A Literature Review on the Coupling of Electromagnetic Sources to Electronic Systems

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A LITERATURE REVIEW ON THE COUPLING OF ELECTROMAGNETIC SOURCES TO ELECTRONIC SYSTEMS

SPECTRUM RESEARCH PROJECT: CS12

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I. INTRODUCTION

An increase in the number of electronic devices and portable wireless communication equipment has resulted in an increase in electromagnetic (EM) signals in most environments. This type of EM pollution has posed serious concerns with the Electromagnetic Compatibility (EMC) and Immunity (EMI) of electronic systems. In this and subsequent projects we will investigate various interaction (and interference) mechanisms of EM fields with electronic equipment. A typical problem encompasses EM penetration through an enclosure, its subsequent coupling to electronic circuitry, its effect on the electronic components, and/or its overall effect on the operation of the Device Under Test (DUT).

In order to identify potential research areas and to update past and present research efforts at CRC, DREO, and other collaborating organizations in this project, a literature survey was performed. Thus, the scope of this literature survey is limited to the identification and modelling of coupling mechanisms of man-made external sources/fields to enclosed/open PCBs.

Although many comprehensive and excellent introductory text books on the subject of EMI and EMC have been published, this survey steers clear of these books since the purpose of the survey is to identify and catalogue the latest research studies and results on the topic. However, a list of introductory text books are referenced in review papers [90] and [106]. The literature survey also avoided an emphasis on articles published in various conference proceedings; it has been the experience of the reviewers that conference publications either add little to subsequently published materials or contain insufficient detail to shed light on their contents. Hence, a thorough survey of the *IEEE Transactions on Electromagnetic Compatibility* (on topics of electromagnetic coupling to enclosures and PCBs and shielding against EMC/EMI) was conducted for the years 1993-7. This was supplemented by a broad search of all EMI/EMC professional journals for the years 1989-97 with specific keywords (*i.e.* immunity, susceptibility, and signal integrity).

In order to limit the scope of the survey a number of technical constraints were placed on the search and review process. The frequency range of interest was hundreds of MHz to tens of GHz. Investigation of radiation from electronic devices was excluded, although this work is somewhat relevant due to the reciprocity theorem. The survey also excluded external sources generated by

Electrostatic Discharge (ESD), lightening, and Electromagnetic Pulses (EMP). These topics were excluded in order to concentrate the efforts of the literature survey on the area of field coupling (rather than coupling through direct contact in the case of ESD).

The search yielded **121** journal papers from over **25** international journals. All of the accumulated papers have been examined and over 90% were extensively and thoroughly reviewed by two or more authors. A brief review of the papers, along with the independent thoughts and comments of the examining researcher(s), are included in Appendix A.

This report contains the results of our literature survey. In section **II**, the initial organization of the literature survey is presented. Section **III** offers a more structured and methodical framework (based on EMI coupling mechanisms) of the previously mentioned research topics. A brief conclusion to our literature survey is given in **IV** and finally some recommendations for new projects and the future direction of research in outlined in **V**.

II. INITIAL ORGANIZATION

Initially, the results of the literature survey were divided into the following categories: (1) Transmission Lines (wires, cables, connectors), (2) Printed Circuit Boards and Electronic Devices, and (3) Enclosures (with slots) and Shields. These categories served as the first attempt in organizing the papers into various sub-topics within each category, even though instances of overlapping topics occurred (*i.e.* a paper related to more than one category). This overlapping is unavoidable in such a review and, to a certain extent, is present in our final review. A summary of the findings of each category is given below.

(1) Enclosures (with slots) and Shields:

The current urban environment is constantly flooded with EM radiation from various sources such as radio, TV, portable transmitters, as well as unwanted RF emissions due to the operation of many electronic devices [113, 119]. Since most often the material cost reduction of an electronic device is desirable, it is facilitated through substitution of plastics or composites for metals in the external enclosure which further increases the penetration of EM fields into (and EM emission from) the device. Also, the performance enhancement of most digital circuits often requires an increase in clock speed which increases the risk of EMI and reduces the EMC of the equipment.

These are due to an increase in the EM radiation from the DUT since at higher frequencies more circuit components (traces, pins, etc.) act as antennas. Hence, it is important to evaluate the shielding effectiveness of the device enclosure and its apertures. The topic covered herein is the shielding effectiveness of enclosures with apertures in order to assess the level of electromagnetic field penetration into electronic devices.

(2) Transmission Lines (wires, cables, connectors)

Transmission lines (TLs) are another significant source of EMI. These EM emissions generally radiate from one of two circuit elements: 1) cables and 2) traces on a PCB. At frequencies below 500 MHz, cables attached to a system are generally the best EMI antennas [13]. However, at higher frequencies, the length of the traces of a PCB are comparable to the operating wavelength and, hence, these elements can act as efficient antennas [7, 14, 39].

(3) Printed Circuit Boards and Electronic Devices

Signal waveforms (rise and fall time, pulse width, magnitude, and period) are significant parameters in determining the radiating emissions or susceptibility of a digital circuit or PCB. Almost all interruptions in the operation of electronic devices are the result of some form of signal degradation/interruption due to either internal (i.e. crosstalk) or external (i.e. external field coupling into circuitry) sources. Increasing circuit clock speeds, which effectively reduce the rise and fall time of pulses, as well as denser component layouts in modern electronic circuits, have led to an increased risk of signal degradation/interruption due to crosstalk. Cross-talk is a primary concern and is becoming a prominent issue in high frequency circuit design. However, the amount of literature dealing with this topic is enormous and to categorize this problem is beyond the scope of this survey. The main focus of our survey was the effects of external field coupling into digital circuits and PCB traces.

There are several ways of modelling the response of the circuit to an external field. The most computationally intensive would be to use a full wave numerical solution, like FDTD. This would produce an accurate EM analysis of the PCB but generally, does not allow modelling of complex circuits. Many alternate methods exist which are more efficient but tend to be less accurate. For example, a multiconductor TL (MTL) method is currently a popular form of analysis which models the circuit traces as a series of very-short, concatenated TLs. The per-unit-length (PUL) impedance characteristics are determined and subsequently the MTL is analysed using a TEM assumption. An alternate method [39] for calculating emissions is the use of a common circuit analysis program like SPICE, to calculate currents in the various traces. These currents are then used as sources to determine the radiated field.

III. RESULTS OF THE LITERATURE SURVEY

Following careful examination of the findings of the literature survey and the initial organization of the research topics, the need for a more structured and methodical framework was apparent. The new proposed categories are aimed at specific forms of circuit coupling and EMI. In any DUT, it is common that more than one EMI mechanism is present; therefore, the proposed organization allows a disciplined and rigorous analysis of the problems at hand. In most cases, the various coupling methods can be studied separately which would result in a better understanding of the overall physical process. In Figure 1, the various EMI mechanisms are illustrated. In the remainder of this section, a brief review of the literature pertaining to each mechanism is presented.

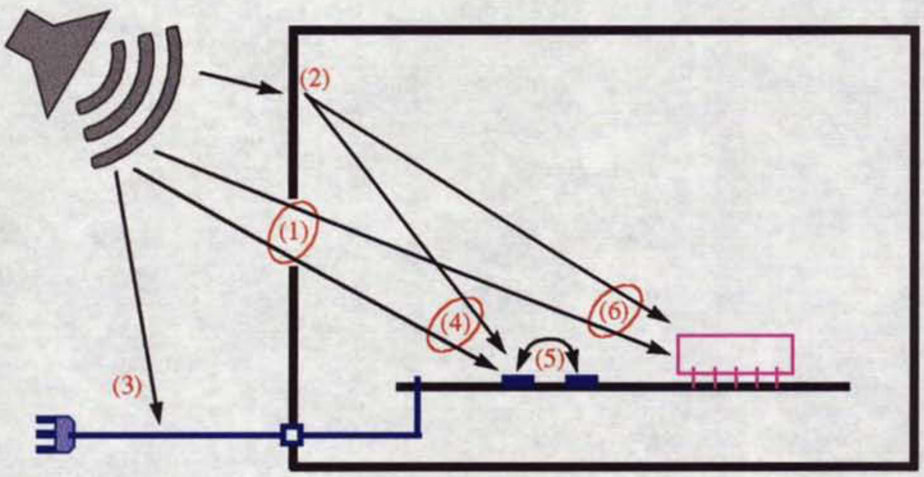

Figure 1. Various EMI mechanisms: (1) Direct Penetration through Apertures in Enclosures, (2) Indirect Penetration through Enclosures or Shields, (3) Direct Coupling into Cables, (4) Direct Coupling into PCB Traces, (5) Cross-talk, and (6) Susceptibility of Devices.

(1) Direct Penetration through Apertures in Enclosures

Although most enclosures are metallic (to increase shielding), the introduction of intentional and unintentional apertures (slots or seams) is often unavoidable. In these cases, it is important to study and calculate the shielding effectiveness of the enclosure due to the existence of both open and loaded (with conducting material) apertures. This survey has revealed four broad approaches:

a) Various rigorous analytical solutions based on the equivalence principle are used to predict fields in aperture-driven cavities. In these methods, the electromagnetic fields at the apertures are represented by equivalent magnetic currents flowing over a Perfect Electric Conducting (PEC) surface covering the apertures, and the resulting integral equation is solved by the Method of Moments (MOM) [115, 116, 120, 121]. Although most papers analysed academic problems of infinitely long multiple perforated plates or cylinders [35, 41] few articles considered more realistic problems such as cabinets with slitted plates, slots, and seams [2, 27, 99].

b) Two classes of two-stage approaches were identified. One was a rigorous solution method based on the induction theorem, and the other was an approximate solution method based on neglecting the interaction of the cavity with the aperture. In the rigorous two-step approach, the first step consists of computing the conduction current flowing over the apertures which would be covered with PEC surfaces. The second step then computes the scattered field radiated by the conduction current now flowing over the uncovered apertures but in the direction opposite to that found in the first step. Afterwards, the total field is calculated by adding the incident and the scattered fields [43, 115, 117]. In the approximate two-step approach, the first step consists of computing the field inside the enclosure in the absence of any circuitry or wires inside the enclosure. The second step then utilizes the fields inside the enclosure computed in the first step as the source of excitation for the circuitry within the enclosure [50, 112].

c) Several full-wave numerical techniques have been used to analyse direct penetration through apertures [61, 103, 111]. However, the Finite Difference Time Domain (FDTD) method has proven to be the most popular technique for computing the fields inside enclosures with apertures [14, 29]. In general, FDTD results agreed well with measurements [2, 8].

d) A probabilistic approach was considered for situations where the structure was either too large, too complex, or the exact details were not known. In this case, the fields inside the enclosure were computed without the complete modelling of the details of the system. Hence, an upper value of the field strength was computed using either averaging schemes [40] or other methods of approximation (i.e. maximum power coupling) [91, 108].

(2) Indirect Penetration through Enclosures or Shields

The emergence of composite enclosures (non-conducting materials embedded within one or many conducting meshes) and wire mesh enclosures have resulted in different types of EM field penetration. An accurate evaluation of the shielding effectiveness of such structures is also of interest. The shielding effectiveness of various structures, such as wire cages [32, 42] composite cylinders, and perforated plates [34, 62, 89] as well as active shielding [15] was also explored.

(3) Direct Coupling into Cables

For many years, cables have been identified as a significant source of EMI and susceptibility in devices; hence, there is an enormous amount of published information on this subject, much of which is now available in textbooks. Therefore, the contributions to the literature referenced herein are simply a continuation of this ongoing research. From an EMC perspective, the focus of the surveyed literature appears to be on issues of cable integrity and radiation leakage from cracks and gaps in cables [20, 60] as, for example, rotary joints in connectors [22]. Reference [20] uses a FDTD model to simulate a gap in a cable shield; the result is then translated into an equivalent source in a NEC simulation of the entire cable. The technique allows a high (spatial) resolution simulation of the problem, but does not make enormous demands on computational resources.

External fields can also couple into poorly shielded power or data cables. Due to the large size and arbitrary position of cables and cable bundles, conventional analytical and numerical methods are often incapable of modelling these types of problems. Hence a relatively new philosophy emerging in the literature is in the area of probabilistic cable positioning and energy bounds. Both of these topics are related in the sense that in most practical scenarios the exact position of a cable is unknown. For example, the position of a particular wire in a computer is not well defined and varies on a unit-to-unit basis, or a wire may be arbitrarily located within a cable bundle. Due to this uncertainty in the physical layout and location of any given wire, the precise coupling parameters are equally difficult to define. Treating the position of a wire within a cable bundle as a probabilistic value allows a statistical representation of the problem [47].

An alternate method treats the problem from an energy coupling point of view [91, 108]. Rather than trying to reproduce the current or voltage waveforms coupled to a cable, the technique attempts to accurately quantify the amount of energy absorbed by a cable, component *etc*. Knowing this quantity establishes the vulnerability of a particular element and determines if further (more detailed) analysis is necessary. This can greatly reduce the amount of analysis required for a large circuit.

(4) Direct Coupling into PCB Traces

As the length of the traces on a PCB become comparable to the wavelength of the external EM field, the traces act as antennas. This mechanism of EM field coupling into PCBs has been studied using various EM analysis methods (such as FDTD, TLM, and MOM) as well as circuit simulation (SPICE and MTL). Although most papers involving the application of EM analysis are well intentioned, significant results on practical problems are not provided. The solution of these practical problems is not possible because of the computer resources required. For example, applications involving the solution of the Sommerfeld integral by MOM to account for an infinite-substrate/ground-plane rarely account for more than one or two traces. Even though the purpose of most papers is to present validation cases, practical solutions to problems containing more than a few dozen traces are unlikely. Also a few researchers have attempted to perform EM analysis of a DUT within an EMI measurement set-up [17, 56, 57]. It is unlikely that this approach is feasible in practice given the number of simulations required.

Many papers attempted to highlight a particular method and its application to EMI/EMC. A few papers provided some EMC/EMI considerations such as the difference between common mode and differential mode radiations [48, 59]. However, some papers contained over-simplified problems that may be of interest to the authors but of little use to anyone else [36, 52, 57]. In general, most papers emphasized numerical methods or analytic models; only a few contained significant discussion of measurements [17]. The papers involving the susceptibility of devices are exceptions to the above concerns, and significant results are obtained [24, 31, 104]. They combine excellent engineering insight into a practical problem, and although the problem is also simplified, significant results are obtained and therefore significant conclusions are provided. As well, the motivation behind their methodology is provided so that others can apply the same techniques to similar problems. A detailed FDTD investigation of a heat-sink was conducted in

[53] which also provided good analysis and conclusions.

(5) Cross-talk

Cross-talk is the unintentional coupling between an active line and its neighbouring wires or PCB traces and is a primary concern in high frequency and/or dense circuits. This topic was not the primary focus of the literature survey. There exists a large body of literature (including several books) devoted to this topic.

One of the methods used in the analysis of crosstalk is MTL. MTL is often used to determine coupling of external fields to a PCB (which is within the scope of this survey). It is worthwhile to discuss the current limitations in MTL analysis which are as follows: (a) The incorporation of non-linear elements is crucial for proper analysis since most modern circuity has some form of diode, transistor, *etc.* The response of these elements generally must be calculated in time-domain since the non-linearity does not allow standard FFTs to be applied [1, 97]. (b) The consequences of the presence of dielectric materials is two fold. First, there are well known formulae which demonstrate the change in the effective dielectric constant (and hence the impedance of the trace) as a function of frequency [65, 66, 94, 96, 97]. Second, the presence of surface waves on the dielectric substrate have been shown to significantly affect the simulation results if not modelled properly [94, 98]. (c) Circuit models must also incorporate bends, tees, vias *etc.* to emulate real circuit boards. Although this incorporation does not pose a problem to full wave numerical techniques, such as FDTD [65] however, bends, tees, and vias may be difficult to implement in other methods; for example, most MTL solutions only deal with straight, parallel TLs.

(6) Susceptibility of Devices

Many electronic circuits and components are susceptible to EM radiation. The coupling of an external field into circuit components (heatsink, integrated circuit, etc.) may either temporally suspend the operation of the device or permanently damage the equipment. In the past, the bulk of this type of investigation was performed experimentally and was done in accordance with standard test procedures. These test procedures were established in order to ensure EMI compliance of products with regulatory requirements that have been placed on manufacturers. However, as both computational resources have increased and numerical codes have been refined (both circuit codes such as SPICE or MTL, and full wave EM solvers such as NEC, FDTD, MOM, TLM, and *etc.*), the ability to numerically model the EM response of a single realistic device has progressed significantly. Despite these advances, modelling of complex circuits and/or entire PCBs is not foreseen in the near future (see discussion **III-4**).

IV. CONCLUSION

The main objective of this literature survey was to identify potential research areas pertaining to the coupling of external fields to enclosed/open Printed Circuit Boards (PCBs). A thorough survey of the *IEEE Transactions on Electromagnetic Compatibility* (on topics of electromagnetic coupling to enclosures and printed circuit boards and shielding against EMC/EMI) was conducted for the 1993-7 issues. The former was complemented by a broad search of all EMI/EMC professional journals for specific keywords (i.e. immunity, susceptibility, and signal integrity) for the years 1989-97. In pursuit of better explanations of certain concepts, analytic methods, or results that sparked some interest, a few papers referenced in articles of particular importance dated before 1989 were also included. However, this survey does not claim to be comprehensive for undoubtedly some noteworthy materials published prior to 1989 might have been overlooked.

The results of the literature survey were divided into the following categories: (1) Direct Penetration through Apertures in Enclosures, (2) Indirect Penetration through Enclosures or Shields, (3) Direct Coupling into Cables, (4) Direct Coupling into PCB Traces, (5) Cross-talk, and (6) Susceptibility of Devices. The survey resulted in **121** journal papers from over **25** international journals; all of which were thoroughly reviewed by at least one researcher currently active in the field of the papers' subject matter. A brief review of the papers, along with independent thoughts and comments of the examining researcher(s), are included in Appendix A.

V. RECOMMENDATIONS

Based on the findings of the literature survey, potential research areas were identified. These have been formulated into the following newly proposed projects given below.

(1) Probabilistic Approach to EM Field Coupling Through Apertures and onto PCBs

This research area has been suggested by the lack of significant results pertaining to practical real world problems as found in the literature survey. Few results were found for anything more complicated than a few traces on a PCB. The analysis of a complete PCB based on deterministic methods (such as the FDTD analysis) is presently not practical due to the extremely high computing resources that would be required to analyse the complete structure at once. The literature survey has revealed the existence of a probabilistic approach to compute the field coupled to the PCB without complete knowledge of the details of the system. Hence the PCB might be modelled on the basis of its number of traces without taking into account how these traces are actually connected. One advantage of this probabilistic approach is that it allows for a gradual improvement of the result, *i.e.* a reduction of the range of uncertainty, as more detailed information is known or taken into account.

We propose to survey more thoroughly the previous probabilistic approaches for investigating complex EM field interaction problems, then to attempt to formulate and validate a probabilistic approach for the problem of coupling through apertures and onto PCBs. The validation would be affected by simulations on a scale afforded by our current computing resources, or by measurements.

(2) Coupling Mechanisms within PCBs

A study should be conducted to gain a better understanding of how RF energy is coupled to and radiated from PCBs. This would involve 1) modelling the coupling mechanisms and simulating mechanisms with equivalent circuits and solving for the response of these circuits using SPICE, and 2) performing experiments to characterize device susceptibility levels in order to better predict circuit upset levels.

APPENDIX A

Paper Reviews

This appendix contains brief summaries and reviews of all the papers deemed relevant to the scope of the literature survey. In addition to the investigator's summary of each paper, over 90% of the papers were considered noteworthy and were also extensively reviewed by at least one other researcher. The independent thoughts and comments of the examining researchers were also included along with the review of each article. Originally, it was intended to structure each review into the following subsections: **Structure**, **Analysis Method**, **Results**, and **Comments**; however, in some cases an abbreviated review seemed to be more appropriate due to the length and content of the journal article. The surveyed papers were organized into the following categories as discussed in section **III** (see ***Figure 1***).

(1) Direct Penetration through Apertures in Enclosures:

[2],	[5],	[8],	[19],	[22],	[26],	[33],
[34],	[35],	[40],	[41],	[43],	[50],	[54],
[57],	[74],	[79],	[87],	[91],	[100],	[105],
[108],	[112],	[115],	[116],	[120],	[121]	

(2) Indirect Penetration through Enclosures or Shields:

[6],	[11],	[15],	[21],	[23],	[25],	[27],
[28],	[32],	[42],	[49],	[55],	[60],	[62],
[63],	[72],	[73],	[80],	[84],	[89],	[106],
[111],	[113],	[117]				

(3) Direct Coupling into Cables:

[3],	[7],	[13],	[14],	[16],	[17],	[20],
[22],	[39],	[45],	[46],	[47],	[56],	[60],
[61],	[65],	[77],	[91],	[99],	[106]	

(4) Direct Coupling into PCB Traces:

[4],	[13],	[29],	[30],	[44],	[46],	[48],
[58],	[59],	[75],	[82],	[88],	[90],	[94],
[95],	[98],	[107],	[117],	[118]		

(5) Cross-talk:

[1],	[25],	[38],	[47],	[66],	[68],	[77],
[78],	[90]	[96],	[98],	[106],	[107],	[118]

(6) Susceptibility of Devices:

[9],	[24],	[31],	[36],	[44],	[53],	[56],
[64],	[67]	[76],	[81],	[92],	[104],	[109],
[110]						

(7) Miscellaneous:

[10],	[12],	[18],	[37],	[51],	[52],	[68],
[69],	[70]	[71],	[83],	[85],	[86],	[93],
[97],	[101],	[102],	[103],	[114],	[119]	

Please note that multiple entries of an article under various categories signifies that several topics were discussed in the body of the paper.

Journal Name Abbreviations

The following notation is used to cite each paper:
[(year of publication), (Journal name abbreviation), v(volume), n(number), pp(page number)].

Journal name abbreviations are given bellow.

AP	IEEE Transactions on Antennas and Propagation
EMC	IEEE Transactions on Electromagnetic Compatibility
MTT	IEEE Transactions on Microwave Theory and Techniques
CPMB	IEEE Transactions on Components, Packaging, and Manufacturing Technology, B
TCSI	IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications
PSMT	IEE Proceedings-Science, Measurement and Technology
IJNM	International Journal of Numerical Modelling: Electronic Networks, Devices, & Fields
BTJ	BT Technology Journal
IEICEC	IEICE Transactions on Communications
EMCEE	EMC Engineering Europe
JCTE	Journal of Communications Technology and Electronics
MR	Microelectronics and Reliability
PCD	Printed Circuit Design
IEEJ	Transactions of the Institute of Electrical Engineers of Japan, Part C
EEEE	EE Evaluation Engineering
EPP	Electronic Packaging and Production
EC	Elektrotechnicky Casopois
TM	Test and Measurement World
RS	Radio Science
EL	Elektron
SAMS	Systems Analysis Modelling Simulation
BIT	Biomedical Instrumentation and Technology
IS	IEEE Spectrum
EMCTD	EMC Test and Design
MRF	Microwave and RF

[1]---[97EMCv39n3pp189]

Explicit Upwind Schemes for Lossy MTLs with Linear Termination (J. LoVetri and T. Lapohos)

INDEX TERMS: Boundary value problem, initial value problem, leap frog, MTL, upwind differencing.

This paper describes two upwind schemes based on a system of first order PDEs for time domain MTL equations terminated with linear loads (Thevenin sources). The main advantage of these two methods is that the slower propagating TEM modes are less numerically dispersed than the standard leapfrog scheme. Also courant number of upwind schemes are twice the leapfrog technique. Full derivations for lossy and lossless lines using both first and second upwind schemes are given (includes a final algorithm). Examples include initial and boundary value problems as well as two and three line MTLs.

14 references, 12 pages.

Structure:

General N-conductor, MTL solution with boundary conditions represented as Thevenin sources.

Analysis Method:

Frequency-dependant losses are not included. Lines are assumed time-invariant and uniform in length. The time-domain MTL equations are written as a general first-order system of first order PDEs and a characteristic decomposition is used to obtain first and second order accurate upwind difference schemes. Linear boundary conditions, in the form of generalized Thevenin sources are incorporated into the scheme.

Results:

Comparisons show that, at the Courant number, both upwind schemes produce less numerical dispersion for the slower propagating modes than standard leapfrog methods. In addition, the Courant number is twice that of standard leapfrog technique and, therefore, execution is faster. A boundary value problem has been successfully formulated and implemented.

Comments:

over- and undershoot is observed at rapid transitions in time-domain responses with these inaccuracies being peculiar to applying upwind to a single line and disappear when applying the schemes to general, N-conductor MTLs.

Joe Seregelyi

[2]---[97EMCv39n3pp260]

Shielding Effectiveness of Single and Double Plates with Slits (J. Kiang)

INDEX TERMS: Galerkin's method, shielding, slits.

