dt}$$

FM: $\omega_{inst}(t) = \omega_c + K_f v_m(t)$ — K_f is the deviation sensitivity

$$\theta_{inst}(t) = \int_0^t \omega_{inst}(t)\,dt = \omega_c t + \int_0^t K_f v_m(t)\,dt$$

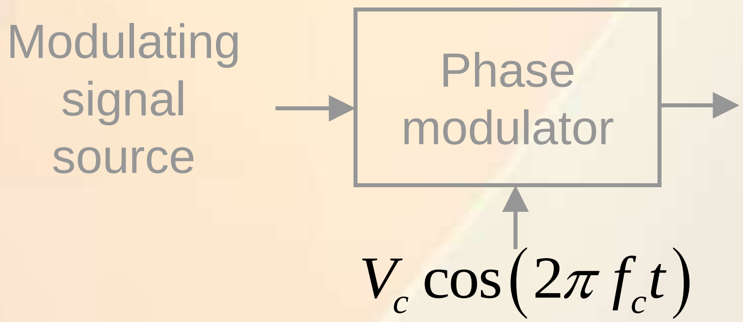
$$v_{FM}(t) = V_c \cos\left(\omega_c t + \int_0^t K_f v_m(t)\,dt\right)$$

TASK: Make block diagrams of PM and FM modulators

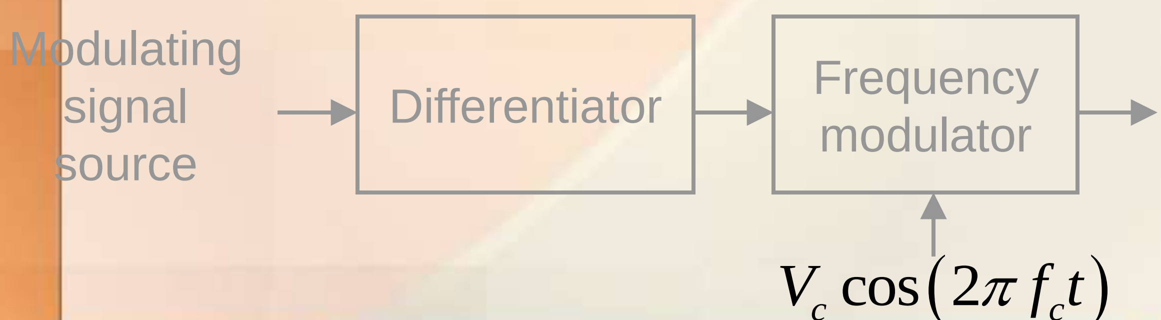
PM: $\theta_{inst}(t) = \omega_c t + K_p v_m(t)$ K_p is the deviation sensitivity

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p v_m(t)\right)$$

$$\omega_{inst}(t) = \frac{d\theta_{inst}(t)}{dt} = \frac{d\left\{\omega_c t + K_p v_m(t)\right\}}{dt} = \omega_c + K_p \frac{dv_m(t)}{dt}$$



Direct

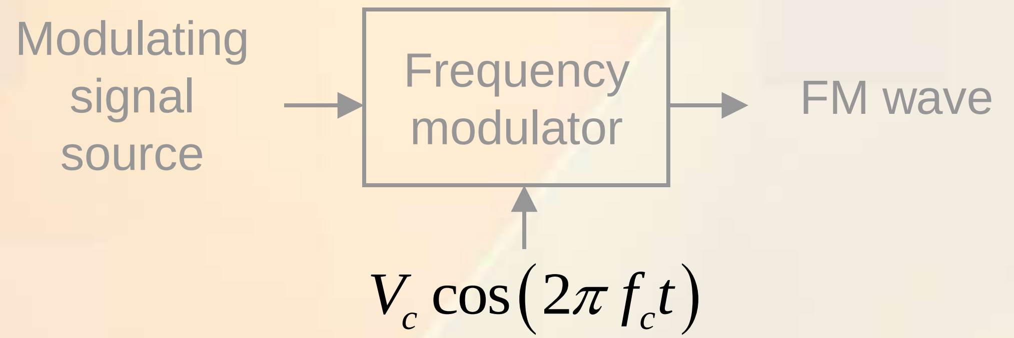


Indirect

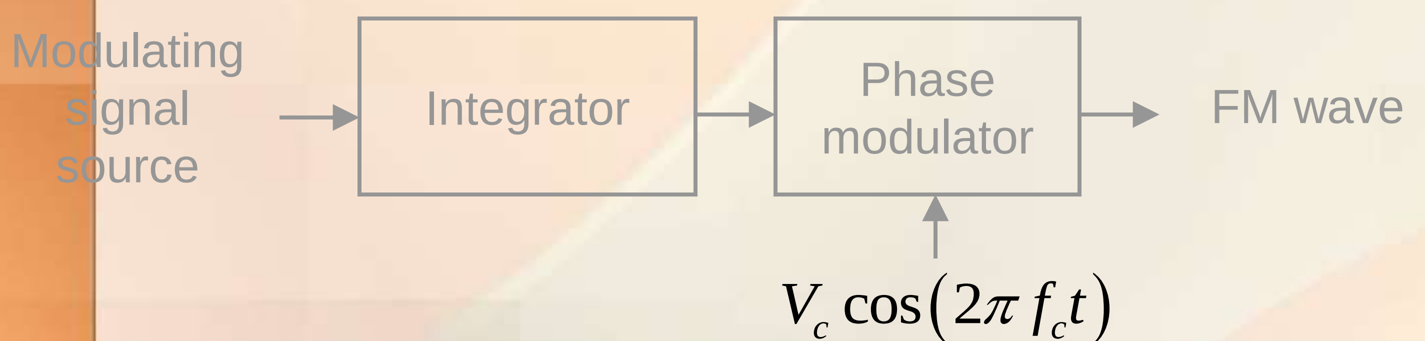
FM: $\omega_{inst}(t) = \omega_c + K_f v_m(t)$ — K_f is the deviation sensitivity

$$\theta_{inst}(t) = \int_0^t \omega_{inst}(t)\,dt = \omega_c t + \int_0^t K_f v_m(t)\,dt$$

$$v_{FM}(t) = V_c \cos\left(\omega_c t + \int_0^t K_f v_m(t)\,dt\right)$$



Direct



Indirect

Frequency modulation of single frequency signal

PM:

$$v_m(t) = V_m \cos(\omega_m t)$$

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p V_m \cos(\omega_m t)\right)$$

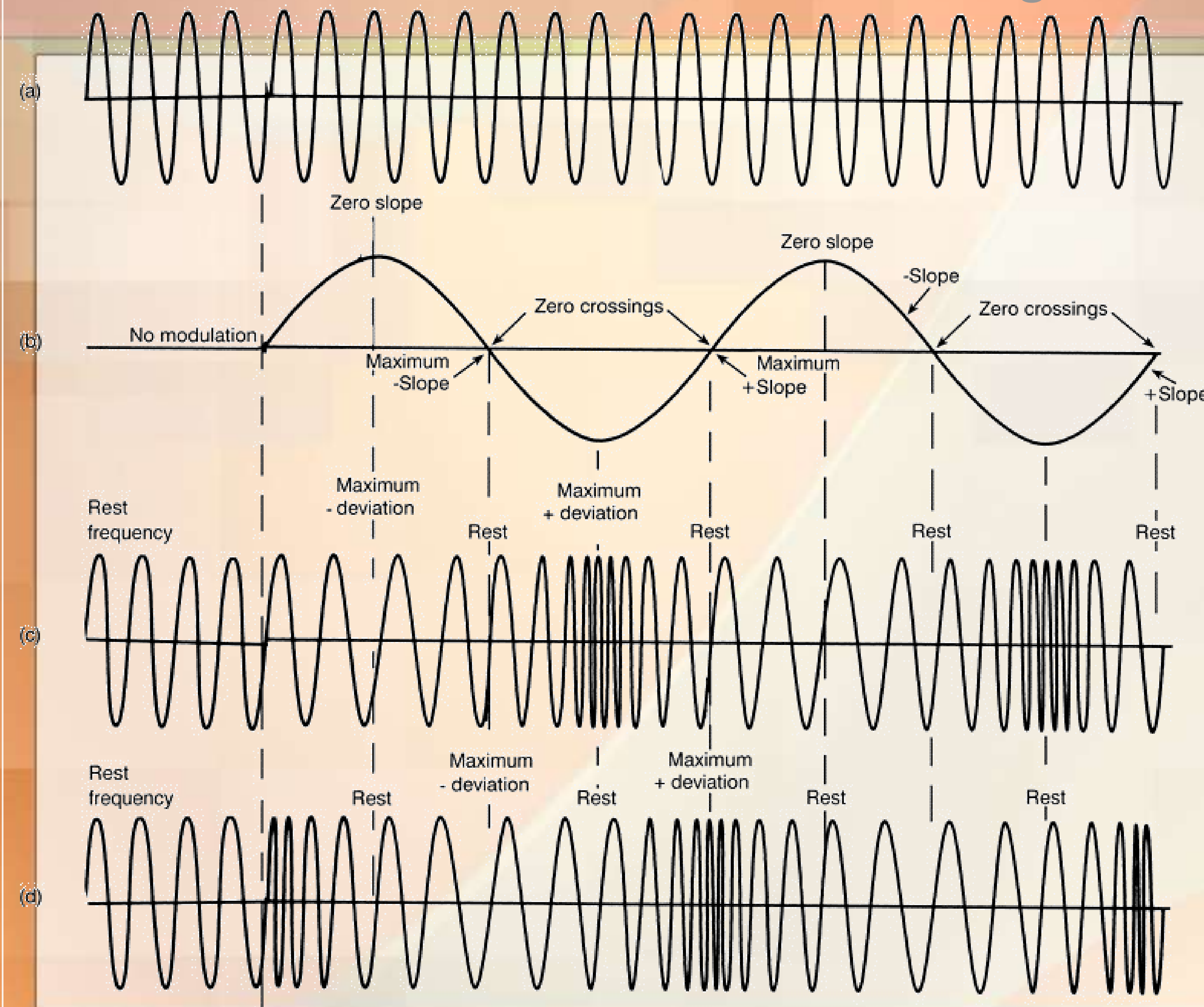
FM:

