E M Wave - Part I

Comprehensive Course on EMFT (ECE)

Vishal Soni • Lesson 1 • Nov 22, 2021

"75 HOURS"

→ BASIC CONCEPT (mediums, travelling f^n, travelling wave, Time Harmonic f^n, PHASORS)

→ EM wave (E.M. Travelling Wave)

→ Tx Line

→ waveguide

→ Antenna ***

RESOURCES : Class Notes

(i) Sadiku
(ii) Hayt
(iii) "Cheng"
(iv) Shevgaonkar

: Short notes

Question Practice: → Kanodiya

ELECTROMAGNETIC WAVE (E.M. Wave)

1) Electro (Electric Field Intensity)

→ $\vec{E}$: $\left(\frac{Volt}{m}, \frac{N}{C} \right)$

→ $\vec{E}(x,y,z)$ = space varying E field or Non uniform E field.

→ $\vec{E}(t)$ = Time varying E field.

$\overline{E}(x, y, z, t) \rightarrow$ space and time varying E field.

2) Magnetic (magnetic field Intensity)

$\overrightarrow{H}$ $\left(\frac{Amp}{m}\right)$

$\overrightarrow{H}(x, y, z)$ = space varying H field

$\overline{H}(t)$ = Time varying H field.

$\overrightarrow{H}(x, y, z, t)$ = Space and time varying H field.

3) WAVE

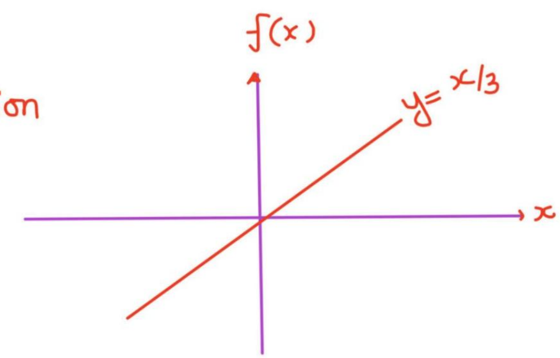
→ Travelling Wave

i) Travelling F^n

ii) Travelling wave

<u>Travelling Function:</u>

$f(x) = \frac{x}{3}$: Function



(i)

$\boxed{x \rightarrow x - 6t}$

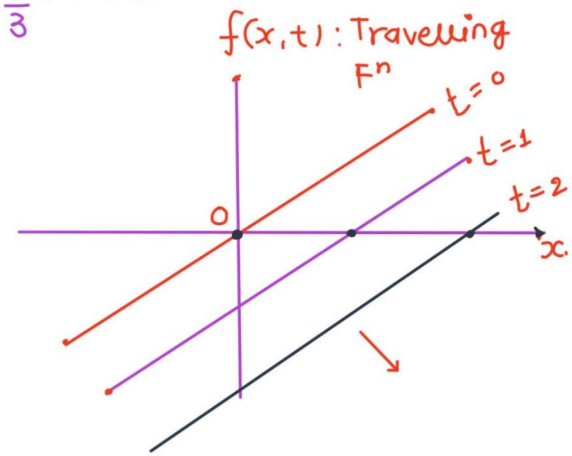
$f(x,t) = \frac{1}{3}(x-6t) = \frac{1}{3}(x-6t)$

