

Ground plane effects on planar inverted-F antenna (PIFA) performance

M.-C. Huynh and W. Stutzman

Abstract: The planar inverted-F antenna (PIFA) is popular for portable wireless devices because of its compact size and low profile. The PIFA is designed to operate with a ground plane and the ground plane is an integral part of the antenna assembly. In fact, the ground plane size is the limiting factor for the PIFA in many applications. Some work has been reported on the performance of PIFAs mounted on a conducting box of fixed size; however, what is lacking is a parametric study on the antenna behaviour as a function of geometry or antenna position and orientation on a finite ground plane. This paper presents results from a comprehensive investigation on the performance of a conventional PIFA mounted on ground planes of various sizes and shapes. The orientation and position of the antenna on a fixed-size ground plane is analysed. The influence of ground plane geometry on resonant frequency, bandwidth, gain, and radiation patterns are presented. These results are very useful in the design of a PIFA for applications requiring a small ground plane. Specifically, the results show the trade-offs between PIFA geometry and ground plane size with electrical performance. Both numerical simulation and experimental data are presented.

1 Introduction

Studies of the effects of ground plane size on antenna performance date back to the 1950s [1–6]. 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 were studied, including microstrip antennas [7–9]. 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 is the so-called perfect ground plane, which assumes the ground plane to be perfectly conducting, planar, and infinite in extent. Then image theory can be employed to remove the ground plane from the analysis. Real ground planes are often metallic, planar in shape, and finite in extent. 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 applications. Generally, when the ground plane is not large compared to a wavelength, electrical performance will be different from that of a finite ground plane.

Planar inverted-F antennas (PIFA) are popular for use in small communications terminals such as handheld radios because they are capable of covering popular wireless communications bands and are low profile. PIFAs require a ground plane, and at the same time the ground plane should be small in order to fit in portable terminals. Some work was performed on PIFAs mounted on a conducting box of fixed size [11]. However, parametric studies of PIFA

behaviour as a function of ground plane size, or as a function of antenna position and orientation on a finite ground plane, have not been reported. This paper discusses results from a comprehensive investigation into the performance of a conventional PIFA mounted on ground planes of various sizes and shapes. Results from numerical simulations and measurements on prototype hardware are presented to show the influence of PIFA geometry on resonant frequency, bandwidth, gain, and radiation patterns. Presented data are very useful in the design of a PIFA for applications requiring a small ground plane. Specifically, the results reveal trade-offs in electrical performance between PIFA geometry and ground plane size.

2 Ground plane size effects on conventional PIFA performance

This paper presents results from an extensive investigation using numerical simulations into the effects of a finite ground plane on the performance of a PIFA. In addition, measurements were made to confirm computational results. The PIFA structure in Fig. 1 was used for all computations and measurements. Both the simulated and measured PIFA consist of a square conducting plate with dimensions $20\text{ mm} \times 20\text{ mm}$ and a short-circuit plate with 5 mm width and 10 mm height. These dimensions are selected to give a resonant frequency in the PCS band, which is 1875 MHz for an infinite ground plane. At 1875 MHz , the PIFA dimensions in terms of wavelength are $G = 0.125\lambda$, $H = 0.065\lambda$, and $S = 0.03125\lambda$. Of course, results can be scaled with frequency for application to other bands. The PIFA is mounted at the centre of a square ground plane with variable side length L . The following ground plane sizes L are used to measure the characteristics of the antenna: $20, 40, 60, 80, 100, 120, 140\text{ mm}$. The PIFA is probe fed and the probe position on the x -axis p_x is determined such that the input impedance is 50Ω at resonance; see Fig. 1. The experimental model is constructed of 0.381 mm thick brass and the probe is

