Bandwidth Enhancement of HF Antennas Mounted on Military Platforms Using a Characteristic-Modes-Based Design Approach

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***Abstract*—Narrow bandwidth is a challenging problem for designing platform-mounted electrically small antennas in the high-frequency (HF) band. In this paper, we demonstrate a process that can be used to improve the bandwidth of a platform-mounted HF antenna or antennas by taking advantage of the presence of the platform. Specifically, we examine a simplified model for the Expeditionary Fighting Vehicle (EFV) and examine how the mounted antennas can be used to excite a desired natural resonant mode of this platform for bandwidth enhancement. The proposed approach is employed to successfully enhance the bandwidth of horizontally-polarized HF loop antennas from 0.64% to 0.79% and 0.89%, by using respectively one, two, or four half loop antennas to excite the desired mode of the EFV.**

***Index Terms*—Antenna arrays, antenna feeds, mutual coupling.**

I. Introduction

In a variety of communication applications operating at the HF bands, antennas are mounted on vehicular platforms, such as Expeditionary Fighting Vehicles (EFVs). Examples include various military applications including communications and electronic warfare applications [1]–[3]. Due to the large wavelengths in the HF band, most of the antennas used for these applications tend to be electrically small radiators. However, as the electrical dimensions of such an antenna decrease, its bandwidth and the radiation efficiency also decrease [4]. This reduced bandwidth is particularly problematic at HF frequencies where antennas tend to have extremely small electrical dimensions. Since many HF antennas are mounted on platforms that are generally larger than the HF antennas mounted on it, if the platform can be used as part of the antenna, the maximum linear dimension of the antenna can be increased and the bandwidth problems may be alleviated. To do this, the combination of the antenna and the platform must be considered as the main radiating structure from the beginning. In the past, various research groups have studied platform-mounted antennas and proposed different techniques for taking advantage of the platform [3], [5]–[8]. In this paper, we demonstrate how the bandwidth of EFV-mounted antennas can be improved by treating the platform as part of the antenna system.

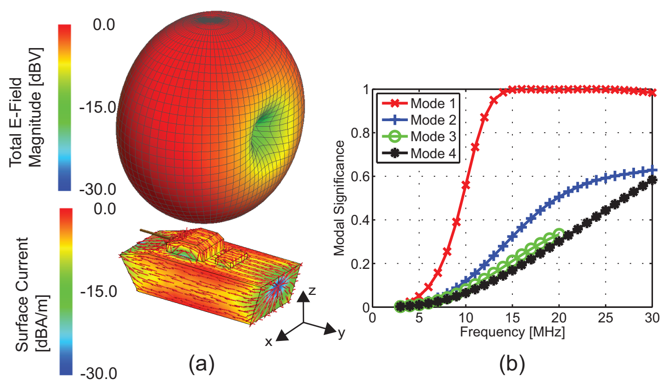

Fig. 1. (a) Simulated normalized current distribution and normalized radiation patterns of mode 1 of the platform. (b) Simulated modal significance of the platform.

II. Antenna Design

We consider the Expeditionary Fighting Vehicle (EFV), as a typical military vehicle and use a simplified model of it shown in Figs. 1(a) and 2(a) in our studies. The design process of the proposed antenna system starts by examining the natural resonant modes of the EFV and their associated current distributions. The modal significance curves of the structure examined in this work are shown in Fig. 1(b). The commercial full-wave software FEKO was used to carry out the analysis of characteristic modes. A mode is considered resonant when the modal significance of that mode attains a value of 1 [9], and a mode is considered significant when the modal significance is greater than or equal to 0.707 [8]. As can be observed from Fig. 1(b), the dominant mode for this structure is mode 1, and this mode is significant above approximately 11 MHz. Fig. 1(a) shows the electric current distribution and the radiation pattern of mode 1 of the platform. Examination of the electric current distribution and radiation patterns of Mode 1 indicates that it has a direction of maximum radiation towards zenith. In the subsequent steps of this process, mode 1 of the platform is selected as the desired mode to be excited by proper placement and design of the mounted antennas.

