APPLICATION CONSIDERATIONS FOR CONDUCTIVE COATINGS

Conductive coatings are line and field proven as cost effective long term performers when they are applied properly.

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INTRODUCTION

With plastics the product of choice for many electronic equipment enclosures, the designer faces a decision of which shielding approach to use. Cost of the approach, as well as cost and availability of the equipment required to make the approach possible, must be considered. Of all the approaches available, only conductive coatings can be applied without a major capital outlay or specialized equipment and controls. Conductive coatings are line and field proven as cost effective long term performers. They are routinely applied without difficulty in even the most remote locations in the world. All coatings need proper mixing, dilution, application, and quality control to ensure the best performance. This article is intended to give general guidelines for the application of shielding materials.

MIXING

Metal based coatings (silver, copper, or nickel) should be shaken thoroughly prior to opening to assure uniformity. Best agitation occurs with a paint shaker sized to match the specific container size (e.g., a one-gallon container will mix more rapidly on a one-gallon paint shaker than on most five-gallon shakers). Usually, 5 to 10 minutes is sufficient time to mix although longer times may be required depending on storage or shipping conditions. Uniformity is easily checked with a paint spatula. No metal pigment should be left settled on the bottom of the container.

If a paint shaker is not available, agitation with propeller mixers is acceptable — provided sufficient power and rpm is available to produce good paint movement (a vortex). Usually a ¾ hp motor at 1200 to 1400 rpm is sufficient for the task. Only non-explosive motors should be used for mixing solvent borne materials.

THINNING

Conductive materials should be thinned by volume in accordance with the mixing instructions listed on product data sheets. Adjustment of the mix ratio to achieve a target viscosity can lead to different percent solids at the gun. This difference can cause variation in dry film thickness per pass on the part and lead to batch-to-batch resistance variations. Some materials are formulated to be electrically consistent so it is best not to adjust solids to attain a target viscosity as solids affect dry film build which, in turn, affects electrical resistance.

RECOMMENDED SOLVENT BLENDS

With the wide range of plastics in use today, solvent sensitivity is important. The blends given in Table 1 have been line proven to be generally compatible with most product/substrate combinations. Percentages are by weight. The solvents listed may be blended to achieve intermediate drying speeds or to meet altered stress levels in plastic blends.

Type	Components
Fast general purpose	65.3% n-propyl acetate 8.4% n-butyl acetate 2.9% isopropyl alcohol (99% anhydrous) 23.4% toluene
Medium general purpose	55% n-propyl acetate 40% isopropyl alcohol (99% anhydrous) 5% n-butyl alcohol
Slow for solvent sensitive plastics	38% n-propyl acetate 28% isopropyl alcohol (99% anhydrous) 4% n-butyl alcohol 30% diacetone alcohol
Very slow for very solvent sensitive plastics	50% PM solvent 50% butyl cellosolve

Table 1. Recommended Solvent Blends.

PRODUCTION EQUIPMENT

Manual Application

Conventional propeller agitated pressure pots are routinely used with shielding coatings. Pressure pot liners are often used to speed replenishment of the spray pot and for staging the ready-to-spray product in the paint mixing area for higher production rates. Use of a pressure pot liner also speeds the cleanup operation at the end of a run. The use of air motor mixers to reagitate the ready-to-spray product, just prior to pot refill so as to counter settling (even for "non settling" products), is recommended.

ACCEPTABLE PRESSURE-FED GUNS

A pressure-fed gun assembly can be used to apply the coatings. Typical products may be applied via pressure or suction through any medium viscocity lacquer gun. Other tip sizes (0.042″ to 0.080″) may be used to optimize application efficiency.

Smaller gun frames are also routinely used to overcome operator fatigue.

ADDITIONAL PRESSURE TANK INFORMATION

Standard 2-gallon through 20-gallon agitator-equipped pressure tanks are being used successfully in production. To ensure uniform applications, moderate and continuous agitation should be used. Excessive fluid line length should be avoided to minimize line settling and to ease cleanup. Fluid lines should be purged prior to production breaks. Dual regulated tanks allow better independent control of pot and agitator pressure and are recommended over single regulated systems. Enough pressure to attain a fluid stream of 6 to 8 inches and only enough gun pressure to ensure proper atomization (e.g., 5 to 10 pounds on the pot and 20 to 30 pounds at the gun) should be used. This pressure setting will minimize overspray losses and dryspray.

