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A New Wideband Unidirectional Antenna Element

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***Abstract*—A novel wideband unidirectional antenna composed of a planar electric dipole and a shorted patch antenna is presented. The antenna is excited by a Γ-shaped strip feed line. A wide impedance bandwidth of 43.8% (SWR≤1.5) from the frequency of 1.85 to 2.89 GHz is achieved. Stable radiation pattern with low cross-polarization, low backlobe radiation, nearly identical E-and H-plane patterns and an antenna gain of ~8dBi is found across the entire operating bandwidth.**

***Index Terms*—dipole, shorted patch, L-probe, wideband antenna, low cross-polarization, low back radiation**

I. INTRODUCTION

The success in second generation (2G) mobile communication service promotes the development of the third generation (3G), WiFi, WiMax, ZigBee and UWB system, which have high demand of wideband and low-profile unidirectional antennas that can accommodate several wireless communication systems with excellent electrical characteristics such as wide impedance bandwidth, low cross-polarization, low back radiation, symmetric radiation pattern and stable gain over the operating band for cost effectiveness, space utilization and environmental friendliness.

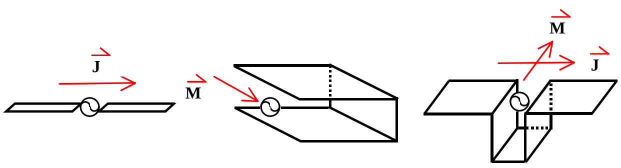
Several studies have been focused on the development of wideband unidirectional antenna elements [1-3]. A unidirectional antenna can be realized by placing a dipole one quarter of a wavelength above a finite ground plane [1]. Since the height of this antenna [1] in terms of wavelength is frequency dependant, the antenna has drawback of the large variation in gain and beamwidth over the operating bandwidth. Another popular unidirectional antenna is the microstrip/patch [4-7] antenna. There are many articles on the design of wideband patch antennas using an L-probe feed [4], an aperture coupled feed [5], stacked patches [6] or a U-slot patch [7] etc. For SWR≤2, within 20% to 40%, can be achieved by these designs which are sufficient for many wireless communication systems. However, the radiation pattern changes substantially across the bandwidth of these designs [4-7]. High cross-polarization usually can be observed, especially in the upper frequency band. Although some techniques such as anti-phase cancellation [8], twin-L probes coupled feed [9], M-probe feed [10] etc, were suggested for suppressing the cross-polarization, these antennas still have the weaknesses in gain and beamwidth variations with frequency as well as different beamwidth in the E- and H-planes.

To achieve an equal E- and H-planes radiation pattern and a stable performance over frequency, the idea of complementary antenna consisting of an electric dipole and a magnetic dipole was revealed in 1954 by Clavin [11]. It is well known that an electric dipole has a figure-8 radiation pattern in its E-plane and a figure-O pattern in the H-plane; while a magnetic dipole has a figure-O pattern in the E-plane and a figure-8 in the H-plane. If both electric and magnetic dipoles can be excited simultaneously with appropriate amplitude and phase, a unidirectional radiation pattern with equal E- and H- planes can be obtained. A practical design was proposed by Clavin again in 1974 [12]. Another design, which consists of a passive dipole placing in front of a slot, was also reported by King [13]. Similarly, this idea was realized by other investigators, based on a slot-and-dipole combination [14,15]; however, all of these designs [11-15] are either narrow in bandwidth or bulky in structure.

In this paper, a new wideband complementary antenna with low cross polarization, low back radiation and symmetric E-and H-plane patterns is presented. The antenna comprises a vertical-oriented quarter-wave shorted patch and a planar dipole, which is equivalent to a combination of an electric dipole and a magnetic dipole. To demonstrate the performance of the proposed antenna, simulation results of input impedance, SWR and gain characteristics are presented. Radiation patterns of the conventional dipole and the proposed design are compared. Experimental data are obtained to verify the theoretical prediction. Due to its excellent electrical characteristics, the proposed antenna finds applications in various wireless communication systems.

II. ANTENNA DESCRIPTION

The proposed design is based on the approach of combining an electric dipole antenna with a magnetic dipole antenna. Among many candidates of electric dipoles, a planar dipole antenna is chosen as shown in Fig.1a; while a wideband short-circuited patch antenna is selected as the magnetic dipole as depicted in Fig. 1b. To combine these two antennas, the short-circuited patch is placed vertically and is connected to the planar dipole as illustrated in Fig. 1c. Based on this idea, a new wideband antenna is proposed and its geometry is shown in Fig. 2.



a) Conventional half-wavelength electric dipole antenna

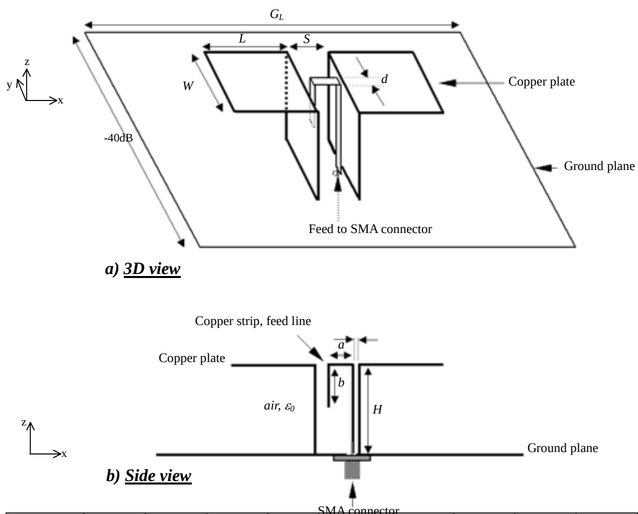
b) Quarter-wave patch antenna fed by L-probe

c) An antenna consisting of an electric dipole and a quarter-wave patch

Fig.1 Principle of operation of the antenna.

