# Appalachian Underground Corrosion Short Course - 2023

Philadelphia Gas Works

## Dynamic Stray Current

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Philadelphia Gas Works

# Types of Stray Current

Static – Covered in Intermediate Course

Steady source of current

AC – Covered in separate class in this course

**Dynamic Stray Current**

# Dynamic Stray Currents

- Dynamic stray currents are caused by variable loads
  - DC transit systems
  - Chemical/smelter plants
  - Welding operations
- Telluric stray currents are caused by solar activity


1007
63rd Street


Haverford Av
40th St
NO TURN ON RED
SEPTA
9090

# The Earth As A Conductor

- Planet Earth is a huge, non-uniform conductor
- Resistivity is the inverse of soil conductivity, which is the measure of *how* conductive the electrolyte (earth/water) is in a given area
- Uniform electrolytic resistivity only exists in the *middle of the ocean*

# What’s More Conductive?

# Resistivity Values

Some values

- Solid rock - >1,000,000 ohm-cm
- Sand – 5,000-100,000 ohm-cm
- Loam – 5,000-15,000 ohm-cm
- Wet Clays – 100-4,000 ohm-cm
- Seawater – <200 ohm-cm
- Iron – 0.000022 ohm-cm
- Copper – 0.000007 ohm-cm

# Why Resistivity Matters

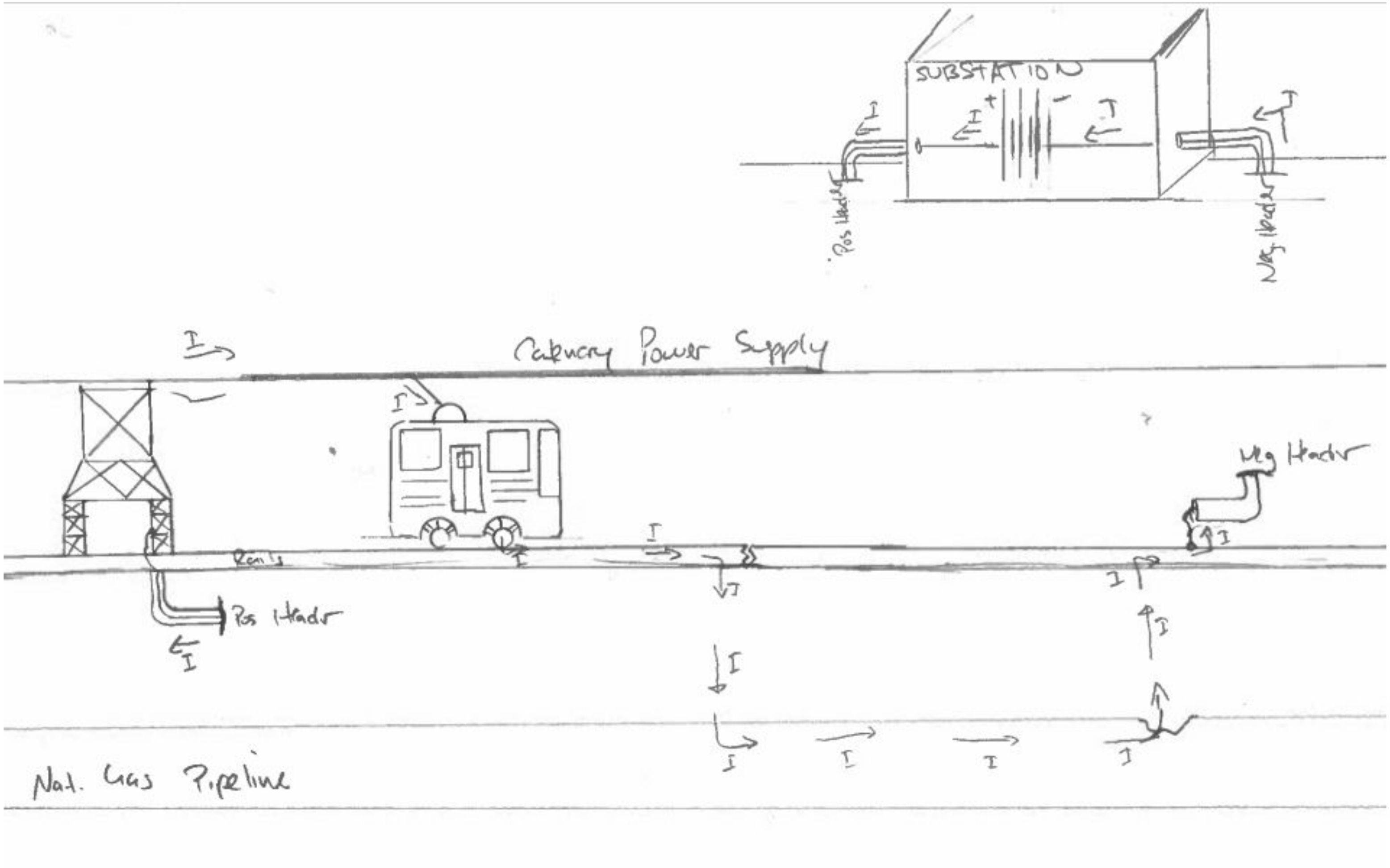
- DC transit systems have MASSIVE loads required to power trolleys, trains, etc.
- Discontinuities in power system are overcome with underground metallics completing circuit
- Even if continuous, the voltage loads are so great that gradient fields can induce voltages on underground metallics

# Why Resistivity Matters

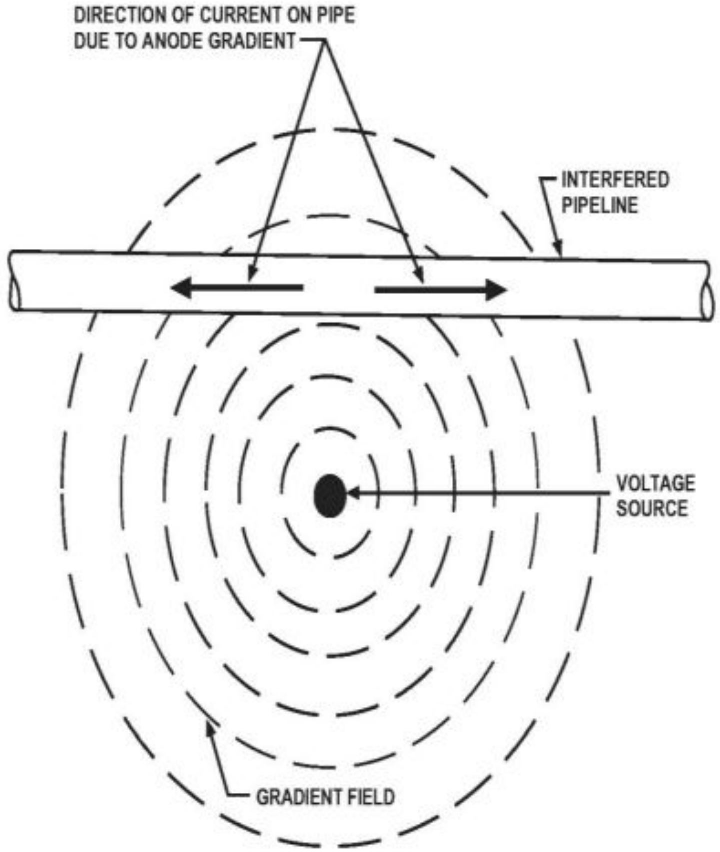
- Electricity wants path of least resistance.
  - Will stray currents in ground conduct on:
    - A vein of low resistivity soil (100 ohm-cm)

