Basic Course

Chapter 5 – Potential Measurements

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AUCSC

Appalachian Underground Corrosion Short Course

Why Are We Here?

- I love corrosion (or the lack of corrosion).
- My boss sent me.
- My company offered to pay for it.
- This is my 2nd time.
- I know the instructor and plan to heckle him during his presentation.
- When is lunch?

Potential Measurements

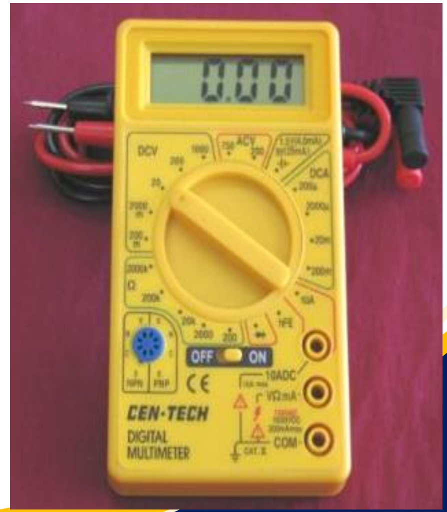
- Accurate potential measurements are critical to many areas of corrosion control work on underground structures.
- Inaccurate potential readings can lead to entirely incorrect conclusions regarding the need for corrosion control or the performance of a cathodic protection system.

Chapter 5 Material

- An overview of instrumentation requirements.
- Reference electrodes used in certain potential measurements.
- Types of potential measurements.
- Potential measurement techniques.
- Polarization effects.
- Criteria for cathodic protection.
- Monitoring cathodic protection systems.

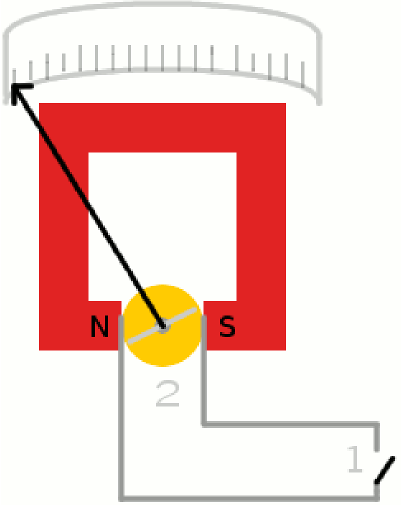
Voltmeters

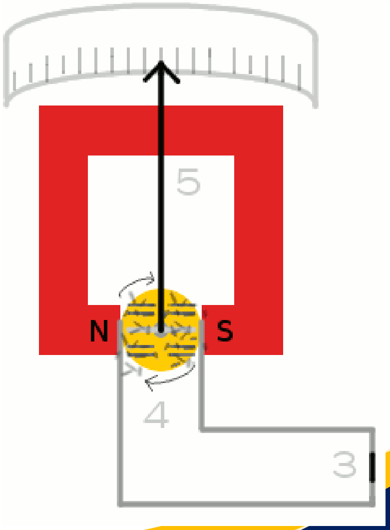
- Analog
  - Moving needle
- Digital
  - Electronic digital readout



Analog Voltmeters

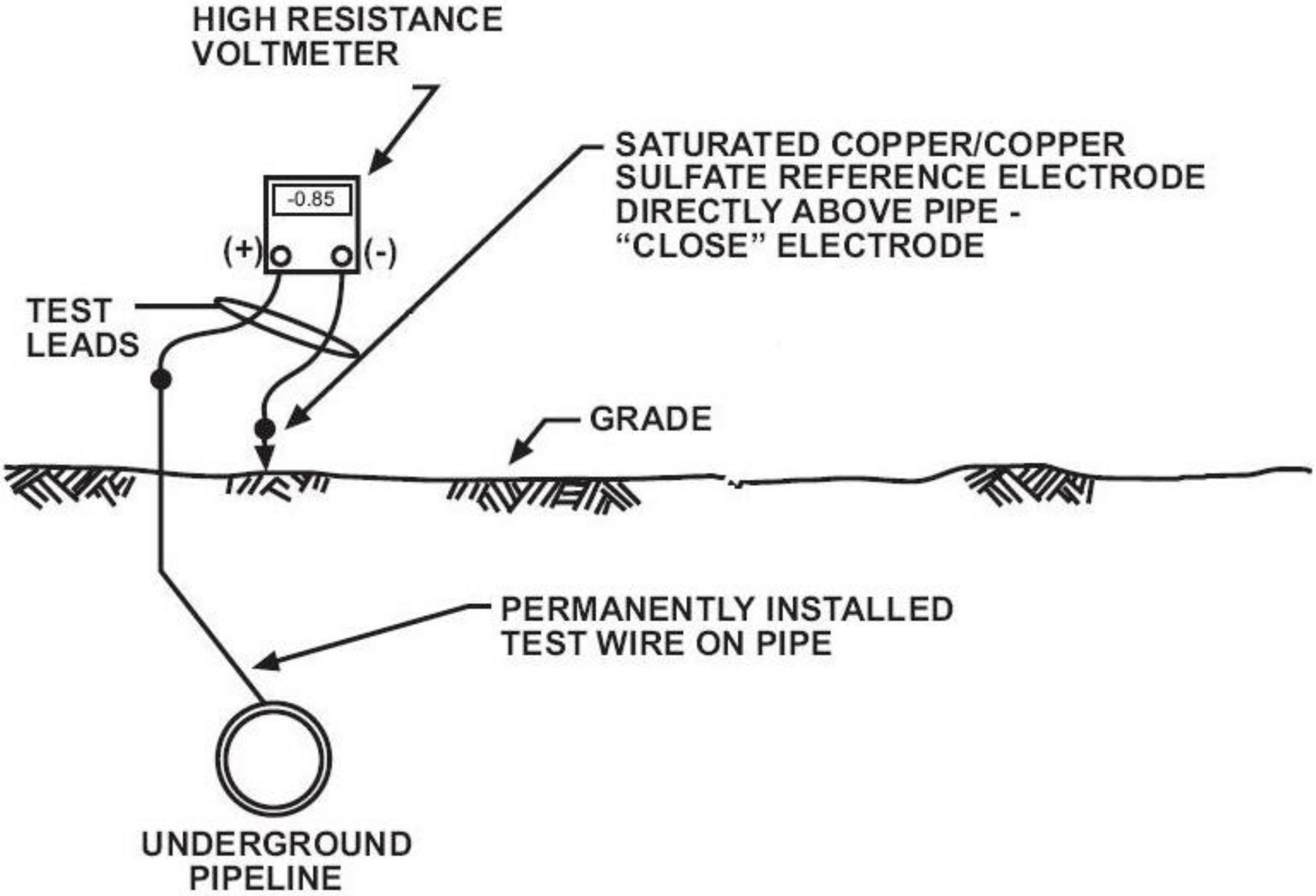
1. With the probes unconnected (switch open) – no current can flow through the circuit.
2. With no current flow, the coil generates no magnetic field – pointer at zero.
3. Connect the probes (switch closed) and current flows through the coil.
4. Current creates a magnetic field in the coil.
5. The greater the current, the greater the magnetic field – the higher up the dial the pointer moves.





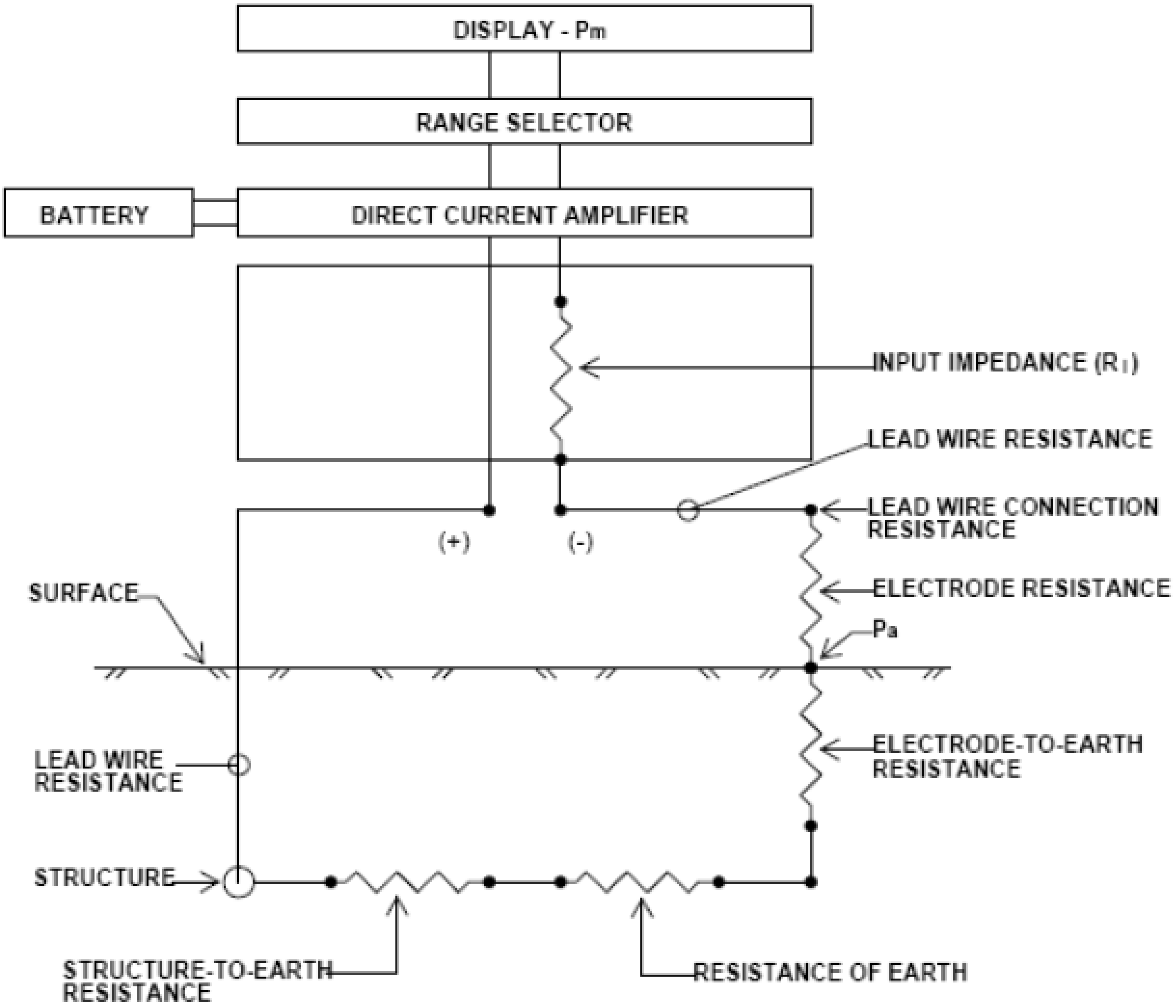
Digital Voltmeters

- Entirely electronic
- Digital readout
- Input resistance is typically very high (>10 Megohms)
- Current taken from external circuit is very small
- Very little voltage drop through external circuit


HIGH RESISTANCE VOLTMETER
-0.85
(+)
(-)
SATURATED COPPER/COPPER SULFATE REFERENCE ELECTRODE DIRECTLY ABOVE PIPE - “CLOSE” ELECTRODE
TEST LEADS
GRADE
PERMANENTLY INSTALLED TEST WIRE ON PIPE
UNDERGROUND PIPELINE

Effect of Voltmeter Resistance

- The internal impedance (R_i) of the voltmeter used must be high with respect to the external circuit resistance (R_e) if accurate results are to be obtained.
- The accuracy of the meter depends on the ratio of the meter impedance to the external resistance.
- (R_e) can be several thousand ohms.


DISPLAY - Pm
RANGE SELECTOR
BATTERY
DIRECT CURRENT AMPLIFIER
INPUT IMPEDANCE (RI)
LEAD WIRE RESISTANCE
LEAD WIRE CONNECTION RESISTANCE
(+)
(-)
SURFACE
ELECTRODE RESISTANCE
Pa
ELECTRODE-TO-EARTH RESISTANCE
LEAD WIRE RESISTANCE
STRUCTURE
STRUCTURE-TO-EARTH RESISTANCE
RESISTANCE OF EARTH

True Pipeline Potential = -0.950v_{cse}

- External resistance
  - 2500 ohms
- Internal resistance
  - 100,000 ohms
- Meter reading
  - -0.927V

- External resistance
  - 2500 ohms
- Internal resistance
  - 1,000 ohms
- Meter reading
  - -0.271V

True Pipeline Potential = $-0.950v_{cse}$

$$E_{ACC} = E_M \times \frac{R_M + R_{EXT}}{R_M}$$

E_{ACC} = Accurate potential in volts

E_M = Voltmeter reading in volts

R_M = Voltmeter resistance in ohms

R_{EXT} = Resistance of external circuit in ohms

- Meter reading

-0.927V

$$E_{ACC} = 0.927 \times \frac{100{,}000 + 2500}{100{,}000}$$

$$= 0.927 \times 1.025 = 0.95 \text{ volts}$$

- Meter reading

-0.271V

$$E_{ACC} = 0.271 \times \frac{1000 + 2500}{1000}$$

$$= 0.271 \times 3.5 = 0.95 \text{ volts}$$

Ohm’s Law I = E / R

- The higher the input impedance (R), the lower the display operating current.
- The lower the operating current, the lower the IR drop through R_e.

- More accurate potentials.

