Analysis of Multi-Layer Composite Cavity Using FEKO

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Abstract— Modeling of a large cavity containing multiple layers inside the structure has been studied using equivalent impedance approximations along with simplified single ray tracing analysis. This modeling effort investigates the effects of radiating with a source enclosed in a large vacant composite structure relative to a short wavelength. The development of the model involves the completion of a two step process. First, the heritage geometric reduction and approximation is investigated. This particular investigation involves an approach that is an application of Poynting's Theorem. This work was performed by Hallett and Reddell at Goddard Space Flight Center in 1998. For this comparison, the Multi-Level Fast Multipole Method (MLFMM) available in the commercial tool FEKO, is used to model a generic multi-layer payload fairing (hollow cone connected to a hollow cylinder) with a radiating source to determine the resonant cavity effects within the fairing as another approximation baseline. The intent is to provide predictions for the electric field levels if a transmitter in the fairing either deliberately or unintentionally is activated. The results show a comparison with the heritage calculation and FEKO software tool. However, FEKO shows the electric field distributions within the composite fairing cavity instead of a single average value.

Index Terms— Inhibits, Resonant Cavity, FEKO, EM Compatibility

I. INTRODUCTION

Monitoring the status of spacecraft through direct transmission while it resides within the payload fairing, or loaded cavity, of a launch vehicle is prohibited through the use of inhibits, but sometimes radiating within the cavity is a mission requirement. In general, radiating within the cavity has been a desire of many space missions either for spacecraft function monitoring or to prevent the reliability issues that inhibits cause. For this desire to become a realization, the spacecraft must power on its transmitter while encapsulated within the payload fairing. If power were applied, the electric field levels would expose both the spacecraft and launch vehicle to levels well beyond the avionics qualification levels that are typically tailored from MIL-STD-461 [1] and MIL-STD-1541 [2]. In the past, the fairings were made entirely of aluminum and provided protection for the spacecraft much like a Faraday cage [3]. Unfortunately, along with protecting the spacecraft from unwanted sources external to the fairing, energy from internal transmitters is trapped inside the fairing. With the advent of composite structures and more precisely with the build up of composite fairings, the space industry performed several tests and rough calculations as documented by Hallett and Redell [4] to determine the effects of radiating within the new composite fairing structure. In this work, it is desired to determine the radiation distribution inside the composite fairing structure. A multi-layer payload fairing is modeled using two techniques: an application of Poynting's Theorem that will be referred to as the heritage method and a commercial tool, FEKO. FEKO is a Computational ElectroMagnetic software tool, EM Software

Systems -S.A. FEKO. FEKO allows the use of Physical Optics (PO), Method of Moments (MoM), Mult-Level Fast Multipole Method (MLFMM) and Hybrid MoM/PO techniques. Due to the nature of the composite and FEKO functionality, MLFMM is used. The results of the two techniques are presented and compared. The heritage method was first performed at Goddard Space Flight Center in 1998. This effort is an extension of that heritage work. Only the geometric representation of the fairing is now characterized as a hollow cone connected to a hollow cylinder. In addition, the impedance was altered from the heritage calculations. The rationale for changing the geometry and impedance is due to the proprietary nature of the original fairing designs and materials used. It has been the desire of the space industry that a comprehensive model be developed to provide a better understanding of radiating within the acoustic blanket lined composite fairing, or cavity.

II. PROBLEM DESCRIPTION

The interior walls of the composite fairings were lined with Dupont's Kapton 377® "blankets". The blankets consist of a layer of Kapton film overlaid onto melamine foam with another layer of Kapton film as seen in Fig. 1. The original intent was to provide protection as acoustic blankets or shields. In the process, it also reduced the interior volume of the fairing. Some experimental studies were performed to determine the effect of having both the acoustic blankets lining and a new composite fairing structure [4]. The actual levels predicted and measured are a matter of some debate even today. Some of the concerns include testing with antennas that are not utilized during a mission as well as the simplistic analytical methods used to predict the electric fields within the cavity. In order to minimize mission risk, the respective spacecraft are not permitted to radiate within the fairing cavity unless adequate mission specific analysis is performed to show electromagnetic compatibility without transmission inhibits.

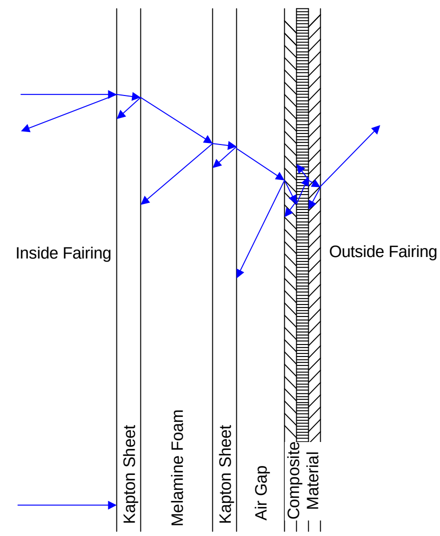


Fig. 1. Multi-layer composite cavity (fairing wall).

