

# Modeling Electrically Small, Thin Surfaces with Wire Grids

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**Abstract**-Wire grids are widely used to model conductive surfaces. Wire grid models reported in the literature have primarily addressed electrically large or resonant configurations. Electrically small surfaces, however, can also have a significant effect on radiation characteristics and these surfaces are often difficult to model using other methods. A structure containing an electrically small, thin plate with wires attached to both sides is analyzed using different wire-grid models. The thin plate is modeled as either an open or closed surface using single and double-layer grids. Comparing the model results with measurements suggests that a closed surface (double-layer) grid may be more accurate and efficient than an open surface (single-layer) grid in many cases. Unlike single-layer grids, double-layer grids do not permit current to flow through the surface and hence enforce an important boundary condition.

## Introduction

Structures with large conductive surfaces are often modeled using wire grids. Wire-grid representations are conceptually simple and can significantly reduce the amount of computation required to calculate the currents, fields, and other radiation parameters of a particular configuration. Powerful, general purpose computer algorithms for analyzing thin-wire structures using moment-method techniques are readily available and make wire-grid modeling especially attractive.

Antenna reflectors, aircraft bodies and ground planes have been successfully modeled using wire-grid structures [1-3]. Yet despite

the popularity of this technique, there is relatively little information in the literature dealing with how or when wire grids can be used to obtain accurate results. In fact, there seems to be a general consensus that wire grids model far-field parameters much more accurately than one might expect based on their near-field behavior. Ludwig [4] demonstrated that a wire grid model can do a relatively poor job of matching the surface boundary condition between wires and still accurately predict the fields even a short distance away from the surface.

Most of the wire-grid results that have been published to date model electrically large or resonant structures. However, electrically small surfaces can also have a significant effect on the radiation parameters of a system. One particular type of configuration that is used to model different sources of electromagnetic interference [5] is illustrated in Figure 1. A small

