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ANTENNA PLACEMENT OPTIMIZATION ON TACTICAL VEHICLES USING A HYBRID METHOD: MODELING AND SIMULATION (M&S) AND HARDWARE IN THE LOOP

Erick E. Ortiz Palou
Timothy J. Garner
George Palafox
Communications and Electronics Research, Development, and Engineering Center
US Army
Aberdeen Proving Ground, Maryland

ABSTRACT

This paper will discuss a hybrid approach for antenna placement optimization on tactical vehicles. Tactical vehicles tend to have collocated antennas that operate in adjacent frequency bands. It may be required that two antennas operate simultaneously to satisfy a wide range of voice and data capabilities. The current process to optimize the location of antennas on platforms involves longer test times, complicated logistics, high costs, and is usually performed in an uncontrolled environment. In order to optimize the placement location and minimize the cosite interference between these antennas with consideration to the top deck obstructions, it is advantageous to use a hybrid method. The hybrid method presented here is the combination of Electromagnetic (EM) Modeling and Simulation (M&S) and Laboratory Hardware in the Loop (HWIL) testing. This paper presents the benefits of using this hybrid method in the areas of test time reduction, lessening costs, easing logistics, and providing the test in a controlled environment.

INTRODUCTION

Military ground vehicles typically have a large number of antennas collocated on a single vehicle. Some of the radios to which these antennas are connected may operate in similar frequency bands. This can lead to cosite interference, which reduces communications performance on the vehicle [1]. To maximize the performance of the antennas and the radios to which they are connected, the antennas must be placed properly. This paper elaborates on a hybrid method for antenna placement using Electromagnetic (EM) Modeling & Simulation (M&S) and Hardware in the Loop (HWIL) testing.

A combination of M&S with HWIL testing can be used to optimize the placement of collocated antennas more efficiently. This paper describes the use of this method and presents some of its benefits, including reducing required time, cost, and logistic complexity.

The traditional method for antenna optimization for performance of collocated antennas is to perform an indoor chamber test where the antennas would be tested for performance on a vehicle for a given configuration. If the performance of the antennas is not satisfactory, they are then moved to another location, and the test is repeated. This method is effective in measuring the performance of the collocated antennas. However, it has a number of inefficiencies. The costs in time and money are significantly high and the logistics of getting a test range and vehicle might be complicated.

The hybrid method presented in this paper uses M&S to calculate the EM isolation between collocated antennas with consideration to the top deck obstructions (e.g. Objective Gunner Protection Kits (OGPK), Remote Weapon Systems, Boomerang {a shooter detection system}, etc). It uses the M&S isolation results as inputs to the laboratory HWIL testing to determine the performance of the radios for a given isolation. Together, both methods allow a prediction of performance to be made for radios with collocated antennas. The hybrid method presented in this paper can reduce the monetary and schedule costs of optimizing the placement of collocated antennas. Furthermore, additional placements can be explored where a better solution might be achieved. This is possible due to the use of cutting edge EM computation technology allowing multiple simulations to be run quickly at a fraction of the cost it would take to perform chamber testing.

TRADITIONAL METHOD DRAWBACKS

The traditional method for antenna placement optimization of collocated antennas would be to test the radios and antennas on the vehicle. This can be done in an anechoic chamber or at an open-air test range. This method provides an accurate assessment of radio performance on a vehicle with a given antenna placement configuration since it allows the tester to evaluate the exact configuration as it will be fielded. However, this method has its disadvantages where the logistics, time, and money involved in performing this type of test are considerably high.

First, this type of test can only be performed once the radios and antennas have been fully integrated on to the vehicle. In some instances, a fully configured test vehicle consisting of the mounted antennas, installed radios, and properly routed cables may not be available for the test. Second, a given test scenario may reveal that there is significant interference between collocated antennas and a new configuration may have to be considered to reduce the interference. This would require the antenna mounts to be redesigned and vehicle cables to be rerouted for the new configuration. These types of changes will significantly increase cost and delay the test schedule. Third, chamber and open-air test ranges can be difficult to book. This can introduce additional delay to the schedule.

