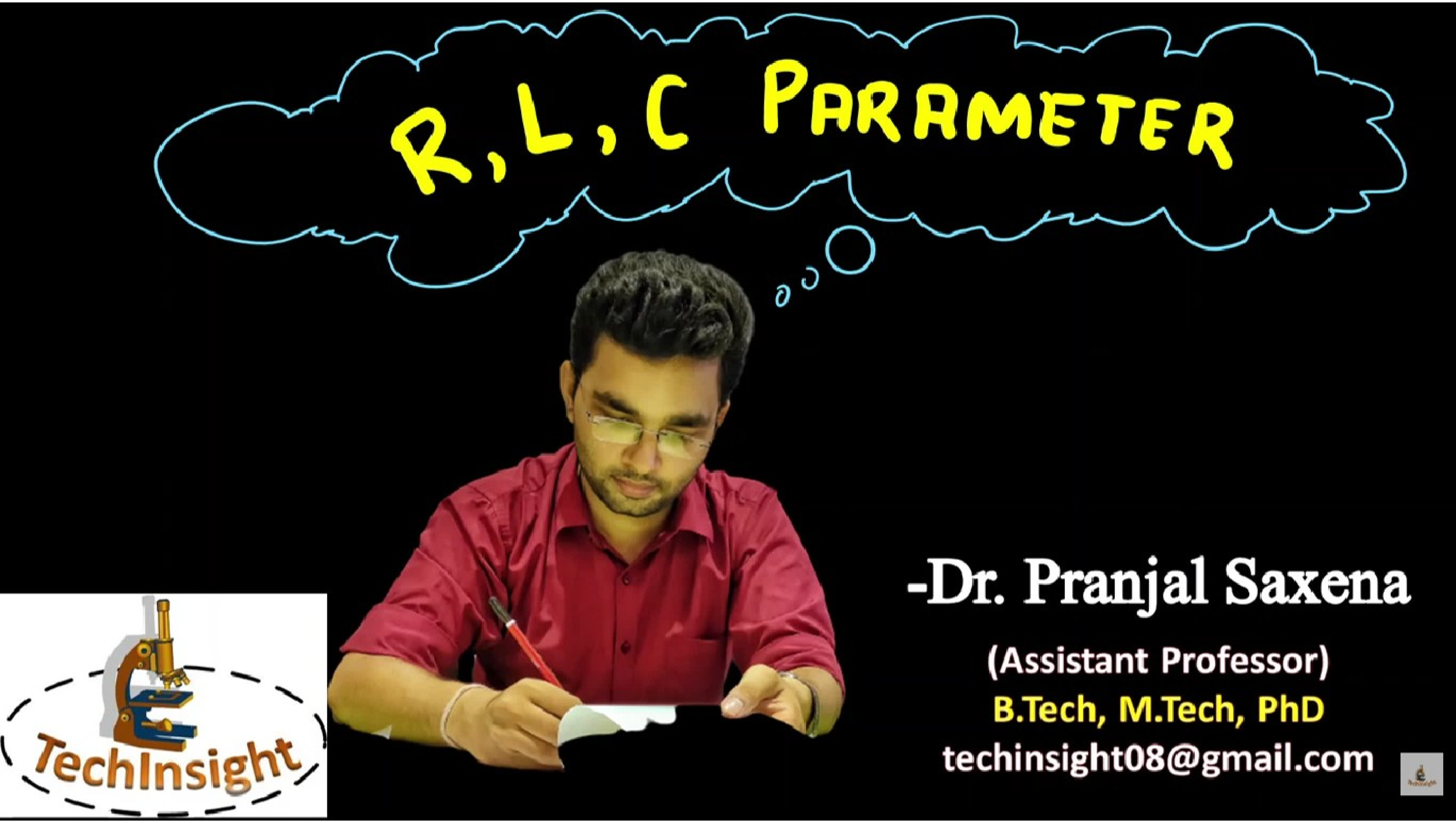
R,L,C PARAMETER
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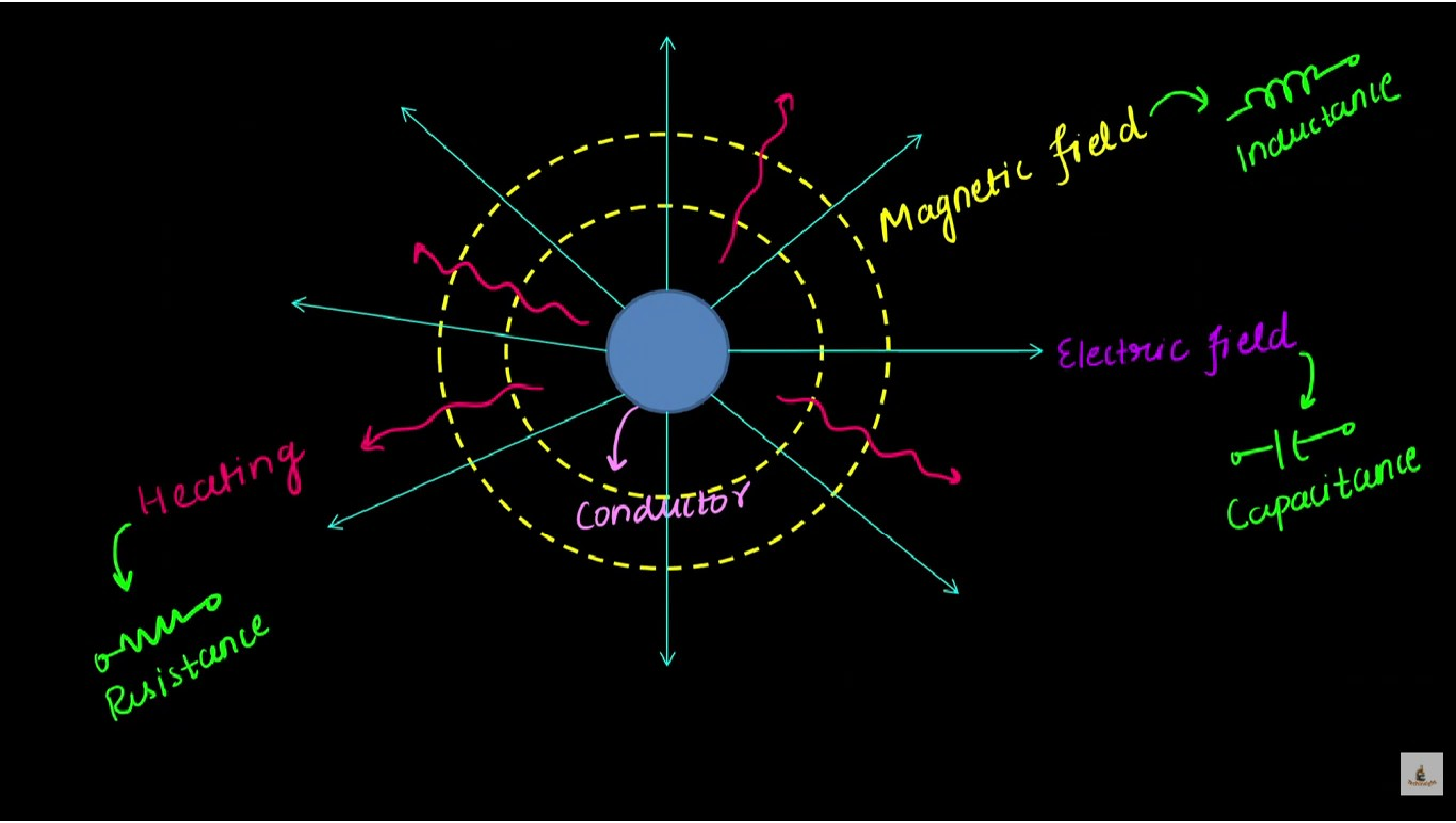
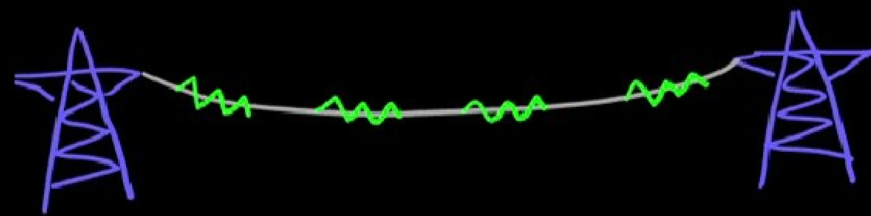

Magnetic field
Inductance
Electric field
Capacitance
Heating
Resistance
Conductor

Resistance

"Opposition offer by transmission line conductors to the flow of current"



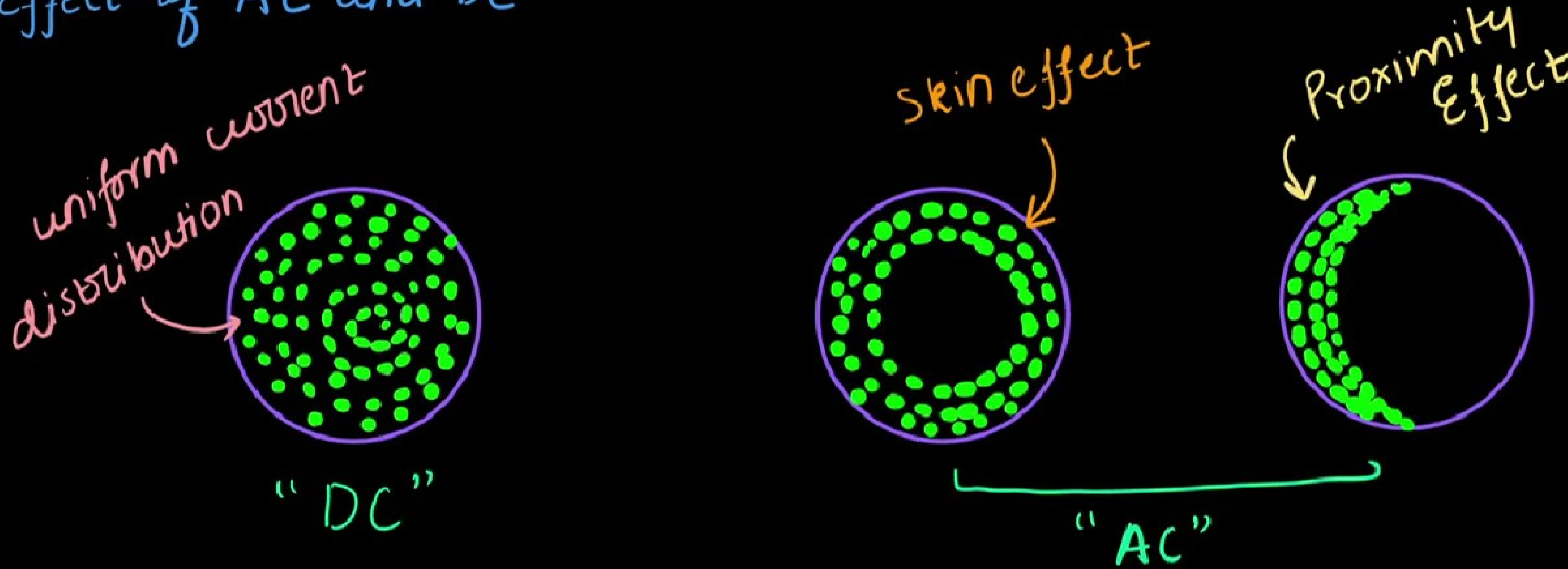
Resistance → distributed Parameter

$$\boxed{R = \frac{\text{Power loss in conductor}}{I^2}}$$

$$\boxed{R = \rho \, l/A}$$

Length of Line	Resistance Type
Short (< 80 km)	Lumped
Medium (80-200km)	Lumped
Long (above 200)	Distributed

