ECE 523
Symmetrical Components

Session 22

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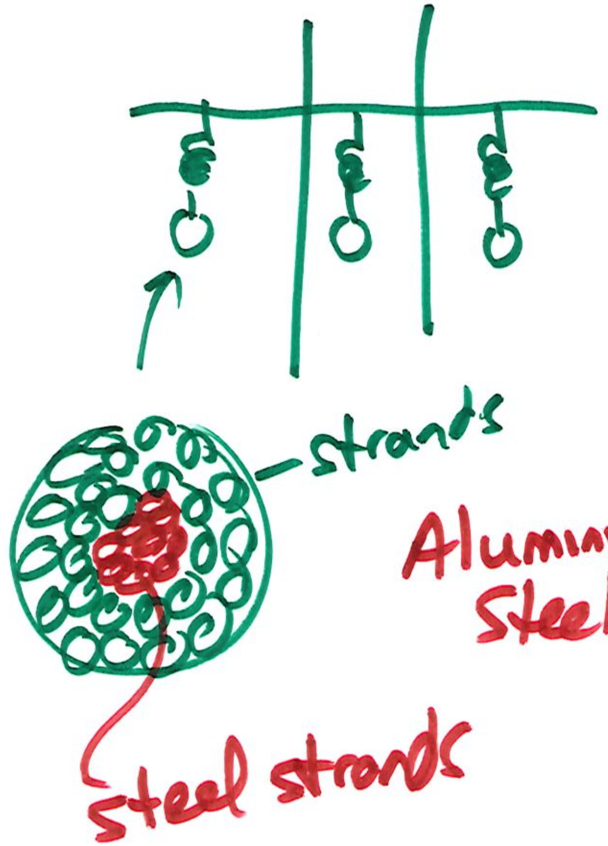


Aluminum Conductor
Steel Reinforced (ACSR)

Conductor data from table

1. conductor material/type
2. Number of strands
3. Diameter
4. Geometric mean radius (50Hz, 60Hz)
5. Rdc
6. RAC → 50Hz, 60Hz } TEMPERATURE

Resistance per length →

From conductor info

→ combine with ~~to~~ tower data to calculate

L' → inductance per length

C' → capacitance per length

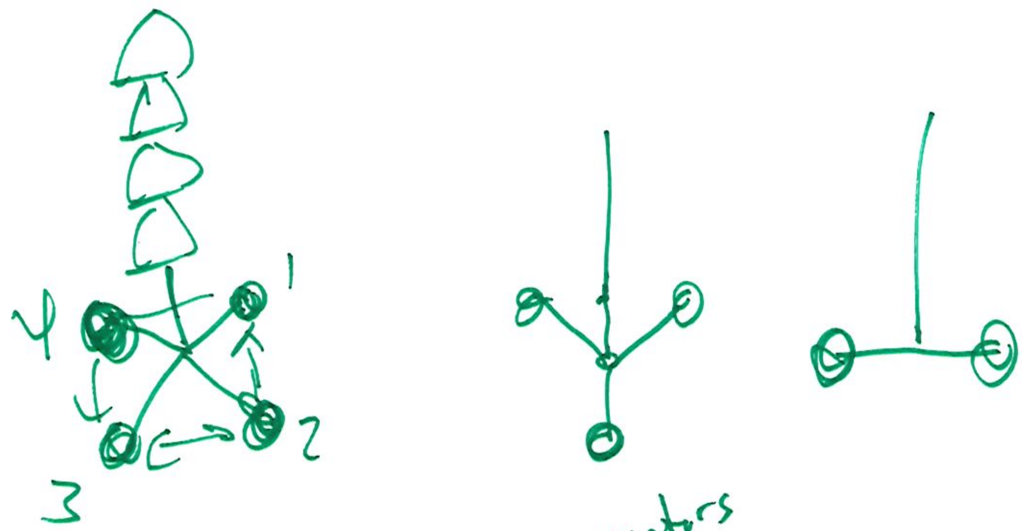
$$C' = \frac{2\pi \varepsilon_0}{\ln\left(\frac{D_m}{R_b^c}\right)}$$

