



**REX2024**  
PRCI Research Exchange

# PRCI Project EC-08-11: Pipeline Cathodic Protection Monitoring Using Real Time Current Measurement

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Pipeline Research Council International

# PRCI EC-08-11 Overview – Scope & Objectives

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## 1) Extensive field-based research to marry well-established manual pipe current measurements with high-resolution remote monitoring technology:

- What is the optimum (maximum) interval(s) for pipe current sensor remote monitoring units (RMUs)?
- What are the pipe current monitoring requirements – Instrumentation? Data capture? Analytics?

## 2) Ultimately:

- Practical guidance to industry on implementation of real-time pipe current monitoring
- Improved pipeline corrosion protection surveillance and overall pipeline reliability/safety
- Faster detection and resolution of corrosion control threats
- Cost effective enhancement to overall *Integrated External Corrosion Management* (IECM) program
- Reduction if not elimination of traditional periodic rectifier checks and annual test station surveys
- Reduced O&M and regulatory compliance costs

## 3) Deliverables:

- Research report
- Guide manual
- Excel-based life-cycle cost calculator and user's manual
- Industry outreach to share research results

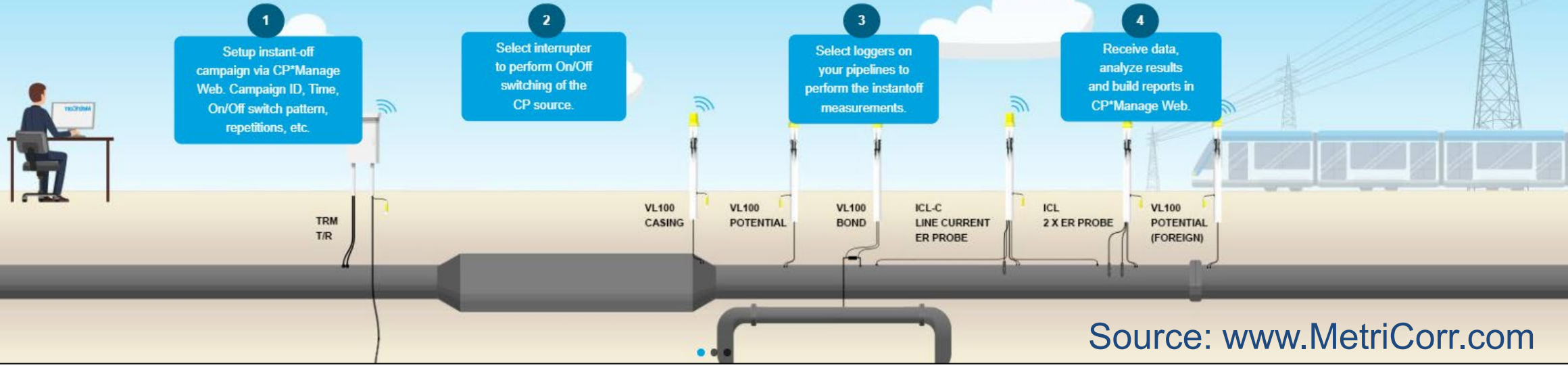
# The “Pipeline of Things”: 24/7/365 Real-Time Surveillance

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- ✓ Can cost-effective remote monitoring reduce/replace periodic rectifier checks and annual CP test station surveys?
- ✓ Can it reduce or even replace close interval surveys?
- ✓ Will regulatory agencies such as PHMSA accept this alternative??

## Get Your CP Survey Done in Minutes!

- ✓ T/R Performance ✓ Coating Condition ✓ Line Currents
- ✓ Critical Bonds ✓ Polarized Potentials
- ✓ Corrosion Rates (ER) ✓ AC/DC Interference





# Research Report: Real-Time Pipe Current Monitoring

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Catalog No. R-229-203604-R01

## Pipeline CP Monitoring Using Real Time Current Measurement

Project number EC-08-11

Contract PR229-203604

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# Guide Manual for Real-Time Pipe Current Monitoring

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# Life-Cycle Cost Calculator for Remote Monitoring Program

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PIPELINE/PROJECT NAME:						EXISTING OR PLANNED:		Planned	LENGTH (Miles):	100
PREPARED BY:						DATE PREPARED:				
TOTAL NO. OF PIPELINE RMUs:			12	NO. OF TEST STATIONS:			100	NO. OF CP CURRENT SOURCES:		4
REF. NO.	DESCRIPTION	QUANTITY	UNIT COSTS				EXTENDED COSTS			
			Material/ Equipment	Installation	Engineering /Start- Up/Other	Total Unit Cost	Material/Equi pment	Installation	Engineering/\$ tart- Up/Other	Total Extended Cost
1) RMU INITIAL COSTS - Equipment & Installation										
1	RMU Type 1 - AC/DC Line Current/Potential/Corrosion Probe	12	\$ 5,000	\$ 2,000	\$ 500	\$ 7,500	\$ 60,000	\$ 24,000	\$ 6,000	\$ 90,000
2	RMU Type 2 - AC/DC Potential/Current Density/Corrosion Probe					\$ -	\$ -	\$ -	\$ -	\$ -
3	RMU Type 3 - AC/DC Potential/Current Density					\$ -	\$ -	\$ -	\$ -	\$ -
4	RMU Type 4 - AC/DC Potential					\$ -	\$ -	\$ -	\$ -	\$ -
5						\$ -	\$ -	\$ -	\$ -	\$ -
6						\$ -	\$ -	\$ -	\$ -	\$ -
7						\$ -	\$ -	\$ -	\$ -	\$ -
8						\$ -	\$ -	\$ -	\$ -	\$ -
9						\$ -	\$ -	\$ -	\$ -	\$ -
1) SUBTOTAL - RMU INITIAL COSTS:			12	--	--	--	\$ 60,000	\$ 24,000	\$ 6,000	\$ 90,000
2) OTHER INITIAL COSTS										
10	RMU Design	1	--	--	\$ 8,000	\$ 8,000	--	--	\$ 8,000	\$ 8,000
11	Prepaid Subscription/Connectivity Charge (1st year)	12	--	--	\$ 120	\$ 120	--	--	\$ 1,440	\$ 1,440
12			--	--		\$ -	--	--		
13			--	--		\$ -	--	--		
14			--	--		\$ -	--	--		
15			--	--		\$ -	--	--		
16			--	--		\$ -	--	--	\$ -	\$ -
2) SUBTOTAL - OTHER INITIAL COSTS:									\$ 9,440	\$ 9,440
3) INITIAL COST SAVINGS (mainly applicable for new pipeline construction)										
17	Elimination of "standard" test stations	30	200	200	100	\$ 500	\$ (6,000)	\$ (6,000)	\$ (3,000)	\$ (15,000)
18	Elimination of "typical" output voltage/current RMUs at CP current sources	4	2500	200	100	\$ 2,800	\$ (10,000)	\$ (800)	\$ (400)	\$ (11,200)
19						\$ -	\$ -	\$ -	\$ -	\$ -
20						\$ -	\$ -	\$ -	\$ -	\$ -
21						\$ -	\$ -	\$ -	\$ -	\$ -
22						\$ -	\$ -	\$ -	\$ -	\$ -
23						\$ -	\$ -	\$ -	\$ -	\$ -
3) SUBTOTAL - INITIAL COST SAVINGS:										\$ (26,200)
4) TOTAL INITIAL COSTS - RMUs										\$ 73,240
Average Initial Cost Per RMU										\$ 6,103
Average Initial RMU Cost Per Pipeline Mile										\$ 732

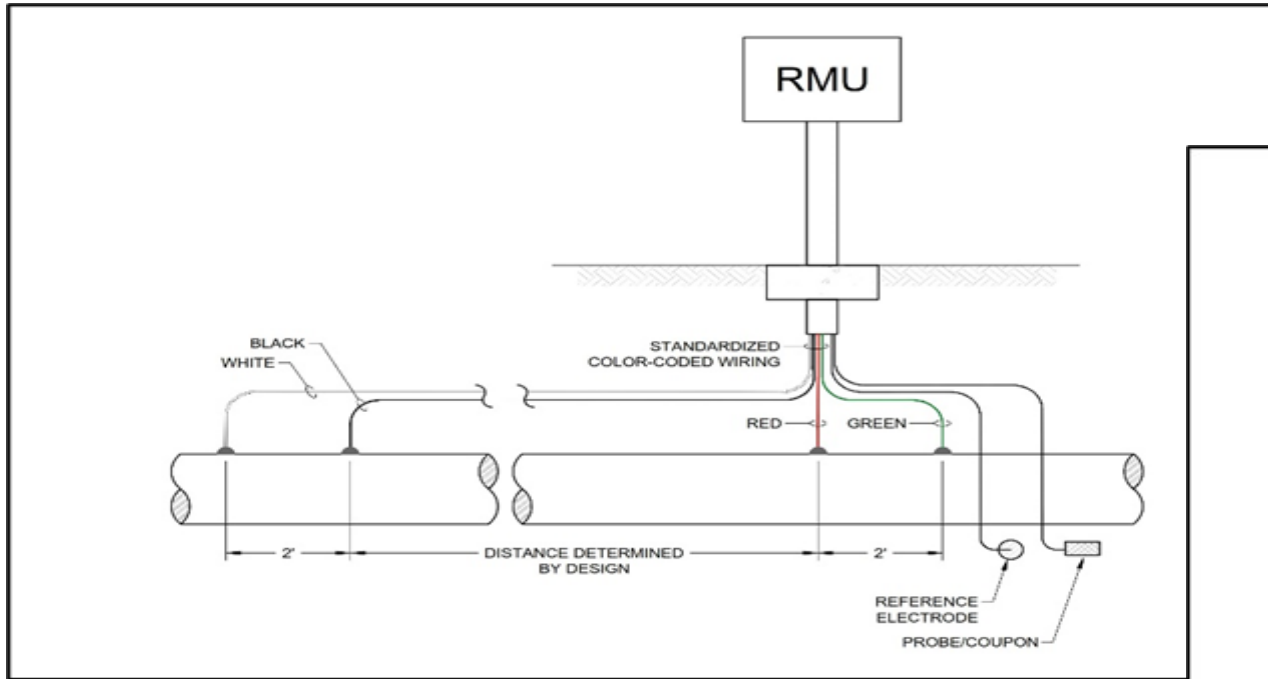
Pipeline/Project Name			
Prepared By			
Date Prepared	01/00/00	--	--
Existing or Planned Pipeline	Planned	--	--
Length (Miles)	100	--	--
Total No. of Pipeline RMUs	12	--	--
No. of Test Stations	100	--	--
No. of CP Current Sources	4	--	--
Annual Interest Rate (%)	3%	--	--
Economic Life (Years)	30	--	--
DESCRIPTION	TOTAL PRESENT VALUE	PRESENT VALUE PER RMU	PRESENT VALUE PER PIPELINE MILE
RMU Initial Cost	\$ 73,240	\$ 6,103	\$ 732
RMU Total Life-Cycle Cost (Initial & O&M)	\$ 187,460	\$ 15,620	\$ 1,875
Annualized RMU O&M Cost (per year)	\$ 3,807	\$ 317	\$ 38
Traditional CP Monitoring Life-Cycle Cost	\$ 418,774	--	\$ 4,188
Annualized Traditional CP Monitoring Costs (per year)	\$ 13,959	--	\$ 140
Payback Period - RMUs vs. Traditional CP Monitoring	5.2 Years		
"Return on Investment" - RMUs vs. Traditional CP Monitoring	123%		
Cost Avoidance - Total Life-Cycle Cost	\$ 756,897	--	\$ 7,569
Annualized Cost Avoidance (per year)	\$ 25,230	--	\$ 252
Payback Period - RMUs vs. Avoidance Cost	2.9 Years		
"Return on Investment" - RMUs vs. Cost Avoidance	304%		

