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TO Adda247

"If you can think, you can Achieve"
So start thinking..

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GATE 2024

GATE

प्रचण्ड Batch

Communication System

FREQUENCY MODULATION (FM)

ECE

Chapter-1

Analog Communications

In today's lecture we will cover the following Topis :

1. *Angle Modulation*
2. *Frequency Modulation Fundamentals*
3. *Types of FM (NBFM & WBFM)*
4. *Generation of NBFM*
5. *Generation of WBFM*
6. *Demodulation of FM*

Frequency Modulation (FM)

FM was invented and commercialized after AM. Its main advantage is that it is more resistant to additive noise than AM.

FOM = Noise figure

$$= \frac{(S/N)_{o/p}}{(S/N)_{i/p}}$$

Voice → SSB-SC → SSB
Video → VSB-SC → VSB
Audio → AM (DSB-FC)
QAM/QCM → DSB-SC → DSB

$\}$ Amplitude Modulation


Modulated signal
Sin, Fmin=500Hz,
Fmax=2kHz,
Amp=600mV
Modulating signal
Up ramp, F=60Hz,
Amp=1.8V
Trig'd
TRIGGER
Type
Edge
Source
CH2
Slope
Mode
Auto
Set Up
= 60.6653Hz
CH1 200mV
CH2 1.00V
M 2.50ms
M Pos:20.20ms
CH2 80.0mV
11-09-06 20:45:35
www.tmatlantic.com

Angle Modulation (FM

FM Signal - Time Domain

$\mu = K_a |m(t)|_{max}$

$V_{max}/E_{max} = A_c[1+\mu]$

- For a pulse train baseband signal:

$V_{min}/E_{min} = A_c[1-\mu]$

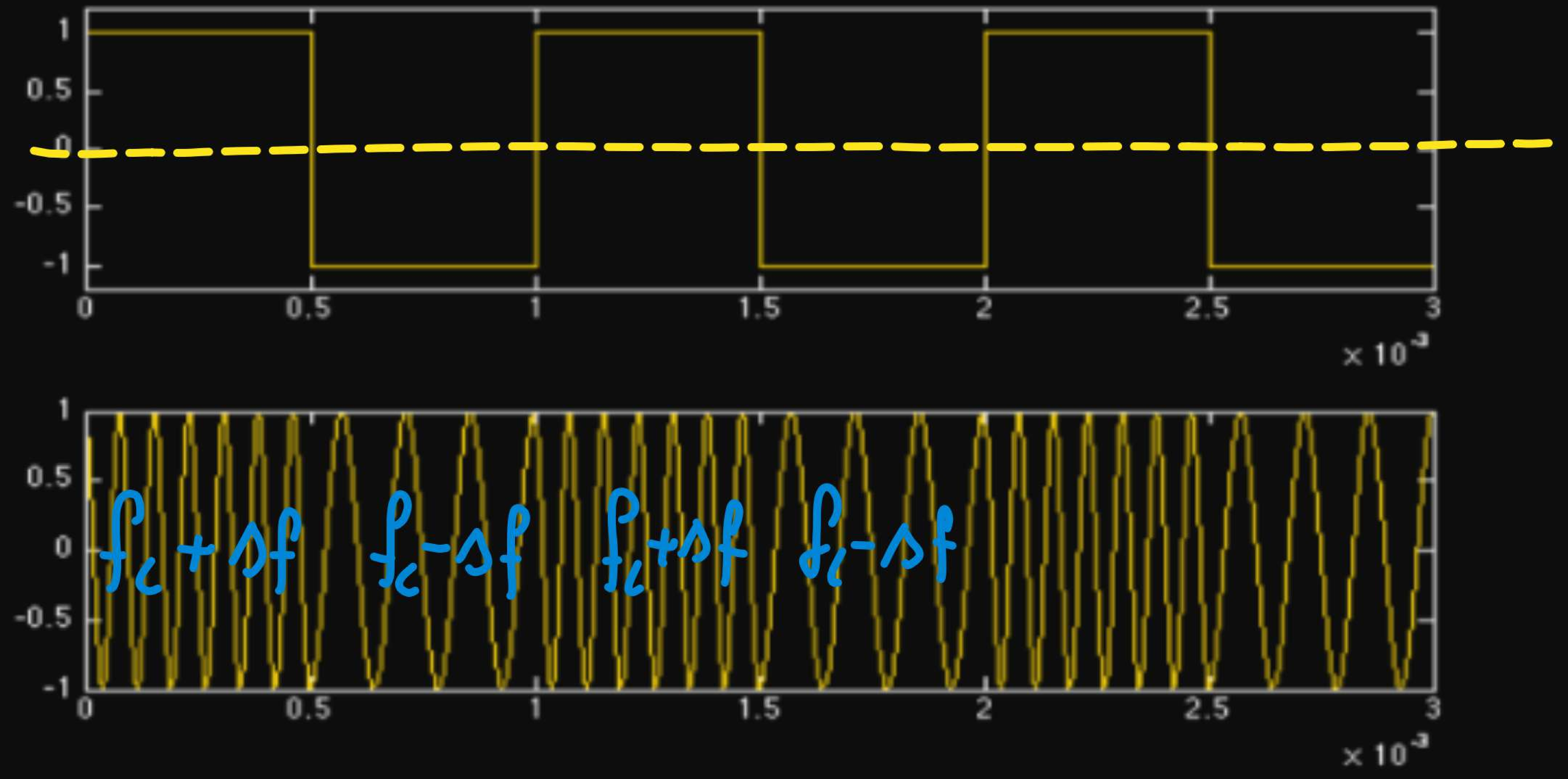
$f_{max} = f_c + \Delta f$

$f_{min} = f_c - \Delta f$

$\Delta f = K_f |m(t)|_{max}$

Baseband signal, x(t)

FM signal



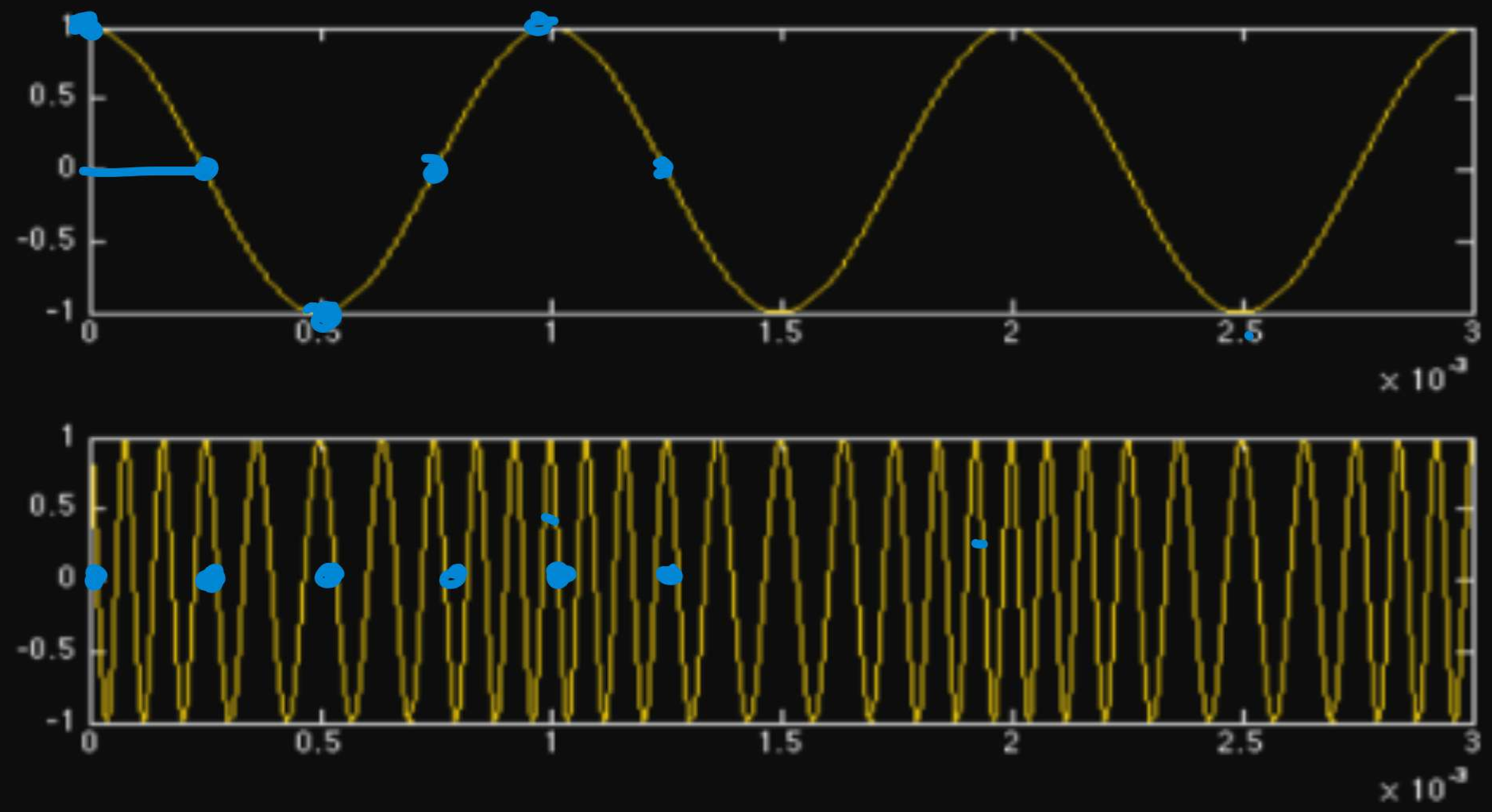
Angle Modulation (FM)

