PL/PA 16 DEC 96

Sensor and Simulation Notes

Note 199
May 10, 1974

Numerical Studies of Volume Dampers for System Generated Electromagnetic Pulse (SGEMP) Simulation Chambers

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Abstract

A lining of lossy material within the SGEMP simulation chamber can dampen both the cavity resonances associated with the vacuum tank and the higher frequency electromagnetic fields radiated by the satellite under test.

In this study, existing finite difference computer codes were used to examine the influence of the thickness and conductivity of the damping liner on the currents on a driven cylindrical antenna at the center of the cavity.

The principal output of this study is an illustration of how damping depends upon both the thickness and conductivity of the damper, and moreover a "best design" for each thickness allowed. Both uniformly conducting and nonuniformly conducting dampers are considered.

I. Introduction

In a previous note Baum described the system generated electromagnetic pulse phenomena (SGEMP) and the type of simulator that would be needed to simulate this environment impinging upon a satellite.[1]

Since then, more work has been done to characterize the needed vacuum chamber[2] (the NASA-LEWIS chamber is adequate); the photon source characteristics needed,[3] and the electron backscatter control grid.[4]

Also needed is a damping grid within the chamber to dampen both cavity oscillations and the EM radiation from the satellite. A wire grid arrangement will be needed, rather than a solid damper to minimize photon induced currents in the damper.

In this study, numerical analysis is used to examine the characteristics of volume dampers lining a cylindrical cavity, with dimensions approximating the NASA-LEWIS tank. Parameter studies are presented that illustrate the influence of damper thickness, conductivity and nonuniformity on the natural response of driven cylindrical antennas within the cavity.

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1. Carl E. Baum, Sensor and Simulation Note 156, A Technique for Simulating the System Generated Electromagnetic Pulse Resulting from an Exoatmospheric Nuclear Weapon Radiation Environment, 18 September 1972.

2. Conrad Longmire, Sensor and Simulation Note 194, Considerations in SGEMP Simulation, May 1974.

3. Daniel Higgins, X-Ray Source Comparisons for SGEMP Simulation (U), Mission Research Corporation, MRC-N-117, November 1973 (SRD/CNWDI).

4. Daniel Higgins, Sensor and Simulation Note 198, Backscatter Control Grid Design Study: Electromagnetic Considerations, March 1974.

Homogeneous solid dampers are examined here rather than the wire grid expected to be used. The effect of the granularity of the wire grid will be examined elsewhere. Fields and currents everywhere within the simulator tank were computed by direct finite difference solution of Maxwell's equations. The procedures used are well documented.[5] The discussion of these procedures will not be repeated herein.

II. Formulation

For simplicity we have examined the current expected on a driven cylindrical antenna located in the center of a cylindrical approximation to the NASA-LEWIS tank (Figure 1). The influence of the damper design (thickness, conductivity and uniformity) on the antenna center current is reported here. Three antenna lengths are examined (3m, 6m and 12m) covering the range between the smallest satellite of interest, DSCS, and the largest FLTSATCOM. This range is large enough to assure that the damper is broadband enough for general use, without redesign for each new satellite to be tested.

The exciting pulse used is a voltage step with a $\sin^2$ rate

$$V(t) = \sin^2 \frac{t}{2T_1} \quad 0 \le t \le T_1$$

$$= 1 \qquad t \ge T_1$$

the rise rate parameter T_1 was taken to be 8 nsec so that the 10-90% rise time is 4.73 nsec. This selection was made to assure that the

5. David E. Merewether, "Transient Currents Induced on a Metallic Body of Revolution by an Electromagnetic Pulse," IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-113, No. 2, May 1971, pp. 41-44. See also Air Force Weapons Laboratory's Interaction Note 93.

