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WIDEBAND L-PROBE FED INVERTED HYBRID E-H MICROSTRIP PATCH ANTENNAS FOR IMT-2000 BAND

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Abstract. This paper presents a novel wideband L-probe fed inverted hybrid E-H shaped microstrip patch antenna (LIEH) covering the International Mobile Telecommunications - 2000 (IMT-2000) band. The design adopts contemporary techniques; L-probe feeding, inverted patch structure with air-filled dielectric, and slotted patch. The composite effect of integrating these techniques and introducing the novel E-H patch shaped offers a low profile, broadband, high gain, low crosspolarization, and compact antenna element. Measurement result showed satisfactory performance with an achievable bandwidth of 17.20% at 14 dB return loss (SWR = 1.5), maximum achievable gain of 8 dBi with 1 dB gain variations, and crosspolarization level of 23 dB below the main lobe level. The LIEH patch has a compact dimension of 79×41 mm^2. The design is suitable for array applications especially for IMT-2000 base station antenna.

Keywords: IMT-2000, broadband antenna, microstrip patch antenna, E-H shaped patch antenna, L-probe fed

Abstrak. Kertas kerja ini menyampaikan antena mikrostrip tampal baru berjalur lebar bentuk hibrid E-H tersongsang tersuap prob-L (LIEH) yang merangkumi jalur *International Mobile Telecommunications - 2000* (IMT-2000). Reka bentuk ini menggunakan teknik terkini; penyuapan prob-L, struktur tampal tersongsang dengan substratum udara, dan tampal penyinar beralur. Kesan komposit dengan mengintegrasi teknik ini dengan penggunaan bentuk tampal hibrid E-H, menawarkan ciri-ciri berprofil rendah, berjalur lebar luas, gandaan tinggi, pengutuban silang rendah, dan elemen antena yang padat. Keputusan pengukuran adalah memuaskan dengan pencapaian lebar jalur 17.20% pada kehilangan kembali 14 dB (SWR = 1.5), gandaan maksimum 8 dBi dengan variasi gandaan 1 dB, dan pengkutuban silang 23 dB di bawah aras cuping utama. Tampal LIEH mempunyai dimensi yang padat iaitu 79×41 mm^2. Reka bentuk ini sesuai bagi aplikasi tatasusun terutamanya bagi antena stesen tapak IMT-2000.

Kata kunci: IMT-2000, antena jalurlebar luas, antena tampal mikrostrip, antena tampal bentuk E-H, suapan prob-L

1.0 INTRODUCTION

The International Telecommunications Union (ITU) proposed a new wireless standard, the International Mobile Telecommunications - 2000 (IMT-2000) [1] or in

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short, Third Generation (3G) to replace the existing wireless network which has limited channel capacity and to cater the ever increasing demand for mobile wireless communications and broadband services. 3G system specifies broadband frequencies (uplink: 1.885 to 2.025 GHz and downlink: 2.110 to 2.200 GHz) to support new mobile services [2].

One of the main focuses of 3G is to develop an antenna system that can direct the antenna beam to the intended users while placing a null to the interferers in a dynamic fashion, the architecture of smart antenna system. The application of smart antenna for 3G networks will revolutionize at least the base station antenna design. As the number of mobile operator increases, the requirements to support better mobile services in a limited radio environment become a major challenge. Hence, a solution whereby a common antenna shared by various operators are needed, this will also reduce the un-aesthetically or unpleasing base station sites. One of the main challenges for the base station antenna design is to come up with an antenna system with smart antenna capabilities covering 3G bandwidth and with a low-profile structure for easy installation and maintenance. The first task for developing such a base station antenna is to develop a new or novel antenna radiator that can fulfil the design requirements, which is the subject of this paper.

This paper presents a novel wideband microstrip patch antenna for 3G band. The design employs contemporary techniques namely, the L-probe feeding, inverted patch, and slotted patch techniques to meet the design requirement. The use of L-probe feeding technique with a thick air-filled substrate provides the bandwidth enhancement [3-5], while the application of superstrate with inverted radiating patch offers a gain enhancement [6], and the use of parallel and series slots [7] reduce the crosspolarization level and the size of the patch [8-10]. The use of superstrate, on the other hand, would also provide the necessary protections for the patch from the environmental effects. These techniques offer easy patch fabrications, especially for array structures.

In this paper, the design and simulations of the novel wideband microstrip patch antenna, referred to as "L-probe fed inverted hybrid E-H shaped" microstrip patch antenna or "LIEH" in short, is described. Included in the paper are the simulation set-up, measurement, and the results of the LIEH patch antenna design.

2.0 ANTENNA DESIGN AND CONSTRUCTION

Figure 1 shows the geometry of the LIEH patch antenna. The inverted rectangular patch, with width W and length L is supported by a low dielectric superstrate with dielectric permittivity ε_1 and thickness h_1. An air-filled substrate with dielectric permittivity ε_0 and thickness h_0 is sandwiched between the superstrate and a ground plane.

