Advanced Chapter 4
Dynamic Stray Current Analysis

PowerPoint created by Earl S. Edwards

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DYNAMIC STRAY CURRENT ANALYSYS
CHAPTER 4

- INTRODUCTION
  - This chapter is to review a means of detecting dynamic stray current from various sources
  - There are many sources for dynamic stray current.

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DYNAMIC vs STATIC

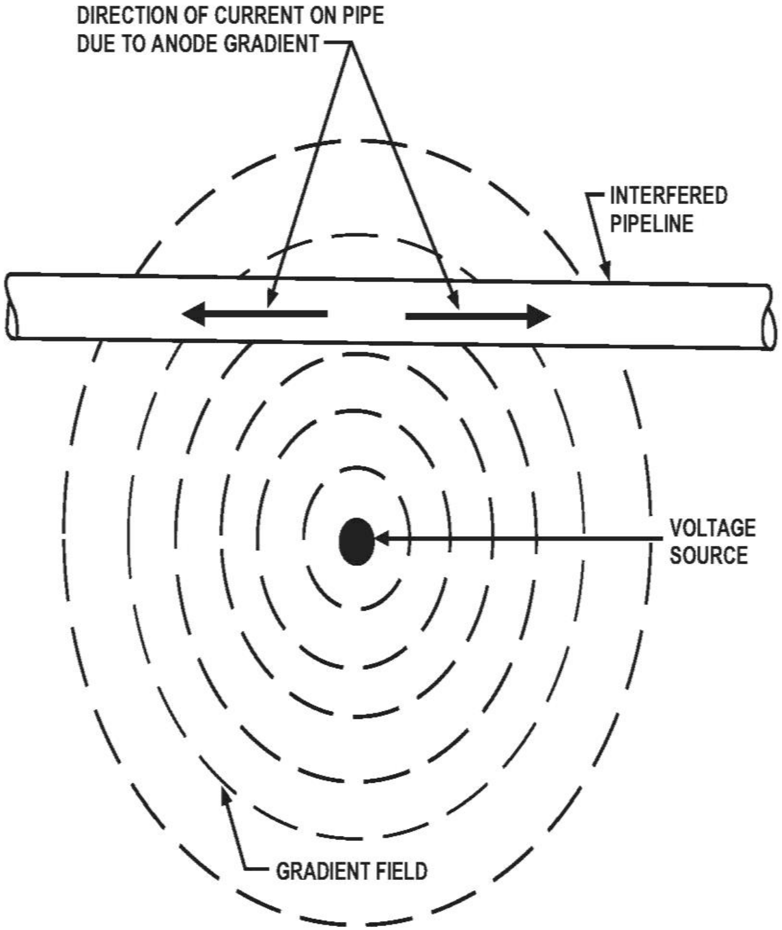
- Static stray current
  - A steady source of current from a foreign source
  - The most common example is a rectifier from another pipeline or tank company
  - Also could be from sources such as railroad signal batteries, or high voltage DC grounding
- Dynamic Stray Current
  - The most common source would be DC rail systems
  - Also could be chemical and smelter plants
  - Telluric current is also a potential source, a result of solar activity
  - AC stray current can also be an issue, but is not focused on in this chapter

THE EARTH AS A CONDUCTOR

- Soil resistivity
  - There is no such thing as uniform soil resistivity, unless you are in the middle of the ocean
  - Can vary from 25 ohm.cm to 1000000 ohm.cm
- Resistivity is the reciprocal of conductivity.
  - Essentially, the lower the resistivity of the soil, the more current can travel to the interfered structure (i.e.: pipeline)
- Regardless, the pipe resistivity is much lower than any soil or water (.000022 ohm.cm)
  - This will allow the current to flow a long way on the pipeline with very little voltage gradient

VOLTAGE GRADIENTS

- The cause of current flow is a potential difference between two points on the pipeline
- Each “line” in the gradient field illustrated can be considered a drop in voltage
- As the pipe traverses though several of these “lines”, this is called a potential difference
- The amount of current generated by this potential difference is inversely proportional to the resistivity of the earth. ($I = V/R$)



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VOLTAGE GRADIENTS (CONT.)

- Any pipe to soil variations should be investigated
  - Especially if the voltage variation is predominantly in the positive direction
- It is generally accepted that if the pipe to soil reading does not drop below (become more positive) than -0.850V instant off, then a corrosive condition is not likely to exist.

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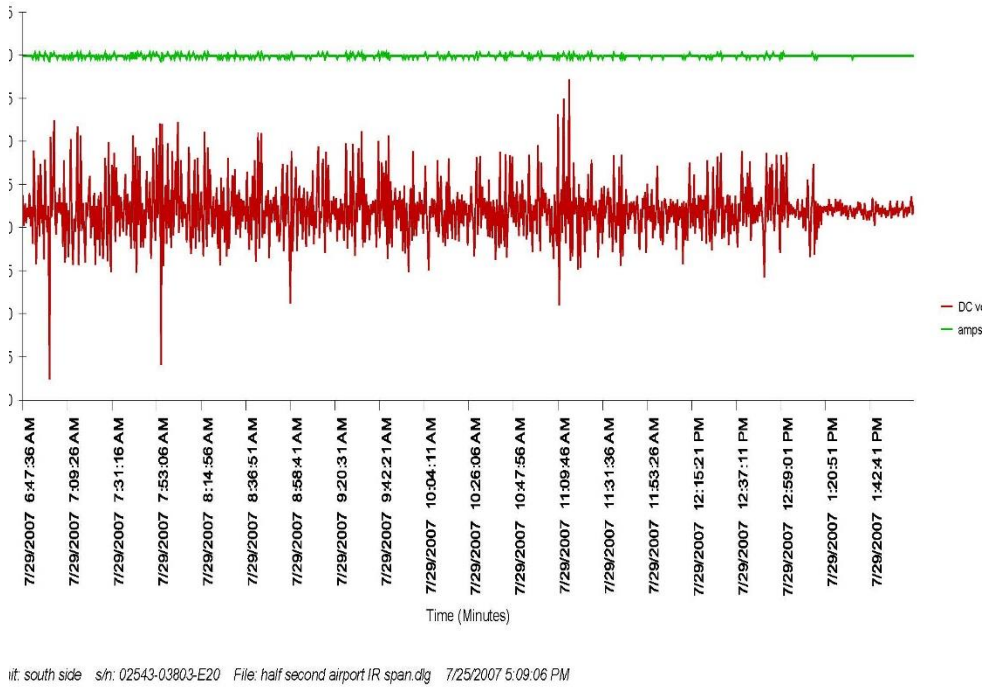
INITIAL DETECTION OF STRAY CURRENTS