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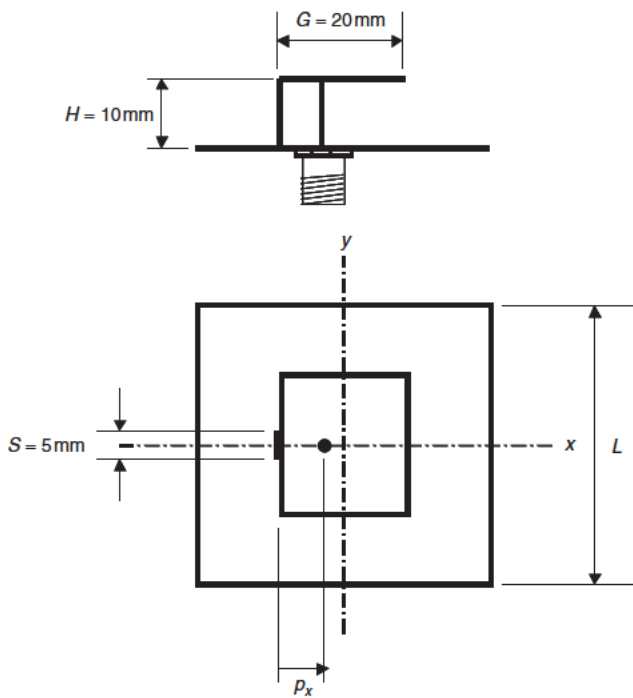


Fig. 1 Geometry of PIFA with square conducting plate, $G = 20\text{ mm}$, and short-circuit plate width and height $S = 5\text{ mm}$ and $H = 10\text{ mm}$, respectively, mounted on finite square ground plane with dimension L (see Table 1)

formed from an SMA connector with probe radius 0.635 mm .

Performance parameters resonant frequency, impedance bandwidth having VSWR less than 2, probe location, and gain are determined using the commercial method-of-moments software package IE3D from Zeland [10].

Figs. 2 and 3 are representative of impedance characteristics for a PIFA with a ground plane size $L = 80\text{ mm}$ over the PCS frequency band. For this example, the simulation resonant frequency is 2.62% below that for the experimental model; see Fig. 3. There is excellent agreement between the numerical and experimental values, giving confidence in the accuracy of the moment-method computational model. Numerical and experimental data are presented in Figs. 4, 5 and 6 for resonant frequency,

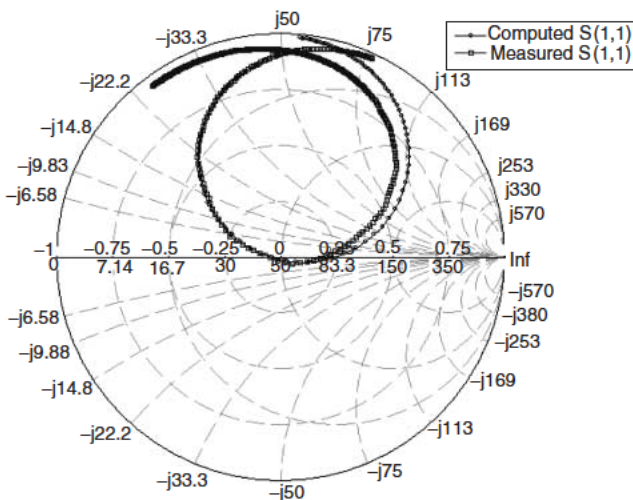


Fig. 2 Smith chart displaying computed and measured impedance of conventional PIFA shown in Fig. 1 mounted at the centre of square ground plane of 80 mm length and probe-fed 2.1 mm away from the short-circuit plate

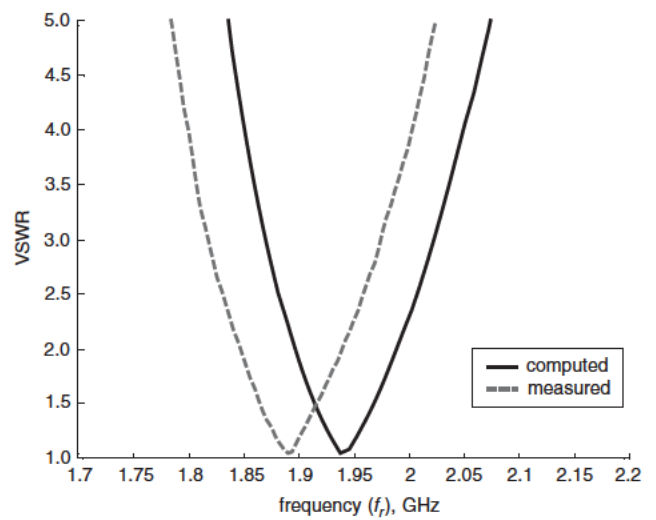


Fig. 3 Computed and measured VSWR of a conventional PIFA shown in Fig. 1 mounted at the centre of square ground plane of 80 mm length and probe-fed 2.1 mm away from the short-circuit plate