$$v_m(t) = V_m \cos(\omega_m t)$$

$$v_{FM}(t) = V_c \cos\left(\omega_c t + \int_0^t K_f V_m \cos(\omega_m t)\, dt\right)$$

$$= V_c \cos\left(\omega_c t + \frac{K_f V_m}{\omega_m} \sin(\omega_m t)\right)$$

PM and FM of sine-wave signal



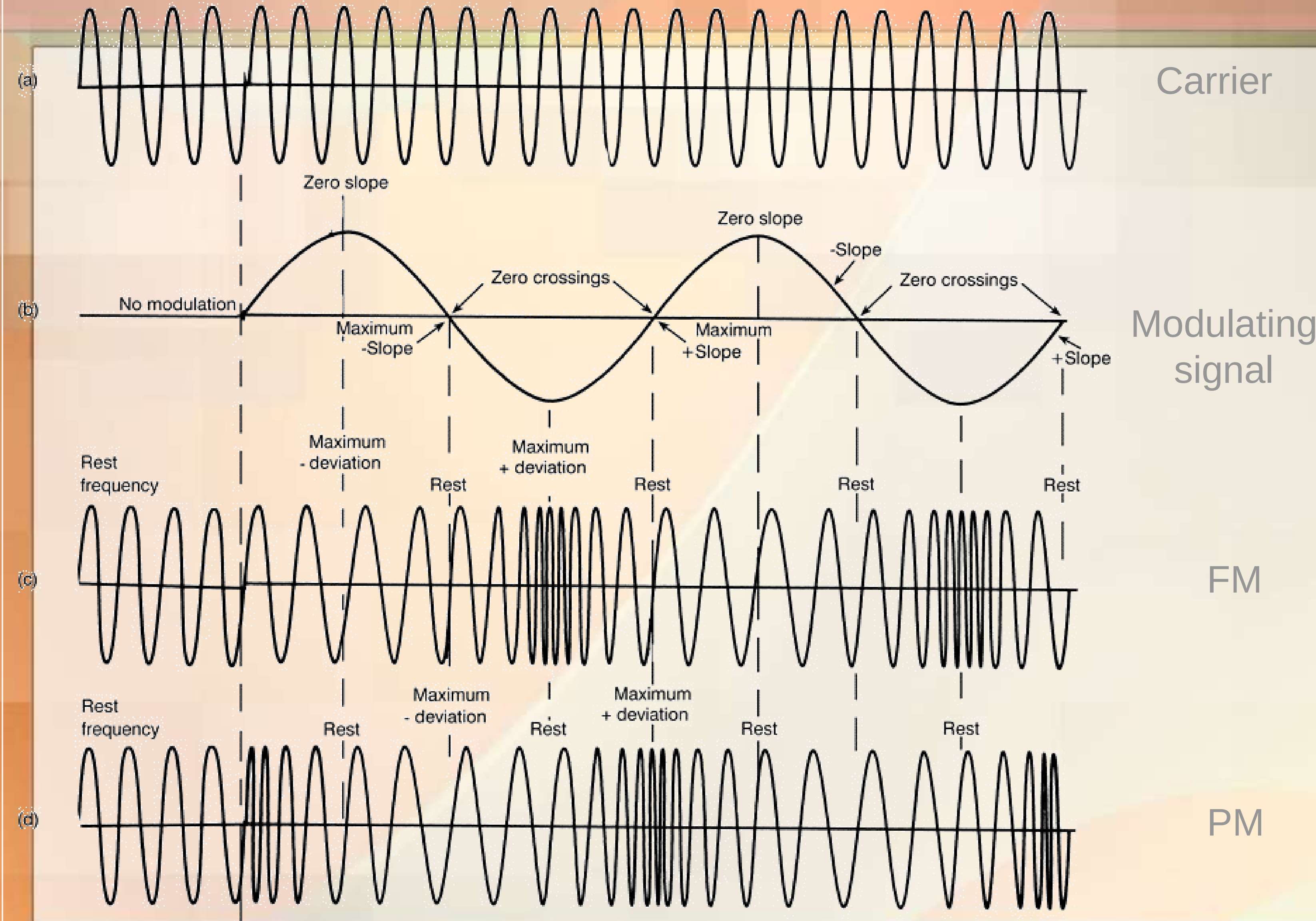
Carrier

Modulating signal

?

?

PM and FM of sine-wave signal



Phase Deviation and Modulation Index

$$v_{angle}(t) = V_c \cos\left(\omega_c t + m\cos(\omega_m t)\right)$$

m is the **peak phase deviation** or **modulation index**

PM:

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p V_m \cos(\omega_m t)\right)$$

$$m = K_p V_m$$ (radians)

FM:

$$v_{FM}(t) = V_c \cos\left(\omega_c t + \frac{K_f V_m}{\omega_m}\sin(\omega_m t)\right)$$

$$m = \frac{K_f V_m}{\omega_m}$$ (unitless)

Frequency Deviation

$$\omega_{inst}(t) = \frac{d\theta_{inst}(t)}{dt}$$

$$m = \frac{K_f V_m}{\omega_m} \quad \text{FM}$$

$$m = K_p V_m \quad \text{PM}$$

FM:

$$v_{FM}(t) = V_c \cos\left(\omega_c t + \frac{K_f V_m}{\omega_m}\sin(\omega_m t)\right)$$

$$\omega_{inst}(t) = \omega_c + K_f V_m \cos(\omega_m t)$$

$\Delta\omega = K_f V_m$ (peak) frequency deviation

$m = \frac{K_f V_m}{\omega_m} = \frac{\Delta\omega}{\omega_m}$ dependent of the frequency

PM:

$$v_{PM}(t) = V_c \cos\left(\omega_c t + K_p V_m \cos(\omega_m t)\right)$$

$$\omega_{inst}(t) = \omega_c + \underline{K_p V_m \omega_m} \sin(\omega_m t)$$

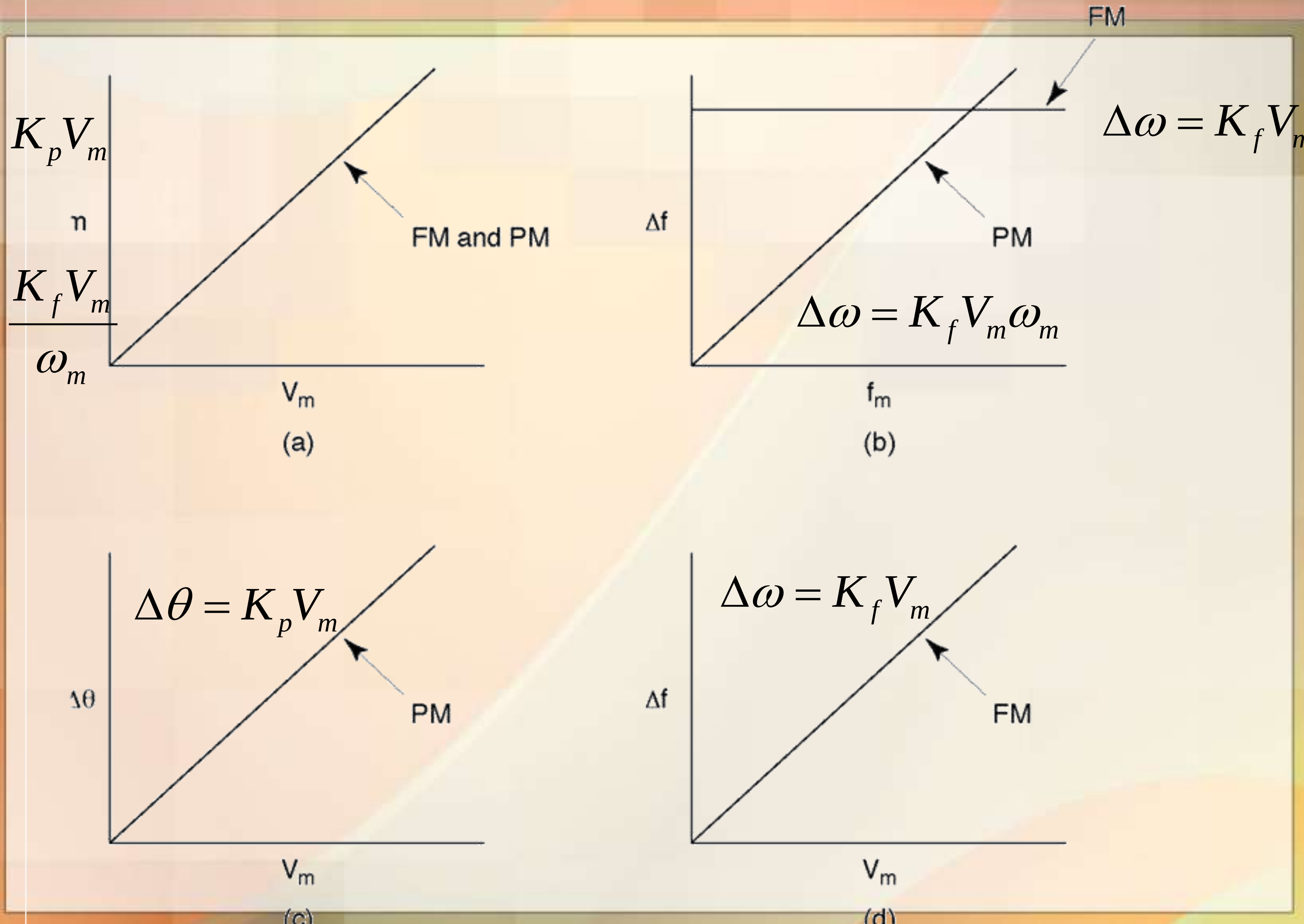
$\Delta\omega = K_p V_m \omega_m$ (peak) frequency deviation

$m = K_p V_m = \frac{K_p V_m \omega_m}{\omega_m} = \frac{\Delta\omega}{\omega_m}$ independent of the frequency

PM and FM of sine-wave signal

$$m_{PM} = K_p V_m$$

$$m_{FM} = \frac{K_f V_m}{\omega_m}$$



Bessel function of the first kind

$$v_{angle}(t) = V_c \cos\left(\omega_c t + m\cos(\omega_m t)\right)$$

m is the modulation index

$$m = \frac{K_f V_m}{\omega_m} \quad \text{FM}$$

$$m = K_p V_m \quad \text{PM}$$

$$\cos(\alpha + m\cos\beta) = \sum_{n=-\infty}^{\infty} J_n(m)\cos\left(\alpha + n\beta + \frac{n\pi}{2}\right)$$

$J_n(m)$ is the Bessel function of the first kind

$$v_{angle}(t) = V_c \sum_{n=-\infty}^{\infty} J_n(m)\cos\left(\omega_c t + n\omega_m t + \frac{n\pi}{2}\right)$$

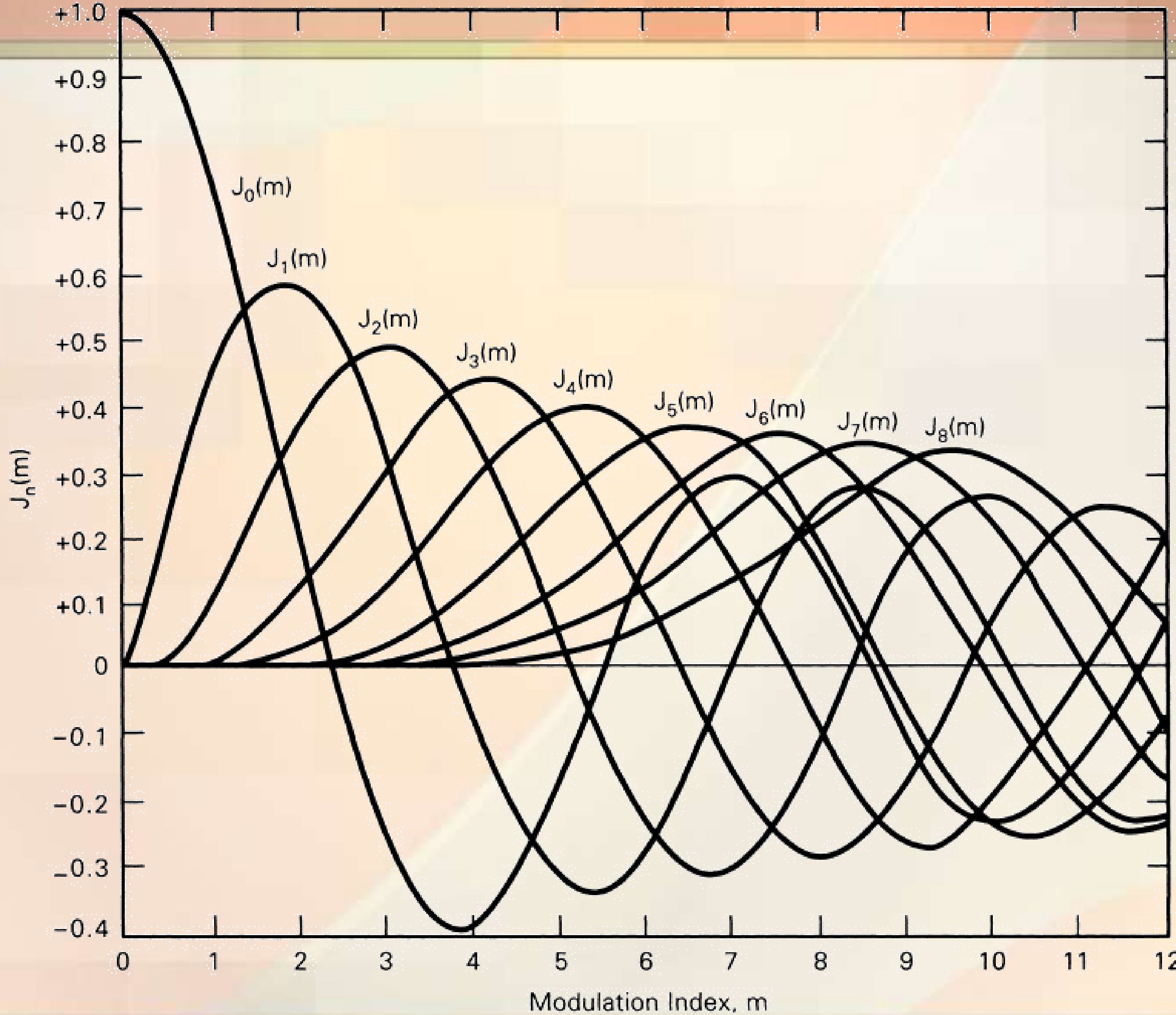
$$v_{angle}(t) = V_c \begin{Bmatrix} J_0(m)\cos\omega_c t + \\ J_1(m)\cos\left[(\omega_c + \omega_m)t + \frac{\pi}{2}\right] - J_1(m)\cos\left[(\omega_c - \omega_m)t - \frac{\pi}{2}\right] + \\ J_2(m)\cos\left[(\omega_c + 2\omega_m)t + \pi\right] + J_2(m)\cos\left[(\omega_c - 2\omega_m)t - \pi\right] + \ldots.. \end{Bmatrix}$$