No, thanks – I don’t do math

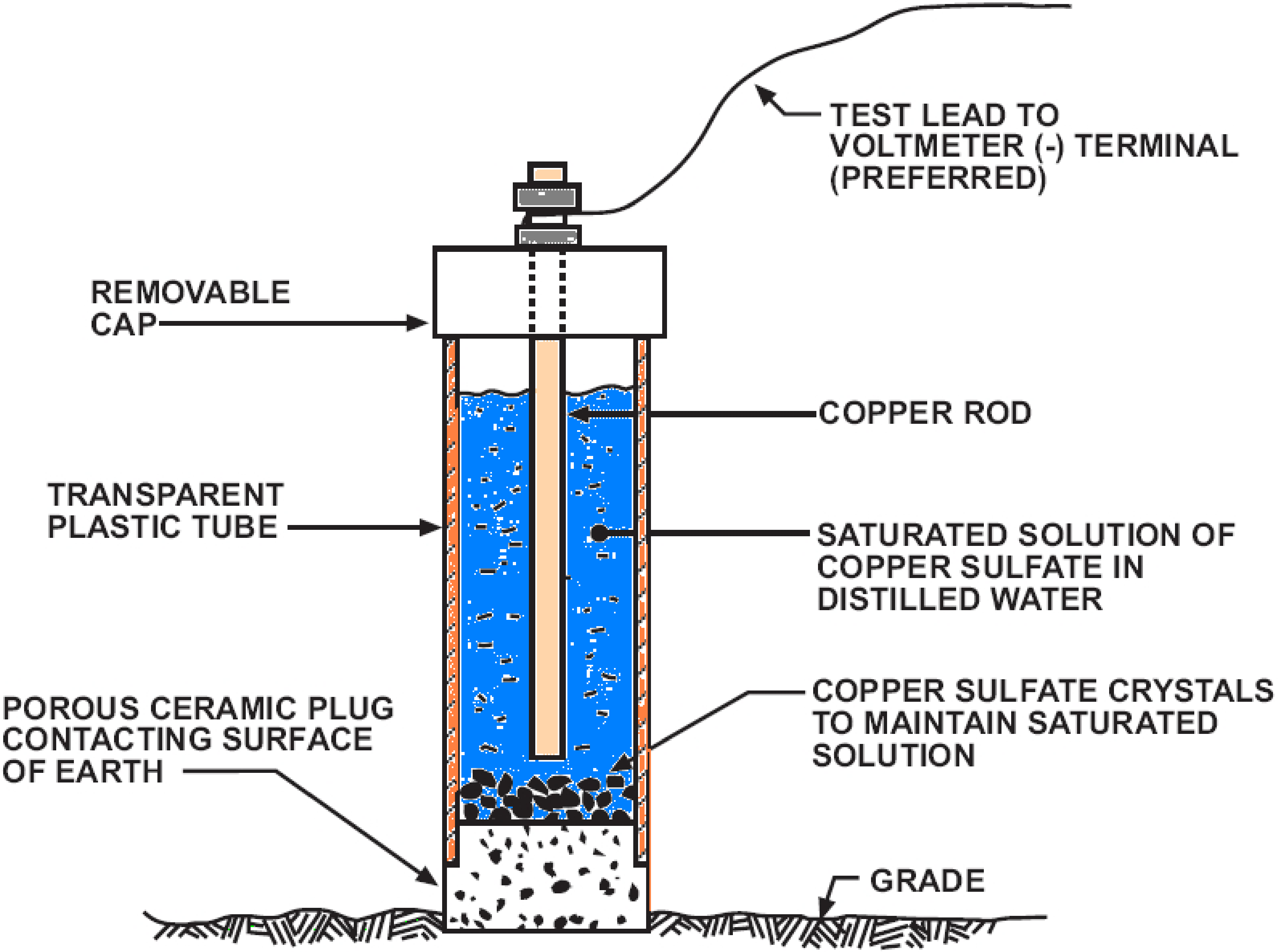
- Conclusion:
  - Use a good high resistance voltmeter!
  - “When taking a potential measurement with a digital voltmeter, the voltmeter resistance is so high (typically 10 megohms or more) that external circuit resistance should seldom be a problem.”

Reference Electrodes

- A reference electrode is simply a device which is used to contact earth or water and to which the test lead from the voltmeter is connected.
  - Must be able to give repeatable and comparable readings
- Most common in corrosion work on underground structures:
  - $Cu\text{-}SO_4$ copper-copper sulfate half cell

Reference Electrodes

- A reference electrode is one half of a corrosion cell – consisting of a metal in a solution of it’s metal ions.
- The “half cell” potential is constant if the concentration of metal ions in the solution around the metal remains constant.
- This is achieved by having a constant concentration of copper ions (saturated) in the solution around the copper rod.


TEST LEAD TO VOLTMETER (-) TERMINAL (PREFERRED)
REMOVABLE CAP
COPPER ROD
TRANSPARENT PLASTIC TUBE
SATURATED SOLUTION OF COPPER SULFATE IN DISTILLED WATER
COPPER SULFATE CRYSTALS TO MAINTAIN SATURATED SOLUTION
POROUS CERAMIC PLUG CONTACTING SURFACE OF EARTH
GRADE

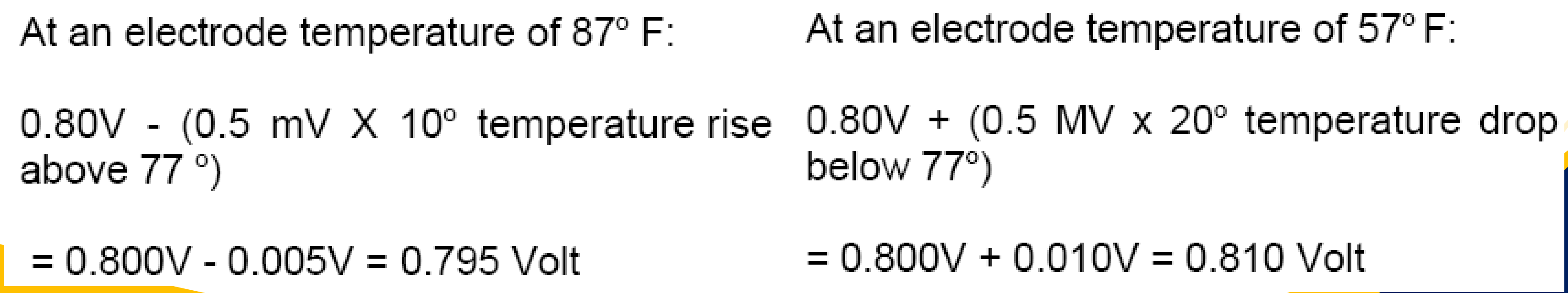
Precautions

- Keep solution saturated
  - Extra crystals to ensure solution stays saturated
- Use distilled water
- Copper rod will gradually become encrusted
  - Clean with sandpaper or dip in 10% nitric acid
- Keep porous plug covered when not in use
- Replace solution if it becomes discolored or “milky”
- Keep an extra unused half cell for calibration – 10mV

Two Things to Remember:

1. Temperature Effect
   - Cu-$CuSO_4$ half cell is subject to change due to temperature.
   - -0.0005V (½ millivolt) per degree change from 77º F

$$E_{CSE}^{*} = E_{CSE} - 0.5\ \mathrm{mv/^{\circ}F}\ (T - 77^{\circ}F)$$



At an electrode temperature of 87° F:

0.80V - (0.5 mV X 10° temperature rise above 77 °)

= 0.800V - 0.005V = 0.795 Volt

At an electrode temperature of 57° F:

0.80V + (0.5 MV x 20° temperature drop below 77°)

= 0.800V + 0.010V = 0.810 Volt

Two Things to Remember:

2. Photoelectric Effect
   - Cu-$CuSO_4$ half cell is subject to change due to sunlight.
   - Usually more of a problem when the copper rod is not clean

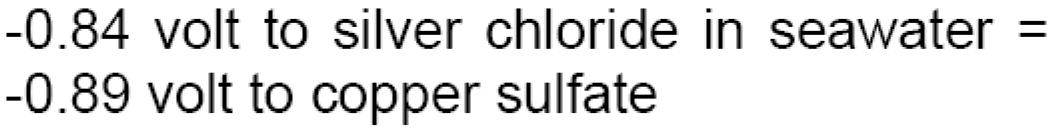
   - Can be checked by shading the electrode to see if there is any change in the voltmeter reading. (Keep shaded)

Other Reference Cells

- Silver-silver chloride Ag-AgCl
  - For use in sea water
    - Off-shore pipelines and drilling platforms
- Does not contain a liquid solution
  - Core of silver gauze with a film of silver chloride.
  - Enclosed in a protective sleeve which allows free entry of sea water.

Other Reference Cells

- The ½ cell potential of the saturated silver/silver chloride reference electrode in 25 ohm-cm seawater is 0.050V less than a copper/copper sulfate reference electrode.



-0.84 volt to silver chloride in seawater =
-0.89 volt to copper sulfate

Conclusions

- Leaving a ½ cell in your vehicle overnight during cold weather can impact the accuracy of measurements.
  - Temperature effect
  - Frozen solution can damage electrode
- Leaving a ½ cell in your vehicle during hot weather or in direct sunlight can impact the accuracy of measurements.
  - Temperature and photoelectric effect
- Not keeping your ½ cell clean can impact the accuracy of measurements.

Electrode-to-Earth Resistance

- Contact resistance between the reference electrode and the earth is usually the cause of high external resistance requiring the use of high resistance voltmeters.

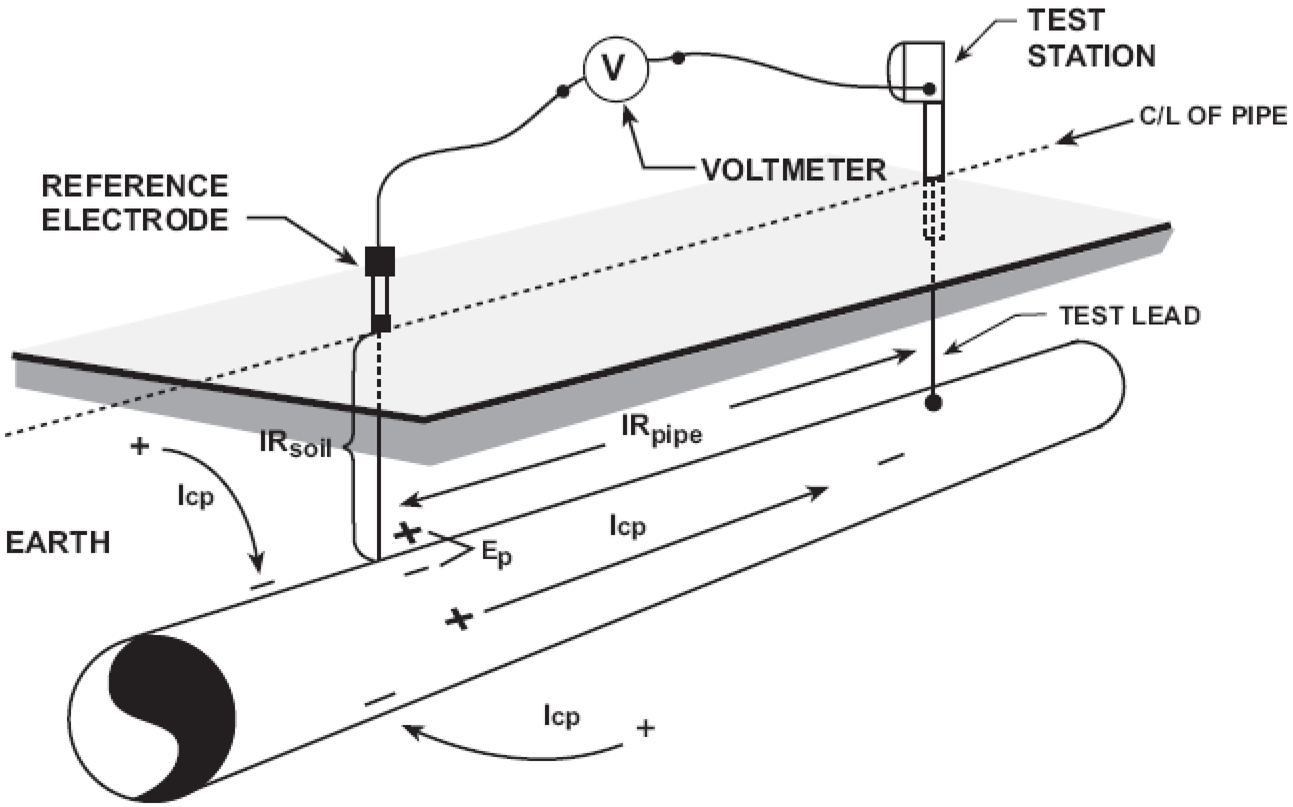
Electrode-to-Earth Resistance

- To reduce this:
  - Scrape away dry surface soil to expose moist surface.
  - Wet the surface with water.
  - No contact with anything foreign.
    - Grass, weeds, etc. – especially when working in wet conditions.
  - Test leads should be well insulated and free of cuts, breaks, or scrapes.

Questions?

