2010 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
VEHICLE ELECTRONICS & ARCHITECTURE (VEA) MINI-SYMPOSIUM
AUGUST 17-19 DEARBORN, MICHIGAN

Conformal and Embedded In-Armor Antenna Solution for Army Ground Vehicles

Dr. Shikik Johnson (Presenter)
Sabre Systems inc.
65 West Street Road suite A-200
Warminster PA, 189

Waliul Mizan
Space & Terrestrial
Communications Directorate
Fort Monmouth, NJ 07703

Nahid Kabir
Space & Terrestrial
Communications Directorate
Fort Monmouth, NJ 07703

Abstract

Present day Army ground vehicles are equipped with numerous communications (COMMS) and counter improvised explosive device (C-IED) antenna systems. These platforms often have numerous highly visible antennas to support the large bandwidth and high power requirements of military radios and jammers. Currently, the demand for additional spectrum functionality for a ground vehicle ultimately leads to another antenna crowding the surface of the vehicle and reducing the survivability by increasing its visual signature. The visual signatures of large legacy whip antennas not only reduce battlefield survivability but also hinder the mobility of the vehicle in tight urban theater scenarios. With so many antenna systems onboard, mutual and joint force interoperability is of grave concern as the cosite interference between antenna systems significantly reduces its communications range and could hamper jamming effectiveness.

The goal of the Army initiated Embedded Platform Antenna System (EPAS) program is to develop a novel antenna solution for the problem of antenna blockage, cosite interference, large antenna visual signature, and platform crowding on Army ground platforms by using antennas that are conformal and embedded in-armor and potentially glass structures. Today's technology make possible next generation antennas that can be integrated onto the Army platform reducing size, weight, and power (SWaP) considerations. The key challenge is to embed these apertures into armor and glass without compromising the structural integrity of the armor (i.e., ballistic performance), while at the same time maintaining optimal operation of the antenna element. To this end, modeling and simulation techniques utilizing computational electromagnetic codes and material science practices are essential in facilitating the engineering of embedded platform armor antenna systems.

1. Introduction

Today's armed forces are faced with several challenges and obstacles to overcome. Whether the mission is covert or large-scale, Warfighters consistently seek a technical edge to gain the advantage and meet their specific objectives. The ability to adapt to changing circumstances and environments, as well as, entering and exiting the strike zone, beneath enemy radar can be the difference between life and death. Indeed, soldiers rely heavily upon dependable communications systems to conduct successful operation, and communications, command, control, computers, intelligence and surveillance, (C4ISR), play a crucial role in US Armed Forces military strategy. Moreover, communications (COMMS) and electronic warfare (EW) are vital components in the execution of all phases of warfare. However, as enemy forces evolve and become more sophisticated so to must US Armed Forces adapt to changing threats. Particularly, threats like roadside improvised explosive devices (IEDs) pose the greatest risks to soldiers in the field. To counter this threat, antenna systems will have the ability to neutralize the IED and possibly disarm it, before it can be detonated. Also, current communications vehicles stand-out in formation, easily identified because of their large profile antennas and number of antennas on top the platform. If one can destroy the command and control networks, one renders that entire platoon extremely vulnerable. Therefore these (COMMs) vehicles are not only prime targets, their maneuverability in rugged terrain is hampered by these large legacy antennas, namely, the "whip" antenna; furthermore, by sheer number and proximity these antennas tend to interfere with each other notwithstanding the fact that they serve different tasks at different frequencies. While this has been a long standing challenge, it is increasingly problematic as communications and electronic warfare systems become increasingly complex and US and Allied forces engage the enemy in urban theater as they take the fight to the nemy's safe haven. One proposed solution to this problem is to reduce antenna size weight and power (SWaP) characteristics, and develop antennas that are conformal and embedded into the armor itself. (Figure 1.) This approach among other things will reduce the large visual signature and increase agility. Along with reducing the visual signatures, novel 21st century embedded platform armor antennas (EPAS) are being developed as multifunctional, multitasking systems, performing over a wide frequency bandwidths minimizing the number of antennas on top a vehicle, reducing the issue of co-site interference and crowding dilemmas. Of course, this endeavor is easier said than done, and there are many challenges (known and forthcoming) we will have to meet in order to accomplish this feat. For example, how will engineers design functioning efficient antennas embedded in the armor without degrading the structural integrity of the armor? How will the radiation pattern of the antennas be affected? These and many other questions will be considered in this article as we will show strong evidence that this is not only possible but feasible and necessary. In summary when you combine these technological advances, namely, low profile armor embedded multitasking low power antennas systems, you greatly improve survivability of the vehicle and Warfighters' chances in combat situations across all stages of military operations giving him assured electronic dominance.