- Normally the stray current will be noticeable because it is fluctuating rapidly while attempting to obtain a pipe to soil reading
- However this is not always the case. With Telluric currents, the voltage swing could take hours to complete a single cycle.
- Contact with technicians and engineers for other pipeline operators can assist in determining if there is a stray current issue in your area
    - A good resource is the Corrosion committee in your area
- Research to determine if there are any DC rail transit systems, mines, or chemical plants that may use high current DC power sources.



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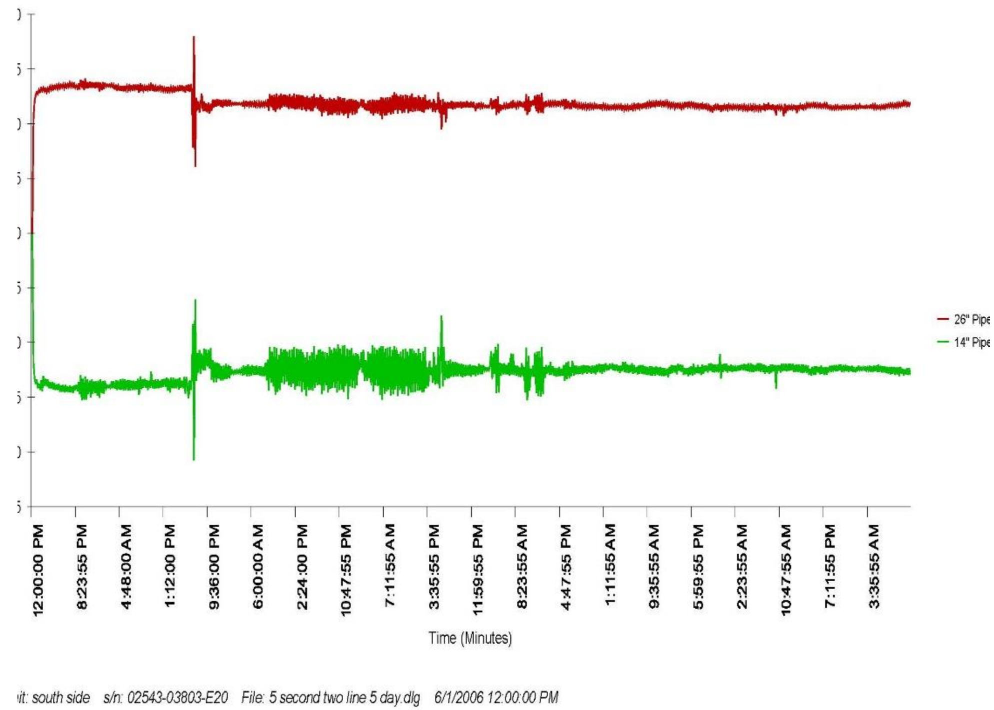
INITIAL DETECTION OF STRAY CURRENTS

- This graph shows a situation where the stray current source was not constant, or even cyclical



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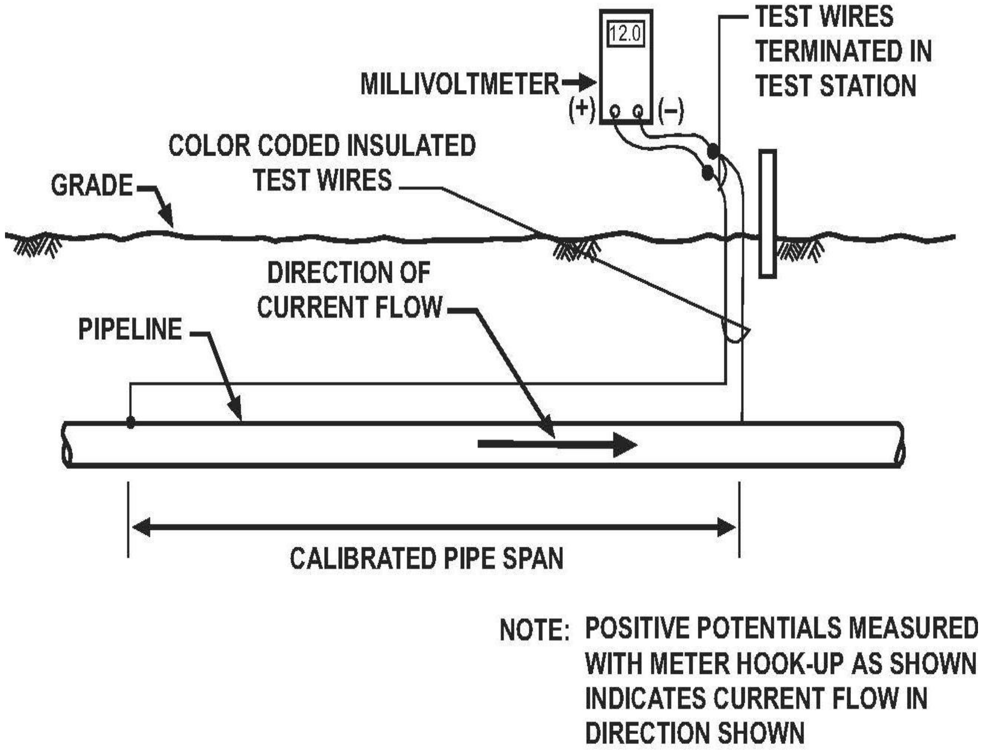
MEASURING CURRENT MAGNITUDE AND DIRECTION ON THE PIPELINE

- A calibrated span on the pipeline can be used to measure current at a particular location on a pipeline
- Although only two wire shown, there is normally 4 wires, to allow for calibration of the span to accurately calculate the current
- Can use standard resistance charts to determine the resistance of the span
  - Not as accurate, but will give a good indication
- Would need a sufficient amount of current spans, and they would need to be properly located to assist in determining the point of maximum exposure.