**INPUT:**  
RMUs, CP monitoring, "avoidance costs"

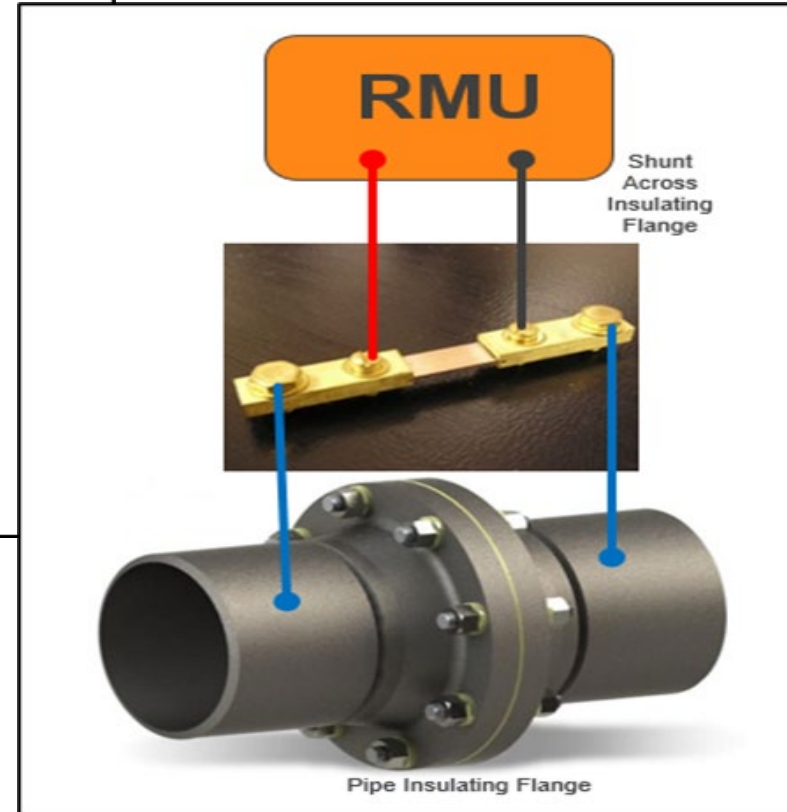
**OUTPUT:** Present Value \$, RMU payback period, RMU return on investment (ROI)

# How does one measure/monitor pipe current?

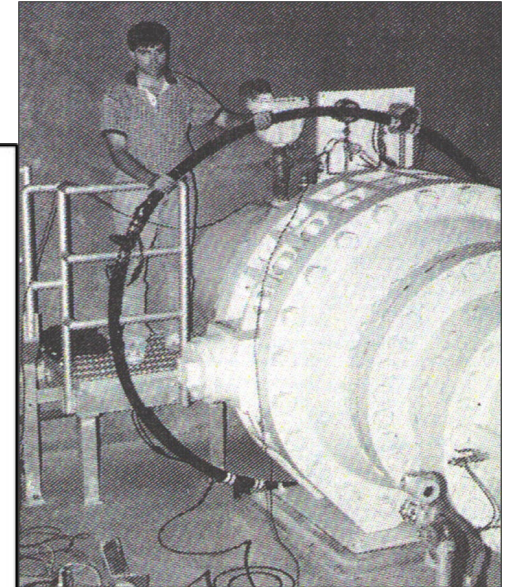
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Pipe Current Span  
(typically 100+ feet)



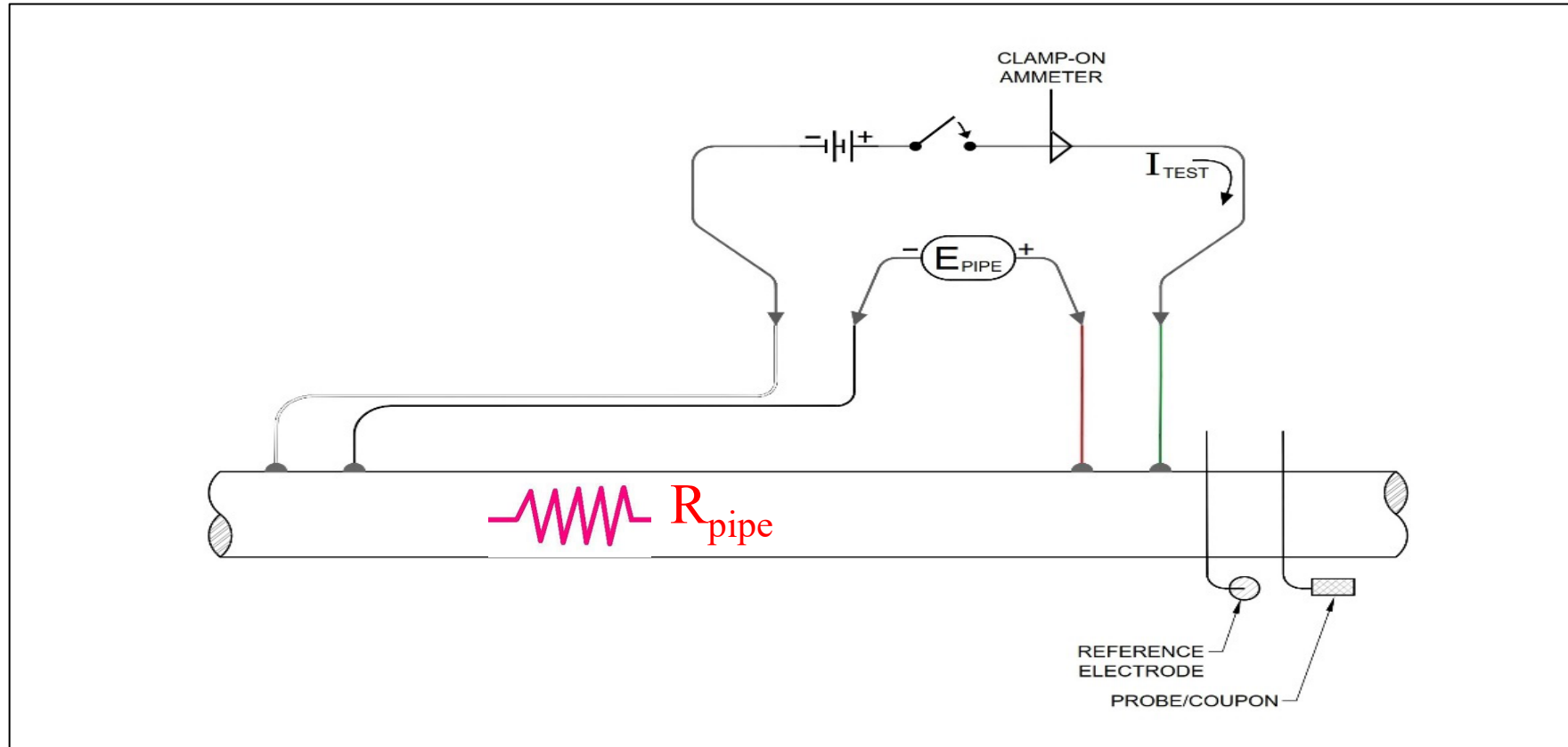
Calibrated Current  
Shunt in Bond Cable