TE wave transmission through slots of an equipment cabinet for the purposes of shielding is studied. The authors observe that by either using thick plate with slits narrower than half a wavelength or double plates with slits wider than half a wavelength but laterally shifted the amount of power transmitted is significantly reduced. Galerkin's method is developed to model incident TE plane waves and to calculate transmission across a slit. A brief derivation and several test cases for shielding effectiveness v.s. slit thickness and width are included.

11 references, 5 pages.

Structure:

One or multiple slitted plates where the slits have infinite transverse lengths but finite thicknesses and conductivities, under TE plane wave illumination with arbitrary incidence angle.

Analysis Method:

The formulation is for harmonic fields and is based on the use of the equivalence principle and plane-wave spectrum decomposition. The resulting integral equation is solved by Galerkin's method using Chebyshev polynomials (not parallel plate waveguide modes) for the expansion and testing functions. The effect of the slit thickness, conductivity, width and for multiple plates, the effect of the lateral offset between slits on adjacent plates, and of the spacing between adjacent plates can be taken into account. The material of the plates is assumed to be PEC.

Results:

For incidence angles > 60 degrees, the results given by this method, Harrington's mode matching solution and Keller's GTD solution all differ between them. The transmission through a slit on a thick plate: 1) follows the diffraction pattern (i.e. the transmission decreases for increasing transmission angles) with multiple lobes for wide slits, or with a single lobe of smooth parabolic-like variation for slit widths comparable to, or smaller than the wavelength; 2) increases exponentially with slit width as for a rectangular waveguide since such a waveguide is formed by the presence of the slit in the thick plate. 3) decreases linearly (according to Fig. 4, but exponentially according to the text?) with the slit thickness, for slit width small enough that the rectangular waveguide formed by the slit in the thick plate is operated below the cutoff frequency of the waveguide; 4) decreases exponentially with the slit conductivity. The spacing between adjacent plates does not seem to have a significant effect on the transmission (if, I suppose, the slits are lined up along the incidence direction).

The lateral offset decreases the transmission linearly once the overlapping width (in the direction of incidence, I suppose) gets below about 0.5 lambda.

Comments:

1) There is an inconsistency between Fig. 4 where the variation is linear, and the text on p. 264 where an exponential variation is cited. 2) The field formulation in the region between adjacent plates (i.e. equation (8) for H2x) is not general enough for it does not allow the wave to propagate at an arbitrary angle, only at normal angle, in the region between adjacent plates. Consequently, the waveguide effect of the adjacent plates is not taken into account and thus, higher transmission levels than predicted should be expected when the lateral offset is large.

Jasmin Roy

[3]--[97EMCv39n3pp251]

Improvements of the FDTD Method for the Study of Wave Penetration Inside a Valley (A. Reineix and B. Jecko)

INDEX TERMS: EMP, FDTD, surface impedance.

The paper concentrates on induced parasitic fields due to an external EMP. In this case a more compuationally efficient method of FDTD is used to model a valley with power lines at its bottom. The paper includes FDTD numerical modelling of ground with surface impedance, EMP with various incident angle, and coupling of the EM wave to a cable. the simulation is repeated for various ground characteristics.

8 references, 5 pages.

[4]-- [97EMCv39n3pp236]

Including Dielectric Loss in Printed Circuit Models for Improved EMI/EMC Predictions (G.A. Hjellen)

INDEX TERMS: dielectric loss, lossy capacitor, printed circuit models.

EMI/EMC studies of PCBs often can be carried out using circuit models. This paper proposes a new method of including effects of frequency-dependent dielectric losses, which are modelled using frequency-dependent series resistance and shunt capacitance. This new method allows approximation of this type of circuit using software packages that use fixed value lumped elements. Micro-Cap III simulation of a low impedance (multi-layer) power bus showed that including dielectric losses could have significant effects on the EMI/EMC performance.

14 references, 11 pages.

Structure:

PCBs with the purpose of characterizing signal integrity and EMI/EMC.

Analysis Method:

Lumped element approaches for modelling PCBs and printed wire boards (PWBs). This paper modifies existing models to include losses relevant at frequencies of 30 to 100 MHz).

Results:

Sample practical problems are considered, and therefore contain important information regarding lumped element models. A lumped element network is provided for a low-characteristic-impedance power bus as found on multi-layer PCBs. The transfer impedance, current transfer ratio, and driving-point impedance are calculated for the lossy and loss-less cases. Comparison of lossy and lossless models indicate the expected decrease in the Q of resonances. Comparison with measurements is not included.

Neil Simons

[5]--[97EMCv39n3pp225]

Numerical and Experimental Corroboration of an FDTD Thin-Slot Model for Slots Near Corners of Shielding Enclosures (M. Li, K. Ma, D.M. Hockanson, J.L. Drewniak, T.H. Hubing, and T.P. Van Doren)

INDEX TERMS: EMI, FDTD, shielding, enclosures, slots.

Although less-than-half-wavelength slots are often used to minimize EMI, this method may be inadequate due to interactions between cavity modes, slots, and sources. A sub-cellular, capacitive, thin slot formulation for FDTD is used to model thin slots near corners with plane wave sources. A comparison of the obtained results indicates that the best agreement is obtained for slot dimensions larger than ten times the cell size. FDTD, MoM, and experimental results agreed well with each other. A discussion of the modelling of probes and their interaction with slots, as well as the numerical modelling of an experimental apparatus is included.

17 references, 8 pages.

Structure:

Thin slots near corners of enclosures, illuminated with a pseudo-Gaussian plane wave polarized in the direction perpendicular to the axis of the slot (TEz case).

Analysis Method:

1) Two different modifications/additions to the ordinary FDTD code in order to account for the presence of a slot of sub-cellular width. a) The first formulation, called C-FDTD, models the slot as a co-planar parallel strip capacitor in the plane perpendicular to the slot, and is based on quasi-static approximation (i.e. slowly varying field quantities across the slot direction are assumed). This formulation is not suitable for modelling slots exactly on a corner, and is only a 2-D approximation. Necessary modifications to Taflove's thin-wire algorithm for modelling the probe were determined for agreement with measurements (i.e. the equivalent wire radius of the probe was taken as 70% of the physical wire radius). Second order Mur's ABC was used herein. b) The second formulation, called HTSA (Hybrid Thin Slot Algorithm), models the slot as a source of equivalent magnetic currents on a PEC screen, based on the equivalence principle. This formulation incorporates the singularity in the charge distribution at the corner for the TEz case, and is capable of taking into account the slot thickness. PML was used here. 2) Mixed-Potential formulation for 2-D case, solved by the method of moments (MoM). 3) Measurements were also made.

Results:

The C-FDTD underestimates the electric-field component across the slot but provides good results immediately adjacent to the slot. Comparison of C-FDTD with MoM was good except when the slot width became large enough to approach the order of the mesh size (e.g. Ws > 0.2 DEL). Because of some late-time instability encountered with the HTSA method, this method was employed herein only to study the effects of the 2-D nature of the C-TSF algorithm near the slot half-wavelength resonance.

The effect of the slot is minimum if the slot is parallel to the flow of the currents induced by the plane wave excitation on the PEC surfaces, for then the slot does not interrupt the original flow of these currents.

It is said that significant power can be radiated for slots of lengths less than a half-wavelength.

Comments:

Some resonances resulting from the interaction of the slot with the feed probe or cavity, and tuning of the reactance, were said to be not well understood.

As many as 40000 time steps for a sine-wave modulated pseudo-Gaussian pulse excitation was required because of the high Q resonances of the enclosure.

In paper [96EMCv38n3pp376], modifications to Taflove's algorithm were not made, thus the wire radius was taken to be the same as the physical wire radius and yet, the input impedance values obtained by the FDTD compared well (the discrepancy never exceeded 5%) with those obtained by NEC provided that the source wire radius in NEC was taken to be the same as that in the FDTD.

Jasmin Roy

[6]-- [97EMCv39n3pp219]

Shielding Effect of Hollow Chiral Sphere (A.H. Sihvola and M.E. Ermutlu)

INDEX TERMS: chiral materials, shielding.

The paper discusses the possibility of using electrically small hollow chiral spheres for shielding, since man made low frequency chiral material provide narrow band dispersive characteristics which in some cases are superior to the broad band attenuating materials used for commercial shielding. Chiral shields could be used in construction of "smart shields" where only some frequencies are blocked. A quasi-static EM case is considered (static since shield is electrically small, quasi since no chiral dispersion in static case). Equations are solved and several studies of shielding effectiveness of various chiral material thicknesses and material chirality numbers are under taken.

16 references, 6 pages.

[7]--[97EMCv39n3pp201]

Field Coupling to Nonuniform and Uniform Transmission Lines (M. Omid, Y. Kami, and M. Hayakawa)

INDEX TERMS: coupling, EMI, NEMP.

The Transmission Lines (TLs) theory assumes uniform TLs (i.e. parallel to ground and no connections etc.). In this paper nonuniform TLs are modelled using a cascaded series of uniform lines parallel to ground. Expressions are derived to predict induced currents on a nonuniform TL. These expressions were evaluated and compared with the results obtained from MoM and with measurements for several test cases for both uniform and nonuniform lines. In general, if the voltage and current at the terminals of TLs are of interest, the current TL formulation is sufficient. The paper includes general, semi-analytical modelling and solutions, background information, and a review of past literature along with several examples.

12 references, 11 pages.

Structure:

uniform and non-uniform TL over a ground plane

Analysis Method:

Line equations are expressed in terms of line currents and voltages. External fields are presented as distributed voltage and current sources. Assumptions made; TEM mode, perfect wire and ground plane conductivity, and surrounding medium is free space. Lines are terminated with arbitrary loads. To account for non-uniform lines, the PUL parameters are cascaded in stair-case fashion to simulate a series of very short TL. Analytical expressions are derived for the chain parameter matrix of the line from the solutions of the modified telegrapher's equation in the frequency domain. Comparison of results is made to NEC simulation and measurements.

Results:

In general, NEC results agree reasonably well with formulation derived in this paper. The authors make a good point when stating that the TL theory only predicts differential and not common mode currents. At the ends of the TL the common mode goes to zero, so the TL results are reasonable. Experimental results agree for most angles of illumination. Possible sources of error are; finite size ground plane, non-uniform illumination or discontinuity in the TL. Non-uniform TL theory, as it is presented in this paper, has difficulty accounting for abrupt bends in line.

Joe Seregelyi

[8]--[97EMCv39n2pp147]

Comparison of FDTD Algorithms for Subcellular Modeling of Slots in Shielding Enclosures (K. Ma, M. Li, J.L. Drewniak, T.H. Hubing, and T.P. Van Doren)

INDEX TERMS: FDTD, slot.

Thin slots were modelled using the FDTD method and two different subcellular approaches; one was a Capacitance-Thin-Slot-Formalism (CTSF) and the other was a Hybrid Thin Slot Algorithm (HTSA). Both techniques were used to model an electrically thin slot for a plane wave scattering from 3D finite and infinite plates. In both cases, CTFS and HTSA agreed well with the measured data for cells smaller than 1/20 of wavelength. In general, both methods are similar; however, HTSA is more susceptible to instabilities where as CTFS is only sensitive to CFL conditions. Some experimental data and a discussion on Liao's, Mur's, and PML ABCs were presented.

17 references, 9 pages.

Structure:

Thin slots in finite or infinite planes and in loaded cavities illuminated with a pseudo-Gaussian plane wave polarized in the direction perpendicular to the axis of the slot (TEz case), as well as a thin slot in a cavity excited by a coaxial probe terminated in 47 ohms attached to a wall of the cavity.

Analysis Method:

The FDTD C-TSF algorithm models the sub-cell slot by means of an effective permittivity (proportional to the parallel strip capacitance per unit length) obtained as the ratio of two line integrals, one integral for the direction across the slot, and the other integral for the direction along the slot. In order to maintain the free-space propagation velocity in the slot, the slot is also modelled with an effective permeability that compensates for the effective permittivity. Consequently, the presence of the slot is accounted for simply by the use of an effective permittivity and permeability without changing the FDTD updating equations.

The HTSA algorithm is more complicated. The technique is based on the field radiated by a slot in an infinite planar conducting plate but experiments show that good results are also obtained for slots in conducting rectangular enclosures. The technique, drawing from the equivalence principle, consists in replacing the sub-cell slot with an equivalent problem developed by covering the aperture and replacing the slot by an equivalent antenna with an equivalent radius (for an infinitely thin plate, this equivalent radius is Ws/4). The presence of the slot is thus accounted for by the presence of a magnetic equivalent current parallel and adjacent within one-half cell to the slot (the electric field across the slot is set to zero).

One advantage of the HTSA is its ability to account for the finite thickness of the slot through the use of an equivalent antenna radius.

Results:

The higher (up to about 1%) slot resonance frequencies predicted by C-TSF over HTSA is said to be attributed to the 3-D formulation of the HTSA versus the 2-D formulation of the C-TSF. However, a late-time instability is plaguing the HTSA. Otherwise, there is a good agreement between the curves predicted by the two methods for all structures investigated in the paper for both the time and the frequency domains.

There is also good agreement between predicted and measured results for the power spectrum delivered to the enclosure by the source feeding a probe terminated in 47 ohms attached to a wall of the enclosure, as well as for the frequency response predicted by C-TSF for the case of a slot in an infinite plane illuminated at normal or 60 degree incidence.

Comments:

The technique consisting of replacing the sub-cell slot with an equivalent problem developed by replacing the slot with an equivalent antenna radiating over a PEC surface is not that of Mereweher and Fisher's two-step technique whereby the aperture is replaced with an equivalent electric (not magnetic) current flowing over a PEC surface.

Jasmin Roy

[9]--[97EMCv39n1pp17]

Via Coupling Within Parallel Rectangular Planes (J. C. Parker)

INDEX TERMS: Probe coupling.

Analytic solution for frequency domain mutual impedance and time domain voltage wave forms are given for arbitrary probe locations in a finite rectangular plane where both edge reflections and skin effect are taken into account. The results are applicable to "bounce" in digital circuits, and transient response of cylindrical waves with discontinuity.

8 references, 7 pages.

Structure:

Characterization of via coupling for two vias located between two finite ground planes.

Analysis Method:

Closed form expressions are derived and can be used to predict time-domain induced voltages. The formulation is based on radial transmission lines, and includes the effects of the finite-ground planes.

Results:

Analytic and measured TDR and TDT data indicate good agreement.

Neil Simons

[10]---[97EMCv39n2pp180]

New Method for Measuring Transfer Impedance and Transfer Admittance of Shields Using a Tri-axial Cell (B. Vanlandschoot and L. Martens)

INDEX TERMS: Shielding, triaxial cells.

The shielding performance of coaxial cables and connector shields is often measured using triaxial cells through the evaluation of surface transfer impedance and admittance. This new method de-embeds the S-parameters up to the test connector and thus allows the measurement of the magnitude and phase of shielding performance parameters. These results agree well with theoretical models and other published results. Measurement setup and method, as well as two different circuit model theories (lumped and distributed) are discussed.

15 references, 6 pages.

Comments:

This paper deals with a specific technique for measuring the field radiated by an aperture in the outer shield of a coaxial cable. It is interesting but not very relevant to our literature survey.

Jasmin Roy

[11]--[97EMCv39n2pp24]

A Circuital Approach to Estimate the Magnetic Field Reduction of Nonferrous Metal Shields (W. M. Frix and G.G. Karady)

INDEX TERMS: Magnetic Shielding.

Magnetic shielding is often accomplished by the use of conduction enclosures, however, the loading effect of these structures and power losses caused by them is of interest. This paper is the first one of its kind to present a simple and efficient method of studying low frequency (60 Hz) nonferrous magnetic shields. The conducting shield is modelled using distributed circuit components and mutual inductance equations. The method was used to calculate the shielding effectiveness of a cylindrical conduit and agreed well with measured results.

22 references, 9 pages.

[12]-- [96EMCv38n4pp600]

Radiated Interference from a High Voltage Impulse Generator (W. H. Siew, S. D. Howat, and I. D. Chalmers)

INDEX TERMS: EMI, EMC, high voltage switching.

High voltage switching often generates arcs which radiate interference fields at high frequencies (up to 100 MHz). This paper measures these fields (E-dot and H-dot) in time domain and uses numerical integration to find approximations for the E and D fields. Fourier Transform was also used to find the frequency components of the transients. Most components were under 60 MHz. Measurements of a transient signal were performed. Includes some recommendations for reducing susceptibility of the electronic equipment.

11 references, 5 pages.

[13]-- [96EMCv38n4pp557]

Investigation of Fundamental EMI Source Mechanisms Driving Common-Mode Radiation from Printed Circuit Boards with Attached Cables (D. M. Hockanson, J. L. Drewniak, T. H. Hubing, T. P. Van Doren, F. Sha, and M. J. Wilhelm)

INDEX TERMS: EMI, Common-Mode, PCB.

Even though the common mode (CM) radiation from cables is a well known and well studied problem, the mechanism which produces/induces the CM currents in the cables is not well understood. This paper uses both numerical methods (NEC) as well as an experimental results to study the problem of EMI antenna sources. Two mechanisms are studied, differential voltages and currents on the PCB or at the connector. Either of the above could be dominate depending on the signal levels or EMI antenna. Also reducing one could make the other one dominate.

14 references, 9 pages.

Structure:

Overview of 2 primary sources of CM radiation in circuits with cables attached.

Analysis Method:

Generic discussion of source of CM radiation. Numerical modelling using NEC. Experiments both on generic circuits and on a real circuit.

Results:

A very good paper which discusses sources of CM radiation. CM can be generated when a circuit has asymmetries (current driven) or when two portions of extended ground are driven against each other (voltage driven). Simple models are used to describe the physics behind these set-ups. NEC models were made of each of the above. It is shown that the CM current on a cable increases about 39 and 20 dB/decade for current- and voltage-driven sources, respectively.

Joe Seregelyi

[14]--[96EMCv38n3pp376]

FDTD Modelling of Common-Mode Radiation from Cables (D. M. Hockanson, J. L. Drewniak, T. H. Hubing, and T. P. Van Doren)

INDEX TERMS: EMI, Common-Mode, FDTD, Cables, Enclosures.

FDTD is used to predict common-mode radiation from cables (EMI antennas) attached to PCBs and shielding enclosures. The resonant frequencies of these EMI antennas may be found using a subcellular, thin wire modelling algorithm of FDTD. Care must be taken to accurately model the diameter of the cables since near-field quantities are sensitive to wire thickness. Two topics are investigated: (1) common mode radiation due to noise voltage at the connector (2) energy coupling to the attached cables through the enclosure apertures. Included are a short review of wire/dipole modelling using FDTD, and a comparison of the modelling of several types of dipoles and cables using FDTD, MoM and NEC.

20 references, 11 pages.

Structure:

EMC/EMI estimate of common-mode radiation from cables (treated as dipoles or wires extending from a semi-infinite ground plane, i.e. attached to PCBs). Radiative emissions and cavity Q of shielding enclosures with; apertures, lossy coatings and aperture with attached wire are also investigated.

Analysis Method:

Taflove subcellular FDTD algorithm is used to accurately model cable diameters. Some cable modelling done with NEC.

Results:

Engineering type analysis. When cable modelled as dipole, FDTD and NEC predict similar impedance results provided wire diameters were chosen appropriately. Inadequate modelling of cable lengths or diameters results in significant shifts in predicted resonance frequencies. (The half-wave resonance of a system is important because it is generally the lowest impedance and will, therefore, result in the greatest radiation.) Use of subcellular FDTD algorithm improved match between FDTD and NEC.

Wires attached to PCB modelled as monopole attached to semi-infinite ground plane. Impedance calculations agree well between NEC and subcellular FDTD.

Shielding enclosures with apertures; energy may couple from a resonant cavity through a non-resonant aperture to a cable located in proximity to the aperture. Resonance was shifted down in frequency from theoretical value because of aperture. Location of source in cavity can strongly effect which mode is excited and determine if radiation occurs. The dimensions of the aperture, relative to the wavelength, with vary for different modes; therefore what is a small aperture for the TE101 mode may be large for the TE301 mode (Note that cavity Q's will vary according to the amount of loss through the aperture). A lossy coating on the interior of a cavity can reduce the Q by 20 dB and loss mechanisms are important to reducing emissions. An attached cable can tune system resonances resulting in increased radiation.

Joe Seregelyi

Structure:

A rectangular enclosure with an aperture on one face, excited by two point current sources at the centre of the enclosure. A lossy layer inside the enclosure on the face opposite to the aperture wall was also investigated as well as the connection of an external wire to the outside of the box at two alternate locations near the aperture.

Analysis Method:

FDTD analysis with Taflove's quasi-static field approximation for modelling a wire of radius smaller than the cell size of the FDTD grid. The results for the input impedance of wires of various radii and lengths were compared with the results obtained by NEC (with the source model controlled by specifying the source wire radius to be the same as that for the FDTD) and by an another MoM program (Sawaya et al.).

Results:

The input resistance at circuit resonance can be predicted within no worse than 5% by the FDTD method with Taflove's scheme for thin wires of lengths up to three-quarter wavelengths or near odd half-wavelengths resonances of the wire.

The radiated emission from an enclosure with an aperture depends on the resonance of the cavity and the resonance of the aperture. High values of radiated field are encountered when the sources excite a resonance of the enclosure even if the aperture is not itself resonant, because of the high Q of the cavity formed by the enclosure. This radiation can be minimized significantly by lowering the Q of the enclosure with the addition of a lossy layer on one or many inside surfaces of the enclosures. Significant, though much lower, values of radiated field are also encountered near the aperture resonance frequency. The presence of a wire near the aperture can modify the resonance parameters of the enclosure and the aperture, as well as direct the radiated energy. Coupling from the aperture to the wire is stronger when the wire is attached to the enclosure at a point near the broad edge of the aperture rather than near the narrow edge.

Comments:

I do not agree with the interpretation that the FDTD field at a node represents the average value of this field throughout the cell containing this node. I believe that the FDTD equations can be derived from the integral form of the Maxwell's equations by assuming the averaging to take place only over a surface or a line segment containing that node, not over the entire volume of the cell.

The source model was controlled by specifying the source wire radius to be the same as, not just 70% of, that for the FDTD. In paper [97EMCv39n3pp225], necessary modifications to Taflove's thin-wire algorithm for modelling the probe were determined for agreement with measurements by taking the equivalent wire radius of the probe to be only 70% of the physical wire radius.

Jasmin Roy

[15]--[96EMCv38n3pp334]

Signal Processing in Active Shielding and Direction-Finding Techniques (B. Audone, and F. Bresciani)

INDEX TERMS: emissions, Signal Processing, Active Shielding.

The security of any information transmitted, received, or processed may be compromised through unintentional emissions from equipment. Often passive shielding and shielded areas are employed to avoid eavesdropping; however, shielded areas are not always available, feasible, or even effective (due to the use of high resolution spectral estimations techniques). An active shield is an emitter that intentionally generates interference and creates a barrier (shielding). For example, for a 4 MHz signal, a interference signal of 0.01 MHz from the reference signal corresponds to a 30 dB shielding effectiveness. Most of this paper is devoted to the derivation of the method. Two numerical simulations/examples are given.

13 references, 7 pages.

Structure:

Active shielding, based on the generation of interference signals capable of creating screening barriers, is compared to traditional passive shielding techniques.

Analysis Method:

It is assumed that the intruder uses high resolution spectral estimation techniques.

Results:

An example is given where active shielding can provide a SE of about 30 dB (for an ideal sinusoidal signal). Interference signal must be selected to match reference signal in order to make technique work. Complex cases are not investigated.

Comments:

This is a naive idea and is probably not very practical in any realistic situation. Note that 80 dB is a common number for the SE of a passive shielded enclosure.

Joe Seregelyi

[16]-- [96EMCv38n3pp237]

A Full-wave Characterization of an Interconnecting Line Printed on a Dielectric Slab Backed by a Gridded Ground Plane (P. Bernardi, R. Cicchetti, and A. Faraone)

INDEX TERMS: Gridded Ground Plane, Spectral Domain.

Gridded ground planes (instead of a continuous plane) are often used in microwave circuits and PCBs for practical reasons. Initially, the lumped equivalent models were used to study spurious effects and voltage drops across PCB lands. However, lumped models fail when the minimum signal wavelength is comparable to circuit dimensions (fast switching and impassive signals). Integral equations (i.e. dyadic Greens functions in close form) are used model the problem and enforce the boundary conditions and are later solved using Spectra Domain Approach. The problem modelled is a planar interconnecting line printed on a dielectric slab backed by a finite gridded ground plane and predicts the amount of spurious emission and the effects of the reactive magnetic and electric fields excited by the discontinuties. The derivation and solution of the method and the equivalent Z-matrix/parameters is outlined. One simple test case studied at 2.5 GHz.

22 references, 6 pages.

[17]---[96EMCv38n2pp165]

Radiated Emissions and Immunity of Microstrip Transmission Lines: Theory and Reverberation Chamber Measurements (D. A. Hill, D. G. Camell, K. H. Cavcey, and G. H. Koepke)

INDEX TERMS: Emission, Immunity, Reverberation Chamber Measurements.

