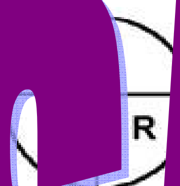
NACE

Reference to the Peabody Book
Peabody's CONTROL OF PIPELINE CORROSION, 2nd Edition
January 27th, 2007
Revision 1.0
US Standard Units

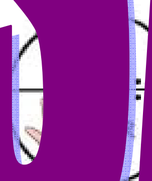
Ohm's Law

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



rrent (a
tance s
(v

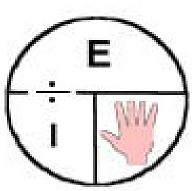
=	00 A	
	00 Ω	
	00 V	



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

e ( )
istance (ohms)
I = Current (amps)

E	=	1000.00 V
R	=	100.00 Ω
I	=	10.00 A



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

E = Voltage (volts)
I = Current (amps)
R = Resistance (ohms)

E	=	1000.00 V
I	=	10.00 A
R	=	100.00 Ω

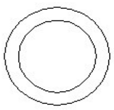
Area of a Circle

$$A = \pi R^2 = \pi\left(\frac{D}{2}\right)^2 = \frac{\pi D^2}{4}$$

D = Diameter of Circle (in)
R = Radius of Circle (in)
A = Area of Circle (in²)

D	=	10.00 in
R	=	5.00 in
A	=	78.54 in²

Area of Pipe Cross-Section



$$A = \pi R_O^2 - \pi R_I^2 = \pi\left(\frac{D_O}{2}\right)^2 \ldots$$

D_O ...ameter ... n)
D_I ...neter ...)
R ...ius o...
R ...eter ...)
A ...re... e C... (in²

		in
		in
		in
		4.88 in
		.88 in²

...ce Area of ... in...

$$S \quad 2 \quad = \ldots$$

D = D... f C...
L = Le... y...
... urf... ea...)

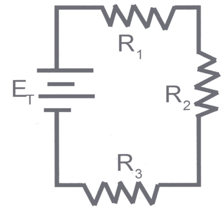
		10.00 in
	=	300.00 in
S	=	9424.78 in²
which is S	=	0.9425 ft²

Power		Actual Number	Abbrev.	Name
10^{-24}		0.000,000,000,000,000,000,000,000,1	y	yocto
10^{-21}		0.000,000,000,000,000,000,000,1	z	zepto
10^{-18}	1E-18	0.000,000,000,000,000,001	a	atto
10^{-15}	1E-15	0.000,000,000,000,001	f	femto
10^{-12}	1E-12	0.000,000,000,001	p	pico
10^{-9}	1E-9	0.000,000,001	n	nano
10^{-6}	1E-6	0.000,001	μ	micro
10^{-3}	1E-3	0.001	m	milli
10^{-2}	1E-2	0.01	c	centi
10^{-1}	1E-1	0.1	d	deci
10^{0}	1E0	1	---	---
10^{1}	1E1	10	D	deka
10^{2}	1E2	100	h or H	hecto
10^{3}	1E3	1,000	k or K	kilo
10^{6}	1E6	1,000,000	M	mega
10^{9}	1E9	1,000,000,000	G	giga
10^{12}	1E12	1,000,000,000,000	T	tera
10^{15}	1E15	1,000,000,000,000,000	P	peta
10^{18}	1E18	1,000,000,000,000,000,000	E	exa
10^{21}	1E21	1,000,000,000,000,000,000,000	Z	zeta

10^{21}	1E21	1,000,000,000,000,000,000,000	Z	zeta
10^{24}	1E24	1,000,000,000,000,000,000,000,000	Y	yotta

Series Circuit

$$R_T = R_1 + R_2 + R_3$$

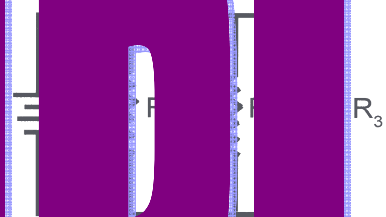


R_1 = Resistance of Resistor # 1 (ohms)
R_2 = Resistance of Resistor # 2 (ohms)
R_3 = Resistance of Resistor # 3 (ohms)
R_T = Total Resistance (ohms)

R_1	=	100.00 Ω
R_2	=	200.00 Ω
R_3	=	[illegible] Ω
R_T	=	[illegible] Ω

Parallel Circuit

$$R_T = \frac{1}{\frac{1}{R\ldots} + \ldots \frac{1}{R\ldots}}$$



... Re... of ... ohms
... esistance of ... ohms
... istance of ... ohms
R... Resista...

	=	...00.00 Ω
	=	...00.00 Ω
	=	[illegible] Ω
	=	[illegible] Ω

I ... R ... = ... R

...Volt...
...Cur...
...at...