The hybrid E-H patch antenna or LIEH integrates both the E- and H-shaped patch on the same radiating element. For the E-shaped, the slots are embedded in

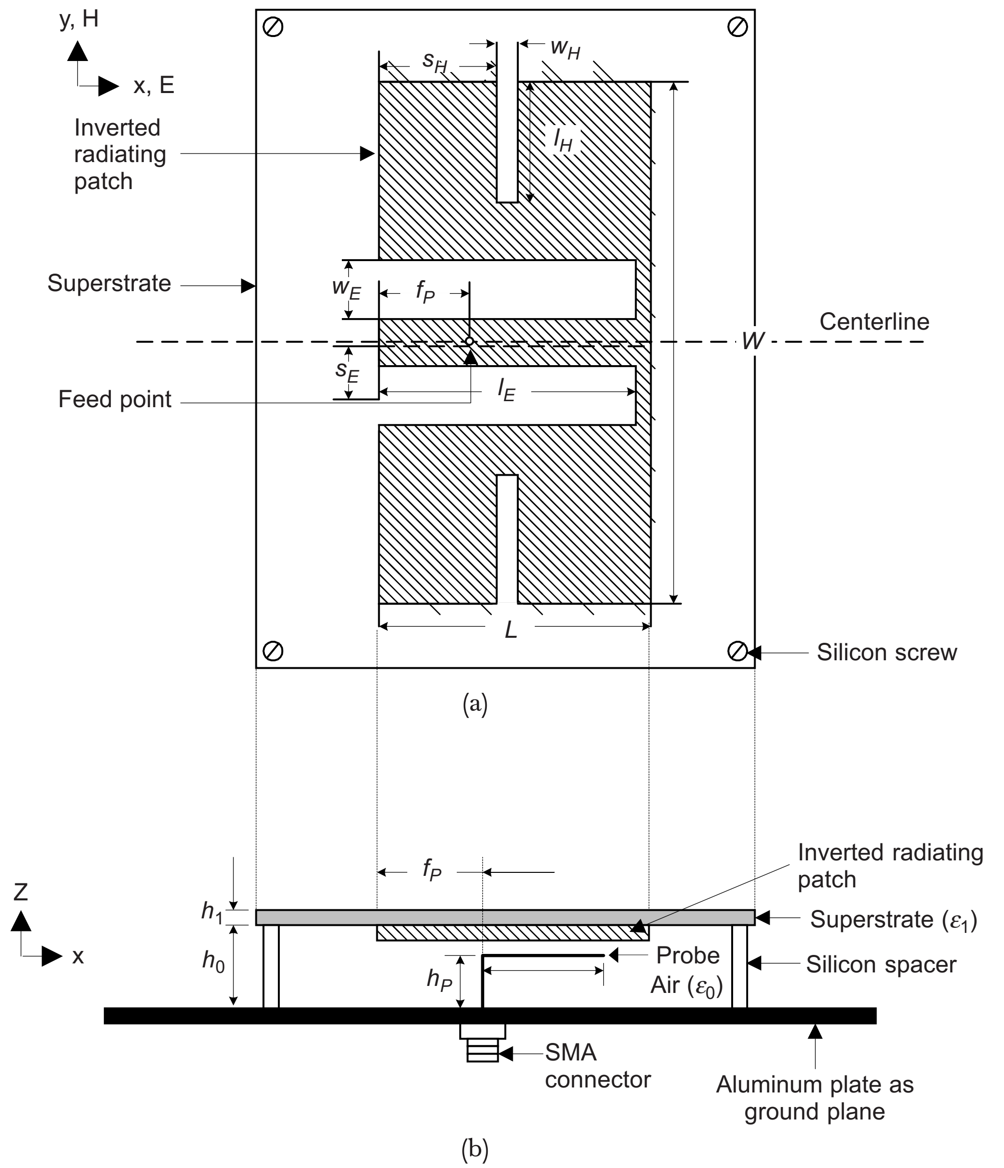


Figure 1 The L-probe fed inverted hybrid E-H shaped patch antenna. (a) Top view and (b) side view

parallel on the radiating edge of the patch symmetrically with respect to the centerline (x-axis) of the patch and for the H-shaped, the slots are embedded in serial on the non-radiating edge of the patch. The E- and H-shaped slots, $\{l_E, w_E$, and $s_E\}$ and $\{l_H, w_H$ and $s_H\}$, are shown in Figure 1 (a), where, l, w, and s are the length, width, and position of the slots respectively. The patch is fed by an L-shaped probe with height, h_P and horizontal length, l_P along the centerline (x-axis) at a distance f_P from the edge of the patch as shown in Figure 1(b).

Table 1 shows the optimized design parameters obtained for the LIEH patch antenna at 14 dB (SWR = 1.5) return loss. The LIEH patch was fabricated on Rogers RT 5880 Duroid^{TM} dielectric substrate with dielectric permittivity, ε_1 of 2.2 and thickness, h_1 of 1.5748 mm. The thickness of the air-filled substrate, h_0 is 16.0 mm. An aluminum plate with dimensions of 200.0×180.0 mm^2 and thickness of 1 mm is used as the ground plane. The fabricated inverted hybrid E-H shaped patch and the ground plane are assembled together using silicon spacers and screws (3 mm diameter).