Automated Application

Today, state-of-the-art robot finishing systems are being used to apply conductive materials. Simple reciprocator systems, as well as more complex six-axis robots, easily apply conductive materials to simple or complex housings for high volume shielding applications. The mixing and supply systems remain the same as with standard decorative materials applied with conventional spray guns. For single or multiple spray stations, special recirculating systems enable premixed coating to be added to the paint supply while providing constantly replenished and freshly agitated paint to the spray guns. The combination of robotics for spray, the indexing table for part placement and reorientation, and the recirculation of the paint results in repeatable application consistency, part-to-part. This consistency would be impossible to achieve with manual application.

SETUP

The operator will always retune the gun regardless of how it is set up initially, and other operators will likely use the same equipment on alternate shifts. Because of these changes, it is often helpful to baseline the rate of delivery for each operator at the beginning of the shift to achieve optimum properties at start-up. When part coating quality is acceptable, atomization air is shut off and a stream of paint is squirted into a beaker while the time required to fill a certain volume is monitored. The time and volume for each operator is noted. At the start of each shift, the operator can set the delivery rate in accordance to painting style and then adjust the fan to the desired width. The result is less respray of parts caused by too thin a shield coating and less loss of paint by application of too heavy a film build.

SURFACE PREPARATION

To ensure good adhesion, the use of mold release should be avoided. Parts should be clean and dry before painting. For structural foam housings, sufficient time should be allowed for outgasing. Times will vary with wall thickness and material. Plastic suppliers can offer specific outgasing recommendations. For certain grades of SMC, it is often helpful to detergent power wash and then to dry prior to painting. This procedure aids coating adhesion. Some materials require the use of primers to assure good adhesion retention through heat and humidity cycling.

PART MASKS

Control of application to precise areas requires the use of spray masks. The speed with which the job can be accomplished is well worth the cost of the tools and associated mask washer station. Metal recovered from the mask washer and spray booth can be recycled and can result in significant cost savings.

SPRAYING PROCEDURE

Most conductive materials handle like ordinary paints. They must be applied to achieve a minimum film build. Dryspray can be avoided by using only enough atomization air to attain good atomization of the paint. Excessive air pressure also increases overspray which should be avoided. A gun-to-part distance of 8 to 12 inches should be maintained and strokes overlapped to apply a glossy wet coating. Dry spray should be avoided for lowest resistance readings. A typical dry film thickness range of 1.5 to 2.5 mils is usually applied, although silvers are applied thinner (usually 0.5 to 1.0 mil). Several cross passes rather than one pass should be used to attain greater uniformity of film build.

TESTING

Underwriters Laboratories UL746-C requires 95 percent adhesion of conductive materials per ASTM 3359 method B for shielding materials to be used on recognized electrical equipment. This cross hatch tape adhesion test can be performed easily in the shop on dry coatings with straight edge, razor blade, and tape. First, six parallel lines are cut at ⅛-inch spacing through the coating in the plastic. Then another six parallel lines are cut perpendicular to the first set using the same spacing. Loose particles are brushed away. 3M Number 670 tape is applied to the crosscut area, then removed to determine the amount of coating removed with the tape.

QUALITY ASSURANCE METHOD

Electrical resistance plays a key role in assuring good shielding. Standardization of resistance measuring probe spacing and contact pressure assures repeatable coating ohm readings. A resistance test fixture may be available from the supplier and is often used as the basis for on-line QA testing. Generally, higher than normal resistance results from wet coating, poor mixing, line settling, too thin a coating, or dry spray. In any case, recoating salvages unaccepted parts and maintains excellent yields.

WORKER PROTECTION

Standard industrial hygiene practices mandate the use of recognized dust particle masks to avoid respiration of particulate matter when applying paints. Physical contact with certain compounds may cause allergic dermatitis. However, with modern-day personal hygiene and the use of appropriate protective gloves and clothing, this is not a common occupational problem.