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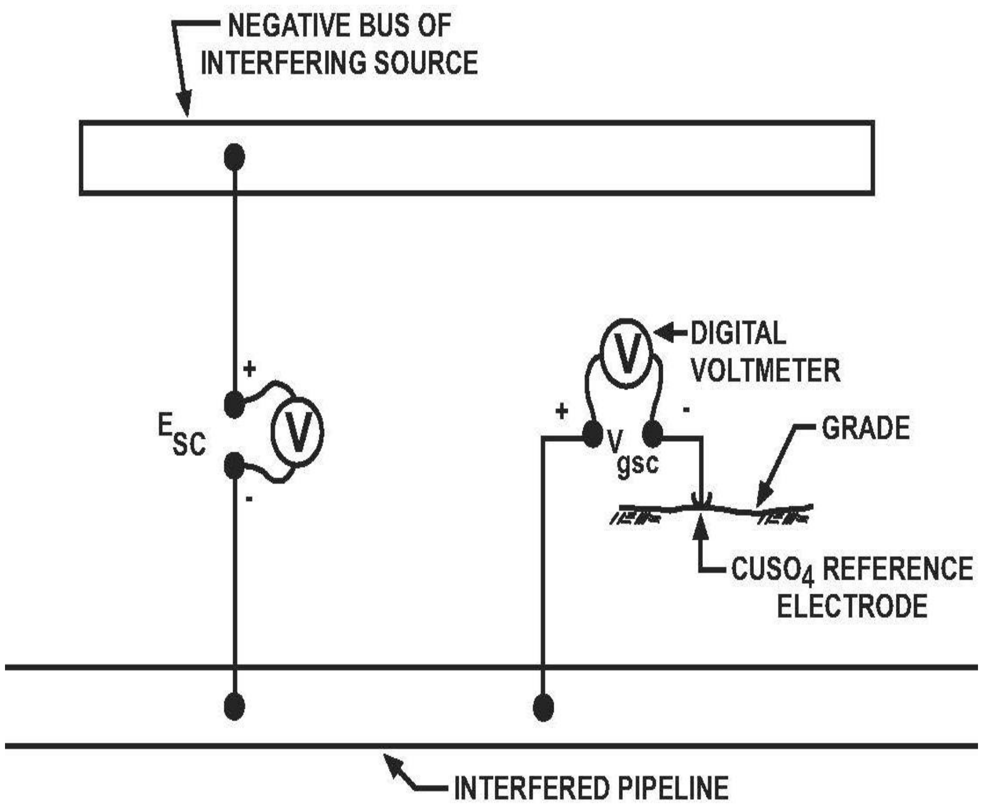
TESTING FOR POINT OF MAXIMUM EXPOSURE

- With a single source of stray current, Beta curves can be used to determine the point of maximum exposure
- This is used to monitor the voltage change on the pipeline with reference to the voltage difference between the pipe and the negative return bus on the rail line.

TEST SET UP FOR DETERMINING POINT OF MAXIMUM EXPOSURE

- $E_{(SC)}$ is the voltage difference between the ground rail and the pipeline
- $V_{(gsc)}$ is the pipe to soil potential obtained at a single location on the pipeline
- Use of synchronized data loggers is critical for obtaining this data.
- The time stamp for the data must be identical.



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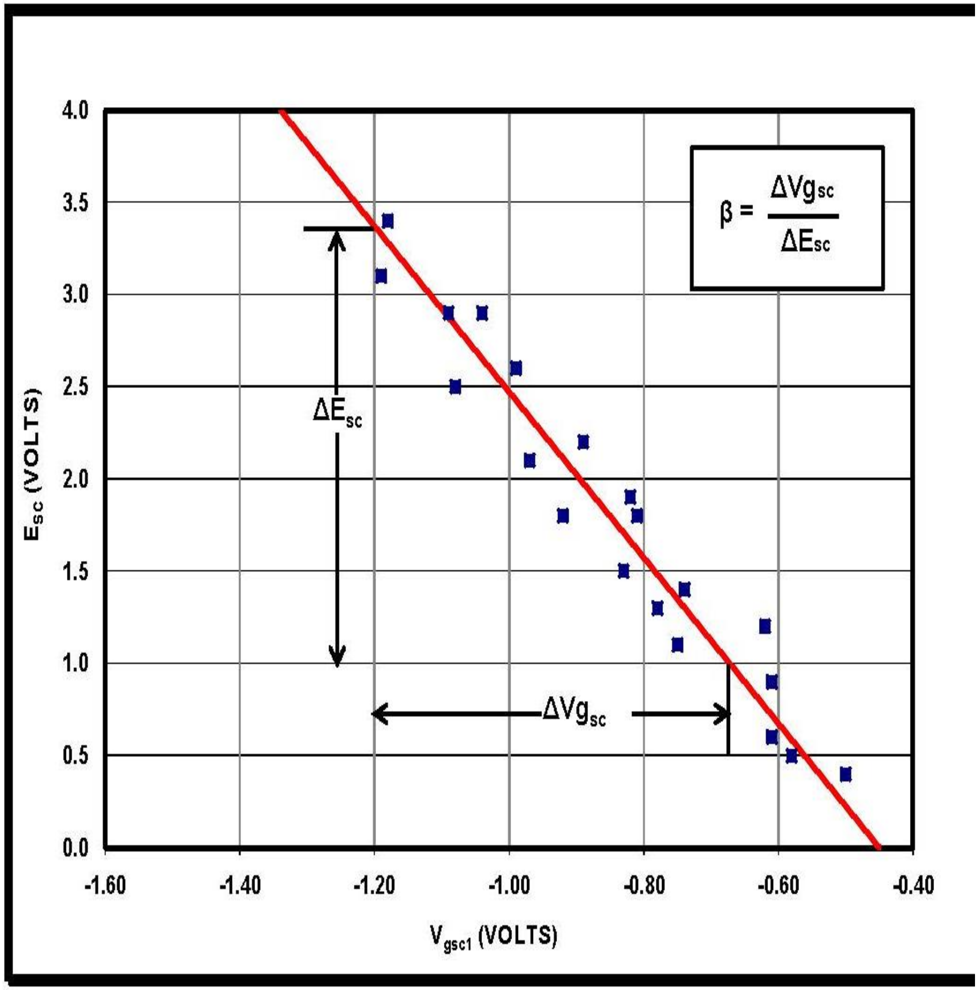
BETA CURVE OF A CURRENT PICKUP AREA

