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From L-shaped planar monopoles to a novel folded antenna with wide bandwidth

G. Ruvio and M.J. Ammann

Abstract: A novel folded monopole antenna is investigated numerically and experimentally. The proposed antenna comprises a short folded monopole suitably shaped at the base with two vertical grounding probes. This small antenna is shown to have a fractional impedance bandwidth up to 125% (1.6 GHz to 7.5 GHz) for a 10 dB return loss. An interesting compromise between impedance bandwidth and pattern control is found by tuning a double side bevel at the base of the monopole, the position of the feeding point and its distance from the ground plane. Measurements and simulations are in good agreement and show a dramatic improvement in terms of impedance bandwidth compared with planar and L-shaped monopole antennas. Impedance and radiation characteristics make this novel folded monopole antenna a remarkable candidate for indoor applications where the wideband coverage of different systems is required. The working bandwidth covers a large number of wireless communication systems including GSM 1800, Personal Communication System (PCS1900), Universal Mobile Communications System (UMTS), the 2.4 GHz (2400–2484 MHz) and 5.2/5.8 GHz (5185–5350/5725–5875 MHz) bands for WLAN communication, Wireless Local Loop (3.4–3.6 GHz), the US-NII bands and the lower bands allocated to ultra-wideband communications.

1 Introduction

Wideband antennas are becoming very attractive for future software-defined and reconfigurable wireless systems, which may operate over multiple bands. Thanks to an intrinsic broad impedance bandwidth, planar monopoles show powerful features for those applications and different feeding techniques can easily be applied to this technology to obtain further benefits [1–3]. Low-profile antennas are particularly interesting for mobile or indoor applications, so that a compromise between size and performance becomes a crucial part of the design [4–8]. Together with the introduction of special feeding techniques, reduction of the height perturbs radiation performance. Effects on impedance bandwidth and radiation pattern are examined and discussed.

Starting from a simple and fully investigated L-shaped monopole [4], the insertion of offset feeding point and bevels [2] are analysed and compared to the novel antenna proposed, in which two vertical grounding probes dramatically enlarge the impedance bandwidth with an acceptable perturbation of the radiation pattern. The horizontal plate improves radiation characteristics of the shorted monopole, whereas the shorting probes compensate for the reduction of impedance bandwidth owing to the decreased height of the antenna. Shorting elements have been already introduced in literature as a valid instrument both to control impedance bandwidth and radiation pattern [2, 5, 9].

Compared to typical planar monopole antennas [2, 3], this novel radiating element allows a reduction of the total height by 33%. At the same time, a 10 dB return loss bandwidth and acceptable radiation patterns are achieved from 1.6 GHz to 7.5 GHz.

The novel geometry proposed in this paper operates in a hybrid mode; a transmission line mode exists in addition to the monopole mode, which greatly reduces the monopole null depth and is advantageous for mobile/wireless communications. The impedance bandwidth is shown to be strongly dependent on the shape of the radiating element in proximity of the ground plane, the position of the feeding point and the feed gap. All these features are investigated and a trend of the tuning is outlined.

2 Antennas investigated

Figure 1 shows the antenna investigated. Starting from a simple L-shaped monopole, first a double side-bevel was introduced and analysed at the base of the radiating element. Finally, the effects of two linear probes connecting the horizontal plate to the ground plane are studied in terms of impedance bandwidth and radiation properties. All the configurations considered are vertically mounted at the centre of a 140×140 mm ground plane, and fed by an SMA connector beneath it. The input signal is launched through a 50Ω coaxial probe of 0.6 mm radius with a feed gap fg between the ground plane and the base of the radiating element. The antennas treated are made of 0.2 mm-thick copper sheet.

The width w is kept equal to 40 mm for all the cases examined throughout the paper. The same for the total height h , which is $fg + 17$ mm and the length of the horizontal element l is equal to 24.3 mm. The width p of the shorting probes introduced in the novel monopole antenna is equal to 5 mm.