FM Signal - Time Domain

- For a sinusoidal baseband signal:

Baseband signal, x(t)

FM signal



Frequency Modulation (FM)

Angle modulation $\rightarrow$ FM
$\rightarrow$ PM

$$c(t) = A_c \cos 2\pi f_c t = A_c \cos\theta(t) = A_c \cos[2\pi f_c t + \phi]$$

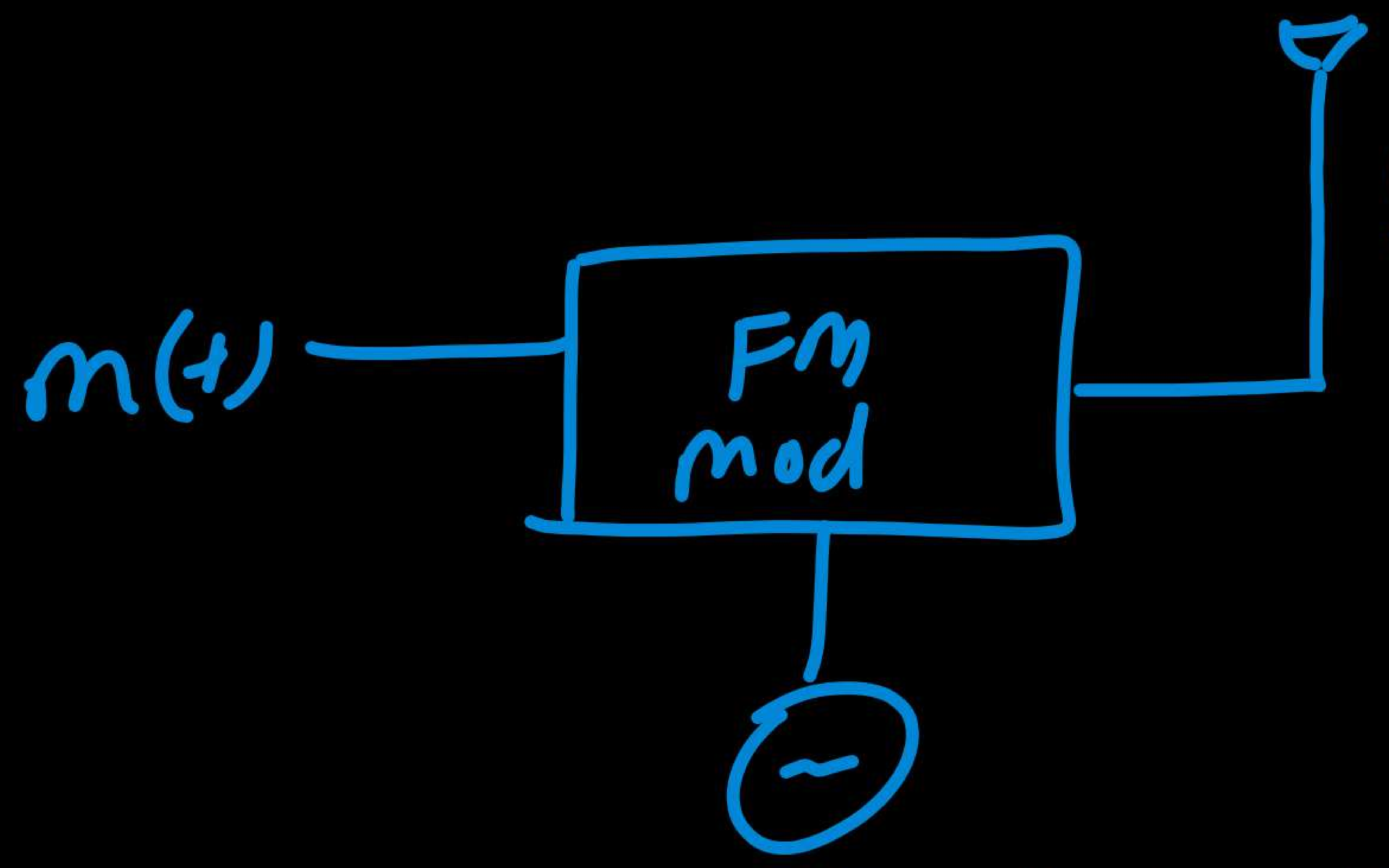
freq. phase

$$m(t) = m(t)$$

$$s(t) = A_c \cos[\theta_i(t)]$$

$$s(t)\big|_{FM} = A_c \cos[2\pi f_i t]$$

$$s(t)\big|_{PM} = A_c \cos[2\pi f_c t + 0 + \phi_i(t)]$$



$$s(t) = A_c \cos \theta_i(t) = A_c \cos\left[2\pi f_c t + 2\pi K_f \int_{-\infty}^{t} m(t)\,dt\right]$$

