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

Renu Raj Garg
M.Tech (VLSI Design)
13 Year of Teaching Experience
Worked 10 Year in NTRO

GATE 2024

प्रचण्ड Batch

Communication System

DEMODULATION OF AM (ENVELOPE DETECTOR)

LEC-01

ECE

Chapter-1

Analog Communications

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

1. *Amplitude Modulation (DSB-FC)*
2. *Generation of AM Signal : Square Law Modulator*
3. *Demodulation of AM Signal : Square Law Demodulator*
4. *Demodulation of AM Signal : Envelope Detector*
5. *Demodulation of AM Signal : Synchronous Detector*

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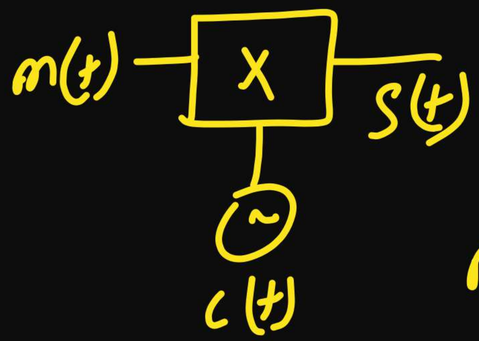
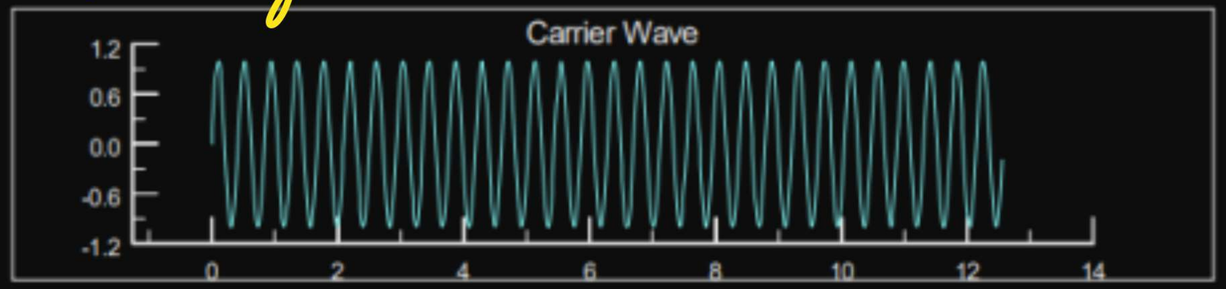
Standard Modulation

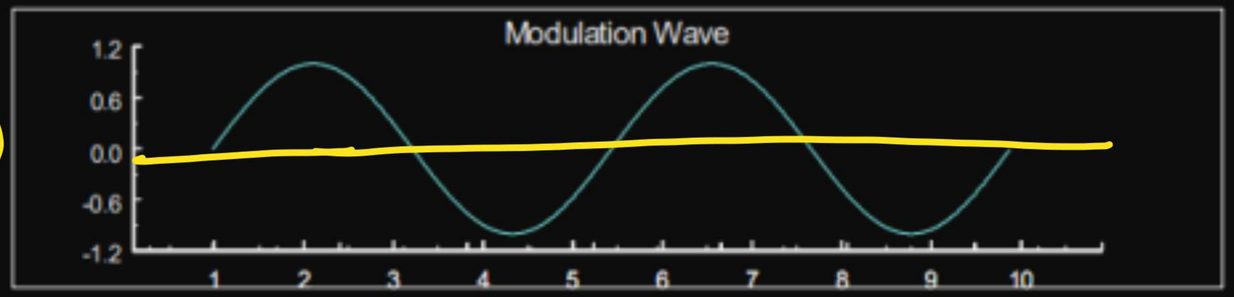
RF Signal



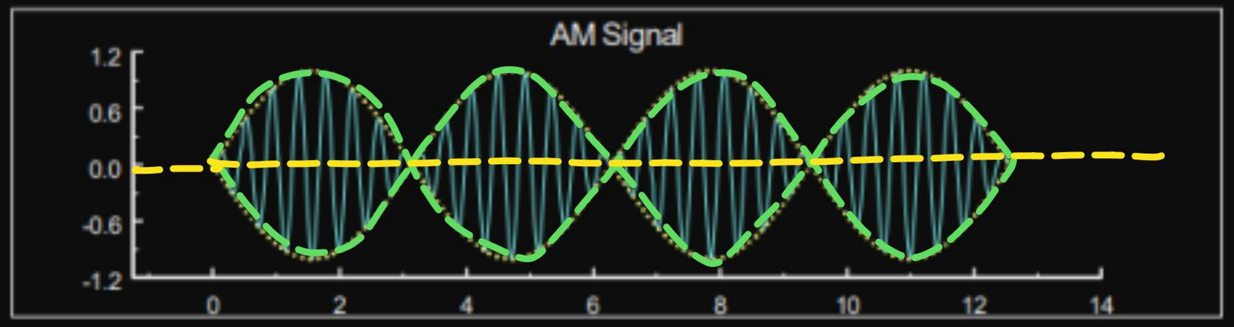
c(t)



m(t)



s(t)