      **OR**
    - A bare steel pipe (0.000022 ohm-cm)
- Additionally – pipe in lower resistivity soil will be more at risk than pipe in higher resistivity soil

# Stray Current – Visualized



# Stray Current – Visualized



# Gradients

- Current flow caused by gradients occurs when the pipe passes through a “line” on the electric field
  - Each “line” represents a step down in intensity the further away it is from the source of the field
  - Current generated depends on the load/intensity of that area of the field and the resistivity of the soil ($I = \frac{V}{R}$)

# In Either Scenario…

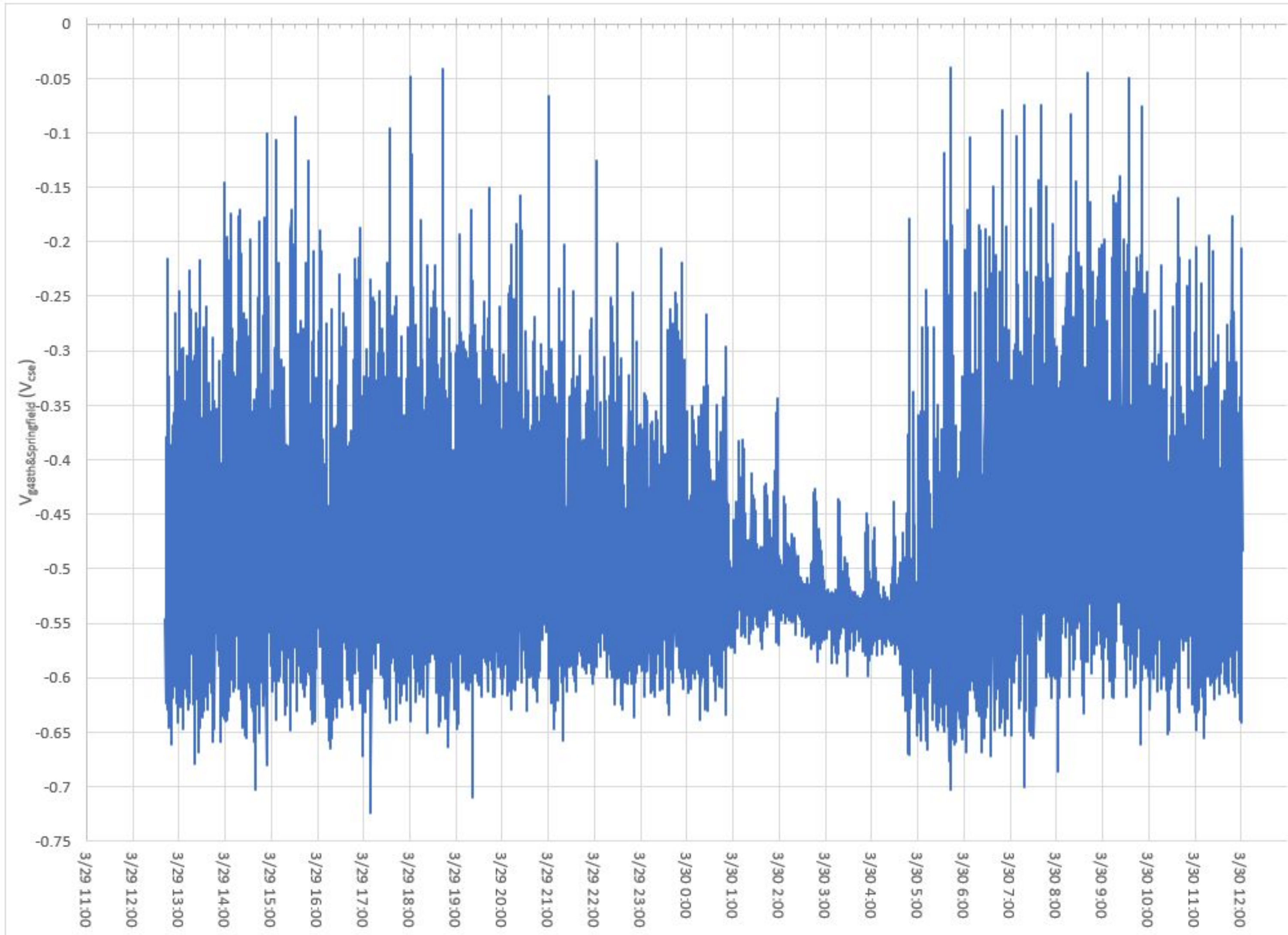
Where current enters the pipe – potentials become more negative (appear protected). Not an area of concern. (although if you see pickup, there's discharge somewhere else!)

Where current discharges from the pipe – potentials become more positive. This is where corrosion occurs!

# Investigating Stray Current

- All pipe-to-soil variations should be investigated
  - Especially if the voltage variation is predominantly indicates discharge
- Generally – if the P/S reading does not become more positive than -0.85 $V_{cse}$ polarized or the electropositive shift is <10 mV, then a corrosive condition does not likely exist

# Initial Detection of Stray Current



# Initial Detection of Stray Current

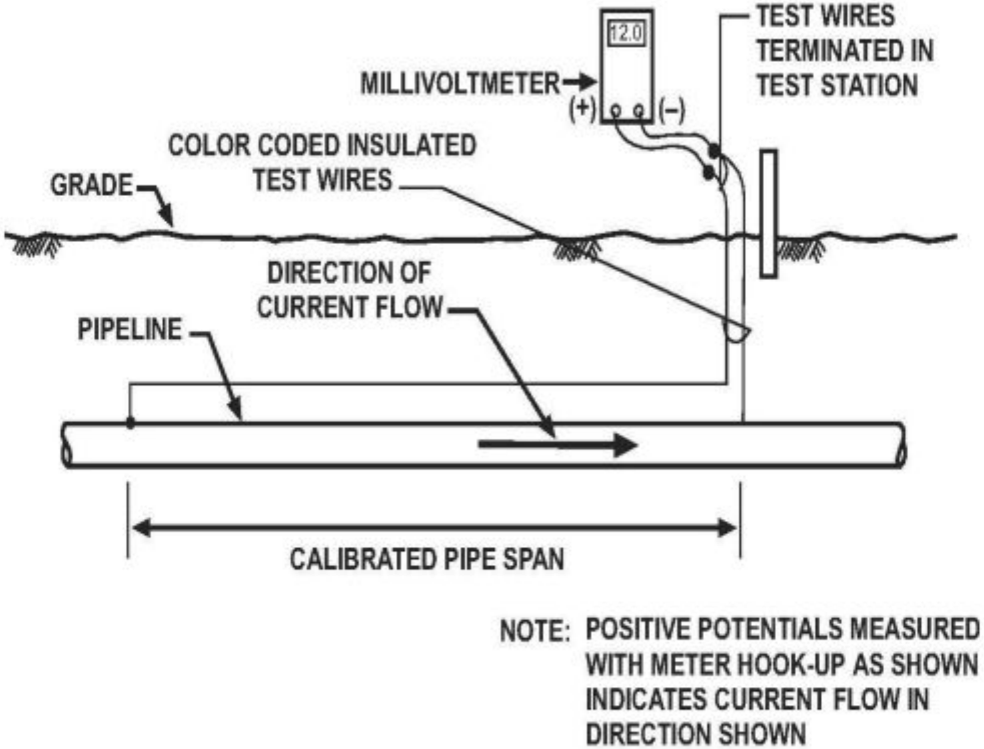
- Rapid fluctuations present in real time
- “Big picture” often unable to be taken in short-term recordings with voltmeters and visual observation
  - Voltage recorders over 24-168-hour periods more reliable
- NOTE: telluric currents may not be noticeable with short-term readings at all

