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Appalachian Underground Corrosion Short Course

# Fundamentals Course

Appalachian Underground Corrosion Short Course
West Virginia University
Morgantown, West Virginia

# APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
# FUNDAMENTALS COURSE

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# Fundamentals of Corrosion

## Mathematics and Electricity

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# Considerations

- This class concentrates on fundamental mathematical and electrical concepts
- All skills require practice regardless of what they are or how they're done
- To learn is to do
- By doing, it becomes easier

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# Agenda

- Units
- Circuit Theory
- Electrical Formulas
- Series and Parallel Circuit Theory

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# Units

- A unit is an object or thing regarded as stand alone and complete
- Can also be a component of a larger or more complex object or thing

# Units

## Examples of Common Units of Length

**Imperial System**

- Inch (in)
- Foot (ft)
- Yard (yd)
- Mile (mi)

**International System (SI)**

- Millimeter (mm)
- Centimeter (cm)
- Meter (m)
- Kilometer (km)

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# Units

## Unit Nomenclature for US Money Denominations

Macro Unit

Two Dollars
Five Dollars
Ten Dollars
Twenty Dollars
Fifty Dollars
One Hundred Dollars

Multiply

One Dollar

Divide

Fractional Unit

Penny or Cent
Nickel
Dime
Quarter
Half-Dollar

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## Units

Concept #1

Any number multiplied by
the number 1 always
equals the same number.

**Examples:**

$$5 * 1 = 5$$
$$354 * 1 = 354$$
$$0.75 * 1 = 0.75$$

**Examples:**

$$5 * 1 * 1 = 5$$
$$354 * 1 * 1 * 1 = 354$$
$$0.75 * 1 * 1 * 1 * 1 = 0.75$$

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## Units

Concept #2

Any number divided by
itself always equals 1.

**Examples:**

$$\frac{6}{6} = 1 \qquad \frac{87}{87} = 1 \qquad \frac{0.375}{0.375} = 1$$

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# Units

## Unit Nomenclature for US Money Denominations

Unit

Two Dollars – (2)
Five Dollars – (5)
Ten Dollars – (10)
Twenty Dollars – (20)
Fifty Dollars – (50)
One Hundred Dollars – (100)

Multiply

One Dollar

Divide

Unit

(100) - Penny or Cent
(20) – Nickels
(10) - Dimes
(4) - Quarter
(2) - Half-Dollar

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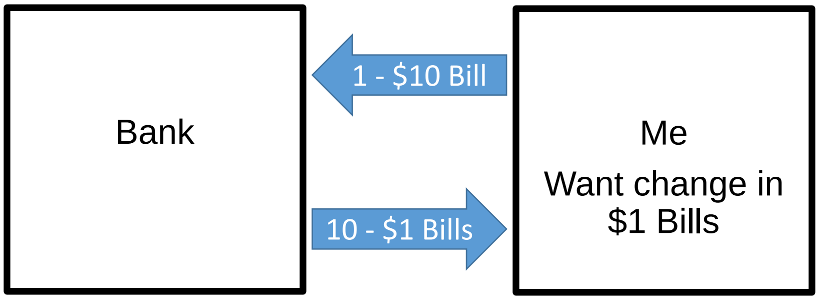
# Units

## Elaboration on Concept #2 – **Conversion Ratio**



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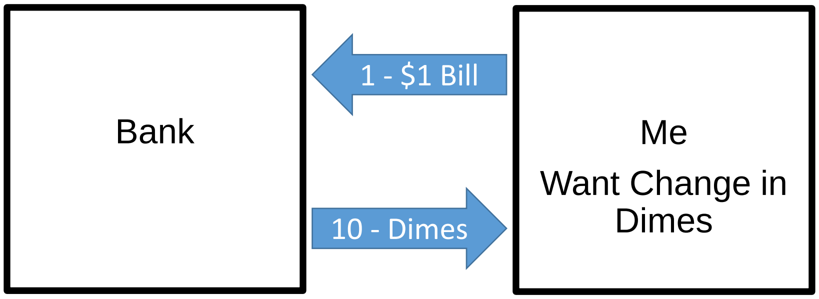
## Units

Elaboration on Concept #2 – **Conversion Ratio**



Bank

1 - $1 Bill

10 - Dimes

Me

Want Change in Dimes

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## Units

Units Make All The Difference – **Conversion Ratio**

The Unit that you want goes on top

The Unit you have goes on the bottom

**Example**

We know there are 5280 feet in 1 mile

Conversion Ratio = 1 mile / 5280 ft

= 0.0001894 miles per ft **OR** 0.0001894 miles/ft

## Units

Units Make All The Difference – **Conversion Ratio**

Conversion Ratio = 0.0001894 miles/ft

**Question**

How many miles are in 52, 864 ft?

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## Units

Units Make All The Difference – **Conversion Ratio**

Conversion Ratio = 0.0001894 miles/ft

We have feet and we want miles

**Example**

52,864 ft * 0.0001894 miles/ft

$$\frac{52{,}864\ \cancel{\text{ft}} * 0.0001894\ \text{miles}}{\cancel{\text{ft}}} = 10.0124\ \text{miles}$$

Units cancel.

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# Units

Units Make All The Difference – **Conversion Ratio**

Conversion Ratio = 1 mile / 5280 ft

We have feet and we want miles

**Example**

52,864 ft * 1 mile / 5280 ft

$$\frac{52{,}864\ \cancel{\text{ft}} * 1\ \text{miles}}{5280\ \cancel{\text{ft}}} = 10.0124\ \text{miles}$$

Units cancel.

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# Units

Units Make All The Difference – **Conversion Factor**

Conversion Ratio = 5280 ft /1 mile

We have miles and we want feet

**Example – Conversion Applied Backward**

52,864 ft * 5280 ft / 1 mi

$$\frac{52{,}864\ \text{ft} * 5280\ \text{ft}}{1\ \text{mi}} = \frac{279121920\ \text{ft}^2}{\text{mile}}$$

Units don’t cancel!

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# Units

## Units Make All The Difference – **Conversion Ratio**

$$\frac{\text{The Unit that you want goes on top}}{\text{The Unit you have goes on the bottom}}$$

### Example – Conversion

We have dollars and we want quarters

Ratio = 4 Quarters per Dollar
OR
4 Quarters / 1 Dollar

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# Units

## Units Make All The Difference – **Conversion Ratio**

How many quarters in $37.75

### Example – Conversion

$$\frac{\cancel{\$}37.75 \;*\; 4\text{ Quarters}}{\cancel{\$}1} = 151\text{ Quarters}$$

Units cancel.

# Units

## Multiple Conversion Ratios

- 6.425 miles of pipeline
- Convert to a distance in mm
- We know the following:
  - 5280ft / 1 mile
  - 12in / 1 ft
  - 25.4mm / 1 in

$$6.425\ \cancel{mi} \quad * \quad \frac{5280\ \cancel{ft}}{1\ \cancel{mi}} \quad * \quad \frac{12\ \cancel{in}}{1\ \cancel{ft}} \quad * \quad \frac{25.4\ mm}{1\ \cancel{in}} \quad = \quad 10{,}340{,}035\ mm$$

Units cancel.

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# SI Units

## The SI System and Layout

Getting Bigger

| Prefix | Symbol | Magnitude | Multiplier |
|---|---|---|---|
| Tera | T | $10^{12}$ | x 1,000,000,000,000 |
| **Giga** | **G** | $10^{9}$ | **x 1,000,000,000** |
| **Mega** | **M** | $10^{6}$ | **x 1,000,000** |
| **Kilo** | **K** | $10^{3}$ | **x 1000** |
| Hecto | H | $10^{2}$ | x 100 |
| Deka | Da | $10^{1}$ | x 10 |
| **Unit** | -- | **1** | **x 1** |

Getting Smaller

| Prefix | Symbol | Magnitude | Multiplier |
|---|---|---|---|
| **Unit** | -- | **1** | **x 1** |
| Deci | d | $10^{-1}$ | x 0.1 |
| **Centi** | **c** | $10^{-2}$ | **x 0.01** |
| **Milli** | **m** | $10^{-3}$ | **x 0.001** |
| **Micro** | **u** | $10^{-6}$ | **x 0.000001** |
| **Nano** | **n** | $10^{-9}$ | **x 0.000000001** |
| **Pico** | **p** | $10^{-12}$ | **x 0.000000000001** |

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# SI Measurement Units

## The SI System and Layout

| Measurement | Unit | Symbol |
|---|---|---|
| Length | Meter | m |
| Mass | Gram | g |
| Volume | Liter | L |
| Time | Second | s |
| **Voltage** | **Volt** | **V** |
| **Current** | **Ampere** | **A** |
| **Resistance** | **Ohm** | **Ω** |
| **Power** | **Watt** | **W** |
| Temperature | Degree | C or K |

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# SI Measurement Units

## Electrical Measurement Terms

### Voltage – Volt (V)

- Named after Alessandro Volta (Italy)
- Similar in function to pressure

### Current – Ampere (I)

- Named after Andre Ampere (French)
- Similar in function to fluid flow

### Resistance – Ohm (Ω)

- Named after Georg Ohm (Germany)
- Similar in function to valve

### Power – Watt (W)

- Named after James Watt (Scotland)
- Identical in function to work

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# SI Measurement Units

## Electrical Measurement Terms

### Voltage – Volt (V)

- kV = 1000V
- mV = 0.001V **OR** 1000mV per Volt
- uV = 0.0000001V **OR** 1000uV per mV

### Current – Ampere (I)

- kA = 1000A
- mA = 0.001A **OR** 1000mA per Amp
- uA = 0.000001A **OR** 1000uA per mA

### Resistance – Ohm (Ω)

- GΩ = 1,000,000,000Ω **OR** 1000MΩ
- 1 MΩ = 1,000,000Ω
- 1 kΩ = 1000Ω
- 1 mΩ = 0.001Ω **OR** 1000mΩ per Ohm
- 1 uΩ = 0.0000001Ω **OR** 1000uΩ per mV

### Power – Watt (W)

- GW = 1,000,000,000W **OR** 1000MW
- MW = 1,000,000W **OR** 1000kW
- kW = 1000W
- mW = 0.001W **OR** 1000mW per Watt
- uW = 0.0000001W **OR** 1000uW per mW

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# SI Measurement Units

## Conversion Examples

$$\frac{\text{Unit you want}}{\text{Unit you have}}$$

$$-0.71A * \frac{1000mA}{1A} = -710mA$$

$$1.325kV * \frac{1000V}{1kV} = 1325V$$

$$956m\Omega * \frac{1\Omega}{1000m\Omega} = 0.956\Omega$$

$$1500W * \frac{1kW}{1000W} = 1.5kV$$

# Review

- Topics
  - Skill requires practice
  - Different types of units and their relationships
  - How to derive a conversion ratio to achieve larger or smaller units of measure
  - Established some electrical units of measure

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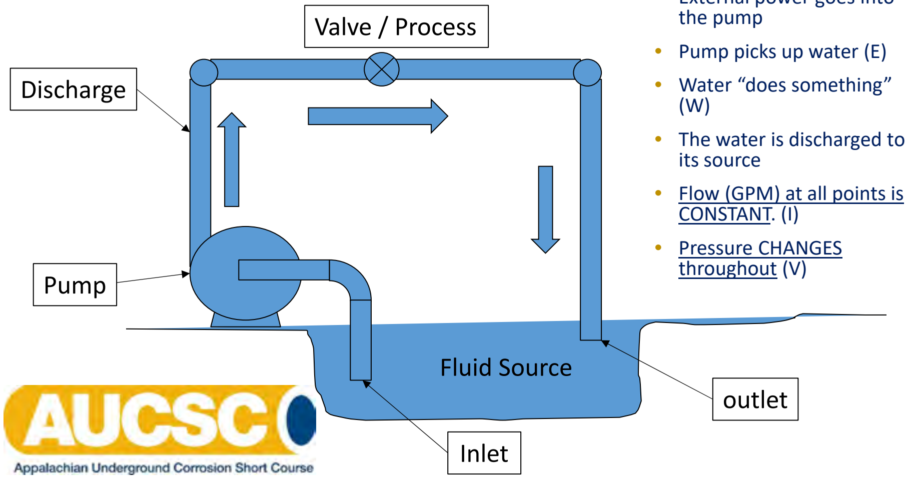
# Circuits

Electric Circuits behave somewhat like fluid or pneumatic flow systems



- External power goes into the pump
- Pump picks up water (E)
- Water "does something" (W)
- The water is discharged to its source
- Flow (GPM) at all points is CONSTANT. (I)
- Pressure CHANGES throughout (V)

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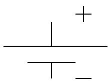
# Circuits

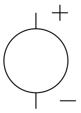
## Electrical Symbols

DC Voltage Source
(Battery)

$E_s = 1.5V_{DC}$

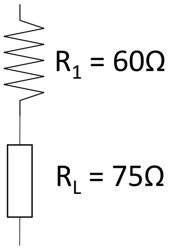


$E = 6V_{DC}$



Current flow – may be represented with an arrow → and an "I"

Resistance – may be represented with zig-zag image or a box with or without a resistance value. Usually labeled R



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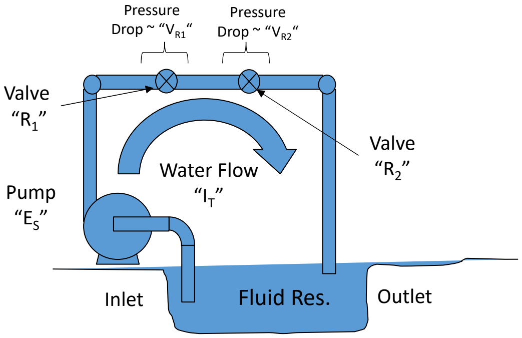
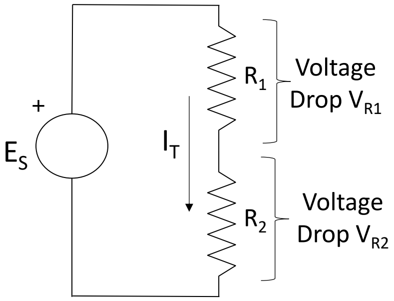
# Circuits

## Series Circuit - Fluid vs. Electricity



- Pump Pressure ~ Source Voltage
- Water Flow ~ Electrical Current
- Valve ~ Resistor



- Pressure around circuit changes
- Flow rate remains constant

- Voltage around circuit changes
- Current flow remains constant

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# Circuits

## Series Circuit - Water vs. Electricity

**Fluids**

- Pressure Drop
  - Pounds per Square Inch
  - Difference between one side of flow resistance and the other
- Flow
  - Gallons per minute
  - Measured by Diverting the Fluid Flow

**Electricity**

- Voltage Drop
  - Volts
  - Difference between one side of flow resistance and the other
- Current
  - Amps
  - Measured by Diverting the Current

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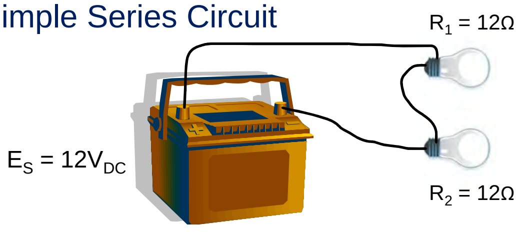
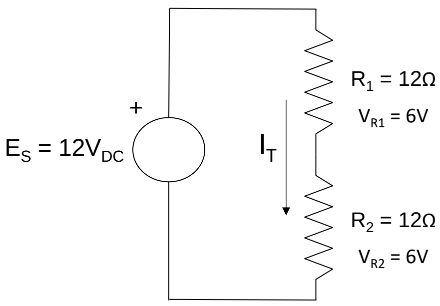
# Circuits

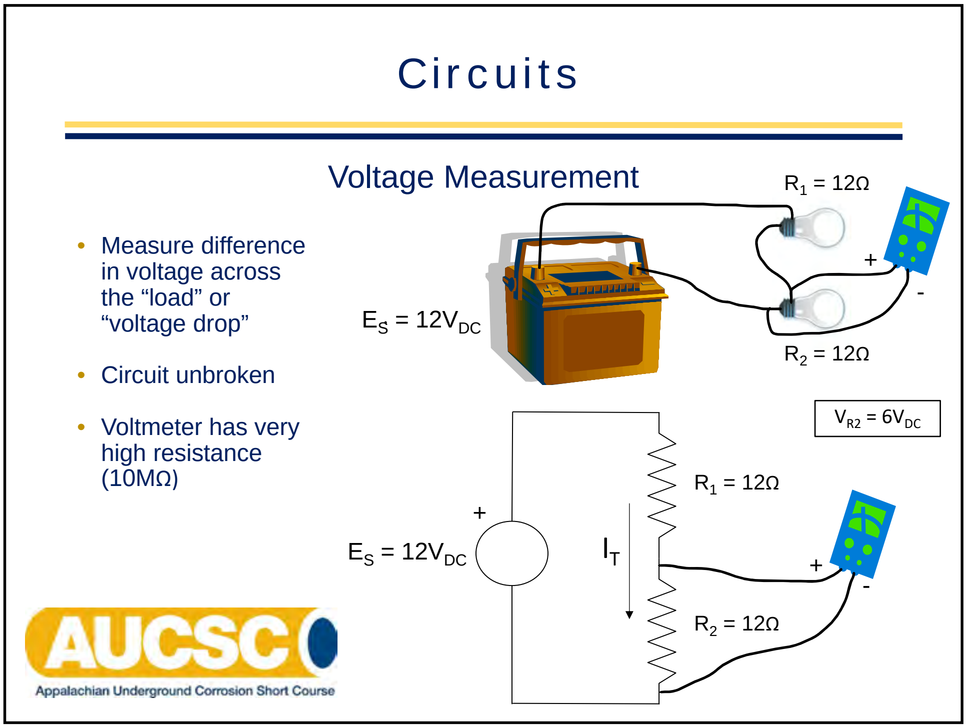
## Simple Series Circuit

- 12VDC Car Battery
- DC Lamp



Electrical current flows from battery (+) terminal through the light bulb filament back to the battery (-) terminal.

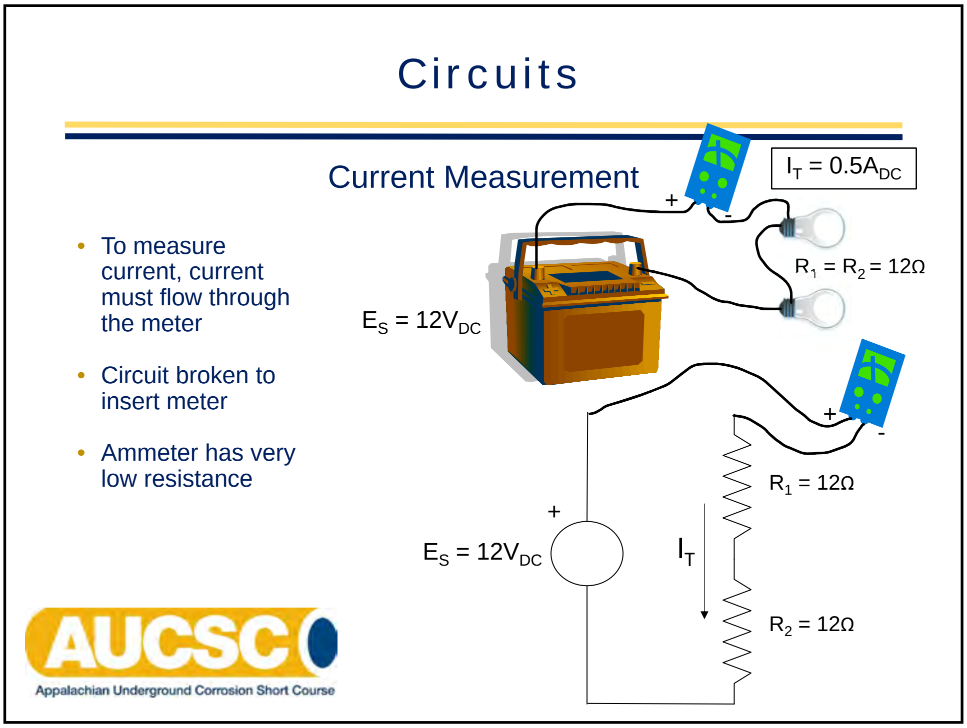




# Circuits

## Voltage Measurement

- Measure difference in voltage across the “load” or “voltage drop”
- Circuit unbroken
- Voltmeter has very high resistance (10MΩ)



# Circuits

## Current Measurement

- To measure current, current must flow through the meter
- Circuit broken to insert meter
- Ammeter has very low resistance

# Circuits

## Circuit Breakers

- Two Types of Circuit Breakers
  - “Normal” Circuit Breaker – Breaks the circuit when the current **exceeds** the rating of the circuit breaker (short circuit)
  - “Ground Fault” Circuit Breaker – Breaks the circuit when the “Hot Side” (Black) current is **different** than the “Neutral” (White) side of the circuit

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# Circuits

## Resistors

- Resistors are generally provided with two basic pieces of information
  - The size of the resistor in ohms
  - The wattage or maximum power the resistor can dissipate before it starts to fail

10 Watt, 1Ω

100 Watt, 1Ω

# The Basic Electricity Formulas

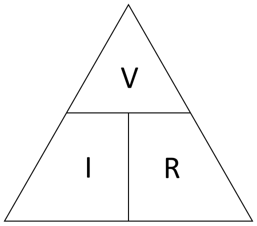
Ohms Law

A potential of 1 Volt across a resistance of 1 Ohm causes 1 ampere of current to flow

$V = I * R$

$I = V / R$

$R = V / I$



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*V can be replaced with E

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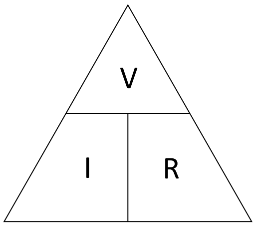
# The Basic Electricity Formulas

Ohms Law

- Using the triangle
- Cover the unknown variable
- Known variables will be in the appropriate configuration



$V = I * R$

$I = V / R$

$R = V / I$

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## The Basic Electricity Formulas

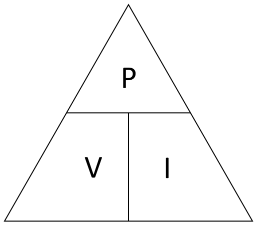
Joules Basic Power Triangle

A potential of 1 Volt across a resistance of 1 Ohm causes 1 ampere of current to flow and dissipates 1 Watt of Power

P = V * I

I = P / V

V = P / I



*V can be replaced with E

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## The Basic Electricity Formulas

Units, Units, Units

- For ease of calculation
- **Always** convert units to Volts, Amps, Ohms, & Watts
- Convert millivolts, milliamps, kilohms, etc. to the parent unit

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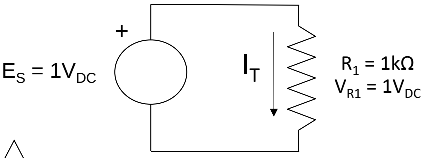
# Circuit Analysis

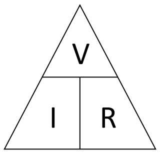
## The Formulas Applied – Example 1

- The voltage ($V_{R1}$) across the resistance is 1 Volt
- The resistance ($R_1$) is 1kΩ or 1000Ω

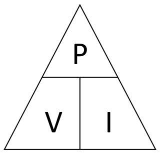
- What is the current through $R_1$?

- What is the minimum wattage for $R_1$ that's required?





- $I_T = V_{R1}/R_1$
- $I_T = 1V / 1000\Omega$
- $I_T = 0.001A$ **or** 1mA



- $P_{R1} = V_{R1} * I_T$
- $P_{R1} = 1V * 0.001A$
- $P_{R1} = 0.001W$ **or** 1mW

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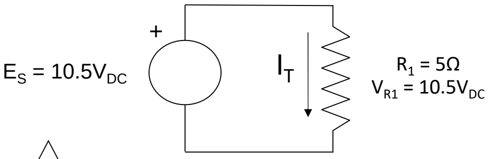
# Circuit Analysis

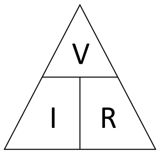
## The Formulas Applied – Example 2

- The voltage ($V_{R1}$) across the resistance is 10.5 Volts
- The resistance ($R_1$) is 5Ω

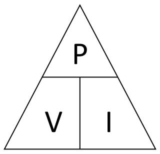
- What is the current through $R_1$?

- What is the minimum wattage for $R_1$ that's required?





- $I_T = V_{R1}/R_1$
- $I_T = 10.5V / 5\Omega$
- $I_T = 2.1A$



- $P_{R1} = V_{R1} * I_T$
- $P_{R1} = 10.5V * 2.5A$
- $P_{R1} = 26.25W$

# Circuit Analysis

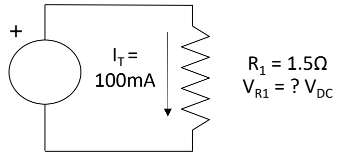
## The Formulas Applied – Example 4

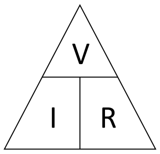
- The total circuit current ($I_T$) is 100mA
- The resistance of $R_1$ is 1.5Ω

- What is the voltage across the resistance $R_1$?

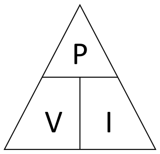
- How many watts are being dissipated across $R_1$?

$E_S$ = ? $V_{DC}$





- $V_{R1} = R_1 * I_T$
- $V_{R1}$ = 1.5Ω * 0.1A
- $V_{R1}$ = 0.15V



- $P_{R1} = V_{R1} * I_T$
- $P_{R1}$ = 0.15V * 0.1A
- $P_{R1}$ = 0.015W **or** 15mW

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# Circuit Analysis

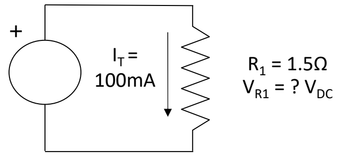
## The Formulas Applied – Example 5 (Common Error)

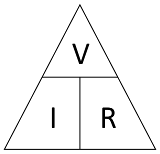
- The total circuit current ($I_T$) is 100mA
- The resistance of $R_1$ is 1.5Ω

- What is the voltage across the resistance $R_1$?

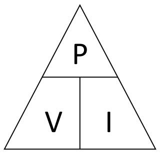
- How many watts are being dissipated across $R_1$?

$E_S$ = ? $V_{DC}$





- $V_{R1} = R_1 * I_T$
- $V_{R1}$ = 1.5 * 100
- $V_{R1}$ = 150V



- $P_{R1} = V_{R1} * I_T$
- $P_{R1}$ = 150V * 100A
- $P_{R1}$ = 15,000W

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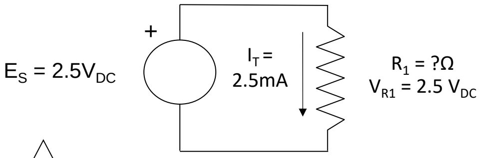
# Circuit Analysis

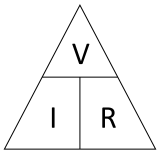
## The Formulas Applied – Example 6

- The total circuit current ($I_T$) is 2.5mA
- The voltage across $R_1$ is 2.5V

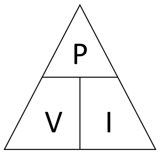
- What is the value of the resistance $R_1$?

- How many watts are being dissipated across $R_1$?





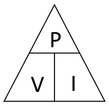
- $R_1 = VR_1 / I_T$
- $R_1 = 2.5V / 2.5mA$
- $R_1 = 1000\Omega$



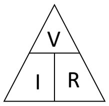
- $P_{R1} = V_{R1} * I_T$
- $P_{R1} = 2.5V * 2.5mA$
- $P_{R1} = 0.00625W$ or 6.25mW

---

# Circuit Analysis



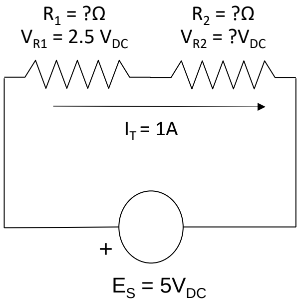
## The Formulas Applied – Example 7



- The total circuit current ($I_T$) is 1A
- The voltage across $R_1$ is 2.5V

- What is the value of the resistance $R_2$?

- How many watts are being dissipated across $R_2$?



- $R_1 = VR_1 / I_T$
- $R_1 = 2.5V / 1A$
- $R_1 = 2.5\Omega$

- $V_{R2} = E_S – V_{R1}$
- $V_{R2} = 5V – 2.5V$
- $V_{R2} = 2.5V$

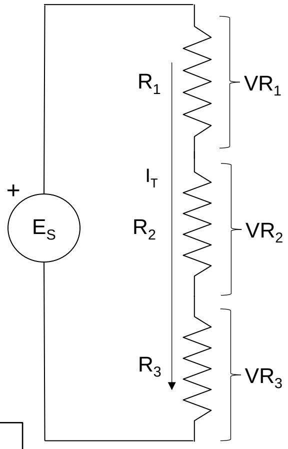
- $V_{R1} = V_{R2}$; $R_1 = R_2$
- $R_2 = 2.5\Omega$

- $P_{R2} = V_{R1} * I_T$
- $P_{R2} = 2.5V * 1A$
- $P_{R2} = 2.5W$

# Circuit Analysis

## Series Circuit Analysis

- A series circuit has all elements connected “end to end” forming a single loop with the power source
- **Current ($I_T$) is the same through all elements**
- Voltage Drops ($V_{R1}$, $V_{R2}$, etc.) may be different
- The sum of all voltage drops = the source voltage
- $V_{R1}+V_{R2}+V_{R3}+ \ldots = E_S$
- Total or Equivalent circuit resistance ($R_T$ or $R_{EQ}$) = the sum of all resistances



Total resistance ($R_T$) is always **larger** than the largest resistance

---

# Circuit Analysis

## Parallel Circuit

- A parallel circuit has all elements “side by side” forming multiple loops with the power source
- **Total Current ($I_T$) is the sum of currents through all elements**
- Voltage Drops ($V_{R1}$, $V_{R2}$, etc.) are the same
- $I_{R1}+I_{R2}+I_{R3}+ \ldots = I_T$
- Total or Equivalent circuit resistance ($R_T$ or $R_{EQ}$) = the inverse of the inverse sum of all resistances

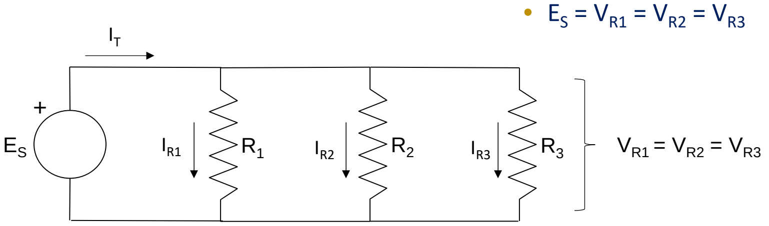
$$R_T = \frac{1}{\left(\frac{1}{R_1}\right)+\left(\frac{1}{R_2}\right)+\left(\frac{1}{R_3}\right)}$$

# Circuit Analysis

## Parallel Circuit

- Each parallel current is a different magnitude
- Voltage across each parallel path or resistance is the same

- $I_T = I_{R1} + I_{R2} + I_{R3}$
- $R_T = \dfrac{1}{((1/R_1)+(1/R_2)+(1/R_3))}$
- $E_S = V_{R1} = V_{R2} = V_{R3}$



Total resistance ($R_T$) is always **smaller** than the smallest resistance

---

# Circuit Analysis

## The Formulas Applied - Example 8

- The total circuit current ($I_T$) is 6mA
- The current through $R_1$ is 1mA & $R_2$ is 5mA

- What is the value of the resistances $R_1$ & $R_2$ & $R_T$

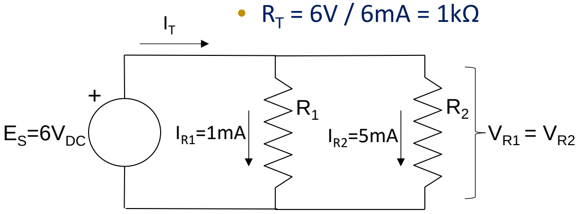
- How would you verify $R_T$?

- $R_1 = V_{R1} / I_{R1}$
- $R_1 = 6V / 0.001A = 6k\Omega$

- $R_2 = V_{R2} / I_{R2}$
- $R_2 = 6V / 0.005A = 1.2k\Omega$

- $R_T = 1/((1/R_1)+(1/R_2))$
- $R_T = 1/(0.000167s+0.000833s)$
- $R_T = 1k\Omega$

- $R_T = E_S / I_T$
- $R_T = 6V / 6mA = 1k\Omega$



# Thank You!

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Michael Baxter

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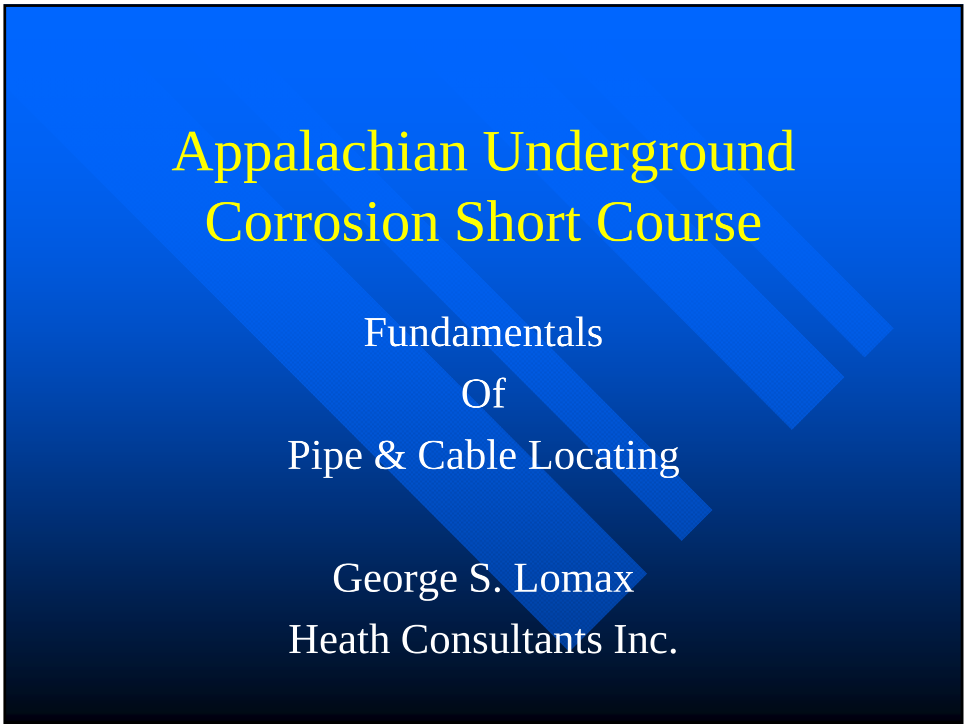
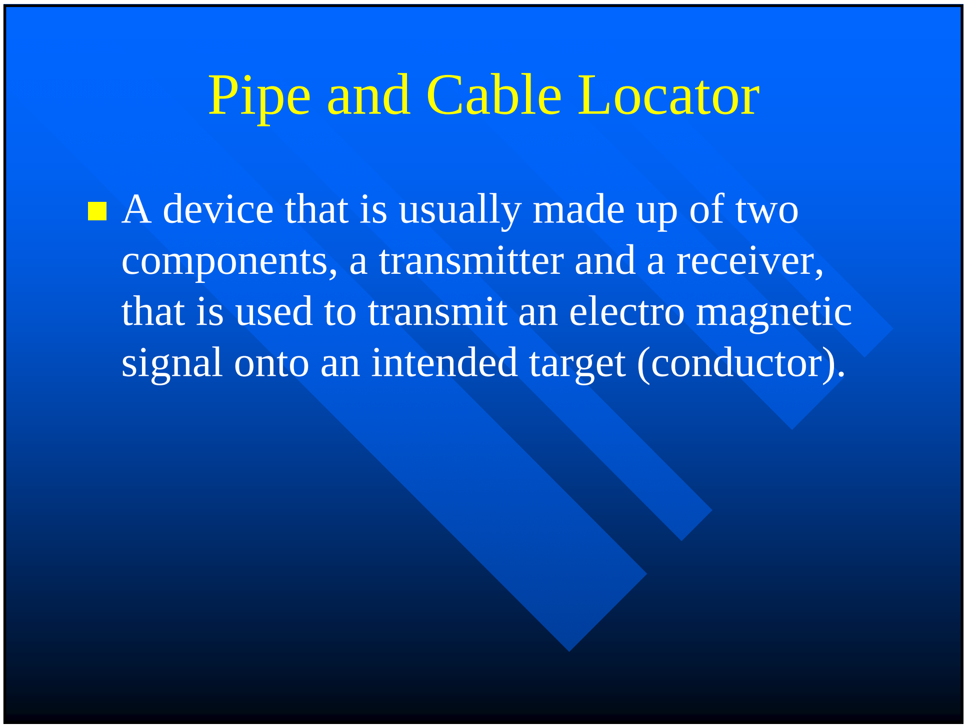


# Appalachian Underground Corrosion Short Course

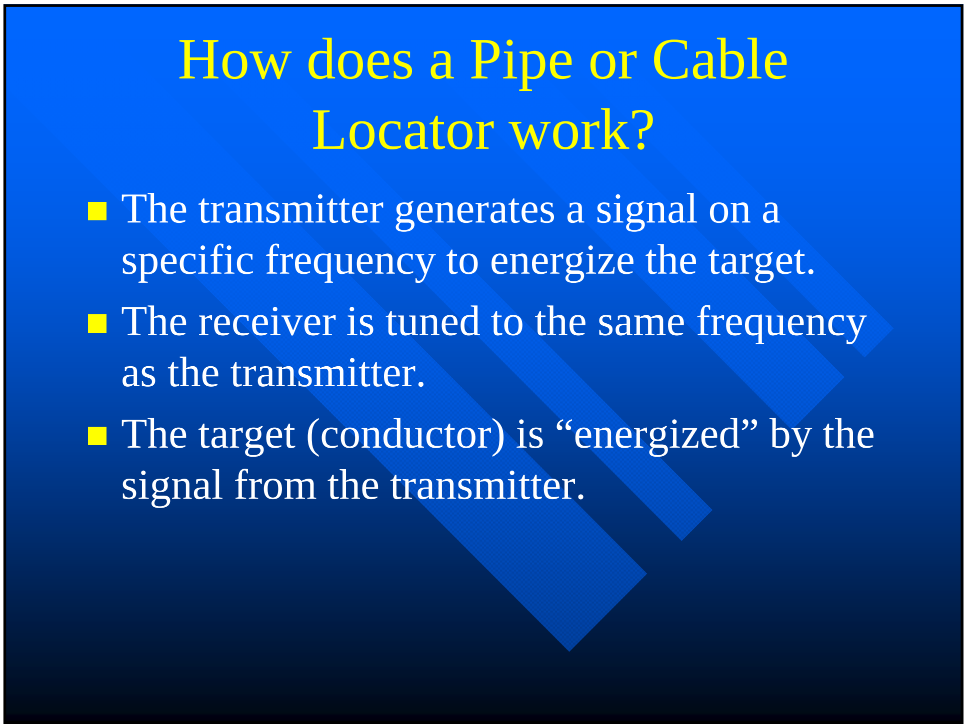
Fundamentals
Of
Pipe & Cable Locating

George S. Lomax
Heath Consultants Inc.