HYBRID METHOD

The hybrid method uses a combination of EM M&S and laboratory HWIL to perform antenna placement optimization on vehicles. The order of these two operations may be interchanged depending on the particular situation.

If M&S is performed first, then the output of the M&S effort can be used to drive the laboratory HWIL testing. M&S is used to predict the isolation between two antennas on the vehicle with consideration to vehicle top deck obstructions. Laboratory HWIL testing is then performed with the two radios separated by that the M&S isolation value using variable attenuators. The results of this test demonstrate the level of interference that the radios have on each other at the given isolation. Using the hybrid method in this order is most effective when an antenna placement on the vehicle is already known. This will determine if the radios will interfere with each other at a given antenna placement configuration.

Alternatively, if HWIL is performed first, then the output of the HWIL test can be taken as the minimum separation distance between two antennas on a vehicle to achieve acceptable radio performance. Multiple M&S antenna placement configurations can be run until the HWIL isolation value is achieved. Please note that top deck obstructions between the antennas such as an (OGPK), the Common Remotely Operated Weapon Station (CROWS), or if an antenna is placed on the side of the vehicle may improve the isolation between the antennas. Using the hybrid method in this order is most useful when antenna placements are not yet determined.

ELECTROMAGNETIC (EM) MODELING AND SIMULATION (M&S)

EM M&S can be used to predict the performance of antennas on vehicles. A number of different methods can be used to perform antenna M&S, including the Finite Element Method (FEM), the Method of Moments (MoM), and the Finite Difference Time Domain (FDTD) method. A number of commercial implementations are available for each code. This paper will focus on the use of the FDTD method.

The Finite Difference Time Domain (FDTD) technique is a full-wave solver that calculates Maxwell's curl equations [2] in the time domain. Yee's Algorithm is used to calculate Maxwell's curl equations based on finite difference approximations of space derivatives and time derivatives. This high fidelity software is used to model antennas and simulate their performance on vehicle models.

Two key parameters that are important for accuracy and stability when using the FDTD technique are the cell size (α) and the time step (Δt) [2]. Equation 1 shows the requirement for the cell size in terms of wavelength (λ) [2].

$$\alpha \le \frac{\lambda}{10} \qquad (1)$$

The maximum cell size must be less than or equal to 1/10th (some cases 1/20th) the wavelength of the highest operational frequency. Equation 2 shows the requirement for time step length in terms of cell edge length in the x, y, and z directions (Δx, Δy, and Δz, respectively) and the velocity of light in the medium (v) [2].

$$\Delta t \le \frac{1}{v\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \qquad (2)$$

The first step in the M&S process is to create and validate the antenna model. This consists of measuring the antenna in an appropriate anechoic chamber or to perform outdoor testing. In parallel, an antenna model must be created based on the manufacturer specifications, schematics of the antenna, or from examining a physical prototype of the antenna. Once the model is developed, it is validated by comparing the simulation outputs of the model to measured data. This is usually an iterative process, with the model being adjusted and refined until its performance closely matches the performance of the actual antenna.

The second step in the M&S process is to develop an EM model of the vehicle to evaluate the performance of the antenna model when mounted on the vehicle. Typically, the vehicle model is created from CAD models provided by the vehicle manufacturer or DoD organization. The different components of the vehicle are given the proper EM material properties such as conductivity (σ), permittivity (ε_r), and loss tangent (δ).

After the vehicle and antenna models are created, they are combined using EM Rapid Antenna Placement Optimization (RAPO) in-house software tool. Once the model configuration is complete, simulations are run to predict the isolation between the antennas. Figure 1 shows a model of a typical tactical vehicle with several whip antennas.