$t=0: f(x,0) = \frac{1}{3}x$

$t=1 \quad f(x,1) = \frac{1}{3}(x-6) = \frac{1}{3}x - 2$

$t=2 \quad f(x,2) = \frac{1}{3}(x-12)$

$= \frac{1}{3}x - 4$



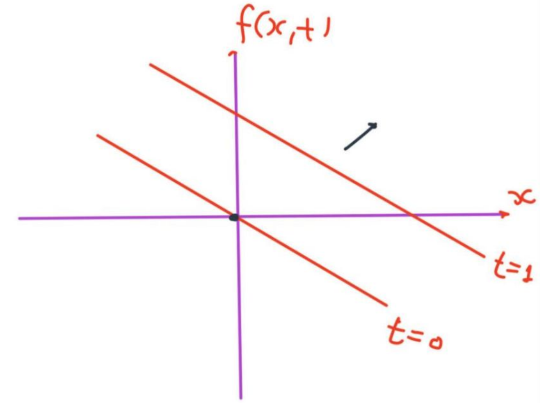
(ii) $x \rightarrow 6t - x$

$f(x,t) = \frac{1}{3}(6t-x)$

$f(x,t) = \frac{-1}{3}x + 2t$

$t=0 : f(x,0) = -\frac{1}{3}x$

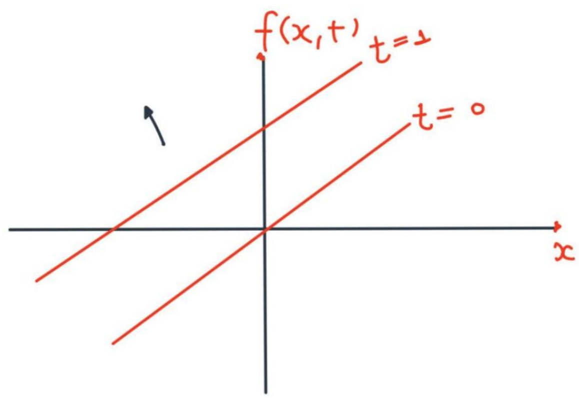
$t=1 : f(x,1) = \frac{-1}{3}x + 2$



(iii) $x \rightarrow x + 6t$

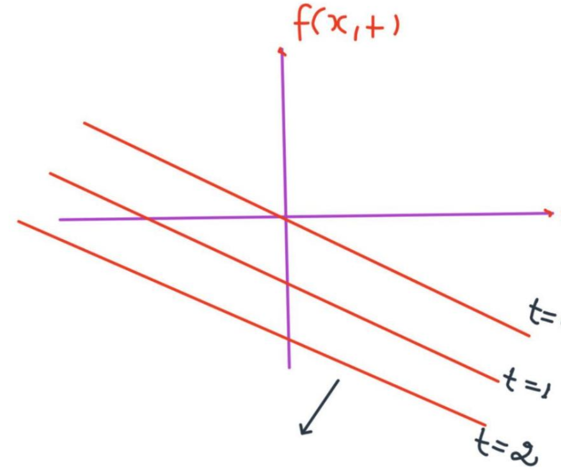
$f(x,t) = \frac{1}{3}(x+6t)$

$= \frac{1}{3}x + 2t$



(iv) $x \rightarrow -x - 6t$

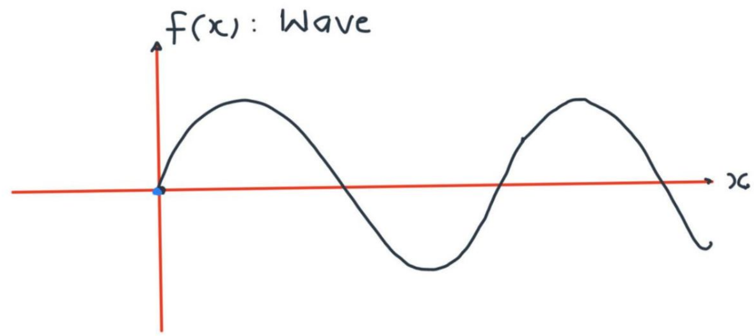
$f(x,t) = -\frac{1}{3}x - 2$



Travelling Wave:

Wave:

$f(x) = \sin 2x$



i) $x \to x + 6t$

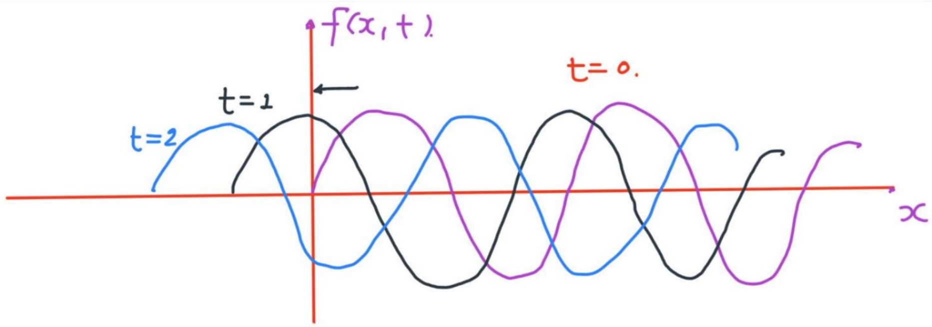
$f(x,t) = \sin[2(x+6t)]$

$f(x,t) = \sin(2x+12t)$

t=0: $f(x,0) = \sin 2x$ ⤵ $x \to x+6$: Left shift

t=1: $f(x,1) = \sin[2(x+6)]$ ⤵ $x = x+12$ left shift

t=2: $f(x,2) = \sin[2(x+12)]$

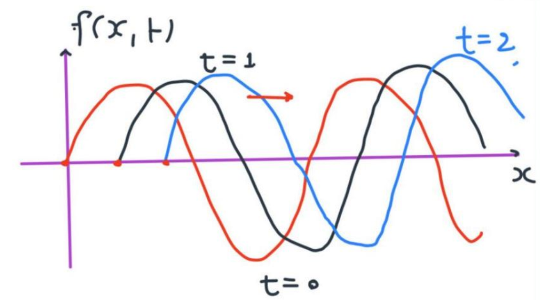


(ii) $x \to x - 6t$

$f(x,t) = \sin(2x-12t)$

t=0: $f(x,0) = \sin 2x$

t=1: $f(x,1) = \sin(2(x-6))$



Q. Identify the direction in which following Travelling Wave propagates:

i) $\sin(\omega t-\beta z) \rightarrow$ $+z$ direction

ii) $\cos(\omega t+\beta y) \rightarrow$ $-y$ direction

iii) $\sin(\beta x-\omega t) \longrightarrow$ $+x$ direction

iv) $\cos(-\beta z-\omega t) \rightarrow$ $-z$ direction.