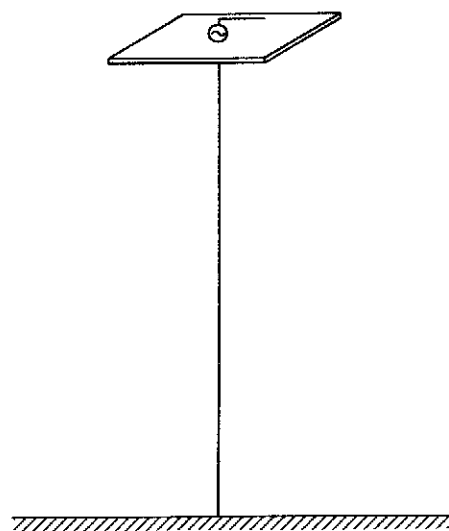


Figure 1: Electrically Small EMI Source Model

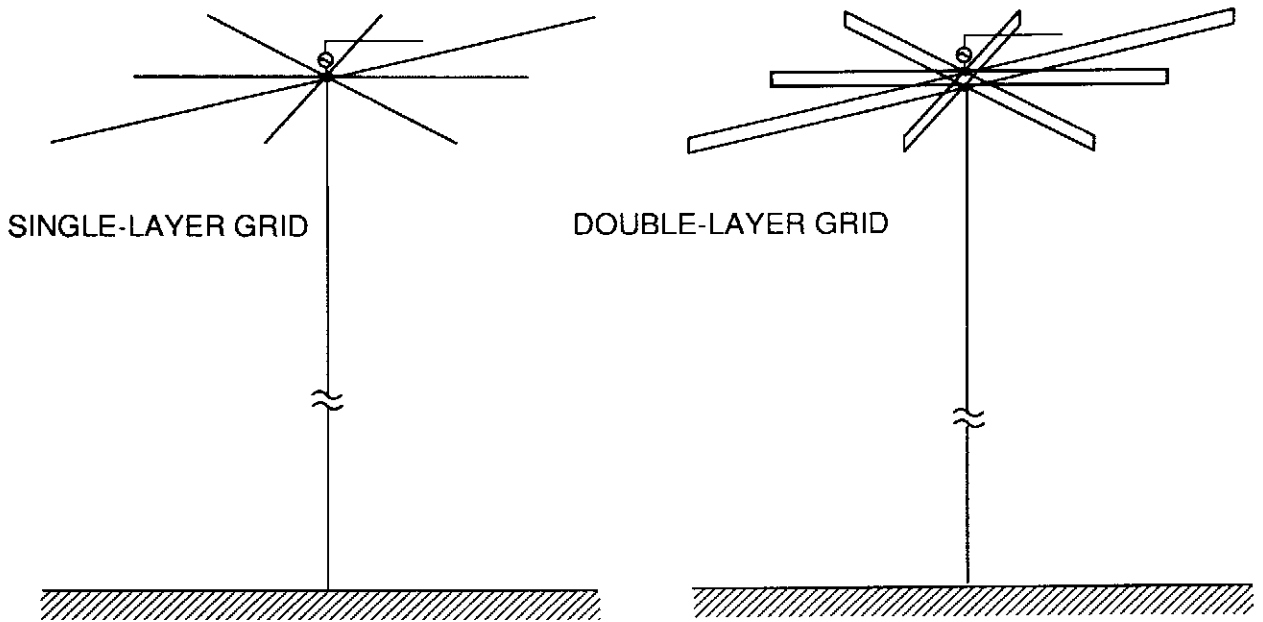


Figure 2: 8-Radial Single-Layer and Double-Layer Wire Grid Models

source drives a wire attached to one side of a metal plate. The wire, source, and plate model a particular circuit in a system and are often electrically small. Another (longer) wire also attaches to the metal plate and is used to model a power or signal cable attached to the system. This cable might in general be attached anywhere on the plate including the side opposite the source attachment.

Although this configuration is fairly simple, it is difficult to analyze using existing surface-patch, moment-method algorithms. Existing codes cannot efficiently model electrically small, thin plates with wire attachments on both sides. Modeling the plate with a wire grid appears to be a promising alternative, but only if the number of wire segments needed to form the grid is not excessive.

Two approaches to the modeling of thin plates were investigated. These approaches are illustrated by the wire-grid representations shown in Figure 2. The first representation, which will be referred to as a single-layer grid, is the simplest. The example in the figure models the entire plate with only 8 radial wires. With this representation, currents on the top

and bottom side of the plate model are identical and the net current at the edge of the grid must be zero. The second representation, referred to as a double-layer grid, models the plate as a closed surface. This representation requires more than twice the number of wire segments to model the plate, but it allows different currents to be calculated for the top and bottom of the grid and does not permit current to flow through the center of the plate. Only radially directed wire segments were initially included in the plate model, taking advantage of the configuration's symmetry to reduce computation.

## Measurements

The test set-up shown in Figure 3 was used to obtain measurements that could be compared to the wire-grid model results. A coaxial cable brought the signal from Port 1 of an S-parameter test fixture to a point just above a thin metal plate. The plate was located 1 meter above a metal ground plane in a semi-anechoic test chamber. The cable's shield was bonded to the metal plate and the ground plane. The center conductor of the cable was connected to