Positive Sequence

Geometric mean distance between phases

Geometric mean radius for capacitance calculations (if one conductor → radius)

Bundled conductors



Inductance

# of conductors

$$R_b = \sqrt[n]{GMR_{cond,} \cdot d_{12} \cdot d_{13} \cdot d_{14} \cdots d_{1n}}$$

From table

$$R_b^C = \sqrt[n]{r \cdot d_{12} \cdot d_{13} \cdot d_{14} \cdots d_{1n}}$$

conductor

Calculating series impedance with
effect of ground return path, static wires,
-mutual ~~to~~ coupling between lines

single conductor

→ Geometric mean radius of conductor

⇒ - Accounts for skin effect

- Accounts for magnetic flux linkage

- Stranding

get from ~~datasheet~~ table

$$\omega L' \cdot \text{length} = \omega \cdot \text{Length} \cdot \frac{\mu_0}{2\pi} \ln\left(\frac{D_m}{R_b}\right)$$

$$\boxed{\bar{Z}_1 = R_{AC} \cdot \text{length} + j\underbrace{\omega L' \cdot \text{length}}}$$

Accurate even if have ground wires or parallel lines..

positive sequence voltage drop across a line for positive sequence current flow

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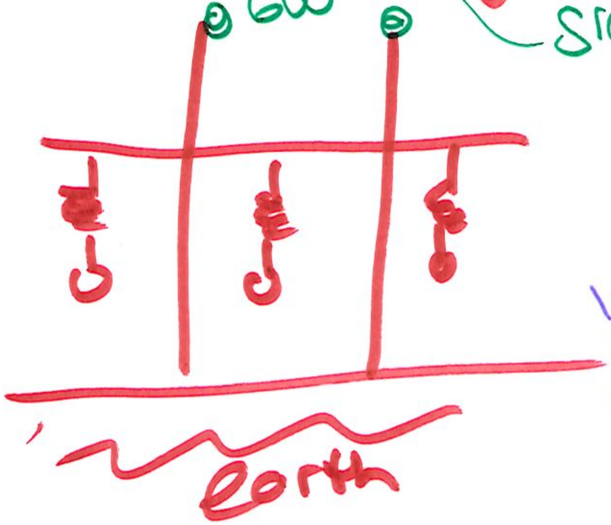
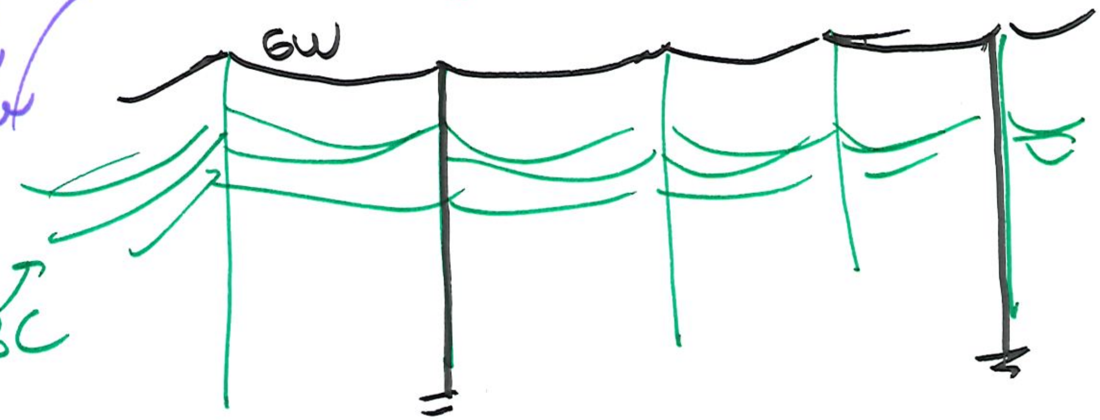
Calculating parameters



