Distance Elements:
Linking Theory With Testing

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Topic Motivation

- Impedance plane ambiguity
- Impedance characteristic derivation
- Understanding theory before testing
- Impedance plots

Content

- Introduction
- Equation of a circle
- Phase and ground distance units
- Memory action
- Reactance unit
- Testing
- Load flow and fault resistance
- Impedance trajectory

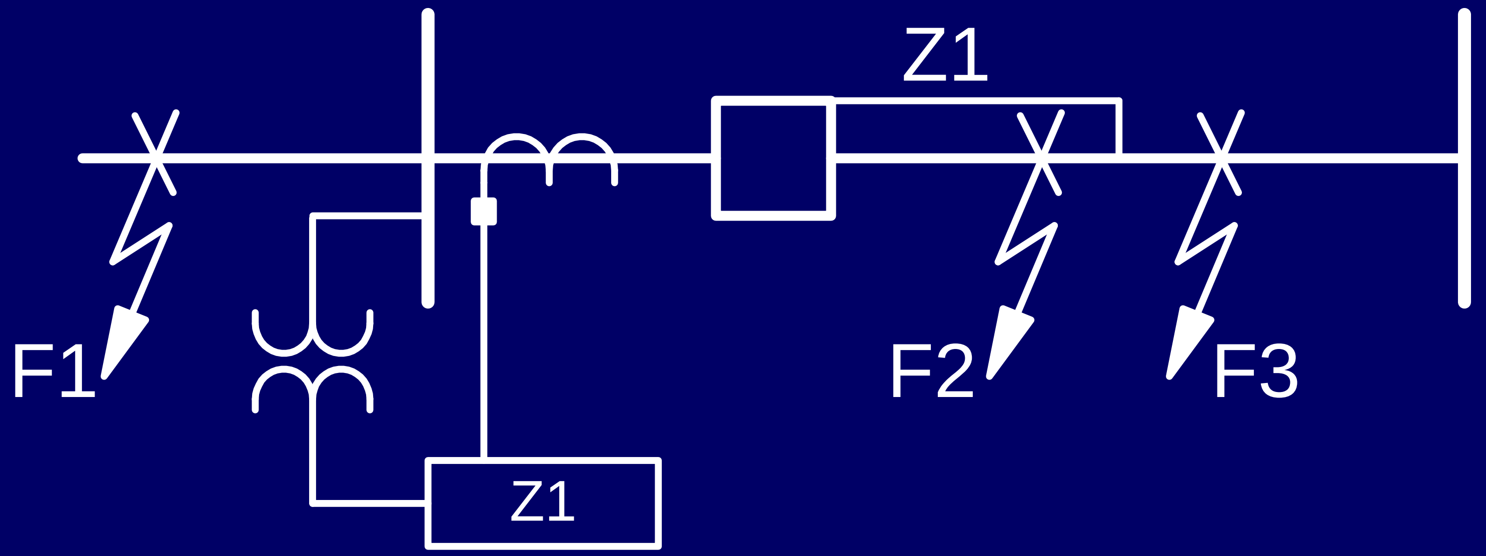
Equations

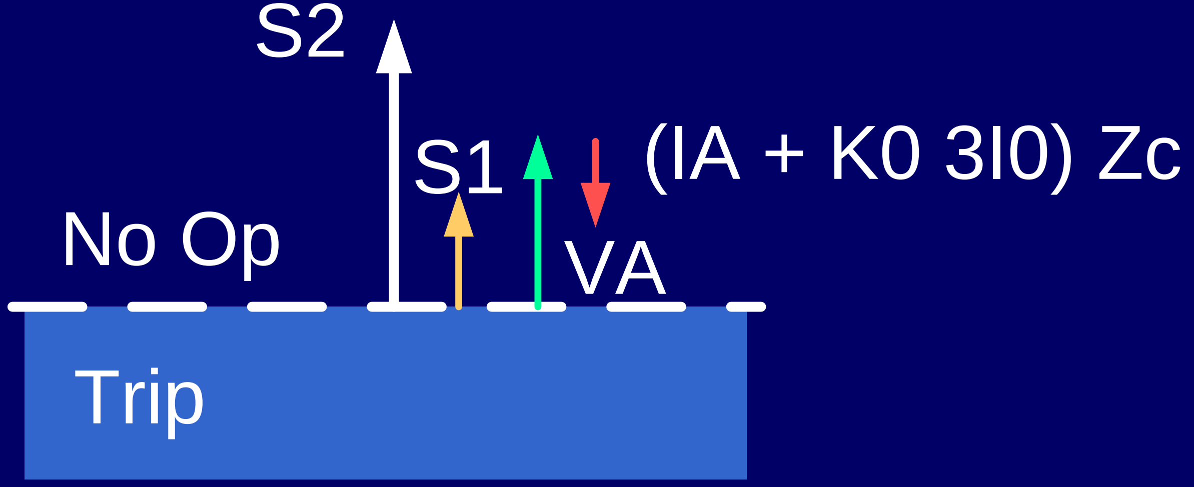
$$S1 = V - Zc\ I$$

$$S2 = Vpol$$

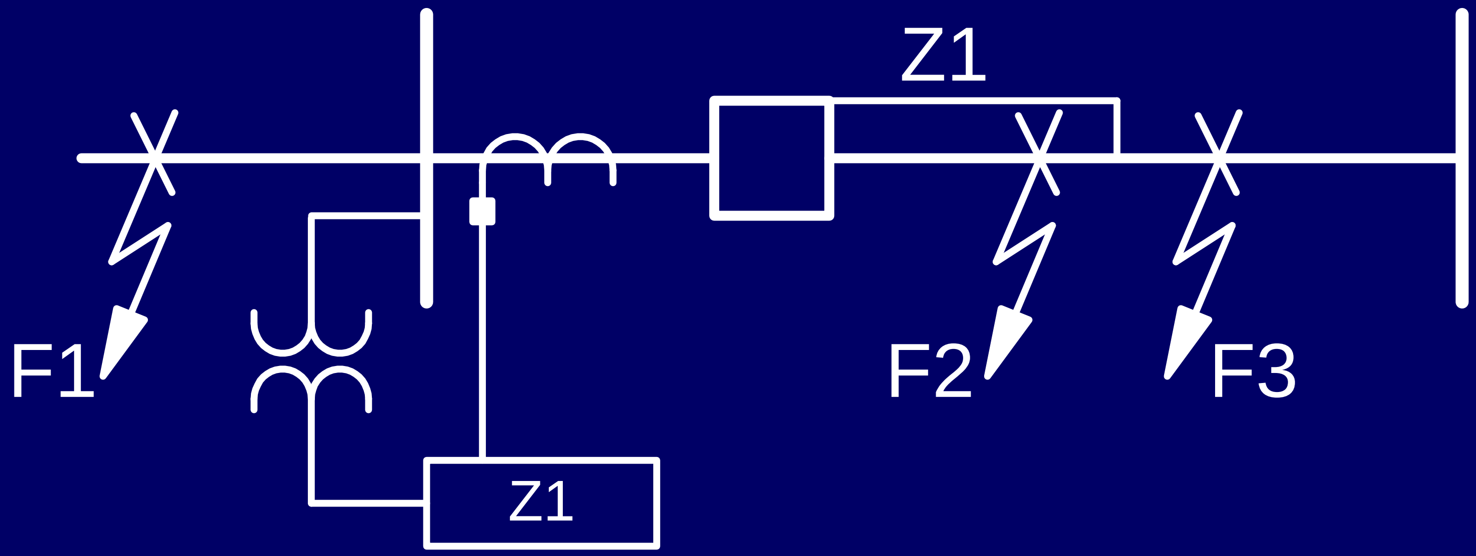
- S1 = operating quantity
- S2 = polarizing quantity
- V = restraint voltage
- Zc = replica impedance
- I = operating current