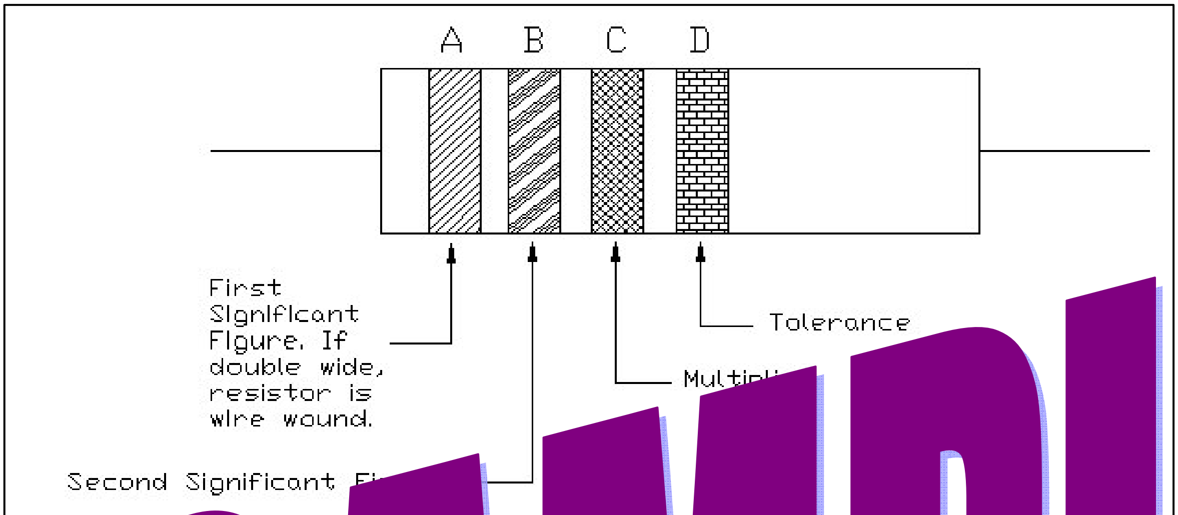
E	=	10.00 V
I	=	20.00 A
P	=	200.00 W

$- OR -$

I ... (amps)
R ...stance (ohms)
P = Power (watts)

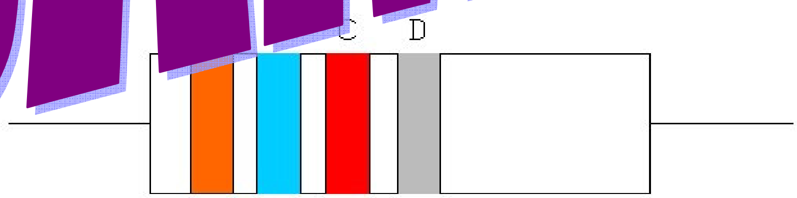
I	=	20.00 A
R	=	0.50 Ω
P	=	200.00 W

Color Code For Resistors



B[illegible]				[illegible]		[illegible] D	
1s[illegible]		2[illegible]		[illegible]		[illegible]ce	
Black	0	[illegible]lack	[illegible]	[illegible]	[illegible]01	[illegible]	± [illegible]
Brown	1	[illegible]row[illegible]	[illegible]	[illegible]	[illegible].1	[illegible]	± [illegible]
Red	2	Red	[illegible]	[illegible]	[illegible]	[illegible]	± [illegible]
Orange	[illegible]	Oran[illegible]	[illegible]	[illegible]	1	[illegible]	± [illegible]
Yellow	[illegible]	Yell[illegible]	[illegible]	[illegible]	[illegible]10	[illegible]	
Green	[illegible]	Gre[illegible]	[illegible]	[illegible]	[illegible]00	[illegible]	
Blue	[illegible]	[illegible]lue	[illegible]	[illegible]	[illegible]00	[illegible]	
Purple	[illegible]	[illegible]ur[illegible]	[illegible]	[illegible]	[illegible]00	[illegible]	
Gray	[illegible]	[illegible]ra[illegible]	[illegible]	[illegible]	[illegible]00	[illegible]	
White	[illegible]	[illegible]h[illegible]	[illegible]	[illegible]	[illegible]00	[illegible]	

[illegible]le



A = Orange = 3　　C = Red = 100
B = Blue = 6　　D = Silver = ± 10%
Resistance Value = 3600 Ω ± 10%, or between 3240 Ω and 3960 Ω.