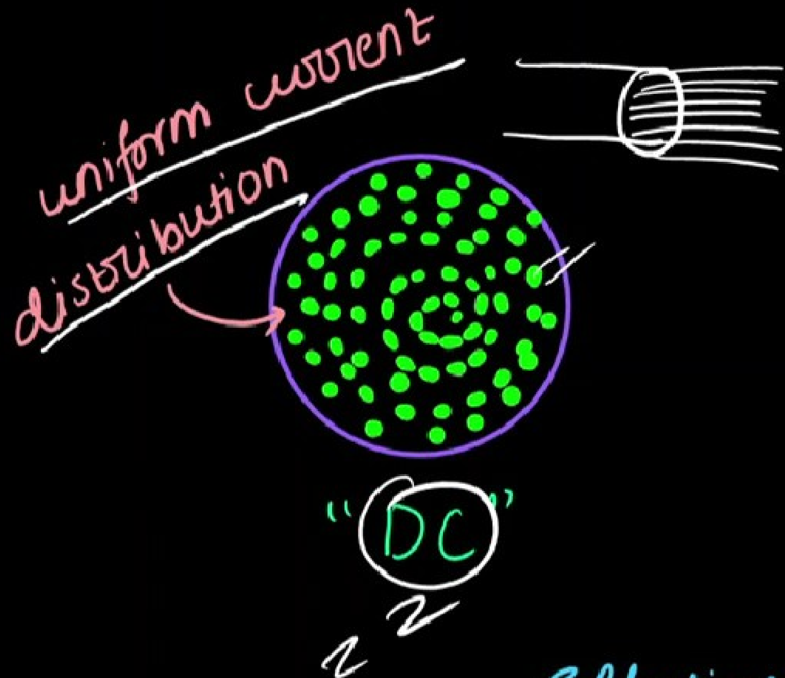
Effect of AC and DC

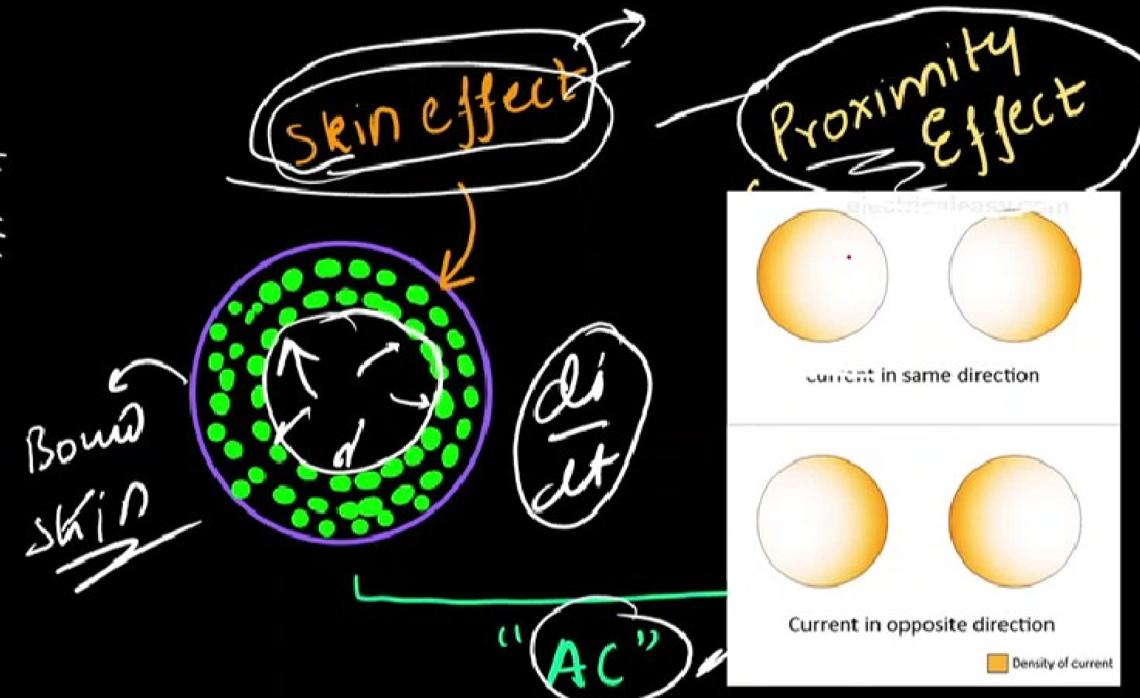


$$\text{Effective area}_{DC} > \text{Effective area}_{AC}$$

$$\boxed{R_{DC} < R_{AC}}$$

Effect of AC and DC





$$\text{Effective area}_{DC} > \text{Effective area}_{AC}$$

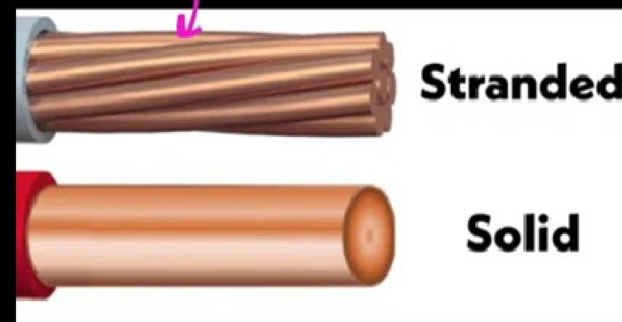
$$\boxed{R_{DC} < R_{AC}}$$

Factors affecting Resistance

1. Stranding

"Due to spiral effect, length of conductor ↑

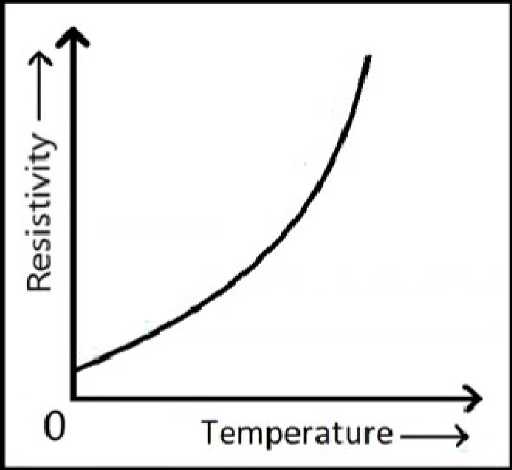
Spiral effect



spiral length = 2 to 3% more than theoritical length

$R_{stranded}$ = 2 to 3% more than solid wire R

2. Temperature Effect



→ For metals;

Temp ↑ ----→ Resistivity ↑

→ $t_1 \longrightarrow R_1$

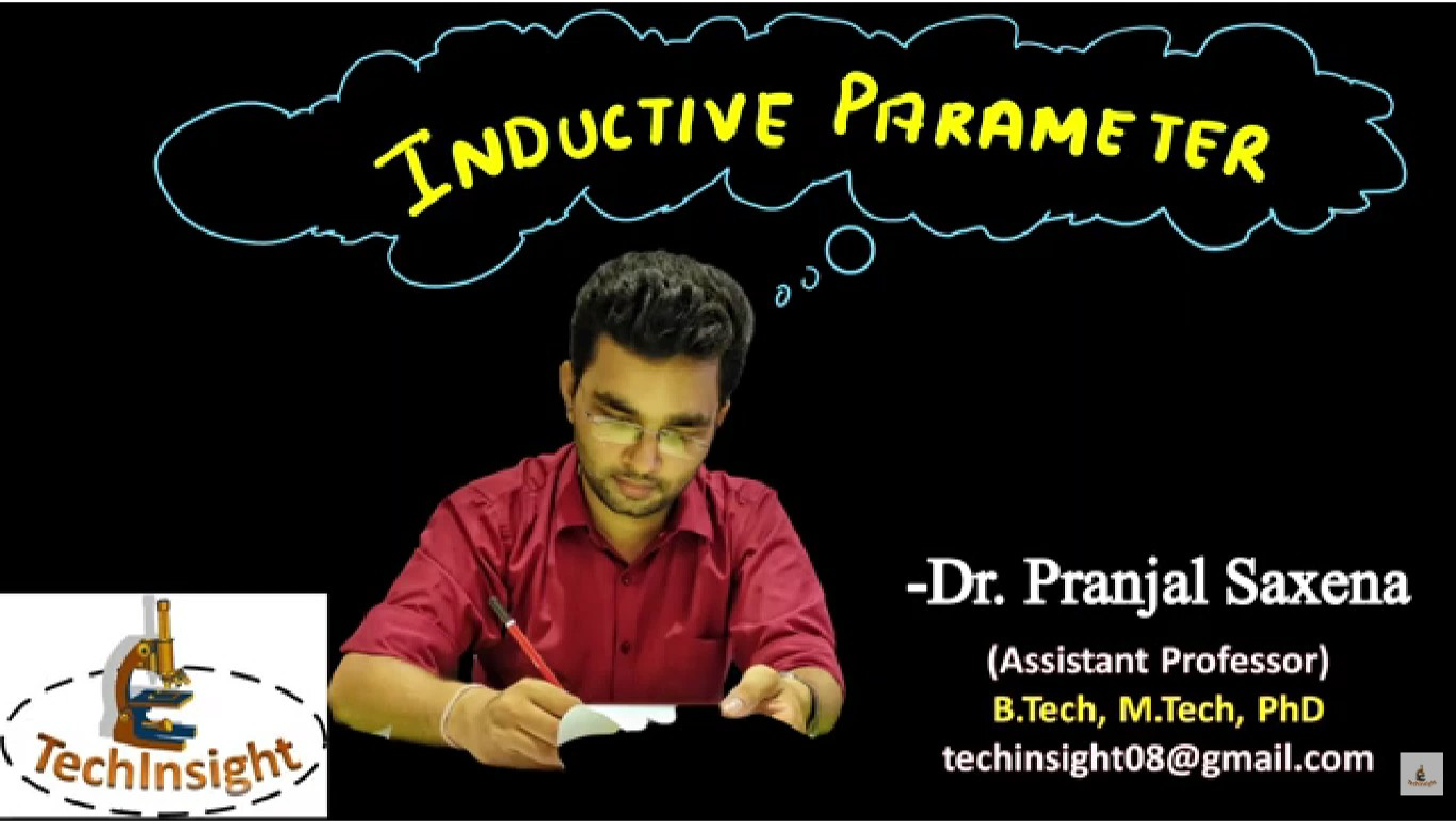
$t_2 \longrightarrow R_2$

$$\frac{R_1}{R_2} = \frac{t_1 + (1/\alpha_0)}{t_2 + (1/\alpha_0)}$$

→ α_0 → Temp. coefficient of Resistance at 0°C

↳ depends on material → value → 0.00427/°C (copper)

↳ 0.00407/°C (Aluminium)


INDUCTIVE PARAMETER
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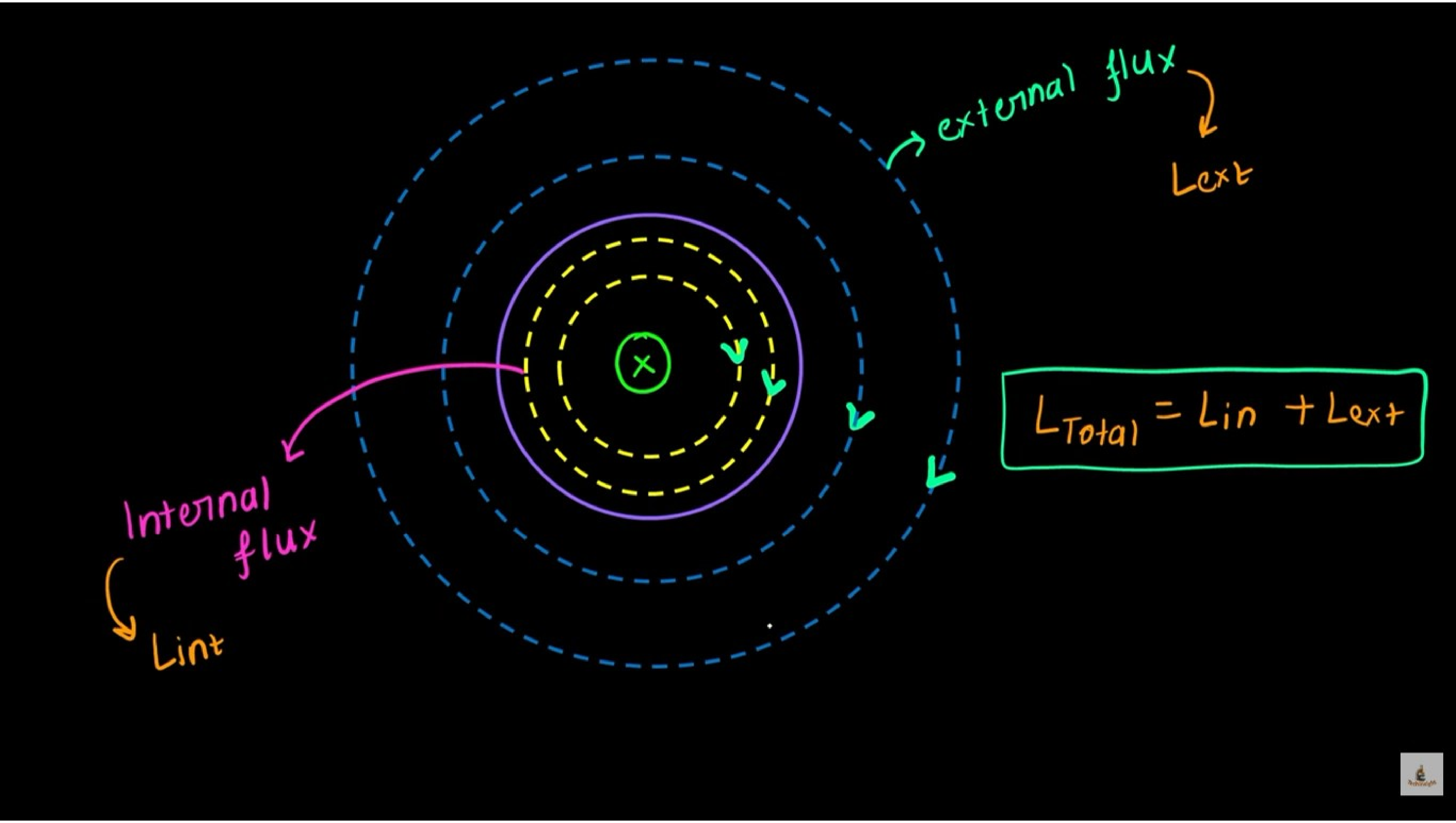
Inductive Parameter

→ Transmission line carry AC current ⟶ variable flux

flux linkage with conductor changes

Inductance came into the picture

$$L = \frac{\text{Total magnetic flux linkage}}{\text{current flowing through it}}$$



external flux
Lext
Ltotal = Lin + Lext
Internal flux
Lint

Inductance Computation

→ $L_{Total} = L_{int} + L_{ext}$

→ Assumptions;

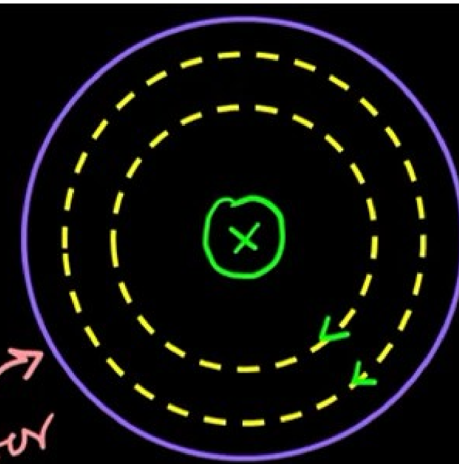
1. No current carrying conductor in the vicinity
2. Presense of earth will not affect the magnetic field.
3. Current is uniformly distributed over the cross-sectional area.

Internal Inductance (L_{in})

$$\boxed{L_{in} = \frac{\psi_{in}}{I}}$$

Internal flux linkage

current in conductor



conductor

$$\boxed{\psi_{in} = \frac{1}{2}\times 10^{-7}\,\mu_r\, I}$$

for non-magnetic conductor

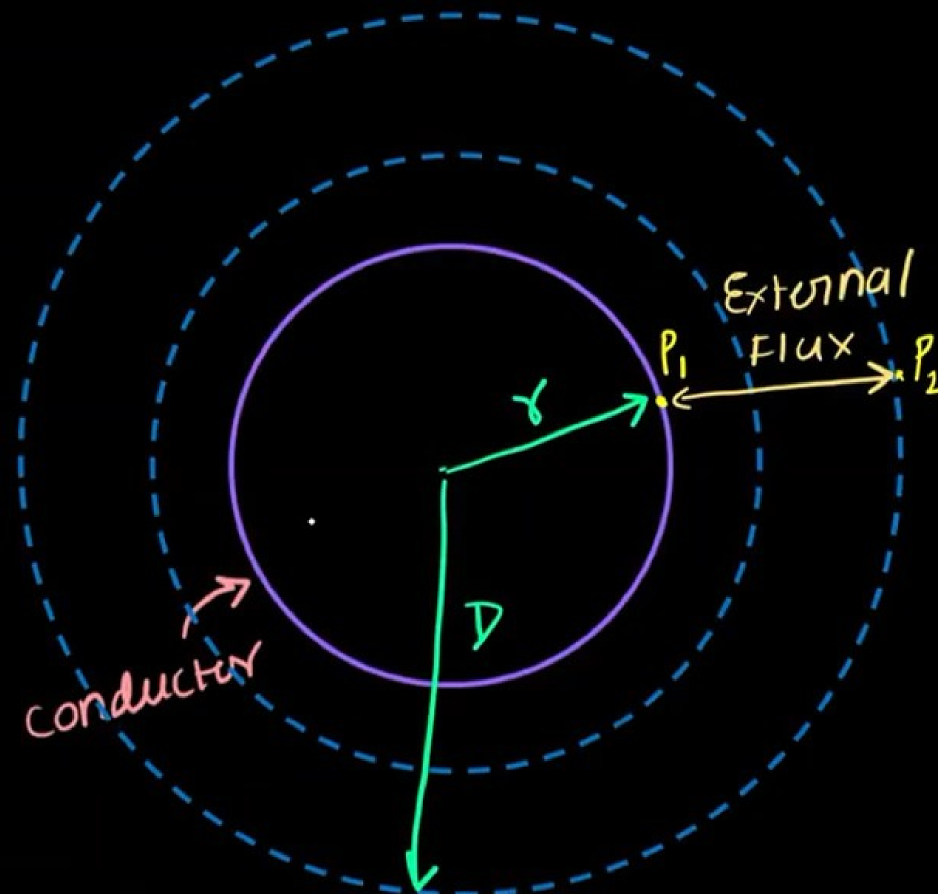
$$\boxed{\mu_r = 1}$$

$$\boxed{L_{in} = \frac{1}{2}\times 10^{-7}\ \text{H/m}}$$

Inductance per unit length due to flux inside conductor

External Inductance (L_{ex})

→ Consider flux linkage due to external flux lies b/w P_1 and P_2 at distance r and D meter from center.



