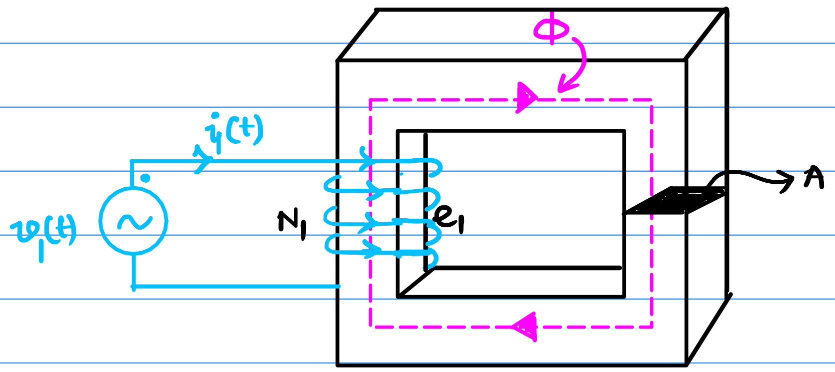


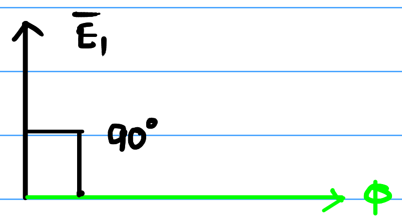
We know $\phi = \vec{B}\cdot\vec{A} = BA\cos\omega t = \phi_m \cos\omega t$

$$e_1 = N_1 \frac{d\phi}{dt} = -N_1 \omega \phi_m \sin(\omega t) = (e_1)_m \cos(\omega t + \pi/2)$$

$$|\bar{E}_1| = (e_1)_{rms} = \frac{N_1 \omega \phi_m}{\sqrt{2}} = \sqrt{2}\pi f N_1 \phi_m$$

$$\boxed{\phi_m = \frac{E_1}{\sqrt{2}\pi f N_1} \approx \frac{V_1}{\sqrt{2}\pi f N_1}}$$

as $R_1 \approx 0$ Therefore, $|\bar{E}_1| \approx |\bar{V}_1|$



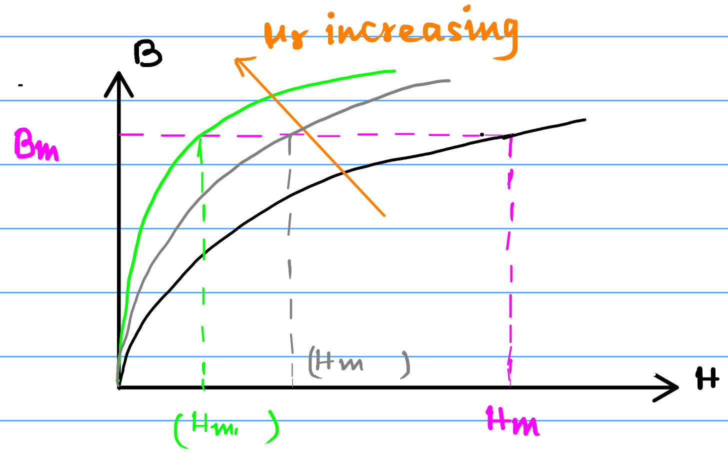
So from the phasor diagram E_1 leads ϕ by $90°$

Important Observations:-

i) ϕ_m only depends on V_1, f for a particular coil. (N_1)

ii) ϕ_m does not depend on permeability μ which varies from core to core. That is for any core is V, f and N are fixed then ϕ_m also will be fixed.