Numerical integration was used to calculate total radiated power from a microstrip line. The far field expression for the fields radiated by an infinitesimal dipole was evaluated numerically using Sommerfeld integrals and/or reciprocity. A reverberation chamber was also used to perform total radiated power and immunity measurements over a frequency range of 200-2000 MHz. This chamber is convenient for measuring total radiated power without moving the radiator or the receiving antenna as well as immunity measurements. Both immunity and emission measurements were compared with theory for both "bottom fed" and "bounded to chamber" microstrip structures with best agreement found for emission measurements. Some derivations for the maximum radiated field calculations are given. Some suggestions for reducing feed cable and finite ground plane effects are made.

29 references, 7 pages.

Structure/Analysis Method:

Only the simple case of radiation from a single microstrip line is considered. The feed and termination currents (vertical currents) as well as those along the microstrip line (horizontal currents) are considered. A constant travelling wave is assumed on the microstrip line (i.e. match terminated transmission line). The effective permittivity of the microstrip is taken simply as the square root of the permittivity of the substrate. The ground plane and substrate are assumed to extend to infinity. Based on this assumption, Sommerfeld theory is used for Green's functions, and radiation is considered in the upper half space only.

Results:

Although the authors state that better agreement is obtained for the emission measurements, the agreement with both data sets is very good.

Comments:

This paper contains a good description of the procedure of using the reverberation chamber. The analytic formulation is not new.

Neil Simons

[18]-- [96EMCv38n2pp181]

A Comparison of Two Conformal Methods for FDTD Modelling (M. W. Steeds, S. L. Broschat, and J. B. Schneider)

INDEX TERMS: Conformal Grids, FDTD.

Uniform FDTD method is easiest to implement however the stairstep approximations of curved surface introduces errors. In employ all features of an FDTD code in modelling of curved surfaces several locally conformal methods have been suggested. One is Contour Path (CPFDTD) and the other is Overlapping Grid (OGFDTD). Both methods use an integral form of the Ampere's and Faraday's law in the vicinity of the curved surface (with OGFDTD being the more rigorous and complex of the two). Overall, OGFDTD is more complex, computationlly intensive, and more accurate than CPFDTD. Both methods perform better than the uniform FDTD. 2D cases of TM and TE cylinders are examined.

25 references, 7 pages.

[19]---[96EMCv38n1pp77]

Fourier-Transform Analysis of Electrostatic Potential Distribution Though a Thick Slit (Y. S. Kim and H. J. Eom)

INDEX TERMS: Fourier-Transform, Potential, Slit.

The study of high frequency scattering from thick grooves and slits could be carried out by considering the potential distribution through a slit in a thick conducting plane. In this paper a rapidly convergent Fourier transform solution and the mode-matching technique were used to solve such a problem.

3 references, 3 pages.

Comments:

This paper deals with electrostatic field distribution, thus not very relevant to our frequency range (a few MHz to a few GHz).

Jasmin Roy

[20]---[96EMCv38n1pp25]

Simulation Measurements for a Cable Radiation Study (P. Harms, R. Mittra, and J. Nadolny)

INDEX TERMS: EMC, FDTD.

This paper uses a uniform FDTD code and a MoM based NEC to compute the total radiated power from a coaxial cable, and compares the obtained results with the measured data. In this case, the 50 ohm cable is 2.5 m long and has a 7 mm air line. The total radiated power is measured for 300-1000 GHz. A combination of FDTD and NEC was useful in computing the total radiated power. FDTD was used to model a detailed structure of the cable and to provide the wide band frequency domain response and the aperture voltage. The NEC code was used to model a large wire structure and to compute the total radiated power and shield current distribution. The paper provided simulation and measurement details as well as the theoretical basis for the modification of the peak power radiated.

19 references, 6 pages.

Structure:

TL with aperture radiating into a mode-stirred chamber. Line forms loop with wall of enclosure.

Analysis Method:

A uniform FDTD code is used to generate a detailed model of the aperture in the air-line TL (which forms a portion of the TL in the chamber). Integration of the field in the aperture is done to calculate a voltage across the aperture. (Line is assumed to go to infinity, resonances ignored, and radial symmetry assumed). This voltage is then used as a voltage gap excitation for a NEC model which includes the overall geometry of the cables and the enclosure wall. Comparison to measurements and analytical solutions (Marcuvitz) made.

Results:

Values for transfer impedance correlate well between analytical and FDTD (to within 1 dB). Values for total radiated power agree reasonably well for NEC and measurement but not with FDTD which doesn't consider cable resonance. Results show structure behaves as a half-loop (which should not have come as too much of a surprise). NEC modelling of shield current confirms loop behaviour. Results of modelling used to modify loop geometry to reduce power radiated.

Comments:

Noise in measurements appears to be ignored and a comment with regard to the measurement concerns me;... graph may be several dB off from original measurements as well.' No explanation is given.

Joe Seregelyi

[21]-- [96EMCv38n1pp92]

A Computational Methodology and Results for Quasi-static Multi-layered Magnetic Shielding (J. F. Hoburg)

INDEX TERMS: Quasistatic, Magnetic Shielding.

When the largest dimension of the region of interest is electrically small, quasistatic field methodology may be used to study effectiveness of various configurations (i.e. material composition and air gaps between layer paris) of multilayerd magnetic shields. General analytical expression based on induced current mechanisms and flux shunting are developed and evaluated. Several practical configurations of shielding is studied and compared at low frequency (60 Hz). Several recommendations for better magnetic shielding are noted.

10 references, 12 pages.

[22]--[95EMCv37n4pp583]

On the Leakage Radiation from a Circumferentially Slotted Cylinder and its Application to the EMI Produced by TEM-Coaxial Rotary Joints (C. M. Knop and L. F. Libelo)

INDEX TERMS: Rotary Joints, Leakage Radiation.

If the outer conductor of a coaxial cable is broken around the cable (often occurs at the rotary joint of the cable), unintentional leakage radiation is produced. This may be calculated by using the admittance of the gap and the internal coupling capacity of the cable. By using the input power of the cable, the radiation pattern, the directivity gain of the gap, and the far field EMI power density are calculated. The analytical solution for the case of an infinite cable was compared with measurements of such a cable at 2 GHz.

17 references, 7 pages.

Comments:

Even a very small gap in the outer shield of a coaxial cable can create a significant radiation problem if the gap encompasses a full path all around the outer cable because the gap interrupts the flow of the conduction current along the cable (the current across the gap becomes of the displacement type as within a capacitor). It is reported that as much as nearly 26% of the power incident in the coaxial cable can be radiated out by a gap as small as about 0.0074 lambda with the cable being terminated in a matched load. Furthermore, the presence of the gap introduces also in the cable a local mismatch that incurs the presence of a reflected wave along the cable.

Jasmin Roy

[23]--[95EMCv37n4pp574]

Principles of Quasistatic Magnetic Shielding with Cylindrical and Spherical Shields (J. F. Hoburg)

INDEX TERMS: Magnetic Shielding.

Both long cylindrical and spherical shield geometries are considered for two cases of magnetic shielding; the first one is the protection of a region against an external uniform field, the second case is a magnetic shield enclosing a dipole source. In both cases, the shield reduces the magnitude of the magnetic field in the shielded region through either the high permeability of material, which results in shunt magnetic flux (geometry dependent) or the material's electrical conductivity (effective only for dc fields). Also includes two case studies.

6 references, 6 pages.

Comments:

This paper deals with quasi-static, i.e. very low-frequency, shielding. It is an interesting paper but not very relevant to our frequency range (a few MHz to a few GHz).

Jasmin Roy

[24]-- [95EMCv37n4pp528]

On the Prediction of Digital Circuit Susceptibility to Radiated EMI (J. Laurin, S. G. Zaky, and K. G. Balmain)

INDEX TERMS: Radio frequency interference, digital circuits.

The MTL technique is not capable of handling arbitrary wire geometries found on real circuit boards. This paper develops two methods to study the effects of Radio Frequency Interference (RFI) on logic circuits for both large and small signals. In both cases, a circuit simulator (such as SPICE) is used to model both the logic circuit as well as the incident RFI fields (in terms of current sources and admittance parameters derived using a moment method code). It was found (using large signal analysis) that static failures are strongly dependent on the wire geometry. Small signal analysis was also used to study dynamic failure which involves the timing of logic transitions.

18 references, 8 pages.

Structure:

The purpose of the paper is stated formally in the paper as “Effect of radiated RF emissions on the operation of systems”, but more fairly represented as “simulated response of simple logic circuits to incident plane waves”. A non-linear model of the circuit elements is used. Frequencies studied are in the 1-5 MHz range. A method for both large-signal and low-signal interference are considered.

Analysis Method:

A linear small-signal analysis is used to predict dynamic failures. These dynamic failures are due to small interference signals which change the timing of logic signal transitions. A non-linear large-signal analysis is used to predict static failures. The static failures resulting from signal excursions which exceed noise margins of components. The interference causes the quiescent logic state of the circuit to change to its complementary state.

Results:

Coupling from plane waves onto a square loop and a square loop with arms are both analysed. The analysis (performed using a thin wire MoM code) are used to predict the induced voltages at the ports of the wire loop structures. These are then utilized as voltage and current sources within the circuit models, and the wire structure replaced with an equivalent network. A CMOS inverter is used as the test structure. Both LIBRA and SPICE are used in the circuit analysis. The LIBRA JFET model was altered to simulate the CMOS MOSFET. From the small signal analysis, delays in the output of the logic circuits are characterized. From the large signal analysis, induced steady-state responses are predicted. Results indicate that for typical PCB configurations, very large fields of 200V/m do not cause static failures in CMOS, however, for the geometry which included the extended arms (i.e., simulated cable) static failures were observed for fields of only 2V/m.

Neil Simons

[25]--[95EMCv37n3pp488]

Multiple Mode Equivalent Transmission Line Model of Crosstalk Between Conductors in Shielded Environment (M. C. Render and A. C. Marvin)

INDEX TERMS: Crosstalk, Cables.

This paper develops an analytical method of computing the coupling between two parallel conductors over a ground plane, separated by an electrically large distance. These types of arrangements are often found in screened rooms used for EMC measurements where the separation between the cables does not guarantee low crosstalk. A multiple mode equivalent transmission line method was used to derive and simulate the coupling between two cables (in an enclosure) 0.6 m apart. The simulation results and measured data for 100-1000 MHz were plotted and compared for several test cases. The advantages of this method over other time or frequency domain methods were also discussed

17 references, 7 pages.

Structure:

Coupling between parallel conductors in a screened enclosure

Analysis Method:

Analytical method based on equivalent circuit analysis. The enclosure is considered to be a waveguide shorted at both ends and multiple modes are allowed to propagate. Models are developed separately for TEM, TE and TM coupling and a comparison of each is made. The PUL for the circuit model are determined by using the method of moments. Modelling and measurements are performed for a 45x45x90cm cavity with two conductors extending across the cavity (1 MHz -1 GHz).

Results:

Modelling and measurement correlate very well. Resonances agree to 5dB, positions agree to 1 MHz, and both the Q's and off-resonance performance agree. TEM mode was found to dominate below cutoff frequency of the dominant mode but higher order modes required for accurate modelling above cutoff (shouldn't be too much of a surprise). Advantage of this modelling technique is short solution time.

Comments:

Results very good for this geometry, but it may be too difficult to calculate the PUL parameters to develop a circuit for more complicate (and realistic) circuits.

Joe Seregelyi

[26]--[95EMCv37n3pp458]

Electric Field Penetration and Perturbation Problems of a Nonuniform Cylindrical Cavity with a Slot (Y. Liu, B. Tang, and Y. Gao)

INDEX TERMS: EMC, FDTD.

When an external field are incident upon a device and arbitrary shaped holes, the EM penetration and field perturbation are of interest to EMC engineers. This paper uses the quasi-static approximation to study such problems for a family of nonuniform cylindrical cavities with a slot. This method is a strict static problem (i.e. electrically small geometries); hence, resonant behaviour is not predicted by this method.

16 references, 5 pages.

Comments:

This paper deals with a strictly static case and thus, is not relevant to our literature survey.

Jasmin Roy

[27]--[95EMCv37n3pp358]

The Penetration of EM Waves Through Loaded Apertures (C. L. Gardner and G. I. Costache)

INDEX TERMS: Surface Current, Loaded Apertures.

Integral-differential equations, Method of Moments, and experimental results were used to determine the surface current on small apertures loaded with several conducting materials (i.e. wire grids/meshes as well as resistive sheets). The obtained magnetic and electric insertion losses were comparable in all cases. In general, small apertures loaded with resistive material have a frequency independent shielding effectiveness. Also wire mesh and wire grids have a shielding effectiveness that is frequency independent up to 500 MHz. A discussion of the results of several case studies is presented.

23 references, 9 pages.

Structure:

To compute the shielding effectiveness of small apertures loaded with isotropic/anisotropic resistive sheet, bounded/unbounded wire mesh or wire grid.

Analysis Method:

From using the equivalence principle, the aperture is replaced with a magnetic surface current. The subsequent application of the boundary conditions at the aperture leads to an integro-differential equation in the equivalent magnetic current. For small apertures, the field penetrating through a small aperture can be approximated by the field radiated by the combination of a magnetic dipole moment and an electric dipole moment, both dipoles being orthogonal to one another and located at the centre of the aperture and being related to the equivalent magnetic current. The magnetic dipole moment is related to the rotational component of the equivalent magnetic current whereas the electric dipole moment is related to the solenoidal component of the equivalent magnetic current. The integro-differential equation is then broken into its rotational and solenoidal parts and further approximations owing to the fact that the apertures are electrically small are used to simplify the integral equations. The resulting equations are then solved by MoM (pulse for expansion functions, Dirac for testing functions). The presence of a load in the aperture is accounted for by a modification of the boundary conditions (the tangential magnetic field is no longer continuous) and results in the presence of an additional term in the integro-differential equation. This term depends on the surface impedance which, for anisotropic material, turns out to be generally a dyed. Measurements were also done with a dual TEM cell. The output of the cell in the forward and backward directions is related to the sum and difference of the electric and magnetic polarizabilities, respectively. The electric and magnetic properties of the material can thus be separated by adding or subtracting the two outputs of the receiving cell.

Results:

1) There is good magnetic shielding from a mesh/grid if there are wires orthogonal to the magnetic field in the aperture so that there is a significant current induced along the wires to counter the original magnetic field behind the aperture. However, the electric shielding is independent of the wire orientation if the electric field is normal to the wires/fibres in the dual TEM cell. This behaviour is reported to be consistent with both experimental and predicted results for the wire mesh or grid. However, the experimental results with the unidirectional resistive sheet show the electric insertion loss to have an unexpected dependency on the orientation. 2) Bonding the wires of a wire mesh makes no difference to the magnetic and electric insertion loss over the results obtained with leaving the wires unbounded. 3) The magnetic insertion loss is the same for a mesh as for a grid when there are wires oriented perpendicular to the magnetic field. However, the electric insertion loss for a grid is lower (as much as half) than that for the corresponding mesh. 4) The electric and the magnetic insertion loss for wire grids and wire meshes was found to be frequency independent over the range of frequencies (2-500 MHz) and spacing (< 0.5 cm)

investigated. 5) The magnetic insertion loss of a resistive material is function of the frequency (linearly for high conductivity) whereas the electric insertion loss of a resistive material is function of the inverse of the frequency (inversely linear for high conductivity). This latter observation is also said to be a new result as far as the authors are aware.

Comments:

There is a contradiction between the conclusion and a statement on p. 361. The conclusion shows an equation with the (1+jwsU) dependency on frequency for the magnetic insertion loss of a resistive material, therefore making the dependency a linear one for high conductivity material, whereas on p. 361, one reads: "The most notable feature of these curves is the inverse dependence of the magnetic insertion loss on frequency for material with high conductivity." I think that the statement on p. 361 has a typographical error and should read: "... is the increasing dependence of the magnetic...".

Jasmin Roy

[28]-- [95EMCv37n3pp449]

The Effects of Intrinsic Test Fixture Insulation on Material Shielding Effectiveness Measurements Using Nested Mode-Stirred Chambers (T. A. Loughry and S. H. Gurbaxani)

INDEX TERMS: Material Shielding.

Material shielding properties is often measured using a mode-stirred reverberation chamber (one small chamber with a transmitter inside and a window of material to be tested on one side with the receiver located in the outer chamber). The data obtained using this method are effected as a result of tightly coupled chambers and hence should be corrected using described procedure.

4 references, 4 pages.

[29]--[95EMCv37n2pp210]

Modelling Good Conductors Using the Finite Difference Time Domain Technique (K. Chamberlin and L. Gordon)

INDEX TERMS: Good Conductor, FDTD.

A linear field assumption is used for the FDTD method; however, this assumption is not valid for the case of good conductors where fields decay exponentially and wavelengths decrease many orders of magnitude (i.e. number of cells per wavelength falls below the recommended ratio). Hence, FDTD will not compute the correct reflection from, and transmissions into, good conductors. This paper uses two approaches in which the above problem is corrected without any changes to the FDTD code or increased computation resources. The first uses a PEC, coated with a lossy material. The second uses synthetic conductivity to model good conductors. The simulation results were compared with measurements for the case of a cavity over a frequency range of 100-2000 MHz.

19 references, 7 pages.

Structure:

Two modelling approaches are used to modify the FDTD method in an effort to better emulate real metal surfaces. Emphasis is placed on model structures which exhibit resonant characteristics and high Q's.

Analysis Method:

A linear field assumption is used for the FDTD method; however, this assumption is not valid for the case of good conductors where fields decay exponentially and wavelengths decrease many orders of magnitude (i.e. number of cells per wavelength falls below the recommended ratio). Hence, FDTD will not compute the correct reflection from, and transmissions into, good conductors. This paper uses two approaches in which the above problem is corrected, without any changes to the FDTD code, by using a surface impedance boundary condition (SIBC). The first uses a PEC, coated with a very-slightly-lossy material. The purpose of the lossy material is to provide the same attenuation of the field passing through it as would be incurred due to imperfect reflection from a real conductor. A ray tracing technique is used to determine the conductivity values of the lossy material. The second uses a synthetic conductivity to model good conductors.

Results:

A comparison of FDTD solutions with closed form solutions was made by calculating the Q of a 31 x 21 x 11cm cavity. Resonance frequencies were accurately predicted for the TE101 mode, however, Q errors ranged from 3-30% depending on conductivity. An effort was made to model and measure seam impedance on a 42.1 x 13 x 32.4 cm cavity. The losses due to the seam were considered by empirically adjusting the conductivity values.

Comments:

As the authors point out, because empirical adjustments to the model parameters were required to achieve agreement with measured values, the correlation to practical enclosures cannot be construed as validation of the modelling approach.

Definition of the problem that the authors are attempting to solve, presentation of the analysis and comparison of the various results are confusing at times.

Joe Seregelyi

[30]-- [95EMCv37n2pp175]

A Full Wave Model for EMI Prediction in Planar Microstrip Circuits Excited in the Near field for a Short Electric Dipole (P. Bernardi, R. Cicchetti, and D. S. Moreolo)

INDEX TERMS: EMI, Dipole.

In this paper, the coupling of sources near printed microstrip lines are simulated. The nearby sources are modelled as arbitrary oriented electric dipoles with the dyadic Greens's function used to include the effects of an assumed infinite ground-plane/substrate. The full wave solution is compared to MoM solution for frequencies of 2.5 and 10 GHz for both straight and curved lines, matched and open ended lines, and horizontally and vertically polarized dipoles.

22 references, 8 pages.

Comments:

Most of the results and analysis contained in the paper are similar to that contained in papers treating MoM analysis of printed antennas. Several "MoM analysis of printed antenna papers" appeared in IEEE MTT and AP Transactions in the 1980s.

Neil Simons

[31]--- [95EMCv37n2pp167]

Prediction of Delays Induced by In-Band RFI in CMOS Inverters (J. Laurin, S. G. Zaky, and K. G. Balmain)

INDEX TERMS: Logic Circuit, RFI.

This paper formulates a method to predict worst case delay in CMOS inverters due to in-band RFI. The delay is calculated as a function of induced voltage and is found to be dependent on the phase and amplitude of the RFI signal as well as the slew rate of the logic circuit. Measured empirical constants are used in frequency domain circuit analysis packages and allows for simulations of large circuits.

15 references, 8 pages.

Structure:

Study of induced delays by RFI in CMOS inverters measured under radiated and capacitively coupled interference. Frequencies studied are in the 5-50 MHz range.

Results:

Measured delays are compared with SPICE predicted delays with excellent agreement. Measurements were performed in a TEM cell for the radiated interference. For the capacitively coupled interference the actual signal was coupled to the microstrip-mounted inverters using a 4.7pF capacitor. The parameters for a simple closed form expression for predicting delay are provided. Delay is significantly increased for interfering sources with frequency less than the gate's maximum switching frequency. Worst-case delays occur for capacitively coupled interference. A growth factor for the compounded delay through a series of inverters is provided.

Neil Simons

[32]--[95EMCv37n1pp126]

A Comparison of Various Measured and Calculated Shielding Effectiveness Data for a Wire Cage (P. Wilson)

INDEX TERMS: Shielding, Wire Cage.

A quick review of several methods of measuring and computing shielding effectiveness is performed. Next, the shielding effectiveness of a wire cage structure (2 m cube) is measured and predicted/computed using various methods for both near and far field coupling through the mesh for frequencies up to 1 GHz. In general the shielding effectiveness is dependent on shield geometry, frequency, wave impedance and antenna type.

5 references, 6 pages.

Structure:

The paper presents the computed and measured results on the shielding effectiveness (SE) of a wire cage structure (2 m cube) with either one of two different mesh densities (5 and 50 cm mesh), located in the near vicinity of a transmitting antenna.

Analysis Method:

For the far-field source SE, the paper uses Casey's analytical results for a square mesh of thin, bonded, circular wires forming an infinite plane illuminated by an obliquely incident plane wave. For the near-field source SE, the paper gives formulas for the case that the planar mesh lies between a transmitting and a receiving dipoles, one coaxial to the another, oriented perpendicular to the mesh. The paper, however, gives no detail as to how the formulas were developed, other than to mention that the development is based on the mesh having rotational symmetry, which assumption does not rigorously apply to a square mesh anyway.

SE formulas for enclosures of certain simple shapes are also given in terms of: a) two time constants, the enclosure and the surface time constants for the magnetic SE, b) a ratio of volume-over-surface of the enclosure for the electric SE. The analytical formulas assume that the mesh size is small compared to both the structure dimensions and the wavelength. Six different measurement methods were used in collecting the empirical results.

Results:

The near-field source SE is found to be very dependent on the shield material as well as on the antenna geometry. Near-field source SE is reduced as the source and the observation point are brought together. The classical far-field shielding effectiveness dramatically overestimates the shielding performance of the screen in the low frequency range. The shielding effectiveness of a mesh against a plane wave illumination decreases at the rate of 20 dB/decade whereas the shielding effectiveness of a solid panel increases, as frequency increases.

Comments:

The paper mentions that both calculated and measured SE data cover a wide range of values depending on the wave impedance, frequency, antenna type and separation, and structure geometry, and thus, the interpretation of SE data without clearly specifying these parameters is difficult.

Jasmin Roy

[33]--[95EMCv37n1pp114]

Transmission Through Corrugated Slots (J. Carlsson and P. Kildal)

INDEX TERMS: Corrugated Slots.

The leakage of electromagnetic energy through slots and seams is of interest to EMC engineers. However, the amount of leakage is dependent on the type and polarization of the incident field as well as the geometry of the slot. For example, for slots smaller than half a wavelength, TM polarization (E field parallel to slot) exhibits a much lower leakage than a similar TE polarization field. In this paper, a version of Method of Moment (with low computational overhead) was used to study leakage through gaps between ground planes as well as leakage through corrugated slots for frequencies of 1-60 GHz. Several configurations were studied and methods for reducing this type of leakage were proposed.

13 references, 8 pages.

Structure:

A wall infinite in one transverse dimension (i.e. 2-D problem) with corrugated slots (i.e. corrugations inside the wall) illuminated by an normally incident plane wave of either TE or TM polarization. The corrugations can be loaded with dielectric slabs.

Analysis Method:

In order to determine the transmission, the authors calculate the tangential fields at the slot faces by using the equivalence principle and by matching the fields at the boundaries between the simple rectangular regions forming the corrugations. Each aperture is closed with a PEC surface on which is taken to flow an equivalent magnetic current. For the two surfaces open to the exterior free space, i.e. the input and the output faces of the entire structure, the magnetic currents are imaged by the continuous infinite PEC surfaces of the structure. The incident magnetic field in the presence of the continuous PEC wall is also imaged and thus, the resulting impressed magnetic field is taken as twice the tangential component of the incident magnetic field existing in the absence of the conducting wall. Inside each rectangular cavity formed by closing the apertures, the field is produced by the equivalent magnetic currents on the two conducting walls where the apertures were closed off. The E field in each cavity is expanded in terms of parallel plate waveguide modes. Then, the H-fields at the covered apertures between adjacent regions are matched to determine the expansion coefficients of the E-fields. This procedure results in a set of integral equations solved numerically by using the method of moments (pulses for expansion functions and Dirac for testing functions). The resulting sparse matrix is solved recursivly. Losses can be taken into account by allowing the wave number to become a complex number.