Resistor Calculator

Band A =	3	Orange
Band B =	6	Blue
Band C =	100	Red
Band D =	± 10 %	Silver

Resistor Value = 3,600 Ω　± 10 %

or between 3,240 Ω **and** 3,960 Ω

Reference Electrode Conversion

Relative Values of Typical Re[illegible]ctrod[illegible]er[illegible]ulfa[illegible]re[illegible]ec[illegible]

[illegible]de ([illegible]	[illegible]nti[illegible]olt[illegible]
Copper - [illegible] (Cu[illegible]	[illegible]
Silver - S[illegible]hl[illegible] Satu[illegible]	[illegible]
Saturated [illegible]me[illegible]	[illegible]
Zinc (Pu[illegible])	[illegible]0

Convert [illegible]f: -0[illegible]

t[illegible]

Co[illegible]o[illegible]e

	[illegible]			
	C[illegible]te[illegible] El[illegible]e:			
	[illegible]	[illegible]gC[illegible]	[illegible]	[illegible]
[illegible]E	-0.[illegible]	[illegible] V	-0[illegible] V	0.533 V
[illegible]re[illegible]-A[illegible]	-0.[illegible]	[illegible] V	-0.547 V	0.483 V
[illegible]CE	-0.[illegible]	-0.587 V	-0.567 V	0.463 V
[illegible]n	-1.667 V	-1.617 V	-1.597 V	-0.567 V

Sacrificial Anode Efficiency and Utilization Factor

Magnesium :

$$L_M = \frac{0.116WE\ldots}{I}$$ [illegible]

W	= Weig[illegible]node (lb[illegible]	W	[illegible]
E	= C[illegible]ncy	E	[illegible]
U_F	= [illegible]or	U_F	[illegible]
I	= [illegible])	I	[illegible] A
L_M	= [illegible] M[illegible]um	L_M	[illegible] yrs

Z[illegible]

$$L_Z = [illegible]$$

W	= W[illegible]e (	W	[illegible]
E	= Curre[illegible]cy	E	0.90
U_F	= Utilizati[illegible]r	U_F	0.85
I	= [illegible]t ([illegible])	I	2.0 A
L_Z	= [illegible] M[illegible]r[illegible]	L_Z	3.90 yrs

Anode [illegible]	[illegible]um[illegible] Rate[2] (lb/amp-yr)	Common Consumption Rates Used[2] (lb/amp-yr)	Current Efficiency[2]	Utilization Factor[3]
Magnesium ([illegible] Alloy)	15.0 - 35.0	25	0.50	0.85
Magnesium (High Potential)	16.0 - 19.0	17	0.50	0.85
Zinc	23.7	23.7	0.90	0.85

[1]Anodes installed in suitable chemical backfill.
[2]Current efficiency with current density. The shown efficiency, and the resulting consumption rate, are at approximately 30 mA/ft² of anode surface. Efficiencies are higher at higher current densities and lower at lower current densities.
[3]The Utilization Factor for all Galvanic Anodes is 85% (0.85).

Dwight's Equation for Single Vertical Anode Resistance to Earth - inches

$$R_V = \frac{\rho}{2\pi L}\left\{\left(\ln\frac{8L}{d}\right)-1\right\}$$

ρ = Soil Resistivity (ohm-cm)		ρ	=	10,000 Ω-cm
L = Length of Anode (in)		L	=	472.44 in
	which is	L	=	1200.00 cm
d = Diameter of Anode (in)		d	=	7.99 in
	which is	d	=	20.30 cm
R_v = Resistance of Single Vertical Anode to Remote Earth (ohms)		R_v	=	[illegible]84 Ω

Dwight's Equation for Distributed Multiple Vertical Anodes Resistance [illegible]h - inc[illegible]

$$R_v = \frac{\rho}{[illegible]L}\left\{\left[[illegible] \right] [illegible] \frac{2L}{S} [illegible] N \right.$$

[illegible]istiv[illegible])			=	[illegible]Ω-cm
[illegible]of Ar[illegible]			=	[illegible]4.00 in
			=	[illegible]13.36 cm
S bet[illegible] (in			=	118.11 in
	[illegible]is		=	[illegible]00.00 cm
Number of [illegible]s			=	[illegible]0 anodes
[illegible]meter o[illegible]e			=	[illegible]37 in
	[illegible]hich is		=	[illegible] cm
[illegible]nce [illegible]tip[illegible]tica[illegible]arth[illegible]s)			=	[illegible]57 Ω

Dw[illegible]q[illegible]e[illegible]n[illegible]ti[illegible]od[illegible]pe) Resis[illegible]o Earth - inches

$$R_H = \frac{\rho}{2[illegible]}\left(\left[\ln [illegible] \frac{[illegible]\sqrt{[illegible]+L^2}}{dS}\right]+\frac{S}{L}-\frac{\sqrt{S^2+L^2}}{L}-1\right)$$

ρ = Soil Resistivity (ohm-cm)		ρ	=	10,000 Ω-cm
L = Length of Anode (in)		L	=	84.00 in
	which is	L	=	213.36 cm
S = Twice the Depth of Anode (in)		S	=	145.67 in
	which is	S	=	370.00 cm
d = Diameter of Anode (in)		d	=	8.00 in
	which is	d	=	[illegible]in
R_H = Resistance of Multiple Vertical Anodes to Remote Earth (ohms)		R_H	=	[illegible]Ω

Dwight's Equation for Distributed Multiple Ho[illegible] An[illegible]e [illegible]h - inc[illegible]

$$R_{N} = \frac{R}{N} F$$ w[illegible] [illegible] $+$ [illegible] $\ln$ [illegible] $.66$ [illegible]