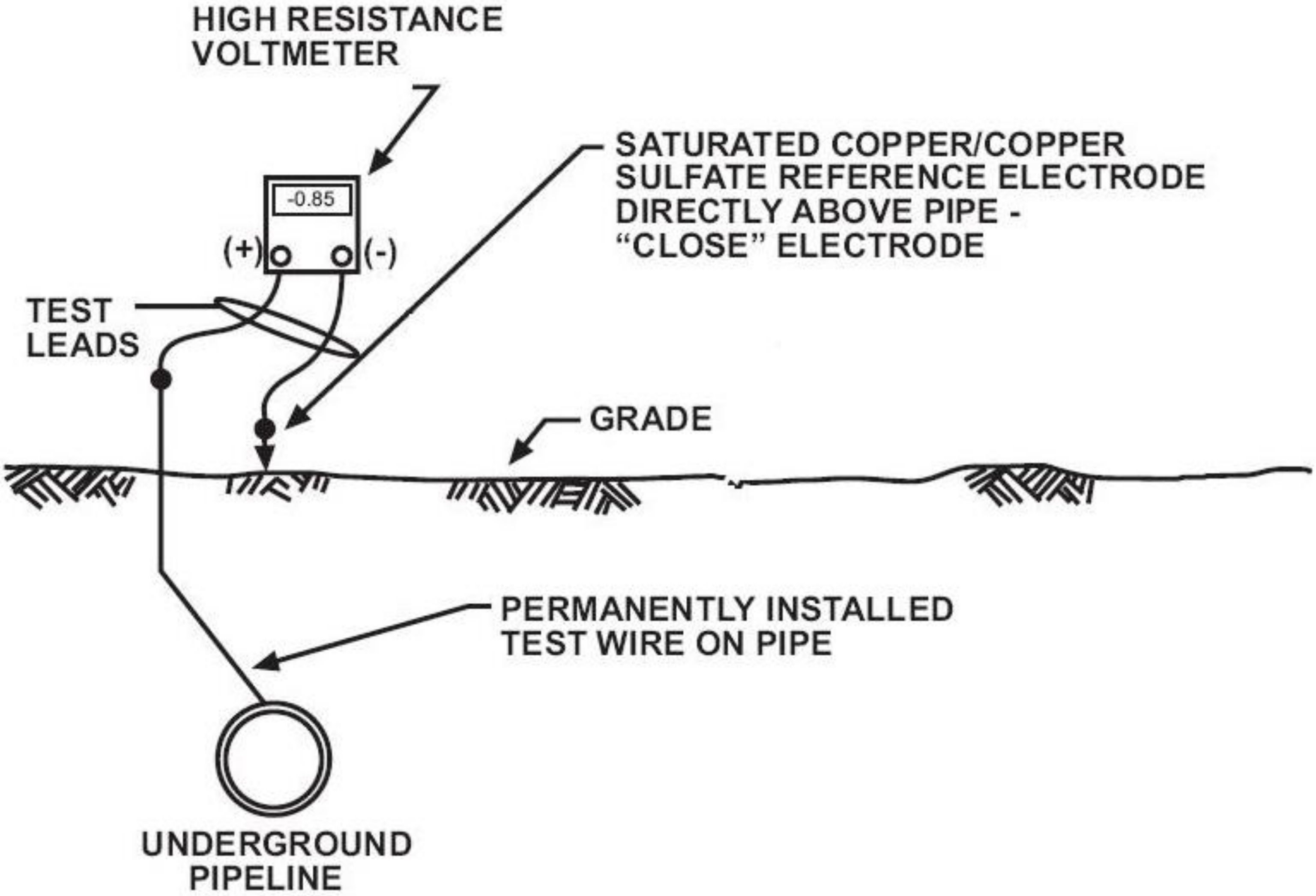
- Voltmeters
- Reference Electrodes

Structure-to-Earth Potential Measurements



P/S Potentials

- A structure-to-earth potential measurement (pipe-to-soil potential [P/S]) is the most common type of measurement for underground corrosion control work.
- P/S potential is recorded using a high input resistance voltmeter (10 megohm or higher) with a reference electrode (half cell) as close as practical to the pipeline


HIGH RESISTANCE VOLTMETER
-0.85
(+)
(-)
SATURATED COPPER/COPPER SULFATE REFERENCE ELECTRODE DIRECTLY ABOVE PIPE - “CLOSE” ELECTRODE
TEST LEADS
GRADE
PERMANENTLY INSTALLED TEST WIRE ON PIPE
UNDERGROUND PIPELINE

“My meter says -1.125V…so?”

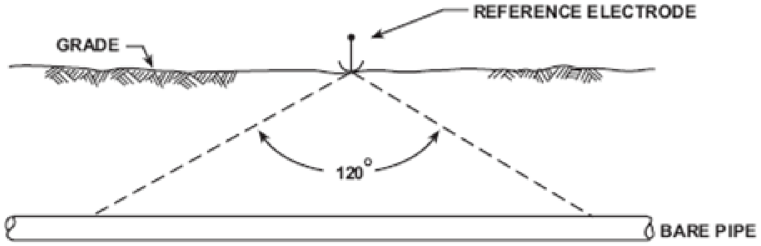
- This potential measurement (V_m) includes:
  - Pipe polarized potential (E_p)
  - Voltage drop in the soil (IR_{soil})
  - Voltage drop in the pipe (IR_{pipe})
    - $V_m = E_p + IR_{soil} + IR_{pipe}$
- With CP current turned ‘ON’ the voltmeter measures the total potential difference without being able to distinguish the pipe polarized potential (E_p).

P/S Potentials

- It is these IR drop voltages which must be taken into account for valid comparison to the criteria.

- $V_m = E_p + IR_{soil} + IR_{pipe}$

And that’s not all…

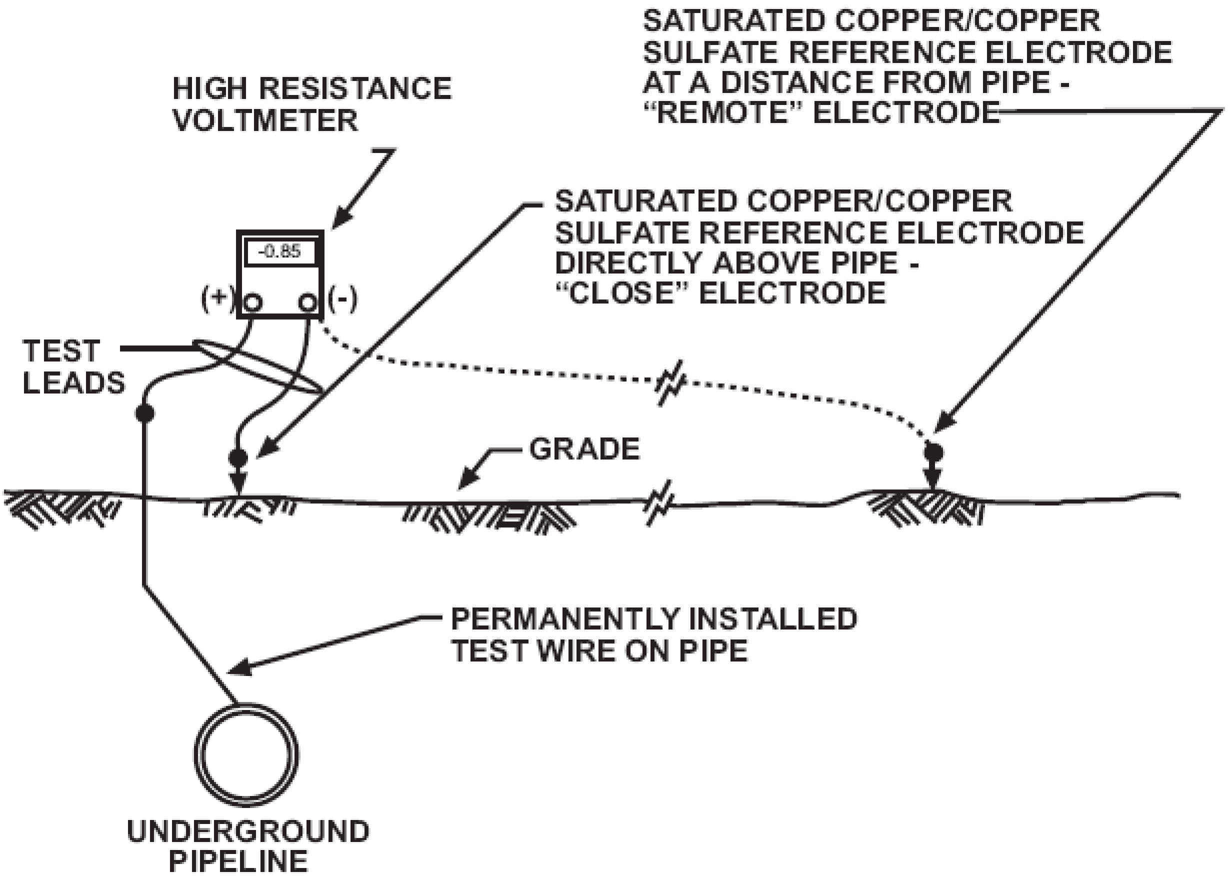


AREA “SEEN” BY REFERENCE ELECTRODE
ON A BARE STRUCTURE

FIGURE 5-4

- Bare Structures
- Depends on Depth
- Directly over the line is critical for accuracy.

- A ‘close’ ½ cell only sees a small portion as opposed to a ‘remote’ ½ cell.

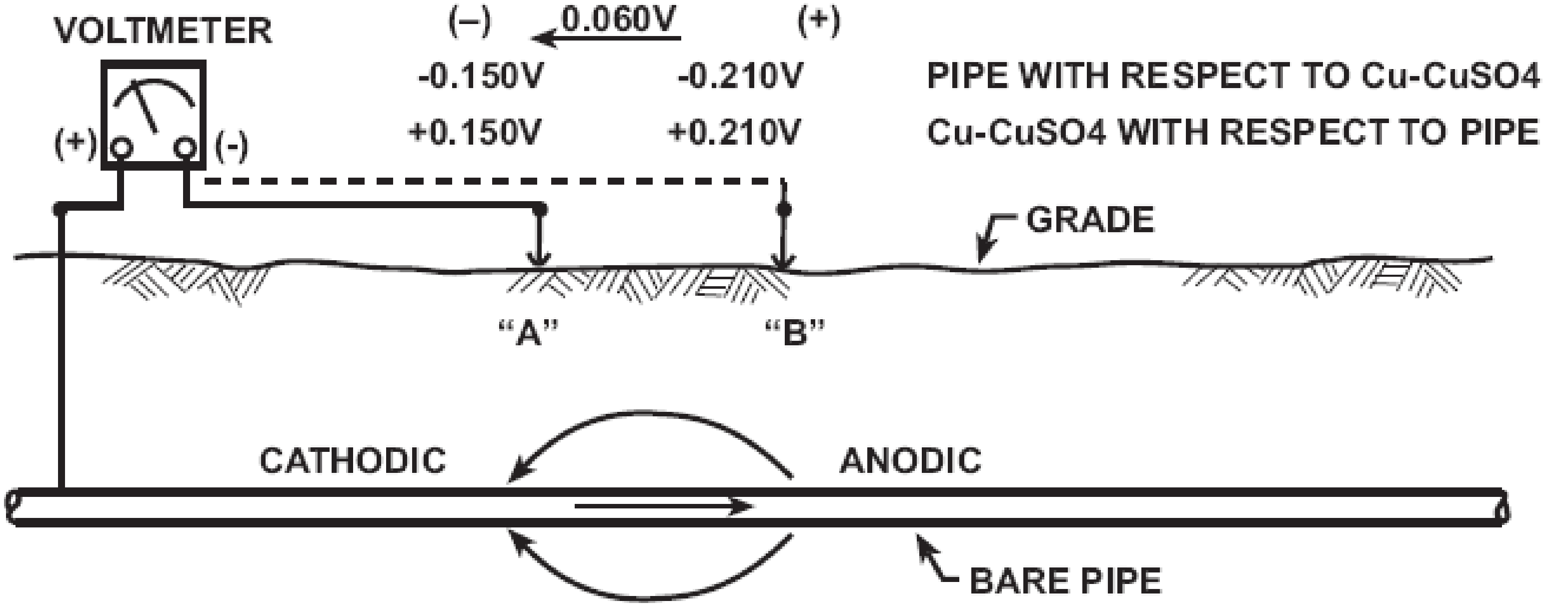

HIGH RESISTANCE VOLTMETER
-0.85
(+)
(-)
TEST LEADS
SATURATED COPPER/COPPER SULFATE REFERENCE ELECTRODE AT A DISTANCE FROM PIPE - “REMOTE” ELECTRODE
SATURATED COPPER/COPPER SULFATE REFERENCE ELECTRODE DIRECTLY ABOVE PIPE - “CLOSE” ELECTRODE
GRADE
PERMANENTLY INSTALLED TEST WIRE ON PIPE
UNDERGROUND PIPELINE

