



NASA STTR 2020 Phase I Solicitation

T5.03 Electric Field Mapping and Prediction Methods within Spacecraft Enclosures

Lead Center: KSC

Participating Center(s): GSFC, JPL, JSC, MSFC

Technology Area: TA5 Communication and Navigation

Scope Title

Expected Electric Field Prediction Methods in Fairing/Aircraft and Spacecraft Enclosures

Scope Description

NASA Launch Services program is responsible for ensuring the safety of NASA payloads on commercial rockets. NASA has also undertaken Gateway. This includes prediction and mitigation of hazardous electric fields created within the payload enclosure and similar areas of the rocket. NASA and industry have commonly used approximation methods to determine the average fields in enclosures. In the last decade the Launch Services Program (LSP) has funded studies to support quantification of electromagnetic field characterization in fairing cavities due to internal and external sources. By accurately predicting these fields, acoustic and thermal blanketing can be optimized for Radio Frequency (RF) attenuation and design changes can be quickly evaluated reducing schedule impacts. Cost savings can also be realized by reducing stringent radiated susceptibility requirements, and reliability improved by accurately predicting signal transmission/reception environments within enclosures. This methodology can also improve human exposure safety limits evaluations for manned vehicle enclosures with transmitting systems.

Initially, studies focused on computational methods using the recent advances in computing power and the improved efficiency of matrix based solutions provided by Graphics Processing Unit (GPU) computing. Results indicate solution of an integrated fairing is deterministic, but sensitive to small variation in structures, materials. As of yet, only the empty or sparse cavity can be reliably solved with 3D computational tools, even with large computing systems and the use of non-linear basis functions. Results also indicate that computational approximation methods such as physical optics and multilevel fast multipole are not reliable prediction methods within enclosures of this scale because of the underlying assumption sets that are inconsistent with enclosure boundaries. More recently, LSP has concentrated on statistically formulating a compilation of test/computational results to produce a maximum expected environment. Preliminary results are promising in the area of statistical bounding of the desired solution. The researched methodology should offer the following advantages over 3D computational and standard volume based approximation methods:

- Predict both statistical mean and maximum expected E field and/or common mode current.
- Consider the over-moded (electrically large conductive cavities) and under-moded (electrically smaller damped enclosures).

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- Consider complex materials with multiple joined enclosures.
 - Applications of this prediction methodology are far reaching and include shielding effectiveness and prediction of fields within a cavity enclosure due to internal transmitters and operating avionics.

To enable bounded solutions in electromagnetic environment prediction, proposals are solicited to develop technology that does the following:

- Bounds the expected peak electric field environment inside enclosures such as rocket fairings, and spacecraft enclosures. The method should include the technology required, the technique, as well as the necessary verification efforts.
- Develops a numerical or statistically based methodology for characterizing shielding effectiveness of enclosures with associated applicable apertures.
- Develops methods field enhancement/reduction based on thermal/acoustic blanketing and metal/composite components such as avionics and Payload Attached Fitting (PAF) structures.
- Develops preliminary user friendly modeling software that can be easily customized to support NASA-specific applications.

References

- [1] Paul G Bremner, Dawn Trout, Gabriel Vazquez, Neda Nourshamsi, James C. West, and Charles F. Bunting, "Modal Q Factor and Modal Overlap of Electrically Small Avionics Boxes", Proc. IEEE Intl. Symp. EMC, Long Beach, August 2018
- [2] D. A. Hill, "Electromagnetic Fields in Cavities. Deterministic and Statistical Theories", John Wiley & Sons, Hoboken, New Jersey 2009
- [3] J. Ladbury, G. Koepke, and D. Camell, "Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility," NIST, Technical Note 1508, 1999.
- [4] A. Schaffar and P. N. Gineste, "Application of the power balance methods to E- field calculation in the ARIANE 5 launcher payloads cavities," Presented at International Symposium on EMC, Long Beach, 2011, pp. 284-289.
- [5] D.H. Trout, "Electromagnetic Environment in Payload Fairing Cavities," Dissertation, University of Central Florida, 2012.
- [6] L. Kovalevsky, R.S. Langley, P. Besnier and J. Sol, "Experimental validation of the Statistical Energy Analysis for coupled reverberant rooms", Proc. IEEE Intl. Symp. EMC, Dresden, August 2015
- [7] Bremner, P.G, Vazquez, G., Trout, D.H and Cristiano, D.J., "Canonical Statistical Model for Maximum Expected Emission of Wire Conductor in an Aperture Enclosure", Proc. IEEE Intl. Symp. EMC, Ottawa, October 2016
- [8] G.B Tait, C. Hager, M.B. Slocum and M.O. Hatfield, "On Measuring Shielding Effectiveness of Sparsely Moded Enclosures in a Reverberation Chamber", IEEE Trans. on EMC, Volume: 55, Issue: 2, October 2012
- [9] P. Bremner, G. Vazquez, D. Trout, P. Edwards "Shielding Effectiveness: When to Stop Blocking and Start Absorbing", IEEE EMC International Symposium, New Orleans, July 2019

