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Theft Deterrent Composite Conductors for Telecommunication Grounding

Equivalence to Traditional Copper Conductor

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1.0 **Abstract:**

Copper conductors used in grounding applications, have served the telecommunications industry well over many decades, both above and below grade. Copper has been the material of choice due to its excellent conductivity, good corrosion performance across a wide range of environmental conditions, ease of handling and its ease of availability. The need for modern conductors, that can be used to substitute copper as a grounding conductor is driven by cost of copper and theft of copper. The choice of alternative materials to copper, need to be considered properly and some testing and calculations may be necessary to validate its equivalence to copper. This paper looks at attributes of a conductor, which could be calculated or tested to establish its performance and benchmark it against copper. The table below summarizes key attributes of conductors that can be tested and method of validating each attribute.

Attribute	Method of Validating
1. Impedance	The impedance of a conductor is made up of several components. There are two components of impedance that can be measured. *Self-Inductance* can be calculated using empirical formula or measured using sensitive LCR Test equipment that is suitable for testing *Resistance* can be measured using traditional methods using test equipment that can measure micro ohms
2. Voltage Drop Under Lightning Conditions	High Frequency Performance Under Lightning can be tested using standard test wave-shapes designated in the industry for testing surge protective devices. These include testing under various magnitudes of the 8/20µs and the 10/350µs surge current and measuring voltage drop across the conductor
3. Corrosion – Degradation of Electrical Performance Under Corrosion	Corrosion and Electrical Performance Testing. Corrosion above ground can be simulated by placing the conductor under test in a salt-spray chamber per ASTM B-117 for long periods – 250 to 500 hours, or even ore. The resistance and inductance measurements can be repeated before and after the testing. For comparative control, appropriate size copper conductor could be used.
4. Ageing Degradation of Electrical Performance Under Ageing	Ageing can be simulated by temperature cycling testing. Temperatures, cycle times and number of cycles can be chosen based upon established procedures like the ANSI C119.4. The resistance and inductance measurements can be repeated before and after the testing. For comparative control, appropriate size copper conductor could be used.
5. Short Circuit Current Rating	Short Circuit Current Testing method can be provided by the manufacturer and calculated or modelled rather than tested. UL 467 Table 5, describes "Short-time test currents" for components used in grounding system. These test can be extended to measure the duration associated with the fusing current provided by manufacturer
6. Ability to Handle Lightning Current	Based on minimum requirements of IEC62305 and NESC, the fusing current of the alternative conductor shall be equal to or greater than to that of 16 mm2 of or 6 AWG copper or 50 mm2 of steel.
7. Galvanic Compatibility & Corrosion Below Grade	Galvanic corrosion can occur between dissimilar metal when and electrolyte is present and there is space between metals for the electrolyte to ingress. Material selected for grounding application should not be prone to this or other types of corrosion effects.

2.0 Impedance Discussion

In telecommunications, the two important criteria for the selection and substitution of a conductor are its performance at higher frequencies and its ability to handle lightning currents. Other than for safety, the key reason for telecommunications grounding is the control of lightning surges and resulting potential differences, voltage transients and noise, which are higher frequency events.

Hence it is the impedance, rather than just resistance alone that needs to be considered to determine the performance of a conductor under these high frequency events.

For the purpose of demonstrating the effect of frequency, the closest available model that one can use for a long horizontally buried ground wire, is the transmission line model. The characteristic impedance of two wires, like transmission line running parallel can be modelled by the equation below. If one was to extend this model to a long buried ground wire, whereby the ground is be considered the return path as shown in Figure 1.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

Where

R is the resistance per unit length
L is the inductance per unit length,
G is the conductance of the dielectric per unit length,
C is the capacitance per unit length,
j is the imaginary unit, and
ω is the angular frequency = 2πf, where f is the frequency