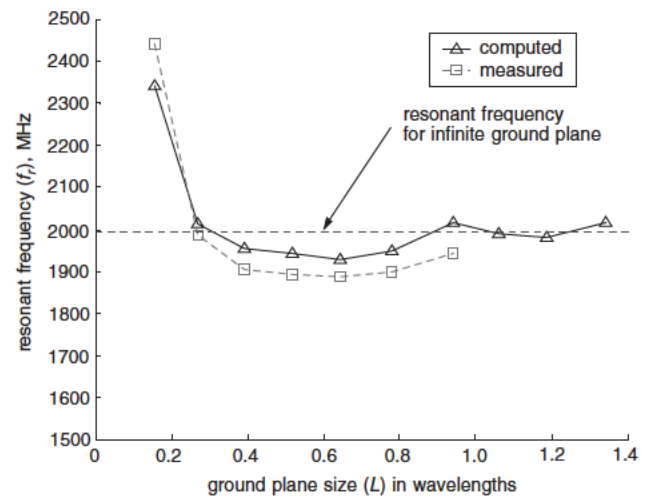


Fig. 4 Computed and measured resonant frequency of conventional PIFA for various square ground plane sizes in terms of wavelength

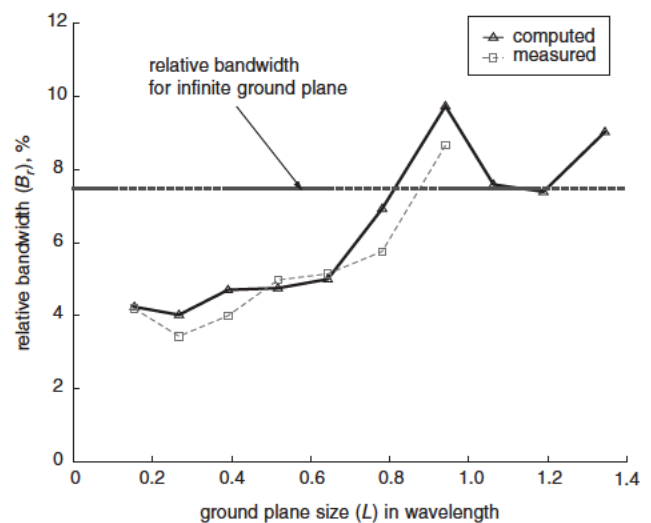


Fig. 5 Computed and measured impedance bandwidth for 2:1 VSWR of a conventional PIFA for various square ground plane sizes in terms of wavelength