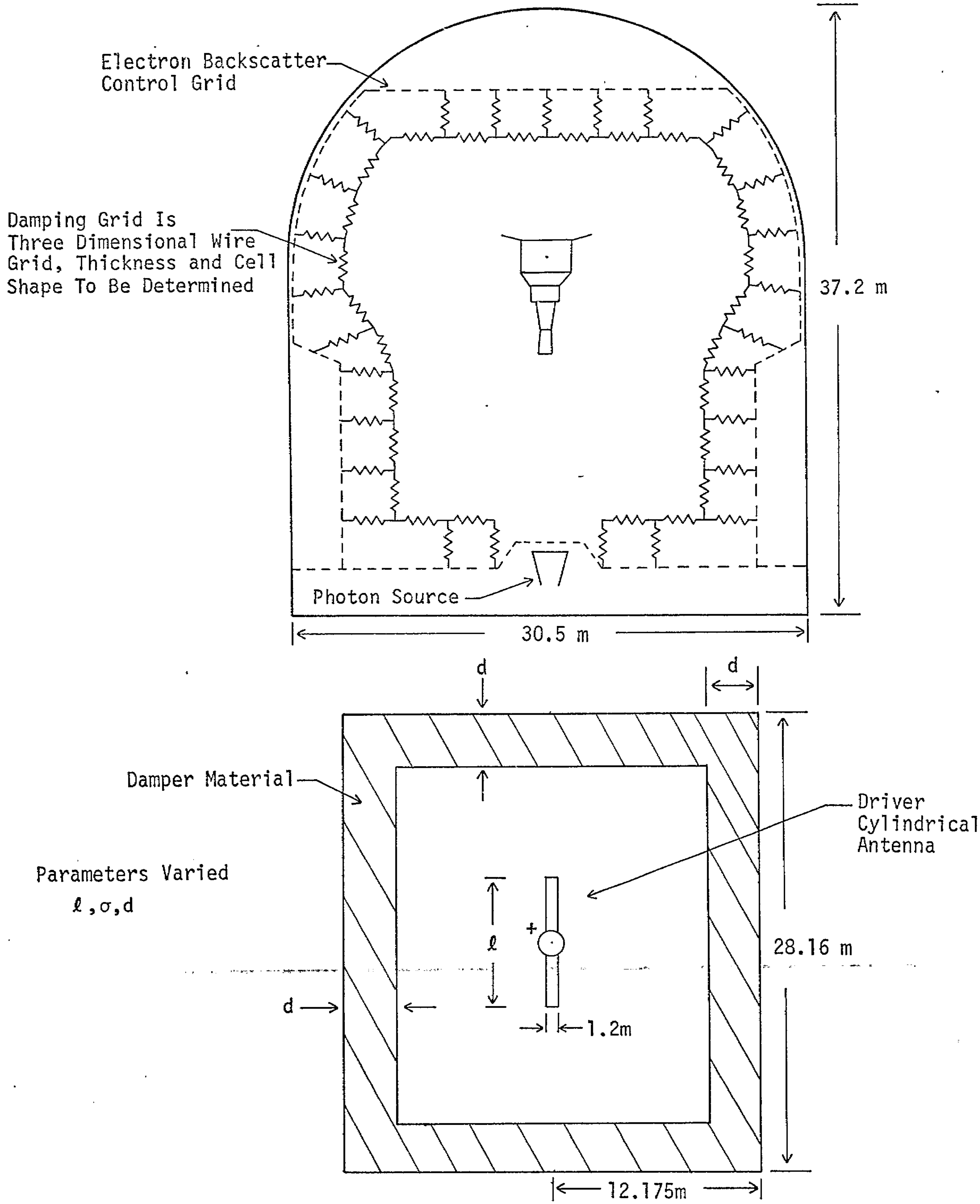

Figure 1. NASA-Lewis Tank and the Simplified Model Analyzed.

high frequency content ($f > 100$ Mhz) of the transient signals was not overemphasized.

III. Undamped Tank Results

With the type of input voltage selected, the current on the antenna exhibits the characteristic frequencies of the structure. For the antenna in free space (Figure 2a) the input current is basically a damped sine wave, with a sharp pulse on the leading edge. This initial spike is the current that charges up the local capacity of the drive terminals. This spike is not apparent anywhere else along the antenna.

When the antenna is contained within an undamped canister, the waveform departs radically from its free field shape at the time when the reflection returns from the wall ($t_w = 2* (r_{wall} - r_{antenna})/c) = 80$ nanoseconds. Clearly, using the NASA-LEWIS facility for SGEMP testing without a damper would be worthwhile only if the data obtained before the reflection returns from the wall can be unfolded or extrapolated to yield the prediction for a real exposure. Threat level testing in this environment would not be advantageous.

The reflection from the ceiling that arrives at $t_c = 2* (Z_{top} - Z_{center})/c = Z_{top}/c = 93.5$ nsec is not apparent in Figure 2c, so the computer program was rerun with r_{wall} large enough that it would not affect the predicted current during the time of observation (Figure 2c). Note that the reflection from the ceiling is still not apparent. Lowering the ceiling reveals that no effect occurs until the ends of the antenna and floor and ceiling are close (Figure 2d). It appears that no damper on the ceiling would be required if the satellite and its excitation were always rotationally symmetric. Since they are not, the best that can be said is that the damper requirements could be relaxed somewhat on the floor and ceiling. For the remainder of the study it was assumed that damper would be the same on the floor, walls and ceiling.

IV. Homogeneous Dampers

Baum[6] considered the damping of natural cavity modes by a thin liner of homogeneous conductivity. He found that for a cavity liner thickness of one fifth the radius of a spherical cavity ($d/a = .2$), the selection of a damper conductivity such that $\sigma d Z_0 = 4.6$, would properly dampen the first TM mode in the cavity. As a starting point we examined the 3 meter thick damper and the conductivity $\sigma = 4 \times 10^{-3}$ such that $d/a = 0.2$ and $\sigma d Z_o = 4.6$. It was found that this value also gave reasonable damping of the high frequency wave radiated by the driven antenna (Figure 3a). However, increasing or decreasing σ did not improve the similarity of the current observed on the satellite.

Holding the antenna length fixed at 6 meters and varying σ and d revealed that the time that the initial reflection from the front face of the damper arrives will critically determine the quality of the time domain approximation. These data revealed that when σ is made large enough to properly dampen the wave a significant reflection is obtained from the front face (Figure 3).

From Figure 3 a selection of a 4.6 meter thick damper appears desirable for use with a 6 meter long antenna. Further study of this case revealed that this thickness is best because the time that the initial reflection from the front face occurs is near a crossover in the center current and, therefore, does not seriously alter the waveform. This thickness is