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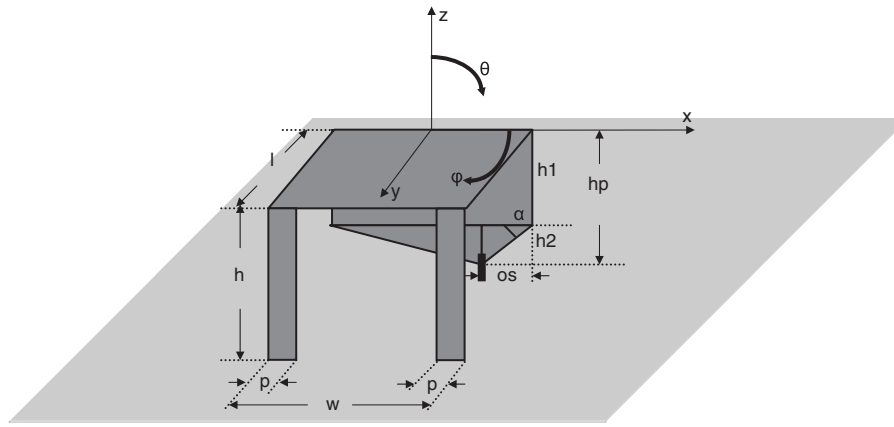


Fig. 1 Grounded L-shaped monopole

The results of bevelling the base of the L-shaped monopole are analysed in terms of four different values for α : 10° , 15° , 20° and 25° . The distance os is also tuned in order to excite more modes and improve the match. Two values are considered (10 and 15 mm), so that the reader can visualise the trend related to this parameter. Together with α , os determines the partial height $h1$ and $h2$, in which h_p is decomposed when the bevel is introduced.

3 Impedance characteristics

Initially, for the parametric analyses, the finite integration time-domain technique CST Microwave Studio is employed, and good agreement with measurement is subsequently illustrated. The first geometric parameter analysed is the feed gap, fg . This parameter has been demonstrated to be very critical for the matching of an L-shaped monopole [3, 10, 11]. Indeed it does affect strongly the capacitive coupling of the radiating element with the ground plane at the hottest region of the antenna. Table 1 details a comparison of simulated return loss against frequency of a simple L-shaped monopole antenna for different values of fg , from 0.8 mm to 2.3 mm.

The widest bandwidth is obtained when $fg = 1.8$ mm and tends to decrease for larger distances from the ground plane. However, the performance changes as soon as special feeding techniques are introduced. Table 2 summarises the effect of a double side-bevel on the L-shaped monopole just studied in the previous comparison when $fg = 1.8$ mm.

It appears clear that bevells dramatically extend the impedance bandwidth. A remarkable increase of the upper-edge frequency is the main consequence [2]. In fact, bevelling the bottom edge of the radiating element extends the current path at the hottest part of the antenna, so that a decisive effect on the performance is expected. We obtain the best results with a double side-bevel with $\alpha = 20^\circ$. But at the same time, a marked upward shift of the first resonance

Table 1: Effects of fg on the first resonance and 10 dB RL impedance bandwidth with $os = 0$, $\alpha = 0$ and no shorting probes

fg	Frequency range (GHz)	Bandwidth _{10dB}
0.8 mm	1.973–2.687	30%
1.3 mm	2.022–2.89	35%
1.8 mm	2.106–3.051	36.6%
2.3 mm	2.218–3.163	35%

is evident; from 2.645 GHz without any bevel to 3.401 GHz when $\alpha = 20^\circ$. As already documented for a typical planar monopole, but also for the case of an L-shaped monopole,

Table 2: Effects of the bevel on the first resonance and 10 dB RL impedance bandwidth with $os = 0$, $fg = 1.8$ mm and no shorting probes

α	Frequency range (GHz)	Bandwidth _{10dB}
0°	2.12–3.044	35%
10°	2.582–3.786	37%
15°	2.743–3.996	37%
20°	2.904–4.493	43%
25°	3.058–4.633	40%

Table 3: Effects of offset on first resonance and 10 dB RL bandwidth with $\alpha = 0$, $fg = 1.8$ mm and no shorting probes

os	Frequency range (GHz)	Bandwidth _{10dB}
–	2.904–4.493	43%
10 mm	2.918–8.03	93%
15 mm	3–3.982	28%

Table 4: Effects of fg on first resonance and 10 dB RL bandwidth with $os = 10$ mm, $\alpha = 10$ and no shorting probes

fg	Frequency range (GHz)	Bandwidth _{10dB}
0.8 mm	2.946–7.608	88%
1.3 mm	2.974–7.559	87%
1.8 mm	3.002–3.969	27.7%
2.3 mm	3.037–3.807	22.5%