The plan for developing and comparing the respective models is broken into two components:

Heritage Geometric Reduction and Approximation

Using a direct application of Poynting's Theorem, the electric field levels using the first analytical technique from Hallett and Redell [4] are calculated. An equivalent impedance is used as illustrated for the 5 - 6 GHz range in Fig 2. However, the geometry is a hollow cylinder connected to a hollow cone as shown in Fig. 4 below. The other parameters found in the open literature will remain the same.

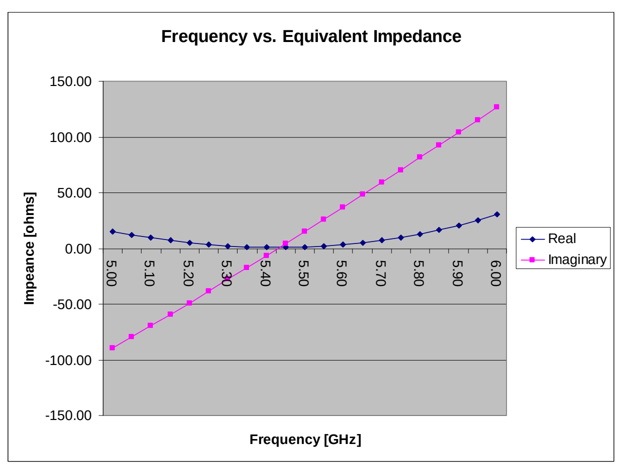


Fig. 2. Equivalent impedance of multi-layer composite cavity (fairing wall).

The values calculated with this method are worst case average approximations of the electric field within the cavity where only one level is obtained at each frequency. This level is used as a baseline value for comparison. This approximation is used as a quick worst case prediction as seen in Fig. 2 below.

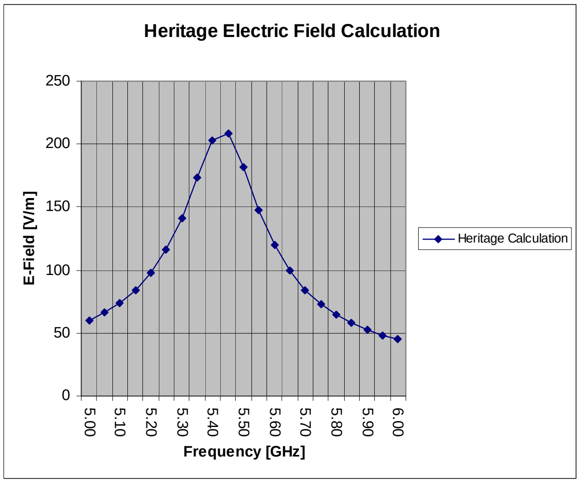


Fig. 2. Heritage electric field calculation.

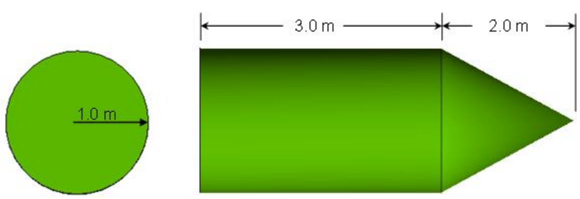


Fig. 3. Cavity geometry.

FEKO Computational Analysis

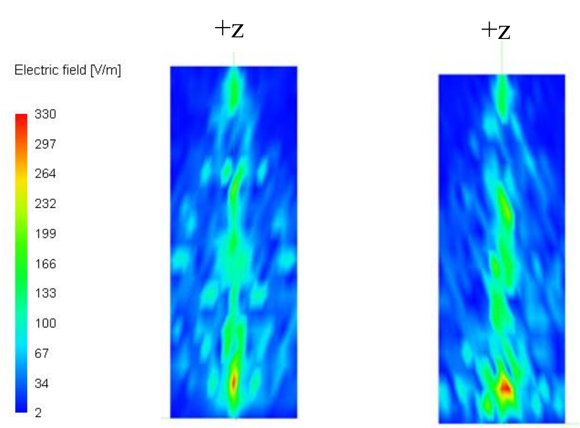
A model with a hollow cylinder connected to a hollow cone with a horn antenna pattern in FEKO CEM software is implemented (Fig. 3). The prior equivalent impedance approximation is used to account for the losses, and the electric fields within the cavity are determined. The distribution of the electric field is found. The implementation of the model in FEKO requires that the geometry is created with primitive elements of the graphical tool and an equivalent impedance that was previously calculated is placed at the inside surface of the cavity as an infinitely thin sheet for the mesh of the geometry. The sources are implemented as a point source with a horn antenna pattern. The MLFMM technique is used in FEKO. The model parameters include a transmitter frequency of 5, 5.2, 5.4, 5.6, 5.8, and 6 GHz, input power of 10 Watts, and an antenna pattern for an EMCO 3115 antenna pattern. In this example, observation points were chosen at the locations of two center-line planes along x-z and y-z, respectively.

