High Gain Directional Antenna for WLAN and WiMAX Applications

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***Abstract*— This letter presents a dual band slot antenna with high gain for WLAN and WiMAX communication covering the IEEE802.11a/b and IEEE802.16d/e standards. The antenna consists of a microstrip fed slot with a complimentary stub on a single dielectric medium. A reflecting ground plane is employed to achieve a unidirectional radiation pattern with an average gain of 9.1 dBi. The feed of the antenna is optimized to achieve radiation efficiency above 95% in the WLAN and WiMAX frequency bands. The radiation properties of a prototype antenna were measured in a compact antenna range. Simulated and measured results (impedance bandwidth, gain and radiation patterns) are presented for the proposed antenna.**

***Index Terms*— Directive antennas, multiband antenna, slot antennas, wireless (local area network) LAN, WiMAX.**

I. INTRODUCTION

WLAN (Wireless Local Area Network) is recognized as a cost-effective and reliable wireless communication solution [1]. The most common WLAN frequency bands include 2.4 – 2.483, 5.15 – 5.25 and 5.725 – 5.825 GHz for the IEEE802.11b/j and IEEE802.11a standards. A high gain directional WLAN antenna covering all three of the most common WLAN frequency bands would be very desirable [1].

Several antennas suitable for WLAN applications have been proposed, viz. a circular dual loop, a triangular monopole, a monopole-ring-patch, slotted and slot coupled patch, super shaped slotted and an angled dipole antenna. These antennas all have an average gain of less than 8.2 dBi in the popular WLAN frequency bands or are larger than 100 mm × 100 mm × 15 mm.

A circular dual loop antenna, 120 mm in diameter and 8.4 mm height, is presented in [2]. In length and height this antenna was larger than 100 mm × 100 mm. The antenna in [2] was also dual-polarized because of its angled array, with gains of about 7 and 8.7 dBi in the 2.4 and 5 GHz frequency bands.

A combination of a fork-monopole, a rectangular ring, a patch and a reflector, was presented in [3]. The reflector, 109 x 78 mm², was positioned 101 mm from the antenna substrate and was therefore much higher than 15 mm. The antenna had peak gains of approximately 6.2 and 10.4 dBi in the 2.4 and 5 GHz frequency bands.

An antenna that used a supershaped annular slotted patch antenna was proposed in [4]. The antenna was etched on a 9.5 mm thick elliptical substrate, with the two diameters being 70 and 80 mm. This antenna had average gains of only 6.8 and 7.1 dBi in the 2.4 and 5 GHz frequency bands respectively.

A slot-coupled patch antenna, proposed in [5], consisted of three substrates, separated by air and had a physical size of about 80 mm x 80 mm x 12.8 mm. This complex antenna had maximum gains of about 6.8, 9.5 and 8.1 dBi in the three WLAN frequency bands.

In this letter, a new high gain antenna that operates in the IEEE802.11a/b WLAN frequency bands is proposed. The antenna with ground plane is 96 mm × 73 mm × 14 mm with measured gain of 9.2, 7.0 and 10.1 dBi in the three WLAN frequency bands, respectively. The proposed antenna, therefore, superseded other high gain dual-band WLAN antennas found in the literature when taking gain and physical size into account. In addition to WLAN applications, the antenna can also be used for WiMAX (Worldwide Interoperability for Microwave Access) applications with frequency bands at 2.5-2.7 and 3.4-3.6 GHz [6].

The radiation properties of a prototype antenna were measured in a compact antenna range. Simulated and measured results (impedance bandwidth, gain and radiation patterns) are presented for the proposed antenna.

II. ANTENNA DESIGN

The proposed antenna design is based on an ultra-wide band slot radiating element (SRE) described in [7] and [8]. The SRE consists of a slot in the ground plane layer of a microstrip line and a complimentary microstrip stub approximately the same size as the slot. The SRE is fed with a microstrip line running perpendicularly through the center of the stub and is terminated in a matched load. The wideband radiating element is used as an omni-direction element in a series-fed linear array. Thus, the individual radiating element is omni-directional with low radiation efficiency. A three dimensional view of the proposed antenna is shown in Fig. 1. A reflecting backplane was added to the SRE to ensure directional radiation patterns and to increase the gain.