ground wires - grounded every few towers

impacts line zero sequence impedance

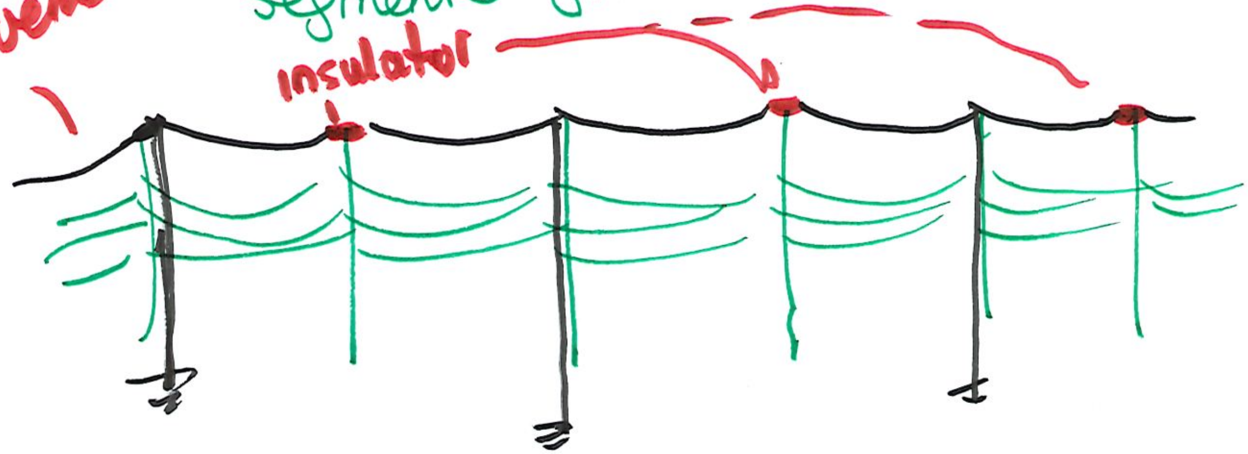