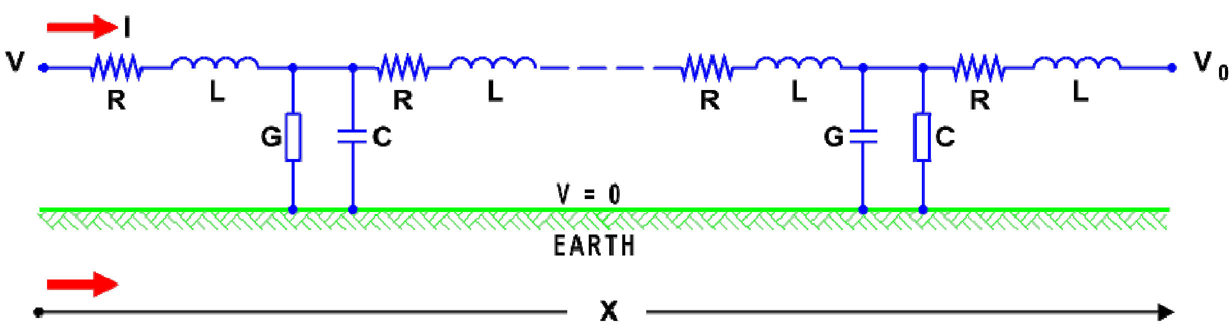


Figure 1: Transmission Line Characteristic Impedance Applied to Ground Conductor

It can be seen from above that at higher frequencies (megahertz range); the inductance and capacitance will be the dominant component because the reactive impedance or the imaginary unit gets multiplied by the frequency value, which will be a large number.

The capacitance is largely a factor for how the two conductors are laid with respect to each other, in the case the ground conductor, how it is laid with respect to the ground. The metal used or the material itself will not affect this. For example, it can be postulated that if the conductor is a tape with much wider diameter than a wire, then the capacitive coupling to ground will increase due to the larger surface area of contact.

The inductance component will constitute of the self-inductance of the conductor as well as the mutual inductance or the loop impedance to the return path of the simulated circuit. The inductance of a single conductor is called self-inductance. This term can be measured with test equipment of calculated using several formulas depending on the level of accuracy one wanted to achieve. The mutual inductance will change depending on how the conductors are laid in the ground. It will largely depend on the way it's laid and to a lesser extent depend on the diameter of the wire.

Hence to compare the performance of a traditional copper wire with an alternative theft deterrent conductor, the self-inductance can be one attribute that can be measured or calculated and compared as a benchmark.

Accurate formulas for computing the inductance of a conductor are complex, but one sufficiently exact for our purposes is given as:

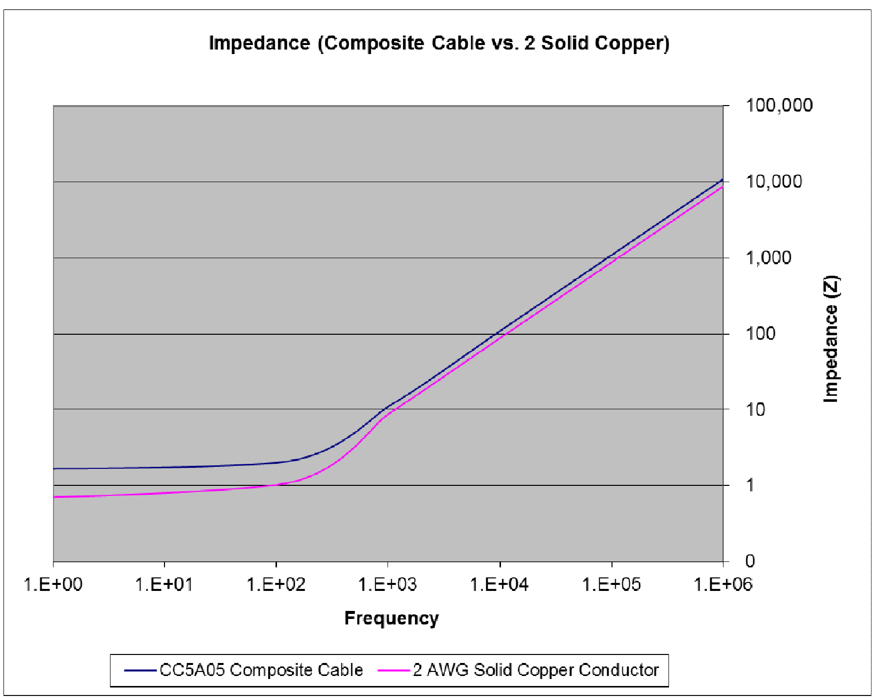
$$L(\mu H) = .002\, l\left[2.5\,\log_{10}\left(4\frac{l}{d} - 0.75\right)\right] \qquad (2.1)$$