The wideband characteristics of the slot and complimentary microstrip stub were exploited to design a high gain directional

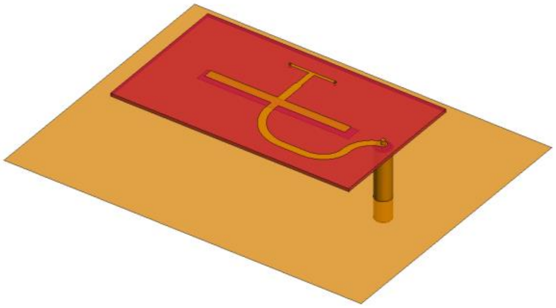


Fig. 1. 3D view of the antenna.

antenna with high radiation efficiency suitable for WLAN and WiMAX applications. Even and odd mode analysis of one microstrip-slotline coupled subsection (half of the slot) was performed in [7] and the electric field distributions of the two modes were studied. In the even mode the electric field was concentrated around the microstrip line and the distribution was similar to that of a microstrip line. In the odd mode the electric field was concentrated in the gap of the slot and the field distribution was similar to that of a slotline. In [7] it was referred to as quasi-strip and quasi-slot modes and therefore when the slot-strip coupling is not too strong the even and odd mode parameters can be approximated by:

TABLE I
ANTENNA DIMENSIONS

Parameter	Value in mm	Dimension
Substrate length	37.26	A
Substrate width	63.90	B
Slot length	40.63	C = 2*L_S
Slot width	3.94	D
Strip length	17.84	E = L_M
Strip width	2.51	F
Feed line width	1.96	G
Taper	0.24	H
Taper to short split length	4.86	I
Short split to via centre length	5.30	J
Coaxial feed centre length	18.51	K
Coaxial feed centre width	3.74	L

(1)

$$Z_{0e} \approx 2Z_M; \quad \varepsilon_{eff,e} \approx \varepsilon_{eff,M}$$

$$Z_{0o} \approx \frac{Z_S}{2}; \quad \varepsilon_{eff,o} \approx \varepsilon_{eff,S} \tag{2}$$

where Z_{0e} and Z_{0o} are the characteristic impedances for the even and odd modes of the substructure, Z_M and Z_S are the characteristic impedances of the microstrip line and the slotline and ε_{eff} are the effective permittivities of the even and odd modes and the microstrip line and slotline. The image impedance of the subsection is then determined by:

$$Z_{im} = \sqrt{Z_{0e}Z_{0o}\cot\theta_e \tan\theta_o} \tag{3}$$

where θ_e and θ_o are the electrical lengths of the even and odd modes respectively. When losses are neglected theses lengths can be expressed in terms of transmission line parameters as:

$$\theta_e = \sqrt{\varepsilon_{eff,M}} \times L_M \tag{4}$$

$$\theta_o = \sqrt{\varepsilon_{eff,S}} \times L_S \tag{5}$$

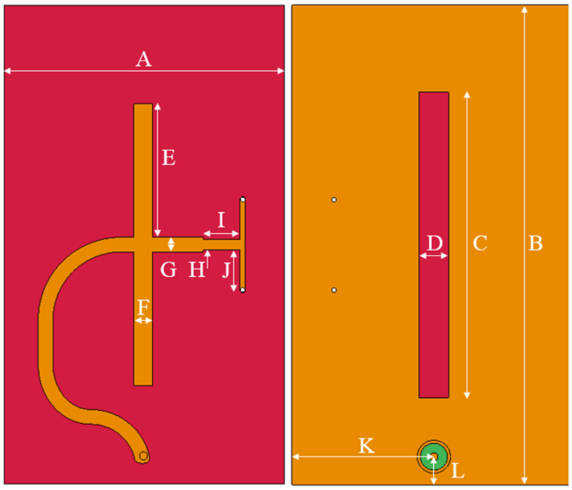
where the length of the microstrip (L_M) is measured from the microstrip feed line and the slot (L_S) is measured from the centre of the slot line (half the slot length). If the electrical lengths of both modes are equal to each other ($\theta_e = \theta_o$), the impedance matching of the total structure can be described by:

$$Z_0 = \frac{1}{2}\sqrt{Z_{0e}Z_{0o}} \tag{6}$$

where Z_0 is the characteristic impedance of the microstrip feed line. This is also the condition for the SRE to be impedance matched which means that the electrical lengths of the subsections ought to be the same and (5) must be satisfied at the same time. The coupling structure can be described by four transmission line parameters w_M, w_S, L_M and L_S, the widths and lengths of the microstrip line and the slot.

The reflector is 96 mm × 73 mm and the spacing (13 mm) between ground plane and antenna was optimized for impedance bandwidth. The radiation efficiency of the antenna was improved by terminating the microstrip feed line with an electrical short. An optimized termination was realized using an impedance transformer, splitter and two short circuited high impedance microstrip transmission lines. The radiation efficiency of the antenna was increased to above 95% in the frequency bands of interest. The dimensions of the antenna structure are shown in Fig. 2 and summarized in Table I.

The microstrip feed line of the antenna is excited with a coaxial feed through the back of the reflecting ground plane. The position of the coaxial feed line was optimized to reduce coupling between the coaxial line and radiated fields. The near fields, close to the antenna at 2.45 GHz as well as the position of the coaxial feed are shown in Fig. 3. To minimize interaction between the feed and antenna the coaxial feed was placed at a position where low current densities were observed on the ground plane (see Fig. 3.).



(a) (b)

Fig. 2. Layout and dimensions of the antenna top (a) and bottom (b).

The slot and complimentary microstrip stub is etched onto a 0.81 mm thick Rogers RO4003C with a relative permittivity of 3.38 and a loss tangent of 0.0029. The antenna is fed with a standard EZ 141 coaxial cable from Huber and Suhner with a center conductor diameter of 0.91 mm and a dielectric diameter of 2.99 mm.

The lower operating frequency band is mostly controlled by die length of the substrate (dimension A). Dimension B has little effect on the performance of the antenna. The ground

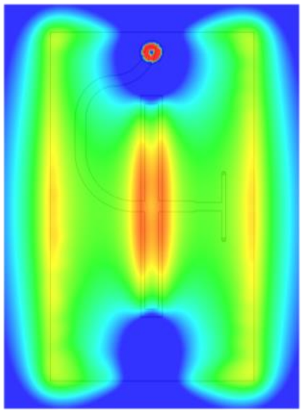


Fig. 3. Electromagnetic field intensity close to the antenna at 2.45 GHz.

plane of the antenna acts as a patch antenna at the lower frequency band. The center frequency of the lower frequency band can be approximated by equation 7, where c is the speed of light and ε_{eff} is the effective dielectric constant of the ground plane, in this case 2.2.

$$f_{cLow} = \frac{c}{2A\sqrt{\varepsilon_{eff}}} \tag{7}$$

The upper operating frequency band of the antenna is controlled by the length of the slot-strip pair (Dimensions C and E). The center frequency of the upper frequency band can be approximated by equation 8, indicating that the upper frequency band operates at a whole wavelength in the slot. The effective dielectric constant for this slot is about 1.9.

$$f_{cHigh} = \frac{c}{C\sqrt{\varepsilon_{eff}}} \tag{8}$$

It should be noted that by changing any of the critical dimension of the antenna, has some effect on all the frequency bands. In order to maintain functionality in one frequency band, the other frequency band can only be move by about 10%. When moving the antenna reflector closer to the substrate improves the antenna performance in the higher frequency bands and decreases the performance at the lower frequency bands. Vice versa for moving the reflector further away from the substrate.

The antenna is more dependent on the length of the reflector than on the width. The width of the reflector can be decreased to as wide as the antenna substrate with little effect on the antenna performance. The length of the reflector can only be decreased to about 1.5 times the length of the antenna substrate to maintain reasonable performance in all the frequency bands.