ρ	[illegible]oil [illegible]vity	[illegible] Ω-cm
S	[illegible]pa[illegible] [illegible]twe[illegible] [illegible]n)	[illegible].080 in
		[illegible]03 cm
N	[illegible]umber of Ano[illegible]	[illegible]anodes
R	[illegible]istance of [illegible] [illegible]hms	[illegible] Ω
F	[illegible]e Anode [illegible]r	[illegible]3
R_{N}	[illegible]ce of [illegible]e [illegible]l A[illegible] [illegible]t [illegible] (c[illegible]	[illegible] Ω

Cable ... n

R_{Cable} ... ce per kilometer (ohm/mi)
L_{Cable} ... of Cable - Sum of Positive and Negative Leads (ft)
R_C = Resistance of Cable (ohms)

R_{Cable}	=	1.341 Ω/mi
L_{Cable}	=	383.50 ft
R_C	=	0.097 Ω

Rectifier Total Circuit Resistance

$$R_T = R_{Gbed} + R_C + R_S$$

R_{Gbed} = Ground Bed Resistance (ohms)
R_C = Resistance of Cable (ohms)
R_S = Structure/Pipeline-to-Earth Resistance (ohms)
R_T = Total Circuit Resistance (ohms)

R_{Gbed}	=	3.08 Ω
R_C	=	0.10 Ω
R_S	=	... Ω
R_T	=	... Ω

Rectifier Efficiency Formula

$P_{AC} = V_{AC} I_{AC}$

... ter Consta... Fac...
... Revolutio... D... bse... im...
... Obse...
P_{AC} ... Pow... att...

V_{DC} = D... v...
A_{DC} = DC ...
P ... DC ... P...

$\%_{Efficie...}$ ... Per... fi...

	=	...05
	=	4
		...ec
		...W
		2.00 V
A_{DC}	=	1.00 A
P_{DC}	=	2.00 W
$\%_{Efficiency}$	=	27.78 %

... Current Output Calculator

$$I_{Out} = V_{\substack{accross\\shunt}} S_{factor}$$

$V_{\substack{accross\\shunt}}$ = Voltage Reading Measured Across Shunt (mV)
S_{factor} = Shunt Factor from Chart (amp/mV)
I_{Out} = Current Output of Rectifier (amps)

$V_{\substack{accross\\shunt}}$	=	25 mV
S_{factor}	=	0.10 A/mV
I_{Out}	=	2.50 A

Faraday's Law

$$W_t = KIT$$

K = Consumption Rate - Electrochemical Equivalent (lb/amp-yr)
I = Current (amps)
T = Time (yrs)
W_t = Weight Loss of Product (lb)

K	=	20.10 lb/A-yr
I	=	0.875 A
T	=	4.0 yrs
W_t	=	70.4 lb

Consumption Rate K for Various Metals[1]

Metal	kg/A-yr	lb/A-yr
Carbon	1.30	2.86
Aluminum	3.00	[illegible]
Magnesium	[illegible]	[illegible]
Iron/Steel	[illegible]	[illegible]
High Silicon/Chro[illegible]n	[illegible]	[illegible]
Nickel	[illegible]	[illegible]
[illegible] (Monov[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Ba[illegible] able 2 [illegible] Cou[illegible]
[illegible] Unde[illegible] Sho[illegible]

[illegible]sed C[illegible] - [illegible] Ano[illegible]

[illegible]

K = [illegible]
$L_{Desired}$ = [illegible] (y[illegible]
$I_{Required}$ = [illegible] (amps)
U_{Factor} = [illegible]ation Factor
W_{Anode} = Weight per Anode (lb)
$\#_{Anodes}$ = # of Anodes to Use

K	=	0.75 lb/A-yr
$L_{Desired}$	=	20 yrs
$I_{Required}$	=	15.00 A
U_{Factor}	=	0.60
W_{Anode}	=	60.0 lb
$\#_{Anodes}$	=	6.25 anodes
rounding up - use $\longrightarrow$ $\#_{Anodes}$	=	7 anodes

of Anodes Required Based on Current Discharge

$$\#_{Anodes} = \frac{I_{Required}}{MD^*}$$

$I_{Required}$ = Current Required (amps)
MD^* = Maximum Discharge per Anode (amps)
* From Anode Manufacturer Data
$\#_{Anodes}$ = # of Anodes to Use

$I_{Required}$	=	14.70 A
MD^*	=	2.50 A
$\#_{Anodes}$	=	5.88 anodes
rounding up - use $\longrightarrow$ $\#_{Anodes}$	=	6 anodes

