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Backscatter Control Grid Design Study: Electromagnetic Considerations

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ABSTRACT

The design of any simulator requires that numerous, and often conflicting, technical factors must be weighed and considered for optimal performance. This note takes a brief look at a number of electromagnetic considerations affecting the design of a backscatter control grid for use in a SGEMP simulator. Thus, the emphasis is on comparing the relative importance of a number of design parameters rather than developing any new analysis techniques. The interaction of various design parameters is discussed and a preliminary electromagnetic design for a backscatter-control grid is presented.

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electromagnetic pulses, electromagnetic pulse simulators, backscatter, electrons, SGEMP

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1. INTRODUCTION

One of the many individual elements that must be considered in designing a SGEMP simulator for satellites is the backscatter control grid. The purpose of this grid is to keep electrons backscattered from the walls of the vacuum tank from entering the working volume of the simulator and affecting the response of the satellite being tested. The grid is held at some high negative potential with respect to the wall so as to "push" electrons emitted from the wall back to the wall. The grid itself should be sparse enough so that not many electrons are backscattered from the grid wires, yet the grid must appear electrically continuous so that the working volume is all at the same potential and electromagnetic noise cannot be transmitted to the satellite being tested.

Thus, it is readily apparent that a number of electromagnetic effects must be considered in the preliminary design of any such grid. This report considers the most important of these effects and their relationships with one another. The goal is to define a reasonable preliminary electromagnetic design of the grid for use in the NASA Lewis vacuum tank. Exact values of physical parameters describing the grid will depend on mechanical and cost considerations in addition to electrical performance. Thus, dimensions and voltage levels given in this report should be considered as guidelines rather than fixed requirements.

2. THE PHOTOELECTRON SPECTRUM

Calculations of the spectrum of photoelectrons ejected from aluminum have been made previously for a variety of X-ray source spectra[1]. Results for a 100 kv bremsstrahlung source (see Reference 2) are reproduced here in Figure 1. This figure plots $N_e(>w)$, the number of electrons ejected per cm^2 having energy greater than w, as a function of electron kinetic energy, w. As indicated by the left- and right-hand scales, the fluence level just enters as a scale factor.

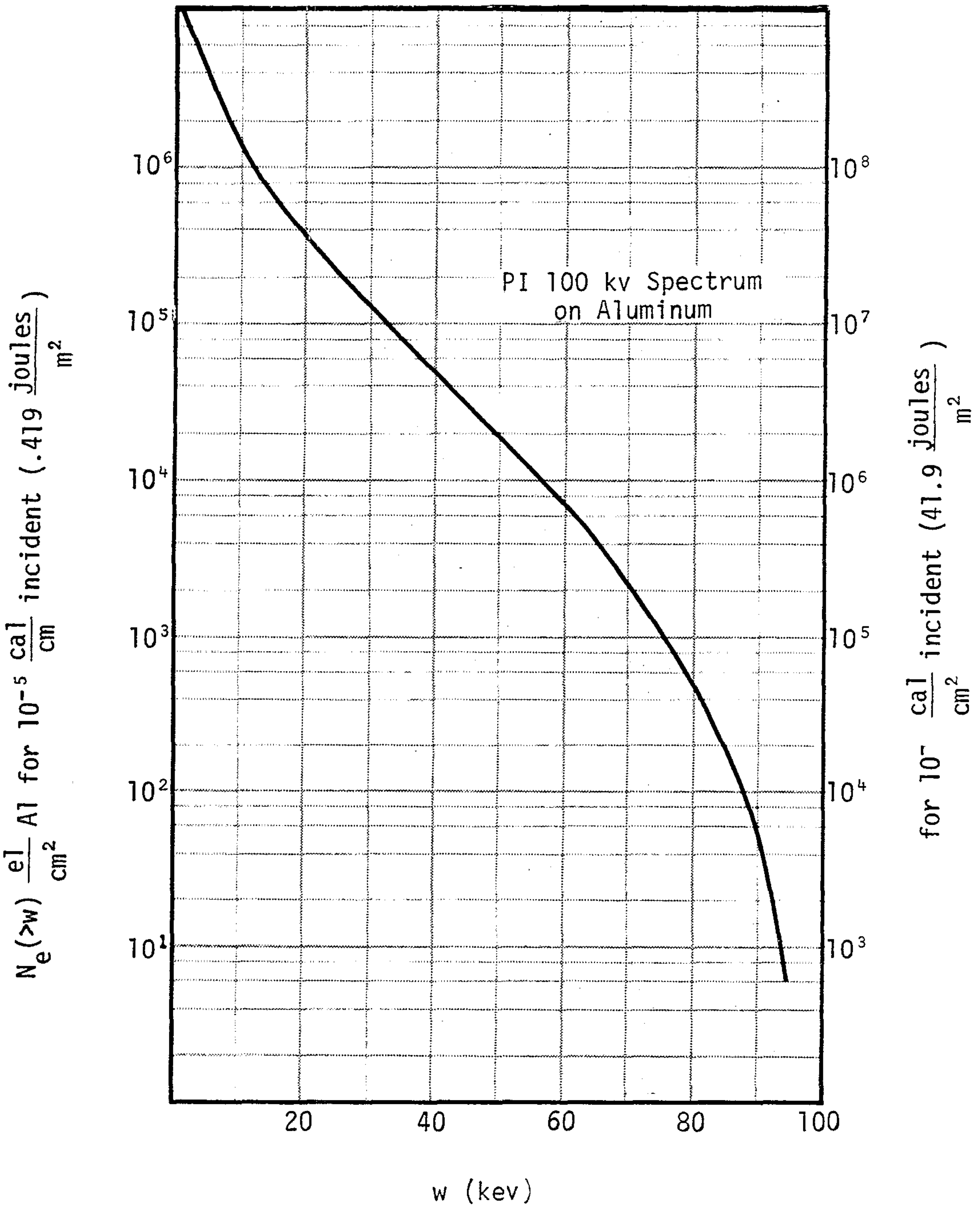

Figure 1. Number of electrons having energy greater than w for backscattering from aluminum of a 100 kev bremsstrahlung spectrum.