$$c(t) = A_c \cos 2\pi f_c t$$
$$= A_c \cos \theta(t)$$
$$\theta(t) = 2\pi f_c t$$

$$\theta_i(t) \rightarrow f_i(t)$$

$$f_i = f_c \pm \Delta f$$
$$\downarrow$$
$$\propto m(t)$$

$$\boxed{f_i(t) = f_c + K_f m(t)}$$

K_f = freq. sensitivity [Hz/Volt]

$$\text{Am} \rightarrow A_c \rightarrow A_c[1 \pm M]$$
$$A_c \rightarrow A_c \pm A_c M$$
$$A_c \rightarrow A_c \pm \Delta A$$
$$\downarrow$$
$$\propto m(t)$$

Frequency Modulation (FM)

$$\frac{d\theta}{dt} = \omega$$

$$2\pi f = \frac{d\theta}{dt}$$

$$2\pi f_i(t) = \frac{d\theta_i(t)}{dt}$$

$$f_i(t) = \frac{1}{2\pi}\frac{d\theta_i(t)}{dt}$$

$$\theta_i(t) = \int_{-\infty}^{t} 2\pi f_i(t)\,dt$$

$$\theta_i(t) = 2\pi\int_{-\infty}^{t} f_i(t)\,dt = 2\pi\int\{f_c + K_f\, m(t)\}\,dt$$

$$\theta_i(t) = \underbrace{2\pi f_c t}_{\theta(t)} + 2\pi K_f\int_{-\infty}^{t} m(t)\,dt$$

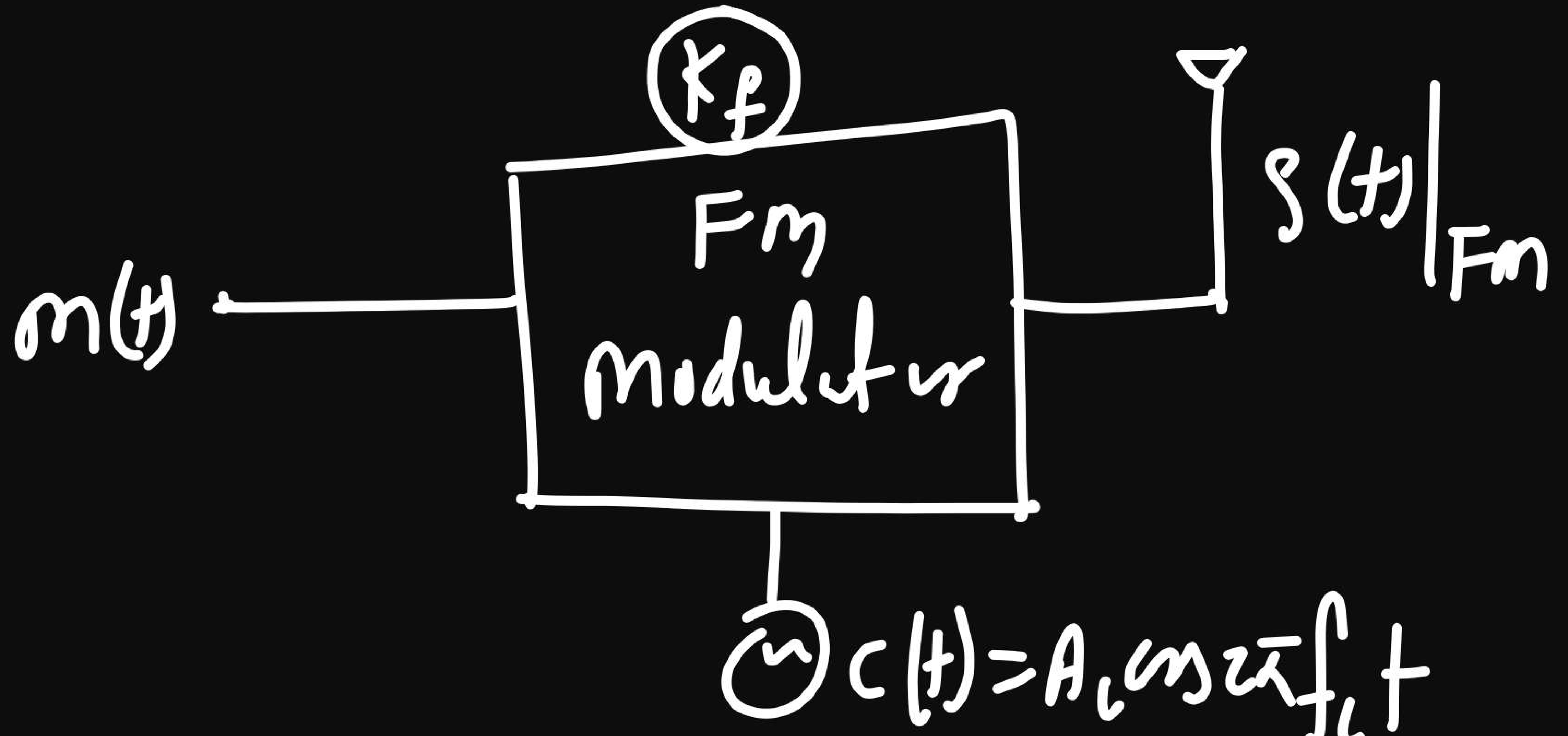
Frequency Modulation (FM)