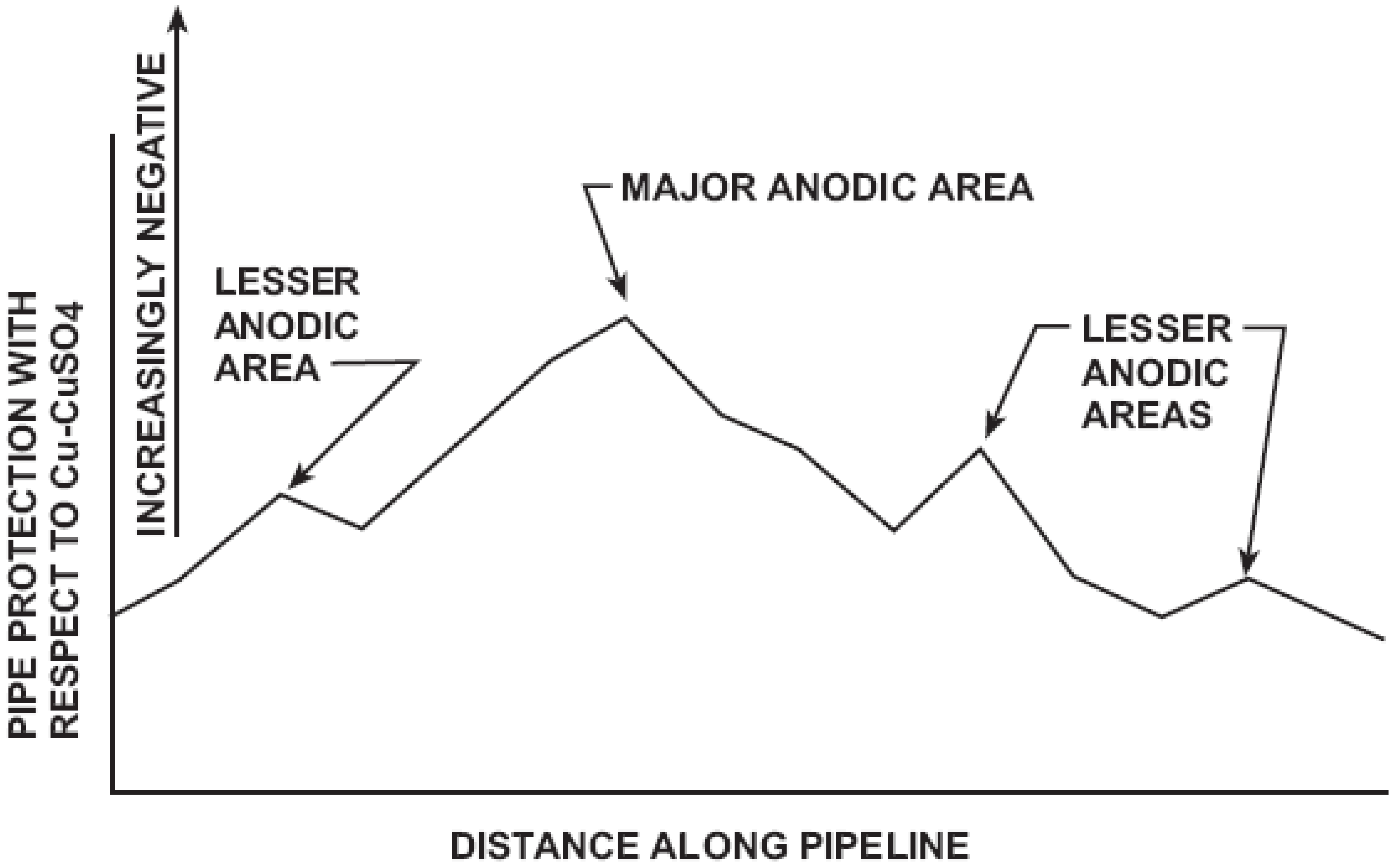
Remote Earth on Bare Structures

- The potential measured between the structure and the reference electrode reflects the average of widely spaced anodic and cathodic areas from long-line corrosion cells.
- Although useful for determining long line corrosion protection, it cannot be used as an indication of when complete protection is attained for all surfaces

Bare Structures

- Age and condition
- Old, bare structure with no CP:
  - $-0.100V_{cse}$ to $-0.300V_{cse}$
- For any two points on a non-cathodically protected structure, the point with the most negative reading is anodic to the other.


VOLTMETER
(–)
0.060V
(+)
-0.150V
-0.210V
PIPE WITH RESPECT TO Cu-CuSO4
+0.150V
+0.210V
Cu-CuSO4 WITH RESPECT TO PIPE
(+)
(-)
GRADE
"A"
"B"
CATHODIC
ANODIC
BARE PIPE


PIPE PROTECTION WITH RESPECT TO Cu-CuSO4
INCREASINGLY NEGATIVE
LESSER ANODIC AREA
MAJOR ANODIC AREA
LESSER ANODIC AREAS
DISTANCE ALONG PIPELINE

End of Period - Break

New and/or Coated Steel

- Non-cathodically protected new steel (and well coated steel) can have potentials:

$-0.700V_{cse}$ to $-0.800V_{cse}$

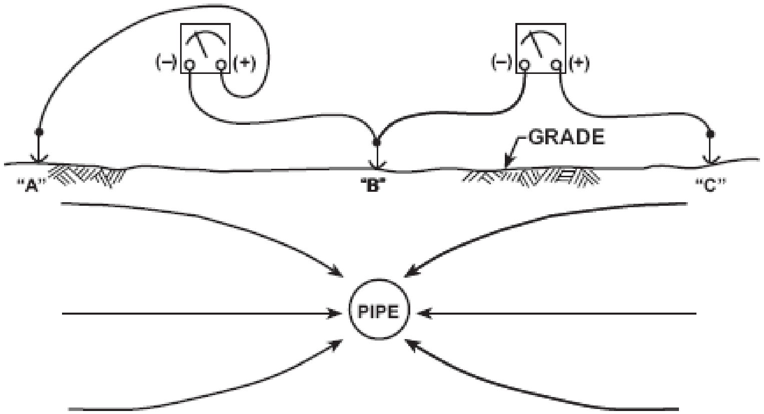
New and/or Coated Steel

- Because the amount of corrosion current flowing to or from a well-coated pipe is extremely small, there is little possibility of significant voltage drops in the earth around the pipe.
  - Reference electrode directly above the pipe is essentially the same as one at a remote earth.
  - Point to point changes along the surface above a coated pipe tend to be much more gradual than on bare pipe.

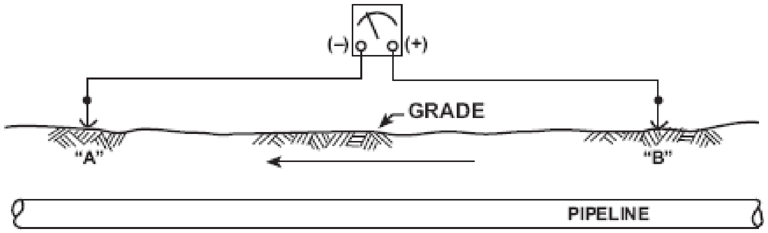
Cell-to-Cell Potential Measurements

- Cell-to-cell potential survey is measurement between two reference electrodes (surface potential survey)
    - Identifies anodic areas on bare pipe in galvanic systems
    - Two types of cell-to-cell potentials – sometimes used in conjunction with one another

Measurements between two reference electrodes



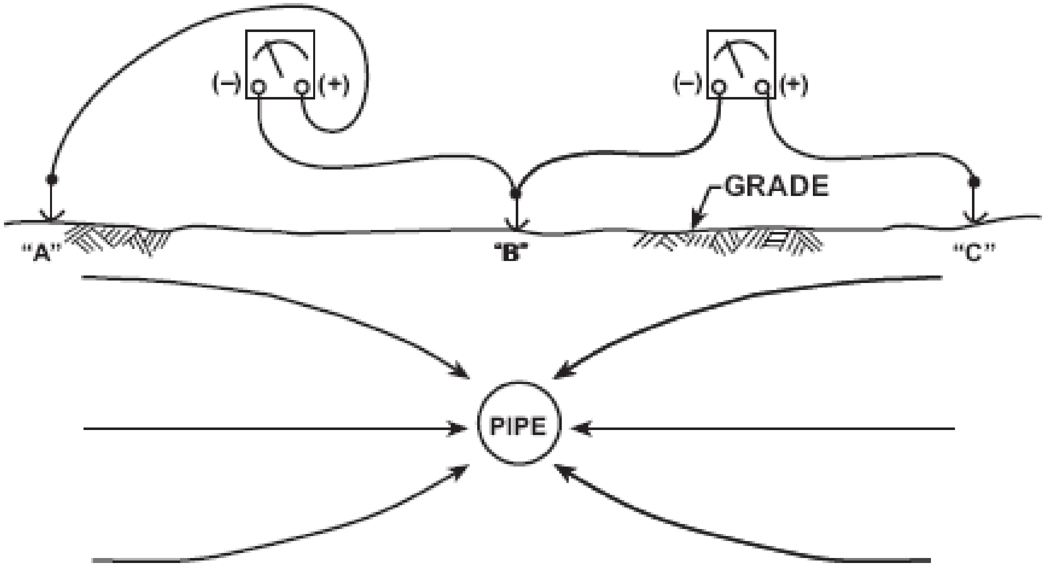
A – LATERAL MEASUREMENTS



B – ALONG-THE-LINE MEASUREMENTS

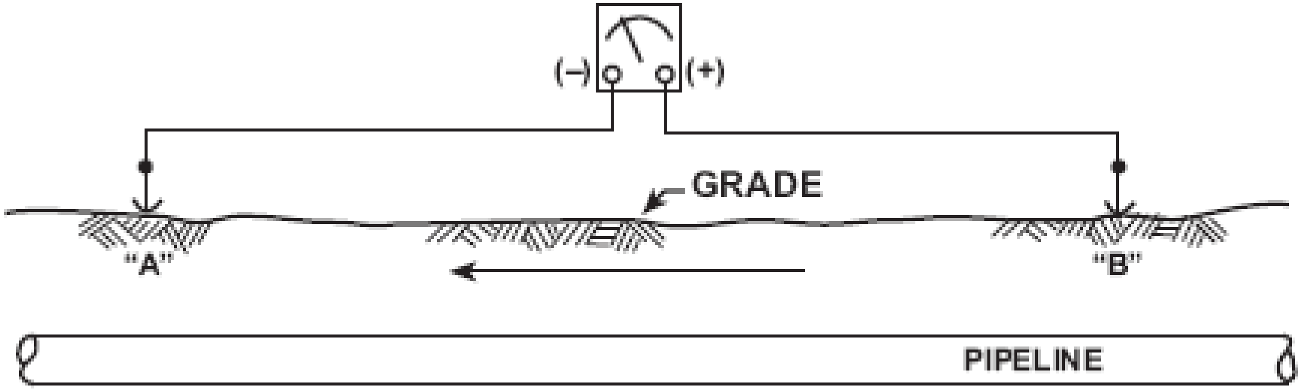
Lateral Measurements

- If ‘A’ is positive with respect to ‘B’, current is flowing towards the pipeline.
- If ‘C’ is positive with respect to ‘B’, current is flowing towards the pipeline.



Along the line Measurements

- If ‘B’ is positive with respect to ‘A’, there is a tendency for current flow in the earth.

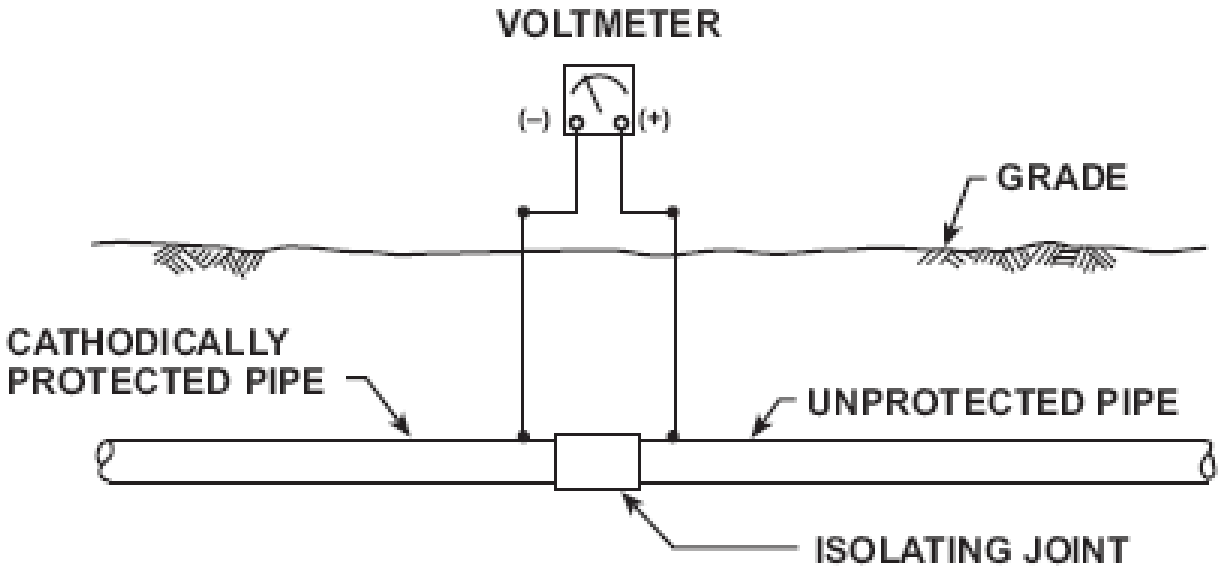


- Cell-to-Cell survey along the pipeline identifies current reversals indicating anodic areas (current flowing away from the area)

Structure to Structure Potential Measurements

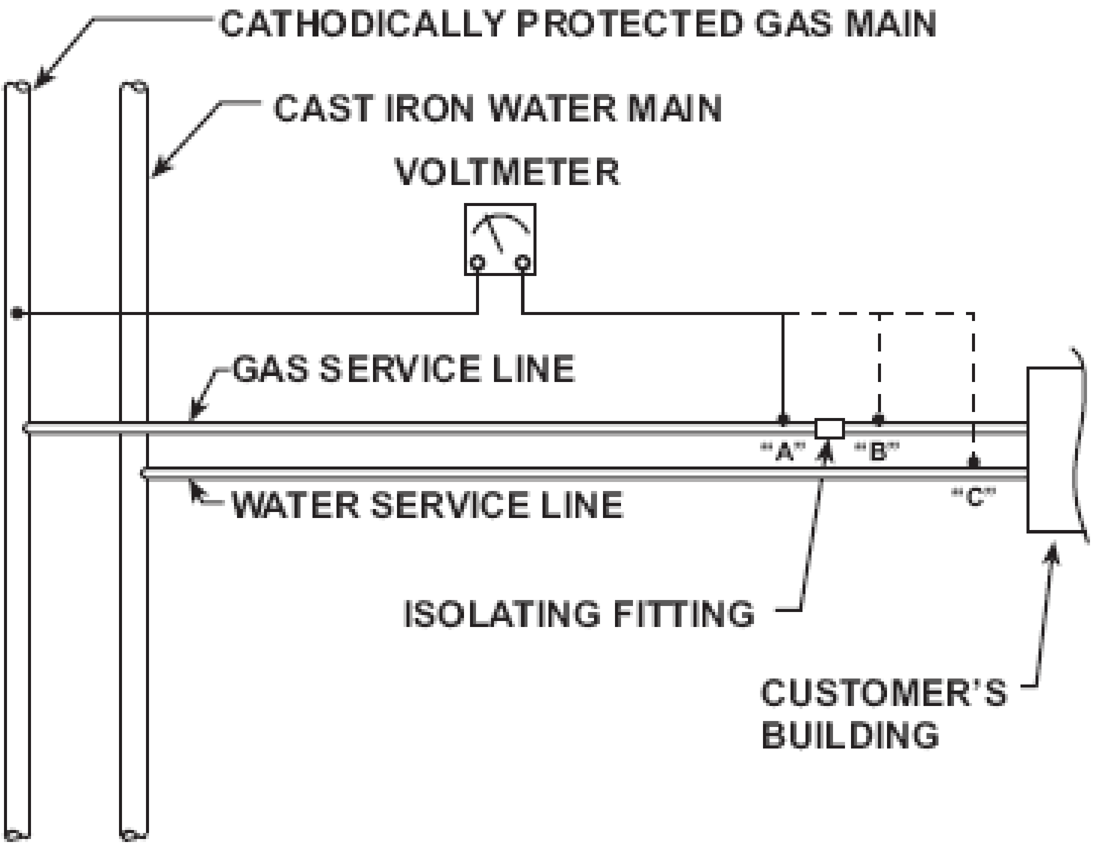
Used to check continuity

- If everything is in good working order there will be a reading on the voltmeter – the difference between the two potentials.