CONCLUSION

Implementation of the guidelines presented here will ensure the high performance and reliable application necessary to conductive coating effectiveness. ■

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Stroke Current kA	Strike Distance rs		Induced Field E (Volt/Meter)	Maximum Induced Voltage V (Volt)	Maximum Induced Current I (kA)
	Meters	Feet			
2	11.94	39.17	49.600	620.000	3.10
3	16.20	53.10	47.800	597.000	2.98
10	39.90	131.00	46.200	578.000	2.89
30	91.00	299.00	44.300	554.000	2.77
100	225.00	736.00	40.500	506.000	2.53

Table 2. Calculations for Induced Currents and Voltages. (For Height of 12.5 Feet)

tall structures the surge impedance of the structure was assumed as in the Example 2. Here methods are described to calculate surge impedance for antennae of various configurations.

Satellite Earth Station Antenna

Figure 11 shows the antenna configuration in a vertical position.

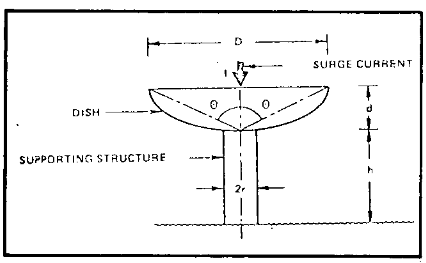

Figure 11. Antenna, Vertical Position.

Z = Surge Impedance
$= 60 \ln (4h/r \sin\theta)$ ohm **(13)**

h = height of supporting structure, ft

r = radius of the supporting structure, ft., or the geometric mean radius

θ = equivalent half cone angle

$\theta = \tan^{-1}(D/2d)$

Where:

D = Diameter of reflector dish, ft

d = depth of the reflector dish, ft

Example 3

Characteristic impedance of an earth station antenna (Figure 12) which has the following parameters is calculated.

D = 444 in

d = 78 in

h = 250 in

and mounted on a three-legged tripod, each of its sides is 125 inches long. The radius of support is five inches each.

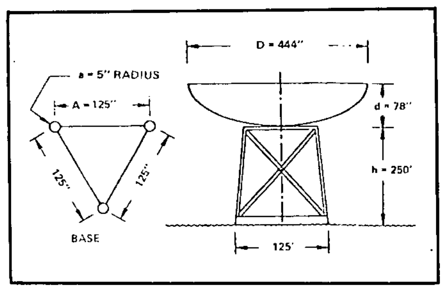

Figure 12. Earth Station Antenna and Base Assembly.

The geometric mean radius

$r = \sqrt[3]{aA^2}$

$= \sqrt[3]{5(125)^2}$

$= 42.73$ in

$\theta = \tan^{-1}(D/2d)$

$= \tan^{-1}(444/156)$

$= 70.64^0$

Z = Surge Impedance

$$= 60 \ln \frac{(4 \times 250)}{(42.73)\sin(70.64)}$$

= 193 ohms

Microwave Self-Supporting Tower:

$Z = 60 \ln(2.828\,h/r)$ ohm **(14)**

h = height of tower (ft)

r = geometric mean radius of the tower cross section in feet (Figure 13).

Three-Legged Tower:

$r = \sqrt[3]{aA^2}$

$\cong 0.46A$ ($a \cong 0.1A$)

Four-Legged Tower:

$r = \sqrt[4]{1.4aA^3}$

$\cong 0.61A$ ($a \cong 0.1A$)

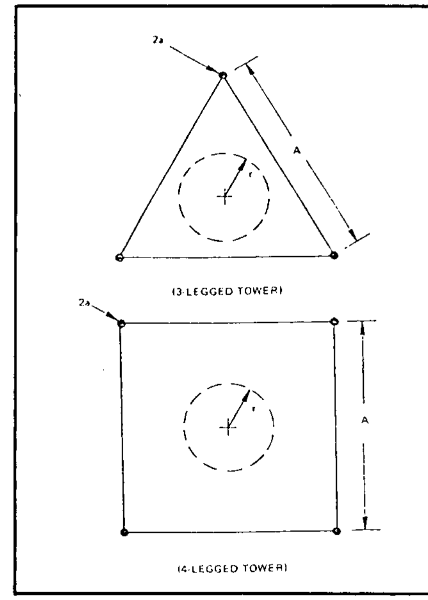

Figure 13. Microwave Tower Geometric Mean Radius.

