Modeling Unintentional Sources of Electromagnetic Radiation

Todd H. Hubing
IBM Communication Systems
Research Triangle Park, NC 27709

J. Frank Kauffman
North Carolina State University
Raleigh, NC 27695-7911

Abstract - Suppressing the electromagnetic emanations from unintentional radiation sources is a growing concern. A variety of simple radiation models are used by electronic circuit and systems designers to help them locate and evaluate potential sources of radiation. However, the powerful numerical modeling techniques that are widely used to analyze antenna designs, are rarely applied to unintentional radiation sources. Numerical EM analysis codes that work well for modeling antennas are not readily applied to devices that are not designed to radiate. The analysis of unintentional radiation sources presents a unique set of problems. This paper investigates some of these problems and illustrates them using simple models for a video display terminal. Approaches to the analysis of this model using existing moment-method algorithms are investigated. This investigation reveals some of the weaknesses of the existing techniques and makes it clear that a new approach is needed. Although this approach is yet to be defined, essential features of such an approach and the incorporation of these features in a computer modeling code are discussed.

Introduction

Unintentional sources of electromagnetic radiation have been the object of an increasing amount of concern. Many countries, including the U.S., regulate the electromagnetic emissions from unintentional sources such as computers and computer peripherals. The trend towards faster, more sophisticated, but less expensive computing devices has made it much more difficult for computer manufacturers to meet these requirements using traditional methods. There is an increasing need for EM modeling algorithms that can be applied to unintentional radiation sources.

Unfortunately, most unintentional radiation sources are very complex. It is not usually clear which parameters of the source are critical to its analysis. For example, a video display terminal may contain several high-frequency circuit cards, internal wires, and external power and signal cables. Modeling every circuit and wire using numerical modeling techniques is not usually practical. Excessive amounts of computation would be required and existing numerical techniques are unable to model this type of highly-complex source. It would be much better to eliminate those wires and circuits that do not have a significant effect on the radiation prior to the application of a numerical technique.

When modeling sources that are designed to radiate, it is relatively easy to determine which parameters are important enough to be included in the model. However, the radiation mechanism of unintentional sources is not usually well-understood. The high-frequency coupling between circuits makes it difficult to determine one specific source and there are often several possible radiating elements.

Example

Consider the video display terminal (VDT) illustrated in Figure 1. Rather than attempting to model all of the significant parameters immediately, it is often useful to start with a simple model of a primary radiation mechanism. Once the behavior and limitations of the simple model are well understood, other parameters of the VDT can be included in the model. In this way, the potential significance of these parameters can be evaluated.

If the VDT is small relative to a wavelength at the frequencies of interest, it is reasonable to expect

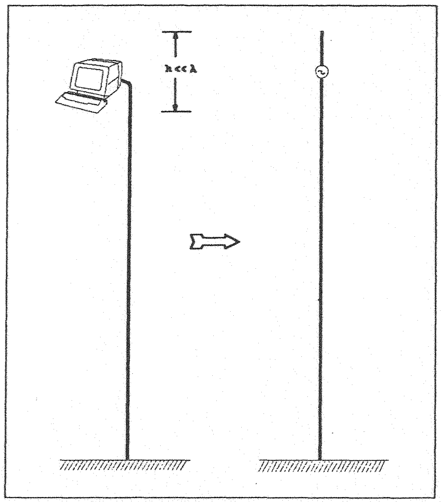

Figure 1. Simple Wire Model of a Video Display Terminal

[1,2] that the common-mode[1] currents induced on the attached cables are the most significant electromagnetic radiation source. The simplest possible model of the VDT therefore consists of a cable and a source that puts current on the cable. Since only common-mode currents are being considered, the cable can be modeled with a solid wire. A source on the end of the wire supplies the current and an undetermined length of wire on the opposite side of the source models the parts of the VDT that are *driven* relative to the cable.

Although Figure 1 represents a very crude model of a complex device, it is readily analyzed and can tell us many important things about the way this device radiates. For example, the current distribution (though not the amplitude) on the cable can be calculated for various cable positions, terminations and frequencies. By setting bounds on the length of the wire segment above the source (based on the dimensions of the VDT), useful information pertaining to the input impedance and possible resonant frequencies can be obtained [2].

This model can be improved somewhat by modeling the source with greater detail. Comparisons with actual measurements or experience with VDT testing are useful for estimating a voltage level and source impedance to use in the model. Filters, ferrites, or shields that are designed to reduce common-mode currents on the cable can be added to the model to predict their effectiveness. For example, a source model for a 50-ohm circuit above a ground plane in a VDT with a ferrite choke on the power cable might be modeled as shown in Figure 2. This type of model is more accurate than the single wire model and can provide useful information about the effect that the ground plane, circuit resistance and ferrite impedance have on the radiation from the VDT.