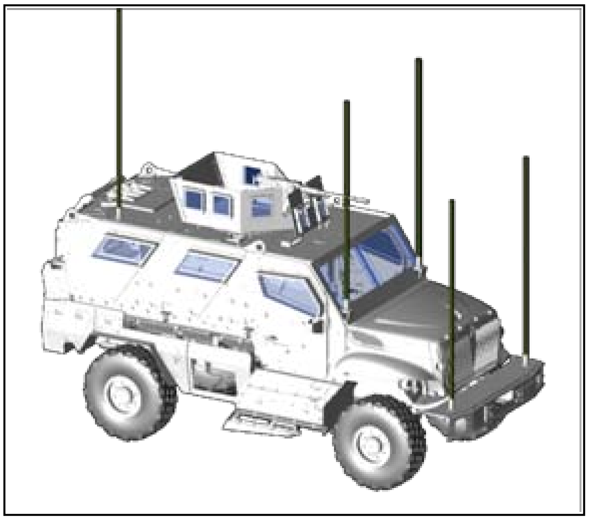

Figure 1: FDTD Model of Tactical Vehicle with Several Whip Antennas

To compute the isolation, one antenna in the model is excited with a voltage or current source; while the other antennas are passively loaded. The power received by the passive antennas is computed by the EM code. Knowing the power transmitted and received allows the isolation to be easily calculated. This process is repeated with a different antenna excited until the isolation between all antennas is known.

In FDTD, the active antenna can be excited with a broadband waveform, such as a Gaussian [3]. This allows the isolation at many frequencies to be computed with a single simulation. This is important because the isolation is a function of frequency and often varies significantly as frequency changes.

Shown below in Figure 2 is the coupling of one antenna to three other collocated antennas. As expected, the antenna further away from the Antenna under Test (AUT) yields the best isolation.

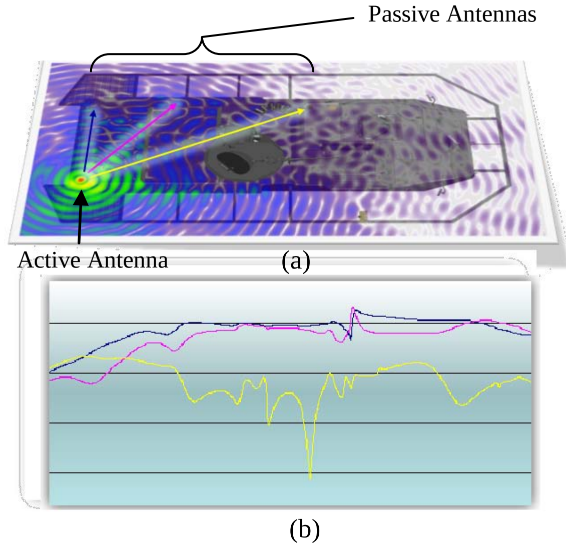

Figure 2: (a) Near fields on platform with collocated antennas. (b) Power coupling between active and passive antennas.

HARDWARE IN THE LOOP (HWIL) TESTING

HWIL testing allows the amount of interference between radios to be determined in the laboratory. It does not require access to a test vehicle or a large test range. HWIL testing also provides the ability of viewing the transmission signals at any connection point using a Spectrum Analyzer. Viewing the signals is important not only to understand how the system behaves but also to perform the analysis of the case study and the formulation of conclusions & recommendations. Viewing brings the RF phenomenon from an “invisible”, “intangible” and “complicated” realm into the “real”, “tangible” and “easier to work with” realm.

When studying the effects of interferers that might affect the antennas on a platform it is very important to correctly set up the equipment on the test bench. The most important consideration when assembling the system on the test bench is to accurately replicate the test scenario. Different antennas along with the wide variety of radios have different behaviors and the challenge lies in accurately representing the actual scenario. In replicating the test scenario, the signals must also be replicated. For example, to replicate many signals coexisting in a system, a coherent combiner can be used. To replicate a signal freely traveling back and forth in space, a dual directional coupler can be used. Furthermore, for networking communications, a circulator is used to ensure the signal travels in a straight path maintaining the integrity of the network while working on the main voice or data signal.

A typical test configurations consists of at least one transmit radio, an interferer signal, couplers, and variable attenuators. Bench tests can be performed for a variety of reasons but typically they validate that a suggested configuration works and it also can provide a minimum coupling value for a suggested configuration to work.