→ $L_{ext} = \dfrac{\psi_{12}}{I}$

$$\boxed{L_{ext} = 2\times10^{-7}\ln\left(\frac{D}{r}\right)}$$

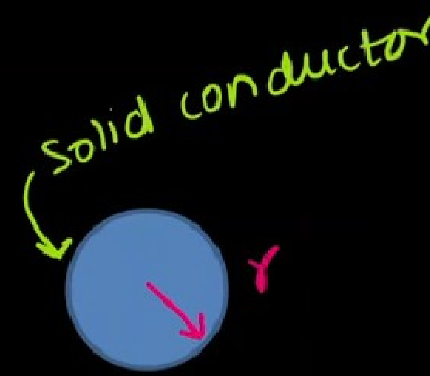
→ Total Inductance

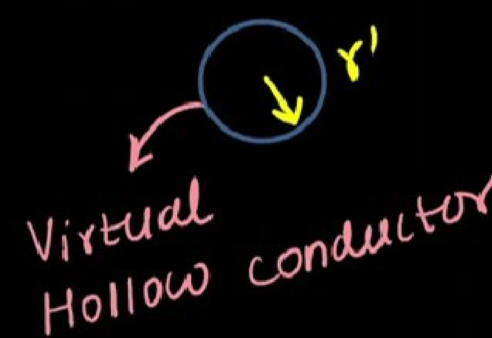
$$L_T = L_{in} + L_{ex}$$

$$= \frac{1}{2} \times 10^{-7} + 2 \times 10^{-7} \ln\left(\frac{D}{r}\right)$$

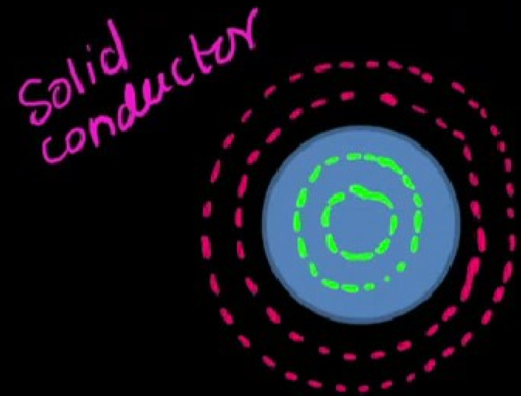
$$\boxed{L_T = 2 \times 10^{-7} \ln\left(\frac{D}{r'}\right)} \quad H/m$$

$$\boxed{r' = 0.7788\, r}$$

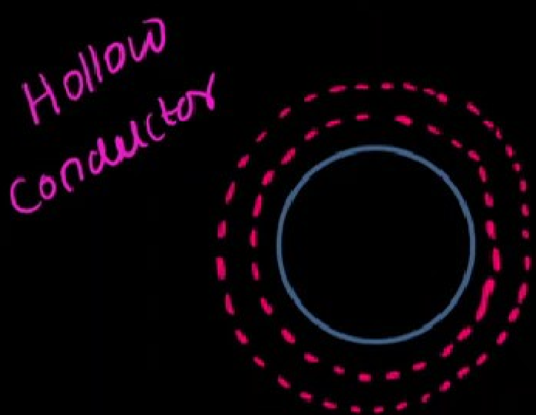




Inductance of solid and Hollow conductor



$$L_T = L_{in} + L_{ex} = \frac{1}{2} \times 10^{-7} + 2 \times 10^{-7} \ln \frac{D}{r}$$



$$L_T = L_{ex} = 2 \times 10^{-7} \ln \frac{D}{r}$$

Concept of Virtual Hollow conductor

Calculation Easy

Solid conductor

$\xrightarrow[\text{Hollow conductor}]{\text{Virtual}}$

Hollow conductor

$L_{solid} = L_{in} + L_{ext}$

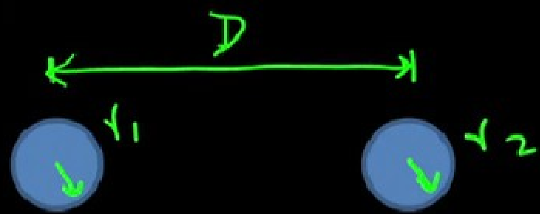
$L_{\substack{virtual \\ Hollow}} = L_{ex}$

$$\boxed{L_{solid} = L_{virtual}}$$

* r' to be selected in such a way that the virtual Hollow conductor produce same inductance as that of solid conductor

$$\boxed{r' = 0.7788\, r}$$

Inductance of 1-ϕ, 2 wire system



$\simeq$

$+I$ $\quad$ $-I$ $\qquad\qquad$ $+I$ $\quad$ $-I$

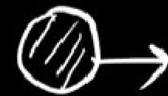
$L_{solid_1} + L_{solid_2}$ $\qquad$ $L_{Hollow_1} + L_{Hollow_2}$

$$\downarrow \qquad\qquad \downarrow$$

$$2\times10^{-7} \ln \frac{D}{r_1^{2}} \qquad 2\times10^{-7} \ln \frac{D}{r_2'}$$

$$r_1 = 0.7788\, r_1 \qquad r_2 = 0.7788\, r_2$$

$$\boxed{L_{T_{1\phi}} = 4\times10^{-7}\ \ln\frac{D}{\sqrt{r_1' r_2'}}}\quad H/m$$


L_ϕ

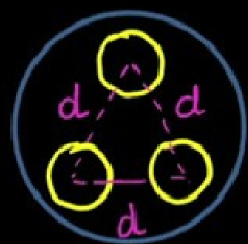
if $r_1 = r_2 = r \longrightarrow r_1' = r_2' = r'$

$$\boxed{L_{T_{1\phi}} = 4\times10^{-7}\ \ln\frac{D}{r'}}\quad H/m$$

* Conclusion,

$$\boxed{L_\phi = 2\times10^{-7}\ \ln\frac{D}{r'}}$$

$$\boxed{L_\ell = 4\times10^{-7}\ \ln\frac{D}{r'}}$$



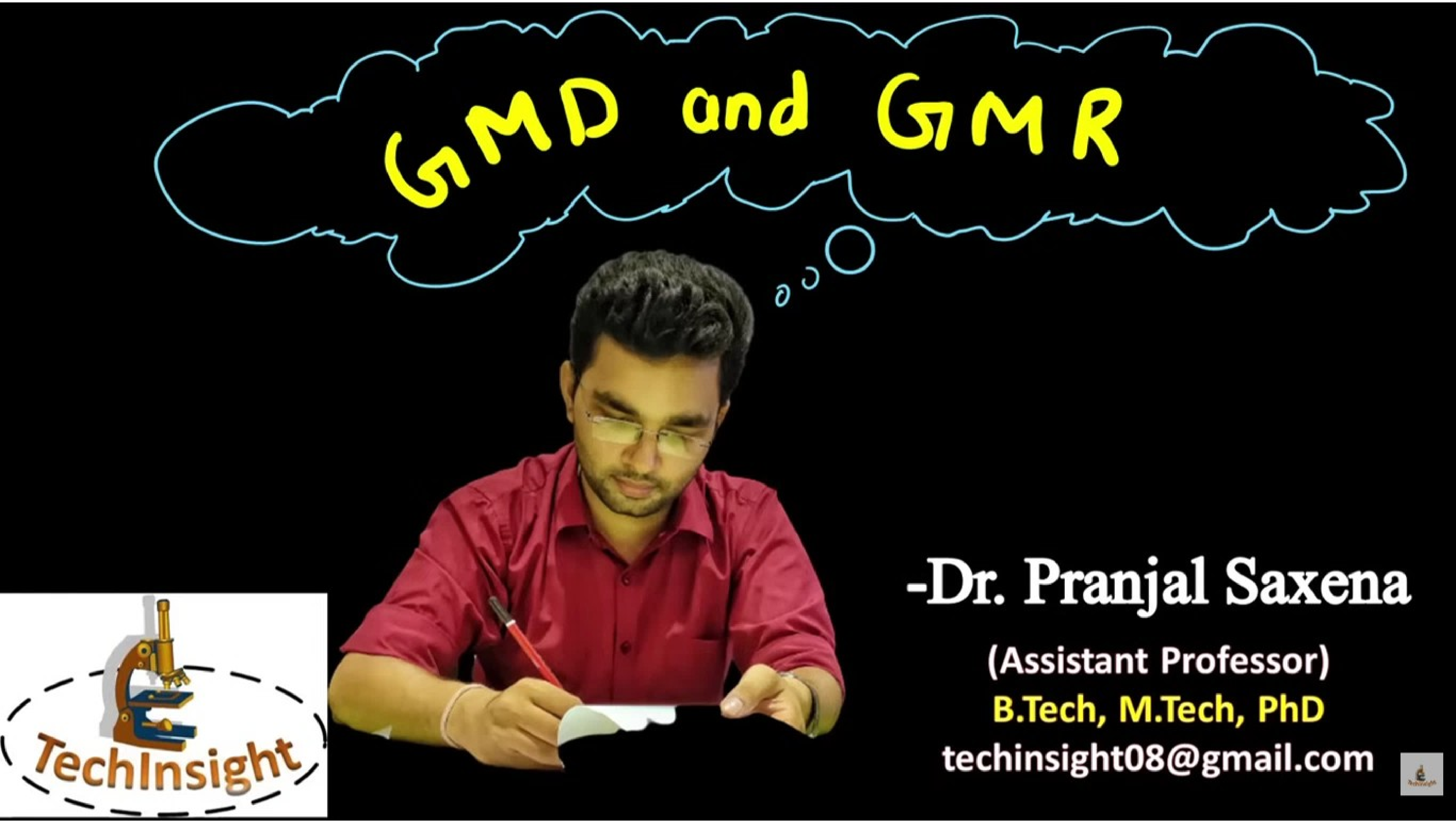
Bundle Conductor

↓

L_T calculation is very complex

$$\xrightarrow[\text{Hollow cond.}]{\text{Virtual}}$$

Equivalent Hollow conductor


GMD and GMR
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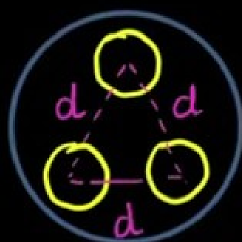
Concept of GMR



$\xrightarrow[\text{Hollow cond.}]{\text{Virtual}}$

Bundle Conductor

↓

L_T calculation is very complex

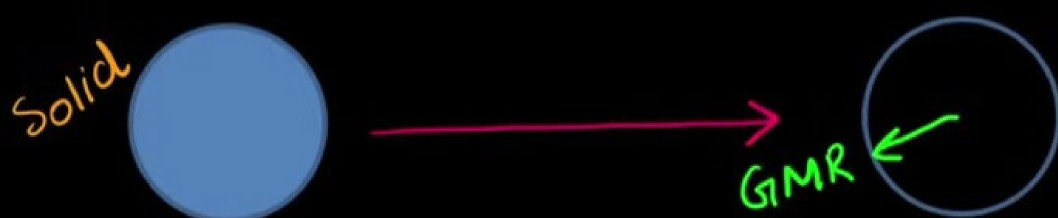
Equivalent Hollow conductor

Geometrical Mean Radius (GMR) or Self GMD → self distance

"It is the effective radius of a hypothetical hollow conductor whose inductance exactly matches the inductance of conductor under consideration."