The graph shows that approximately 1.0×10^7 electrons having energy greater than 1 kev will be emitted per cm^2 for an incident X-ray fluence of 10^{-5} cal/cm^2.* This number does not include low-energy secondary electrons ($w < 1$ kev). These low-energy secondaries are usually considered unimportant; however, when the emitting surface is at some high-negative voltage, the field will pull all these low-energy electrons away from the surface, increasing the electron yield and the net-charge transfer. Experiments[3,4] indicate that such an effect may increase the transmitted charge by factors of 2 to 7.

2.1 Charge Emitted From Satellite

As a worst case consider FLTSATCOM, the largest satellite now being considered for testing. FLTSATCOM has an illuminated surface area of about 23 m^2. Assuming a fluence level of 2×10^{-4} cal/cm^2 over this area, the number of electrons emitted from the satellite, N_s, is

$$N_s \simeq 1.0 \times 10^7 \frac{\text{electrons}}{\text{cm}^2} \times 2.3 \times 10^5 \text{ cm}^2 \times \frac{2.0 \times 10^{-4} \frac{\text{cal}}{\text{cm}^2}}{1.0 \times 10^{-5} \frac{\text{cal}}{\text{cm}^2}} \tag{1}$$

$$= 4.6 \times 10^{13} \text{ electrons ,}$$

which represents a total charge of 7.4×10^{-6} coulombs. Some of these electrons will return to the satellite due to space charge limiting, but for comparison to the electron yield from the wall we will ignore that effect.

2.2 Charge Emitted From the Tank Wall

Estimating the number of electrons emitted from the wall of the vacuum tank is a bit more complicated than calculating the emission from the satellite because the incident fluence varies with position along the wall. This varying fluence is indicated by the isofluence contours shown

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* $1 \frac{\text{cal}}{\text{cm}^2} = 4.19 \times 10^4 \frac{\text{joules}}{\text{m}^2}$

in Figure 2 (see Reference 5). From this figure one can estimate an average fluence of 1.2×10^{-5} cal/cm^2 and an exposed area of 2393 m^2. Thus, the number of electrons emitted from the wall, N_w, is given by

$$N_w \simeq 1.0 \times 10^7 \frac{\text{el}}{\text{cm}^2} \times 2.39 \times 10^7 \text{ cm}^2 \times \frac{1.2 \times 10^{-5} \frac{\text{cal}}{\text{cm}^2}}{1.0 \times 10^{-5} \frac{\text{cal}}{\text{cm}^2}}$$

$$\simeq 2.9 \times 10^{14} \text{ electrons} , \qquad (2)$$

which represents a total charge of 4.6×10^{-5} coulombs. Thus

$$\frac{N_w}{N_s} = 6.3 , \qquad (3)$$

and the need for an electron repelling grid is readily apparent. Without such a grid, the current emitted from the tank wall would be substantially larger than the current emitted from the satellite, giving a poor simulation of a satellite in space.

A reasonable backscatter control grid criteria would be that the number of electrons escaping through the grid plus those emitted by the grid itself be only a few percent of the number of electrons emitted by the satellite. The various design parameters discussed here will be based on that premise.

3. ELECTRON REPELLING GRID DESIGN PARAMETERS

Some basic features of an electron repelling grid have been previously examined[6,7,8]. Basically, the grid is just some configuration of wires spaced a short distance from the tank wall and held at some negative potential with respect to the wall. The negative potential creates an electric field that pushes electrons emitted from the wall back toward the wall. Thus only a small percentage of the emitted electrons can penetrate the grid and be "seen" by the satellite.