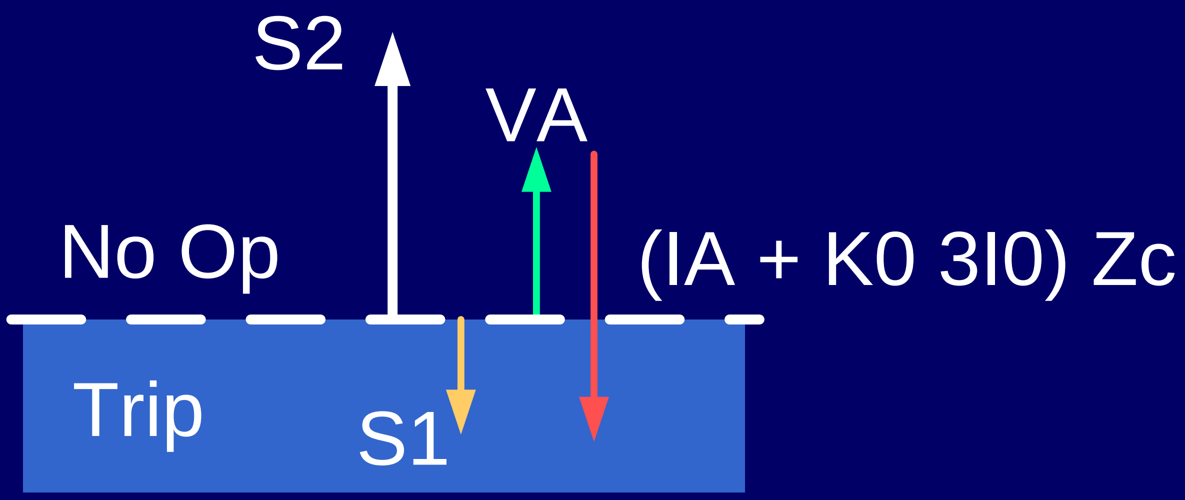
F3 Out-of-Zone Fault



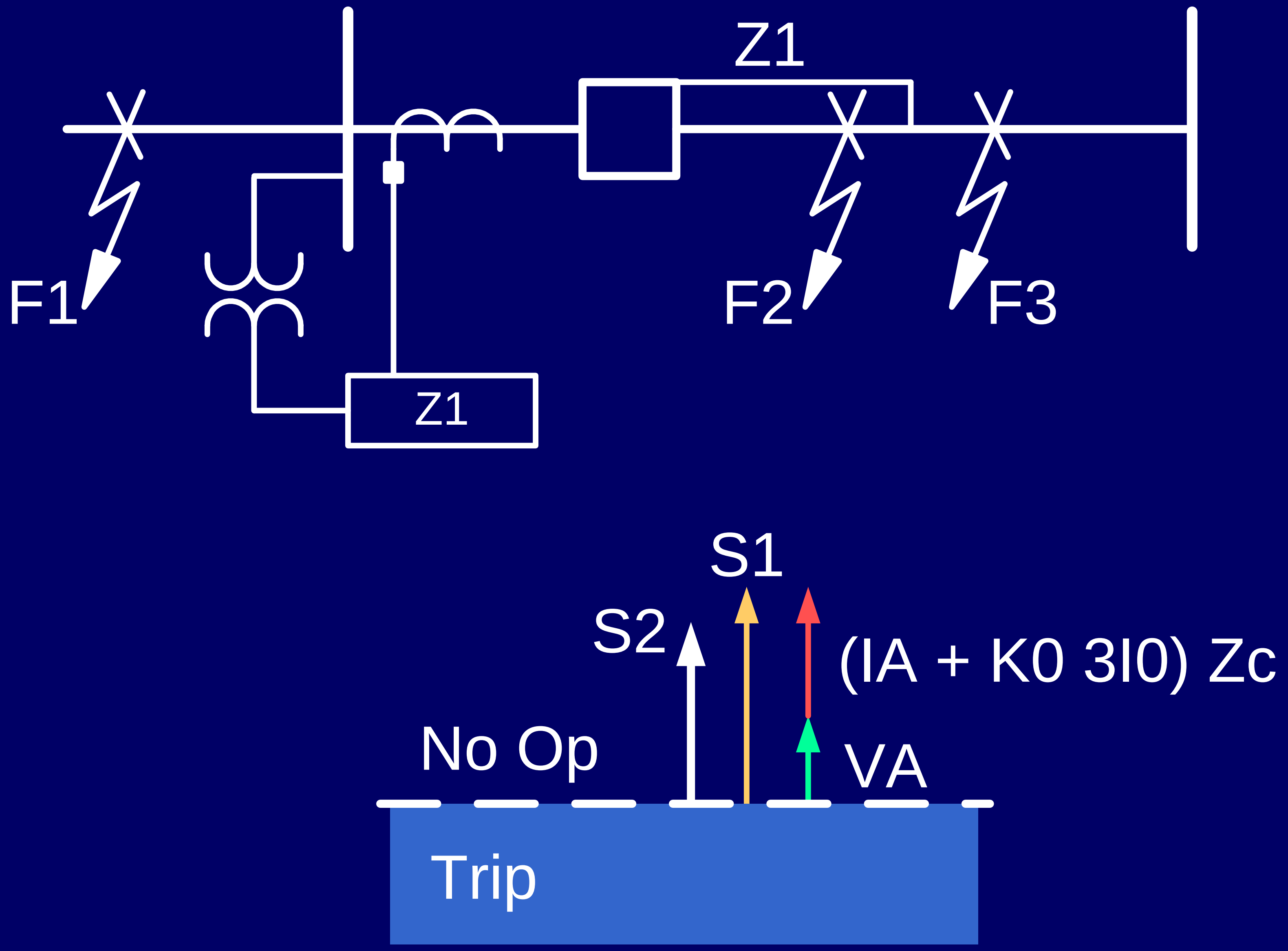


F2 In-Zone Fault



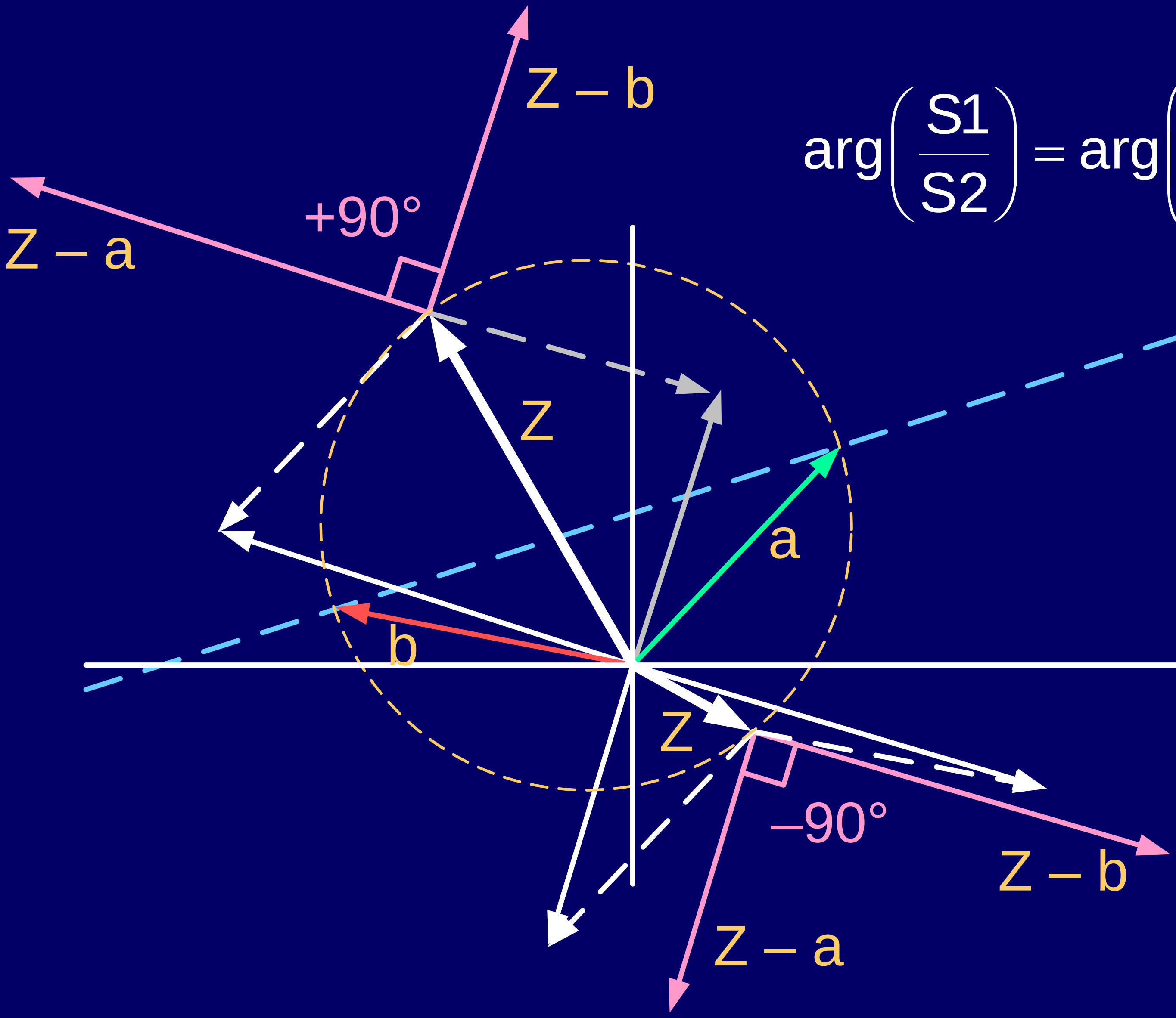


F1 Reverse Fault



Describe Circle on Z Plane

$$\arg\left(\frac{S1}{S2}\right) = \arg\left(\frac{\vec{Z} - \overline{a}}{\vec{Z} - \vec{b}}\right) = \pm 90°$$



Derive Impedance Characteristic

- Find S1 and S2
- Propose fault type and symmetrical component networks
- Express S1 and S2 on Z plane
- Find *a* and *b* vectors
- Plot circle