Expected TRL or TRL range at completion of the project: 3 to 6

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

Phase I Deliverables: Research, identify and evaluate candidate algorithms or concepts for electromagnetic field mapping of typical spacecraft and rocket enclosures. Demonstrate the technical feasibility, and show a path towards a computer model development. It should identify improvements over the current state of the art for both time/resource savings and systems development and the feasibility of the approach in a varied-enclosure environment. Lab-level demonstrations are required. Deliverables must include a report documenting findings.

Phase II Deliverables: Emphasis should be placed on developing usable computer model and demonstrating the technology with under and over-moded conditions with testing. Deliverables shall include a report outlining the path showing how the technology could be matured and applied to mission-worthy systems, verification test results, computer model with user's and other associated documentation. Deliverable of a functional computer model with associated software is expected at the completion of the Phase II contract.

State of the Art and Critical Gaps

Reliability of communications systems is critical for all spacecraft. Determining RF exposure limits in cavity environments is also critical. Given this criticality it is often desired to transmit and receive before separation from the launch vehicle where there is precise tracking information to improve the probability of signal capture. When the transmission or reception is in the launch vehicle fairing whether for pre-flight checks or during launch, the presence of the cavity surrounding the antennas causes significant uncertainties in the desired signal. In addition, there is a significant increase in the RF environment in which the spacecraft and launch vehicle hardware are exposed. Since hardware qualification testing is based on free space environments the higher fields in the cavity can lead to an increase mission risk of failure due to susceptible hardware. Prediction of fields within rectangular highly conductive over-moded chambers is well studied in the reverberation testing community; however, launch vehicle fairings are sometimes composite and always covered with acoustic damping materials that have unknown RF damping characteristics. There are also thermal materials surrounding launch vehicle and spacecraft avionics and instruments leading to further complications in defining the communication path losses and RF environment exposure and cavity mode underdamping characteristics where more research is needed especially in the layered wall covering case.

Determining the RF environment in the fairing cavity is a significant problem that affects every launched mission; even if transmission with the fairing is not planned, it has historically happened inadvertently and the effects of failed inhibits are required to be provided. Shielding effectiveness to external range and launch vehicle transmitters are also significantly affected by not only the material conductive properties, but also the characteristics of the penetrated cavity.

3D computational electromagnetic tools are limited by the size of the matrix required to solve the typical transmit frequency of at least 2GHz in a cavity with 5 meter diameters and over 10 meter length. The size of just modeling the fairing alone is daunting using method of moments (limited also by non-uniqueness for external radiators) and unachievable with finite difference frequency domain. When internal spacecraft and blanketing structures are added, the computational limits are quickly surpassed. Approximation techniques such as physical optics and multilevel fast multipole methods are limited by underlying assumptions that do not hold in cavity environments. Time domain techniques are not clearly fitted for frequency specific applications and have shown similar size/complexity limitations.

Substantially, new methods are needed to predict path loss, shielding effectiveness and RF environment in launch vehicle fairings and spacecraft cavities.

Relevance / Science Traceability

This subtopic is intended for STTR, but all NASA payloads, particularly those with hardware sensitive to electric fields, will benefit from launch and ascent risk reduction.