Clamp-On Ammeter  
Around Pipe or  
Bond Cable

# Pipe Current Span Resistance Measurements (Ohm's Law)

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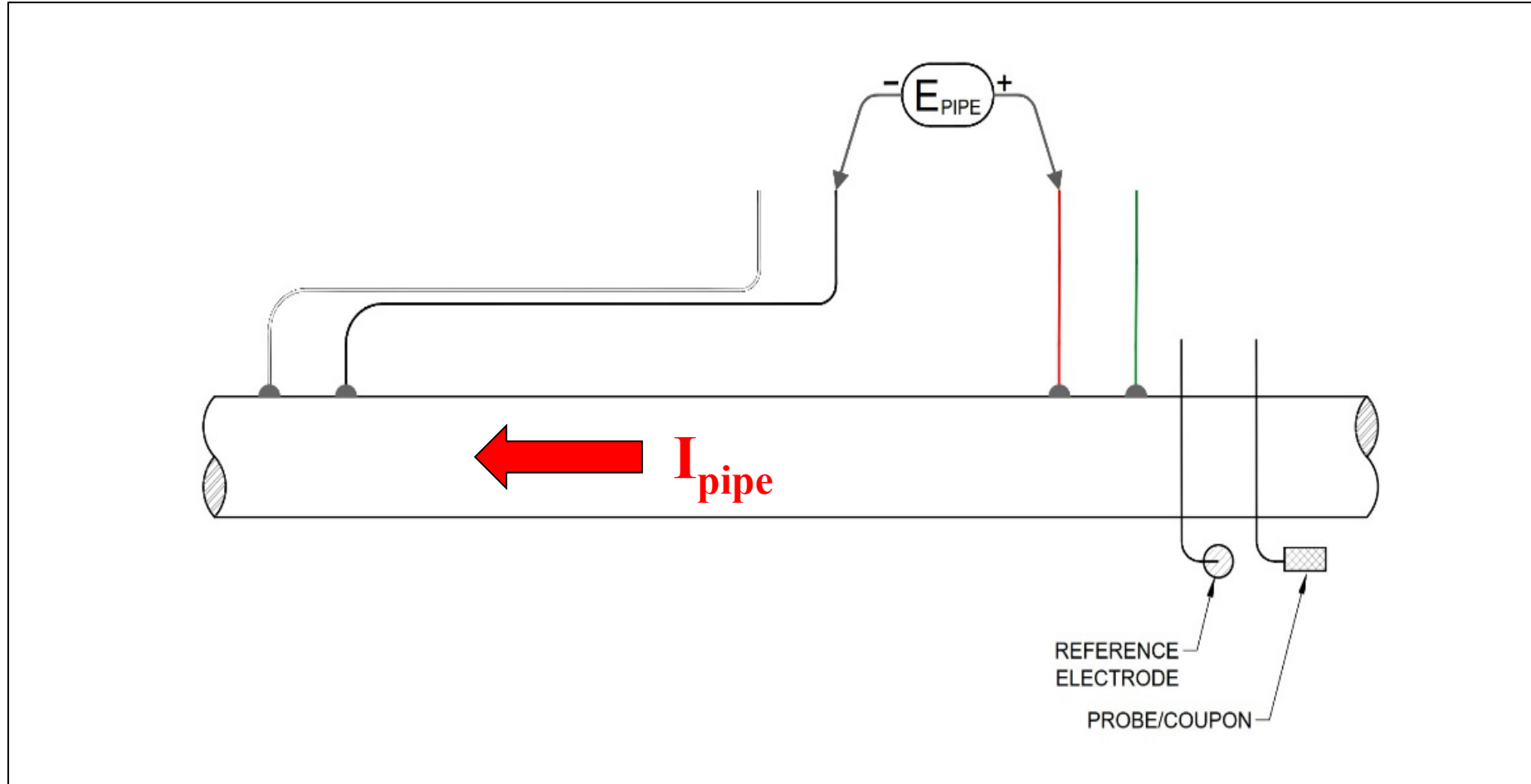
$$R_{\text{pipe}} \text{ (milliohm)} = [E_{\text{pipe-on}} \text{ (mV)} - E_{\text{pipe-off}} \text{ (mV)}] / I_{\text{test}} \text{ (A)}$$

$$C_f \text{ (A/mV)} = 1 / R_{\text{pipe}}$$



# Pipe Span Voltage Converted to Line Current (Ohm's Law)

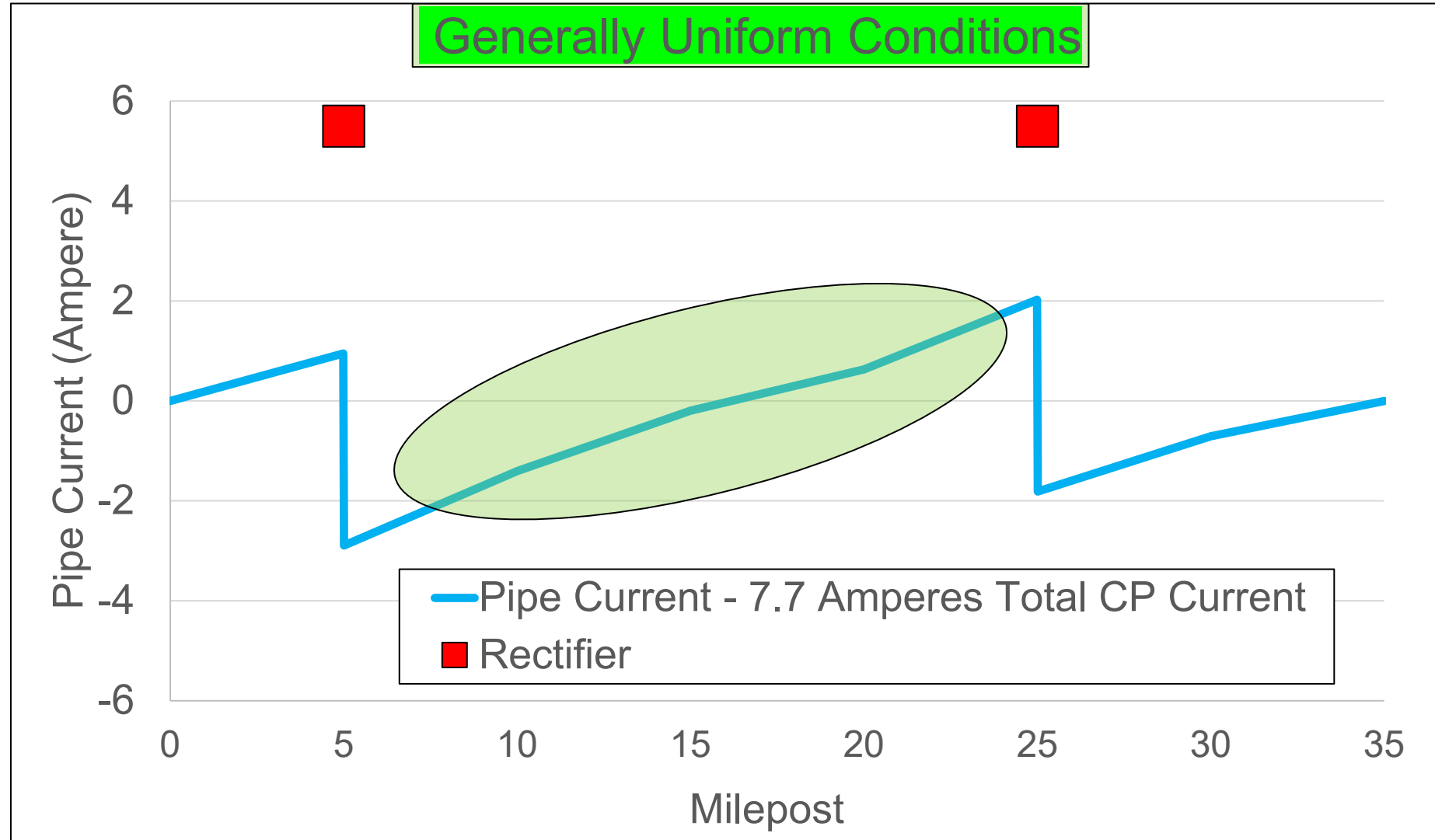
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$$I_{\text{pipe}} \text{ (A)} = E_{\text{pipe}} \text{ (mV)} \times C_f \text{ (A/mV)}$$

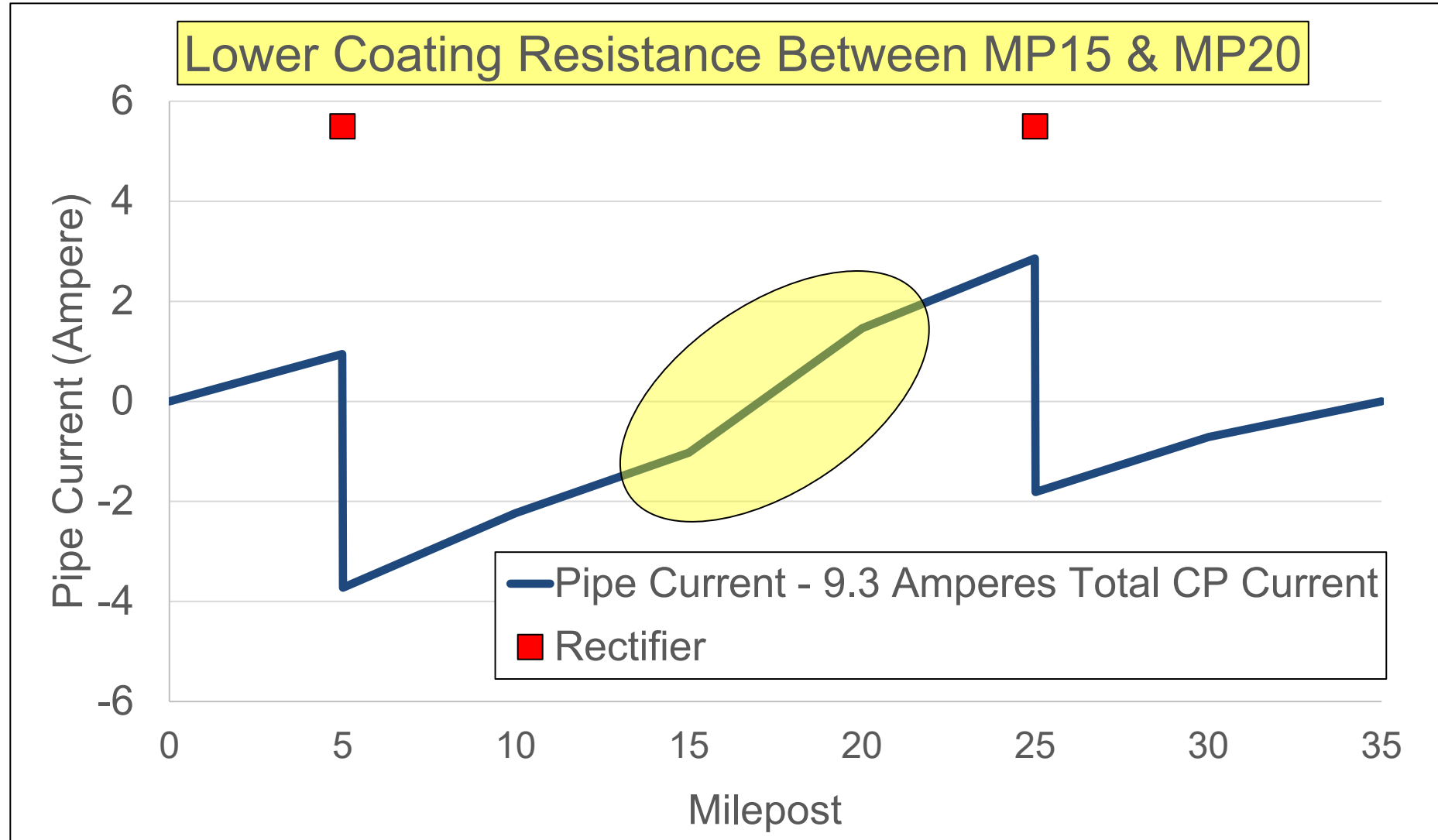
# Cathodic Protection Current Distribution (1 of 3)