- The Beta curve is calculated at each point as follows
  - ΔEsc – CHANGE IN VOLTAGE
  - ΔVgsc – CHANGE IN PIPE TO SOIL POTENTIAL
- $\frac{\Delta Vgsc}{\Delta Esc} = \beta$
- A negative slope as shown to the right is indicative of a current pickup area.



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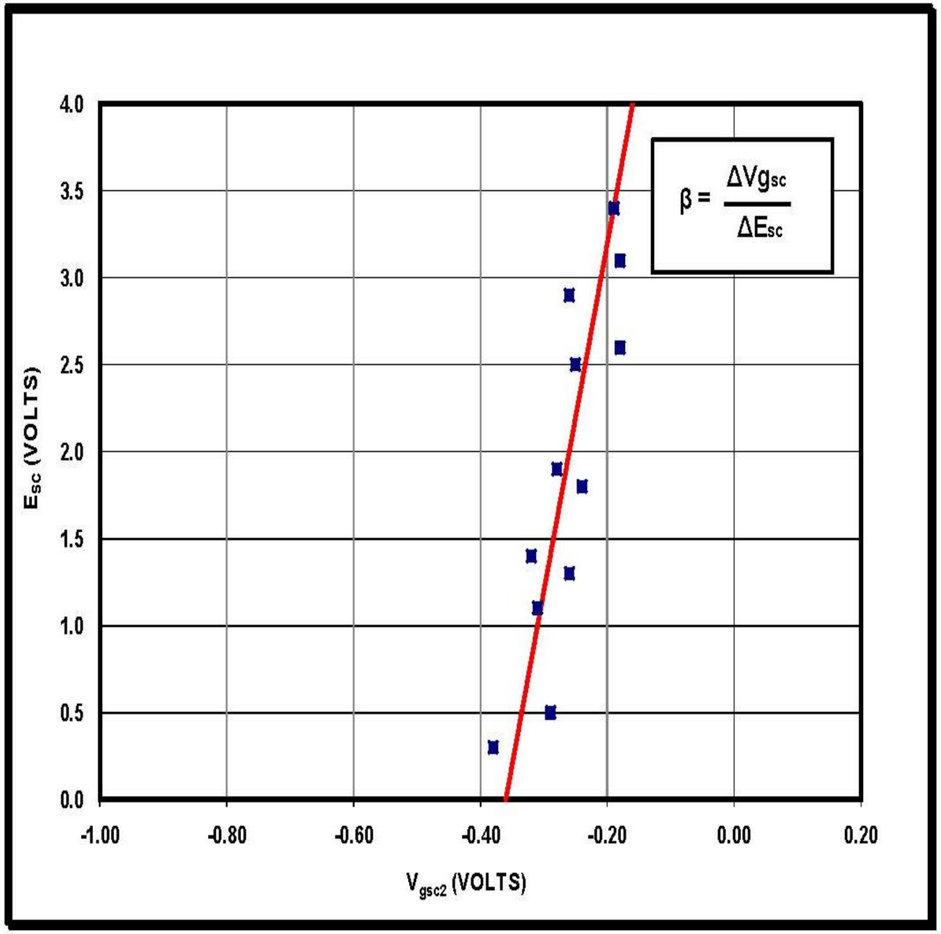
BETA CURVE OF A CURRENT DISCHARGE AREA

- A positive slope will indicate a location of potential current discharge
- The steeper the slope, the smaller the Beta number will be
- A vertical slope indicates no influence from the stray voltage.
  - This rarely happens, and if this is plotted, the equipment that is used should be verified
- The larger the Beta (Shallower the slope) the more potential for current discharge.
- Need to obtain curves at several locations