Table 5: Effects of fg on first resonance and 10 dB RL bandwidth with $os = 10$ mm, $\alpha = 20^\circ$ and shorting probes

fg	Frequency range (GHz)	Bandwidth _{10dB}
0.8 mm	1.763–7.608	124%
1.3 mm	1.714–7.7615	126%
1.8 mm	1.679–7.524	127%
2.3 mm	1.644–7.349	126%

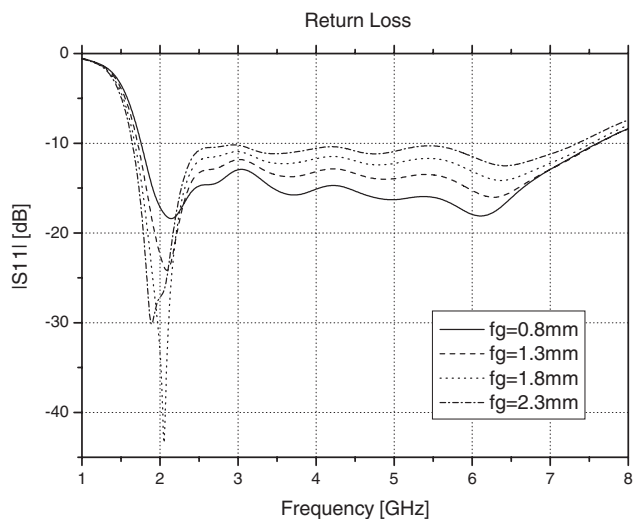


Fig. 2 Effect of fg on the return loss of the L-shaped grounded monopole when $\alpha = 20^\circ$ and $os = 10$ mm

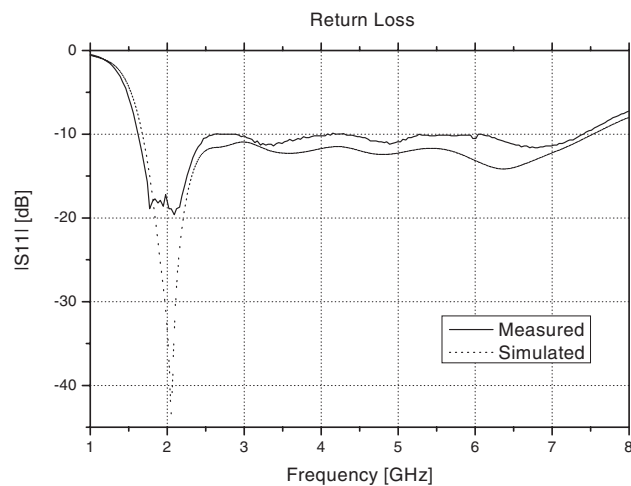
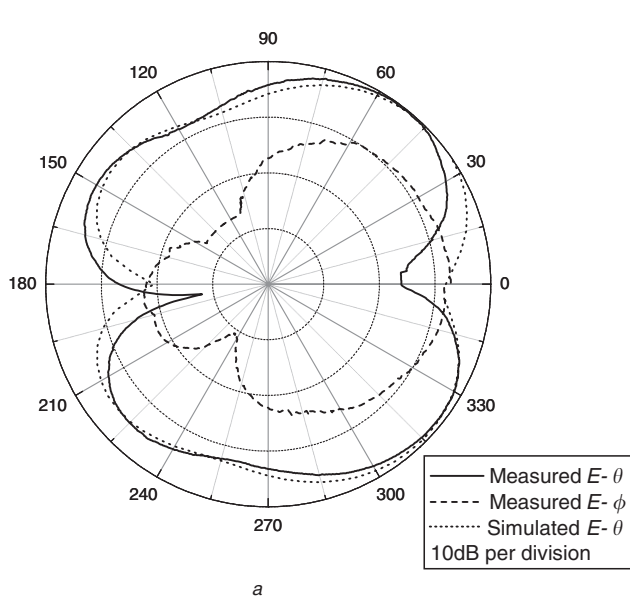
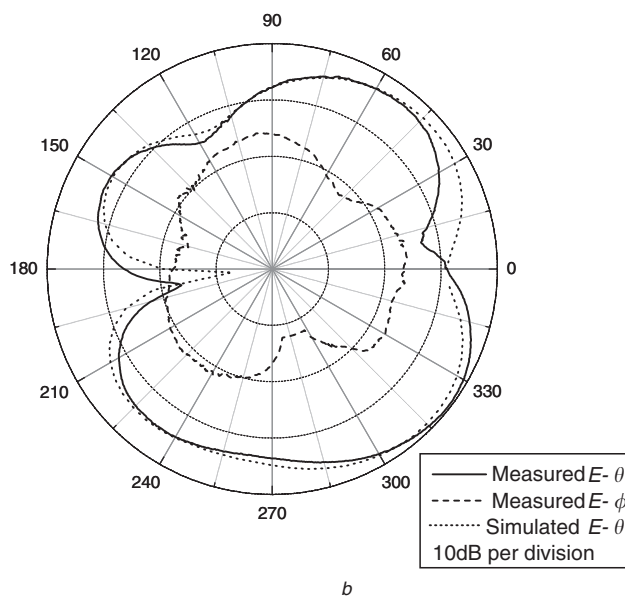


