Sensor Note XVIII

Electric Field Sensor for EMP Simulators

This sensor note describes an electric field sensor utilizing the plate antenna configuration of Wilson[1] developed for use in an EMP simulator.* The purpose of this sensor development was to design a small sensitive unit to make measurements inside shielding containers exposed to large-electromagnetic-field environments and also to make measurements directly in the large-field environment to calibrate the simulation facility. For both these measurements, it is very desirable to eliminate the conductors usually connecting the antenna or antenna-preamplifier to a remote receiver and metering facility. In the case of measurements within a shield enclosure, fields will be coupled from outside to inside by these conductors, and in the case of calibration measurements the fields are distorted. To eliminate these conductors, either an optical link or a high-frequency RF link can be used. For shielded-enclosure measurements using an RF transmitter, the signals from the preamplifier must be connected to the RF transmitter which must be located outside the enclosure; this allows coupling of fields into the enclosure. The optical transmission of the preamplifier output signals to the receiver eliminates entirely the coupling and distortion problems.

The electric field sensor considered here is composed of a small plate antenna, a preamplifier, a modulated light source, and optical transmission line, and a light receiver and demodulator. The preamplifier and light transmitter were placed inside one of the antenna plates which provides shielding from extraneous field pickup and eliminates the distortion of the fields by the usual antenna

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1 C. T. R. Wilson, "On Some Determinations of the Sign and Magnitude of Electric Discharges in Lightning Flashes," Phil. Trans., Vol. 221A, pp. 73-115, (1916).

* This unit was developed under contract to USAERDL, Fort Belvoir, Virginia.

connecting wires. To permit placing the preamplifier in one of the plates and yet minimize the overall size, the antenna was made asymmetric. The size of the preamplifier--and therefore the size of the plate containing the preamplifier--was determined mainly by the size of the batteries and the range switch. Seven sensitivity ranges and a battery life of approximately 18 hours were provided. Measurement of field strengths of 3 mV/m to 300 kV/m is possible in a 1-MHz bandwidth, with correspondingly better sensitivity for a narrower bandwidth. The prototype sensor is shown in Fig. 1. The unit is 4 inches in diameter and stands 3-1/4 inches high; the cylinder containing the preamplifier and the light transmitter is 2-1/2 inches high, so that the plate spacing is 3/4 inch.

The preamplifier was designed to offer optimum broad-band signal-to-noise ratio when operated with the capacitive plate antenna. The antenna equivalent circuit is an 8-pf capacitance with a voltage source which is directly related to electric field strength (independent of frequency). The source impedance seen by the preamplifier thus varies with frequency, being about 20 MΩ at 1 kHz and decreasing as frequency increases; this impedance is a poor noise match for a conventional bipolar transistor, but it matches a small-geometry field effect transistor (FET) quite well. Preamplifier noise temperature can be maintained below 50°K over the frequency range from less than 1 kHz to 1 MHz. In the three most sensitive attenuator positions, the antenna is loaded only with the input capacitance of the preamplifier ($\approx$ 8 pf) and a 30-MΩ bias resistor. On the less sensitive attenuator positions, various shunt capacitances are added across the antenna terminals. Therefore, the antenna is sensitive to both the electric field strength and the electric displacement current. (The voltage on an open-circuit plate antenna would be sensitive only to the electric field strength.) This is, of course, no problem for free-space measurements, where the electric field strength and displacement current are related by the constant free-space permittivity, and the sensor calibration is made in a free-space environment. The capacitive attenuator provides a response constant with frequency.

The preamplifier contains a seven-position attenuator (20-dB/step) followed by the FET and a conventional feedback amplifier to drive a gallium arsenide light-emitting diode. The light is amplitude modulated with the preamplifier output signal and applied to a 20-mil fiber optic light pipe. The light pipe carries the signal to the remote receiver. The basic limitation of the light pipe is its inefficiency--about 1.5 dB of loss for every meter of length. This gives a loss of about 20 dB for the 15-meter length used with the system developed. Another basic limitation is the poor quantum efficiency of the gallium arsenide diode, which is less than 0.001 photon/electron. The quantum efficiency of the light-receiver sensor (silicon PIN photodiode) is approximately 0.5 electron/photon. This represents about 106 dB of loss between the preamplifier output and the input to the light-receiver amplifier; i.e., for a maximum 100 mA of modulation current, the current into the light receiver amplifier is 0.5 μA. The dynamic range of the system is then determined by the ratio of this 0.5 μA to the minimum detectable current in the light-receiver amplifier. By using a low-noise FET amplifier, the minimum detectable current in a 1-MHz bandwidth is approximately 5 nA, providing a dynamic range of 80 dB; for narrow-band operation, the dynamic range can be correspondingly increased.

