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HIGH CURRENT PULSE TESTING FOR GROUND ROD INTEGRITY

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ABSTRACT

A test technique was developed to assess various grounding system concepts used for mobile facilities. The test technique involves applying a high current pulse to the grounding system with the proper waveshape and magnitude to simulate a lightning return stroke. Of concern were the step voltages present along the ground near the point of lightning strike. Step voltage is equated to how fast the current pulse is dissipated by the grounding system. The applied current pulse was produced by a high current capacitor bank with a total energy content of 80 kilojoules. A series of pulse tests were performed on two types of mobile facility grounding systems. One system consisted of an array of four 10 foot copper-clad steel ground rods connected by 1/0 gauge wire. The other system was an array of 10 inch long tapered ground rods, strung on stainless steel cable. The tests were performed by personnel from the Wright Laboratories Aero Propulsion and Power Directorate and the 1839 Engineering Installation Group of the Air Force Communications Command. The tests were performed adjacent to a concrete pad at the top of what is known as the Accelerated Runway in Area B, Wright-Patterson AFB. This paper focuses on the pulse test technique used and its relevance to actual lightning strike conditions.

INTRODUCTION

A series of tests using high current pulses similar to lightning return strokes were performed to evaluate the risk to personnel and equipment from the step potentials generated near grounding systems during lightning strikes [1]. Two types of grounding systems were evaluated. One system employed the conventional long ground rod and the other used a short rod. A low resistance to ground was achieved by the short rod system by employing a larger number of ground rods than the conventional type.

LIGHTNING SIMULATION TEST

The tests were conducted to determine the effectiveness of the grounding systems in dissipating the energy from a lightning stroke. The more rapidly the lightning currents could be dispersed throughout the soil the lower the step potentials would be. The problem facing the test program was that in actual use a grounding system would not have the current return path as in the test circuit. In reality the lightning currents would disperse into the ground. This phenomenon had to be duplicated to some degree to insure that the test was realistic and was valid. The following sections describe the test setup and how this current dispersion was achieved and validated.

TEST SETUP

Current Pulse Generator. The current pulse was produced by a generator consisting of two capacitor banks, each with a capacitance of 8 microfarads. Each capacitor bank can be charged to 100 kilovolts resulting in a total charge voltage, when triggered, of 200 kilovolts and a resultant capacitance of 4 microfarads. Total energy content of the pulse generator is 80 kilojoules. The output current waveshape was a damped sinusoid with parameters such as current rate-of-rise, peak magnitude and fall time determined by generator capacitance, C, total circuit inductance, L and circuit resistance, R. The current pulse generator is shown in Figure 1 in place at the test site.

Test Site and Ground System. The test site had to be an open area with standard soil conditions with approximate earth resistivity, ρ of 10^2 to 10^3 ohm-meters. The site had to be large enough to accommodate a ground rod system and have the simulated lightning return stroke currents dissipate evenly into the surrounding soil. There could not be any drainage pipes, electrical conduits or unknown buried debris where the ground array was located.

The test site chosen was adjacent to the top of the Accelerated Runway, a sloping concrete area in Area B at Wright-Patterson AFB. At the top of the Accelerated Runway there is a level concrete pad. This was an ideal location for the AC power generators, the capacitor banks producing the simulated lightning pulse and supporting control equipment, and the van housing the data acquisition equipment. The ground systems tested were placed in the soil adjacent to the concrete pad so that the length of the leads from the capacitor bank were kept to a minimum. An effort was made to maintain a low inductance test circuit by using 12" wide aluminum flashing for the leads. The return lead to the capacitor bank was not directly connected to the ground array. Instead, a separate rod was driven to a point below the soil surface and adjacent to one of the array ground rods and the return lead was attached to this separate rod. What was then created was a gap below the surface that the pulse current had to arc across. This circuit configuration encouraged the pulse current to diffuse into the soil and not flow along the wires connecting the ground rods on the surface.

