A Discussion on Small Antennas Operating with Small Finite Ground Planes

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INTRODUCTION

In the design of small device integrated antennas, there are a number of physical properties that together establish the antenna's electrical performance characteristics. With small wire antennas, these physical properties include overall wire length, wire diameter, geometry and perhaps most important, the antenna's overall height and occupied volume. Many times, the performance properties of the small antenna are determined through simulation or measurement, where the small antenna is located on an infinite or large conducting ground plane. With small device integrated antennas, the ground plane dimensions may be less than the operating wavelength and may closely approach the size of the antenna. These factors can substantially affect the performance characteristics of the small antenna. In fact, the ground plane itself becomes an integral component of the radiating structure and must be included in determining the antenna's effective electrical size. Here, we examine the performance properties of several small antenna configurations located on a device sized ground plane. We consider the relative effects of the ground plane size and the antenna's location on the ground plane, in terms of how these factors establish the antenna's performance characteristics.

THE SMALL ANTENNA

Many, if not most small device integrated antenna designs are based on derivatives of the well known planar inverted-F antenna or PIFA. The small, single resonant PIFA is a straight-forward design, derived from the transition of a straight-wire monopole into an inverted-L antenna or ILA (for height reduction), then into an inverted-F antenna or IFA (for impedance matching) and finally, into a PIFA for increased operating bandwidth. From the perspective of input impedance and bandwidth, the ILA [1] is a reduced height monopole with correspondingly decreased resonant resistance and bandwidth. The IFA [1] is a parallel stub matched Inverted-L and the PIFA is an IFA with increased conductor volume, which allows for increased operating bandwidth and increased flexibility in terms of achieving multiband operation.

In recent years, there have been a number of PIFA configurations described in the literature for single and multiband operation [2-6]. These are generally designed to operate in one or more of the wireless communications bands, which may include: AMPS band Cellular/GSM 850 (824 – 894 MHz), GSM 900 (890 – 960 MHz), GSM 1800 (1710 – 1880 MHz), PCS/GSM 1900 (1850 – 1990 MHz), and 802.11 (2.4 – 2.485 GHz and 5 GHz [3 bands between 5.15 – 5.825 GHz]). Given the number of PIFA based antenna designs presented in the recent literature for these wireless applications, this work in not intended to present new design solutions that add to the available options for single or multiband device integrated antennas. Rather, this work is intended to provide a discussion on how the ground plane configuration affects the antenna's performance. For this reason, the designs presented here do not necessary provide optimal performance in the usual wireless operating bands.

It is a known fact that the ground plane size affects the small device antenna's performance [4]. The most comprehensive study of the ground plane's effect on the performance of PIFA antennas, known to the author at the time of writing, is presented in [7].

BASELINE CONFIGURATIONS

The baseline configurations considered here include the ILA, IFA, PIFA and the disk loaded folded monopole antenna (DLFM) depicted in Fig. 1. These initial configurations are considered where they are located at the edge of a nominally device sized ground plane having dimensions of 105 x 40 x 1 mm as illustrated in Fig. 2. The ILA is designed for a single operating band (defined by the -10 dB return loss points with respect to 50 Ω) of 2.176 – 2.596 GHz; the DLFM is designed for a single operating band of 1.735 – 1.903 GHz; the IFA is designed to operate in two

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bands: 810.75 – 839.3 MHz and 1.976 – 2.094 GHz; and the PIFA is designed to operate in three bands: 951.75 – 1012.5 MHz, 1.870 – 1.90 GHz, and 2.398 – 2.4146 GHz. The corresponding return loss of the antennas is presented in Fig. 3. All results are simulations performed with Microwave Studio [8].

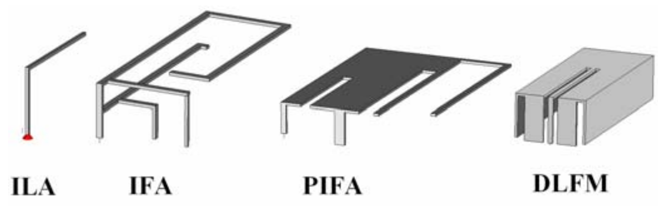

Fig. 1. Depiction of the four small device integrated antennas: The inverted-L (ILA), the inverted-F (IFA), the planar inverted-F (PIFA) and the disk loaded folded monopole (DLFM).

THE EFFECTS OF GROUND PLANE SIZE AND ANTENNA POSITION

In [7], the performance properties of a PIFA, exhibiting a single operating band near 2.0 GHz, were evaluated as a function of decreasing the ground plane size. The PIFA was located in the center of a square ground plane, and the ground plane size was decreased from approximately $2.8\lambda^2$ to $0.04\lambda^2$. It was shown that the resonant frequency of the PIFA was nearly constant until the ground plane size was reduced to $0.04\lambda^2$, where it increased to approximately 2.4 GHz. It was also shown that the operating bandwidth of the PIFA decreased with decreasing ground plane size.