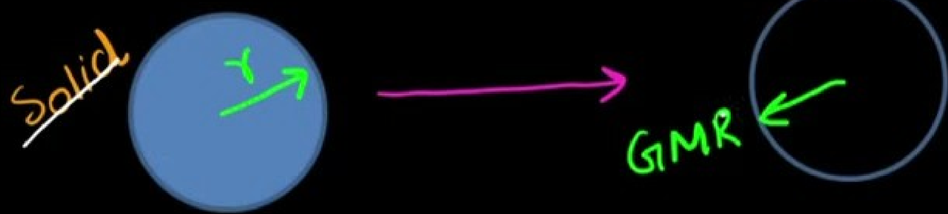
conductor
- → solid
- → Bundle

$$L_{Bunde} = L_{Hollow} = 2 \times 10^{-7} \ln \frac{D}{GMR}$$

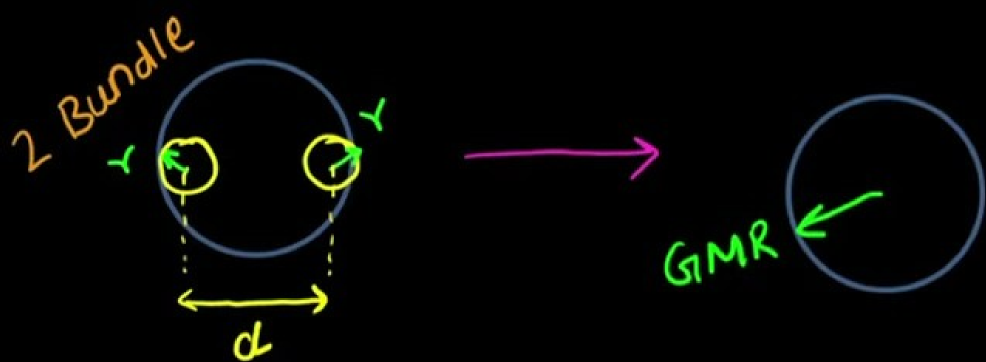


$$L_{solid} = L_{Hollow} = 2 \times 10^{-7} \ln \frac{D}{GMR}$$

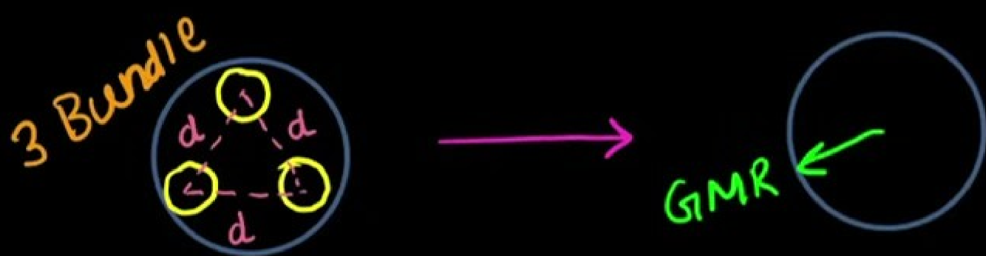
GMR Calculation



$$GMR = r' = 0.7788\,r$$



$$GMR = \sqrt{r'd}$$
$$= \sqrt{0.7788\,rd}$$



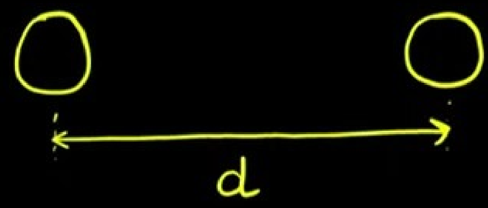
$$GMR = \sqrt[3]{r'\,d.d}$$
$$= (0.7788\,rd^2)^{1/3}$$

Features of GMR

1. Denoted by D_s → self GMD, self distance
2. Depends on → shape of conductor
   - → Type of conductor → solid, Bundle
   - → Size of conductor → radius
3. It doesn't depends on spacing b/w conductors.
4. If we increase GMR, L↓ and C↑
5. Usually Bundle conductors are used to increase GMR of transmission line.

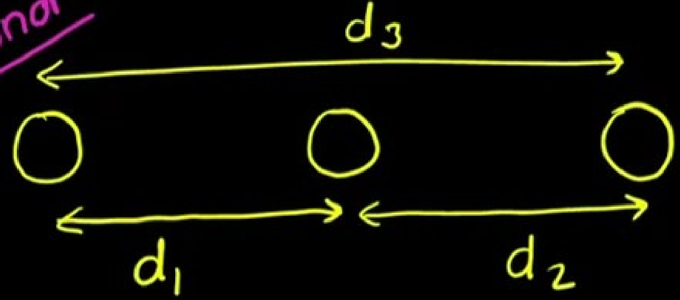
Concept of GMD

2 cond

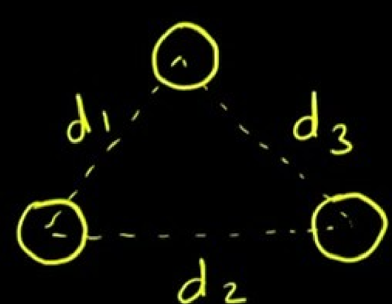


$$L_\ell = 4\times10^{-7} \ln \frac{d}{GMR}$$

3 cond



3cond



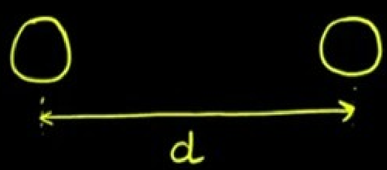
we need equivalent distance for calculating L and C.

GMD

Geometrical Mean distance (GMD) ⟶ mutual distance

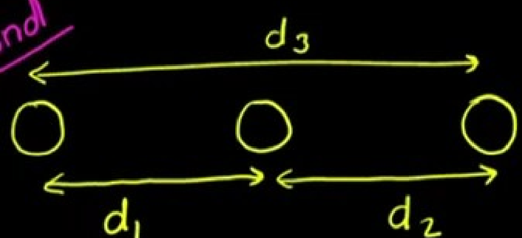
"GMD represents the equivalent distance b/w conductors"

2 cond



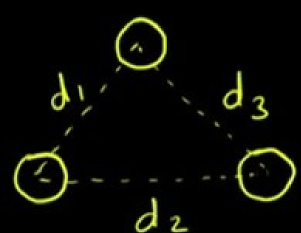
$\xrightarrow{GMD}$ $D_m = d$

3 cond



$\xrightarrow{GMD}$ $D_m = (d_1 d_2 d_3)^{1/3}$

3cond



$\xrightarrow{GMD}$ $D_m = (d_1 d_2 d_3)^{1/3}$

$D_m = d$ (if $d_1 = d_2 = d_3$)

Features of GMD

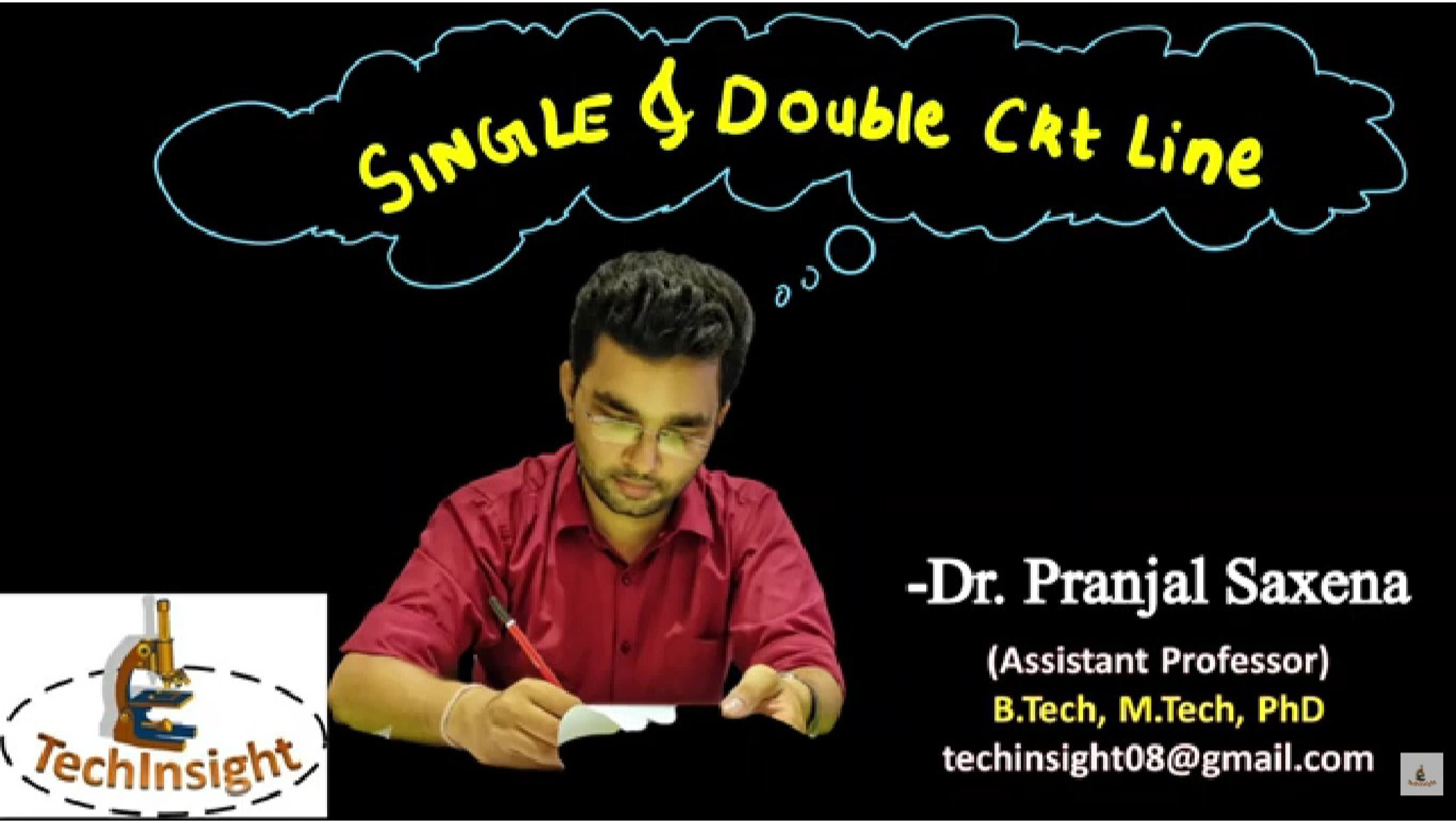
1. Denoted by D_m → mutual distance b/w conductors.

2. Used to calculate mutual Inductance.

3. It changes if → Spacing b/w conductors change
   → arrangement of conductors change

4. It doesn't depends on shape, size and orientation of conductors.

5. If we increase GMD, L↑ and C↓ $\left[L = 2 \times 10^{-7} \ln \frac{GMD}{GMR} \right]$


SINGLE & Double Ckt Line
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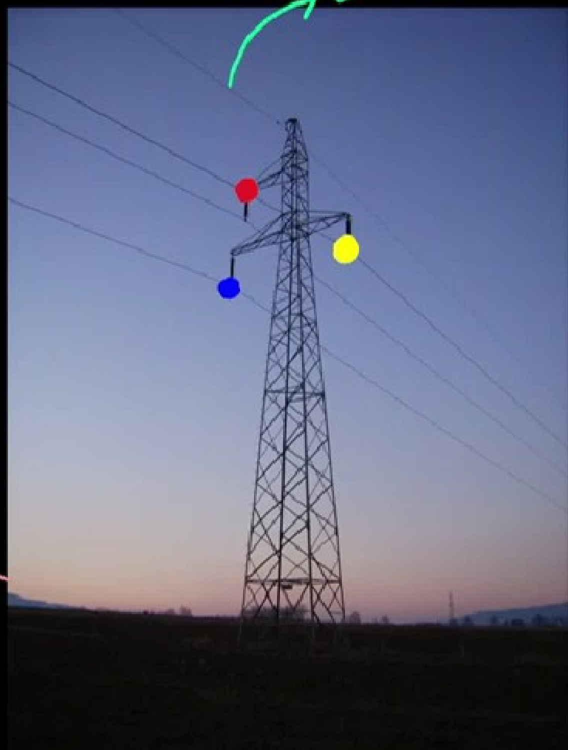
Double ckt 3-ϕ line

Single ckt 3-ϕ line

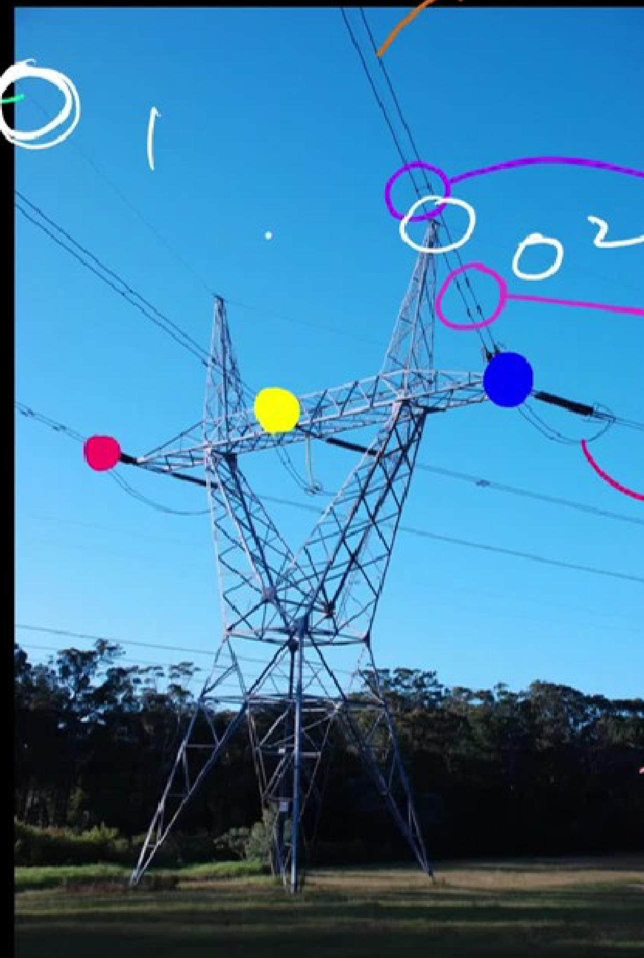
Single ckt - 3φ Line

shield wire



Low voltage

Bundle conductor (2)



