Sensor and Simulation Notes

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# A Technique for Measuring Electric Fields Associated with Internal EMP

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Abstract

Using wire grids we can measure the electric fields associated with Internal EMP. With small enough wires the charge accumulated during a pulse of $\gamma$ rays (or X rays) produces a signal much less than that from the fields in the cavity.

## I. Introduction

As has been known for some time, electromagnetic fields are generated by $\gamma$ and X rays in passing through evacuated cavities.[1] This phenomenon has been generally referred to as Internal EMP. The purpose of this note is to describe a technique for measuring the potentials associated with the space-charge electric fields produced in such cavities.

Consider measuring the electric field by measuring the potential difference between some position inside the cavity and the cavity wall, or between two positions inside the cavity. We shall treat the former case since the latter requires only a slight extension in the technique. In EMP Theoretical Note IX we have considered some of the phenomena associated with placing electrodes in evacuated cavities exposed to intense $\gamma$-ray fluxes. Under certain circumstances the solid electrodes can measure the potential in the cavity due to the space charge from the Compton electrons. However, this measurement depends on the proper differencing of the currents into and out of the electrode. This accurate differencing of the currents may be difficult to achieve in many practical circumstances due to many effects, such as the divergence of the high energy Compton electrons from the forward direction. Thus, if we wish to measure the potential inside the evacuated cavity it would be desirable to have a better technique.

## II. Measurement Technique

Figure 1 illustrates the measurement technique. The general idea is to use an electrode which presents a sufficiently small cross section to the $\gamma$ rays (or X rays as appropriate) and to the resulting electrons in the cavity. We can try to make the noise signal introduced in a wire grid small compared to the signal from the potential in the cavity. We shall consider only the case of a single flat grid in parallel plate geometry, but this can be easily extended to two (or more) grids. Also, this technique should apply (using appropriately shaped grids) to the cases of cylindrical and spherical geometry considered in EMP Theoretical Note V.

Consider first the open circuit voltage on this grid due to the Internal EMP and compare this with the open circuit noise voltage due to photon and electron interaction with the grid. Assuming no photon or electron interaction with the grid and removing any resistive load, R, from the grid we have an open circuit voltage[2]

$$V = \frac{J_o}{v_z} \frac{1}{8\varepsilon_o} (d^2-4z^2) \tag{1}$$

where $v_z$ is the mean value of the electron velocity in the z direction (or more accurately the reciprocal of the mean value of the reciprocal of the electron velocity in the z direction), $J_o$ is the current density (negative) in the z direction, and $\varepsilon_o$ is the permittivity of free space. Note that in this parallel plate geometry (figure 1) the grid has been placed along what is, to first order, an equipotential (a plane of constant z). Equation (1) only applies within

1. See, for one example, Lt Carl E. Baum, EMP Theoretical Note V, Unsaturated Compton Current and Space-Charge Fields in Evacuated Cavities, Jan. 1965.
2. Ref. 1, equations (8) and (20).