Figure 1. The need for conformal embedded antenna systems

2. Experimental Procedures

To accurately model and simulate antennas mounted on land vehicles in computational electromagnetic software programs we need to quantify the physical dielectric, electrical, and magnetic properties of the materials components comprising the armor panel. In conjunction with modeling and simulation procedures, testing on actual structures is required to fully understand how an antenna will behave on a specific vehicle in a real environment.

The Agilent E4991A impedance analyzer was employed to characterize the effective dielectric properties different materials, namely, fiberglass, rubber, and Teflon, (as a calibration standard). A full permittivity calibration procedure was performed prior to every measurement conducted using Agilent issued Teflon standards as the load. As the Teflon standard was issued by Agilent, the thickness of the standard is already preloaded in the calibration kit on the impedance analyzer. However, if one were to use his/her own standards they should be mindful to change the thickness and permittivity values in the specified areas itemized under the calibration kit menu button. After calibration, the Teflon sample measured in Figure 2. is thicker than the standard issued by Agilent, and exhibits congruent permittivity values ensuring our calibration is accurate. In our measurements we chose to display all 3, namely, real part (ε_r'), the imaginary part (ε_r''), and the loss tangent ($\tan \delta$) parameters. Below illustrates Table

1. with physical descriptions of the materials under test along with their measured permittivity values.

Table 1. Material under test, where (mU) indicates 10^{-3}-units.

Material	Texture color	Thickness (mm)	Ɛr’ (mU)	Ɛr’ (mU)	Tanδ (mU)
s-glass	Glassy	3.62	~3.4	60	-60
Rubber	Black	1.77	4 -3.3	300-100	50 -25
Teflon	White	1.529	2.08	0	0

The relationship between thickness and permittivity can be described as:

$$C = {}^{A\varepsilon}/_{d}$$

where *C* indicates capacitance, *A* is the cross sectional area of the sample, $\varepsilon_r{}'$, is the permittivity, and *d* is the thickness.

2.1 Discussions

The plots below, (Figures 2a, 2b and 2c) are actual bitmap illustrations generated by the E4991A impedance analyzer. In the figures it is evident that all the materials measured exhibit predictable and relatively constant permittivity frequency response trends over a wide frequency range. It is suggested from this data that fiberglass, and rubber can provide engineers predictable electrical properties needed for EPAS design.