Table 1 The LIEH patch antenna design parameters

Parameters	Value [mm]
h_1	1.5748
h_0	16.0
W	79.0
L	41.0
s_H	19.0
l_H	18.0
w_H	2.0
s_E	16.0
l_E	37.0
w_E	1.0
f_P	8.5
h_P	14.0
l_P	25.0

3.0 SIMULATION AND MEASUREMENT SET-UP

Parametric studies of the LIEH patch antenna were carried out using *Sonnet® em* Version. 6.0a electromagnetic simulator to obtain the optimize design parameters. The design flow diagram is shown in Figure 2, starting with a baseline design of the inverted rectangular patch with an air-filled dielectric, the baseline parameters (L, W, h_1, and h_0) are determined at centre frequency, f_0 and dielectric permittivity ε_1. Next, the L-probe is introduced to feed the patch and its parameters are adjusted to achieve the broadband requirement. The H- and E-shaped are then introduced on the patch with the initial values slots parameters to reduce the patch size and crosspolarization level. Through a series of systematic simulations of varying the design parameters, the optimized values are obtained for the required return loss.

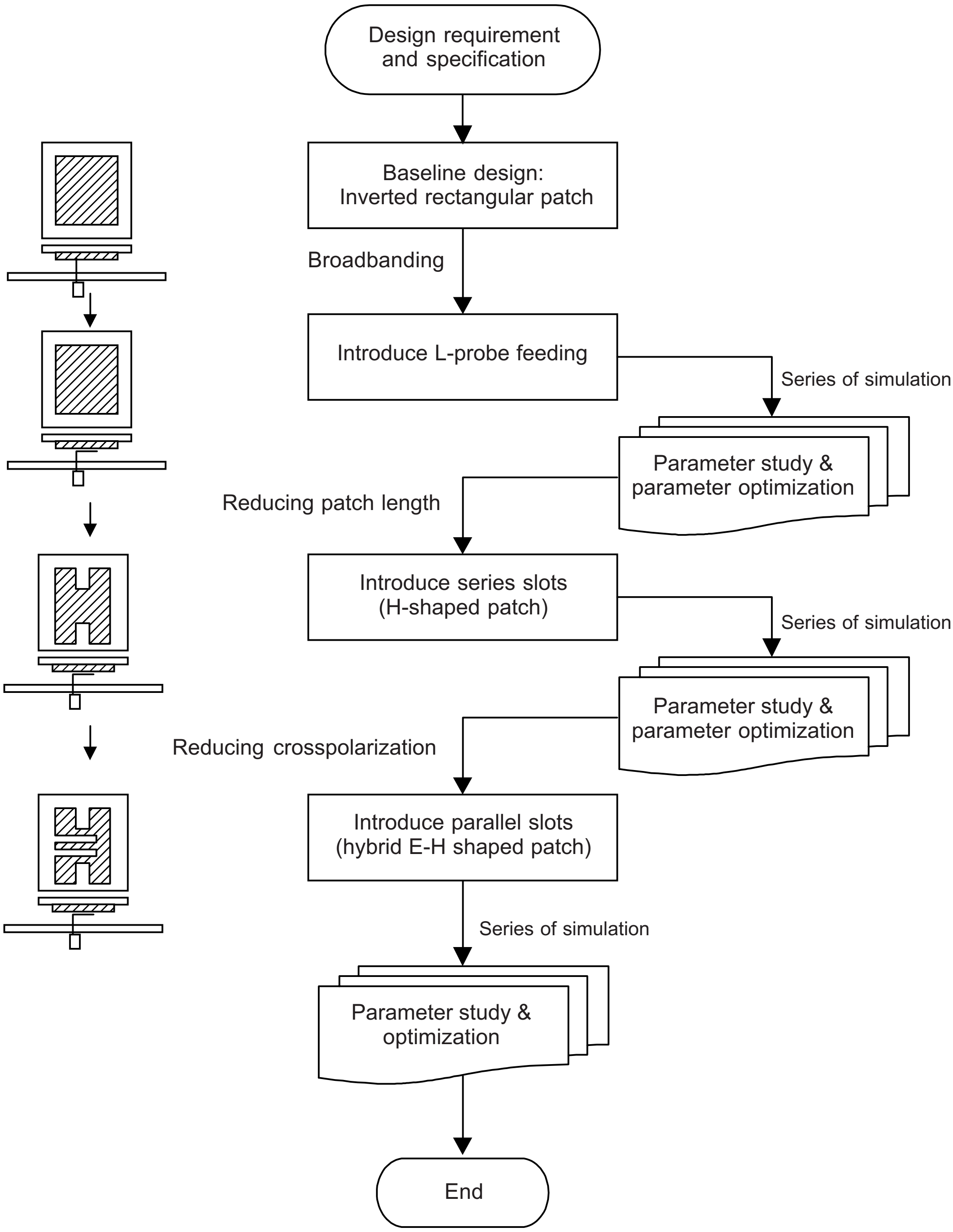


Figure 2 Design flow diagram for LIEH patch antenna

For the antenna measurements, the impedance characteristics of the fabricated LIEH patch antenna was measured using the Agilent PNA E8358A network analyzer and the radiation pattern measurement was carried out in the free space range (open space) using the Agilent E4436B signal generator and Advantest R3131A spectrum analyzer.