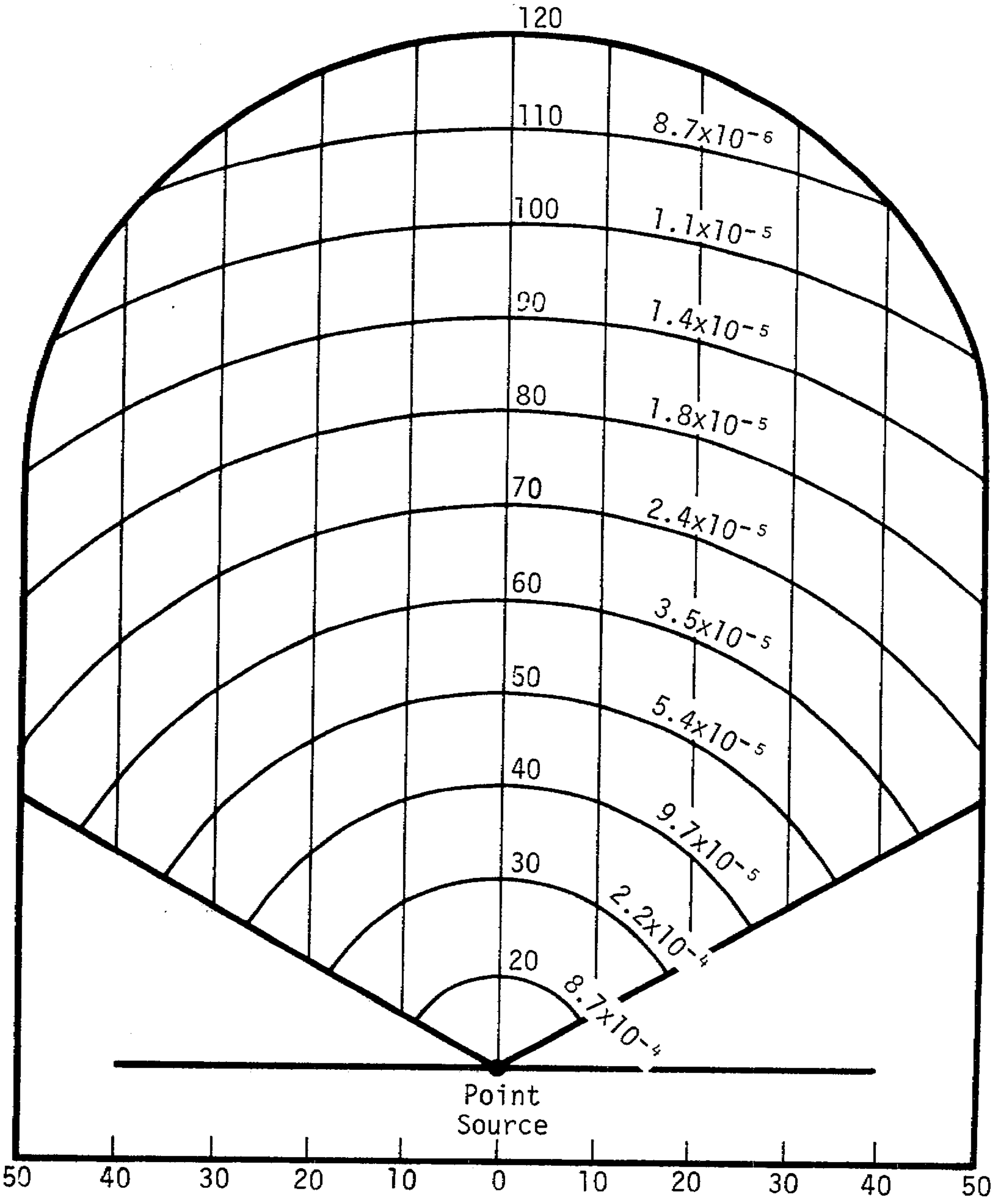

Figure 2. Isofluence contours (in cal/cm^2) inside the NASA Lewis vacuum tank.

Actual electrical design of such a grid involves a number of trade-offs and competing factors. Some of the basic parameters involved include grid spacing from the wall, individual grid wire spacing, grid-wire diameter, and materials the grid is constructed from. These basic physical parameters then determine a number of inter-related electromagnetic factors, including the charge escaping through the grid, the charge emitted by the grid itself, the capacitance between the grid and the wall, the field penetration through the grid, the resonances set up between the grid and wall, the field strength at the grid (and resulting field emission or arcing problems), and the high-voltage source requirements. In this report a number of these factors will be considered for several sets of reasonable physical parameters.

For calculational purposes, we will assume that the grid and wall are planar and that the grid is made up of parallel wires. The basic geometry is shown in Figure 3.

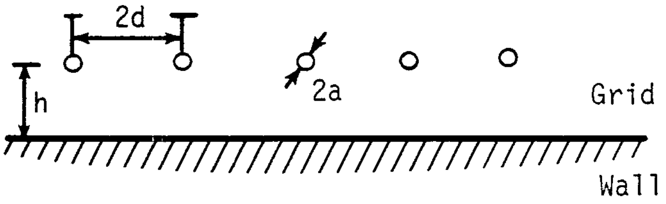

Figure 3. Wall-grid geometry.

3.1 Grid Photoemission

Even if the backscatter control grid stopped all of the X-ray generated electrons emitted by wall, one would still have to worry about electrons ejected from the grid itself. One figure-of-merit for studying the relative number of electrons emitted by the grid and wall is just the ratio of emission surface areas. If we use ξ for this ratio, then

$$\xi = \frac{\pi a}{2d} \ . \tag{4}$$

The effective value of ξ can be reduced below this value if the grid wires are coated with a low Z material as pointed out by Schaeffer[9] and Longmire[8].

To estimate the required value of ξ, assume that, at most, the number of electrons emitted from the grid should be 1 percent of the number emitted from the satellite. Then

$$\xi = .01 \frac{N_s}{N_w} = 1.6 \times 10^{-3} \ . \tag{5}$$

3.2 Grid Effectiveness

Tesche[7] has studied the effectiveness of a charged-wire grid for reducing electron backscatter; however, his work is directly applicable only for monoenergetic electrons with a known angle of departure. In the actual case the ejected electrons are distributed both in angle and energy. A worst case estimate of grid effectiveness can be made, however, by assuming that all electrons are emitted normal to the surface of the wall and that all electrons leaving the wall with kinetic energy $w = eV_\infty$ escape through the grid. In this case, V_∞ is the potential far away from the grid and the wall. The actual potential on the grid wires, V_0, will be greater than V_∞ by an amount to be calculated later.

The value of V_∞ for any desired grid effectiveness is easily found from Figure 1. For instance, if we want only 1 percent of the electrons emitted from the wall to escape through the grid, we simply look for the value of w where $N_e(>w)$ is down to 1 percent of the value at the peak of the curve. For 1 percent this value is about 33 kev, corresponding to a V_∞ of 33 kv.

3.3 Capacitance of a Grid of Rods Over a Ground Plane

In Reference 10, Marin treats the problem of a grid of rods over a ground plane. Although Marin's calculations were done for a parallel plate transmission line, the potential and capacitance calculations are just the same as the electron repelling grid problem.

The capacitance per unit area of solid parallel plates is given by

$$C' = \frac{\varepsilon_0}{h} , \tag{6}$$

where $\varepsilon_0 = 8.854 \times 10^{-12}$ fd/m and h is the plate separation. If one plate of the capacitor is made up of a grid of parallel rods (Figure 3) then one can define an effective separation, h_1, so that

$$C' = \frac{\varepsilon_0}{h_1} . \tag{7}$$

Values of h_1 are given in Reference 11 for various normalized a, d, and h values. The ratio h_1/h then is a measure of how closely the grid approaches a solid plate, in terms of electrical performance.

It can also be shown that the potential on the grid, V_0, is related to the potential at infinity, V_∞, by

$$\frac{V_0}{V_\infty} = \frac{h_1}{h} . \tag{8}$$

Therefore, once V_∞ is determined as a function of grid effectiveness, then the ratio h_1/h can be used to find the required grid voltage, V_0.