III. NUMERICAL RESULTS

From Hallett and Reddell [4], the equivalent impedance is calculated using Eq. (1) and the electric field is calculated from the incident power using Eq. (2) as seen below. A description of the pertinent variables follows Eq. (2), respectively.

The electric field found with the heritage calculation method provides a maximum value of 60 V/m at 5 GHz.

Using FEKO, the MLFMM approximation is implemented to create the electric field distribution at 5 GHz shown below in Fig. 4. As shown, the maximum values (330 V/m) are much higher when compared to the maximum value (60 V/m) provided in the heritage calculation. While the heritage calculation only provides the singular estimate relative to the surface area of the cavity, the MLFMM technique shows the distribution of the electric field inside the fairing. The heritage calculation is within the FEKO data range.



(a) x-axis plane ωt=90 (b) y-axis plane ωt=90

Fig. 4. FEKO calculations at cross-sections along the x- and y- axes.

$$\eta_L(l) = \eta_1 \left\{ \frac{\left[(\eta_2+\eta_1)e^{\alpha_1 l} + (\eta_2-\eta_1)e^{-\alpha_1 l}\right]\cos\beta_1 l + j\left[(\eta_2+\eta_1)e^{\alpha_1 l} - (\eta_2-\eta_1)e^{-\alpha_1 l}\right]\sin\beta_1 l}{\left[(\eta_2+\eta_1)e^{\alpha_1 l} - (\eta_2-\eta_1)e^{-\alpha_1 l}\right]\cos\beta_1 l + j\left[(\eta_2+\eta_1)e^{\alpha_1 l} + (\eta_2-\eta_1)e^{-\alpha_1 l}\right]\sin\beta_1 l} \right\} \quad (1)$$

$$\vec{E}_0^{inci} = \sqrt{\frac{P_T^{inci}}{\sum_{i=0}^{k}\left((2SA_i)\, real\left\{\left|\frac{\eta_i}{\eta_0+\eta_i}\right|^2\right\}\right)}}. \quad (2)$$

where:
η is the impedance of the media.
α is the attenuation constant of the media.
β is the phase shift constant of the media.
l is the length (thickness) of the media.

Similarly for the remainder of the frequencies of interest (5.2, 5.4, 5.6, 5.8, 6.0 GHz), the results were similarly distributed for the respective curves. The comparison of the results for these curves is shown in Fig. 5. below. In future calculations, the work of Demir and Elsherbeni [6] will be taken under consideration for the calculation of the layered media relative to the blanket and composites in free space.

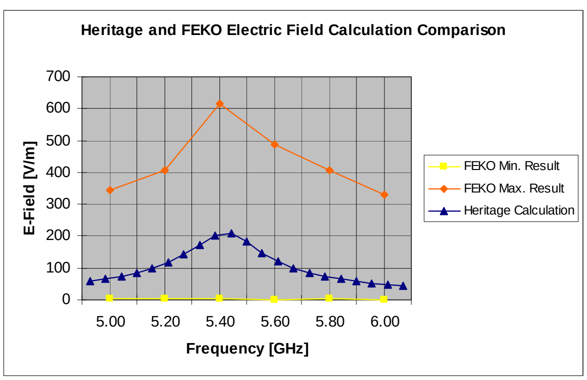


Fig. 5. Heritage and FEKO electrical field calculation comparison.

IV. CONCLUSIONS

The MLFMM technique in FEKO and Heritage Calculation estimated the maximum electric field 330 V/m and 60 V/m, respectively, within the cavity at 5 GHz. Additionally, values for the other frequencies of interest were compared to heritage calculations. The distribution of the field predicted by FEKO provides added information when compared to the location of critical launch vehicle avionics and spacecraft components. This allows the mission managers to assess risk relative to electromagnetic compatibility, and the analysis provides insight regarding cavity resonances as a "radiated environment" within the cavity. Although this maximum value prediction of the heritage method is shown to be within the range of the FEKO values, it could also drive sensitive spacecraft equipment to test to levels not indicative to the actual RF environment.

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James E. Stanley received his B.E.E. from Auburn University in 1988 and his Masters of Science in Engineering (Electrical Engineering) from Mercer University in 1997. He is currently pursuing his Ph.D. in Electrical Engineering at Florida Institute of Technology. He has worked in DoD on multiple airframes and subsystems. After moving to the commercial sector with General Electric and communication companies, he is contributing to the Qinetiq-North America team as a NASA contractor.
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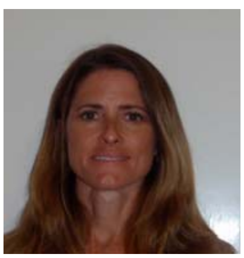

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She was the Technical Program Chair for the 1999 IEEE International AP/URSI symposium and the General Chair for the 1998 IEEE Region 3 Southeastcon conference. She has served many times on the technical program committee for the IEEE AP/URSI conferences. Dr. Wahid is a Senior Member of the IEEE and a member of the Eta Kappa Nu and the Tau Beta Pi Societies.