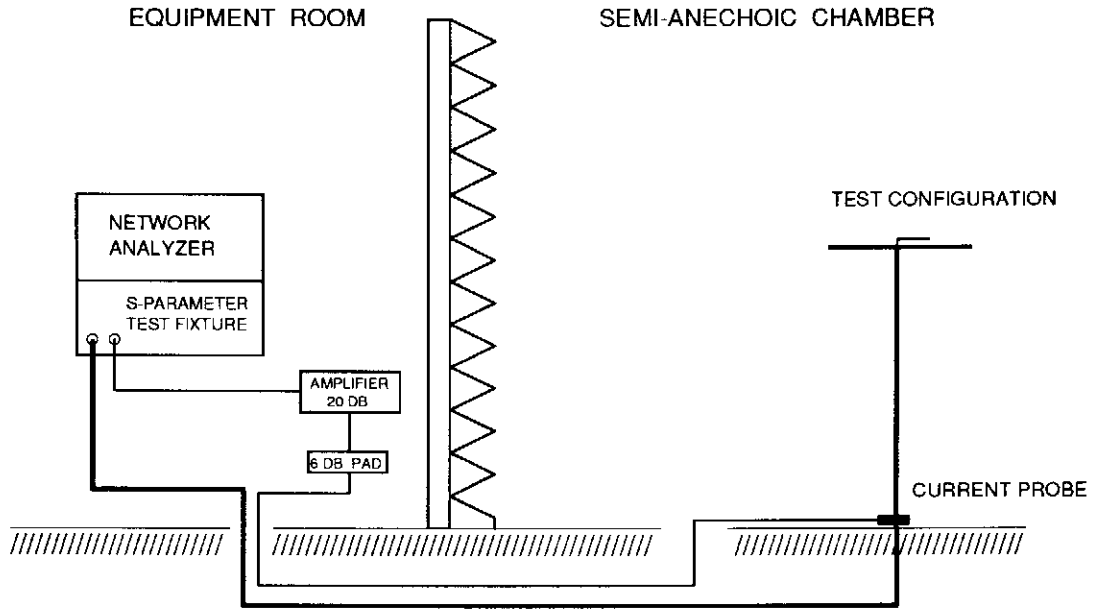


Figure 3: Measurement Set-Up

an antenna extending 15 cm above the plate. This resulted in a source configuration similar to the model in Figure 1. The effective height of the voltage source above the plate was 5 mm.

A current probe at the base of the configuration was connected to Port 2 of the S-parameter test fixture. Locating the current probe at the base of the cable just above the ground plane minimized the effect of the probe's cable and reduced the likelihood of being at a null in the current distribution.

Measurements of the transfer ratio,  $S_{12}$ , were converted to a current measurement and

normalized to a 1-volt source potential using the following formula,

$$I \text{ dB}(\mu A) = S_{12} \text{ dB} + 6 \text{ dB}(\text{volts}) + G_T \text{ dB}(\text{mhos}) + 120 \text{ dB}$$

where  $G_T$  is the transfer conductance of the current probe. The source voltage is 6 dB instead of 0 dB because the S-parameter test fixture is designed for a 50-ohm system. The input impedance of this configuration is well above 50 ohms at these frequencies, therefore the actual voltage at the input is approximately twice the voltage assumed in the calculation of  $S_{12}$ .

Details of the test configuration are shown in Figure 4. A straight (vertical) and bent (horizontal) antenna were used for these measurements. Although the thickness of the plate used for the measurements was only 3 mm while the spacing used for the double-layer grid was 10 mm, previous measurements with similar configurations [6] indicated that this type of measurement is insensitive to the exact thickness of the plate. It was not practical to analyze a double-layer grid with a 3-mm spacing due to constraints on the wire spacing and radius near the multiple wire junction points.

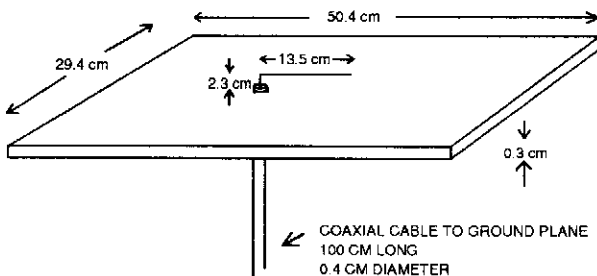


Figure 4: Model Dimensions and Specifications

## RESULTS

Several wire-grid configurations were initially analyzed using different wire radii and a different number of wire radials to represent the plate. Surprisingly, the radius of the wires in the grid was not a critical parameter as long as it was chosen within the constraints of the algorithm. The algorithm used for these calculations was the Numerical Electromagnetics Code [7] developed at Lawrence Livermore National Laboratory. The grid-wire radius used to obtain all of the results reported here was 3 mm. Note that the same-surface-area rule of thumb [4] could not be used to determine the radius of wire segments in the grid. Excessively thick wire radii are calculated when this rule of thumb is applied to sparse, electrically small grids. In many cases 4 wire radials were all that were needed to get stable results although sometimes 8 radials were required. Using more than 8 radials did not produce significantly differently results than those obtained with 8-radial models.