Fm signal $\boxed{s(t) = A_c \cos\left[2\pi f_c t + 2\pi K_f \int_{-\infty}^{t} m(\tau)\, d\tau\right]}$

$\Delta f = K_f |m(t)|_{max}$

$\boxed{f_i(t) = f_c + K_f m(t)}$

K_f – freq. sensitivity (Hz/Volt)



$K_f\, m(t)|_{max} = \Delta f \rightarrow$ freq. deviation (Hz)

$f_i|_{max} = f_c + \Delta f$

$f_i|_{min} = f_c - \Delta f$

Commercial FM

$\Delta f = 75\text{ KHz}$

Frequency Modulation (FM)

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi K_f \int_{-\infty}^{t} m(t)\,dt\right]$$

Single tone:

$$m(t) = A_m \cos 2\pi f_m t \longrightarrow \Delta f = K_f |m(t)|_{max} = K_f A_m$$

$$s(t) = A_c \cos\left[2\pi f_c t + \frac{2\pi K_f \cdot A_m}{2\pi f_m} \sin 2\pi f_m t\right] = A_c \cos\left[2\pi f_c t + \frac{\Delta f}{f_m} \sin 2\pi f_m t\right]$$

$$s(t) = A_c \cos\left[2\pi f_c t + \beta_f \sin 2\pi f_m t\right] \leftarrow \text{singletone FM signal}$$

$$\beta_f = \frac{\Delta f}{f_m} = \frac{K_f A_m}{f_m} = \text{modulation index of FM}$$

Frequency Modulation (FM)

$$\beta_f = \frac{\Delta f}{f_m} \Rightarrow \Delta f = \beta_f f_m$$

$\Delta f = K_f A_m \leftarrow$ Deviation only depends on A_m

$\beta_f = \frac{\Delta f}{A_m} \leftarrow$ Modulation index depends on both A_m & f_m.

Frequency Modulation (FM)

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(\tau)\, d\tau\right]$$

Single tone FM:

$$s(t) = A_c \cos\left[2\pi f_c t + \beta_f \sin 2\pi f_m t\right]$$

- $\beta_f << 1$ ($\beta_f \le 1$) (NBFM)
- $\beta_f > 1$ ($\beta_f > 1$) (WBFM)

FM

- NBFM (BW = less)
- WBFM (BW = larger)

NBFM $(\beta_f \le 1)$

$$s(t) = A_c \cos\left[2\pi f_c t + \beta_f \sin 2\pi f_m t\right]$$

$$= A_c \cos 2\pi f_c t \underbrace{\cos\left[\beta_f \sin 2\pi f_m t\right]}_{1} - A_c \sin 2\pi f_c t \cdot \underbrace{\sin\left[\beta_f \sin 2\pi f_m t\right]}_{\beta_f \sin 2\pi f_m t}$$

$\beta_f \le 1$

if θ is very small $\left.\begin{array}{l}\cos\theta \simeq 1 \\ \sin\theta \simeq \theta\end{array}\right\}$

$$s(t) = A_c \cos 2\pi f_c t - A_c \beta_f \sin 2\pi f_m t \cdot \sin 2\pi f_c t$$

$$s(t) = \underbrace{A_c \cos 2\pi f_c t}_{\text{Carrier}} + \underbrace{\frac{A_c \beta_f}{2} \cos 2\pi (f_c + f_m) t}_{USB} - \underbrace{\frac{A_c \beta_f}{2} \cos 2\pi (f_c - f_m) t}_{LSB} \leftarrow \text{Same as AM}$$

$\mu \rightarrow \beta_f$

$$s(t)\big|_{AM} = A_c \cos 2\pi f_c t + \frac{A_c M}{2}\cos 2\pi (f_c + f_m)t + \frac{A_c M}{2}\cos 2\pi (f_c - f_m)t$$

$$s(t)\big|_{NBFM} = A_c \cos 2\pi f_c t + \frac{A_c \beta_f}{2}\cos 2\pi (f_c + f_m)t - \frac{A_c \beta_f}{2}\cos 2\pi (f_c - f_m)t$$