6. Baum, *op. cit.*, p. 104

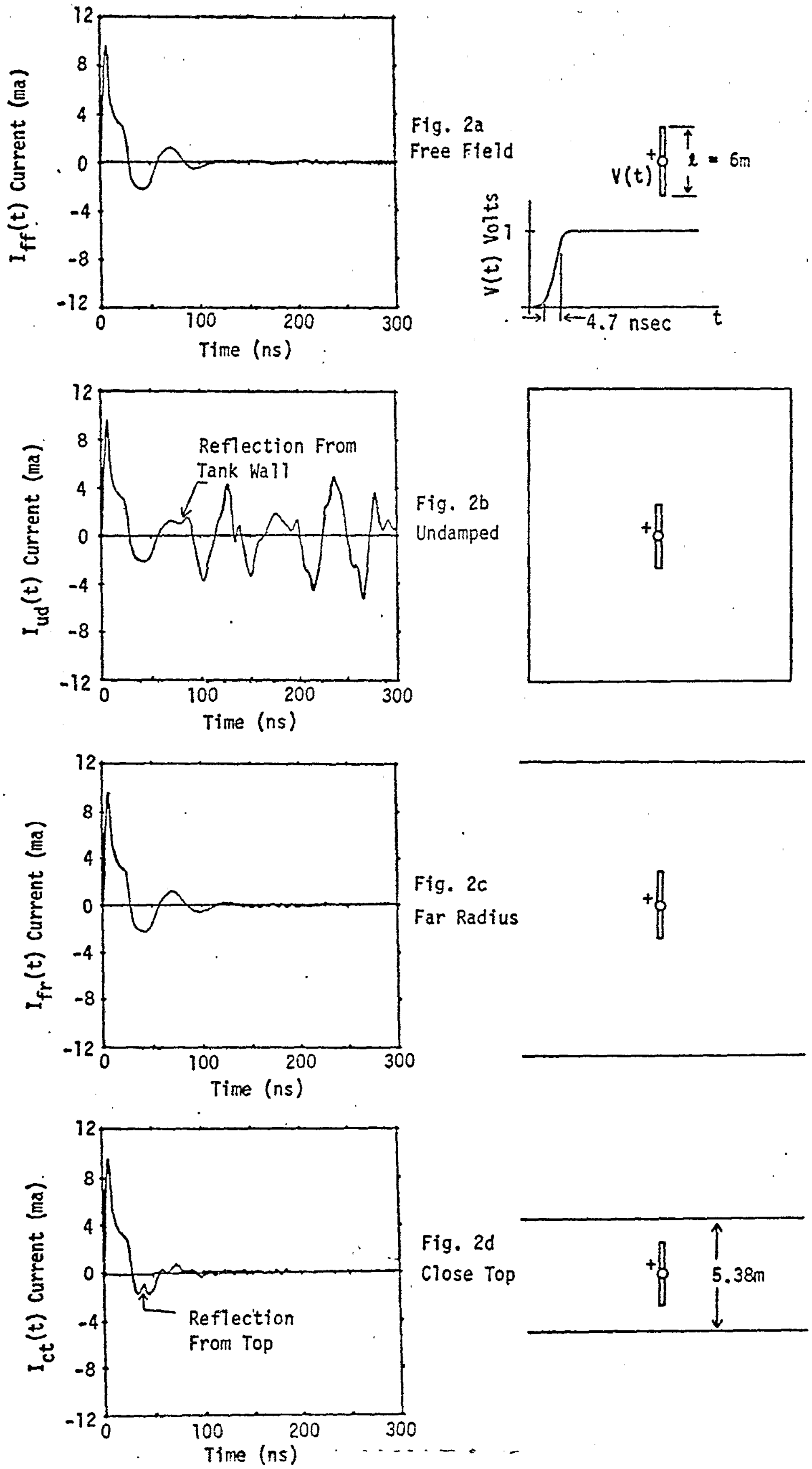

Figure 2. The influence of the undamped tank on the center current of a cylindrical antenna driven by a modified voltage step.

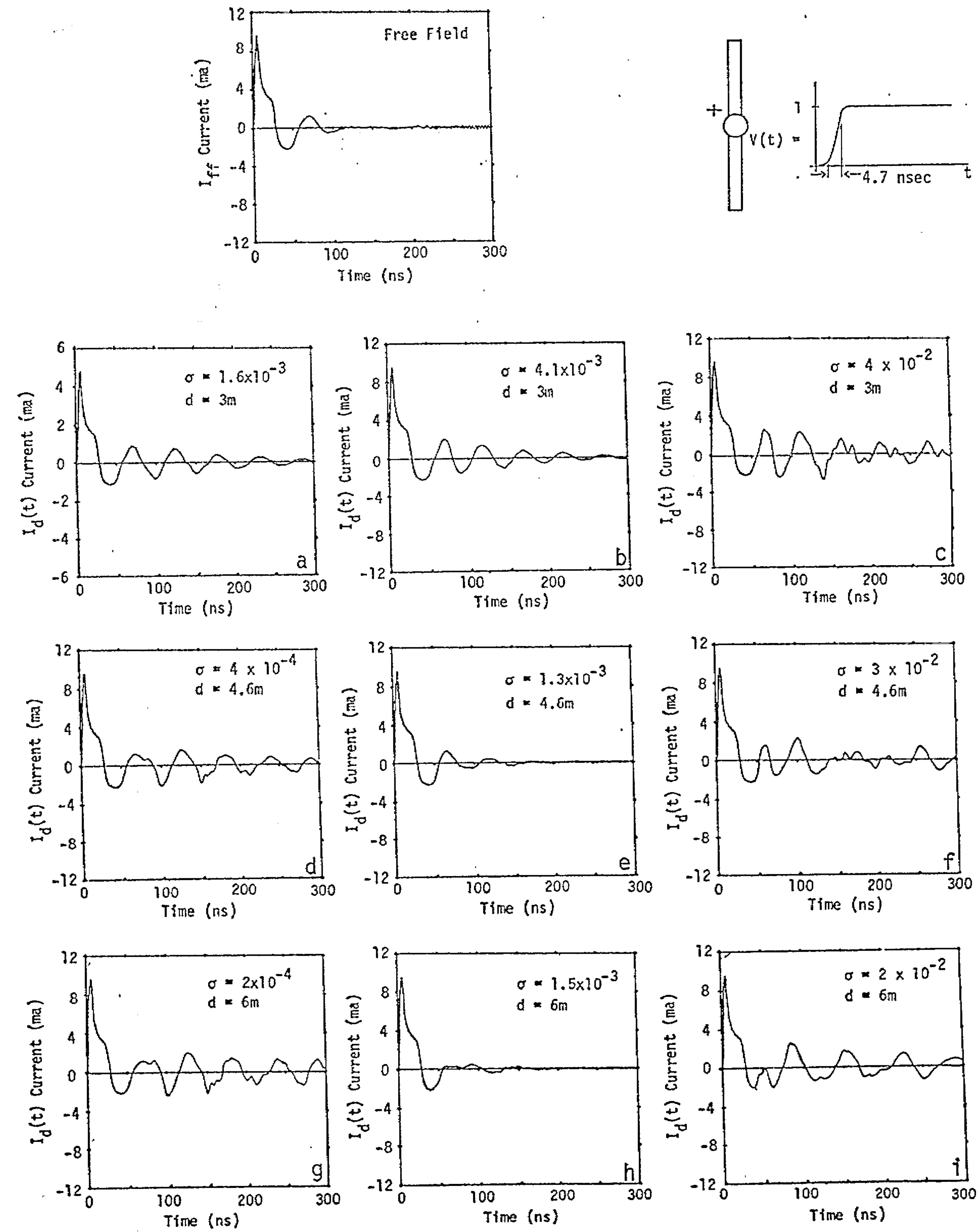

Figure 3. Effect of homogeneous dampers on the center current of a cylindrical antenna in the NASA-LEWIS tank driven by a modified voltage step.

"tuned" to the antenna length of six meters. This damper does not work well for either a 3 meter long antenna or a 12 meter long antenna (Figure 4).