This sensor illustrates the basic technique of making an electric field measurement at a point in space without appreciably distorting the fields measured. Variations of this technique include miniaturizing the sensor where long battery life and high sensitivity are not required, reducing the preamplifier input capacitance to allow true electric field measurements, and making the preamplifier input a low impedance to allow displacement current measurements. The capability of electrically isolating the sensor is of course extremely useful for testing the performance of experimental antennas exposed to uniform undistorted fields.

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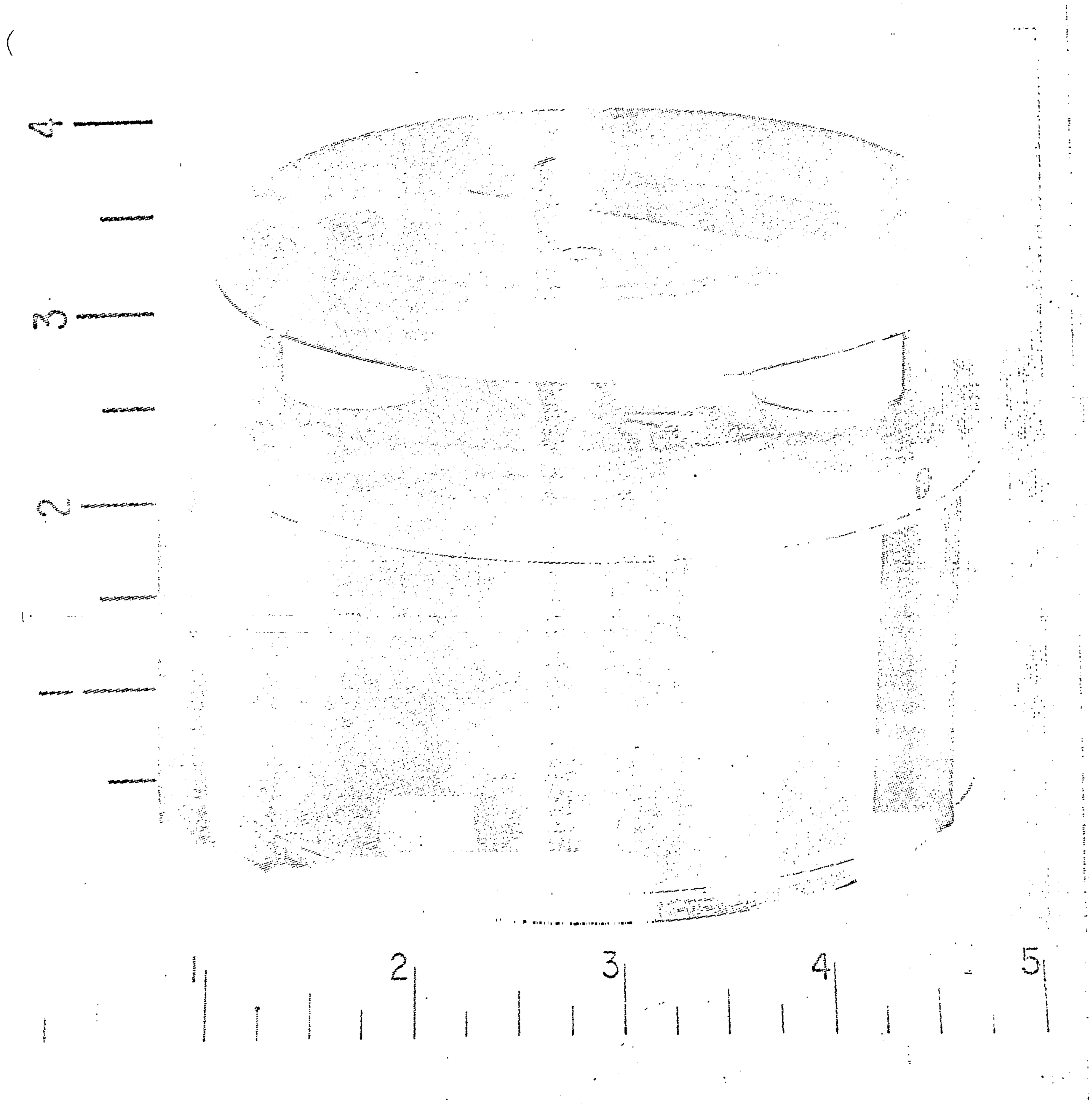
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