$BW = 2f_m$
$= 2W$

$P_t = P_c\left[1 + \frac{\beta_f^2}{2}\right]$

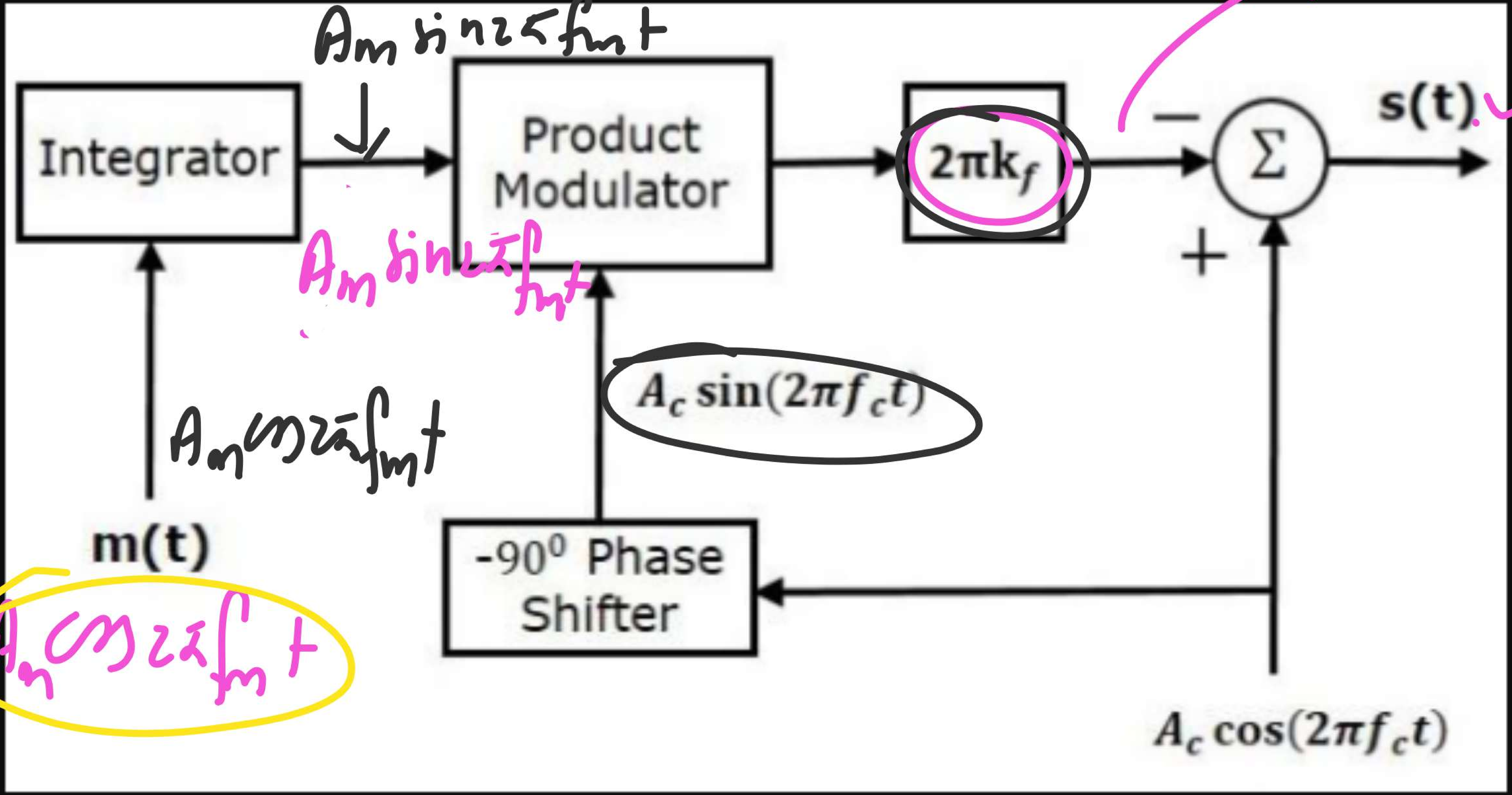
$\%\eta$ = same as AM

NBFM Modulator

$s(t) = A_c \cos 2\pi f_c t - A_c \beta \sin 2\pi f_m t \cdot \sin 2\pi f_c t$

$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int m(\tau)\, d\tau\right]$

$A_c \beta_f \sin 2\pi f_c t \sin 2\pi f_m t$



WBFM :

$$s(t) = A_c \cos[2\pi f_c t + \beta_f \sin 2\pi f_m t]$$ ← single tone Eq.

↓

Bessel fn.