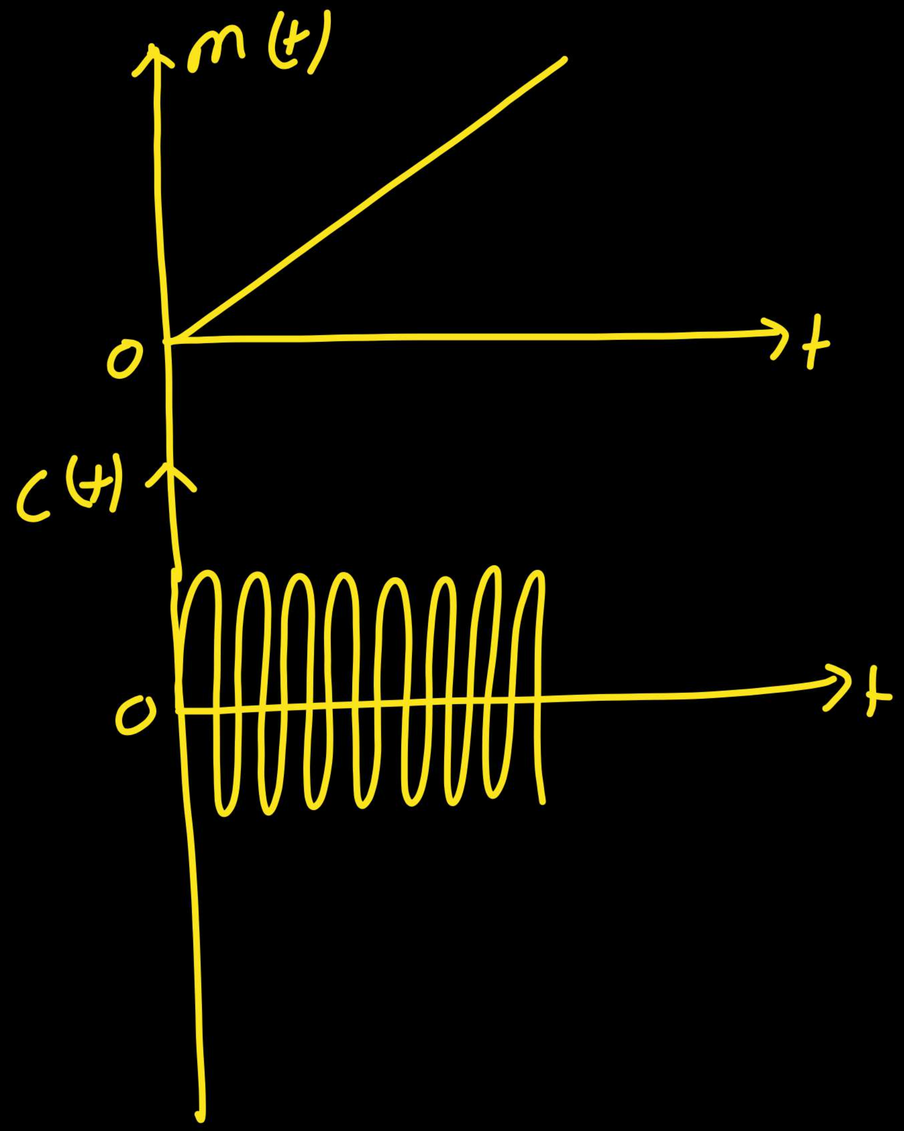
$m(t) \cdot c(t)$

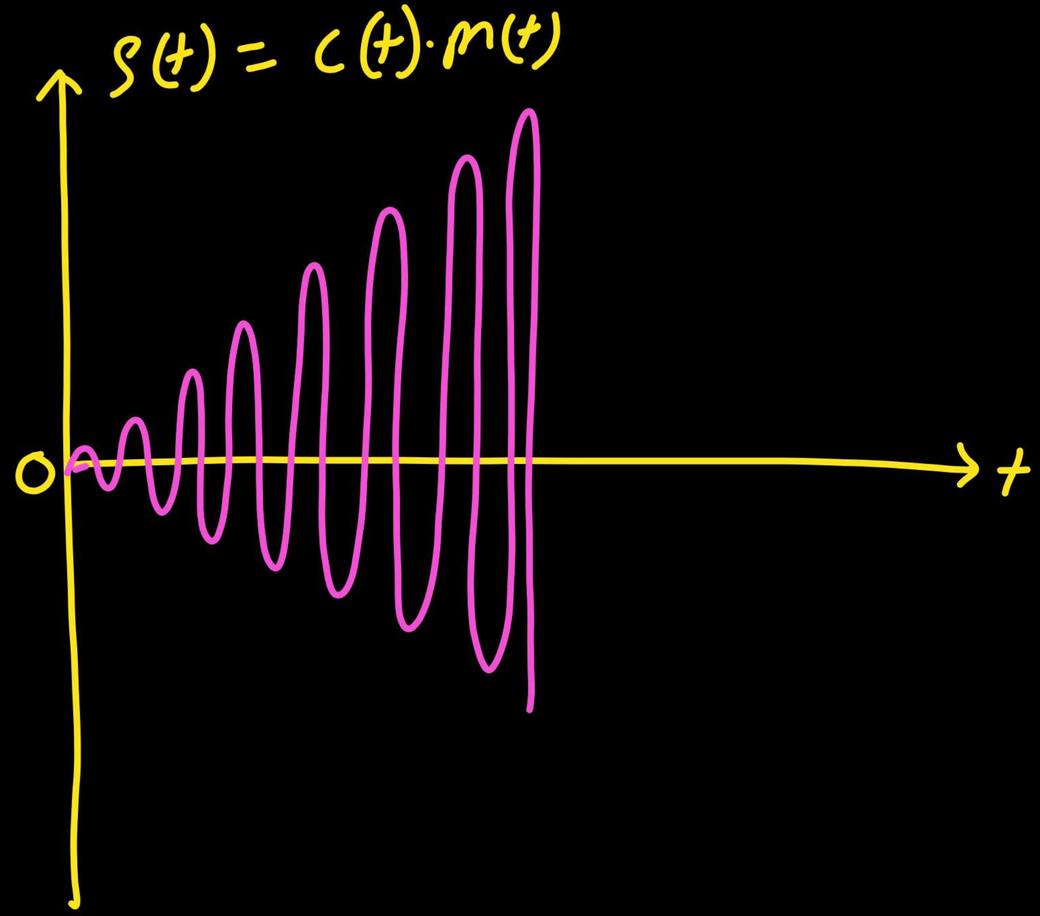
$m(t) = A_m \cos 2\pi f_m t$

↓

Single tone msg

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


m(t)
0
t
c(t)
0
t

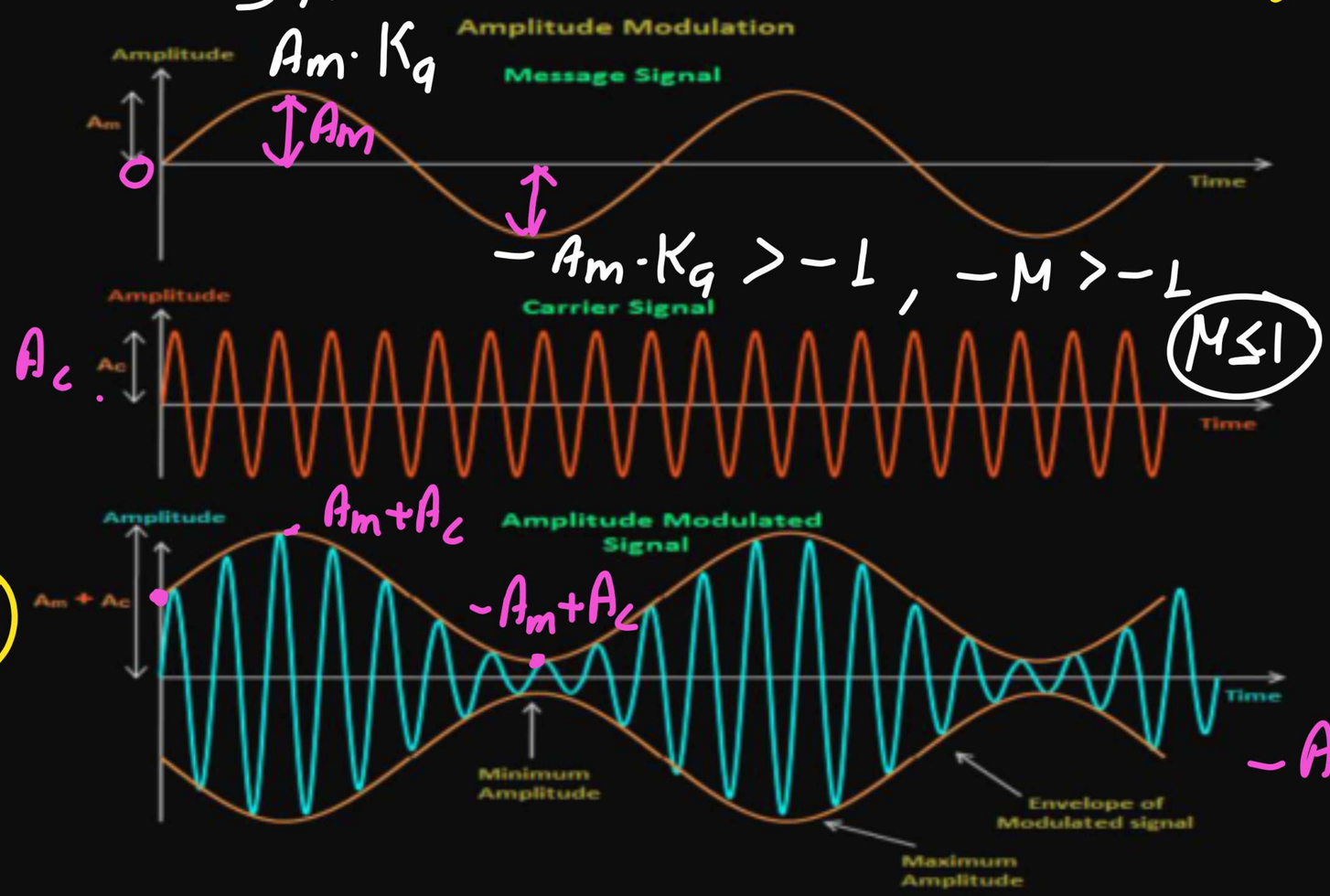

s(t) = c(t)·m(t)
0
t

Amplitude Modulation (AM), Double Side Band-Full Carrier (DSB-FC)

