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Estimating the Effects of Lightning on Antennas

Specific parameters can be used to model the typical strike for the purposes of estimating the coupling and illustrating effects.

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Introduction

It is important to estimate the effect of lightning on a typical antenna system in order to determine risk of damage, and to estimate the requirements of a suppressor capable of meeting that threat. What is presented here is a simplified method for sizing the risk, and a method for determining the appropriate parameters for a surge suppressor. While this is to show typical effects, it should be noted that it is common practice to select a suppressor with approximately a ten-fold safety margin due to inaccuracies in modelling these types of events. Also, since the model presented here does not include direct column or branch attachment effects, *this does not show worst-case conditions, but rather reasonable design levels that are useful where safety is not involved*.

The effects of lightning on modern antenna systems originate from two primary sources:

• *E-field coupling* into the exposed antenna.

• *Current injection* into ground, including manmade structures such as towers.

In order to model these two effects, the threat parameters must first be characterized. Despite the fact that there can be variations in lightning in nature, parameters can be used to model the typical strike for the purposes of estimating the coupling and illustrating effects (Table 1).

Parameter	Magnitude
E Field	500 kV/m
Peak Current	90 kA
Pulse Width	20 µs
Voltage Rise Time	1 µs
Current Rise Time	<5 µs

Table 1. *Lightning Characteristics at 100 m.*

Antenna Coupling

Estimates of the open circuit voltage, short circuit current, and the maximum energy coupled into a monopole antenna yield

$$V_{oc} = H_{eff} \times E \quad (1)$$

where

H_{eff} = Effective antenna height, or about one half the physical height, and

E = Electrical field strength in V/m.

The short circuit current of the antenna is approximately

$$I_{sc} = c \times d\,(V_{oc}(t))\,/dt \quad (2a)$$

or for the initial rise time,

$$I_{sc} = c \times V_{oc} / t_r \quad (2b)$$

where

c = antenna capacitance in pF, and

t_r = pulse rise time in seconds.

The capacitance of a monopole antenna, in pF, can be modeled as:

$$c \cong 24.2 \times h / (\log(2h/d) - .7353) \quad (3)$$

where

h = the physical height of the antenna above its ground plane, in meters;

d = the diameter of the antenna.

The estimates of the voltage and current and derived information such as the coupled energy are given for a range of antenna lengths (Table 2).

Note that to protect and last an acceptable lifetime a protector would need the current capacity for a time duration of the rise time of the pulse, on the order of 10 times or more than the current listed in Table 2.

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Monopole Antenna Length (m)	Antenna V_{oc} (kV)	Antenna I_{sc} (A)	Maximum Energy (J)
0.25	63	0.03	0.02
0.5	125	0.11	0.14
1	250	0.44	1.1
2	500	1.77	8.8
5	1250	11.05	138
10	2500	44.20	1105

Table 2. *Antenna Voltage Pick-up.*

Current Injection Coupling

The direct effect of the lightning current into the earth and man-made structures is to produce voltage potentials and currents across resistive and inductive impedances. These voltages are estimated respectively by:

$$V = i(t)\ (\rho/2\pi)\ /\ (1/r_1 - 1/r_2) \quad (4)$$

and

$$V = L\ (di/dt) \quad (5)$$

where

i = Lightning current

r_1 = Distance from the lightning injection point to the nearest end of the shielded cable

r_2 = Distance to the far end of the cable

ρ = Soil resistivity, and

L = Inductance of any lightning current path in the direction of the cable.

The inductance is usually 5 to 100 nH per meter of length for most structures and towers. Typical soil resistivities are 25 to several hundred Ω-m.

Note that the current limit i_{sc} for the shield to ground is nearly unlimited, and can approach a large portion of the value of the lightning current, while the differential or normal mode current is limited by the voltage divided by the source and load impedances. Also note that these voltages are orthogonal phase vectors, which are not directly additive.

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An example is the voltage for a 200-meter RG-402 cable run, 100 meters along the ground and 100 meters up a building and tower (Figure 1). For the lightning parameters listed in Table 1 and for the site parameters listed in Table 3 the values in Table 4 result.

Thus, the electrical energy is again significant, with an even higher current than antenna coupling into the source/load of 50 ohms. Actually, the current through a shorting type suppressor can be considerably higher, as a shorting device will provide much less than 50 ohms of impedance. In this case the current is limited by the resistance and impedance of the center coaxial conductor, or about 5.3 ohms.

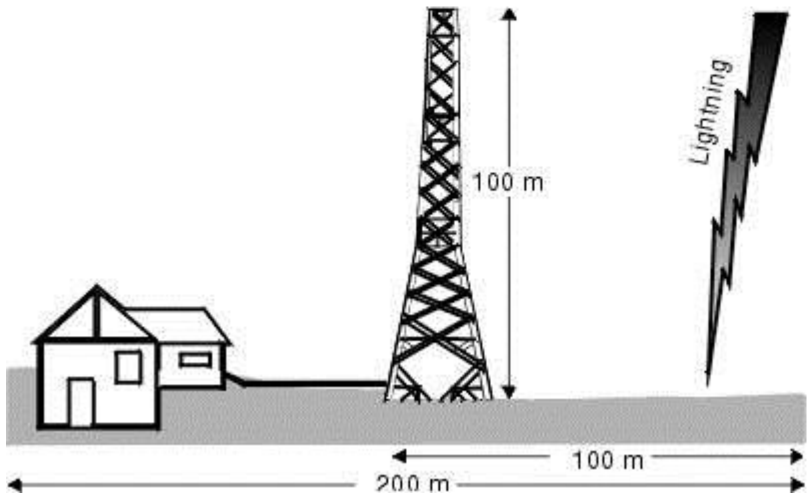

Figure 1. *Typical Antenna Configuration.*

Parameter	Value
Antenna Wiring Inductance	0.5 mH
Soil Resistivity	150 Ohm-m
Source/Load Impedance	50 Ohms
Distance (r1) to near end of cable	100 m
Length (r2) to far end of cable	200 m

Table 3. *Sample Site Parameters.*

Parameter	Value
Current	90 kA
Resistive Voltage	10748 V
Inductive Voltage	4500 V
Total Voltage	11652 V
50-Ohm Differential Current	117 A
Shorted Differential Current	2200 A
Energy	3.1 J

Table 4. *Current Injection Energy.*

Conclusion

It can be seen that the physical layout of antennas alone provide considerable energy pick-up, and the cable run itself can provide significant energy coupling, even if the cable provides full shielding of the center conductor. This effect is highly influenced by the intentional and unintentional grounding of the shield including parasitic capacitance and inductive coupling and the geometry of the installation.

If suppressors are required for preventing hazards to humans, or if maintaining equipment operation has critical economic or safety applications, usually one or more of the following is required: a more detailed estimate of threats, redundant systems for failure resistance, or multiple levels of protection with testing and maintenance programs.

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