To illustrate the effects of the ground plane size on the antennas' performance, we begin considering the return loss of the four small antennas, presented in Fig 4a, where the antennas are located in the center of a 240 x 240 x 1 mm ground plane. The most significant changes occur with the two antennas designed for single band operation, the ILA and the DLFM. In each case, there is only a small change in the antenna's resonant frequency, with a maximum frequency shift of approximately 7%. However, there is a substantial decrease in the resonant resistance. The resonant resistance of the ILA decreases to 13.5 Ω from 41.6 Ω, while the resonant resistance of the DLFM decreases to 6.9 Ω from 67.1 Ω. With the multiband antennas, there is a similar degradation in the return loss at the lowest operating band. The resonant resistance of the PIFA antenna decreases to 8.1 Ω from 67.6 Ω, while the resonant resistance of the IFA decreases to 3.2 Ω from 47.9 Ω. At the higher operating bands, there is not a significant change in the PIFA's performance characteristics, however, there is a noticeable change in the operating properties of the IFA, particularly in the operating bandwidth near 2.0 GHz.

At this point, one might conclude that the ground plane size, in and of itself, is the significant factor in establishing the performance properties of the small antenna located on a finite ground plane. To investigate this point further, we locate the four antennas at the corner edge of the larger 240 x 240 x 1 mm ground plane. The return loss of the four antennas is presented in Fig. 4b. It is significant to note that the single operating bands of the ILA and DLFM and the lowest operating bands of both the IFA and the PIFA are restored. At the higher frequencies, the operating band of the IFA is not fully restored, while the operating bands of the PIFA are no longer matched to 50 Ω. It is evident that both the ground plane size and location of the small antenna are significant in establishing the antenna's performance.

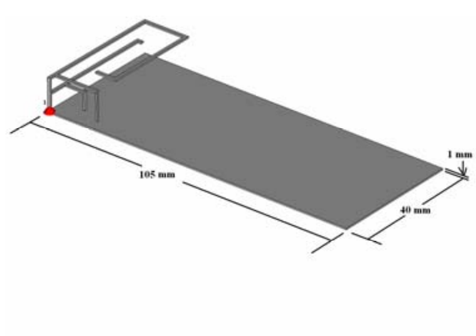

Fig. 2. Depiction of the IFA, edge located on the small (105 x 40 x 1 mm) ground plane.

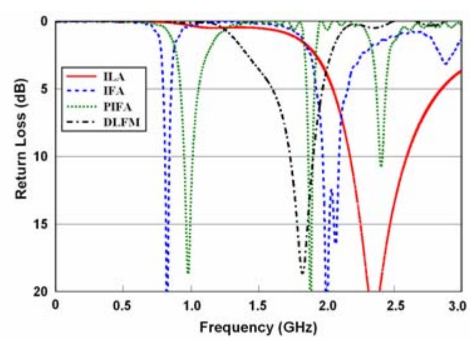

Fig. 3. Return loss of the four baseline antenna configurations on the small ground plane.

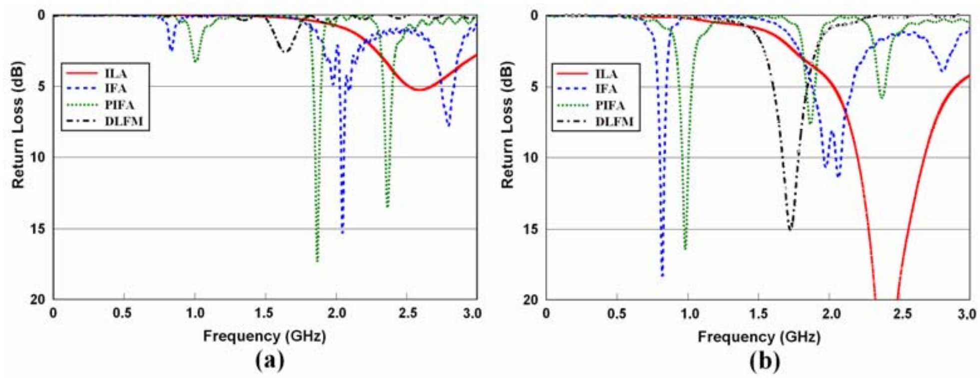

Fig. 4. The return loss of the four small device integrated antennas: (a) Located in the center of a 240 cm x 240 x 1 mm ground plane, and (b) Located at the corner edge of a 240 cm x 240 x 1 mm ground plane.

As further evidence of the significance of the antenna's location on the ground plane, we consider the four antennas located at the center of the 105 x 40 x 1 mm ground plane. The return loss of the four antennas is presented in Fig. 5. The single band return loss of both the ILA and the DLFM are significantly decreased. The return loss in both the lower and upper operating bands of the IFA is degraded. However, with the PIFA, only the lower operating band return loss is degraded. There is not a significant change in the upper operating bands of the PIFA, illustrating that the antennas are not affected in exactly the same manner.