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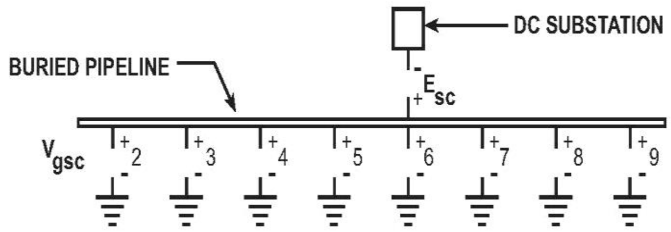
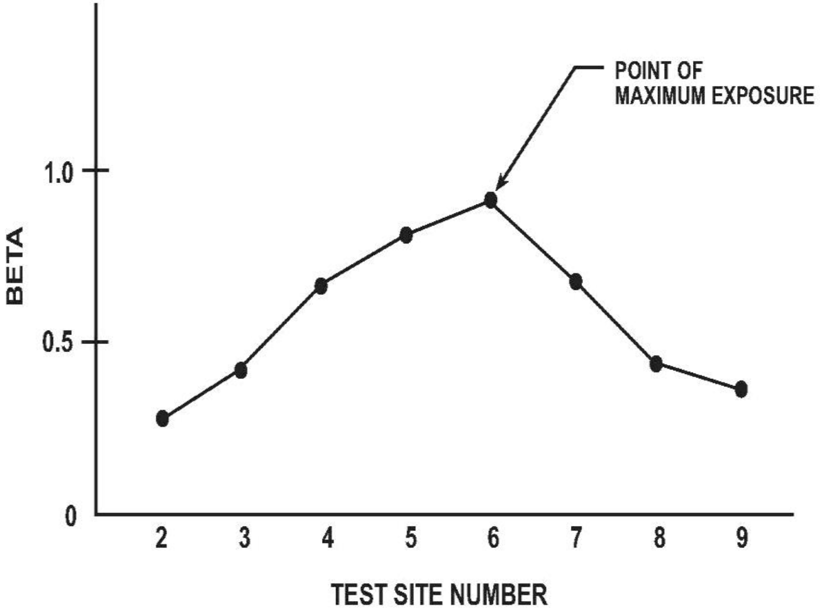
LOCATING THE POINT OF MAXIMUM EXPOSURE ON PIPELINE

- The calculated beta curves can be plotted on a graph as shown
- Remember the positive Beta curve is a discharge location
- The point of maximum exposure can be determined by using the largest Beta
- In this example, it is at the test station closest to the substation





MITIGATION(NOT ELIMINATION) OPTIONS

- Controlling the source
  - The biggest culprit is the ground rails on DC transit systems.
  - Maintaining electrical isolation from the earth is critical to minimizing stray currents
  - Use of insulated fasteners to the tie down locations.
  - In locations of welding (such as factories), the ground and the electrode should be as close together as possible

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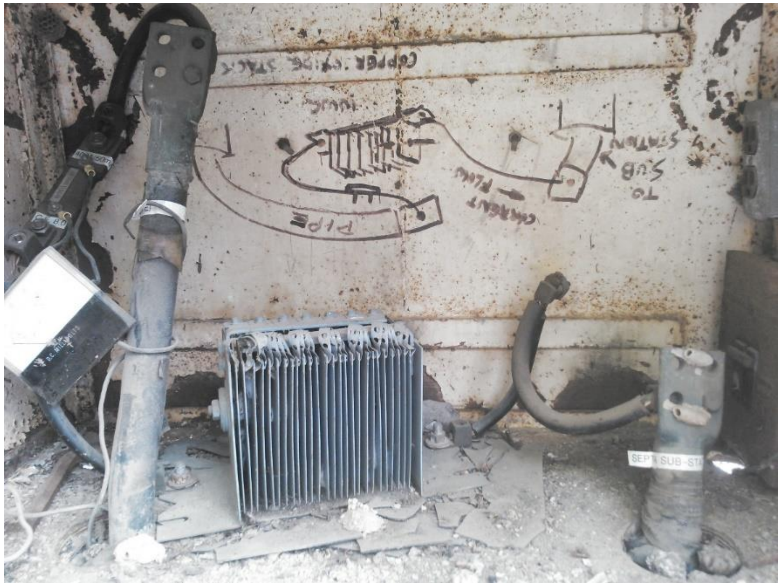
DESIGNING A DRAINAGE BOND

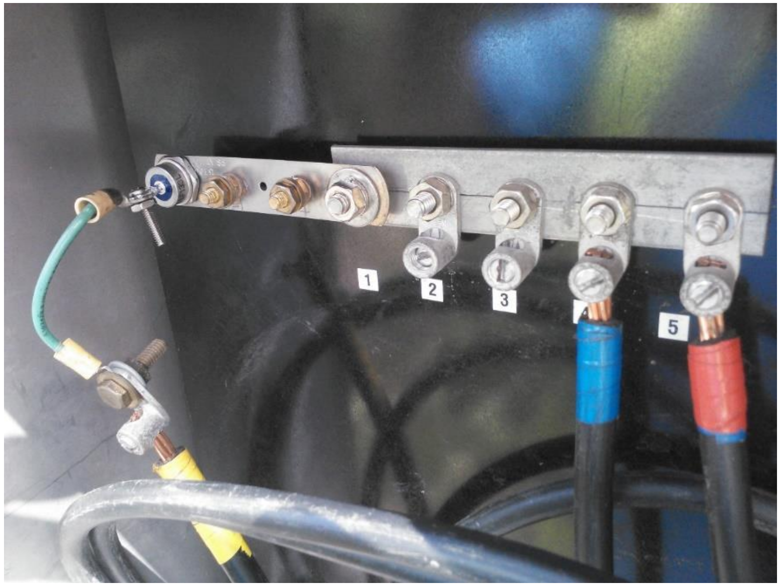
- A bond can be used to drain the current back to the substation
- This should be avoided on the newer transit systems
  - Modern rail systems are normally well grounded
  - The bond will significantly lower the circuit resistance between the rail system and the pipeline
  - This will cause a large increase in interference current that would normally not be present.
- There is a need to calculate the resistance of the bond, to ensure that not too much current is drained

BONDS AND REVERSE CURRENT SWITCHES

Selenium stack to mitigate large currents



Simple diode to mitigate lower current levels



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LOCATION OF BOND

- As stated previously, the bond should be located at the point of maximum exposure
- Testing needs to be completed to properly size the bond, and ensure it is sufficient to mitigate the interference
- The proper equipment will be required
  - Data loggers
  - Cables large enough to handle the current expected.