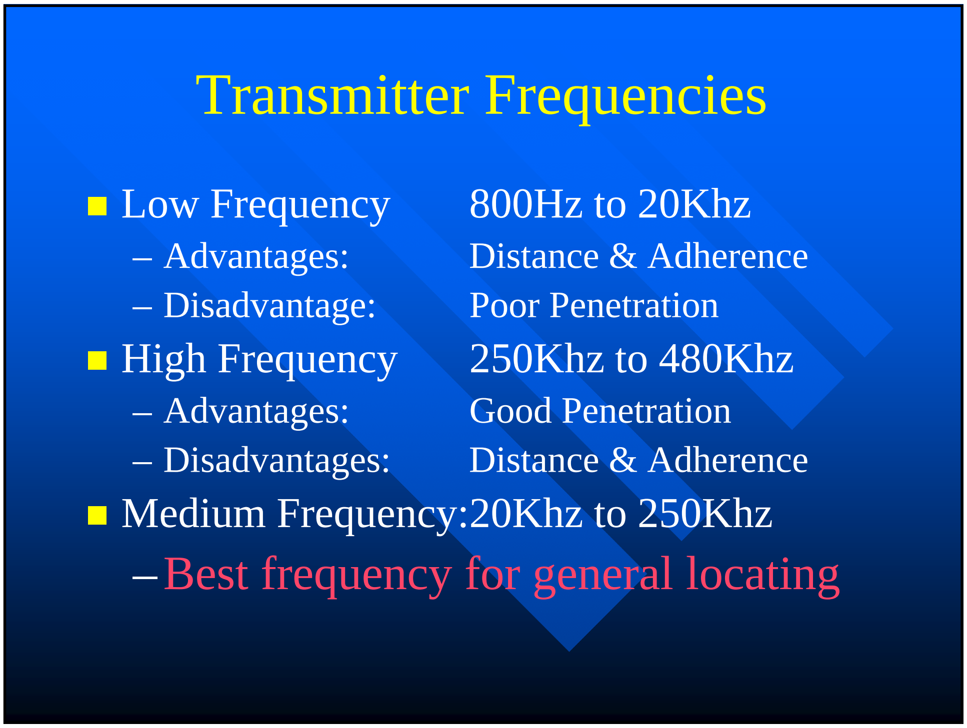
## Pipe and Cable Locator

- A device that is usually made up of two components, a transmitter and a receiver, that is used to transmit an electro magnetic signal onto an intended target (conductor).



## How does a Pipe or Cable Locator work?

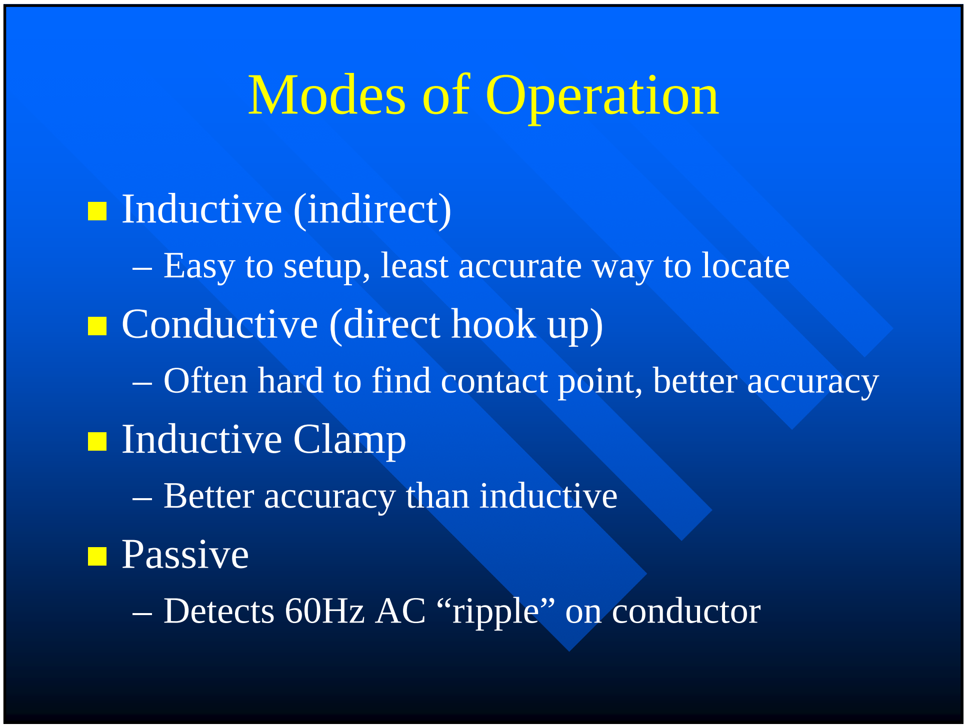
- The transmitter generates a signal on a specific frequency to energize the target.
- The receiver is tuned to the same frequency as the transmitter.
- The target (conductor) is “energized” by the signal from the transmitter.



## Transmitter Frequencies

| | |
|---|---|
| ■ Low Frequency | 800Hz to 20Khz |
| – Advantages: | Distance & Adherence |
| – Disadvantage: | Poor Penetration |
| ■ High Frequency | 250Khz to 480Khz |
| – Advantages: | Good Penetration |
| – Disadvantages: | Distance & Adherence |
| ■ Medium Frequency: | 20Khz to 250Khz |

– Best frequency for general locating

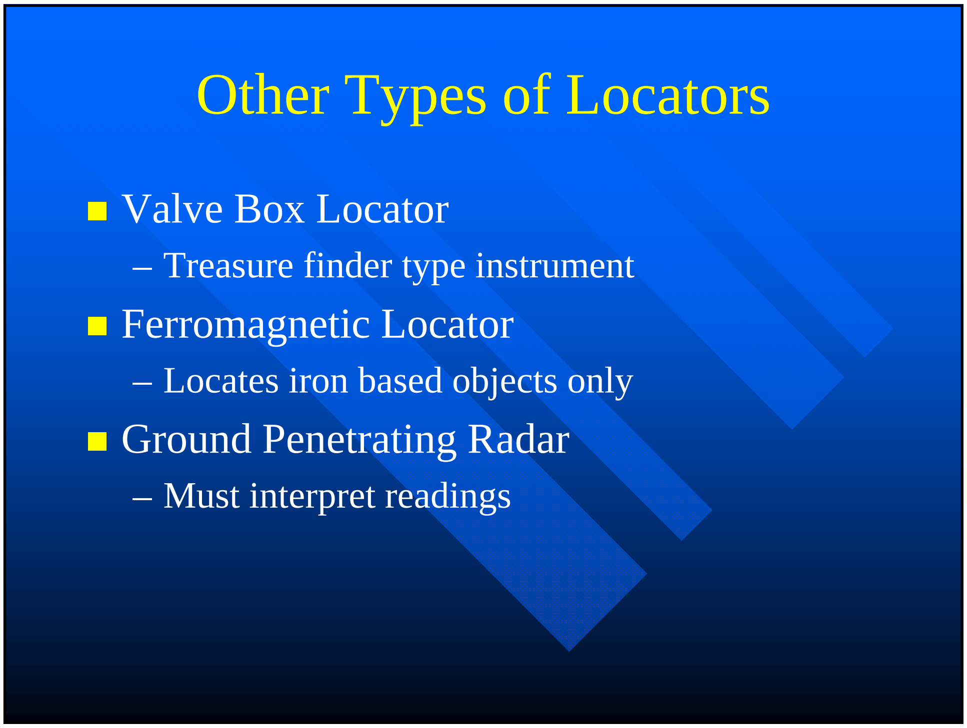


## Modes of Operation

- Inductive (indirect)
  - – Easy to setup, least accurate way to locate
- Conductive (direct hook up)
  - – Often hard to find contact point, better accuracy
- Inductive Clamp
  - – Better accuracy than inductive
- Passive
  - – Detects 60Hz AC “ripple” on conductor

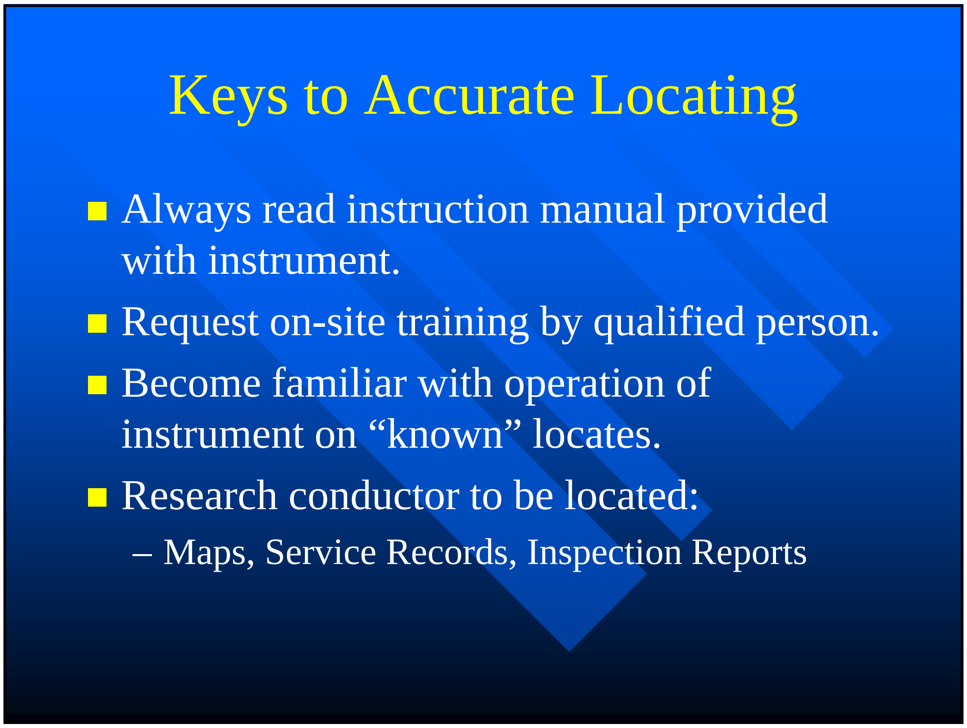
## Choosing the Right Tool

- Simple Split Box vs. Electronic Locator
  - – Split Box Locator should be used for short incidental locates, C&M crew, leak repair, etc.
  - – Single Frequency Electronic Locator is recommended for more accurate locates where depth measurements are needed.
  - – Multi-Frequency Electronic Locators are recommended for Damage Prevention and trouble shooting Cathodic Protection Systems.



## Other Types of Locators

- Valve Box Locator
  - Treasure finder type instrument
- Ferromagnetic Locator
  - Locates iron based objects only
- Ground Penetrating Radar
  - Must interpret readings

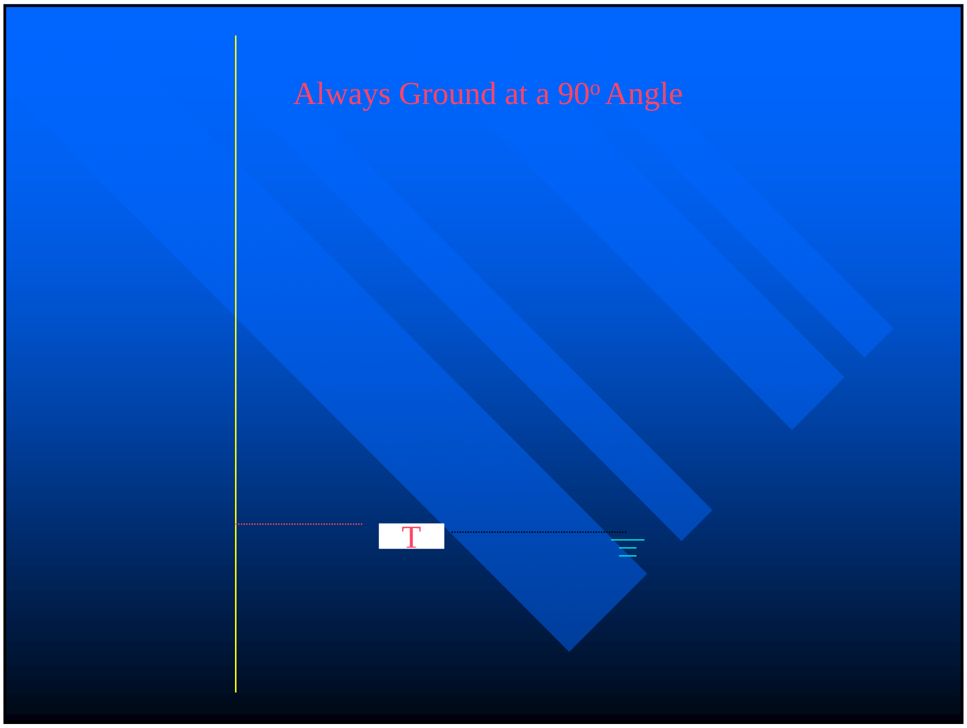


## Keys to Accurate Locating

- Always read instruction manual provided with instrument.
- Request on-site training by qualified person.
- Become familiar with operation of instrument on “known” locates.
- Research conductor to be located:
  - Maps, Service Records, Inspection Reports

# Keys to Accurate Locating

- Read the Street before locating:
  - Look for visual indicators, valves, hydrants, pedestals, test stations, etc.
- For best accuracy, always use the Conductive Mode .
- When grounding the transmitter, try to run ground cable at a 90$^{o}$ angle to the conductor.



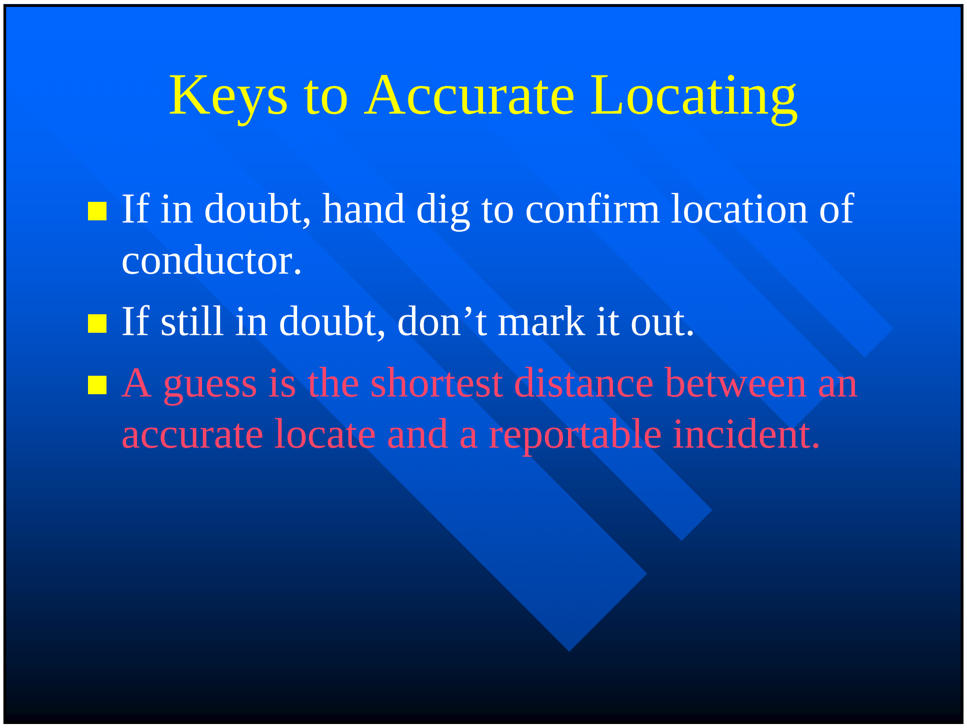
Always Ground at a 90$^{o}$ Angle

## Keys to Accurate Locating

- Always connect cable assembly from transmitter to “clean shiny metal”.
- Never run ground wire over or near other conductors.
- When locating in the inductive mode, make sure transmitter is aligned properly with the intended conductor.

## Keys to Accurate Locating

- Depth measurements using a “split box” type locator are most inaccurate.
- Depth measurements using an Electronic Locator are only accurate when used in Conductive Mode.
- Depth measurements are for your information only.



## Keys to Accurate Locating

- If in doubt, hand dig to confirm location of conductor.
- If still in doubt, don’t mark it out.
- A guess is the shortest distance between an accurate locate and a reportable incident.

## The End

# Fundamentals Course

Basic Corrosion

Fundamental introduction and theory behind the corrosion process

Presented By: Heather Groll

AUCSC

Appalachian Underground Corrosion Short Course

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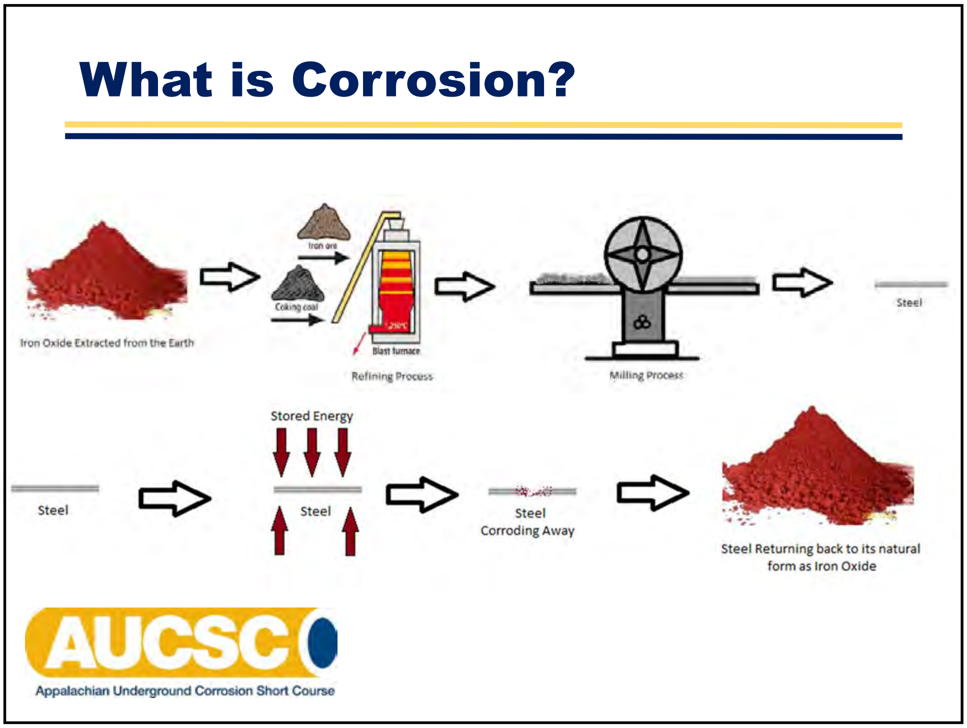
## What is Corrosion?

The deterioration of a material, usually a metal, due to a reaction with its environment

Or

The tendency of a refined metal to return to its natural state as an ore



## What is Corrosion?

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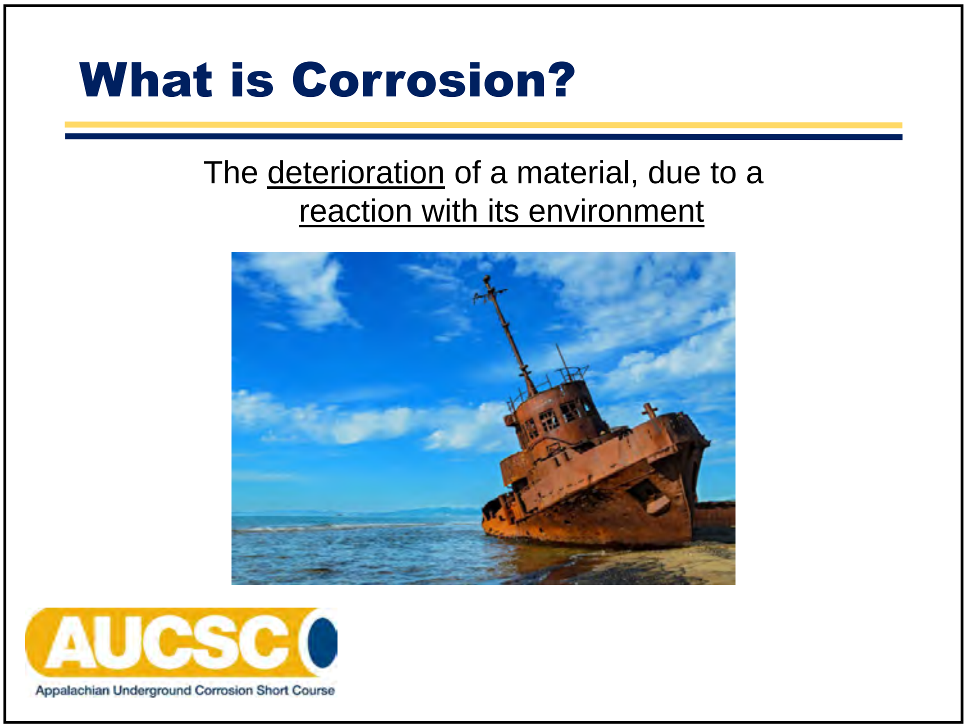

## What is Corrosion?

The deterioration of a material, due to a reaction with its environment

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# Causes of a Corrosion Cell

**Naturally Occurring Corrosion**

- Dissimilar metals
- Dissimilar surface
- Dissimilar Soils (Electrolyte)
- Different Aeration (including Oxygen Concentration)
- Cinders
- Stress
- Graphitization
- Microbiological Influenced Corrosion

# What is a Corrosion Cell?

Corrosion cannot occur without the **four** components of a corrosion cell;

1. ANODE
2. CATHODE
3. METALLIC PATH
4. ELECTROLYTE

*Take one of the four away and corrosion will be mitigated.

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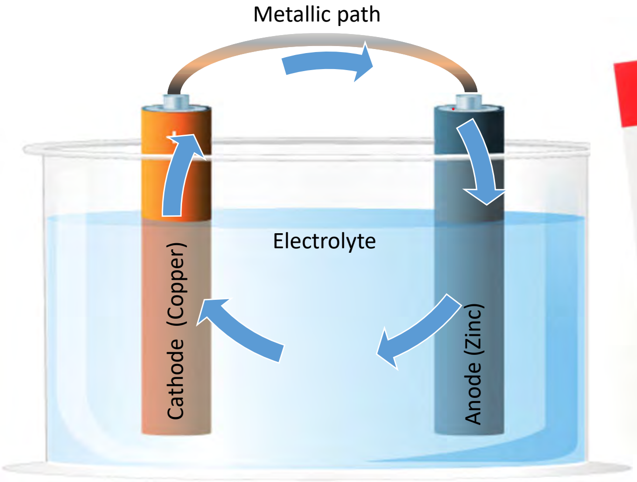
# Corrosion Cell

*Image shown in terms of conventional current



Current flowing due to a difference in potential

---

# Galvanic Series

Potentials measured with respect to saturated Cu-$CuSO_4$ Half Cell

**Active (More Electro-Negative)** (-)

- High Potential Magnesium (-1.75 v)
- Magnesium Alloy (-1.5 v)
- Zinc  (-1.1 v)
- Aluminum Alloys (-1.05 v)
- Clean Carbon Steel (-0.5 to -0.8 v)
- Rusted Carbon Steel (-0.2 to -0.8 v)
- Lead (-0.5 v)
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

**Noble (More Electro-Positive)** (+)

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# Galvanic Series

Defining an Anode and Cathode

**Active (More Electro-Negative)**

- High Potential Magnesium (-1.75 v)
- Magnesium Alloy (-1.5 v)
- Zinc  (-1.1 v)
- Aluminum Alloys (-1.05 v)
- Clean Carbon Steel (-0.5 to -0.8 v)
- Rusted Carbon Steel (-0.2 to -0.8 v)
- Lead (-0.5 v)
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

**Noble (More Electro-Positive)**

*Anode is more electro-negative than the cathode

*Cathode is more electro-positive than the anode

---

# Galvanic Series

Defining an Anode and Cathode

**Active (More Electro-Negative)**

- High Potential Magnesium (-1.75 v)
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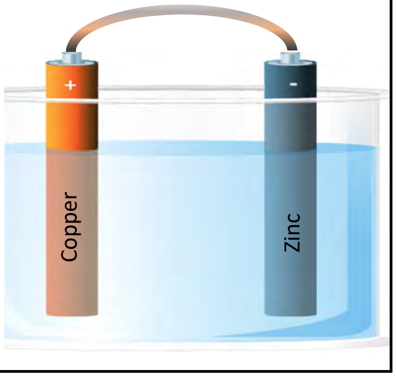
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

**Noble (More Electro-Positive)**

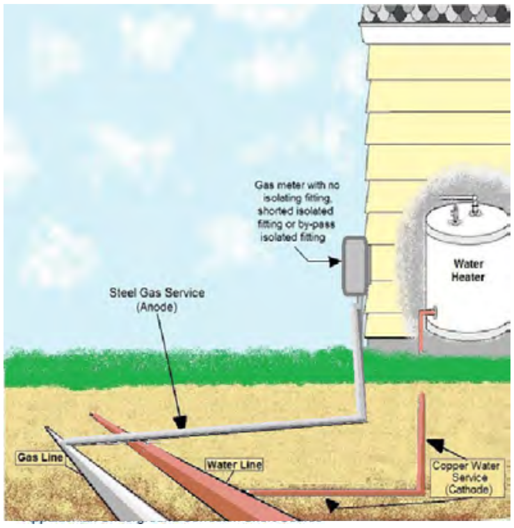
*Anode is more electro-negative than the cathode

*Cathode is more electro-positive than the anode



# Dissimilar Metal Corrosion

Steel Gas Line and Copper Water Line



**Active (More Electro-Negative)**

- High Potential Magnesium (-1.75 v)
- Magnesium Alloy (-1.5 v)
- Zinc (-1.1 v)
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- Clean Carbon Steel (-0.5 to -0.8 v)
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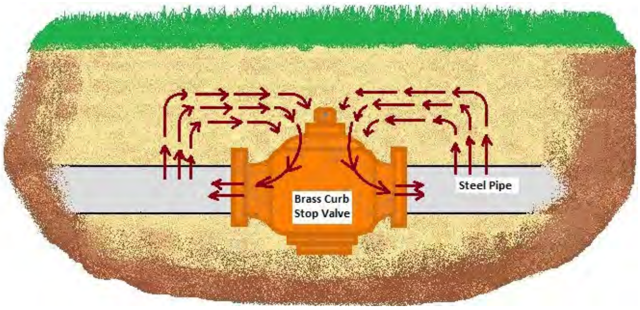
- Lead (-0.5 v)
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

**Noble (More Electro-Positive)**

---

# Dissimilar Metal Corrosion

Brass Stop in a Steel Line



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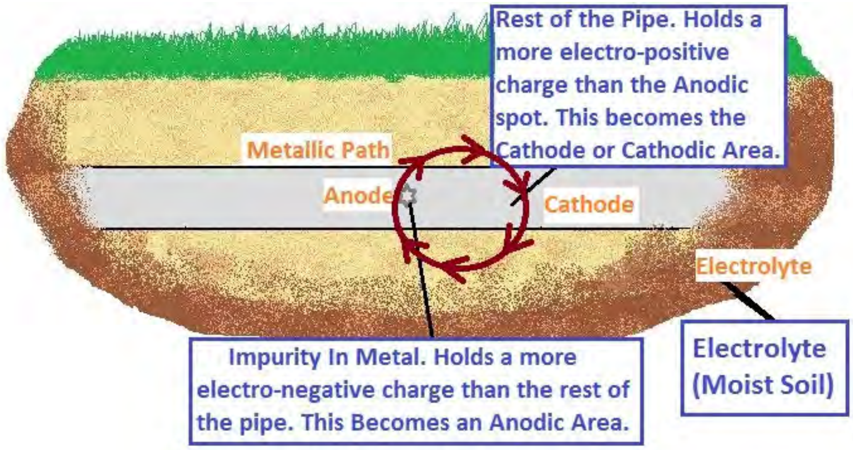
## Surface Conditions



Rest of the Pipe. Holds a more electro-positive charge than the Anodic spot. This becomes the Cathode or Cathodic Area.

Impurity In Metal. Holds a more electro-negative charge than the rest of the pipe. This Becomes an Anodic Area.

Electrolyte (Moist Soil)

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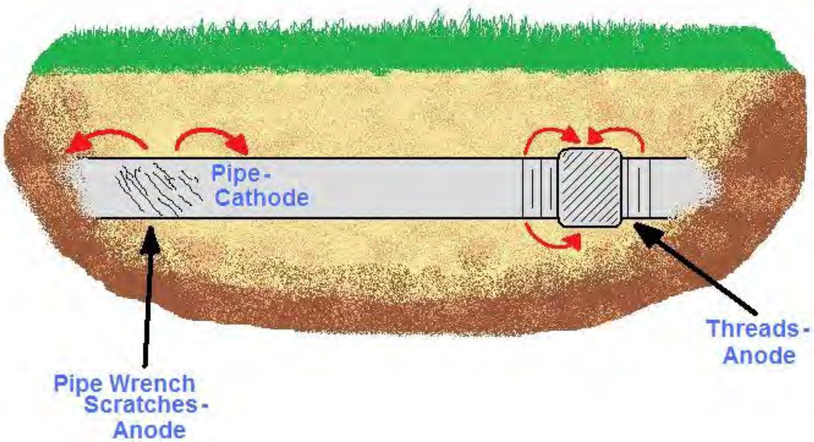
## Surface Conditions



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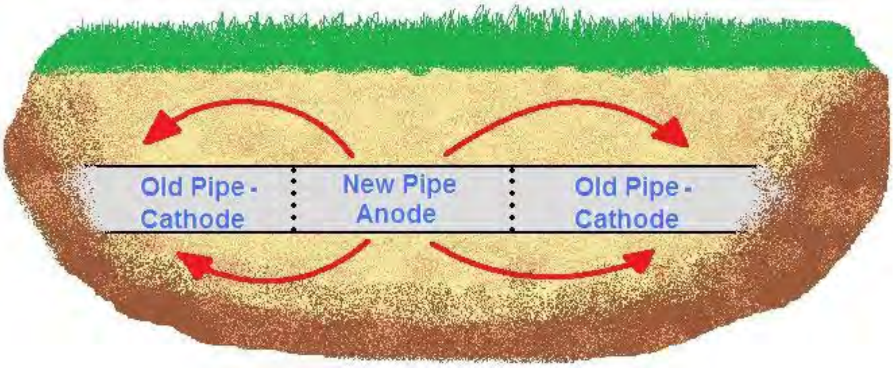
## New-Old Pipe Corrosion Cell



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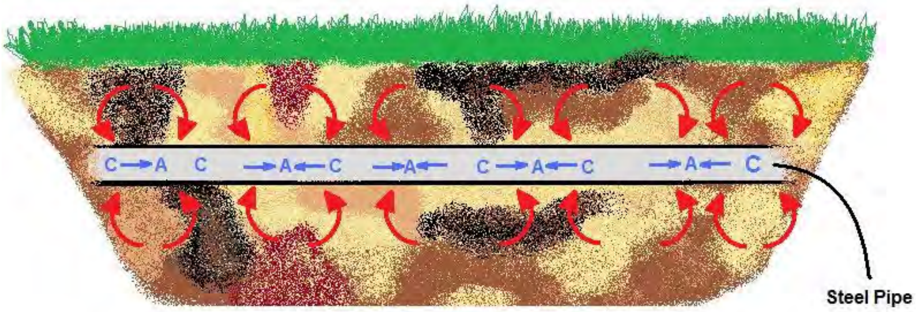
## Dissimilar Electrolyte



A= Anodic Areas
C= Cathodic Areas

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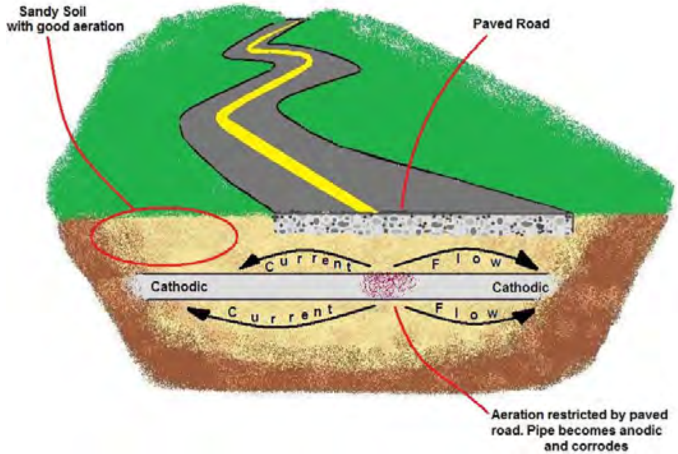
## Different Aeration



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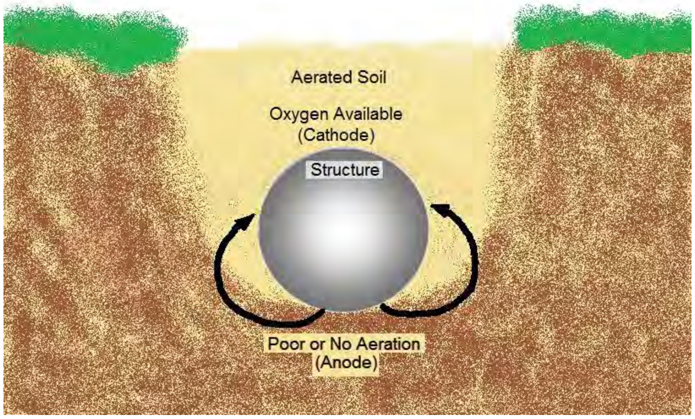
## Different Aeration



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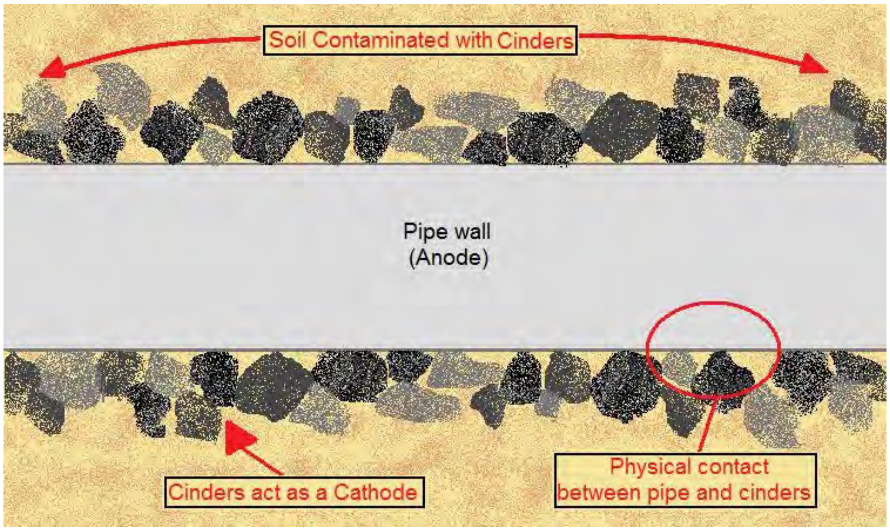
# Cinders



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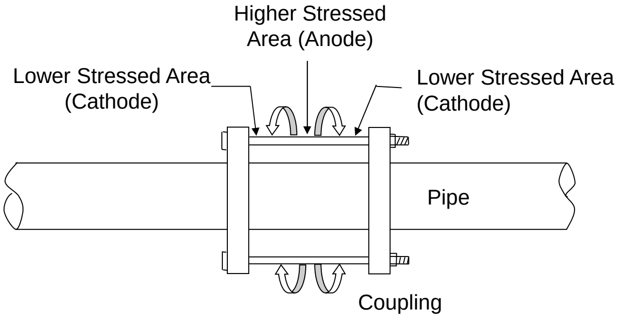
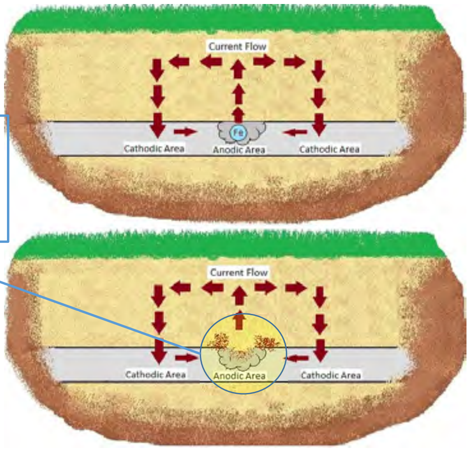
# Stress Points



# The Big Picture



Reaction happens here, at the anode/cathode interface

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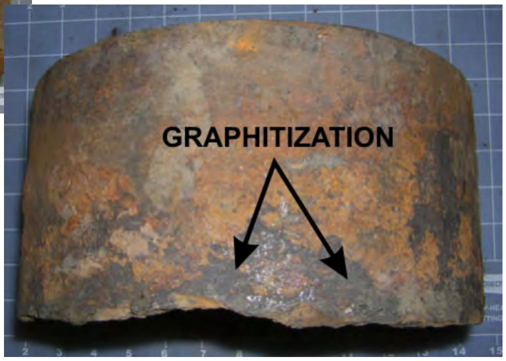
# Graphitization

Grey blotchy areas



Can also lead to inner granular cracking (separation between the grains)

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# Microbiologically Influenced Corrosion (MIC)

Identified by: white pasty material; turns light brown when exposed to the air

- Black, flaky substance

Causes: Old pieces of rope, rags, wood, leaves: organic material in contact with metal

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# Microbiologically Influenced Corrosion (MIC)

- Can occur internally and externally.
- Mitigated internally: use of chemical inhibitors, added to the gas stream, or by removing the water from the system.
- Mitigated externally: certain types of coatings, or CP with potentials over 1.5 volts.

# Microbiologically Influenced Corrosion (MIC)

Two types:
Acid Producing Bacteria (APB)
Sulfur Reducing Bacteria (SRB)

Unique pitting of metal:
Step wise pitting
Smooth "Thumb print" pitting
Worm hole pitting

The bacteria does not eat the pipe, but rather their waste by products, when mixed with water can create acids- which dissolve the metal.