INTERACTION OF LIGHTNING RETURN STROKES AND GROUND ROD SYSTEMS

When lightning strikes a ground rod or ground rod array a situation exists as shown in Figure 2. The current, I, disperses radially in a hemispherical fashion [2]. The current density, J, in amperes per square meter, at a distance, X, in meters from the center of the hemisphere is:

$$J=\frac{I}{2\pi X^2} \quad Amps/meter^2 \tag{1}$$

If ρ is the resistivity of the earth in ohm-meters, the current density produces an electrical-field strength, E, given in volts per meter as:

$$E=\rho J=\frac{\rho I}{2\pi x^2} \quad volts/meter \tag{2}$$

The step potential, V, created by the current pulse on the surface of the ground is a line integral of the E field strength from the point of attachment to any distance X. If:

$$V=\int_0^x Edx=\frac{\rho I}{2\pi}\int_0^x \frac{dx}{x^2} \quad volts \tag{3}$$

then:

$$V=\frac{\rho I}{2\pi}\int_0^x x^{-2}dx=-\frac{\rho I}{2\pi x} \quad volts \tag{4}$$

With the step potential directly proportional to soil resistivity and lightning current, and inversely proportional to distance from the lightning strike, the step potential between point a and point b as illustrated on Figure 2 can be minimized by insuring that the lightning current will flow along a good conductive path which includes the ground rods, interconnecting leads and low soil resistivity.

TEST TECHNIQUE VALIDITY

As noted previously, the test was performed with an additional gap located below ground. When the pulse generator was triggered the pulse current would flow along the ground rod system and into the ground. Evidence of this taking place was found when the ground rod adjacent to the return path rod was dug up. Pitting and discoloration of the ground rod was observed at the point where arcing would occur. The breakdown of that gap below ground can be observed as discontinuity on the measured step potential waveshape. Figure 3a and 3b show an applied current pulse and a step potential. The voltage waveshape is upheld until the buried gap breaks down and then is abruptly truncated. This buried spark gap would not exist in reality but for the first tens of microseconds an accurate simulation takes place where the test results can be recognized as valid data. Also, pitting and burning were detected where the steel wire ground lead interfaces with the short ground rods. This is evidence of the simulated lightning current arcing from the leads to the ground rod to ground. In actuality, this is what would happen as the currents flow to ground and disperse through the soil.

Further proof of validity is shown by viewing Figures 4a and 4b, showing the locations where the step potentials were measured. Profiles of these voltages are shown in Figures 5a and 5b. The voltages are highest near the point of current application. They decrease and increase in relation to how close the measured voltages are to the ground rod. When the step voltage is measured outside of the ground rod configuration a gradual decrease is observed. If all current were flowing on the ground rod interconnecting wires no discernible step voltage would be observed.

CONCLUSIONS

There are many factors that determine whether or not a good, low impedance ground system can be formed. Soil characteristics are a dominant factor. The proper moisture content and granularity are important to insure low impedance. Resistance to earth measurements of the ground system can insure the system is properly installed. This paper has shown that a high current pulse technique can be used in addition to the resistance to earth measurements to depict a ground system under the dynamic effect of a lightning strike. Through a controlled dispersion of the simulated lightning currents and measurements of surface step voltages the proper safe design of a ground system can be attained.

REFERENCES

1. Bailey, J. W.: **Surface Wire Grounding System Step Potential Study, 1839 EIG Engineering Report Number EMC-89-29**, Aug. 1989.

2. Taylor, R. E.: **Radio Frequency Interference Handbook**, NASA SP-3067, 1971.

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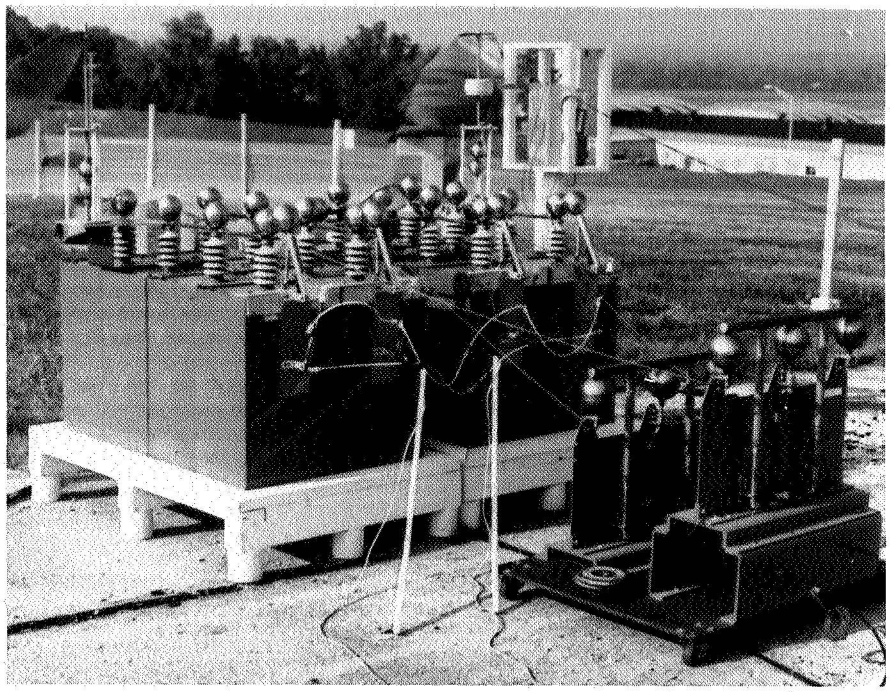