$= M$

$A_m \cdot K_q$

$m(t)$



A_m

$-A_m \cdot K_q > -1, \quad -M > -1$

A_c

$M \leq 1$

$m(t) + dc$

$m(t) + A_c$

$A_m + A_c$

$-A_m + A_c$

$s(t) = [m(t) + K] A_c \cos 2\pi f_c t$

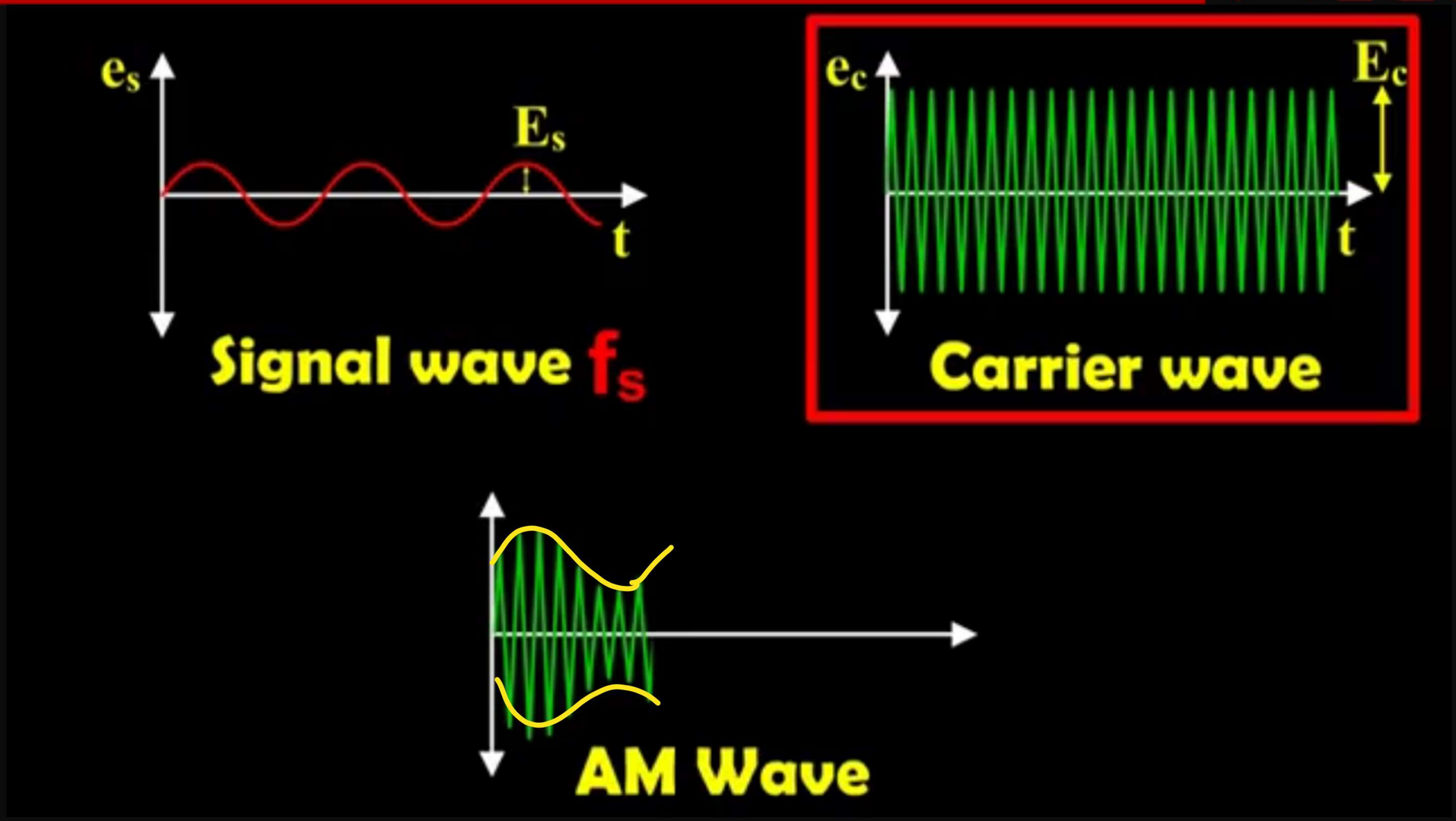
$= [m(t) + K] c(t)$

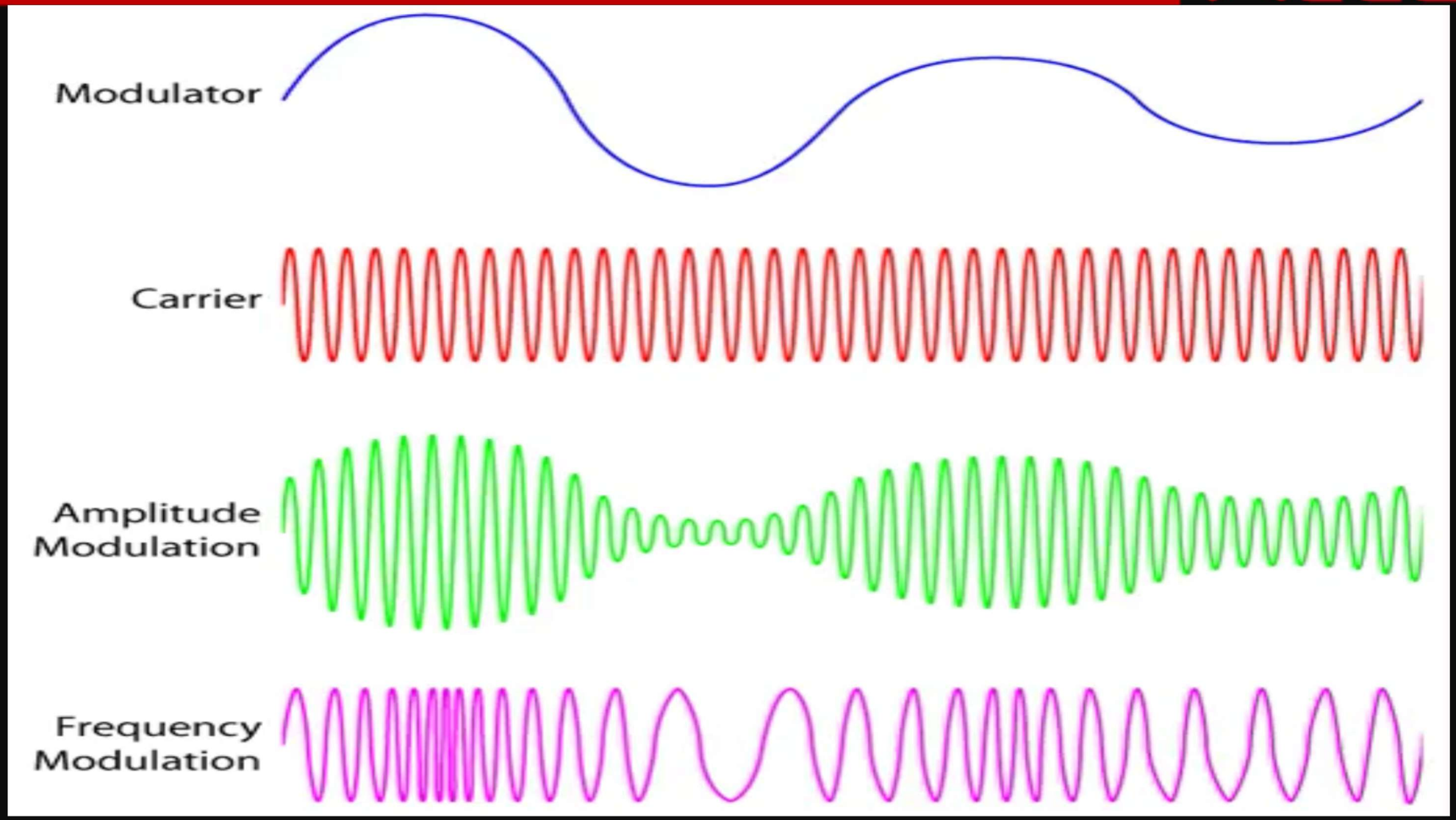
$AM = DSB\text{-}FC$

AM signal $M \leq 1$

$-A_m + A_c \geq 0$

$A_c \geq A_m \Rightarrow \frac{A_m}{A_c} \leq 1$


e_s
E_s
t
Signal wave f_s
e_c
E_c
t
Carrier wave
AM Wave

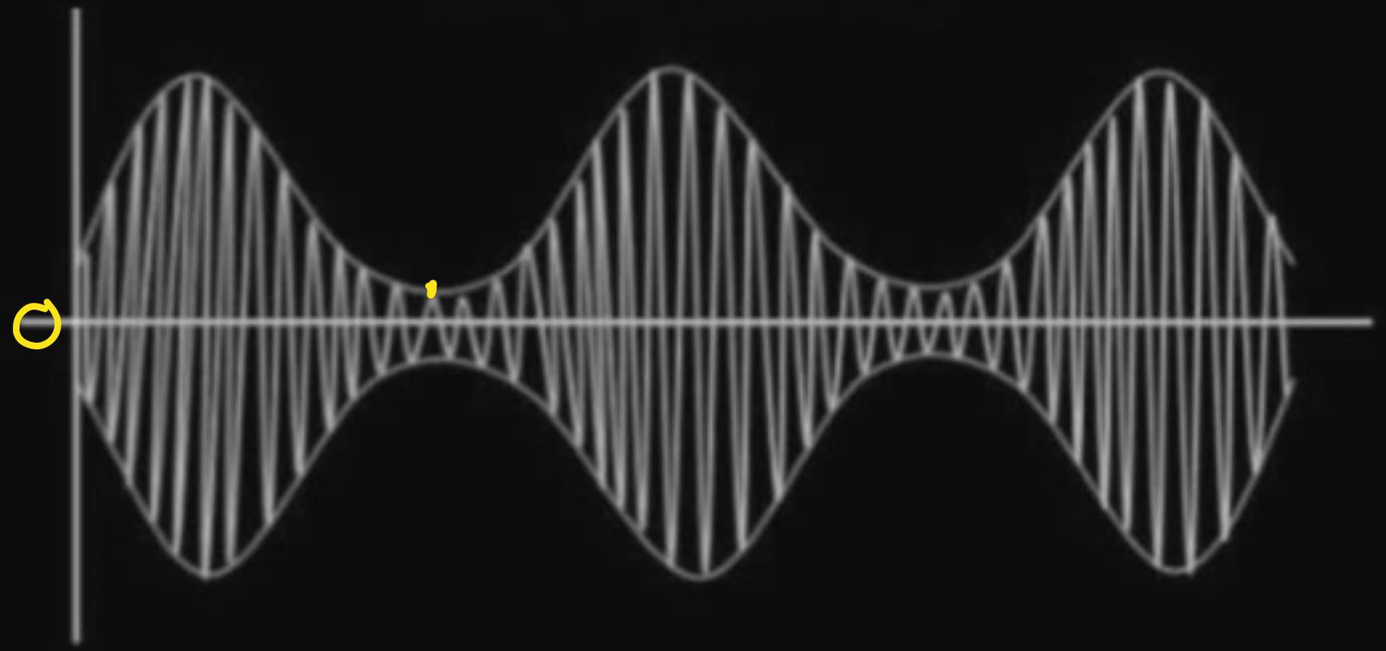

Modulator
Carrier
Amplitude Modulation
Frequency Modulation

Amplitude Modulation (AM), Double Side Band-Full Carrier (DSB-FC)

$[m(t)+dc]_{min} > 0$

$\mu < 1$ $m_a < 1$

Under-Modulated wave



$(m(t)+dc)_{min} = 0$

Critical modⁿ

$\mu = 1$

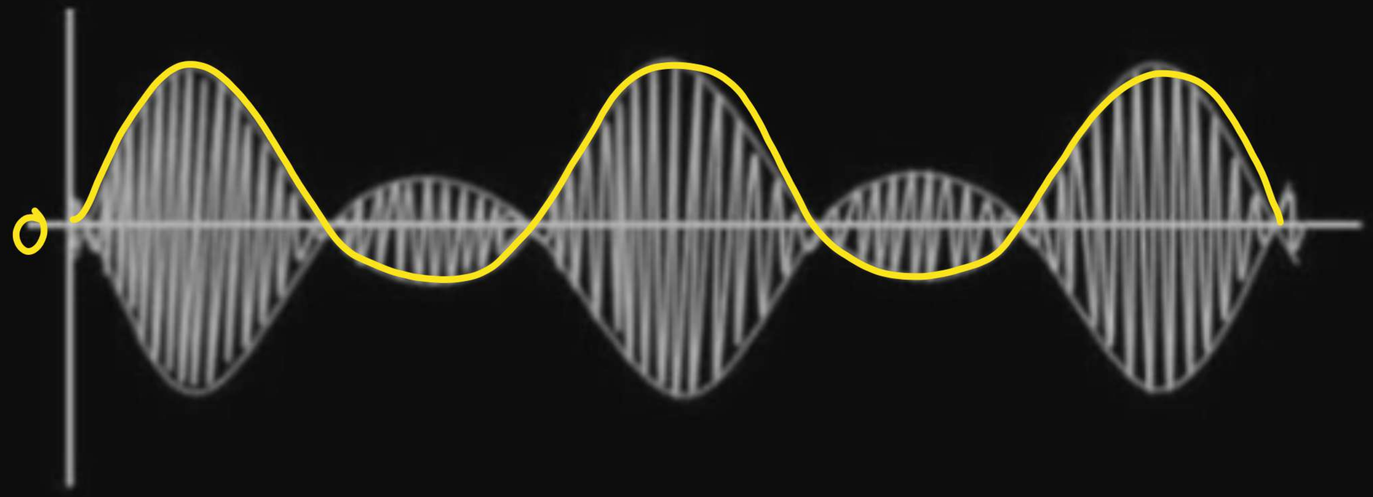
$m_a = 1$

Amplitude Modulation (AM), Double Side Band-Full Carrier (DSB-FC)