# How to Find the Source

- After noticing fluctuations, the next step is to figure out where they're coming from
- Observation – are there any tracks or overhead power cables nearby?
- Local corrosion committees – other utilities/consultants with historical documentation of local transit/mining/chemical ops
  - Transit authority might also sit on committee

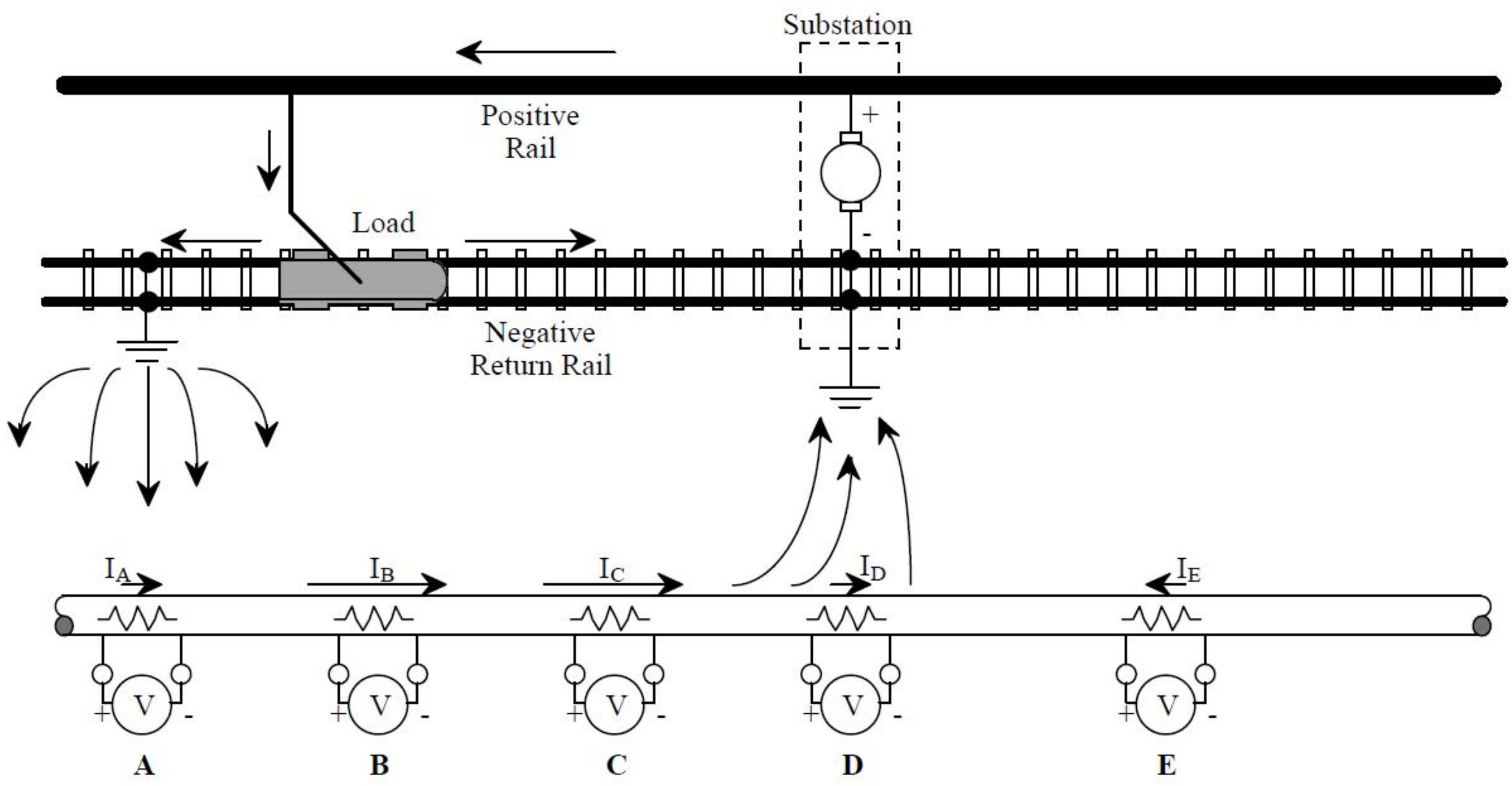
# Measuring Stray Current

Use of calibrated pipe spans to measure current magnitude and direction



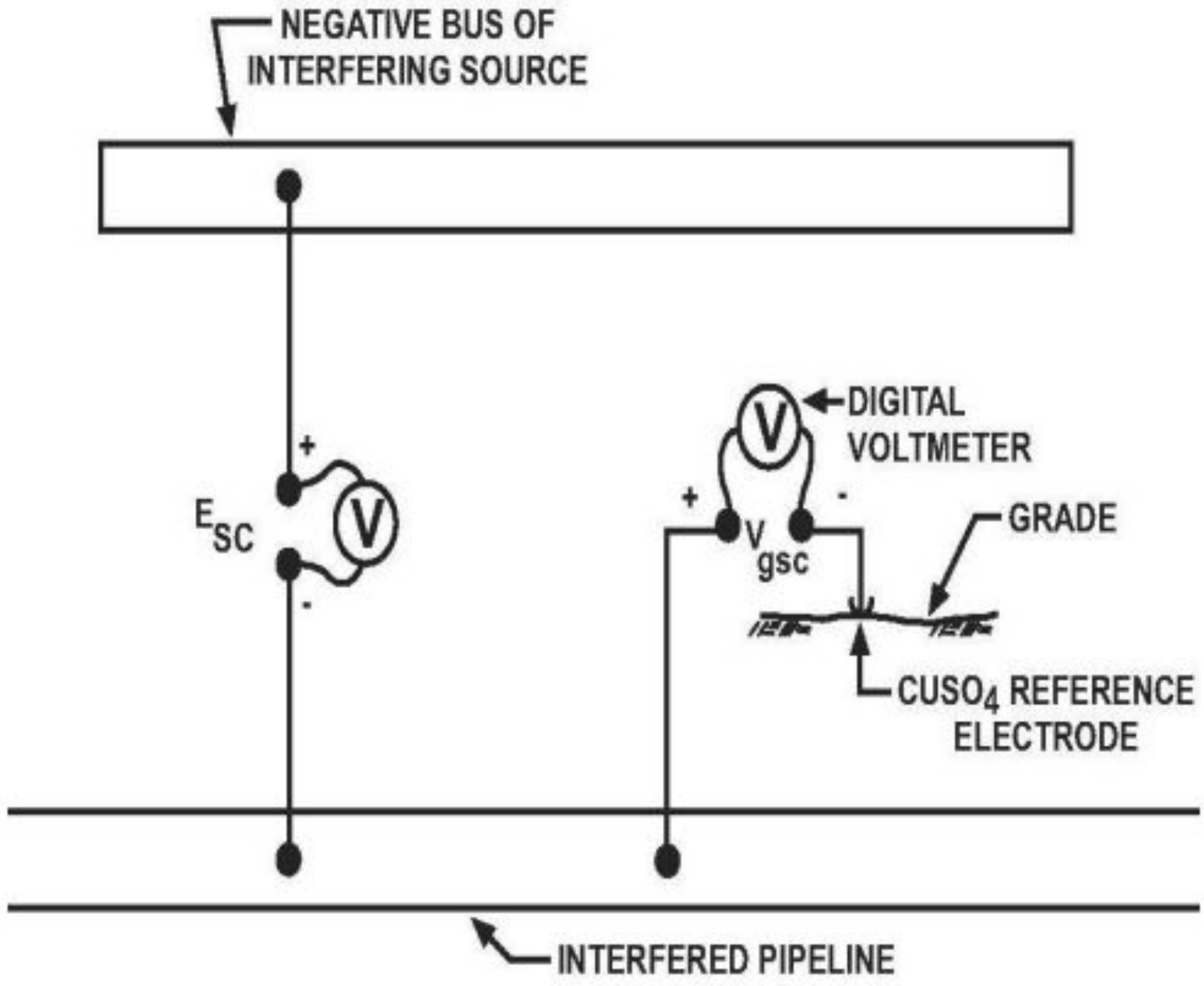

Measures current on pipe, not relationship w/ source

# Measuring Stray Current



# Measuring Stray Current

- Correlations
  - Measurement of relationship between source of interference/structure voltage and structure-to-earth potential plotted on x-y graph