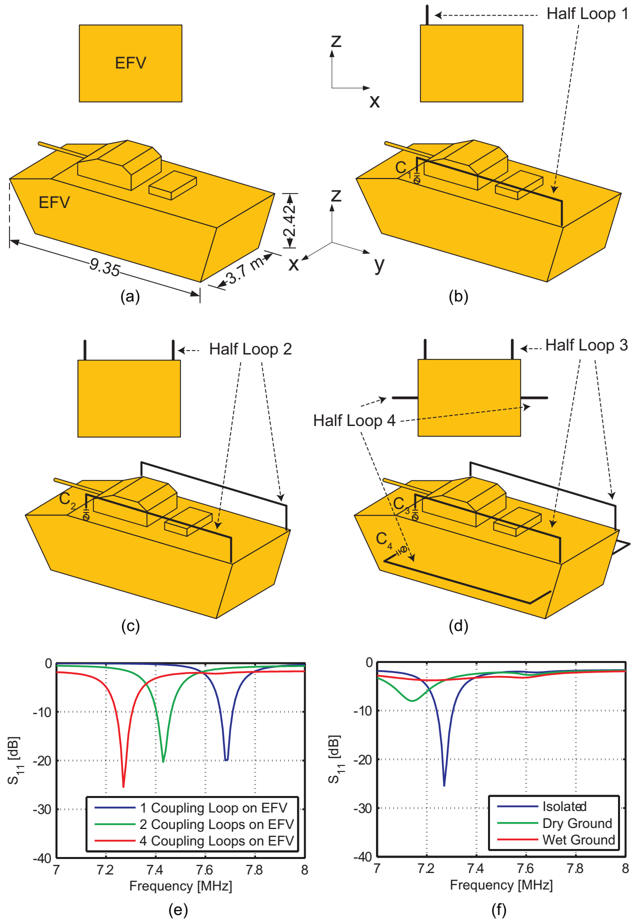

Fig. 2. (a) The simplified EFV platform. (b) One half loop antenna at the edge of the platform. (c) Two half loop antennas on top and at the edges of the platform. (d) Two half loop antennas on the top and one half loop antenna on each side of the platform. (e) Simulated S_{11} of the EFV-mounted antennas. (f) Simulated S_{11} of the platform-based antenna shown in (d) when the platform is isolated or when it is placed on a dry or wet ground.

Examination of the current distribution of mode 1 of the platform, shown in Fig. 1(a), reveals that the entire antenna acts as a fat dipole for this mode. Such a dipole antenna can be fed by a voltage gap placed at the center of the dipole. However, this requires dividing the platform in two, which is not practical. Alternatively, a magnetic current loop with constant amplitude placed on the periphery of the platform at its central part can also be used to excite this mode. Such a magnetic current can be approximated by placing multiple loops that are all fed with the same magnitudes and phases and placed on the periphery of the platform. Fig. 2(b) shows an example of this excitation scenario where a single loop antenna is used to excite the desired platform mode. To magnetically excite mode 1 on the EFV, where the current direction on the platform is in the $\hat{y}$ direction and the H-plane of the fat dipole is on the $x-z$ plane, the ideal direction of the matched half loop antenna is on the $y-z$ plane as shown in Fig. 2(b). Examining Fig. 1(a) reveals that the electric current density of Mode 1 is strongest at the edges of the structure. Therefore, the loop is placed at the edge of the platform.

