Control of Ground Plane Influence on Antenna Radiation Pattern for Mobile Handheld Devices

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Abstract—This paper presents the effects of a choke-slot on solid ground plane of an antenna, fabricated on FR4 substrate to be used in mobile communication system. Techniques have been discussed to control the ground plane current and reduce any degradation. The simulations and measurements show that introducing a slot on a conventional solid ground plane can significantly improve the radiation pattern of an antenna. Good performance at the Personal Communication Service (PCS 1900) band promises the use of this antenna on personal mobility, advance cellular phone services and wireless communication services. Achieving the maximum gain towards the expected direction for mobile phone application with the help of a choke-slot on antenna’s ground plane demonstrates the effectiveness of this technique.

I. INTRODUCTION

The boom in consumer wireless devices has driven designers to seek smaller and more compact antennas. This is typified by recent developments in mobile phone antennas. Quarter-wave monopoles were replaced by external stubby helical elements while modern handsets use ‘internal’ elements based upon bent wire structures such as PIFA’s. A similar design approach is being adopted by other small wireless modules (WLAN modules, GPS navigation units, DAB receivers, etc.). These antenna design solutions are generally successful but can suffer a pitfall to the unwary designer. The usual design approach places emphasis on tuning the ‘element’ for VSWR and makes the assumption that the other half of the antenna is realised by image currents in the ground plane. However, image theory is based on the concept of an infinite ground plane. Once the ground plane becomes finite then standing waves may be set up and this may cause severe distortion to the radiation pattern from that expected. In this paper we consider ways to correct for such ground-plane currents. Studies on the effects of ground plane on antenna performance had been discussed in open literature back in late 1960s [1–3]. Most such work focused on the characteristics of a monopole antenna mounted on a finite circular ground plane. Later, the effects of the ground plane on other antenna types including microstrip antennas were also been studied [4-5]. Current applications require antennas to be mounted on small ground planes such as found in handheld communication devices. The most popular model for a ground plane assumes to be perfectly conducting, planar, and infinite in extent. But real ground planes are finite in extent and can be in the plane of the element rather than orthogonal as in [1-6]. The finite extent is responsible for results that deviate from those for a perfect ground plane. Thus, models for antennas on a ground plane of infinite extent are not sufficiently accurate for most of these applications. Generally, when the ground plane is comparable to a wavelength electrical performance can be different from that of an infinite ground plane [6].

In this paper, the effects of finite ground plane current have been studied for typical handheld application. Simulated and measurement results show that the antenna radiation pattern possesses significant distortion due to ground plane effects. Techniques to compensate for the finite ground plane effect for maintaining good electrical performance are investigated.

II. EFFECTS OF GROUND PLANE

An early example of the reduced size antenna element for mobile phones is the pinpatch antenna proposed in [7]. Whilst this design offered significant reduction in antenna size at that decade, but careful examination of the polar diagram shows a significant problem. In principle the pin-patch element operates like a reduced size monopole if placed above an infinite ground plane, with maximum radiation uniformly radiated in the azimuth plane. In the example of [7] the radiation pattern actually exhibits a significant 10 dB null in this plane, with major lobes at oblique angles. For a mobile phone application this is far from ideal as this would be in the principal direction towards a base station. The problem is caused by the finite sized ground plane. In the example the ground plane is in fact 3λ/4 at the operating frequency; hence the entire structure is operating like a 1λ dipole, hence the nulls on azimuth. While the antenna is essentially defined by the antenna element, the ground plane structure must be included as this is very much part of the antenna. In [7] is seen that while the antenna element appears to provide the desired
bandwidth and impedance and radiates, the ground plane currents can dominate the radiation pattern. To compound the problem the size and shape of the ground plane is often outside the remit of the antenna designer (i.e. overall structure). However it is proposed here that the antenna designer can apply techniques to control the ground plane current and limit any degradation.

A. Antenna with Solid Ground Plane

We considered an antenna with finite ground plane similar to [7]. Instead of using a metallic case, a planar form of that antenna had been introduced with similar dimensions. The planar ‘Tee’ antenna is fabricated on a FR4 substrate with relative permittivity of 4.3 and a thickness of 1.6 mm. The antenna element line width is 1.5 mm. Because of the trend for smaller handheld devices a second design was considered with a smaller ground plane. Here the overall length of the structure has been reduced from 137mm to 88.5mm, which would easily fit in contemporary mobile devices.

To illustrate the effects of ground plane current the radiation properties for the design assembly has been computed at resonance using CST MWS. The radiation patterns of fabricated antennas were also explored in azimuth plane inside the anechoic chamber of University of Greenwich at the frequency of 1.9GHz. In the simulation an ideal source is used at the feed point but for measurement a physical cable is attached. This is indicated in Fig. 1(a), although in experiments the cable extends along the x-axis and a balun arrangement was used to reduce currents on the outer braid of the cable. Also, patterns are taken for E_y polarization in the YZ plane, such that any cable radiation effects are minimized. The results of the antennas with solid ground planes of different lengths are plotted in Fig. 2.