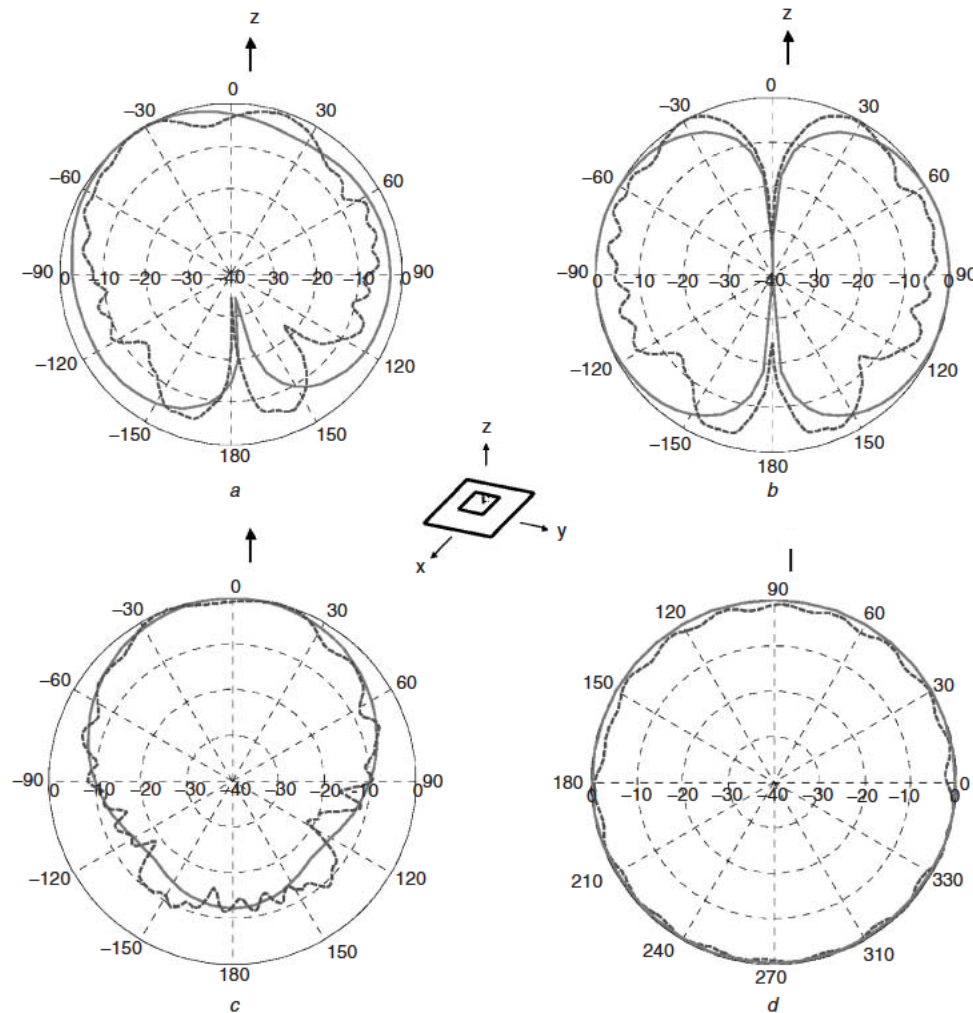


Fig. 6 Computed (—) and measured (---) normalised radiation patterns of the PIFA of Fig. 1 at resonance, mounted on square ground plane of size $L=80\text{ mm}$ in the (a) elevation ($\phi=0^\circ$) E_ϕ -plane, (b) elevation ($\phi=90^\circ$) E_θ -plane (c) elevation ($\phi=90^\circ$) E_ϕ -plane, (d) azimuth ($\theta=90^\circ$) E_θ -plane

bandwidth, and gain, respectively, as a function of ground plane size in terms of wavelength.

Previous work [1 6] showed that the impedance of an antenna oscillates about the infinite ground plane value as ground plane size increases, eventually converging to the perfect ground plane impedance. Since resonant frequency and impedance bandwidth are related to the impedance of the antenna, they should have the same behaviour; this is demonstrated in Figs. 4 and 5. Fig. 4 demonstrates the important conclusion that the size of the PIFA ground plane has no significant influence on the resonant frequency until the ground plane is reduced below about 0.2λ . However, Fig. 5 shows that ground plane size has a strong influence on bandwidth. Popular wireless bands require about 8% bandwidth and this bandwidth is achieved by a square ground plane of at least $L=0.8\lambda$; see Fig. 5. This relatively large ground plane size can be the limiting factor in PIFA design.

Radiation patterns of the PIFA mounted at the centre of each ground plane were computed at resonance to examine the radiation behaviour. Patterns were also measured using the Virginia Tech indoor anechoic chamber for the PIFA mounted on a square plane of size $L=80\text{ mm}$ (0.5λ). As indicated in Fig. 6, there is good agreement between measured patterns and IE3D simulations. This gives confidence in using IE3D to examine antenna parameter influences.

Fig. 7 shows the computed E_θ -component in the xz plane for a few ground plane sizes. For the infinite ground plane case and when the ground plane is the same size as the PIFA upper plate, maximum directivity occurs at the horizon, since the antenna acts like a short monopole and a short dipole, respectively, and it is known that power is radiated from the short-circuit plate element where the current is concentrated. For the other cases, peak directivity directions vary from $\theta=315^\circ$ to $\theta=335^\circ$ when the ground plane size is less than a wavelength.