Now as ϕ_m is decided then we are interested in finding out the value of the current that creates ϕ_m.



$$B_m = \mu_0 \mu_r H_m$$

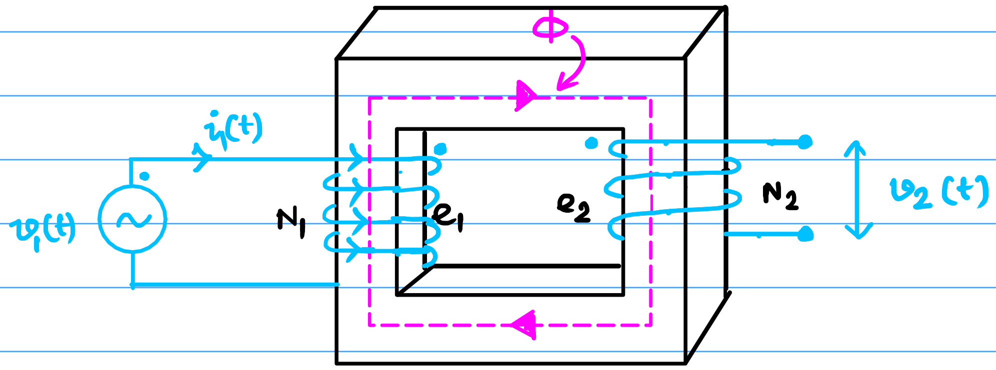
$$B_m = \frac{\phi_m}{A}$$

$$H_m = \frac{N_1 i_\mu^m}{l}$$

$$I_\mu = \frac{i_\mu^m}{\sqrt{2}}$$

For a fixed value of B_m, H_m decreases as μ_r increases.

Q. Now we attach a second coil to the another limb



Flux linkage with coil-2 $\quad \lambda_2 = N_2 \phi$

$= N_2 \phi_m \cos\omega t$

$$e_2 = \frac{d}{dt}(\lambda_2) = -N_2 \phi_m \omega \sin\omega t = N_2 \phi_m \omega \cos(\omega t + \pi/2)$$

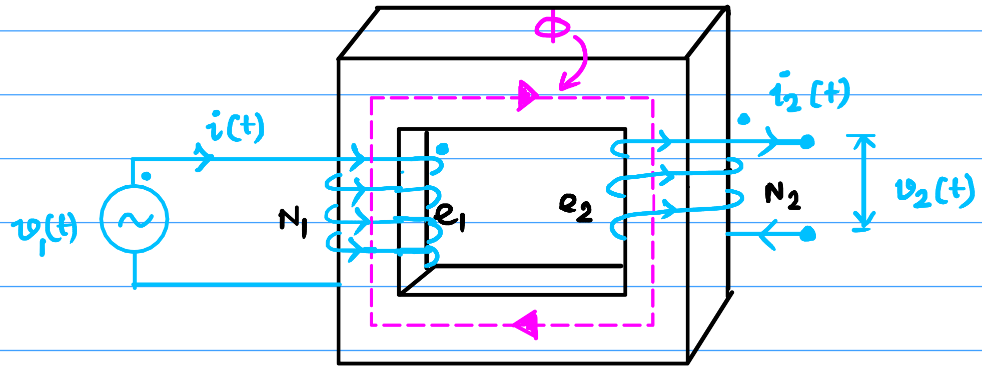
$$|\bar{E}_2| = (e_2)_{rms} = \frac{N_2 \phi_m 2\pi f}{\sqrt{2}} = \sqrt{2}\pi f N_2 \phi_m$$

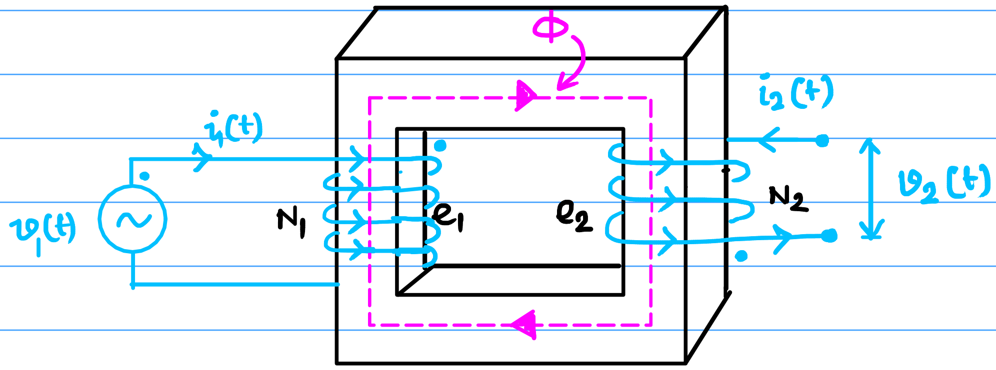
If $\quad R_2 \approx 0 \quad$ then $\quad |\bar{E}_2| \approx |\bar{V}_2|$