Relation AM and angle mod

$$v_{am}(t) = E_c \left\{ \cos(2\pi f_c t) + \frac{m}{2} \cos(2\pi [f_c + f_m] t) + \frac{m}{2} \cos(2\pi [f_c - f_m] t) \right\}$$

$$v_{angle}(t) = V_c \left\{ \begin{array}{l} J_0(m)\cos\omega_c t + \\ J_1(m)\cos\left[(\omega_c + \omega_m)t + \frac{\pi}{2}\right] - J_1(m)\cos\left[(\omega_c - \omega_m)t - \frac{\pi}{2}\right] + \\ J_2(m)\cos\left[(\omega_c + 2\omega_m)t\right] + J_2(m)\cos\left[(\omega_c - 2\omega_m)t\right] + \ldots.. \end{array} \right\}$$

Bessel function of the first kind



Bandwidth requirements of Angle-mod waves

$$\omega = 2\pi f$$

$$m = \frac{K_f V_m}{\omega_m} = \frac{\Delta\omega}{\omega_m} = \frac{\Delta f}{f_m}$$

1 Low-index modulation (narrowband FM)

$m < 1$ ($f_m >>> \Delta f$) $B = 2 f_m$ (Hz)

2 High-index modulation (wideband FM)

$m > 10$ ($\Delta f >>> f_m$) $B = 2\Delta f$

3 Actual bandwidth (look at Bessel table page 266)

$$B = 2nf_m$$

where n is the number of significant sidebands

4 Carson's rule (approx 98 % of power)

$$B = 2(\Delta f + f_m)$$

Example

FM modulator

Δf = 10 kHz
f_m = 10 kHz
V_c = 10 V
f_c = 500 kHz

Draw the spectrum?

What is the bandwidth using Bessel table?

What is the bandwidth using Carson's rule?

Example

Δf = 10 kHz

f_m = 10 kHz $\qquad m = 1$

V_c = 10 V

f_c = 500 kHz

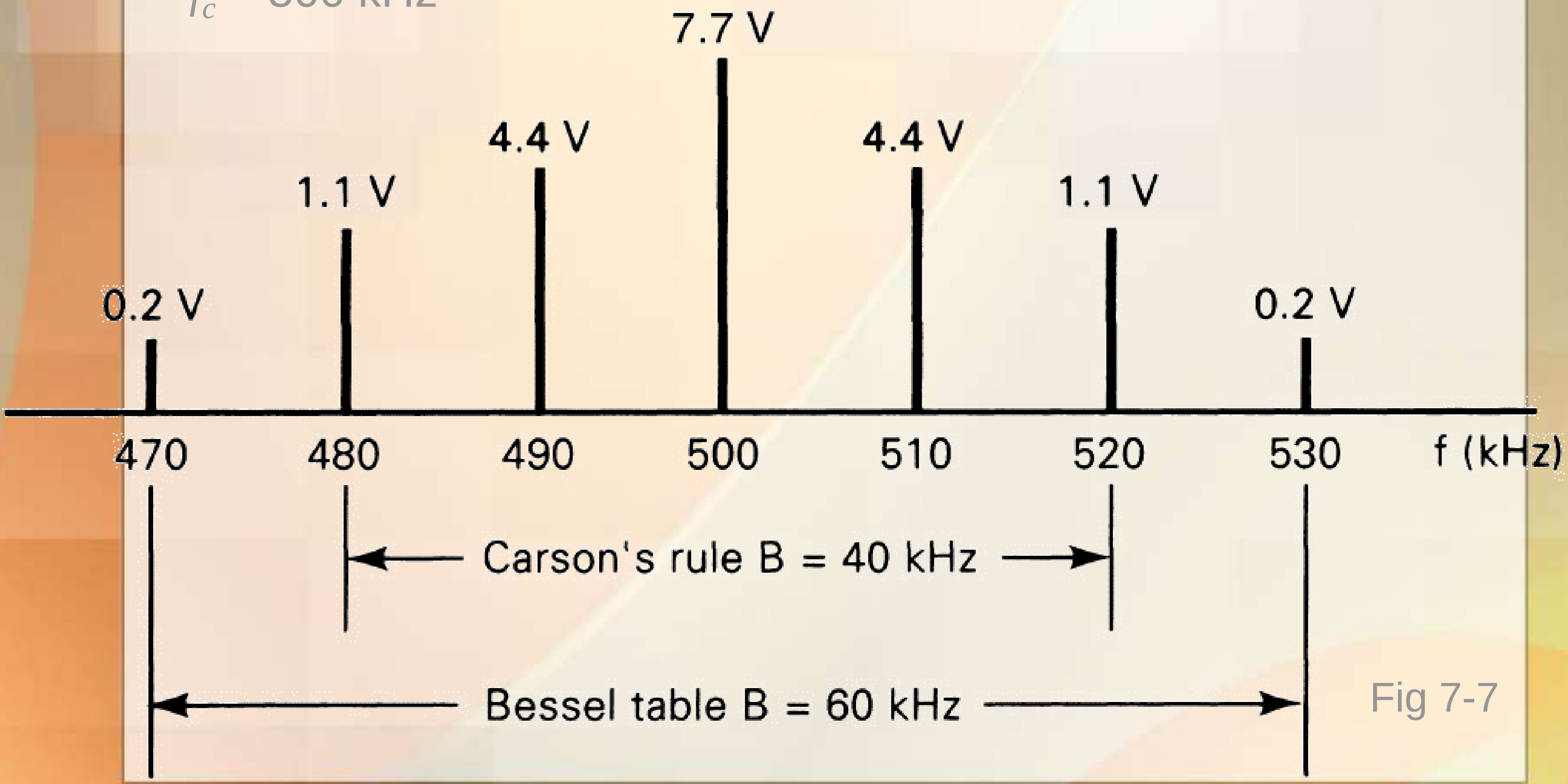


Fig 7-7

Phasor representation of Angle-mod wave

$m < 1$ (narrowband FM)

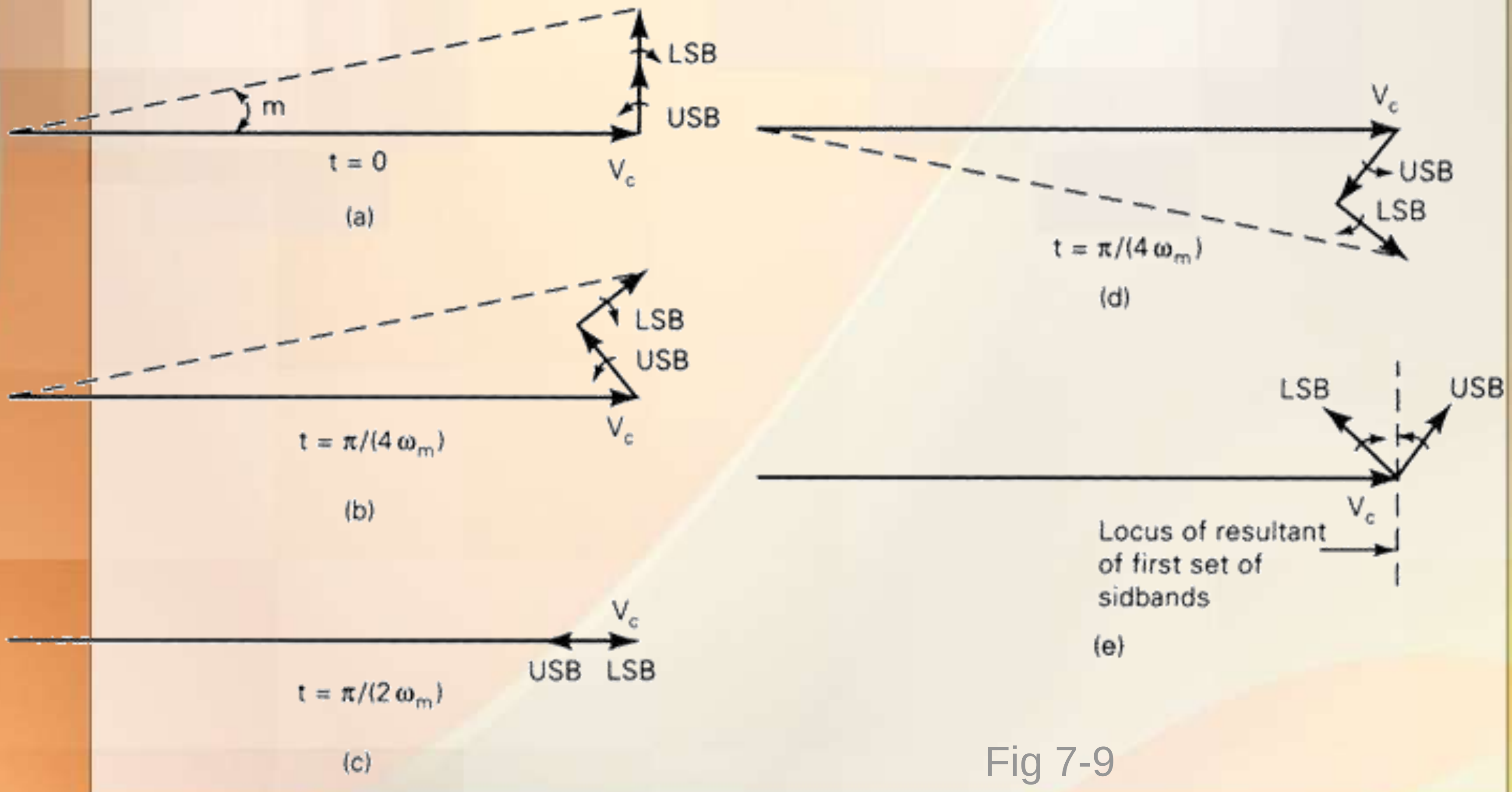


Fig 7-9

Phasor representation of Angle-mod wave

m >> 1 (Wideband FM)