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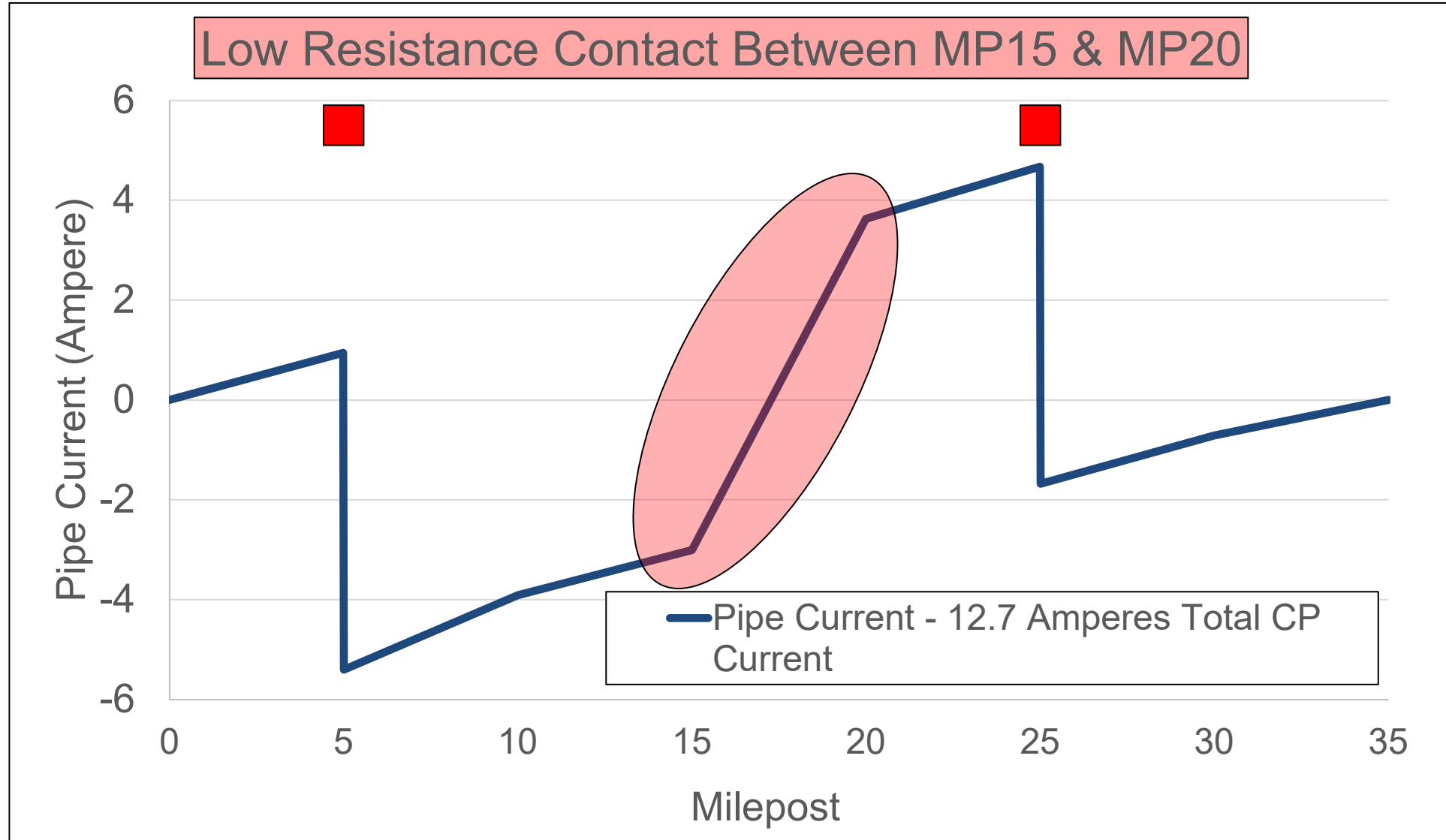


# Cathodic Protection Current Distribution (2 of 3)

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# Cathodic Protection Current Distribution (3 of 3)

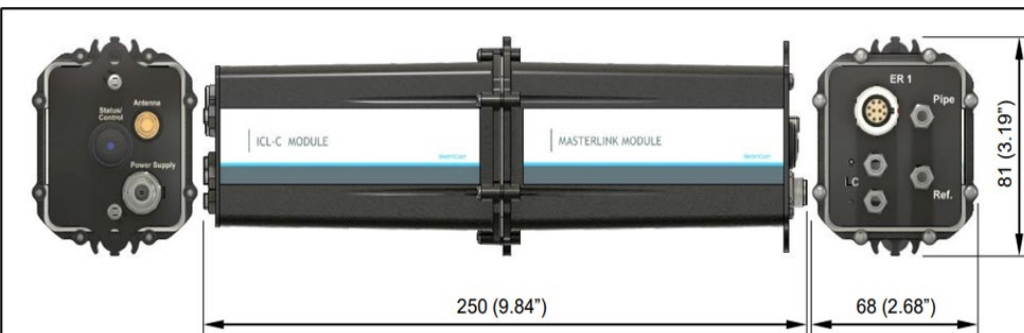




## Extensive Field-Based Research – 6 pipelines, 253 miles

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- 6 pipelines, 253 miles total, assorted coating quality and pipe-to-earth resistance
- 72 temporary pipe current/potential RMU locations across the 6 pipelines – average spacing = 3.3 miles, maximum = 13.5 miles
  - Precision RMU used with 0.1 microvolt resolution (1-3 mA pipe current resolution)
  - Data sampling rate = 1 measurement set (pipe potential & current) every 10 minutes
- 74 total simulated upset conditions



Pipeline No.	State	Coating	Diameter (Inch)	Evaluation Section - From Milepost	Evaluation Section - To Milepost	Evaluation Length (Miles)	Cathodic Protection Current Demand Per Mile (A/Mile)	Average CP Current Density (μA/Sq.Ft)
1	OK	FBE	16	29.8	72.4	42.6	0.12	6
2	PA	FBE	12	0.1	31.1	31.0	0.08	5
3	TX, LA	X-Tru-Coat	12	121.2	181.0	59.8	1.0	61
4	LA	Coal Tar	22	83.8	126.1	42.3	1.7	56
5	TX	FBE	8	0.0	8.2	8.2	2.3*	207*
6	IL	FBE / Coal Tar	36/22	15.9	50.3	68.9	0.10	1
TOTAL						252.8	--	--

\* Pipeline 5 has multiple interconnects and bonds. CP current demand and current density values shown do not account for the interconnects & bonds, i.e. values for pipeline alone would be less than shown.