Results:

When the electric field vector is parallel with the slot axis, i.e. TM polarization, the leakage is much lower than the power density times the slot width, provided the slot width is less than half a wavelength. This is because the tangential E-field for the TM-case is tangential to the conducting ground plane edges and thereby forced to be zero at the edges. This creates a cutoff condition for the field over the slot. For the TE polarization, on the other hand, the leakage is very high because the electric field is normal (and high valued) rather than tangential (and zero) to the edges, so the field can easily propagate through the slot. The amount of leakage will in this case be given very approximately by the power density times the width of the slot. The corrugated slots reduce the transmission for the TE-case only. The TM-case remains low both with and without the corrugations. The corrugations can be designed to act as chokes to the field penetrating through the slot. Filter design techniques can be used to improve the frequency bandwidth of the choking action. The results show that properly designed corrugations can reduce the transmitted power by about 20 dB with respect to having no corrugations.

A good agreement was obtained with empirical data taken with a network analyser with time gating capability for measuring the transmitted power while reducing the effect of multiple reflections and scattered field from the surrounding. The resonance frequencies were predicted within 5% error. The definition of the transmission coefficient was, however, somewhat different for the experimental and the calculated cases. The measured results were defined as the difference in amplitude for the corrugated slot and for the non-corrugated slot measured at one point straight in front of the slot. The calculated results were defined as the ratio of the transmitted power per unit length to the incidence power density times the slot width, and thus related to the integral of the E-field over the half space, not just at one point in front of the slot.

Comments:

I do not understand how many figures can show a transmission coefficient greater than unity!

Jasmin Roy

[34]--[95EMCv37n1pp109]

Plane-Wave Shielding Properties of Anisotropic Laminated Composite Cylindrical Shells (C. Chiu and C. H. Chen)

INDEX TERMS: Composite Materials, Shielding.

Composite materials and fibre-reinforced composites are increasingly employed to replace metals in modern aircraft. These composites are often laminated, anisotropic, and lossy, which may affect their shielding properties. In this paper, the plane-wave shielding effectiveness of an anisotropic laminated, composite, cylindrical shell is studied for frequencies up to 400 MHz. The study considers graphite/epoxy shells and their material properties, the number of layers, radius of shell, fibre orientation, polarization frequency, and the incident angle of plane wave. Empirical values for various composite materials are presented.

13 references, 5 pages.

Structure:

An anisotropic, multi-layered, a lossy cylindrical shell structure with complex permittivity and permeability tensors that are function of the radial distance. The anisotropic composite shell is assumed to consist of highly conducting fibres wound in the helical shape inside the cylindrical material shell. The structure is illuminated with an incident plane wave of TE or TM polarization with respect to the axial direction of the cylindrical structure.

Analysis Method:

The incident, the scattered and the transmitted waves are expressed in terms of the axial E and H field components which are expressed as a summation of cylindrical waves. The solution is assumed to have a harmonic form in the axial and the azimuthal directions. The equations are framed into a state equation form (i.e. all variables are expressed in terms of derivatives of order no higher than one). The differential operator is then approximated with a finite difference and the propagator matrix is obtained. After some substitutions, both scattered and transmitted fields are said to be evaluated as a summation over all the angular harmonics. The analysis is said to be rigorous.

Results:

Extremely large differences (up to about 80 dB) in the values of shielding effectiveness, between circular and planar structures, specially in the lower frequency region, suggest the need for modelling the practical two-dimensional structure instead of using the simplified one-dimensional planar structure.

The shielding effectiveness is minimum for the incident wave impinging at normal incidence, and increases with the incidence angle departing from normal incidence, for both the TE and the TM polarization. However, the magnetic shielding effectiveness increases while the electric shielding effectiveness decreases with increasing frequency, at least for low frequencies. Resonance phenomena corresponding to the zeros of the Bessel function Jo for the electric field, and the zeros of the Bessel function J1 for the magnetic field, reduce dramatically the shielding effectiveness. The resonance frequency is shifted by a factor of sin(theta) as the illuminating plane wave is obliquely incident, with the angle theta defined with respect to the axis of the cylindrical structure.

The shielding effectiveness was shown to be greatly improved (30 dB or more) by applying a thin metallic coating on either the inner or the outer side of the cascade of cylindrical shells.

Good agreement was obtained with the results computed by another method (not mentioned directly).

An empirical formula is proposed for the magnetic shielding effectiveness at low frequency.

Comments:

The description of the analysis method is skimpy.

The helical shape of the fibres is modelled by an anisotropic conducting sheet characterized by a conductivity tensor matrix. This is valid only for lower frequencies for which the effect of having individual fibres is not apparent. This is confirmed also by a comment made in a subsequent paper by the same authors.

The incidence is oblique, not general, i.e. the incidence plane contains the axis of the cylindrical structure.

Jasmin Roy

[35]--[95EMCv37n1pp105]

Electromagnetic Coupling Between Two Half-Space Regions Separated by Multiple Slot-Perforated Parallel Conducting Screens (A. El-Hajj, K. Y. Kabalan, and S. Khoury)

INDEX TERMS: Coupling, Slot.

A characteristic mode theory is used to study and solve the problem of electromagnetic coupling between two half-space regions separated by multiple slot parallel conducting screens. The structure is assumed to be illuminated by either a TE or TM plane wave; the fields in each half of the space, and the power transmitted through the slots, are computed. Several parameters of this structure are examined using a numerical evaluation of the derived equations.

14 references, 5 pages.

Structure:

Multiple parallel infinite PEC zero-thickness plates perforated periodically in one transverse dimension with a finite number of parallel slots infinite in the other transverse dimension. The structure is illuminated by an obliquely incident plane wave of TE or TM polarization. The propagation medium can be different between any two adjacent plates.

Analysis Method:

From the use of the equivalence principle, the apertures are closed with PEC, thus transforming the perforated plates into infinite PEC plates, thereby separating the whole space into many de-coupled regions. In accordance with the equivalence principle, equivalent magnetic currents are taken to flow on the PEC sections corresponding to the apertures. Since the normal unit vector is taken to point inwardly into the region where the field is produced by an equivalent current, and since the two equivalent magnetic currents on either side of a full PEC plate are derived from the same electric field in an aperture, it results that the two equivalent magnetic currents on either side of a plate have opposite directions. The field between two adjacent plates results from the radiation of the equivalent magnetic currents on the two PEC surfaces confining the region between the two PEC plates, thus results from the radiation by equivalent magnetic currents of opposite directions. The field in the incidence region in front of the first plate results from the super-position of the radiation of the equivalent magnetic currents on the surface side of the first PEC plate which is in contact with the incidence region, and the field of the incident plane wave. The incident magnetic field in the presence of the continuous PEC wall is also imaged and thus, the resulting impressed magnetic field is taken as twice the tangential component of the incident magnetic field existing in the absence of the conducting wall. The field in the transmission region behind the last plate results from the radiation of the equivalent magnetic currents on the surface side of the last PEC plate which is in contact with the transmission region. The expression of the magnetic field is then found in each region. Enforcing the continuity of the tangential magnetic fields in the apertures between adjacent regions leads to a set of simultaneous equations that is put into an admittance vector operator format. The originality of the method consists here in expressing each equivalent magnetic current in terms of a summation of characteristic currents that are the eigenfunctions of a generalized eigenvalue equation written in terms of the conductance and the susceptance operators. The solution of the eigenvalue problem is obtained by Galerkin's method (pulse functions for TE excitation and triangular functions for TM excitation) and yields the knowledge of the eigenvalues and the coefficients of the characteristic currents for the series expressing the equivalent magnetic currents. Once the equivalent magnetic currents are known, the electromagnetic fields in every region and the power transmitted through all the plates can be computed.

Results:

As expected, the power transmitted behind the last plate is maximum when the slots on all plates line up face to face. The transmitted power increases periodically as the distance between the plates increases. The peaks correspond to the resonance phenomenon when the distance between the plates is an odd number of half-wavelengths in the propagation medium between the plates.

Comments:

The incidence is oblique but not general, i.e. the incidence plane corresponds to a principal plane, not an arbitrary plane.

The paper mentions that the power transmitted behind the last plate is maximum when the slots on all plates line up face to face but it is not said how the incidence angle affects the result. One would expect that the power transmitted be also significant when the slots line up in a way that there exists a line of sight through all the plates at the angle corresponding to the incidence angle.

The use of the characteristic currents represents an intermediary step whereby the unknown equivalent magnetic currents in the equation embodying the continuity of the tangential magnetic field in the apertures, is not solved directly by MoM but as a summation of characteristic currents which themselves are solved by MOM. However, the use of characteristic equations lends a physical interpretation akin to the eigenfunctions of a coordinate system. In fact, the characteristic modes can be seen as a generalization of the classical eigenmodes in that the characteristic modes remain valid even when the geometry does not conform to the axes of a separable coordinate system, i.e. a coordinate system in which the vector Helmholtz equation is separable.

The paper does not give details as to whether the field was expanded in parallel plate waveguide modes in order to take into account the infinity of images created by two continuous PEC plates parallel to one another.

Jasmin Roy

[36]-- [94EMCv36n4pp385]

Computer Modelling of Electromagnetic-Wave Impact on Electronic Equipment (M. S. Tharf and G. I. Costache)

INDEX TERMS: Electronic Equipment.

This paper attempts to address field coupling into electronic equipment. The Finite Element Method (FEM) was used to compute the fields since this method uses unstructured meshes and enables the user to model arbitrary shaped structures and boundaries as well as inhomogeneous domains. This paper discusses the occurrence of spurious (nonphysical) solutions and the treatment of unbounded domain. Some cases considered are infinite plane shield, dielectric cylinders for frequencies of 600 -1500 MHz.

12 references, 5 pages.

Analysis Method:

A variational formulation of the edge-element FEM method with an asymptotic field expansion applied to simulate the unbounded domain.

Comments:

The problems solved using the formulation are of limited use. The paper successfully validates the code for a few simple test cases.

Neil Simons

[37]-- [94EMCv36n4pp355]

A Simple Method for Calculating Electric and Magnetic Fields in GTEM Cell (K. Huang, and Y. Liu)

INDEX TERMS: EMC, GTEM Cell.

Gigahertz TEM (GTEM) cells are used for susceptibility and emission measurements. Due to the modifications of the GTEM cells (in order to improve size and frequency restrictions of TEM cell) the well known electric and magnetic field distribution of the TEM cells no longer is valid. This paper uses coordinate transformation to calculate the E and H fields in the GTEM cell using a quasi-static approximation; hence, the results are only valid for operational frequencies well below the cutoff frequency. The method introduced is useful in EMC/EMI measurements.

8 references, 4 pages.

[38]--[94EMCv36n4pp314]

Crosstalk Between Microstrip Transmission Lines (D. A. Hill, K. H. Cavcey, and R. T. Johnk)

INDEX TERMS: Crosstalk.

Several methods for the prediction of crosstalk between microstrip lines are reviewed. They include the classical coupled transmission line theory for uniform lines, potential, and induced EMF method. The test structure consisted of a pair of microstrip lines placed on a single grounded substrate. The predicted results agreed well with the measurements for frequencies of 50-5000 MHz. Also included is a short discussion on the scale modelling of MMIC lines.

26 references, 8 pages.

Structure:

Crosstalk between a pair of microstrip lines on a single grounded substrate. Analysis done for parallel and arbitrary orientation.

Analysis Method:

Methods for prediction of crosstalk between microstrip lines are reviewed and simplified for the weak-coupling case. Analysis done for parallel and arbitrary orientation. Classical coupled TL theory used for uniform lines. Potential and induced EMF perturbation methods used for nonuniform lines (multiple interactions are neglected, i.e. weak coupling assumed). Comparison of measured and calculated S parameters made from 50 MHz to 5 GHz for a pair of uniform lines.

Results:

Methods for prediction of crosstalk between microstrip lines are reviewed and simplified for the weak-coupling case. For the uniform case, even and odd mode propagation constants and impedances are calculated. All S parameters are calculated for port 1. Low frequency approximations are applied to simplify these equations. It is shown that S21 is proportional to the excitation waveform and that S31 and S41 are proportional to the time derivative of the excitation waveform. The crosstalk between two 19.6cm, 50ohm lines (spaced 4.8mm) was measured and shown to correlate well with theory. Good agreement is achieved to 3 GHz. Above this frequency, dispersion, surface waves or higher order modes may be effecting results. Scaling to MMIC is proposed.

Joe Seregelyi

[39]--[94EMCv36n4pp201]

Calculation of Radiated Electromagnetic Fields from Cables Using Time-Domain Simulation (D. W. P. Thomas, C. Christopoulos, and E. T. Pereira)

INDEX TERMS: Radiated Fields.

This paper considers the electromagnetic fields produced by transient currents in an electrical circuit. These fields are assumed to radiate from parts of the circuits (say cables) that behave like an ideal antenna excited with a transient current. The Transmission Line Matrix (TLM)method was used to simulate and to derived the transient current for short dipole elements. A cable was assumed to be a chain of short dipoles, and the overall near and far field response of each radiator was calculated and compared to other numerical methods. the TLM method worked well for low frequencies (below 100 MHz) and was shown to work well for high frequencies as well.

7 references, 5 pages.

Structure:

TD simulation of radiated fields from cables and circuits. Emphasis is placed on the calculation of electrostatic and inductive terms at low frequency and near radiating elements (relevant to 3m spacing in EMC testing).

Analysis Method:

Fields are calculated by first finding the current in a radiating cable using any TD circuit simulation (TLM is used here), then treating the cable as a chain of ideal radiating dipoles. The lengths are chosen such that the current can be approximated as being constant along the length of the dipole and the value used is the one determined from the TD simulation. The fields are determined by summing the contributions of each dipole. Analytical solutions are used for the fields from the dipoles. One difficulty is that the field due to the line terminations are not included, so large un-compensated charges can build up at the line terminations. The problem is circumvented by omitting the electrostatic terms in the formulations.

Results:

Two wire TL is calculated as example. It is shown that, for frequencies above 100 MHz, there is very good agreement between computed results and analytical solutions. Below 100 MHz this is not true because of inherent assumptions made in the analytical solutions.

Joe Seregelyi

[40]--[94EMCv36n3pp169]

Aperture Excitation of Electrically Large, Lossy Cavities (D. A. Hill, M. T. Ma, A. R. Ondrejka, B. F. Riddle, M. L. Crawford, and R. T. Johnk)

INDEX TERMS: Cavities.

In the case of electrically large enclosures (say inside of an aircraft), it is important to know the shielding effectiveness of the enclosure and the average value of the interior fields due to either a continuous or pulsed external field. This paper uses the power balance theory to predict shielding effectiveness, cavity Q, and cavity time constant for aperture excitation of electrically large and lossy cavities. The advantage of this method is that it does not require fine geometrical details of enclosure; however, it only provides the average field strength throughout the cavity. The theoretical results were confirmed with measurements for frequencies of 1-18 GHz.

25 references, 9 pages.

Structure:

Electrically large lossy cavities where the average power density is assumed to be uniform throughout the chamber (as with a mode stirrer). The cavity contained lossy bodies (salt-water spheres) and was excited via a large arbitrarily shaped or a small circular aperture by a CW plane wave illumination with equal power densities in the parallel and perpendicular polarization, or by a CW source inside the chamber.

Analysis Method:

The analysis is statistical and does not depend on the fine features of the structure. It assumes that the energy density is uniform throughout the cavity volume, and that the stored electric and magnetic energies are equal. The field variable is interpreted as an ensemble average as a result of the field being taken as the superposition of plane waves of all incidence angles and polarization in different cavity shapes. The shielding effectiveness of the cavity is obtained from the knowledge of the losses by the Q theory and by applying the power balance principle. The Q theory takes into account the finite conductivity of the walls, the power absorption by lossy bodies inside the chamber, the aperture leakage, the power dissipation in loads attached to the receivers (including the effect of effective area of the receiving antenna, the impedance mismatch and the polarization mismatch but not the antenna pattern because it is averaged over all possible incidence angles and polarization), and possibly even the water absorption in the air. Power balance equates the sum of all power losses to the power transmitted through the aperture or the power delivered by a source inside the chamber.

Results:

A lossy cavity (low-Q) has a greater shielding effectiveness than a high-Q cavity. The shielding effectiveness is constant with frequency for large apertures. The Q was determined by two methods: the time-constant method from a turned-on or turned-off sinusoidal, and the loss-ratio method. The time-constant method yielded a better agreement with the measured Q values. Comparison between measured and predicted values of shielding effectiveness for a cavity excited by a circular aperture over the range of 0.20 GHz to 20.0 GHz showed a good agreement in the trend of the values.

Comments:

The analysis does not take into account the strong resonances from long narrow apertures. For a circular aperture, the analysis covers the frequency range by using only the electrically small and electrically large approximations of transmission cross-section, neglecting the resonance effect. The crossover wave number between these two approximations was taken as k=1.29 and corresponds quite well to the break point seen in the measured results of shielding effectiveness with frequency.

Jasmin Roy

[41]---[94EMCv36n3pp196]

Scattering from and Penetration into a Dielectric-Filled Conducting Cylinder with Multiple Apertures (A. El-Hajj, and K. Y. Kabalan)

INDEX TERMS: Coupling, Slots.

The characteristic mode theory was used to study coupling between different media through apertures. In these problems, a vector equation (with equivalent magnetic currents as unknowns) was derived for each aperture and later was solved using the moment method as its numerical solution. As a case study, a conducting cylinder with a limited number of slots was illuminated with both TE and TM plane waves. The fields inside and outside of the cylinder were then computed.

7 references, 5 pages.

Structure:

Infinitely long PEC zero-thickness cylinder perforated azimuthally with parallel slots infinite in the height dimension. The structure is illuminated by an obliquely incident plane wave of TE or TM polarization. The propagation medium can be different inside and outside the cylinder.

Analysis Method:

From the use of the equivalence principle, the apertures are replaced with PEC, thus transforming the perforated PEC cylinder into a full PEC cylinder, thereby separating the whole space into two decoupled regions. In accordance with the equivalence principle, equivalent magnetic currents are taken to flow on the PEC sections corresponding to the apertures. Since the normal for the interior and the exterior regions point in opposite directions, the equivalent magnetic currents on the outside surface of the PEC cylinder have opposite directions to the equivalent magnetic currents on the inside surface of the PEC cylinder. The field in the interior region results from the radiation of the equivalent magnetic currents on the inside surface of the PEC cylinder whereas the field outside the cylinder results from the superposition of the radiation of the equivalent magnetic currents on the outside surface of the PEC cylinder, and the field of the incident plane wave. The expression of the magnetic field is found in each region and the continuity of the tangential magnetic fields in the apertures leads to an admittance vector operator. The originality of the method consists here in expressing each equivalent magnetic current in terms of a summation of characteristic currents that are the eigenfunctions of a generalized eigenvalue equation written in terms of the conductance and the susceptance operators. The solution of the eigenvalue problem is obtained by Galerkin's method (pulse functions for TE excitation and triangular functions for TM excitation) and yields the knowledge of the eigenvalues and the coefficients of the characteristic currents for the series expressing the equivalent magnetic currents. Once the equivalent magnetic currents are known, the electromagnetic fields in both regions and the power transmitted to the interior region can be computed.

Results:

The results show the first 4 characteristic currents and corresponding scattering patterns for a two-slot problem, but no value of shielding effectiveness or power transmitted into the interior region.

Comments:

The incidence is oblique but not general, i.e. the incidence plane corresponds to a vertical plane (i.e. a plane containing the axis of the cylinder), not an arbitrary plane.

The use of the characteristics currents represents an intermediary step whereby the unknown equivalent magnetic currents in the equation embodying the continuity of the tangential magnetic field in the apertures, is not solved directly by MoM but as a summation of characteristic currents which themselves are solved by MOM. However, the use of characteristic equations lends a physical interpretation akin to the eigenfunctions of a coordinate system. In fact, the characteristic modes can be seen as a generalization of the classical eigenmodes in that the characteristic modes remain valid even when the geometry does not conform to a separable coordinate system, i.e. a coordinate system in which the vector Helmholtz equation is separable.

It is interesting to note that the treatment accounts for the curvature of the apertures as if they laid on the boundary of the cylinder. The image principle could not be used herein because the surface was not planar and of infinite extent.

Jasmin Roy

[42]---[94EMCv36n3pp161]

Theoretical and Experimental Near-Field Characterization of Perforated Shields (S. Criel, L. Martens, and D. DeZutter)

INDEX TERMS: Near-Field, Shielding.

The near-field shielding effectiveness of periodically perforated planes has received much less attention than the case of far-field shielding effectiveness. However, in many high frequency applications, the far field shielding conditions are not fulfilled which results in large near field strengths. This paper analyses the electromagnetic coupling between two loop antennas through an infinitely large perforated plane shield using both the moment method as well as near-field measurements. Both methods agreed well for frequencies of 1-1000 MHz. The classical far field shielding effectiveness method was found to drastically overestimates the near-field shielding performance.

15 references, 8 pages.

Structure:

The shielding effectiveness of an infinitely large, infinitely thin, PEC screen with doubly periodical rectangular perforations and illuminated by the near-field of a radiating loop with uniform current distribution, is predicted and measured.

Analysis Method:

The magnetic field radiated by the loop is obtained as a series of incident plane waves impinging on the perforated screen, via the plane wave spectrum decomposition. For each plane wave, an integral equation for the tangential electric field in the apertures is formulated in terms of Floquet modes owing to the periodicity of the perforations, and solved by MoM using Chebychev polynomials in order to account for the edge effect of the apertures. All the transmitted propagating and evanescent plane waves corresponding to the various Floquet modes are obtained for each incident plane wave. The resulting transmitted field is obtained as the summation of all transmitted plane waves for all incident plane waves. The voltage of a receiving loop located behind the screen is computed from applying Faraday's law rather than from solving a boundary value problem (i.e. the perturbing effect of the presence of the physical loop on the transmitted magnetic field is not accounted for). This process results in integrating the various transmitted plane waves over the surface of the receiving loop. Taking into account the finite size of the loop proved to be important in order to account for the averaging effect of the non-infinitely small loop.

Results:

Comparison with measured results obtained with a scanner in a shielded room showed a good agreement. Some asymmetry in the measured results owed to the necessity of connecting to the receiving loop. It was found that the predicted classical far-field shielding effectiveness dramatically overestimates the shielding performance of the screen under test as far as magnetic near-field applications are concerned.

Comments:

No mention is made in the paper about using the equivalence principle for obtaining the integral equation that holds over the aperture portion of the shield. The maximum radiation level shifts away from the centre of the screen at higher frequencies due to the increasing importance of high-order Floquet modes. The inverse Fourier transformation involved in the process of integrating the transmitted plane waves over the surface of the receiving loop yields a field map at the plane location of the loop.

Jasmin Roy

[43]--[94EMCv36n1pp76]

Scattering and Coupling Properties of a Slotted Elliptic Cylinder (M. Hussein, A. Sebak, and M. Hamid)

INDEX TERMS: Coupling, Slotted Cylinder.

This paper studies near-field coupling from and to a perfectly conducting slotted elliptic cylinder due to an external plane wave or an external line source or an internal line source excitation. The derived equations are evaluated using separation of variables and Galerkin's technique. Several cases of design parameters such as cylindrical axial ratio, aperture width, and dielectric loading material were investigated.

12 references, 6 pages.

Structure:

Infinitely long zero-thickness PEC cylinder with an infinitely long slot parallel to the axis of the cylinder. The interior of the cylinder is loaded with a material of permittivity and permeability values different from those for free space. The exterior of the cylinder is free space. The source is a line inside or outside the cylinder. A z-polarized plane wave excitation is obtained if the line source is exterior to the cylinder at a very large distance from the cylinder.

Analysis Method:

The separation of variables technique is used to express external and internal fields in terms of Mathieu and modified Mathieu functions (i.e. the eigenfunctions of the elliptical coordinate system) with unknown expansion coefficients. The problem is then reduced to an integral equation in terms of the aperture field by enforcing the boundary conditions (both tangential electric and tangential magnetic fields) on the cylindrical surface and the slot. The solution of the integral equation is carried out by expressing the aperture field in terms of a sinusoidal Fourier series expansion of even and odd parts with unknown coefficients. Then Galerkin's technique is used to solve for the unknown aperture field coefficients.

Results:

Results for the radiated (when the source is inside the cylinder) and penetrated (when the source is outside the cylinder) fields are given in terms of different parameters such as location and type of the excitation, aperture width, cylindrical axial ratio, and the loading of the cylinder. The validity and accuracy of the numerical results are examined by making use of limiting cases such as circular cylinders and narrow slotted cylinders. Very good agreement was obtained with a MoM scattering solution for a slotted circular cylinder and a complete elliptical cylinder.