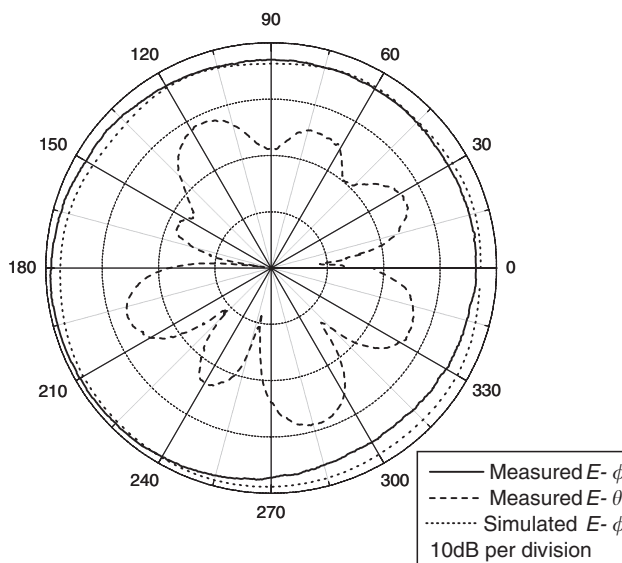
Fig. 3 Comparison of RL for the L-shaped grounded monopole in measurement and simulation



a



b



c

Fig. 4 Comparison of measurement and simulations of the radiation pattern of the L-shaped grounded monopole
a $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. E-plane $\phi = 0^\circ$ 1.8 GHz
b $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. E-plane $\phi = 90^\circ$ 1.8 GHz
c $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. H-plane 1.8 GHz

an enlargement of the impedance bandwidth with increase in bevel angle can be seen. In Table 2 an increase of 6% in the 10 dB RL bandwidth when α passes from 10° to 20° is observed.

Table 3 shows a comparison of simulated return loss when the double side bevel is kept fixed ($\alpha = 20^\circ$) and three different positions of the feeding point are analysed (fg remains equal to 1.8 mm). As expected, by tuning os a strong reaction in terms of return loss is obtained. In fact, this geometric parameter controls the number of higher modes, which can be excited in the radiating element. The configuration $os = 10$ mm allows the excitation of more modes than the other configurations compared.

Alternatively, when both a double side-bevel and an offset feeding point are introduced, the value of $fg = 1.8$ mm is not optimum any more. This behaviour is detailed in Table 4. As expected, by bevelling the bottom edge of the radiating element, the weight of fg to control the return loss is drastically modified. Indeed it is necessary to reduce fg in order to recreate a strong interaction between the monopole and the ground plane when a bevel has been introduced.

The best results in terms of impedance bandwidth for the L-shaped monopole with a double side-bevel ($\alpha = 20^\circ$) at the base and an offset of the feeding point ($fg = 10$ mm) are obtained when $fg = 0.8$ mm.

Finally, by introducing two shorting probes, we can notice a remarkable increase in the bandwidth. The introduction of an additional mode is the most significant consequence of this particular and novel grounding system. These vertical elements produce a significant downward shift of the lower edge frequency (see Table 5 and Fig. 2).