Fig. 1. CURRENT PULSE GENERATOR

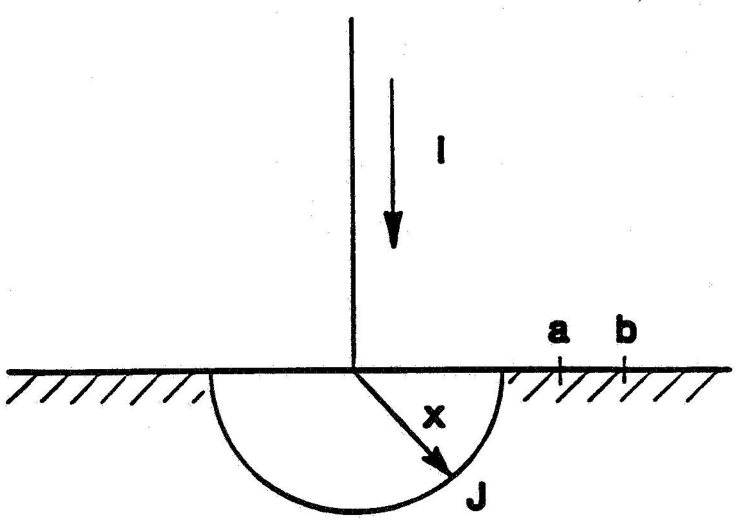
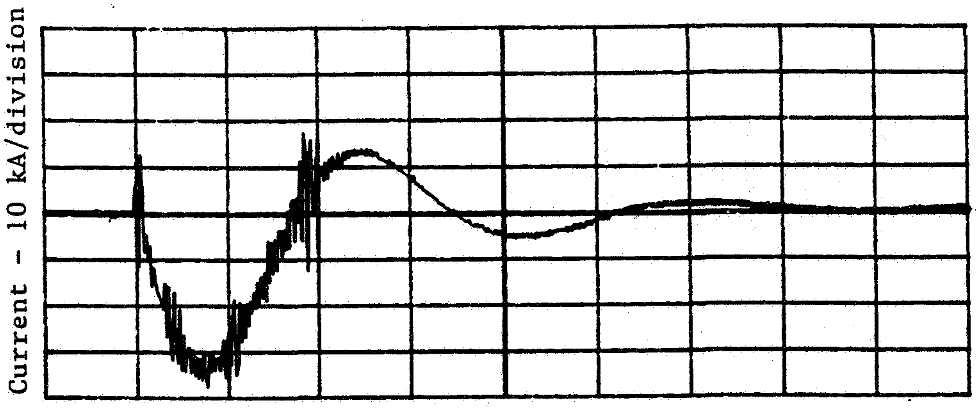
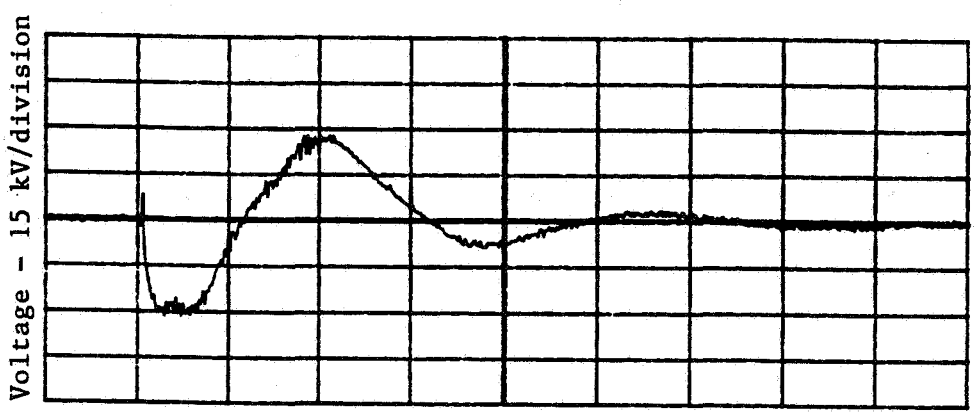


Fig. 2. LIGHTNING CURRENT DISPERSION IN EARTH SHOWN AS CURRENT DENSITY, J, AT X DISTANCE FROM POINT OF LIGHTNING ATTACHMENT