---

# Stray Current

Stray Current is current traveling a path in which it was not intended to go

Electricity Reminder:

- Current takes the path of least resistance
- Flows from positive to negative (conventional current)
- Returns to the source

## Stray Current

Alternating current, is mainly a safety issue. AC can be induced from overhead high voltage power lines. A measured voltage over 15 volts AC, must be mitigated. Can be measured by setting meter on AC volts, and taking a structure to electrolyte reading.

Direct current, is a large concern to the corrosion person. Due to the fact that 1 ampere leaving a steel structure, removes 20 pounds of iron per year. DC stray currents can be a rather large amount. There is two types of DC stray current, **static** or steady state and **dynamic** or fluctuating current.

Example:
2 amps per year
2amps X 20 pounds = 40 pounds lost
Times 3 years = 120 pounds of lost iron
6 inch pipe weights 18.974 pounds per foot

---

## Stray Current

### Sources: Man-Made and/or Natural

**Dynamic Stray Current**

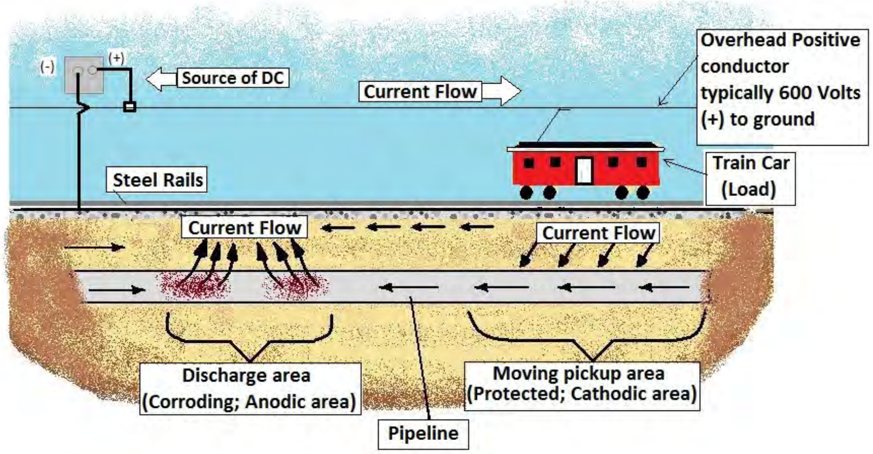
- Electrified railroads/Transit systems
- Underground mine railroads
- High Voltage AC Transmission Lines
- Telluric Currents

**Steady State Stray Current**

- Impressed Current Cathodic Protection
- High Voltage DC Transmission Lines

1 Ampere removes 20 pounds of iron per year, from structure

# Dynamic Stray Current



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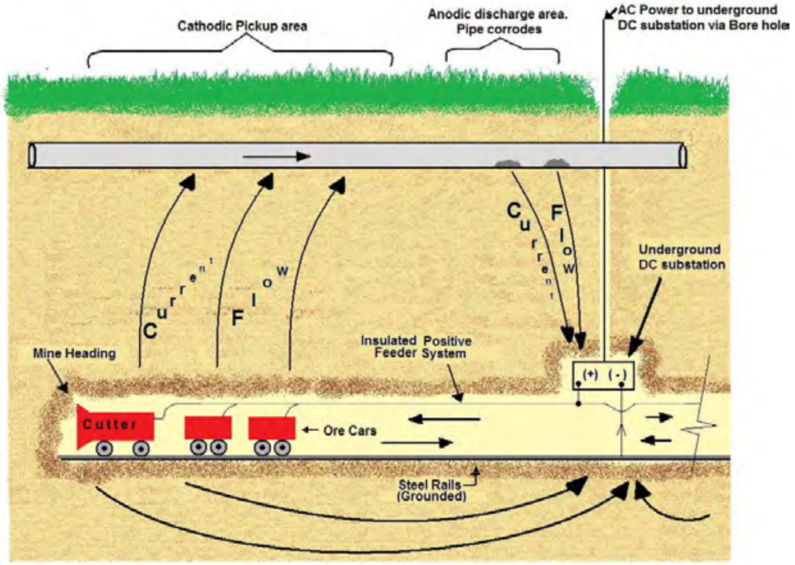
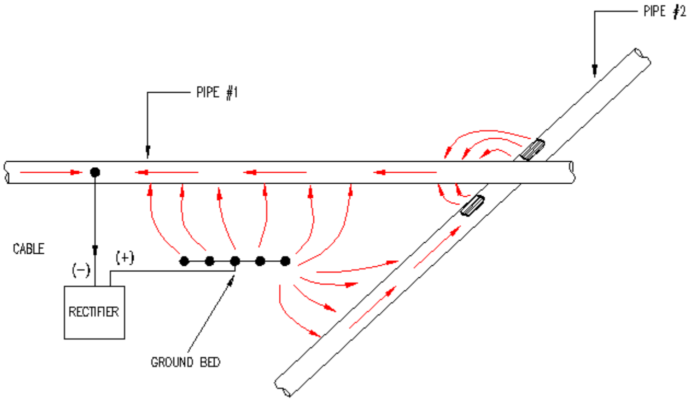
# Dynamic Stray Current



# Steady State (Static) Current



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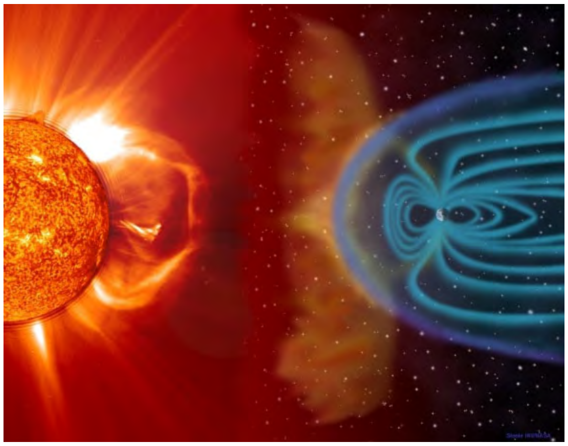
# Telluric Currents



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# Rate of Corrosion

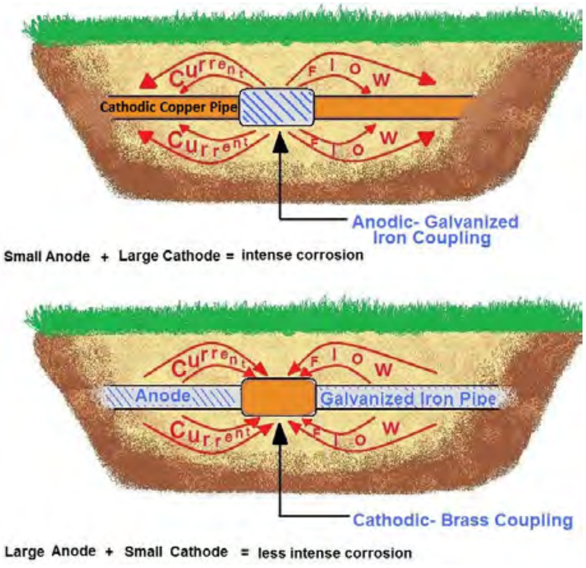
**Factors Effecting Rate of Corrosion:**

- Soil Resistivity
- Anode/Cathode Ratio
- Potential Difference between
- Polarization

# Soil Resistivity

| | |
|---|---|
| Below 500 ohm-cm | Very Corrosive |
| 500 to 1000 ohm-cm | Corrosive |
| 1000 to 2000 ohm-cm | Moderate Corrosive |
| 2000 to 10,000 ohm-cm | Mildly corrosive |
| 10,000 ohm-cm and above | Progressively less Corrosive |

# Anode to Cathode Ratio



Small Anode + Large Cathode = intense corrosion

Large Anode + Small Cathode = less intense corrosion

Small Anode vs Large Cathode

current discharge is concentrated in smaller area resulting in more severe material loss

# Potential Difference

## Active (More Electro-Negative)

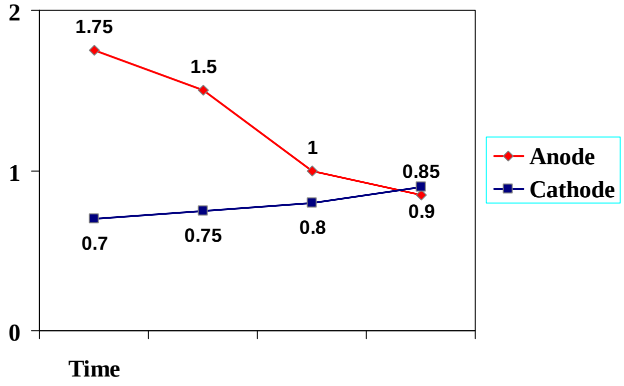
- High Potential Magnesium (-1.75 v)
- Magnesium Alloy (-1.5 v)
- Zinc (-1.1 v)
- Aluminum Alloys (-1.05 v)
- Clean Carbon Steel (-0.5 to -0.8 v)
- Rusted Carbon Steel (-0.2 to -0.8 v)
- Lead (-0.5 v)
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

Bigger potential difference = Bigger reaction

## Noble (More Electro-Positiv

# Polarization

| | |
|---|---|
| High Potential Magnesium | -1.75 Volts |
| Clean Carbon Steel | -0.50 to –0.80 Volts |



# Questions???

Heather Groll
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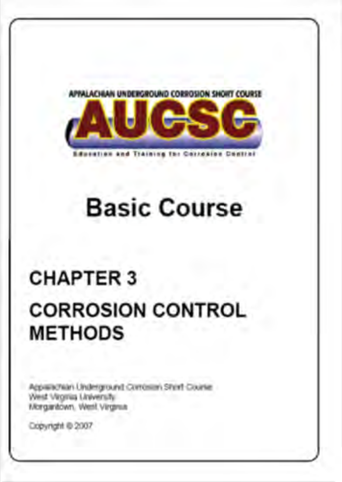
# Introduction to Cathodic Protection

Daniel R Younkin
BHE GT&S
Daniel.Younkin@bhegts.com

- This is “Fundamentals” so I will keep it simple.
- I am going to show you some formulas to help illustrate some “concepts” of cathodic protection.
- At the end of the class I will finish with a cathodic protection joke that you will be forced to awkwardly laugh at.
- After going through the class you should get the joke or I have failed you.
- You might not think it’s funny but you should at least get it.



APPALACHIAN UNDERGROUND CORROSION SHORT COURSE

AUCSC

Education and Training for Corrosion Control

Basic Course

CHAPTER 3

CORROSION CONTROL METHODS

Appalachian Underground Corrosion Short Course
West Virginia University
Morgantown, West Virginia

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Much of the material in this class comes from the Basic Course Chapter 3 – Corrosion Control Methods

## What is Cathodic Protection?

NACE Definition

- A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

# Introduction to Cathodic Protection

- A review of the fundamental corrosion cell
- Coatings and cathodic protection
- Electrical isolation fittings and cathodic protection
- When have we achieved cathodic protection?
- Cathodic protection current requirements
- Galvanic anode cathodic protection
- Impressed current cathodic protection

---

# What structures can be cathodically protected?

- Any metallic structure that is buried or submerged

EXAMPLES -

- Pipelines
- Underground storage tanks
- The bottom of aboveground storage tanks
- The internal surface of water storage tanks
- The internal surface of household water heaters
- Lead sheath electric and telephone cables
- Waterfront structures such as docks and piers
- Power plant structures such as waterboxes and traveling screens
- Steel building piles
- Cars – if they are buried or submerged

# Corrosion Control Methods

- Cathodic Protection
- Coatings
- Electrical Isolation

# The 4 Parts of a Corrosion Cell

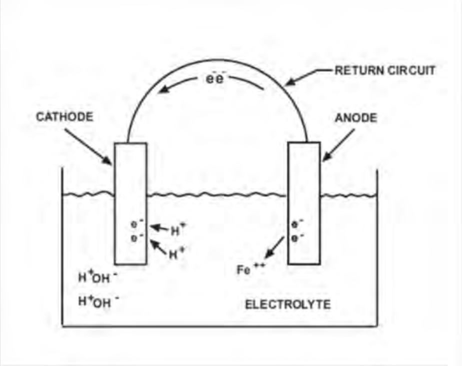
- Anode
- Cathode
- Electrolyte
- Return Circuit

If we are missing any one of these four things we will not have a corrosion cell.

Keep this in mind because we can use this to our advantage.

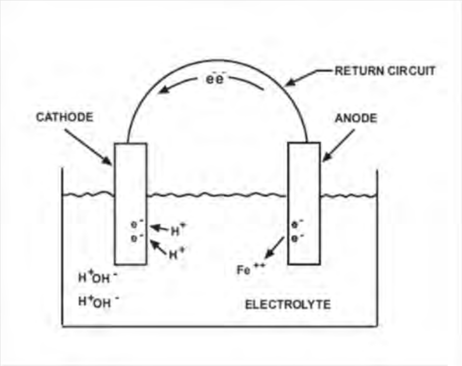
# The Fundamental Corrosion Cell

- There are 4 parts to a corrosion cell:



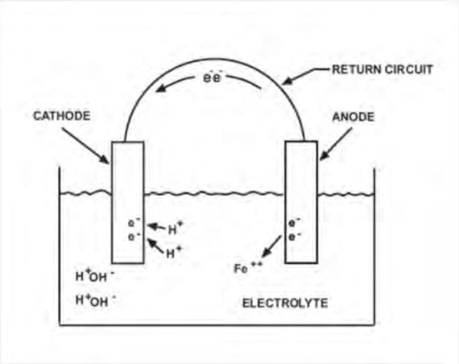
# The Fundamental Corrosion Cell

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.



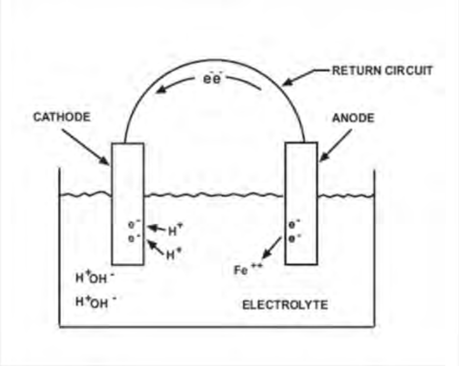
# The Fundamental Corrosion Cell

- Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves the metal is called the anode. Corrosion occurs at the anode.



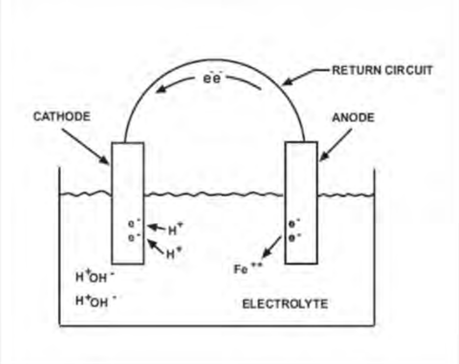
# The Fundamental Corrosion Cell

- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A cathodic reaction occurs at the cathode. Most often this is the build up of a hydrogen film. This cathodic reaction is referred to as “polarization.”



# The Fundamental Corrosion Cell

- The flow of current is caused by a potential (voltage) difference between the anode and the cathode.



# The Fundamental Corrosion Cell and Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
- Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves the metal is called the anode. Corrosion occurs at the anode.
- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A cathodic reaction occurs at the cathode. Most often this is the build up of a hydrogen film. This cathodic reaction is referred to as "polarization."
- The flow of current is caused by a potential (voltage) difference between the anode and the cathode.
- If we do not have any one of these four things we will not have a corrosion cell. We can use this to our advantage.

## What is Cathodic Protection?

NACE Definition

- A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

## Coatings and Cathodic Protection

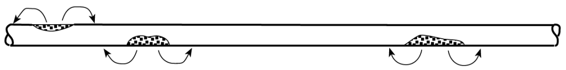
- Coatings are the first line of defense in corrosion control.
- We don’t need cathodic protection if the metal is not in contact with the electrolyte. We have eliminated one part of the corrosion cell, the electrolyte.
- If we had a perfect coating, we would not need cathodic protection.
- Unfortunately, there is no such thing as a perfect coating. But very fortunate for corrosion technicians.
- The better the coating, the less cathodic protection we need. We only need to protect the bare areas.

# Electrical Isolation and Cathodic Protection

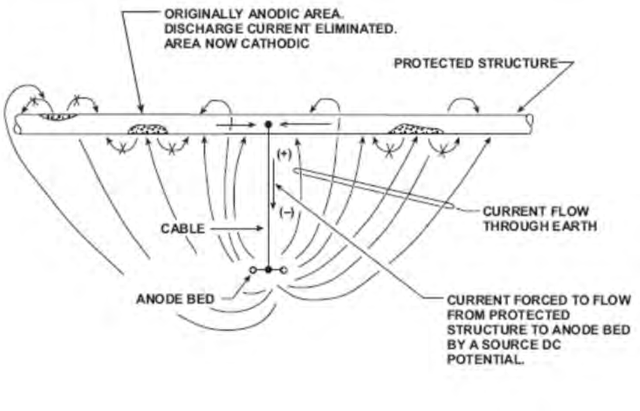
- Electrical isolation fittings are used to confine cathodic protection current to a structure (or portion of a structure) to be cathodically protected.
- Electrical isolation fittings eliminate the return circuit.
- We only want to protect the bare areas of our structure. Not the bare areas of other underground structures.
- Electrical isolation fittings are also used to separate cathodic protection systems from each other.

# Theory of Cathodic Protection

- Anodes Corrode.
- Cathodes do not corrode.
- If we make the entire surface of our structure a cathode there will be no corrosion. Hence the name "cathodic protection" for this method of corrosion control.
- Direct current is forced to flow into the earth through a ground connection outside the structure (anode bed) and then through the earth to the structure to be protected.
- The amount of current forced to flow onto the structure is adjusted to a level which will nullify current discharge in anodic areas and result in net current collection in those areas.



Anodic areas on a pipeline.
Arrows indicate current leaving the metal and causing corrosion.

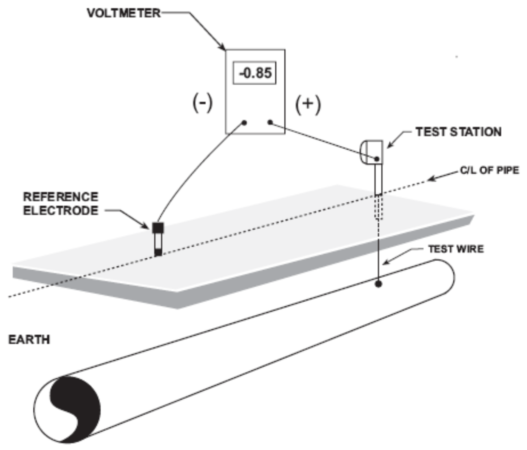


HOW CATHODIC PROTECTION WORKS

FIGURE 3-2

## We have achieved cathodic protection when:

- We have net current flow onto our structure and we have caused a cathodic reaction to occur.
- In soil this cathodic reaction is typically the formation of a hydrogen film also know as polarization.
- We can determine if we have achieved cathodic protection by measuring the structure-to-electrolyte voltage.
- If the structure-to-electrolyte voltage meets a criterion we have achieved cathodic protection. The most common criterion for steel is -0.85 volts to a saturated copper/copper sulfate reference electrode (CSE) with IR considered.



PIPE-TO-SOIL POTENTIAL MEASUREMENT

## Cathodic Protection Current Requirement

- The total amount of current needed to cathodically protect a structure.
- Primarily related to the amount of bare metal that our structure has in contact with the electrolyte.
- Short, well coated structures have a low current requirement.
- Long, poorly coated structures have a high current requirement.
- Electrical isolation fittings keep the current on the intended structure.

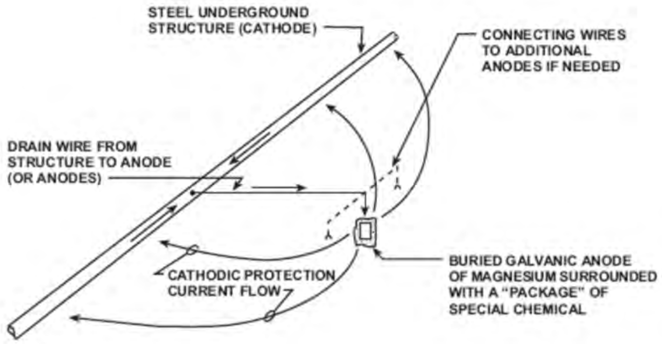
## Two methods of cathodic protection:

- Galvanic anode or sacrificial anode cathodic protection. Sometimes referred to as a “passive” system.
- Impressed current cathodic protection. Sometimes referred to as an “active” system.

Both of these methods are ways to create a corrosion cell in which our structure is a cathode.

# The Fundamental Corrosion Cell and Galvanic Anode Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit. The anode must be connected to the structure!
- Corrosion occurs wherever current leaves the metal and enters the soil (electrolyte). The point where current leaves the metal is called the anode. Corrosion occurs at the anode. The anode is “consumed” as it corrodes and will eventually need to be replaced.
- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A hydrogen film builds up at the cathode. The hydrogen film is referred to as “polarization.”
- The flow of current is caused by a potential (voltage) difference between the anode and the cathode. This is the “driving voltage” and in galvanic anode cathodic protection is caused by the natural potential difference between the protected structure and the galvanic anode.



GALVANIC ANODE CATHODIC PROTECTION

FIGURE 3-3

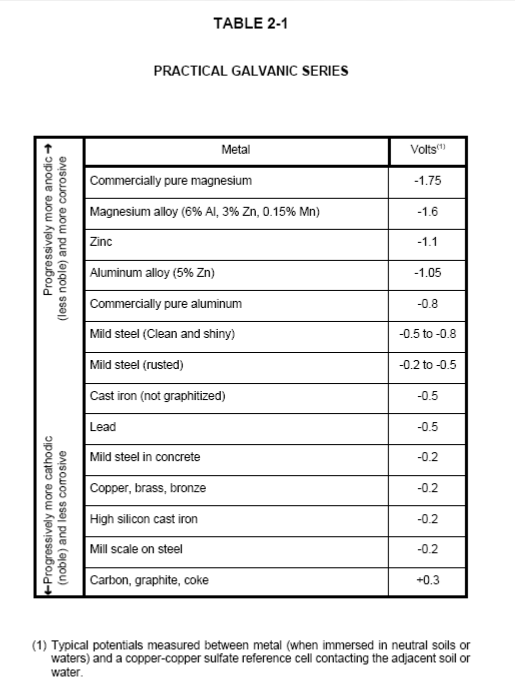


TABLE 2-1

PRACTICAL GALVANIC SERIES

| | Metal | Volts(1) |
|---|---|---|
| ↑ Progressively more anodic (less noble) and more corrosive | Commercially pure magnesium | -1.75 |
| | Magnesium alloy (6% Al, 3% Zn, 0.15% Mn) | -1.6 |
| | Zinc | -1.1 |
| | Aluminum alloy (5% Zn) | -1.05 |
| | Commercially pure aluminum | -0.8 |
| | Mild steel (Clean and shiny) | -0.5 to -0.8 |
| | Mild steel (rusted) | -0.2 to -0.5 |
| | Cast iron (not graphitized) | -0.5 |
| | Lead | -0.5 |
| ↓ Progressively more cathodic (noble) and less corrosive | Mild steel in concrete | -0.2 |
| | Copper, brass, bronze | -0.2 |
| | High silicon cast iron | -0.2 |
| | Mill scale on steel | -0.2 |
| | Carbon, graphite, coke | +0.3 |

(1) Typical potentials measured between metal (when immersed in neutral soils or waters) and a copper-copper sulfate reference cell contacting the adjacent soil or water.

## Common Galvanic Anode Materials

- Magnesium. High potential magnesium anodes have a potential of -1.75 volts to CSE. Other alloys are around -1.50 volts to CSE. Most common anode for use in soil.
- Zinc. Typically -1.1 volts to CSE. Significantly less “driving voltage” than magnesium. Used in low resistivity soil and sea water. Also used for AC mitigation.
- Aluminum. Typically -1.05 to -1.15 volts to CSE. Most commonly used in sea water.

## Advantages of Galvanic Anode Cathodic Protection

- They are self-powered. No dependence on outside sources of power.
- Low maintenance requirements.
- Minimum probability of stray current interference on other underground structures.

## Disadvantages of Galvanic Anode Cathodic Protection

- Low, fixed driving voltage.
- Relatively high consumption rate which means a relatively low life expectancy.

# Ohm’s Law

$$E = IR$$

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

---

## Driving Voltage

- The difference in voltage between the anode and the protected structure (the cathode):

$$\text{Driving Voltage} = E_{\text{Anode}} - E_{\text{Cathode}}$$

- The voltage that causes current to flow in a corrosion cell, or a cathodic protection system.
- If R remains the same, the current will increase in proportion to the driving voltage:

$$I = \frac{E_{\text{Anode}} - E_{\text{Cathode}}}{R}$$

## Driving Voltage Effect on Current Output for Galvanic Anodes

- For a magnesium anode:

$$I = \frac{1.75\,V - 0.85\,V}{R} = \frac{0.90\,V}{R}$$

- For a zinc anode:

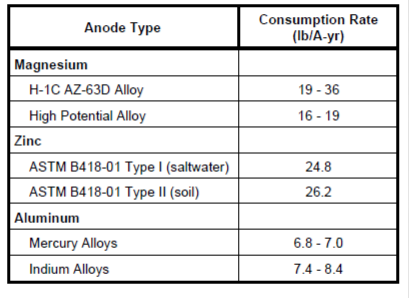
$$I = \frac{1.10\,V - 0.85\,V}{R} = \frac{0.25\,V}{R}$$

- For an aluminum anode:

$$I = \frac{1.05\,V - 0.85\,V}{R} = \frac{0.20\,V}{R}$$

## Consumption of Galvanic Anode Materials

- As current flows, the anode material is corroded or “consumed”.
- After it has been consumed, the anode will need to be replaced.
- Different anode materials have different consumption rates:



| Anode Type | Consumption Rate (lb/A-yr) |
|---|---|
| **Magnesium** | |
| H-1C AZ-63D Alloy | 19 - 36 |
| High Potential Alloy | 16 - 19 |
| **Zinc** | |
| ASTM B418-01 Type I (saltwater) | 24.8 |
| ASTM B418-01 Type II (soil) | 26.2 |
| **Aluminum** | |
| Mercury Alloys | 6.8 - 7.0 |
| Indium Alloys | 7.4 - 8.4 |

- The lower the consumption rate the longer the anode will last.

## Magnesium and zinc anodes for use in soil are commonly packaged with a prepared backfill consisting of:

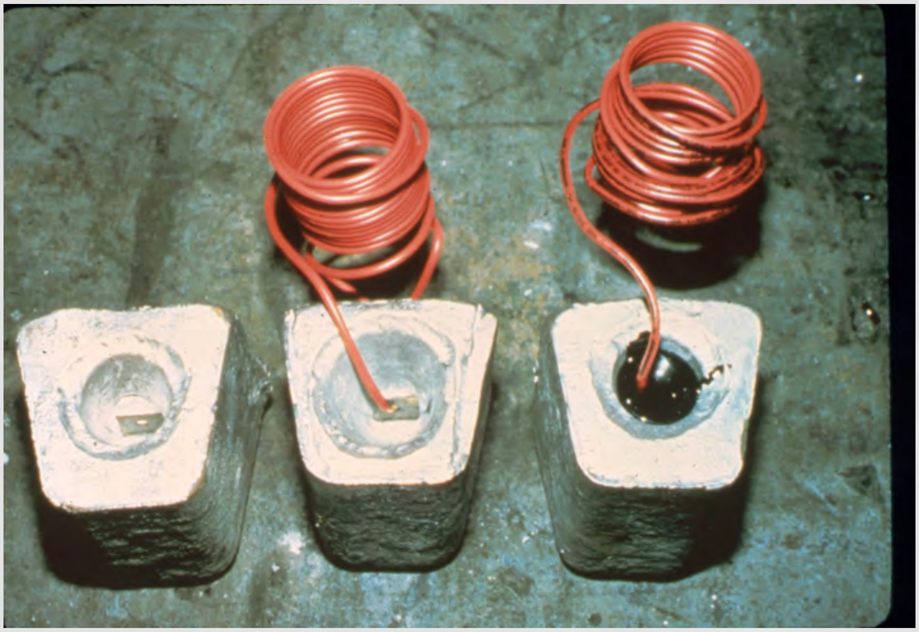
- 75% Hydrated Gypsum ($CaSO_4{\cdot}2H_20$)
- 20% Bentonite Clay
- 5% Sodium Sulfate

## The purpose of the prepared backfill is (the short answer):

- They work better.

## The purpose of the prepared backfill is (the long answer):

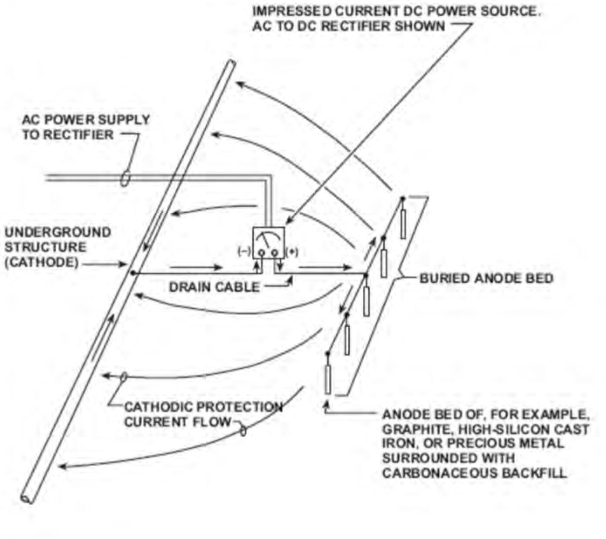
- It increases the effective surface area which lowers the anode to earth contact resistance.
- The bentonite clay absorbs and retains moisture.
- The gypsum provides a uniform, low resistance environment.
- The sodium sulfate (a depolarizing agent) minimizes pitting attack and oxide film formation on the anode.
- It provides uniform environment directly in contact with anode to assure even consumption.




GALVOPAK
GALVOMAG
HIGH POTENTIAL
2 UNITS TYPE 17D3
MAGNESIUM
ANODE
WITH BACKFILL
PACKAGED BY
CATHODIC PROTECTION SERVIC
HOUSTON
TULSA - FARMINGTON - LOS ANGELES - MIDLAN
CORPUS CHRISTI - NEW ORLEANS - DENV

# The Fundamental Corrosion Cell and Impressed Current Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
- Corrosion occurs wherever current leaves the metal and enters the soil (electrolyte). The point where current leaves the metal is called the anode. Corrosion occurs at the anode. The anode is “consumed” as it corrodes and will eventually need to be replaced.
- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A hydrogen film builds up at the cathode. The hydrogen film is referred to as “polarization.”
- The flow of current is caused by a potential (voltage) difference between the anode and the cathode. This is the “driving voltage” and in impressed current cathodic protection is caused by the DC source (usually a rectifier) which creates a potential difference between the protected structure and the impressed current anode.



IMPRESSED CURRENT CATHODIC PROTECTION

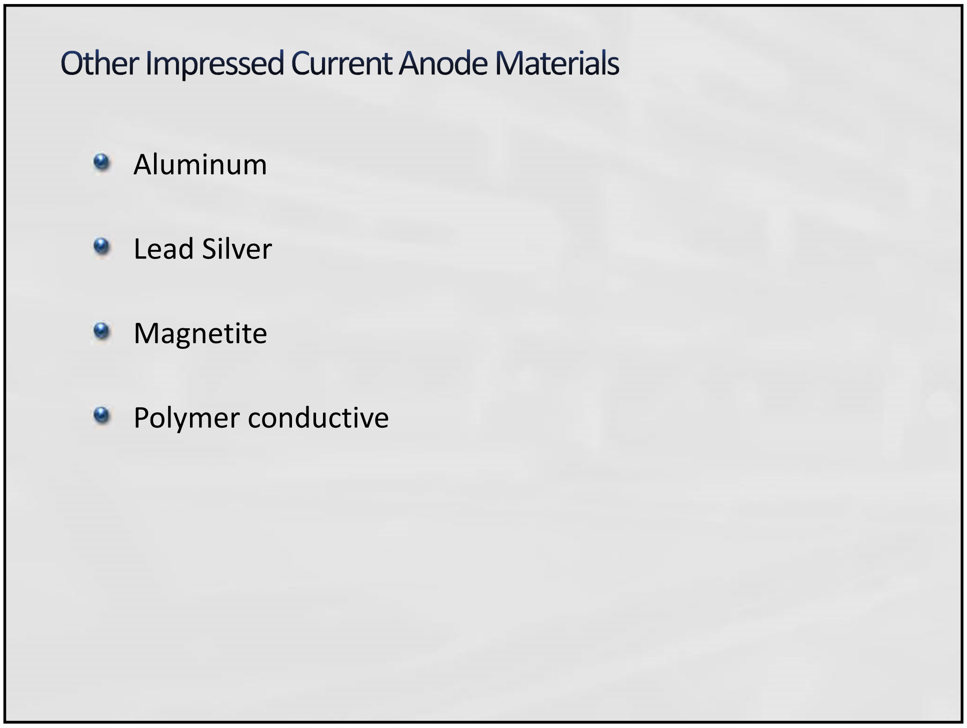
FIGURE 3-4

## Sources of DC for Impressed Current Cathodic Protection

- Transformer - Rectifier Units or simply “Rectifiers”
- Solar Photovoltaic Cells
- Thermoelectric Generators
- Turbine Generator Units
- Engine Generator Units
- Wind Powered Generators

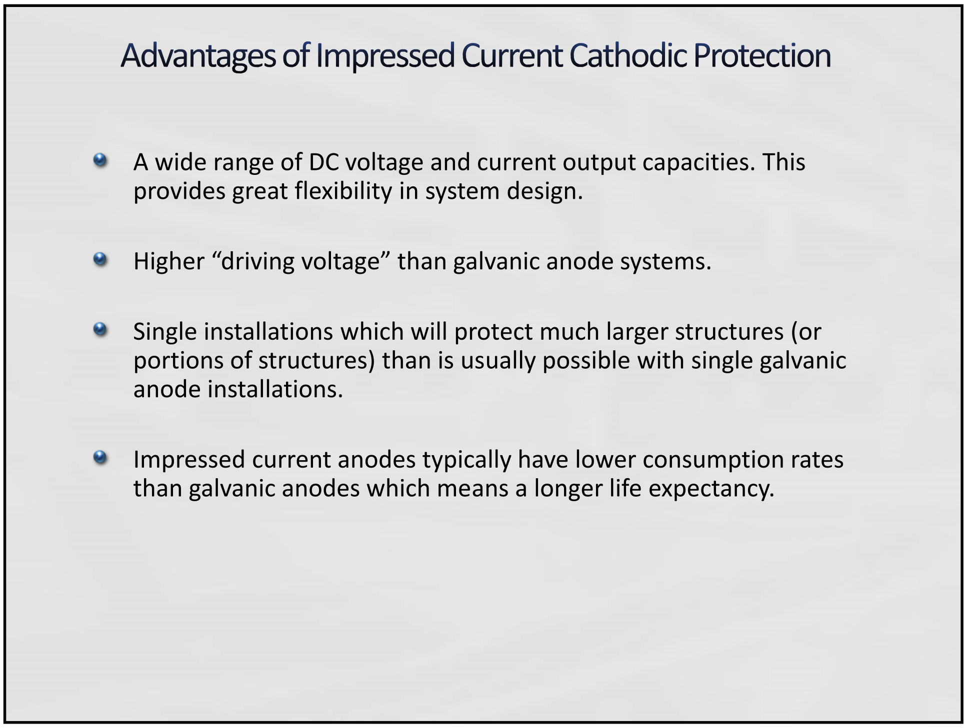
## Common Impressed Current Anode Materials

- High silicon cast iron
- Graphite
- Mixed metal oxide (MMO)
- Platinum
- Scrap steel – abandoned structures



## Other Impressed Current Anode Materials

- Aluminum
- Lead Silver
- Magnetite
- Polymer conductive



## Advantages of Impressed Current Cathodic Protection

- A wide range of DC voltage and current output capacities. This provides great flexibility in system design.
- Higher “driving voltage” than galvanic anode systems.
- Single installations which will protect much larger structures (or portions of structures) than is usually possible with single galvanic anode installations.
- Impressed current anodes typically have lower consumption rates than galvanic anodes which means a longer life expectancy.

## Disadvantages of Impressed Current Cathodic Protection

- Greater maintenance requirements than for galvanic anode installations.
- Dependence on availability of a dependable power supply or fuel supply.
- Continuing cost of energy where AC power or a fuel supply is required.
- Greater possibility of stray current interference on other underground structures than is the case with galvanic anode installations.

## Driving Voltage Effect on Current Output for Impressed Current Anodes

- For a magnesium anode:

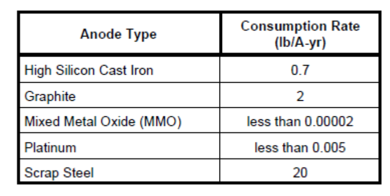
$$I = \frac{1.75\,V - 0.85\,V}{R} = \frac{0.90\,V}{R}$$

- For an impressed current anode, whatever you set the DC source (rectifier) at. For example:

$$I = \frac{80.0\,V - 0.85\,V}{R} = \frac{79.15\,V}{R}$$

## Consumption of Impressed Current Anode Materials

- As current flows, the anode material is corroded or “consumed”.
- After it has been consumed, the anode will need to be replaced.
- Different anode materials have different consumption rates:



| Anode Type | Consumption Rate (lb/A-yr) |
|---|---|
| High Silicon Cast Iron | 0.7 |
| Graphite | 2 |
| Mixed Metal Oxide (MMO) | less than 0.00002 |
| Platinum | less than 0.005 |
| Scrap Steel | 20 |

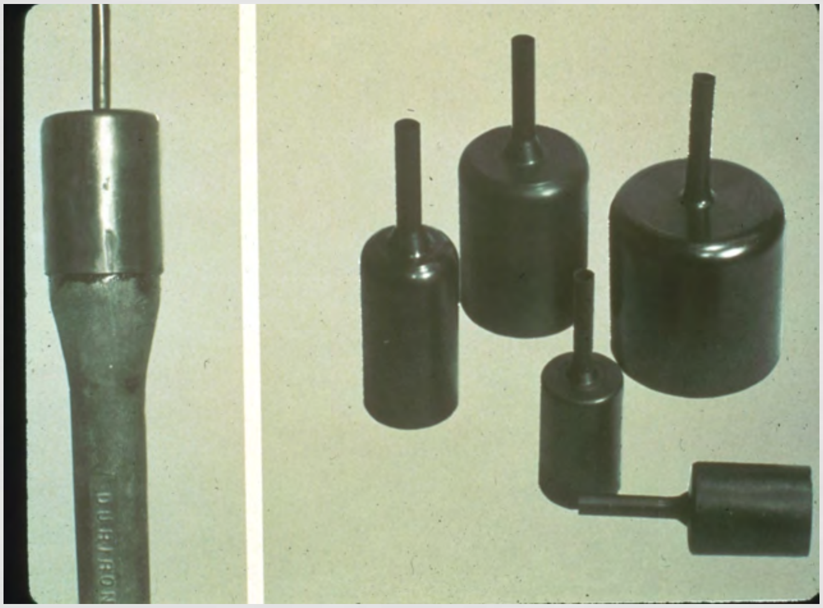
- The lower the consumption rate the longer the anode will last.
- Most impressed current anode materials have a much lower consumption rate than galvanic anode materials.