4.0 CURRENT DENSITY ANALYSIS

This section presents the analysis of current densities of the L-probe fed patch antenna to obtain a better understanding of the broadband and crosspolarization characteristics as well as size reduction mechanism of the patch antenna. In this analysis, *Sonnet*® *emvu* (e-m visualization) was employed to simulate the current densities of the patch.

In general, the L-probe fed patch antenna exhibits two resonance frequencies characteristic, represented as low and high frequency, as shown in Figure 3. These low and high resonance frequencies must be closely exited for the patch to be broadband. For the analysis, the low and high frequencies are determined at 1.9 GHz and 2.1 GHz. With this setting, the following paragraph analyzed the current densities for the L-probe fed rectangular-, H-, and hybrid E-H shaped inverted

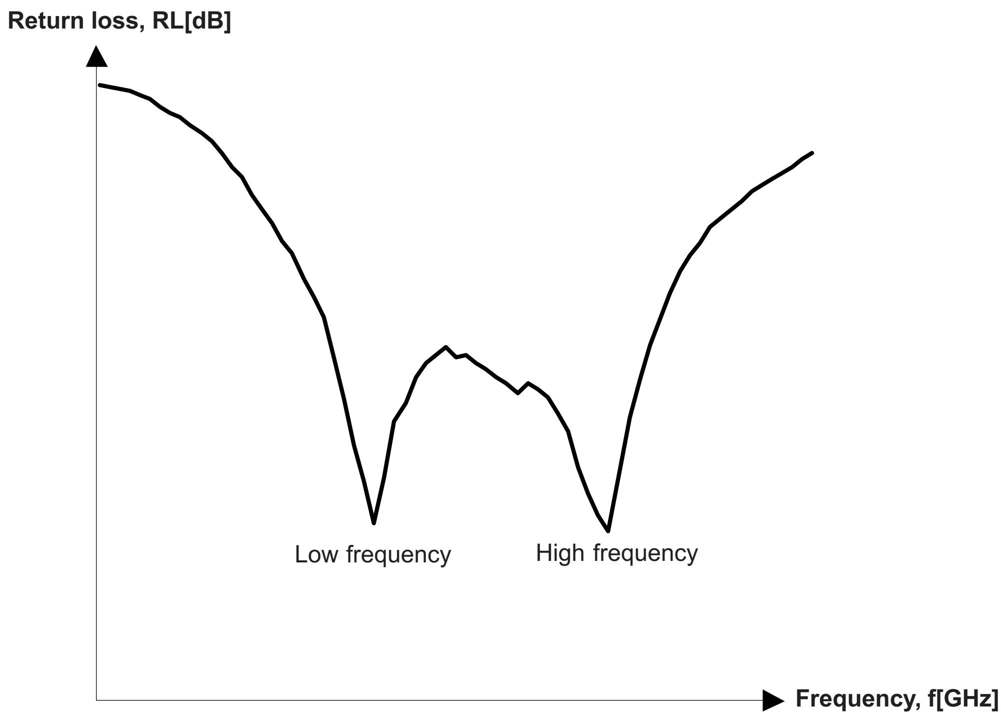


Figure 3 Return loss characteristic of a typical L-probe fed inverted patch

patch antenna with an air filled dielectric. In the analysis, the patch antennas are simulated using the same dielectric permittivity, thickness, and air gap. Noted in the following figures, the current density is represented by the colour distributions on the surface of the patch, where the colour level represents the intensity of the current density. The current densities in the E- and H-plane are marked as *Jx* and *Jy* in these figures.

4.1 Broadband Mechanism

Figure 4(a) shows the current density of the L-probe fed rectangular patch at low and high frequencies. It can be observed that the current *Jx* is stronger than the current *Jy*, indicating the fundamental cavity mode of the patch is TM_{10} mode. Also shown in the figure, strong current *Jx* flows along the L-probe on the patch at low frequency. At this low frequency, the patch acts as a conventional radiating element with its low resonant frequency determined by its length. However, at higher frequency, stronger current *Jx* flows along the L-probe on the patch and cover larger area. This effect can be modelled as additional capacitance that reduces the electrical path of the patch and excites the high resonance frequency. With appropriate adjustment of the L-probe parameters, the two resonance frequencies can be excited closely to obtain broadband characteristic.

4.2 Size Reduction Mechanism

Figure 4(b) shows the current densities for L-probe fed H-shaped (LIH) patch antenna. As shown in the figure, strong current *Jy* is observed along the edge of the slots while strong current *Jx* is observed at the end of the slots at both high and low frequencies. These observations show that the current continuously flows around the slots, with higher intensity observed at low frequency. This perturbation of the current density distribution on the patch results in a longer electrical length of the patch, hence reducing the patch size.