$$\boxed{\frac{\bar{V}_1}{N_1} = \frac{\bar{V}_2}{N_2}}$$

$|\bar{E}_1| = 4.44 f \phi_m N_1 \qquad |\bar{E}_2| = 4.44 f \phi_m N_2$

☐ Sense of winding:-





Ideal Transformer :-

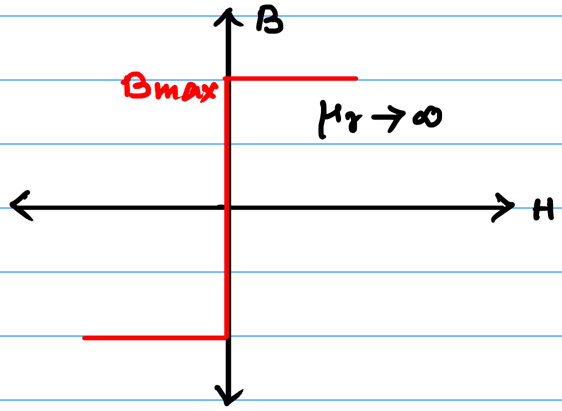
1. winding resistances $R_1 = 0$; $R_2 = 0$

   Voltage drop = 0 ; $I^2(R_1+R_2) = 0$

2. $(\mu_r)_{core} \rightarrow \infty$ i.e magnetizing current $I_m = 0$

$$\mathcal{R} = \frac{l}{A\mu_0\mu_r} = 0$$

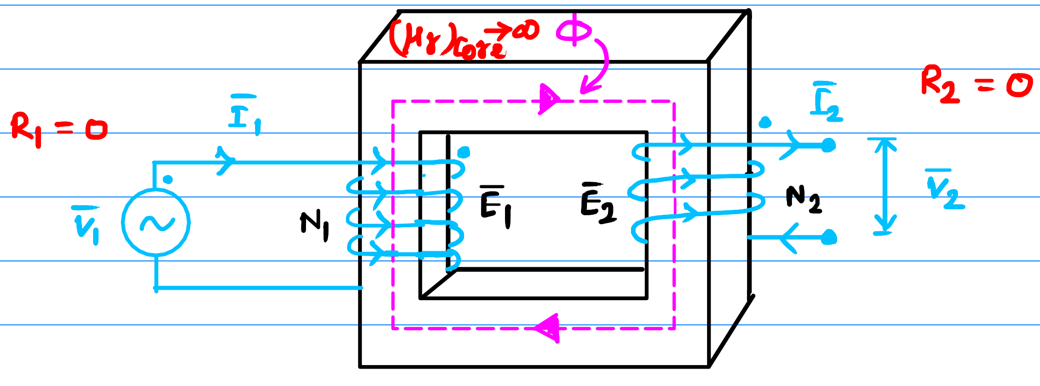
As $\mathcal{R}$ is zero no mmf is required to create flux

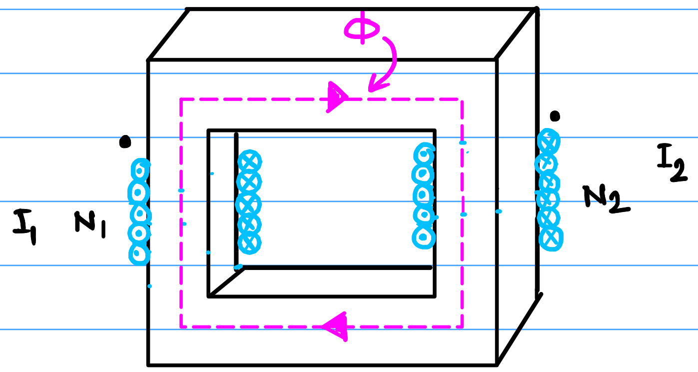


3. Losses are zero, therefore efficiency $\eta = 100\%$

4. leakage flux = 0 ; Flux linked to coil-1 is equal to flux linked to coil-2

5.