Where l is the length in cm. of a straight piece of wire and d is its diameter in cm (2.54 cm. = 1 inch and 1 mil = 0.001 in.).

Similarly the resistance of a conductor can also be measured with equipment like a micro-ohm meter.

Care should be given not to give too much importance to these 2 attributes, which is the self-inductance and resistance because this value will contribute only partly to the characteristic impedance of the buried ground conductor. These values should form part of the comparison criteria of the two conductors and should not form the only criteria.

In the example below the calculated impedance of a composite cable and #2 solid copper wire is compared and graphed.



3.0 Voltage Drop Under Surge Conditions

Measuring the voltage drop across a define length of a conductor when a surge current is applied, is a practical way of establishing one aspect of equivalence of a non-copper theft deterrent conductor to the copper conductor it would replace.

These measurements take account of various terms of the overall impedance into account. Two conductors being tested have to be laid out in exactly the same way to provide a comparative result. The voltage drop V, is largely given the formula below:

$$V = L\,di/dt$$ *where L = inductance and di/dt is the rate of rise of current*

If the di/dt can be kept the same in various experiments then the voltage drop comparison will be directly proportional to the inductance. There are two established current wave-shapes that are commonly used for the testing of surge protective device in the industry which have a predefined di/dt. These are the 8/20µs and the 10/350µs test wave-shapes as defined in IEC61643-1 Surge protective devices connected to low-voltage power distribution systems - Part 1 Performance requirements and testing methods. The 8/20 µs test wave-shape is also used in IEEE C62.41 IEEE Guide on Surge Environment in Low Voltage AC Power Circuits. Various magnitudes of these test wave shape impulses can be applied to the sample conductor being tested and the resulting voltage drop from this test can be compared with the copper conductor that is being replaced.

In interpreting the results from this, care must be taken to understand that not all the parts of impedance that cause the voltage drop are an attribute of the actual conductor. Conductors have to be significantly different in size to provide significant differences in voltage drop. In any case, establishing that the voltage drop is similar or lower than that of the copper conductor being replaced, is a reasonable point of validation.

Please refer to the case study at the end of this technical paper to see an example and results of this testing.

4.0 Corrosion – Degradation of Electrical Performance Under Corrosion

ASTM B117 Salt Spray (Fog) Testing ASTM B117 is the oldest and most widely used of the salt spray cabinet tests. Purportedly used as early as 1914 with roots in the National Bureau of Standards, and formalized as an ASTM B117 specification in 1939 by the American Society for Testing and Materials (ASTM). Test specimens are placed in an enclosed salt spray cabinet or chamber and subjected to a continuous indirect spray of a neutral (PH 6.5-7.2) salt water solution. This climate is maintained throughout the duration of the test

The conductor under test can be placed in salt spray chamber per ASTM B-117 for a defined time frame. A copper conductor that is being substituted can be placed in the same spray chamber.

Electrical resistance, inductance or voltage drop measurements can be carried out before and after the testing on the alternative conductor and the incumbent copper conductor. The percentage change in these attributes before and after the test can be calculated and compared with the changes observed on the copper conductor being tested. A suitable variance on % changes of these attributes should be established as the acceptable range, perhaps a variance range of, say 0-15%.

5.0 Ageing Degradation of Electrical Performance Under Ageing

ANSI C119.4-2011 “Electrical Connectors” covers connectors used to make electrical connections between aluminum-to-aluminum, aluminum-to-copper and copper-to-copper conductors on distribution and transmission lines. It establishes electrical and mechanical test requirements for electrical connectors.