The configuration in Figure 1 was modeled using the plate and wire dimensions shown in Figure 4. 21 equal length wire segments were used to model each grid radial. The wire above the plate was modeled using 12 (1 mm radius) segments and the long wire below the plate was modeled using 19 (2 mm radius) segments. An

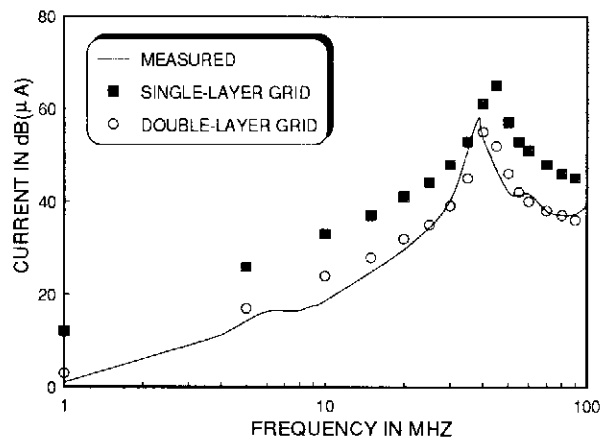


Figure 5: Single and Double-Layer Calculations

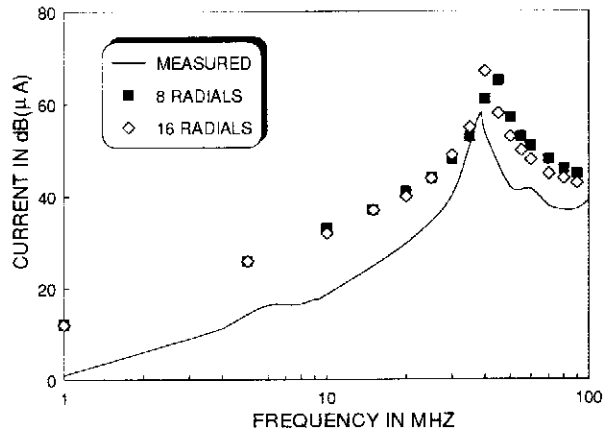


Figure 6: 8 vs. 16 Radials on a Single-Layer Grid

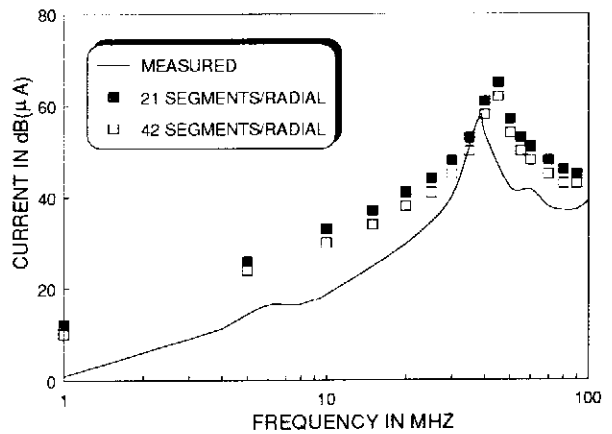


Figure 7: Effect of Additional Segmentation

applied E-field (type 0) voltage source was centered on a segment 5 mm above the plate. The current just above the ground plane on the 1-meter long attached wire was calculated at several frequencies between 1 and 100 MHz. 8-radial single-layer and double-layer grid results are plotted in Figure 5. Note that the double-layer grid requires roughly twice as many wire segments to represent. However, as Figures 6 and 7 illustrate, doubling the number of wire radials or the number of wire segments per radial in the single-layer grid does not result in a model as accurate as the double-layer grid. This would indicate that the double-layer grid approach is a more efficient way to analyze this type of configuration.