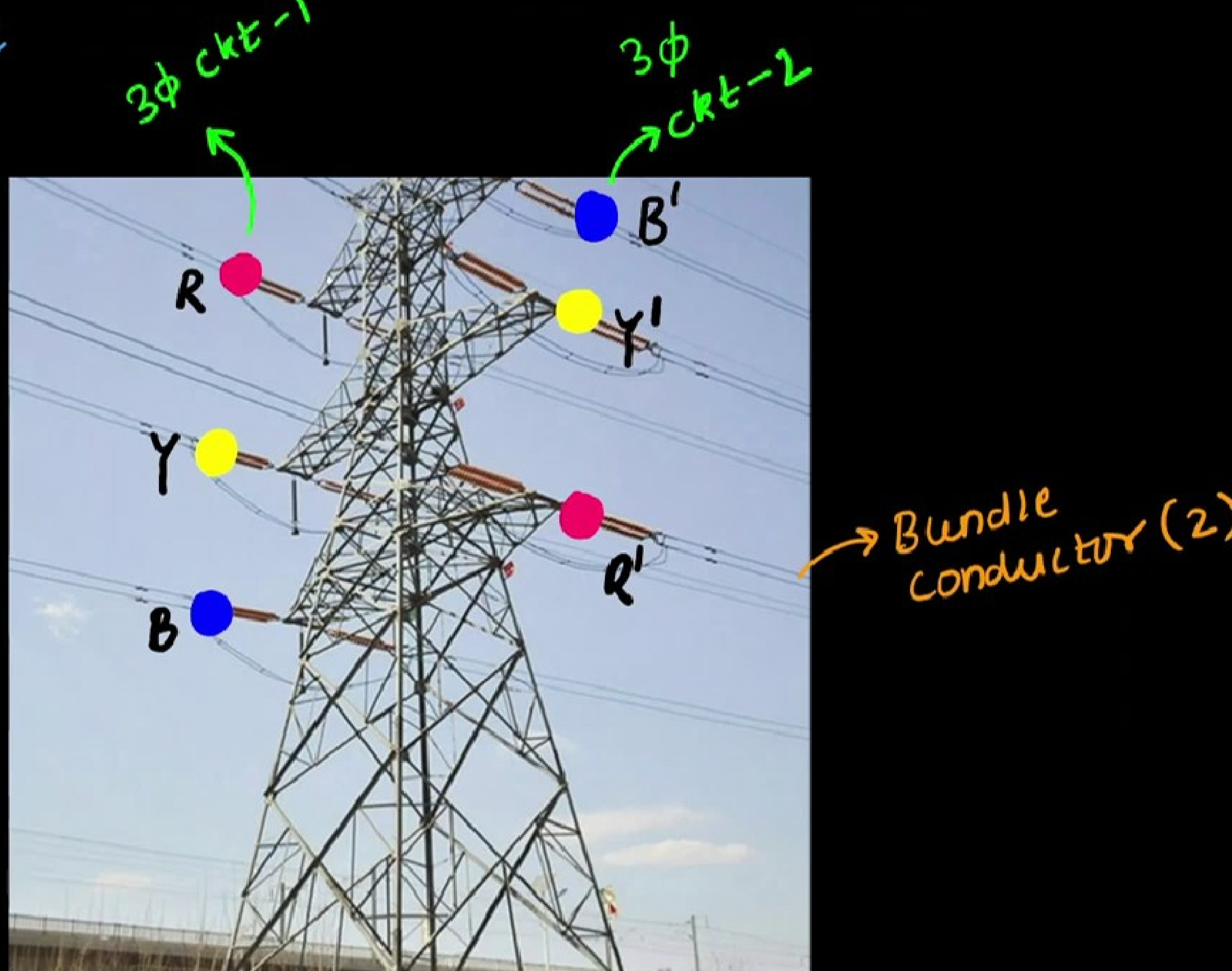
Spacers

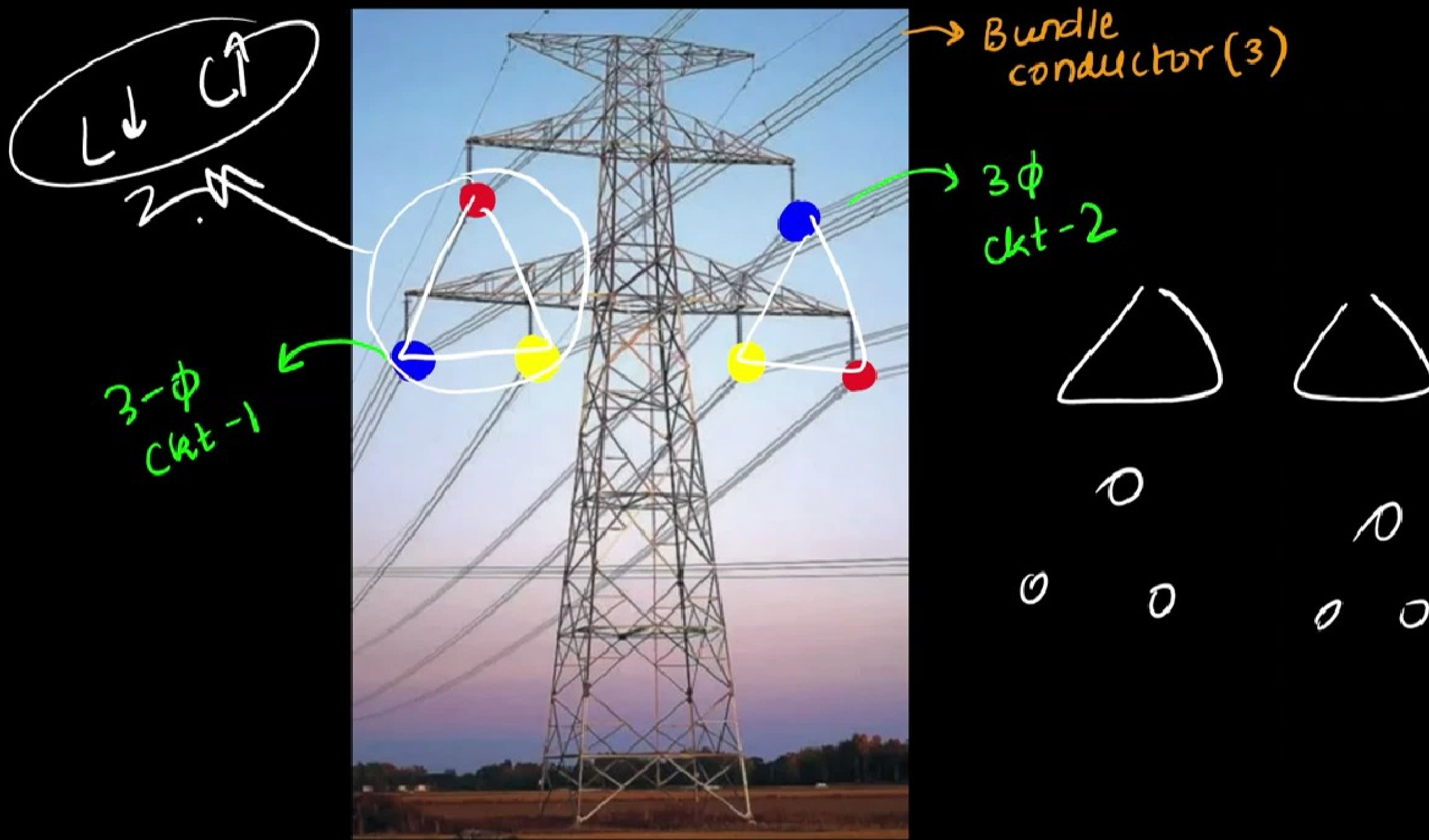
Vibrational dampers

Jumper wire

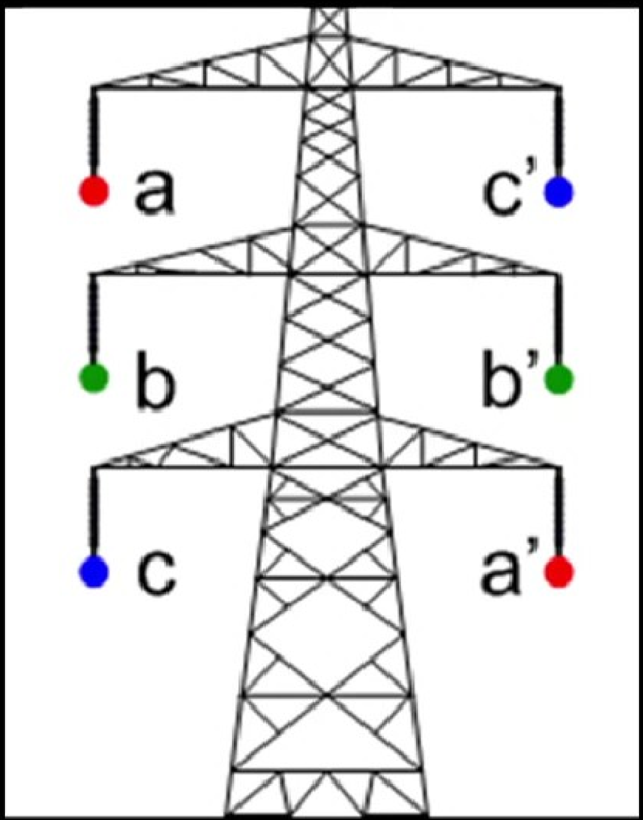
High voltage

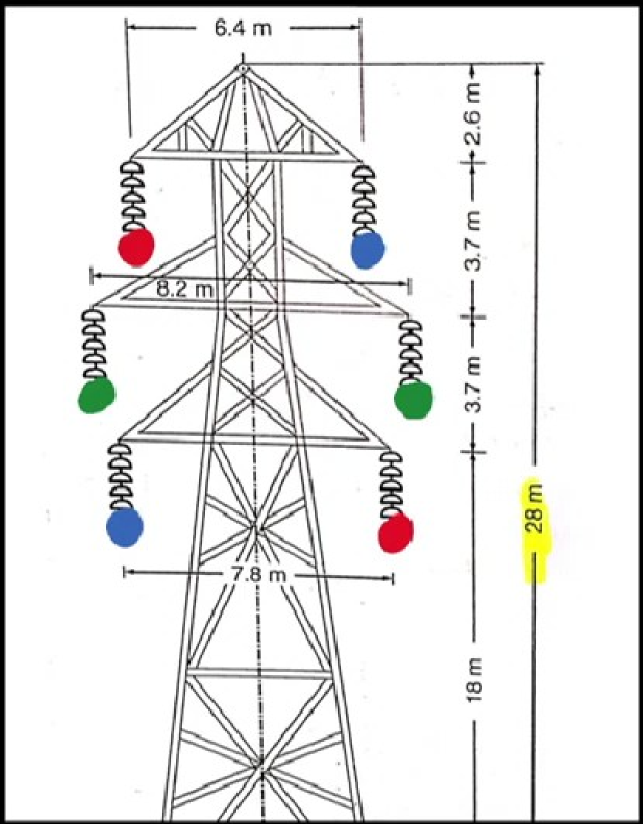
Double ckt Line




L↓ C↑
Bundle conductor (3)
3φ ckt-2
3-φ ckt-1

Q. Why we use this type of conductor sequence?





→ It is desired to have low Inductance of TL.

→ $\uparrow P_{transfer} = \frac{V_s V_R}{X \downarrow} \sin\delta$

→ $\downarrow L = 2 \times 10^{-7} \ln \frac{GMD \downarrow}{GMR \uparrow}$

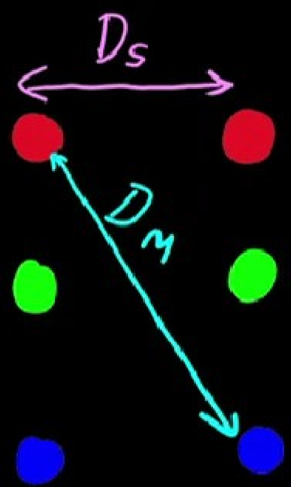
→ GMR ↑ ⟶ Spacing b/w conductor of same phase increase

↳ Use Bundle conductor

$a - a' \rightarrow$ conductors of same phase

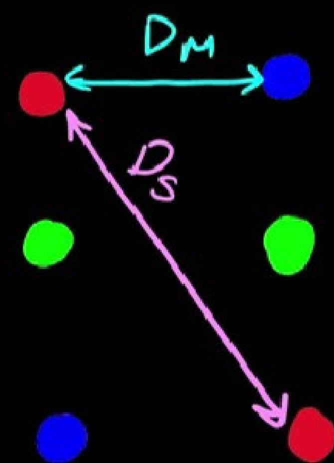
$b - b' \rightarrow$ conductors of same phase

$c - c' \rightarrow$ conductors of same phase.