↓

Simplify

$$P_t = P_c = A_c^2/2$$

$$BW = 2(\beta_f + 1) f_m = 2\Delta f + 2 f_m$$

$$\boxed{s(t)\Big|_{WBFM} = s(t)\Big|_{FM} = A_c \sum_{n=-\infty}^{\infty} J_n(\beta_f)\, A_c \cos 2\pi (f_c + n f_m) t}$$

$$J_{-n}(\beta) = J_n(\beta) \leftarrow n = \text{Even}$$

$$= -J_n(\beta) \leftarrow n = \text{odd}$$

WBFM

$$P_t = P_{avg} = P_c = \frac{A_c^2}{2}$$

$\% \eta = 100\%$

Practical BW = By Carsons Rule

$$= 2(\beta_f + 1) f_m \checkmark$$

$$= 2\left(\frac{\Delta f}{f_m} + 1\right) f_m = 2\Delta f + 2f_m \checkmark$$

Ideal BW $= \infty$

Frequency Modulation (FM)

$J_0(\beta_f) = 0$

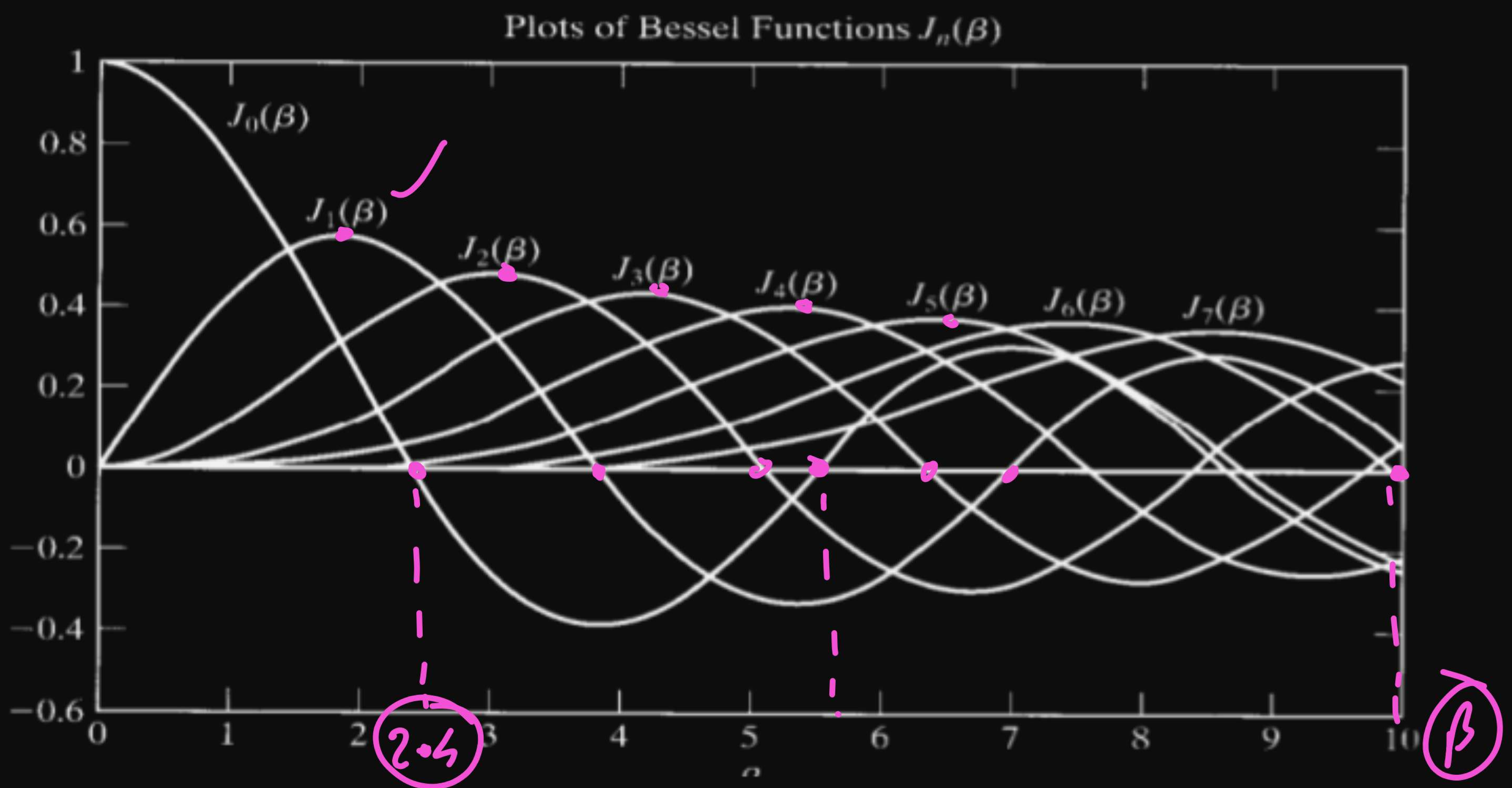
for

$\beta_f = 2.4$

$\beta_f = 5.5$

$\beta_f = 8.6$

$\beta_f = 11.7$



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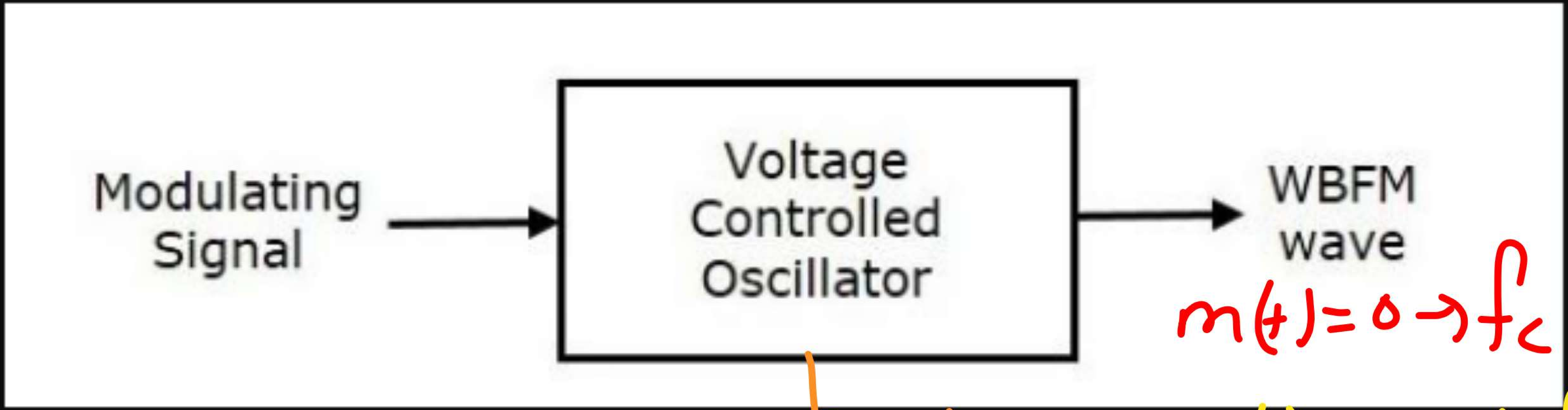
WBFM Modulator (Direct Method) : VCO

Generation of WBFM → Direct method → VCO
→ Indirect —"—



$c(t)$

$m(t) = 0 \rightarrow f_c$

$m(t) = +ve \rightarrow f_c + K_f m(t)$

$m(t) = -ve \rightarrow f_c - k_f m(t)$

WBFM Modulator (Indirect Method) : V~~C~~O Armstrong method.

MLD + Filters

Sq. law Device ×2

MLD

$$MLD(\text{degree } 3) = K_1 v_1 + K_2 v_1^2 + K_3 v_1^3$$

Frequency Modulation (FM)

$$s_1(t) = A_c \cos[2\pi f_c t + \beta \sin 2\pi f_m t] = A_c \cos\theta$$