  - Source/structure voltage – $E_{sc}$
    - $E_{SC}$ polarity – (+) on source, (-) on pipe
  - For complete picture, $E_{sc}$ is compared to P/S measurements at multiple locations along pipeline/interfered-with structure

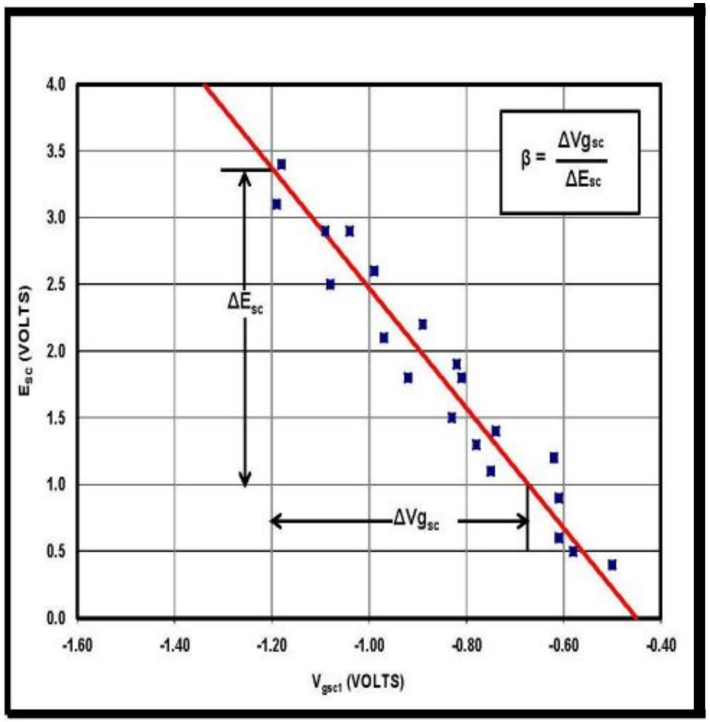

NEGATIVE BUS OF
INTERFERING SOURCE
+
$E_{SC}$
V
-
DIGITAL
VOLTMETER
V
+
-
$V_{gsc}$
GRADE
$CUSO_4$ REFERENCE
ELECTRODE
INTERFERED PIPELINE

# Tools

- Voltage measurements
  - X-Y Plotter (for the oldheads)
  - Dual channel voltage recorder
  - Sychronizable single channel voltage recorders
- Reference electrode
- Wire reels

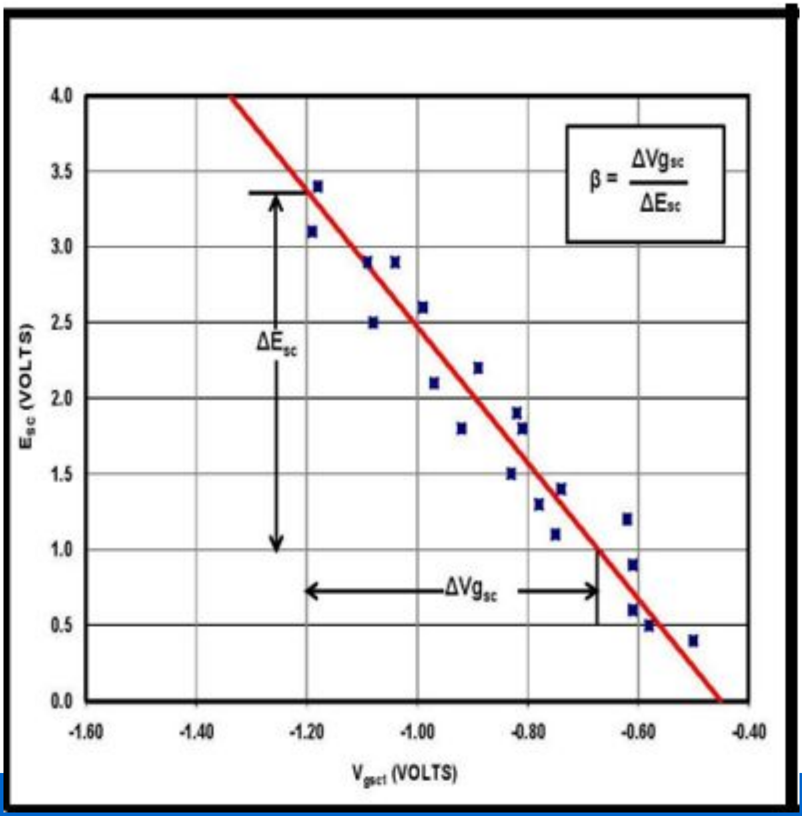
# Correlations – Beta

- Plot the $E_{sc}$ on Y-axis
- Plot P/S measurement on X-axis
- Beta = slope
  - $\beta = \frac{\Delta V_{gsc}}{\Delta E_{sc}}$