continuous ground wire



segmented ground wire

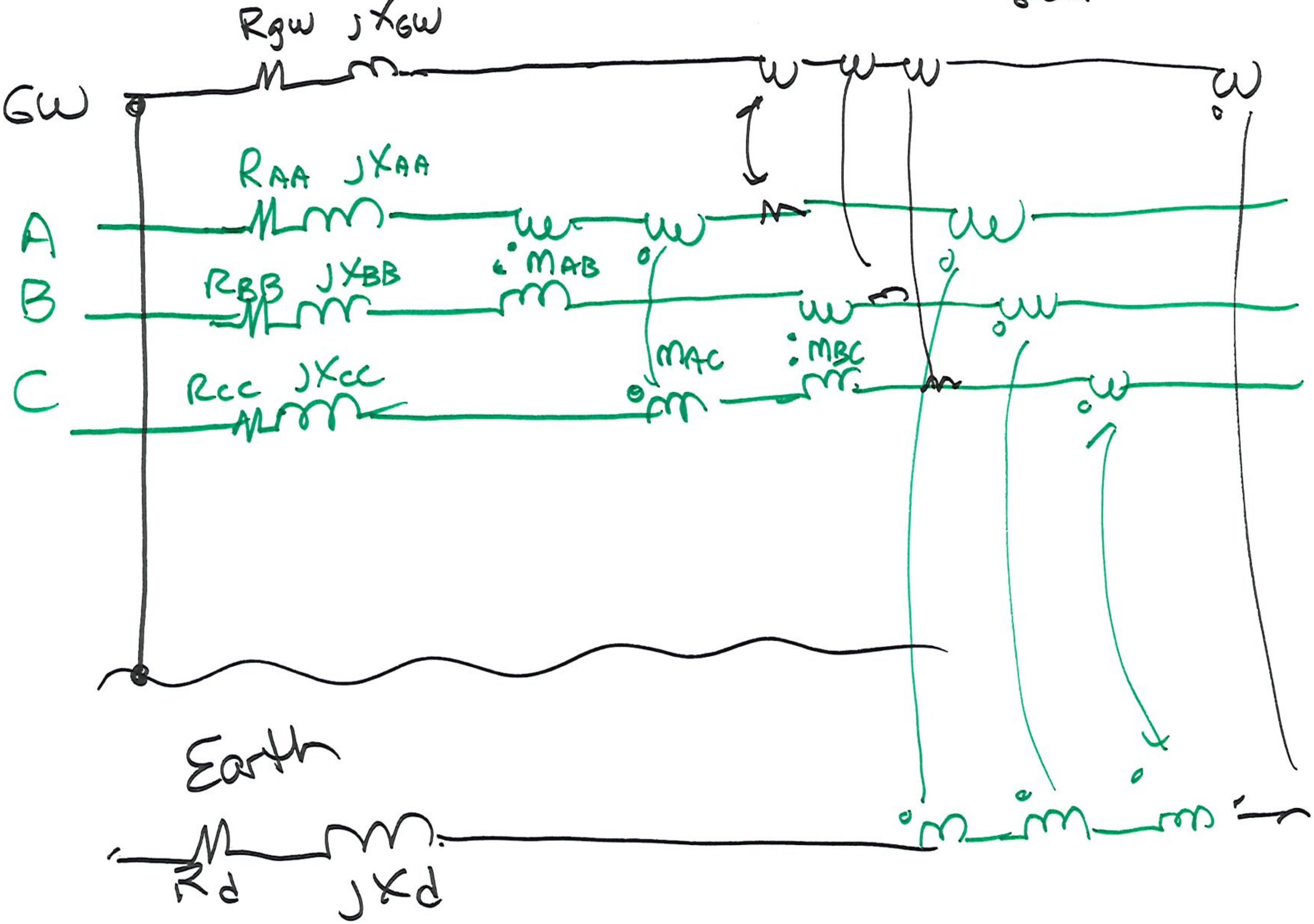
No effect on zero sequence impedance of line