According to Amperes circuital law

$$\oint \vec{H}\cdot d\vec{l} = Ni \qquad \mathcal{R} = \text{Reluctance}$$

$$\Rightarrow N_1 i_1 - N_2 i_2 = H \cdot l$$

$$\Rightarrow N_1 i_1 - N_2 i_2 = \phi \mathcal{R}$$

$$\Rightarrow N_1 i_1 - N_2 i_2 = \phi \frac{l}{A \mu_0 \mu_r}$$

Now $\mu_r \to \infty$

Therefore $N_1 i_1 - N_2 i_2 = 0$

$$\boxed{N_1 \bar{I}_1 = N_2 \bar{I}_2} \qquad \boxed{\frac{\bar{V}_1}{N_1} = \frac{\bar{V}_2}{N_2}}$$

Together we have

$$\boxed{\bar{V}_1 \bar{I}_1 = \bar{V}_2 \bar{I}_2} \rightarrow \text{VA rating of T/F (capacity)}$$

Nameplate of a 1ϕ T/F :-

Example:-

For a 1-phase T/F $N_1 = 250$ and $N_2 = 500$. The net cross sectional area of the core = $60\ cm^2$.

If the primary is connected to a 50 HZ supply at 230V then calculate

a) The peak value of the flux density in the core.

b) The voltage induced in the secondary.

Example:-

A 1-phase T/F has a core with cross sectional area is 150 cm^2.
It operates at a max. flux density of 1.1 Wb/m^2 when connected to a 50 Hz supply.
The secondary winding has 66 turns.

Determine the o/p in KVA if a load of 4 Ω impedance is connected to its secondary.

[Assume all internal voltage drops are negligible]

Solution:-

Phasor Diagram of an ideal T/F :-

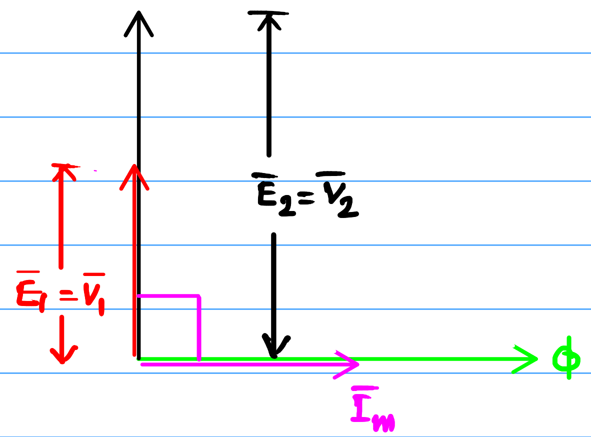
i) ϕ and i_m are in same phase

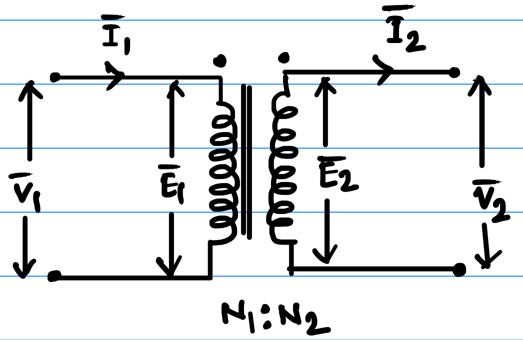
ii) $\bar{E}_1$ leads ϕ by 90°

iii) $\bar{E}_1$ and $\bar{E}_2$ are in phase.

iv) $\bar{V}_1 = \bar{E}_1$ and $\bar{V}_2 = \bar{E}_2$

$$\frac{\bar{V}_1}{\bar{V}_2} = \frac{N_1}{N_2} = \frac{\bar{E}_1}{\bar{E}_2}$$





Real Transformer :-

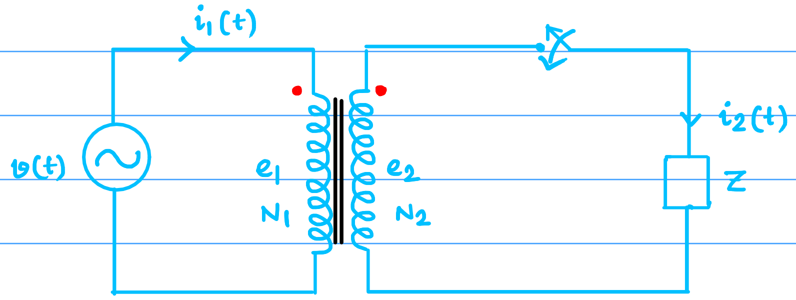
Ideal T/F $\longrightarrow$ **Real T/F**