Example 4

The surge impedance is calculated for a 100-foot self-supporting microwave tower with a rectangular base of four feet.

$r = 0.61 \times 48 = 29.28$ in $= 2.44$ ft

$Z = 60 \ln(2.828 \times 100/2.44)$
$= 285$ ohms

Microwave Guyed Tower:

$Z = 60 \ln(1.414/\sin\theta)$
$+ 60 \ln(2.828L/r)$ **(15)**

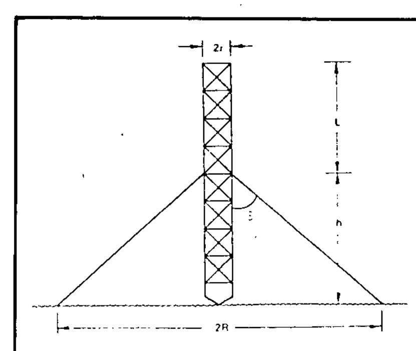

Figure 14. Microwave Guyed Tower Assembly.

Where:

$\theta = \tan^{-1}(R/h)$

h = height of guys, ft

R = distance between base of tower and anchors, ft

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Example 5

The surge of impedance is calculated for a 100-foot guyed tower with a rectangular base of four feet, where the distance between the tower base and the anchors are 50 feet.

Let L = h = 50

$\theta = \tan^{-1}(50/50) = 45°$

Z = 60 in 1.414/sin 45 + 60 in (2.828 x 50/2.44)

= 285 ohms

AERIAL COMMUNICATION LINES

A lightning stroke has a wide range of effects on cable facilities depending upon whether it is a direct hit or near miss (indirect stroke). These effects are also dependent on the type of cable installations and whether they are aerial and underground lines. This article considers the aerial lines which are overhead lines carrying bare conductors (open wire) or conventional lead-sheathed cables.

Direct Stroke

A direct hit on an open-wire line places an unusually high voltage directly on the conductor. Conventional lead-sheathed aerial cables are quite vulnerable to a stroke due to dielectric breakdown of insulation.

Indirect Stroke

The variation in the electric field at ground level near a communication line caused by nearby lightning discharges will produce voltages and currents at the end of the line conductors which depend on the distance between the point where lightning hits the ground and the line (Figure 15). The nearer a lightning stroke is to the line, the higher the voltage induced on the line. The terminal voltage depends on the length of the line; the shorter the line, the higher the terminal voltage due to multiple end reflections of surges, and because short lines will have lower leakage to ground.

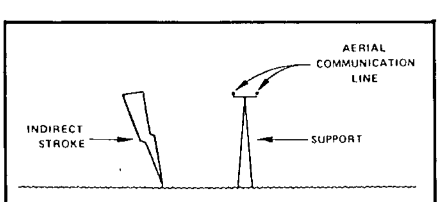

Figure 15. Aerial Line, Near Miss.

The following paragraphs evaluate the influence of aerial lines and the magnitude of induced current and voltages due to lightning charges.

EXPECTANCY OF STROKES:

Unshielded Lines

Aerial lines tend to attract direct lightning strokes from their area of influence. The area of influence is defined as shown in Figure 16 (Eq. 4).

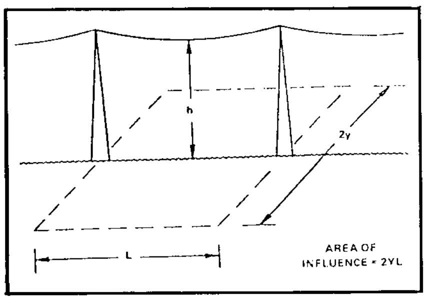

Figure 16. Area of Influence, Continuous Aerial Line.