As expected, the magnitude of the radiated electric field increases as the aperture angle increases. The field decays faster away from the cylinder as the axial ratio of the elliptical cylinder increases. Surprisingly, the variation of the penetration field does not show a monotonic behaviour as the permittivity value of the medium inside the cylinder increases. The solution is also capable of showing resonances.

Comments:

It is interesting to note that the treatment accounts for the curvature of the aperture as if it laid on the boundary of the elliptical cylinder. The boundary value technique, not the equivalence principle, was used herein. The boundary value technique consists in expressing the fields in terms of a summation of the eigenfunctions of the coordinate system, and thus is valid only when the geometry of the structure conforms to the axes of the coordinate system and that the vector Helmholtz equation is separable in this coordinate system.

Jasmin Roy

[44]-- [94EMCv36n1pp40]

Generalized Expressions for Characterizing a Linear Multiport Circuit Coupled with External Fields (S. Ishigami and I. Yokoshima)

INDEX TERMS: Coupling, Multiport Circuit.

The output voltages and currents of a circuit coupled with external fields have been measured for low frequencies, for various loads and operating conditions, however, for higher frequencies (few hundreds of MHz) these measurements must be done under limited conditions. This paper uses S-parameters and measured matched output voltages to analyse characteristics of linear multiport circuits coupled to external fields. General expressions which allow for systematic analysis of coupling to electronic circuits are derived both in frequency and time domain.

9 references, 3 pages.

Structure:

Characterization of the coupling between external fields and a circuit.

Analysis Method:

Measurement of terminal voltages induced by external EM fields can be determined from S-parameter measurements.

Results:

Unfortunately, only the simple problem of a segment of a transmission line is considered.

Neil Simons

[45]--[93EMCv35n4pp409]

Comparison of Coupling Mechanisms on Multiconductor Cables (F. Broyde and E. Clavelier)

INDEX TERMS: Coupling, Cables.

This paper considers the problem of field-to-wire coupling for shielded cables of circular cross section. Using five different types of possible coupling mechanisms, the relevant parameters of transfer impedance and through elastance have been computed. However, the use of these parameters restricts some applications to frequencies below 3 GHz. A limited comparison between the computed parameters and measurements is performed. Also, it is stated that some previously neglected types of coupling should be included in the calculation of shielding effectiveness.

5 references, 8 pages.

Structure:

Systematic analysis of cable coupling mechanisms to both co-axial and multiconductor cables with shields. Limited to electrically short cables with circular symmetry and frequencies to 3 GHz.

Analysis Method:

An extensive discussion of the coupling mechanisms to cables is presented. It appears the authors have spent a significant amount of time thinking about the interaction of EM waves with cables and have developed a good understanding of the problem. Analysis is primarily analytical with some simple numerical modelling presented in the Appendix. Some experimental work is performed, however, a quantitative correlation is not presented in any obvious way.

Results:

Five predominant coupling mechanisms are identified. Only two of these, a circumferential B-field, radial E-field, are relevant for co-axial. The remainder; an axial B-Field, asymmetric E-Field and a perpendicular B-field (penetrating the shield), are relevant to multiconductor lines. The authors claim that the first two types of coupling, which are included in conventional calculations, are insufficient and that the third type of coupling, axial B-Field, can also make a significant contribution. (Earlier, in the paper they mention that this type of coupling is only relevant for skewed wires - like twisted pairs).

Comments:

Some of the precautions taken during the measurements appear unnecessary and the authors never confirm that more conventional techniques are inadequate. They also describe a technique where they reduce the electric field in a TEM cell by introducing a grounded plate. They measure a reduction in the E-field and claim that the B-field is responsible for the coupling - but they never confirm that the B-field is unperturbed by this set-up. They do not consider the repercussions of the obstruction on the operation of the TEM cell.

Joe Seregelyi

[46]--[93EMCv35n3pp404]

Formulation of Field-to-Transmission Line Coupling Equations in Terms of Magnetic Excitation Field (F. Rachidi)

INDEX TERMS: Coupling, Magnetic Excitation.

This paper reviews two different formulations of field-to-transmission line coupling for the case of a wire above a lossy ground plane. The first formulation represents the excitation field in terms of E and H field components while the second formulation only involves horizontal and vertical field components. Since it is often easier to obtain magnetic field data, a new formulation is introduced where the excitation field is represented in terms of magnetic field components only.

11 references, 4 pages.

Structure:

Different formulations of the field-to-transmission line coupling for the case of a wire above a lossy ground plane are presented.

Results:

Three different formulations of the field-to-transmission line coupling for the case of a wire above a lossy ground plane are presented. The first two have been presented in the past. The first expresses the coupling in terms of the vertical electric and transverse magnetic fields. The second reformulates these expressions so that only the E-field is required. This paper reformulates the coupling equations over again so that only the H-field is required. The author's justification is that a magnetic field is easier to measure and is a more practical starting point for the analysis.

Comments:

In general the measurement of a magnetic field is easier but in this paper the numerical formulation is only set up for relatively simple case of plane-wave excitation, and under these circumstances the conversion from E to H is relatively straight forward.

Joe Seregelyi

[47]--[93EMCv35n3pp387]

A Probabilistic Model for the Evaluation of Coupling Between Transmission Lines (S. Shiran, B. Reiser, and H. Cory)

INDEX TERMS: Coupling, Probabilistic.

Although many models have been developed to consider the coupling between transmission lines of various configurations, there remains some uncertainty in realistic situations. For example, in the case of a cable bundle the exact wire position is unknown. This paper considers the problem of coupling between two wires separated by a random distance and distributed over a given range. The probabilistic model first derives expressions for distributed lumped elements and then predicts the coupling for the given distribution separation distance.

10 references, 6 pages.

Structure:

Coupling between two wires whose distance of separation and height above a ground plane are only known probabilistically. Statistical variations such as coupling distribution variation and standard deviation are developed.

Analysis Method:

A probabilistic model is developed for predicting the distribution of coupling between a pair of wires whose separation is not known accurately but is given as a random quantity bounded between a max and min value. This is a first step towards derivation of a probabilistic analytical model for the prediction of coupling between wires in a bundle. The analysis is based on deterministic TL model derived for weak coupling, at low frequency, for lossless lines in a homogeneous medium.

Results:

Probability density functions (PDF) and cumulative distribution functions (CDF) for the wire separation are determined. Mutual inductance and capacitance are found. Calculation of the distribution of coupling is performed. In the derived model, the fact that the two wires could overlap was ignored. A numerical simulation was performed to evaluate this assumption. Small changes were observed between the analytical and numerical results but the overall shapes of the CDF were similar.

Comments:

No attempt was made by the authors to explain how the results could be interpreted in an engineering type of application (which is what this type of analysis is intended for).

Joe Seregelyi

[48]-- [93EMCv35n3pp366]

Full-Wave Analysis of Radiated Emission from Arbitrarily Shaped Printed Circuit Traces (K. Naishadham, J. B. Berry, and H. A. N. Hejase)

INDEX TERMS: Emission, PCB.

This paper solves a mixed-potential surface integral equation formulation using the method of moments to predict the radiated emissions from arbitrary shaped traces of a printed circuit. In this case, a parallel trace configuration on glass epoxy substrate was terminated by open or short circuit loads and excited by a delta-gap voltage generator. A frequency range of 30-1000 MHz was investigated. A comparison of a quasi-dynamic approximation with the full-wave Green's function solution yields (radiation) results of within five percent of each other for structure of dimensions not comparable to resonant dimensions.

29 references, 12 pages.

Structure:

The structures are essentially microstrip antenna problems on an infinite substrate/ground plane.

Analysis Method:

The well known formulation of Mosig and Gardiol for microstrip structures is applied.

Results:

A discussion of common-mode and differential-mode currents on a loop is provided to differentiate from previous microstrip antenna papers. Most of the results and analysis contained in the paper are similar to that contained in papers treating MoM analysis of printed antennas. Several "MoM analysis of printed antenna papers" appeared in IEEE MTT and AP Transactions in the 1980s.

Neil Simons

[49]--[93EMCv35n3pp357]

Transient Propagation in Anisotropic Laminated Composites (M. Lin, C. Lin, R. Wu, and C. H. Chen)

INDEX TERMS: Laminated Composites.

Since the use of composite materials in many applications has been increasing, it is important to quantify their electromagnetic and shielding properties. The Equivalent Transmission Line Circuit (1D-ETLC) model and the 1D-FDTD method were used to study graphite-epoxy laminated panels and the obtained results were compared to those computed by the Wave Transmission Matrix (WTM) method. Factors such as material properties, laminated thickness, and the polarization and frequency content of the incident pulse were also investigated. In general, this type of composite material exhibits the characteristics of a low pass filter.

16 references, 8 pages.

Structure:

Multiple infinite composite plates consisting of an infinite planar array of parallel conducting rods embedded in a dielectric substrate slab. The composite plates are illuminated with a normal incident plane wave of TE or TM polarization.

Analysis Method:

The Equivalent-Transmission-Line-Circuit (ETLC) is used to compute both the frequency and the time domain responses. The frequency domain response is compared to that obtained by the Wave-Transmission-Matrix method that the same authors used in paper [93EMCv35n1pp21]. The time-domain response is compared to that obtained by a 1-D FDTD solution with Mur's first order ABC.

Results:

The agreement in both cases is excellent although only the normal incidence case was used for the comparison. The paper also includes the time domain response for a four ply composite which is illuminated with an EM pulse waveform of the double exponential type. There is no comparison of this result with measured data or other researchers' computed data.

Comments:

There is no development as to how the equivalent distributed parameters for the equivalent circuit were arrived at.

Jasmin Roy

[50]--[93EMCv35n2pp295]

Electromagnetic Coupling Through a Wire-Penetrated Small Aperture in an Infinite Conducting Plane (W. Zheng, R. F. Harrington, and J. R. Mautz)

INDEX TERMS: Coupling, Small Aperture.

This paper investigated electromagnetic coupling (due to an incident plane wave) through a wire penetrated, electrically-small, aperture in an infinite conducting screen. Norton's equivalent theorem was used to model wire-aperture coupling and the moment method was used to find equivalent circuit parameters. The developed method was then used to analyse several cases of wires of various shapes and loads.

5 references, 6 pages.

Structure:

An arbitrarily bent thin wire trough a small arbitrarily shaped aperture in an infinitely large, infinitely thin PEC plane, illuminated by an obliquely incident TM plane wave. The medium is different on either side of the plane.

Analysis Method:

The dimensions of the aperture are assumed to be very small compared to the wavelength so as to use circuit concepts for modelling the aperture as a port with an aperture voltage, and then to close the aperture with a short-circuit and applying the aperture voltage between the wire and the now fully completed plane. Both the wire on each side of the plane and the excitation (incident field and aperture voltage) can thus be imaged through the full PEC plane. The structure is then modelled with a Norton equivalent circuit where a source current represents the short-circuit current due to the aperture voltage resulting from the excitation fields, and two admittances represents the two half-spaces, one on either side of the PEC plane.

The short-circuit current is determined from the knowledge of the current distribution on the wire resulting from imaging the illuminated segment of the wire and the incident plane wave into the full PEC plane. The integral equation that determines the current distribution is solved by Galerkin's method. The two admittances, Ya and Yb, representing the two half spaces in the Norton equivalent circuit are obtained in terms of the input admittance of each wire resulting from imaging the wire segment of the corresponding half space into the full PEC plane. The input admittance of each one of the two resulting wires is known separately from solving the integral equation for the current distribution with the wire of interest excited by an aperture voltage of arbitrary value.

Results:

The paper presents no comparison with measured results, only with a wire with a sinusoidal current distribution in free space. The peak power transmitted in the half space behind the PEC plane occurs at the frequency where the imaginary part of Ya+Yb is zero. The power increases as the incidence angle departs from the normal, owing to the TM nature of the incident wave.

Comments:

No radiation is taken in account from the aperture itself. In fact, the shape and size of the aperture are not even invoked. The closing of the aperture does not arise from applying the equivalence principle since no equivalent magnetic current over the covered aperture appears in the formulation. No indication is given on how to compute the field contribution from the current on the wire in the integral equation. The paper is not clearly written and the above analysis comes from my reading between the lines.

Jasmin Roy

[51]---[93EMCv35n2pp264]

Decomposition of Radiating Structures Using the Ideal Structure Extraction Methods (K. B. Hardin and C. R. Paul)

INDEX TERMS: Radiation, asymmetrical Structure.

A complex structure is decomposed into substructures with either symmetric or asymmetric attributes. For example, in the case of parallel transmission lines, the symmetric structure supports differential mode currents, where as the asymmetric structure supports common mode currents. Using super-position, the total effect of the structure (radiation, voltage, and current) can be computed using the sum of the effects of each substructure. This method identifies the contribution of each structure and identifies the dominant ones. It was concluded that the asymmetrical substructure is the dominant component of the emissions. The proposed method provided insight into how to reduce the unwanted emissions from the total structure.

12 references, 10 pages.

Comments:

This paper does not deal with a structure that is relevant to our study but the method proposed is said to be general for any scattering body. The technique is based on the use of the equivalence principle to remove an extension from, or to add a completion to an otherwise symmetrical geometry for the purposes of obtaining insight in the radiation of both common-mode and differential mode currents. Impedance and source relocation schemes are also worked out. Thus, the field solution for the actual geometry is said to be obtained as the superposition of the field solution for the symmetric body with symmetric impressed currents, and the field solution for the asymmetric body with asymmetric impressed currents.

The cavity filling scheme developed here is equivalent to that developed in paper [82EMCv24n4p406].

I question the validity of the scheme about the extension removal because the equivalence surface cuts through the PEC body whereas mathematically, the field solution cannot be analytically continued on and beyond the surface of the PEC body because of the presence of surface currents which represent sources of field discontinuties. Furthermore, I disagree with the claim that the extension removal and the cavity filling schemes are valid when used simultaneously in a combined application because the asymmetrical body cannot be obtained as though the extension and the completion regions could be treated independently of one another since impressed currents in one region induces currents in the other region. Furthermore, it is clear from the figures that the asymmetrical structures are different for the extension and the completion cases and thus, superposition cannot not be applied since superposition of the fields is valid only for the boundary conditions being the same, i.e. for the bodies being the same. Moreover, the symmetrical body and the asymmetrical body are not the same in the combined application and thus, superposition does not apply once again. The paper claims that the same extension and completion schemes can be proven on the basis of the linearity of the equations corresponding to the matrix of a MoM solution. Although this situation is possible for the simple structure mentioned in the paper, the paper does not present the example of a combined application. As to the comparison between the measurements and the solution by the extension removal scheme, the comparison deals only with the magnitude, not the magnitude and phase, of the frequency spectrum. Therefore, the test of validity is not satisfactory because the corresponding time waveform is not uniquely defined by the frequency spectrum magnitude alone.

The problem of solving the asymmetric structure with the asymmetric excitation is just as complicated as that of solving the original structure, thus the method has mostly a theoretical interest, not a practical one.

Jasmin Roy

[52]-- [93EMCv35n2pp241]

Finite Element Analysis as an EMC Prediction Tool (D. S. Dixon, M. Obara, and N. Schade)

INDEX TERMS: EMC Prediction, Finite Element Method.

A sophisticated finite element method was evaluated to model complex problems such as EMC prediction of a system or a group of systems (sources, susceptors, and the surrounding environment). The method correctly solved and predicted a basic EMI problem (wire above a ground plane) for low frequencies. More development of the tool is required in order analyse practical problems.

6 references, 8 pages.

Structure:

Two-dimensional simplification of a room-environment, with a cable illuminating the room with filing cabinets/obstacles present. Their motivation is to study EMI within a shipboard installation.

Analysis Method:

A 2D version of the MSC/EMAS commercial FEM code.

Results:

Comparison of free-space radiation from the cable with measurements and with FE calculations. All three agree very well, indicating the room behaviour is well modelled by the 2D approximation. This is due to the selection of a simple room environment. The fact that the free-space model and measurements agree indicates the benefit of using the free-space model as a first-order approximation for modelling room environments, and not the FEM approach.

Comments:

The introduction of the paper provides excellent motivation, discussing very complex environments, and concluding that EM analysis tools such as FEM are necessary for their analysis. It is, therefore, rather surprising they conclude the simple free space model provides results which are essentially as good as the FEM model for their test environment.

Neil Simons

[53]-- [93EMCv35n2pp204]

Application of FDTD Method to Analysis of Electromagnetic Radiation from VLSI Heatsink Configurations (K. Li, C. F. Lee, S. Y. Poh, R. T. Shin, and J. A. Kong)

INDEX TERMS: VLSI, Radiation, Heatsink.

This paper uses a multizone gridding version of the FDTD method to model a VLSI chip, its packaging, and its heatsink. The radiation pattern of the heatsink is computed which turns out to be similar to a microstrip patch antenna. The source (i.e. the VLSI chip) is modelled using either a horizontal magnetic dipole or a vertical electric dipole. It was demonstrated that (for typical dimensions) the heatsink will have resonances in the low GHz frequency range. Several methods for reducing the electromagnetic emissions such as grounding and shielding are explored.

12 references, 10 pages.

Structure:

Characterization of the radiation (quantified using both radiation patterns and a measure of the total radiated power) from a VLSI Heatsink, and an attempt to determine how reduce it.

Analysis Method:

FDTD with graded mesh and Mur ABCs. Total radiated power is calculated by integrating the Poynting vector over a closed surface.

Results:

Lots of numerical results with no experimental validation. Typical heatsink has a resonance in the low-GHz range. Numerical investigation of the effects of shielding and grounding is presented.

Neil Simons

[54]--- [93EMCv35n2pp215]

A New Finite Difference Time Domain Algorithm for the Accurate Modelling of Wide Band Electromagnetic Phenomena (A. R. Omick, and S. P. Castillo)

INDEX TERMS: FDTD, Lax-Wendroff.

Since coupling into systems could be either through slots and cavities (for low frequency) or through cracks and seams at high frequencies, a wide band time domain simulation tool is desirable. Yee's Finite Difference Time Domain (FDTD) method has become one of the most popular time domain methods of modelling electromagnetic problems. However, several problems are associated with the Yee's FDTD method due to its use of staggered (and often cartesian) grids, its inaccurate application of material boundaries, and its inability of modelling highly transient pulses (and introduction of numerical dispersion). This paper proposes to replace FDTD method with Lax-Wendroff technique which is more complex and less computationlly efficient, yet does not have the problems associated with the Yee's FDTD method.

12 references, 8 pages.

[55]--- [93EMCv35n2pp235]

Mixed-Dimensional Finite Element Models of Electromagnetic Coupling and Shielding (J. R. Brauer and B. S. Brown)

INDEX TERMS: Coupling, Finite Element Method.

The finite elements analysis (MSC/EMAS) was used to accurately model geometrically complex structures. These models were initially used to calculate static capacitance and inductance matrix of the given structure, then zero-dimensional elements were included to model circuit components, finally, a mixed dimensional finite element model was employed to analyse several electromagnetic shielding effectiveness problems (i.e. dynamic leakage fields from an enclosure). The obtained results agreed well with the measured data.

12 references, 6 pages.

[56]-- [93EMCv35n2pp185]

The Application of Transmission Line Modelling to Electromagnetic Compatibility Problems (C. Christopoulos and J. L. Herring)

INDEX TERMS: TLM, EMC.

This paper considers three EMC test problems of reasonable complexity, namely proximity effects on a spherical dipole antenna, radiated emissions of a device under test, and current induced on wires placed on either side of a thin plate. In each case, the Transmission Line modelling (TLM) method was used to analyse the above structures (for frequency range of 100-1000 MHz) and the obtained results compared well with the experimental data. It was concluded that TLM is a good candidate for time domain analysis of EMC problems.

18 references, 7 pages.

Structure:

EM emission from a simplified device in a device-under-test measurement set-up, and coupling of wires attached to a metallic plate.

Analysis Method:

Symmetric Condensed TLM with wire grid modelling and graded meshing

Results:

No validation was presented for the DUT simulations, where the DUT was a metallic box with its lid ajar. Validation of the TLM solution with measurements is presented for an ACES canonical problem, consisting of a wires attached to opposite sides of a thin plate.

Neil Simons

[57]-- [93EMCv35n2pp170]

Field Modelling with the MMP Code (P. Leuchtmann and F. Bomholt)

INDEX TERMS: Coupling, MMP.

Multiple MultiPole (MMP) code is based on Generalized Multipole Technique (GMT) which is based on Maxwell's equations and can be used to calculate harmonic electromagnetic fields in any piece of wire homogenous, lossy media. This paper considers analysing EMC using a MMP code by discussing choice of expansion functions, boundary condition weighting and using symmetry in a given problem. EMC coupling through an aperture is examined.

16 references, 7 pages.

Structure:

Plane wave illumination of a slot, and an attempt at a simplification of the DUT on a table problem.

Results:

None, except the authors point out a potential problem with their formulation for modelling table legs of the DUT problem.

Neil Simons

[58]-- [93EMCv35n2pp159]

Efficient Prediction of Radiation from Printed Transmission Line Discontinuties (K. Naishadham, T. W. Nuteson, and H. Yao)

INDEX TERMS: MoM, Radiation.

In order to analyse circuit board traces with discontinuties, bends, gaps, non-symmetric ground planes, as well as to take into account the effect of substrate, radiation, and metalization losses, various full wave time and frequency domain methods have been used to analyse such problems.

In this paper, the method of moments is applied to compute current distribution and radiation from an arbitrary shaped microstrip structure. The method was use to calculate radiation from an open circuit stub and a microstrip loop. In both cases the obtained results agreed well with analytical results derived from quasi-TEM transmission line theory.

36 references, 10 pages.

The same authors have published paper #48 (see comments).

Comments:

All of the results and analysis contained in the paper are similar to that contained in papers treating MoM analysis of printed antennas. Several "MoM analysis of printed antenna papers" appeared in IEEE MTT and AP Transactions in the 1980s.

Neil Simons

[59]--- [93EMCv35n1pp102]

A Rigorous Model for Radiated Emissions Prediction in PCB Circuits (G. Cerri, R. De Leo, and V. M. Primiani)

INDEX TERMS: Emissions, PCB.

This paper considers both common mode and differential mode currents in complex printed traces and/or cables of an electronic circuit in order to predict electromagnetic emissions. The currents are determined by solving an integral equation using the method of moments. Predictions for a test case of a rectangular loop were compared with the measured results for a frequency range of 100-1000 MHz. Some additional tools were also developed to predict signal characteristics and circuit layout.

16 references, 8 pages.

Structure:

Characterization of the radiation from a PCB environment, i.e., microstrip with an assumed infinite substrate/ground plane.

Analysis Method:

Although the formulation is well known, this paper is not excessively similar to those treating MoM analysis of printed antennas (several "MoM analysis of printed antenna papers" appeared in IEEE MTT and AP Transactions in the 1980s). The investigation is motivated and formulated from an EMI/EMC point-of-view. The common mode/differential mode emissions are built into the formulation (as is a CISPR measurement).

Results:

While only the simplified DUT on a bench test set-up is considered, rigorous comparison with measurements is included.

Comments:

Paper contains a good introduction regarding the difference between the common-mode and differential mode effects on radiated emissions.

Neil Simons

[60]--[93EMCv35n1pp69]

Aperture Coupling to a Coaxial Air Line: Theory and Experiment (D. A. Hill, M. L. Crawford, M. Kanda, and D. I. Wu)

INDEX TERMS: Coupling, Coaxial Air Line.

The shielding performance of cable shields with connectors is studied for a frequency range of 1-18 GHz both experimentally and theoretically. In this case, the entire cable assembly is modelled as a receiving antenna, using the polarizability theory. The effective dipole moments of the structure are computed which excite the internal region of the coaxial line. The experimental and theoretical data show qualitative agreement. Some recommendations are made to improve both the measurement as well as the theoretical models.

15 references, 6 pages.

Comments:

The effect of a small circular hole in the outer shield of a cable is much less pronounced than that of a circumferential gap.

Jasmin Roy

[61]--[93EMCv35n1pp46]

Numerical Simulation of Electromagnetic Coupling and Comparison with Experimental Results (A. P. Duffy, P. Naylor, T. M. Benson, and C. Christopoulos)

INDEX TERMS: Coupling, TLM.

Transmission Line Modelling (TLM) is used to analyse the coupling between a dipole antenna and a receiving rod placed inside a screened room. This type of complex environment was used to demonstrate the ability of variable mesh TLM to successfully analyse an EMC problem such as a non-idealized, non-plane wave source coupling through apertures, slots, etc. The test problem was analysed for a frequency range of 50-250 MHz and good agreement between simulation and measurements was obtained.

17 references, 9 pages.

Structure:

A 1cm diameter 1m long dipole transmitting over the frequency range of 50 MHz-250 MHz to a 1cm diameter 1m long copper tube inside a screened room, with the receiving tube lying over a conducting bench. The frequency range encompasses both the room resonances and the resonances of each wire.

Analysis Method:

TLM with symmetrical condensed node, with regular or hybrid variable mesh (i.e. mesh with varying link-line impedances and capacitive node loading) and modelling the wire diameter with only one TLM node but adjusting the wire length of the model so as to obtain the same (circuit, not geometrical) resonance frequency as for a 1cm diameter wire in free space.