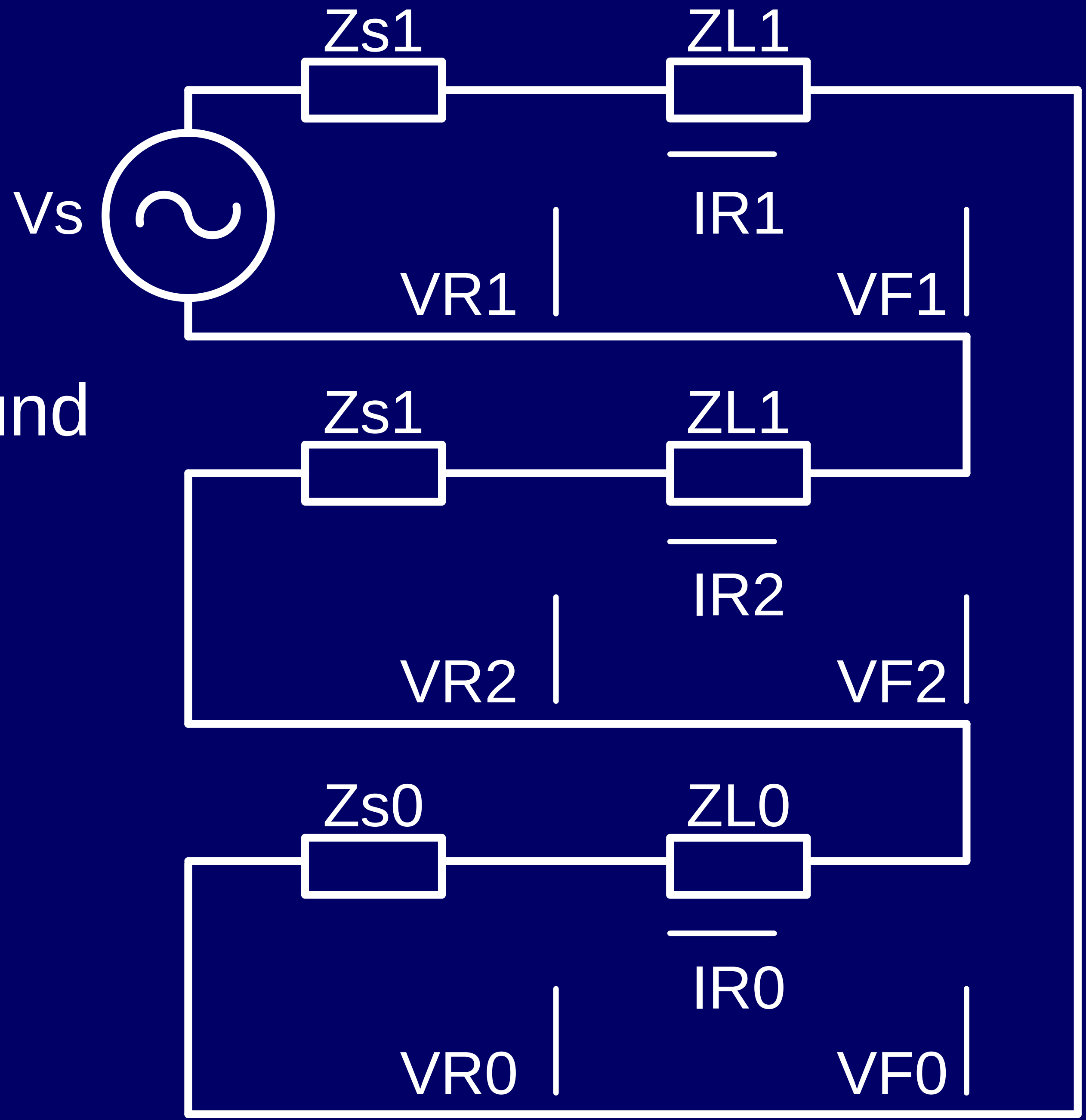
Find S1 and S2

S1 = VRA – Zc1(IRA – Kc0 3IR0)

S2 = VA1

Propose Fault Type

Phase A to Ground



Express S1 and S2 on Chosen Z Plane

Chosen impedance plane: $ZL1 = \dfrac{VR1 - VF1}{IR1}$

$$\frac{S1}{IR1} = ZL1\left(2 + \frac{ZL0}{ZL1}\right) - Zc1\left(2 + \frac{Zc0}{Zc1}\right)$$

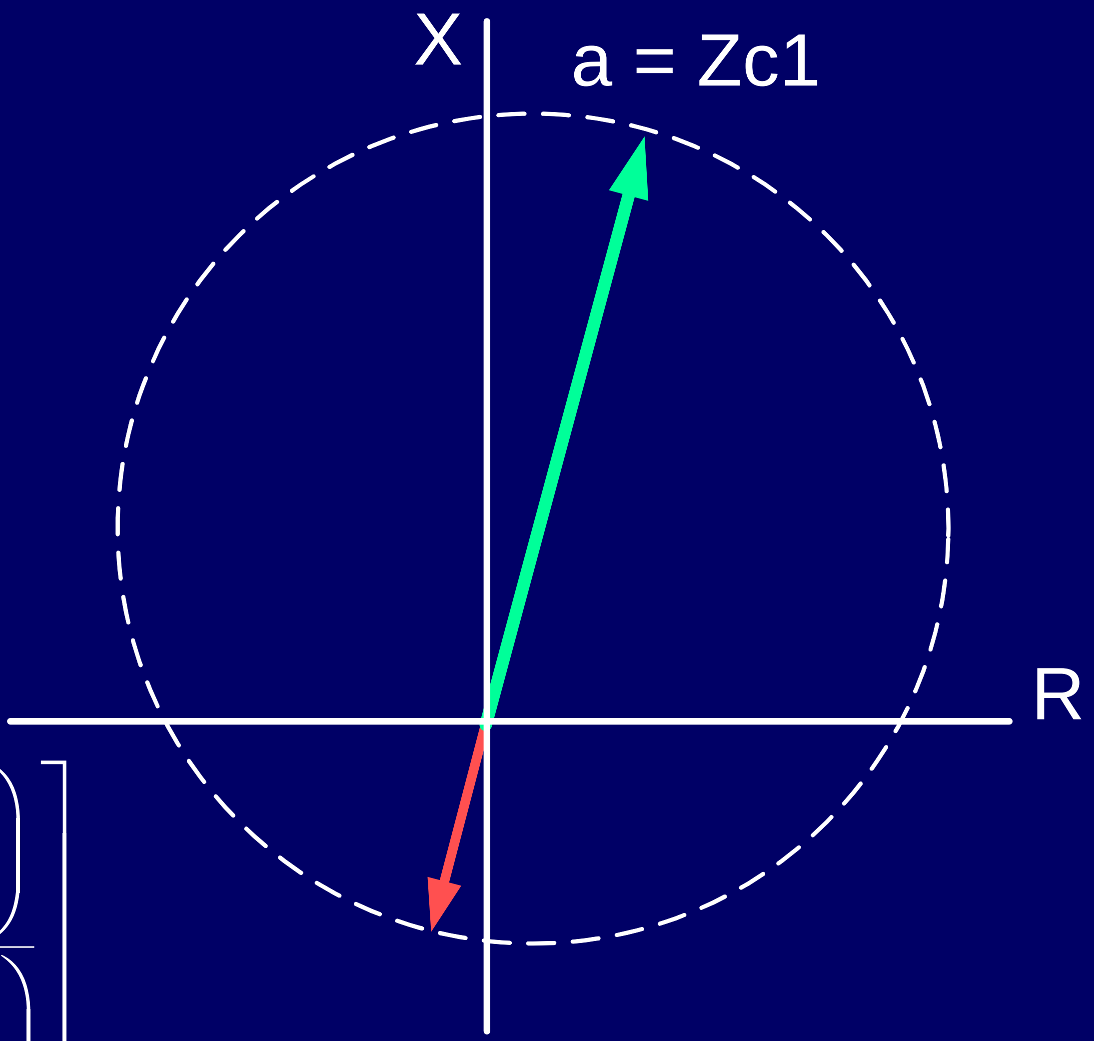
$$\frac{S2}{IR1} = ZL1\left(2 + \frac{ZL0}{ZL1}\right) + Zs1\left(1 + \frac{Zs0}{Zs1}\right)$$

Find Corresponding *a* and *b* Vectors

$$a = Zc1\left[\frac{\left(2+\frac{Zc0}{Zc1}\right)}{\left(2+\frac{ZL0}{ZL1}\right)}\right]$$

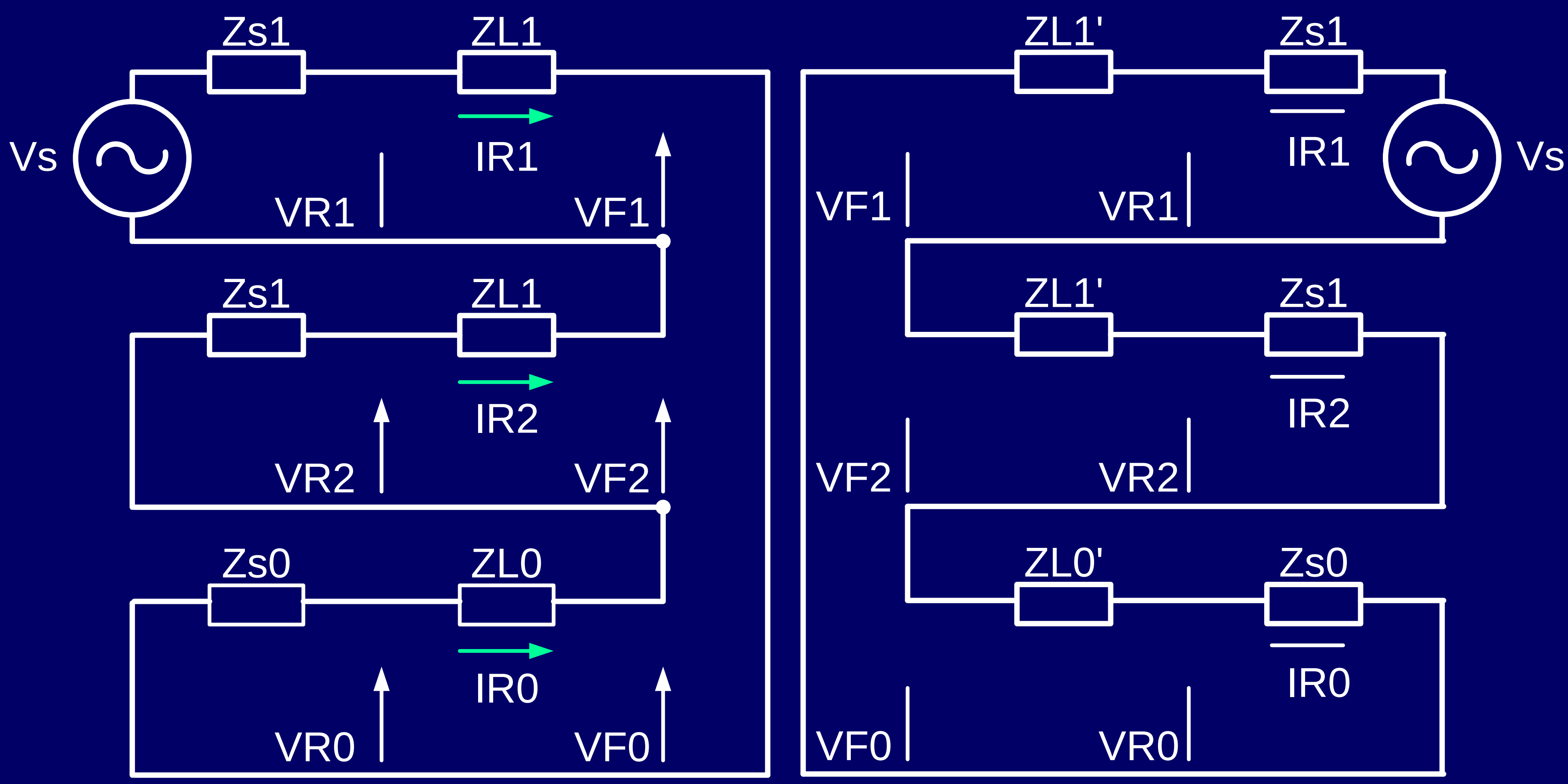
$$b = -Zs1\left[\frac{\left(1+\frac{Zs0}{Zs1}\right)}{\left(2+\frac{ZL0}{ZL1}\right)}\right]$$