Coating Resistance Calculations

$$R_{CE} = A_S R_{P/S}$$

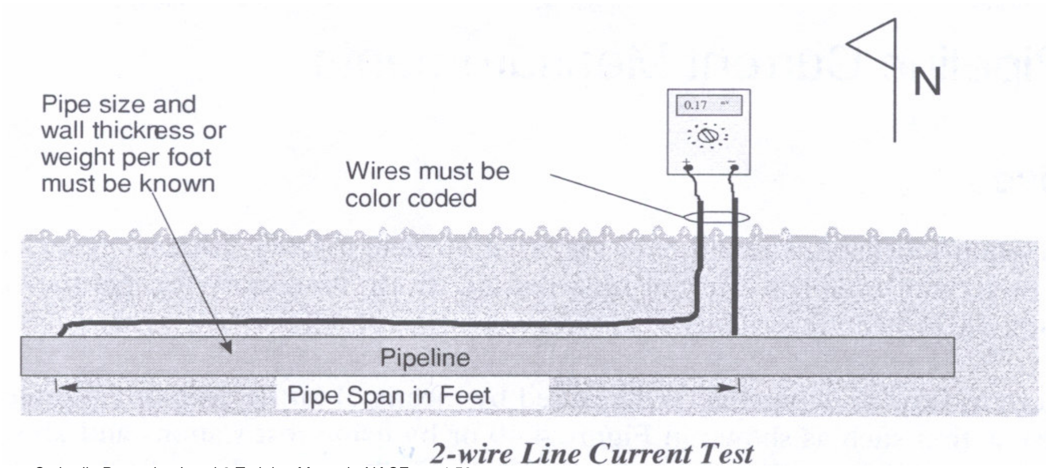
where

$$A_S = D\pi L$$

$$R_{P/S} = \frac{\Delta E_{ave}}{I_C} = \frac{\dfrac{\Delta E_{TS1} + \Delta E_{TS2}}{2}}{\Delta I_{TS1} - \Delta I_{TS2}} = \frac{\dfrac{(EOFF_{TS1} - EON\ [illegible]) \ [illegible]\ OF\ [illegible] - EO\ [illegible]}{[illegible]}}{[illegible]\ O\ [illegible]\ O\ [illegible]\ N\ [illegible]\ OFF\ [illegible]}$$

D	[illegible] of Pi[illegible]	[illegible]	=	[illegible] in
L	[illegible] Test [illegible]	[illegible]	=	[illegible]50.00 ft
A_S	[illegible] ea [illegible] pan	[illegible]	=	[illegible]8.63 ft²
EON_{TS1}	[illegible] Re[illegible] Site	EO[illegible]	=	[illegible].000 V
$EOFF_{TS1}$	[illegible] ff Voltage Re[illegible] Site	EOF[illegible]	=	[illegible].900 V
ΔE_{TS1}	[illegible] Drop Voltag[illegible] Te[illegible]	Δ[illegible]	=	[illegible] V
ION_{TS1}	[illegible] rrent R[illegible] ite [illegible]	IO[illegible]	=	[illegible] A
$IOFF_{TS1}$	[illegible] ent R[illegible] ite [illegible]	IOF[illegible]	=	[illegible] A
ΔI_{TS1}	[illegible] urre[illegible] Te[illegible] 1 [illegible]	Δ[illegible]	=	[illegible] A
EON_{TS2}	= [illegible] R[illegible] te [illegible]	EO[illegible]	=	[illegible] V
$EOFF_{TS2}$	= C[illegible] F[illegible] te [illegible]	EOF[illegible]	=	-0.850 V
ΔE_{TS2}	= IR [illegible] Te[illegible] 2 [illegible])	Δ[illegible]	=	0.850 V
ION_{TS2}	[illegible] n [illegible] F[illegible] e [illegible] ps	ION_{TS2}	=	2.800 A
$IOFF_{TS2}$	[illegible] ff [illegible] F[illegible] e [illegible] ps	$IOFF_{TS2}$	=	0.100 A
ΔI_{TS2}	[illegible] R D[illegible] ere[illegible] 2 ([illegible] s)	ΔI_{TS2}	=	2.700 A
E_{ave}	[illegible] er [illegible] (volts)	E_{ave}	=	0.975 V
I_C	[illegible] est [illegible] (amps)	I_C	=	0.100 A
$R_{P/S}$	[illegible] ce [illegible] - to - Soil (ohms)	$R_{P/S}$	=	9.750 Ω
R_{CE}	[illegible] ve Coating Resistance of Pipe Test Span (ohm-ft²)	R_{CE}	=	323,296.65 Ω-ft²

2-Wire Current Test over Pipe Test Span



Cathodic Protection Level 2 Training Manual - NACE pg. 4:58

$$I_{PS} = \frac{\Delta E_{PS}}{R_{PS}}$$ where $$R_{PS} = L_{PS} R_P$$

D	= Diameter of Pipe (in)		[illegible]
t	= Thickness of Pipe Wall (in)		[illegible]
L_{PS}	= Length of Pipe Test Span (ft)	L[illegible]	[illegible].00 ft
R_P	= Resistance of Pipe per meter from Table (μoh[illegible]	R[illegible]	[illegible] μΩ/ft
R_{PS}	= Resistance of Pipe Test Span (o[illegible]	R[illegible]	[illegible]800 Ω
ΔE_{PS}	= Measured Voltage D[illegible]r Pip[illegible]n	Δ[illegible]	[illegible]017 V
I_{PS}	= Calculated Curre[illegible] Tes[illegible]	I[illegible]	[illegible]A