Results:

The results are in terms of Current Transfer Ratio (i.e. current flowing in the receiving element over current flowing in the transmitting element). Comparison between the predicted and the measured results shows a good agreement in the placement of the resonances but not in their magnitude for the hybrid variable mesh. The comparison for the regular mesh is poorer even in the placement of the resonances.

Comments:

The approximate corrective method required element shortening slightly greater than that predicted by theory. However, the radiation pattern should be somewhat affected if the dipole length is varied. No cable was modelled in the simulation and ferrite loading was used over the cables in the experiment in order to minimize the effect of their presence resulting from induced currents on the outer shields of the cables.

Jasmin Roy

[62]--[93EMCv35n1pp21]

Plane Wave Shielding Characteristics of Anisotropic Laminated Composites (M. Lin and C. H. Chen)

INDEX TERMS: Shielding, Composites.

Anisotropic laminated composites (graphite/epoxy) were modelled using a wave-transmission matrix method (where Maxwell's equations were formulated in each layer with boundary conditions of E and H fields applied at interfaces). This allowed for the analysis of the shielding effectiveness of the composite as a function of its parameters. Some of the material properties studied included the number of plies, the fibre orientation pattern, and lamina thickness. Some properties of the incident plane wave such as angle, polarization, and frequency were also discussed.

11 references, 7 pages.

Structure:

Multiple infinite composite plates consisting of an infinite planar array of parallel conducting rods embedded in a dielectric substrate slab. The composite plates are illuminated with an oblique plane wave of TE or TM polarization.

Analysis Method:

Each plate is characterized by its wave-transmission matrix with the plate being illuminated by a normally incident plane wave with the incident E field parallel or perpendicular to the conducting rods. The wave-transmission matrix is obtained for the whole plate at once by constructing the solution of Maxwell's equations in the plate then imposing the boundary conditions on tangential E-field and H-field components at the interfaces. The wave-transmission matrix for the entire cascade of composite plates is obtained by multiplying the wave-transmission matrices of all plates in the appropriate order. For oblique incidence, the transmission-line analogy and the concept of wave impedance are used to obtain for each plate the transmission matrix equivalent to the case of having normal incidence, before using the wave-transmission matrix method. When the orientation of the conducting rods vary between two consecutive plates, each plate is analysed in its principal coordinate system where the two axes are parallel or perpendicular to the axes of the conducting rods, and a rotation matrix is introduced between the transmission matrices of the two consecutive plates. A propagation matrix is also introduced to take into account the propagation delay between two consecutive plates.

Results:

A good agreement is observed, although only up to about 10 MHz, with the experimental results of Skouby for a specific case.

For lower frequencies, an empirical formula for anisotropic laminated composite under oblique incidence was developed in terms of the equivalent conductivity of each plate. The examples shown in the paper demonstrate a very good agreement between the results predicted by this empirical formula and the results obtained by the transmission-matrix method.

The paper reports the appearance of a dip phenomenon whereby the shielding effectiveness decreases rather than increases with increasing frequency. This phenomenon is said to result from the multiple reflections between the planar array of conducting rods of adjacent plates when the spacing between these planar array approaches a quarter wavelength, provided that the orientation of the conducting rods allow for some reflection at each plane of the two consecutive conducting array. The shielding effectiveness was shown to be greatly improved (30 dB or more) by applying a thin metallic coating on either the input or the output side of the cascade of plates.

Comments:

No expression is given for the transmission matrix of a plate that embeds conducting rods. A subsequent paper by some of the same authors mentions that the tensor constitutive parameters of the composites may be estimated by the method suggested by Casey. Also I do not agree that SE(dB)=D(dB)+R(dB) with SE(dB)=-10log(T), D(dB)=-10log((1-G)/T) and R=-10log(1-G). I suspect the presence of a typographical error.

The use of the wave-transmission matrix does not take into account the near-field coupling between closely neighbouring plates unless the evanescent waves are taken into account as well as the propagating waves. In this paper, there is no mention of whether the evanescent modes can be neglected for the spacing values used in the paper. In order to take into account the evanescent waves as well as the propagating waves, the wave-transmission matrix would need to be generalized as was the generalized scattering matrix.

In this paper, Collin's definition of the wave-transmission matrix is used so that the appropriate order of the matrix multiplication is just the order of appearance of the plates from the input face to the output face of the cascade of plates.

Alternatively to computing the wave-transmission matrix for a plate by solving the Maxwell's equations for the boundary conditions of the plate, the wave-transmission matrix could be obtained as the cascade of the discontinuity plane formed by the input planar interface between the plate substrate and the immersion medium, a transmission line accounting for the propagation delay between the input interface plane and the plane of conducting rods, a discontinuity plane formed by the array of parallel conducting rods, another propagation line accounting for the propagation delay between the plane of rods and the output planar interface, and finally the discontinuity formed by the output planar interface between the plate substrate and the immersion medium. The transmission line analogy consists in taking the transverse E and H fields of the TE or TM wave propagating in a medium as the E and H fields of a TEM wave on an equivalent transmission line of characteristic impedance equal to the wave impedance in the propagation medium. The dependence on the incidence angle is taken into account as part of the expression of the wave impedance of each medium, defined as the ratio of the transverse E field to the transverse H field components of the wave propagating in the medium, where the transverse direction is perpendicular to the direction with respect to which the plane wave is TE or TM. At the planar interface between two different media, the reflection and the transmission coefficients incurred by the discontinuity between the two media is then computed from the impedance mismatch between the two equivalent transmission lines representing the two media. The discontinuity presented by the planar array of parallel conducting rods is treated as a lumped element across the transmission line, provided that the discontinuity plane be a transverse plane. Thus, the transmission line analogy holds only if all discontinuties lie in transverse planes. This is not necessarily the case for more general anisotropic plates. Therefore, the generalization of the wave-transmission matrix from the case of normal incidence to the case of a general incidence by merely taking the incidence angle as part of the wave impedance at the interfaces of a plate without solving Maxwell's equations inside the plate for the general incidence angle is not valid in general. It is valid in this paper only because all discontinuities inside each plate satisfy the conditions for applying the transmission line analogy inside the plate as well as outside the plate.

It is not said if the empirical formula accounts also for the dip phenomenon.

The previously mentioned resonance phenomenon could no doubt take place between any two plates of the whole cascade if the resonance conditions are satisfied, not just between two adjacent plates.

Jasmin Roy

[63]-- [93EMCv35n1pp1]

Optimized Single Braided Cable Shields (T. Kley)

INDEX TERMS: Cable Shields.

Most of the previous methods of computing parameters of single braided shields do not compare well with the measured data. In this paper, a new formulation for prediction of shielding parameters of single braided cable is developed based on qualitative analysis of the coupling mechanisms (only the basic differential TEM mode for a time harmonic case was considered) which are adjusted using measured values of various braided cables. This new formulation gives new insight into high frequency shielding parameters as allow for the design of optimized single braided shields.

12 references, 9 pages.

[64]-- [91EMCv33n4pp334]

EMI Induced Failures in Crystal Oscillators (J. Laurin, S. G. Zaky, and K. G. Balmain)

INDEX TERMS: EMI, Crystal Oscillator.

Either pulsed or continuous external electromagnetic fields could interfere with the operation of a Voltage Controlled Oscillator (VCO). The interference often manifests itself in the form of a switch from the operating mode to a higher mode which results in a change in the oscillators frequency and failure in the operation of the digital system. Two types of oscillator circuits were tested for a frequency range of 20-100 MHz with EMI failure (mode switching) occurring at about 50 MHz. The experimental data confirmed predicted values obtained either by theoretical models or numerical (SPICE) simulations. It was concluded that although in most cases the intensity of the external field needed for EMI failure is much higher than the current standards, scattering from nearby long conductors can reduce the failure threshold to a value much below the current specified standards.

18 references, 9 pages.

[65]-- [92EMCv34n4pp320]

Skin Effect Considerations of Transient Response of a Transmission Line Excited by an Electromagnetic Pulse (E. S.M. Mok and G. I. Costache)

INDEX TERMS: Skin effect, EM Pulse.

External time-varying electromagnetic fields induce voltages in transmission line and/or cables of electronic devices. These induced voltages are calculated using classical telegraphist's equations where both dc resistance and transient resistance (due to skin effect, a nonuniform distribution of current inside a conductor) are taken into account. The external electric field is modelled by equivalent voltage sources inserted into the transmission line. The equations developed above are solved using finite difference method for the case of a bent multiconductor transmission line over a lossy ground plane subjected to an external field. The predicted induced voltages are verified with the measurements and the calculations presented in other references,

10 references, 10 pages.

Structure:

Circular wire over a ground plane TL, illuminated by a plane wave. Obstructions, bends in line and multiconductors are considered. Skin effects considered. Varying ground conductivity considered.

Analysis Method:

Laplace transform is used to account for transient skin losses. FDTD technique used to solve telegrapher's equation incorporating skin-effect and external field. Bent TL treated as a cascaded TL.

Results:

As is shown in other papers, the skin-effect is important and generally reduces peak values when compared to simulations which exclude the effect. Comparison of line results (with obstruction) made to published data and good agreement is claimed (but not shown). Varying ground conductivity considered and it is shown that the skin-effects are more pronounced with poor ground conductivity. Multiple reflections for bent lines are compared to published data and the results are very briefly discussed.

Joe Seregelyi

[66]-- [95MTTv43n5pp1115]

Generalized Coupled Interconnect Transfer Function and High Speed Signal Simulations (Y. Eo and W. R. Eisenstadt)

INDEX TERMS: VLSI.

The theoretical analysis of high speed coupled interconnect circuits is important in prediction of signal delay jitter and crosstalk. A mathematical model was used to derive transfer function for coupled lines, and along with the frequency dependent parameter modelling of coupled interconnect, high speed VLSI simulations were preformed. The simulation results agreed well with the experimental data.

21 references, 7 pages.

Structure:

Transfer function of generalized, n-coupled, interconnect circuit model with frequency dependant parameters and general, linear load conditions.

Analysis Method:

An analytical approach/formulation.

Results:

Simulation and measurement of a two wire line are performed. Simulation shows there is cross-talk, noise and dispersion due to coupling.

Comments:

The measurements and simulations appear to correlate but the results are poorly presented.

Joe Seregelyi

[67] -- [94PSMTv141n6pp464]

Prediction and Measurement of EMC Radiated Immunity Problems in Interconnected Digital Electronics Systems (T. Konefal and A. C. Marvin)

INDEX TERMS: EM Coupling, digital Interaction, Inter-modulation Products.

The coupling of external electromagnetic waves into interconnecting cables of digital systems is studied by theoretical, computer simulation, and experimental means. In all cases, the illuminated line was carrying a 1 MHz square clock signal and was terminated by a inverter circuit in order to study the inter-modulation product and its nonlinear interaction with active devices. The interference signal was applied using a nearby nonuniform monopole antenna at various angles for frequencies of 100-1000 MHz. In general, experimental data agreed well with both theoretical and simulation results. It was concluded that an exposed transmission line link is the most likely source of most EMC problems.

11 references, 7 pages.

[68]-- [94PSMTv141n4pp263]

Electromagnetic Compatibility of Building Cables (K. Bromley)

INDEX TERMS: Power Cables, EMC.

Current EMC standards only specify immunity and emission levels of products, however, few standards exist that provide guidelines in installation of these systems. For example, the power and signal cables are rarely segregated or a safe separation distance between them is maintained. The noise coupling between various power and signal cables could cause interference and interruption of digital systems such as computer networks etc. This paper reports initial results of the cable coupling measurements and calculations. Along with some recommendations of minimum separation distance between different types of signal and power cables, the need for standards for cable installation is emphasized.

1 references, 3 pages.

Comments:

General discussion of cable layout. Not a very important paper.

Joe Seregelyi

[69]--- [97IJNMv10pp13]

A Transmission Line Simulator for EMC in Complex Electronic Systems (EMCSIM) (S. Pignari, and F. G. Canavero)

INDEX TERMS: EMC, MTL.

Although a rigorous approach of investigation of EMC aspects of electronic systems is ideal, due to complexity of most systems and required data and computational resources, it is often impossible. This paper models a complex device in terms of its subsystem- level functional descriptions. In general, termination networks are modelled using lumped parameters and the wire bundles and buses are modelled using distributed parameter multiports. External fields as well and losses and dispersion along the interconnections are also taken into account. The formulation is solved for several frequencies and FFT was used to obtained transient responses. However, this method is restricted to linear networks (devices) only. The paper includes full derivation of the method as well as a complete (step by step) example.

13 references, 22 pages.

Structure:

MTL and lumped elements formulations with field coupling applied to whole circuits

Analysis Method:

Traditional MTL methods applied. External sources accounted for by equivalent sources distributed in model. FFT and NILT algorithm applied for TD response (i.e. linear systems only). TL models for uniform, twisted-wire and shielded-wire lines applied. Application package called EMCSIM. Frequency dependant losses are accounted for.

Results:

One simulation example is given of a 4-bit bus composed of 7 lines (40 cm long), however no validation of results is given. This paper is an application of techniques developed by several other authors. It is unique in the fact that the solution of the problem is wrapped up into a simulation package and it attempts to solve a rather ambitious circuit.

Joe Seregelyi

[70]-- [96BTJv14n3pp132]

Cellular Environmental Issues (P. R. Tattersall)

INDEX TERMS: Cellular systems.

Three environmental issues associated with cellular telephone systems have been discussed. These are possible EMC problems, effects on health and related devices and visual impact of base stations. All three issues were qualitatively discussed and the following conclusion were made. Although little interference is observed in most electronic devices, in order to avoid possible EMC problems with critical electronic equipment better immunity standards are required. The data on possible health effects is inconclusive and continues to be monitored. Visual effects can be minimized through use of existing structures.

11 references, 10 pages.

[71] --- [95IEICECvE78Bn2pp88]

Methodology for Electromagnetic Interference Measurements (M. Kanda)

INDEX TERMS: Anechoic Chamber, Open Site, Photonic Probe, TEM Cell, Waveguide Chamber, Electronic Probe.

This paper summarizes several popular measurement techniques for qualitative evaluation of EMI/ EMC of electronic devices. They included microwave anechoic chamber measurements, open site measurements, and waveguide chamber (TEM cell) measurements. These methods expand a frequency range of 10 KHz to 40 GHz. As well as a discussion of the methodology and short coming of each method of measurement, some issues related to instrumentation associated with each technique is also discussed.

33 references, 21 pages.

Comments:

This paper treats the measurement techniques of electromagnetic fields. Not very relevant to our survey.

Jasmin Roy

[72]-- [95IEICECvE78Bn2pp207]

Electromagnetic Shielding Effectiveness: Effects due to Gap Size and Angle of Cut (B. D. Mottahed and S. Manoochehri)

INDEX TERMS: EMC, Shielding Effectiveness, Joint.

One of the most common EM leakage into electronic systems is due to the joints and seams. In order to reduce EMC/EMI in electronic systems, various methods of shielding must be used. In this paper various joint configurations and gap sizes are studied and evaluated for best value of shielding effectiveness/efficiency (SE). In general, experiments show that simple joints have lower value of SE than complex joints (with 'S' type bend joints being the best). Also, it was observed that in all types of joints, gaps reduce SE asymptotically.

3 references, 5 pages.

[73]---[95IEICEvE78-Bn2p238]

Analysis of the Shielding Properties of Planar Wire-Mesh Shields, Loaded by General Stratified Structures (R. E. Zich)

INDEX TERMS: Shielding, Chiral and Complex Media, Meshes, Fast Transient.

Structure:

Time waveform of an EM pulse through an anisotropic or chiral slab with square thin bonded conducting wire mesh embedded in the input surface, illuminated with an oblique plane wave impinging along one of the two directions of the wires of the square mesh.

Analysis Method:

Spectral domain method (i.e. the transverse field components are spatial Fourier transform with respect to the two orthogonal directions transverse to the normal of the planar screen) combined with equivalent circuit modelling.

Results:

No comparison with measurements or another researcher's results.

Comments:

I do not grasp the general formalism of this paper as the paper gives no development that would help the reader understand the link between using the spatial frequency domain technique and the circuit formalism.

Jasmin Roy

[74]--- [95IEICECvE78Bn2pp173]

Radiated Emission Estimation of a Metallic Enclosure Model Source by Inverse Forward Analysis (S. Hayashi, K. Masuda, and K. Hatakeyama)

INDEX TERMS: EMC, Inverse Problem.

In order to compute the EM radiation from a given source, inverse analysis was used. In this case, the magnetic field surrounding a metallic box containing a loop antenna (with a cross shaped slit on the top surface) were measured. The inverse and forward analysis were used to calculate the current distribution on the surface of the box from the measured magnetic field values. The current distribution on an enclosure can be used to determine the location of the current leakage and its shielding effectiveness. The difference between the estimated and measure values of the magnetic field was found to be 4% which is a sum of both numerical as well as measurement errors.

8 references, 8 pages.

Comments:

This paper deals with emitted radiation rather than susceptibility. It presents the use of inverse scattering to obtain the currents flowing on an enclosure from measurements of the magnetic field taken around the enclosure, then compute the radiated field from the currents so found. The paper mentions that results accurate to within 4% were obtained between the measured and the computed radiated fields.

Jasmin Roy

[75]--- [95IEICECvE78Bn2pp181]

Prediction of Peak Frequencies on Electromagnetic Emissions from a Signal Line on a Printed Circuit Board (T. Miyashita, O. Wada, R. Koga, and H. Sano)

INDEX TERMS: near field EM emission, EMI, PCB.

Most numerical analysis or simulation of EM emission from a PCB concentrate on the voltage waveform or current distribution and little attention is paid to the peak frequencies of the EM spectrum. This paper concentrates on both numerical analysis and simulation of EM radiation due to a current flowing in a loop composed of an IC package and a de-coupling capacitor. The spectral profile of the near-field EM emission of a signal of a PCB was investigated (both measured and predicted) for several circuit parameters such as load resistance, load capacitance, and parasitic capacitance.

10 references, 6 pages.

Structure:

Emissions from a circuit board with a CMOS NAND gates analysed and measured. Wiring treated as loop. Similar to paper 39.

Analysis Method:

Current in circuit calculated using SPICE, line then considered to be composed of may dipoles and emitted field calculated analytically on this basis. Only differential mode considered. Parametric analysis performed on the various components.

Results:

Resonance frequencies predicted, but peak values are not. Engineering-type paper with little new information.

Joe Seregelyi

[76]--- [97TCSIv44n2pp130]

EMI Effects and Timing Design for Increased Reliability in Digital Systems (J. F. Chappel and S. G. Zaky)

INDEX TERMS: Asynchronous circuits, Digital Systems, EMI, Timing Design.

EMI causes failures in digital circuits either through false switching due to sufficiently large amplitude of the interfering signal (static failure) or by changing the propagation delay of signals (dynamic failure). Since dynamic failures are often due to much lower amplitude of EMI, this paper is devoted to study of this phenomenon. Delay margin is defined as maximum allowable change in propagating delay under which the circuit continues to operate reliably. Experiments show that EMI immunity increase for circuits designed to have maximum delay margins. It was also observed that under certain conditions, the circuit become phase locked to a sub-harmonic of the EMI signal and a technique was developed to take advantage of this phenomenon and improve the EMI immunity of the synchronizers in communication links.

16 references, 13 pages.

[77]--- [96CPMBv19n4pp775]

Application of Path Integrals in Modelling Transmission Line (L. M. Rubin)

INDEX TERMS: Nonuniform lines, Skin effect, Signal integrity, TL.

In digital circuits operating at high speeds the ideal transmission line assumption is no longer valid. In this paper, the path integral formulation is employed to model transmission line delay and losses (due to dielectric losses and skin effect) in time domain. This formulation allows modelling of both frequency dependent and frequency independent mechanisms (losses) for a large number of parameters in digital interconnects. Numerical simulation of this method showed it to be equally effective for investigation of high and low loss circuits.

25 references, 14 pages.

Structure:

Reflection and transmission in lossy transmission line and multiconductor lines.

Analysis Method:

Non-ideal TL behaviour is modelled taking into consideration ohmic, dielectric and skin effect losses. This is done by breaking the TL down into a large number of lossy stages composed of a perfect TL and an impedance. Reflections and multiple reflections (to various number of bounces) are considered in the formulation. An extension to general n-conductor lines is made via the standard matrix representation of the Telegrapher's equation. An extension is also made to nonuniform TLs.

Results:

The formulations are numerically implemented on a SPARC-2 with execution times typically less than 2 sec. depending on the problem complexity. Three examples are given where results are compared to SPICE evaluations (TL also broken into a small number of segments). Results typically compare to within a few percent with fewer numerical artifacts (such as, for example, overshoot at leading edges of ringing waveforms) observed in the derived formulations. The author claims that the artifacts displayed in the SPICE results are due to the forced discrediting of the TL. Comparison is also made to experimental results. Results agree reasonably well with variations due to modelled impedance variations along the length of the line.

Advantage of the method; more compuationally efficient in low loss regime, simulations stable over a wide range of time steps and TL parameters.

Comments:

The results of these computations are very similar to those found using SPICE. The deviations are comparable to those observed between this formulation and the experimental results. If SPICE gives such reasonable results, why write your own code when you can use SPICE's user-friendly GUI and huge component library?

Joe Seregelyi

[78]--- [97CPMBv20n1pp64]

Electrical characteristics of High-Performance Pin-in-Socket and Pad-on-Pad Connectors (A. Deutsch, C. W. Surovic, J. S. Campbell, P. W. Coteus, A. P. Lanzetta, J. T. Holton, A. D. Knight)

INDEX TERMS: Surface mount Connectors, Pinned sockets.

This paper studies two types of high density connectors used in large panel and card to board applications. Both pin-in-socket and pad-on-pad connectors are investigated for signal integrity, connector delay, impedance discontinuity, crosstalk, and maximum current capability. Time domain reflectometry measurements were compared with numerical simulation results obtained from advanced statistical analysis program circuit simulator for various case studies (rise time distortion, connector crosstalk, and current carrying limit). It was concluded that the newly introduced pan-on-pad connectors perform better than the standard pin-in-socket connectors and they were capable of transmission rates of 1-1.5 Gb/s as compared to.5-1 Gb/s for pin-in-socket connectors.

10 references, 14 pages.

[79]--[95IEICECvE78-Bn2p207]

Electromagnetic Shielding Effectiveness: Effects due to Gap Size and Angle of Cut (B. D. Mottahed and S. Manoochehri)

The paper presents measured results of shielding effectiveness for four gap designs (straight, slanted, V- and S-shaped). As expected, the shielding effectiveness increases with the presence of bends and with increasing the effective length along the gap. Not very relevant to our literature survey.

3 references, 5 pages.

[80]-- [94JCTEv39n3pp98]

The Electromagnetic Field of Currents in Thin Plates (E. S. Kochanove and V. A. Reznik)

INDEX TERMS: Jamming Immunity, Leakage current.

In order to estimate the jamming immunity of shipboard electronic systems, the EM field due to a current carrying conductor, connected to a metal plate at the ends, was investigated using analytical methods for both steady state and quasi-steady state cases. It was shown that the radiated EM field was due to both conductor's current as well as the leakage currents through the plate.

5 references, 7 pages.

[81]-- [92MRv22n11pp1551]

EMI-Induced Failures in Integrated Circuit Operational Amplifiers (S. Graffi, Z. M. V. Kovacs, G. Masetti, and D. Golzio)

INDEX TERMS: EMI, Circuit design.

In this paper the failure of integrated circuit opamps due to external RF signals (i.e. EMI) is investigated using both numerical simulation (SPICE) and measurements. The results of the simulations and experiments are analysed for bipolar as well as FET input opamps; the level and cause of EMI susceptibility are discussed. Finally, the results of the above analysis are given as guidelines for future design of integrated opamps with low EMI susceptibility.

13 references, 7 pages.

[82]-- [97MRFv36n3p116]

Characterizing Conformal Thin-Film Coatings From 200 to 1200 MHz (A. R. Tellakula, J. Wang, V. V. Varadan, and V.K. Varadan)

INDEX TERMS: Conformal Coatings.

A thin film of conformal coatings of unique dielectric properties are often used in high frequency circuits. In addition to protection of PCB from moisture, dust, corrosion and reduction of crosstalk, the coating also reduces unwanted radiation and EMI susceptibility of the PCB. In order to choose the coating with appropriate properties for a given task as well as modelling such coatings in numerical simulations, the characteristics of such thin films must be measured. This paper introduces a system based on synthesized frequency sweeper and automatic vector network analyser which is capable of characterizing permittivity and loss tangent of a variety of very thin (<0.5 mm) dielectric coatings for a frequency range of 200 - 1200 MHz. The paper includes the plot of several of such measurements.

9 references, 5 pages.

[83]-- [93MRFv32n9p155]

Transmission Line Device Delivers EMC Measurements (L. Carbonini)

INDEX TERMS: EMC testing.