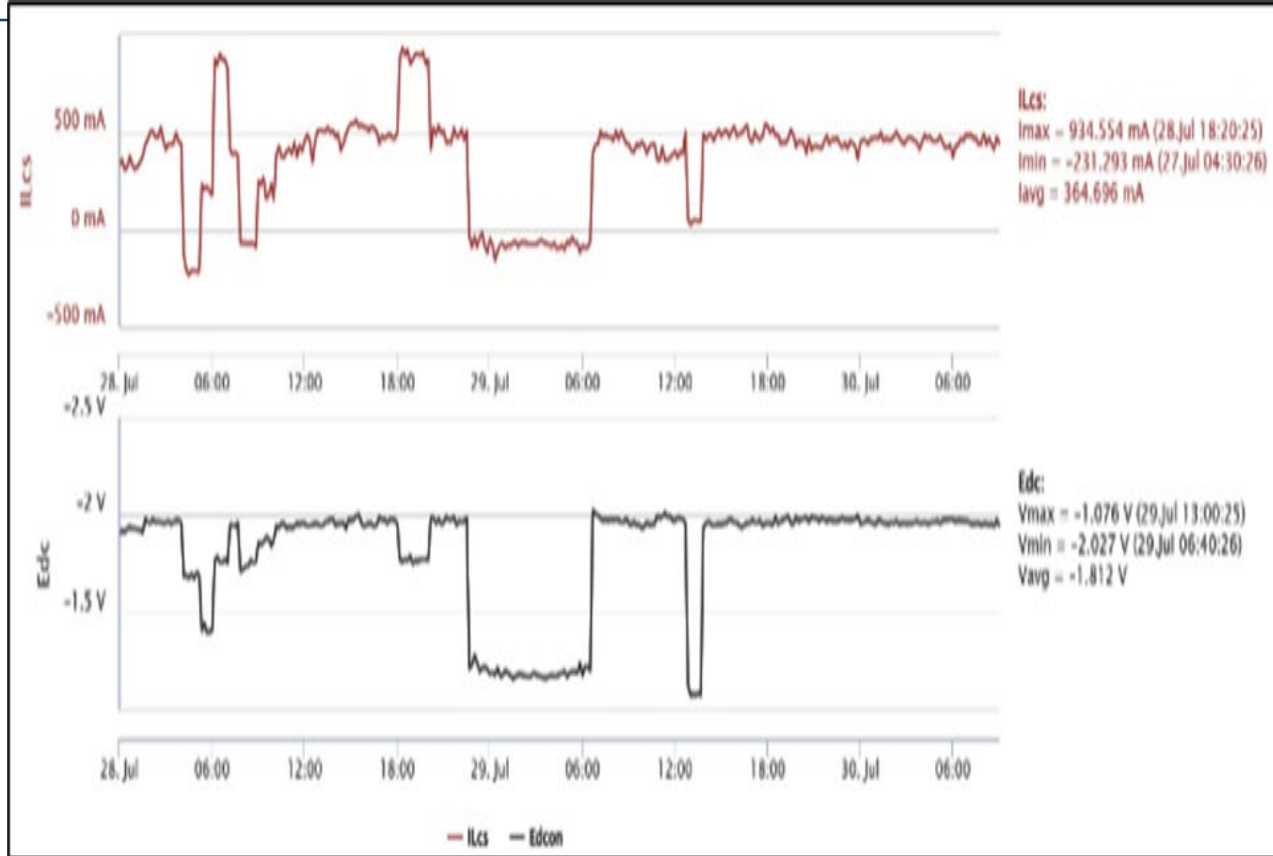
# Simulated Upset Conditions – 74 total

14

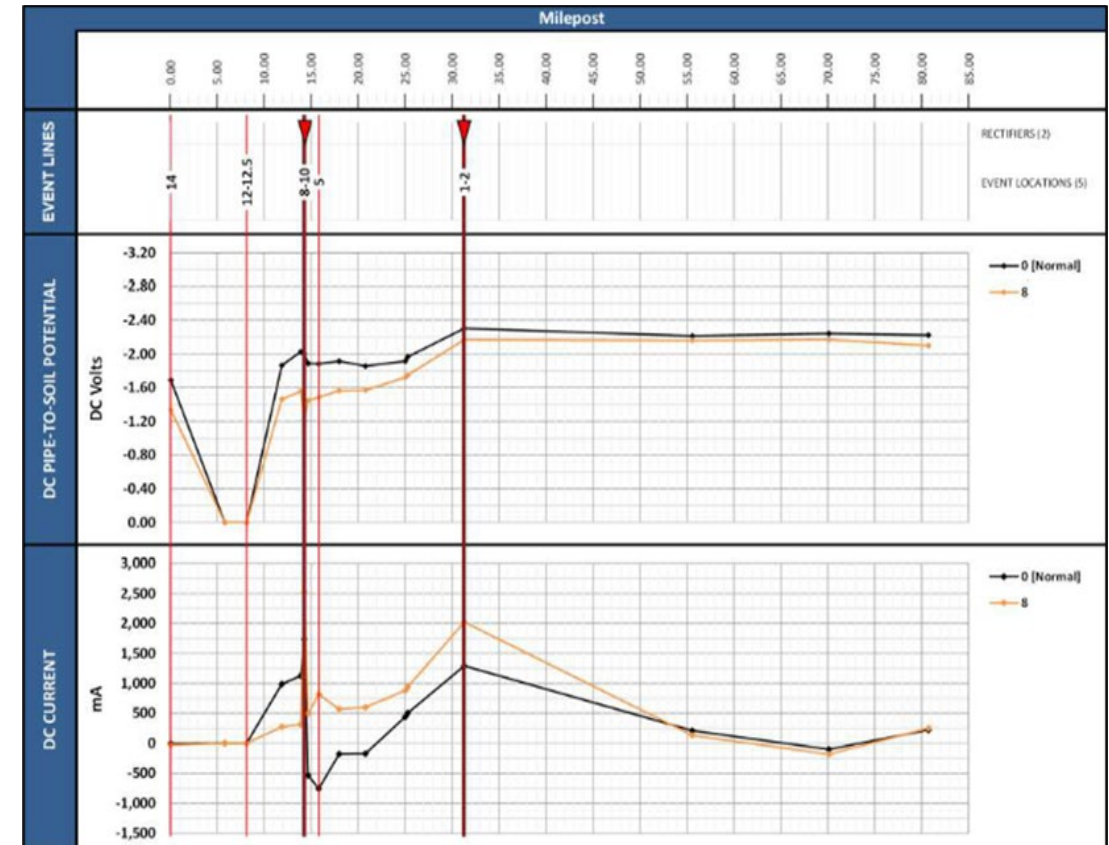
- 1) Interference from a nearby cathodic protection system
- 2) Temporarily shorting the pipe to electrical ground
- 3) Temporarily shorting the pipe to a casing
- 4) Localized coating damage, simulated by temporarily connecting the pipe to a probe rod driven into the ground a few feet
- 5) Loss of cathodic protection for a portion of the pipeline system
- 6) Temporarily turning off one or more cathodic protection rectifiers associated with the pipeline being evaluated, individually and together

# Representative Field Data and Results

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DC Pipe Current & Potential vs. Time – 3 days before, during, and after assorted simulations

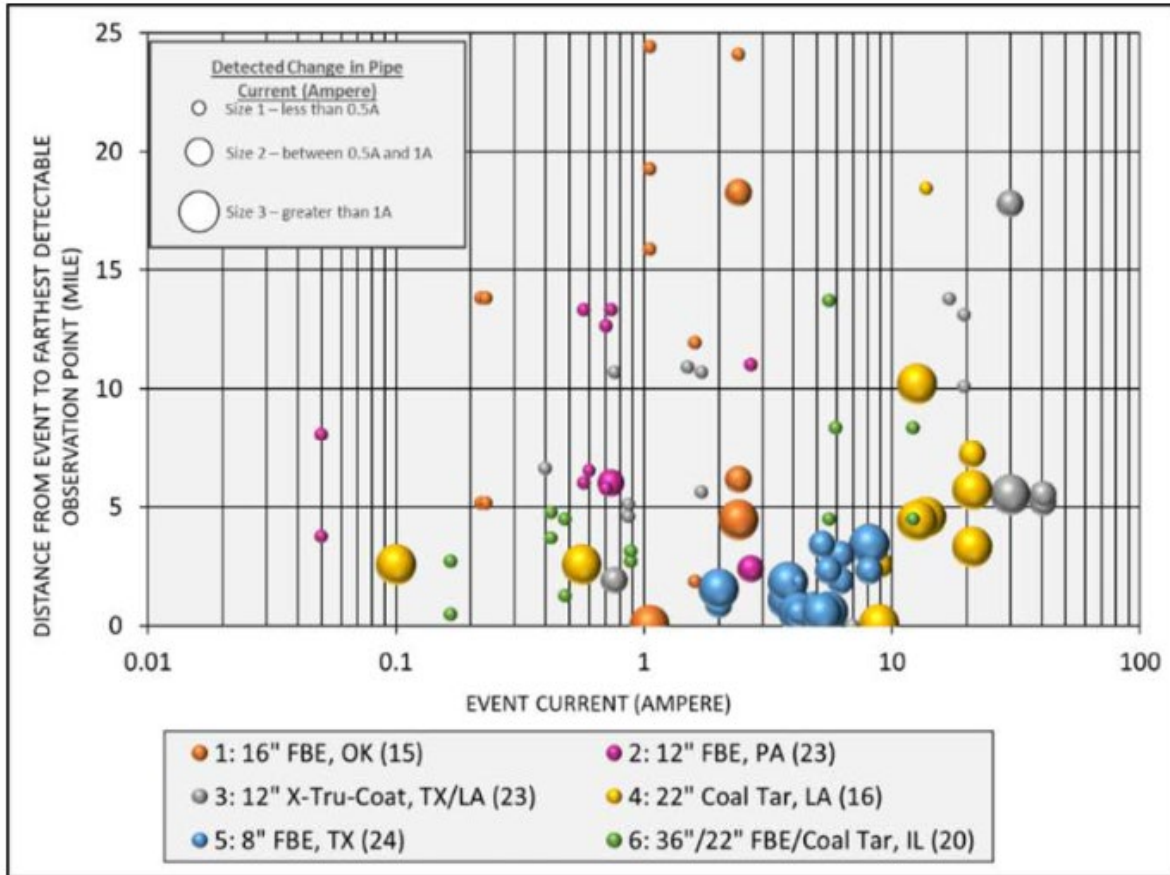


DC Pipe Current & Potential vs. Distance – 85 miles  
“Normal” vs. simulated event

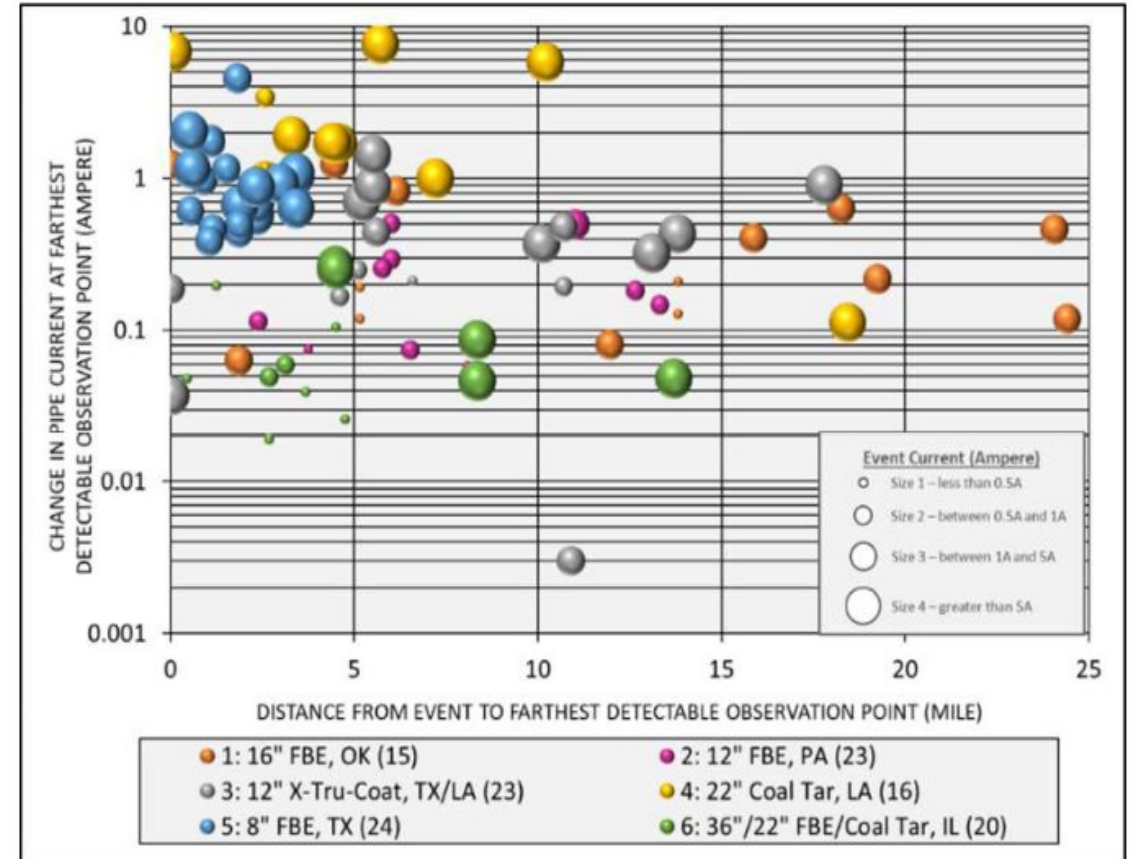
**\*Simulated event readily observed 15+ miles away\***

# Lots and lots of data to analyze!

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Observation distance (miles) vs. controlled event current (amperes)