[illegible]ble o[illegible] Res[illegible] [3]

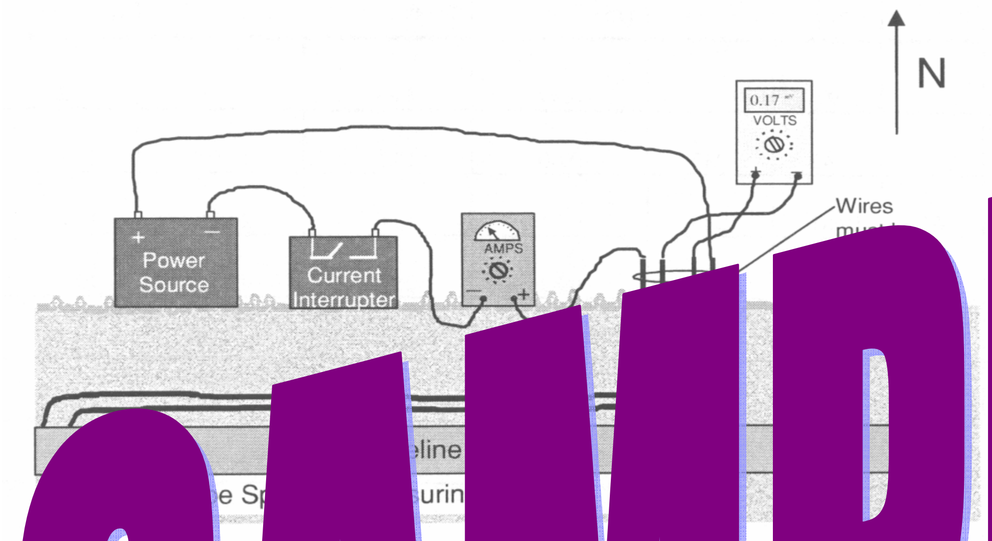
Pipe Siz[illegible] (in)	[illegible]si[illegible] [illegible])	[illegible]met[illegible] (cm[illegible]	[illegible]	Thi[illegible]	[illegible]	[illegible]eig[illegible]	(μΩ/[illegible]	[illegible]sistan[illegible] ([illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.12
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.09	13.42
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	116.97	3.68	12.07
22	[illegible]	[illegible]	[illegible]	[illegible]	86.60	128.88	3.34	10.96
24	[illegible]	[illegible]	[illegible]	[illegible]	94.60	140.78	3.06	10.04
26	[illegible]	[illegible]	[illegible]	0.148	102.60	152.69	2.82	6.25
28	[illegible]	[illegible]	0.375	0.148	110.60	164.59	2.62	8.60
30	[illegible]	11.811	0.375	0.148	118.70	176.65	2.44	8.01
32	32.00	12.598	0.375	0.148	126.60	188.41	2.28	7.48
34	34.00	13.386	0.375	0.148	134.60	200.31	2.15	7.05
36	36.00	14.173	0.375	0.148	142.60	212.22	2.03	6.66

1 Conversions based on 1in = 2.54cm and 1ft = 0.3048m.

2 Based on steel density of 489 lbs/ft³ (7832 kg/m³) and steel resistivity of 18 μΩ/cm.

3 R = 16.061 x resistivity in μΩ/cm = Resistance of 1 ft of Weight per foot of pipe in μΩ.

4-Wire Current Test over Pipe Test Span



$$I_{PS} = K \ldots \frac{\ldots}{E \ldots E_{OFF}}$$

E_{ON}	=	[illegible]
E_{OFF}	=	Vo[illegible]
I_A	=	Appl[illegible]
K		[illegible]
ΔE_{P}		[illegible]
I_{PS}		[illegible]

E		[illegible] V
E_{O}		0.00017 V
I		10.00 A
K	=	2.037 A/mV
ΔE_{PS}		0.00017 V
I_{PS}	=	0.346 A

C… nce

$$C = \frac{1}{R}$$

units are in Siemens (S) or microSiemens (µS)

units of Siemen (S) = $\frac{1}{\Omega}$

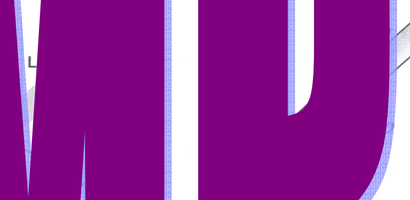
R = Resistance (ohms) — R = 9,750 Ω

C = Conductance (S) — C = …3 S

Resistivity Calculations

* Area may be Cross - Sect… Ar… ma… S… ctrolye…
* For Soil Box Measu… & … e t… s… t… cel ou…