METHODS TO SIZE A BOND

- Trial and Error method
  - Involves using temporary bonds and obtaining readings
  - As with any testing, the testing needs to be coordinated with the railway
  - Need to use cables that can handle very large amounts of current
    - In excess of 200A
  - May involve several attempts.

METHODS TO SIZE A BOND

- Mathematical method
  - Still involves testing with the railway to obtain some of the variables involved in the calculations

- Consider the total voltage Vg
  - $Vg = \Delta Vgo + \Delta Vgcp + \Delta Vgsc + \Delta Vgb$
    - Vg – Total pipe to soil
    - ΔVgo- Native pipe to soil of the pipeline (No CP applied)
    - ΔVgcp – Added voltage from applied CP
    - ΔVgsc – Voltage change created by stray current sources
    - ΔVgb – Voltage change created by the bond being installed

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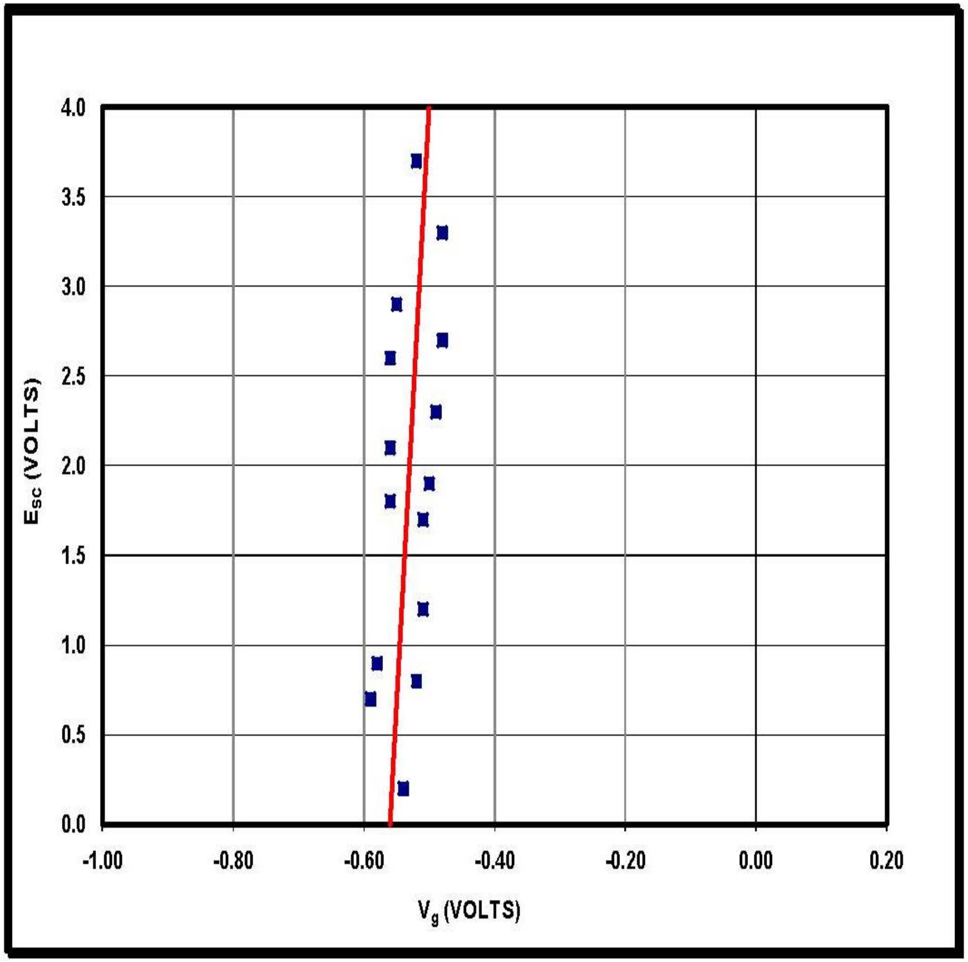
MATHMATICAL METHOD

- ΔVgsc can be determined using the beta curve
  - $\Delta Vgsc = \beta * \Delta Esc$
- Assume ΔVgcp = 0
- Then substitute for ΔVgsc
  - $Vg = \Delta Vgo + (\beta * \Delta Esc) + \Delta Vgb$
- For current to be mitigated
  - $\Delta Vgb = \beta * \Delta Esc$
  - And $\Delta Vg = \Delta Vgo$



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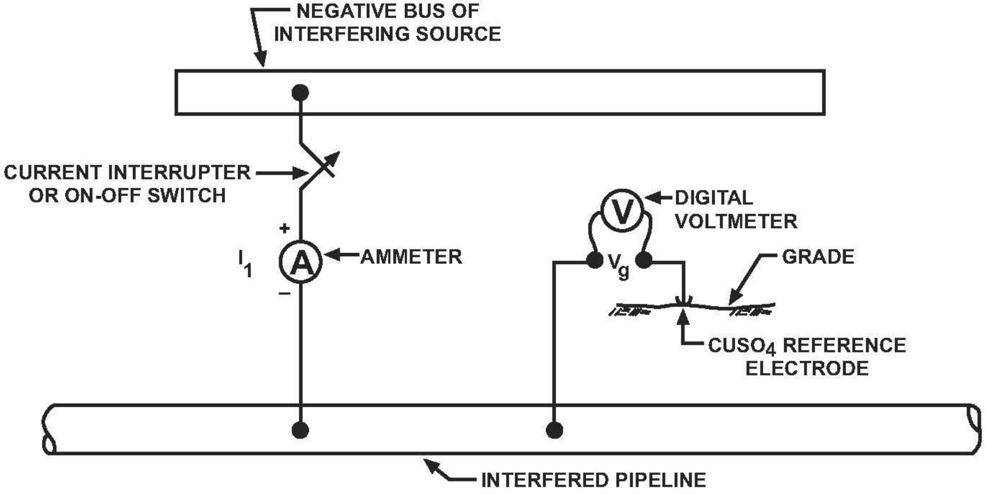
TESTING TO PERFORM FOR CALCULATIONS