$[m(t)+dc]_{min} < 0$

$M > 1$

Over-Modulated wave ✗



$M \leq 1$

$m_a \leq 1$

$M_{max} = 1$

Time Domain Equation of AM Signal

$$s(t)|_{AM} = [m(t) + A_c]\cos 2\pi f_c t$$

$$M_a = M = m_a = \frac{A_m}{A_c} = \frac{|m(t)|_{max}}{A_c}$$

1st Rep. of AM signal (Europe)

$$s(t)|_{AM} = [1 + K_a m(t)] A_c \cos 2\pi f_c t$$

2nd Rep. of AM signal (Asia)

$$= A_c[1 + K_a m(t)]\cos 2\pi f_c t$$

K_a = Amplitude sensitivity (Per volt)

$K_a < 1$

$$M_a = M = m_a = K_a |m(t)|_{max} = K_a A_m$$

$K_a \neq \frac{1}{A_c}$ ✗

Carrier + SB's
Carrier + USB + LSB

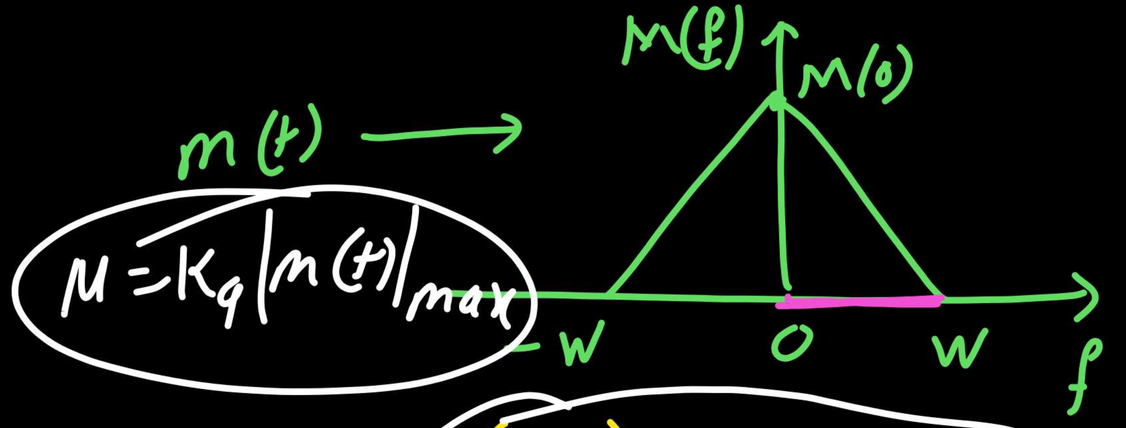
$$S(t) = A_c[1 + K_a m(t)] \cos 2\pi f_c t$$

$$S(t) = A_c \cos 2\pi f_c t + A_c K_a m(t) \cos 2\pi f_c t$$

Carrier — Unuseful Component

Sidebands — Useful Component

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

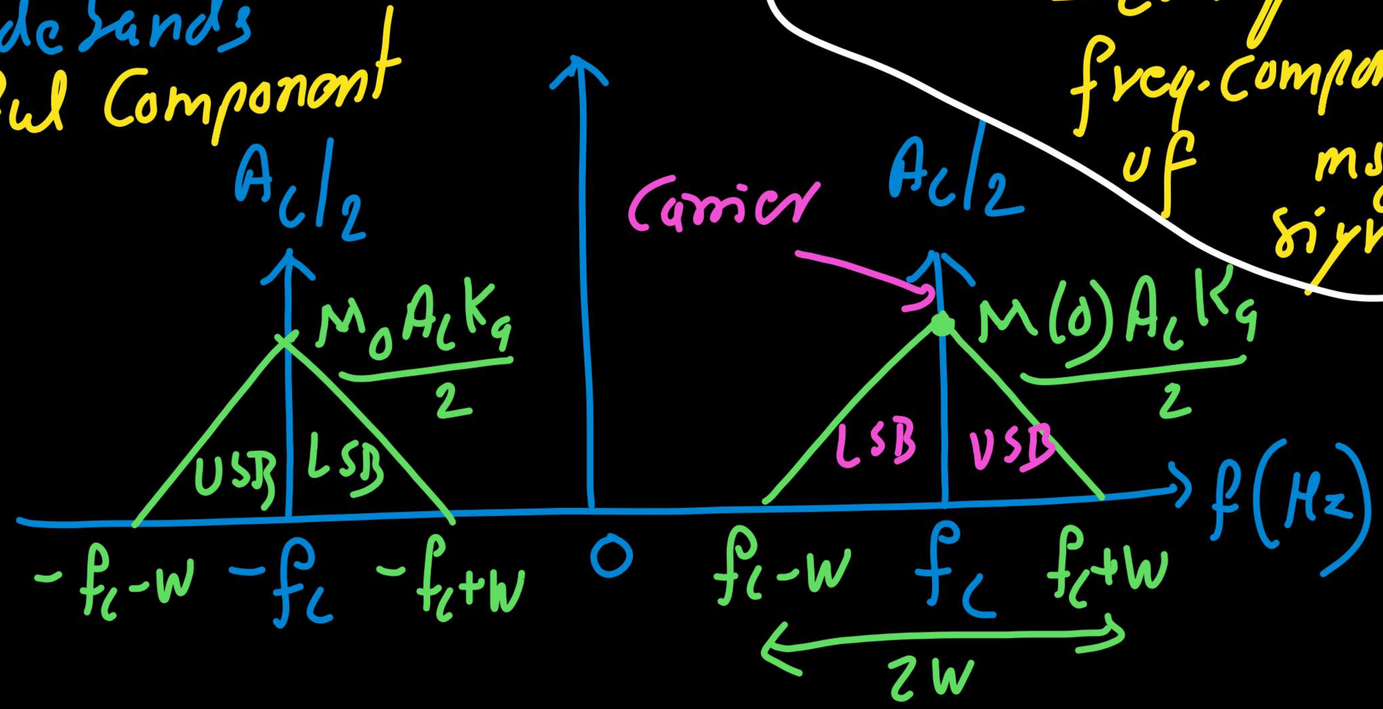


$(BW)_{AM} = 2W$
= 2 × Highest freq. component of msg signal

$A_c \cos 2\pi f_c t$

$A_c \left[\frac{1 \cdot e^{j2\pi f_c t} + 1 \cdot e^{-j2\pi f_c t}}{2} \right]$

FT $\longrightarrow$

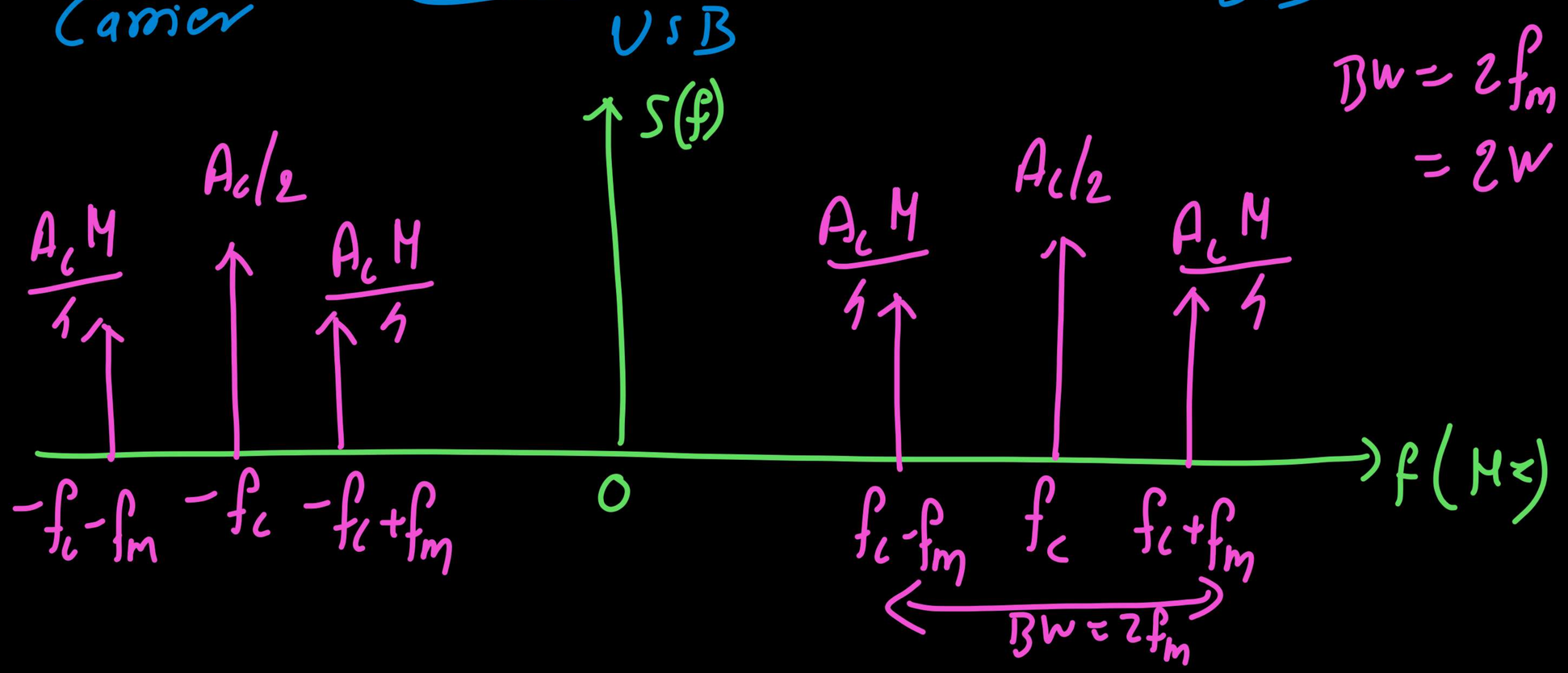


Single tone AM Signal:

$m(t) = A_m \cos 2\pi f_m t$

$$S(t) = A_c [1 + K_a A_m \cos 2\pi f_m t] \cdot \cos 2\pi f_c t$$

$$S(t) = \underbrace{A_c \cos 2\pi f_c t}_{\text{Carrier}} + \underbrace{\frac{A_c M}{2} \cos 2\pi (f_c + f_m) t}_{\text{USB}} + \underbrace{\frac{A_c M}{2} \cos 2\pi (f_c - f_m) t}_{\text{LSB}}$$



$BW = 2f_m = 2W$

Double tone AM Signal:

$$m(t) = A_{m_1}\cos 2\pi f_{m_1} t + A_{m_2}\cos 2\pi f_{m_2} t$$

$$s(t) = A_c\left[1 + K_a A_{m_1}\cos 2\pi f_{m_1} t + K_a A_{m_2}\cos 2\pi f_{m_2} t\right]\cos 2\pi f_c t$$

($M_1 = K_a A_{m_1}$, $M_2 = K_a A_{m_2}$)

$$= A_c\cos 2\pi f_c t + \frac{M_1 A_c}{2}\cos 2\pi(f_c + f_{m_1})t + \frac{A_c M_2}{2}\cos 2\pi(f_c - f_{m_1})t$$

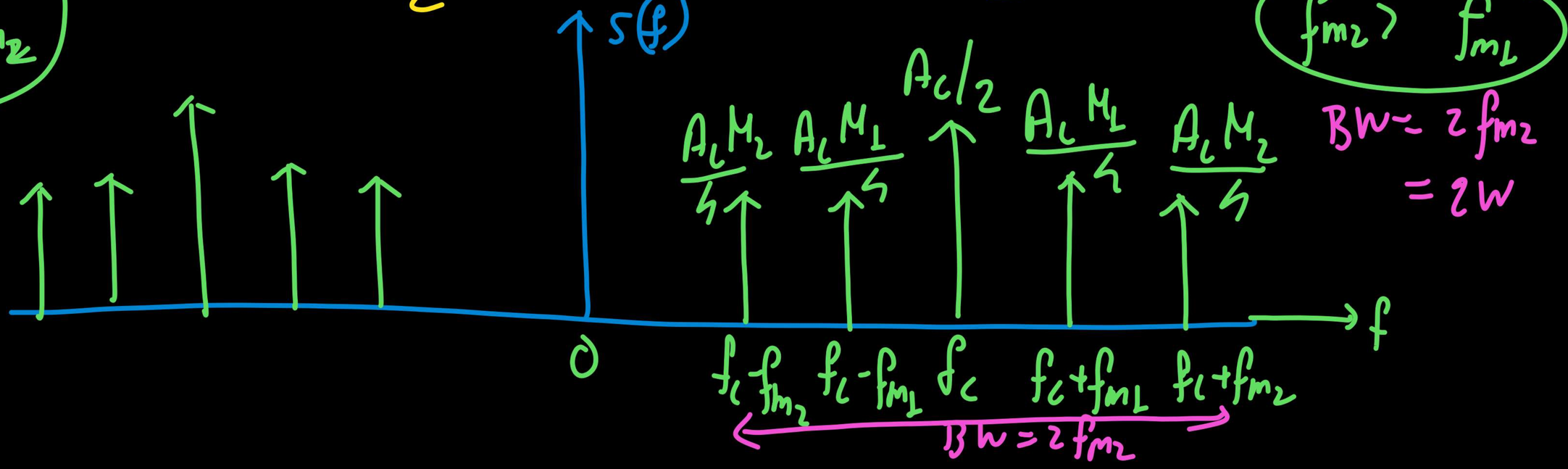
$A_c\cos 2\pi f_c t$ — Carrier

$\frac{M_1 A_c}{2}\cos 2\pi(f_c + f_{m_1})t$ — USB

$\frac{A_c M_2}{2}\cos 2\pi(f_c - f_{m_1})t$ — LSB

$$+ \frac{M_2 A_c}{2}\cos 2\pi(f_c + f_{m_2})t + \frac{A_c M_2}{2}\cos 2\pi(f_c - f_{m_2})t$$

$f_{m_2} > f_{m_1}$



$BW \sim 2f_{m_2} = 2W$

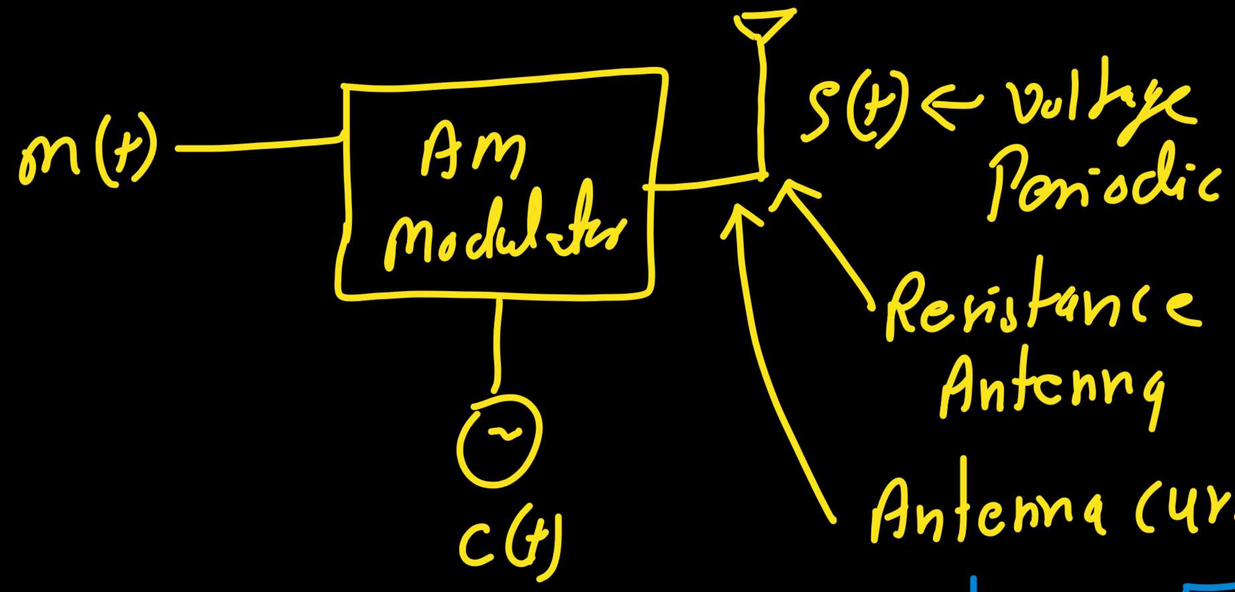
$BW = 2W$

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

$\mu = \frac{A_m}{A_c} = \frac{|m(t)|_{max}}{A_c}$

$S(t) = [m(t) + A_c] \cos 2\pi f_c t$

* Power calculation of AM signal [Single tone]



$P_{avg} = \frac{V_{rms}^2}{R} = I_{rms}^2 \cdot R$

$R = 1\ \Omega$

$x(t) = x_1(t) + x_2(t) + x_3(t) \Rightarrow$ (f_1, f_2, f_3)

$x(t)|_{Rms} = \sqrt{(x_1|_{Rms})^2 + (x_2|_{Rms})^2 + (x_3|_{Rms})^2}$

$$P_{avg} = \frac{\left[s(t)\big|_{RMS} \right]^2}{R} = \frac{A_c^2}{2R} + \frac{A_c^2 M^2}{8R} + \frac{A_c^2 M^2}{8R}$$

$$P_{avg}\Big|_{\text{single tone AM}} = \frac{A_c^2}{2R} + \frac{A_c^2 M^2}{8R} + \frac{A_c^2 M^2}{8R} = P_c + P_{USB} + P_{LSB}$$

