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APPLICATION OF FERSNEL ZONE TO CROSS TALK

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Introduction

Unintentional radiation results in cross coupling to nearby cables. As frequency increases, the amount of this coupling becomes significant especially in high speed data transmission and space lab experiments. There has been considerable amount of research to model this radiation and design the electronic equipment accordingly so that operation of space lab instruments will be immune to unwanted radiation. Here at MSFC, Electromagnetics and Aerospace Environment Branch has the responsibility to analyze, test, and make the necessary recommendation as to the safe operation of instruments used in space program. Rules, regulation, and limits as set by this group are published in Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook (T.L. Clark, etl. 1995). This document contains both conducted and radiate emission rules and limits are set by NASA. However cross coupling have not been included. At the time of assigning research task for the author, the Group decided that a more in-depth investigation of Near Field is needed before establishing set of rules and limits for cross coupling. Thus this task was assigned to the author with hope that his work will be more beneficial to NASA's Space mission experiments. The model and the method which will be described shortly is intended to improve the present approach of this Group and suggests a method for measuring the cross field coupling capacitance.

Methodology

Basically three methods have been used to model unintentional radiation coupling. These are; Circuit model, Transmission Line Method, and Field Approach.

First method uses lumped element approach. This method is used by most of the authors for short length of cable i.e. $l < \lambda$, (λ is the wave length) and low frequency regions, (Mills, 1993, Paul, 1992). For cross talk consideration the distance is so short that cable looks infinitely long and thus in the frequency range of interest current can not be considered constant as is required by this method.

Second method was introduced by (C.R.Paul, 1976) and was published in his text book on INTRODUCTION TO ELECTROMAGNETIC COMPATIBILITY. In this method, after evaluating the capacitance and the inductance of multiconductor transmission line, he determines exact expressions for the calculations of Near End and Far End coupled voltages using distributed transmission line approach with sinusoidal steady state excitation, in matrix form. In his later work he also introduces Spice Model for coupled transmission lines. His work is quite remarkable but requires considerable amount of computer's memory and experienced programmer.

The third method was introduced by (A.A.Smith, Jr, 1977) in " Coupling of External Electromagnetic Fields to Transmission Line" with the latest edition in 1989. He uses transmission line exposed to radiated emission and calculates the transfer function of radiation, i.e. the ratio of induced current to incident electric field. This method is not suitable for industrial applications since it requires elaborate mathematics.

Time domain approach to distributed transmission line was introduced by (Sol Rosenstark, 1994). He separates coupling in to forward and reversed talk and calculates the corresponding coefficient under different termination. His method is quite recent and authors believe that it can be used to effectively determine the coupling capacitor and the inductor. His work is under the investigation by the authors.

Present Approach

Our method is concentrated on field equations using Fresnel Zone to analyze radiated emission and problem of cross coupling. It seems that this method has not been explored as yet even though it is a direct application of Near Field radiation. It is important to note that in the Fresnel Zone the wave front are no longer plane waves but rather spherical and thus electric and magnetic fileds have no simple relation of 377 Ohms as for plane wave but require some mathematics and applications of Maxwell equations. In spite of these difficulties we prefer to explore this method because cross talk is the result of Near Field radiation, it seems natural to apply field theory directly. Using field theory with careful approximations a very simple and useful result can be obtained which can be used without regarding the mathematics. This was the primary concern , to obtain a simple workable equation. There are, however, two ways to apply field equations to Near Field radiated emission; Vector Potential, and Electric Field methods.

Vector Potential Method: In this method the vector potential of a short element of a radiator is calculated first, then the total vector potential in the Fresnel Zone is determined by direct integration and by careful approximation. The magnetic and the electric field are then obtained by applying Maxwells' equations with no additional approximations.

Electric Field Method: This method involves the direct application of the electric field of elemental radiator to Fresnel Zone and obtaining the total electric field by integration and carefully using reasonable approximation.

We have derived rather simple expressions for magnetic and electric field using above methods. But the two methods have yielded different numerical results due to the nature of approximations. Vector potential method has yielded familiar and more accurate results than the second method. Thus in the following we will explain this method.

Vector Potential Method

Consider a radiator along the z-axis as shown in figure 1.