4.3 Lower Crosspolarization Mechanism

The addition of parallel slots on the patch forming the hybrid E-H shaped patch, as shown in Figure 4(c), introduced a favourable effect. Strong current *Jx* is observed along the slots and strong current *Jy* are observed at the end of the slots. Noted in the figure, the introduction of parallel slots suppress the current from flowing towards the non-radiating edge of the patch from the feed position. This can be clearly seen by comparing *Jy* for the H-shaped and hybrid E-H, where for H-shaped, strong *Jy* is observed to flow towards the non-radiating edge at the left edge of the patch. Therefore, the LIEH patch antenna has lower crosspolarization compared to the H-shaped patch.

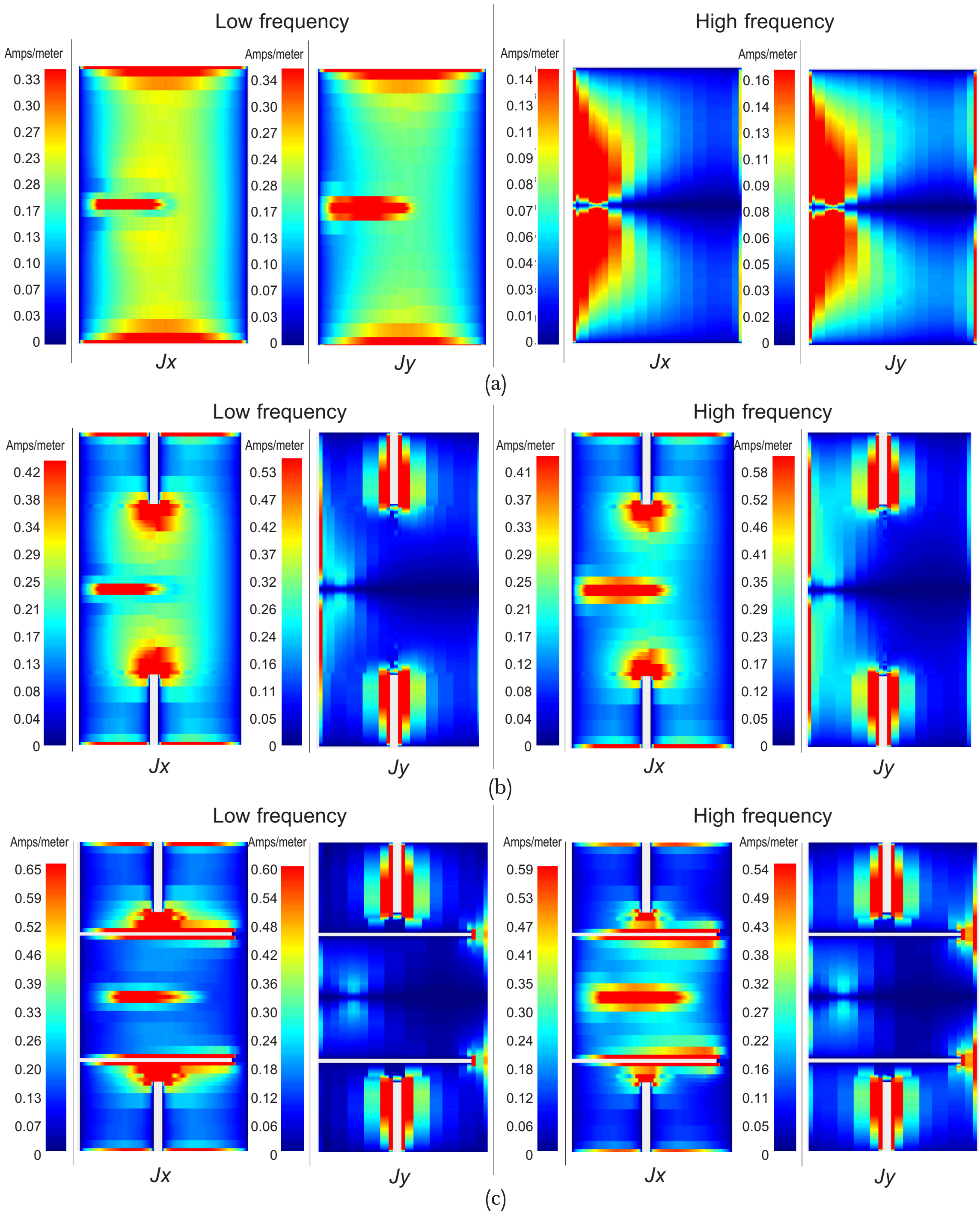


Figure 4 Current density distribution at low and high frequency for (a) L-probe fed inverted patch antenna, (b) L-probe fed inverted H-shaped (LIH) patch antenna, and (c) LIEH patch antenna. Colors on the patch represent amplitude/meter^2

