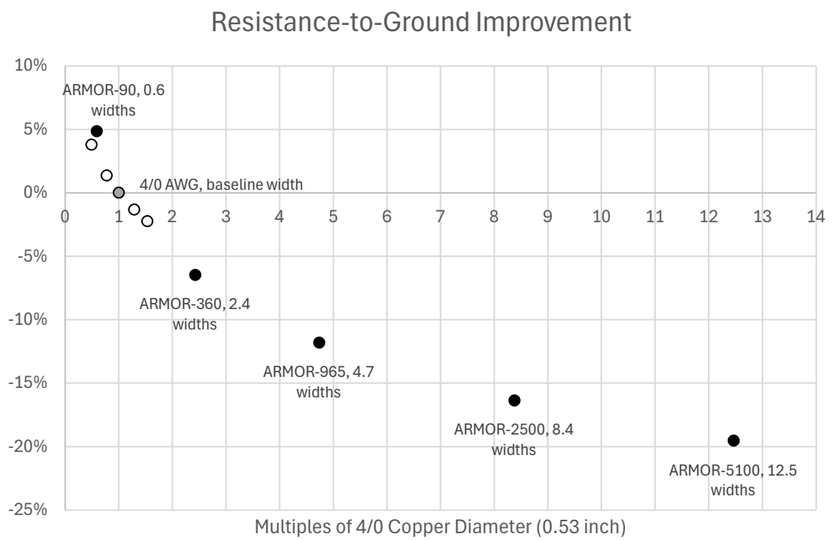
GRAPH VALUES

Size	4/0 Widths (#)	Improvement (%)
#2 AWG	0.5	4%
2/0 AWG	0.8	1%
4/0 AWG, bas	1.0	0%
350 kcmil	1.3	-1%
500 kcmil	1.5	-2%
ARMOR-90, 0	0.6	5%
ARMOR-360,	2.4	-6%
ARMOR-965,	4.7	-12%
ARMOR-2500	8.4	-16%
ARMOR-5100	12.5	-20%



Size	Diameter (inch)	Width (inch)	Thickness (inch)	4/0 Widths (#)	Resistance (Ω/kft)	Improvement (%)
#2 AWG	0.26	-	-	0.5	0.095	3.8%
2/0 AWG	0.41	-	-	0.8	0.093	1.4%
4/0 AWG, baseline width	0.53	-	-	1.0	0.091	0.0%
350 kcmil	0.68	-	-	1.3	0.090	-1.3%
500 kcmil	0.81	-	-	1.5	0.089	-2.3%
ARMOR-90, 0.6 widths	-	0.31	0.083	0.6	0.096	4.9%
ARMOR-360, 2.4 widths	-	1.28	0.083	2.4	0.085	-6.5%
ARMOR-965, 4.7 widths	-	2.50	0.083	4.7	0.081	-11.8%
ARMOR-2500, 8.4 widths	-	4.42	0.083	8.4	0.076	-16.3%
ARMOR-5100, 12.5 widths	-	6.58	0.083	12.5	0.073	-19.5%

Rudenberg Deep Wire

	English		Metric	
ρ			100	Ωm
L	3,279	ft	1,000	m
A	0.07	ft	0.0206	m
z	1.641	ft	0.500	m

Rudenberg Deep Strip

	English		Metric	
ρ			100	Ωm
L	3,279	ft	1,000	m
T	0.01	ft	0.002	m
W	0.55	ft	0.167	m
z	1.641	ft	0.500	m

Rudenberg AC Resistance to Ground [1]

	Term 1	Term 2	Term 3	Ω/km	Ω/kft
wire calcs	*0.016*	*11.485*	*1.602*	*0.293*	*0.089*
strip calcs	*0.016*	*10.083*	*1.502*	*0.241*	*0.073*
#2 AWG	0.016	12.622	1.547	0.311	0.095
2/0 AWG	0.016	12.166	1.568	0.304	0.093
4/0 AWG	0.016	11.909	1.580	0.299	0.091
350 kcmil	0.016	11.660	1.592	0.296	0.090
500 kcmil	0.016	11.485	1.602	0.293	0.089
A-90	0.016	13.139	1.502	0.314	0.096
A-360	0.016	11.721	1.502	0.280	0.085
A-965	0.016	11.051	1.502	0.264	0.081
A-2500	0.016	10.481	1.502	0.251	0.076
A-5100	0.016	10.083	1.502	0.241	0.073
A-1720	0.016	10.700	1.502	0.256	0.078
A-1090	0.016	10.977	1.502	0.262	0.080
A-690	0.016	11.267	1.502	0.269	0.082
A-350	0.016	11.759	1.502	0.281	0.086