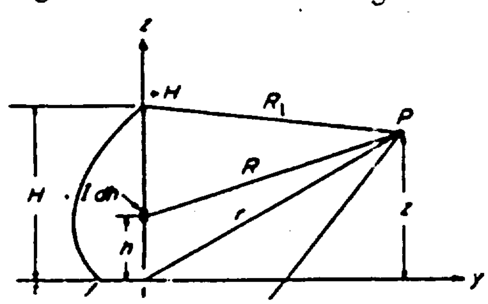


Fig. 1- Geometry for calculating vector potential

If the radiator is small, then in the vicinity of the radiator, (in the Fresnel Zone) the wavefront will be spherical and will reach the observer at point P with a time delay of t-R/c. The proper expression for the vector potential at point P for such a radiator is given by (Jordan, 1968):

$$A_z = \frac{\mu}{4\pi} \int \frac{I(z)\, e^{j\omega(t-R/c)}}{R}\, dz \qquad (1)$$

μ is the permeability of transmitting medium, ω is $2\pi f$ with f in Hertz, c is the speed of wavefront, and R is shown in figure 1. It is customary to write this equation in term of wave number as defined below;

$$k = \frac{2\pi}{\lambda}; \qquad \lambda = \frac{c}{f}; \qquad k = \frac{\omega}{c} \tag{2}$$

Thus equation (1) can be written as

$$A_z = \frac{\mu}{4\pi} \int \frac{I(z)\, e^{j(\omega t - kR)}}{R}\, dz \tag{3}$$

If we can determine I(z), current distribution along the radiator, then the magnetic and electric fields can be obtained from A_z by taking its curl and applying Maxwell's equation respectively. Following cases have been investigated by the author:

Case 1-$I(z)= I_o$
Case 2-$I(z)= I_o\, e^{j\omega t}$
Case 3-$I(z)= I_o\, e^{j\omega t}\, \mathrm{Sin}[k(H-z)]$

There are other expressions for current variation along the cable like $I(z) = I_o\,(1- h/l)$ (Tesche 1997), but sinusoidal variation is more practical. The true current distribution can only be found from experimental measurements. We have carried out this experiment in the MEDIC Lab of our Branch, the results and the experimental setup are shown in figure 2 with the computer plots for two different terminations. It is concluded, from these plots, that the current distribution in fact is sinusoidal. Thus the expression for the vector potential becomes;

$$A_z = \frac{\mu\, I_o\, e^{j\omega t}}{4\pi} \int \frac{\mathrm{Sin}[k(H-h)]\, e^{-jkR}}{R}\, dz \tag{4}$$

for convenience we will drop $e^{j\omega t}$ as long as there is not operation on t. We now outline the evaluation of magnetic field H_x, and the electric field E as following.

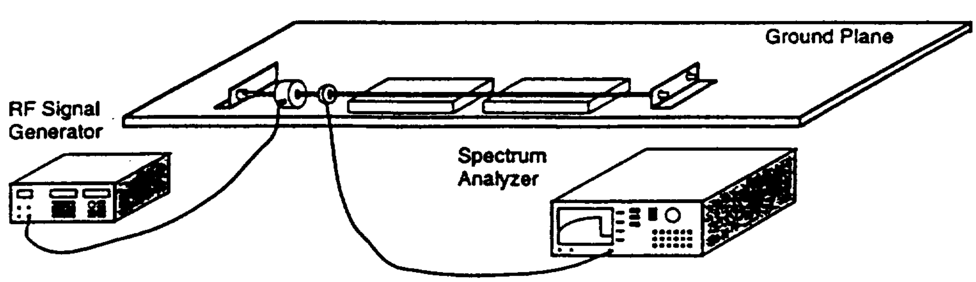
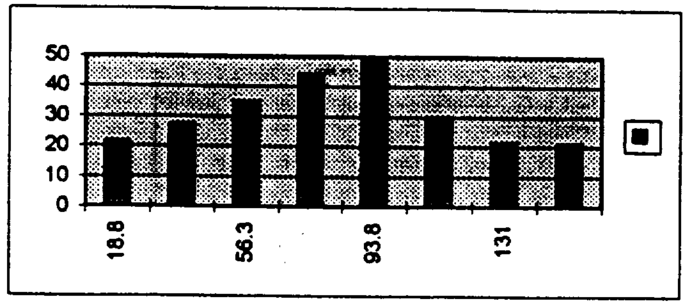