Feed gap, bevels, offset feed arrangements and shorting probes have been demonstrated to be very effective ways to increase the impedance bandwidth of a typical L-shaped monopole antenna. However, a strong interaction between the effects caused by these exists, so that prediction of the return loss response to tuning the structure becomes difficult, when all of them are employed simultaneously.

CST Microwave Optimizer is a tool that allows multiple tuning of geometric parameters in terms of performance goals expected. By using the interpolated quasi-Newton optimiser, the most favourable results in terms of 10 dB return loss impedance bandwidth were achieved for this

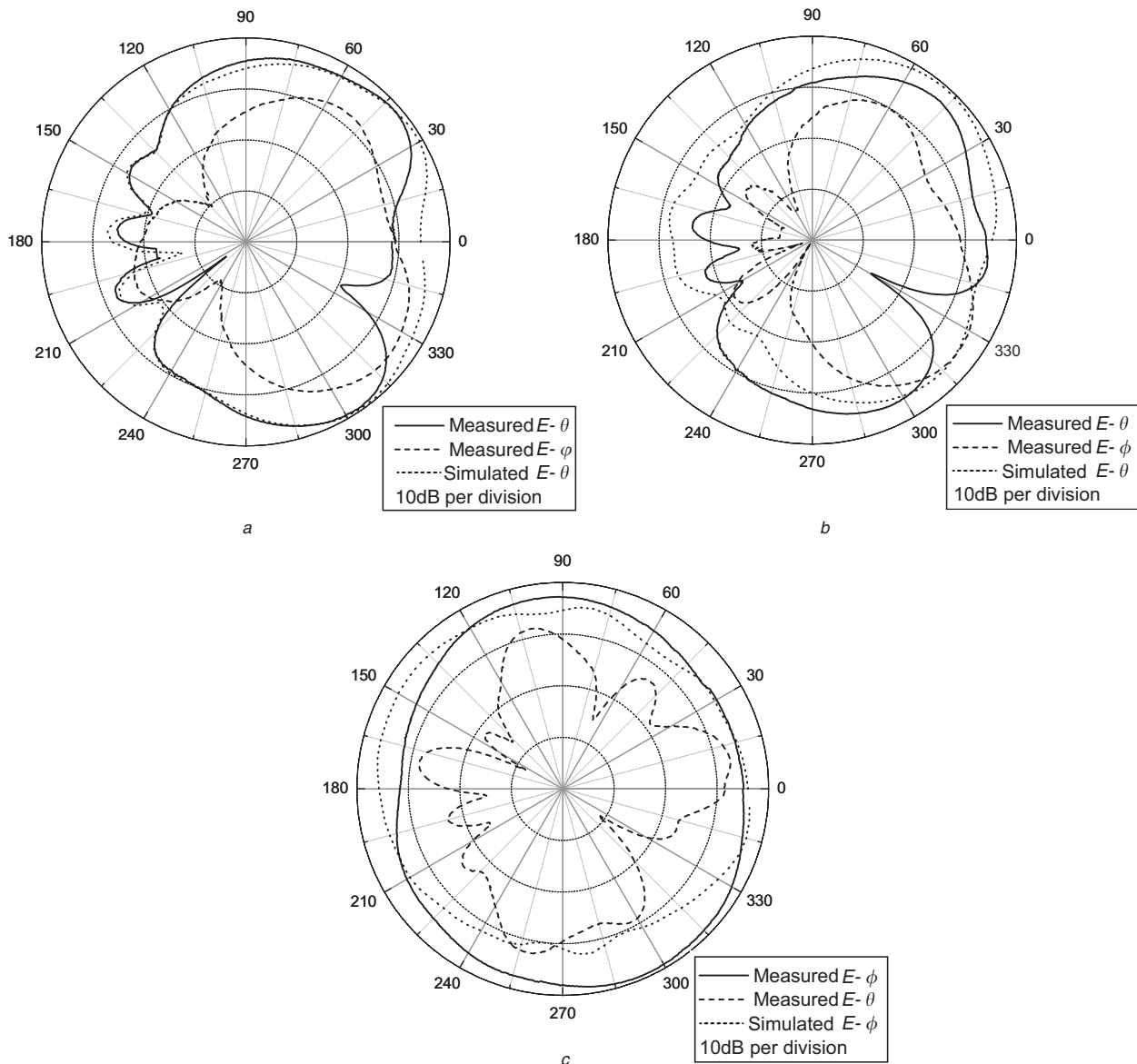


Fig. 5 Comparison of measurement and simulations of the radiation pattern of the L-shaped grounded monopole
a $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. E-plane $\phi = 0^\circ$ 4.7 GHz
b $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. E-plane $\phi = 90^\circ$ 4.7 GHz
c $\alpha = 20^\circ$, $fg = 1.8$ mm and $os = 10$ mm. H-plane 4.7 GHz

novel grounded L-shaped monopole antenna when $\alpha = 20^\circ$, $os = 10$ mm and $fg = 1.8$ mm. The introduction of two symmetrical shorting probes significantly alters the current density especially at low frequency. It is believed that this new current distribution reduces the influence of fg to control the return loss performance of the antenna as the capacitive coupling at the feed gap is weakened in the novel configuration. Figure 3 shows a comparison between the return loss obtained by measurement and by numerical analyses using CST Microwave Studio for the ultimate antenna obtained. A very good agreement is achieved.

4 Radiation properties

Measurements and simulations of the impedance properties of the antennas investigated show that the folded monopole with two grounding probes has broad impedance bandwidth, much larger than the other cases observed and with the same dimensions. Therefore, it is important to evaluate and compare the radiation properties when particular feeding techniques are introduced. Measurements and simulations are carried out in xz , yz and xy planes (respectively E-plane with $\phi = 0^\circ$, 90° and H-plane) at 1.8 and 4.7 GHz. Generally a good agreement is achieved (see Figs. 4a–c and 5a–c). A gain of 4.138 dB and 5.71 dB was measured at 1.8 GHz and 4.7 GHz respectively. Radiation patterns in Figs. 4a–c and 5a–c have been normalised to the maximum gain.