Numerical Techniques

Models such as the one in Figure 2 consisting of three-dimensional circuit layouts in the presence of nearby metal plates and cables are very useful for analyzing a variety of electromagnetic compatibility problems. Unfortunately, this type of configuration

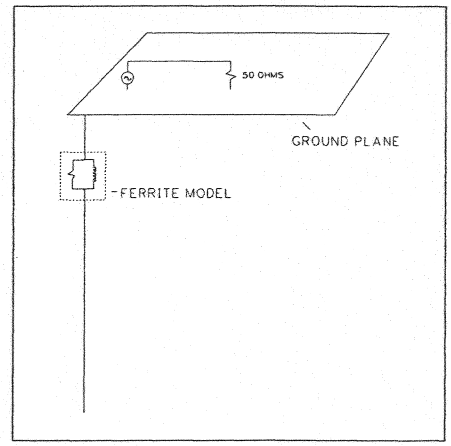

Figure 2. Circuit with Ground Plane and Attached Cable

---

[1] Common-mode current is the component of the cable current that flows in the same direction on all conductors as opposed to differential or normal-mode current which flows in opposite directions using different conductors in the same cable.

is not readily analyzed using existing numerical EM analysis techniques.

A finite-element technique would appear to be appropriate for modeling electrically small circuits and metal plates, however most practical unintentional source models have relatively long attached wires [2]. For this reason, a moment-method technique is preferred. Unfortunately, a survey of existing moment-method algorithms did not turn up any readily-available codes capable of modeling this type of configuration.

Two of the codes that were evaluated did come close however. The ESPII code [3] developed at Ohio State University models wires and conductive surfaces and can accurately calculate the input impedance of a source near a wire attachment. It does not model wire attachments near the edge of a plate however (prohibiting wire attachments to electrically small plates) and it could not analyze wire attachments to opposite sides of a thin plate. The Numerical Electromagnetics Code (NEC) [4] developed at Lawrence Livermore National Laboratories models wire attachments near the edge of a surface and on both sides of a surface. It does not however, model thin surfaces very well and calculations of the input impedance of a source near a wire attachment point are not always accurate. Modifications to the NEC code were attempted in an effort to use this algorithm for modeling unintentional sources [5]. These modifications improved the detail and accuracy of the wire attachment calculations at the expense of additional computer time and memory. The result was a relatively inefficient code that accurately calculated the input impedance of sources near a wire attachment, but could still not model thin surfaces. The inability of NEC to model thin surfaces is due in part to properties of the magnetic field integral equation (MFIE), which it uses to solve for the currents on conductive surfaces. This limitation can be overcome by modeling the surface with smaller patches so that the length and width of each patch are comparable to the thickness of the metal plate. This requires a large number of patches however, and the computing resource required to model the conductive surfaces found in most unintentional sources is prohibitive.

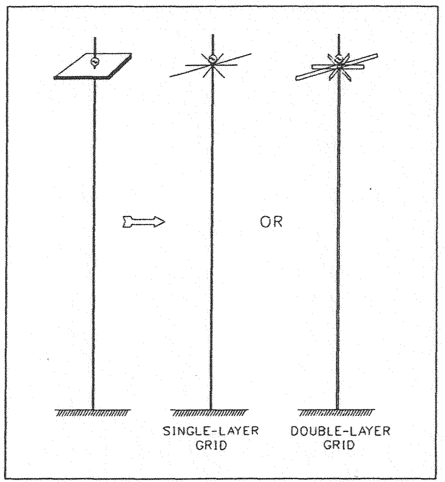

Figure 3. Wire-Grid Models of an Radiation Source with a Metal Plate

Wire Grid Modeling

Another possible approach to the analysis of this type of configuration is wire-grid modeling. Conductive surfaces are often modeled by a *grid* of wires, which facilitates their analysis using one of many moment-method codes that accurately model wire configurations.

Two techniques for modeling electrically small, thin plates with a wire grid were investigated. They are illustrated in Figure 3. The first technique (single-layer grid) represents the entire plate with one grid. The second technique (double-layer grid) uses a separate grid to model each side of the plate.

Various wire-plate structures were built and tested in order to obtain measured data to compare with wire-grid model results. In general, the wire-grid models were capable of modeling the plate very well except at frequencies near the system resonance. The results were relatively insensitive to the diameter of the wires in the grid, which was surprising since the wire diameter is a critical parameter in the analysis of electrically large or resonant surfaces [6]. For these electrically small plates, it was only necessary to choose wire diameters within the constraints of the algorithm and to insure that the sum of the wire diameters at an attachment point was on the order of the diameter of the attaching wire.