Plot Circle



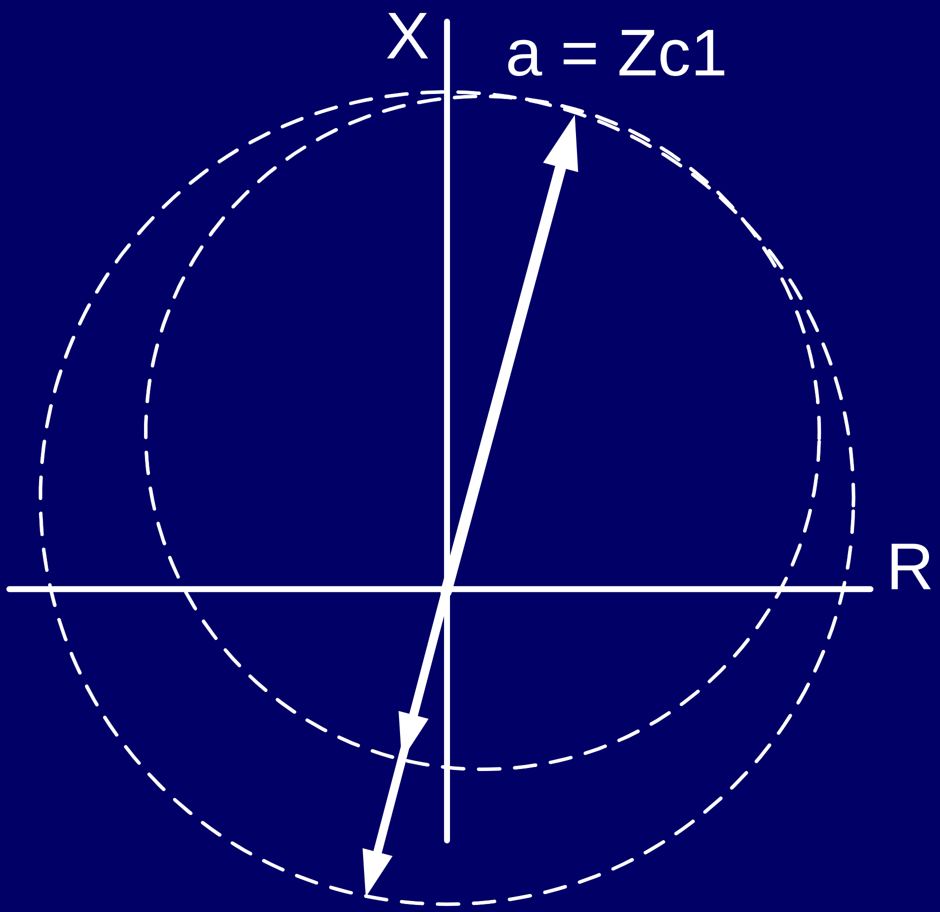
$$b = -Zs1\left[\frac{\left(1+\frac{Zs0}{Zs1}\right)}{\left(2+\frac{ZL0}{ZL1}\right)}\right]$$