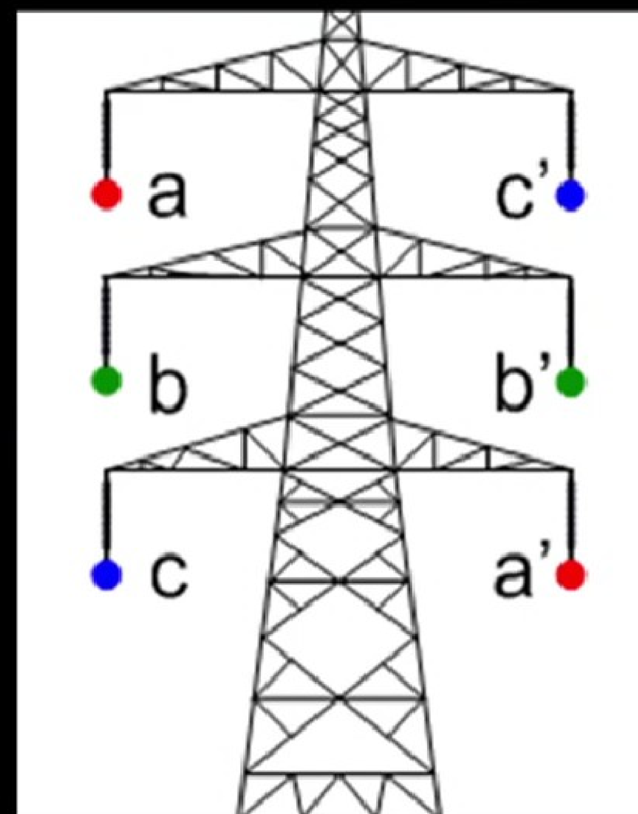
GMR↓, GMD↑

Inductance↑



GMR↑, GMD↓

Inductance↓

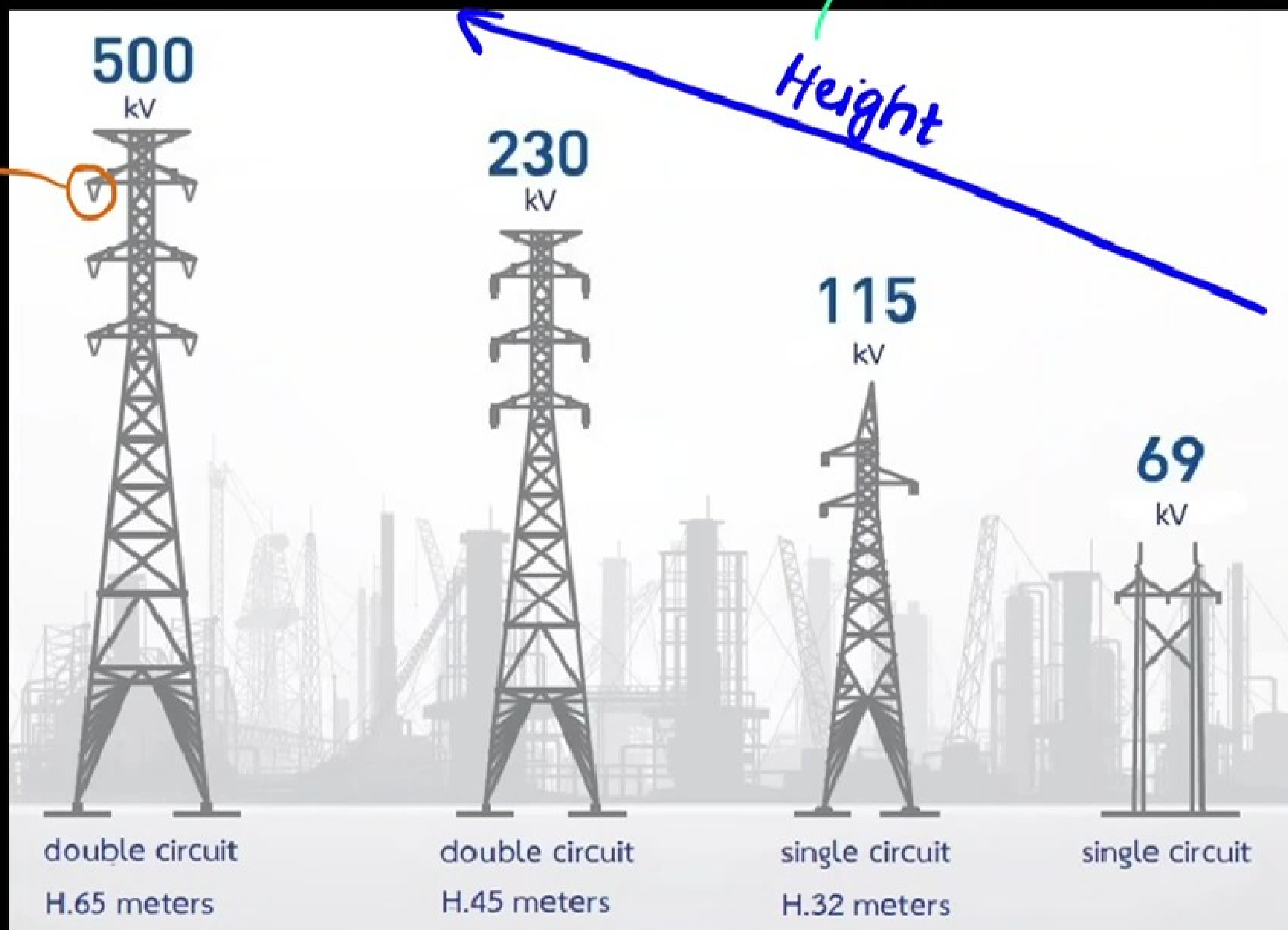


Tower structure

Ground clearance

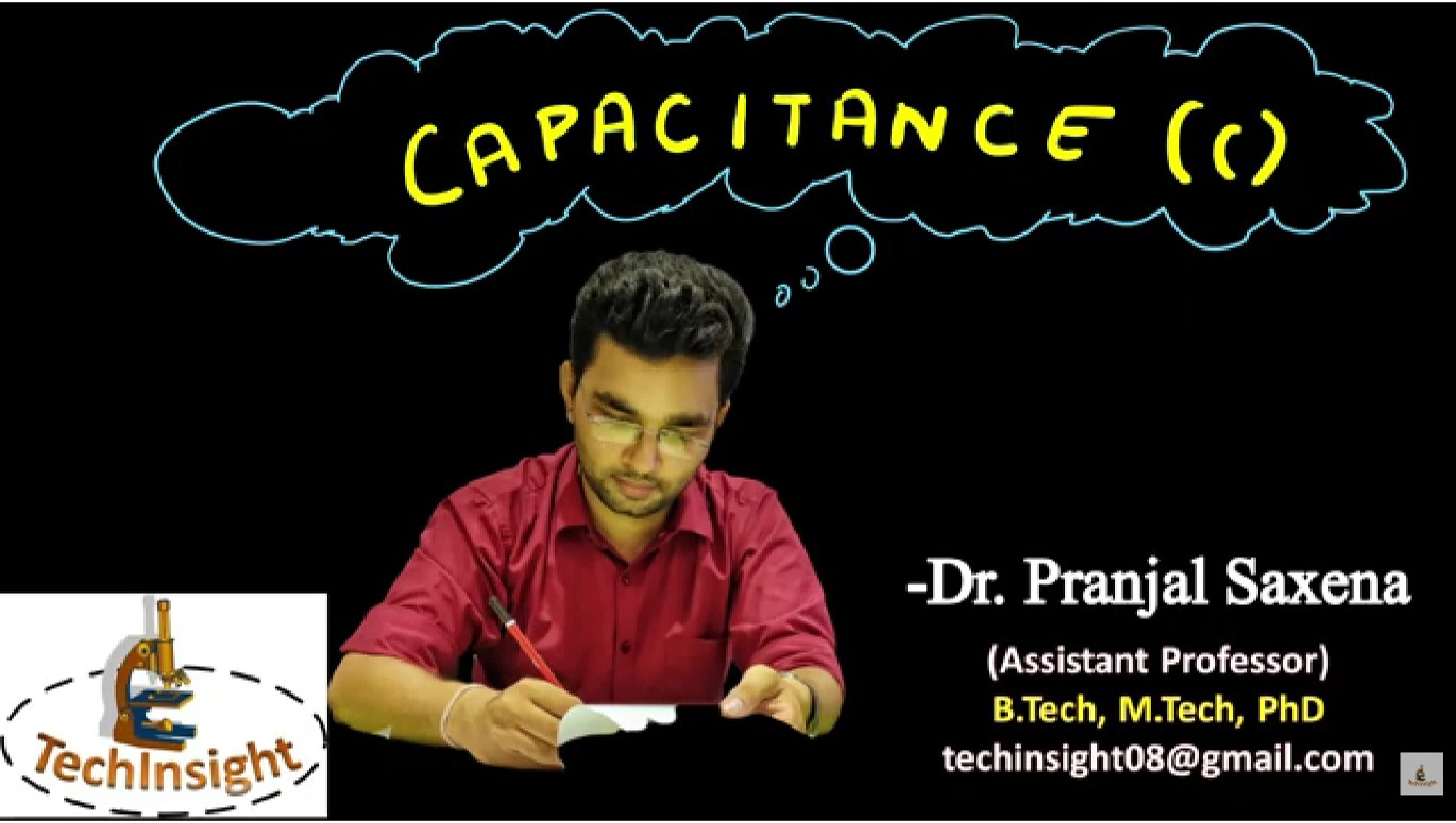
Height

double Insulator strings



Features of double ckt line

1. More Power Transfer Capability.
2. Economical → same structure for double ckt
3. More Reliability
4. More opportunity for maintainance
5. Inductive coupling should be take into account during fault calculation → Otherwise relays (Distance) may false operate


CAPACITANCE (C)
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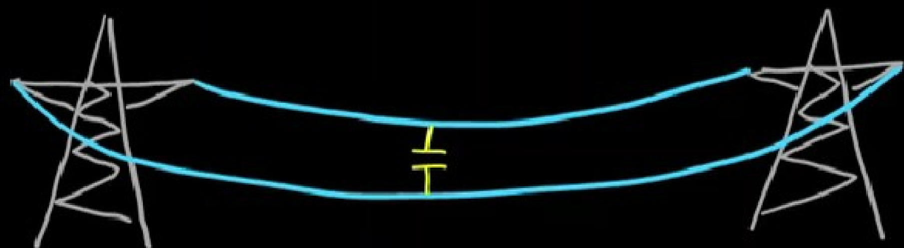
Capacitance in Transmission Line



" 2 conductors at different potential separated by air (as insulator) forms Capacitance "

* NOTE: Capacitance is distributed parameter. Its effect is dominated with distance.

↓

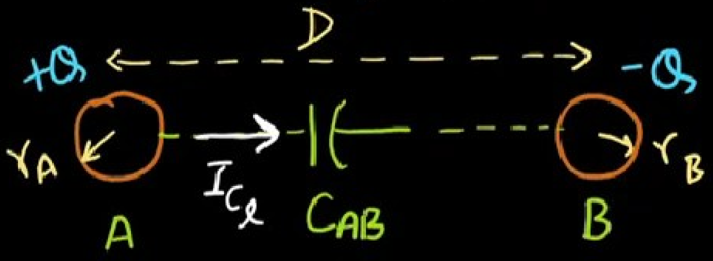
Only effective in medium and Long Trans. Line.

$$\boxed{C = \frac{q}{V}}$$

V → potential difference

q → charge

Capacitance of 1-ϕ line (Line Value)



$$C_{AB} = \frac{q}{V_{AB}} = C_l$$

$$= \frac{2\pi\epsilon}{\ln\left(\frac{D^2}{r_A r_B}\right)} \quad F/m.$$

if $r_A = r_B = r$

$$\therefore \quad C_{AB} = \frac{2\pi\epsilon}{\ln\left(\frac{D^2}{r^2}\right)} = \frac{\pi\epsilon}{\ln(D/r)} \quad F/m$$

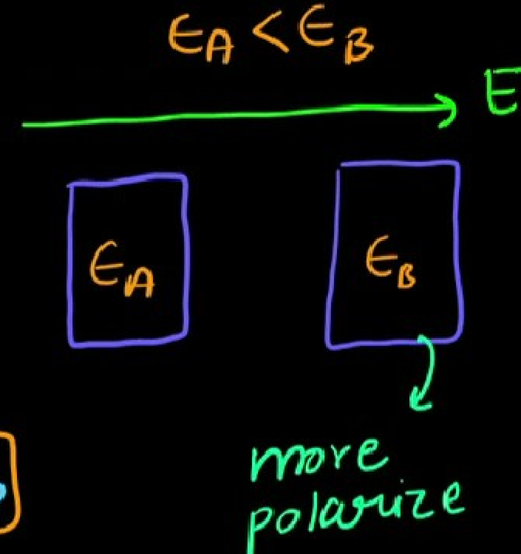
$$\boxed{C_l = \frac{\pi\epsilon}{\ln(D/r)}} \quad F/m$$

line capacitance.

* Charging current = $\boxed{I_{C_l} = j\omega C_{AB} \cdot V_{AB}}$ A/m

Concept of ϵ

* $\epsilon \rightarrow$ permittivity $\rightarrow$ absolute permittivity
  - $\rightarrow$ Represent polarizability of dielectric



* Relative permittivity $\epsilon_r = \dfrac{\epsilon}{\epsilon_0} \rightarrow \boxed{\epsilon = \epsilon_r \cdot \epsilon_0}$

  $\downarrow$

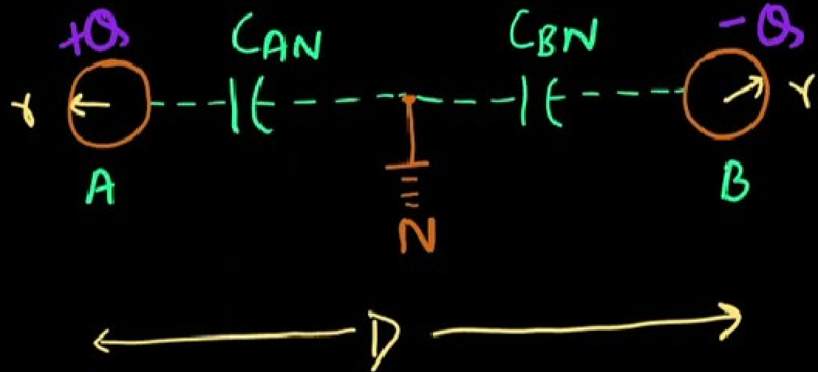
  performance of dielectric w.r.t vaccum having permittivity of free space (ϵ_0)

$$\boxed{\epsilon_0 = 8.85 \times 10^{-12}\ F/m}$$

Air (ϵ_r) = 1

$$\therefore \boxed{\epsilon = \epsilon_0}$$

Phase Capacitance



$$C_{AN} = C_{BN} = 2C_{AB} = C_\phi$$

$$= \frac{2\pi\epsilon_0}{\ln(D/r)}$$

$$\therefore \boxed{C_\phi = \frac{2\pi\epsilon_0}{\ln(D/r)}} \quad F/m$$

$$\boxed{\epsilon_0 = 8.85 \times 10^{-12}}$$

* Charging current

$$\boxed{I_{C\phi} = j\omega C_\phi V_\phi} \quad A/m$$

* Capacitive Reactance

$$\boxed{X_C = \frac{1}{2\pi f C}}$$

Capacitance Calculation using GMD and GMR

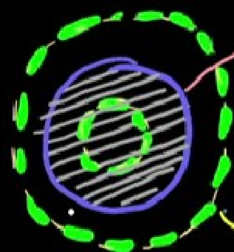
* $$\boxed{C_\phi = \frac{2\pi\epsilon_0}{\ln\left(\frac{GMD}{GMR}\right)}}$$ F/m

$C_\phi = 2\cdot$

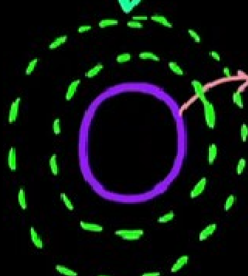
* NOTE: → GMD and GMR are adopted as in case of Inductance with one exception.