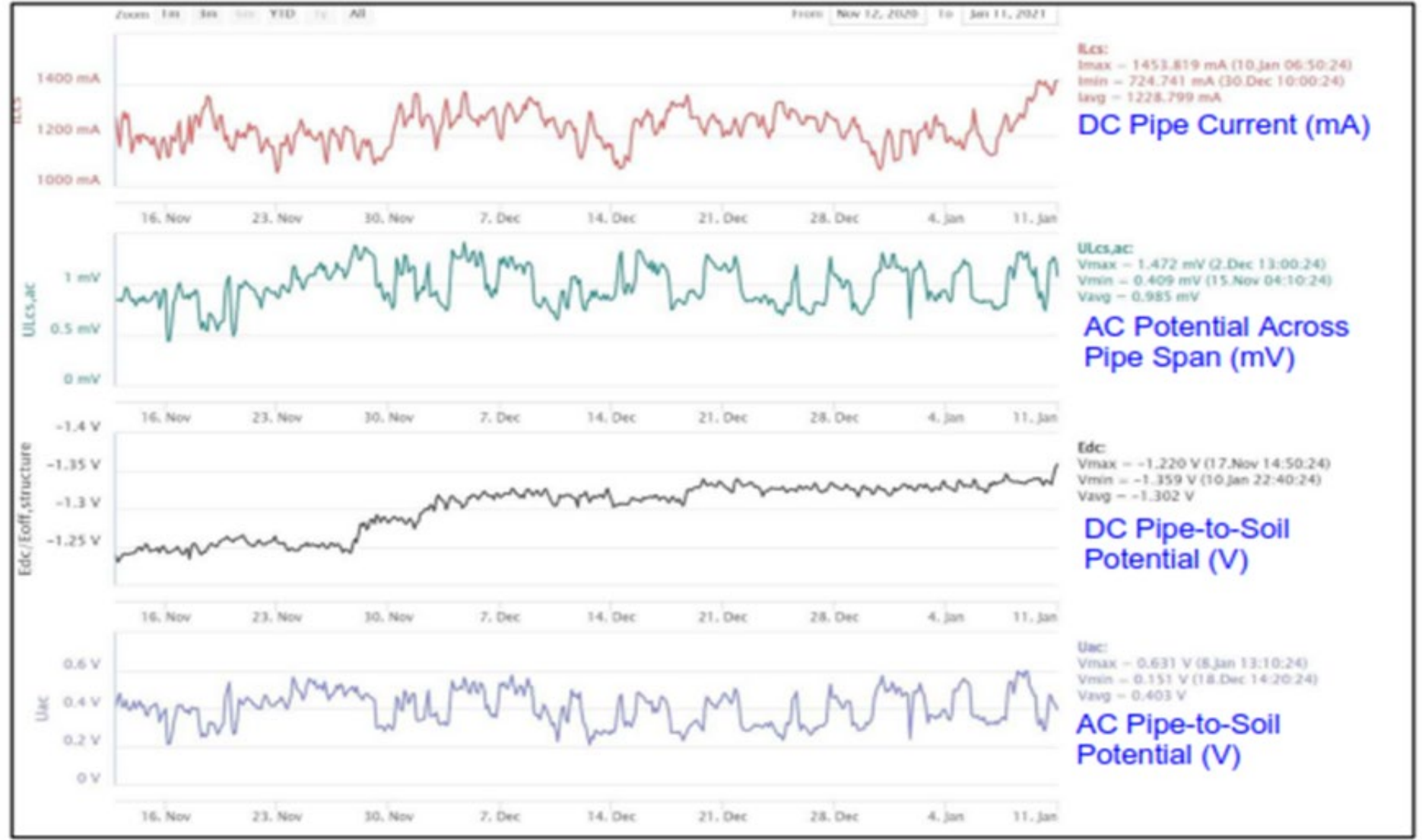
Pipe current change (amperes) vs. distance from controlled event (miles)



# “Normal” doesn’t necessarily mean “constant”

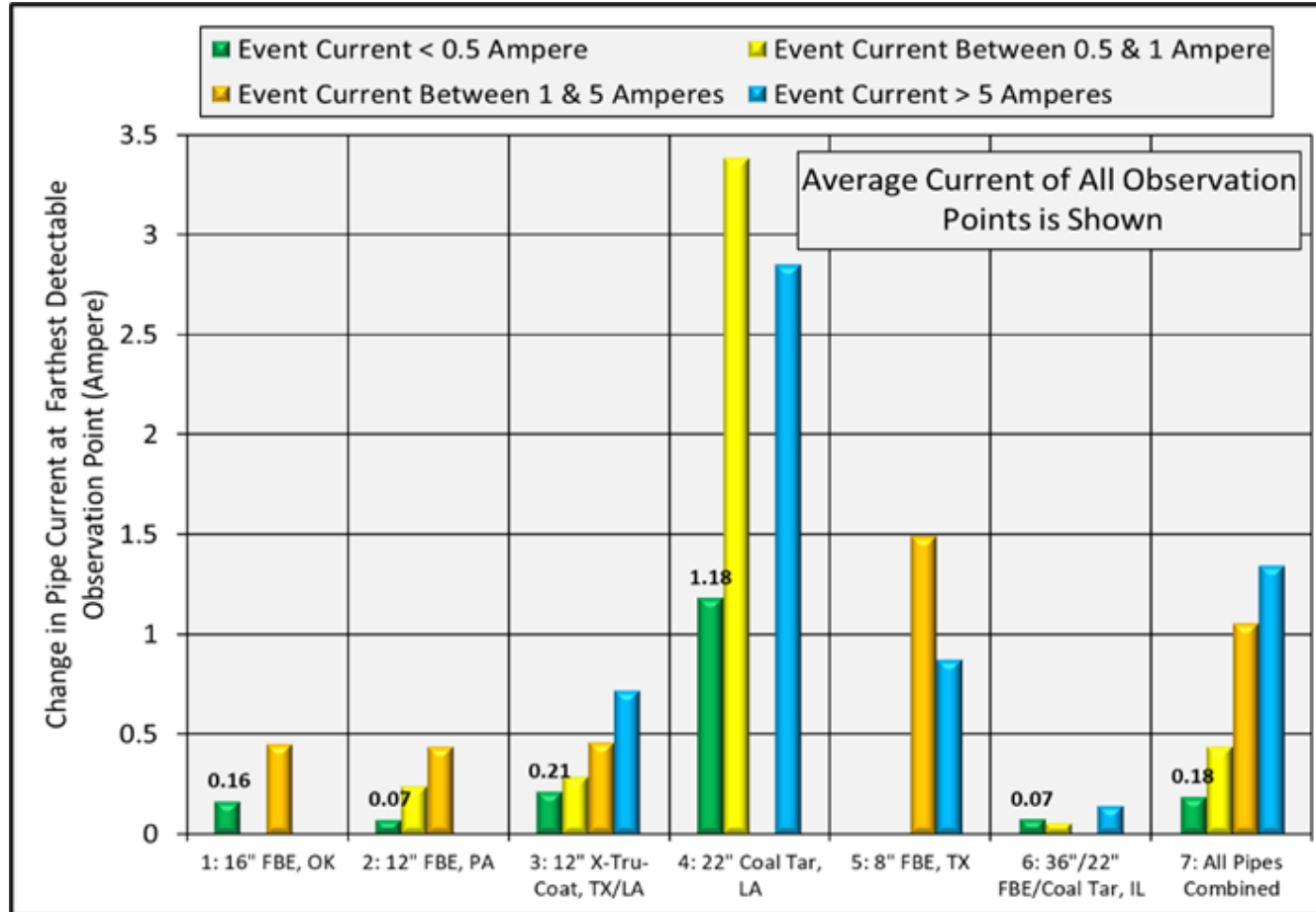
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2-month  
monitoring  
period