## Factors is Choosing Common Impressed Current Anode Materials

- Cost
- Life
- Size
- Ease of construction
- Compatibility with environmental conditions
- Historical performance – what you have used in the past that works for you

## Impressed current anodes for use in soil are commonly placed in a prepared backfill.

- Carbonaceous backfill aka coke breeze.
- Impressed current anodes can be purchased prepackaged with prepared backfill or it can be placed around anode during construction.
- The backfill lowers the effective resistance to earth of the anode by increasing its size.
- The backfill also increase the life of the anodes.



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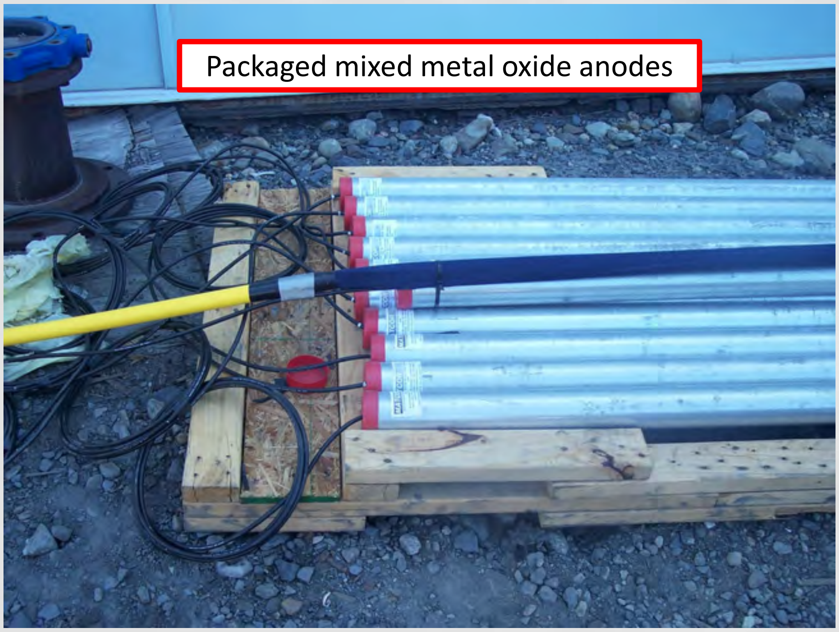
Packaged mixed metal oxide anodes



Packaged mixed metal oxide anodes

Drill rig installing packaged mixed metal oxide anodes

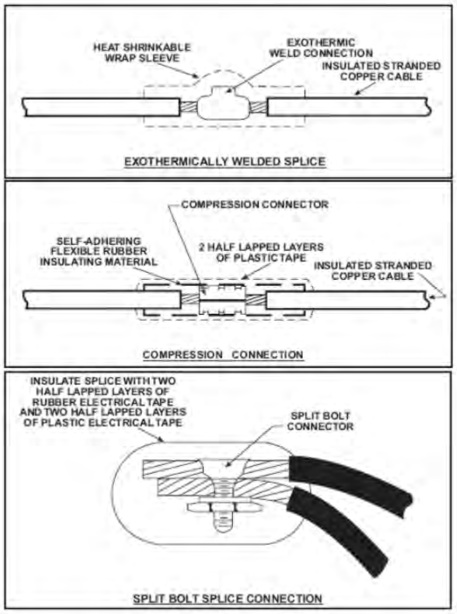
## Impressed Current Cables and Splices

- Since the cable on the positive side of the rectifier becomes an anode, it is critical that there be no exposed conductor in the electrolyte or it will corrode quickly and the system will fail.
- There must be a high quality connection between the anode lead wire and the anode.
- High quality cable insulation must be used for the anode lead wires and anode header cables. Most commonly this is HMWPE insulation.
- The anode lead wires are typically spliced to the anode header cable with split-bolt connectors, crimp connectors or exothermic welds.
- The splices are typically covered with taping systems, epoxy kits or shrink sleeves.

## Impressed Current Cables and Splices (cont)

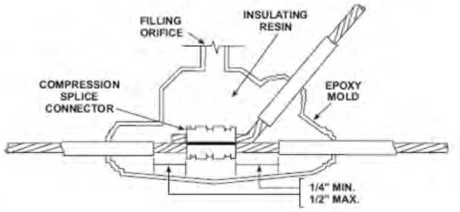
- The cable on the negative side of the rectifier is cathodically protected so the cable integrity is less important.
- Galvanic anode cables get protected by the anode.

Anode junction box



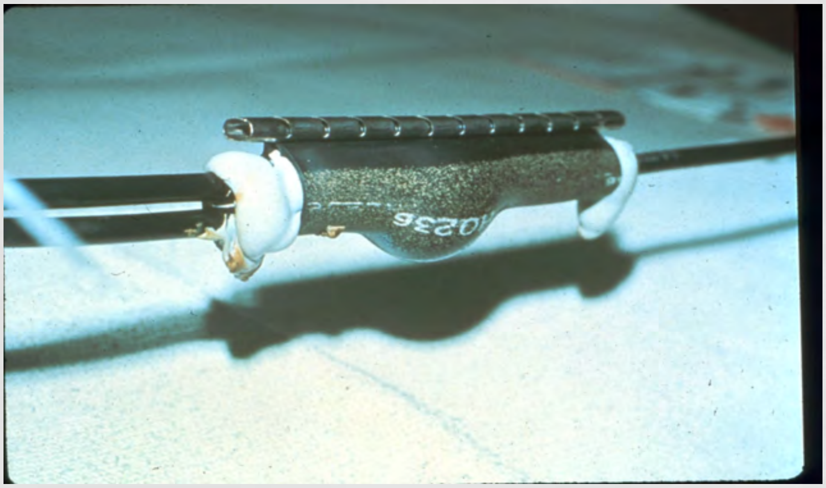
CABLE SPLICE CONNECTIONS

FIGURE 3-13



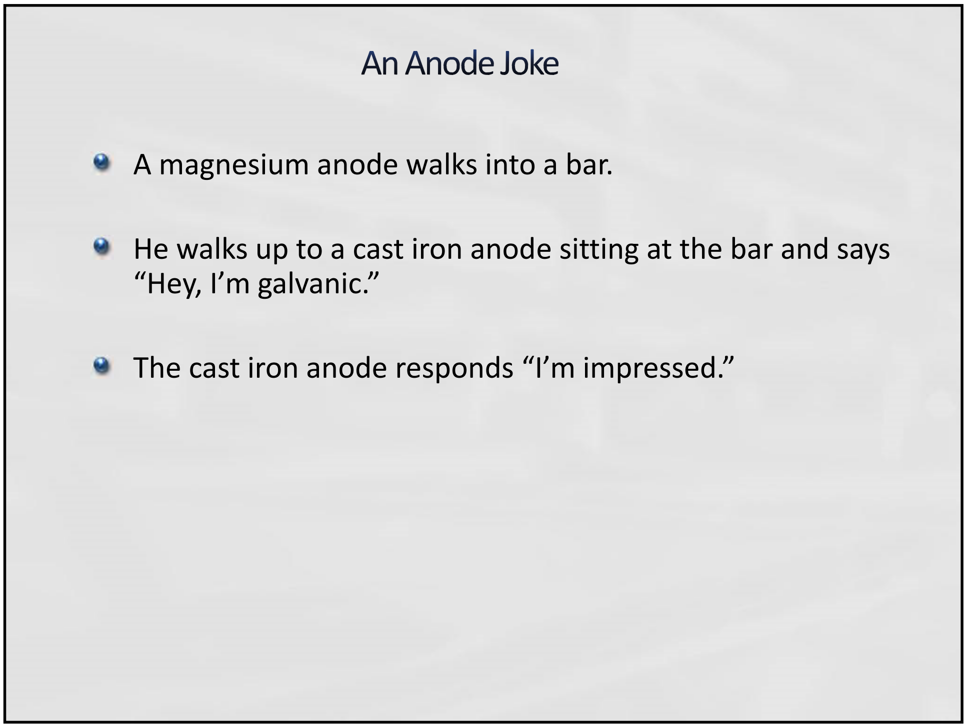
EPOXY ENCAPSULATED SPLICE

FIGURE 3-14



## What structures can be cathodically protected?

- Any metallic structure that is buried or submerged
- Pipelines
- Underground storage tanks
- The bottom of aboveground storage tanks
- The internal surface of water storage tanks
- The internal surface of household water heaters
- Lead sheath electric and telephone cables
- Waterfront structures such as docks and piers
- Power plant structures such as waterboxes and traveling screens
- Steel building piles
- Cars – if they are buried or submerged



## An Anode Joke

- A magnesium anode walks into a bar.
- He walks up to a cast iron anode sitting at the bar and says "Hey, I'm galvanic."
- The cast iron anode responds "I'm impressed."

# Day 1 Review

Heather Groll

AUCSC

Appalachian Underground Corrosion Short Course

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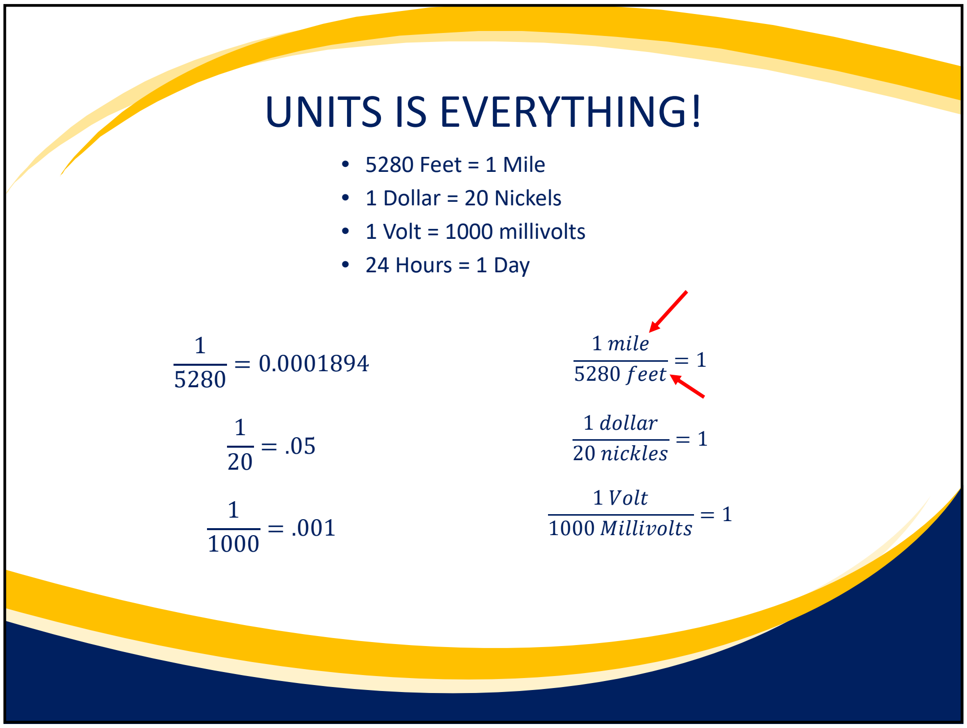
# Mathematics Reminder!

- Any number times itself is always equal to itself!
  - 1 x 18 = 18
  - 235 x 1 = 235
  - 64 x 1 = 64
  - 73526 x 1 = 73526
  - 53 x1 x 1 x 1 x 1 = 53
  - 1 x 348 x 1 x 1 x 1 = 348

- A number divided by itself is “1”
  - $\frac{5}{5}$ = 1
  - $\frac{23}{23}$ = 1
  - $\frac{156}{156}$ = 1
  - $\frac{7846}{7846}$ = 1



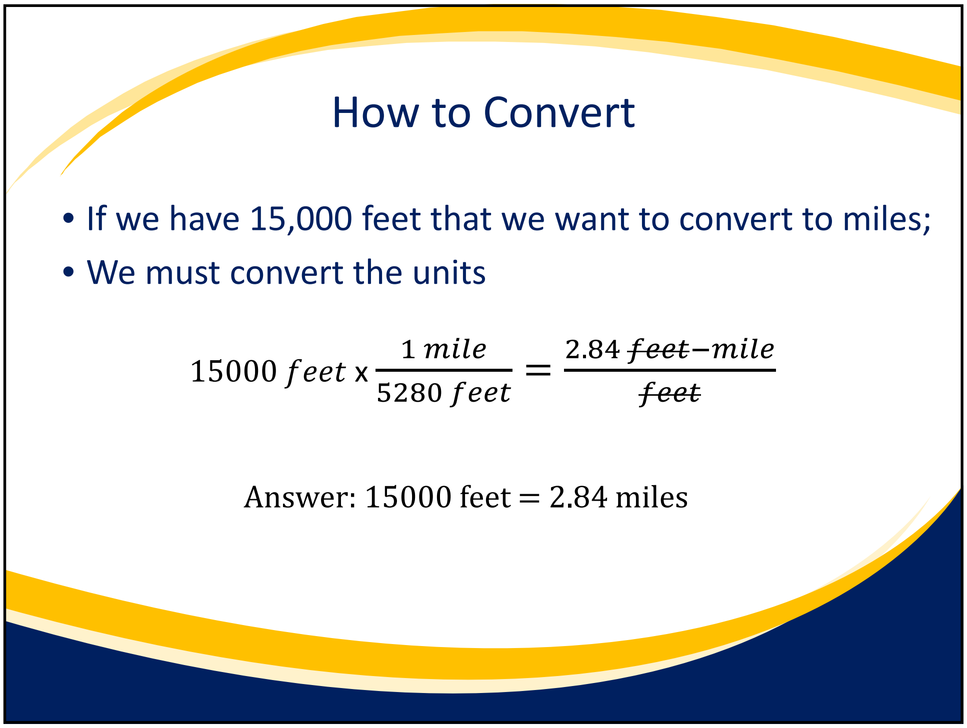
# UNITS IS EVERYTHING!

- 5280 Feet = 1 Mile
- 1 Dollar = 20 Nickels
- 1 Volt = 1000 millivolts
- 24 Hours = 1 Day

$$\frac{1}{5280} = 0.0001894 \qquad \frac{1\ mile}{5280\ feet} = 1$$

$$\frac{1}{20} = .05 \qquad \frac{1\ dollar}{20\ nickles} = 1$$

$$\frac{1}{1000} = .001 \qquad \frac{1\ Volt}{1000\ Millivolts} = 1$$



# How to Convert

- If we have 15,000 feet that we want to convert to miles;
- We must convert the units

$$15000\ feet \text{ x } \frac{1\ mile}{5280\ feet} = \frac{2.84\ \cancel{feet}{-}mile}{\cancel{feet}}$$

Answer: 15000 feet = 2.84 miles

## How to Convert

- If we have 8.62 miles that we want to convert to feet;
- We must convert the units

$$8.62\ mile \text{ x } \frac{5280\ feet}{1\ mile} = \frac{45{,}513.6\ \cancel{mile}-feet}{\cancel{mile}}$$

Answer: $8.62\ miles = 45{,}513.6\ feet$

---

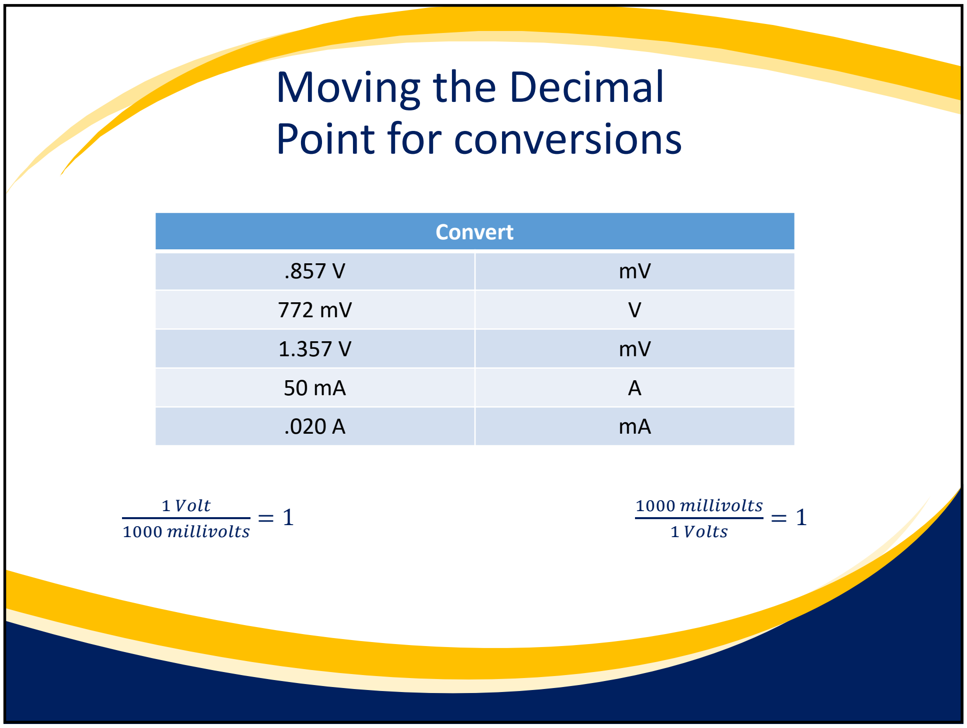
## How to Convert

- If we have Volts to Millivolts [1 Volt = 1000 mV]
- We must convert the units; .084 Volts to millivolts

$$\frac{1\ Volt}{1000\ millivolts} = 1 \qquad \frac{1000\ millivolts}{1\ Volts} = 1$$

$$.084\ \text{Volts x } \frac{1000\ mV}{1\ Volt} = \frac{840\ \cancel{Volt}-mV}{\cancel{Volt}}$$

Answer: $.084\ Volt = 840\ mV$



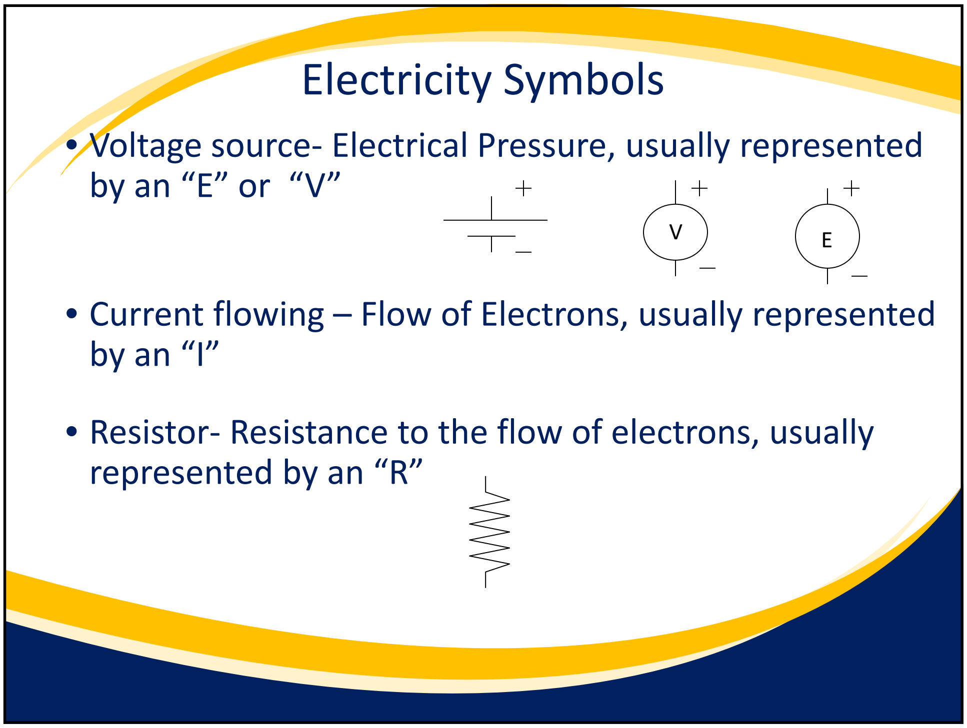
# Moving the Decimal Point for conversions

| Convert | |
|---|---|
| .857 V | mV |
| 772 mV | V |
| 1.357 V | mV |
| 50 mA | A |
| .020 A | mA |

$\frac{1\,Volt}{1000\,millivolts} = 1$

$\frac{1000\,millivolts}{1\,Volts} = 1$

---



# Electricity Symbols

- Voltage source- Electrical Pressure, usually represented by an “E” or “V”
- Current flowing – Flow of Electrons, usually represented by an “I”
- Resistor- Resistance to the flow of electrons, usually represented by an “R”

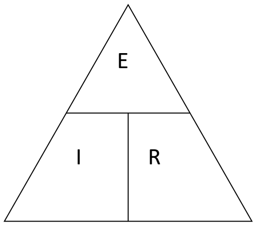
# Ohm’s Law

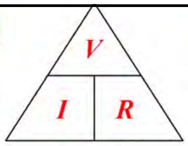
A potential of 1 volt across a resistance of 1 ohm causes 1 amp of current to flow

E = I * R

I = E / R

R = E / I





Volts = 12 V
Resistance = 3.5 Ω
Current = ? A

$\frac{12\ V}{3.5\ \Omega}$ = 3.42 A

Volts = 6 V
Resistance = ? Ω
Current = 1.5 A

$\frac{6\ V}{1.5\ A}$ = 4 Ω

Volts = ? V
Resistance = 5 Ω
Current = .4 A

.4 A × 5 Ω = 2 V

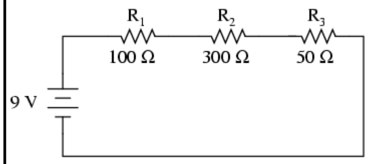
Volts = 2 mV
Resistance = .04 Ω
Current = ? A

$\frac{2\ mV}{.04\ \Omega}$ = .05 A

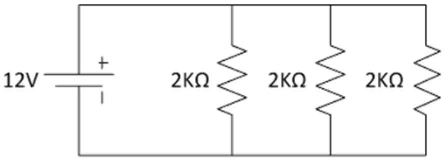
$\frac{.002\ V}{.04\Omega}$ = .05 A

# Circuits

Series Circuit



Parallel Circuit



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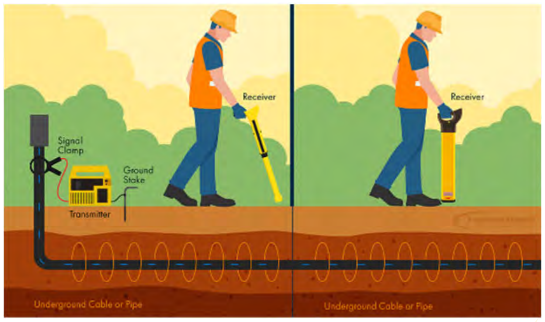
# Locating

- An electrical device used to locate underground metallic structures.
- Modes of Operation include:
  - Inductive (indirect)
  - Conductive (direct)
  - Inductive Clamp
  - Passive



# Locating

- Choosing the Right Tool; <u>ALWAYS FOLLOW MANUFACTURERS' INSTRUCTIONS</u>!
  - Low Frequency
  - High Frequency
- If in Doubt- Don't Mark it out and Hand Dig

# What is Corrosion?

The <u>deterioration</u> of a material, due to a <u>reaction with its environment</u>

# What is a Corrosion Cell?

Corrosion cannot occur without the **four** components of a corrosion cell;

1. **ANODE**
2. **CATHODE**
3. **METALLIC PATH**
4. **ELECTROLYTE**

*Take one of the four away and corrosion will be mitigated.

# Galvanic Series

**Active (More Electro-Negative)**

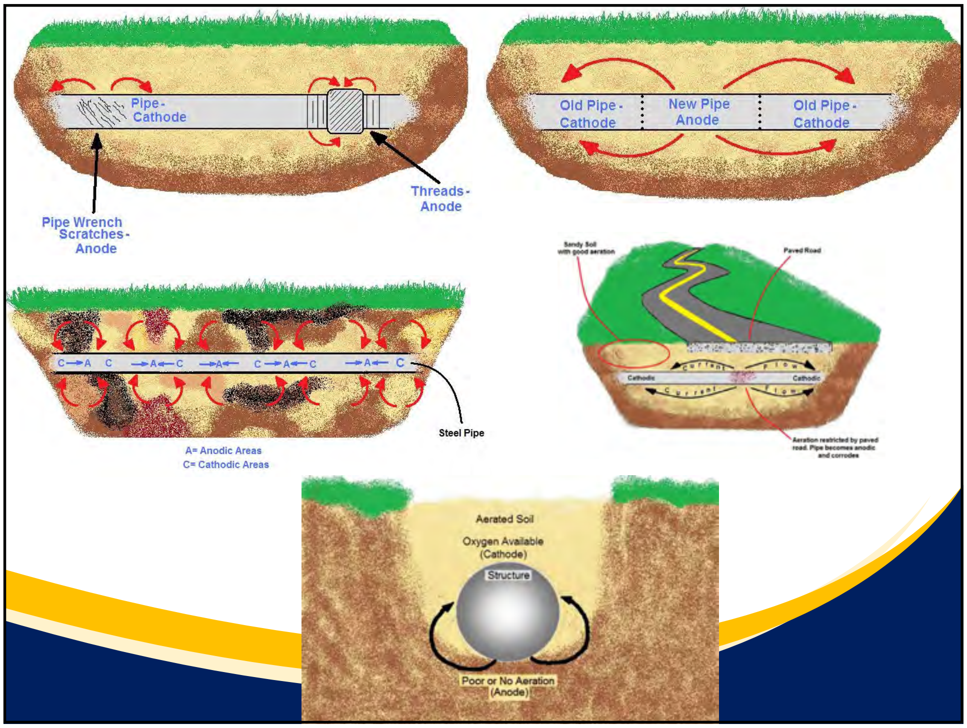
- High Potential Magnesium (-1.75 v)
- Magnesium Alloy (-1.5 v)
- Zinc (-1.1 v)
- Aluminum Alloys (-1.05 v)
- Clean Carbon Steel (-0.5 to -0.8 v)
- Rusted Carbon Steel (-0.2 to -0.8 v)
- Lead (-0.5 v)
- Copper (-0.2 v)
- High Silicon Iron (-0.2 v)
- Gold (+0.2V)
- Graphite, Carbon (+0.3v)

**Noble (More Electro-Positive)**

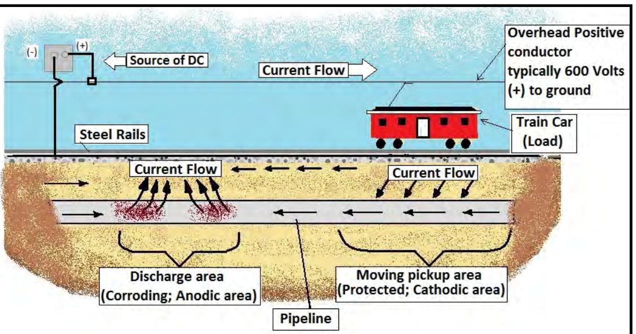
Potentials measured with respect to saturated Cu-$CuSO_4$ Half Cell

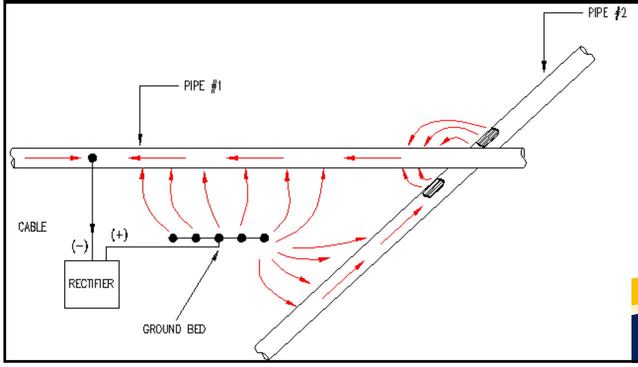
*Anode is more electro-negative than the cathode

*Cathode is more electro-positive than the anode



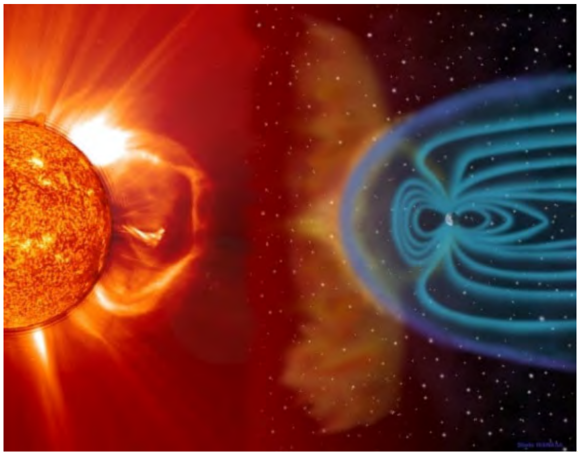
## Dynamic Stray Current





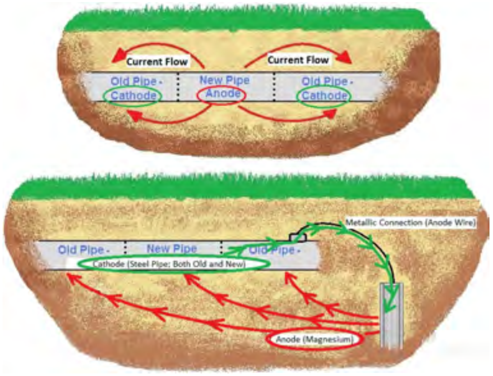
## Static Stray Current

## Telluric Currents



## Cathodic Protection

# Galvanic Anode Cathodic Protection



Advantages:

- Seldom cause stray current interference
- Relatively low installation cost
- Self-Powered
- Low Maintenance

Disadvantages:

- Limited on current output- doesn't work in high-resistivity soils
- Not practical for bare or poorly coated pipelines
- Relatively high consumption rate

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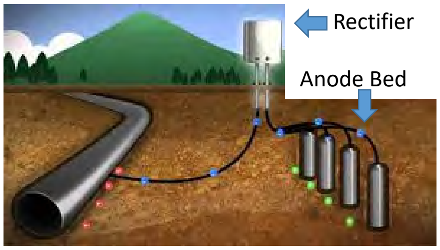
# Sacrificial Anodes

Zinc, Aluminum, and Magnesium

# Impressed Current Cathodic Protection



Advantages

- Capable of protecting large structures
- Capable of protecting structures which require greater magnitudes of current (Higher Driving Voltage)
- May be more economical than sacrificial anode systems
- Lower consumption rates than galvanic anodes
- Better in High Soil Resistivity areas

Disadvantages

- Increased maintenance requirements
- Tendency for higher operating costs
- Possibility of contributing to stray current interference on neighboring structures
- Electric power may be needed

# Impressed Current Anodes

- Graphite Anode
- High Silicon Cast Iron
- Mixed Metal Oxide Anode
- Platinum
- Scrap Steel – Abandoned Structures
- Aluminum
- Lead Silver
- Magnetite

# ELECTRICAL ISOLATION

Heather Groll

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## ISOLATORS

- Isolators electrically isolate undesirable metal structures from the pipeline that is cathodically protected. Isolators work by eliminating the metallic path from the corrosion cell.

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# CODE REQUIREMENTS

## §192.467 External corrosion control: Electrical isolation.

- (a) Each buried or submerged pipeline must be electrically isolated from other underground metallic structures, unless the pipeline and the other structures are electrically interconnected and cathodically protected as a single unit.
- (b) One or more insulating devices must be installed where electrical isolation of a portion of a pipeline is necessary to facilitate the application of corrosion control.

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# CODE REQUIREMENTS

- (c) Except for unprotected copper inserted in a ferrous pipe, each pipeline must be electrically isolated from metallic casings that are a part of the underground system. However, if isolation is not achieved because it is impractical, other measures must be taken to minimize corrosion of the pipeline inside the casing.
- (d) Inspection and electrical tests must be made to assure that electrical isolation is adequate.
- (e) An insulating device may not be in-stalled in an area where a combustible atmosphere is anticipated unless precautions are taken to prevent arcing.

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# ISOLATORS (cont)

Isolators are used but not limited to the following uses:

- Separate foreign metal structures from protected pipelines (casings and grounded structures).
- Separate different types metals from each other
- Separate coated lines from bare lines
- Separate C/P lines from unprotected lines
- Electrically isolate pipes for troubleshooting purposes

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# DIELECTRICAL ISOLATION Primary Function (WHY?)

- Method of Corrosion Control
  - To stop the flow of CP current.
  - To limit the amount of current needed.
  - To prevent a corrosion cell.
- Inserted in pipelines and structures to **BLOCK** the flow of electrical current.

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## Failure to Provide Dielectric Isolation

- Severe corrosion can take place.
- New pipelines may become anodic when connected to bare or poorly coated pipelines.
- Non-isolated sections of coated and bare piping would allow the potentials to fall below cathodic protection criteria.

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## Failure to Provide Dielectric Isolation (Cont.)

- Current requirements would increase in order to protect the poorly coated or bare pipe not isolated from the coated piping.
- Cost of cathodic protection will increase.
- Corrosive environments can impact the pipeline above (Atmospheric Corrosion) and pipe below ground.

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## Dielectric Isolation Materials

- Weld-in insulator
- Compression couplings
- Insulated bolted couplings
- Fiber board gaskets
- Insulated unions
- Plastic Pipe
- Insulated meter swivels
- Dielectric Coatings
- Isolation flanges

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## Dielectric Isolation Types

- Coatings isolate the surrounding environment from the structure, this prevents the electrolyte from coming in contact with the pipeline above and below ground.

  - Coatings are our number one defense against corrosion on pipelines.

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# Dielectric Isolation Types (Cont)

- Coatings can vary on dielectric strengths, in most cases based on mil thickness and type of materials.

- Coatings keep the current on the pipeline. Current leaving the pipeline results in corrosion

- Coatings reduce the amount of holidays on a pipeline, and lessen the amount of protective current required. This lowers the cost of materials.

# Dielectric Isolation – Coating Materials

- Types of coatings used –

  - Liquid Epoxy – field applied two part - resin and hardener, one coat thickness of 20-50 mils.

  - Extruded Coatings – high density polyethylene with an under coat of mastic approx. 60 mils thickness.

  - Asphalt Based Mastics – cold applied with brush to desired thickness

## Dielectric Isolation – Coating Materials (Cont.)

- Fusion Bonded Epoxy – thin film coating, preheated to 400 to 500 F, with applied resin 10 to 18 mils depending on customer's design requirements

- Cold Applied Tapes – plastic film with butyl rubber backing 15 to 35 mils.

- Cold Applied Waxes – grease type materials, blend of petroleum wax 20 to 30 mils.

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## Dielectric Isolation – Coating Materials (Cont.)

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# Dielectric Isolation Devices

- **Meter Isolation & Above Ground Installations**

Meter Swivels

- Installed at meter, isolates customer from pipeline

- Should be installed on outlet of meter

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# Dielectric Isolation Devices

- **Meter Isolation & Above Ground Installations (Cont'd)**

Insulated Unions

- Used on above ground metering & regulation stations to isolate piping

- Usually installed on threaded pipe

- Not recommended for below ground installation

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## Dielectric Isolation Devices

- Plastic Pipe
  - More economical to use versus weld-end fittings or flanges
  - Recommended installing a minimum of 5 ft. of plastic pipe when insolating from steel pipe
  - Very high dielectric properties
  - No chance of failure due to shorting

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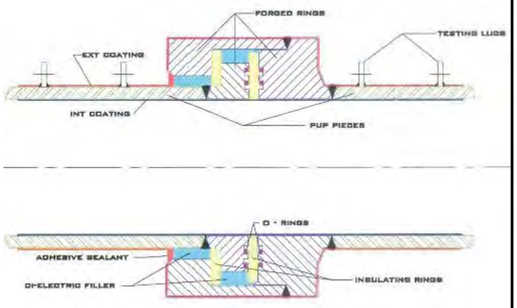
## Dielectric Isolation Devices

- Weld-in Isolator
  - Can only be installed by qualified welder (usually require NDE – x-ray and hydro test)
  - Internal isolator components must be protected during welding process



## Dielectric Isolation Devises

- Insulated Flange Kit
  - Components are non-conductive and provide isolation of pipes and fittings connected by flanges
  - Flange kits consist of:
    - Nonconductive gasket
    - Isolation sleeves
    - Nonconductive washers

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## Dielectric Isolation Devices

- Isolation Compression Couplings
  - For low to medium pressure pipelines
  - For pipe up to 2” in diameter
  - Non-conductive interior components
  - Some devices prone to leakage
  - Can fail due to soil stress or movement
  - Less expensive than other alternatives

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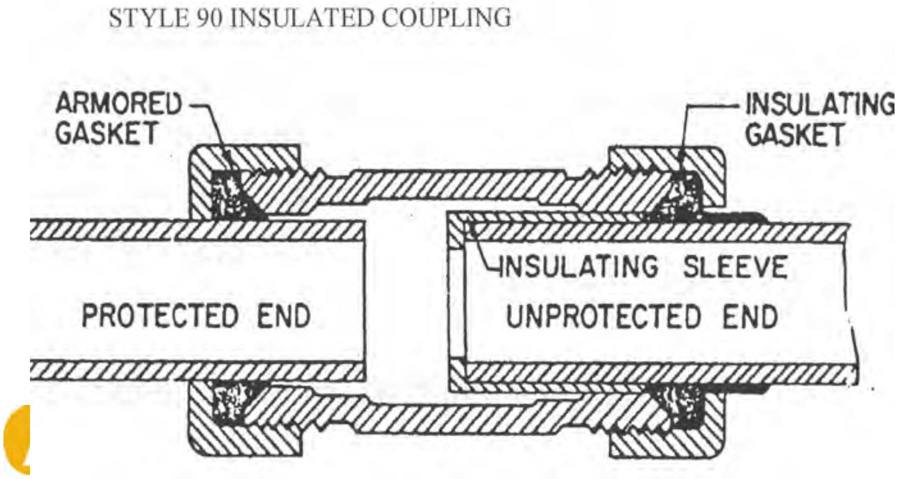
## Isolation Compression Coupling



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## Dielectric Isolation Devises

- Isolation Bolted Couplings
  - For pipelines 2” & larger in diameter
  - Non-conductive interior components
  - Can fail due to soil stress or movement
  - Less expensive than other alternatives

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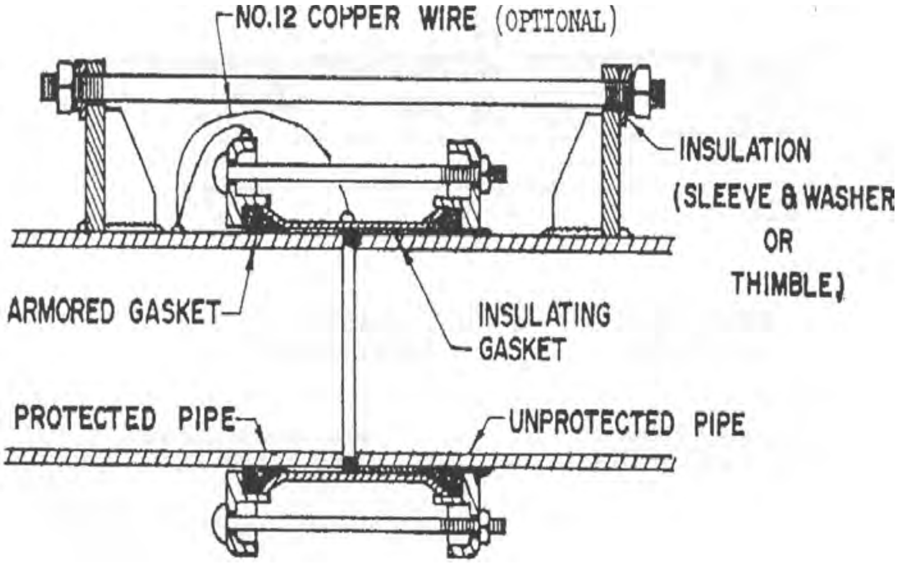
# Isolation Bolted Coupler



# Testing Isolators

- Before installation check all isolators for electrical leakage. The resistance should be OL (over limit) on the meter.
- Test all isolators after installation **before** backfilling **do not** use a ohm meter after the isolator has been installed.
- Take pipe/soil potential reading on both sides of the isolator keeping the half cell in the same place. If the two readings are not different then the isolator may be shorted.