The Temperature Cycling Testing contained in this standard can be used is the method of ageing a specified length on conductor under test.

Like the testing done after the corrosion tests above, the electrical resistance, inductance and voltage drop measurements can be carried out before and after the testing on the alternative conductor and the incumbent copper conductor. The percentage change in these attributes before and after the test can be calculated and compared with the changes observed on the copper conductor being tested.

6.0 Short Circuit Fusing Current

The short circuit fusing current of the alternative conductor can be compared with short circuit fusing current rating of copper being replaced if the conductor is used for conduction of electrical fault current. Examples of such applications would include electrical extra high voltage, high voltage and medium voltage grounding applications.

This comparison of this attribute is not required for the use of the conductor in a typical telecommunications applications, except when establishing suitability to handle lightning currents

The manufacturer would establish the short circuit current rating through calculations or modelling. A test procedure for testing of short circuit fusing current is not proposed.

Test methods for validating fusing currents of grounding components or connectors do exist within UL 467 “Short-time test currents”. These could be extended for use on conductors whereby the conductor could be tested at the rated level according to the manufacturer and the duration taken to fuse the conductor measured.

7.0 Ability to Conduct Lightning Currents

IEC62305 series of lightning protection standards is one of the most widely used lightning protection standards in the world. It states that a minimum of 16 mm2 of copper OR a minimum of 50 mm2 of steel is required to carry a lightning current safely. NESC requires a 6AWG minimum for overhead lightning arresters. It should be shown that the fusing current of the alternative conductor is at least that of 16 mm^2 copper, 50 mm^2 steel or 6AWG conductor.

If testing is used to establish the suitability of a conductor for lightning protection, the IEC62305-1, 10/350µs test wave-shape shall be used. This wave-shape is the more onerous in how much energy it contains. While its use to test surge protective devices is sometimes challenged, its suitability to simulate direct strike lightning strike is well established. Typical currents to carry out the testing could be in the 50 to 100kA range. 10/350µs.

8.0 Galvanic Compatibility and Corrosion Below Grade

Galvanic corrosion occurs when two dissimilar metals are in contact with each other in the presence of an electrolyte. In this circumstance one metal becomes the anode and the other the cathode and they form a galvanic couple. The metal of higher potential becomes anodic, tends to go into solution and therefore corrode. An almost identical condition is obtained in an alloy which is not perfectly homogenous or in a metal of which different parts have been subjected to different heat treatments or mechanical stresses. Under these conditions certain parts within the alloy will have a higher potential than others and in the presence of an electrolyte will tend to corrode. Hence grounding materials that are made of alloy should be treated with care and the composition of the alloy understood.

The electrolyte need only be rain water with impurities dissolved from the air or from the surface of the metal itself. Hence this form of corrosion can occur both below and above ground level. The environment is of primary importance in any consideration of methods for retarding corrosion. Metals which perform well in one environment may be entirely unsuited in another simply because the agents causing galvanic attack differ.

For example, Aluminum has exceptional corrosion performance above ground, in water and when not in contact with new concrete. This is because the aluminum oxide layer that readily forms on aluminum provides excellent corrosion protection. However chlorides such as calcium salts present in soil and new concrete can react with the oxide layer exposing the bare aluminum which corrodes at a rapid rate even under mild condition.

The table below shows the potential developed between dissimilar metals by galvanic action and is expressed in Volts x 10-2. Combinations of metals with values above 0.5 volts should be rejected to avoid excessive corrosion. This table refers only to corrosion due to galvanic action between dissimilar metals in contact. Other types of corrosion like that describe above associated with aluminum also exist. The nearer any two metals are in electrochemical potential the less readily they will corrode.