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

$P_c = \frac{A_c^2}{2R}$ = Unmodulated Carrier Power

$$P_{avg} = P_c + P_c \frac{M^2}{4} + P_c \frac{M^2}{4}$$

$$\boxed{P_{avg} = P_c \left[1 + \frac{M^2}{2} \right]}$$

$$P_c = \frac{A_c^2}{2R} = \frac{A_c^2}{2}$$

$$P_{f_c} = P_c = \frac{A_c^2}{2R} \longrightarrow P_c$$

$$P_{f_c+f_m} = P_{USB} = \frac{A_c^2 M^2}{8R} = \frac{P_c M^2}{4}$$

$$P_{f_c-f_m} = P_{LSB} = \frac{A_c^2 M^2}{8R} = \frac{P_c M^2}{4}$$

$$P_{SB} = P_{USB} + P_{LSB} = \frac{P_c M^2}{2}$$

$$P_{avg}\Big|_{\text{single tone}} = P_c + P_c\frac{M^2}{2} = P_c\left[1+\frac{M^2}{2}\right]$$

$$P_{avg}\Big|_{\text{Double tone}} = P_c\left[1+\frac{M_1^2+M_2^2}{2}\right]$$

$$P_{avg}\Big|_{\substack{\text{tone msg} \\ \text{(Sinusoidal msg)}}} = P_c\left[1+\frac{M_t^2}{2}\right]$$

$$P_c = \frac{A_c^2}{2R}$$

$$M_t^2 = M_1^2 + M$$

$$P_f = P_c\left[1 + \frac{M^2}{2}\right]$$

$$P_f = P_c\left[1 + \frac{K_a^2 A_m^2}{2}\right]$$

$$P_f = P_c\left[1 + K_a^2 \overline{m^2(t)}\right]$$

$$P_f = P_c\left[1 + \frac{M_t^2}{2}\right]$$

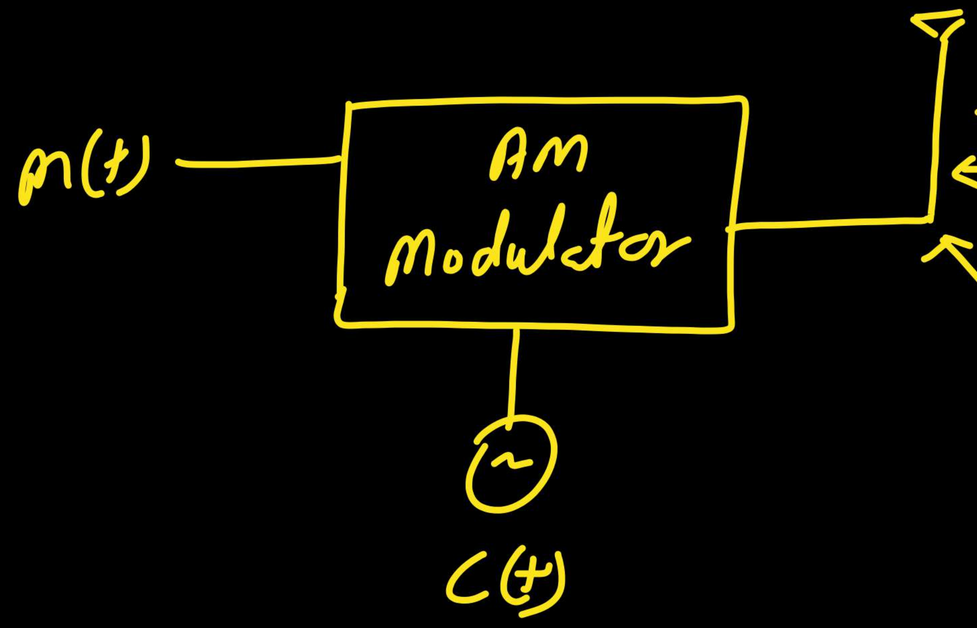
$$BW = 2W$$

$$m(t) = A_m \cos 2\pi f_m t$$

$$m(t)\big|_{RMS} = \frac{A_m}{\sqrt{2}}, \quad m(t)\big|_{MSV} = \frac{A_m^2}{2} = \overline{m^2(t)}$$

$$P_c = \frac{A_c^2}{2R} = \frac{A_c^2}{2}$$

$$M_t^2 = M_1^2 + M_2^2 + M_3^2 + \cdots$$



I_c = Antenna Current when

I_t = total Antenna Current ($m(t) \neq 0$)

Antenna current due to AM signal

Antenna Current to

* If Antenna current is given

$$P_{total} = P_{avg} = P_c\left[1 + \frac{M_t^2}{2}\right] = P_c\left[1 + K_a^2 \overline{m^2(t)}\right]$$

$$I_t^2 \cdot R = I_c^2 \cdot R\left[1 + M_t^2/2\right]$$

$$I_t = I_c\sqrt{1 + M_t^2/2}$$

$$\frac{I_t}{I_c} = \sqrt{1 + \frac{M_t^2}{2}} = \sqrt{1 + K_a^2}$$

* Modulation Efficiency of AM Signal:

$$\%\eta = \frac{\text{Useful Power}}{\text{Total Power}} \times 100\% = \frac{P_{SB}}{P_{total} = P_{avg}} \times 100\% = \frac{o/p}{i/p} \times 100\%$$

$$\%\eta = \frac{P_c M_f^2/2}{P_c[1 + M_f^2/2]} \times 100\% = \frac{P_c K_f^2 \overline{m^2(t)}}{P_c[1 + K_f^2 \overline{m^2(t)}]} \times 100\%$$

$$\%\eta = \frac{M_f^2}{2 + M_f^2} \times 100\% = \frac{K_f^2 \overline{m^2(t)}}{1 + K_f^2 \overline{m^2(t)}} \times 100\%$$

$$\%\eta = \frac{M_t^2}{2+M_t^2} \times 100\% = \frac{K_q^2 \overline{m^2(t)}}{1+K_q^2 \overline{m^2(t)}} \times 100\%$$

(x) for single tone sinusoidal

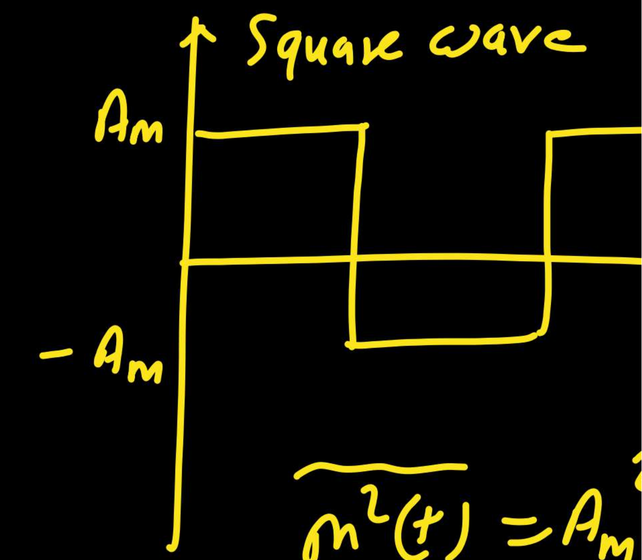
$$M_t = M = M_{max} = 1$$

$$\%\eta_{max} = \frac{1}{2+1} \times 100\% = 33.33\%$$

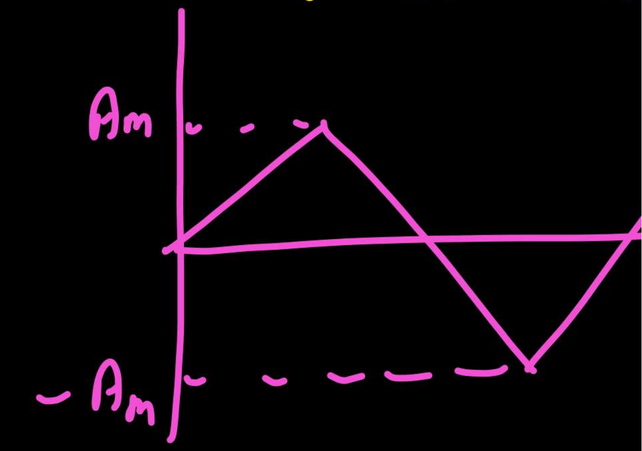
(x) for square wave ⇒

$$\overline{m^2(t)} = A_m^2$$

$$\%\eta_{max} = \frac{K_q^2 A_m^2}{1+K_q^2 A_m^2} \times 100\% = \frac{M^2}{1+M^2} \times 100\% = 50\%$$