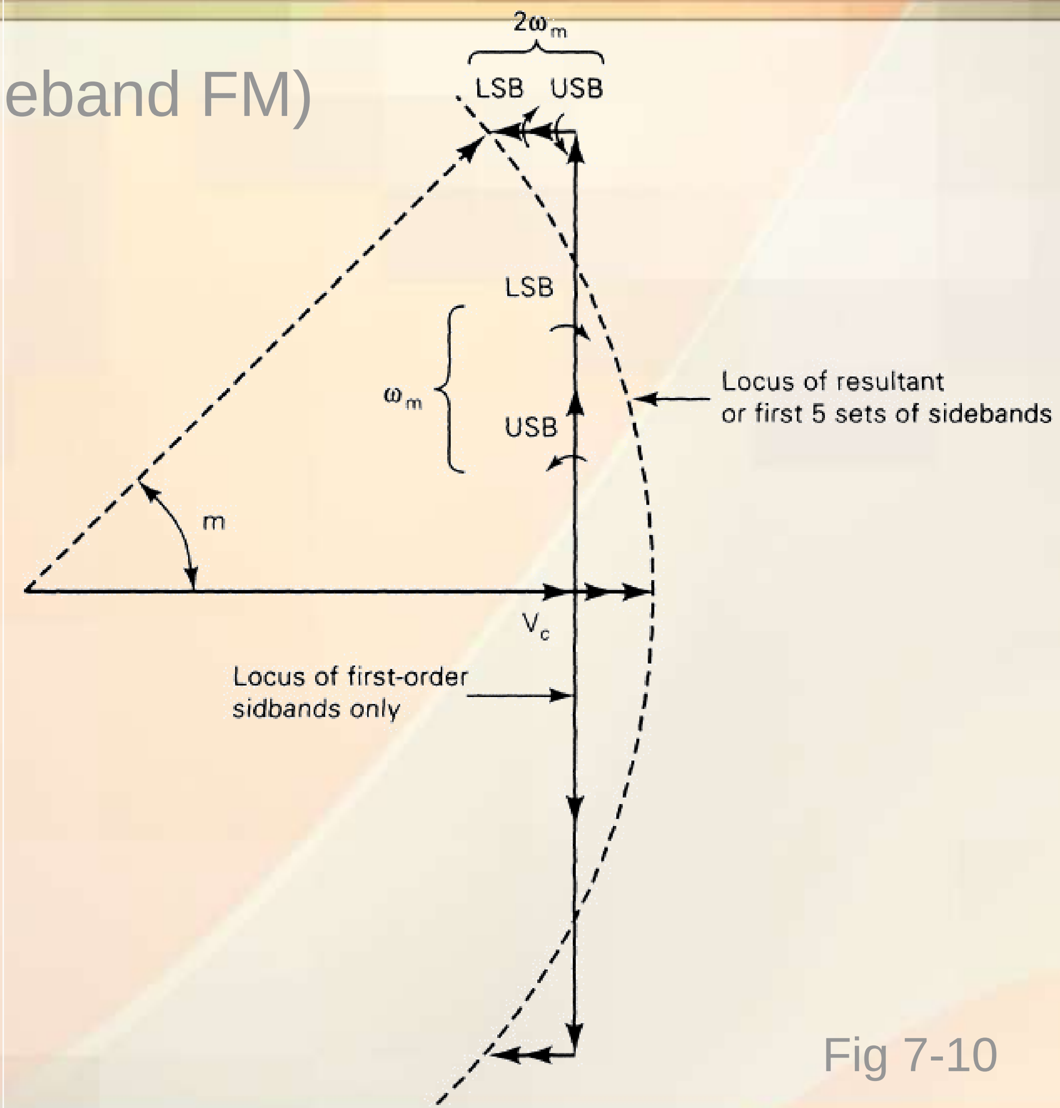


Fig 7-10

Average Power of Angle-mod wave

Instantaneous power in unmodulated carrier is

$$P_c = \frac{V_c^2}{2R} \qquad (W)$$

P_c = carrier power (Watts)
V_c = peak unmodulated carrier voltage (volts)
R = load resistance (ohms)

Instantaneous power in angle-mod carrier is

$$P_t = \frac{v_{angle\,\mathrm{mod}}(t)^2}{R} = \frac{V_{c\_un}^2}{R}\cos^2\left[\omega_c t + \theta(t)\right] = \frac{V_{c\_un}^2}{R}\left\{\frac{1}{2} + \frac{1}{2}\cos\left[2\omega_c t + 2\theta(t)\right]\right\}$$

So the average power of the angle-mod carrier is equal to the unmodulated carrier

$$\langle P_t \rangle = \frac{V_{c\_\mathrm{un}}^2}{2R} = \frac{V_c^2}{2R} + \frac{2(V_1)^2}{2R} + \frac{2(V_2)^2}{2R} + \ldots.. + \frac{2(V_n)^2}{2R}$$