5.0 RESULTS

Figure 5 shows the measured and simulated results of the return loss of the LIEH antenna. The measured result fits fairly well with the simulated result. The two closely excited resonant frequencies at 1.92 and 2.15 GHz as shown in the figure give the measure of the wideband characteristic of the patch antenna. Based on this result, the fractional bandwidth of 17.2% is achieved at 14 dB (SWR = 1.5) return loss and at 10 dB

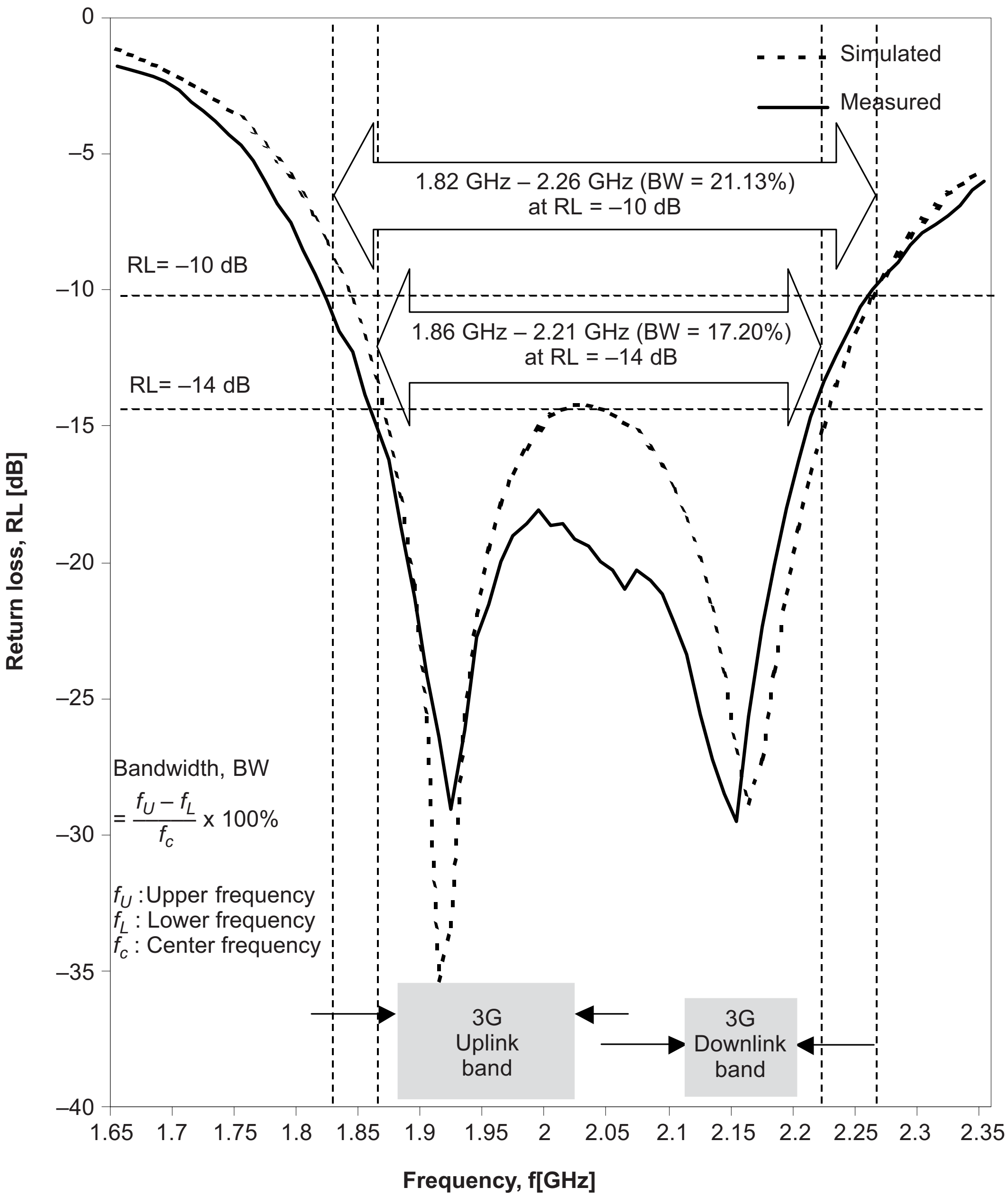
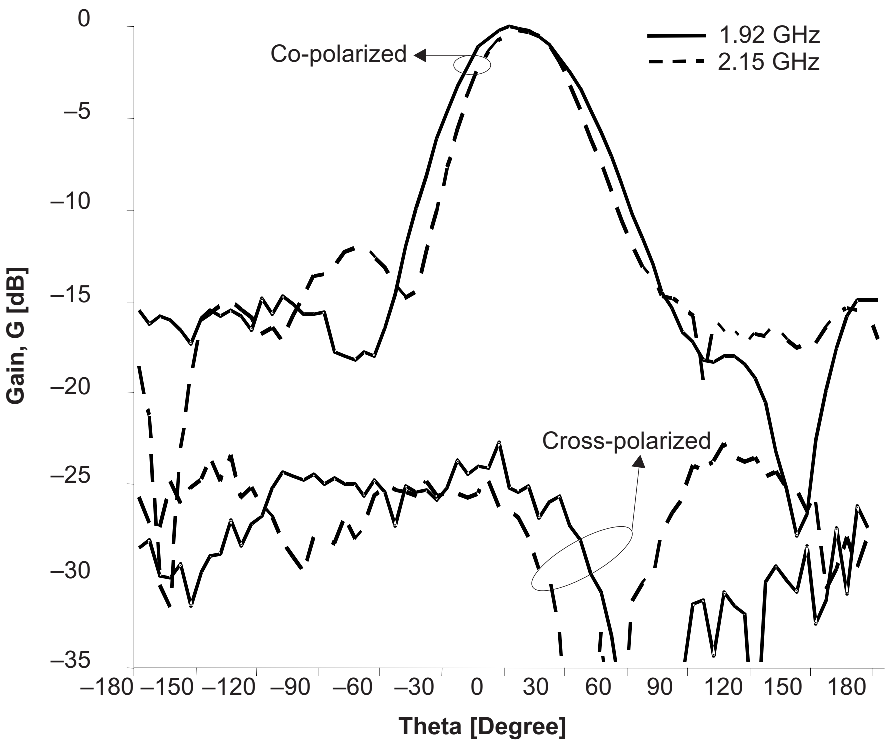