Q. $f(x) = \sin x^2$

$\boxed{f(x) = \sin x^2}$ Not a wave But f^n

$x \rightarrow x-t$

i) $f(x,t)$ is Travelling F^n (True)

ii) $f(x,t)$ is Travelling Wave (false)

Imp points:

1) A function of space $[f(x)]$ can be converted into Travelling function by replacing

$$\boxed{x \rightarrow \pm x \pm mt}$$

2) A sinusoid function (wave) of space $[f(x)]$ can be converted into travelling wave by replacing $\boxed{x \rightarrow \pm x \pm mt}$

TRAVELLING WAVE

Planar T.W. ✓

$\sin(\underbrace{\omega t \pm \beta x}_{\phi = \text{constant}})$

Non Planar T.W. ✗

$\sin(\underbrace{\omega t \pm \beta x}_{\phi \neq \text{constant}})$

formulae in ToWo:

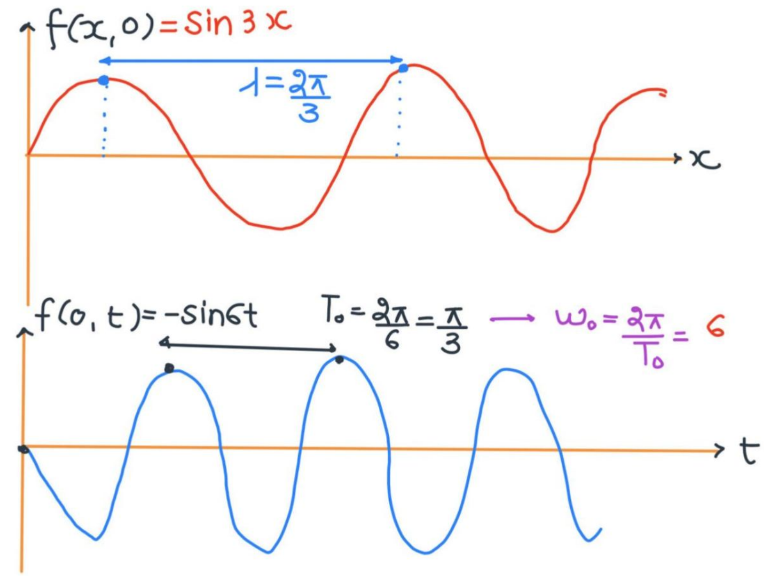
$\rightarrow \sin 3x$

$x \rightarrow x - 2t$

$\rightarrow \sin(\underbrace{3x-6t})$

$\phi = 3x - 6t = c$

$\frac{d\phi}{dt} = 3\frac{dx}{dt} - 6 = 0 \rightarrow \boxed{\frac{dx}{dt} = \frac{6}{3} = 2 = v}$



Velocity $= \frac{\text{dist}}{\text{Time}}$

$v = \frac{\lambda}{T_0}$

$\boxed{v = f_0 \lambda}$

$\boxed{f_0 = \frac{1}{T_0}}$

$\boxed{v = \frac{3}{\pi} \times \frac{2\pi}{3} = 2 \text{ m/sec}}$

$\sin 3x$

$x \rightarrow x - 2t$ (v)

$\boxed{\sin(\underbrace{3x}_{\beta} - \underbrace{6t}_{\omega})}$

$\boxed{\frac{2\pi}{\lambda} = \frac{2\pi}{2\pi/3} = 3 = \beta}$ $\rightarrow$ phase constant