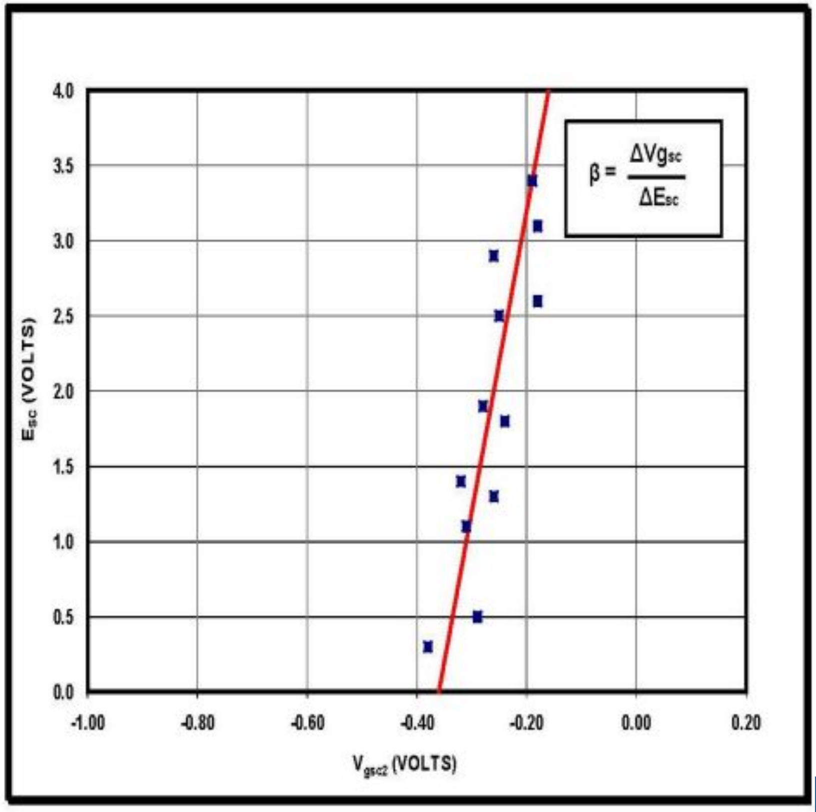


# What the Beta Means

Negative beta – pickup




Positive beta – discharge

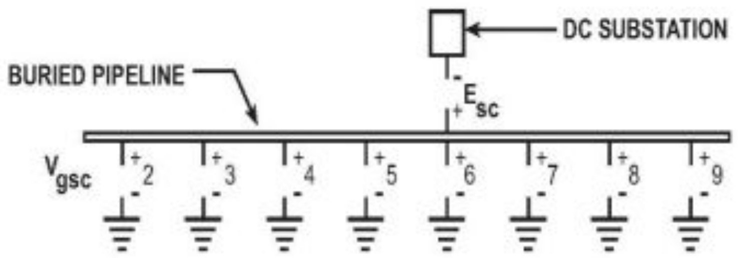


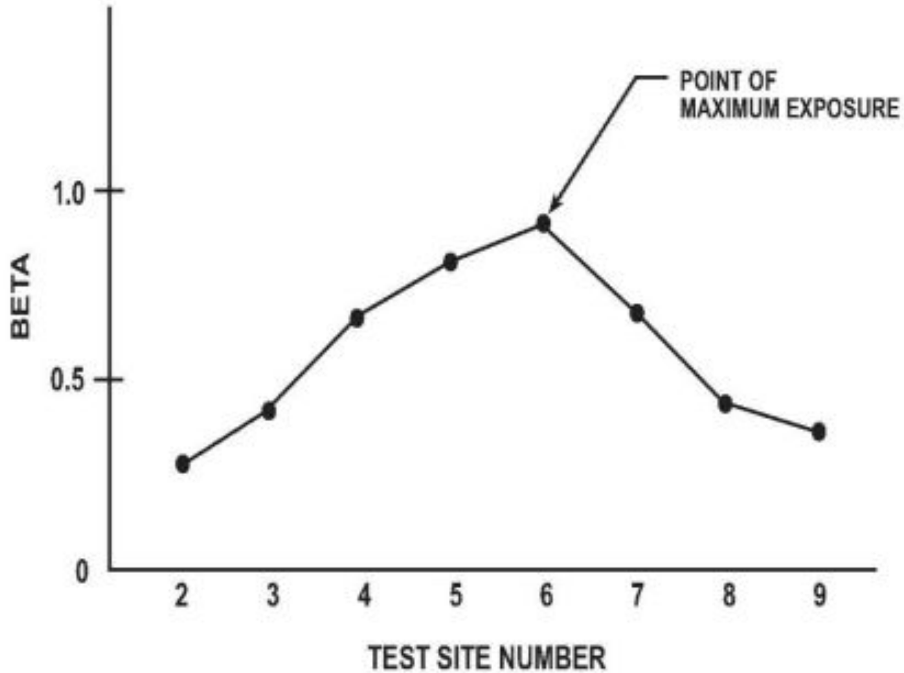
# What the Beta Means

- Vertical slope ($\beta = 0$) – no influence from stray current
    - RARE – double-check equipment and re-run test for repeatability
- No beta/no correlation – you've got the wrong source, bubba. Try again.

# Beta Analysis

- Correlations must be measured at multiple locations on pipeline to determine areas of pickup and discharge
- Location with largest (shallowest) positive beta – area of greatest potential discharge


DC SUBSTATION
BURIED PIPELINE
$E_{sc}$
$V_{gsc}$
2
3
4
5
6
7
8
9


POINT OF
MAXIMUM EXPOSURE
BETA
1.0
0.5
0
2
3
4
5
6
7
8
9
TEST SITE NUMBER

# Mitigation – Controlling the Source

## Embedded Track

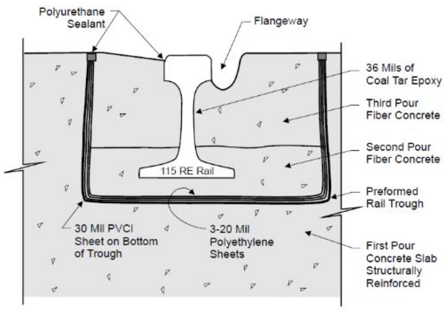



**Figure 2-42a: Typical Embedded Track Installation**
Source: Sidoriak, W., Rail Isolation on the Baltimore Central Light Rail Line, MP, Vol. 32(7), July 1993, p.36

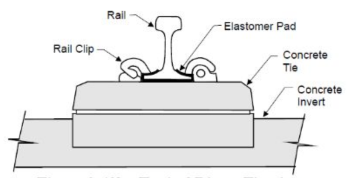



**Figure 2-42b: Typical Direct-Fixation Isolating Fastener**

Source: Fitzgerald J.H. and Lauber, M.D., Stray Current Control for the St. Louis Metrolink Rail System, MP, Vol. 34(1), Jan. 1995, p.22