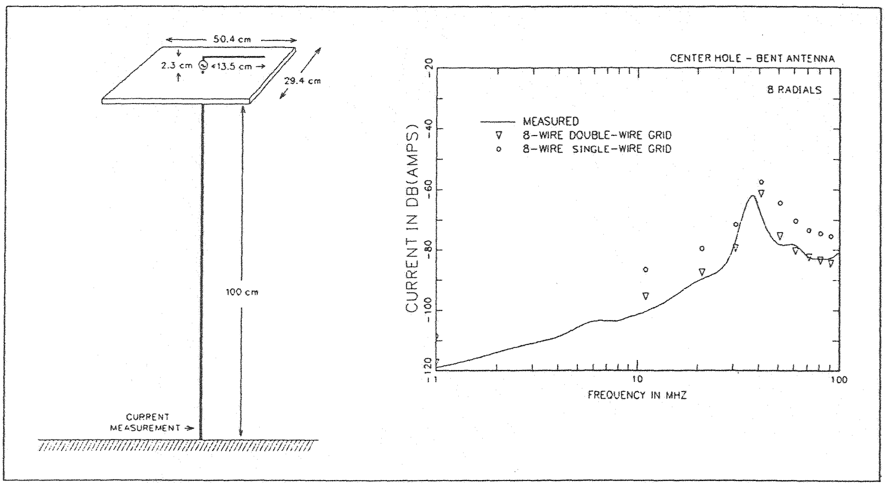

Figure 4. Wire-Grid Analysis of a Bent Wire over a Metal Plate

Figures 4-7 show the results obtained when single and double-layer grids were used to model four different configurations. The source amplitude was 1 volt and the current was measured at the base of the long wire just above the ground plane. Details of the measurement procedure and additional results are presented in [5].

The double-layer grid did a good job of modeling the metal plate in a variety of configurations. The single-layer grid worked well in some configura-

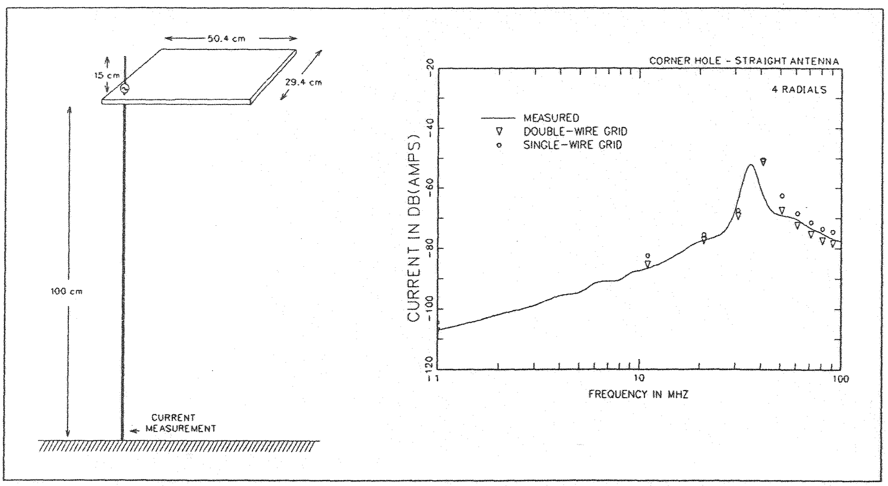

Figure 5. Wire-Grid Analysis of a Straight Wire over a Metal Plate

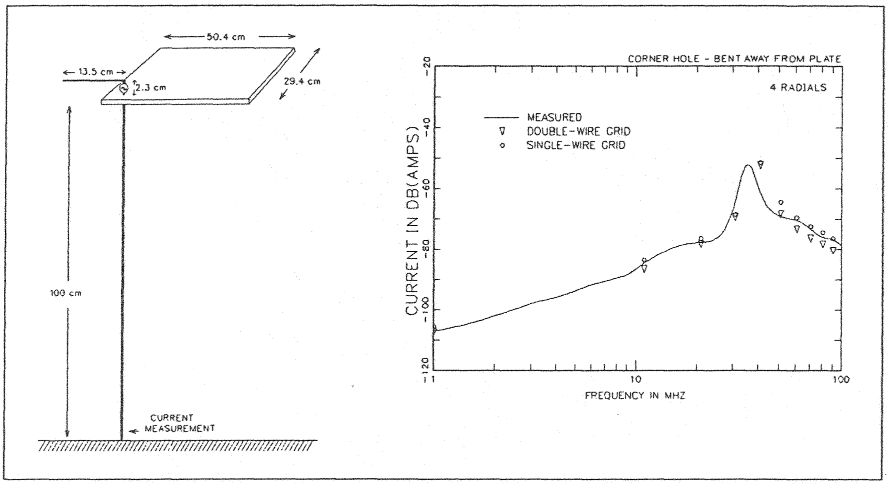

Figure 6. Wire-Grid Analysis of a Wire Bent Out Away from Plate

tions, but did not generally perform well when the attached wire was bent over the plate.