Ideal T/F	Real T/F
i) Winding Resistance $R_1 = R_2 = 0$	i) $R_1, R_2 > 0$ a) Voltage drop b) Cu loss (ohmic) c) efficiency $\eta \neq 100\%$
ii) $(\mu_r)_{core} \to \infty$; $\mathcal{R} \to 0$ $I_\mu = 0$	ii) $(\mu_r)_{core} \Rightarrow$ finite value ; $\mathcal{R} \neq 0$ $I_\mu \neq 0$
iii) Leakage flux $= 0$ Tight coupling	iii) Leakage flux exists Induced emf due to ϕ_ℓ
iv) Core loss $= 0$ $\eta = 100\%$	iv) Core loss $= P_H + P_E$ $P_H \propto B_{max}^n f$ $P_E \propto B_{max}^2 f^2$ $\boxed{P_{core} = E_1^2}$

Real Transformer :-

In practical T/F μ_r is high but finite
Therefore a finite amount of current I_μ (say) is required to establish the flux ϕ_{max}.

$$\phi_m = \frac{N_1 I_\mu}{R}$$ I_μ = Magnetizing current



After the switch is closed a current I_2 flows through coil-2 which produces a flux that according to the Lenz's law try to oppose the main flux Φ_m in the core.

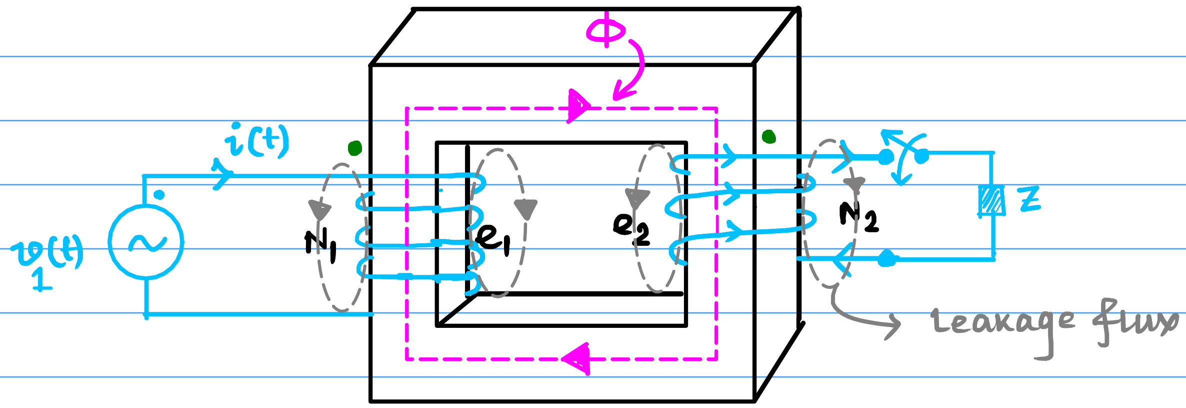
$$\Phi_m' = \frac{N_1 I_\mu - N_2 I_2}{R}$$

As $\Phi \downarrow$ $E_1 \downarrow$ So the Coil-1 draws more current.
Let this extra current is I_2'

$$\phi_m'' \frac{N_1 I_\mu - N_2 I_2 + N_1 I_2'}{R}$$

This transient part exist untill and unless

$$\boxed{N_1 I_2' = N_2 I_2}$$



For coil-1 we can write $\phi_1 = \phi_m + \phi_{l1}$

For coil-2 we can write $\phi_2 = \phi_m - \phi_{l2}$

For coil-1

$$\bar{V}_1 = \bar{I}_1 R_1 + \bar{E}_1'$$

We know $E_1' = \sqrt{2}\pi f \phi_1 N_1$

$$= \sqrt{2}\pi f (\phi_m + \phi_{l1}) N_1$$

$$= \sqrt{2}\pi f \phi_m N_1 + \sqrt{2}\pi f \phi_{l1} N_1$$

$$= E_1 + E_{l1}$$

voltage induced due to mutual flux

voltage induced due to leakage flux

$$\boxed{\bar{V}_1 = \bar{I}_1 R_1 + \bar{E}_1 + \bar{E}_{l1}}$$

The leakage flux is the flux that does not link the other coil. Therefore this flux has nothing to do with energy transfer b/w the coils. Therefore it is represented by a small leakage inductance.