For $d \ll h$ and $a \ll d$, one can write the approximation

$$h_1 \approx h + \frac{d}{\pi} \ln\left(\frac{d}{\pi a}\right) . \tag{9}$$

3.4 Field Enhancement at the Grid

Another important parameter calculated in Reference 11 is the field enhancement factor, e_1, which is defined as the ratio of the electric field at the surface of each rod making up the grid to the average field at the wall. This factor is important in determining whether breakdown, field emission, or other field dependent effects are important.

The average field at the wall is given by

$$\overline{E}_{wall} = \frac{V_0}{h_1} , \tag{10}$$

where V_0 is the potential of the grid and h_1 is the effective height (see previous section). The field at the surface of each wire is then given by

$$E_{wire} = e_1 \overline{E}_{wall} = e_1 \frac{V_0}{h_1} . \tag{11}$$

In the limit that $d \ll h$ and $a \ll d$

$$e_1 \approx \frac{d}{\pi a} . \tag{12}$$

4. GRID DIMENSIONS AND SPACING

Thus far we have discussed a number of parameters and figures-of-merit that are important for grid design. We will now evaluate these various parameters for some reasonable combinations of grid dimensions and spacing.

First, let us consider some preliminary "guesses" at reasonable dimensions (see Figure 3) for the grid. We want the wire radius, a, as small as possible without having to worry about mechanical strength or high-voltage problems due to field enhancement near a small wire. A reasonable first guess is to make the wire diameter about 1 mm, i.e., a = .05 cm. The spacing from the wall, h, should be small to maximize capacitance but high-voltage problems must be avoided. Also, any resonances set up between the grid and wall should occur at frequencies higher than those of interest to the satellite. A choice of h = 30 cm (which corresponds to a frequency of 5×10^8 hz) appears to be a good starting point. The wire spacing, 2d, should be large to minimize the cross section of the grid for electron emission, but not much larger than the distance to the wall (h) so that any resonances set up between the wall and the grid will not "leak" through the grid to the test chamber.

Based on these preliminary estimates, Table 1 was set up to show the electromagnetic effect of varying the geometrical dimensions of the grid. For various values of a, d, and h, the table gives values of ξ, h_1/h, and e_1 as well as the capacitance per unit area. In addition, the required grid voltage and maximum electric field at the grid wires are given for the criteria that 1 percent or .1 percent of the electrons emitted by the wall escape through the grid.

An examination of Table 1 points out a number of the trade-offs that have to be considered in the design of an actual grid. First of all, consider the effect of increasing the wire spacing (d) for a given wire radius and grid separation from the wall. As the wires are moved apart, the effective height, h_1, increases. This decreases the capacitance between the grid and the wall and increases the required voltage for a given grid repelling effectiveness. Also, the field enhancement factor, e_1, and thus the maximum electric field at the wire is increased as the wire spacing is increased. These are all undesirable effects. On the other hand, the relative electron backscatter yield from the grid itself (ξ)

Table 1. Parameter study of grid dimensions.

All Dimensions In cm	ξ	$\frac{h_1}{h}$	e_1	C' (fd/m^2)	(1% escape i.e., $V_\infty = 33$ kv)	(.1% escape i.e., $V_\infty = 56$ kv)	E_{wire} (1% escape)	E_{wire} (.1% escape)
a = .05 h = 30 d = 1.5	.052	1.07	10.2	2.76×10^{-11}	35 kv	60 kv	1.1 $\frac{Mv}{m}$	1.9 $\frac{Mv}{m}$
a = .05 h = 30 d = 5	.016	1.23	32	2.40×10^{-11}	41 kv	69 kv	3.6 $\frac{Mv}{m}$	6.1 $\frac{Mv}{m}$
a = .05 h = 30 d = 10	7.8×10^{-3}	1.47	68	2.01×10^{-11}	49 kv	82 kv	7.6 $\frac{Mv}{m}$	12.7 $\frac{Mv}{m}$
a = .05 h = 30 d = 15	5.2×10^{-3}	1.75	100	1.69×10^{-11}	58 kv	98 kv	11.0 $\frac{Mv}{m}$	18.6 $\frac{Mv}{m}$
a = .05 h = 15 d = 5	.016	1.4	33	4.22×10^{-11}	46 kv	78 kv	7.2 $\frac{Mv}{m}$	12.2 $\frac{Mv}{m}$
a = .05 h = 60 d = 5	.016	1.1	32	1.34×10^{-11}	36 kv	62 kv	1.7 $\frac{Mv}{m}$	2.9 $\frac{Mv}{m}$
a = .05 h = 60 d = 5	5.2×10^{-3}	1.45	95	1.02×10^{-11}	48 kv	81 kv	5.2 $\frac{Mv}{m}$	8.8 $\frac{Mv}{m}$
a = .1 h = 30 d = 15	.01	1.7	48	1.74×10^{-11}	56 kv	95 kv	5.3 $\frac{Mv}{m}$	9.0 $\frac{Mv}{m}$
a = .1 h = 30 d = 10	.016	1.4	33	2.11×10^{-11}	46 kv	78 kv	3.6 $\frac{Mv}{m}$	6.1 $\frac{Mv}{m}$

decreases as the wires are moved apart, and one wishes to minimize ξ for best grid performance.

Similarly, increasing the diameter of the wires making up the grid, while keeping the other dimensions constant, has little effect on the capacitance but the field enhancement problem is somewhat alleviated. However, the relative electron yield from the grid itself is increased as the wire diameter increases.

Finally, consider the effect of increasing the distance of the grid from the wall (h). This decreases the capacitive coupling between the grid and the wall, thus increasing the voltage change for a given charge transfer between the grid and wall. Also, as h increases the frequencies of resonant modes that may exist between the grid and wall become lower and thus nearer to frequencies that may be important to satellite response. On the other hand, as h decreases the possibility of arcing between the grid and wall increases.