It Is the Forward Impedance Fault

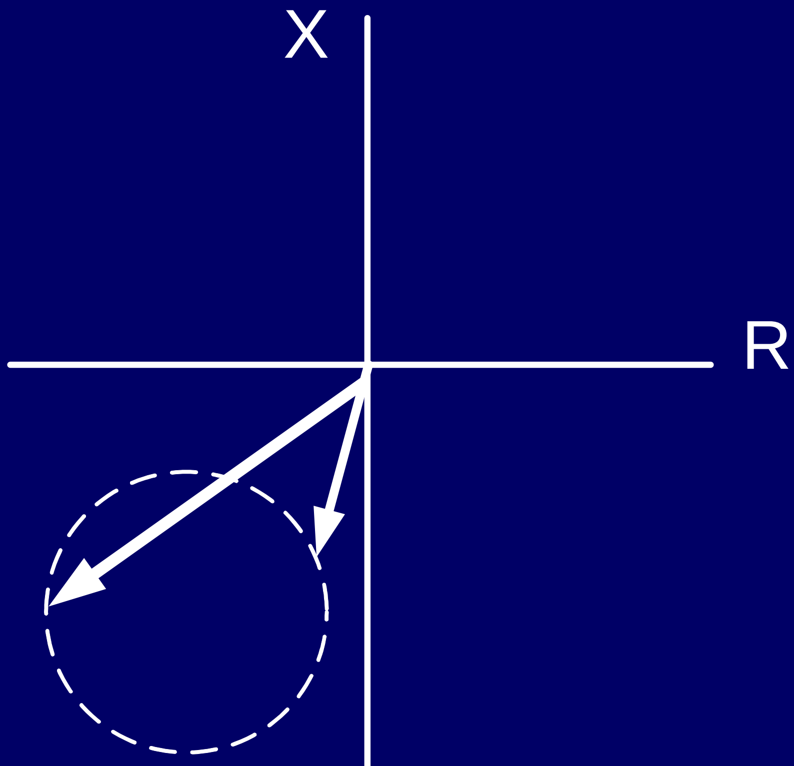


Two Different Impedance Planes

Forward ZL1 Plane

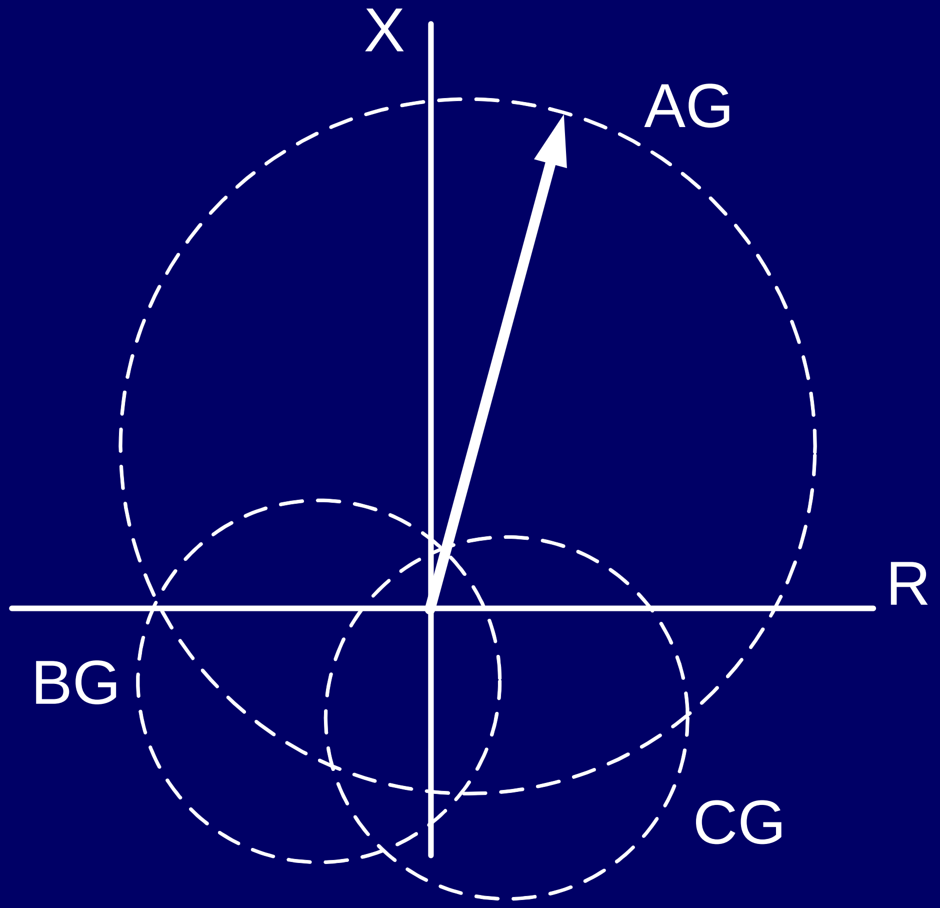


Reverse ZL1′ Plane



Distance Element Response

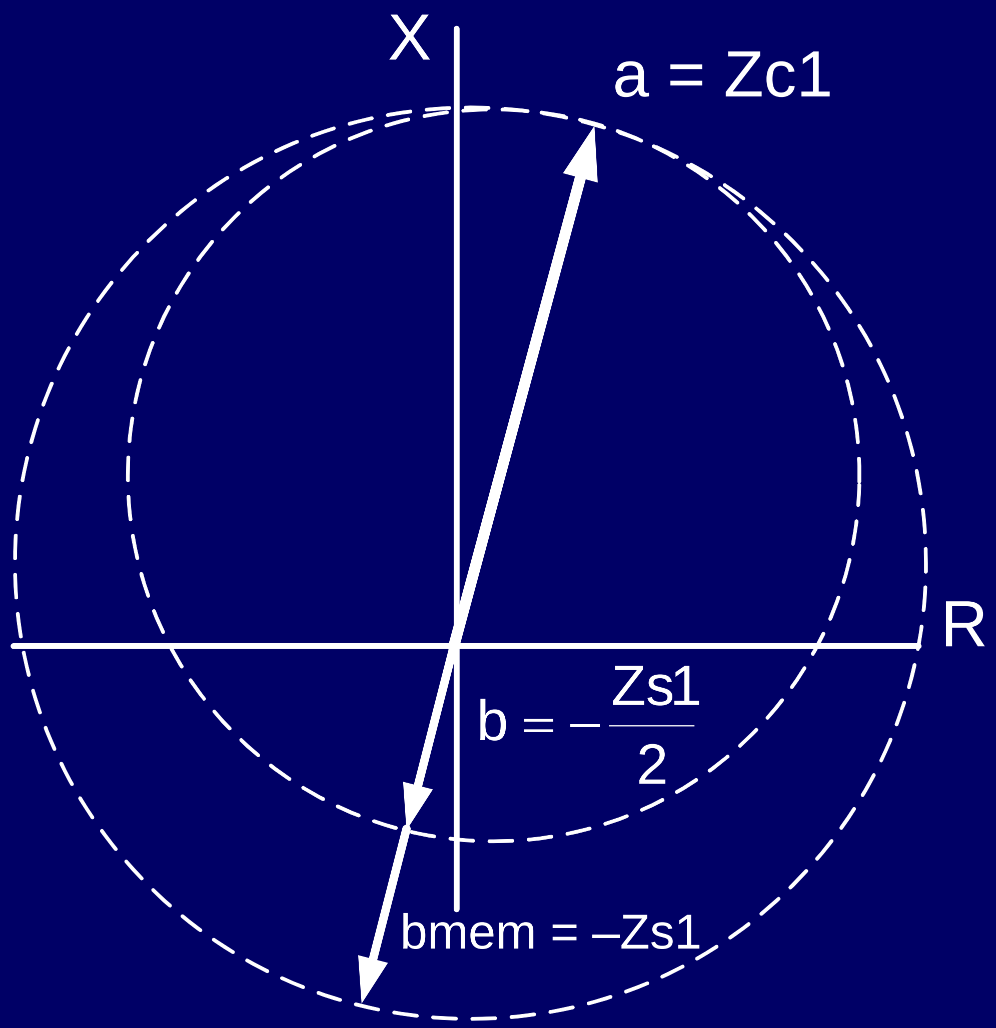
- Full scheme includes six measuring loops
- Response of all three ground measurements for an AG fault



Memory in S2

- Memory only required for three-phase faults
- Phase and ground elements detect three-phase faults (design choice)
- Memory algorithms include time constant
- Short memory constant benefits expansion of mho circle

Phase (BC) Distance Example



- Memory expands mho circle
- Largest expansion occurs with healthy prefault voltages

Reactance Line

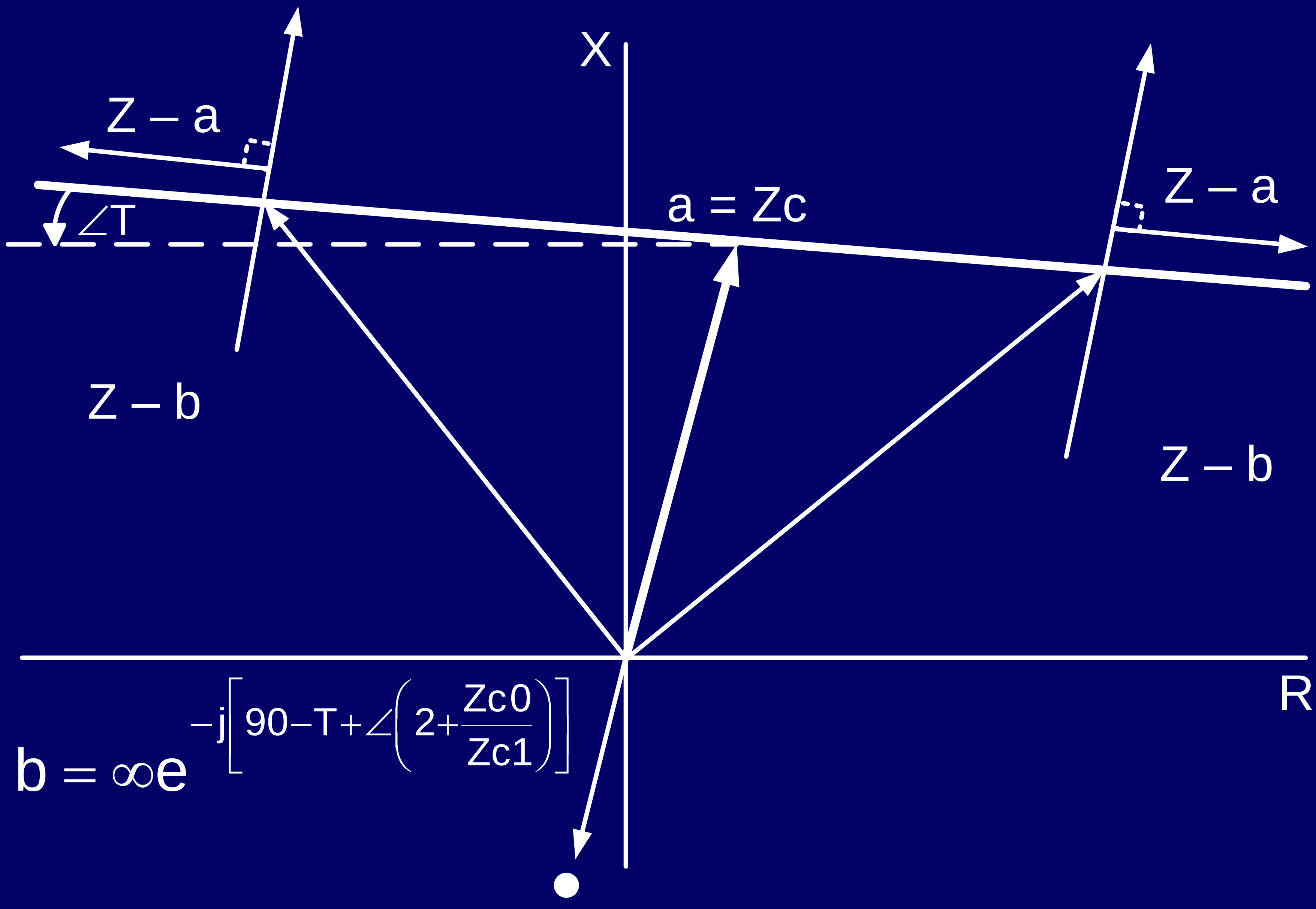
$$S1 = VRA - Zc\,(IRA + Kc0\ 3I0)$$

$$S2 = j\ IR2\ e^{jT}$$

S2 requires a nonacademic trick:

$$\frac{S2}{IR1} = \frac{0}{0}\left(ZL1 + \frac{j\ e^{jT}}{0} \right)$$

Reactance Line



$$b = \infty e^{-j\left[90 - T + \angle\left(2 + \frac{Zc0}{Zc1}\right)\right]}$$

Apparent Impedance

- Measures ZL1 in radial system
- Is not real impedance when load and fault resistance are present
- Can be derived from symmetrical component analysis

Apparent Impedance Equations

Phase A to Ground:

$$ZL1 = \frac{VRA}{IRA + Kc0\left(3I0\right)} \qquad KL0 = \frac{ZL0 - ZL1}{3ZL1}$$

Phase B to Phase C:

$$ZL1 = \frac{VRB - VRC}{IRB - IRC}$$

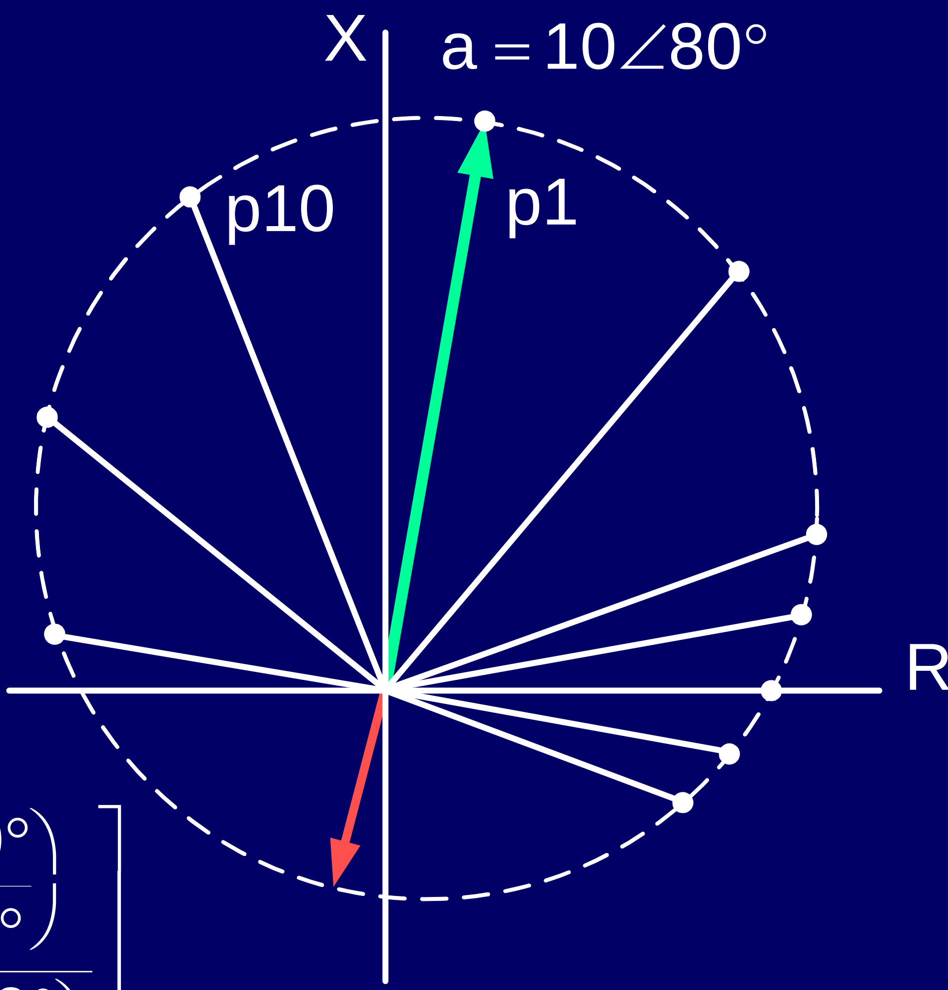
Testing Distance Unit

- Choosing V and I to satisfy apparent impedance equations — NO
- Fixing V and changing I — NO
- Fixing I and changing V — NO
- Using symmetrical components — **YES**

Determine Impedances

Parameter	Value
Zc1	$10\angle 80°$
Zc0	$30\angle 70°$
Kc0	$0.674\angle -14.93°$
Zs1	$1\angle 85°$
Zs0	$3\angle 80°$

Solve for Test Points



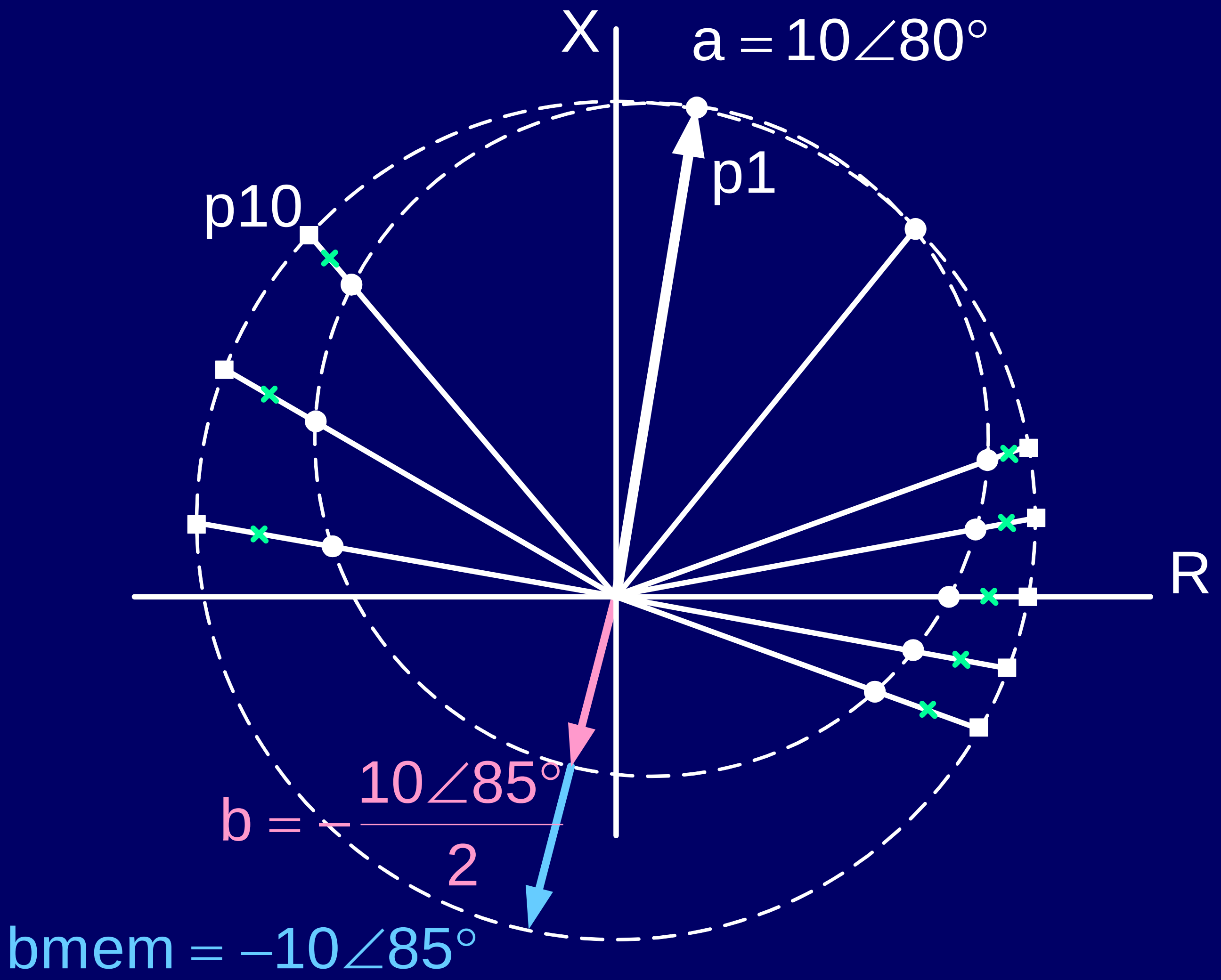
$$b = -\left(1\angle 85^\circ\right)\left[\frac{\left(1+\dfrac{3\angle 80^\circ}{1\angle 85^\circ}\right)}{\left(2+\dfrac{30\angle 70^\circ}{10\angle 80^\circ}\right)}\right]$$

Solve for V and I
Adjust Currents Slowly

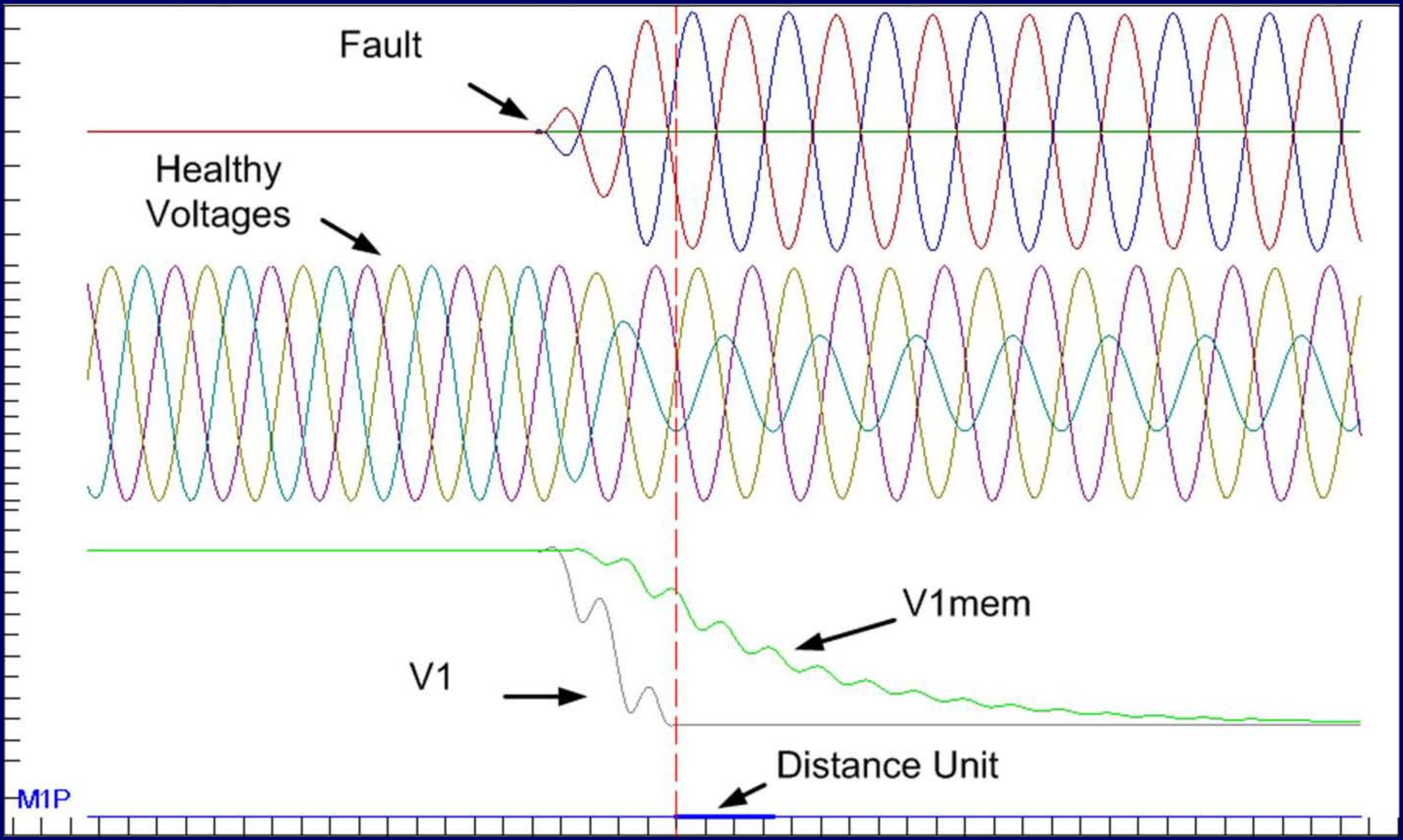
Point **ZL1**	**Voltages and Currents**
p1 10.00∠80°	Va = 63.68∠0°, Vb = 71.76∠–120.70°, Vc = 70.81∠122.78° Ia = **3.84**∠–74.15°, Ib = 0, Ic = 0
p2 8.95∠50°	Va = 64.24∠0°, Vb = 72.91∠–117.11°, Vc = 69.58∠126.03° Ia = **4.32**∠–44.31°, Ib = 0, Ic = 0