Similarly for coil-2

$$\bar{E}_2' = \bar{V}_{load} + \bar{I}_2 R_2$$

$$E_2' = \sqrt{2}\pi f(\phi_m - \phi_{l2}) N_2$$

$$= \sqrt{2}\pi f \phi_m N_2 - \sqrt{2}\pi f \phi_{l2} N_2$$

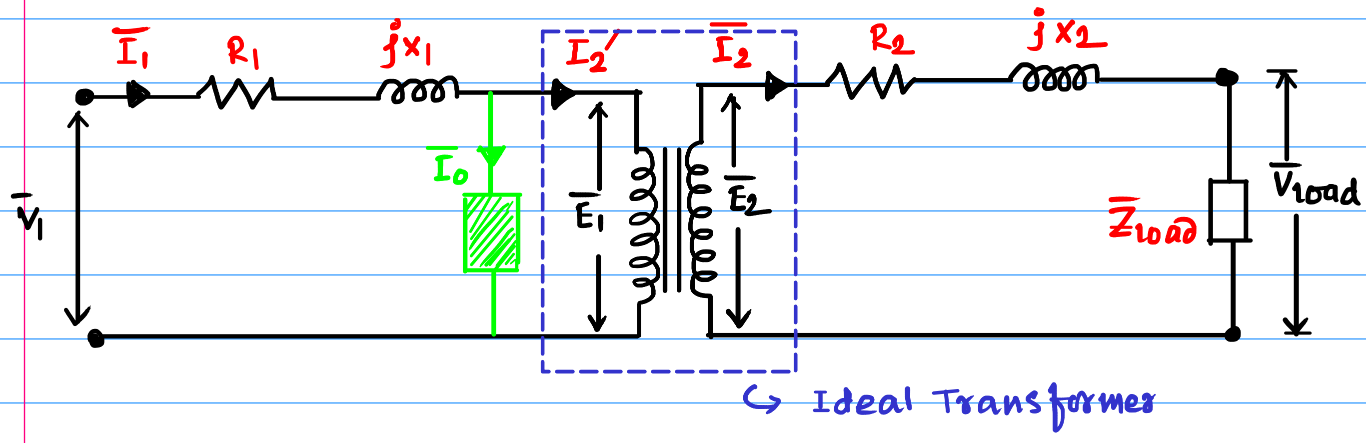
$$= E_2 - E_{l2}$$

$$\boxed{\bar{E}_2 - \bar{E}_{l2} = \bar{V}_{load} + \bar{I}_2 R_2}$$

$\bar{E}_{l1}$ and $\bar{E}_{l2}$ are the voltages induced due to leakage flux. $\bar{E}_{l1}$ and $\bar{E}_{l2}$ can be represented by the corresponding reactances x_1 and x_2 which is basically the leakage reactances of coil-1 and coil-2.

$$\boxed{\begin{aligned} \bar{V}_1 &= \bar{I}_1 R_1 + j\bar{I}_1 x_1 + \bar{E}_1 \\ \bar{E}_2 &= \bar{I}_2 R_2 + j\bar{I}_2 x_2 + \bar{V}_{load} \\ N_1 \bar{I}_2' &= N_2 \bar{I}_2 \end{aligned}}$$

$\rightarrow$ Transformer Action



$\bar{I}_1$
R_1
jx_1
$\bar{I}_2'$
$\bar{I}_2$
R_2
jx_2
$\bar{V}_1$
$\bar{I}_0$
$\bar{E}_1$
$\bar{E}_2$
$\bar{Z}_{load}$
$\bar{V}_{load}$
Ideal Transformer