4.1 Balanced Design

It is apparent that a number of factors must be simultaneously evaluated in order to obtain an optimal grid design. In considering such effects it is important to consider the concept of balanced design. The basic idea of balanced design is that it is useless to try to obtain .01 percent accuracy in one part of a system's response when 10 percent accuracy is all that can be achieved elsewhere. A more specific example is to consider the relative number of electrons emitted from wall that escape through the grid and the number that are backscattered from the grid itself. It makes little sense to raise the grid potential to a high level so that only .1 percent of the electrons emitted from the wall escape, if the grid itself emits 10 percent as many electrons as the wall and all of these electrons reach the working volume of the simulator. A balanced design would require the two electron sources to be roughly equal in magnitude.

It is readily seen that the first set of dimensions in Table 1 (a = .05 cm, h = 30 cm, d = 1.5 cm) is not a well balanced design. The value of ξ indicates that the grid itself will emit 5 percent as many electrons as the wall, yet a grid voltage of 60 kv would keep all but .1 percent of the wall emitted electrons from escaping. Thus the limiting factor is the surface area of grid wire itself. One way to better balance the design would be to coat the grid wires with a low-Z material. This could reduce the emission from the wires by a factor of 10 (see Reference 10) making the number of escaping electrons from the wall and from the grid more comparable.

5. GRID VOLTAGE OSCILLATIONS

As mentioned previously, charge transfer between the grid and the wall will cause a change in voltage between the two. Then either the voltage supply itself or capacitive coupling will cause redistribution currents on the grid or wall which may radiate energy to the satellite. Thus one wishes to minimize such voltage changes.

The cause of such changes is charge transfer. Some electrons emitted from the wall will pass through the grid into the working volume of the simulator. In addition, electrons backscattered from the grid itself will move into the working volume. The forward scattered (toward the wall) electrons emitted by the grid, however, will be attracted to the wall and tend to cancel the effect of electrons escaping from there. In addition, because of the negative potential of the grid, the numerous, low-energy secondaries emitted from the grid wires will be attracted to the wall. Finally, the electrons emitted by the satellite that escape as far as the grid will be collected at the wall of the chamber.

Let us consider the magnitude of these various charge transfer effects for a specific grid design. For example, let a = .05 cm, d = 15 cm, and h = 30 cm. The capacitance per unit area is then $C' = 1.7 \times 10^{-11} \frac{\text{fd}}{\text{m}^2}$. The change in voltage due to some charge transfer between the wall and grid is described by

$$C'\Delta V = \Delta\sigma \ , \tag{13}$$

where ΔV is the voltage change and $\Delta\sigma$ is the change in charge density.

First consider $\Delta\sigma$ due to charge emitted from the wall escaping through the grid. Assuming 1 percent of the charge emitted from the wall escapes, then

$$\begin{aligned}\Delta\sigma &= .01 \times 1.0 \times 10^{7} \frac{\text{el}}{\text{cm}^2} \times 10^{4} \frac{\text{cm}^2}{\text{m}^2} \times \frac{1.2}{1.0} \times 1.6 \times 10^{-19} \frac{\text{coul}}{\text{el}} \\ &= 1.92 \times 10^{-10} \frac{\text{coul}}{\text{m}^2} \ .\end{aligned} \tag{14}$$

The change in voltage is then

$$\Delta V = \frac{\Delta\sigma}{C'} = 11.4 \text{ volts} \ . \tag{15}$$

This voltage change is only .02 percent of the 58 kv voltage across the grid-wall spacing required for 1 percent charge escape. We are thus creating only minor changes in the potential and there appears to be no need for adding extra capacitance or using multiple high-voltage feed points.

Since the capacitance scales linearly with the wall-grid spacing, a spacing of three meters would imply a voltage change of 100 or so volts and one might consider adding capacitance to the grid to decrease this change.

Note that charge is also backscattered from the grid itself. If the charge backscattered from the grid is approximately equal to the charge from the wall that escapes, the change in voltage will be approximately doubled. However, some charge emitted by the grid will be forward scattered and thus collected at the wall. In particular most of the low-energy secondary electrons will be pushed to the wall by the potential difference between the wall and grid. This effect will tend to cancel any voltage difference due to electrons escaping into the working volume.

The other charge transfer effect to be considered is the collection at the wall of electrons escaping from the satellite. As seen earlier, approximately 4.6×10^{13} electrons will be emitted by the satellite. This corresponds to a $\Delta\sigma$ of approximately $1.2 \times 10^{-8} \frac{\text{coul}}{\text{m}^2}$ at the tank wall. This implies a voltage change of

$$\Delta V = \frac{\Delta\sigma}{C'} = 689 \text{ volts} , \tag{16}$$

which represents about a 1 percent change in the grid voltage. Collection of electrons emitted by the satellite thus appears to be a worse problem than backscattered electrons escaping through the grid.

The value of ΔV can be decreased by adding capacitance between the grid and wall in the lower portions of the tank where electrons backscattered from the satellite will be collected. The capacitance can be increased by physically adding capacitors between the grid and tank walls or by adding wires to the grid and decreasing the grid-wall spacing. Note that increasing the grid density (ξ) in the lower section of the tank presents no problem since this area will not be directly illuminated by the photon beam (except for the grid section directly above the photon source). To decrease ΔV to a few volts, the capacitance in the lower sections of the tank needs to be increased to about $2 \times 10^{-9} \frac{\text{fd}}{\text{m}^2}$.

5.1 Voltage Gradients

An important effect to consider in addition to voltage changes between the grid and wall is the resultant voltage gradient along the surface of the grid. Such gradients create current flow along the grid; in turn, such currents will create fields in the working volume which will affect the satellite being tested.

The reason for such gradients can easily be seen from Figure 2. The side walls of the tank sees an incident photon fluence roughly three times as great as top of the tank resulting in proportional differences in the number of photoelectrons created. On the other hand, most of the electrons ejected from the satellite will be collected along the bottom and lower walls of the tank. (One should also remember that there is a difference between times when electrons are ejected from various portions of the wall and times when satellite-ejected electrons reach the wall.)