Testing Distance Units With Memory

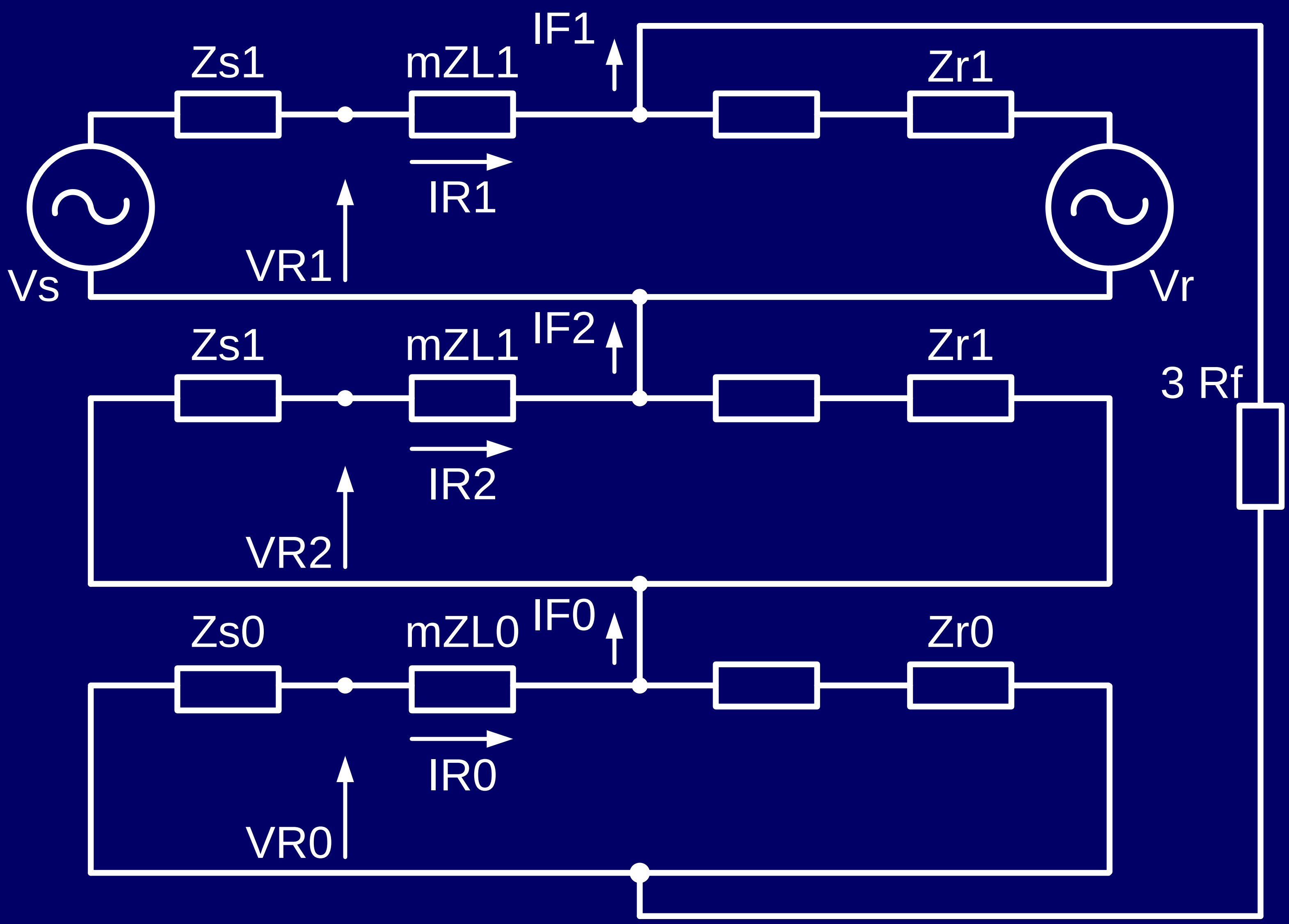
Solve for impedance in middle:



Testing Distance Units With Memory



Load Flow, Rf, and Impedance Plots

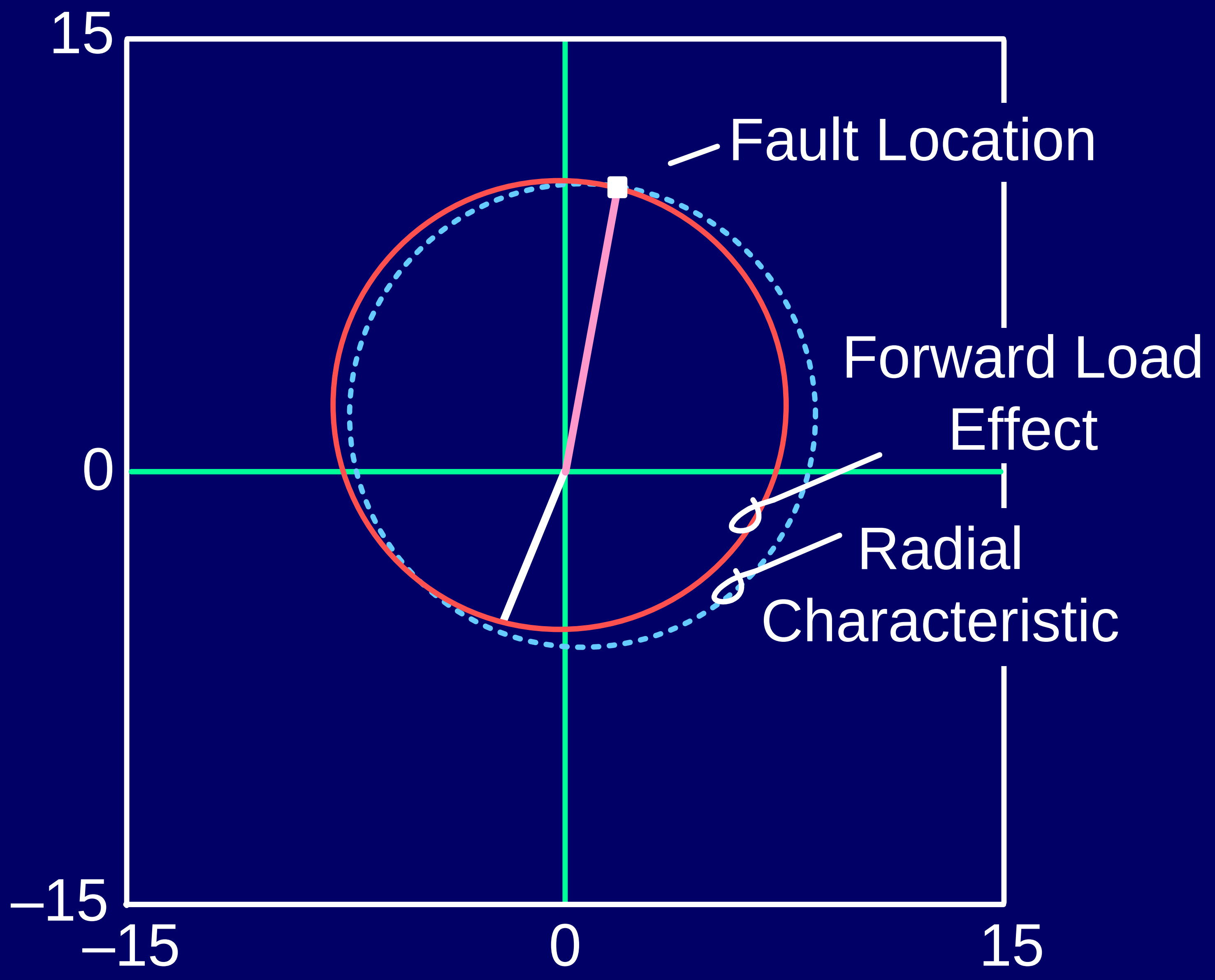


Load Flow, Rf, and Vectors *a* and *b*

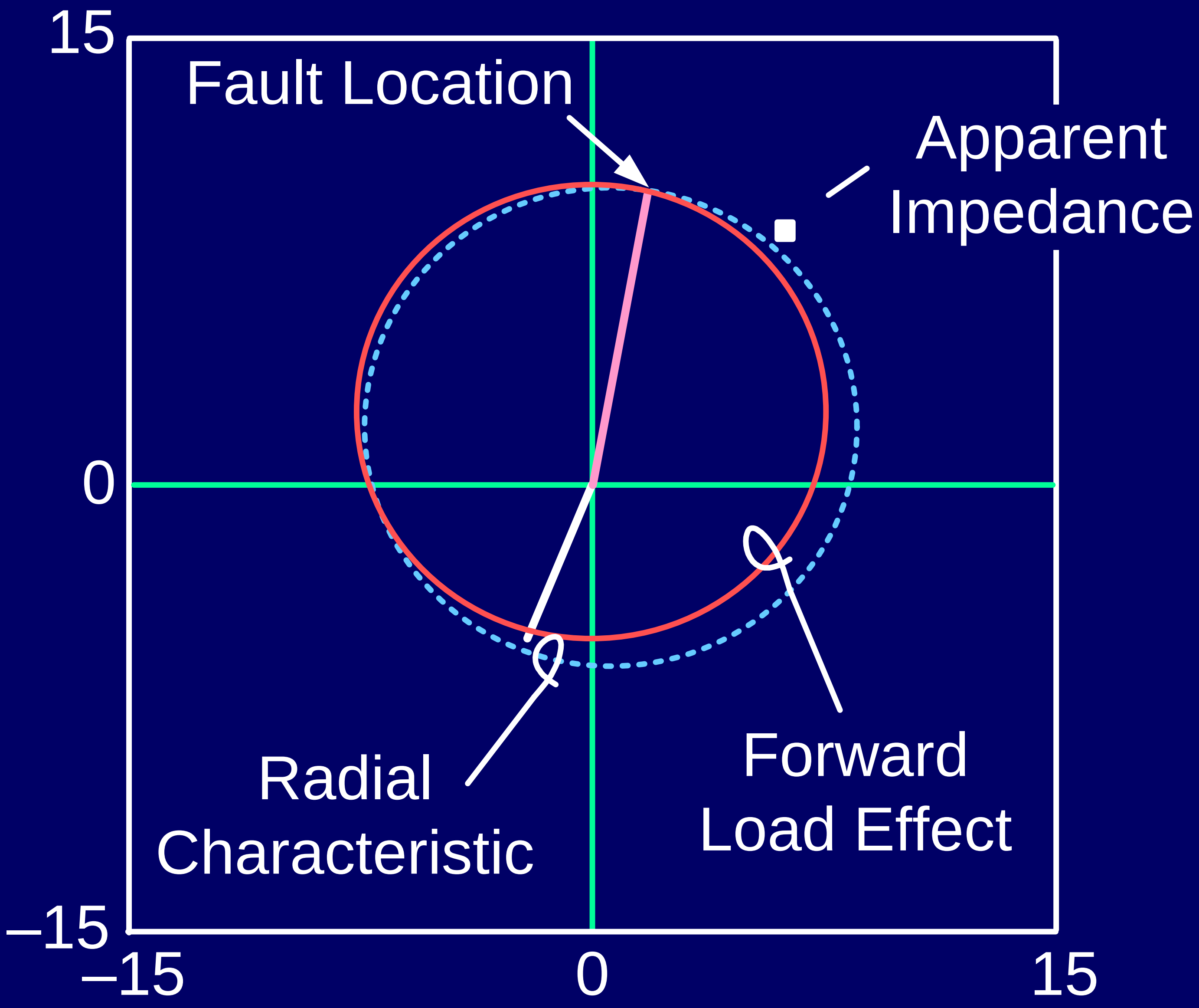
$$a = Zc1$$

$$b = -Zs1\left[\frac{\left(\frac{IR2}{IR1}+\frac{IR0}{IR1}\frac{Zs0}{Zs1}\right)}{1+\left(\frac{IR2}{IR1}+\frac{Zc0}{Zc1}\frac{Zs0}{Zs1}\right)}\right]$$

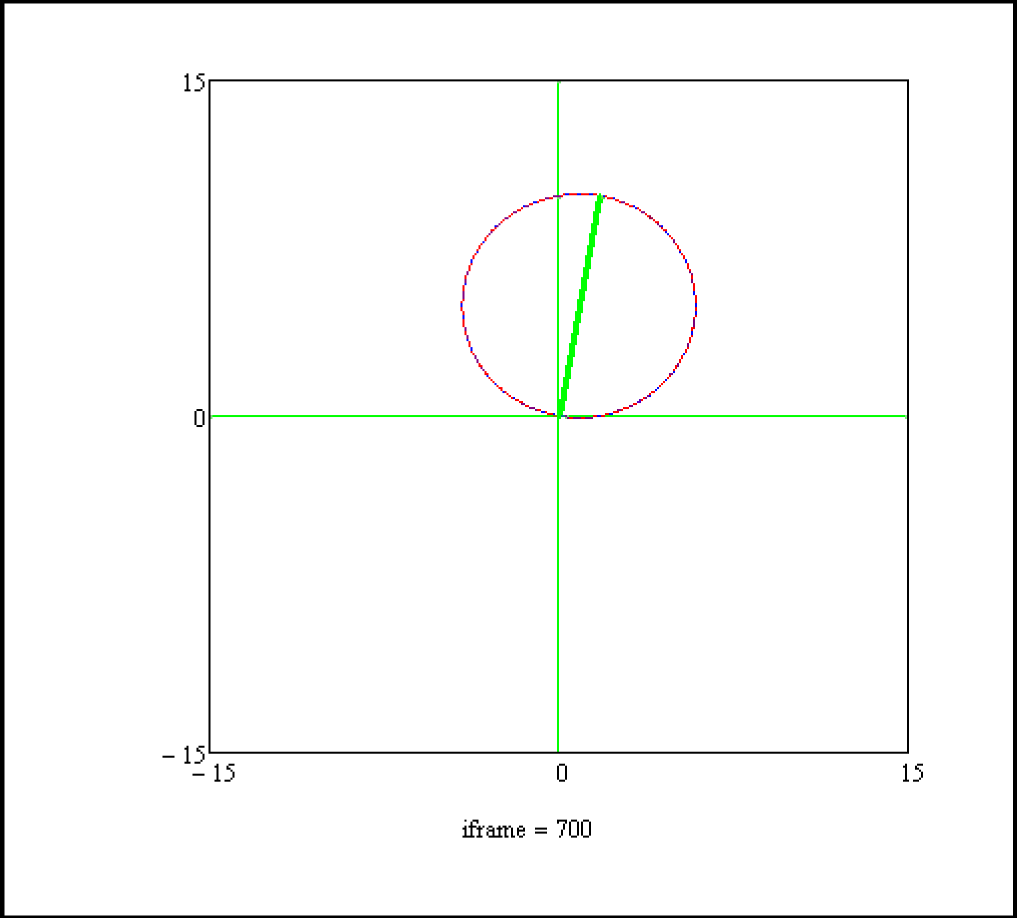
Load Flow Influence



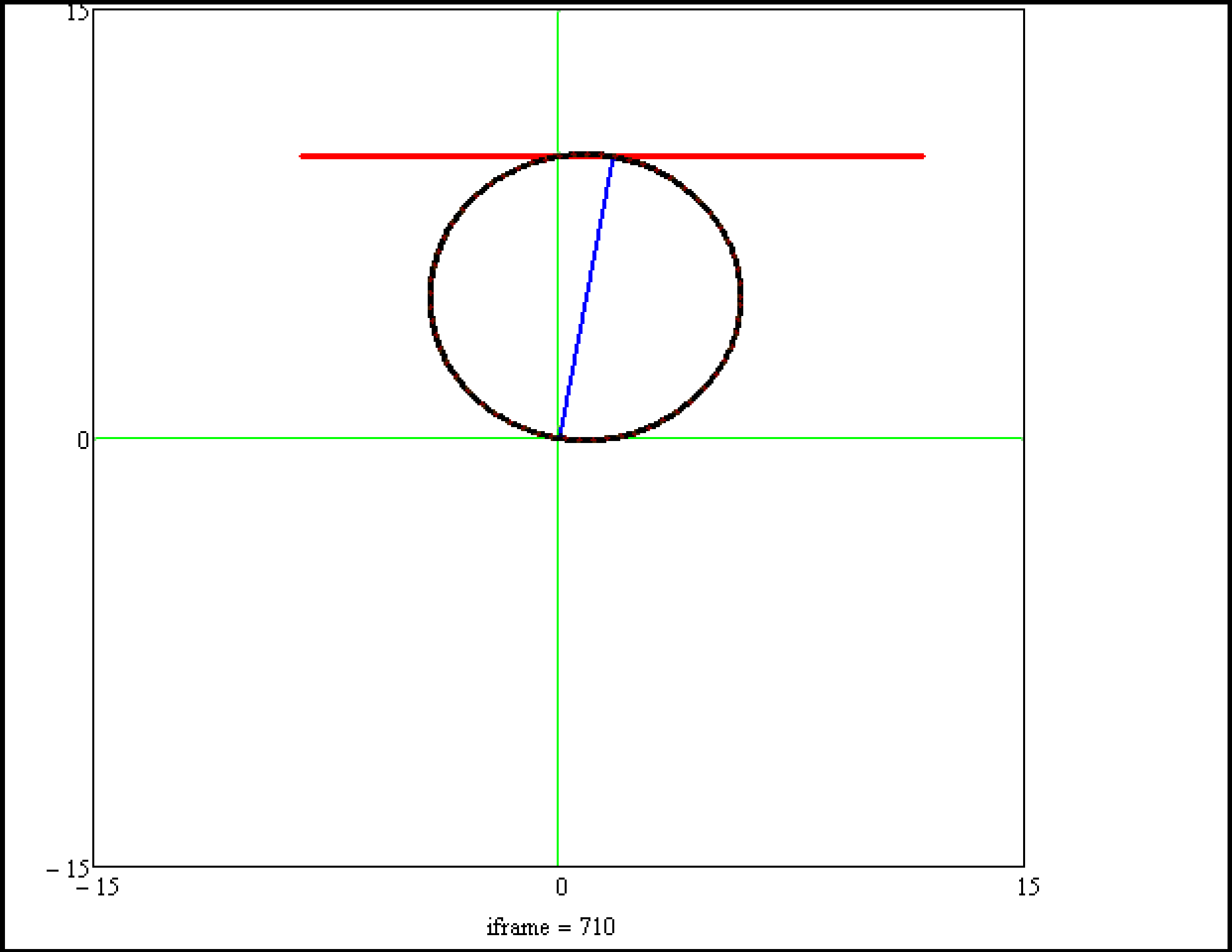
Fault Resistance



Impedance Plot AG
m = 0.25, Rf = 0.5



Impedance Plot AG
m = 0.75, Rf = 1



Summary

- Derive distance elements with generic method
- Note impedance plane importance
- Test with symmetrical components