Frequency and Phase modulators
Direct FM Modulator

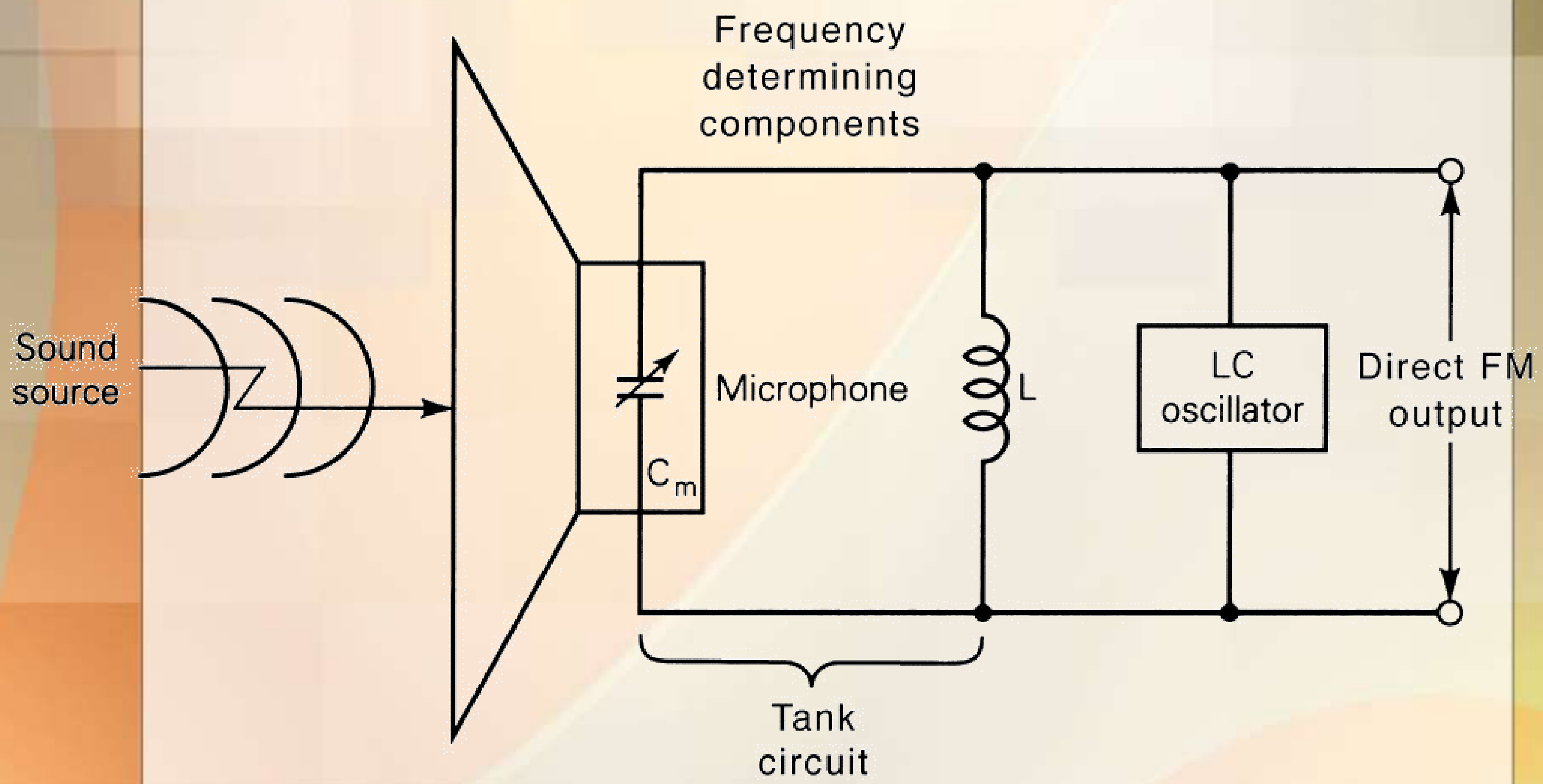
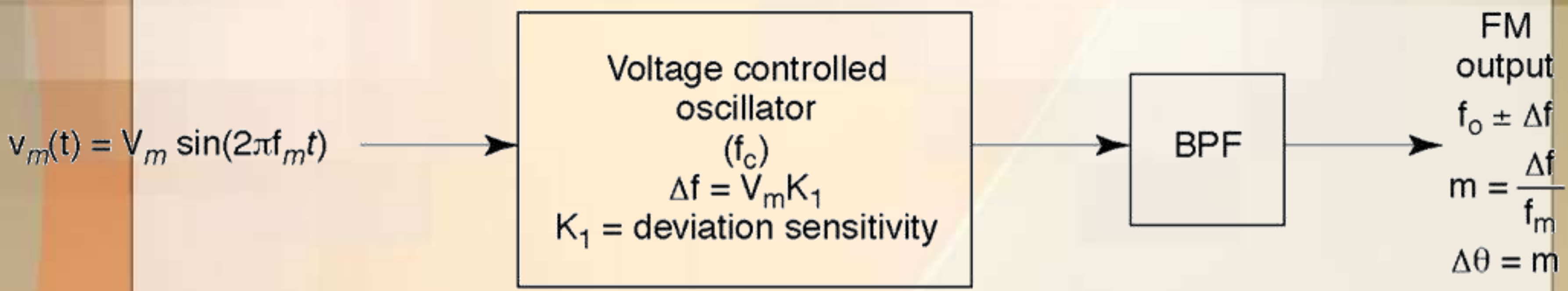


Fig 7-16

Linear integrated-circuit direct FM modulator



High-frequency deviations and high modulation indices.

Fig 7-20

Frequency up-conversion heterodyne method

With FM and PM modulators, the carrier at the output is generally somewhat lower than the desired frequency of transmission