Time - 20 μs Per Division

Fig. 3a. APPLIED LIGHTNING CURRENT



Time - 20 μs Per Division

Fig. 3b. MEASURED STEP POTENTIAL

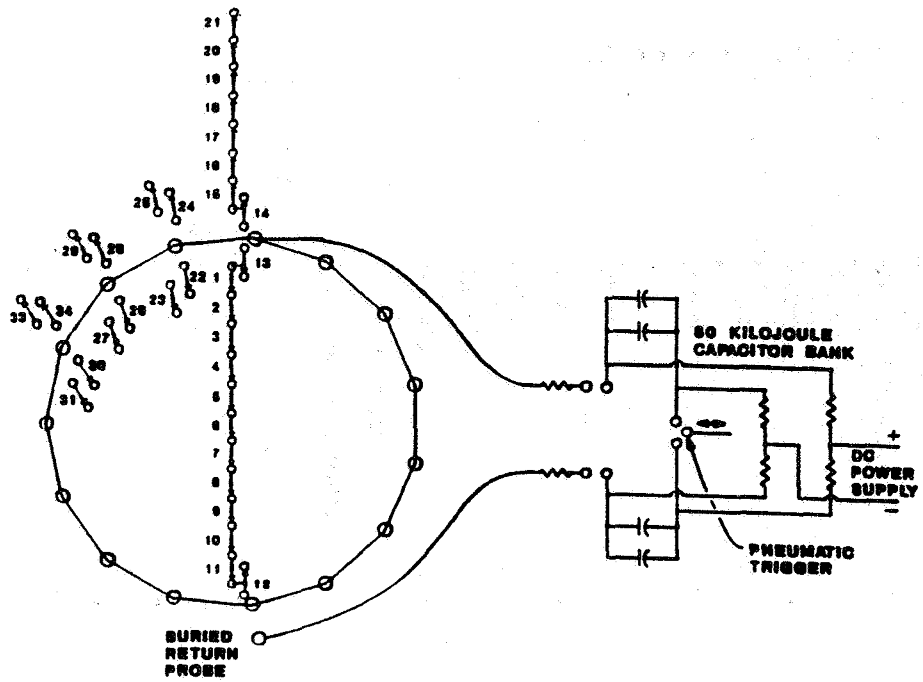


Fig. 4a. SHORT GROUND ROD SYSTEM

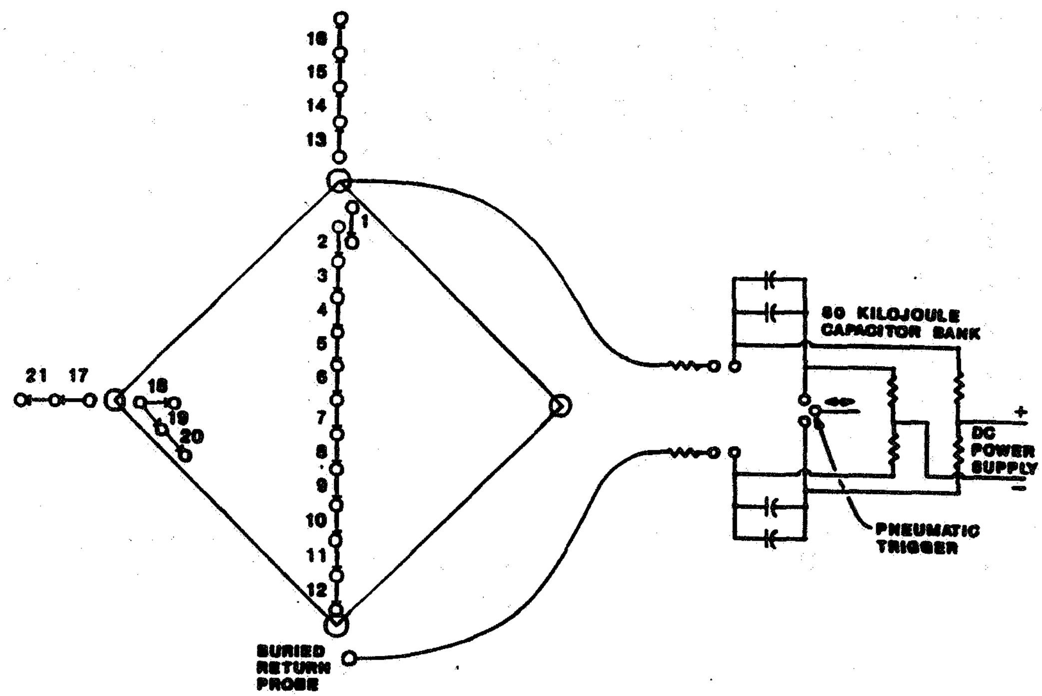