In the case of validating a configuration, all the parameters should be accurately replicated on the test bench [3]. These include but are not limited to: over-the- air loss (coupling) transmit power, interferer signal, couplers, and a spectrum analyzer. The coupling effect is typically replicated by the use of high power variable attenuators. The interferer signal is typically replicated with a signal replicator or a white noise generator. Finally, the spectrum analyzer is used to monitor the system. Figure 3 shows a typical test setup for a HWIL test.

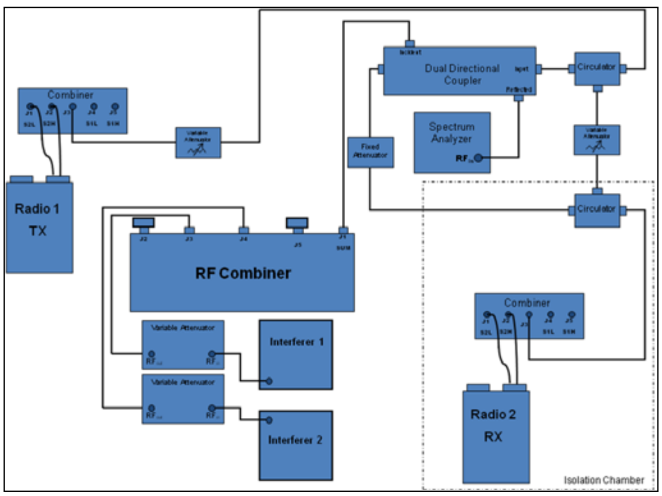

Figure 3: Sample Setup for Hardware in the Loop Testing

In the case of providing a minimum coupling value for a configuration, the system is set up to recreate the suggested changes but one of the many variables is fixed. For example, if the intent is to measure the needed antenna coupling from an interferer, the test runs will be repeated until an acceptable coupling value is achieved by progressively changing the variable attenuator for the over the air loss. The number at the variable attenuator that would allow the system to work at the desired performance would be the coupling needed. This information will then be validated by running a M&S configuration to verify where in the platform the needed coupling can be achieved, thus resulting in an optimal antenna placement configuration.

This hybrid system is feasible due to the availability of many hardware items necessary to recreate a scenario that mimics an actual indoor/outdoor test scenario. For example, it is possible to recreate a chaotic atmosphere were many signals are interacting with each other by adding interferers with couplers. It is also possible to force signals into taking a specific path in a loop by using circulators. Finally, the distance between antennas can be simulated by using attenuators.

CASE STUDY

CERDEC used the hybrid method presented in this paper to perform antenna placement optimization on the M1 Abrams tank. The need for the work arose when a new system was added to the Abrams. To incorporate this system, one of the antennas on the Abrams needed to be relocated.

EM M&S was used to evaluate new placements for the antenna in terms of gain pattern performance. A CAD model of the Abrams was used to create an EM model of the platform. This model was created using the aforementioned EM software. The antenna models were readily available from the CERDEC S&TCD RFMS Branch library of antenna models. The platform model was then populated with the antenna models. Multiple simulations were run to determine the isolation as the active antenna was moved from the other passive antennas. In this optimization study, the effects of the antenna radiation pattern were analyzed ensuring they were minimal or negligible. The results of the simulations were used to choose a potential location where acceptable gain performance and enough isolation from other antennas are achieved.

HWIL testing was then performed to see if other radio frequency systems would cause interference with the antenna at the new location. Based on the results from the hybrid method, an optimized location for the antenna was determined.

CONCLUSION

The method presented in this paper can be used earlier in the acquisition life cycle to help avoid the need for costly redesigns. It can also be used to quickly identify and resolve issues with fielded systems. The hybrid method should not be used to completely replace the traditional testing. It should be used to supplement and enhance the traditional test method. The hybrid method can serve to mitigate cost, schedule, and performance risk for the integration of radios and antennas onto ground vehicles.

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