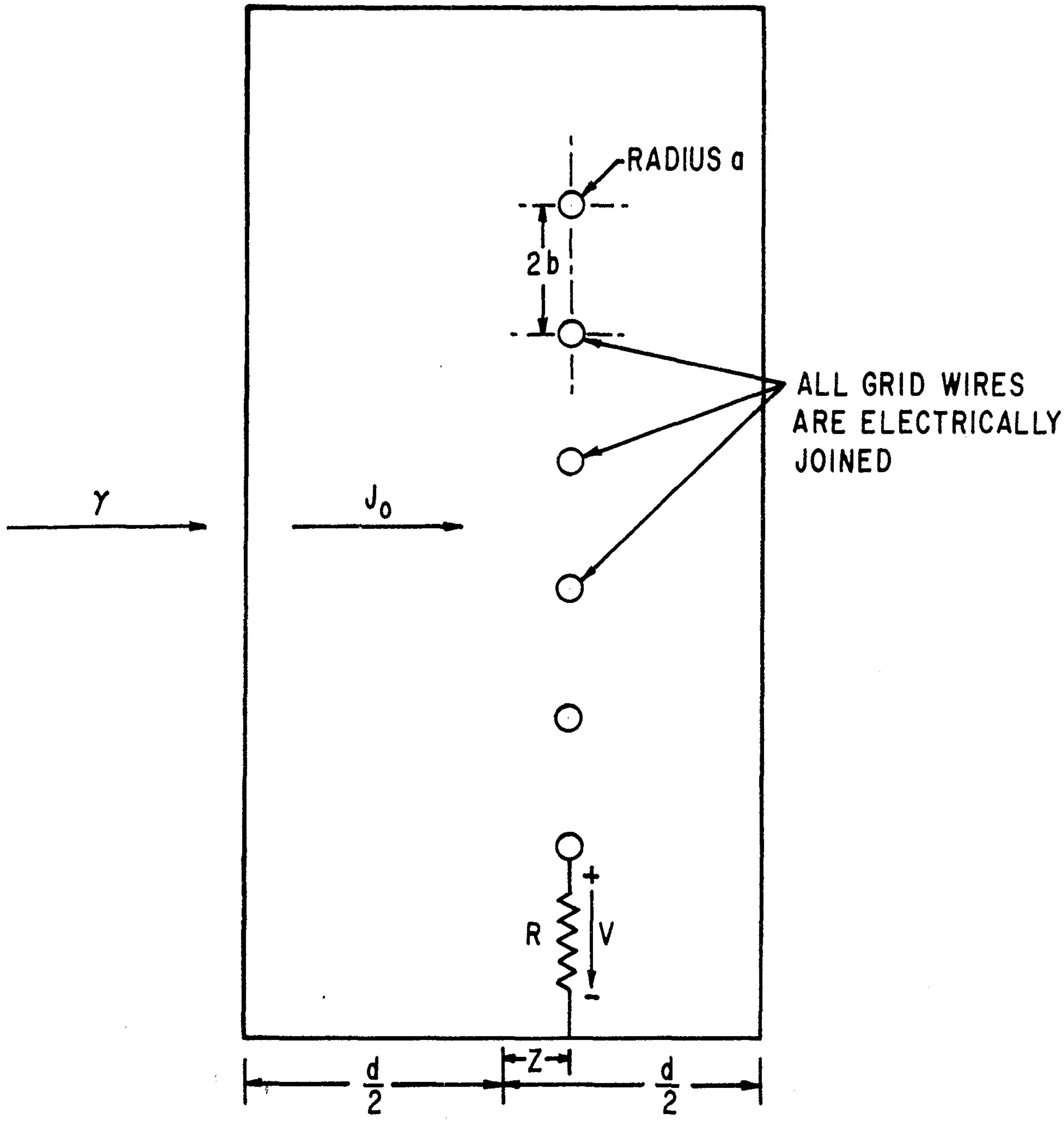


FIGURE I. GRID FOR MEASURING SPACE CHARGE POTENTIAL IN PARALLEL PLATE GEOMETRY certain restrictions regarding the voltage range and $\gamma$-ray (or X-ray) pulse widths as discussed in EMP Theoretical Note V.

The current density in the cavity is given approximately by

$$J_o \approx -e \frac{r_e}{r_\gamma} \gamma \tag{2}$$

where e is the magnitude of the electron charge, $r_e$ is the electron range in the wall material, $r_\gamma$ is the photon mean free path in the wall material, and $\gamma$ is the photon flux (photons/meter$^2$-sec). Letting the grid be made of the same conductor as the cavity walls we have a current from electrons ejected from the grid by the photons of

$$I_{n_o} \approx e \frac{\pi a}{2r_\gamma} A_w \gamma \approx -\frac{\pi a}{2r_e} A_w J_o \tag{3}$$

where $\pi a/2$ is the mean wire thickness and $A_w$ is the area of the grid wires normal to the photon direction of travel. We have assumed that $2a \ll r_e$. There is also a current due to electrons being stopped by the grid and this should be comparable to the current in equation (3). However, we might get a larger current from the low energy electrons ejected from the grid by the high energy electrons (produced by the direct photon interaction) from the cavity walls. This latter current would be about

$$I_{n_1} \approx -f \pi A_w J_o \tag{4}$$

where f is the number (in the neighborhood of one) of low energy secondary electrons ejected per unit surface area of the grid wires for each high energy electron per unit area normal to the z axis.[3] For the circular wire, since the area of the wire (per unit length) normal to the photon direction of travel is 2a, we have $f2\pi a$ (or the secondary electron ratio times the circumference) as the number of low energy secondary electrons (in a unit flux of high energy electrons) leaving the wire. This secondary electron current may not entirely escape the grid but it provides an upper limit for noise current calculations. It is then advantageous to minimize f.