Fig. 2-Experimental setup for measuring I(z)

Table 1-Current Distribution

Location	dbm short	dbm open
18.75 cm	-21.5dbm	-20dbm
37.5	-27.5	-22
56.25	-35	-24
75	-44	-27
93.75	-49	-30
112.5	-30	-33
131.25	-21.5	-38
150	-21	-46



1.Evaluation of Magnetic Field: Using curl A, we obtain for H_x:

$$H_x = -\frac{\partial A_z}{\mu\,\partial y} = -\frac{I_o}{8\pi}\left[e^{jkH}\int \frac{\partial}{\partial y}\left(\frac{e^{-jk(R+h)}}{R}\right) dh - e^{-jkH}\int \frac{\partial}{\partial y}\left(\frac{e^{-jk(R-h)}}{R}\right) dh\right] \quad (5)$$

using the geometry of figure 1 and carrying out the indicated integration, we obtain

$$H_x = -\frac{I_o}{8\pi}\left[\frac{-2H\,e^{-jkR_1}}{R_1\,y} - \frac{y\,e^{-jkr}}{r(r-z)}\,2j\sin(kH)\right] \quad (6)$$

2.Evaluation of Electric Field: Using curl H, components of electric field are calculated as followings:

$$E_z = \frac{1}{j\omega\varepsilon}(\nabla x H) = \frac{1}{j\omega\varepsilon y}\frac{\partial}{\partial y}(y\,Hx) = \frac{I_o\,e^{-jkr}}{4\pi\varepsilon c}\left[\frac{1}{y^2(1-1/2z^2)}\right]\frac{\sin(2\pi f/c)H}{(2\pi f/c)} \quad (7)$$

$$E_y = \frac{I_o\,ej\omega t}{4\pi\varepsilon c}\left[\frac{1}{z(1+y^2/2z^2)(1-1/2z2)}\right]\frac{\sin(2\pi f/c)H}{(2\pi f/c)} \quad (8)$$

In order to compare our results with the experimental values we must determine the total electric field as following;

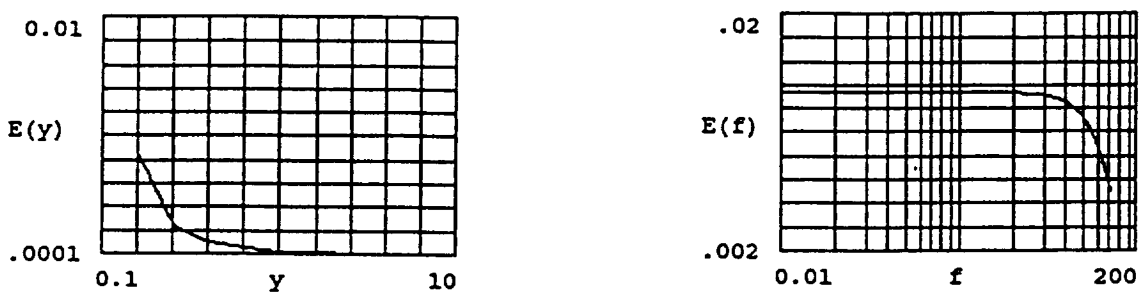
$$|E|^2 = |E_y|^2 + |E_z|^2 \quad (9)$$

instrument will read the RMS value of this equation. We have used equation (7,8) and have calculated this value. The results are shown in table 2. Figure 3,4 show these results in graphical forms. The frequency plots agree with plots given by (Mills, 1993)

Case 3 - $I(z) = I_0 e^{j\omega t} \sin[k(H\text{-}z)]$

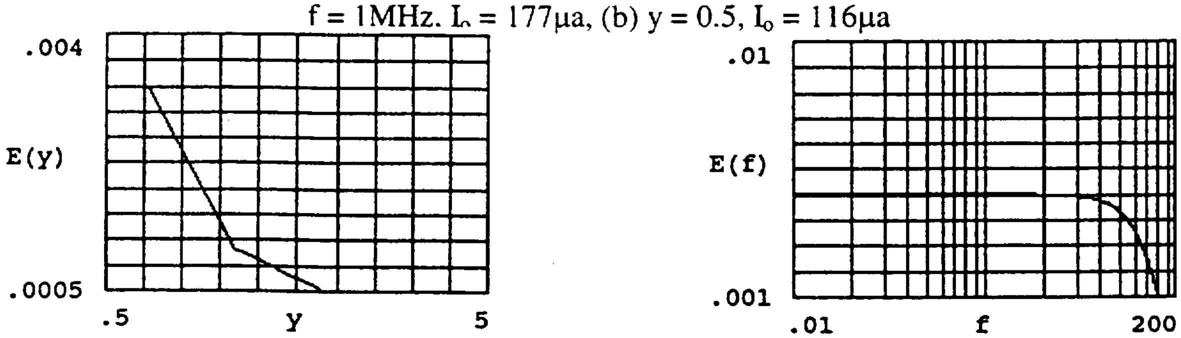
TABLE 2 - COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS

Model	H = 1met., Io = 177μa@f = 1Mhz y = 0.5met.	 y = 1met.	H=1met.,Io=56μ@f= 10MHz y = 0.5	 y = 1met.
Present Model	0.02 V/m	0.0064V/m	0.0067V/m	0.0017V/m
Point Source	2	0.25	0.2	0.025
Experiment (Evans, 1995)	0.03	0.02	0.01	0.01
Experiment (McCollum, 1997)		0.003		0.017



(a) (b)

Fig. 3- Variation of $|E_z|$, equation (7) for z = H/2,
f = 1MHz. I_o = 177μa, (b) y = 0.5, I_o = 116μa



(a) (b)

Fig. 4- Variation of $|E_y|$, equation (8) for z=H/2.
(a) f = 1MHz, I_o = 177μa, (b) y = 0.5, I_o = 116μa

Evaluation of Coupling Capacitor: Coupling capacitor is the most important parameter of cross talk. It is the distributed capacitance along the cables between them. It is necessary to obtain an expression for its dependence on distance and the frequency in order to reduce its effect efficiently. Our method yield direct expression for it as following;

$$C = \frac{dQ/dz}{dV/dz} \qquad (10)$$

dV/dz is equal to $-E_z$ and is given by equation (7), no further math is needed. DQ/dz can be evaluated as following;

$$dQ/dz = \frac{d}{dz} \int I(z)\, dt = \frac{d}{dz} \int Io\, ej\omega t\, Sin[k(H-z)] \quad (11)$$

using the result of this integration and equation (7) for E_z, capacitance c, can now be written as;

$$|C| = \frac{8\pi^2 \varepsilon f}{c}\, y^2 (1-1/2z^2) \frac{Cos[k(H-z)]}{Sin(kH)} \quad (12)$$

Figure 5 is a plot of this equation. The values computed from this equation range between 0.5 to 5 pf, in excellent agreement with (Paul, 1992).

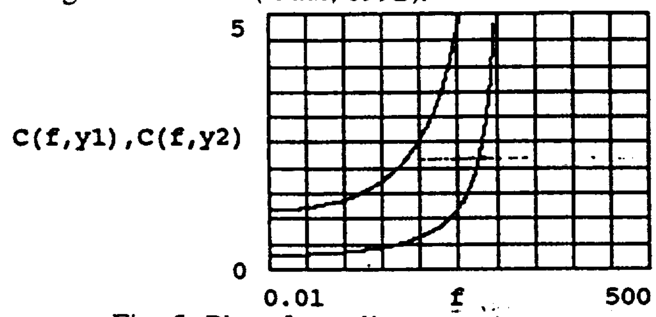


Fig. 5- Plot of coupling capacitance, equation (12)

Conclusion

In conclusion I have applied field theory and investigated the radiated emission and cross coupling in the Fresnel Zone. I have provided:

1. Simple expressions for magnetic and electric fields. It is shown that electric field decreases with inverse square distance modified by current distribution function.
2. Expression for the coupling capacitance, it is shown that this parameter in addition to its dependence on inverse square distance also depends on frequency. This is a new finding.
3. Near End or the Far End effect by simply changing the coordinate of observation point.
4. Our results apply for worst case termination, i.e. open circuit

Our work, however does not include:

1. Losses in the cable or the dispersion effects, thus the propagation constant, k, has been taken $2\pi/\lambda$.
2. Skin effect. This effect will increase the effective AC resistance of the cables, and thus the cable losses. Its effect becomes significant at higher frequencies.
3. Matched termination
4. In applying the results of this work we should adhere to the following constraints:

$$z/\lambda < 1, \qquad y/z << 1$$

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