The final point we consider is effect of the ground plane on the radiation pattern of the antennas. To illustrate this point, we consider the DLFM located at both the edge and center of the small, device sized ground plane. The radiation pattern for both configurations is presented in Fig. 6. There is a substantial difference in the radiation pattern of each configuration. The difference in the radiation patterns is directly a function of how the antenna and ground plane couple, establishing the current distribution on both the antenna and ground plane surface. In the design of small antenna elements on small finite ground plane, the ground plane is an integral part of the radiating structure.

DISCUSSION

It is first important to note that in theory, the impedance of any of the antenna and ground plane configurations considered here can be impedance matched to 50 Ω in any single operating band. It is the antenna's operating bandwidth that is the limiting performance characteristic, determined as a function of the antenna's size or occupied volume. Here, we did not consider impedance matching or operating bandwidth per se, but rather sought to demonstrate that the performance characteristics of the small antenna are defined not only by the antenna element itself but also by the ground plane size and location of the antenna on the ground plane.

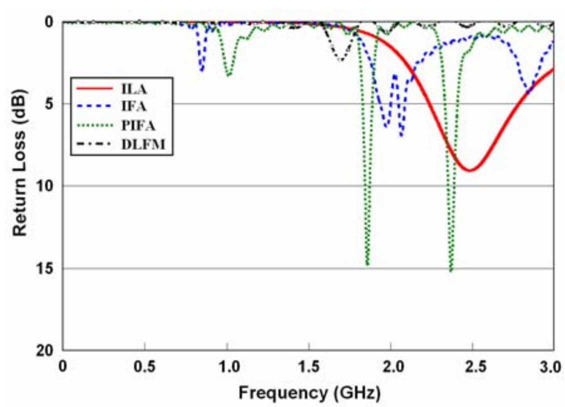

Fig. 5. Return loss of the four small device integrated antennas located in the center of the small (105 x 40 x 1 mm) ground plane.

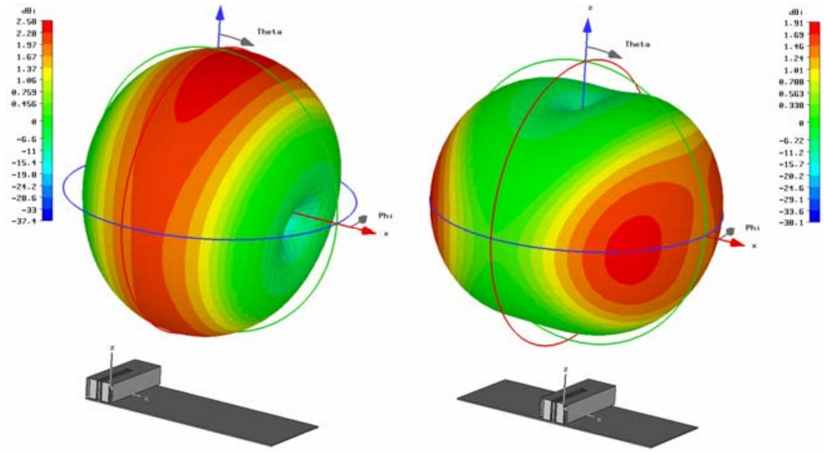

Fig. 6. Radiation patterns of the DLFM antenna located at the edge and center of the small (105 x 40 x 1 mm) ground plane.

The performance characteristics of the small device integrated antenna are a function of the antenna's current distribution as well as the induced current distribution on the finite ground plane. While some generalizations can be made, it is important to note that not all antennas couple to the ground plane in exactly the same manner. With the single operating band designs, the IFA and DLFM, center mounting the antenna on the ground plane significantly deteriorated the return loss. With center mounting, the antennas tend to behave as short monopoles, exhibiting reduced resonant resistance and operating bandwidth. The effect is more pronounced with increasing ground plane size. Similar behavior is exhibited by the IFA and PIFA at their lowest operating bands. At the upper operating bands, where the ground plane size approaches 1 λ, all four of the antennas exhibit improved or degraded performance as a function of how they couple to the ground plane. Note that all of the antennas did not behave in the same manner at the upper frequency bands since they couple differently to the ground plane.

In all cases, center mounting the antenna on a large ground plane allows the antenna's occupied volume to be determined by the radius of a sphere circumscribing the maximum dimension of the antenna. The currents on the ground diminish at the ground plane edge and the ground plane size does not need to be included in the antenna's dimension. With the edge mounted configuration, and particularly with the small finite ground plane, the antenna's occupied volume extends beyond the antenna dimensions and the finite ground plane size must be included in the radius of the circumscribing sphere.

Finally, in the case of small antenna elements located on device sized ground planes, we recognize that the radiating structure includes both the antenna element and the ground plane. For this reason, the element design and the resulting performance properties are valid only when the ground plane size and antenna location are considered.

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