insulator



frequency domain model of $L\frac{di}{dt}$

Calculate circuit parameters to model this relationship set.



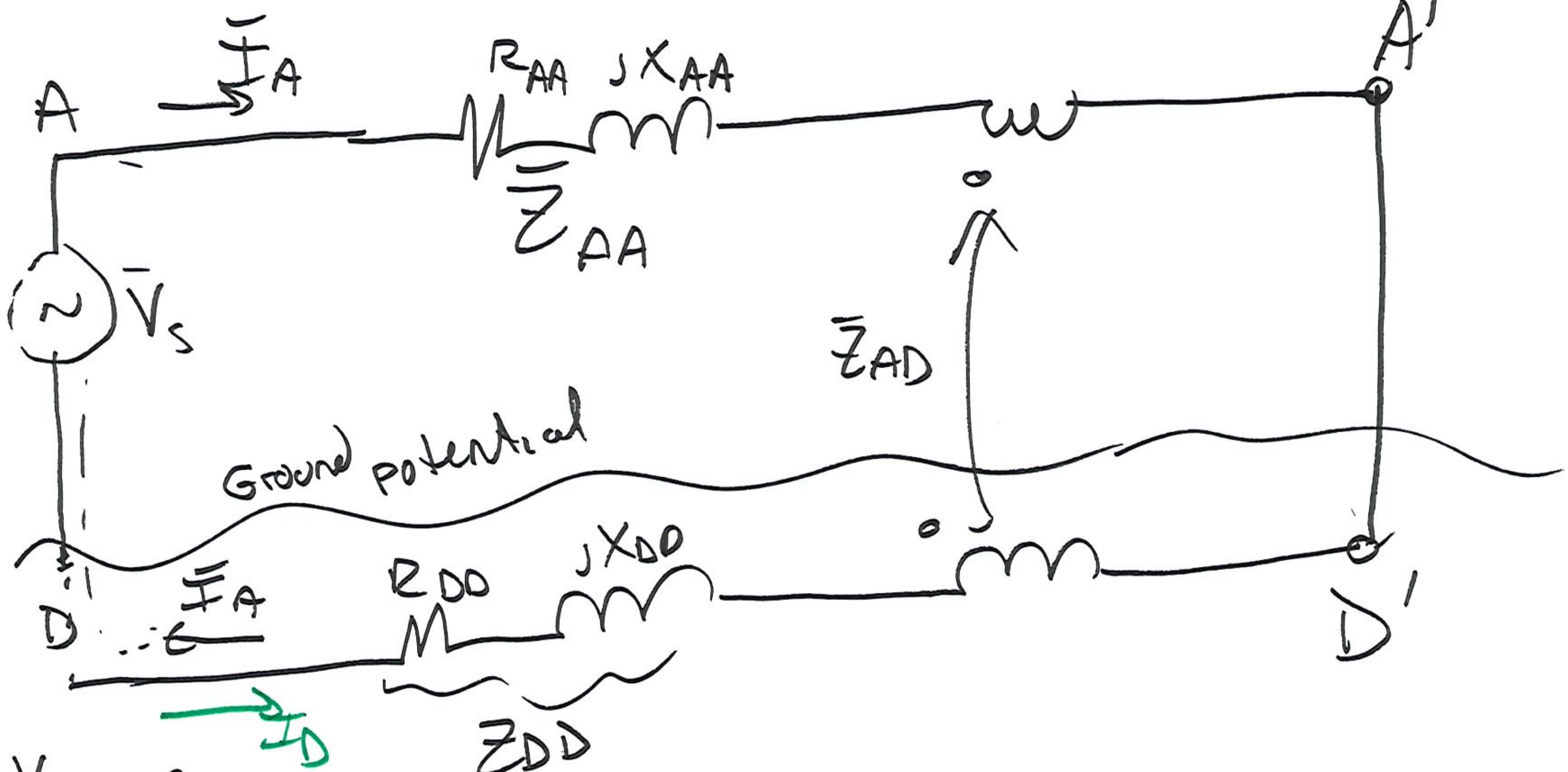
Carson's Line Model

→ developed originally to model telegraph cable circuits

- models conductors in air relative to ground.

  R, L

1 conductor, earth return



$V_{DG} = 0$

$$\bar{V}_{DD'} \neq 0$$

$$= -\bar{I}_A (R_{DD} + jX_{DD}) - I_A Z_{AD}$$

$$\begin{bmatrix} V_{AG} - V_{A'G} \\ V_{DG} - V_{D'G} \end{bmatrix} = \begin{bmatrix} Z_{AA} & Z_{AD} \\ Z_{DA} & Z_{DD} \end{bmatrix} \begin{bmatrix} I_A \\ -I_A \end{bmatrix}$$

$\Downarrow$

I_D

$Z_{AD} = Z_{DA}$ symmetric matrix

$V_{DG} = 0$ - reference point

$V_{D'G} - V_{A'G}$

$$V_{AG} - V_{A'G} = Z_{AA} I_A - Z_{AD} I_A \qquad (1)$$

$$0 - \cancel{V_{D'G}} = Z_{AD} I_A - Z_{DD} I_A \qquad (2)$$

$$V_{A'G}$$

subtract (2) from (1)

$$\underbrace{V_{AG} - V_{A'G} - (0 - V_{A'G})}_{V_{AG}} = I_A \left[Z_{AA} - Z_{AD} - (Z_{AD} - Z_{DD}) \right]$$

$$V_{AG} = I_A \left[\underbrace{Z_{AA} - 2 Z_{AD} + Z_{DD}}_{\text{from Carson's formulas}} \right]$$

From Carson's formulas

$$\bar{Z}_{DD} = \left(r_d + j\omega L_{self\_earth}\right) \cdot \text{Length}$$