Continuous Line

Area of influence of line = 2 YL (ft^2)

= 101.6 L $(h)^{0.293}$ (ft^2)

Where:

Y = 50.8 $(h)^{0.293}$ (See Table 1)

h = Height of line clearance above ground at mid-point (ft)

L = Length of the exposed line (ft)

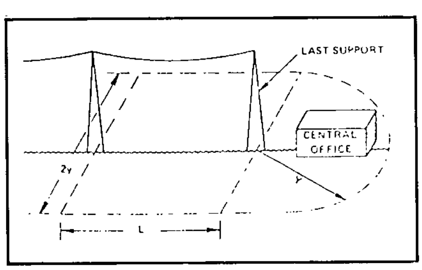

Figure 17. Area of Influence, End of Line.

End of Line

Area of influence of line

= 2 YL + 1.57Y^2 **(16)**

The area in this case is larger than that of the continuous line due to the inclusion of the last support's area of influence; however, the evaluation of the annual number of strokes that will hit the line should be based on the case for the continuous line. The annual number of strokes that will hit the line equals the flash density of the site times the area of influence of the total exposed length. It is customary for cable systems to specify (n_o) which represents the number of strokes to aerial communication lines per 10 mile/year at a flash density of 1 stroke/mile^2/year.

n_o = (0.19) (h)0.293 Stroke/10 mile/year **(17)**

Annual number of strokes per 10 miles = n_o x FD **(18)**

It should be noted that if there is more than one conductor mounted on the overhead line:

Area of influence of line = 2 YL + 2 WL **(19)**

Where:

W = Separation between conductors (ft)

In this case:

n_o = 0.19 x $(h)^{0.293}$ + (0.0038)W Stroke/10 mile/year **(20)**

Figure 18 represents the plotting of Equation 20.

Shielded Lines

If aerial lines are installed in the vicinity of overhead power transmission lines or a forested path, as shown in Figure 19, the stroke current will be limited by an upperbound; this value of current is dependent on the maximum striking distance which is determined by the following equation (Eq. 5,6):

$(r_s)_{max}$ = 0.3 [C2 (y + h) + 2CX$\sqrt{yh}$]/2 (h − y)^2 (meters) **(21)**

$I_{max} = (r_{smax}/7.1)^{1.333}$ **(22)**

Where:

Y = average height of trees, ft

h = average height of line, ft

C = $\sqrt{X^2 + (Y - h)^2}$, ft

x = horizontal distance between tree top and the line, ft

Example 6

The annual number of strokes/10

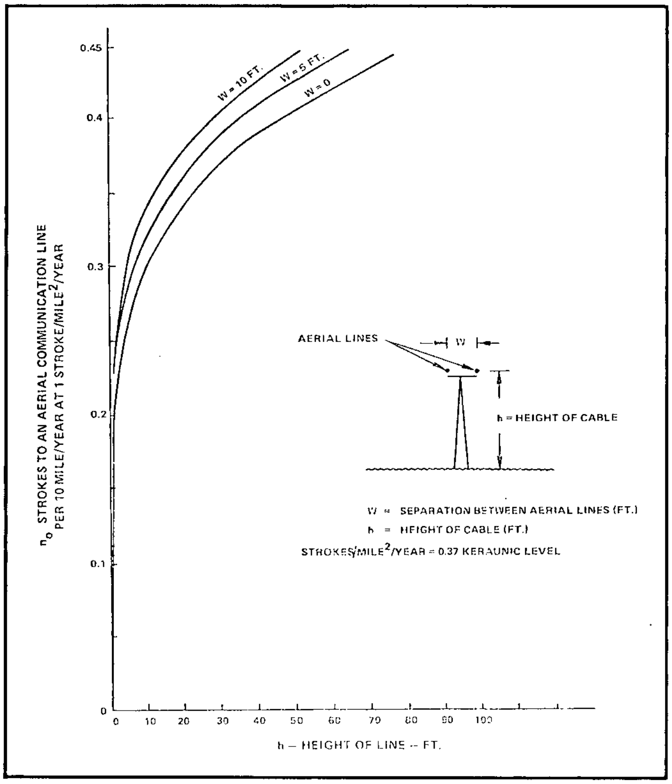

Figure 18. Strokes To Aerial Line, 10 Mile/Year.