	ANODIC (-)																						
CATHODIC (+)	SILVER	NICKEL	MONEL METAL	CUPRO-NICKEL(70-30)	COPPER	SILVER SOLDER	BRONZES	GUNMETAL	BRASSES	STAINLESS STEELS	TIN	TIN-LEAD SOLDER	SILVER-LEAD SOLDER	LEAD	GREY CAST IRON	STEELS (NOT STAINLESS)	ALUMINIUM ALLOYS	ALUMINIUM	CADMIUM	GALV. IRON OR STEEL	ZINC BASE ALLOYS	ZINC	MAGNESIUM ALLOYS
SILVER	0	15	17	19	19	21	23	25	26	33	47	48	51	56	71	72	77	77	79	109	110	111	159
NICKEL		0	2	4	4	6	8	10	11	16	32	33	36	41	53	57	62	62	64	94	95	96	144
MONEL METAL			0	2	2	4	6	8	9	16	30	31	34	39	54	55	60	60	62	92	93	94	142
CUPRO-NICKEL(70-30)				0	0	2	4	6	7	14	28	29	32	37	52	53	58	58	60	90	91	92	140
COPPER					0	2	4	6	7	14	28	29	32	37	52	53	58	58	60	90	91	92	140
SILVER SOLDER						0	2	4	5	12	26	27	30	35	50	51	56	56	58	88	89	90	138
BRONZES							0	2	3	10	24	25	28	33	48	49	54	54	56	86	87	88	136
GUNMETAL (RED BRONZE)								0	1	8	22	23	26	31	46	47	52	52	54	84	85	86	134
BRASSES									0	7	21	22	25	30	45	46	51	51	53	83	84	85	133
STAINLESS STEELS										0	14	15	18	23	38	39	44	44	46	76	77	78	126
TIN											0	1	4	9	24	25	30	30	32	62	63	64	112
TIN-LEAD SOLDER												0	3	8	23	24	29	29	31	61	62	63	111
SILVER-LEAD SOLDER													0	5	20	21	26	26	28	58	59	60	108
LEAD														0	15	16	21	21	23	53	54	55	103
GREY CAST IRON															0	1	6	6	8	38	39	40	88
STEELS (NOT STAINLESS)																0	5	5	7	37	38	39	87
ALUMINIUM ALLOYS																	0	0	2	32	33	34	82
ALUMINIUM ALLOYS																		0	2	32	33	34	82
CADMIUM																			0	30	31	32	80
GALV. IRON OR STEEL																				0	1	2	50
ZINC BASE ALLOYS																					0	1	49
ZINC BASE ALLOYS																						0	45
MAGNESIUM ALLOYS																							0

8. Case Study 1: Inductance & Resistance Measurements

Test Setup

In this case study four conductor types were tested: solid 6 AWG copper conductor stranded 6 AWG copper conductor, ERICO CC5A04 composite cable, and ERICO CC5A05 composite cable. All 4 cable types were cut to the same length

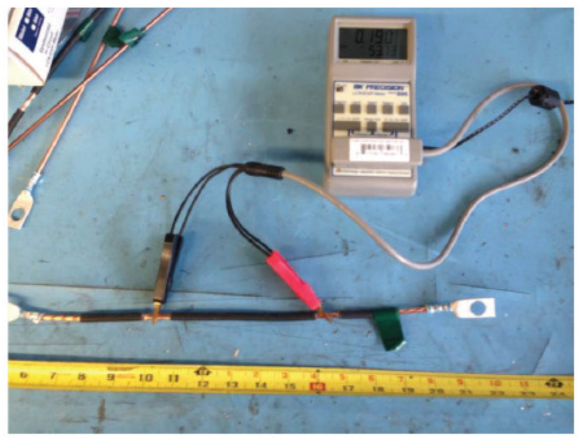
Two samples of each conductor were prepared using compression lugs and two samples using CADWELD lugs. Standard copper lugs for #6 AWG were used for the 6 AWG solid and stranded compression samples.

Standard copper lugs for 1/0 conductor were used for the CC5A04 and CC5A05 composite cable samples. (Penn-Union BBLU-1/0). The same copper CADWELD copper lugs were used for all CADWELD samples (ERICOB922CC14A).

The inductance and resistance of each cable sample was measured and recorded. The resistance was taken using the micro-ohm meter. The probes of the micro-ohm meter were placed 12 inches apart on each cable sample. The inductance was measured using the LCR. The probes of the LCR meter were placed 6 inches apart on each sample.