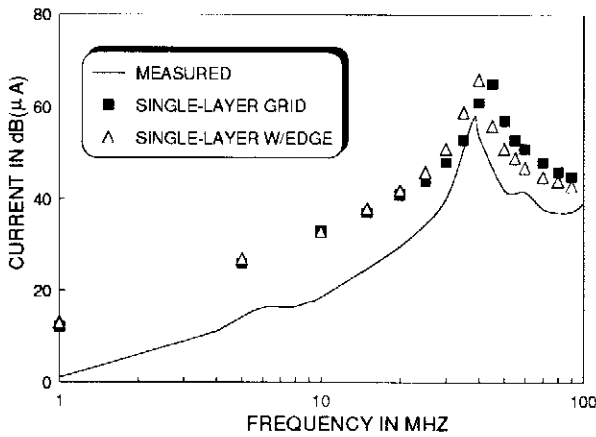


Figure 8: Effect of Adding Wire to Edge of Grid

In order to determine if the single-layer grid could be improved by adding segments to allow transverse or circulating currents, wires were added that connected the ends of each radial. As Figure 8 illustrates, there was very little change in the result despite the large number of additional wire segments required to model the grid.

Several variations of the configuration in Figure 1 were evaluated and the double-layer grid consistently produced calculated results that more closely approximated the measured results. Although, when the source was located near the corner of the plate and attached to a straight wire or a wire bent away from the plate, the single-layer and double-layer results were

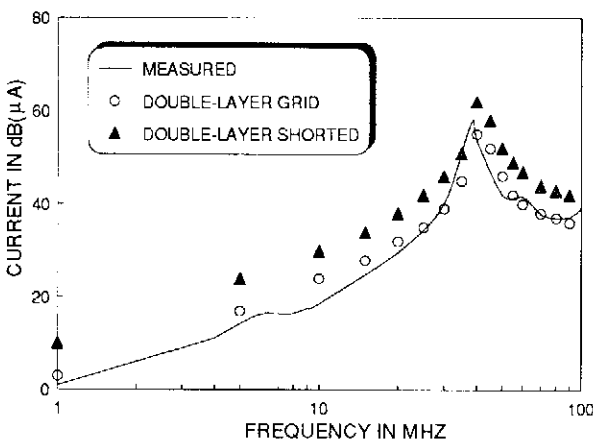


Figure 9: Segment Added Through Grid Center

within a few dB of each other [5]. This suggests that perhaps one reason a sparse double-layer grid works so well is that it forces all of the current at the wire attachments to flow out around the edge of the grid just as the physical currents must flow around the edge of the plate. The single-layer grid does not prevent some current from flowing directly from one wire attachment point to the other.

In order to determine how significant this difference between the single-layer and double-layer models is, the double-layer calculation of Figure 5 was repeated with one additional wire segment. The new segment connected the upper wire attachment point directly to the lower wire attachment point. As the result in Figure 9 illustrates, this one extra segment significantly degraded the results. In fact, with the wire attachment points shorted by this segment, the double-layer grid calculations more closely resemble the single-layer grid results in Figure 5.

## CONCLUSIONS

Electrically small, thin plates with wire attachments on both sides are not readily analyzed using surface-patch algorithms. In some cases however, relatively sparse wire grids can provide a fairly accurate model.

When a sparse grid is used and the wire attachment points are not near the edge of the plate, it is probably more accurate and efficient to model the plate as a closed surface using a double-layer grid. For the configurations analyzed in this paper, double-layer grids consistently yielded more accurate results than more elaborate single-layer grids requiring as many or more wire segments to model.

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