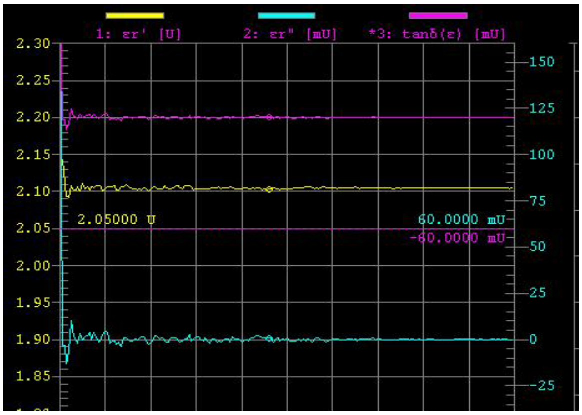


Figure 2a. Teflon calibration standard (er’= ~2.1)over wide frequency range

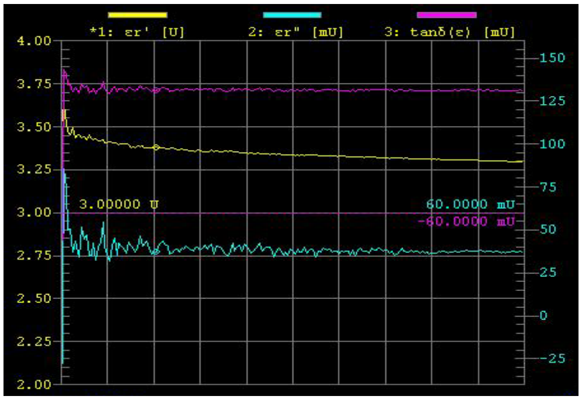


Figure εtivity frequency response of Fiberglass

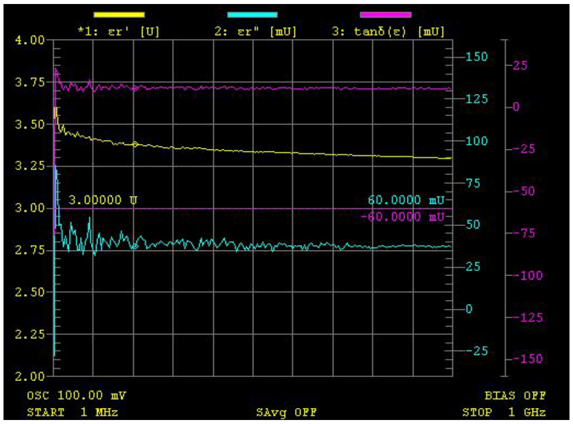
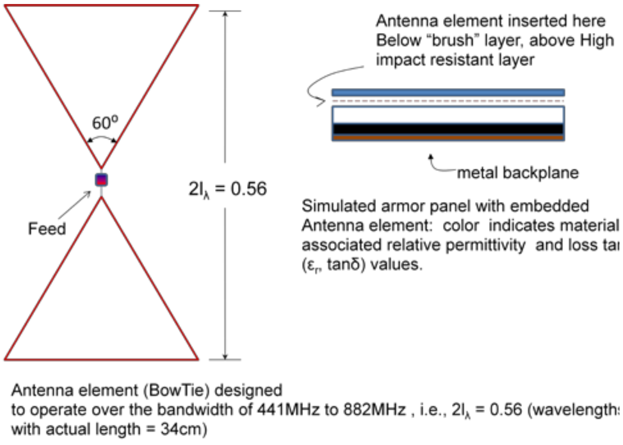


Figure 2c. Permittivity frequency response for Rubber

3. Modeling and Simulations

Electromagnetic modeling and simulation was employed to determine the effect of the materials on a planar antenna design. A triangular planar dipole (bowtie) design was chosen for ease of simulation and its inherent wideband response. Figures (3a, 3b) illustrate graphic depiction and simulated polar plots of the antenna embedded in a generic armor panel, respectively. The simulated armor panel was modeled using measured values listed in Table 1, and for the high impact resistant layer (in this case Alumina) we used ε_r = 10, and tanδ = ~10^{-4}. The antenna element was designed to operate over the bandwidth 400MHz to 882MHz, hence Figure 3b, shows an azimuth cut at

800MHz. (We are calling this panel “generic” because among the various vendors, the basic constituents are similar in their functionality but of course differ by choice of material.) The plots in the Figure, show the embedded antenna in armor superimposed with the antenna in free space. As shown in Figure 3b, the materials comprising the armor has minimal effects on the radiation gain patterns and virtually no effects on the antenna’s performance in the forward direction.



Antenna element inserted here Below “brush” layer, above High impact resistant layer

Simulated armor panel with embedded Antenna element: color indicates material associated relative permittivity and loss ta (ε_r, tanδ) values.