Both emission and immunity testing (EMC/EMI) are often required for electronic devices. In the past these tests were performed either in open area sights or in shielded chambers. However, both of the above methods have poor low-frequency performance. A Wire TEM (WTEM) cell is used to perform both EMC/EMI tests from DC to several Gigahertz. This paper address immunity and emission measurement issues (using WTEM cells) as well as field uniformity in WTEM cells.

9 references, 5 pages.

[84]--[93EMCTDv4n8p33]

Design Geometry for Enclosure Shielding (E. Kultsar)

INDEX TERMS: Shielding, EMI.

The paper presents very summarily the idea of using a non-line of sight path through a gasket for increasing the shielding effectiveness of seams of an enclosure.

4 references, 2 pages.

[85]--- [93EMCTDv4n10pp33]

Low Cost Radiated Emissions Analysis (B. Yordanov, R. Yordanov, S. Fragiacomo, and K. Doughty)

INDEX TERMS: EMC.

This paper introduces a low cost EMC/EMI test system which is capable of locating and partially characterizing sources of radiation (of a digital circuit) from 30 - 1100 MHz. The system is also capable of injection of noise into the system in order to test for circuit immunity. Both E-field and H-field probes as well as spectral analysis unit and noise source unit are discussed. A brief product assessment was included for a range of EMC/EMI problems.

5 references, 4 pages.

[86]-- [94EMCTDv5n5pp18]

Near-Field Probes for EMC Applications (B. Yordanov, K. Doughty, and R. Yordanov)

INDEX TERMS: EMC, Near-field measurement.

In order to identify and quantify EM emissions from digital circuits and PCBs some instrumentation for local measurements is required. Unlike the far field, there is little correspondence between the E and H field strengths in near field. Hence in order to quantify EM radiation from a given circuit both E and H field must be measured. This paper reviews various types of probes for near field measurements of E and H fields for frequencies up to 1 GHz. In each case, advantages and disadvantages of each class of probes is noted.

16 references, 8 pages.

Comments:

This paper treats the design of electromagnetic field probes. Not very relevant to our survey.

Jasmin Roy

[87]--[97EMCv39n4pp377]

ESD Field Penetration Through Slots into Shielded Enclosures: A Time Domain Approach (G. Cerri, R. De Leo, R. De Rentiis, and V. M. Primiani)

INDEX TERMS: ESD, Metallic Enclosure, MoM in Time Domain, Slot.

Structure:

A cavity with a slot on the front face, and a pick-up loop inside the cavity, illuminated with a fast wavefront consisting of an ESD discharge across the slot.

Analysis Method:

The equivalence principle is applied to close the aperture, thereby separating the problem into two separate regions. The load region is represented by the metallic box characterized in the time domain by its impulse response. The magnetic field inside the cavity is known by convolution of the impulse response with the time waveform of the magnetic current distribution in the aperture. The unknown magnetic current distribution in the aperture is determined by solving an integro-differential equation representing the continuity of the tangential magnetic field across the aperture. The numerical solution of the final equation is performed by applying a time domain treatment of the MoM whereby the unknown magnetic current distribution of the integro-differential equation is expanded with basis functions in both time and space, and tested by point matching technique in both time and space. The resulting process leads to a marching-in-time procedure for determining the temporal dependence of the unknown magnetic current distribution. This approach is said to combine the main advantages of both the time and the frequency domain methods.

The plane face of the cavity is assumed to be large enough so as to apply the image principle and to use the free-space Green function in the time domain as a basis for developing the integro-differential equation. The incident magnetic field in the presence of the continuous PEC wall is also imaged and thus, the resulting impressed magnetic field is taken as twice the tangential component of the incident magnetic field existing in the absence of the conducting wall. The cavity impulse response is achieved by analytical inverse Fourier transform of the transfer function between source and field. The impulse response is given as a summation of two parts: a divergenceless and a rotational parts.

Herein, they modelled the ESD current source with a four exponential function rather than the usual double exponential function, in order to model more precisely the actual current time-waveform of the ESD generator.

Measurements were performed inside a TEM cell, and the filtering effect of the 1GHz oscilloscope was taken into account.

Results:

The predicted results are in somewhat good agreement with the measured results, meaning that one can observe both strong similarities as well as strong discrepancies between the measured and the computed time waveforms.

Comments:

The presence of the loop inside the cavity is not modelled. The front face where lies the slot, is assumed to have zero thickness.

17 references, 10 pages.

Jasmin Roy

[88]--[96EMCv38n3pp274]

ESD Indirect Coupling Modelling (G. Cerri, R. De Leo, and V. M. Primiani)

INDEX TERMS: ESD, Coupling, Coaxial Cables, Shield, PCB.

Essentially the same enclosure structure as that in paper [97EMCv39n4pp377] except that this paper includes also an example of coupling to a cable, and an example of coupling to a printed circuit board (for both crossing lines and parallel lines), along with the different analytical approaches required for these different structures.

They modelled the ESD current source with the usual double exponential function. Herein, they obtained the time waveforms not from a time domain treatment of the MoM but from a frequency domain treatment followed by inverse Fourier transformation of the solution for each frequency of the spectrum of the current source, then vectorially adding the results. It seems to me that the agreement between the computed and the measured time waveforms was somewhat better in their other paper where the time-marching MoM method was used.

16 references, 8 pages.

Jasmin Roy

[89]--[97EMCv39n4pp332]

Near-Field Shielding and Reflection Characteristics of Anisotropic Laminated Planar Composites (H. Chiu, M. Lin, and C. H. Chen)

INDEX TERMS: Composite Materials, Near-field Shielding.

Structure:

Multiple infinite composite plates consisting of an infinite planar array of parallel conducting rods embedded in a dielectric substrate slab. The composite plates are illuminated with the near-field of an electric or a magnetic dipole with its dipole moment parallel to the normal of the plates.

Analysis Method:

The analysis for the plate proceeds as in their previous paper [93EMCv35n1pp21] for the same structure. The only difference is the illumination by an electric or magnetic dipole rather than by an obliquely incident plane wave. The field radiated by the dipole is obtained by the plane wave spectral decomposition so that the analysis for the obliquely incident plane wave of their previous paper can be applied separately to each plane wave of the decomposition. The overall transmitted and reflected fields is obtained by a recombination of the individual transmitted and reflected plane waves, respectively.

Results:

Based on the lower-frequency bulk tensor model, this near-field theory is applicable only for frequencies below 100 MHz. Their previous paper showed some results up to 10 GHz but a good agreement with empirical results by Skouby was observed for frequencies only up to about 10 MHz. A good agreement was obtained in this paper with the results of Yang (up to 10 MHz).

Two different measurement techniques were used: 1) collinear dipole; 2) dual TEM cell. Both techniques were said to yield very nearly the same results. A good agreement was also obtained with the measured results.

In the near-field region, the co-polarization magnetic shielding effectiveness increases but the co-polarization electric shielding effectiveness decreases, as the frequency or the observation distance increases. Both electric and magnetic co-polarization shielding effectiveness approach the far-field shielding effectiveness from opposite sides, the electric one being above while the magnetic one being below the plane wave shielding effectiveness. As the observation distance increases to fulfil the far-field conditions, these two near-field shielding effectiveness approach the far-field plane wave one (the result given in Figure 7 of this paper checks out with the result given in Figure 5 of their previous paper). The cross-polarization values are much higher than the co-polarization (i.e. the cross-polarization coupling is very low) so that the presence of cross-polarization components can be neglected altogether.

As the number of layers increases, the shielding effectiveness increases, but the difference in reflection parameters is not so obvious. Physically, the reflection is mainly governed by the surface layer (i.e. the face of the first plate) of the laminated composite.

The results from their empirical formula does not fair as well here as in their previous paper dealing with the case of one strictly plane wave illumination. The trend is definitely there but the co-polarization electric shielding effectiveness shows a constant vertical offset of about 5 dB for lesser conductivity values.

Comments:

Generally the same remarks as those for the previous paper by some of the same authors.

15 references, 8 pages.

Jasmin Roy

[90]--[92EMCv34n2pp109]

EMI/EMC in Printed Circuit Boards - A Literature Review (L. B Gravelle and F. Wilson)

This paper is a review of the literature pertaining to EMI/EMC of printed circuit boards. Therefore is highly relevant to our work. The review contains lots of references (95). The paper was published in 1992 - however references exist only as recent as 1990. The structure of the review is not entirely consistent. We have improved upon the structure of this paper and have used it as a starting point for the organization of the PCB section in our review. The paper begins with a good categorization of General Problem Areas as 1) signal integrity, 2) radiated emissions, 3) susceptibility. The introduction continues with this theme, however the topic of logic families is added. The discussion of logic families sticks out, and raises the question of what to do with topics which fit into all the categories. The introduction discusses the relevance and approaches of each of the General Problem Areas, not much detail is provided (since it is the introduction), but provides the reader with an idea of the issues. The remainder of the review consists of one section (PCB EMI Literature), with many subsections. Unfortunately, the structure of this entire section does not mirror that of the introduction. The remainder of the paper addresses 1) PCB Traces (susceptibility, emission, cross-talk), 2) Cables (susceptibility, radiation), 3) Ground Plane - Grounding, and 4), Circuit Configuration (Switched Mode Power Supply, Components). The last section must have been the one called Miscellaneous Stuff in their draft. Significant results are provided in many circumstances. References with similar results are grouped.

An excellent starting point into the EMC/EMI literature as it pertains to PCBs.

95 references, 8 pages.

Neil Simons

[91]--[92EMCv34n3pp154]

Trends and Bounds in RF Coupling to a Wire Inside a Slotted Cavity (K. S. H. Lee, and F. Yang)

Structure:

An arbitrary wire inside an arbitrary cavity with an arbitrary slot, averaged for all polarization and incidence angles of the impinging plane wave.

Analysis Method:

Power conservation is used to obtain the maximum power picked up by the wire.

Results:

If the length of the wire is much greater than the slot length, then at frequencies below the wire's fundamental resonance, the absorption cross-section is approximately equal to the slot penetration cross-section excluding re-radiation out of the cavity. At frequencies greater than the slot's fundamental resonance, the absorption cross-section is about twice as large.

Comparison with some measured results for a thin rectangular or circumferential slot showed disagreement at resonance frequencies. The good agreement over most of the range is said to be an indication that the effect of the cavity loading of the aperture on the upper bound estimate is negligible. If this is true, the upper bound estimate based on a power conservation consideration will be useful because the estimates of penetration cross-section without the cavity loading effects are readily available for many apertures.

Comments:

The authors write that accurate prediction of RF coupling to real systems is out of reach, and that the most that one can hope for is to calculate its bound and/or to estimate its trend.

10 references, 7 pages.

Jasmin Roy

[92]---[96BITv30n5pp418]

Applying Standardized Electromagnetic Compatibility Testing Methods For Evaluation Radio frequency Interference with Ventilators (J. P. Casamento and P. S. Ruggera)

Structure:

The susceptibility of a ventilator (i.e., the medical device) is measured in a GTEM cell. Frequencies tested range from 5 MHz to 1,000 MHz, field strengths tested were 3V/m and 10V/m, with modulations of CW, 0.5 Hz square wave, and 1 KHz square-wave. Various ventilator operational activities were measured to determine if proper functioning was maintained. The 0.5 Hz square wave was included because this is a physiologically relevant signal.

Results:

A variation greater than 20% from the normal operating mode of the device was considered to be a failure of the device. Failures were noted for specific frequency bands, are were also dependent upon the modulation scheme. This paper is an extremely detailed susceptibility investigation of a specific device. It is therefore of limited value with respect to our more general interests. However, it is a very thorough investigation of a practical problem.

4 references, 9 pages.

Neil Simons

[93]--[97ISv34n12pp53]

How to Choose EM Software? (M. S. Mirotznik and D. Prather)

This paper appeared in IEEE Spectrum and is a review of commercial software for the analysis of EM field problems. It contained all the notable EM software packages and quite a few obscure ones which I was not familiar with. It will become out-of-date within a year or so due to the amount of changes within this area. It contains no information regarding details of methods, etc. The paper is much too short to provide that kind of detail. As an archival paper, it is of no value. For someone interested in buying software it is a reasonable starting point.

6 pages.

Neil Simons

[94]--[92EMCv34n2pp100]

Transient Response of a Microstrip Line Circuit Excited by an External Electromagnetic Source (P. Bernardi, R. Cicchetti, and C. Pirone)

Structure:

TL with multiple dielectrics excited by (plane wave) external field.

Analysis Method:

Distributed source TL model. Frequency domain solution for active and passive (linear) components. FFT into TD and response of lines to impulse, burst CW and NEMP. Dispersive and non-dispersive case studied.

Results:

Sources of reflections studied for impulse response. Interesting reflections from end of lines and within substrate. Only broadside illumination considered. Voltage pick-up for typical circuit is about 0.3mV/(V/m). Dispersion can cause significant distortion of the pulse waveform.

13 references, 9 pages.

Joe Seregelyi

[95]--[91MTTv39n12pp2100]

Asymmetric, Multi-Conductor Low-Coupling Structures for High-Speed, High Density Digital Interconnects (J. P. K. Gilb and C. A. Balanis)

Structure:

Coupling and signal distortion in TLs are minimized through the use of substrate compensation, the use of multiple super- and substrates to equalize the effective dielectric constant of the substrate and minimize the distortions between the various even and odd modes of propagation.

Analysis Method:

Spectral domain approach (SDA) with a recursive formulation for input impedances of structures with multiple layers. FFT used to obtain TD results.

Results:

Symmetric and asymmetric lines and symmetric 4-line structures are studied. Pulse propagation looked at in 4-line structure. Coupling and cross-talk reduced by proper choice of epsilon value and thickness.

12 references, 7 pages.

Joe Seregelyi

[96]---[96EMCv38n3pp221]

Analysis of Crosstalk and Field Coupling to Lossy MTLs in a SPICE Environment (I. Maio. F. G. Canavero, and B. Dilecce)

Structure:

Circuit model for lossy MTL suitable for implementation in SPICE

Analysis Method:

Line characteristics are expressed in terms of differential representations of its matched transient scattering parameters, which are computed using a numerical Laplace inversion of the frequency dependant PUL parameters. Frequency dependant losses and skin effect taken into consideration. Field coupling considered as distributed effect. Linear and non-linear terminations can be accommodated. Models take advantage of SPICE environment.

Results:

Results applied to an asymmetric 3 wire line connected to an ECL gate.

28 references, 9 pages.

Joe Seregelyi

[97]--[96EMCv38n3pp388]

FDTD Analysis of Lossy, MTL Terminated in Arbitrary Loads (A. Orlandi and C. R. Paul)

Structure:

TLs are characterized using FDTD with the (linear or non-linear) terminations characterized using a state-variable formulation.

Analysis Method:

Skin losses considered by Laplace transform. Non-linear terminations are incorporated by using state-variable equations and iterative Newton-Raphson algorithm.

Results:

Results for a simple model of three-conductor line with and without diode compared for 3 methods; FDTD, SPICE and TDFD (no diode only). Good correlation between results was found. Resistive losses are important. EM plane wave impinging on circuit (no diode) is shown to give similar results for 3 methods.

11 references, 10 pages.

Joe Seregelyi

[98]--[95EMCv37n4pp559]

Linear Two-Wire TL Coupling to an External EM Field Part I: Theory (S. A. Podosenov and A. A. Sokolov)
Linear Two-Wire TL Coupling to an External EM Field Part II: Specific Cases, Experiment (S. A. Podosenov, K. Yu. Sakharov, Ya. G. Svekis, and A.A. Sokolov) pp 566

Structure:

Two wire line illuminated by external field. Dielectric material considered.

Analysis Method:

Analytical solution of TL equations with dielectric material considerations. Experimental measurements of structure in latter paper.

Results:

Surface wave induced in dielectric material which significantly alters the response of the TL. The formulations in these papers are too specific to be of much use in general. However, they do point out the importance of considering the surface wave induced in the dielectric. The experimental work is also reasonably well done.

28 references, 8 pages.
13 references, 9 pages.

Joe Seregelyi

[99]--[91IJNMv4pp241]

Calculation of Radiated Electromagnetic Fields From Electronic Systems (S. Oing, w. John, and G. Mrozynski)

Structure:

The paper considered general structures consisting of enclosures with apertures and thin wires. Dielectric materials are not included.

Analysis Method:

The electric field integral equation is discretized using the method of moments. The equivalence principle is used to handle apertures. B-splines up to third degree are used as basis functions for the apertures and thin plates.

Results:

Convergence rates (error versus number of segments) are provided for different orders of basis functions. Nothing surprising here, the higher order basis functions increase the numerical convergence. Estimates of computation time are provided, based on N (number of segments). Simple problems are investigated for validation purposes. Current distributions induced on flat plates (which represent ground planes), wire loops on top of ground planes, radiation from wire loops, and electric surface current on half wave sections of microstrip (with free space substrate).

14 references, 18 pages.

Neil Simons

[100]--[96EMCv38n3p290]

Controlling Radiated Emission from a Physically Large Telecommunication System (S. Caniggia, L. Catello, V. Costa, G. Marano, N. O'Riordan, and L. Vitucci)

This paper deals with emitted radiation rather than susceptibility, hence addresses sources of radiated emission from within the system. The part dealing with apertures in the enclosure, however, is relevant since the phenomenon of radiation is reciprocal to the phenomenon of reception. The authors advocate the use of the aperture polarizability approach, though they concede that it is valid only for apertures that are small compared with the wavelength under consideration, and apertures that are located on a conducting face of large dimensions so as to consider the aperture as lying on an infinite PEC plane. The aperture polarizability approach consists in replacing the aperture with two collocated but orthogonally oriented dipole moments, one electric and the other magnetic. The values of each dipole moment depends on the shape of the aperture. A good agreement was presented between the predicted and the measured results.

14 references, 9 pages.

Jasmin Roy

[101]--[95IEEJv115Cn4p508]

Finite Element Applied to EMI/C Problems (G.I. Costache)

A purely theoretical exposition of the FEM.

12 references, 4 pages.

Jasmin Roy

[102]--[94PCDv11n7p17]

High Speed Digital System Design (D. DiMatteo and K. Willis)

A discussion of issues pertaining to the design of PCBs and MCMs. The authors are with Cadence, and so undoubtedly highlight Cadence design tool procedures. We are not interested in design (unless it pertains to EMC/EMI issues) so for our review the paper is of limited value. There is a brief mention of crosstalk and interconnection delays.

6 pages.

Neil Simons

[103]---[96EEEEv35n12p46]

Modelling Real-World EMI/EMC Situations (B. Archambeault)

A short critique of three popular numerical methods applied to EMC problems: FDTD, FEM, MOM. The advantages and disadvantages of each method is given. The useful conclusion of "no one modelling technique will accomplish all modelling tasks effectively and accurately" is provided.

5 pages.

Jasmin Roy, Neil Simons

[104]---[96MRv36n7-8p955]

Failures Induced on Analog Integrated Circuits by Conveyed Electromagnetic Interference: A Review (G. Masetti, S. Graffi, D. Golzio, and Zs. M. Kovacs)

Structure:

Investigation of failures of analog opamp circuits caused by induced RFI. Susceptibility of opamps implemented using several technologies are investigated: all-bipolar μA741, LM307, ultra-high gain ultra-low offset OP77, FET-input LF355, two CMOS designs, JFET/BJT LF355, and two BiCMOS designs.

Results:

Measurements of the mean output DC voltage versus frequency of interfering signals are provided for all the different opamps (ideally this would be zero). Interfering frequencies range from 0.01 to

100 MHz. Unwanted DC output voltages range from 0 to 5 Volts (the worst cases being the LM307 and OP77). The authors conclude the offset is due to an asymmetric slew-rate. The authors present two designs using BiCMOS technology. The authors state several advantages of BiCMOS technology. The authors' improved design indicates less than a 0.1V DC offset (across the band of interfering signals) - a significant improvement.

The authors mention the need for EMI-oriented macro-models. Macro-models are simple circuit representations which allow evaluation of circuit performance through simulation. For the purpose of the authors' investigation, slew-rate details are necessary within a macro-model to evaluate the effect of induced RFI.

28 references, 18 pages.

Neil Simons

[105]--[95EMCv37n1p84]

Development of the Equivalence Principle for SGEMP and Source-Region EMP Problems (R. Holland)

This paper generalizes the equivalence principle of paper [EMC82v24n4p406] on which their two-step approach is based. The development is generalized in that the reciprocity principle is not invoked at all, and the media linearity is invoked only in a vanishingly small volume near the apertures. This generalization thus allows the presence of non-linearity components and phenomena in the cavity, provided that no current be driven, drifted or conducted through the aperture.

7 references, 5 pages.

Jasmin Roy

[106] ---[91IJNMv4p259]

Annotated Bibliography of Numerical Modelling in Electromagnetic Compatibility (M. N. Sadiku and C. N. Obiozor)

This paper lists a number of papers on numerical modelling in Electromagnetic Compatibility and interference in open literature between 1980 and 1990. The emphasis is on coupled Transmission lines and shielding.

As described in the title, it is an annotated bibliography and not a literature review. It is Worth noting, but contributes little in the way of a global understanding.

87 references, 11 pages.

Neil Simons

[107]--[96EPPv36n3p27]

Differential Signal Transmission Through Backplanes and Connectors (M. A. Fusi and F. Z. Teradyne)

Some preamble is given regarding trade-off between bus width and clock frequency to obtain a given bandwidth (or throughput). With high speeds the problems of cross talk and radiation emerge. Differential or balanced signalling can be used to reduce these problems. Devices which can drive high speed differential signals are PECL, LVDS, GTL, and differential PCI. Differential pairs are transmitted over balanced transmission lines to ensure low noise and good impedance matching. Balanced transmission media include twisted pairs, ribbon cables and strip-line.

The paper mentions an in-house Teledyne boundary element solver to calculate the impedance of strip-line cross-sections. A brief discussion of performing differential TDR measurements is included.

2 references, 4 pages.

Neil Simons

[108]---[95EMCv37n4pp543]

Bounds on Aperture Coupling from Radar and Other EM Pulses (A. Louie and C. L. Gardner)

First, some comments on the analysis of complex structures.

When a structure containing apertures is too complex or too large to be solved at once, the analysis can be carried out in two steps. The first step is to calculate the interior fields using a simplified model that neglects the interior components. The second step is then to calculate the coupling of these fields to the electronic systems of interest and to estimate system susceptibilities. This approach has two difficulties: 1) If there is a strong coupling to the interior fields, the Q of the structure will be lowered and the maximum fields calculated will be overestimated; 2) The coupling calculated using this two-stage approach can violate energy conservation (i.e. the calculated coupled energy can be more than that which can be transmitted through the apertures in the structure). Because of these difficulties and because it is virtually impossible to model all of the detail of any real-world system, an alternative approach based on the use of energy bounds attempts to determine the maximum energy/power that can couple to an electronic system inside a structure with apertures, independently of the system details.

Regarding this specific paper, the energy transmitted through an aperture which is unspecified other than for the assumption that its scattering amplitude varies inversely with the square of the radian frequency, is computed for the RF pulse, the damped sine pulse, and the inverse exponential pulse. In practice, however, the scattering cross-section of an aperture varies as the fourth power of the radian frequency for low frequencies, and is independent of frequency as the cross section approaches the geometrical area of the aperture for high frequencies.

9 references, 4 pages.

Jasmin Roy, Neil Simons

[109] -- [94SAMSv21n7p203]

Multiprocessor Solution for a Signal Integrity Analysis on Printed Circuit Board (W. Rissiek, H. Holzheuer, and O. Rethmeier)

Structure:

The paper discusses implementation of an MTL formulation on a Multiprocessor computer. Multiconductor transmission line systems are considered. The MTL formulation presented can analyse cross-talk, reflection, and non-linear terminations. Frequency dependent parameters are included, and therefore convolutions are required in the time-domain analysis.

Comments:

The paper contains details regarding parallel algorithms for solving the MTL system. This is not within the scope of our review.

4 references, 12 pages.

Neil Simons

[110] --- [94EPPv34n7p40]

Avoiding Signal Integrity Problems in Backplanes (J. Scaminaci)

As the title suggests, the author discusses signal integrity issues in backplanes. The paper is relevant to designers. It contains little EM theory or advancement of analysis methods. A basic discussion of propagation velocity and reflection coefficients is included. A simple formula is provided to estimate the propagation delay caused by a plated through via (due to its capacitance). Qualitative discussions of designing for minimized ground-bounce and crosstalk are provided.

5 pages.

Neil Simons

[111] ---[95ECv46n5p195]

TLM Modelling as a Tool for Shielding Effectiveness Evaluation (V. Smiesko, K. Kovac, J. Catrysse, and P. Macaj)

Structure:

1) A laminated composite of 5 layers under normal incidence; 2) a shielding wall made of two overlapping but non-touching copper walls illuminated by a point source; 3) a PEC plane of infinite extent with a narrow slot; 4) a PEC plane of infinite extent with a small circular aperture; 5) a PEC cubical box with a small circular aperture;

Analysis Method:

2-D or 3-D TLM (Transmission Line Matrix) method with symmetric condensed nodes was used for all above structures and the results were compared with those for: 1) the equivalent transmission line model for the laminate composite; 2) measurements for structures 2) and 3); 3) simple formulas for far-field electric SE or near-field magnetic SE (Kaden's formula was derived from the combination of an electric and a magnetic dipoles collocated and orthogonal at the small aperture) for structure 4); 4) measurements for structures 5.