V. Inhomogeneous Dampers

Considerable experience has been developed on the problem of damping outgoing waves on linear antennas.[7,8] One result of these studies indicates that the loading should be increased as you get further from the drive source. The problem at hand is analogous; however, the spacings allowed in long wire antennas are longer. With the earlier work as a guide, logarithmic loading was investigated (Figure 5).

$$\sigma = 0 \qquad 0 \le r \le r_{damp} \qquad 0 < r \le r_{damp}$$

$$\sigma = \sigma_0 \left\{1 - \frac{1}{\alpha}\, \ell n\left[1 - \frac{r - r_{damp}}{d}\right]\right\} \qquad r_{damp} \le r \le r_{wall}$$

Three parameters may be varied: the thickness d ($r_{damp} = r_{wall} - d$), the initial conductivity σ_0, and the rise rate α. The conductivity is always infinite at the wall of the canister. For lower frequencies increasing α has the same effect as lowering the initial conductivity (Figure 6).

The central figure in 6 indicates the α and σ_0 which seems to give the best response for ℓ = 6m and d = 6m. The precise values of these two parameters are not important because the currents are relatively insensitive to small changes in α or σ_0 (Figure 7).

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7. David E. Merewether, Sensor and Simulation Note 71, Transient Electromagnetic Fields Near a Cylindrical Antenna Multiply Loaded With Lumped Resistors, August 1968.

8. T. S. Shumpert, Sensor and Simulation Note 105, Some Theoretical Numerical Procedures for the Study of the Impedance Loaded Dipole Antenna, August 1969.

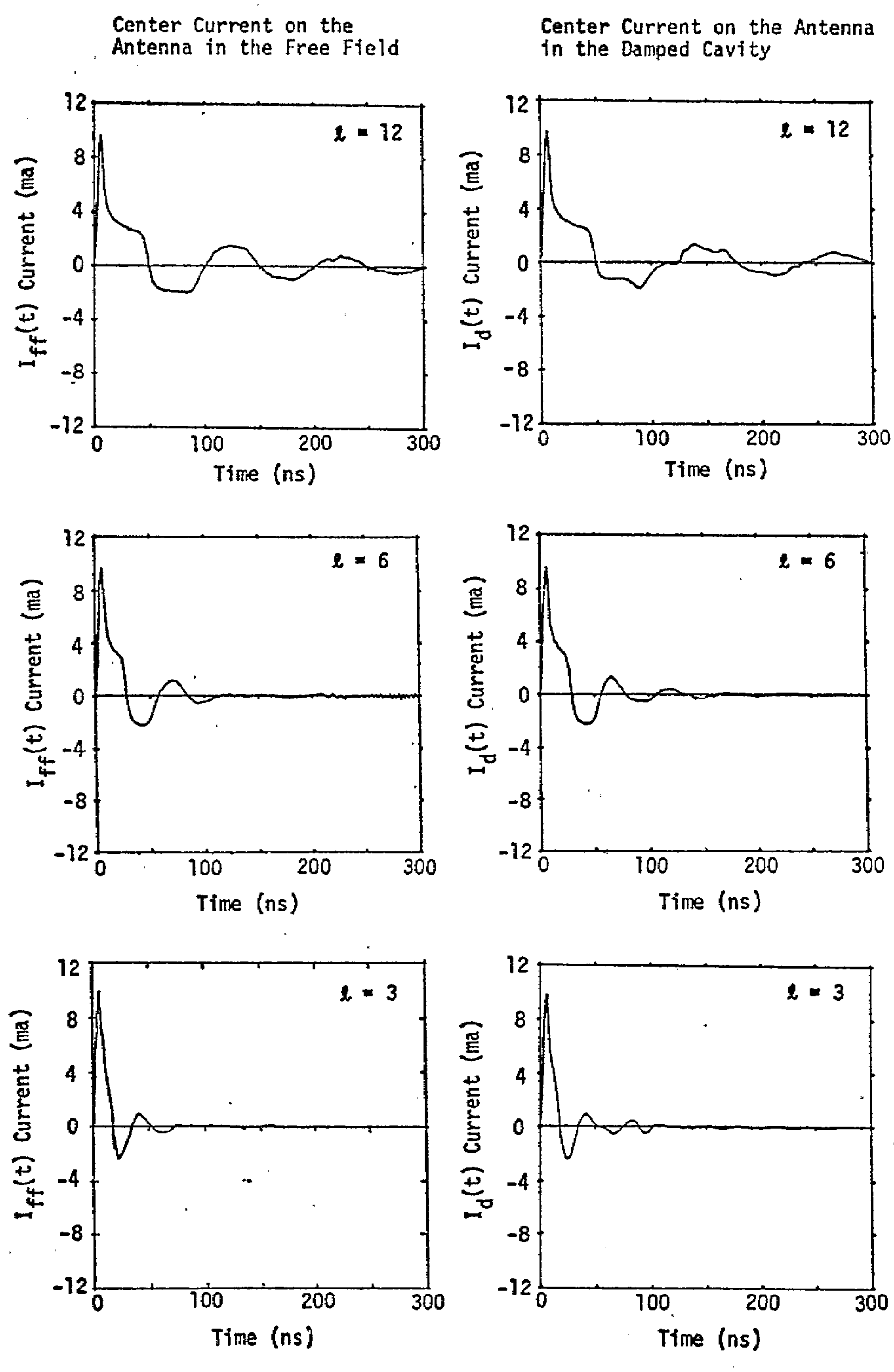

Figure 4. The effects of antenna length on the damping provided by a homogeneous damper within the NASA-LEWIS tank ($\sigma = 1.3\times10^{-3}\ \frac{\text{mhos}}{\text{m}}$, $d = 4.6\text{m}$)