Structure to Structure Potentials

- If the Voltmeter reads zero, it is an indication that something is wrong.
  - Isolating joint is shorted
  - Isolating joint is OK, but there is a parallel metallic path around the isolating joint.
  - There is no CP (or the CP system is off) and both sides of the isolating joint are exactly the same. (highly improbable – but possible)


CATHODICALLY PROTECTED GAS MAIN
CAST IRON WATER MAIN
VOLTMETER
GAS SERVICE LINE
"A"
"B"
"C"
WATER SERVICE LINE
ISOLATING FITTING
CUSTOMER'S BUILDING

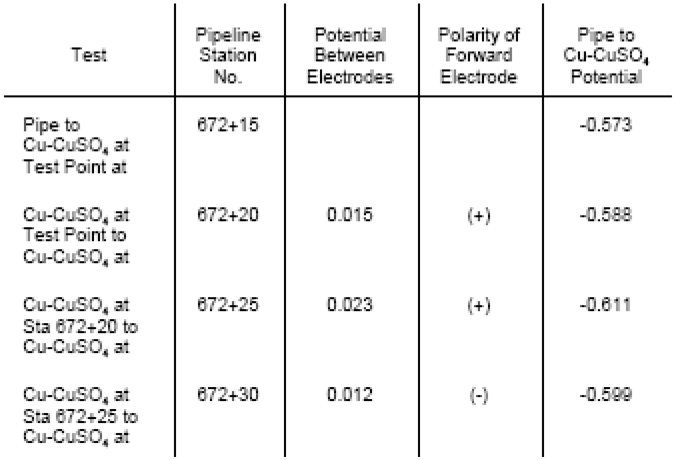
PART B

Potential Surveys

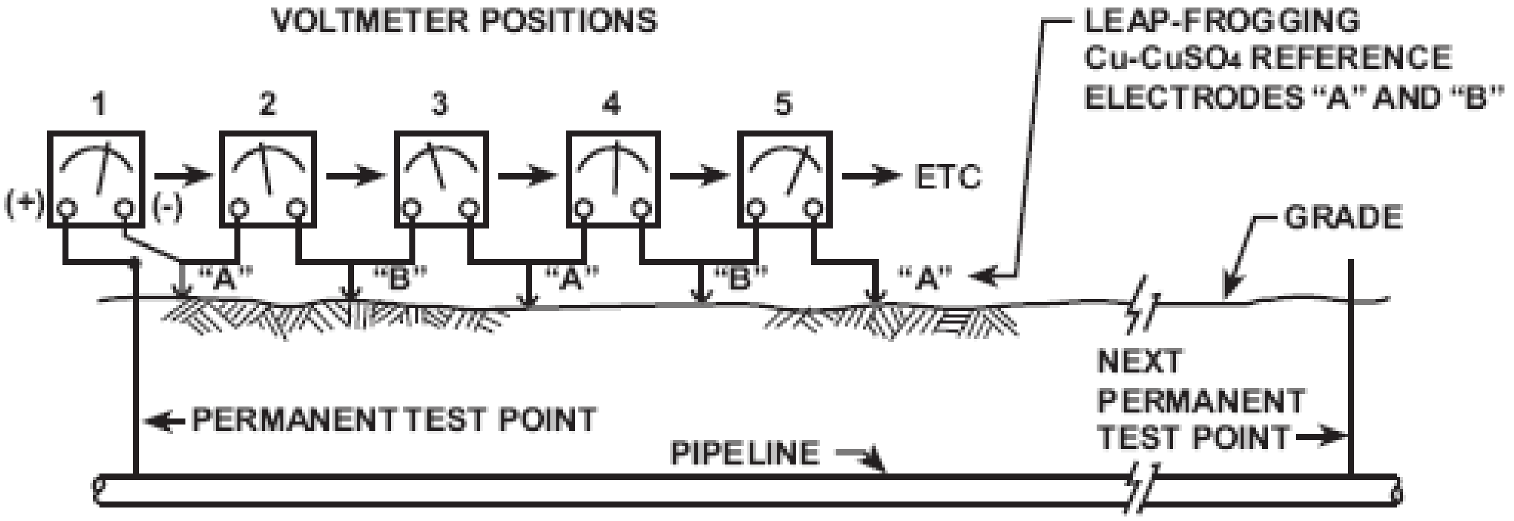
- Used to determine anodic (corroding) areas on non-cathodically protected pipe.
- Used in evaluating the performance of cathodic protection systems.

Two Electrode Survey Method

- Leap-frog
- Polarity is key



Test	Pipeline Station No.	Potential Between Electrodes	Polarity of Forward Electrode	Pipe to Cu-CuSO$_4$ Potential
Pipe to Cu-CuSO$_4$ at Test Point at	672+15			-0.573
Cu-CuSO$_4$ at Test Point to Cu-CuSO$_4$ at	672+20	0.015	(+)	-0.588
Cu-CuSO$_4$ at Sta 672+20 to Cu-CuSO$_4$ at	672+25	0.023	(+)	-0.611
Cu-CuSO$_4$ at Sta 672+25 to Cu-CuSO$_4$ at	672+30	0.012	(-)	-0.599

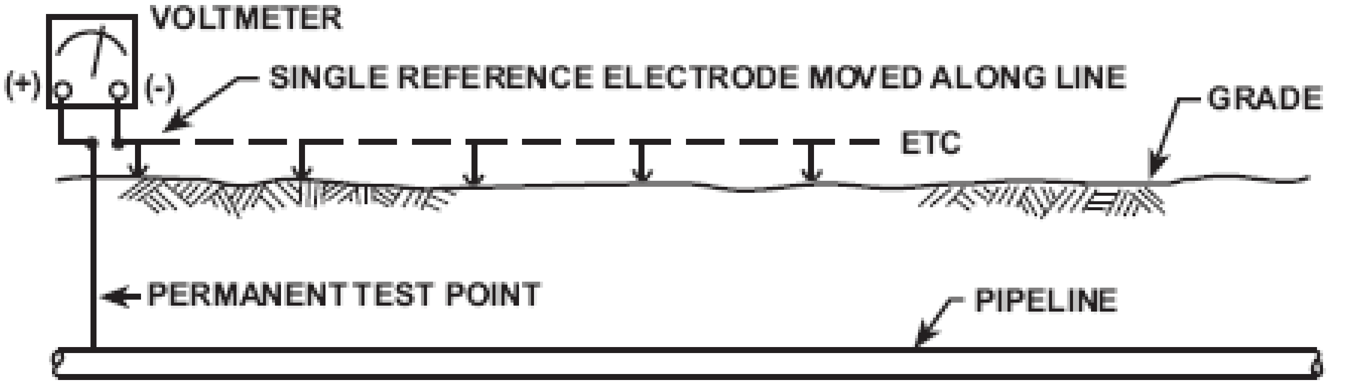


PART A – TWO ELECTRODE SURVEY METHODS

Two Electrode Survey Method

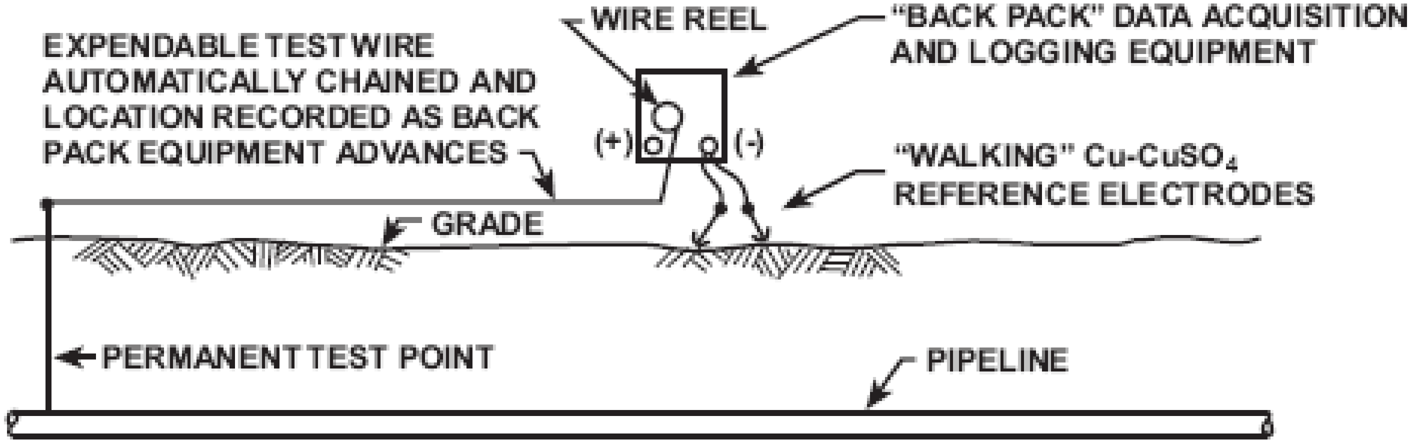
- Very hard to record potentials and polarity
- An error at any one point will carry forward
- Stray currents and long line currents can also be present and impact potentials

Single Electrode Survey Method



PART B – SINGLE ELECTRODE SURVEY METHOD

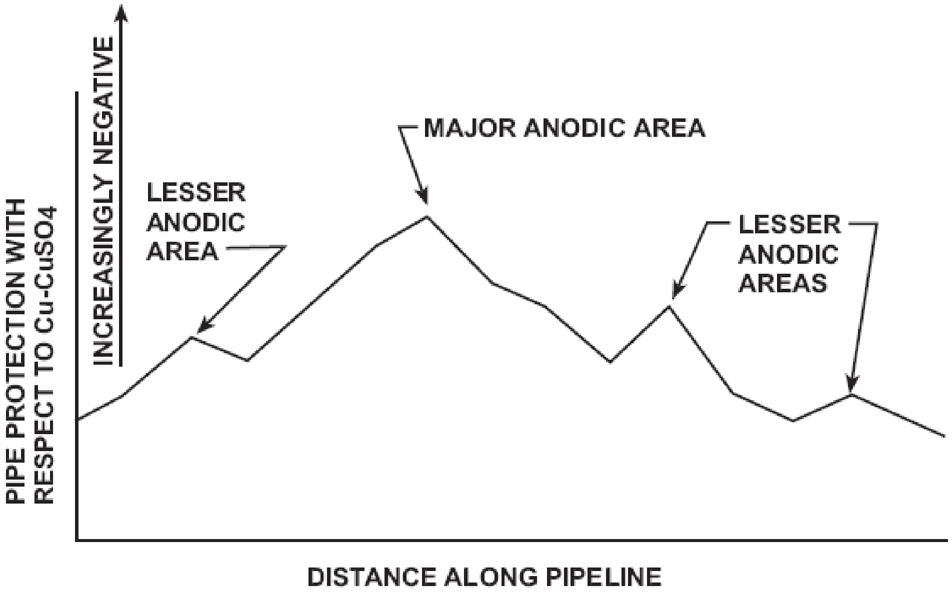
Close Interval Survey - CIS



PART C – SOPHISTICATED PROPRIETARY COMPUTER – COMPATIBLE SURVEY SYSTEM

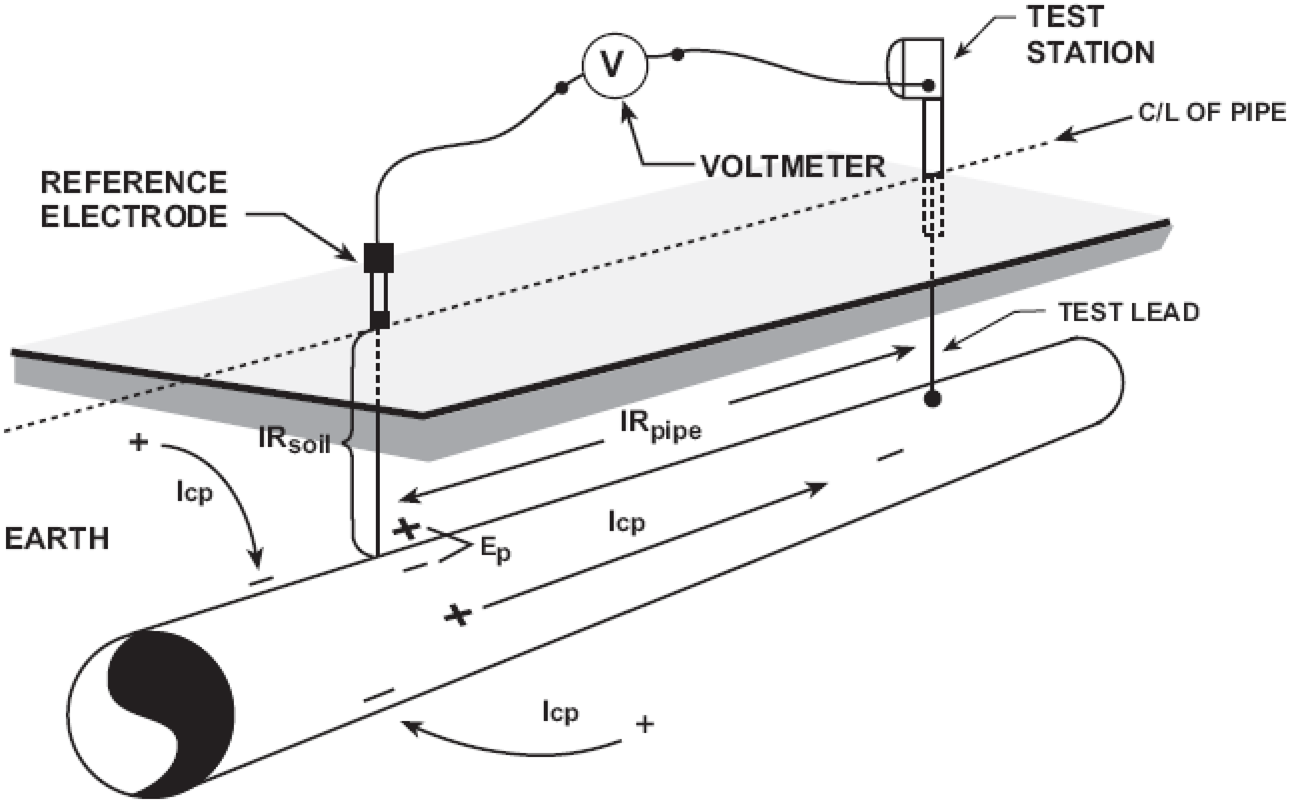
- Two reference electrodes are walked forward and measurements taken at “close-intervals”
- Potentials are recorded in the data logger and processed by computer