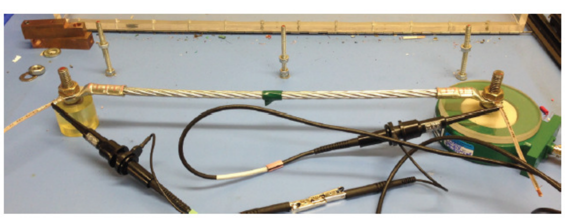
Figure 1: Mirco-ohm meter – Resistance Measurements

Figure 2: LCR – Inductance Measurments



The samples were then tested for voltage drop while experiencing 3kA, 10kA, and 20kA 8x20μs surge currents. Test leads were placed at each lug for connection to the oscilloscope probes. The oscilloscope was then configured to run a math function to subtract probe B from A in order to capture the voltage drop.

Typical Test Setup on Pre-Defined Length of Conductor



Summary of Results

The summary below shows the voltage drop across various conductors measured at 3 different current ratings of the 8/20us test wave-shape. The test were done using CADWELD and compression connections

	Lug Type	Surge Magnitude 8x20µs	Conductor Samples			
			6 AWG Solid	6 AWG Stranded	CC5A04	CC5A05
Average Voltage Drop (V)	Compression Lugs	3kA	199	208	182	185
		10kA	575	583	502	512
		20kA	1172	1114	1054	1065
	CADWELD Lugs	3kA	182	173	157	165
		10kA	545	494	450	482
		20kA	1034	1040	825	864

9. <u>Case Study 2:</u> Salt Fog and Ageing Test

Method

1. Salt Spray Corrosion

Three cable samples of different construction were cut to 12" pieces and both ends were wrapped with electrical tape to ensure the protection of any exposed inner metal that resulted from cutting. The samples were then attached to a rod in the salt chamber at an angle to allow salt spray runoff. The samples remained in the salt spray chamber for 250 hours with observations occurring every 24 hours, noting what kind of oxides how much rust and whether or not the rust seems to be propagating.

2. Conductivity

Samples were cut to 24", with each sample being within 1/8" comparatively to ensure a fair resistance measurement. DC resistance was measured with a 4 probe micro ohm meter with the clamps at both ends spanning the entire 24". Inductance was measured using an LCR meter with the clamps spread at 11", which was as far as possible. Each measurement was recorded three times and recorded.

Prepared samples from left to right- 1, 2, 3

Salt Spray Setup

Figure 7: 24 Hours

Figure 8: 168 Hours

Sample	Conductor Type	MFG	Signs of 1st Rust	Signs of Base Metal Rust	End of Test
1	Tinned Copper	Competitor	White rust within 24 hrs	Red rust at 192 hrs	some white rust, areas of bare copper visible on surface, green film, few small areas of brighter green corrosion
2	Galvanized steel/tinned copper (CC5A05)		White rust within 24 hrs	Red rust at 168 hrs	white rust, small areas of yellow rust, a few areas of dark orange
3	Galvanized steel		White rust within 24 hrs	Green at 168 hrs	white rust, more widespread yellow and darker orange. Areas of very dark orange/brown

Sample	Conductor Type	MFG	DC Resistance Average Per Foot	Inductance Average Per Foot
1	Tinned Copper		.07832 mΩ/ft	.247 µH/ft
2	Galvanized steel/tinned copper (CC5A05)		.4679 mΩ/ft	.252 µH/ft
3	Galva		.9324 mΩ/ft	.277 µH/ft

10. Conclusion

Copper conductors, ground bars and connections have served the industry well for many years in grounding systems. The industry is in search for alternatives to copper for use in grounding, for reasons of copper theft prevention. It has been observed that amount of attention paid to technical attributes of the conductor other than its theft deterrent properties has been limited. The reason for this is that the need to implement theft deterrent solutions has been immediate for many telecommunications carriers and tower operators. The industry could not wait for technical solutions with all the attributes of copper to be available as theft became an endemic problem. This paper proposes a set of methods that could form a good test regime for evaluating alternative conductors for its equivalence to traditional, but theft prone copper conductors.

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