$$\frac{RA}{L}$$



…anu… pg 1:4

…a of Cros…) — $=$ … in²

…ich is — … cm²

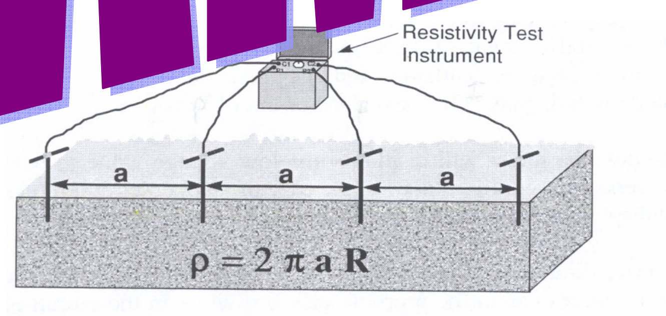
R … nce …) — … Ω

L … in) — … in

…ich is — 472.44 cm

ρ = R… — $=$ 423.332 Ω-cm

…en… …th…



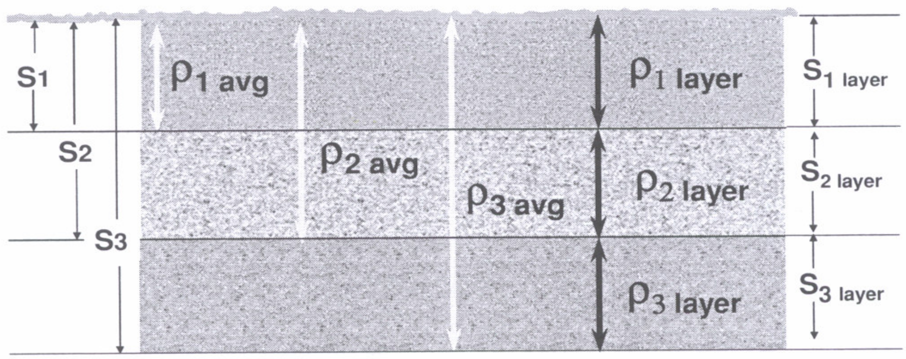
Four-Pin (Wenner) Method of Measuring Soil Resistivity

Cathodic Protection Level 1 Training Manual - NACE 2000 pg 4:28

$$\rho = 2\pi aR$$

a = Spacing of the Pins (in)		a =	1.58 in
	which is	a =	4.00 cm
R = Resistance Measured - shown on Instrument (ohms)		R =	450.00 Ω
ρ = Resistivity of Measured Medium (ohm-cm)		ρ =	11309.734 Ω-cm

Layer Resistivity Calculations



Average and Layer Resistivity

Cathodic Protection Level 2 Training Manual - NACE 2000 pg 4:67

Parallel Resistance Formula

$$R_c = \frac{R_a R_b}{R_a - R_b}$$

Layer 1

$\rho_{1avg} = 2\pi S_1 R_1$

$S_{1layer} = S_1$

R_{1layer} [illegible]

ρ_{1lay} [illegible] $_{er} R$

Layer 2

$\rho_{2avg} = 2\pi S$ [illegible]

S_2 [illegible] S_2

R_2 [illegible]

ρ_2 [illegible] R_{2l}

L[illegible]

[illegible] πS_3 [illegible]

[illegible] $S_3 -$ [illegible]

[illegible] $\frac{R_2}{R_2 -}$ [illegible]

[illegible] $2\pi S_3$ [illegible] $_{3layer}$

[illegible] ayer 1 Spa[illegible] D[illegible] Mea[illegible] = [illegible]64 in

[illegible] hich is = [illegible] cm

[illegible] 1 Re[illegible] ([illegible] = [illegible]00 Ω

ρ_{1a}[illegible] Av[illegible] Re[illegible] ([illegible] = [illegible]-cm

S_{1layer} [illegible] Sp[illegible] D[illegible] ea[illegible] ([illegible] = [illegible] cm

[illegible] hich is = 62.64 in

R_{1lay}[illegible] = L[illegible] Re[illegible] ([illegible] R_{1layer} = 10.00 Ω

ρ[illegible] = L[illegible] R[illegible] n [illegible] ρ_{1layer} = 9996.90 Ω-cm

[illegible] L[illegible] S[illegible] T[illegible] ur[illegible] n) S_2 = 125.28 in

which is S_2 = 318.21 cm

[illegible] Resistance Measured - shown on Instrument (ohms) R_2 = 7.40 Ω

ρ_2[illegible] 2 Average Resistivity (ohm-cm) ρ_{2avg} = 5824.97 Ω-cm

S_{2layer} [illegible] er 2 Spacing - Layer Depth Measured (cm) S_{2layer} = 159.11 cm