Close Interval Survey - CIS



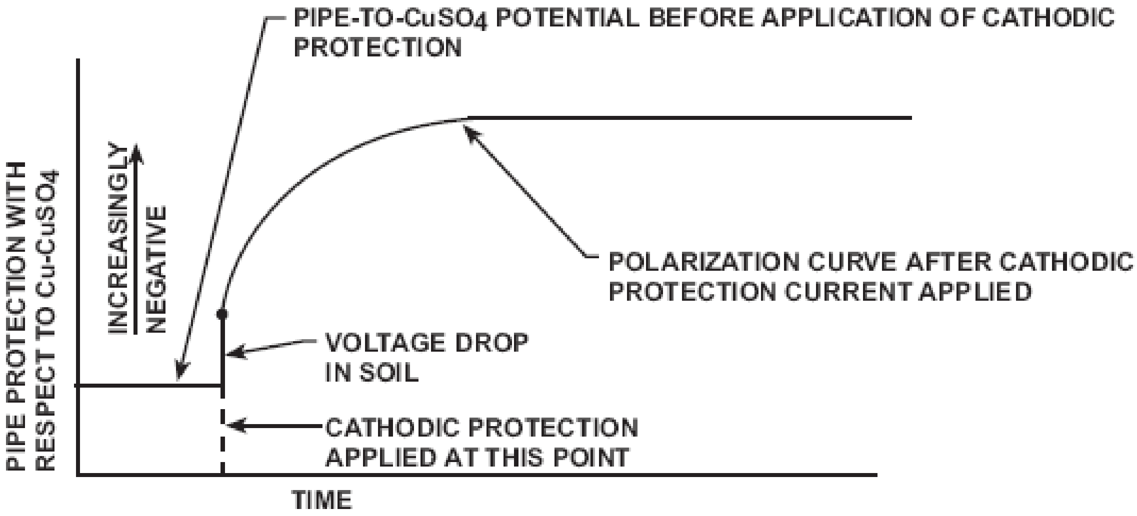
- Keep in mind the survey does not tell all the results
- “Lesser” anodic area in very low resistivity soil may be more actively corroding than a “major” anodic area in higher resistivity soil

Now Let's add some CP -

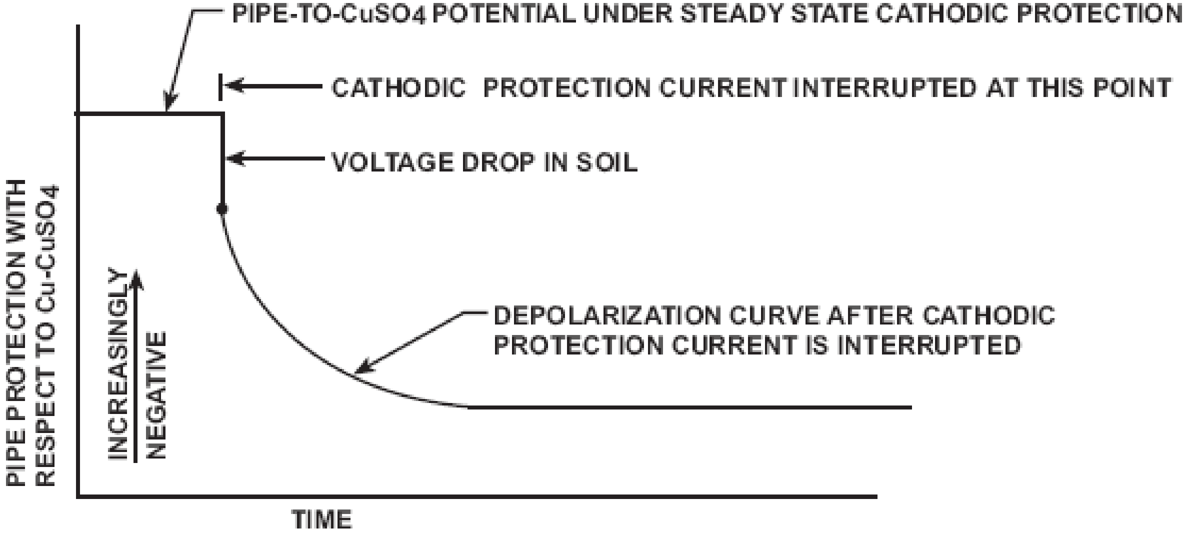

TEST STATION
C/L OF PIPE
VOLTMETER
V
REFERENCE ELECTRODE
TEST LEAD
IRpipe
IRsoil
+
Icp
EARTH
+
Ep
Icp
+
Icp
+

Polarization Effects on Potential

- What is polarization?
  - The deviation from the open circuit potential of an electrode resulting from the passage of current. (or Fig. 5-11)
- What is a polarization curve?
  - A plot of current density versus electrode potential for a specific electrode-electrolyte combination.



PART A – POLARIZATION



PART B – DEPOLARIZATION

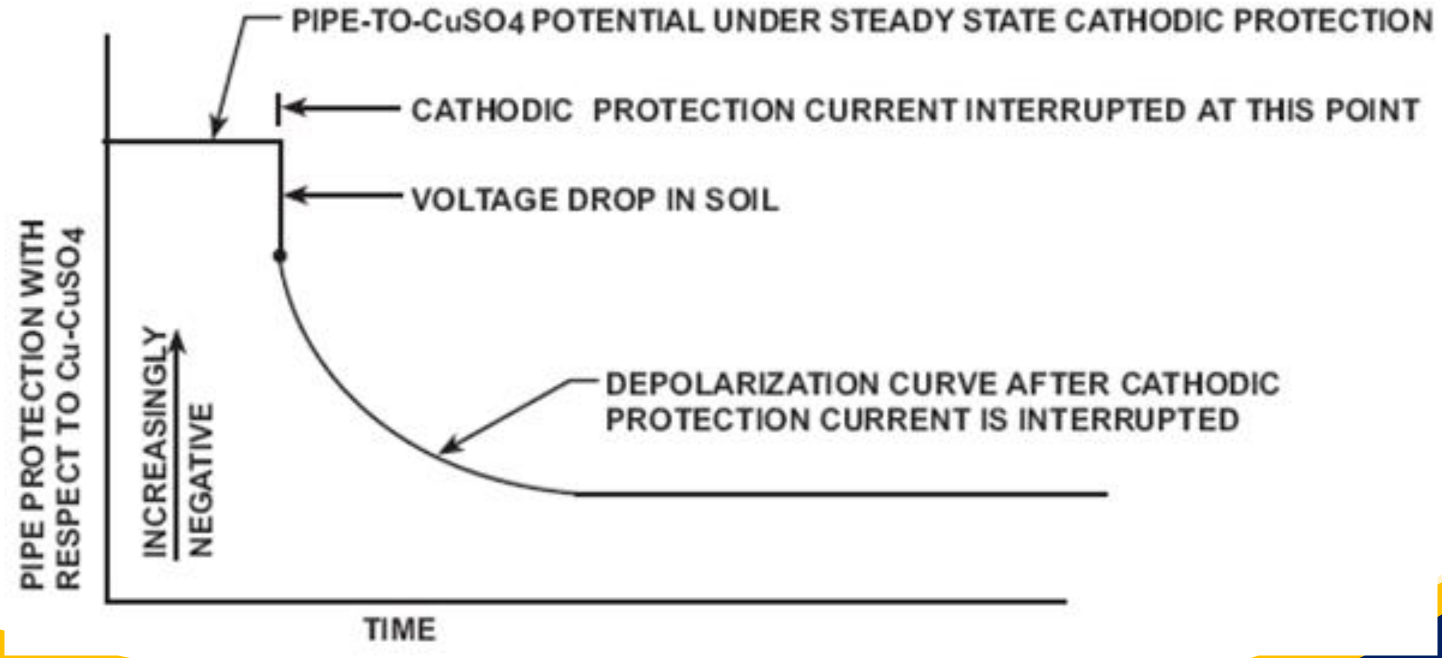
Polarization and Depolarization

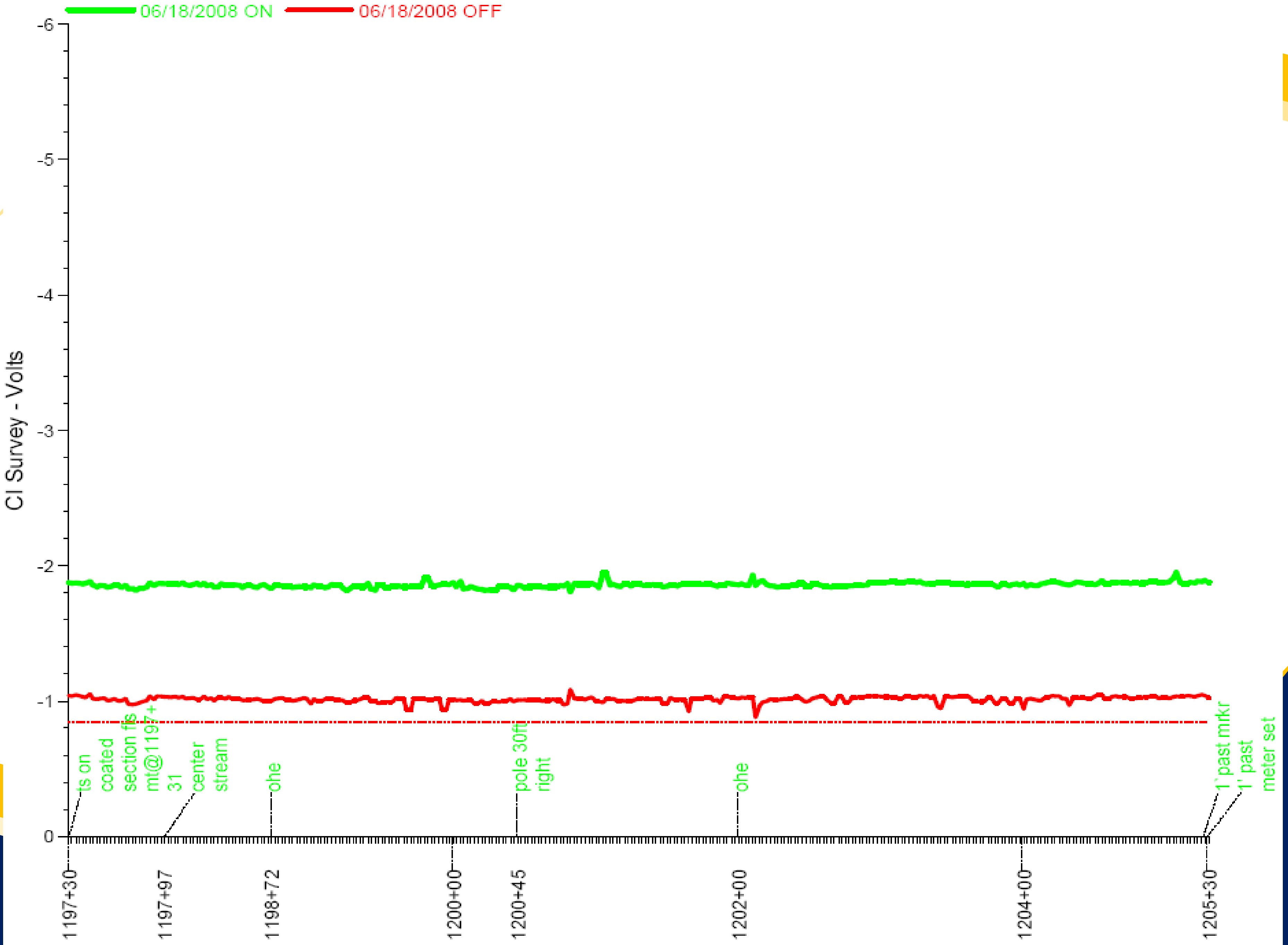
- Bare or poorly coated pipe may be slow to polarize – days or weeks.
- Well coated pipe – typically fast to polarize (seconds to minutes).