III. SIMULATIONS AND MEASUREMENTS

The simulated performance of the antenna is compared to measured results. The simulations were performed with a commercial software package, FEKO [9].

The simulated and measured reflection coefficients of the antenna are shown in Fig. 4. The measurement was performed using a HP8510 Vector Network Analyser. The antenna has a reflection coefficient below -10 dB in all three the WLAN frequency bands, as well as the WiMAX bands, as indicated.

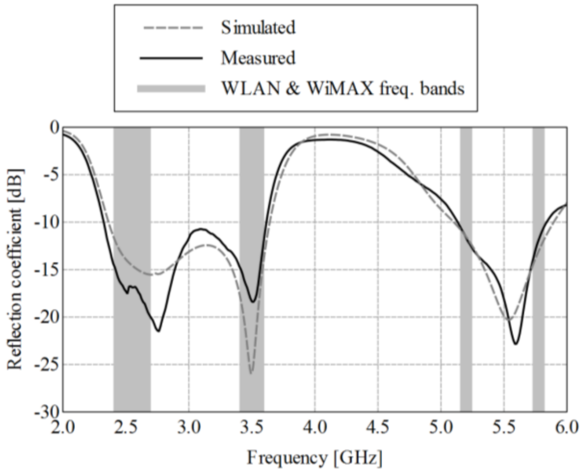


Fig. 4. Simulated and measured results of the reflection coefficient of the antenna.

The gain and radiation patterns of the proposed antenna were measured in the compact antenna test range at the University of Pretoria as shown in Fig 5. The measured gain of the antenna is within 1.6 dB of the simulated realised gain and is shown in Fig 6. The average gain was measured as 9.2, 7.0 and 10.1 dBi in the three WLAN frequency bands, respectively. The average measured gain in the WiMAX frequency bands were 9.2 and 10.0 dBi. The differences between the measured and simulated gain values are most likely due to the measurement setup, viz. interaction between the small antenna, positioner and feeding cable in the compact range. The gain of the antenna is about 3

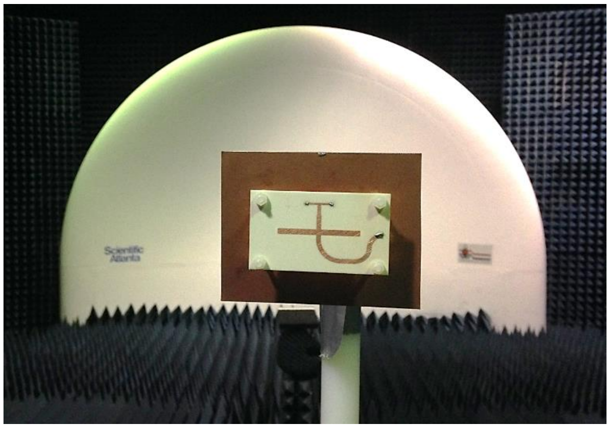


Fig. 5. Manufactured antenna in the compact antenna test range.

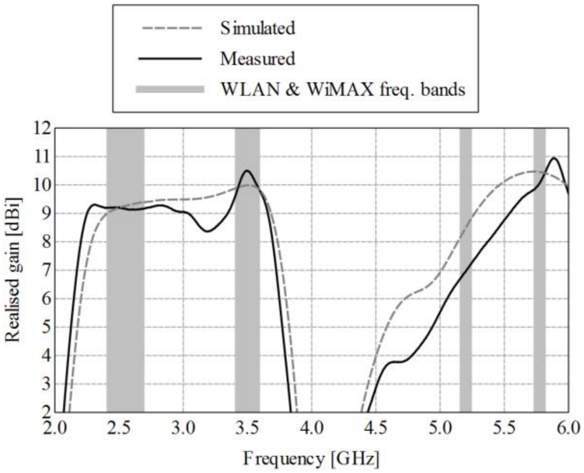
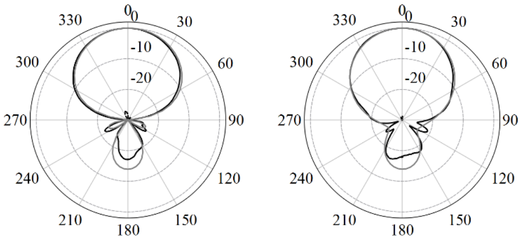