Edge diffraction due to a finite ground plane introduces high crosspolarisation, as shown in Fig. 8. For the cases of an infinite ground plane, and when the ground plane size is the same as that of the upper plate, PIFA polarisation is purely linear in the θ -direction, similar to a dipole, and no crosspolarisation appears in the ϕ -direction. However, crosspolarisation appears for other ground plane sizes and can become significant, as illustrated in Fig. 8. Note that high crosspolarisation can be useful in applications where the antenna is positioned randomly, such as for hand-held devices that require linear polarisation response in all directions for good performance.

Directivity, taken to be equal to gain, was computed using IE3D and is plotted in Fig. 9 as a function of ground plane size. It is seen that gain is affected strongly by ground plane size, and rather than increasing uniformly with ground plane size, the dependence is complex. The gain is

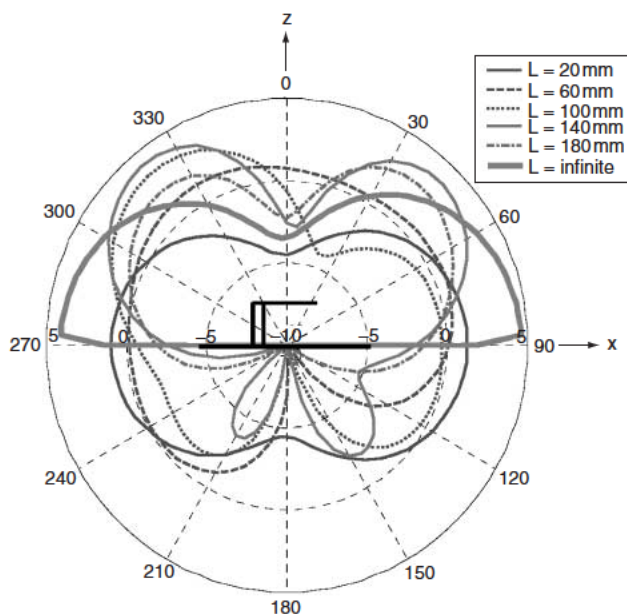


Fig. 7 Computed E_θ -component radiation patterns at resonance for the PIFA of Fig. 1 (see Table 1 for resonant frequencies for each case) in the xz -elevation plane ($\phi=0^\circ$) for ground plane sizes $L=20\text{ mm}$ (0.156λ), $L=60\text{ mm}$ (0.391λ), $L=100\text{ mm}$ (0.643λ), $L=140\text{ mm}$ (0.940λ), $L=180\text{ mm}$ (1.188λ), and $L=\infty$. Refer to Fig. 1 for the structure geometry

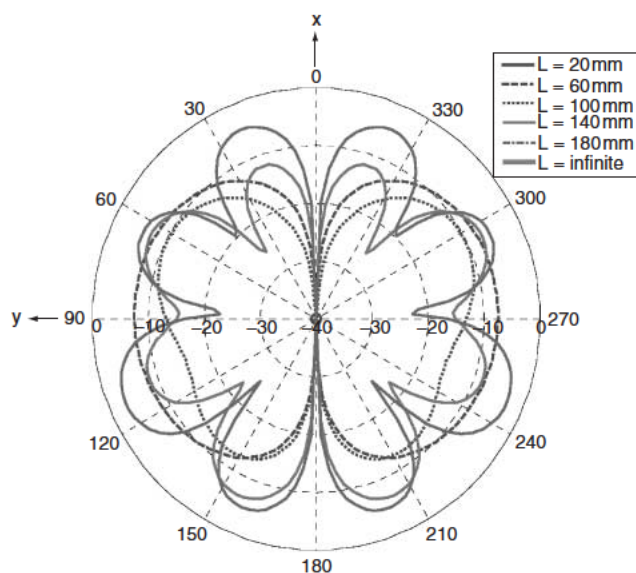


Fig. 8 Computed E_θ -component radiation patterns at resonance for the PIFA of Fig. 1 (see Table 1 for resonant frequencies for each case) in the xy -azimuth plane ($\theta=90^\circ$) for ground plane sizes $L=20\text{ mm}$ (0.156λ), $L=60\text{ mm}$ (0.391λ), $L=100\text{ mm}$ (0.643λ), $L=140\text{ mm}$ (0.940λ), $L=180\text{ mm}$ (1.188λ), and $L=\infty$