- The diagram shows the test set up for getting the results needed for this calculation below.
- This test is to determine the change in the pipe to soil potential per ampere of current
  - $\Delta Vg = Vg(on) - Vg(off)$
  - $\Delta I1 = I1(on) - I1(off)$
  - Volts per amp = $\Delta Vg / \Delta I1$



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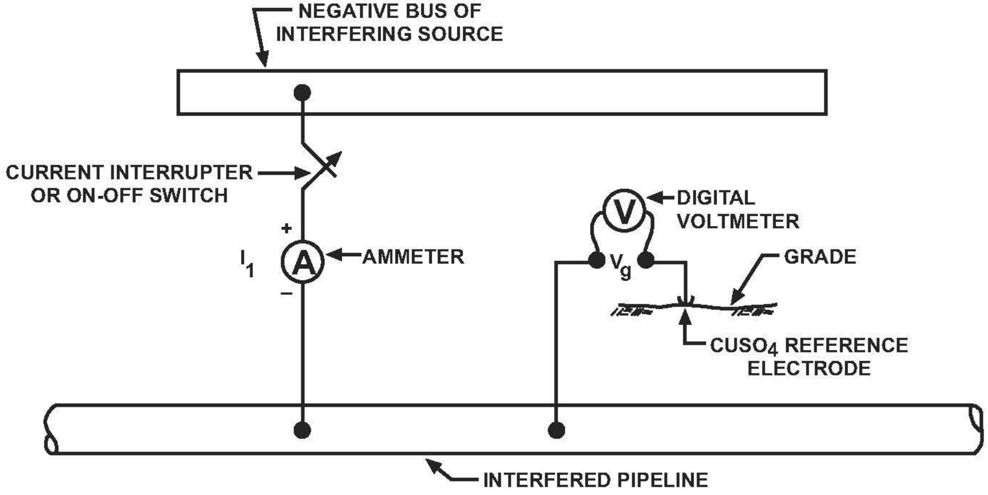
DERIVE THE FORMULA TO CALCULATE THE BOND CURRENT

- The change in voltage as a result of the bond can be calculated by
  - $\Delta Vgb = Ib * (\frac{\Delta Vg}{I1})$
- Substitute for ΔVgb
  - $\beta * Esc = Ib * (\frac{\Delta Vg}{I1})$
- Solve for Ib
  - $Ib = \beta * Esc/(\frac{\Delta Vg}{I1})$



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CALCULATE THE RESISTANCE OF THE BOND

- The resistance of the circuit is a combination of the internal resistance (R_{int}) and the bond resistance (R_b)
- Use ohms law – V=IR to solve for the resistance
  - Substitute V with E_{sc} (Stray voltage between rail and pipeline)
  - Substitute I with I_b (Bond current)
  - Substitute R with $R_{int} + R_b$ (Combined resistance)
    - $Esc = Ib * (Rint + Rb)$
    - $Rb = \frac{Esc}{Ib}$-Rint

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CALCULATE THE RESISTANCE OF THE BOND

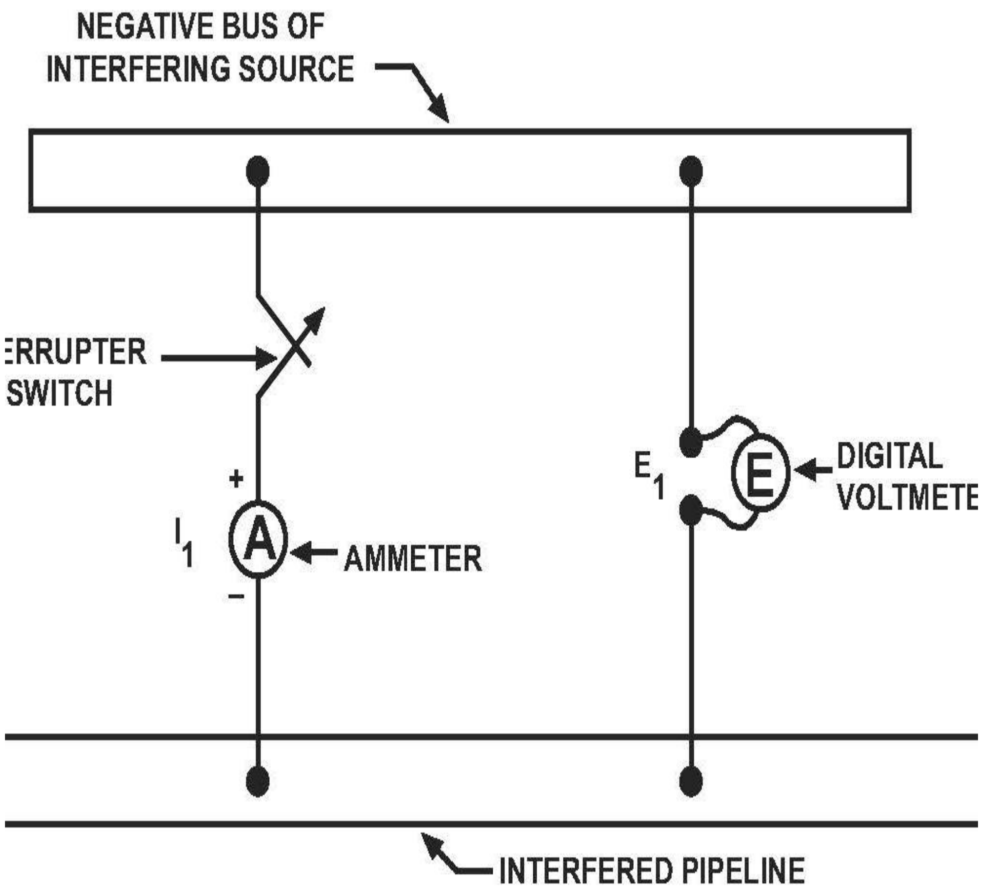
- Since I_b is still unknown, it needs to be substituted from the formula derived previously
  - $Ib = \beta * Esc/(\frac{\Delta Vg}{I1})$