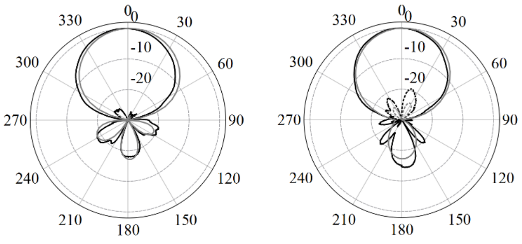
Fig. 6. . Simulated and measured results of the gain of the antenna.

dB lower at 5.2 GHz than at 5.775 GHz. From the radiation patterns in Fig. 7 it is clear that the H-plane radiation pattern at 5.2 GHz is much wider than at 5.775 GHz. This is the reason for the lower gain at 5.2 GHz in the measurement as well as in the simulation.

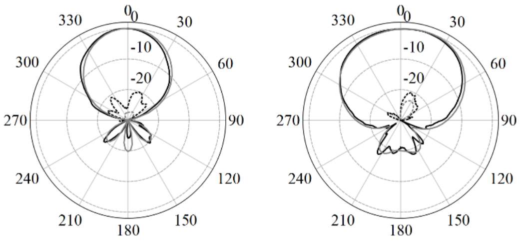
The measured and simulated radiation patterns in the E- and H-plane of the proposed antenna at 2.45, 3.5, 5.2 and 5.775 GHz are shown in Fig. 7. The measured radiation patterns correspond very well with the simulated radiation patterns; even the cross-polarizations are close to that of the simulations. In the WLAN and WiMAX frequency bands the cross-polarizations are less than -19 dB. The front-to-back ratio of the antenna is better than -14 dB. The 3dB beamwidth of the antenna in the E-plane is stable and constant at 66° in the lower WLAN frequency band and 49° in both of the upper WLAN frequency bands. In the H-plane the antenna has good beamwidths at 2.45 and 5.775 GHz at 62° and 63° respectively. At 5.2 GHz the H-plane beamwidth is 89°.



a) 2.45 GHz E-plane　　b) 2.45 GHz H-plane



c) 3.5 GHz E-plane　　d) 3.5 GHz H-plane



e) 5.2 GHz E-plane　　f) 5.2 GHz H-plane

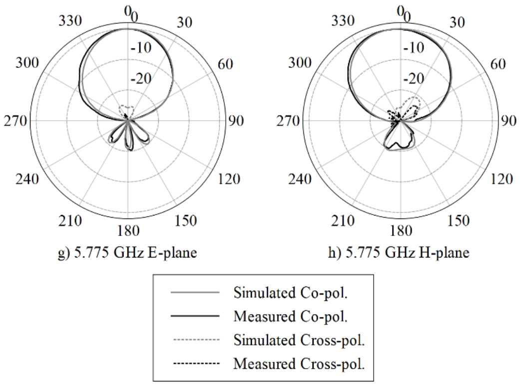


Fig. 7. Measured and simulated Co- and Cross-polarised radiation patterns of the antenna at four frequencies, 2.45, 3.5, 5.2 and 5.775 GHz.

IV. CONCLUSION

A high gain, directional multi-band antenna suitable for WLAN and WiMAX applications is presented in this letter. The antenna consists of a slot in a ground plane with a complimentary microstrip stub, approximately the same size as the slot. A reflecting ground plane ensures directional radiation patterns with high gain. An optimized termination was realized to ensure high radiation efficiency. The position of the coaxial feed line was optimized to reduce coupling between the coaxial line and radiated fields. The SRE antenna structure results in an antenna with higher gain compared to other WLAN antennas with similar physical dimensions found in the literature.

The radiation properties of a prototype antenna were measured in a compact antenna range. Simulated and measured are presented for the proposed antenna. Good front- to-back characteristics of the radiation patterns make the antenna suitable as a wall-mounted access point for WLAN and WiMAX applications.

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