Voltage gradients along the grid are due to different values of ΔV at different locations. As seen previously, ΔV values are larger at the bottom of the tank where electrons from the satellite are collected. One way to alleviate the voltage gradient problem is to taper the capacitance per unit area so that ΔV is approximately constant over the whole area of the grid.

6. PRACTICAL GRID DESIGN

For computational purposes we have assumed an oversimplified geometry with planar wall and grid and parallel grid wires running in only one direction. The planarity assumption is a good approximation as long as the grid-to-wall spacing is much less than the radius of curvature of the tank wall (which is true for all parameters considered here.) The assumption that the grid wires run only in one direction is not necessarily valid or desirable, however.

In terms of grid effectiveness in preventing electrons from the wall from reaching the working volume of the tank, a crossed wire grid is probably more effective than a parallel wire grid of the same spacing. However, the effective cross section for electron production from the grid itself (ξ) is greater for such a crossed-wire grid than for a parallel-wire grid. To make the two roughly equivalent (in terms of $C^{\prime}$ as well as ξ) the spacing of wires in a crossed-wire grid should be twice that of a parallel-wire grid.

The crossed-wire grid, however, is a better electromagnetic shield than the parallel wire grid (depending on the polarization of the field). Thus in areas where electromagnetic shielding is required (such as the bottom of the tank where one wishes to filter out the "noise" of the photon sources) a crossed-wire grid is highly desirable. Near the top of the tank, however, the need for connecting adjacent grid wires may be less as long as damping reduces the focusing of EM energy there (see Appendix B).

We now need to combine all the various considerations mentioned previously into an overall, practical grid design. A diagram of such a grid inside the NASA Lewis vacuum tank is shown in Figure 4.

At the top of the tank the grid cannot be placed too near the ceiling of the tank because of a crane attached in this area. A wire spacing of about 30 cm is suggested and 2 mm diameter wires coated with a low Z layer are assumed. The spacing to the wall varies; where the spacing is large it is suggested that capacitance be added to obtain approximately 3×10^{-11} farads/m^2 evenly distributed over the top of the tank. A radial mesh of wires seems reasonable and these radial wires need be connected together (in the azimuthal direction) only every meter or two.

At the bottom of the tank a square mesh with wires approximately 30 cm apart is needed. A finer mesh would even be better for shielding the noise of the photon source and no low Z coating would be necessary except where the beam passes through the mesh (one might make the mesh sparser there). Wire diameters of 2 mm and a wall-grid spacing of 30 cm seem

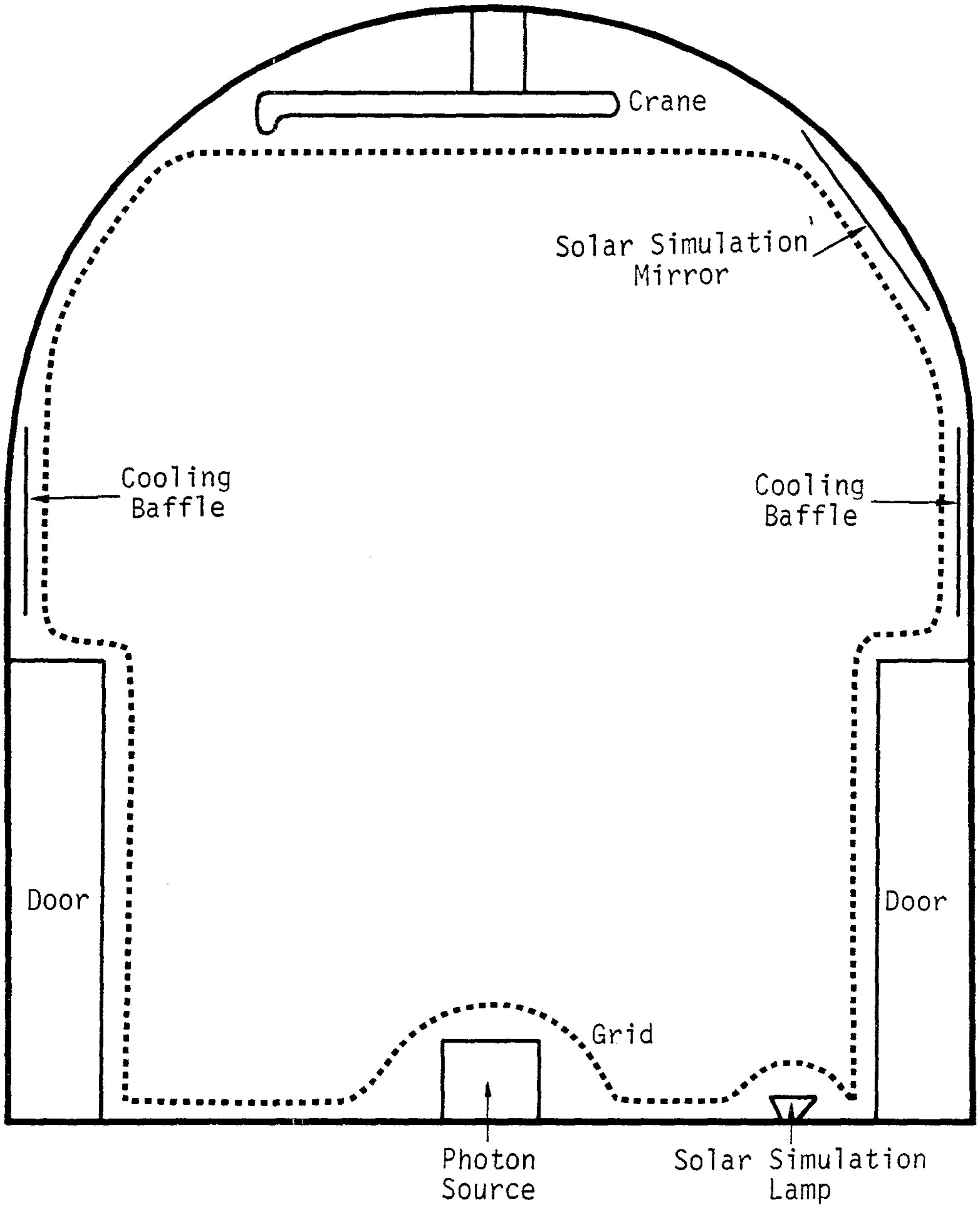

Figure 4. Electron repelling grid in NASA Lewis Tank.

reasonable. In this floor section capacitors of about 2×10^{-9} farads should be connected every m^2 between the grid and the floor.