$$r_d = 1.588 \times 10^{-3} \cdot \text{frequency} \quad \Omega/\text{mile}$$

changes if use Ω/km

$$L_{self\_earth} = \frac{\mu_0}{2\pi}\left(\frac{R_f}{D_{sd}}\right)$$

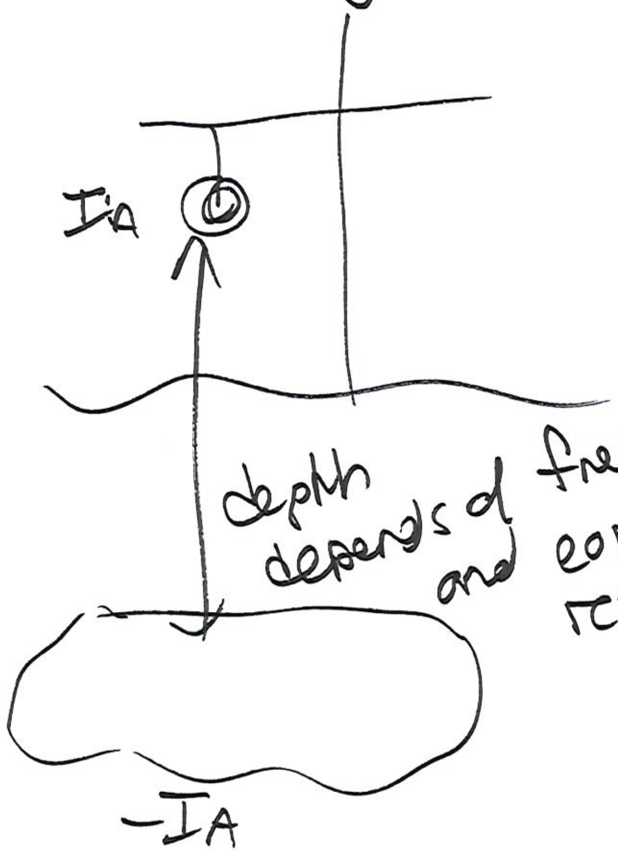
distance to an arbitrary reference

GMR of earth return path ≈ 1

$$\bar{Z}_{AD} = j\omega \frac{\mu_0}{2\pi} \ln\left(\frac{R_f}{D_{AD}}\right) \quad \frac{\Omega}{\text{length}}$$

mutual coupling $M\frac{di}{dt}$

$D_{AD} \rightarrow$ distance between phase conductor about concentration of earth current.



depth depends of frequency and earth resistivity

- Carson formula describes this distance

$$Z_{AA} = R'_{AC} + j\omega \frac{\mu_0}{2\pi} \ln\left(\frac{R_f}{D_{SA}}\right) \quad \Omega/\text{length}$$

GMR of conductor

of phase A

$$\frac{V_{AG}}{I_A} = Z_{effective} = Z_{AA} - 2Z_{AD} + Z_{DD}]$$

$$= \left[\left(R'_{AC} + r_d\right) + j\omega \frac{\mu_0}{2\pi}\left[\ln\frac{R_f}{D_{SA}} - 2\ln\frac{R_f}{D_{AD}} + \ln\frac{R_f}{D_{SD}}\right]\right] \cdot \text{length}$$

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Natural log terms

$$\ln\left(\frac{R_f}{D_{AD}}\right)^2 \Rightarrow -\ln\left(\left(\frac{R_f}{D_{AD}}\right)^2\right) = +\ln\left(\frac{D_{AD}}{R_f}\right)^2$$

$$\ln\frac{R_f}{D_{SA}} - 2\ln\frac{R_f}{D_{AD}} + \ln\frac{R_f}{D_{SD}}$$

$$= \ln\left(\frac{R_f}{D_{SA}}\right) + \ln\left(\left(\frac{D_{AD}}{R_f}\right)^2\right) + \ln\left(\frac{R_f}{D_{SD}}\right)$$

collect inside natural log

$$= \ln\left(\frac{\cancel{R_f}}{D_{SA}} \cdot \left(\frac{D_{AD}}{\cancel{R_f}}\right)^2 \cdot \frac{\cancel{R_f}}{D_{SD}}\right)$$

$$= \ln\left(\frac{D_{AD}^2}{D_{SA} \cdot \underbrace{D_{SD}}_{1}}\right) = \ln\frac{D_{AD}^2}{D_{Se}}$$

$$\frac{D_{AD}^2}{D_{SD}} \equiv D_e = 2160\sqrt{\frac{\rho}{f}}\ \text{ft}$$

$\rho \equiv$ earth resistivity

$$D_e = 685.85\sqrt{\frac{\rho}{f}}\ \text{m}$$