lowest when ground plane size is comparable to the upper plate size of the PIFA. As ground plane size increases, the peak gain increases, reaching a maximum at about $L=0.9\lambda$ for ground plane sizes of less than one wavelength. The gain at that size is 4.45 dB, which is close to the gain for an infinite ground plane. For most wireless hand-held applications, 3 dB gain is usually required. To achieve 3 dB gain, the ground plane size of a PIFA should be at least a half wavelength ($L=0.5\lambda$); see Fig. 9.

The previous discussion was for a conventional PIFA mounted on a square ground plane. Rectangular ground plane configurations were also modelled and show beha-

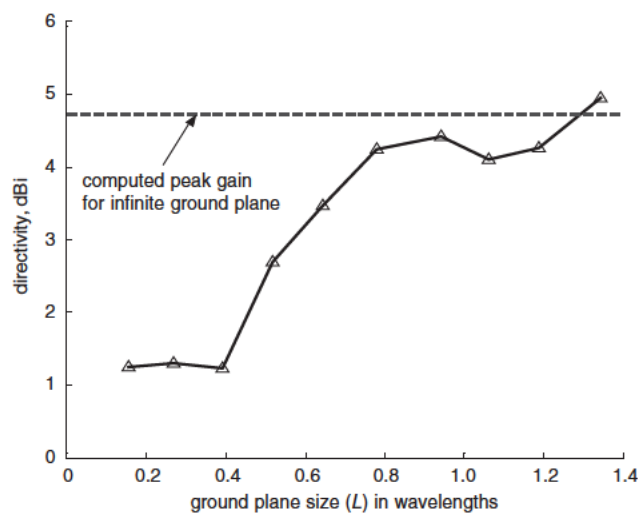


Fig. 9 Computed peak gain of a conventional PIFA for various square ground plane sizes in terms of wavelength

viour similar to that for square ground plane. The influence of ground plane size and shape on resonant frequency, bandwidth, and gain were investigated by simulations for rectangular ground plane sizes smaller than one wavelength. For a fixed PIFA size, one can select optimum characteristics or vary its resonant frequency by adjusting the size of the ground plane. For optimum performance, the rectangular ground plane should have a length L of about 0.45λ for the case when the short-circuit plate of the PIFA is oriented parallel to the longer edge of the ground plane, and a length L of about 0.85λ when the short-circuit plate is oriented parallel to the shorter edge of the ground plane. These sizes give large bandwidth and directivity for the same resonant frequency. Similar characteristics were also seen in the case of a square ground plane, as shown in Figs. 4, 5, and 9.

Investigations into the characteristics of PIFAs mounted at different locations on a ground plane and with different orientations were also performed. Results showed that, for optimal performance with high gain and large bandwidth, PIFAs should be placed near a corner of the ground plane with the shorting plate located at the ground plane shorter edge.

3 Conclusions

Extensive simulations using IE3D and measurements on a finite ground plane-mounted PIFA were performed to investigate the effects of ground plane size and shape. Electrical performance determined by simulations and measurements showed very good agreement. The results of the study should be valuable to designers seeking to achieve minimum ground plane size for a specific electrical performance.

The influence of ground plane on the PIFA performance is summarised as follows:

- There is no significant impact of ground plane size and shape on the resonant frequency of the antenna, unless the ground plane is below a certain size; for a square ground plane, this occurs at $L<0.2\lambda$.
- Bandwidth is low (less than 8%) for $L<0.8\lambda$ in the square ground plane case, and for $L<0.4\lambda$ in the rectangular ground plane case.
- Gain is low for a ground plane size $L<0.4\lambda$.

- Ground plane size significantly influences antenna radiation patterns.
- Finite and small ground plane size introduces high crosspolarisation in the plane of the ground plane.

The position and orientation of a PIFA on a fixed-size ground plane were also studied. It was found that the PIFA should be placed close to the corner of the ground plane where the short-circuit plate is at the ground plane edge for optimal gain and bandwidth performance.

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