Along the side walls of the chamber, the grid design should vary from nearly that of the floor at the bottom to a configuration similar to that at the top of the chamber on the upper wall areas. A 30 cm square grid with wires of 2 mm diameter and 30 cm from the wall would be reasonable over the whole side wall area. In the area illuminated by the photon source (see Figure 2) the wires should be coated with a low Z material, while near the bottom of the tank (where electrons backscattered from the satellite are collected) some extra capacitance should be added. Also, along the side walls one has the worry of not getting to close to irregularities such as the door frames or cooling baffles.

The grid should be charged to a voltage of about -60 kv with respect to the wall. Details of high-voltage feed arrangement are probably not too important as long as capacitance is added in the places specified.

7. SUMMARY

In this report a number of interrelated factors concerning the design of a backscatter-control grid have been considered. The effects of these various factors have been weighed and a preliminary design for the NASA Lewis tank has been described. Mechanical and cost considerations must be included in any practical design and thus the dimensions and voltage levels given here should be considered as guidelines rather than requirements.

APPENDIX A
DAMPING

It has been suggested that the electron repelling grid might also be used for damping the electromagnetic oscillations set up inside the vacuum tank. In this section, we will take a brief look at this concept.

The use of a thin, finitely conducting membrane in front of a perfectly conducting wall for damping has been investigated previously[6,12]. A frequency domain calculation of the energy reflectivity of such a membrane has been done and the coordinate system and results are reproduced from Reference 11 in Figures A-1 and A-2.

Now assume that the backscatter-control grid is made of a finitely conductive material so as to approximate the sheet shown in Figure A-1. Furthermore, if we approximate the NASA Lewis tank as a spherical cavity, the frequency of the lowest mode is given by $K_0R = 2.74$, where $R \simeq 15$ meters. The spacing of the backscatter control grid from the tank wall is approximately 30 cm so that $D \simeq .02\ R$, giving $K_0D/\pi = .0175$. A brief examination of Figure 6 indicates that the energy flow reflectivity is nearly 1 no matter what the membrane reflectivity is. Thus, the backscatter control grid will provide little or no damping for the lowest frequency modes of the tank no matter how it may be loaded.

The grid would be more effective in damping higher frequencies, but it is primarily the lowest order modes of the tank that will be excited. It thus appears that a second grid between the backscatter control grid and the satellite will be required in order to damp the low-frequency oscillations of the tank.

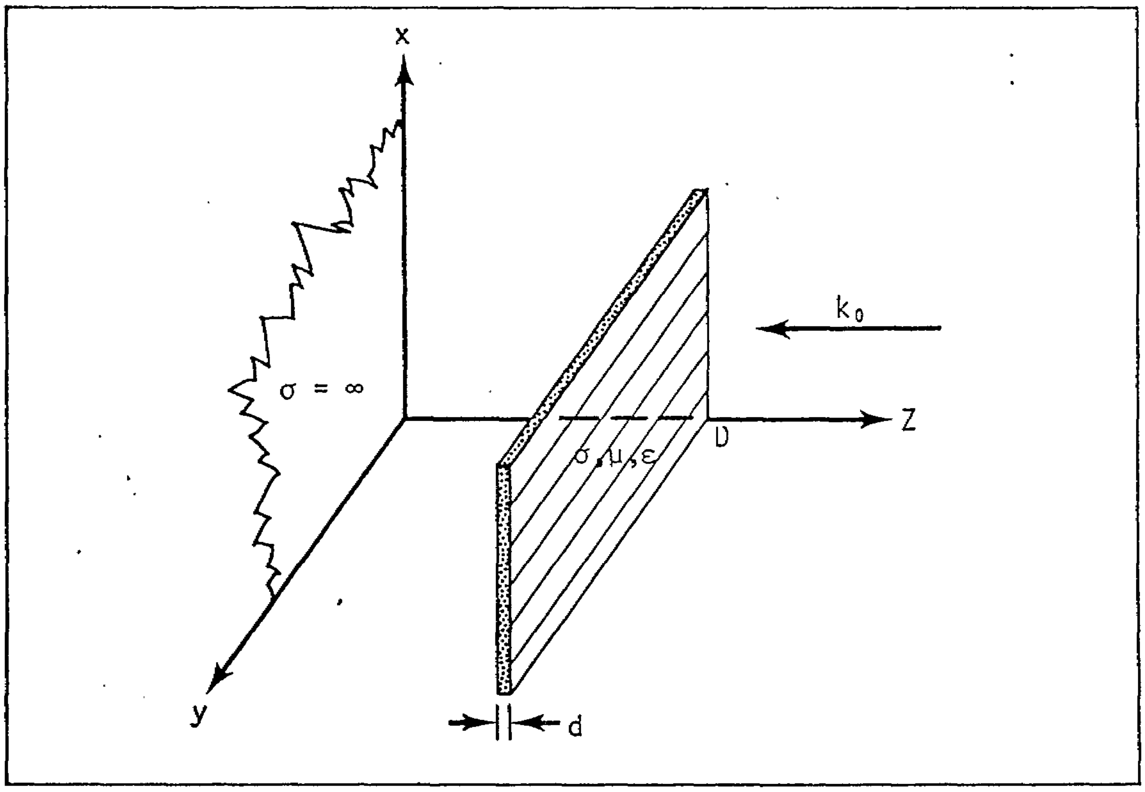

Figure A-1. Coordinate system for membrane calculation.