$$\overline{m^2(t)} = A_m^2$$



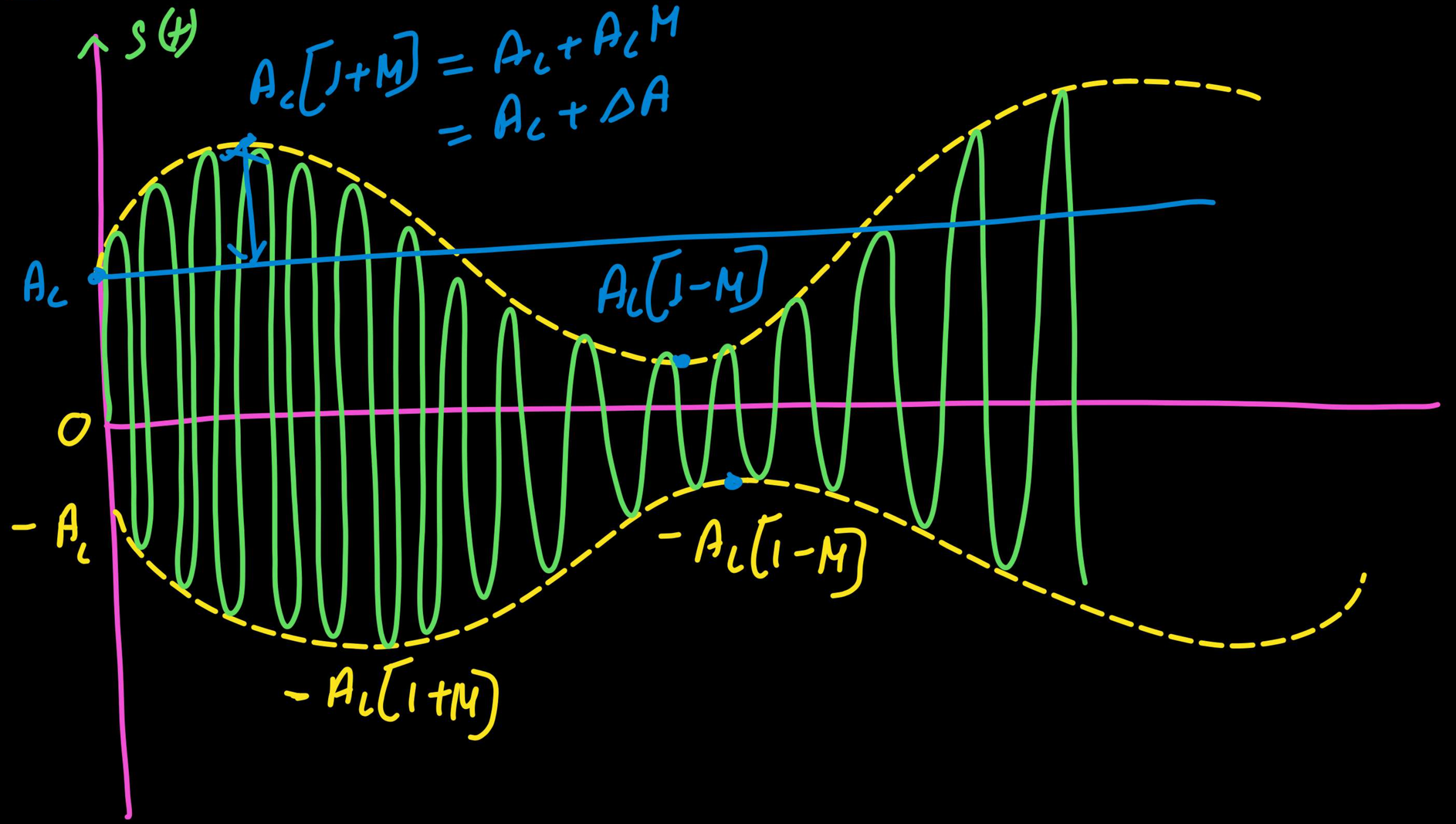
$$\overline{m^2(t)} = \frac{A_m^2}{3}$$

$$\%\eta_{max} = 25\% = \frac{M^2}{3+M^2}$$

$$s(t) = A_c[1 + K_a m(t)] \cos 2\pi f_c t \Rightarrow s(t)|_{max} = A_c[1+M] = E_{max} = V_{max}$$

$$s(t)|_{min} = A_c[1-M] = E_{min} = V_{min}$$

for single tone AM



$$\Rightarrow V_{max} = E_{max} = A_c[1+M]$$

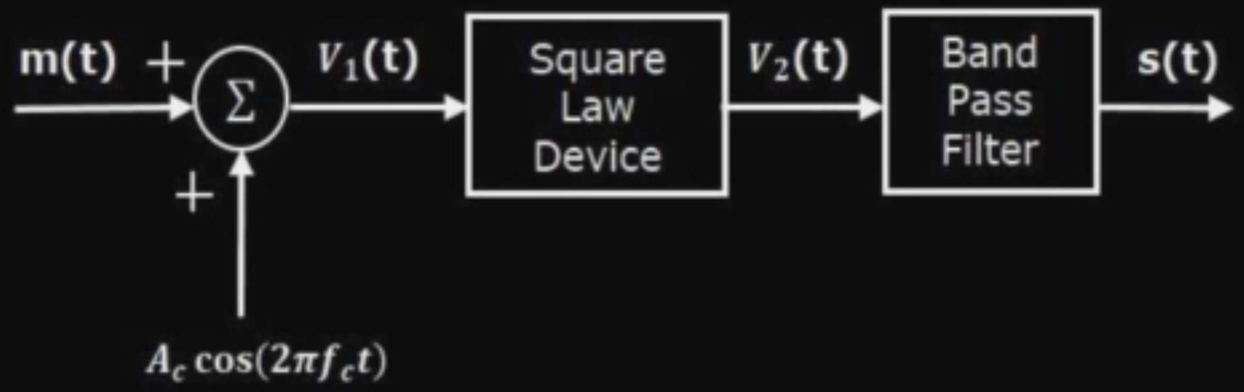
$$V_{min} = E_{min} = A_c[1-M]$$

$$A_c = \frac{E_{max} + E_{min}}{2} = \frac{V_{max} + V_{min}}{2}$$

$$M = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

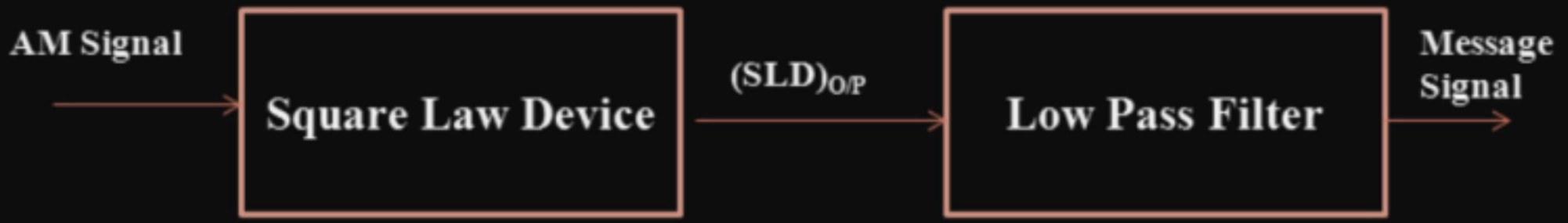
Generation of AM Signal

Square Law Modulator :