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## Gas Electronics
## Model 601
## Insulation Checker

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## Dielectric Isolation Precautions

- If the isolator is installed near high voltage AC lines or is in close proximity to electrical towers, precautions should be taken to prevent risks to personnel and damage from lightning strikes and stray AC currents.

  - Methods commonly used:

    Zinc ribbon

    Magnesium anodes

*To provide a low resistant grounding system

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## Dielectric Isolation Precautions

- DOT subpart I, 192.467:

  An insulating device may not be installed in an area where a combustible atmosphere is anticipated unless precautions are taken to prevent arcing.

  - Methods commonly used:
    - Solid state device
    - Zinc grounding cell

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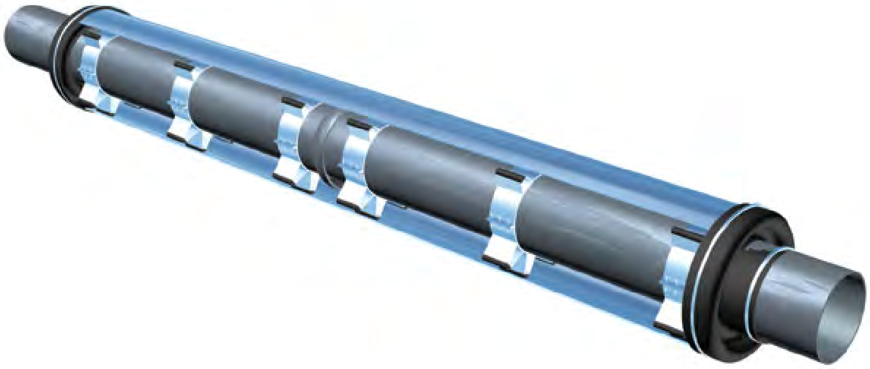
## Cased Pipeline Crossing



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## Cased Pipeline Crossings

## Cased Pipeline Crossings

# Cased Pipeline Crossing

# Cased Pipeline Crossings

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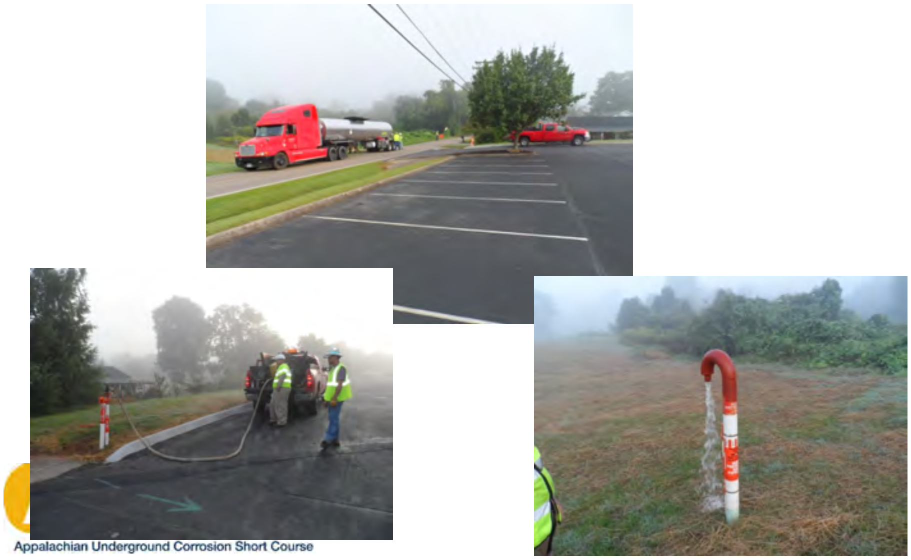
## Cased Pipeline Crossing



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## Dielectric Isolation Protection

- DOT Subpart I, 192.455:
  - All isolated metallic fittings shall be coated and cathodically protected.
- Improper installation and application practices are the primary reasons for failure of isolators!

## Questions???

Thank You

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# Pipeline Coatings

2024 AUCSC
Fundamentals Session
Jeff Didas – Kinder Morgan - Tucson, AZ

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## Remember This!

- Coatings are the #1 defense against corrosion.
- This is true for underground, transition and above ground service.

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## Coating Types

- Underground – buried or immersion service
- Transition area coatings
- Atmospheric coatings
- Internal coatings & linings

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## Underground Pipeline Coatings

- Mill or Plant Applied
- Field Applied
- Line Coatings
- Repair Coatings
- Coating Discussion
- Coating Cost
- Coating Quality

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## Mill or Plant Applied

- Most economical method to apply coatings
- Highest level of quality and quality control
- Plant/Mill conditions allow use of higher performing coatings
- Normally, high quality storage, handling and shipping
- Normally allows for some coated pipe storage

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## Field Applied

- Costly method either over the ditch or in the ditch
- Hard to manage quality control due to environmental conditions
- Normally lower performing coatings
- Newer field coatings do allow higher productivity
- Keyhole applications can be a problem
- Includes Field Joint – FJC / Weld Joint – WJC Coatings

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## Line Coatings

- Coal Tar Enamel
- Asphalt Enamel
- Extruded Polyethylene
- Fusion Bonded Epoxy
- Somastic
- Pritec
- Liquid Epoxy
- 3 Layer – 3LPE & 3LPP
- ARO – Abrasion Resistant Overlay or Overcoat

## Repair Coatings

- Tapes
- Wax
- Shrink Sleeves
- Two - Part Epoxy
- Mastic
- Epoxy Mastic
- Visco-Elastic
- Misc.

## Coatings Discussion

- Most important component of a pipeline
- High quality holiday free coating requires almost no cathodic protection current
- Coatings need to be specified
- Coatings need to be tested
- Every coating has a use, but most coatings are used improperly – follow procedures

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## Coating Cost

- Cost of material
- Cost of application
- Cost to repair
- Handling
- Expected life
- Dielectric strength

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## Coating Quality

- Quality determines price
- Quality is normally dependent upon surface preparation & application methods
- Quality is assured with competent inspection
- Quality is determined by good procedures and good specifications

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## Transition Area Coatings

- Used where piping transitions from buried service to atmospheric service
- Used to protect from mechanical damage – freeze/thaw cycle, weed whackers, gravel, etc.
- Used to protect buried service coatings from Ultraviolet light when used above ground

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## Atmospheric Coatings

- Various types, quality and expected life
- Primary purpose is corrosion prevention, secondary purpose is appearance
- Problem areas, flanges, nuts, bolts, hold down clamps, high temperature service, beneath insulation, through walls/foundations, etc.

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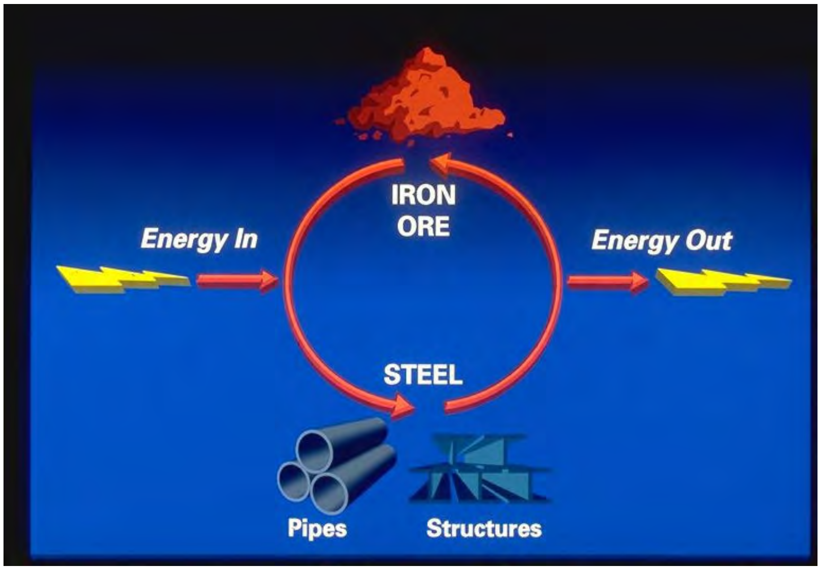
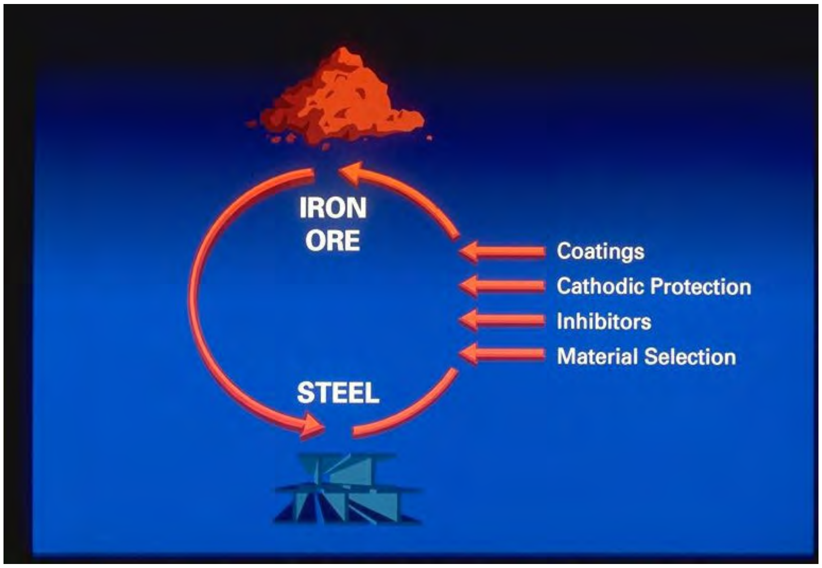
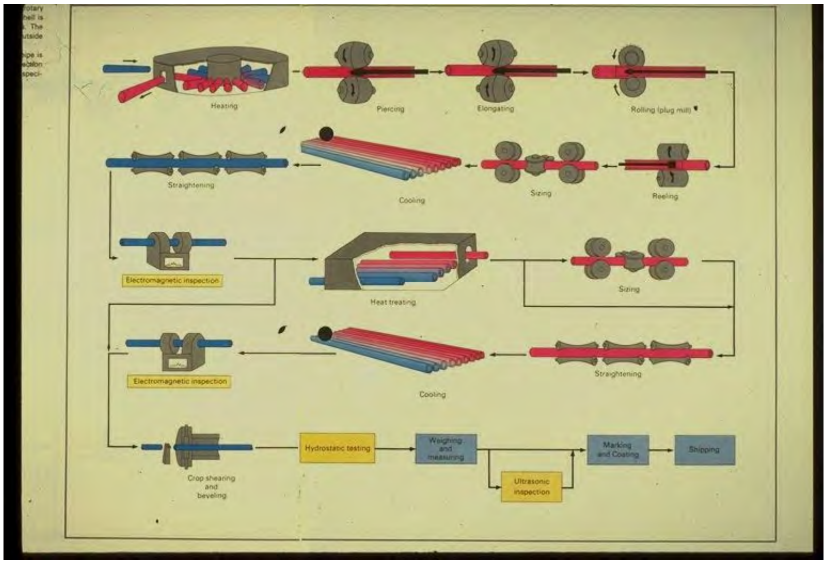
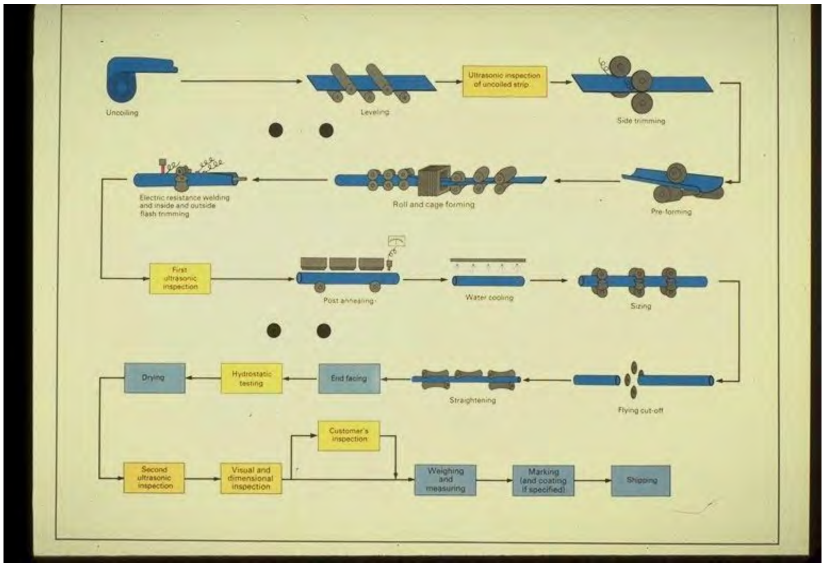
WHAT IS
CORROSION?

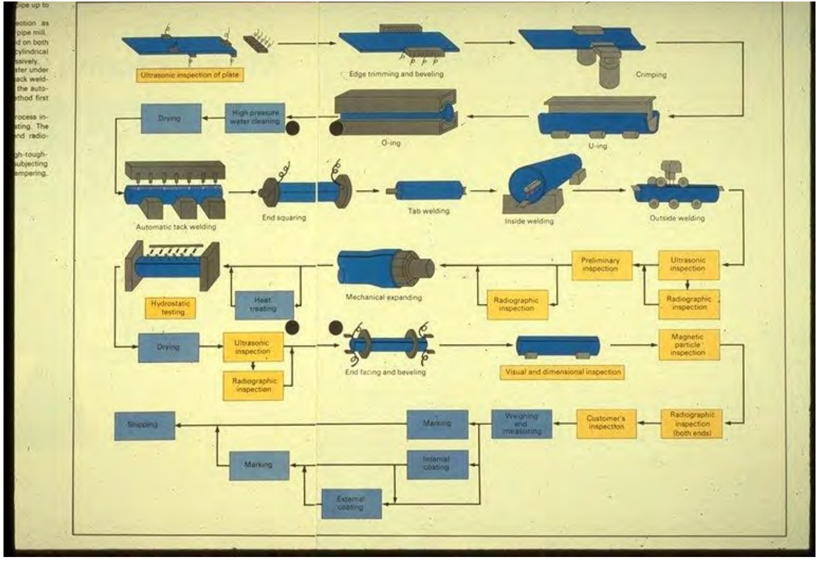
CORROSION IS THE DESTRUCTION OF A SUBSTANCE, USUALLY A METAL, OR ITS PROPERTIES BECAUSE OF A REACTION WITH ITS ENVIRONMENT.




IRON
ORE
STEEL
Coatings
Cathodic Protection
Inhibitors
Material Selection


Heating
Piercing
Elongating
Rolling (plug mill)
Straightening
Cooling
Sizing
Reeling
Electromagnetic inspection
Heat treating
Sizing
Electromagnetic inspection
Cooling
Straightening
Crop shearing and beveling
Hydrostatic testing
Weighing and measuring
Ultrasonic inspection
Marking and Coating
Shipping


Uncoiling
Leveling
Ultrasonic inspection of uncoiled strip
Side trimming
Pre-forming
Roll and cage forming
Electric resistance welding and inside and outside flash trimming
First ultrasonic inspection
Post annealing
Water cooling
Sizing
Flying cut-off
Straightening
End facing
Hydrostatic testing
Drying
Second ultrasonic inspection
Visual and dimensional inspection
Customer's inspection
Weighing and measuring
Marking (and coating if specified)
Shipping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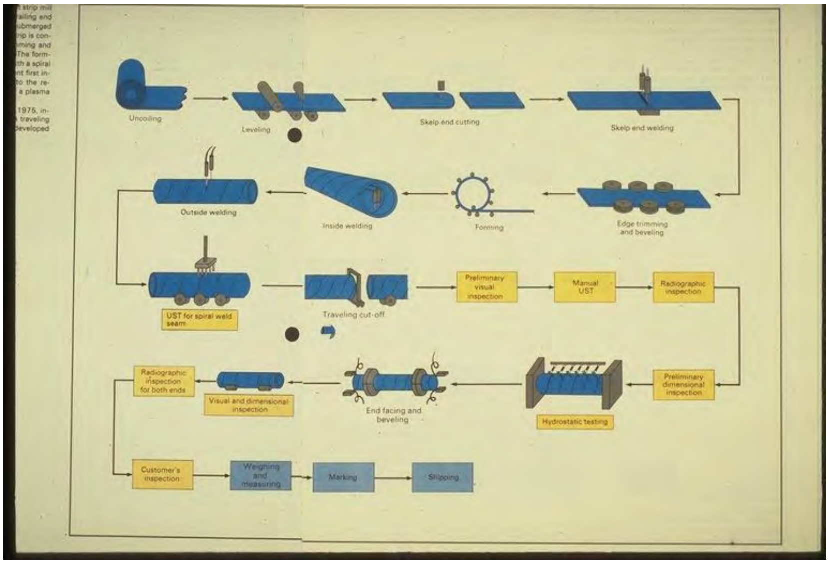
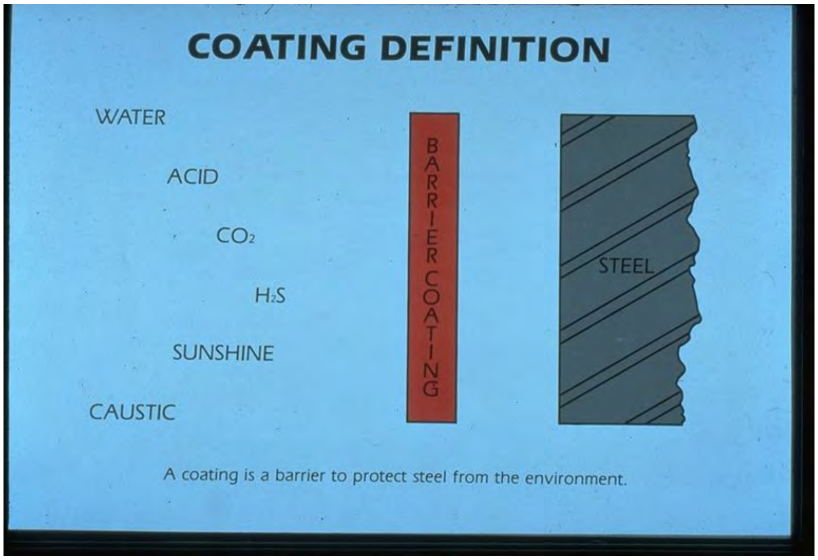
ubjecting
mpering.
Ultrasonic inspection of plate
Edge trimming and beveling
Crimping
U-ing
O-ing
High pressure water cleaning
Drying
Automatic tack welding
End squaring
Tab welding
Inside welding
Outside welding
Ultrasonic inspection
Radiographic inspection
Preliminary inspection
Radiographic inspection
Mechanical expanding
Heat treating
Hydrostatic testing
Drying
Ultrasonic inspection
Radiographic inspection
End facing and beveling
Visual and dimensional inspection
Magnetic particle inspection
Radiographic inspection (both ends)
Customer's inspection
Weighing and measuring
Marking
Shipping
Internal coating
Marking
External coating



# COATING DEFINITION



A coating is a barrier to protect steel from the environment.

# Perfect Coating

- Ease of Application - It can be applied with a mop on any surface or from above ground.
- Cost Effective - Cost $1.00/Gallon or less!
- Environmentally Safe and Friendly – OK to Drink it.
- Performance - Lasts forever.

Appalachian Underground Corrosion Short Course

# In Reality a Perfect Coating

- Requires a quality standard
- Requires a quality specification
- Requires a quality coating Mill/Plant
- Requires a quality material or materials
- Requires a quality inspector or inspectors

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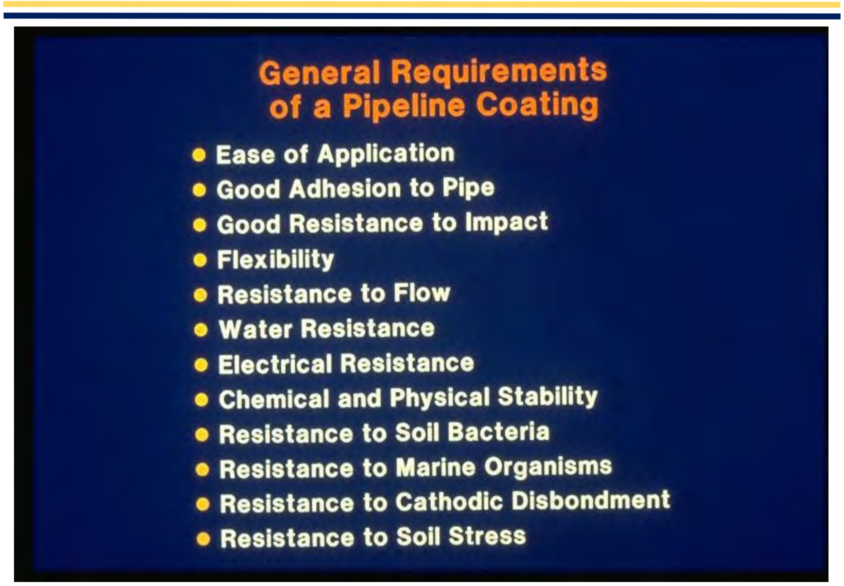
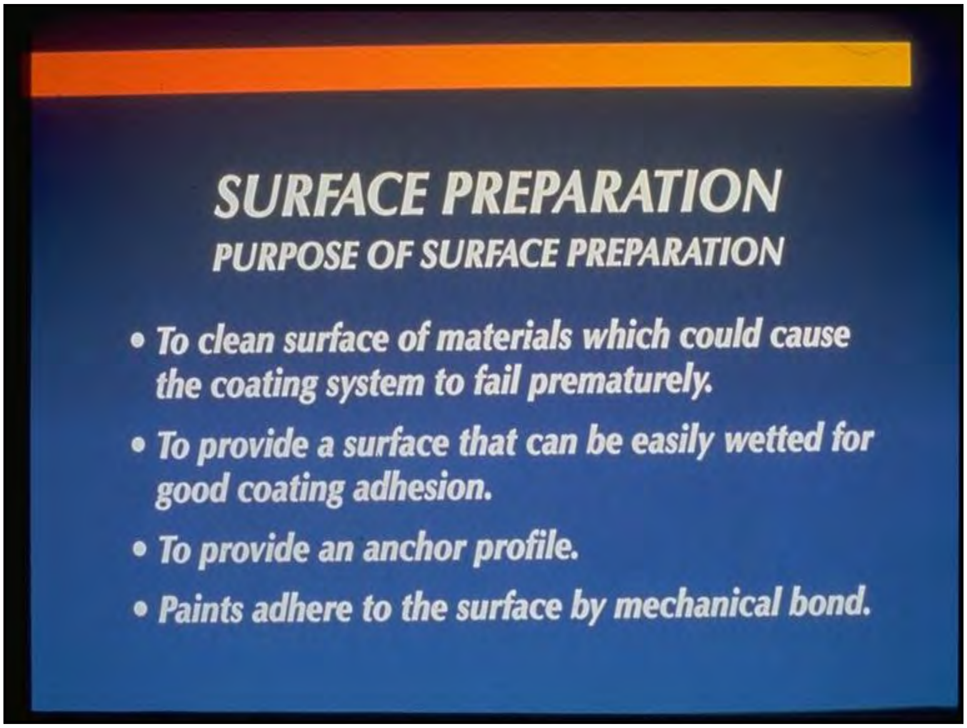


## General Requirements of a Pipeline Coating

- Ease of Application
- Good Adhesion to Pipe
- Good Resistance to Impact
- Flexibility
- Resistance to Flow
- Water Resistance
- Electrical Resistance
- Chemical and Physical Stability
- Resistance to Soil Bacteria
- Resistance to Marine Organisms
- Resistance to Cathodic Disbondment
- Resistance to Soil Stress

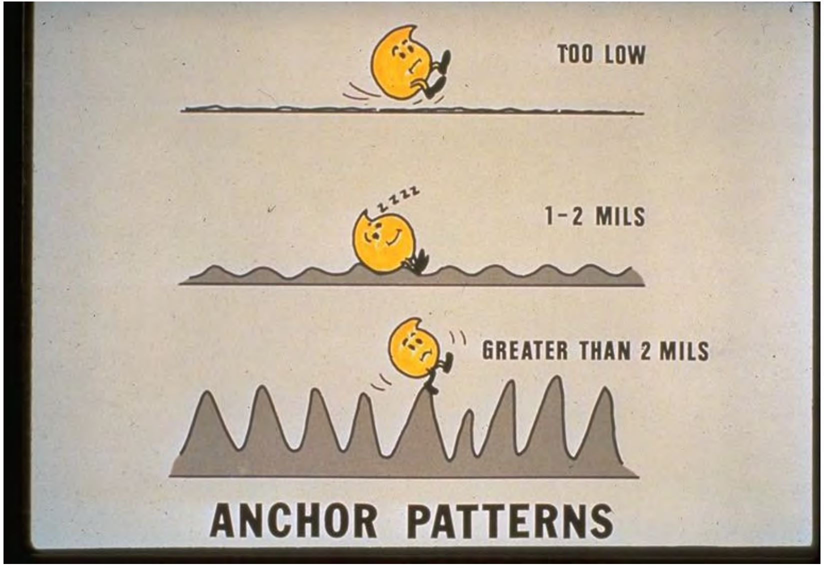
## SURFACE PREPARATION



## SURFACE PREPARATION

### PURPOSE OF SURFACE PREPARATION

- *To clean surface of materials which could cause the coating system to fail prematurely.*
- *To provide a surface that can be easily wetted for good coating adhesion.*
- *To provide an anchor profile.*
- *Paints adhere to the surface by mechanical bond.*

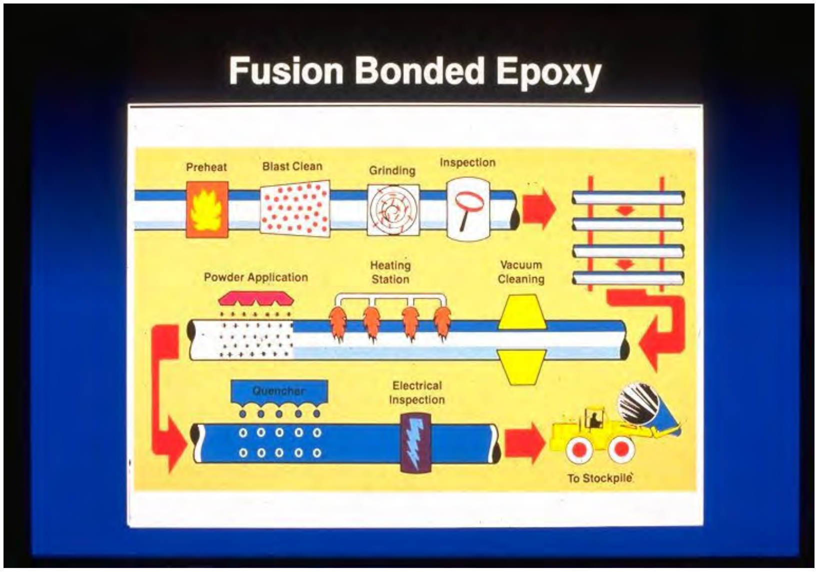


ANCHOR PATTERNS

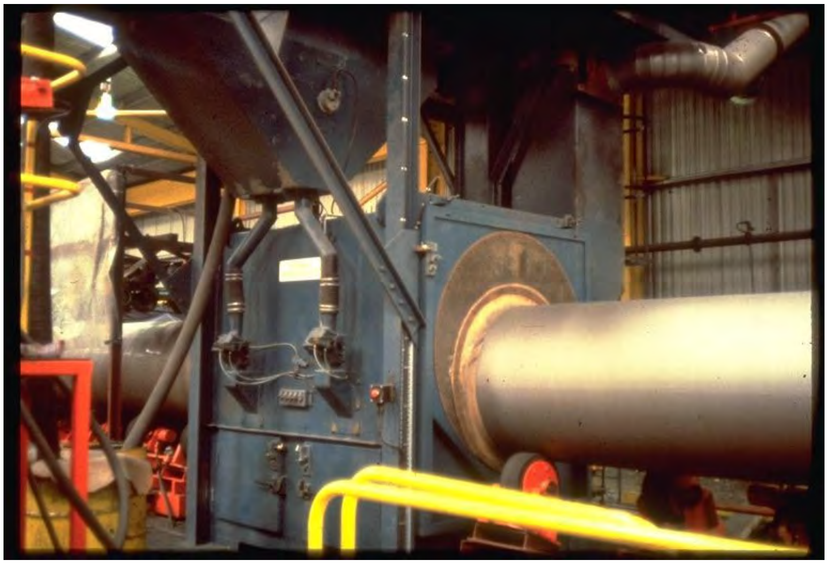
# FUSION BONDED COATINGS

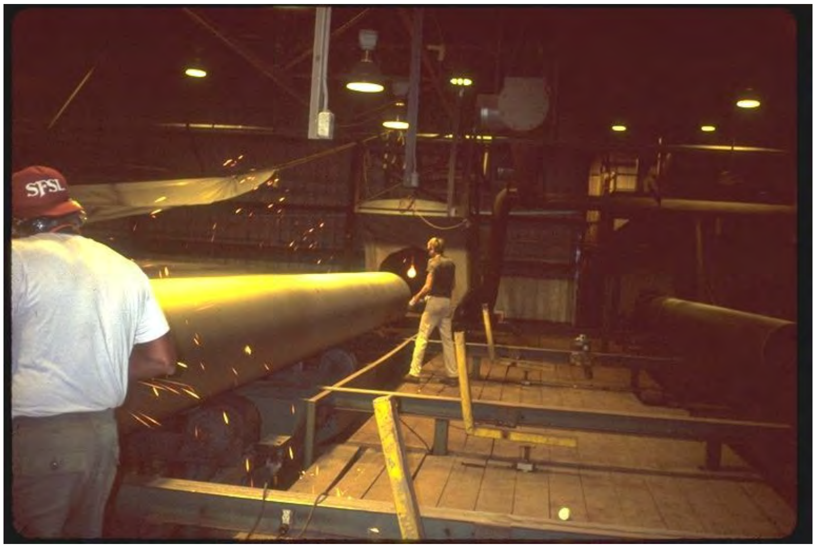
# APPLICATION PROCEDURE

1. CLEAN
2. HEAT
3. APPLY
4. CURE
5. INSPECT
6. REPAIR

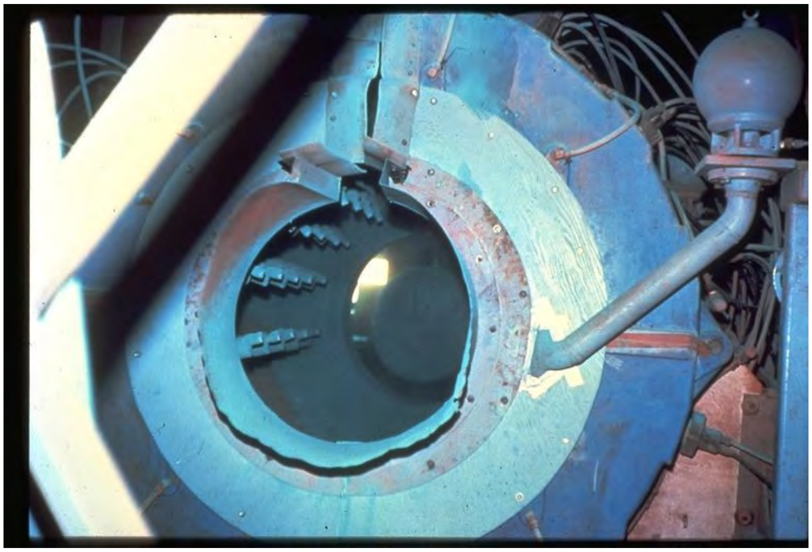


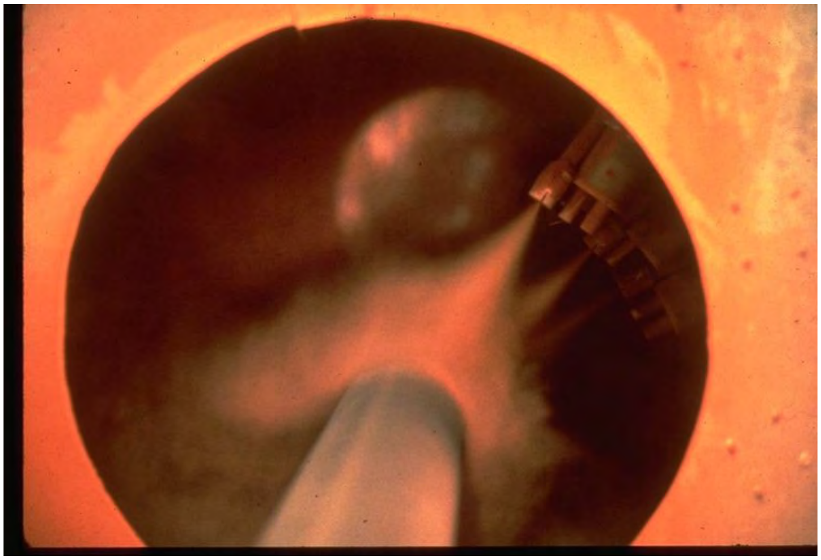
Fusion Bonded Epoxy

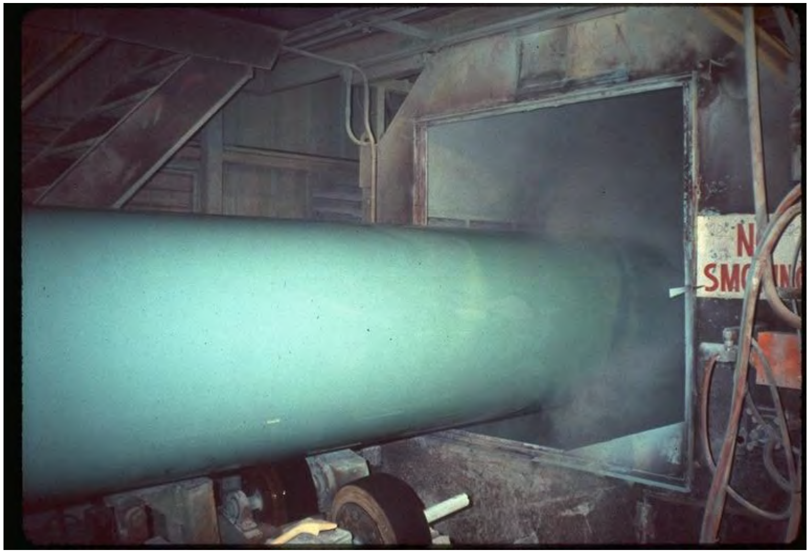


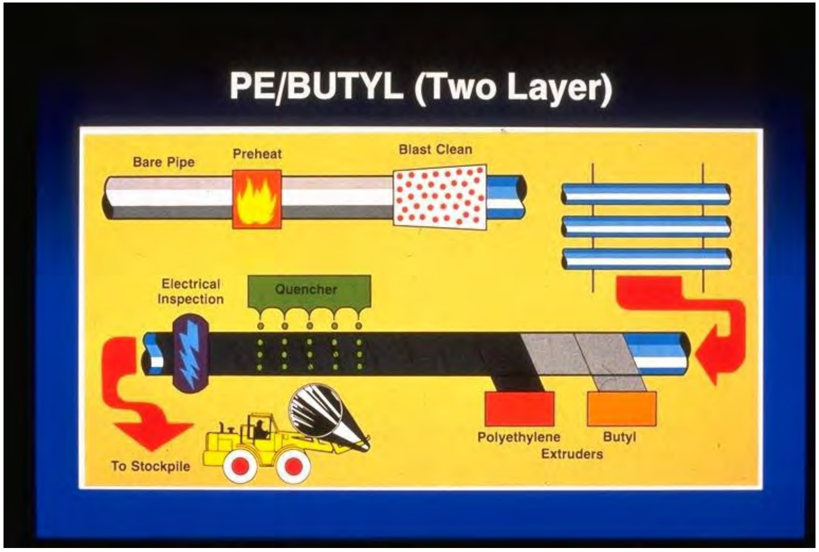

SFSL

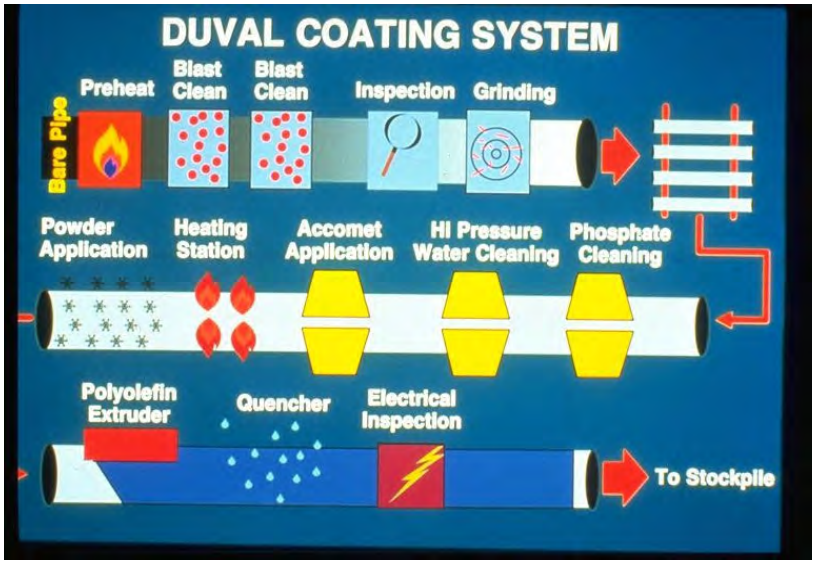

ER



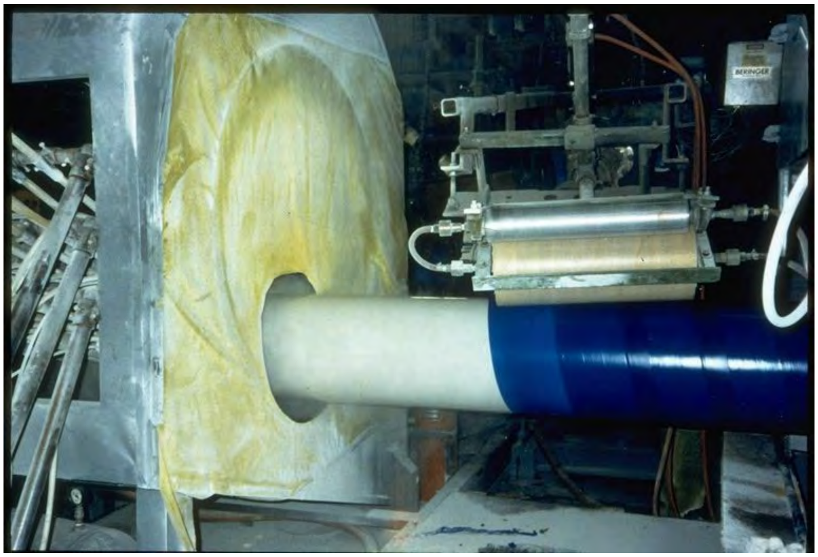


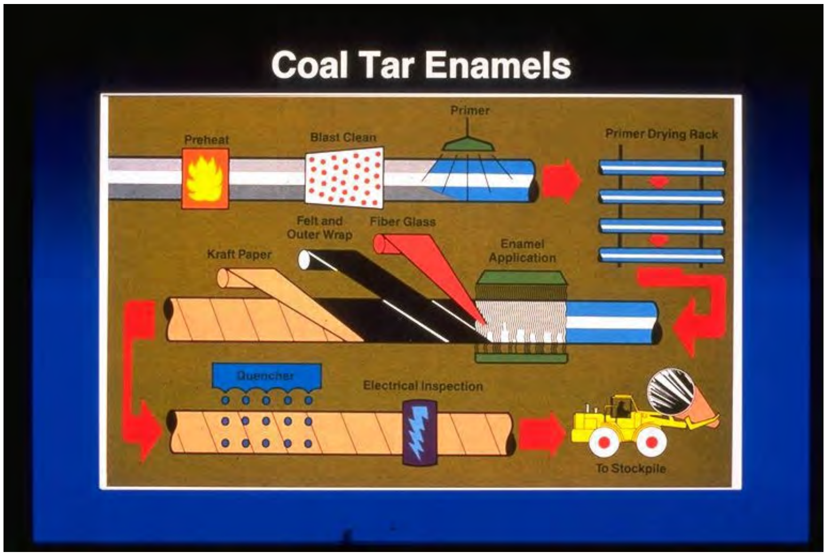



PE/BUTYL (Two Layer)