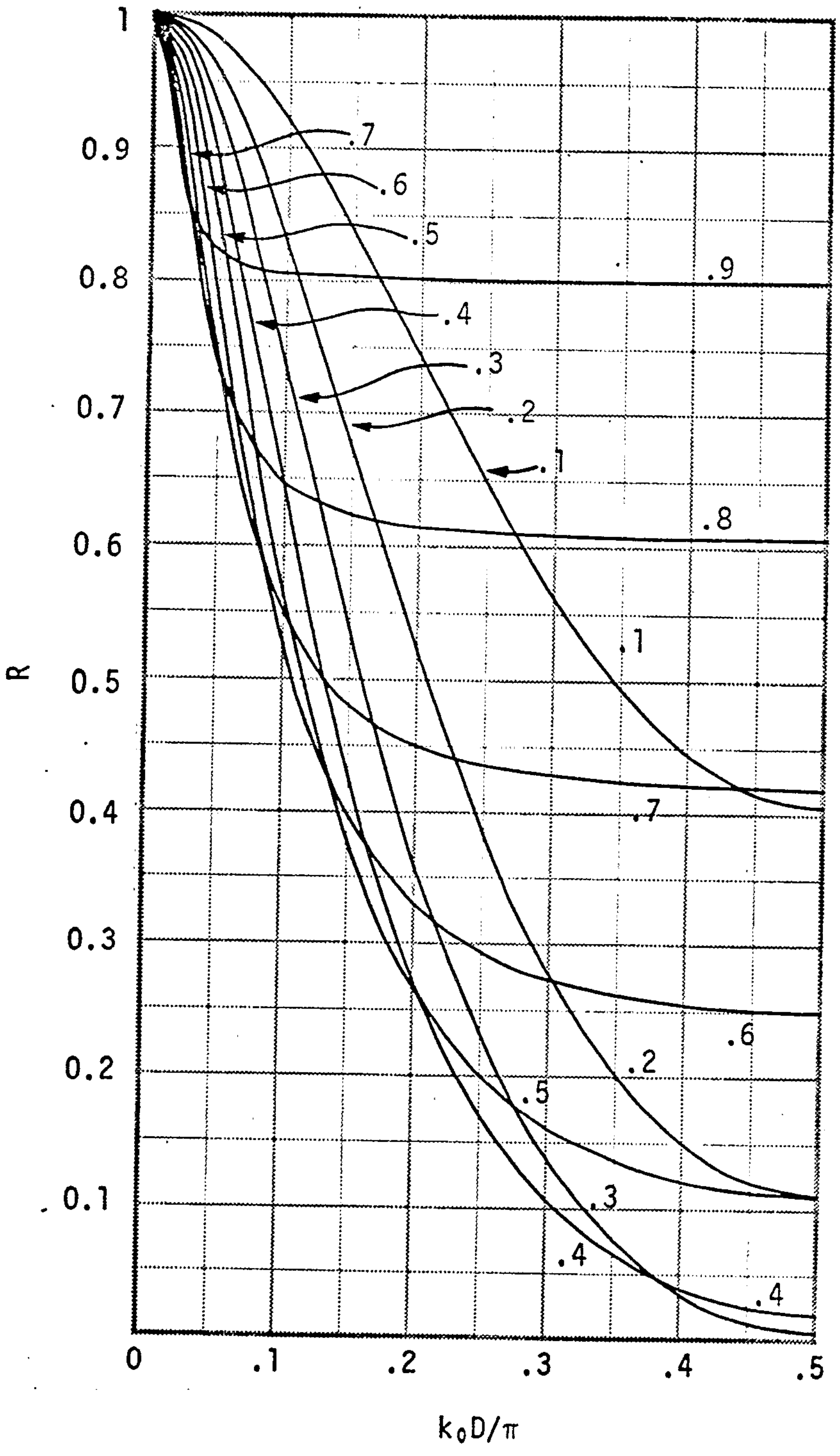

Figure A-2. Energy flow reflection coefficient vs. k_0D/π for various membrane reflectivities.

APPENDIX B

EM OSCILLATIONS BETWEEN THE GRID AND TANK WALL

Another question not previously considered is what, if anything, needs to be done about electromagnetic oscillations set up in the space between the grid and the tank wall. Electrons knocked off the tank wall will serve as the source for such fields, and even though the grid acts as an electromagnetic shield, some energy will leak through the grid into the working volume (especially the higher frequency components). It is thus useful to consider some method of absorbing the energy in such oscillations.

One method is to include some finite resistance in the grid wires themselves. Another is to consider some series resistance-capacitance elements connected between the grid and wall. To estimate what resistance values might be needed, one can assume that the grid and tank wall form a transmission line; thus resistance values should be chosen to match the characteristic impedance of the line. As a first cut, assume the tank and grid form a cylindrical transmission line. For the NASA Lewis facility and a grid-to-wall spacing of 30 cm, the ratio of outer conductor radius to inner conductor radius is approximately 1.02. For a cylindrical transmission line, this implies a characteristic impedance of 1.2 ohms.

A practical method of implementing such a damping resistance would be to add a number of RC elements between the grid and tank wall. An azimuthal ring of N such elements about half way up the wall of the tank should effectively stop oscillations from running up and down in the space between the wall and grid. Since the resistors are added in parallel, the value of each resistor should be about 1.2 N. The capacitance value is probably not too critical, but should be of the same order as the grid-to-wall capacitance. If such elements are added every few meters, $N \simeq 50$, $R \simeq 52\,\Omega$, and C should be about 5×10^{-11} farads.

One might also consider adding such RC elements along the axial direction (up and down the wall), but symmetry considerations indicate that little damping is needed for azimuthal-wave propagation.

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