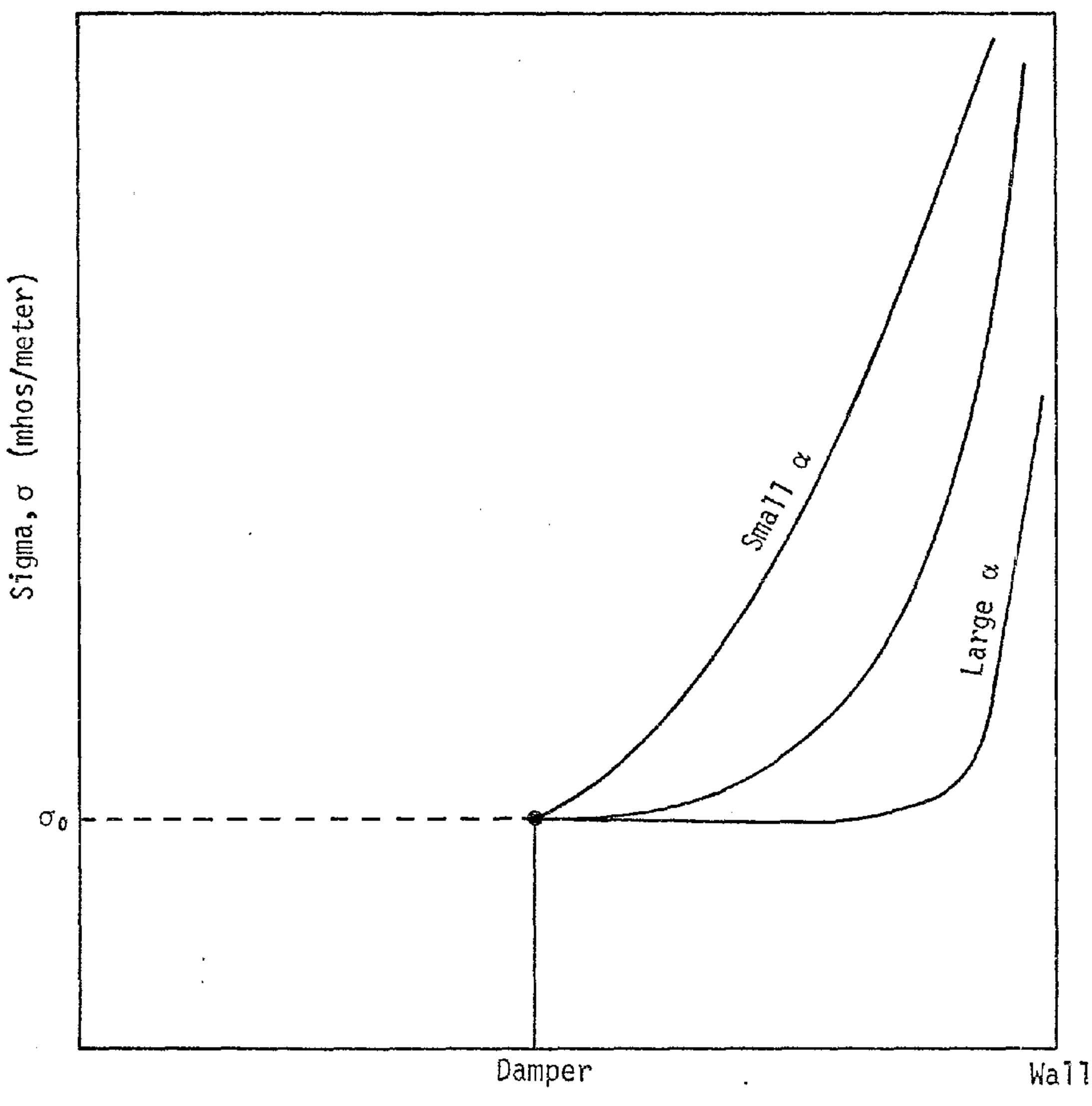

Figure 5. Logarithmic Loading of Damper Cavity

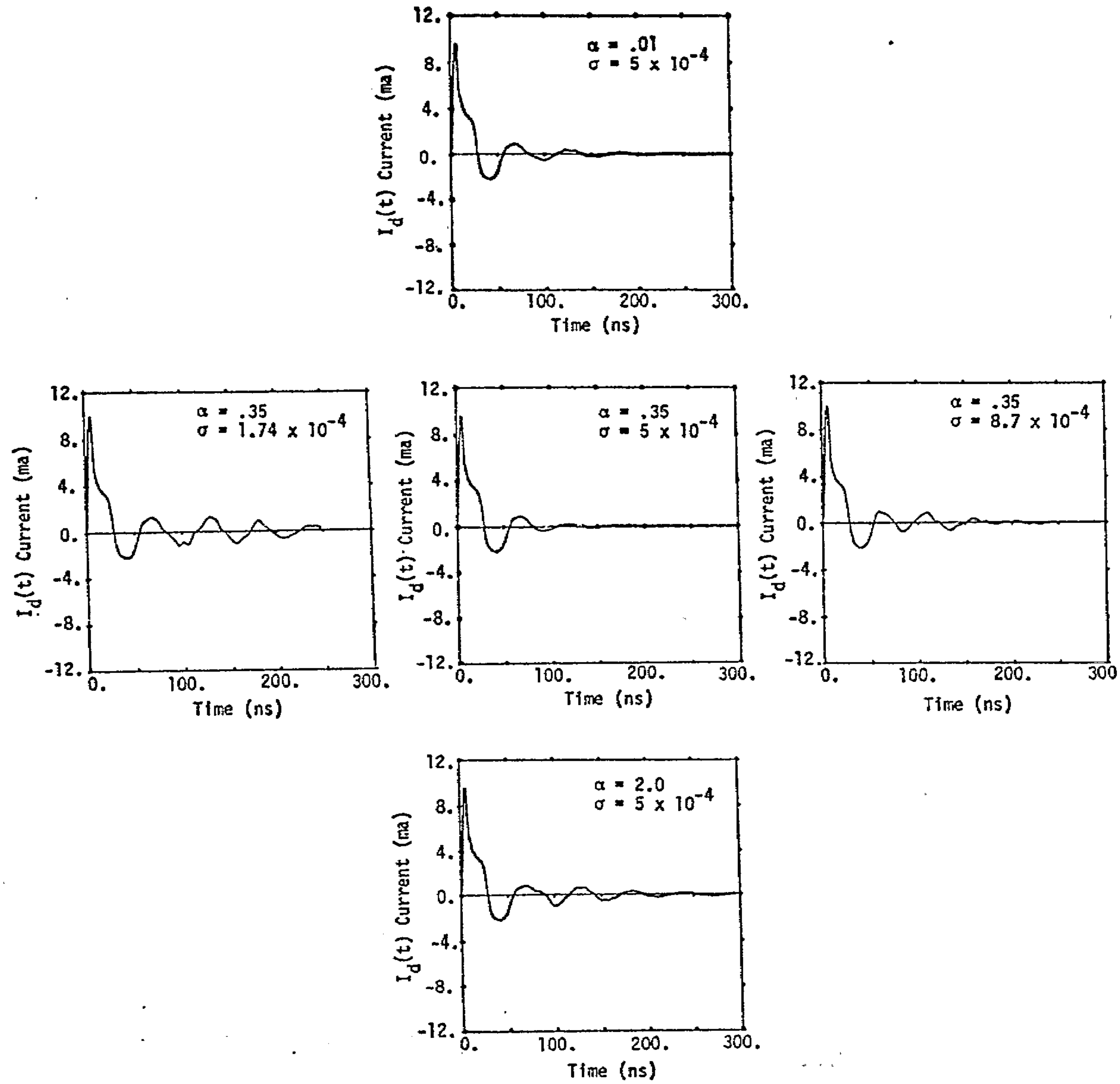

Figure 6. Effects of large variations in logarithmic damping factors on the center current of a 6 meter cylindrical antenna driven by a modified unit voltage step.