![Fig. 1: (a) Planar antenna with conventional solid ground plane with similar dimensions to [7] (b) Similar antenna printed on PCB with smaller ground plane.](image1)

![Fig. 2: Radiation pattern for Ey polarization in the YZ plane (a) antenna of Fig. 1(a) (b) antenna of Fig. 1(b) (reduced size)](image2)

Results show that, the test antenna with bigger solid ground plane suffers from a 10dB null along the z-axis, similar to [7]. But this is the direction we would expect maximum gain if the Tee element were acting as a reduced height monopole. We examined the radiation pattern of a second design with smaller ground plane and found the power distribution to be even worse if it is to be used as a communication device antenna. This is due to the radiation pattern being dominated by the ground plane current. The unwanted influence of ground plane currents is not a new problem and solutions that have been applied by antenna designers to other antenna installation problems can be adopted here. A coaxial cable ‘choke’ baluns can be used to feed the antenna in order to reduce the effects of currents flowing on the external surface of the feeding cable. Similarly choke–slot technique can be applied to the ground plane surrounding an antenna such as in [8].
III. COMPENSATION TECHNIQUE

A. \( \lambda/4 \) truncated ground plane

To control the ground plane effect over the radiation pattern a transverse slot cut on a distance of \( \lambda/4 \) on the ground plane has been introduced. The dimensions of the upper part Tee antenna and the overall size of the antenna are same as the smaller solid ground plane antenna. The width of the slot is 1.5mm, which is a simple line across the X axis. The feeding cable is along the X-axis such that any currents on this cable have minimal effect on the YZ pattern. The overall design has been shown in Fig. 3 (a).

B. Use of \( \lambda/4 \) Choke-Slot Configuration

An alternative solution using a ‘choke-slot’ was considered on the same design. Here a slot is cut in the ground plane to create a longitudinal slot line that can be used to create a \( \lambda/4 \) transformer. The width of the slot cut is kept 1.5mm. The antenna ‘ground’ currents then flow on the outer section of this slot line but the inner section, connected to the lower portion of ground plane is then isolated. The design configuration is illustrated in Fig 3 (b) below:

Fig. 3: Structures of smaller ground plane antennas
(a) with truncated ground and
(b) with \( \lambda/4 \) choke-slot

To demonstrate the effect of a choke slot the radiation pattern of two antennas with slot cut has been simulated using CST MSW. The power distribution of the fabricated second approach has been measured with the same experimental setup as solid ground plane antennas. Again \( E_y \) polarization in the YZ plane is considered. The results are presented in Fig 4. From the figures, it is clear that, after introducing the choke-slot the null and degradation is completely eliminated and the resultant structure is now approximating the ‘doughnut’ shaped pattern. The radiation characteristic has appeared as an ideal doughnut shaped pattern. One of the reasons of this might be that, on the antenna without any slot, the electric currents are mainly concentrated around the feeding strip. Thus, the ground plane significantly affects the impedance and radiation performance of the antenna. As a result, the performance of the slotted ground plane antenna has the advantage of the suppressed ground plane effects over the conventional designs without choke-slot.

Fig. 4: Radiation pattern of the antenna with ground plane compensation
(a) Structure of Fig. 3(a) with truncated ground
(b) Structure of Fig. 3(b) with \( \lambda/4 \) choke-slot

Computed and experimental results show good agreement between them. The slight discrepancies are due to the interaction of the essentially ‘balanced’ antenna being fed by an unbalanced co-axial connection cable. Thus, the experiments results evaluate that there is a significant effect on the antenna’s radiation performance due to the change in ground plane structure.
IV. RETURN LOSS

The return loss of the solid ground plane antenna (Fig. 1(b)) and the choke-slot ground plane antenna (Fig. 3(b)) were simulated in CST Microwave Studio Suite. The impedance performance of the slotted ground plane antenna shows its efficiency at PCS band as we can see a resonance at 1.9GHz from Fig. 3. While the ‘Tee’ antenna with solid ground plane is tuned to 1.7GHz. Though there is no significant impact of ground plane size and pattern on the resonance frequency, still we can observe noticeable change in the impedance performance after the slot has been put on the antenna. The return loss of the fabricated antenna was also measured by using an Agilent Vector Network Analyser. The simulated and measured return loss of both the antennas is demonstrated in Fig. 5. Reasonable agreement is observed between simulated and measured results. There are a number of ripples in the measured Return Loss plots due to the inefficiencies of the Balun used on the connecting cable. All the antenna structures are essentially ‘balanced’ antennas whilst the connecting coaxial cable and related measurement system is unbalanced. The return loss is in effect the sum of reflection form the antenna and from the Balun. Closer agreement would be obtained using an improved Balun.

![Simulated and Measured return loss of antennas presented on Fig. 1(b) and Fig 3(b).](image)

V. CONCLUSION

The ground plane effect on a planar, reduced height monopole antenna has been studied using simulations from CST MWS and measurement of prototypes. It has been seen that the finite ground plane can cause significant distortion in the radiation pattern, creating unwanted nulls. It was then demonstrated that these effects can be compensated by introducing ‘choke-slots’ to limit the flow of current on the ground plane, resulting in more desirable dipole like radiation patterns. Introducing the choke-slot also affected the impedance, causing a small shift in the resonant frequency. This provides more evidence that design of antennas for small portable devices needs to encompass the whole structure – and cannot simply introduce a ‘radiating’ element – whilst also providing a solution.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Anthony Dodson for his help with antenna fabrication and Mr. John Jenkins for his assistance with measurement set-up.

REFERENCES