Wire grid models are a convenient and relatively accurate way of modeling the conductive surfaces in a variety of unintentional source configurations. They are not the ultimate solution, however. Although they do a good job of modeling the far-field effects of a metal plate, the fields calculated near a wire grid do not approximate the fields near a smooth conductive surface. This makes it

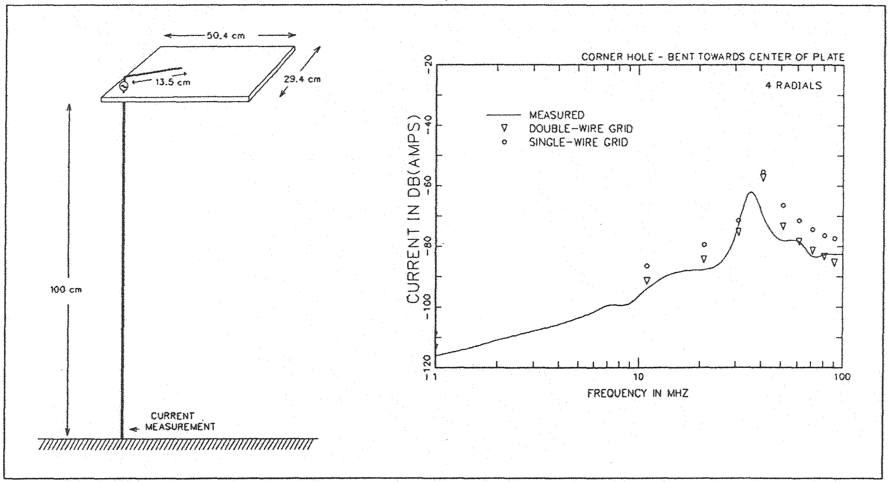

Figure 7. Wire-Grid Analysis of a Wire Bent In Over a Metal Plate from Corner

very difficult to model the details of a circuit or component near a metal surface accurately.

Conclusions

Even simple models of an unintentional radiation source are likely to contain electrically thin plates with attached wires. Existing numerical EM modeling techniques generally cannot model these configurations effectively. Wire models can be used in some cases, and in fact, wire models have been used by the authors to analyze a variety of unintentional source configurations. However, the fields near a conductive surface are not modeled accurately by wires or wire grids and thus wire models cannot be used to analyze the effect of subtle changes in a circuit's design or layout.

A new technique is needed before numerical modeling of unintentional sources can become as useful and routine as intentional source modeling. This new technique should be able to analyze circuit card configurations with a relatively high degree of detail and then analyze the entire system, which may contain several circuit cards, shields and cables. One possible approach would be to use a hybrid technique. For example, a finite element method might be used to analyze the cards and define boundary conditions to be used in a moment method analysis of the whole system.

Radiation from unintentional sources has become a critical concern of electronic device manufacturers and developers. Stringent military and nonmilitary requirements are becoming more difficult to meet as operating speeds of electronic systems increase. A numerical EM modeling technique that could be applied to digital circuits and systems would find a large number of potential users. The availability of such a technique could make EM radiation modeling an integral part of the development process for state-of-the-art electronic systems.

References

[1] C. R. Paul and D. R. Bush, *Radiated Emissions from Common-Mode Currents*, Proceedings, 1987 IEEE International Symposium on Electromagnetic Compatibility, Atlanta, GA, August 1987.

[2] T. H. Hubing and J. F. Kauffman, *Modeling the Electromagnetic Radiation from Electrically Small Table-Top Products*, IEEE Transactions on Electromagnetic Compatibility, Vol. 31, Feb. 1989, pp. 74-84.

[3] E. H. Newman and D. M. Pozar, "Electromagnetic Modeling of Composite Wire and Surface Geometries," *IEEE Transactions on Antennas and Propagation*, vol. AP-26, Nov 1978, pp. 784-789.

[4] G. J. Burke and A. J. Poggio, *Numerical Electromagnetics Code (NEC) - Method of Moments,* Naval Ocean Syst. Center, San Diego, CA, NOSC Tech. Document 116, Jan. 1981.

[5] T. H. Hubing, *Modeling the Electromagnetic Radiation from Electrically Small Sources with Attached Wires,* Ph.D. Dissertation, North Carolina State University, May 1988.

[6] A. C. Ludwig, "Wire-Grid Modeling of Surfaces," *IEEE Transactions on Antennas and Propagation*, vol. AP-35, Sep 1987, pp. 1045-1048.