Antenna element (BowTie) designed to operate over the bandwidth of 441MHz to 882MHz , i.e., $2l_\lambda = 0.56$ (wavelength with actual length = 34cm)

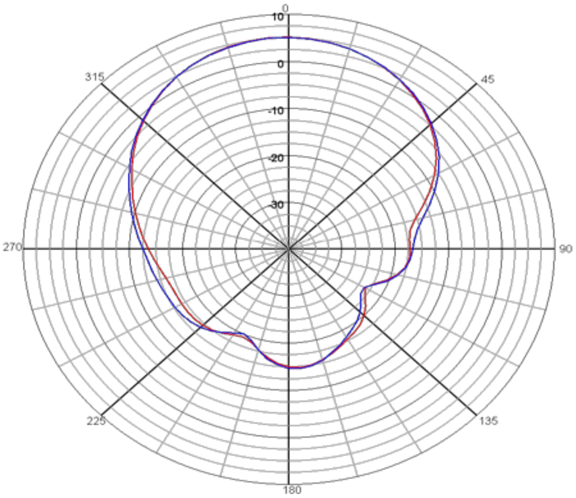


Figure3a. Bowtie antenna in generic armor panel

Figure 3b – Azimuth antenna pattern of bowtie in freespace (blue) vs. bowtie on armor (red). Notice that minimal degradations are seen in the forward direction at zero degrees.

Antenna to antenna coupling was also simulated to observe if cosite interference could be minimized using a conformal antenna in armor. Figure 4 shows a S_{21} simulation between a high power dipole to a typical legacy whip antenna (blue). Another S_{21} simulation was done with the same high power dipole to the EPAS bowtie antenna (green). As observed in the graph, the green plot shows substantially less coupling between antenna systems. [1,2,3]

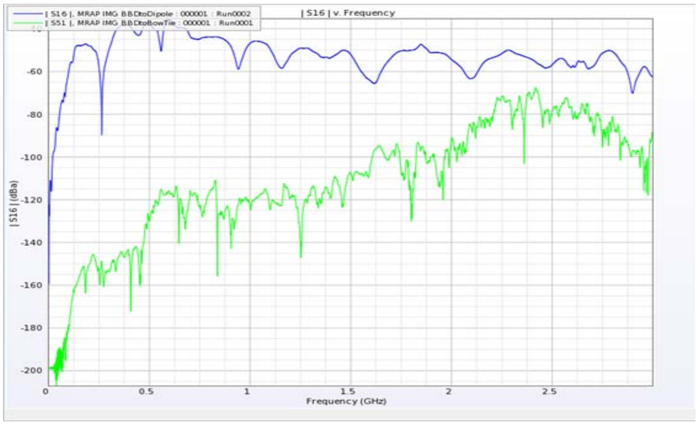


Figure 4 – Coupling plot beween high power dipole and legacy whip (blue) and high power dipole to EPAS bowtie design (green)

Conclusion

The goal of the Army initiated Embedded Platform Antenna System (EPAS) program is to develop a novel antenna solution for the problem of antenna blockage, cosite interference, large antenna visual signature, and platform crowding on Army ground platforms by using antennas that are conformal and embedded in-armor and potentially glass structures. The key challenge is to embed these apertures into armor and glass without compromising the structural integrity of the armor (i.e., ballistic performance), while at the same time maintaining optimal operation of the antenna element. To this end, modeling and simulation techniques utilizing computational electromagnetic codes and material science practices are essential in facilitating the engineering of embedded platform armor antenna systems. The simulated results indicate that an antenna design can be embedded into materials and still maintain an adequate gain and pattern performance.

References

1. Luebbers, Raymond J. Finite Difference Time Domain Method for Electromagnetics, CRC Press, NY, 1993.

2. Burke, Gerald J. Numerical Electromagnetics Code – NEC – 4.1 Users Manual, Lawrence Livermore National Laboratory, UCRL-MA-109338, 1992.

3. Balanis, C. Antenna Theory: Analysis and Design, John Wiley & Sons, Publishers, Inc., New York, 2005.