Fig. 2(e) shows the input reflection coefficients of the half loop antenna on the EFV, shown in Fig. 2(b). The simulation was conducted in FEKO. Since the half loop is electrically small, the input impedances is reactive. To minimize the internal reactance, a capacitor is placed in series with the excitation source and the half loop, as shown in Fig. 2(b). As can be observed, this EFV-mounted antenna exhibits a 10-dB return loss fractional bandwidth of 0.64%. This is an extremely narrow bandwidth. This is to be expected since a single loop does not effectively synthesize the required magnetic current distribution on the periphery of the platform. To improve the efficiency of excitation of Mode 1, the number of loops placed on the platform can be increased as shown in Fig. 2(c) and 2(d). This will in turn enhance the bandwidth of the antenna system because the radiating components of the current are now distributed over a larger volume. In other words, the available volume (i.e., the platform surface) is more efficiently utilized. Fig. 2(c) shows a scenario where two half loops are placed on top of the EFV platform and at its edges where the current density of Mode 1 is strongest. Fig. 2(d) shows a similar scenario where the number of antennas is increased to four to provide a more uniform excitation of Mode 1. In both cases, all half loops mounted on the platform are excited in phase and with the same magnitudes. In Fig. 2(d), two of the half loops were placed on the side of the EFV due to practical reasons. The height of these half loops (Half Loop 4) were tuned to match the operating frequency of the other two half loops (Half Loop 3), which were placed on the top of the platform. The dimensions of the half loops and the values of the capacitors used in the different scenarios are listed in Table I. Fig. 2(e) shows the simulated input reflection coefficients of these antennas calculated by FEKO. S-parameter files of realistic two-way and four-way power splitters were used in the simulation of the two half loop and four half loop scenarios. As can be seen, by using multiple loops strategically placed at different locations on the platform, the bandwidth of the antenna system is considerably increased. Specifically, for the case of two loops, the 10-dB return loss fractional bandwidth is increased to 0.79%, and for the case of four loops, it is increased to 0.89%. These enhancements correspond to factors of 1.2 and 1.4 respectively compared to a single half loop mounted on the same EFV platform. This is despite the fact that the maximum linear dimensions of the structure (feed loops and the platform) are not changed. The bandwidth of the antenna system increased because the volume occupied by the entire structure (platform and the feed loops) is more efficiently utilized by the radiating components of the electric currents. As the number of loops increases in the scenarios shown in Fig. 2(b)-(d), the radiation patterns approach that of mode 1 (Fig. 1(a)). Fig. 2(f) shows the simulated input reflection coefficients of the platform-based antenna shown in Fig. 2(d) when the platform is isolated (i.e. no ground) or when it is placed on a dry or wet ground. As can be observed, the presence of real ground does impact the responses of platform-based antennas.

TABLE I
DETAILS OF THE HALF LOOPS AND THE RELATED MATCHING CAPACITORS USED IN THE DIFFERENT SCENARIOS.

Half Loop*	Capacitor	Loop Height
Half loop 1	17 pF	1 m
Half loop 2	20 pF	1 m
Half loop 3	21 pF	1 m
Half loop 4	16 pF	1.33 m

* The diameter of all loops are 81.92 mm. The length of all loops are 6.5 m.

III. CONCLUSION

The results presented in this paper show that magnetic excitation of the natural resonant modes of a large platform can be used as a method for bandwidth enhancement of HF antennas intended to be mounted on large vehicular platforms. In the example examined in this paper, a simplified EFV platform acts as the main radiator, and one or more small loop antennas are used to couple energy from a source to the desired resonant mode of the platform. It was demonstrated that the desired resonant mode of the platform can be successfully excited, and that the bandwidth of this EFV-mounted antenna can be enhanced by a factor of 1.2 or 1.4 compared to one half loop antenna on the platform by using two or four half loop antennas to excite the desired mode. This is despite the fact that the maximum linear dimensions of the structure (feed loops and the platform) are not changed. This bandwidth enhancement is due to the fact that, as the number of feed loops are increased, the available volume (i.e., the platform surface) is more efficiently utilized. While our work demonstrates the feasibility of using platform-based antennas to achieve wide band HF antennas, there are a number of important issues that need to be taken into account when designing antennas for more realistic and practically relevant platforms. For example, the impact of real ground or water on the performances of these antennas has to be considered.

ACKNOWLEDGMENT

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