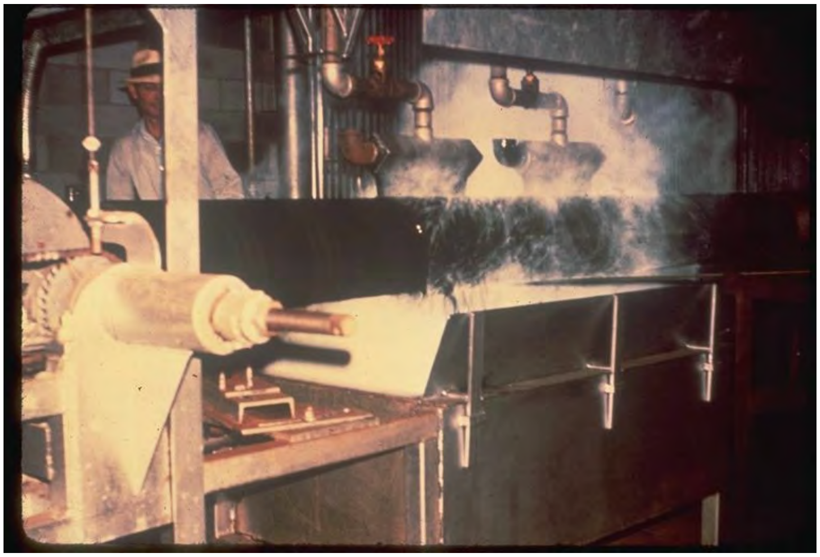


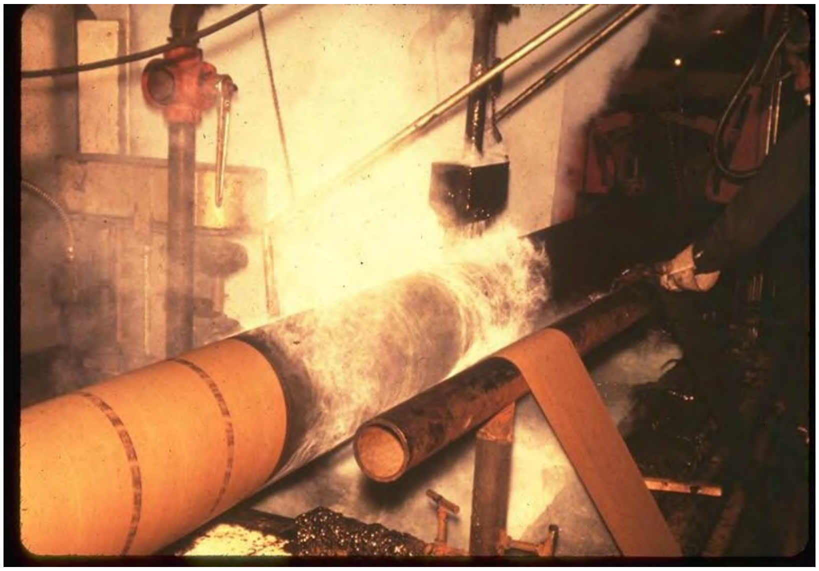
## DUVAL COATING SYSTEM

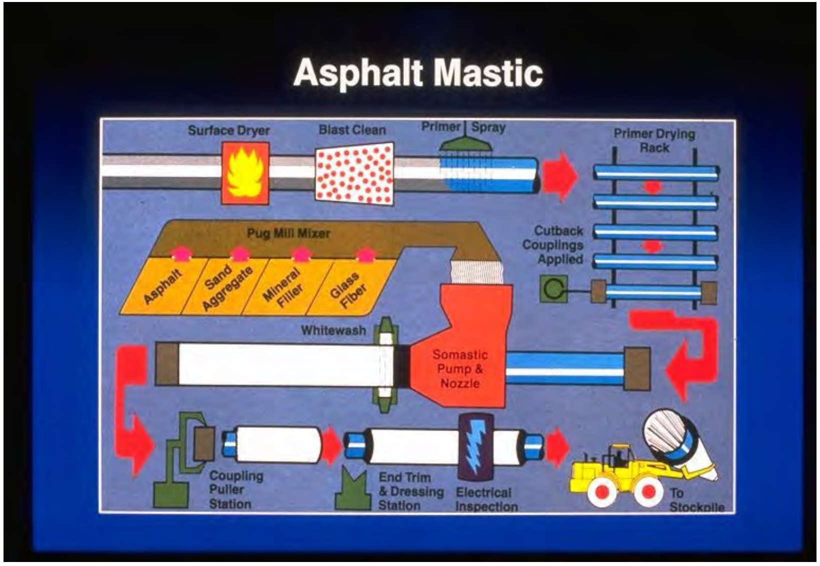




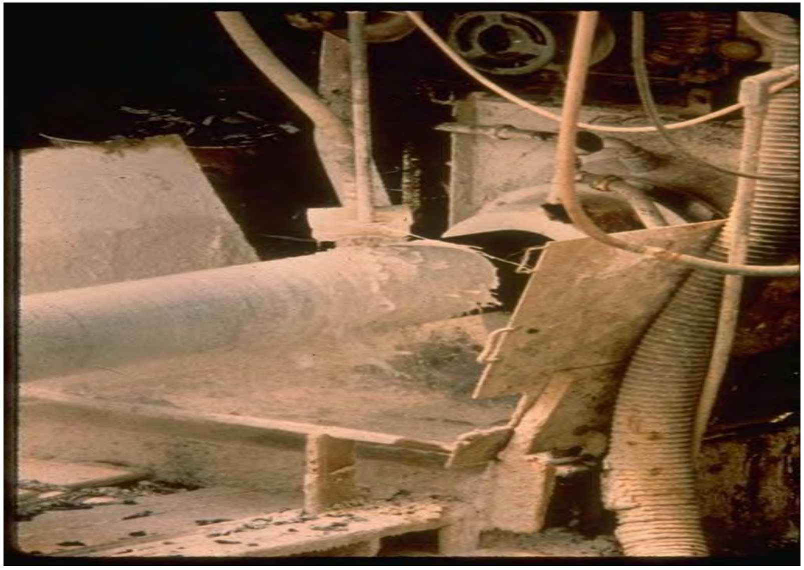
## Coal Tar Enamels

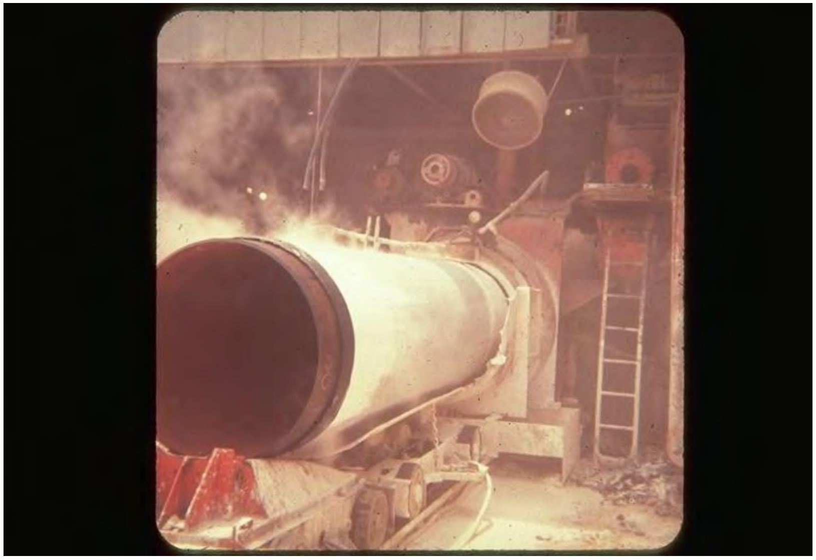






## Asphalt Mastic





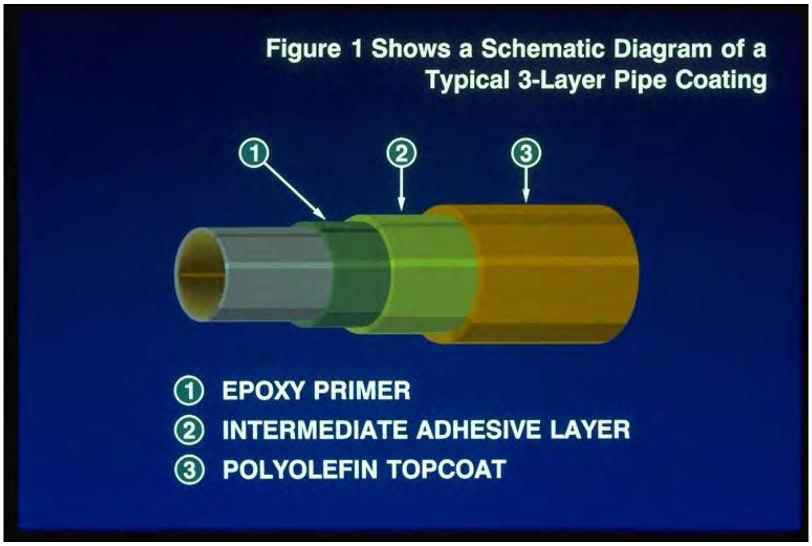
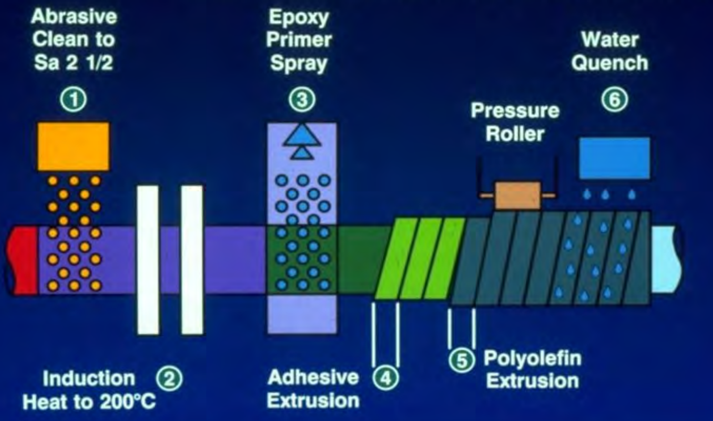
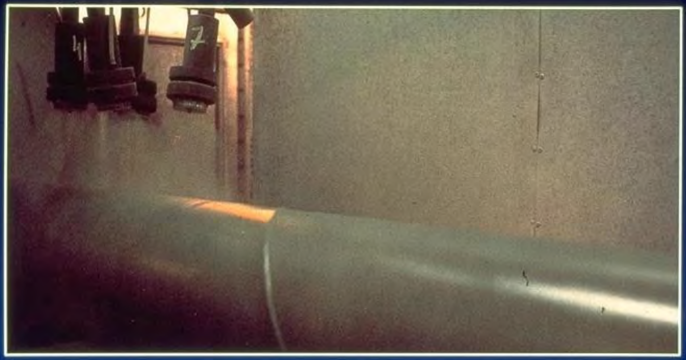


Figure 1 Shows a Schematic Diagram of a Typical 3-Layer Pipe Coating

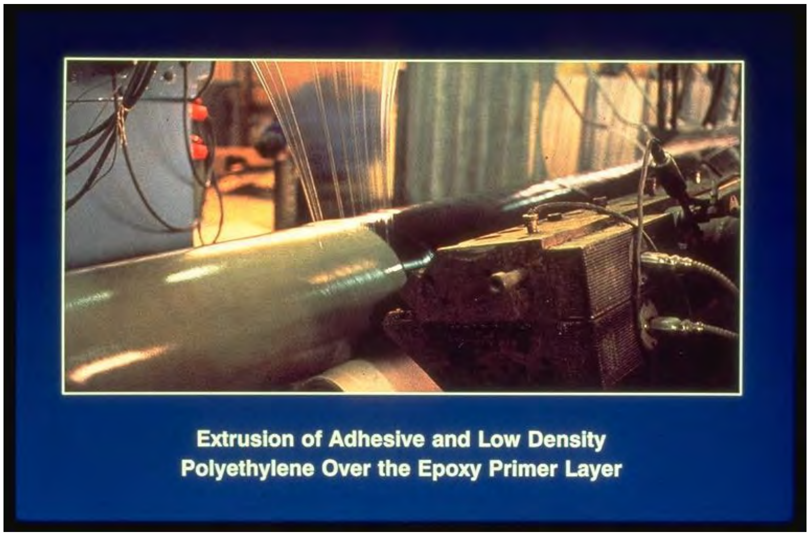
① EPOXY PRIMER
② INTERMEDIATE ADHESIVE LAYER
③ POLYOLEFIN TOPCOAT

## Schematic Diagram of 3-Layer Pipe Coating



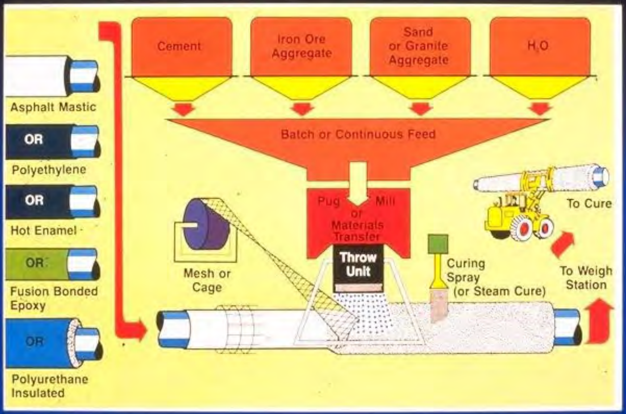


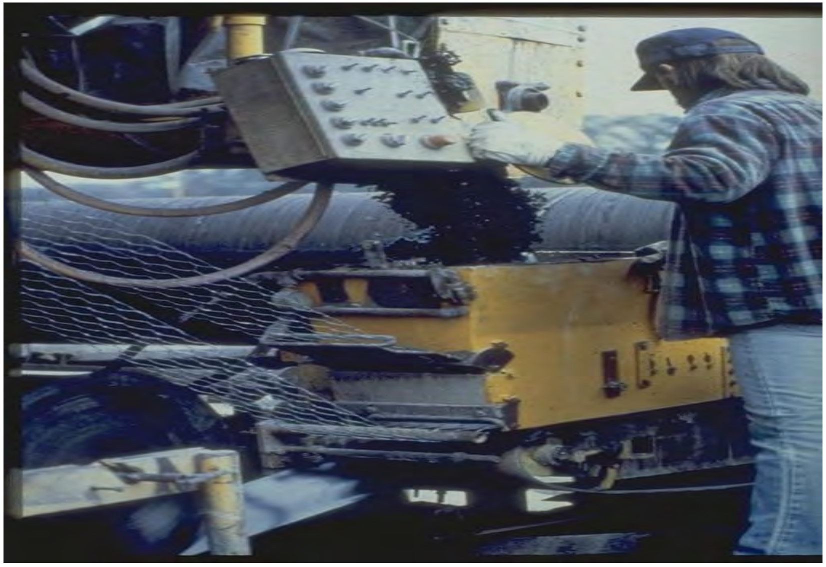
Application of EUROKOTE Epoxy Powder Primer Layer



Extrusion of Adhesive and Low Density Polyethylene Over the Epoxy Primer Layer

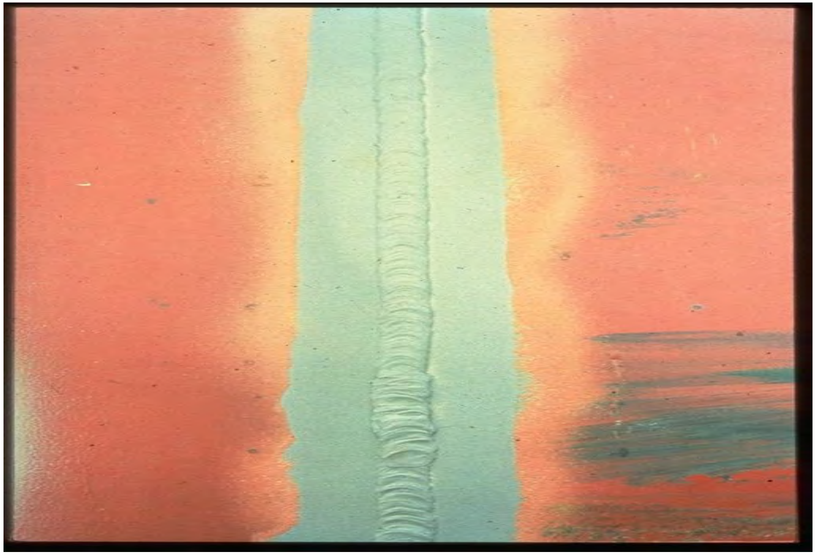
## Impingement Concrete Coating

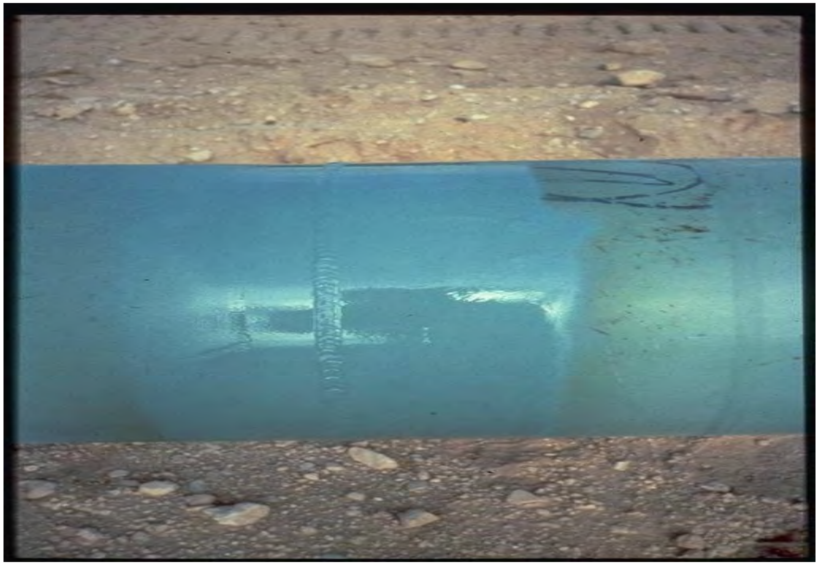


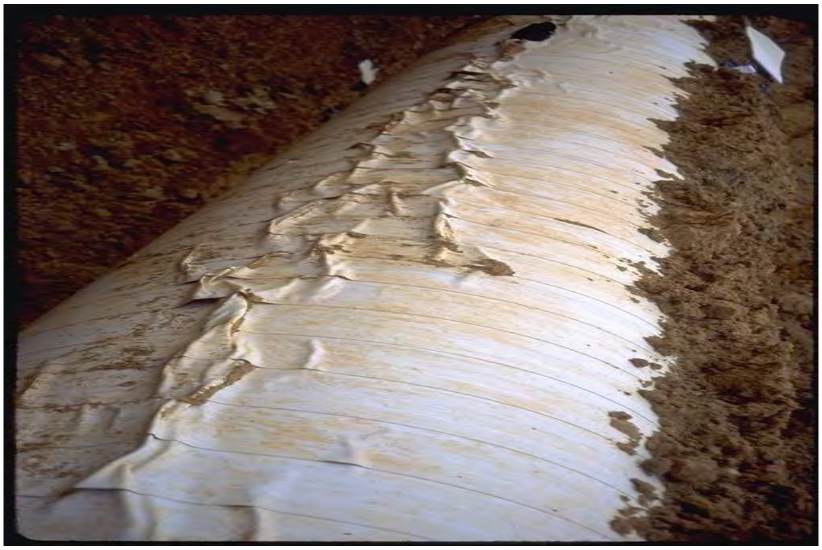



MARTIN DECKER


2







# Line Pipe Coating Process

AUCSC

Appalachian Underground Corrosion Short Course

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## INTRODUCTION

This slideshow steps you through the process of Plant/Mill-Applied external thin film – Fusion Bonded Epoxy (FBE) coating.  The guideline for this process is set forth in NACE Specification SP0394 – latest revision.

## The pipe enters the mill and is ready for the abrasive blasting procedure.

---

## The pipe enters the pre-heat oven where its temperature is raised to approximately 130 degrees. It then enters the abrasive blasting booth.

## The pipe exits the blasting booth with a near-white surface finish and the required anchor profile.

## At this stage, the blasted pipe surface is checked for raised slivers, scabs, laminations, or bristles which are removed by file or abrasive sanders. A coupler is then inserted into the end of each joint of pipe.

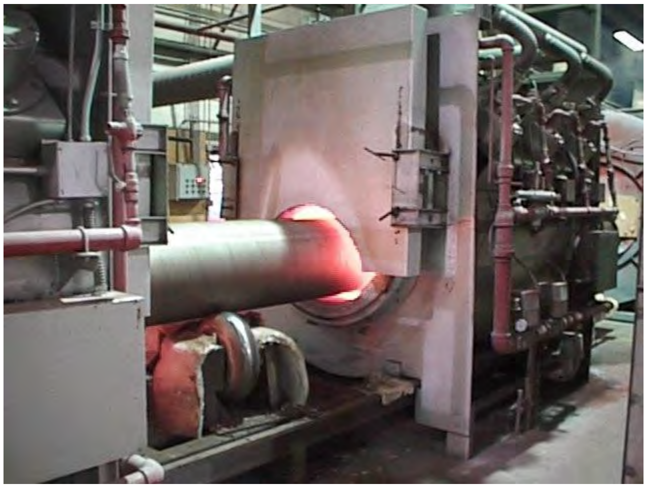
## The coupler is used to connect and seal two joints of pipe together, so one pushes the other through the rest of the process.

## Two pipe joints joined with coupler.

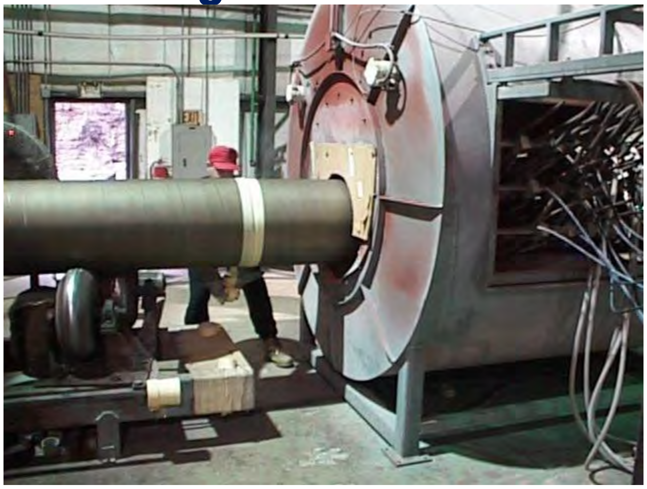
## The pipe then enters an acid bath to remove surface contaminants.

## After the acid bath and rinse, the pipe enters a series of ovens that raise the temperature of the pipe to approximately 475 degrees before application of the coating.

## Pipe entering last oven before coating.



## The joint between pipes is covered, so that the ends of each joint are left free of coating. This is done to allow welding in the field.



## The pipe exits the coating booth where jets have applied a coating to the hot pipe with an average coating thickness of 15 mils.

## The tape around the joint is now removed and pipe continues to the quenching chamber.

## In the next step of this process, the pipe enters a quenching chamber and is water cooled to around 250 degrees.

## Pipe coming out of quenching chamber.

## Stencil being added to pipe stating the company name, API information and size and wall thickness of pipe.

## Company Inspector verifying that the coating thickness is acceptable.

## Ropes are put around pipe to keep joints of pipe separated and to prevent coating damage.

## A 2,000 volt , nonpulsating, low ripple DC dry-type holiday detector is then used to detect any holidays that may exist in the coating.

## Repair of a pinhole size holiday in the coating. Patching with these touch up sticks is only allowed in the mill while the pipe is still hot. Preheating the pipe properly is the limiting factor for field application.

## Holiday repair using touch-up sticks.

## Each pipe is measured and given a number.

---

## The pipe is then carried into the yard. The forklift has protective padding on the jaws.

## The pipe is stacked with padded boards between them to prevent damage to the coating.

## The joints of pipe are unloaded on to the padded boards and the ropes separate the joints and protect them from damage when striking other pipes.

## The End!

- Questions
- Comments
- Concerns
- Thank you for attending!

AUCSC
Appalachian Underground Corrosion Short Course

# Rectifier Monitoring

Fundamentals Course

Period 8

Instructor: Josh Brewer

JUSTICE NEWS

**Department of Justice**

Office of Public Affairs

FOR IMMEDIATE RELEASE

Wednesday, January 7, 2015

**Pipeline Corrosion Monitor Pleads Guilty to Pipeline Safety Violations and False Statements**

Randy Jones, 44, a former corrosion coordinator for Shell Pipeline Company L.P. (Shell), pleaded guilty in Milwaukee today to failing to conduct bi-monthly voltage readings and an annual survey of a pipeline used to transport jet fuel in violation of the Pipeline Safety Act (PSA) and making a false statement to the Pipeline and Hazardous Material Safety Administration (PHMSA).

Jones, a resident of Louisiana, pleaded guilty to knowingly failing to conduct required safety test between January and December 2011 and submitting false data to PHMSA. The violations were in connection with a pipeline owned by Shell that delivered commercial aviation jet fuel to General Mitchell International Airport in Milwaukee, Wisconsin. In January 2012 a hole was discovered in the pipeline at Mitchell Airport after jet fuel began showing up in soil surrounding the airport and in nearby Wilson Creek. Fuel eventually reached and melted asphalt on airport property. Shell reported that approximately 9,000 gallons of jet fuel was released. The response and cleanup cost for the spill was approximately $19.3 million.

Jones was employed by Shell from 1992 through 2012. From 2010 until 2012, Jones was employed as a corrosion coordinator and was responsible for Shell pipelines servicing Mitchell and Chicago O'Hare airports. Jones failed to conduct the required testing for 2011 and when advised of an audit by PHMSA scheduled for December 2011, he submitted false data indicating the required test had been conducted.

Consistent with requirements of the PSA, which establishes standards for the safe operation of the hazardous materials in pipelines, buried or submerged metal pipelines must be protected to prevent corrosion. This involves the use of a device called a rectifier which applies a negative current to soil near the pipeline to keep corrosion away from the pipe. The operator of the pipeline is required to conduct bi-monthly readings of the voltage generated from a rectifier and conduct an annual survey of the pipeline to insure that the pipeline is adequately protected from corrosion. PHMSA is the primary agency responsible for regulating and enforcing the PSA.

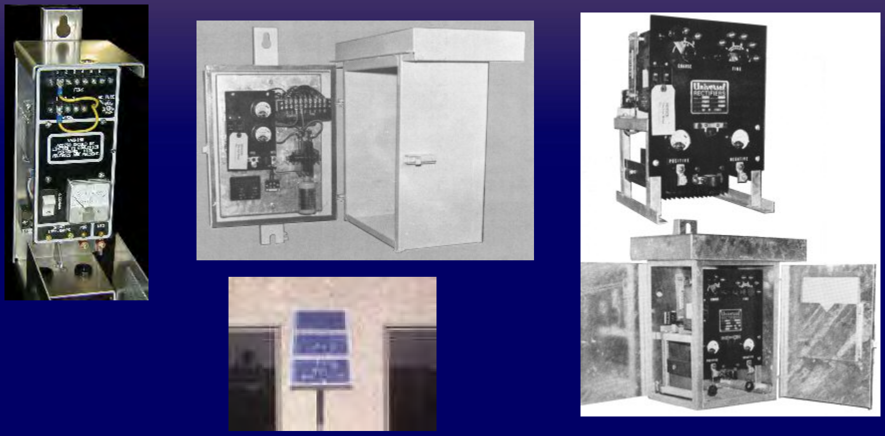
# Objective of Presentation

- Familiarize everyone with components of Rectifiers
- Understand workings of components
- Understand the Why, What, How, and When of Rectifier Monitoring

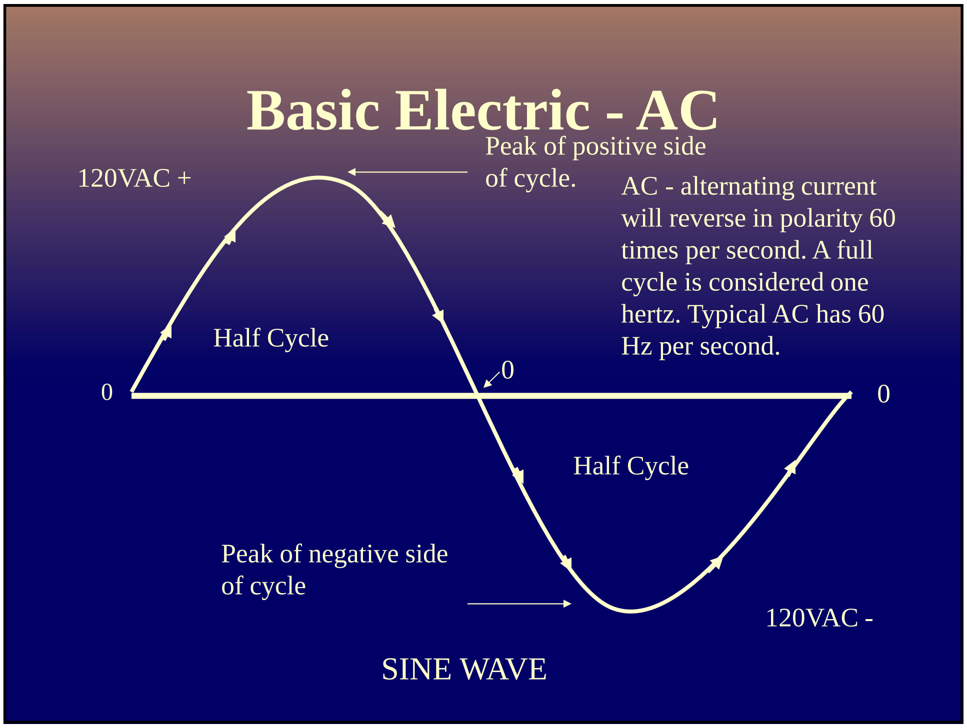
# What is a Rectifier ?

- Rectifier converts or rectifies alternating current (AC) to direct current (DC)
- DC current then flows to groundbed - then to structure needing cathodic protection

## Samples of Rectifiers

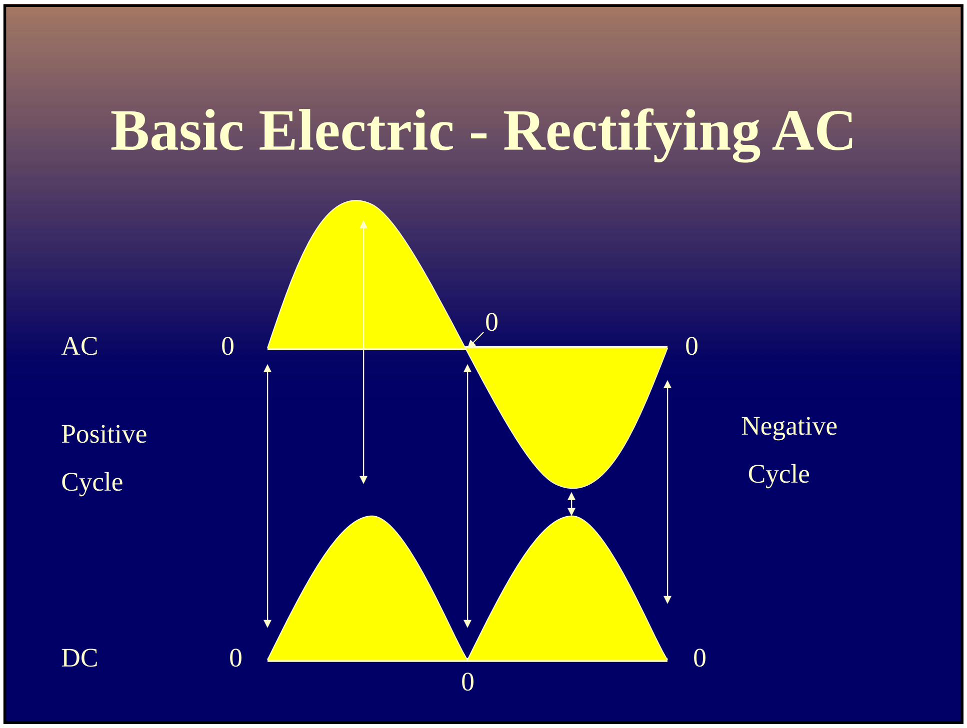


## Samples of Rectifiers

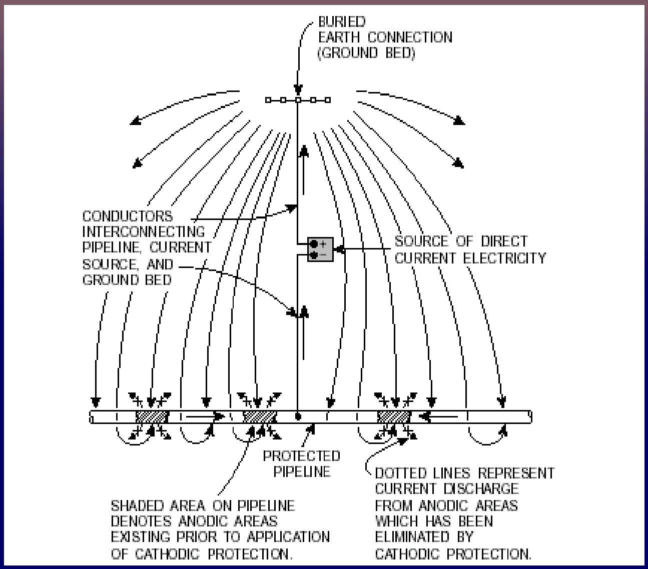


## Basic Electric - AC

AC - alternating current will reverse in polarity 60 times per second. A full cycle is considered one hertz. Typical AC has 60 Hz per second.