* NOTES:

1.) The three terms shown in the calculations of resistance are discussed in detail on Sheets 2-4 of this drawing XDWG-105. These values are intended to allow engineers to check the math presented and graphed herein for designing substations with better resistance to ground.

PATENT PENDING

CONFIDENTIAL AND PROPRIETARY INFORMATION OF EXETER GROUND, LLC.

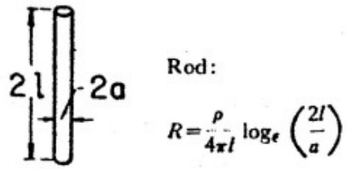
EXETER GROUND, LLC

Title: RESISTANCE-TO-GROUND IMPROVEMENTS AS A FUNCTION OF MULTIPLE OF 4/0 COPPER DIA.

Drawn	JTJordan	Size	Drawing No.	Rev
Approved	JTJordan	B	XDWG-105	-
Date	10/25/2024			Sheet 1

Rudenberg Table II Deep Wire (1945)

i.e. Resistance to Ground for a Buried Wire



Rod:

$$R = \frac{\rho}{4\pi l} \log_e\left(\frac{2l}{a}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***4/0 copper*** conductor buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
A	= 2 * a	0.04	ft	0.0134	m	dimensions of 4/0 copper
z		1.6405	ft	0.500	m	assumed

R_z multiplier term = $1 + \log_e(l/z) / \log_e(2l/a)$

= $1 + \log_e(500 / .500) / \log_e(1000 / 0.0067)$

= 1 + 0.58

$R_{4/0,1000m,0.5mdeep}$ = $(\rho / 4\pi l) * (\log_e 2l/a) * [1 + \log_e(l/z) / \log_e(2l/a)]$

= $((100 / (4 * 3.14 * 500)) * (\log_e(1000 / 0.00675)) * [1.58]$

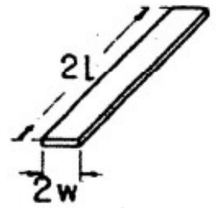
= 0.016 * 11.915 * 1.580

$R_{4/0,1000m,0.5mdeep}$ = 0.300 Ω / km

0.091 Ω / 1000ft

Rudenberg Table II Deep Strip (1945)

i.e. Resistance to Ground for a Buried Strip



Strip:

$$R = \frac{\rho}{4\pi l} \log_e\left(\frac{4l}{w}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***Shining Armor 965*** conductor buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
T	= 2 * t	0.01	ft	0.0021	m	dimensions of ARMOR-965
W	= 2 * w	0.21	ft	0.0635	m	dimensions of ARMOR-965

R_z multiplier term = $1 + \log_e(l/z) / \log_e(2l/t)$

$1 + \log_e(500 / .500) / \log_e(1000 / 0.001)$

= 1 + 0.50

$R_{ARMOR-965,\ 1000m,0.5mdeep}$ = $((\rho / 4\pi l) * (\log_e 4l/w) * [1 + \log_e(l/z) / \log_e(2l/t)]$

= $(100 / (4 * 3.14 * 500)) * (\log_e(2000 / 0.032)) * [1.50]$

= 0.016 * 11.051 * 1.50

$R_{ARMOR-965,\ 1000m,0.5mdeep}$ = 0.264 Ω / km

0.081 Ω / 1000ft

$R_{XGT-965}$ = 88% * $R_{4/0}$

"Resistance to ground (R) for an Shining Armor-965 ™ ground grid is 12% lower than for 4/0 AWG copper ground grid."