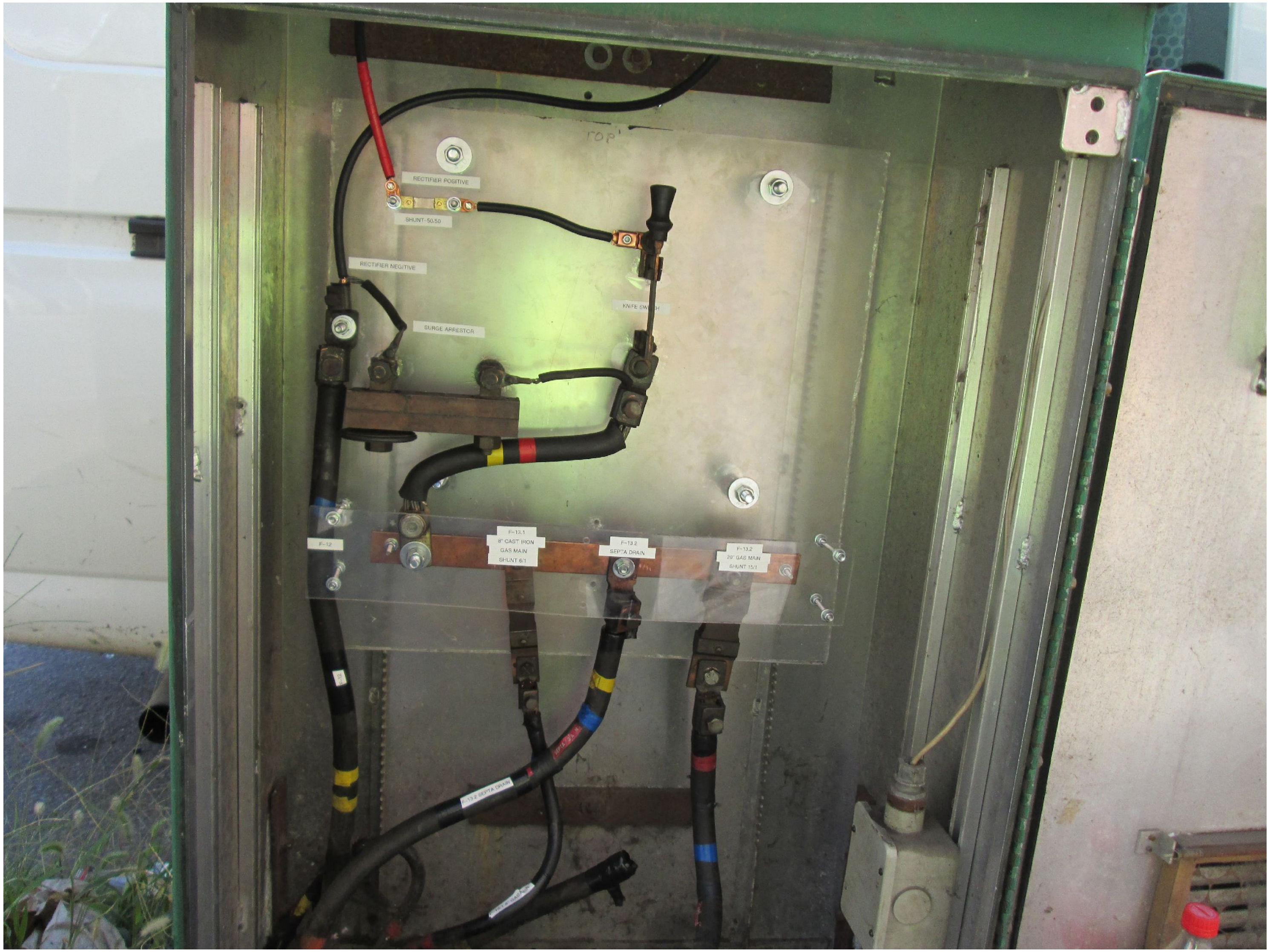
## Ensuring Rail Continuity

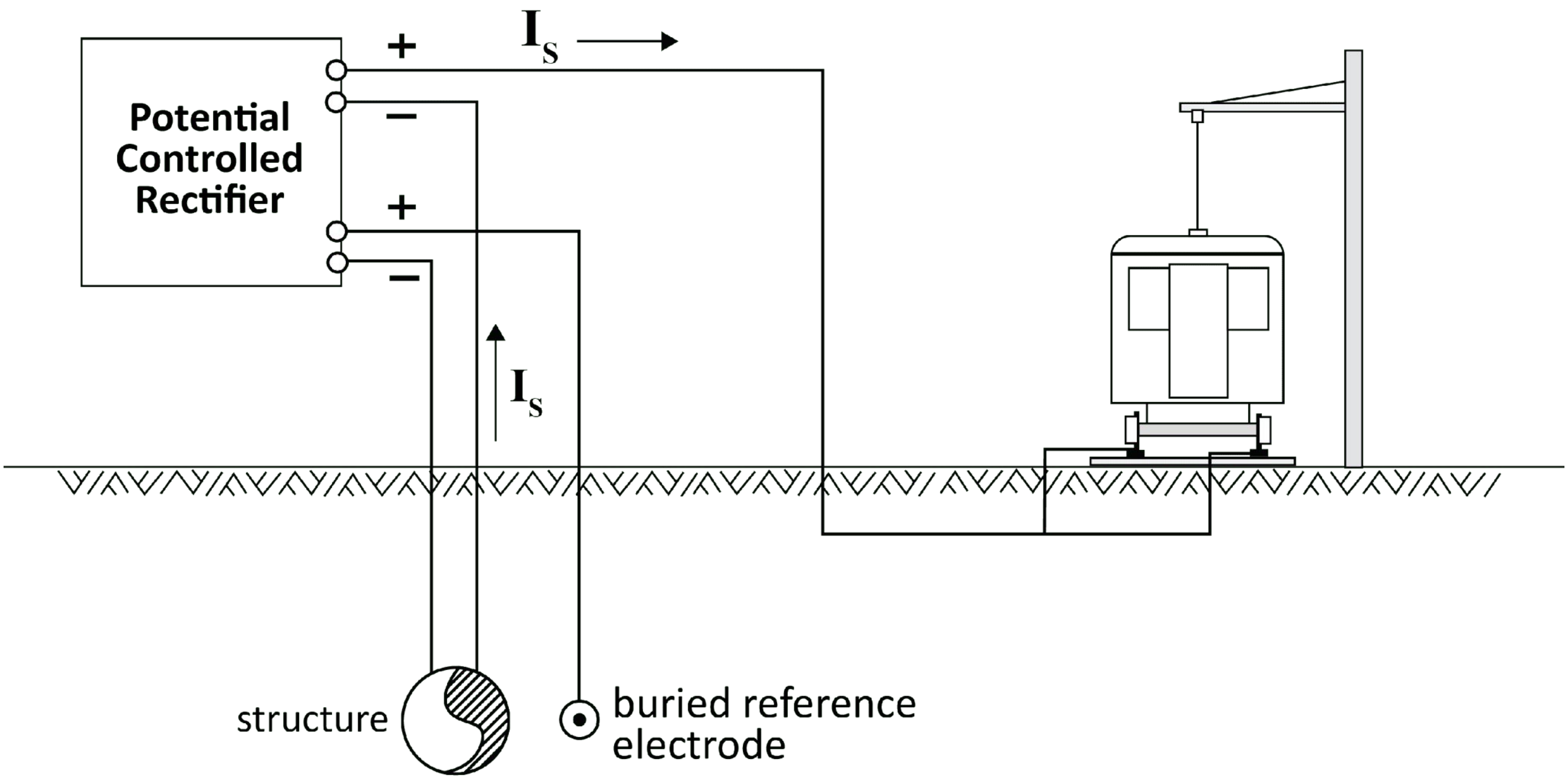
# Mitigation – Galvanic Anodes

- For small magnitude stray current mitigation, galvanic anodes can be used
  - Onshore – magnesium
  - Rare for dynamic stray current because of the magnitude of voltage gradients/current produced
  - Generally reserved for static stray current mitigation

# Mitigation - Bonds

- Solid bonds
- Reverse current switches
- Resistance bonds
- Potential controlled force drain rectifiers
- Goal: return current safely back to its source
    - Metallic path in the corrosion circuit


TOP
RECTIFIER POSITIVE
SHUNT-50/50
RECTIFIER NEGITIVE
SURGE ARRESTOR
F-12
F-13.1
8" CAST IRON
GAS MAIN
SHUNT 6/1
F-13.2
SEPTA DRAIN
F-13.2
20" GAS MAIN
SHUNT 15/1


Potential Controlled Rectifier
+
−
+
−
$I_s$
$I_s$
structure
buried reference electrode

# Calculations

- GOAL: Reduce variation in $V_g$ at point of greatest discharge to negligible levels
  - Stray current elimination is impossible without shutting down the source, especially with magnitudes as great as produced by DC transit systems
- Accomplished through draining current back to source

# Mitigation – Resistive Bond

## Master equation

$$V_g = V_{go} + \Delta V_{gcp} + \Delta V_{gsc} + \Delta V_{gb}$$

Where:

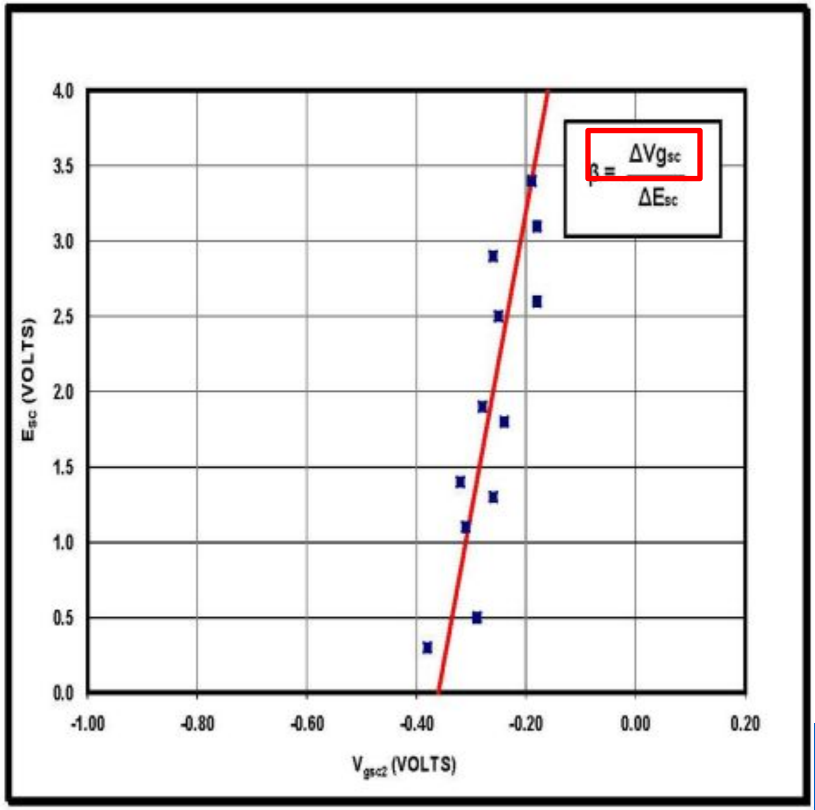
- $V_g$ – Aggregate P/S potential
- $V_{go}$ – Natural/native P/S potential
- $\Delta V_{gcp}$ – Change in P/S potential due to CP
- $\Delta V_{gsc}$ – Change in P/S potential due to stray current
- $\Delta V_{gdb}$ – Change in P/S potential due to mitigation bond

# Mitigation – Resistive Bond

- Stray current is mitigated when:

$$\Delta V_{gcs} + \Delta V_{gb} = 0$$

- $\Delta V_{gcs}$ – discerned from beta correlation

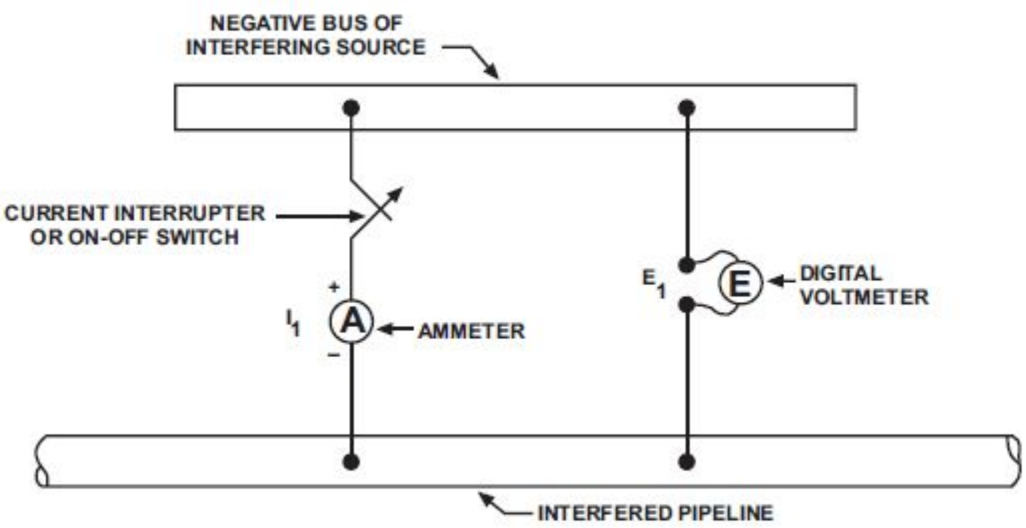


# Mitigation – Resistive Bond

- Testing to solve for $R_b$
- ASSUMPTIONS:
  - Test setup is at maximum discharge point
  - Temporary bond has zero resistance
  - Zero leakage discharge from bond to soil
  - Current values are all positive (flow from structure back to source)

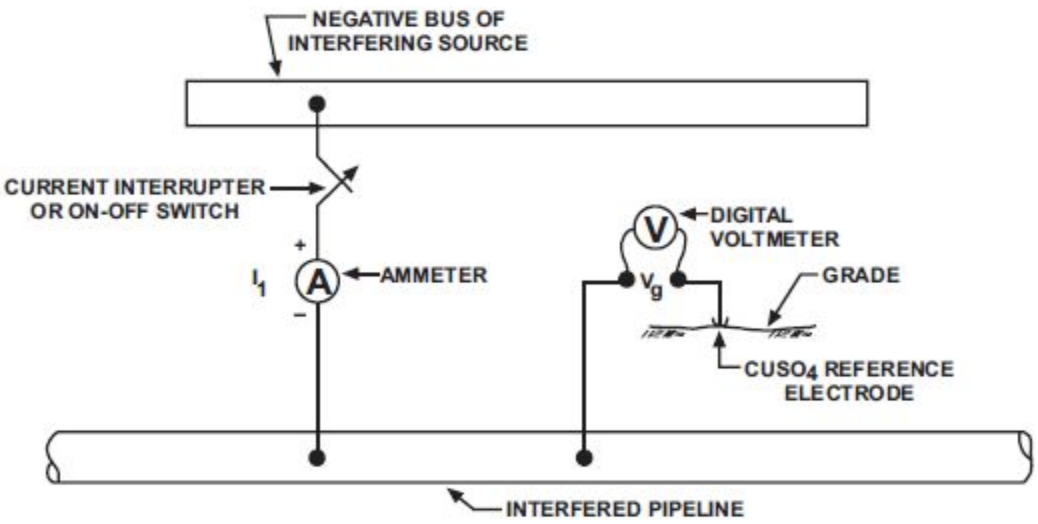
# Mitigation – Resistive Bond

Determine internal resistance of stray current circuit:



# Mitigation – Resistive Bond

Determine internal resistance of stray current circuit:




$$R_{discharge} = \frac{\Delta V_g}{\Delta I_1}$$

* - $I_1$ OFF should always be 0 A. $\Delta V_g$ at discharge is negative.

# Mitigation – Resistive Bond

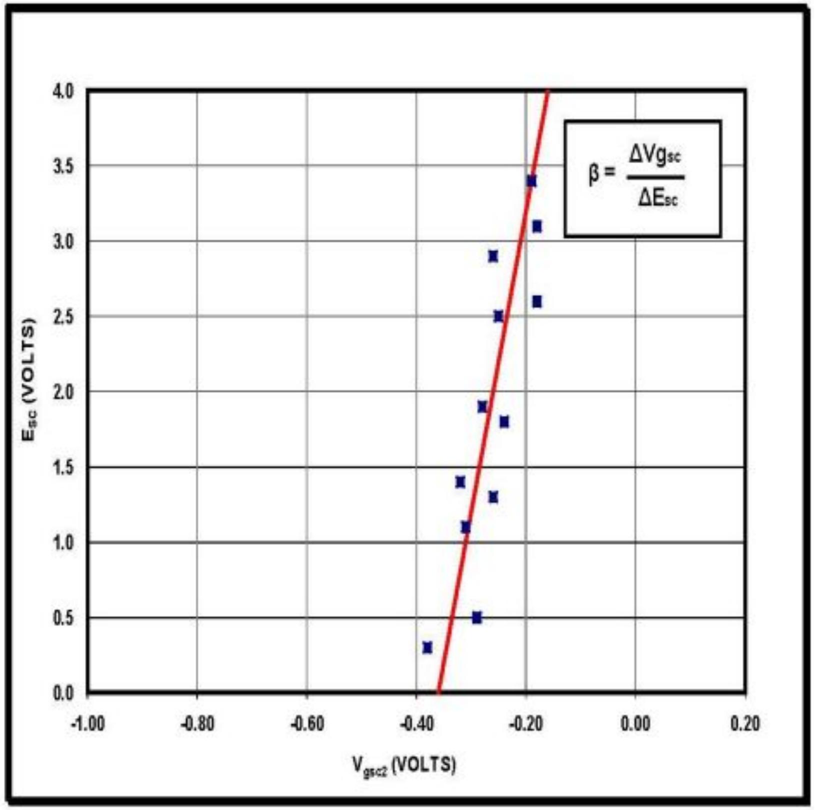
$$V_g = V_{go} + \Delta V_{gcp} + \Delta V_{gsc} + \Delta V_{gb}$$