## Basic Electric - Rectifying AC



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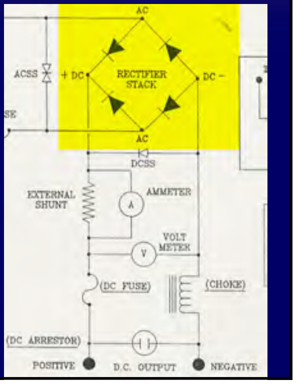
# Header Cables

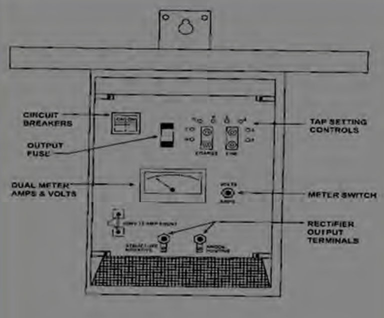
- ❖ Negative cable connected to the structure
- ❖ Positive cable hooked to the groundbed



## Basic Components of a Rectifier

- Circuit Breaker
- Transformer
- Rectifying Elements
- Accessory Equipment

## Standard Rectifier Unit



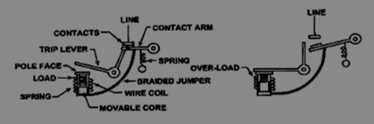
TYPICAL AIR COOLED RECTIFIER

FIGURE 7-17

- Standard Rectifier
  - Circuit Breaker
  - Output Fuse
  - Tap Setting Controls
  - Dual Meter - Amps and Volts
  - Meter Switch
  - Rectifier Output Terminals

# Circuit Breaker

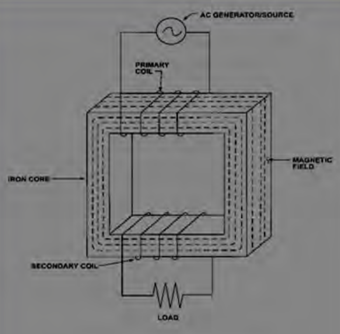
- **Primary Function**
  - provide overload protection for the circuit in which it's installed
  - serves as an on-off switch for the rectifier



FULLY MAGNETIC CIRCUIT BREAKER

FIGURE 7-13

# Standard Transformer



TYPICAL TRANSFORMER DIAGRAM

FIGURE 7-14A

- **Primary Function**
  - used to "step up" or "step down" voltage
  - isolate voltage from source

# Rectifying Elements

- ❖ Allow current to flow in only ONE direction
- ❖ Two Types of Rectifying Elements
  - ❖ Selenium Cell
  - ❖ Silicon Diode

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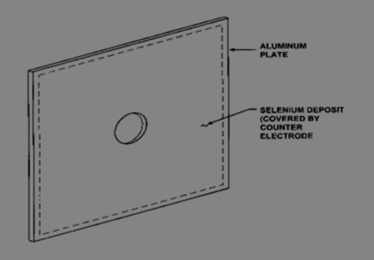
# Selenium Cell

- **Primary Function**
- ❖ barrier layer on selenium side of plate prevents current from passing from the selenium side to the aluminum side

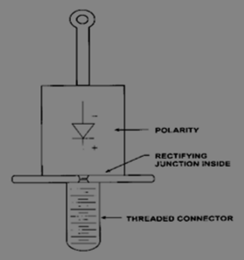


TYPICAL SELENIUM CELL DIAGRAM

FIGURE 7-15

# Silicon Diode

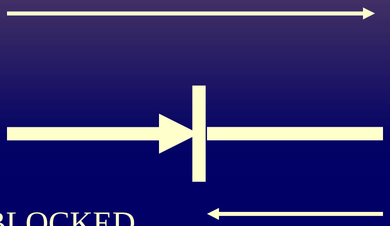
- **Primary Function**
  - permits current to flow in only one direction
  - provides high current and voltage outputs



TYPICAL SILICON DIODE DIAGRAM

FIGURE 7-16

# Basic Electric - Diodes



Current Flow

PASSES THROUGH

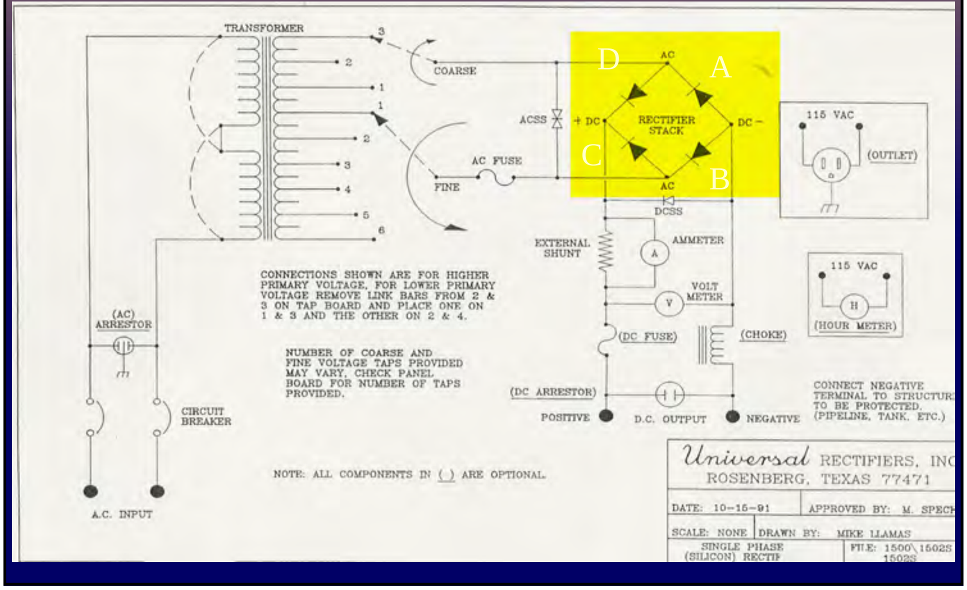
BLOCKED

Current Flow

Current Flows one direction.

Used in rectified systems to change AC to DC with a Rectified diode.

## Basic Electric - Rectified diode bridge



CONNECTIONS SHOWN ARE FOR HIGHER PRIMARY VOLTAGE. FOR LOWER PRIMARY VOLTAGE REMOVE LINK BARS FROM 2 & 3 ON TAP BOARD AND PLACE ONE ON 1 & 3 AND THE OTHER ON 2 & 4.

NUMBER OF COARSE AND FINE VOLTAGE TAPS PROVIDED MAY VARY. CHECK PANEL BOARD FOR NUMBER OF TAPS PROVIDED.

NOTE: ALL COMPONENTS IN ( ) ARE OPTIONAL.

CONNECT NEGATIVE TERMINAL TO STRUCTUR TO BE PROTECTED. (PIPELINE, TANK, ETC.)

*Universal* RECTIFIERS, INC
ROSENBERG, TEXAS 77471

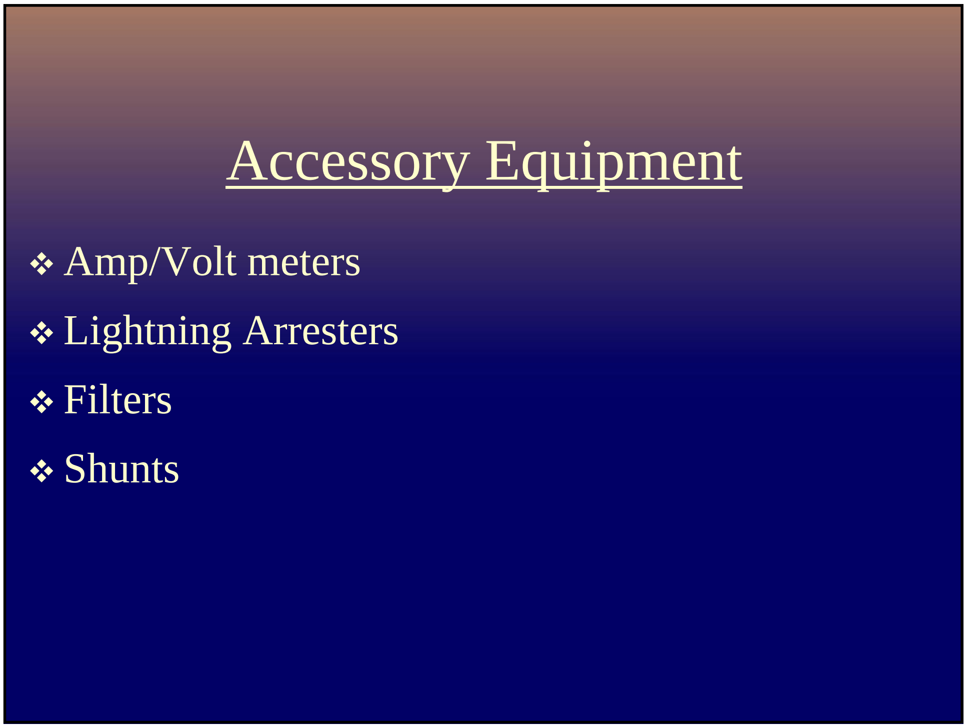
DATE: 10–15–91
APPROVED BY: M. SPECH
SCALE: NONE
DRAWN BY: MIKE LLAMAS
SINGLE PHASE (SILICON) RECTIF
FILE: 1500\1502S 1502S

## Basic Electric
## Checking the Diode Module

- Place your meter on the diode checker
- Disconnect the structure or ground bed cable
- Remove the tabs on the course and fine
- Do the four part test

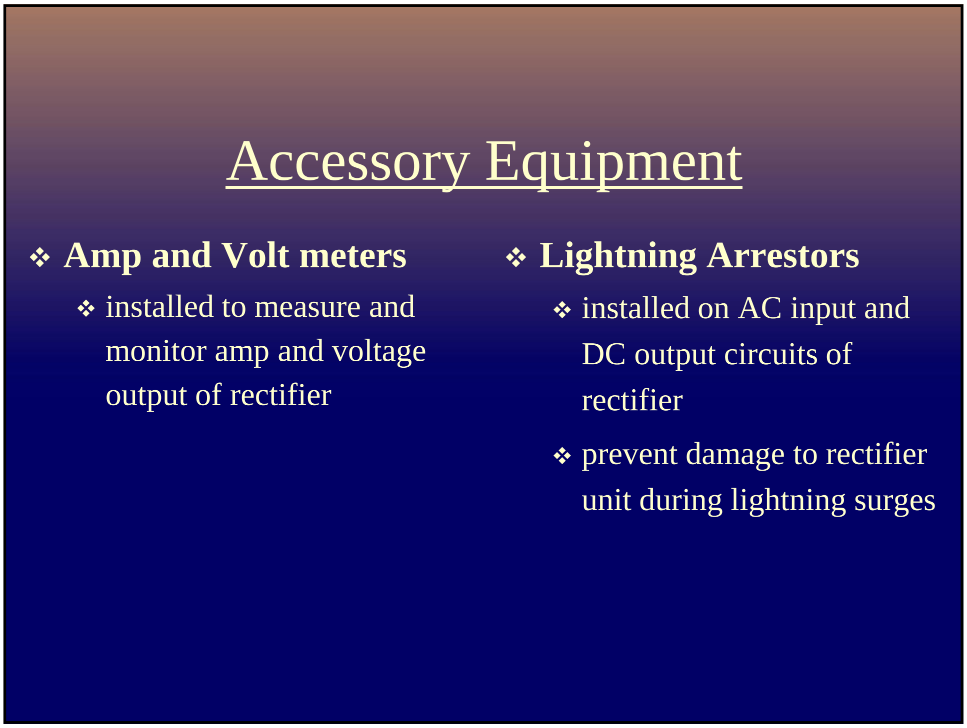
## Basic Electric
## Diode Module Check
## Four Part Test

- Test across the course and the structure terminal
- Test across the fine and the ground bed terminal
- Test across the course and the ground bed terminal
- Test across the fine and the structure terminal
- Reverse all polarities on lead for each test



## Accessory Equipment

- Amp/Volt meters
- Lightning Arresters
- Filters
- Shunts



## Accessory Equipment

- **Amp and Volt meters**
  - installed to measure and monitor amp and voltage output of rectifier
- **Lightning Arrestors**
  - installed on AC input and DC output circuits of rectifier
  - prevent damage to rectifier unit during lightning surges

# Accessory Equipment

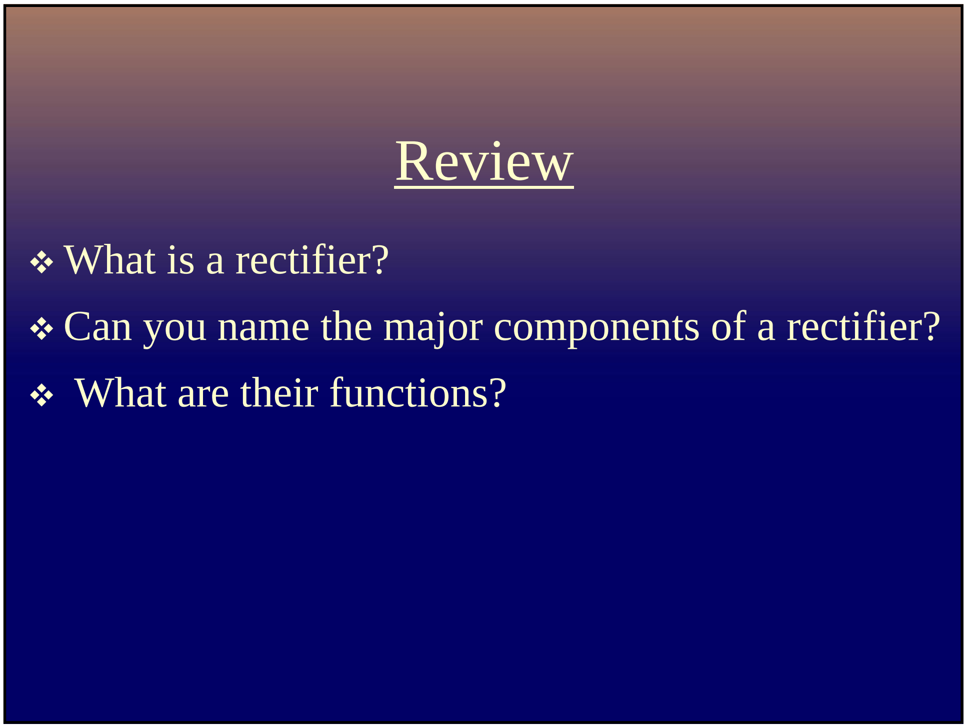
- **Efficiency Filters**
  - improve the efficiency of the rectifier
  - eliminate electronic noise /interference on electronic circuits
  - can also provide lightning protection to the DC side of circuit
- **Shunts**
  - provide a way of measuring the output current of the rectifier

# Impressed Current Groundbed

- Cast Iron
- Platinum
- Graphite
- Mixed Metal Oxide
- Coke Breeze

## Groundbed Design

- Leave it to the experienced Corrosion Control Engineer
  - Things to consider
    - Right-of-way
    - Soil resistivity
    - Pipe diameter
    - Pipe wall thickness
    - Coating condition and type
    - Proximity to other structures



## Review

- What is a rectifier?
- Can you name the major components of a rectifier?
- What are their functions?

# Rectifier Monitoring

Department of Transportation
Inspection Requirements

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## Monitor and Evaluate New and Existing Rectifiers Per CFR-49 Part 192

- **Rectifiers inspected 6(six) times per year not to exceed 2.5 months between inspections**
- **Inspection Includes**
  - **General Condition of rectifier**
  - **Recording rectifier DC volts and amps output**

- **Additional Information**
  - **readings taken from either rectifier meters OR handheld digital meters**
  - **record all data and changes made**

## Rectifier Required Inspections

- **Importance of Inspections**
  - **To ensure rectifier unit and ground bed are in good condition**

## Required Inspections

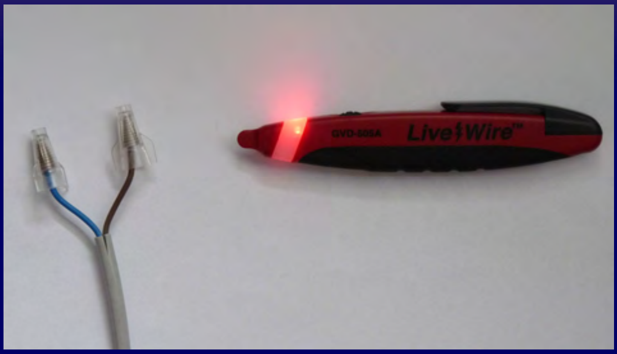
- **Will detect any outside interference problems**
- **Ensure entire area surrounding rectifier is maintained**

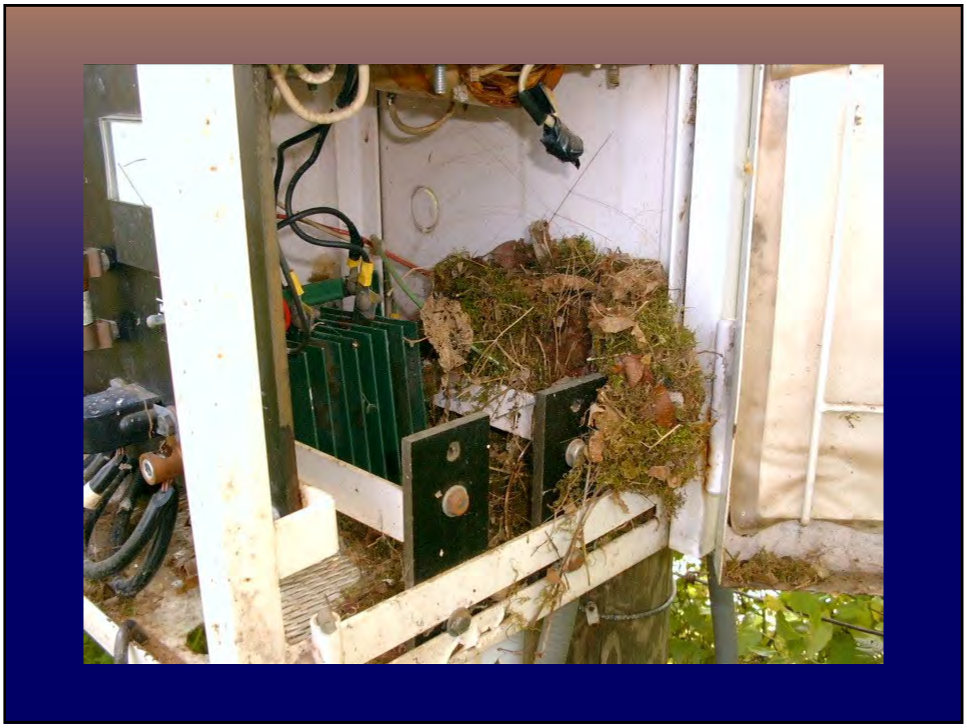
## Rectifier Inspection
## Safety Precautions

- Look for presence of insects, rodents or other hazards around rectifier
- Check for electrical shorts by brushing rectifier unit with back of your hand

## Rectifier Inspection
## Safety Precautions

no contact voltage detector





## Required Electrical Inspections

- DC voltage output readings
  - reading DC volts meter on rectifier unit
    - To ensure meter accuracy
  - multimeter is connected in parallel to rectifier output terminals

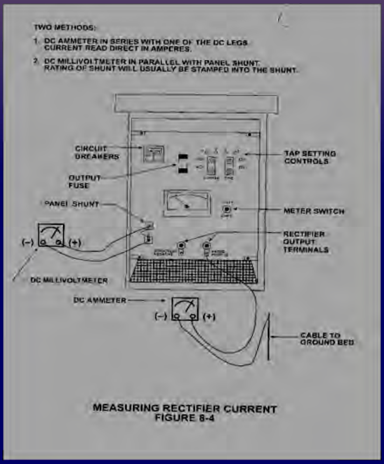
## Required Electrical Inspections

- DC voltage output readings
  - reading DC volts meter on rectifier unit
    - To ensure meter accuracy
  - multimeter is connected in parallel to rectifier output terminals

## Required Electrical Inspections

- DC Amperage Output reading obtained by
  - Reading DC amps meter on rectifier unit
  - With mtr. On DC amps setting -connect in series to rectifier output terminals
    - ensure rectifier is turned off then on

## Required Electrical Inspections



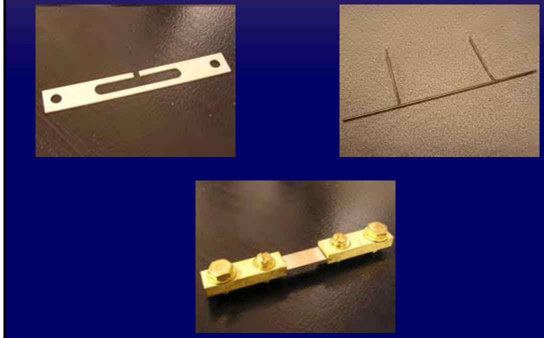
TWO METHODS:

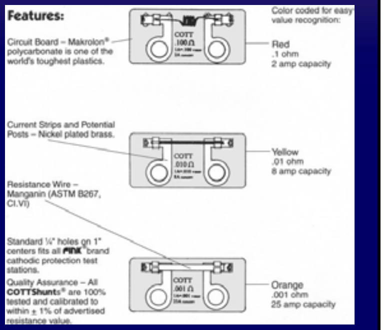
1. DC AMMETER IN SERIES WITH ONE OF THE DC LEGS CURRENT READ DIRECT IN AMPERES.
2. DC MILLIVOLTMETER IN PARALLEL WITH PANEL SHUNT. RATING OF SHUNT WILL USUALLY BE STAMPED INTO THE SHUNT.

MEASURING RECTIFIER CURRENT
FIGURE 8-4

- DC amperage output reading also can be obtained by
  - connecting multimeter in parallel with panel shunt
  - obtain reading and perform calculations

# Various types of shunts





**Features:**

Circuit Board – Makrolon® polycarbonate is one of the world's toughest plastics.

Current Strips and Potential Posts – Nickel plated brass.

Resistance Wire – Manganin (ASTM B267, Cl.VI)

Standard ¼" holes on 1" centers fits all FINK® brand cathodic protection test stations.

Quality Assurance – All **COTTShunts**® are 100% tested and calibrated to within ± 1% of advertised resistance value.

Color coded for easy value recognition:

Red
.1 ohm
2 amp capacity

Yellow
.01 ohm
8 amp capacity

Orange
.001 ohm
25 amp capacity

## Basic Electric - Shunt

- Shunts are resistors; therefore is considered a load.
- Measure voltage across shunt with meter connected in parallel.
- Shunts are used mainly for measuring current flow in a circuit.
  - Rectifiers
  - Bonds

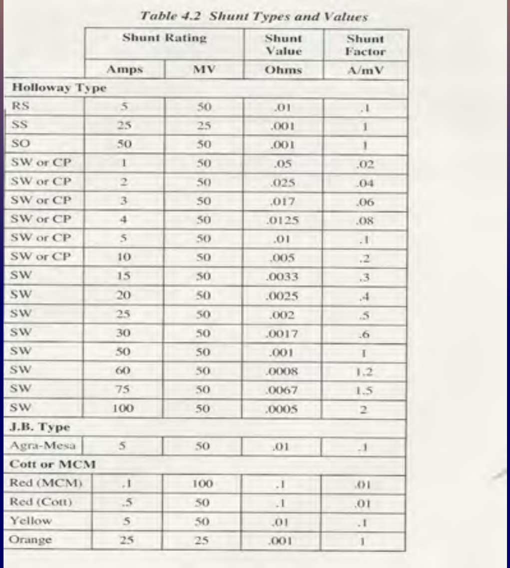


*Table 4.2 Shunt Types and Values*

| | Shunt Rating | | Shunt Value | Shunt Factor |
|---|---|---|---|---|
| | Amps | MV | Ohms | A/mV |
| **Holloway Type** | | | | |
| RS | 5 | 50 | .01 | .1 |
| SS | 25 | 25 | .001 | 1 |
| SO | 50 | 50 | .001 | 1 |
| SW or CP | 1 | 50 | .05 | .02 |
| SW or CP | 2 | 50 | .025 | .04 |
| SW or CP | 3 | 50 | .017 | .06 |
| SW or CP | 4 | 50 | .0125 | .08 |
| SW or CP | 5 | 50 | .01 | .1 |
| SW or CP | 10 | 50 | .005 | .2 |
| SW | 15 | 50 | .0033 | .3 |
| SW | 20 | 50 | .0025 | .4 |
| SW | 25 | 50 | .002 | .5 |
| SW | 30 | 50 | .0017 | .6 |
| SW | 50 | 50 | .001 | 1 |
| SW | 60 | 50 | .0008 | 1.2 |
| SW | 75 | 50 | .0067 | 1.5 |
| SW | 100 | 50 | .0005 | 2 |
| **J.B. Type** | | | | |
| Agra-Mesa | 5 | 50 | .01 | .1 |
| **Cott or MCM** | | | | |
| Red (MCM) | .1 | 100 | .1 | .01 |
| Red (Cott) | .5 | 50 | .1 | .01 |
| Yellow | 5 | 50 | .01 | .1 |
| Orange | 25 | 25 | .001 | 1 |

---

# OHM'S Law

- **Mathematically it can be stated three ways:**

(1) $I = E/R$

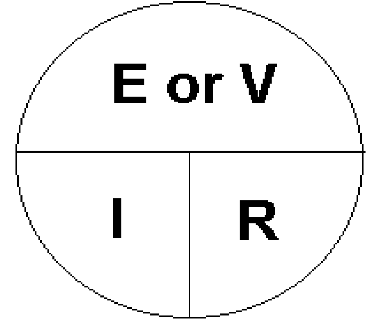
(2) $R = E/I$

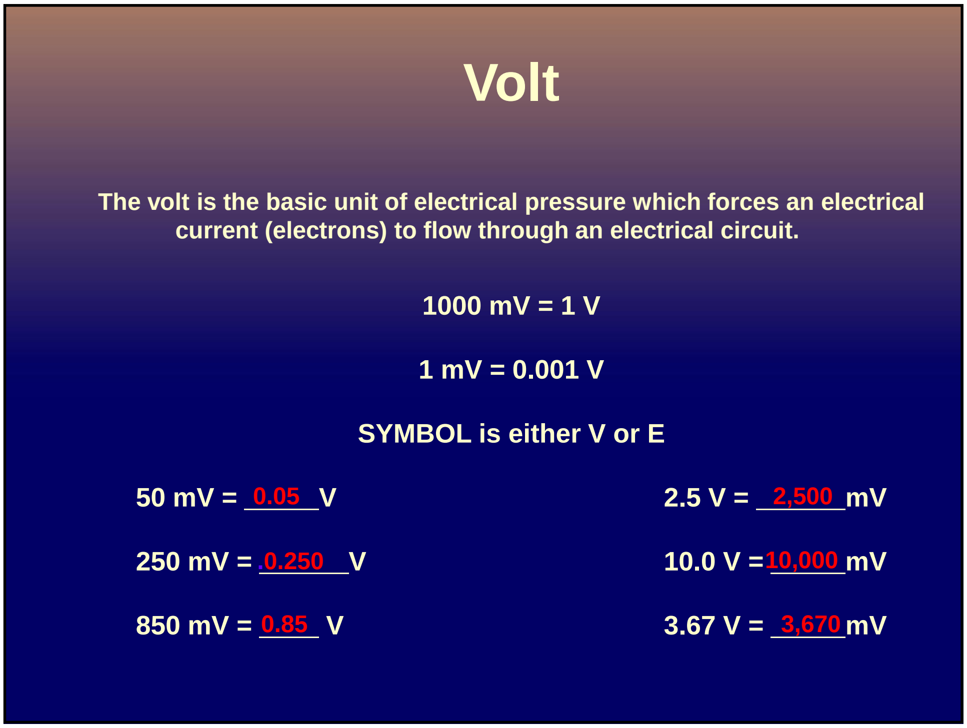
(3) $E = I \times R$ or $E = IR$

$I$ = Current in Amperes

$E$ = Voltage in volts

$R$ = Resistance in Ohms





## Volt

The volt is the basic unit of electrical pressure which forces an electrical current (electrons) to flow through an electrical circuit.

1000 mV = 1 V

1 mV = 0.001 V

SYMBOL is either V or E

50 mV = 0.05 V

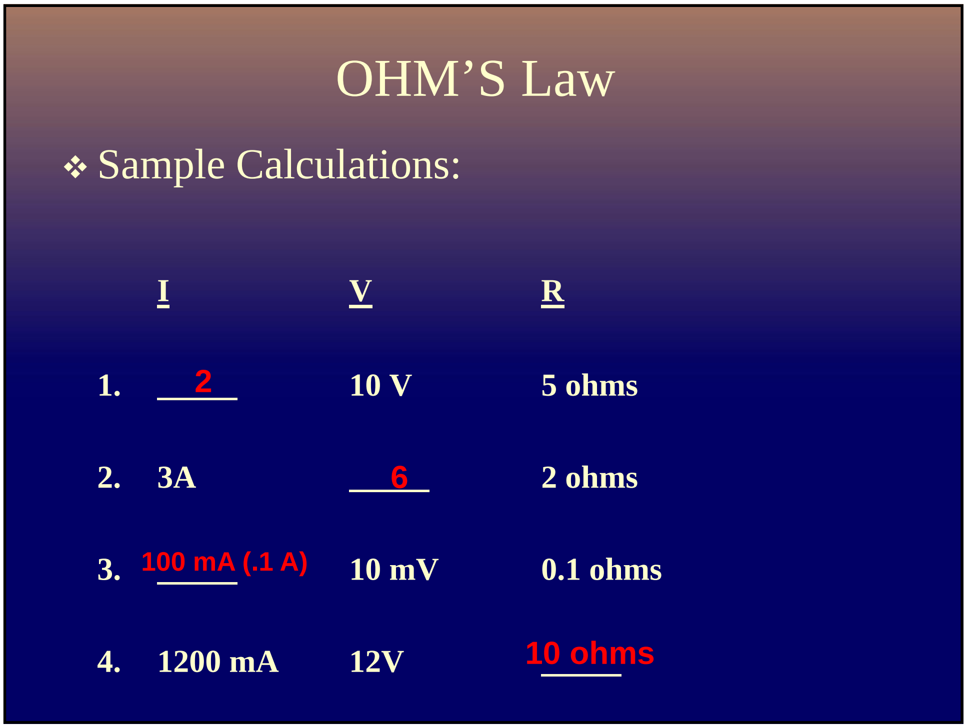
250 mV = 0.250 V

850 mV = 0.85 V

2.5 V = 2,500 mV

10.0 V = 10,000 mV

3.67 V = 3,670 mV



## OHM'S Law

- Sample Calculations:

| | I | V | R |
|---|---|---|---|
| 1. | 2 | 10 V | 5 ohms |
| 2. | 3A | 6 | 2 ohms |
| 3. | 100 mA (.1 A) | 10 mV | 0.1 ohms |
| 4. | 1200 mA | 12V | 10 ohms |

## Shunts

### Calculation

50 mV - 50 A

Determine Amps/mV

$$1\ \text{mV} = \frac{50\ \text{A}}{50\ \text{mV}} = \underline{\ 1\ }\ \text{A / mV}$$

Shunt Resistance

$$R = \frac{E}{I} = \frac{0.050\ \text{V}}{50\ \text{A}} = \underline{\ 0.001\ }\ \Omega$$

If Measure - 50 mV

$$I = \frac{V}{R} = \frac{50\ \text{mV}}{0.001\ \Omega} = \frac{50{,}000\ \text{mV}}{\Omega} = \underline{\ 50\ }\ \text{A}$$

Additional samples provided at the end of the chapter.

---

## Shunts

### Calculation

Determine Shunt Factor (SF)

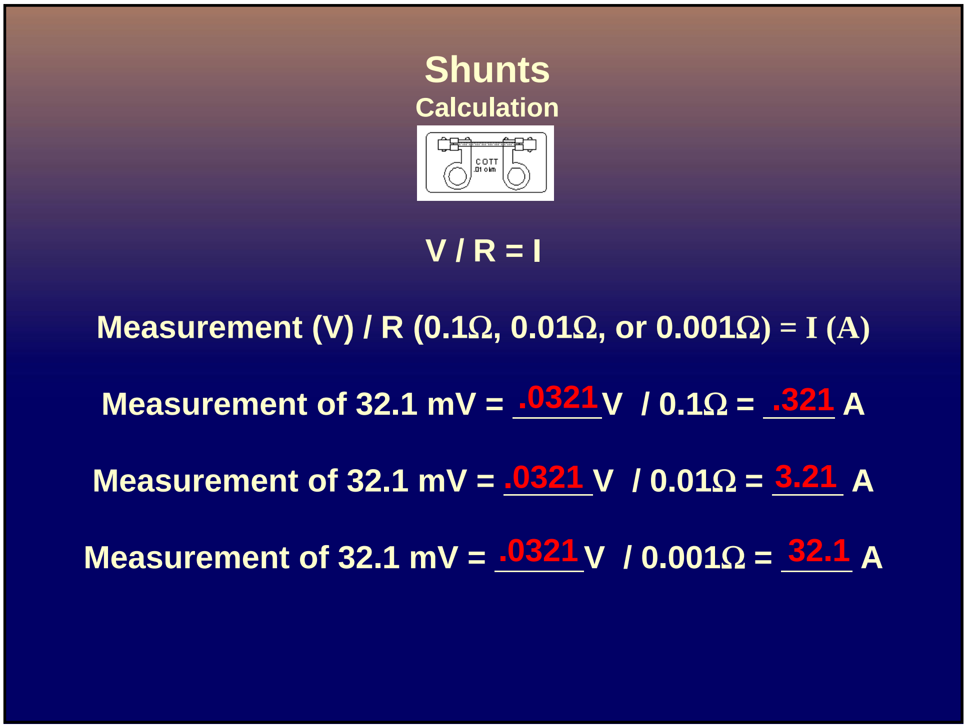
SF X Measurement (mV) = Amps

50A / 50mV shunt = SF of <u>1</u>

SF <u>1</u> X 4.2 mV = <u>4.2</u> A

50A / 25mV shunt = SF of <u>0.5</u>

SF <u>0.5</u> X 4.2 mV = <u>2.1</u> A



## Shunts

### Calculation

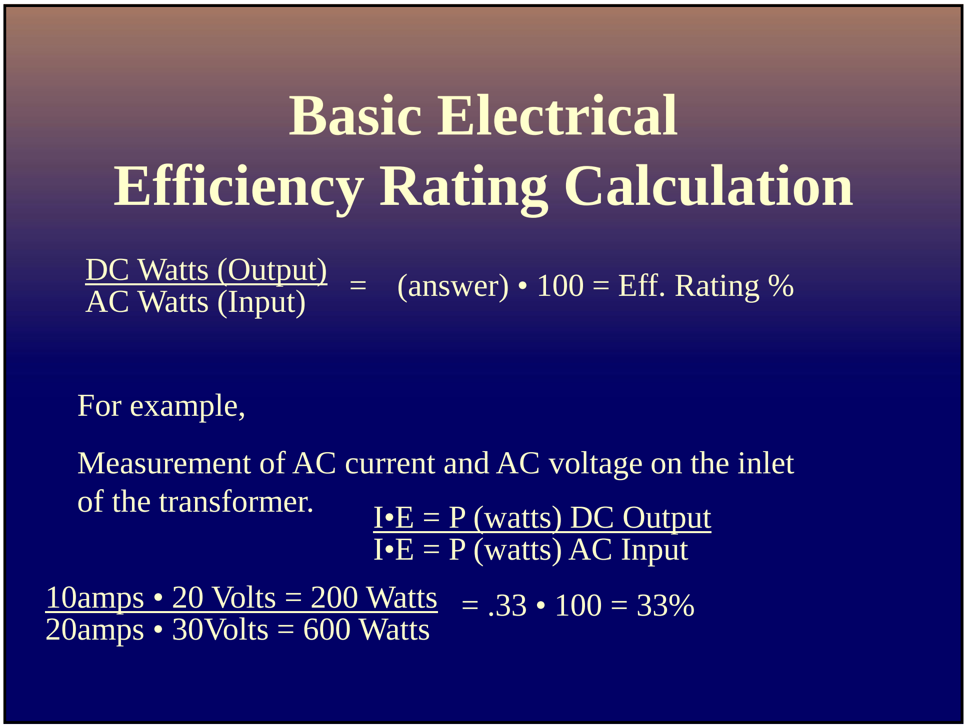
V / R = I

Measurement (V) / R (0.1Ω, 0.01Ω, or 0.001Ω) = I (A)

Measurement of 32.1 mV = .0321 V / 0.1Ω = .321 A

Measurement of 32.1 mV = .0321 V / 0.01Ω = 3.21 A

Measurement of 32.1 mV = .0321 V / 0.001Ω = 32.1 A



## Basic Electrical Efficiency Rating Calculation

$$\frac{\text{DC Watts (Output)}}{\text{AC Watts (Input)}} = \text{(answer)} \cdot 100 = \text{Eff. Rating \%}$$

For example,

Measurement of AC current and AC voltage on the inlet of the transformer.

$$\frac{\text{I•E = P (watts) DC Output}}{\text{I•E = P (watts) AC Input}}$$

$$\frac{\text{10amps • 20 Volts = 200 Watts}}{\text{20amps • 30Volts = 600 Watts}} = .33 \cdot 100 = 33\%$$

## Review: Rectifier Inspections

- **Observe all safety precautions while performing rectifier inspections !**
- **Check physical condition of rectifier unit and area surrounding rectifier**
- **Obtain DC voltage reading and record**
- **Obtain DC amps reading by either method illustrated**
- **Record accurate readings on appropriate forms**

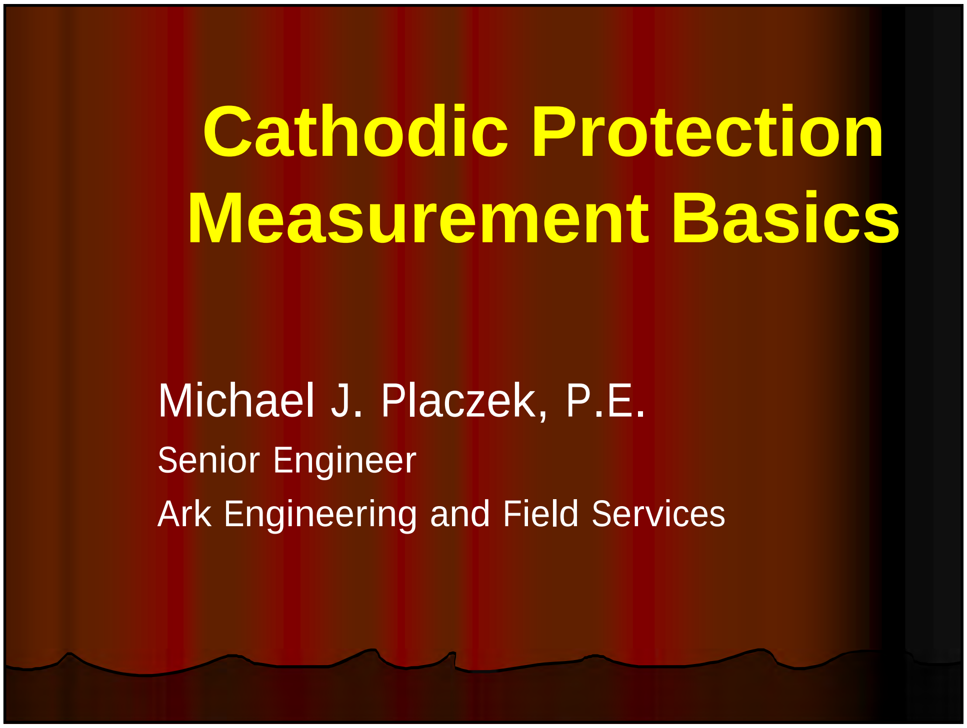
## Additional Information - Annual Inspections

- **Clean and tighten all connections**
- **Clean all screens, vents**
- **Check all meters for accuracy**
- **Replace damaged wires**
- **Check all protective devices - fuses, lightning arresters**
- **Inspect all components for damage**
- **Clean rectifier unit of dirt, insects,**