* NOTES:

1.) Reinhold Rudenburg 1945. “Grounding Principles and Practices I – Fundamental Considerations on Grounding Currents, Electrical Engineering Vol 64, Number 1, January 1945.

2.) These formulas are found in 1961 R. F. Stevens, et al. "Guide for Safety in AC Substation Grounding" up to the modern version of IEEE Std-80.

PATENT PENDING

CONFIDENTIAL AND PROPRIETARY INFORMATION OF EXETER GROUND, LLC.

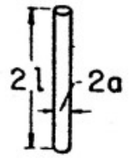
EXETER GROUND, LLC

Title: RESISTANCE-TO-GROUND BENEFIT (ARMOR-965™ IS 12% LOWER THAN 4/0 COPPER)

Drawn	JTJordan	Size	Drawing No.	Rev
Approved	JTJordan	B	XDWG-105	-
Date	10/25/2024			Sheet 2

Rudenberg Table II Deep Wire (1945)

i.e. Resistance to Ground for a Buried Wire



Rod:

$$R = \frac{\rho}{4\pi l} \log_e \left(\frac{2l}{a}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***500 kcmil*** copper conductor buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
d	= 2 * a	0.07	ft	0.0206	m	dimensions of 500 kcmil copper
z		1.6405	ft	0.500	m	assumed

R_z multiplier term = $1 + \log_e (l / z) / \log_e (2l / a)$

= $1 + \log_e (500 / .458) / \log_e (1000 / 0.0103)$

= 1 + 0.60

$R_{500,1000m,0.5mdeep}$ = $(\rho / 4\pi l) * (\log_e 2l / a) * [1 + \log_e (l / z) / \log_e (2l / a]$

= $((100 / (4 * 3.14 * 500)) * (\log_e (1000 / 0.0103)) * [1.61]$

= 0.016 * 11.485 * 1.602

$R_{500,1000m,0.5mdeep}$ = 0.293 Ω / km

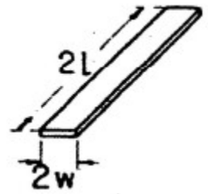
0.089 Ω / 1000ft

$R_{XGT-965}$ = 90% * R_{500}

"Resistance to ground (R) for an Shing Armor-965 ™ ground grid is 10% lower than for 500 kcmil copper ground grid."

Rudenberg Table II Deep Strip (1945)

i.e. Resistance to Ground for a Buried Strip



Strip:

$$R = \frac{\rho}{4\pi l} \log_e \left(\frac{4l}{w}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***Shining Armor 965*** conductor buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
T	= 2 * t	0.01	ft	0.0021	m	dimensions of ARMOR-965
W	= 2 * w	0.21	ft	0.0635	m	dimensions of ARMOR-965

R_z multiplier term = $1 + \log_e (l / z) / \log_e (2l / t)$

$1 + \log_e (500 / .500) / \log_e (1000 / 0.001)$

= 1 + 0.50

$R_{ARMOR-965, 1000m,0.5mdeep}$ = $((\rho / 4\pi l) * (\log_e 4l / w) * [1 + \log e (l / z) / \log e (2l / t)]$

= $(100 / (4 * 3.14 * 500)) * (\log_e (2000 / 0.032)) * [1.50]$

= 0.016 * 11.051 * 1.50

$R_{ARMOR-965, 1000m,0.5mdeep}$ = 0.264 Ω / km

0.081 Ω / 1000ft

* NOTES:

1.) Reinhold Rudenburg 1945. “Grounding Principles and Practices I – Fundamental Considerations on Grounding Currents, Electrical Engineering Vol 64, Number 1, January 1945.

2.) These formulas are found in 1961 R. F. Stevens, et al. "Guide for Safety in AC Substation Grounding" up to the modern version of IEEE Std-80.

PATENT PENDING

CONFIDENTIAL AND PROPRIETARY INFORMATION OF EXETER GROUND, LLC.