The noise voltage is then

$$V_n = \frac{1}{C} I_{n_1} \Delta t \tag{5}$$

where $\Delta t$ is the time width of the radiation pulse (assumed square) and C is the capacitance of the grid with respect to the cavity walls. This capacitance is approximately

$$C = \varepsilon_o A \left( \frac{1}{\frac{d}{2} + z + \Delta z} + \frac{1}{\frac{d}{2} - z + \Delta z} \right) \tag{6}$$

3. S. Kronenberg, High Intensity Radiation Dosimetry with SEMIRAD, Department of the Army Monograph, Preprint.

where A is the total geometric area of one side of the grid structure, including area between the wires. The correction factor, $\Delta z$, is about[4]

$$\Delta z \simeq 2 \frac{b}{\pi} \ln \left(\frac{b}{\pi a}\right) \tag{7}$$

where we have assumed a parallel set of wires of spacing 2b for this calculation. The important point here is that $\Delta z$ only varies logarithmically with b/a so that as we decrease a to decrease $A_w$ (in equation (4)) the capacitance is decreased very little. In practice we may wish to use a screen mesh with wires in more than one direction but this should not change the results very much.

Combining equations (4), (5), and (6) we have

$$V_n \simeq -f\pi \frac{A_w J_o \Delta t}{\epsilon_o A} \left( \frac{1}{\frac{d}{2} + z + \Delta z} + \frac{1}{\frac{d}{2} - z + \Delta z} \right)^{-1} \tag{8}$$

The signal-to-noise ratio, S, is then

$$S = \left| \frac{V}{V_n} \right| \simeq \frac{1}{8} \frac{A}{A_w} \frac{1}{f\pi} \frac{1}{v_z \Delta t} (d^2 - 4z^2) \left( \frac{1}{\frac{d}{2} + z + \Delta z} + \frac{1}{\frac{d}{2} - z + \Delta z} \right) \tag{9}$$

Assume that

$$\Delta z << \left|\frac{d}{2}\right| - |z| \tag{10}$$

This requires that

$$b << \left|\frac{d}{2}\right| - |z| \tag{11}$$

or that the wire spacing in the grid is much smaller than the spacing between the grid and the nearest cavity wall. Then, neglecting $\Delta z$, equation (9) reduces to

$$S \simeq \frac{1}{2} \frac{A}{A_w} \frac{1}{f\pi} \frac{d}{v_z \Delta t} \tag{12}$$

which is conveniently independent of z. The signal-to-noise ratio is then improved by making the wire radius, a, small, to decrease $A_w$.

The limitation in this technique, as can be seen in equation (12), is the radiation pulse width. If we take the upper limit of $v_z$ as the speed of light in vacuo, then the signal-to-noise ratio is proportional to the ratio of the

4. Lt Carl E. Baum, Sensor and Simulation Note XXI, Impedances and Field Distributions for Parallel Plate Transmission Line Simulators, June 1966.

transit time across the cavity to the time width of the radiation pulse. This latter ratio is assumed small to permit the quasi-static calculation of the fields and potentials as in equation (1). We can compensate for the small size of this ratio by making the wire radius sufficiently small, within practical limits.

This technique for measuring space-charge fields (or potentials) is similar to a technique for measuring electric fields associated with the EMP in ionized air.[5] However, since the air conductivity is not important we do not have the same constraint on the resistive load. If we desire to measure the open circuit voltage then

$$RC \ll \Delta t \tag{13}$$

but we could also measure the short circuit current by making R sufficiently small. Since this technique is similar to one which can be used in ionized air we may be able to use it for measurements of Internal EMP in cavities with gases as well as for evacuated cavities. However, we should look at the problems peculiar to the specific cases.

## III. Summary

By using a wire grid with sufficiently small wires, the charge accumulated on the grid during a pulse of $\gamma$ rays (or X rays) can be made small enough, so as to not interfere with the measurement of the space-charge electric fields associated with the Internal EMP. This is still limited in that it applies only for finite width radiation pulses.

5. Lt Carl E. Baum, Sensor and Simulation Note XV, Radiation and Conductivity Constraints on the Design of a Dipole Electric Field Sensor, Feb. 1965.