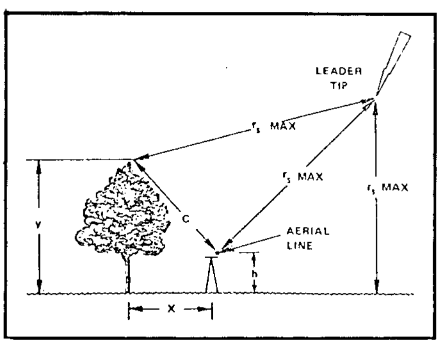

Figure 19. Aerial Line Shielded by Trees.

mile and maximum lightning stroke current for an aerial line which is installed parallel to a power transmission line is calculated as shown in Figure 20. Flash density is assumed to be 15 strokes/mile^2/year.

$$C = \sqrt{(165)^2 + (100 - 30)^2}$$
$$= 150 \text{ feet}$$

$$r_{smax} = 0.3\,[(150)^2\,(100 + 30) + 2 \times 150 \times 165 \sqrt{100 \times 30}]/\,2(100-30)^2$$
$$= 172.5 \text{ meters}$$

$I_{max.}$ = maximum stroke current

$$= [172.5/7.1]^{1.333} = 70 \text{ kA}$$

The horizontal protect area by power line Y_p (Figure 21) is obtained from Equation 4 or Table 1.

$$Y_p = 196 \text{ (ft)}$$

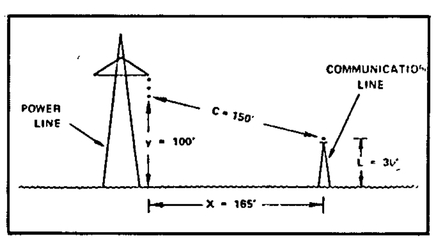

Figure 20. Aerial Line and Power Line.

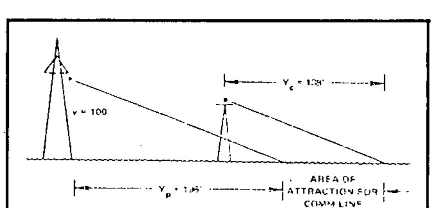

Figure 21. Horizontal Protect Area.

The horizontal protect area is determined by communication line Y_c,

$$Y_c = 50.8 \times (30)^{0.293} \text{ (ft)} = 138 \text{ (ft)}$$

Width of area of attraction for communication line

$$= (X + Y_c) - Y_p$$
$$= (165 + 138) - 196 = 107 \text{ ft}$$

The attraction area of communication line:

$$\text{Width} \times \text{Length} = 107/(1760 \times 3) \times 10$$
$$= 0.203 \text{ mile}^2$$

N = number stroke/10 mile/year

$$= 15 \times 0.203$$

$$= 3 \text{ strokes}$$

It will be interesting to compare (N) with the number of strokes corresponding to (n_o), the unshielded case from Figure 18 for h equals 30, where the corresponding value of n_o was found to be 0.36 stroke/10 mile/year. The number of strokes for an unshielded line is obtained from Equation 18:

$$N_o = 0.36 \times 15$$

$$= 5.4 \text{ strokes}$$

Thus, the percentage reduction of number of strokes due to shielding:

$$(N_o - N / N_o) \times 100$$
$$= (5.4 - 3 / 5.4) \times 100$$
$$= 44.6\%$$

SURGE CURRENTS AND VOLTAGES

Two cases will be considered: direct stroke and indirect stroke.

Direct Stroke

The conductor current in each direction is half the stroke current (Figure 22).

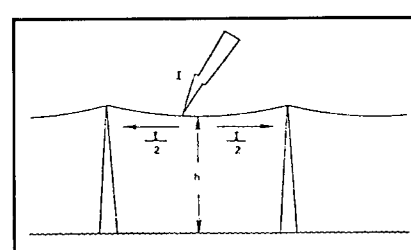

Figure 22. Direct Stroke on Aerial Line.

If the conductor surge impedance is (Z_o) ohms, the voltage at the point of stroke = $(I/2)Z_o$ (kV)

The value of (Z_o) can be calculated from the following equation:

Z_o = 60 in (2h/a) ohm **(23)**

Where:

h = height of midspan (ft)

a = radius of line (ft)

At the open end of line, the terminal voltage will be much smaller than $IZ_o/2$ due to corona losses and leakage to ground due to line capacitance.