Let $f(x,t) = \sin(\omega t - \beta x)$

1) $\boxed{\omega = \omega_0 = 2\pi / T_0}$

2) $\boxed{\beta = \frac{2\pi}{\lambda}}$

3) $\boxed{v = f\lambda = \frac{\omega}{\beta}}$

TIME HARMONIC FIELDS

TIME HARMONIC : Periodic in Time

FIELDS : $\longrightarrow$ Function of space

Vector Field $\boxed{\bar{A} = \bar{A}(x,y,z)}$

Scalar field $\boxed{V = V(x,y,z)}$

TIME HARMONIC VECTOR FIELDS

$$\vec{A}(x,y,z,t) = \bar{A}(x,y,z)e^{j\omega t}$$

$$\bar{A}(x,y,z,t) = \bar{A}(x,y,z)\cos\omega t$$

$$\vec{A}(x,y,z,t) = \bar{A}(x,y,z)\sin\omega t$$

STD Time Harmonic fn:

i) $\bar{A} = Ae^{j(\omega t - \beta z)}\hat{a_x}$

ii) $\vec{A} = A\cos(\omega t - \beta z)\hat{a_x}$

iii) $\vec{A} = A\sin(\omega t - \beta z)\hat{a_x}$

CONCEPT OF PHASORS FOR TIME HARMONIC FIELDS

CASE 1:

$$\vec{A}(x,y,z,t) = \vec{A}(x,y,z)\underbrace{e^{j\omega t}}_{\text{drop}}$$

$$\boxed{\vec{A}_s(x,y,z) = \vec{A}(x,y,z)}$$

$\boxed{\text{CASE 2:}}$

$$\vec{A}(x,y,z,t) = \vec{A}(x,y,z)\cos\omega t$$

$$\vec{A}(x,y,z,t) = \cancel{Re}[\vec{A}(x,y,z)\cancel{e^{j\omega t}}]$$

$$\vec{A}_s(x,y,z) = \vec{A}(x,y,z)$$

$\boxed{\text{CASE 3:}}$

$$\vec{A}(x,y,z,t) = \vec{A}(x,y,z)\sin\omega t$$

$$\vec{A}(x,y,z,t) = \cancel{Im}\{\vec{A}(x,y,z)\cancel{e^{j\omega t}}\}$$

$$\boxed{\vec{A}_s(x,y,z) = \vec{A}(x,y,z)}$$

$\boxed{\text{Q.1}}$

$$\vec{A} = \vec{M}e^{j(\omega t-\beta z)}$$

PHASOR = ?

$$\boxed{\vec{A}_s = \vec{M}e^{-j\beta z}}$$ ✓

Q.2

$\vec{A} = \vec{M}\sin(\omega t - \beta z)$

$\vec{A} = \cancel{Im}\{\vec{M}\cancel{e^{j\omega t}}e^{-j\beta z}\}$

$$\boxed{\vec{A_s} = \vec{M}e^{-j\beta z}}$$

Q.3

$\vec{A} = \vec{M}\cos(\omega t - \beta z)$.

$\vec{A} = Re\{\vec{M}e^{j(\omega t - \beta z}\}$

$$\boxed{\vec{A_s} = \vec{M}e^{-j\beta z}}$$

Q.

$\vec{A} = 10\cos(10^8 t - 10x + 60^\circ)\hat{ax}$

1) Time Harmonic Fields : YES / NO $\longrightarrow$ YES

2) PHASOR

3) Travelling wave : YES/NO $\longrightarrow$ YES

4) ω

5) β

6) v

(2) $\vec{A} = 10\cos(10^8 t - 10x + 60^\circ)\hat{ax}$

$\vec{A} = \cancel{Re}[10\cancel{e^{j10^8 t}}e^{+j(-10x+60^\circ)}]\hat{ax}$

$$\boxed{\vec{A_s} = 10e^{-j(10x - \frac{\pi}{3})}\hat{ax}}$$

(3) $\vec{A} = 10\cos(10^8 t - 10x + 60^\circ)\hat{a_x}$

ω β

$\boxed{\begin{array}{l} \omega = 10^8 \text{ rad/sec} \\ \beta = 10 \text{ rad/m} \\ v = \dfrac{\omega}{\beta} = 10^7 \text{ m/sec} \end{array}}$ → Travelling in +ve x direcn

Q. $\vec{A} = 2\sin(10t + x - \frac{\pi}{4})\hat{a_y}$

1) TH : YES/ NO → YES
2) PHASOR
3) T.W.O. : YES/NO → YES
4) ω
5) β
6) v

(2) $\vec{A} = 2\sin(10t + x - \pi/4)$

$\vec{A} = \text{Im}[2e^{j(10t + x - \pi/4)}]$

$\boxed{\vec{A_s} = 2e^{j(x - \pi/4)}}$ → If not present in option

$\boxed{\sin\theta = \cos(\theta - 90)}$

OR

$\vec{A} = 2\cos[10t + x - \frac{\pi}{4} - \frac{\pi}{2}]$

$\boxed{\vec{A_s} = 2e^{j(x - \frac{3\pi}{4})}}$ ✓

(3) $\boxed{\begin{array}{l} \omega = 10 \\ \beta = 1 \\ v = \dfrac{\omega}{\beta} = 10 \end{array}}$ ✓