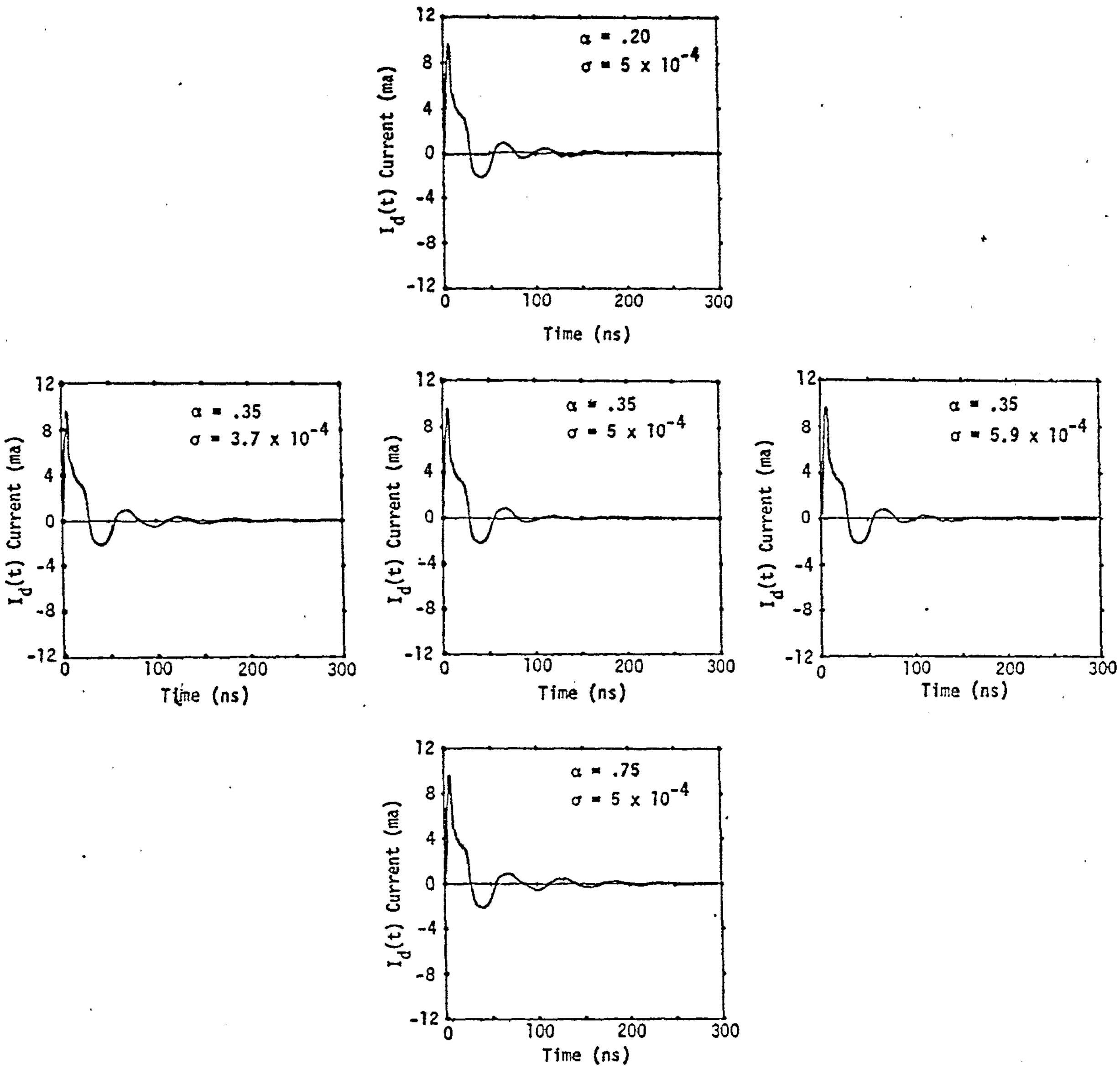

Figure 7. Effects of small variations in logarithmic damping factors on the center current of a 6 meter cylindrical antenna, driven by a modified unit voltage step.