# Questions?

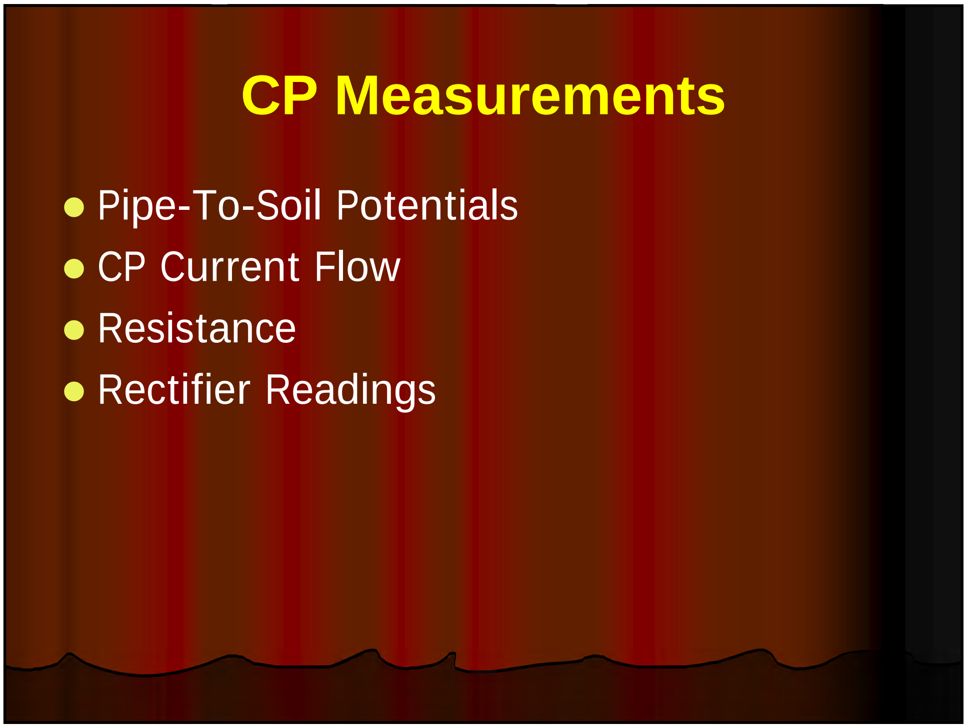
**Thanks!**

**Contact Information**
**Josh Brewer**
**josh.brewer@isfieldservices.com**
**989-388-3051**



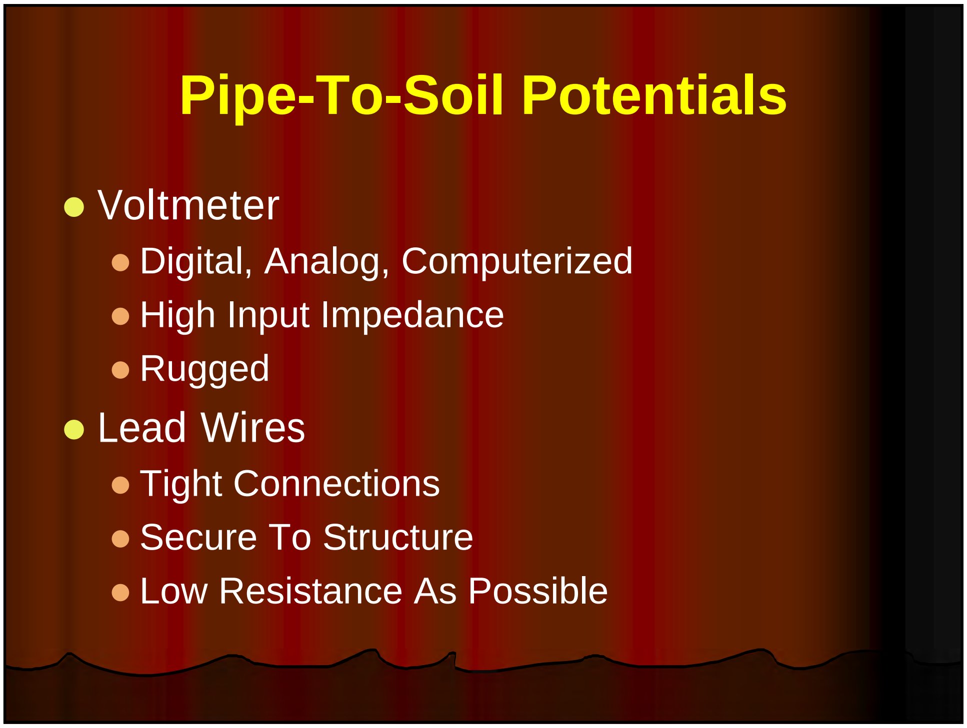
# Cathodic Protection Measurement Basics

Michael J. Placzek, P.E.
Senior Engineer
Ark Engineering and Field Services



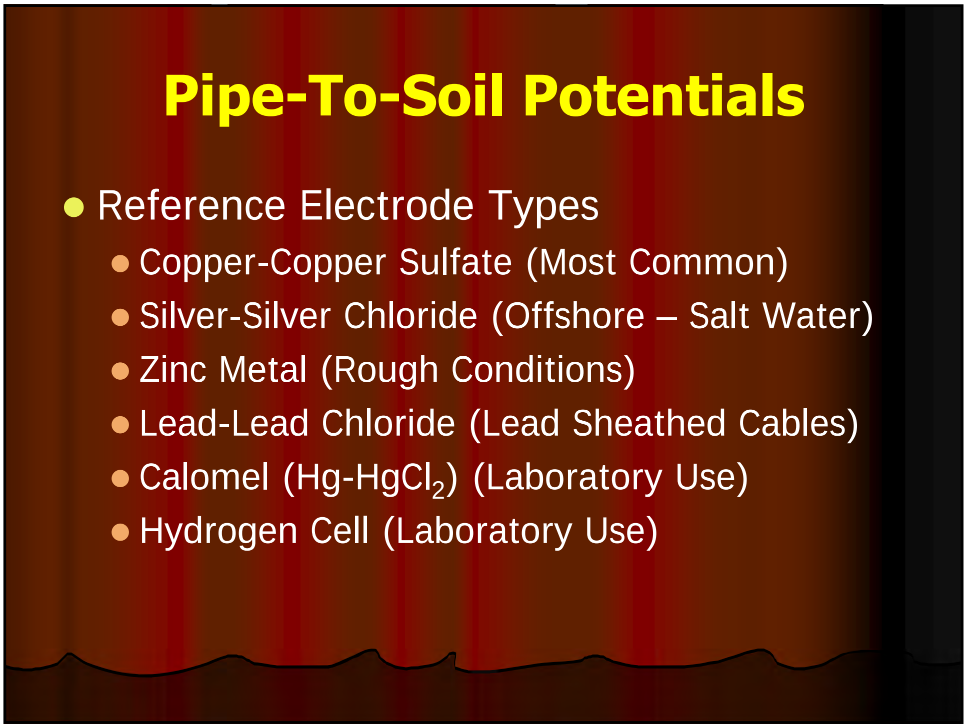
## CP Measurements

- Pipe-To-Soil Potentials
- CP Current Flow
- Resistance
- Rectifier Readings



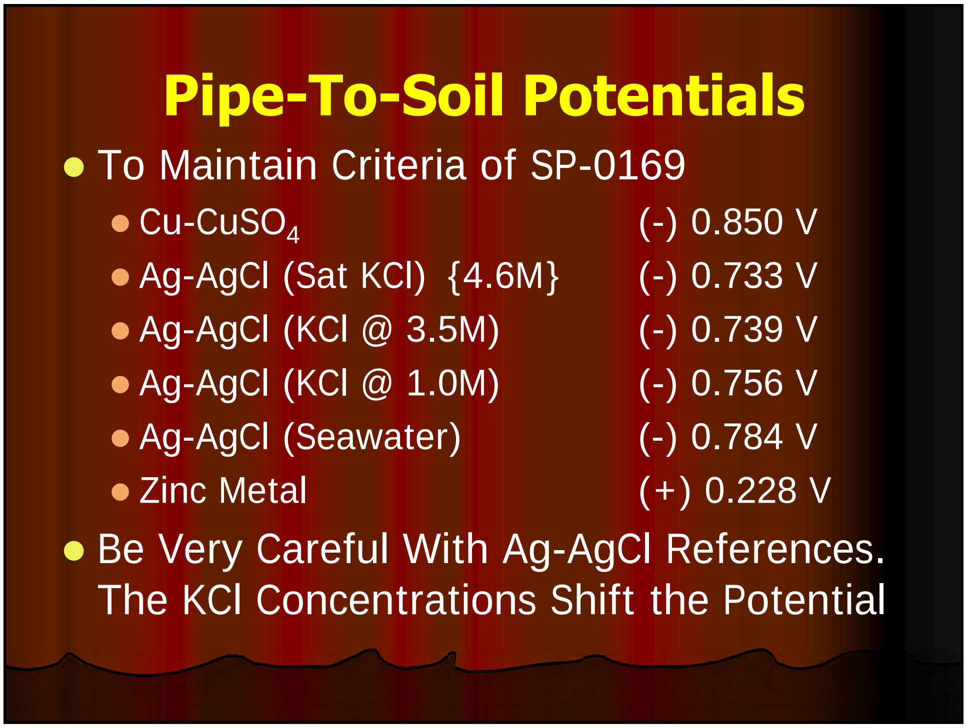
## Pipe-To-Soil Potentials

- Voltmeter
  - Digital, Analog, Computerized
  - High Input Impedance
  - Rugged
- Lead Wires
  - Tight Connections
  - Secure To Structure
  - Low Resistance As Possible



## Pipe-To-Soil Potentials

- Reference Electrode Types
  - Copper-Copper Sulfate (Most Common)
  - Silver-Silver Chloride (Offshore – Salt Water)
  - Zinc Metal (Rough Conditions)
  - Lead-Lead Chloride (Lead Sheathed Cables)
  - Calomel ($Hg-HgCl_2$) (Laboratory Use)
  - Hydrogen Cell (Laboratory Use)

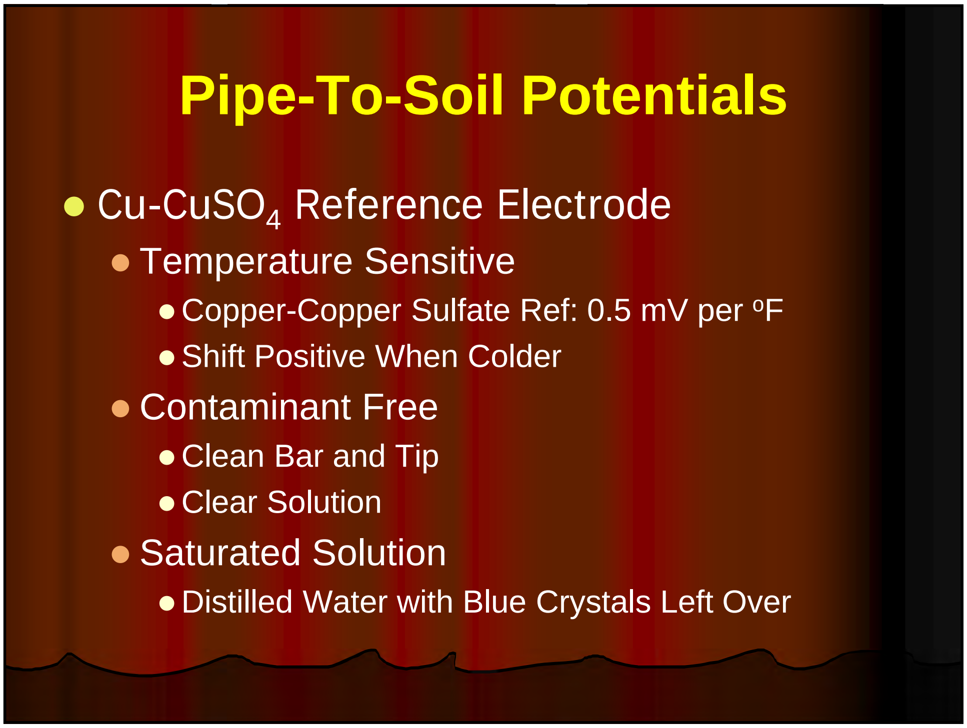


## Pipe-To-Soil Potentials

- To Maintain Criteria of SP-0169

| | |
|---|---|
| $Cu$-$CuSO_4$ | (-) 0.850 V |
| Ag-AgCl (Sat KCl) {4.6M} | (-) 0.733 V |
| Ag-AgCl (KCl @ 3.5M) | (-) 0.739 V |
| Ag-AgCl (KCl @ 1.0M) | (-) 0.756 V |
| Ag-AgCl (Seawater) | (-) 0.784 V |
| Zinc Metal | (+) 0.228 V |

- Be Very Careful With Ag-AgCl References. The KCl Concentrations Shift the Potential



## Pipe-To-Soil Potentials

- $Cu$-$CuSO_4$ Reference Electrode
  - Temperature Sensitive
    - Copper-Copper Sulfate Ref: 0.5 mV per ºF
    - Shift Positive When Colder
  - Contaminant Free
    - Clean Bar and Tip
    - Clear Solution
  - Saturated Solution
    - Distilled Water with Blue Crystals Left Over

## Pipe-To-Soil Potentials

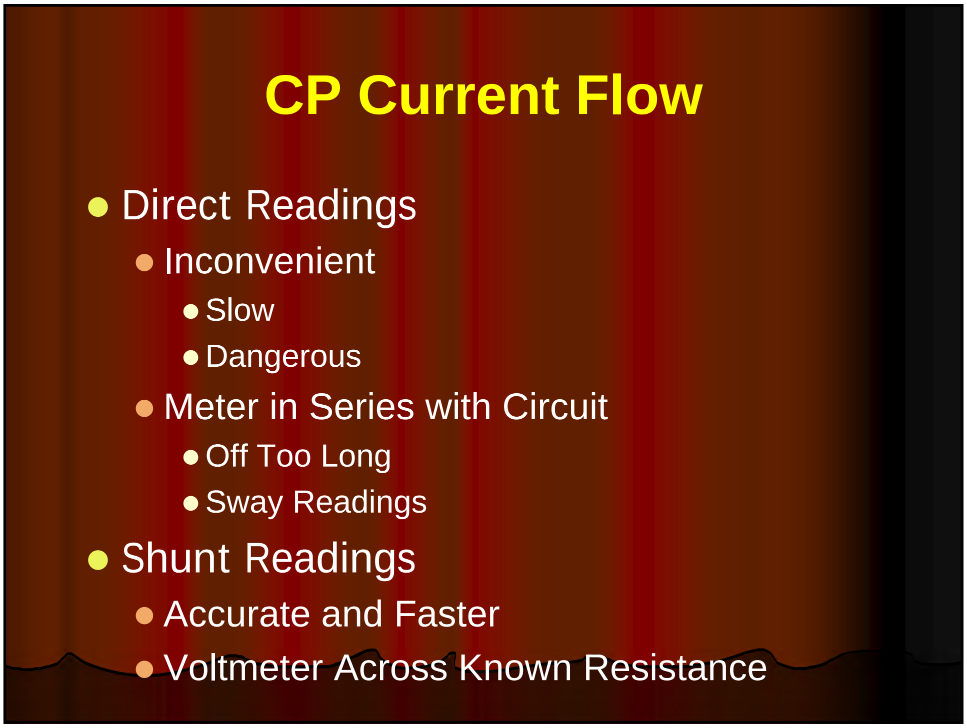
- Position
  - Directly Over Structure
  - Closer The Better But Don’t Touch Structure
- Good Electrolyte Contact
  - Tip Contact to Ground
  - Thick Layers of Crushed Rock
  - Watch out for Unknowns like:
    - Geoplastic sheets under stone
    - Asphalt layers under concrete pavement (old roads)
    - Paved Over Trolley Tracks (Old Cities)

---

## Pipe-To-Soil Potentials

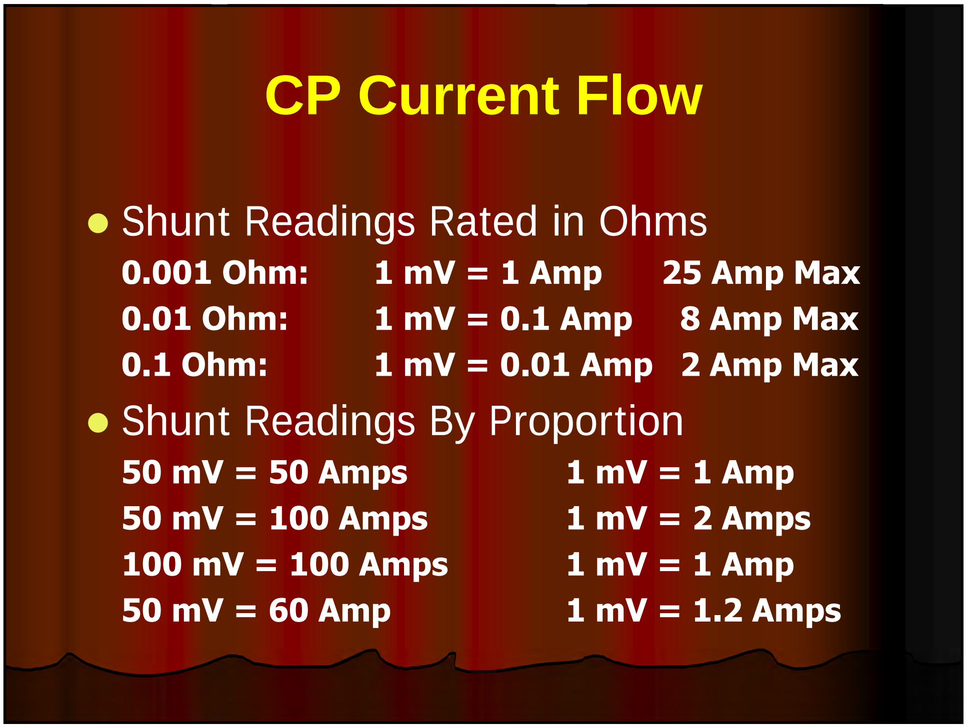
- Sign Convention

| Voltmeter (-) Lug | Voltmeter (+) Lug | Sign Convention |
|---|---|---|
| Structure | Half Cell | 0.850 |
| Half Cell | Structure | (-) 0.850 |



## CP Current Flow

- Direct Readings
  - Inconvenient
    - Slow
    - Dangerous
  - Meter in Series with Circuit
    - Off Too Long
    - Sway Readings
- Shunt Readings
  - Accurate and Faster
  - Voltmeter Across Known Resistance



## CP Current Flow

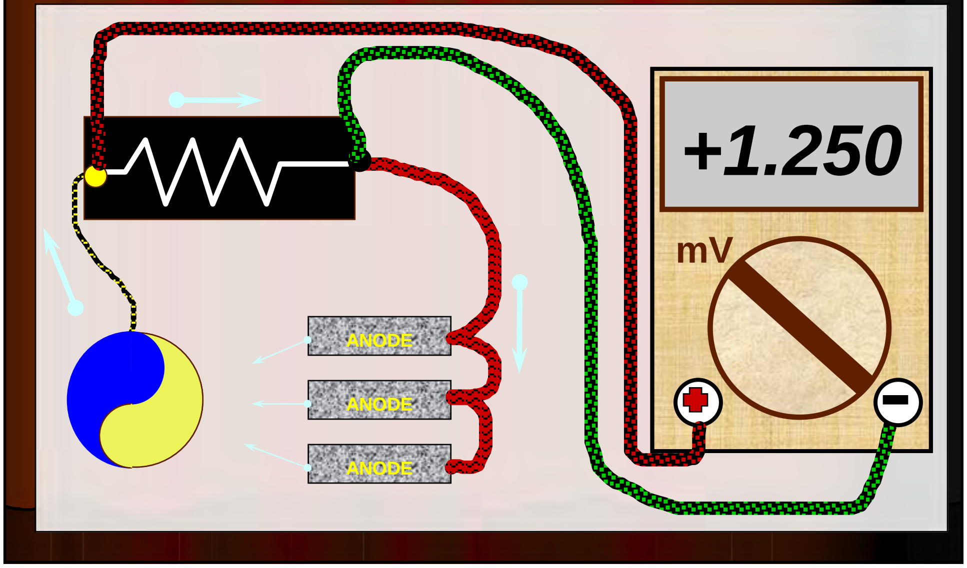
- Shunt Readings Rated in Ohms

| | | |
|---|---|---|
| **0.001 Ohm:** | **1 mV = 1 Amp** | **25 Amp Max** |
| **0.01 Ohm:** | **1 mV = 0.1 Amp** | **8 Amp Max** |
| **0.1 Ohm:** | **1 mV = 0.01 Amp** | **2 Amp Max** |

- Shunt Readings By Proportion

| | |
|---|---|
| **50 mV = 50 Amps** | **1 mV = 1 Amp** |
| **50 mV = 100 Amps** | **1 mV = 2 Amps** |
| **100 mV = 100 Amps** | **1 mV = 1 Amp** |
| **50 mV = 60 Amp** | **1 mV = 1.2 Amps** |

## CP Current Flow



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## Resistance

- Direct Readings
  - Isolate Circuit
  - Turn Off Power
- Calculated
  - Known V & Known I
  - Calculate: R = V / I
- Other Method
  - B3 Series Meter

# Rectifier Readings

- AC Input
  - Voltage at Disconnect or Behind Breaker
  - Current by Clamp-On Ammeter
  - Power = (3600 x Kh x N) / T
- AC Throughput
  - Voltage Across Main Lugs of Taps
- DC Output
  - Voltage Across the Output Lugs
  - Current:  Voltage Across the Shunt
- Efficiency
  - Power Out / Power In

# So...Where Are We On The Graph???

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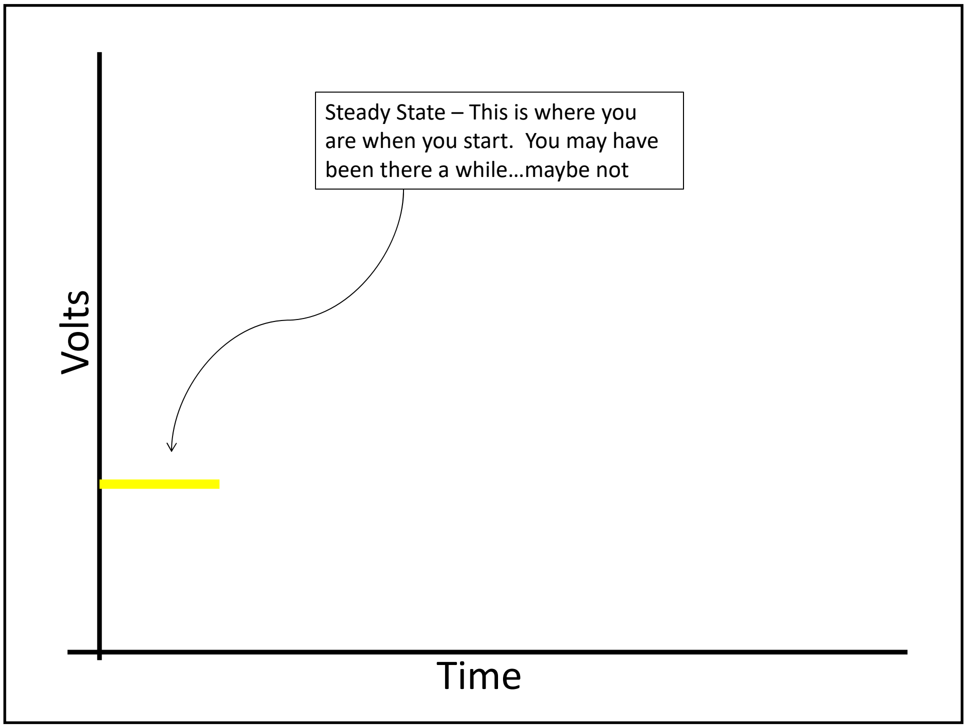
**Senior Engineer**
**Ark Engineering and Services**

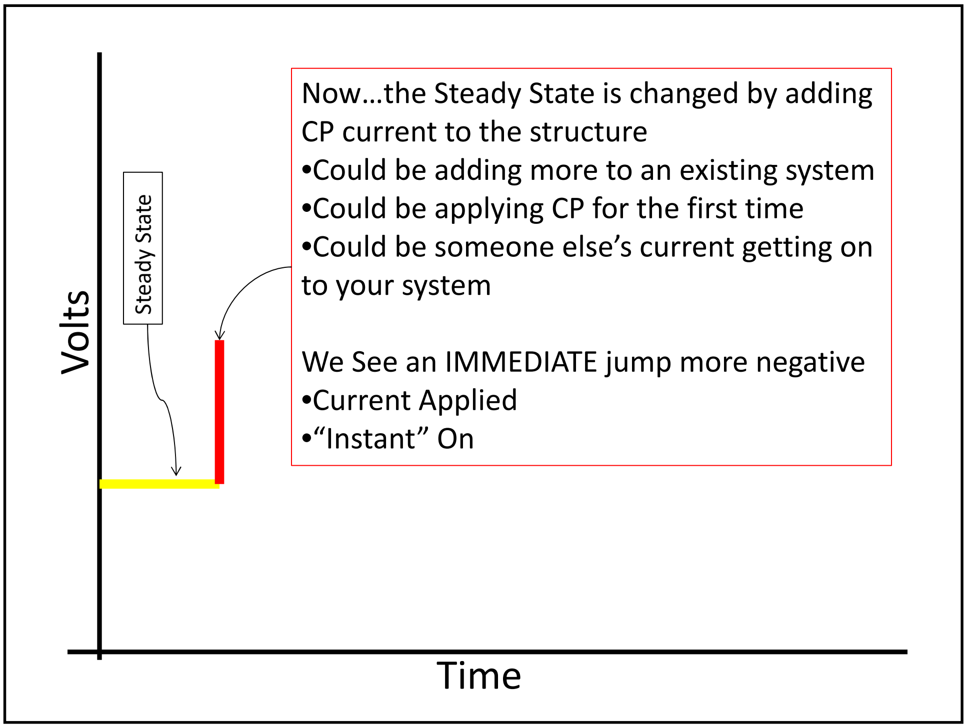
---

# Terminology

- ✓ On
- ✓ Off
- ✓ "Instant" Off
- ✓ "Instant" On
- ✓ Current Applied
- ✓ Polarized
- ✓ Depolarized
- ✓ IR Drop
- ✓ Native
- ✓ Steady State
- ✓ CP Criteria
- ✓ Adequate CP
- ✓ 8 – 5 On
- ✓ 8 – 5 Off
- ✓ IR Drop Considered
- ✓ 100 mV Depol



Steady State – This is where you are when you start.  You may have been there a while…maybe not

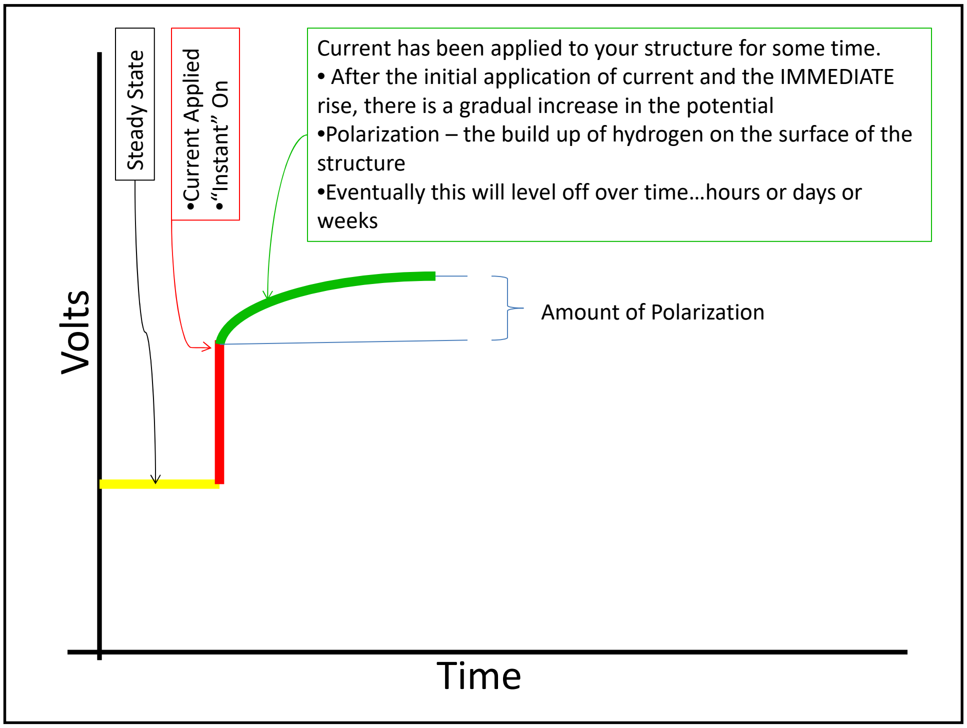


Now…the Steady State is changed by adding CP current to the structure

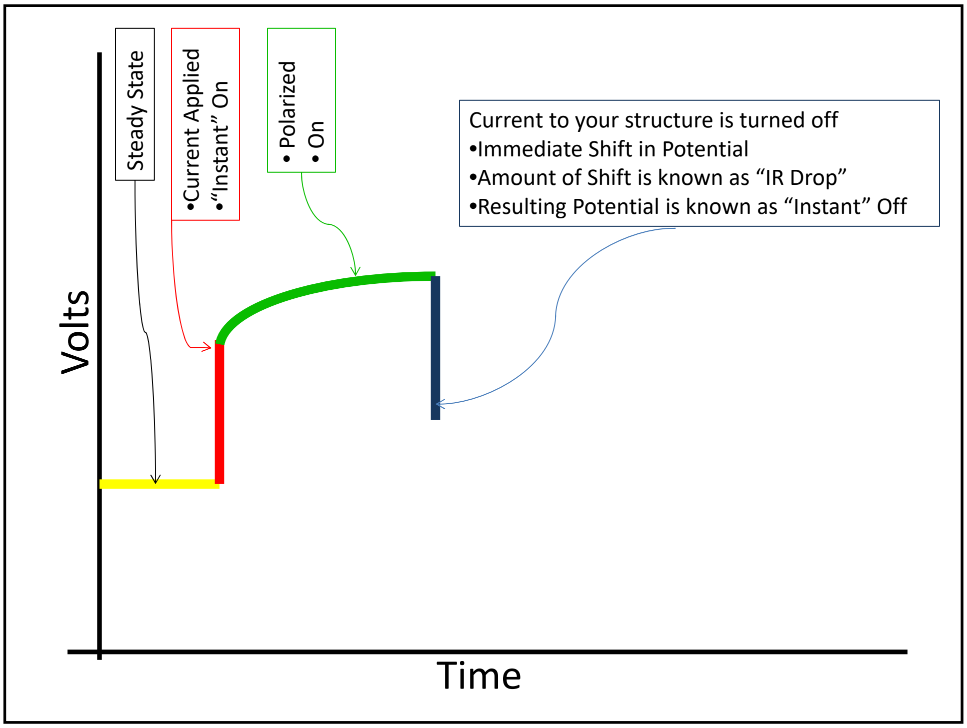
- Could be adding more to an existing system
- Could be applying CP for the first time
- Could be someone else's current getting on to your system

We See an IMMEDIATE jump more negative

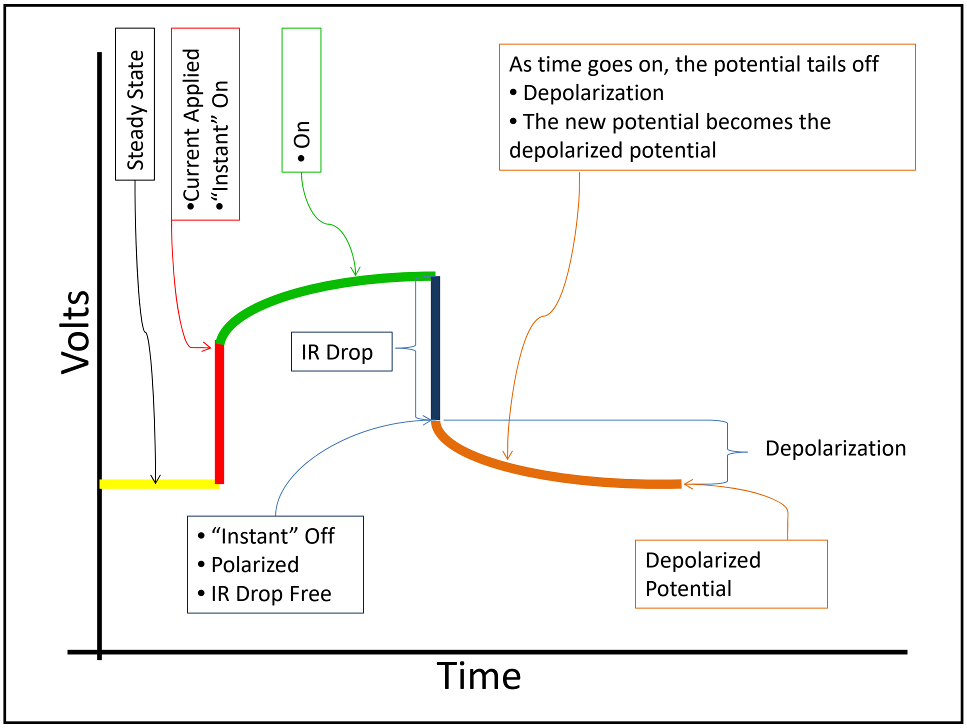
- Current Applied
- "Instant" On



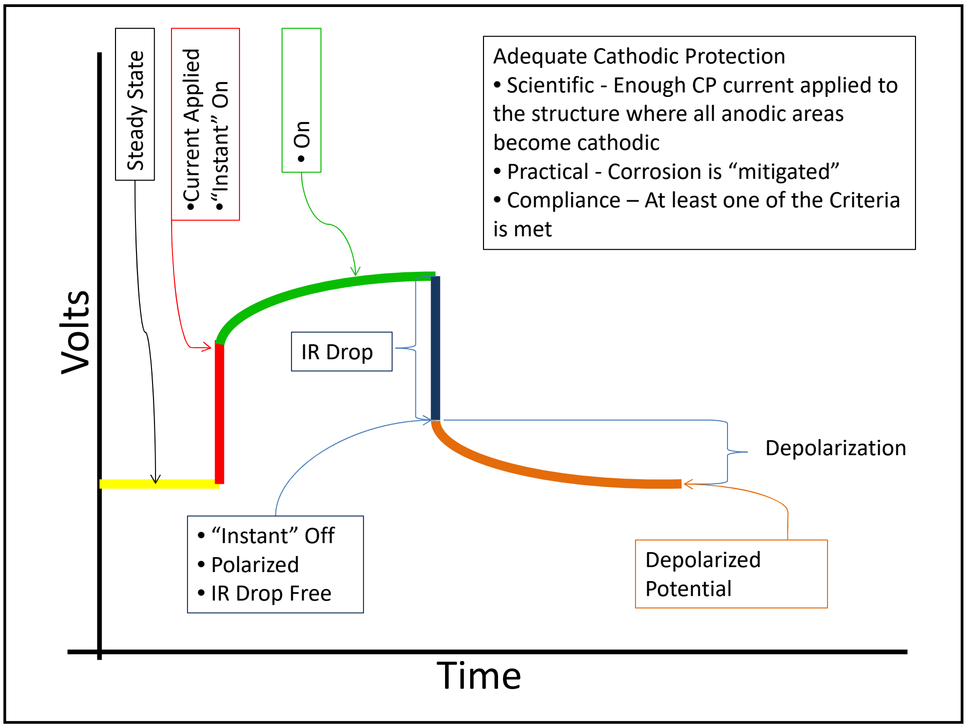
Current has been applied to your structure for some time.
- After the initial application of current and the IMMEDIATE rise, there is a gradual increase in the potential
- Polarization – the build up of hydrogen on the surface of the structure
- Eventually this will level off over time…hours or days or weeks



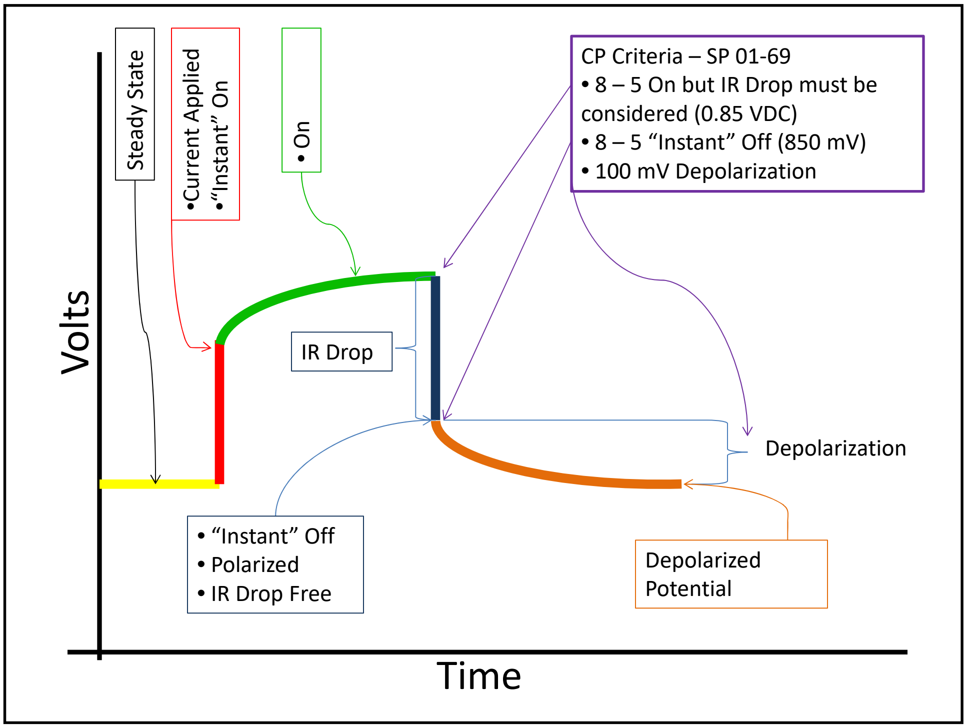
Current to your structure is turned off
- Immediate Shift in Potential
- Amount of Shift is known as "IR Drop"
- Resulting Potential is known as "Instant" Off



As time goes on, the potential tails off
- Depolarization
- The new potential becomes the depolarized potential



Adequate Cathodic Protection
- Scientific - Enough CP current applied to the structure where all anodic areas become cathodic
- Practical - Corrosion is "mitigated"
- Compliance – At least one of the Criteria is met



Steady State

- Current Applied
- "Instant" On

- On

CP Criteria – SP 01-69
- 8 – 5 On but IR Drop must be considered (0.85 VDC)
- 8 – 5 "Instant" Off (850 mV)
- 100 mV Depolarization

IR Drop

Depolarization

- "Instant" Off
- Polarized
- IR Drop Free

Depolarized Potential