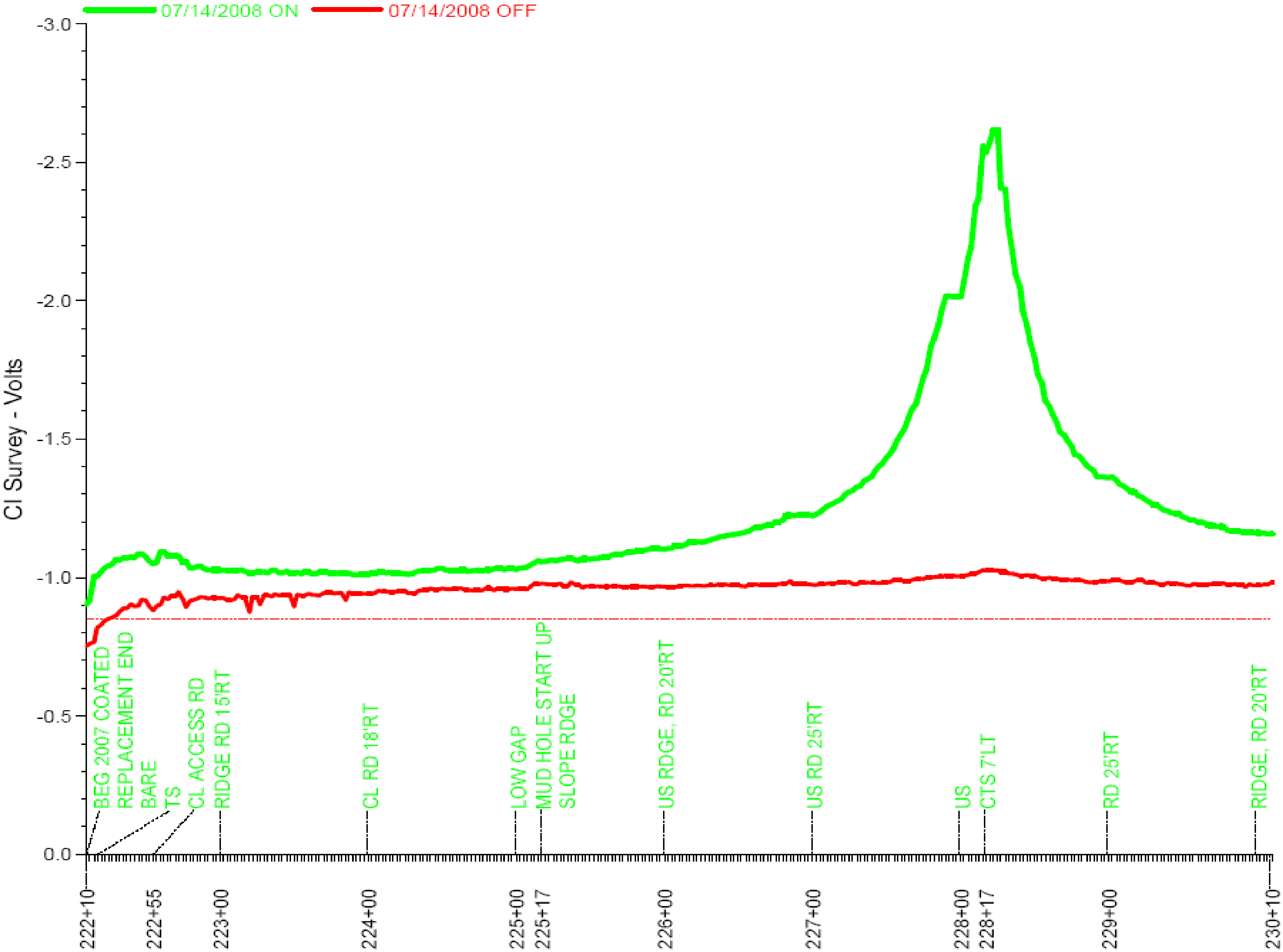
- Bare or poorly coated pipe will depolarize rapidly compared to well coated pipe.

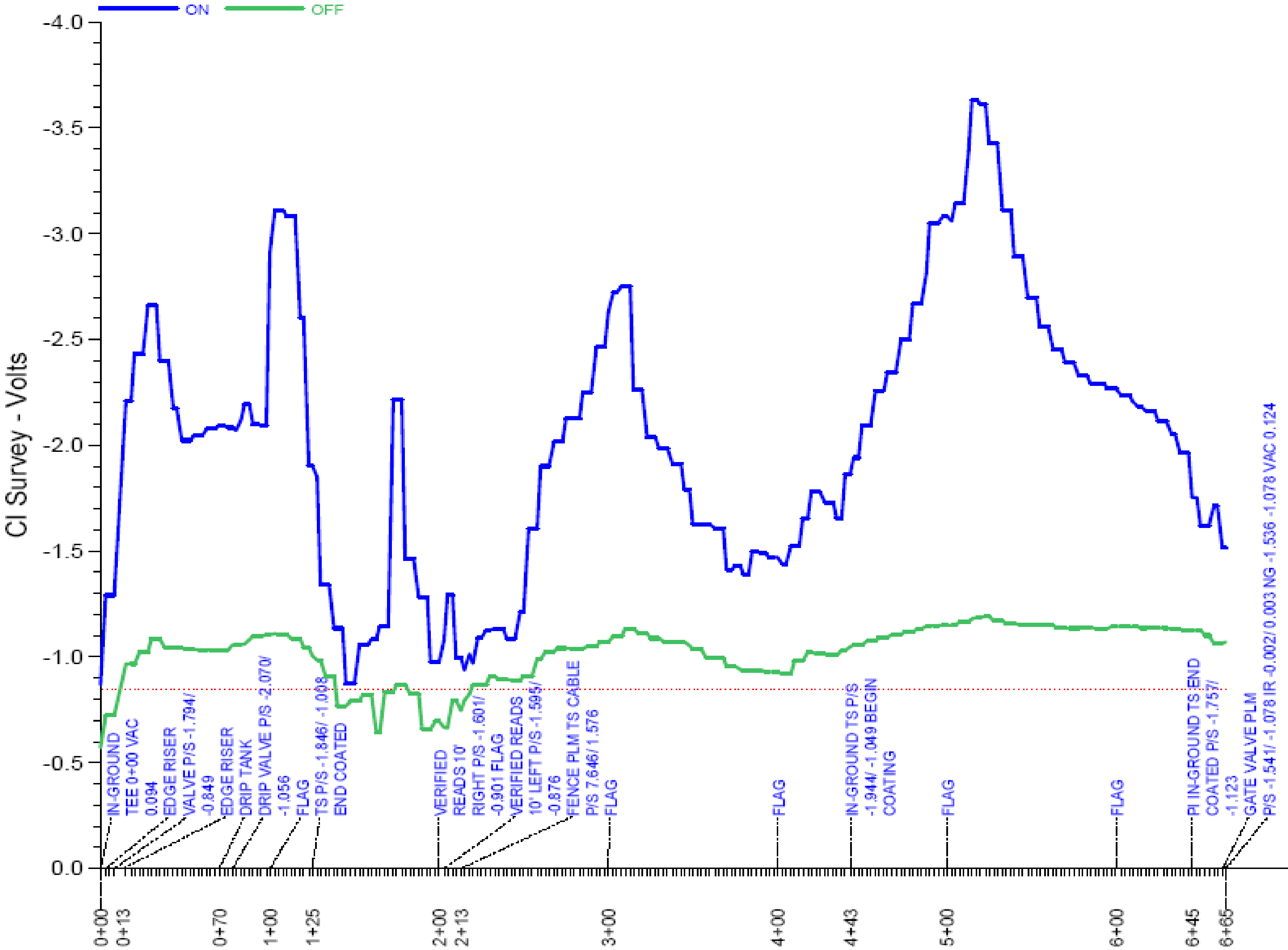
Criteria for Cathodic Protection

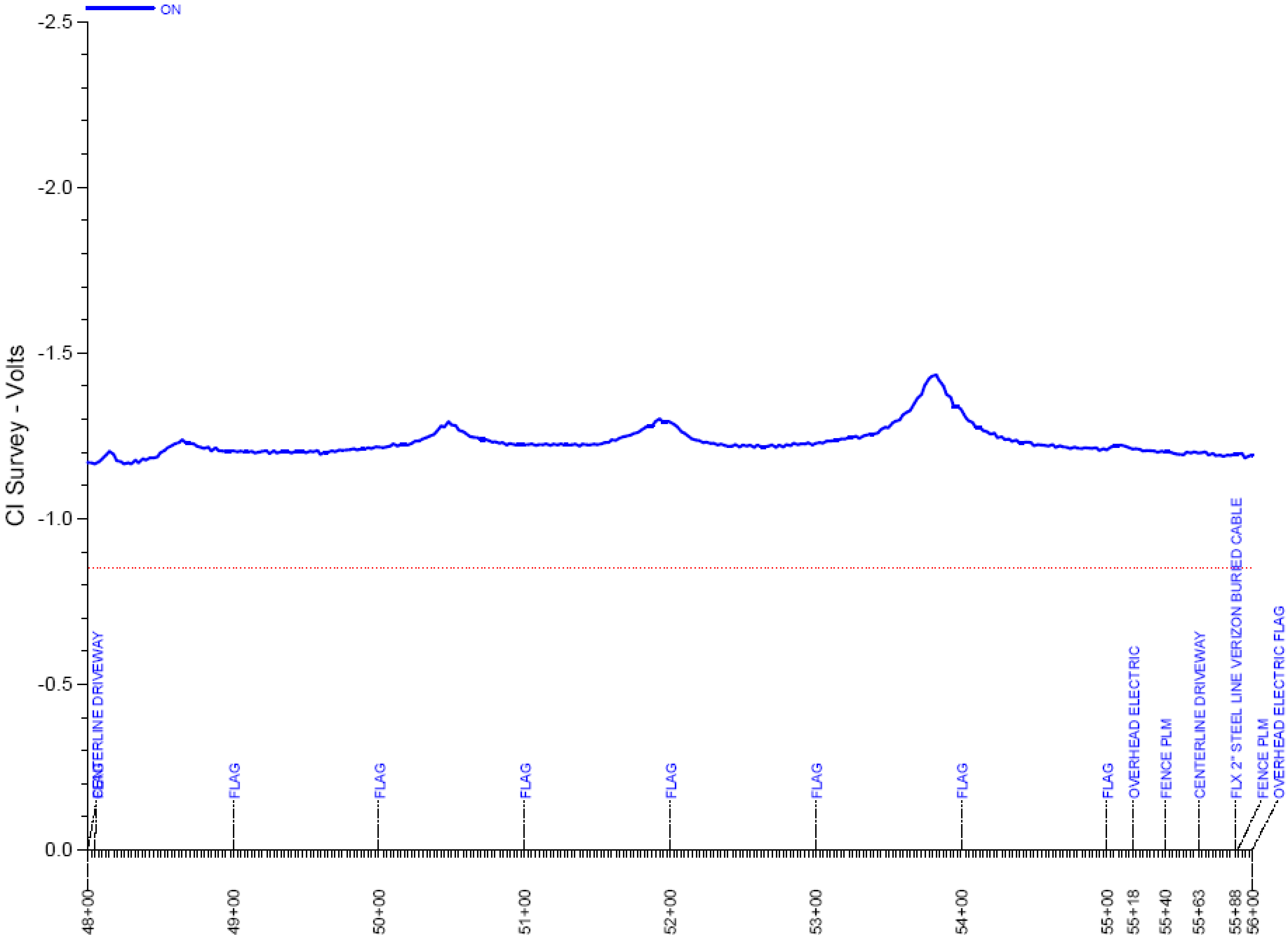
- -0.850 V_{cse} Criteria
- Discussed in chapter 3 (3-3) “How CP works”