Figure 5 Simulated and measured return loss of the LIEH patch antenna

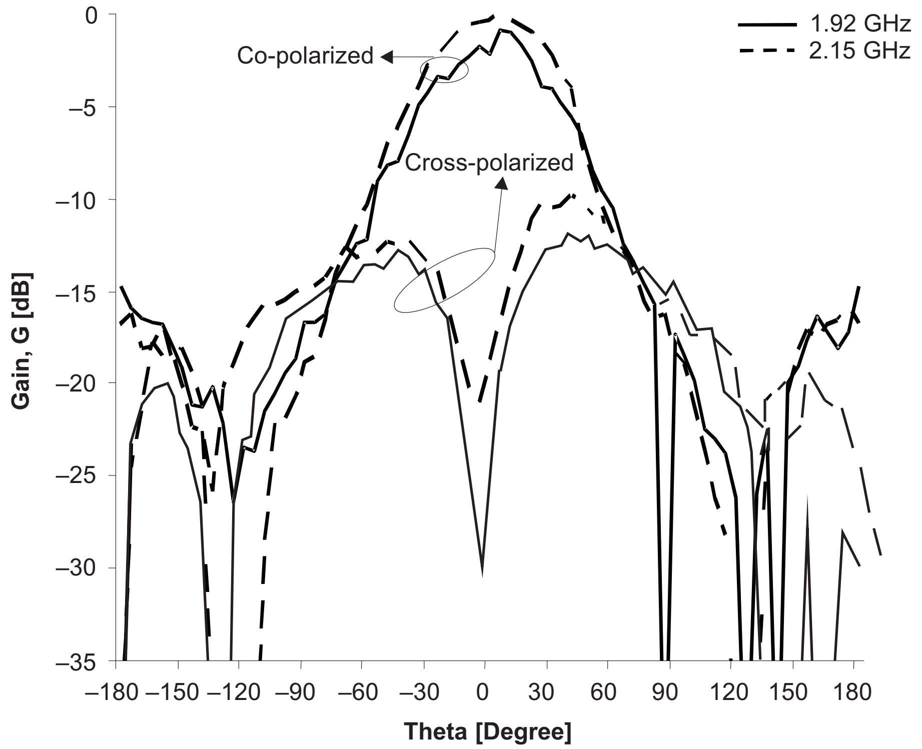
return loss the fractional bandwidth equals to 21.13%, covering the IMT-2000 band.

Figure 6(a) shows the measured E-plane radiation pattern of the antenna at 1.92 GHz and 2.15 GHz. At these frequencies, the measured 3-dB beamwidth are approximately 60° and 50°, respectively. The asymmetry characteristic of the copolarization pattern is clearly shown in the figure. This is due to the thick substrate structure of the design, similar to the result reported in [11]. The peak crosspolarization level of the antenna is observed to be 25 dB below the copolarization level of the main lobe. For the conventional L-probe fed inverted H-shaped patch antenna, crosspolarization peak can reach as high as –15 dB [6].

The measured H-plane radiation pattern of antenna is presented in Figure 6(b) with the measured 3-dB beamwidth of about 75°, broader than that in the E-plane. The radiation pattern in the H-plane is observed to have higher crosspolarization level compared to the E-plane, with crosspolarization peak of –11.87 dB and -9.82 dB, at low and high resonance frequencies. However, the observed crosspolarization pattern for the LIEH is better compared to the conventional L-probe fed inverted H-shaped patch antenna [6]. The improvement in the crosspolarization characteristic of the patch is due to the embedded parallel slots which reduce the current flow in H-plane direction, as discussed earlier in Section 4.0.