* Exception → Self GMD of conductor : Inductance $r' = 0.7788\, r$; Capacitance r

Inductance



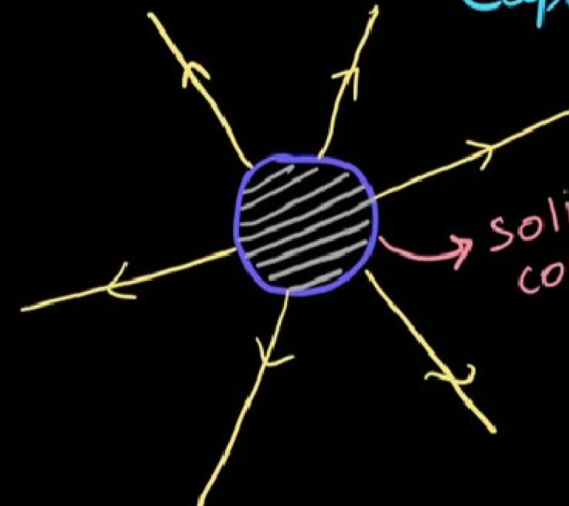
$L_T = L_{ex} + L_{in}$



$L'_T = L'_{ex} = L_T$

Self GMD $= r' = 0.7788r$

Capacitance

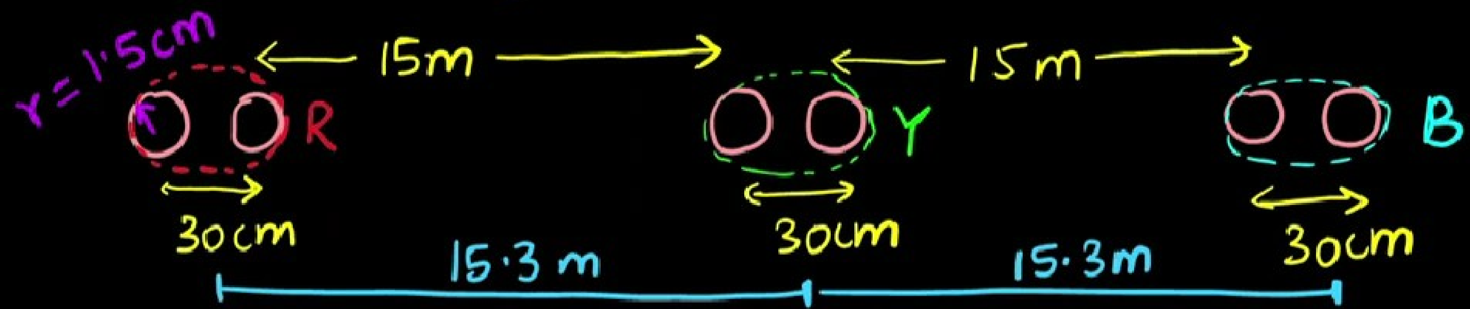


$C_T = C_{ex}$

$GMR = r$

* NOTE:- Concept of self GMD of conductor is not used for C calculation.

eg Calculate GMR for L and C calculation



Ans

For Inductance

$$GMR_R = (r' . d)^{1/2} = (0.7788 \times 1.5 \times 30)^{1/2} = 5.92\,cm$$

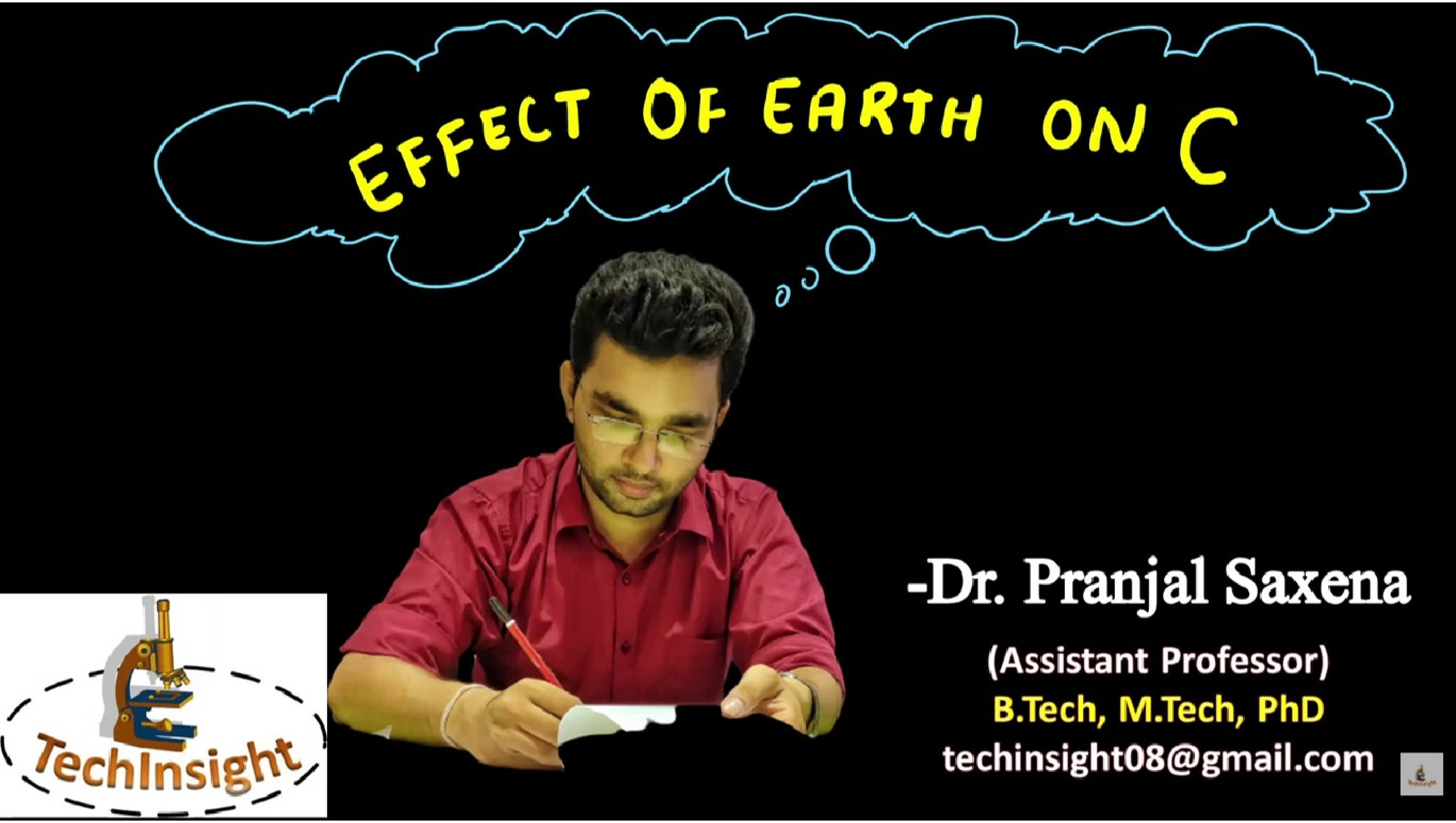
For capacitance

$$GMR_R = (r d)^{1/2} = (1.5 \times 30)^{1/2} = 6.708\,cm$$

For both L and C

$$GMD = (D_{RY} . D_{YB} D_{BR})^{1/3} = (15.3 \times 15.3 \times 30.6)^{1/3}$$

$$= 19.28\,m$$


EFFECT OF EARTH ON C
-Dr. Pranjal Saxena
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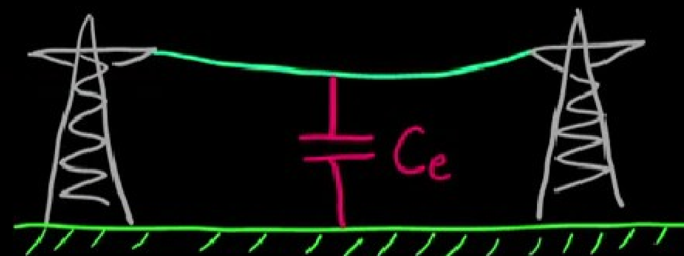
TechInsight

Effect of Earth

* During capacitance calculation it was assumed that conductors are far away from earth

Capacitance due to earth neglected

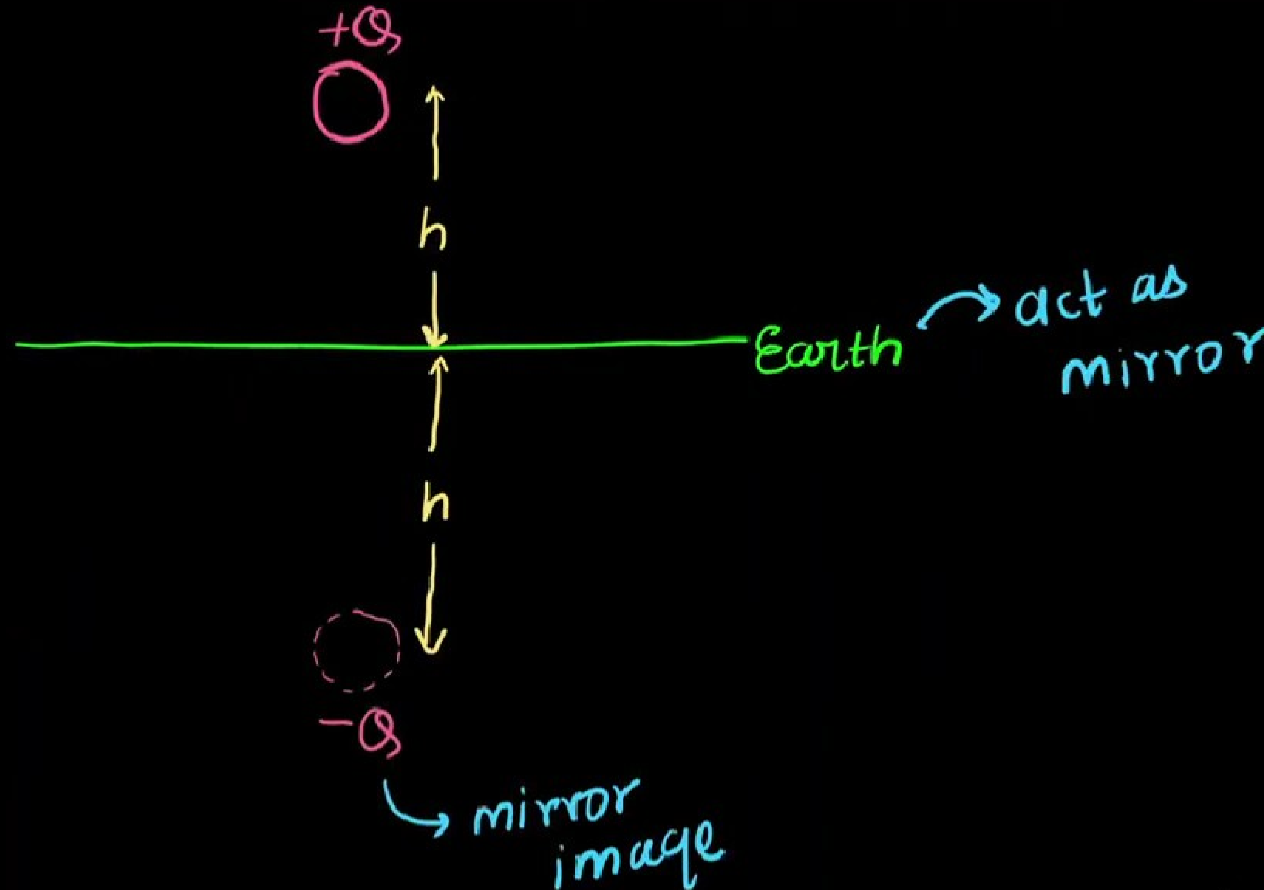
* But, in actual practice, earth's affect Capacitance of TL.



$C_e \rightarrow$ Capacitance b/w conductor and earth

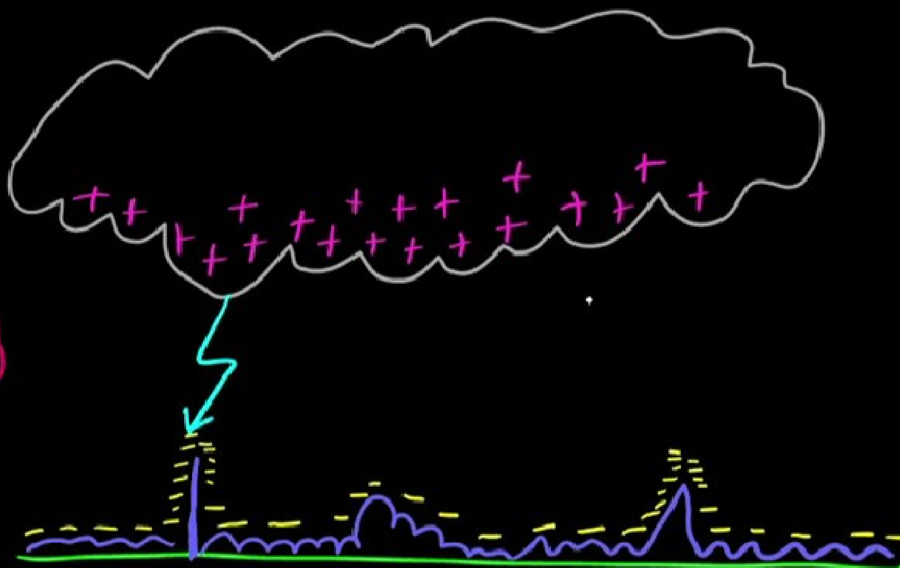
Method of Images (Lord Kelvin)

* Earth treated as perfectly conducting horizontal sheet of infinite extent → act as equipotential surface



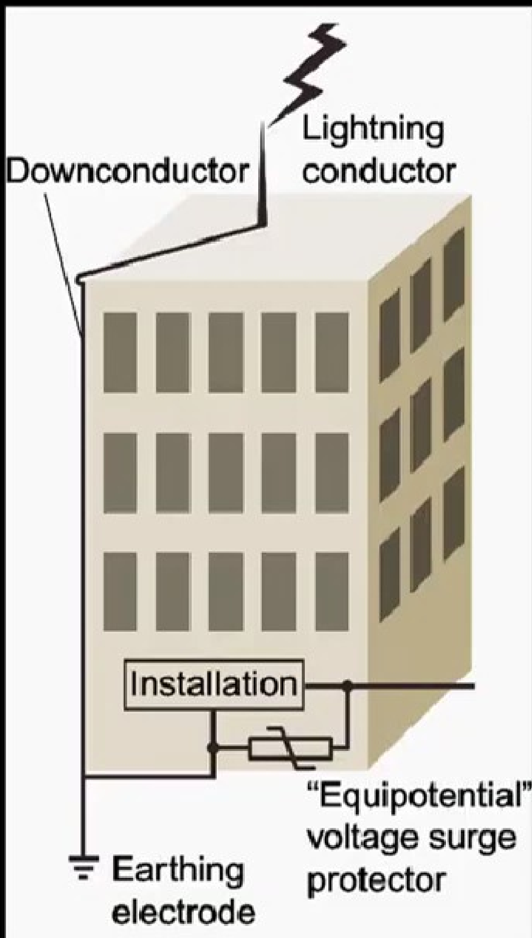
Cloud mirror image

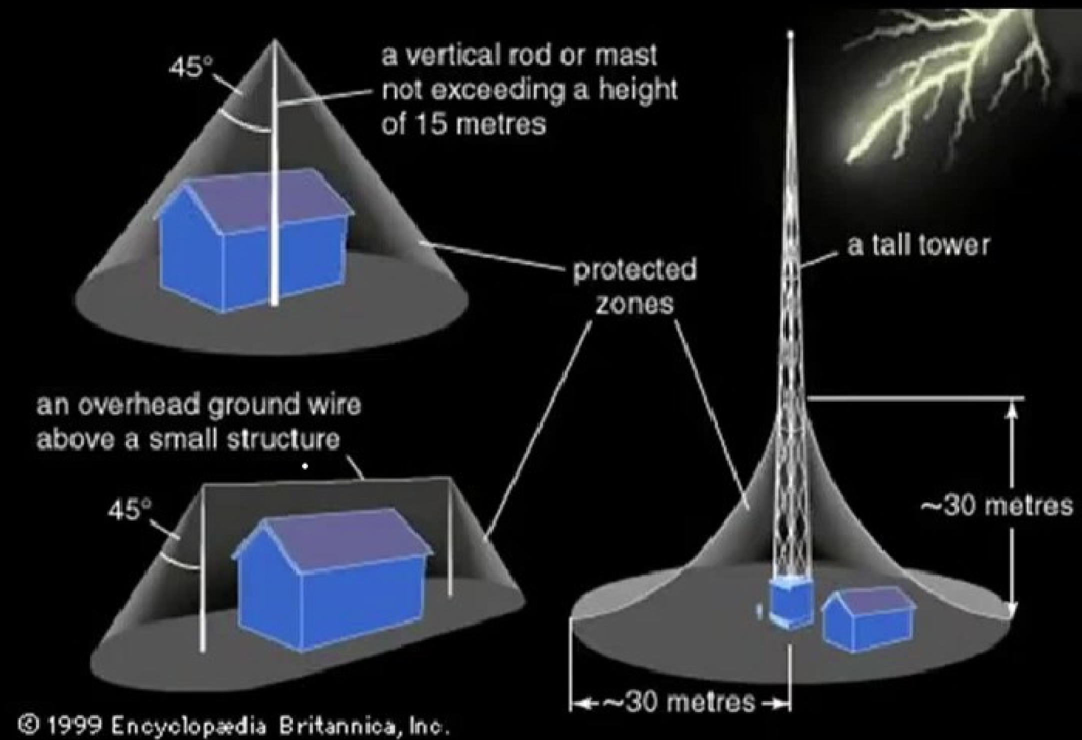
Lightning



charge density max^m at sharp edges

↳ earth's act as <u>equipotential surface</u>


Lightning conductor
Downconductor
Installation
"Equipotential" voltage surge protector
Earthing electrode