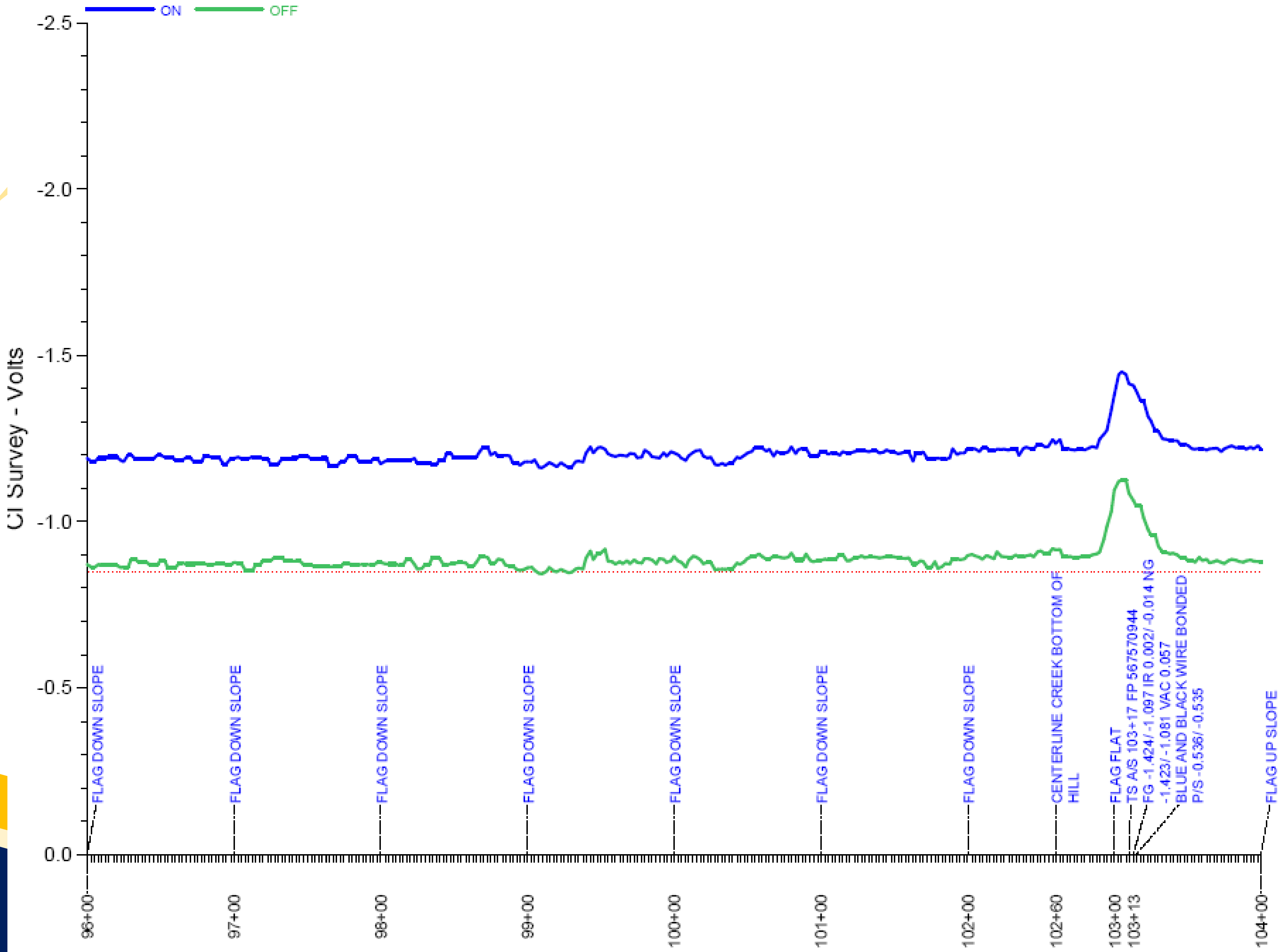



06/18/2008 ON
06/18/2008 OFF
CI Survey - Volts
-6
-5
-4
-3
-2
-1
0
ts on
coated
section fis
mt@1197+
31
center
stream
ohe
pole 30ft
right
ohe
1' past mrkr
1' past
meter set
1197+30
1197+97
1198+72
1200+00
1200+45
1202+00
1204+00
1205+30


07/14/2008 ON
07/14/2008 OFF
CI Survey - Volts
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
BEG 2007 COATED
REPLACEMENT END
BARE
TS
CL ACCESS RD
RIDGE RD 15'RT
CL RD 18'RT
LOW GAP
MUD HOLE START UP
SLOPE RDGE
US RDGE, RD 20'RT
US RD 25'RT
US
CTS 7'LT
RD 25'RT
RIDGE, RD 20'RT
222+10
222+55
223+00
224+00
225+00
225+17
226+00
227+00
228+00
228+17
229+00
230+10


ON
OFF
CI Survey - Volts
-4.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
IN-GROUND
TEE 0+00 VAC
0.094
EDGE RISER
VALVE P/S -1.794/
-0.849
EDGE RISER
DRIP TANK
DRIP VALVE P/S -2.070/
-1.056
FLAG
TS P/S -1.846/ -1.008
END COATED
VERIFIED
READS 10'
RIGHT P/S -1.601/
-0.901 FLAG
VERIFIED READS
10' LEFT P/S -1.595/
-0.876
FENCE PLM TS CABLE
P/S 7.646/ 1.576
FLAG
FLAG
IN-GROUND TS P/S
-1.944/ -1.049 BEGIN
COATING
FLAG
FLAG
PI IN-GROUND TS END
COATED P/S -1.757/
-1.123
GATE VALVE PLM
P/S -1.541/ -1.078 IR -0.002/ 0.003 NG -1.536 -1.078 VAC 0.124
0+00
0+13
0+70
1+00
1+25
2+00
2+13
3+00
4+00
4+43
5+00
6+00
6+45
6+65


ON
CI Survey - Volts
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
BEND
CENTERLINE DRIVEWAY
FLAG
FLAG
FLAG
FLAG
FLAG
FLAG
FLAG
OVERHEAD ELECTRIC
FENCE PLM
CENTERLINE DRIVEWAY
FLX 2" STEEL LINE VERIZON BURIED CABLE
FENCE PLM
OVERHEAD ELECTRIC FLAG
48+00
49+00
50+00
51+00
52+00
53+00
54+00
55+00
55+18
55+40
55+63
55+88
56+00



ON
OFF
CI Survey - Volts
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
FLAG DOWN SLOPE
FLAG DOWN SLOPE
FLAG DOWN SLOPE
FLAG DOWN SLOPE
FLAG DOWN SLOPE
FLAG DOWN SLOPE
FLAG DOWN SLOPE
CENTERLINE CREEK BOTTOM OF HILL
FLAG FLAT
TS A/S 103+17 FP 567570944
FG -1.424/ -1.097 IR 0.002/ -0.014 NG
-1.423/ -1.081 VAC 0.057
BLUE AND BLACK WIRE BONDED
P/S -0.536/ -0.535
FLAG UP SLOPE
96+00
97+00
98+00
99+00
100+00
101+00
102+00
102+60
103+00
103+13
104+00

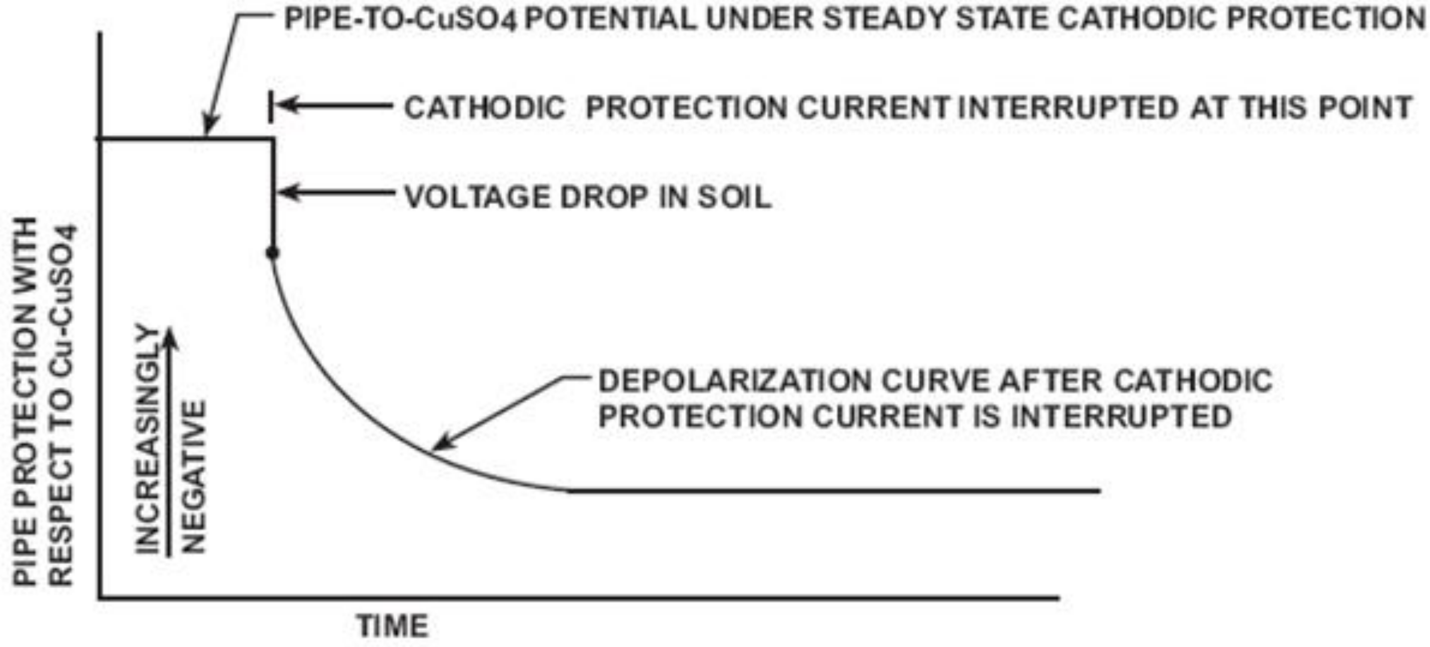
Important Note:

- Avoid placing the electrode close to buried galvanic anodes
  - If placed over the anode it will include voltage drop in the earth caused by anode current discharge
  - Rule of thumb: Place the reference electrode at least 15 feet from the nearest galvanic anode
  - Check potentials on either side of the high reading point should clarify

100 mV of Polarization Criteria

- Where influencing current sources can be interrupted
- Current sources turned off for period of time

100 mV of Polarization Criteria



- Need at least 100 mV between the polarized potential and the depolarized potential

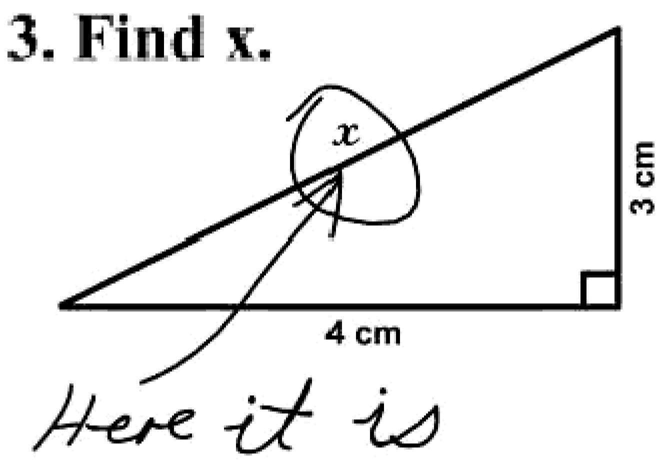
300 mV Shift Criteria

- This is not as sound a criterion as the -0.85 volt criterion (for steel) or the 100-millivolt polarization criterion.
- It has had reasonably good results.
- This criterion was dropped from the list of criteria in Section 6 of the NACE RP0169 (latest revision).
- Although still recognized and listed as a criterion for cathodic protection in Appendix D to Part 192 of the CFR, it is being interpreted by inspectors as 300 mV of cathodic shift after correction for IR Drop.
- In effect, they are requiring a 300-mV polarization shift.

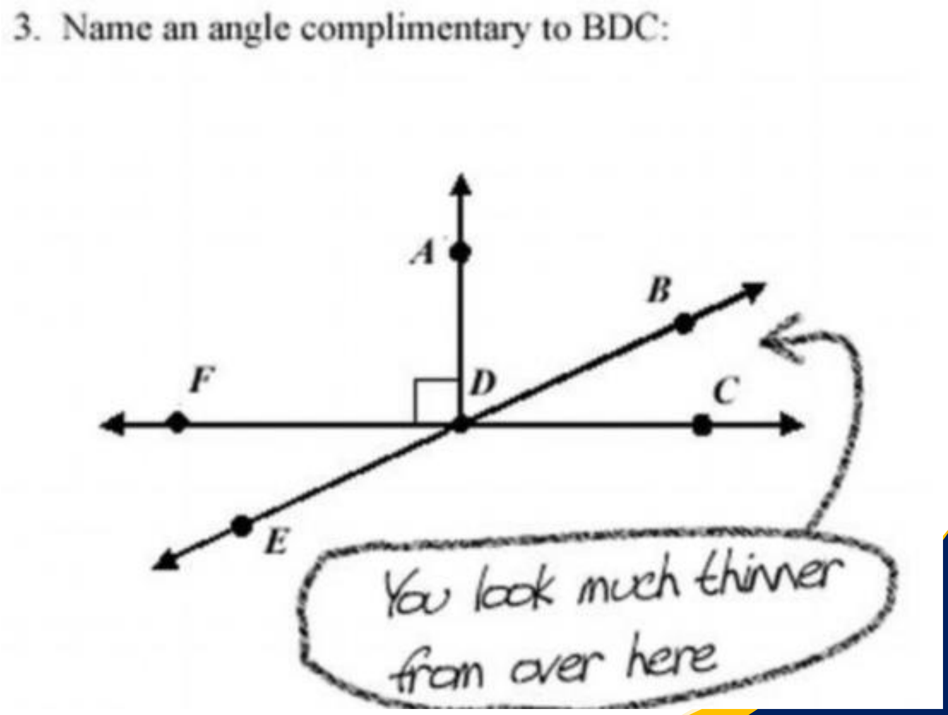
Monitoring Cathodic Protection Systems

- Potential Measurements used to periodically verify that CP is effective
    - Over the line potential surveys and at intervals between those surveys by monitoring test points

Things You May See Again on Thursday



3. Find x.



3. Name an angle complimentary to BDC:

Good Things to Know

- Don't put your reference cell directly over a galvanic anode when measuring pipe-to-soil potential.
- Keep your CuSO4 solution saturated with crystals, keep the Cu clean, and keep it capped when NOT in use.
- Just because your CuSO4 solution is blue doesn't mean it is OK. If you see no crystals, prepare new solution and clean the rod.
- 100 mV polarization and –0.85V P/S are the criteria; "300 mV transverse gradient" IS NOT.
- Voltage drop in the soil (IR) MUST be considered when using the 100 mV polarization criterion.

Good Things to Know

- Structure-to-earth measurement requires a minimum of 1 reference cell.
- Depolarization is faster on a BARE structure than polarization.
- On a BARE structure with no cathodic protection, the more negative area is ANODIC.
- Monitoring CP efficiency can be done by periodic over line surveys AND/OR potential measurement at test stations along the line.
- A cell-to-cell survey is a good way to verify CP flow to a BARE structure.

Good Things to Know

- Internal resistance of a digital multimeter must be HIGHER than the external circuit resistance for accurate potential measurements.

- When using a digital multimeter:
    - Pos (+) = Structure
    - Neg (-) = Reference electrode.
    - Usually have a negative reading.

- For practical purposes, remote earth is pretty close on a well coated structure. Most of the resistance is in the coating.

End