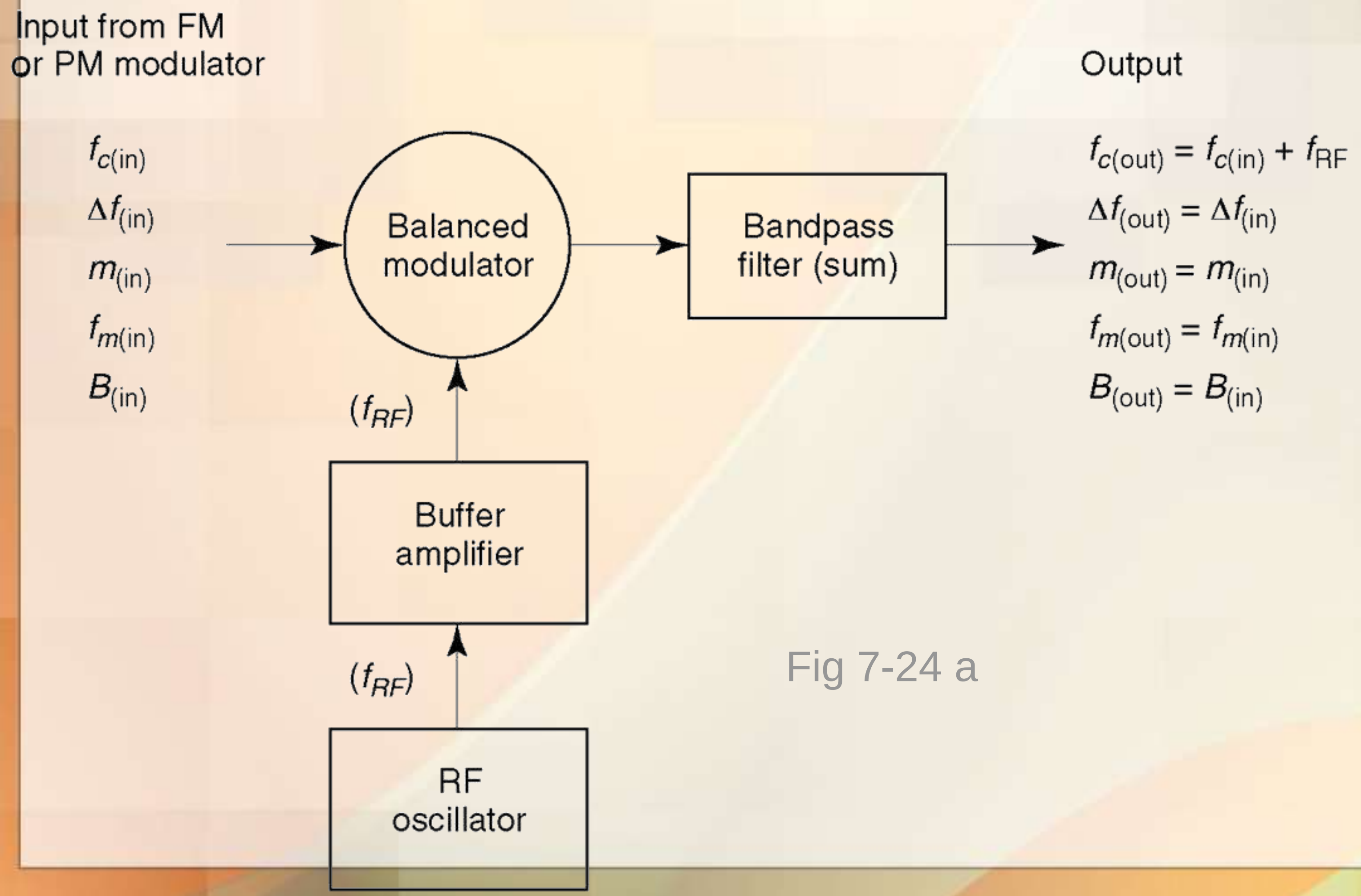


Fig 7-24 a

Frequency up-conversion multiplication

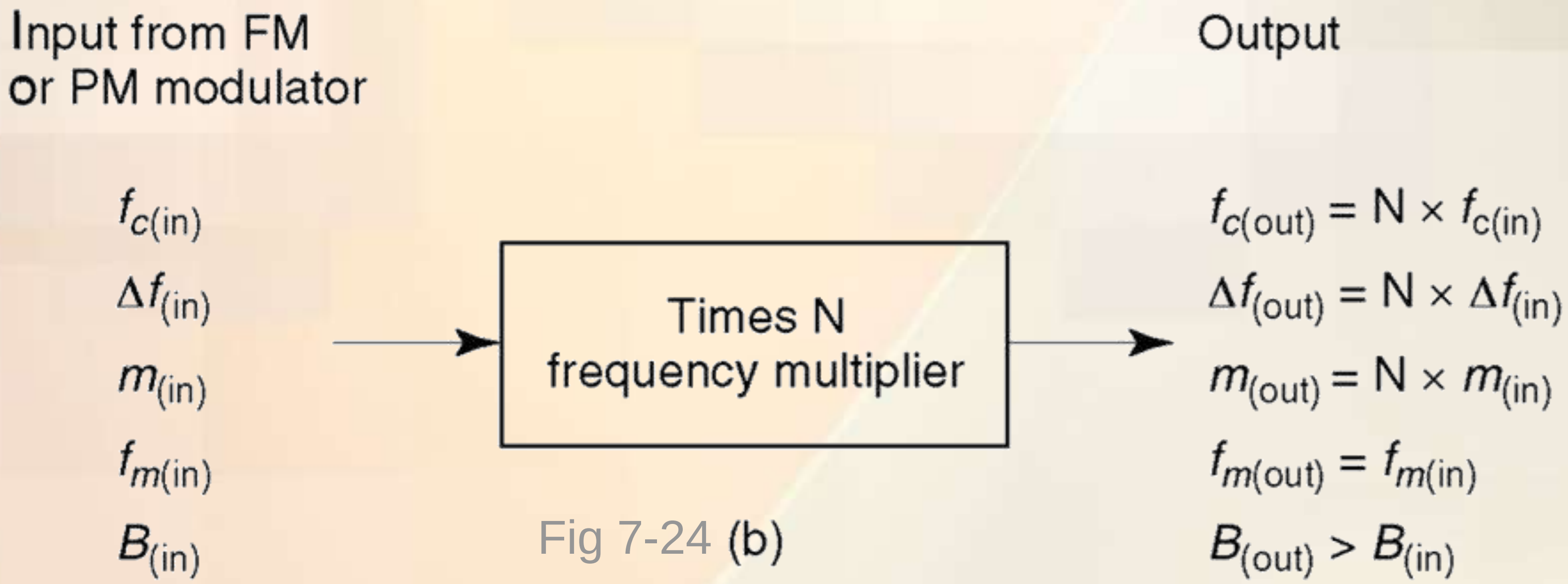
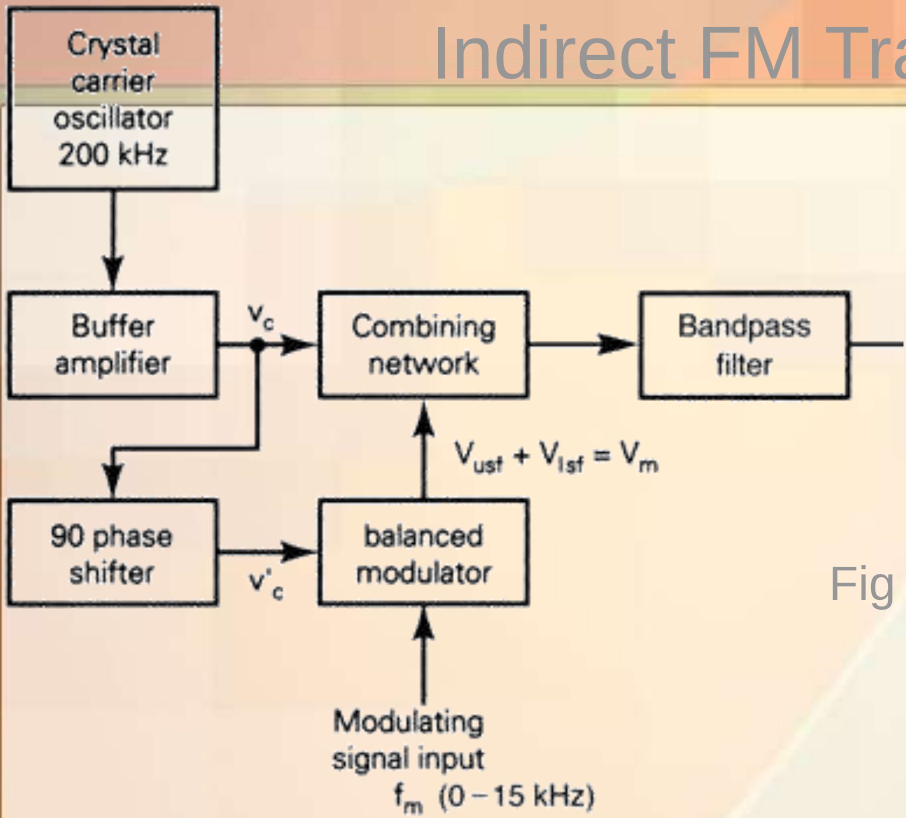


Fig 7-24 (b)

Indirect FM Transmitter



$$f_m = 15 \text{ kHz}$$

$$f_c = 200 \text{ kHz}$$

Fig 7-27

$$v_{angle}(t) = V_c \left\{ \begin{array}{l} J_0(m)\cos\omega_c t + \\ J_1(m)\cos\left[(\omega_c+\omega_m)t+\dfrac{\pi}{2}\right] - J_1(m)\cos\left[(\omega_c-\omega_m)t-\dfrac{\pi}{2}\right] + \\ J_2(m)\cos\left[(\omega_c+2\omega_m)t\right] + J_2(m)\cos\left[(\omega_c-2\omega_m)t\right] + \ldots.. \end{array} \right\}$$

Indirect FM Transmitter

m < 1

$$f_m = 15 \text{ kHz}$$

$$f_c = 200 \text{ kHz}$$

$$\theta_{max} = m = \arctan\frac{V_m}{V_c} \approx \frac{V_m}{V_c}$$

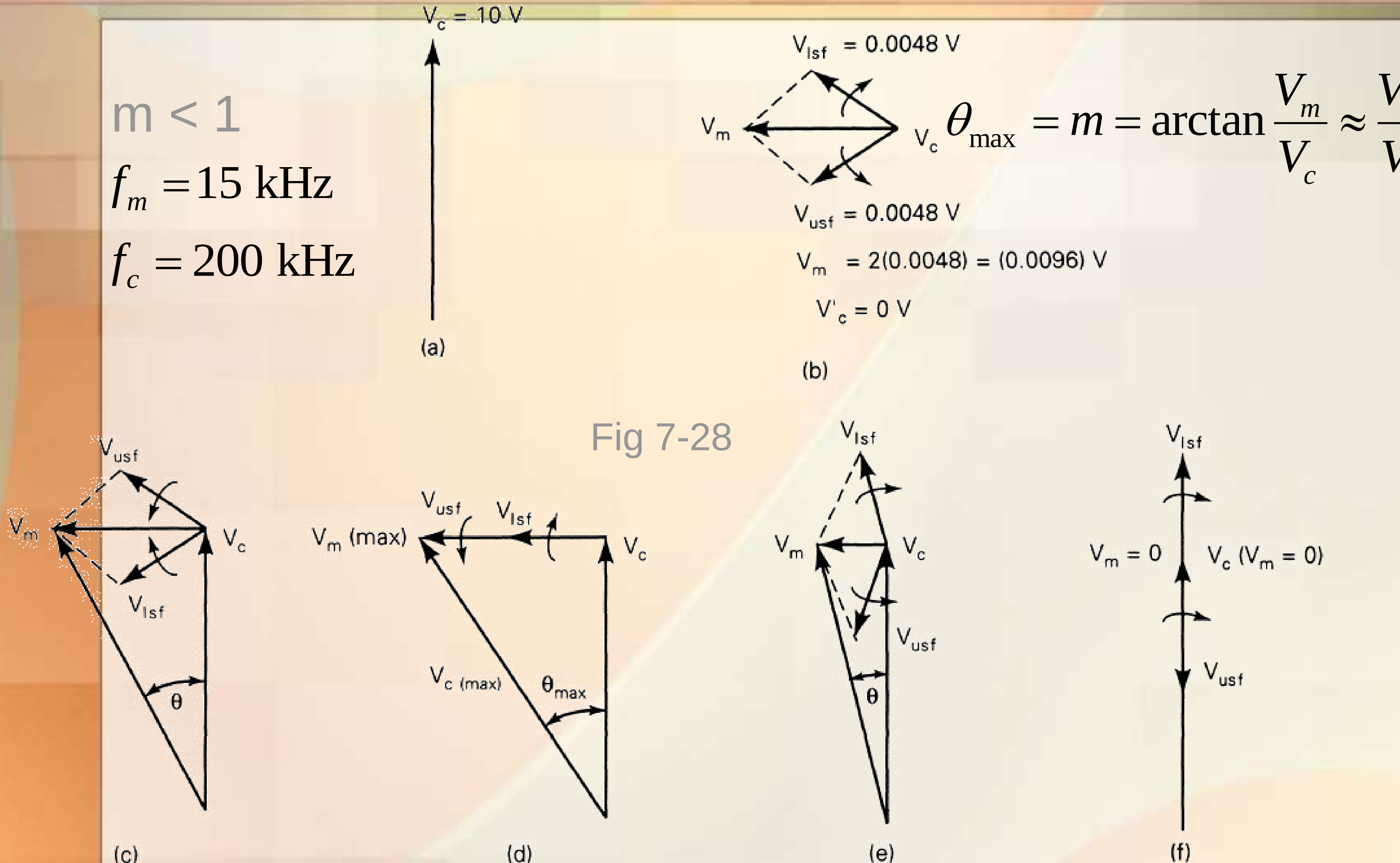


Fig 7-28

Problem !!!!!