45°
a vertical rod or mast not exceeding a height of 15 metres
a tall tower
protected zones
an overhead ground wire above a small structure
45°
~30 metres
~30 metres
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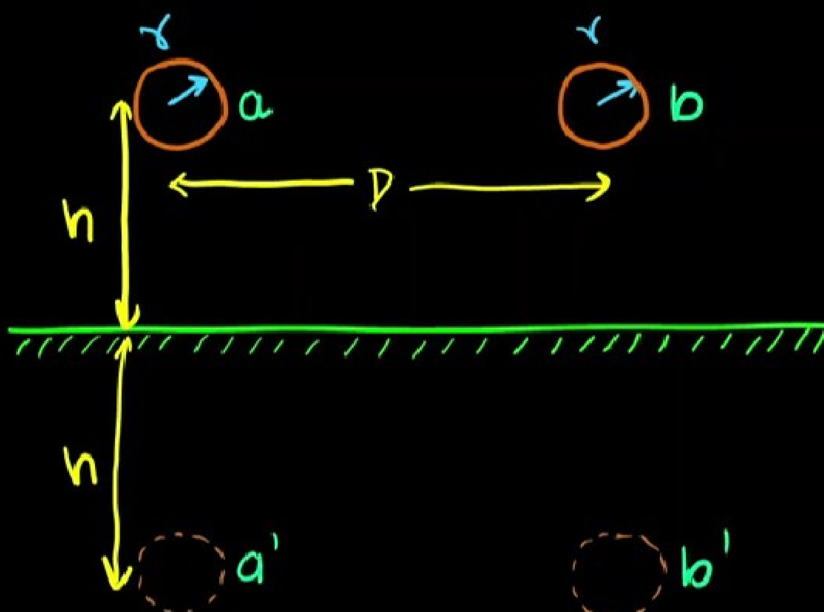
OVERHEAD SHIELD or GROUND WIRES

Single Phase Line Capacitance.



$$C_{ab_E} = \frac{\pi \epsilon_0}{\ln\left[\dfrac{D}{r\sqrt{1+\dfrac{D^2}{4h^2}}}\right]}$$

Because of earth

Important Conclusion *

without Earth

$$C_{ab} = \frac{\pi \epsilon_0}{\ln\left(\frac{D}{r}\right)}$$

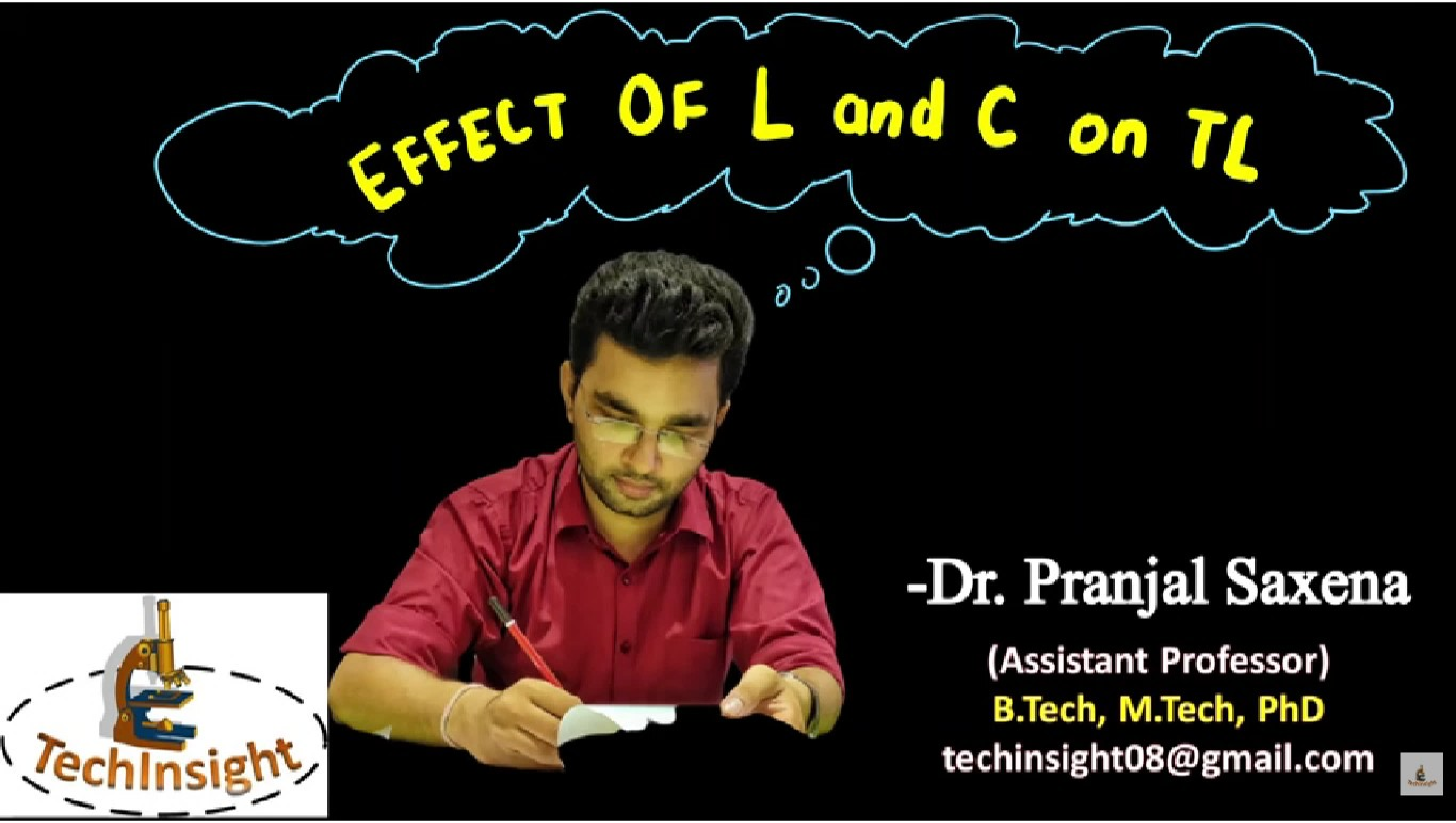
with earth

$$C_{ab_E} = \frac{\pi \epsilon_0}{\ln\left[\frac{D}{r\sqrt{1+\frac{D^2}{4h^2}}}\right]}$$

* Due to earth, $r \longrightarrow r\sqrt{1+\frac{D^2}{4h^2}}$, $\boxed{C_{ab_E} > C_{ab}}$

* if $h >> D$, height of conductor from ground is very large compare to distance b/w them $\longrightarrow$ Effect of Earth is negligible.

if $\frac{d}{2h} << 1 \longrightarrow C_{ab_E} \approx C_{ab}$ $\therefore$ In practice, we keep $\frac{d}{2h} << 1$


EFFECT OF L and C on TL
-Dr. Pranjal Saxena
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B.Tech, M.Tech, PhD
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TechInsight

Nature of L and C

* L and C ⟶ Passive Components ⟶ Affects Reactive power ⟶ Receiving End voltage

*

Absorb Q

Deliver Q

* $Q_{supply} > Q_{demand} \longrightarrow V_R > V_S \longrightarrow$ Ferranti Effect

  $Q_{supply} < Q_{demand} \longrightarrow V_R < V_S \longrightarrow$ voltage dip (Normal)

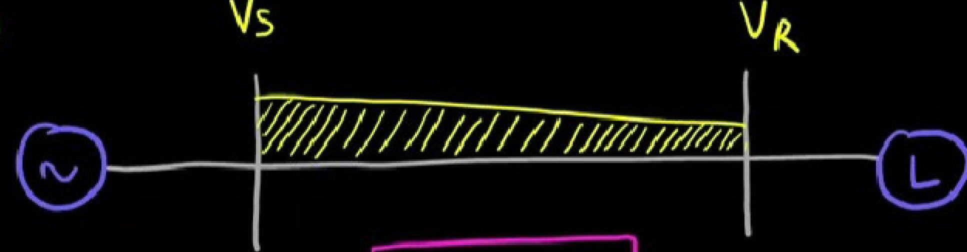
* $Q_{demand} = Q_L + Q_{Load}$ ⟶ $\boxed{Q_{supply} < Q_{demand}}$ generally

Q_L ↓ Reactive power demand of Transmission Line

Line Inductance ↑ → Q_L ↑ → Q_{demand} ↑

↓

poor voltage profile



$\boxed{V_s > V_R}$

* To improve voltage profile, utility opt different strategies.

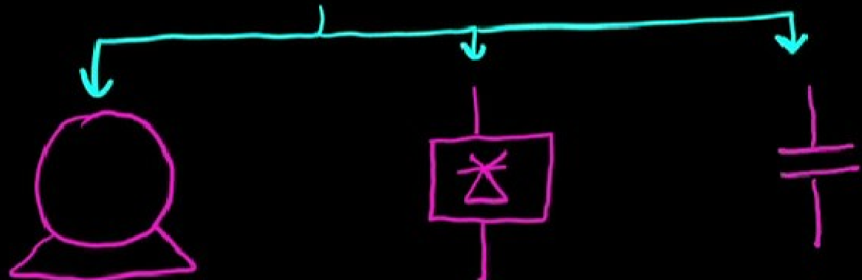
Methods of Reduce Q_L

* Reducing Line Reactive power Demand

$$L\downarrow = 2\times 10^{-7} \ln \frac{GMD\downarrow}{GMR\uparrow}$$

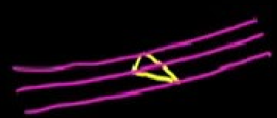
$$C\uparrow = \frac{\pi \epsilon_0}{\ln \frac{GMD\downarrow}{GMR\uparrow}}$$

Reactive Power compensator



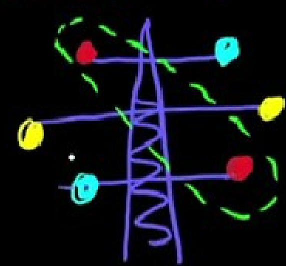
Methods to Improve GMR

a. use Bundle conductors



b. use Transposition or

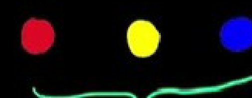
same phase conductor distant apart.



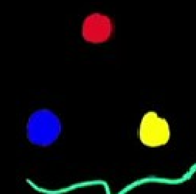
c. Use stranded conductor

Methods to Reduce GMD

a. use equilateral Δ configuration

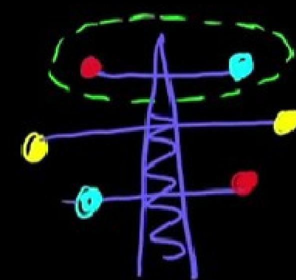


GMD ↑



GMD ↓

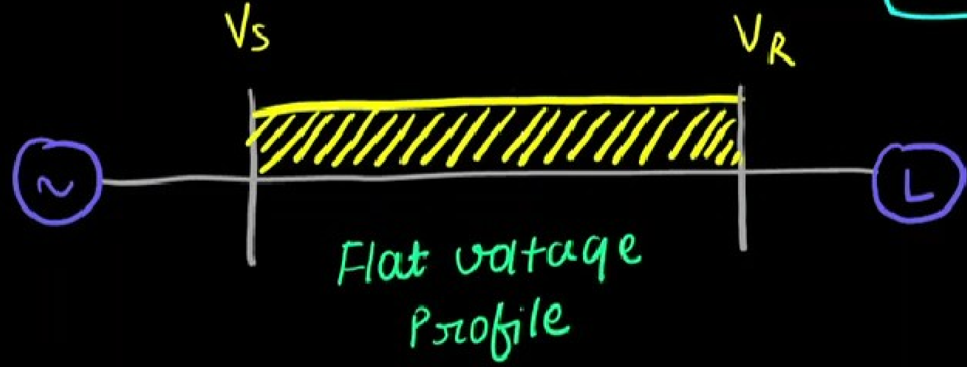
b. Put opposite phase conductor close.



opposite phase conductor

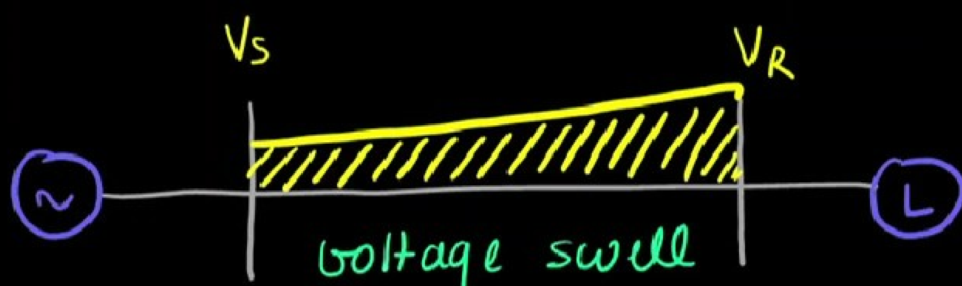
* Ideal conditions;

$$\boxed{Q_{supply} = Q_{demand}} \rightarrow \boxed{V_s = V_R}$$



PRECAUTIONS

we have to maintain $Q_{supply} \leq Q_{demand}$ and avoid $Q_{supply} > Q_{demand} \longrightarrow V_R > V_s$



Ferranti Effect