which is S_{2layer} = 62.64 in

R_{2layer} = Layer 2 Parallel Resistance (ohms) R_{2layer} = 28.46 Ω

ρ_{2layer} = Layer 2 Resistivity (ohm-cm) ρ_{2layer} = 28452.714 Ω-cm

S_3 = Layer 3 Spacing - Total Depth Measured (in) S_3 = 187.92 in

which is S_3 = 477.32 cm

R_3 = Layer 3 Resistance Measured - shown on Instrument (ohms) R_3 = 3.10 Ω

ρ_{3avg} = Layer 3 Average Resistivity (ohm-cm) ρ_{3avg} = 9297.12 Ω-cm

S_{3layer} = Layer 3 Spacing - Layer Depth Measured (cm) S_{3layer} = 159.11 cm

which is S_{3layer} = 62.64 in

R_{3layer} = Layer 3 Parallel Resistance (ohms) R_{3layer} = 5.33 Ω

ρ_{3layer} = Layer 3 Resistivity (ohm-cm) ρ_{3layer} = 5333.230 Ω-cm

Shunt Types and Values

	Shunt Rating		Shunt Value	Shunt Factor
	Amps	mV	Ohms	A/mV
Holloway Type				
RS	5	50	0.01	0.1
SS	25	25	0.001	[illegible]
SO	50	50	[illegible]	[illegible]
SW or CP	1	[illegible]	[illegible]	[illegible]
SW or CP	2	[illegible]	[illegible]	[illegible]
SW or CP	3	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	[illegible]	[illegible]
[illegible]	10	[illegible]	[illegible]	[illegible]
[illegible]	15	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1
[illegible]	[illegible]	[illegible]	[illegible]	1.2
[illegible]	[illegible]	[illegible]	[illegible]	1.5
[illegible]	[illegible]	[illegible]	[illegible]	2
[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	0.1
[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	0.01
[illegible]	[illegible]	[illegible]	[illegible]	0.01
[illegible]	[illegible]	[illegible]	[illegible]	0.1
[illegible]	[illegible]	[illegible]	0.001	1

SAMPLE

...denberg Formula

$$V_x = \frac{0.038 I \rho}{\pi y} \log_{10}\left(\frac{y + \sqrt{y^2 + x^2}}{x} \right)$$

i... th... = ...005... / x

ρ	...f Ear...)	1... ...m
y	...ode...)	...in
		...00 ft
x	...ta... n A...	...000 ft
I	...re... of Grou... ...ps	...2.0 A
V_x	...age Potentia... s... ca... ...e C... volts)	...520 V

Ne[illegible]on

E^0	= [illegible] Cell Electrode Potential - from table (volts)	
R	= [illegible] Gas Constant = 8.31434 (J/mol·K)	
T	= Absolute Temperature (K) [1]	
n	= Number of Valence Electrons Transferred - from table	
F	= Faraday's Constant = 96,485.309 (C/g·mol)	
a_M^{+ne}	= Activity of Metal Ions in Solution [2]	
a_M	= Activity of the Metal (a_M = 1 for pure metal)	
E	= Electrode Potential in Existing Solution (volts)	

E^0	=	-0.763 V
R	=	8.31434 J/mol·K
T	=	298.15 K
n	=	2
F	=	96485.31 C/g·mol
a_M^{+ne}	=	0.71
a_M	=	1
E	=	[illegible] V

[1] Absolute Temperature is -273.15 ºC. Standard Conditions for pu[illegible]ls in t[illegible] are based on one unit activity of metal ions in [illegible] at [illegible]th no [illegible] in the metal or electrolyte and wit[illegible]ce t[illegible]dr[illegible]ectrode[illegible]

[2] Activity Coefficients [illegible]nd[illegible]stry[illegible]gin[illegible]ha[illegible]ks at a [illegible] con[illegible]f 0.0[illegible]

R[illegible]vanic[illegible]eaw[illegible]ce[illegible]n[illegible]tals

Half-C[illegible]	[illegible]l	[illegible]dar[illegible] Pot[illegible] olts[illegible]	[illegible]	[illegible]al[illegible]
Au/Au+[illegible]	-[illegible] to -1.[illegible]	[illegible].55[illegible]	[illegible]	[illegible]
Pt/Pt++	-1.10	-[illegible]	[illegible]	[illegible]
Cu/Cu+[illegible]	-1.05	-[illegible]	[illegible]	[illegible]
H2/2H+[illegible]	[illegible] to -0.[illegible]	[illegible]45[illegible]	[illegible]	[illegible]
Pb/Pb++	[illegible] -0.[illegible]	[illegible]015[illegible]	[illegible]	[illegible]
Ni/Ni++	[illegible]	-[illegible]	[illegible]	[illegible]
Fe/Fe++	[illegible]	-[illegible]	[illegible]	[illegible]
Zn/Zn++	[illegible]	-[illegible]	[illegible]	[illegible]
Al/Al++	[illegible]	-[illegible]	[illegible]	[illegible]
Mg/Mg+[illegible]	[illegible]	-[illegible]	[illegible]	[illegible]

* Standa[illegible]r[illegible]ec[illegible] SH[illegible]