Example 7

An aerial line is 20 miles long, the height of the line is 10 feet above ground and the radius of the cable is 4 inches. What is the anticipated annual number of strokes on this line if the average flash density is 15 strokes/mile^2/year and maximum voltage and current due to direct stroke is 30 kA.

Average flash density equals 15 strokes/mile^2/year. From Figure 18:
W = 0
L = 10
N_o = annual strokes per 10 mile/year
= 0.3

Number of Annual Strokes = (Length of line/10) x n_o = (20/10) x 0.3 = 0.6 strokes

Maximum stroke current due to direct stroke
= 30/2
= 15 kVA

Maximum voltage on line to lightning surge equals 15 Z_o.

Z_o = Surge Impedance of line in ohms

= 60 in (2h/a) ohms

$= 60 \ln (2 \times 10)/0.17 = 287$ ohms

Maximum voltage $= 287 \times 15$

$= 4{,}300$ kV

Indirect Stroke

Figure 23 illustrates the geometry of the closest approach of an indirect stroke.

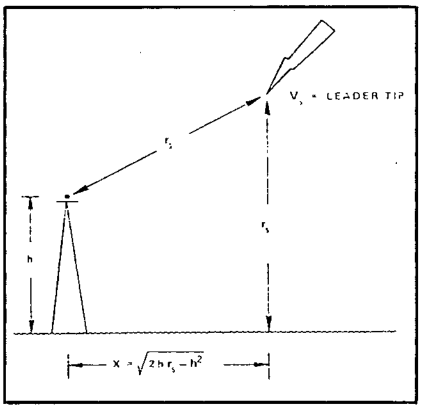

Figure 23. Indirect Stroke on Aerial Line.

The maximum induced voltage on the line is approximately 5:

$$\text{Max}V_{induced} \cong hE \text{ (volts)} \qquad \textbf{(9)}$$

Where:

$$E = \frac{1.07 \times 10^5 (r_s)^{0.83}}{(r_s^2 + X^2)^{1/2}} \text{ (volt/meters)} \qquad \textbf{(10)}$$

$$r = 7.1(I)^{0.75} \text{ (meter)} \qquad \textbf{(1)}$$

I = stroke current in kilo-amperes

$$\mathbf{X^2 = 2(h)(r_s) - h^2 \text{ (meter}^2\text{)}} \qquad \textbf{(11)}$$

If the line is protected by a surge protector having a ground resistance R_o (ohm):

Maximum current in the protector $= hE/R_o$ **(24)**

Example 8

The voltage induced by the closest indirect stroke from 16 kA is calculated on a communication line 10 feet high and 4 inches in diameter.

$r_s = 7.1(I)^{0.75} = 7.1\,(16)^{0.75}$

$= 56.83$ meters

$X^2 = 2(10)/(3.28)\,(56.83) - (10/3.28)^2$

$= 337.22$ meters^2

$E = 1.07 \times 10^5 (56.83)^{0.83} / (56.83)^2 + 337.22^{1/2}$

$= 51{,}232$ volts/meters

$V_{induced} = 51{,}232 \times 10/3.28$

$\doteq 156$ kV

If the line has a surge protector, and the ground resistance of the protector is 200 ohms, the current in protector (I).

$I = 156/200 = 0.78$ kA $= 780$ A

FLASHOVER VOLTAGE

Air at normal atmospheric pressure and temperature breaks down at 30 kV/cm (peak or crest value). For a conductor, this stress may be determined from the expression:

$$E = V/30a \ln(h/a) \text{ kV/cm} \qquad \textbf{(25)}$$

Where:

V = voltage on conductor, kV

a = radius of conductor, ft

h = height of conductor above ground, ft

Example 9

In Example 8, it was found that the induced voltage on the conductor is 156 kV. Equation 25 can be used to determine whether or not a breakdown in air will result.

$E = V/30a \ln(h/a)$ kV/cm

$V = 156$ kV

$h = 10$ feet

$a = 2'' = 0.17$ feet

$E = 156/[(30 \times 0.17) \ln (10/0.17)]$

$= 7.66$ kV/cm

which is smaller than 30 kV/cm, i.e., no breakdown in air will result. ■

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