It has been observed that the double side-bevel introduces a very modest perturbation on the radiation pattern of the L-shaped monopole. However, reshaping the bottom edge of the radiating element in proximity of the ground plane helps the performance in terms of omni-directionality of the H-plane pattern. This means that the bevels introduced have to be considered not only as a way to enlarge the impedance bandwidth, but also as a technique to control the pattern.

Compared to the case of a symmetric feed-point, the offset is demonstrated to have a strong effect on the pattern. The null visible at high frequencies in the yz plane for $\theta \approx 45^\circ$ is reduced when the offset is introduced. At the same time the insertion of the offset and the shorting probes affects the typical omni-directional pattern of a monopole in the H-plane but not dramatically.

From Figs. 4a and b and 5a and b, a maximum in the xz and yz elevation patterns is visible around $\theta = 330^\circ$. This phenomenon is due to the presence of monopolar modes and transmission-line (patch) modes which exist, owing to the low-profile geometry [4]. This is also supported by the fact that the typical monopolar null depths are shallow and shifted from $\theta = 0^\circ$. The two symmetrical shorting probes moderately perturb the radiation properties of a typical L-shaped antenna. This final configuration is believed to represent the best grounding solution that matches with the hybrid operating mode of this antenna. Figures 4a–c and

5a–c show a comparison between measurements and simulations. A good agreement is obtained at low frequency. However, at higher frequency discrepancies become more evident.

Polarisation purity is more strongly affected at higher frequencies as shown in Fig. 5a–c. However, a tolerable cross-polar level is observed in the H-plane for both of the frequencies considered. The horizontal ground plane is considered to add spurious radiation to the co-polar components of the field. This phenomenon becomes more evident as the ground plane becomes larger in terms of wavelength.

5 Conclusions

Effects of bevels, feed gap and asymmetric feed-point on the impedance and radiation properties of an L-shaped monopole have been carried out both experimentally and numerically. The insertion of two vertical shorting probes has been proposed and shown to be a convenient way to control impedance bandwidth and radiation pattern. Measurement data and simulations proved that vertical probes, together with bevels and offset of the feed-point, dramatically improves the performance of L-shaped planar monopoles and make them a convenient and low-cost radiation element for in-door and mobile applications where a large portion of the spectrum has to be covered.

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