- With no CP applied, if $\Delta V_{gsc} + \Delta V_{gb}$ = 0, then $V_g = V_{go}$ and $V_g - V_{go} = 0$
- Equation then simplifies to:

$$-\Delta V_{gsc} = \Delta V_{gb}$$

# Mitigation – Resistive Bond

- From the graph on right:
  $$\Delta V_{gsc} = \beta * \Delta E_{sc}$$
- If $-\Delta V_{gsc} = \Delta V_{gb}$, then
  $$\Delta V_{gb} = -\beta * \Delta E_{sc}$$
- Ohm's Law:
  $$V = IR$$
- $V = \Delta V_{gb}$
- $R = R_{discharge}$



# Mitigation – Resistive Bond

- If:

$$\Delta V_{gb} = -\beta * \Delta E_{sc} \text{ and}$$
$$\Delta V_{gb} = I_B * R_{discharge}$$

- Then:

$$-\beta * \Delta E_{sc} = I_B * R_{discharge}$$

- Simplifying:

$$I_B = \frac{-\beta * \Delta E_{sc}}{R_{discharge}}$$

# Mitigation – Resistive Bond

- Basic electrical theory also states that the sum of all resistances:

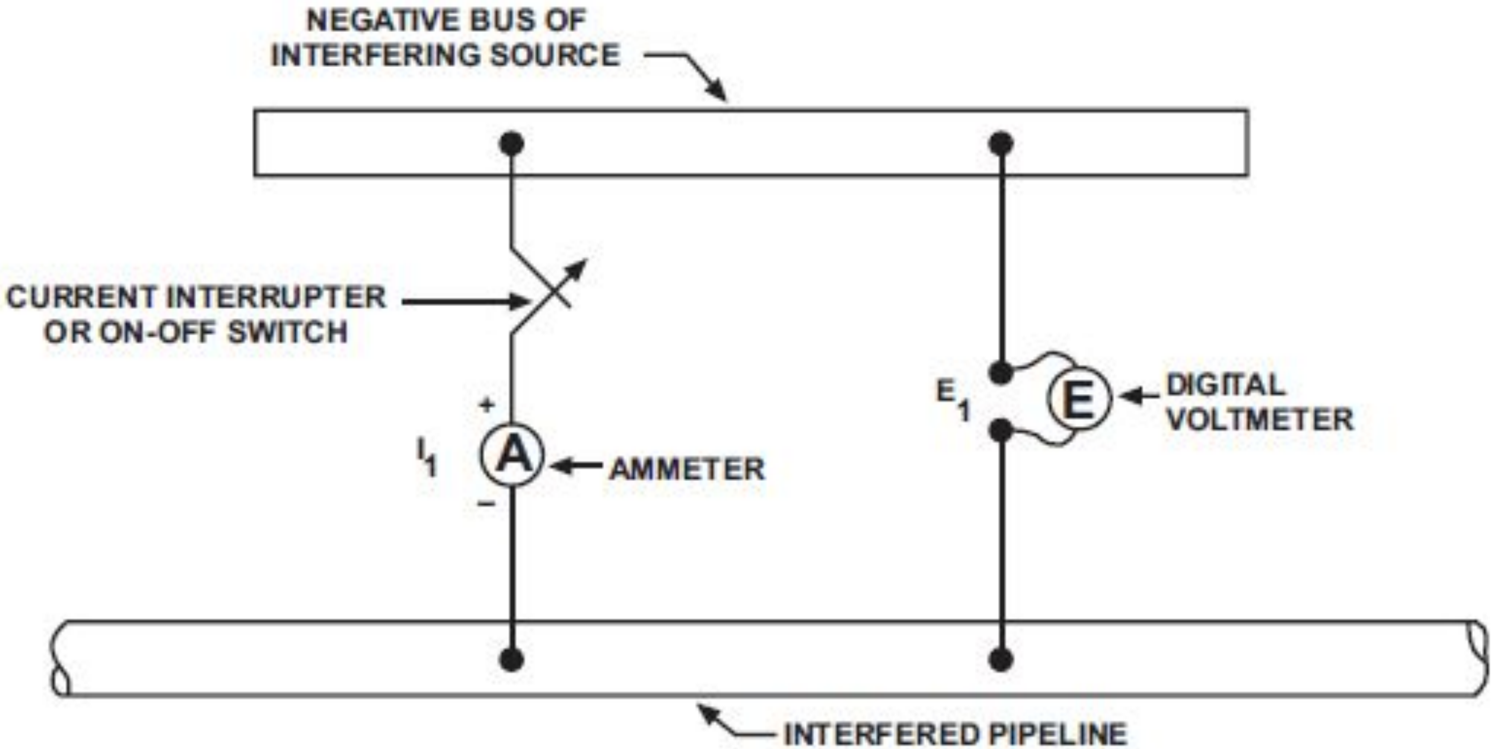
$$E_{SC} = I_b * \sum R_N$$

- With a bond installed:

$$\sum R_N = R_b + R_{int}$$

- $R_{int}$ is the resistance at the point on the pipe where current pickup occurs

# Repeat this at pickup spot




$$R_{int} = \frac{\Delta E_{SC}}{I}$$

# Mitigation – Resistive Bond

$$E_{SC} = I_b * (R_b + R_{int})$$

Solving for $R_b$:

$$R_{b=} \frac{E_{sc}}{I_b} - R_{int}$$

# Mitigation – Resistive Bond

Substitute value for $I_b$:

$$R_b = \left(E_{SC} * \left(\frac{R_{discharge}}{-\beta * E_{SC}}\right)\right) - R_{int}$$

The $E_{SC}$ values cancel out, and you're left with:

$$R_b = \frac{R_{discharge}}{-\beta} - R_{int}$$

# A Note About AC

While it will be covered in another class in this course, it is important to account for AC for safety reasons. Always take an AC voltage measurement to your reference electrode. Voltages-to-earth in excess of 15 $V_{AC}$ are dangerous for both step and touch potentials. Always measure before you start work!

# The Effects of Stray Current

- Dynamic stray current can have disastrous effects on pipelines if left ignored
- Impressed current densities can reach hundreds of amperes causing accelerated metal loss
- Graphitization – leaching of iron from steel, cast iron, and ductile iron structures, leaving behind only the carbon from within the matrix

# Special Thanks

- Kevin Groll
- Ed Richey
- James Jameison
- Lake Barrett
- SEPTA
- Philadelphia Gas Works

# QUESTIONS?