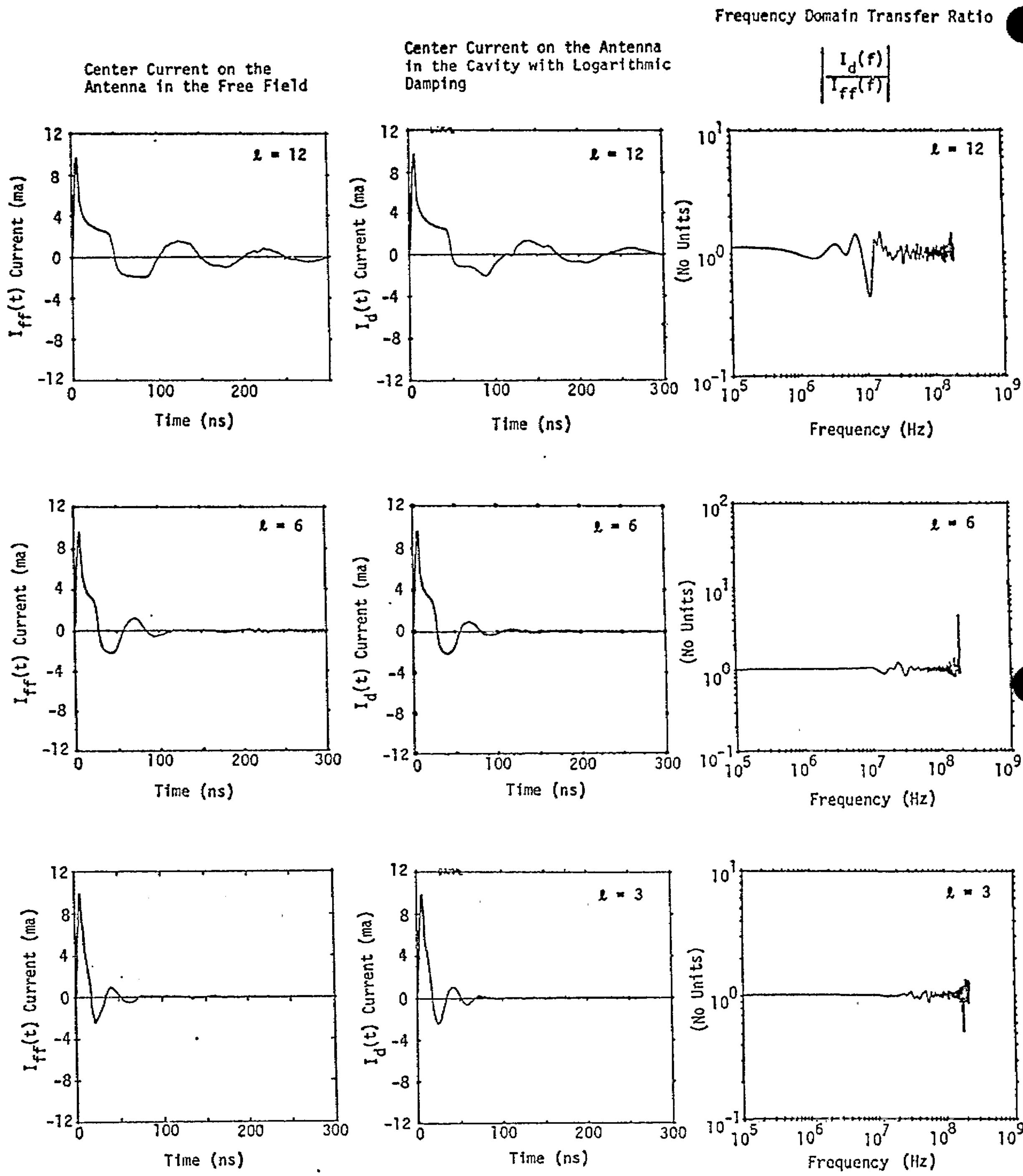

Figure 8. The effect of antenna length on the damping provided by a logarithmic damper within the NASA-LEWIS tank
$(d = 6m, \sigma_0 = 5x10^{-4} \frac{mhos}{m}, \alpha = .35)$

Varying the antenna length indicates that this 6 meter thick inhomogeneous damper is broadband enough to damp the field radiated by any satellite of interest without any damper changes (Figure 8). The transfer functions indicated here are the ratio of the center current inside the damped cavity to the center current when the antenna is in free space.

Since a damper 6 meters thick may project into the photon beam too far it is important to quantify how well the damping can be accomplished with a thinner shell. Fixing d at 4.6 meters, α and σ_o were varied to establish the best looking response for the 6 meter long radiating antenna. The damper is not as broad band as the 6 meter thick damper and some loss in the quality of the simulator is apparent (Figure 9). A similar parametric study of a 3 meter thick damper was made. This damper is thin enough that nonuniformity is no great advantage. The nonuniformity parameters σ_o and α could be varied by a factor of 4 from the "best case" (Figure 10) without producing any appreciable change in the current on the driven antenna. The damper with $\sigma = 4\times10^{-3}$ (Figure 3a) will produce about the same result.

VI. Conclusions

There are two facets of the SGEMP simulation problem that must be considered when selecting the design of a damping grid. One is the EM damping qualities of the grid and the other is the interaction of the grid with the photon beam and the electron cloud around the satellite.

The studies provided here examine solely the EM reflection properties of the grid. A "best" conductivity profile was determined for each