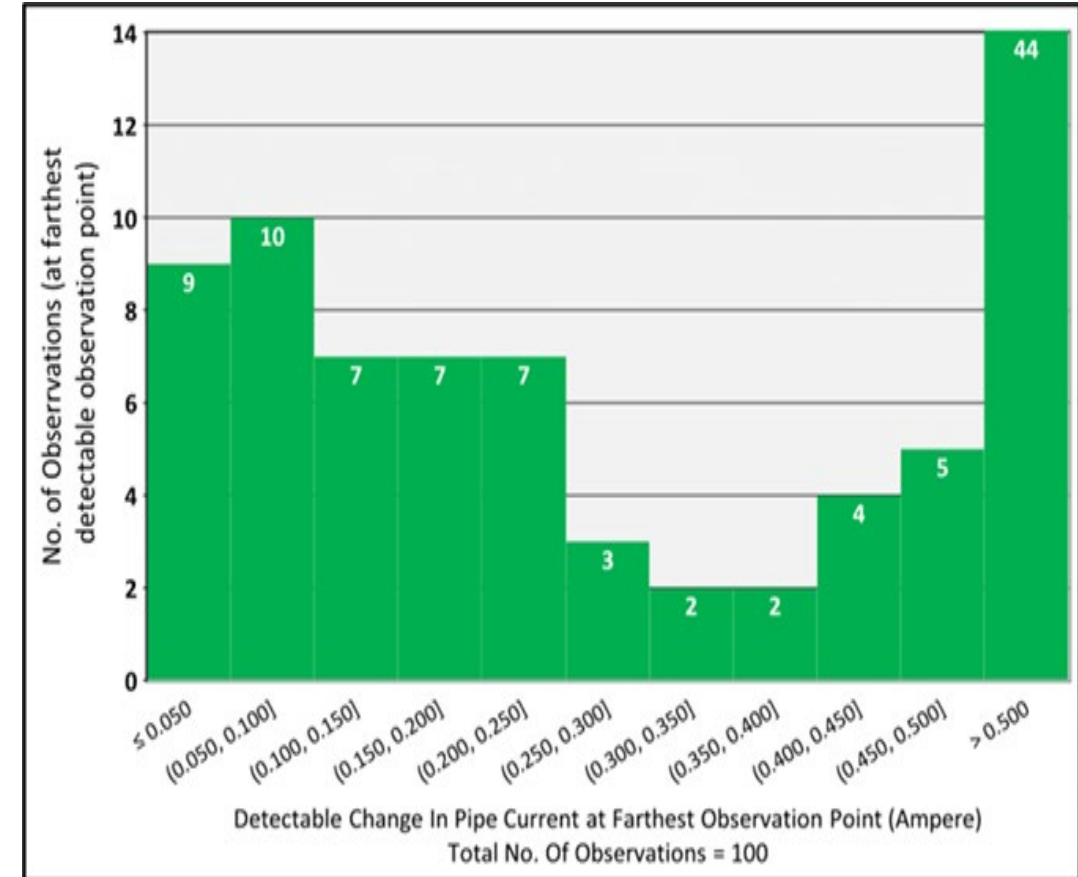


# Key Findings (1 of 2)

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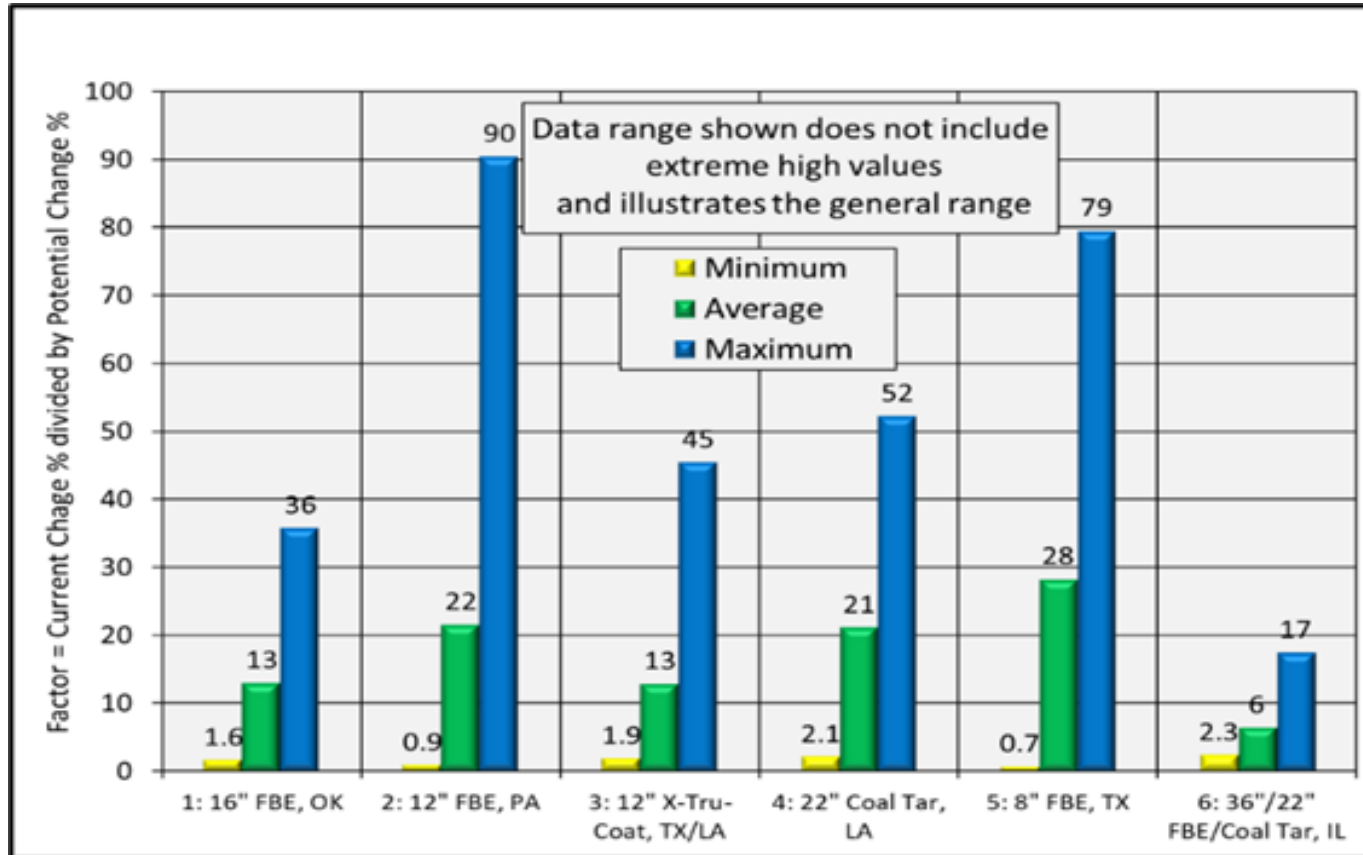
Detectable Change in Pipe Current miles away  
(average values)



Histogram  
Detectable Change in Pipe Current miles away  
(all pipelines combined)

# Key Findings (2 of 2)

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Pipe current monitoring is consistently more sensitive than pipe-to-soil potential at a given observation point

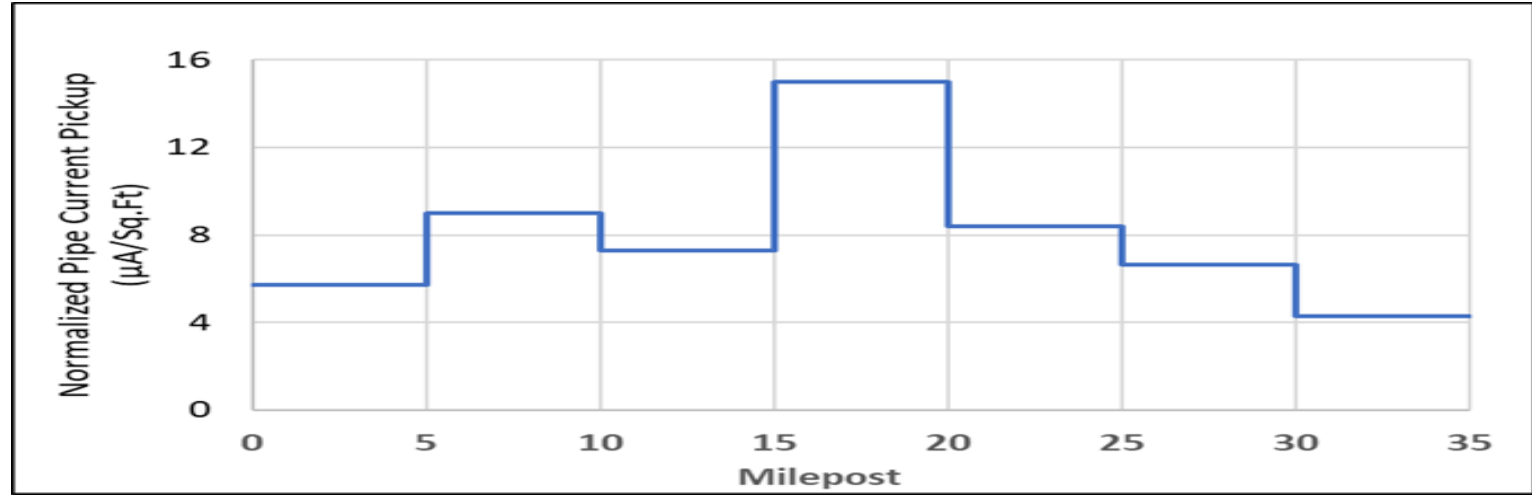
Nominal Interval Between Pipe Current Sensors to Detect < 0.5 Ampere Upset/Change	
High quality coating, electrically isolated	8-10 Miles, Possibly Further
Modest quality coating, electrically isolated	4-5 Miles
Poor quality coating, electrically grounded, and or multiple interconnects	2-3 Miles Maximum

General guidance on pipe current RMU spacing (pipeline-specific RMU plan should be tailor-made based on known and potential future corrosion risks, acknowledging dynamic conditions & changes over time, following guidelines in manual)

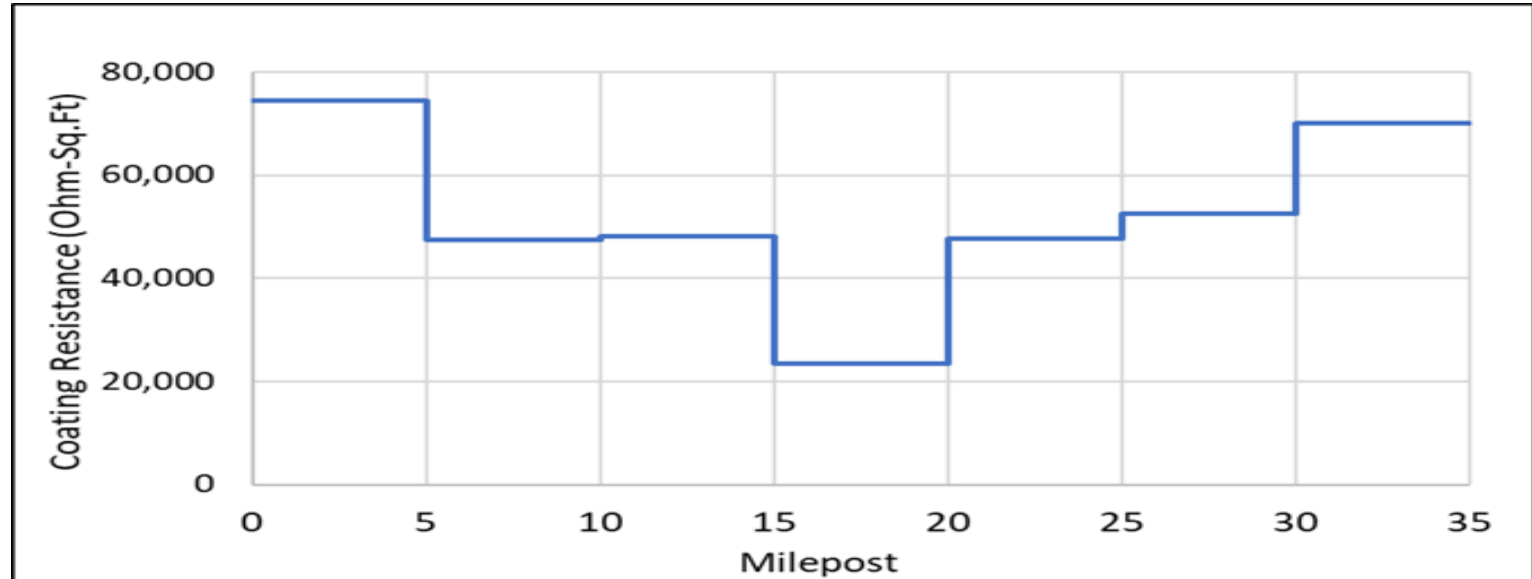
# Trending data over distance and time

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Normalized  
Pipe Current  
Pickup  
( $\mu\text{A}/\text{Sq.Ft.}$ )



Normalized Pipe  
Coating  
Resistance  
( $\text{Ohm}/\text{Sq.Ft.}$ )