Results:

Good agreement was noted for structure 1), leading the authors to comment that high values of SE can be obtained by combining materials with much lower conductivities than that of metals. Good agreement was noted for structures 2) and 3) in the range of 80-400 MHz. Good agreement was noted for structure 4), noting a good agreement with Kaden's formula for the magnetic SE. Good agreement was noted for structure 5) with Kaden's formula up to 300 MHz.

While the electric SE for a small circular aperture in an infinite PEC plane decreases 20 dB/decade with increasing frequency over the range of 10-1000 MHz, the electric SE for the same aperture in a cubical box is constant with frequency but of smaller value. In contrast, the near-field magnetic SE for the same aperture in the infinite PEC plane or in a cubical box is constant with frequency and is well approximated by Kaden's formula. In the far-field, the magnetic SE decreases with increasing frequency.

Comments:

The quality of the copy of this paper was so poor as to make most plots illegible.

11 references, 6 pages.

Jasmin Roy

[112]---[96APv44n5p659]

Two-Pass Finite-Difference Time-Domain (FDTD) Calculations on a Fighter Aircraft (R. Holland)

Structure:

Fighter aircraft including the cockpit.

Analysis Method:

Two-pass method with the FDTD method (THREDE code) as the computational method.

Results:

Results from various approximations of the cockpit cavity and of the rest of the aircraft were compared. No measured results were shown.

Comments:

The author remarks that another two-pass method used with the FDTD code consists in re-computing the problem with a finer mesh using the previous results obtained with a coarser mesh. The scheme backstores the tangential electric or magnetic field during the first pass on a surface which encloses the small volume of particular interest. A coarse solution is actually obtained everywhere, including through the small volume of interest. For studies of cavity penetration through an aperture, the two-pass method based on the equivalence principle is more efficient as first-pass information only needs to be backstored over a minimal area (the aperture itself), while other schemes require first-pass data to be backstored over a larger enclosing surface. Furthermore, in dealing with aperture penetration, the two-step method based on the equivalence principle also minimizes the volume external to the aperture, which must be finely meshed and solved on the second pass. There are scenarios, however, where the two-step method based on the equivalence principle would not be preferable, as for instance, for determining the EMP coupling to a small external helical antenna or for an aperture in an imperfectly conducting wall.

13 references, 6 pages.

Jasmin Roy

[113] --[96EPPv36n1p61]

Proper Shielding Controls EMI Emissions and Provides Immunity (H. W. Markstein)

A general discussion if shielding issues intended for a practitioner.

A frequency of 30 MHz is given as the separation of low frequency and high frequency shielding. Low frequency shielding is accomplished through absorbing the magnetic field - using thick sections of magnetic permeable materials. High frequency shielding is accomplished through reflection of the incoming wave - using thin metallic sheets with high conductivity. Various types of gaskets are described (to prevent leakages through seams in enclosures).

5 pages.

[114]--[95TMv49n7p43]

You Can Troubleshoot EFT Problems (D. Smith)

EFT - Electrical Fast Transient Pulses. The sources of EFT are sparks on AC mains, opening and closing of electrical switches, and motor commutators running, powering up or powering down. An EFT event contains thousands of pulses occurring at intervals of less than 1μs. Measurement and levels which can cause problems are provided. Ferrite core filters and shielded cables are suggested solutions to the problem.

3 pages.

[115]---[82EMCv24n4p406]

Finite-Difference Analysis of EM Fields Inside Complex Cavities Driven by Large Apertures (D. E. Merewether and R. Fisher)

Structure:

Arbitrary aperture driven problems.

Analysis Method:

The induction principle is used to close all apertures with PEC surfaces for computing by the FDTD, in a first pass, the conduction currents on the covered apertures. In a second pass, the FDTD is used again to compute the fields inside the cavity, using the conduction currents computed in the first step as excitation for the scatterer.

Results:

A numerical example consisting of a cavity-backed aperture was treated but no comparison was presented to validate the predicted time waveform of the interior fields.

Comments:

This paper presents an original two-step method for computing the field scattered by a PEC body that incorporates apertures and cavities connected to these apertures. This two-step approach is based on the use of the induction theorem and the use of splitting the scattered field into a reflected Er and a perturbing Ep fields such that the reflected field corresponds to that which would be scattered if the apertures of the scatterer were covered with a PEC surface, and the perturbing field corresponds to the field difference between the true scattered field radiated by the scatterer with apertures uncovered, and the reflected field radiated by the scatterer with apertures covered.

The induction theorem is a special formulation of the equivalence principle which allows to compute the scattered field in terms of the incident field without invoking explicitly the total field in the resulting equation. The induction theorem is applied to the problem for the scatterer with apertures uncovered such as to divide the problem into two separate, but not independent, regions. This division of the original problem in two regions, however, must follow the geometry of the scatterer with apertures covered. In the exterior region, the field is chosen as Ep while, in the interior region, the field is chosen as the actual field Et = (Ei + Er + Ep) where Ei is the incident field. On the surface separating these two zones are taken to flow equivalent electric surface currents Js = (Ht - Hp) x n and equivalent magnetic surface currents Ms = n x (Et - Ep) where n is the unit vector normal to the surface and points from the exterior to the interior regions. However, owing to the definition of Et = (Ei + Er + Ep), there obtains: Ms = n x (Et - Ep) = n x (Ei + Er) = (n x Esc) = 0 at the surface of the PEC scatterer with apertures covered. Esc is the scattered electric field for the scatterer with apertures covered (i.e. short-circuited). Similarly, there obtains: Js = (Ht - Hp) x n = (Hi + Hr.) x n = (Hsc x n) at the surface of the PEC scatterer with apertures covered. Only the equivalent electric surface currents on the portions of the scatterer corresponding to the apertures contribute to the field Ep because an impressed electric surface current acting over a PEC surface does not radiate by the application of the reciprocity theorem (i.e., since an impressed electric current at some point in space can never develop a non-zero field contribution tangential to a PEC surface, then by reciprocity, an impressed surface electric current acting over a PEC surface can never develop a non-zero radiated field at some point in space).

In the first step, the electric surface currents and the scattered field Er are computed by the FDTD method for the scatterer with all apertures covered by a PEC surface, illuminated by the incident field Ei. In the second step, the electric currents flowing over the PEC-covered apertures, as computed in the first step, are used to illuminate the scatterer with apertures uncovered, and the resulting scattered field Ep is computed by the FDTD. The desired scattered field corresponding to the scatterer with apertures uncovered, is obtained as (Er + Ep) in the exterior region, and as Et in the interior region.

Each different choice of the shape of the PEC surface covering an aperture leads to a different value of the perturbation field. If the choice of the PEC surfaces of the covers for all apertures happened to coincide with the surfaces of all the cavities of the original scatterer, Er alone would account for the desired scattered field since we would be, in effect, solving the original problem in the first step, whereas Ep would be zero in the second step because the equivalent electric surface currents would be acting over the PEC surface of the cavities. The greater the difference between the surfaces of the aperture covers and the surfaces of the cavities, the greater the value of Ep. Thus, although the true scattered field (Ep + Er) is unique by the application of the uniqueness theorem, however, Ep and Er taken individually are not uniquely chosen. Note that this approach is capable of taking into account the curvatures of the apertures. However, the choice of the shapes of the aperture covers cannot be totally arbitrary since the covering surfaces must not cut through the PEC medium. Mathematically, the field solution cannot be analytically continued on and beyond the surface of the PEC body because of the presence of surface currents which represent sources of field discontinuities. If this mathematical law were transgressed herein, i.e. if the covering surfaces did cut through the PEC body, the electric surface currents, computed in the first step, would be located inside the PEC body as part of the second step and then Ep would be clearly zero regardless of the shape of the cavity, which result would be incorrect.

Another way of looking at this approach is to start with the problem of the scatterer with apertures covered, and to apply the equivalence principle such as to transform this problem into the desired problem with apertures uncovered. Taking the case of a single aperture and applying the equivalence principle, the scatterer is divided into two regions such that the interior region includes the cavity of interest, and the rest of the scatterer belongs to the exterior region. Since the aperture is covered, the field of the interior region is taken as zero but the field of the exterior region is taken as the scattered field Er. The equivalent surface current for such a case is purely electric because the equivalent surface magnetic current M = (E x n) = 0 since the tangential electric field is zero at the surface of the aperture-covered PEC body. In the interior region where the field is zero, the medium is then changed from PEC medium to the medium existing outside the scatterer, thus forming the cavity of interest inside the aperture-covered PEC body. The equivalent surface electric current exists only over the region corresponding to the aperture surface since Js = (n x H) = 0 because H=0 inside the aperture covered PEC body. If the presence of the equivalent electric surface current on the aperture surface is interpreted as accounting for the presence of the cover (i.e. the field in the interior region is reduced to zero by the presence of the equivalent electric surface current on the uncovered aperture), then removing the presence of the cover requires simply to introduce a surface electric current equal and opposite to Js = (n x Hsc) such that the sum of these two surface electric currents be zero as was the case for the original scatterer with the aperture uncovered. From the principle of superposition, the field (Er + Ep) for the problem of the scatterer with the aperture uncovered and with no surface electric current flowing on the aperture, is the vectorial sum of the field Er for the problem of the scatterer with the aperture covered (or equivalently so as to emphasize that the superposition of two fields Er and Ep can be made only if the boundary conditions are the same when obtaining each field separately, the problem of the scatterer with the aperture uncovered but with the surface current Js flowing on the aperture), and the field for the problem of the scatterer with the aperture uncovered but with the surface current -Js = (Hsc x n) flowing on the aperture. Since the sum of these two contributions is (Er + Ep) and since Er represents the contribution for the scatterer with the aperture covered, then Ep must represent the contribution due to the presence of the aperture and the cavity. Therefore, Ep is computed as the field produced by the surface electric current (Hsc x n) flowing over the uncovered apertures. This point of view was taken in paper [93EMCv35n2pp264].

The two-stage approach of this paper is not the usual two-stage approach whereby an aperture field is computed for one (say, the exterior) problem without modelling the details of the other (the interior) problem, and is subsequently used as the illumination field for the other (interior) problem without modelling the details of the first (the exterior) problem, thus neglecting the effect of the interior problem onto the exterior problem. In this paper, the two-step solution would turn out to be the same as that obtained by solving the entire problem in a single pass. The two-step method in this paper is rigorous in that it does not neglect the interaction between the interior and the exterior regions, even though the approach does not rely on the process of matching explicitly the interior and the exterior solutions at the apertures. This two-step approach is practical only if the equivalent electric surface currents and the reflected field Er can be known by some other means (here, they are computed by the FDTD method), and if the problem of the original scatterer illuminated by the equivalent electric surface currents over the uncovered apertures can be solved somehow (herein, by the FDTD again). This two-step approach is efficient only if the choice of the shapes of the aperture covers does not make Ep=0 for otherwise, the method corresponds, in effect, to solving the problem in the first step and to wasting computation time to obtain Ep=0 in the second step. Furthermore, this approach does not save any effort in modelling since both the interior and the exterior surfaces of the scatterer end up being modelled in the course of the two steps. Moreover, the Yee mesh for the FDTD ends up being no smaller in the first step than that needed to solve the original problem in a single pass. Hence, this two-step method offers no real advantage over solving the problem in a single step by the FDTD method, unless the grid size used in the second pass is finer than that used in the first pass. For such cases, good results have been obtained with modelling only the details near the aperture as far as modelling the outside surface was concerned, thus, resulting in a large saving in modelling and computing efforts.

12 references, 5 pages.

Jasmin Roy

[116]--[76RSv11n7p611]

Electromagnetic Penetration Through an Aperture in an Infinite, Planar Screen Separating Two Half Spaces of Different Electromagnetic Properties (C. M. Butler and K. R. Umashankar)

Structure:

An aperture of general shape in a perfectly conducting screen, of vanishing thickness and infinite extent, separating two half spaces of different electromagnetic characteristics, with illumination incident upon the aperture/screen in both half spaces. The problem is further specialized to the case of an infinite slot of uniform width, illuminated by an incident plane wave of TE or TM polarization.

Analysis Method:

From the use of the equivalence principle, each aperture in the PEC screen is closed with PEC material, thus making the PEC screen complete and thus decoupling the two half-spaces that the screen separated, and an equivalent magnetic current M=(Ea x n) is taken to flow over each covered aperture. Ea is the unknown total electric field tangential to each aperture, and n is normal to the screen and points into the half-space under consideration. Since the direction of the normal is opposite for the two half-spaces that the screen separate, the equivalent magnetic current on one side of the full PEC screen is the opposite of the equivalent magnetic current on the other side of the full PEC screen for each covered aperture. The fact that the equivalent magnetic current in one half-space is M=(n x Ea) and that in the other half-space it is -M=(-n x Ea) ensures that the tangential component of electric field Ea is continuous across the apertures by the mere fact that the same Ea was used in both expressions.

From the use of the image principle, the presence of the complete PEC planar screen is then taken into account by removing the screen and introducing the image of each impressed current. Since the equivalent magnetic current on a covered aperture laid in the plane of the screen, it is collocated with its own image, thus doubling the strength of this current. The excitation currents or the incident fields must also be imaged, thus resulting in a doubling of the incident magnetic field in the plane of the screen. The process of imaging the excitation currents or incident fields accounts for the presence of reflected waves in the half-space under consideration. Thus, the field radiated by the (doubled) equivalent magnetic current over each covered aperture accounts only for the presence of the aperture itself, i.e. it does not account also for the reflected waves. The PEC screen is no longer present and all impressed (whether excitation or equivalent) currents are now radiating in an unbounded homogeneous space characterized by the constitutive parameters of the half-space under consideration. Since the two half-spaces on the two sides of the screen could possibly have different constitutive values, the imaging process would produce two different unbounded homogeneous spaces, one for each half-space on each side of the screen.

From the use of the superposition principle for linear equations, the total magnetic field for each half-space is then computed as the sum of the excitation magnetic fields produced by all sources (both real and imaged) present in the half-space under consideration and the magnetic fields radiated by the (doubled) equivalent magnetic currents in the same half-space, computed from the electric vector potential as the convolution of the equivalent magnetic currents and the free space Green function of the half-space under consideration. The total magnetic field for the two half-spaces are then matched across each aperture, thus yielding an integro-differential equation in the equivalent magnetic current over each aperture. Solving this equation by the Method Of Moments (MOM) yields the knowledge of the equivalent magnetic current over each covered aperture. The electromagnetic field scattered by each aperture is then computed from its corresponding (doubled) equivalent magnetic current radiating in the unbounded homogeneous space corresponding to the half-space under consideration. Simplifying the problem to that of a single slot, the incident field is taken, without loss of generality, as the sum of TEu and TMu waves where u is the axial direction of the slot. The basis function used here for the solution by MoM was the pulse function, and the testing functions were either the Dirac function (collocation) for the TE case or the triangular function for the TM case, respectively.

From the use of the superposition principle, it is also possible to compute the total electromagnetic field of the problem with multiple external sources as the sum of the electromagnetic field computed for the problem with one external source at the time, i.e. with all other external sources being absent, provided that equivalent magnetic currents are assumed to exist in each problem with a different external source.

Results:

The component of the equivalent magnetic current which is normal to the aperture edge is zero along this edge and the component parallel to the edge is unbounded along the edge according to the edge condition for Ea (since M=Ea x n and the electric field component normal to an infinitely thin PEC edge varies inversely proportionally to the square root of the radial distance from the edge).

For a slot of uniform width and infinite length, there is no variation of the electromagnetic quantities (constitutive parameters, fields, currents) in the axial direction of the slot. For TE illumination, the effect of increasing the permittivity value of the half-space behind the screen is to reduce the magnitude, but not the general shape, of the slot current and to cause the edge singularity to manifest itself closer and closer to the screen edge. For TM illumination, no edge singularity arises but both a reduction of the magnitude and a significant change of the shape of the slot current (the distribution of the equivalent magnetic current becomes similar to that of a wider slot) occur as the permittivity value of the half-space behind the screen is increased.

For a large aperture in a screen separating half-spaces of the same media, it is well known that the field in the aperture at locations remote from the aperture/screen edges is essentially equal to the incident field evaluated at such points. In the two-media problem, however, with different wavelengths in the two half-spaces, the size of an aperture must be judged on the basis of both wavelengths. With sufficiently high contrast between the two permittivity values of the two half-spaces, the electric field near the centre of a moderately wide slot excited by a normally incident plane wave is approximately equal to the value that would calculate there for the two-media problem with the screen removed.

8 references, 9 pages.

Jasmin Roy

[117]--[96ITEMp95]

Modelling EMI Emissions Using Multi-Stage Models (B. Archambeault)

Structure:

This very short (2 pages) paper advocates the use of breaking the overall problem into two stages (the first stage for analysing inside, and the second stage for analysing outside the enclosure) and optimizing the individual models for the specific needs of that stage. The output from one stage is used as an input to the next stage. In stage 1, the inside of an enclosure containing traces on a circuit board and a connector was analysed by the FDTD method to find the common-mode voltage existing on connector pins due to the current of the source circuit. In stage 2, the outside of the box with a long wire attached to the box, was analysed by MoM with the common-mode voltage found in stage 1 placed between the shielded box and the long wire in order to predict the radiated emission.

Comments:

To study the susceptibility rather than the radiated emission of the system, the sequence of the two stage process would be reversed, or if the system is linear, the reciprocity theorem could be invoked to claim that the susceptibility would be the same as the emissivity.

The paper presents no comparison between predicted and measured results from this multi-stage approach.

2 references, 2 pages.

Jasmin Roy

[118] --[96ITEMp144]

Software Calculation of EM-Field Coupled Current and Voltage Levels (J. J. Laggan and W. A. Rogers)

MathCAD implementation of a simple formula for calculating plane-wave-induced-voltages on a transmission line. The transmission line may have arbitrary load impedances. Good agreement between induced voltages from the MathCAD implemented formula and measurements for a PCB trace connecting two HCMOS OR gates is demonstrated.

4 references, 3 pages.

Neil Simons

[119]--[96ELv13n5p15]

EMI Immunity and EMC with Electronic Process Control and Telecommunication equipment (S. Benda)

EMI and EMC of systems is discussed in the context of proper earthing, grounding, and shielding. Various industry standard symbols for earthing and grounding are discussed as well as the potential for confusion between them. Various cables shields are discussed - single-shield single-grounding, single-shield double-grounding, double-shield cables, coaxial cables. A qualitative common-sense discussion of enclosures and crosstalk conclude the paper.

2 references, 5 pages.

Neil Simons

[120]--[78AP26n1p82]

Electromagnetic Penetration Through Apertures in Conducting Surfaces (C. M. Butler, Y. Rahmat-Samii and R. Mittra)

This is a review paper on small apertures, with 116 references, There is some interesting information on the treatment of small apertures over vanishingly thin PEC shells (the material inside and outside the shell could possibly be different). The equivalence principle is still used to cover the apertures with equivalent magnetic currents flowing over PEC material, but the image theory cannot be used here because the shell is not a PEC plane of infinite extent. An interior and an exterior electric dyadic Green functions now account for the presence of the curved PEC surfaces with all apertures closed from the use of the equivalence principle. Hence, the PEC surface becomes completely closed. The apertures could be construed as following the natural curvatures of the surface in the vicinity of the apertures, so as to mitigate the difficult task of finding the Green function for the surface under consideration.

The paper mentions also the dipole moment approach consisting in treating a small aperture as the superposition of an equivalent electric and an equivalent magnetic dipoles, collocated and mutually orthogonal. The electric polarizability scalar and the magnetic polarizability tensor for the circle, the ellipse and the very narrow ellipse in a PEC planar screen are given. An alternative method, said to be valid even for non-separable geometries is presented for small apertures whereby the unknown equivalent magnetic currents over the covered apertures or the corresponding electric vector potential are expanded in a Rayleigh series (series in powers of the wave number k). The coefficients of the series are identified by equating the like powers of the wave number k in the integro-differential equation obtained from matching the magnetic field components tangential to the apertures, thus breaking the equation into multiple integral equations. The solution of a higher order equation depends on the solution of the lower order equations, except for the zeroth order equation, the solution of which can be determined directly. Coupling between the two vector components of the equivalent magnetic currents corresponding to a given power of k is realized through relationships among constants in the homogeneous solutions of the differential operator equations rather than through the operators themselves. A comparison for the predicted electric field along the principal axes of a small (less than one tenth of a wavelength) square aperture, computed by the integral equation method, and its corresponding inscribed circular aperture computed by the Rayleigh series method, shows a good agreement.

A comparison between the predicted results for the electric field transmitted by a one wavelength square aperture, computed by using Kirchhoff approximation or the integral equation, and the measured results for the electric field transmitted by a small circular aperture, shows a good agreement for separation distances greater than about 1.5 wavelengths directly on axis behind the aperture. A similar comparison between the predicted electric field transmitted by a small (0.05 wavelength) square aperture computed by the integral equation method, and the electric field transmitted by the corresponding inscribed circular aperture computed by the dipole moment approach, shows a good agreement for separation distances greater than about 0.08 wavelength directly on axis behind the aperture. However, another comparison between the electric field distribution computed for a small (0.15 wavelength) square aperture by the integral equation method and the dipole moment approach indicates a good agreement only for radial distances greater than about 0.75 wavelength behind the aperture for edge-on incidence, hence one must exercise caution in using the dipole moment approach to compute the diffracted field close to an aperture.

The paper presents also the example of a time domain solution obtained by summing up the inverse-Fourier transformation of the frequency domain solution for all the frequencies of the incident plane wave. No comparison, however, is made with measured data or with other researchers' data.

116 references, 12 pages.

Jasmin Roy

[121]--[76AP24n4p456]

Electromagnetic Excitation of a Wire Through an Aperture-Perforated Conducting Screen (C. M. Butler and K. R. Umashankar)

Structure:

An electrically thin PEC wire of arbitrary shape behind an aperture of arbitrary shape in an infinitely large, vanishingly thin, PEC planar screen. The special case of a narrow slot and a straight wire parallel to the plane of the screen is treated.

Analysis Method:

Same as in paper [76RSv11n7p611], except that the wire behind the aperture needs also to be imaged and its contribution added to the contribution of the other impressed sources and the incident field. The boundary condition on the thin wire, consisting of zero tangential electric field along the wire, needs also to be enforced. The field scattered back by the wire to the aperture is, in effect, introduced as part of the forcing function in the integro-differential equation. In this paper, the slot is assumed to be very narrow so as to approximate the electric field as being essentially transverse to the axial direction of the slot, with a transverse variation given by the electrostatic distribution of the slot (provided that the slot excitation does not possess an appreciable component which is an odd function with respect to the transverse direction of the slot). Moreover, the slot herein has a finite length, thus giving rise to periodical resonances. Hence, it turns out that the kernel for the electric vector potential from which to compute the electric field contribution of the slot, is just the kernel for the magnetic vector potential from which to compute the electric field contribution of the wire, for an equivalent wire radius of one quarter of the slot width. The two integro-differential equations, one for the wire and the other one for the slot, are solved simultaneously by MOM, using pulse basis functions and triangular testing functions.

Results:

When the narrow slot is viewed as the dual of a thin wire, subject to the usual thin-wire/narrow-slot assumptions, one readily sees that the wire is not excited by the fields which penetrate the slot whenever the two are parallel (i.e. the field transmitted through the slot is the same as that in the absence of the wire) and, also, that the coupling between wire and slot is maximum when they are perpendicular.

Serious errors may be incurred in a two-step analysis in which, first, the slot field or magnetic current is calculated in the absence of the obstacle behind the screen and, second, induced current on the obstacle is calculated on the basis of illumination determined from the slot field of the first step.

The distribution of current on an anti-resonant-length wire or slot is highly dependent upon wire/ slot coupling (i.e. upon the location of the wire centre with respect to the slot centre, and the angle between the slot axis and the wire axis) and incident field, whereas the influence is minimal near resonant lengths; however, the magnitude of the current can be strongly dependent upon coupling for any lengths.

Comments:

This paper is very significant in that it demonstrates the case where the validity of a two-step analysis is refuted. In trying to assess the effect of the slot onto the wire, one cannot always neglect the reciprocal effect of the wire onto the slot. When the coupling between the wire and the slot is significant, the two-step analysis consisting in, first, computing the field transmitted through the slot as that in the absence of the wire, and second, computing the field scattered by the wire as that if the wire was excited by the field transmitted through the slot computed in the first step, is far from being rigorous.

The paper does not give the details on how to pass from the EFIE to the scalar equation for the wire.

Since an anti-resonant magnetic current can be excited in a one-wavelength slot by an obliquely incident plane wave, the assumption of the electrostatic field distribution for the transverse variation of the transverse electric field seems to be violated for such a slot length, thus invalidating the analysis for that case by the same token.

7 references, 7 pages.

Jasmin Roy