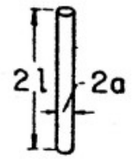
EXETER GROUND, LLC

Title: RESISTANCE-TO-GROUND BENEFIT (ARMOR-965™ IS 10% LOWER THAN 500 KCMIL COPPER)

Drawn	JTJordan	Size	Drawing No.	Rev
Approved	JTJordan	B	XDWG-105	-
Date	10/25/2024			Sheet 3

Rudenberg Table II Deep Wire (1945)

i.e. Resistance to Ground for a Buried Wire



Rod:

$$R = \frac{\rho}{4\pi l} \log_e \left(\frac{2l}{a}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***Three 500 kcmil*** copper conductors buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
d	= 2 * a	0.20	ft	0.0618	m	dimensions of 3 x 500 kcmil copper diameters
z		1.6405	ft	0.500	m	assumed

R_z multiplier term = $1 + \log_e (l / z) / \log_e (2l / a)$

= $1 + \log_e (500 / .500) / \log_e (1000 / 0.0309)$

= 1 + 0.67

$R_{Triple500s,1000m,0.5mdeep} = (\rho / 4\pi l) * (\log_e 2l / a) * [1 + \log_e (l / z) / \log_e (2l / a]$

= ((100 / (4 * 3.14 * 500)) * ($\log_e$ (1000 / 0.00675)) * [1.67]

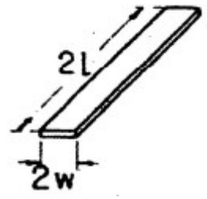
= 0.016 * 10.386 * 1.665

$R_{Triple500s,1000m,0.5mdeep}$ = 0.275 Ω / km

0.084 Ω / 1000ft

Rudenberg Table II Deep Strip (1945)

i.e. Resistance to Ground for a Buried Strip



Strip:

$$R = \frac{\rho}{4\pi l} \log_e \left(\frac{4l}{w}\right)$$

Deep wire:

$$R_z = R\left[1 + \frac{\log_e\left(\frac{l}{z}\right)}{\log_e\left(\frac{2l}{a}\right)}\right]$$

Resistance to ground for ***Shining Armor 965*** conductor buried 18 inches deep in soil resistivity ρ = 100 ohm-meters

where

		English		Metric		
ρ				100	Ωm	assumed
L	= 2 * l	3,279	ft	1,000	m	assumed
T	= 2 * t	0.01	ft	0.0021	m	dimensions of ARMOR-965
W	= 2 * w	0.21	ft	0.0635	m	dimensions of ARMOR-965

R_z multiplier term = $1 + \log_e (l / z) / \log_e (2l / t)$

$1 + \log_e (500 / .500) / \log_e (1000 / 0.001)$

= 1 + 0.50

$R_{ARMOR-965, 1000m,0.5mdeep} = ((\rho / 4\pi l) * (\log_e 4l / w) * [1 + \log e (l / z) / \log e (2l / t)]$

= (100 / (4 * 3.14 * 500)) * ($\log_e$ (2000 / 0.032)) * [1.50]

= 0.016 * 11.051 * 1.50

$R_{ARMOR-965, 1000m,0.5mdeep}$ = 0.264 Ω / km

0.081 Ω / 1000ft

$R_{XGT-965}$ = 96% * $R_{Triple500s}$

"Resistance to ground (R) for Shining Armor-965 ™ ground grid 4% better than Triple Parallel 500 kcmil coppers."

* NOTES:

1.) Reinhold Rudenburg 1945. “Grounding Principles and Practices I – Fundamental Considerations on Grounding Currents, Electrical Engineering Vol 64, Number 1, January 1945.

2.) These formulas are found in 1961 R. F. Stevens, et al. "Guide for Safety in AC Substation Grounding" up to the modern version of IEEE Std-80.

PATENT PENDING

CONFIDENTIAL AND PROPRIETARY INFORMATION OF EXETER GROUND, LLC.

EXETER GROUND, LLC

Title: RESISTANCE-TO-GROUND BENEFIT PRESENTED AT CEATI 2024 (ARMOR-965™ IS EQUIVALENT TO TRIPLE PARALLEL 500 KCMIL)

Drawn	JTJordan	Size	Drawing No.	Rev
Approved	JTJordan	B	XDWG-105	-
Date	10/25/2024			Sheet 4