Indirect FM Transmitter

$$m = \frac{\Delta f}{f_m}$$

m < 1

$f_m = 15$ kHz

$f_c = 200$ kHz

$\theta_{max} = ?$

$\Delta f = ?$

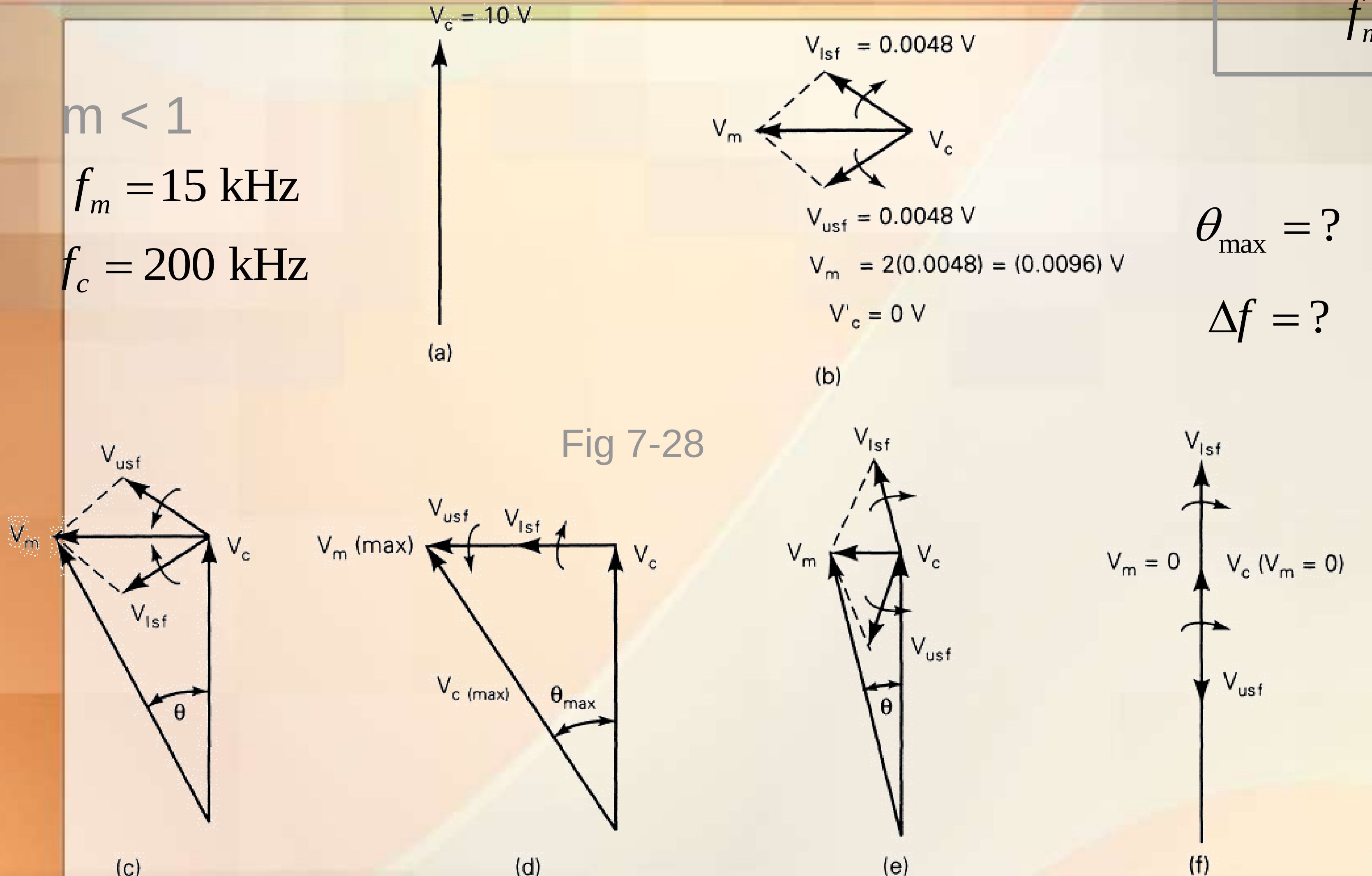


Fig 7-28

θ_{max} = 1.67 miliradiance

Aim Δf = 75 kHz and f_t = 90 MHz

Armstrong Indirect FM Transmitter

Where are the frequency conversions ?

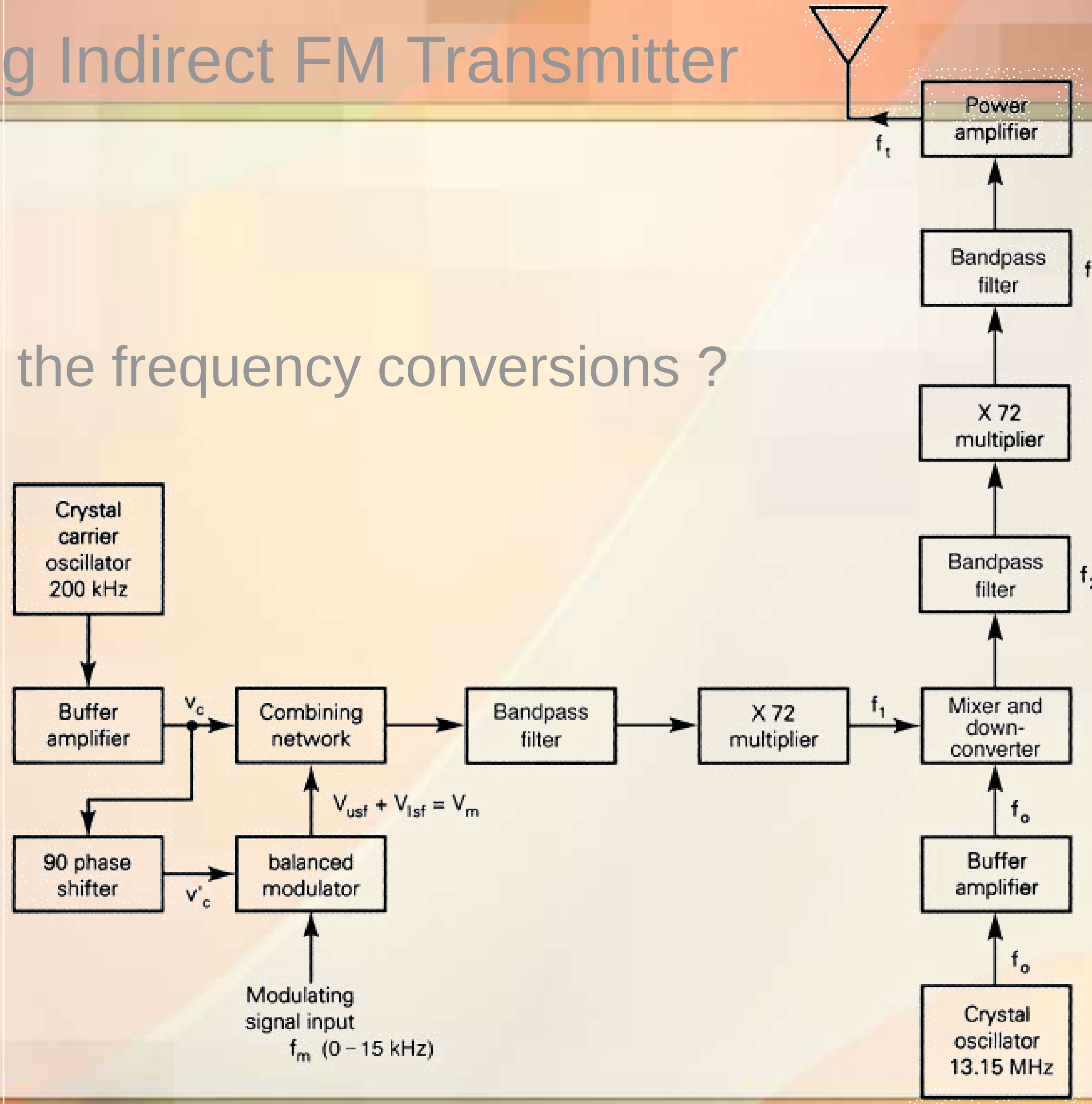


Fig 7-27

Angle mod versus AM

Advantages of Angle modulation

- Noise immunity
- Noise performance and signal-to-noise improvement
- Capture effect
- Power utilization and efficiency

Disadvantages of Angle modulation

- Bandwidth
- Circuit complexity and costs

End Lecture 7

Summary and Outlook

g

Next lecture: Chapter 8
Angle modulation reception