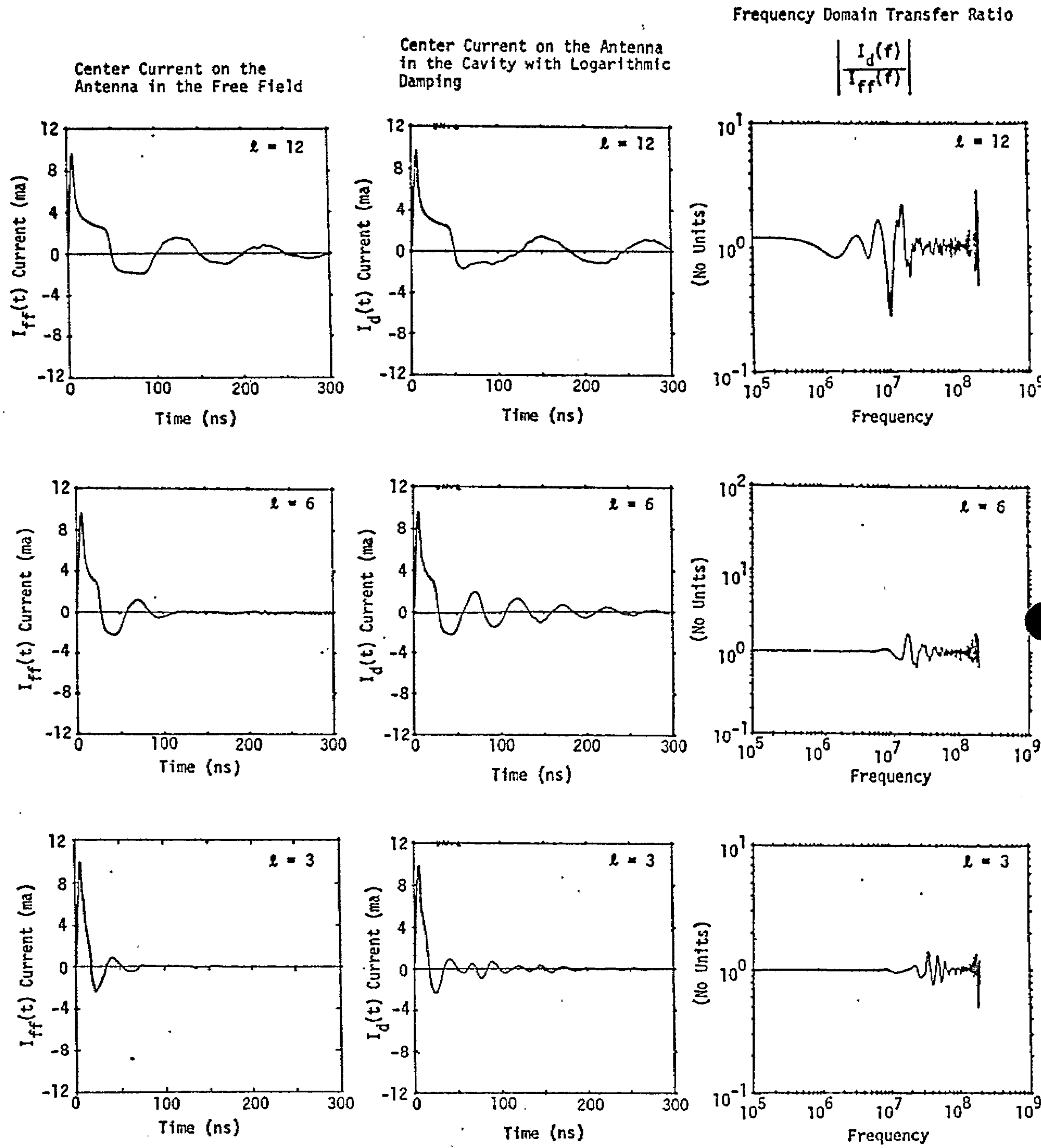

Figure 9. The effect of antenna length on the damping provided by a logarithmic damper within the NASA-LEWIS tank ($d = 4.6m$, $\sigma_o = 2.5\times10^{-4}\ \frac{\text{mhos}}{\text{m}}$, $\alpha = .5$)

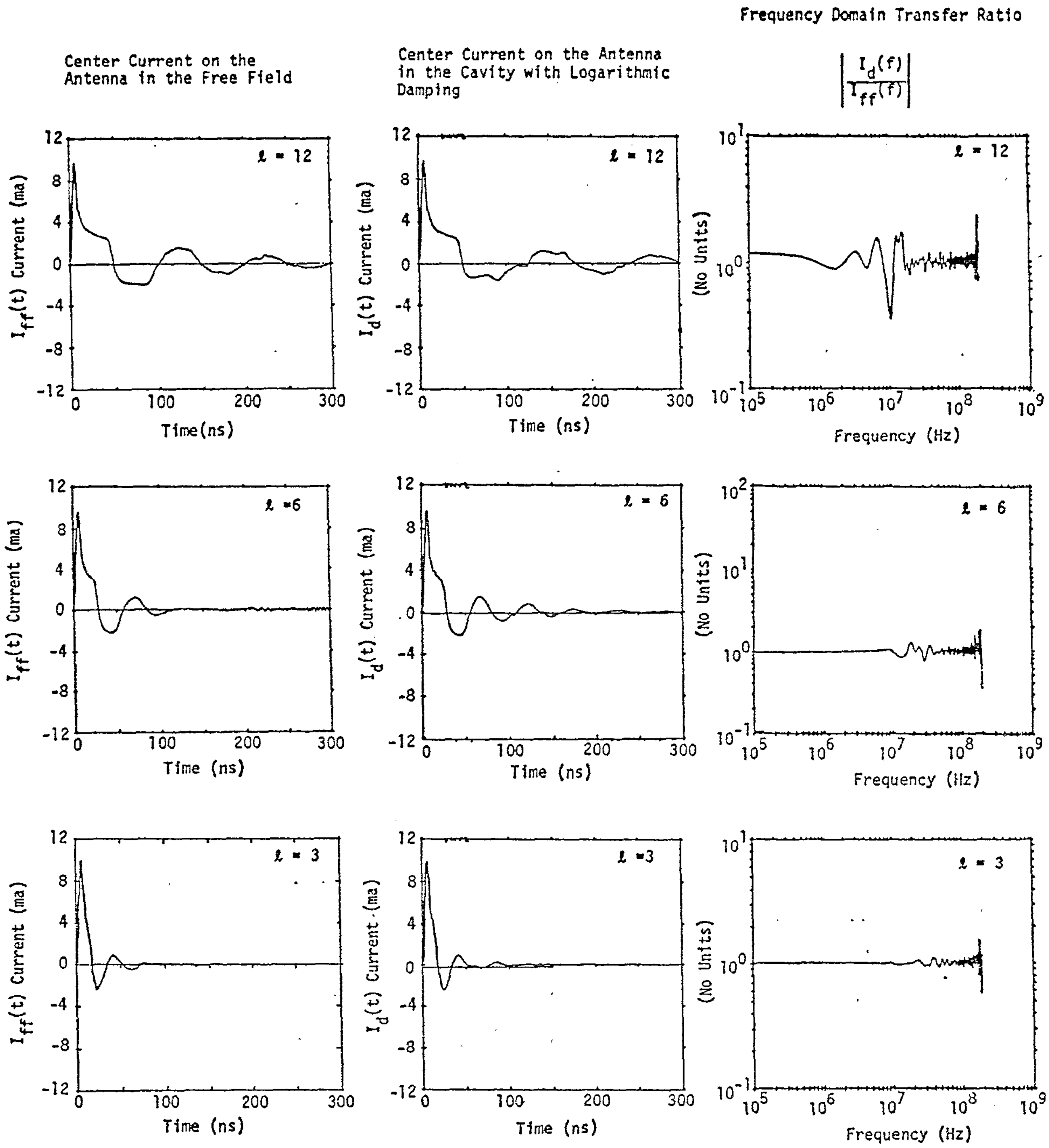

Figure 10. The effect of antenna length on the damping provided by a logarithmic damper within the NASA-LEWIS tank ($d = 3$, $\sigma_o = 2.7 \times 10^{-3}$, $\alpha = 2.0$)

of the damper thicknesses studied. It is evident that if the damper can be allowed to project into the cavity for as much as 6 meters, a very fine damping of the fields radiated by a satellite can be obtained. However, some penalty must be paid for using thinner dampers.

It may be true that a thinner damper will provide the best overall simulation when the influence of the damper on the electron trajectory is included and the influence of the photocurrents emitted by the damper are recognized.

Probably the next study to be done is to determine how dense a wire grid structure must be to adequately approximate a homogeneous volume damper. Fortunately, for a nonuniform damper the density of elements can be made smaller near the center of the cavity. This will minimize the problems of the interaction of the damping grid with the photon beam. The output of this study will be needed to quantify the damper photocurrents.