- $Rb = Esc * \frac{\Delta Vg}{I1}/(\beta * Esc) - Rint$

- E_{sc} cancels out and the formula simplifies to
  - $Rb = \frac{\Delta Vg/I1}{\beta} - \mathrm{Rint}$

CALCULATING INTERNAL RESISTANCE Rint

- The circuit shown is interrupted several times, and the data tabulated to get an average internal resistance
- The data obtained is as follows
  - $\Delta E1 = E1(on) - E1(off)$
  - $\Delta I1 = I1(on) - I1(off)$
  - $Rint = \Delta E1/\Delta I1$



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MEASUREMENTS TAKE
OBTAIN INTERNAL RESIS

	E_1 (Volts)	I_1 (Amperes)	R_{int} (ohms)
On	+1.30	36.0	
Off	-1.15	0	
Delta	+2.45	36.0	0.068
On	+0.80	39.0	
Off	-1.80	0	
Delta	+2.60	39.0	0.067
On	+0.50	41.0	
Off	-2.30	0	
Delta	+2.80	41.0	0 .068
On	+2.10	29.0	
Off	0.00	0	
Delta	+2.10	29.0	0.072
On	+2.00	29.5	
Off	-0.15	0	
Delta	+2.15	29.5	0.073
On	+1.30	35.0	
Off	-1.25	0	
Delta	+2.55	35.0	0.073
On	+0.35	43.0	
Off	-2.65	0	

MEASUREMENTS TAKEN TO OBTAIN THE POTENTIAL CHANGE PER AMPERE

TABLE 4-2

$\Delta V_g/I_1$ Data - See Figure 4-11

	V_g (Volts)	I_1 (Amperes)	$\Delta V_g/I_1$ (V/A)
On	0.645	34.0	
Off	0.590	0	
Delta	0.055	34.0	0.00162
On	0.635	23.0	
Off	0.600	0	
Delta	0.035	23.0	0.00150
On	0.770	82.0	
Off	0.620	0	
Delta	0.150	82.0	0.00183
On	0.770	86.0	
Off	0.625	0	
Delta	0.145	86.0	0.00168
		Average $\Delta V_g/I_1$ =	**0.00169**

USING THE DATA

- To calculate the required bond resistance
  - $Rb = \frac{\Delta Vg/I1}{\beta} - \text{Rint}$
  - $^{\Delta Vg}/_{I1}$=.00169 (From table 4-2)
  - B = .017 (Calculated at point of maximum exposure)
  - R_{int} = .070 (From table 4-1)

  - R_b = (.00169/.017)-.070 = 0.0294ohm
- The resistance in this case is low enough, no resistor would be added to the circuit

DETERMINING EXPECTED BOND CURRENT

- Need to determine the maximum voltage difference (E_{sc}) that will be seen by the bond
  - Use the maximum voltage recorded on a data logger over a 24 hour period
- For this example, use 12V
- Using ohm's law V=IR
  - $Esc = Ib * (Rint + Rb)$
  - $Ib = Esc/(Rint + Rb)$
  - $Ib = \frac{12}{.070+.0294}$
  - $Ib = 120.7A$

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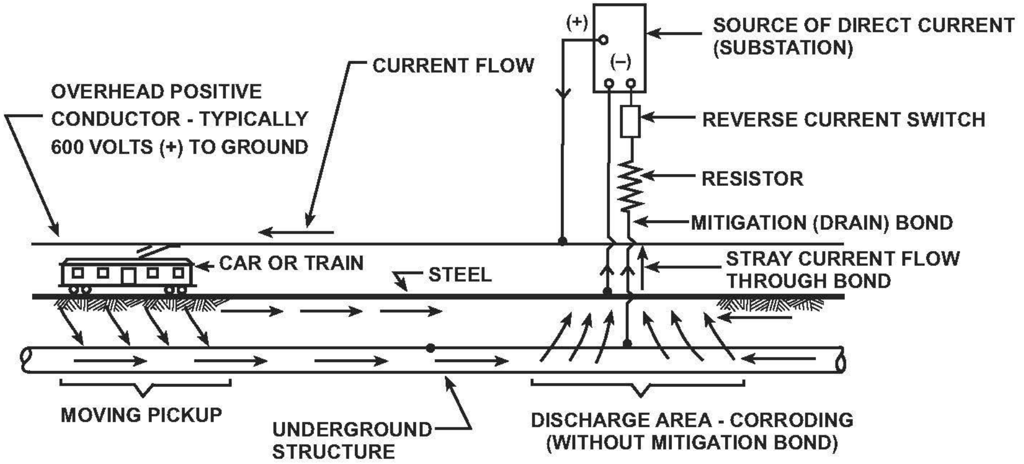
SKETCH OF TYPICAL BOND INSTALLATION



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GALVANIC ANODES

- Galvanic anodes can be used to mitigate very small amounts of current
  - Their driving voltage is low, and can not produce much current
  - The soil resistivity is also high, also limiting the amount of current it is produced
- The anodes also have a high consumption rate, and have a short life span

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IMPRESSED CURRENT

- An impressed current system (rectifier) can be used to generate larger amounts of current, that will offset the stray current from the interfering source
- The rectifiers can also be potential controlled to allow the current to fluctuate to offset the stray voltage
- These are usually designed by trial and error.

AC CORROSION

- AC current density that is greater than 20A/m2 needs to be remediated
- Most common issue is induced AC from a power line
- AC rail lines can also produce sufficient current to be of concern

INDUCED AC

- Step potential becomes a hazard
- Any AC pipe to soil voltages greater than 15V need to be addressed
- NACE SPO 177 provides a standard to follow when mitigating AC

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