$$s_2(t) = A_c \cos(n\theta) = A_c \cos[2\pi n f_c t + n\beta \sin 2\pi f_m t]$$

$$\Big\downarrow \text{mixer}$$

$$s(t) = A_c \cos[2\pi f_c t + n\beta \sin 2\pi f_m t]$$

Frequency Modulation (FM)

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

$$\Delta f \rightarrow n\,\Delta f$$

$$K_f A_m \rightarrow n K_f A_m$$

$$\text{NBFM} \longrightarrow \boxed{\begin{array}{c}\text{freq.}\\ \text{multiplier}\end{array}}_{\times n} \longrightarrow \boxed{\begin{array}{c}\text{mixer}\\ \text{(down)}\end{array}} \longrightarrow \text{WBFM}$$

$$BW = 2(\beta+1)f_m$$
$$= 2\Delta f + 2f_m$$

$$\beta_f \longrightarrow n\beta_f \longrightarrow n\beta_f \qquad BW = 2(n\beta+1)f_m$$

$$f_c \longrightarrow nf_c \longrightarrow f_c \qquad = 2n\Delta f + 2f_m$$

$$f_m \longrightarrow f_m \longrightarrow f_m$$

$$\Delta f \longrightarrow n\Delta f \longrightarrow n\Delta f$$

$$A_m \longrightarrow nA_m \longrightarrow nA_m$$

Demodulation of Frequency Modulation (FM)

→ NBFM/WBFM

PLL is used → VCO

- Frequency discrimination method
  - Slope Detector
  - Balance Slope Detector
- Phase discrimination method
  - Foster–Seeley discriminator
  - Ratio Detector
  - Phase Locked Loop (PLL)

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