(a)



(b)

Figure 6 Radiation pattern measurement of the LIEH patch antenna: (a) E-plane and (b) H-plane

The measured gain of the L-probe fed inverted E-H shaped patch antenna at various frequencies is shown in Figure 7. As shown in the figure, the maximum achievable gain is 8.04 dB with 1.03 dB gain variation at the operating frequency. Measured characteristics of the LIEH antenna are summarized in Table 2.

6.0 CONCLUSION AND DISCUSSION

Simulation and experimental results of a wideband microstrip patch antenna for antenna array applications covering the IMT-2000 or 3G band have been presented. Techniques for microstrip broadbanding, size reduction, and crosspolarization reduction are applied with significant improvement in the design by employing novel hybrid E-H shaped design, inverted patch, and L-probe feeding. Current density analysis using *Sonnet®* *emvu* are given to give a clear picture of the electrical characteristic of the designed patch.

Simulated and measured impedance bandwidth results are in good agreement. The LIEH microstrip patch antenna achieves a fractional bandwidth of 17.20% (1.86 to 2.21 GHz) at 14 dB return loss and 21.13% at 10 dB return loss. The maximum

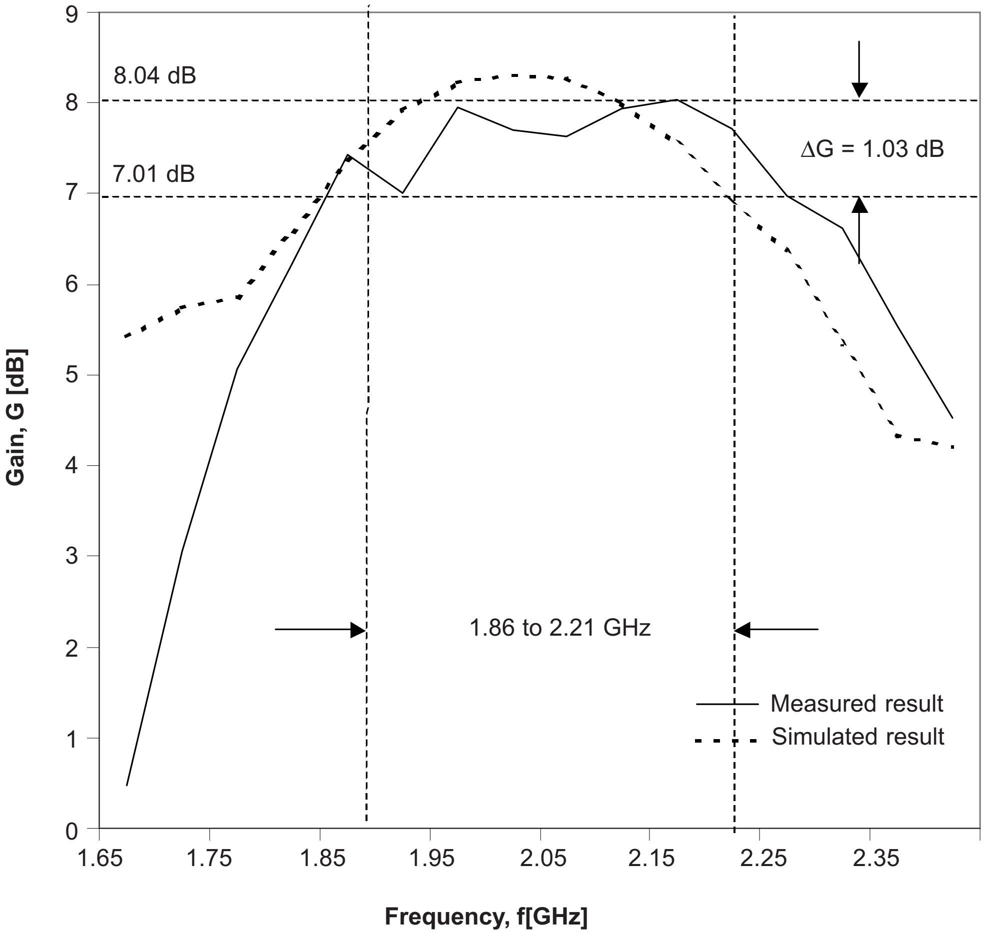


Figure 7 Measured and simulated gain of LIEH patch antennas at different frequencies

achievable gain of the antenna is 8 dBi with 1 dB gain variation while the crosspolarization level is 23 dB below the main lobe level. The LIEH patch has a compact dimension of 79×41 mm^2.

The wideband characteristic of the antenna is achieved by using the L-shaped probe feeding techniques and the use of series slots (H-shaped) lead to the patch size reduction. Better radiation performance and crosspolarization level are achieved by embedding parallel slots onto the patch (E-shaped) while the use of inverted patch improves the gain of the antenna. The composite effect of integrating these techniques offers a low profile, broadband, high gain, low crosspolarization, and compact antenna element suitable for array applications especially for IMT-2000 base station antenna.

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