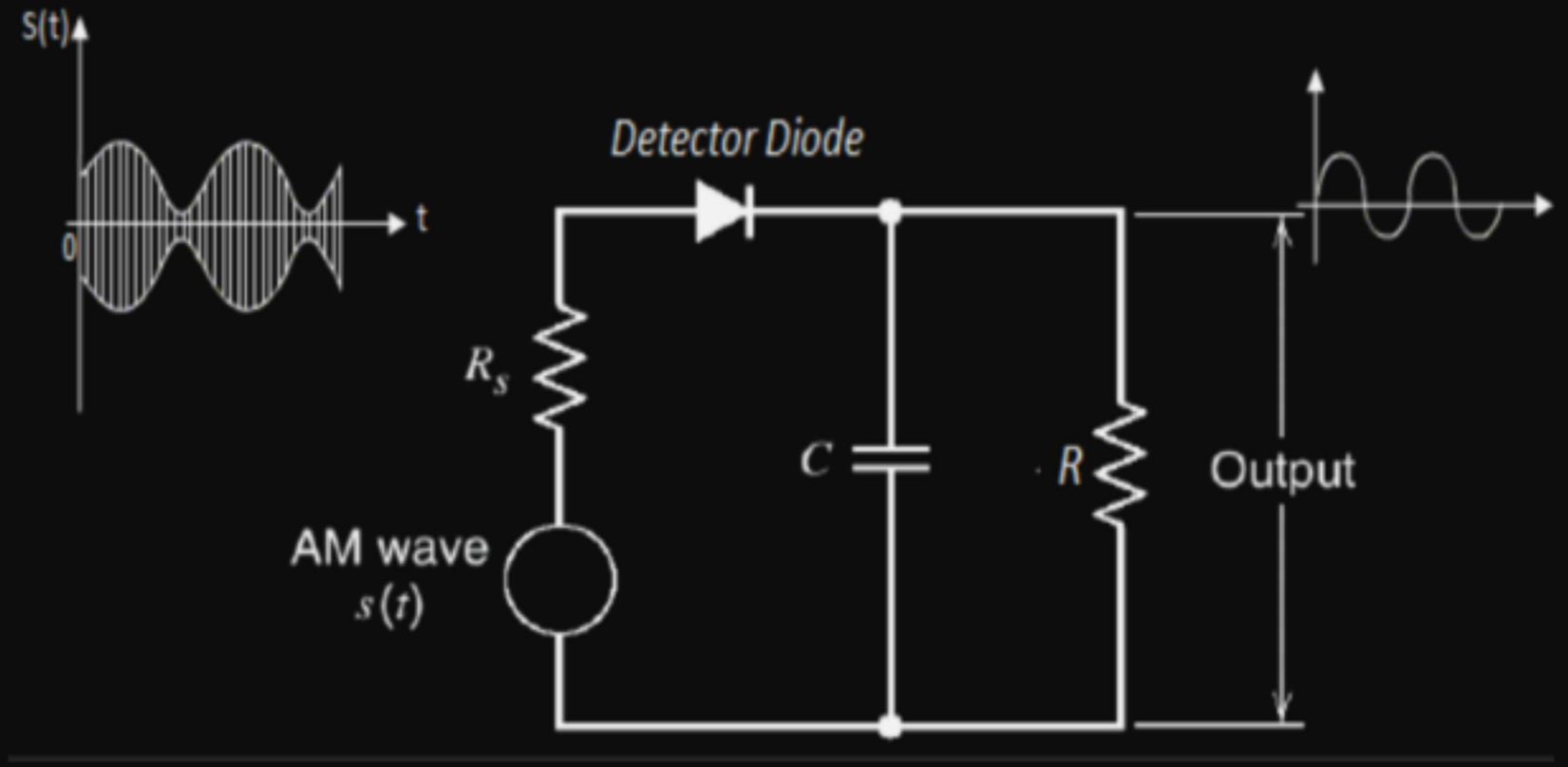
Demodulation of AM Signal

Square Law Demodulator



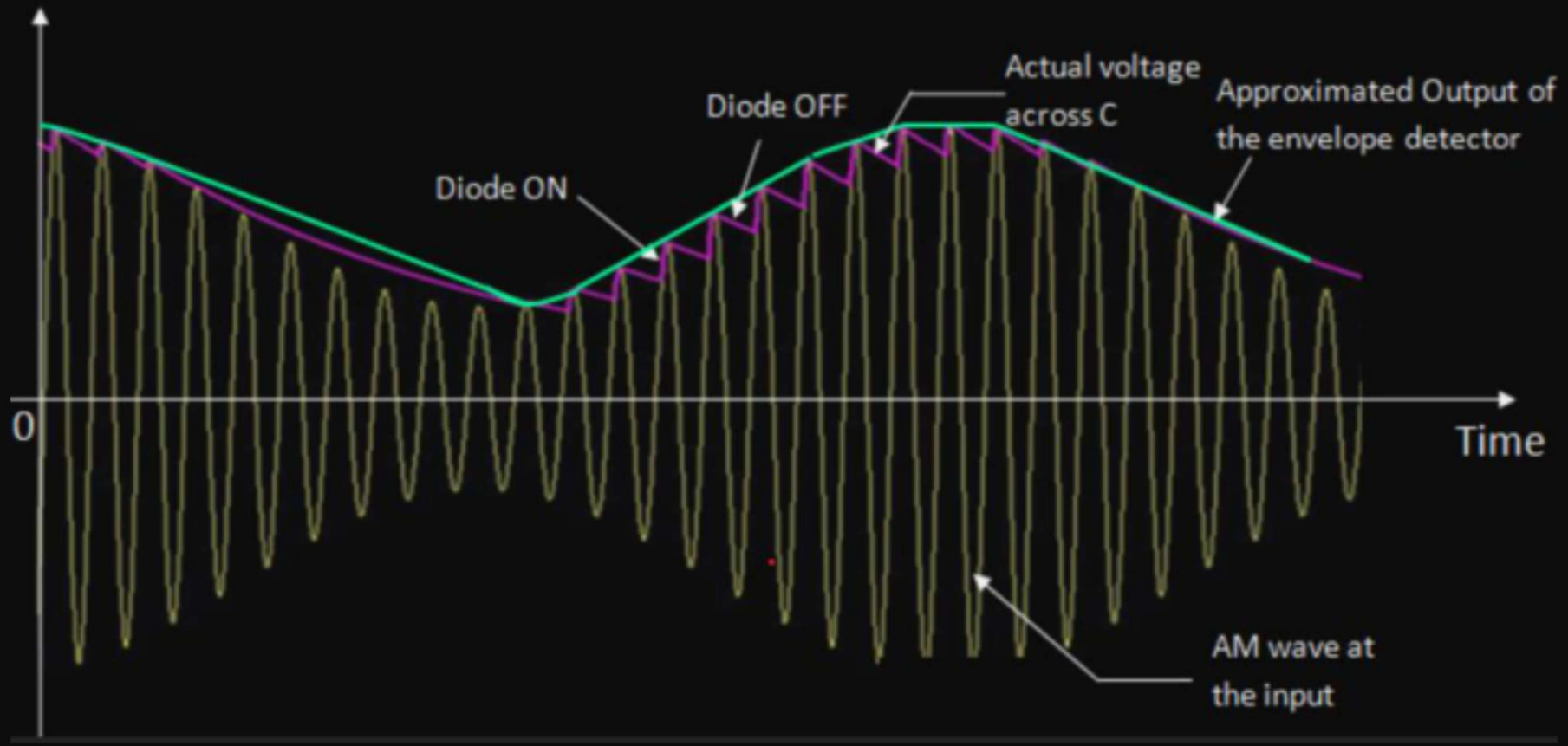
Demodulation of AM Signal

Envelope Detector



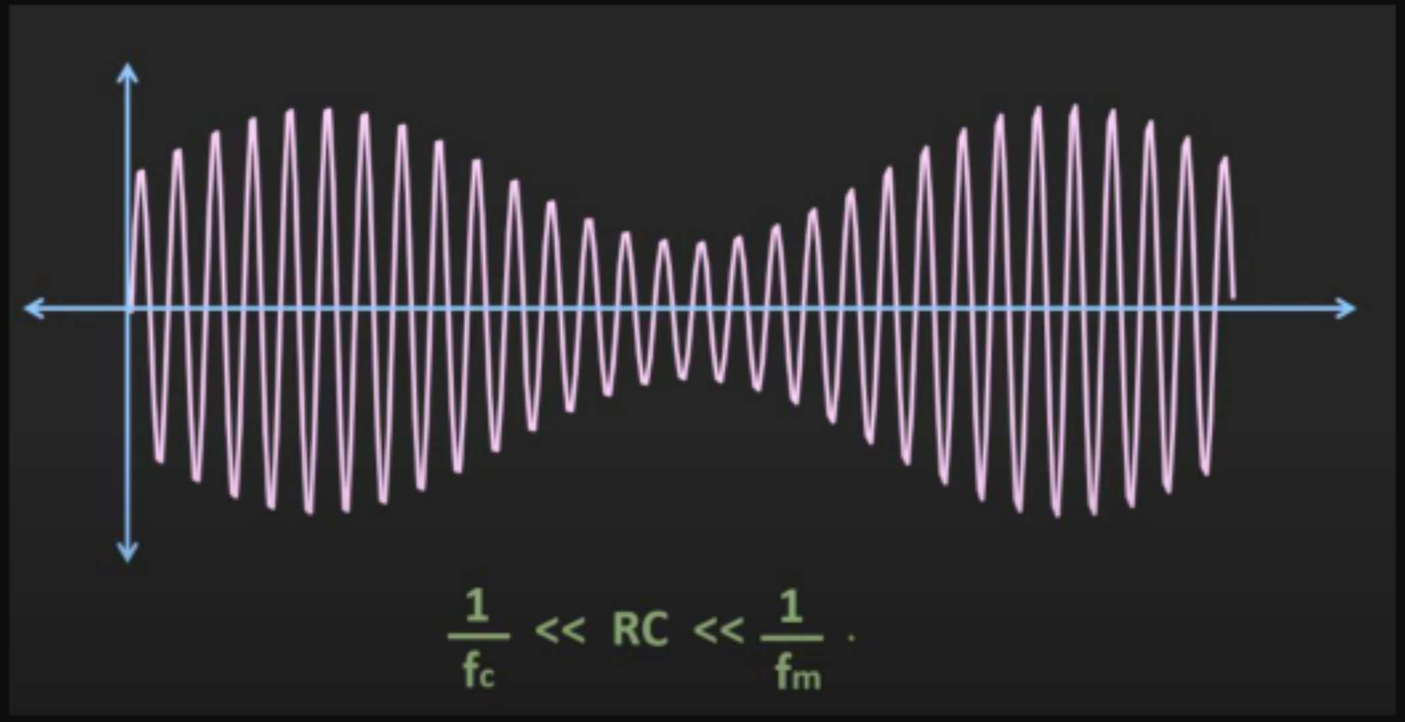
Demodulation of AM Signal

Envelope Detector (Cont..)



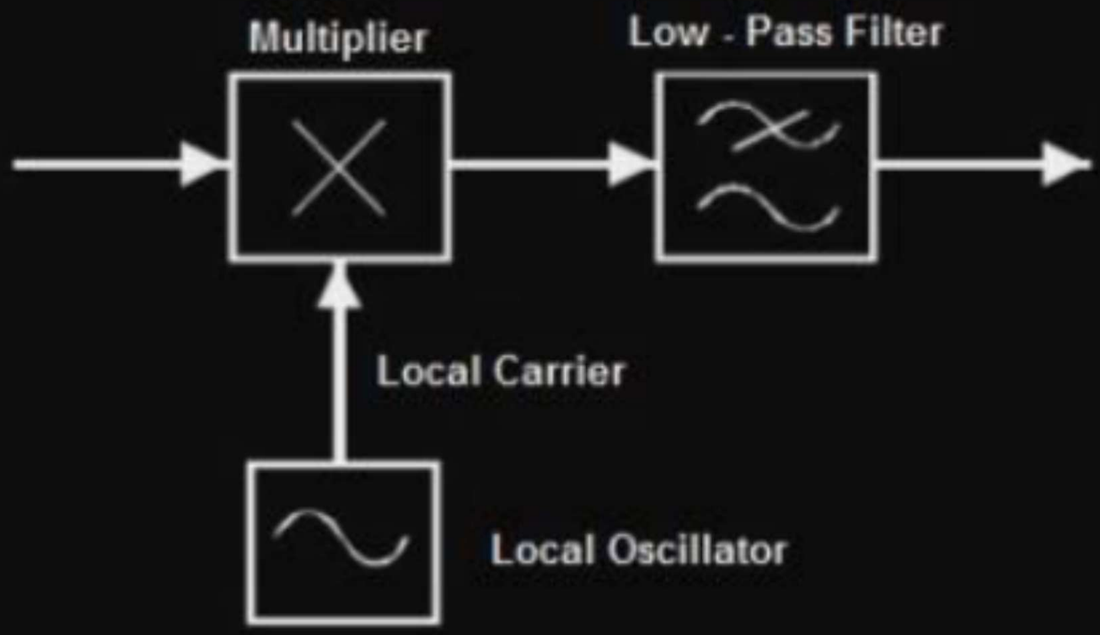
Demodulation of AM Signal

Envelope Detector (Cont..)



Demodulation of AM Signal

Synchronous Detector



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