Fig. 4b. LONG GROUND ROD SYSTEM

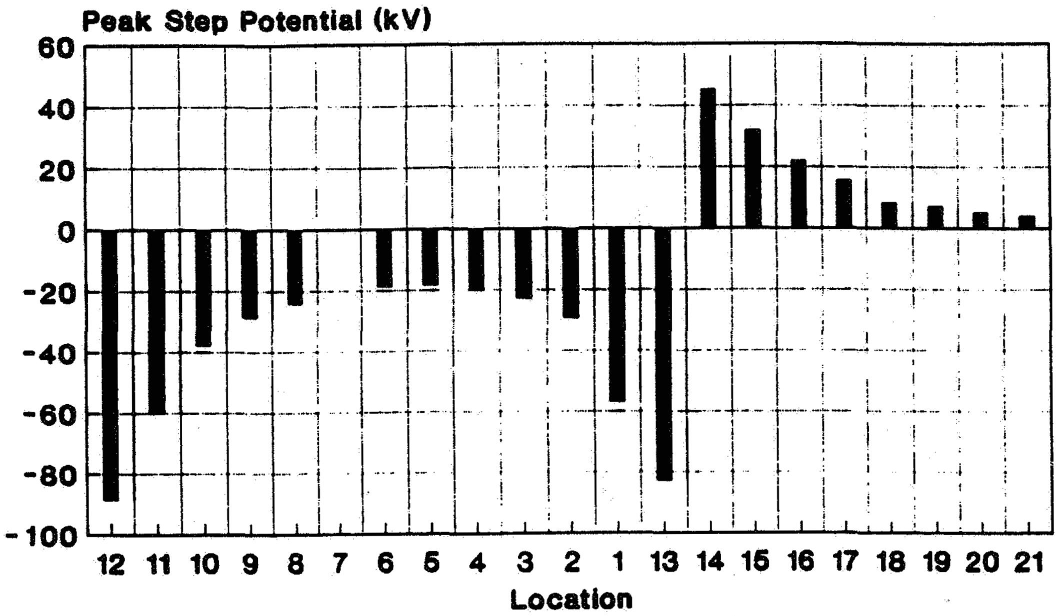


Fig. 5a. SHORT GROUND ROD SYSTEM

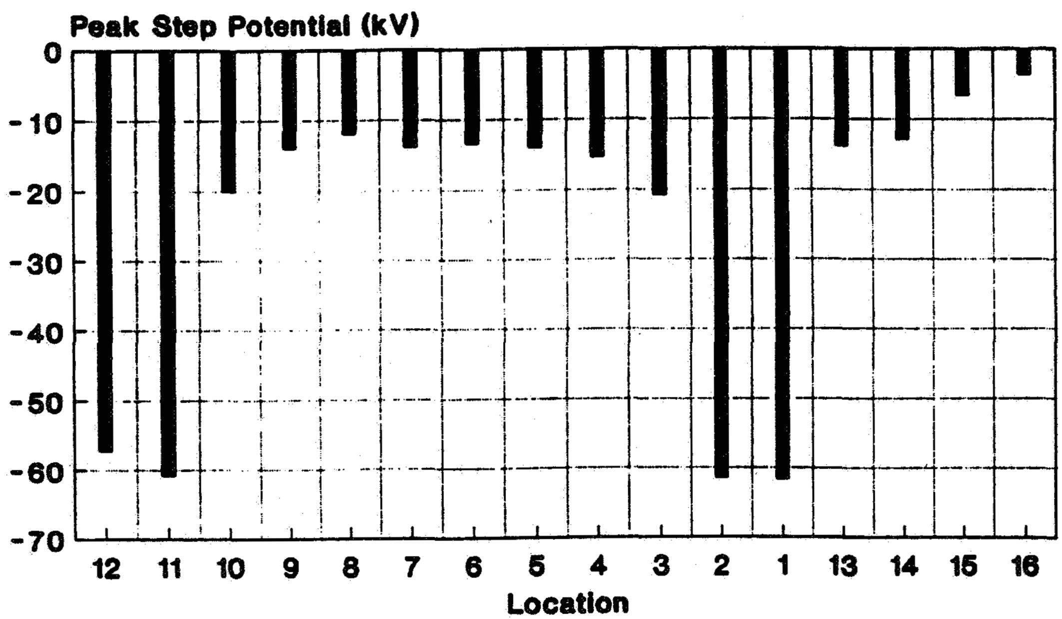


Fig. 5b. LONG GROUND ROD SYSTEM

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