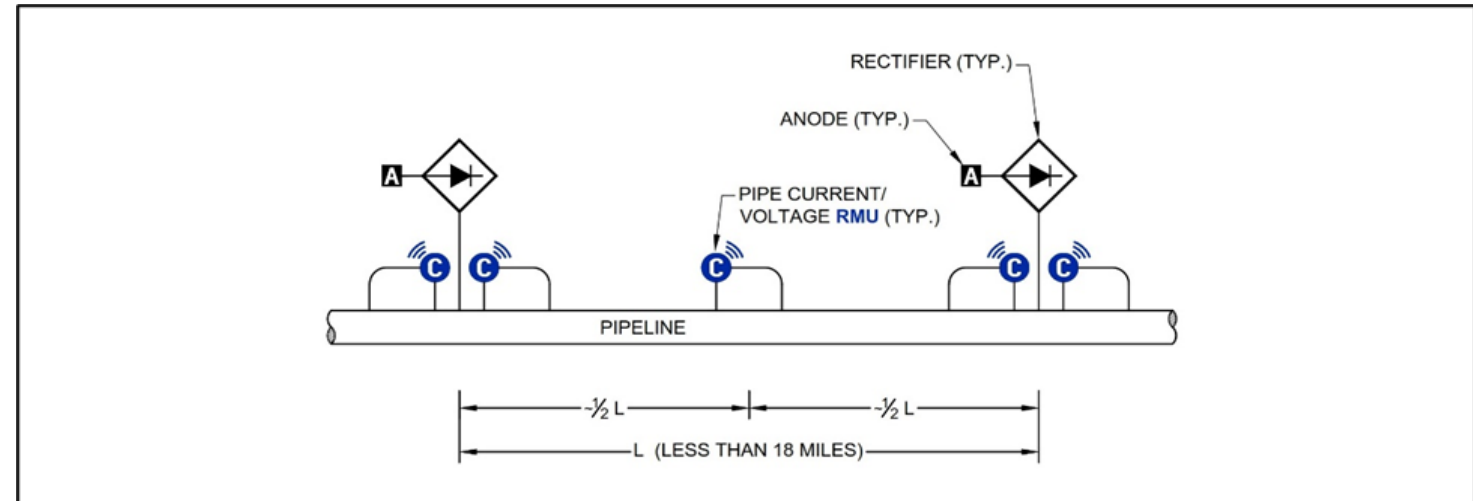




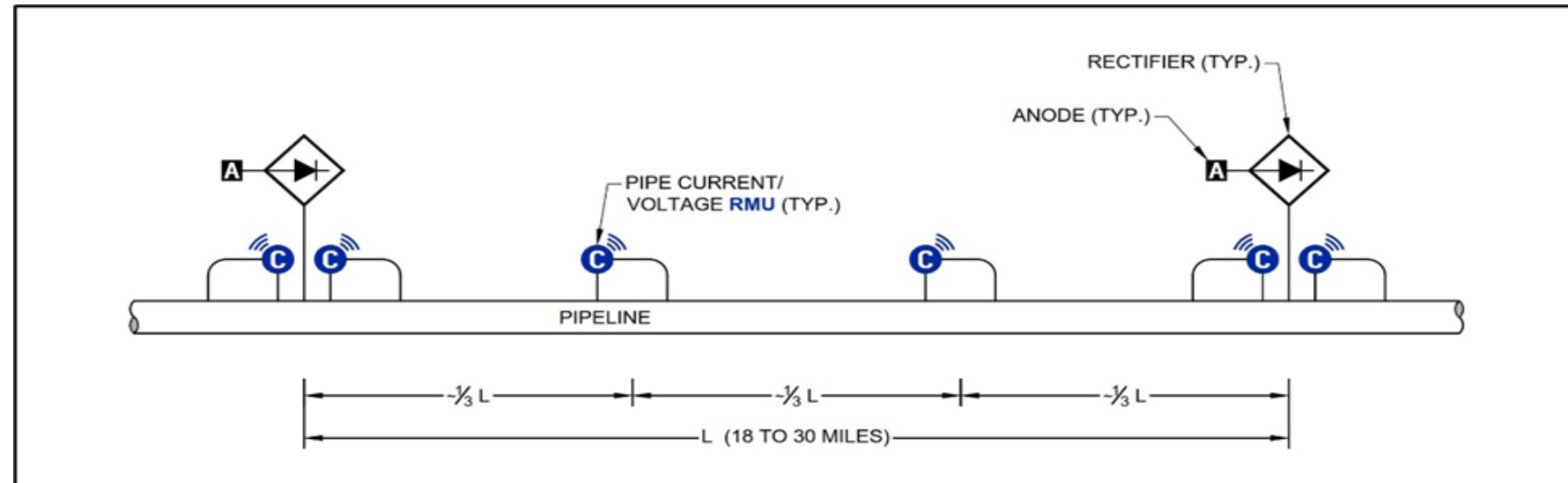
# Selecting Pipe Current RMU Locations

(minimum locations determined by CP current source “zones”)

Scenario #1: CP current sources <18 miles apart =  
**3** pipe current RMUs between sources



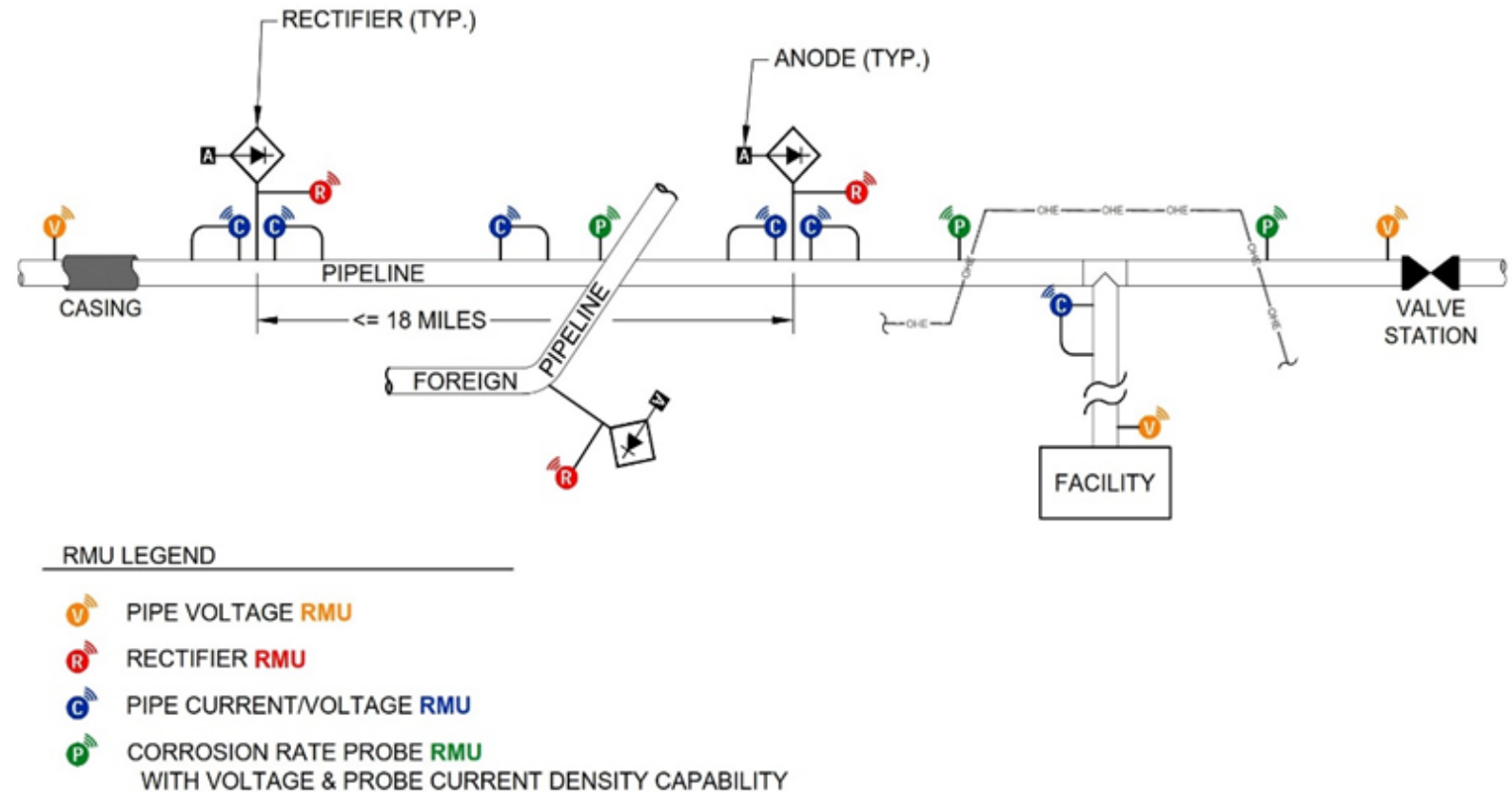
Scenario #2: CP current sources 18-30 miles apart =  
**4** pipe current RMUs between sources



# “The Smart Pipe”

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RMU/sensor type(s) and locations should be tailor-made based on known and potential future corrosion risks, acknowledging dynamic conditions & changes over time

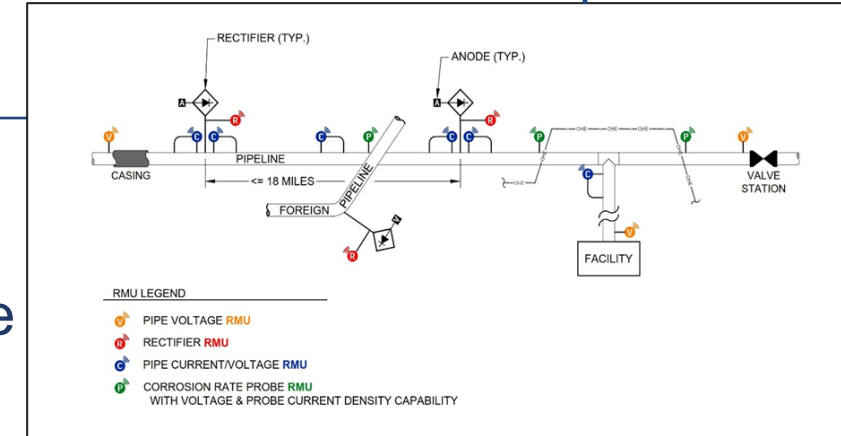


# Summary

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- 1) Continuous real-time pipe current measurements should be an integral part of a CP remote monitoring program
- 2) Small pipe currents and small changes in pipe current are readily detected with commercially available high-resolution instrumentation
- 3) Pipe current monitoring is more sensitive to upsets when compared to pipe-to-soil potential monitoring alone
- 4) Remote monitoring is cost effective and applicable to existing and new pipelines
- 5) Machine learning and artificial intelligence can enhance the smart pipe monitoring process

## “The Smart Pipe”



Thank you



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