After a detailed parametric study, an antenna operated at the center frequency of 2.5GHz is designed for demonstration. Each side of the planar dipole has a width *W=60mm* (0.5 λ), and a length *L=30mm* (0.25 λ). The shorted patch antenna has a length *H=30mm* (also close to 0.25 λ), where λ=2πf. For wideband operation, the separation of the two vertical plates, *S=17mm*, of the shorted patch antenna should be close to 0.14 λ and the width of the dipole and the patch *W* should be around 0.5 λ. The size of the ground plane can be used to adjust the back radiation. The optimum dimensions of the ground plane are 120mm ×120mm (1 λ by 1 λ).

To excite the antenna, an Γ-shaped probe feed is employed. This feed consists of three portions, which is made by folding a straight metallic strip of rectangular cross-section into a Γ-shape. The first portion which is vertically-oriented has one end connected to a coaxial launcher mounted below the grounded plane.



Parameters	a	b	c	d	H	L	S	W	G_L	G_W
Value/mm	9.5 (0.079λ)	22 (0.183λ)	1 (0.008λ)	4.91 (0.040λ)	30 (0.25λ)	30 (0.25λ)	17 (0.141λ)	60 (0.5λ)	120 (λ)	120 (λ)

Fig. 2 Configuration of a wideband antenna composed of a planar dipole and a quarter-wavelength patch.

This portion together with one vertical plate of the shorted patch antenna acts as an air microstrip line with 50Ω characteristic impedance, which transmits the electrical signal from the coaxial launcher to the second portion of the feed. The second portion which is located horizontally is responsible to couple the electrical energy to the planar dipole and the shorted patch antenna. The input resistance of the antenna is controlled by the length of this portion. This portion is vers inductive reactance which can make the antenna totally be mismatched.

The third portion incorporated with the second vertical plate forms an open circuited transmission line. The equivalent circuit of this line is a capacitor. By selecting appropriate length for this portion, its capacitive reactance can be used to compensate the inductive reactance caused by the second portion.

III. PARAMETRIC STUDY

It is desirable to observe the effects of various parameters including *dipole length (L), aperture width (S) and antenna width (W)* on the performance of the proposed antenna. This is achieved by using a commercial EM solver, IE3D [16]. Throughout the study, the metallic layers are assumed to have zero thickness for relatively fast computation. The results are useful to provide design guideline for antenna engineers.

A. Impedance

Fig. 3 shows the dependance of input impedance, $Re(Z_{11})$ and $Im(Z_{11})$, on various parameters *L*, *S* and *W* . In Fig. 3a, shows the study of varying the antenna width, *W*. It can be observed that there are two local maxima in the curve of $Re(Z_{11})$ within the frequency range from 2GHz to 3GHz. When the value of *W* is decreased, the frequency of the second maximum (upper resonant frequency at around 3GHz) shifts to higher frequency whereas the first maximum (lower resonant frequency at about 2GHz) is insensitive to the variation of *W*. Noted that, the narrow-band resonant response at frequency around 1.3GHz is due to the Γ feed.

Antenna Width, W*		***Aperture Width, S^***		***Length of Dipole, L+***	
W(mm)	*BW%, SWR≤1.5 GHz*	*S(mm)*	*BW%, SWR≤1.5 GHz*	*L(mm)*	*BW%, SWR≤1.5 GHz*
40	13.4%, 1.95-2.23	*13*	14.0%, 1.65-1.90	*20*	13.5%, 2.23-2.56
50	39.9%, 1.94-2.92	*15*	17.5%, 1.82-2.17	*25*	26.6%, 2.07-2.70
60	35.7%, 1.94-2.79	*17*	35.7%, 1.94-2.79	*30*	35.7%, 1.94-2.79
70	31.5%, 1.94-2.67	*19*	29.4%, 2.04-2.74	*35*	13.9%, 1.85-2.13
80	27.5%, 1.94-2.56	*21*	24.0%, 2.11-2.69	*40*	10.9%, 1.79-2.00
**Fixed S=17mm and L=30mm*		*^Fixed W=60mm and L=30mm*		*+Fixed W=60mm and S=17mm*	

Table 1. Summary of simulated SWR versus parameters *L*, *S* and *W*.

Antenna Width, W*		***Aperture Width, S^***		***Length of Dipole, L+***	
W(mm)	*1-dB Gain BW (%); Max. Gain (dBi); Freq. Range(GHz)*	*S(mm)*	*1-dB Gain BW (%); Max. Gain (dBi); Freq. Range(GHz)*	*L(mm)*	*1-dB Gain BW (%); Max. Gain (dBi); Freq. Range(GHz)*
40	50.93%; 8.24; 1.80 – 3.03	*13*	65.19%; 8.27; 1.52 – 2.99	*20*	30.89%; 8.53; 2.08 – 2.84
50	50.83%; 8.18; 1.79 – 3.01	*15*	54.94%; 8.23; 1.69 – 2.97	*25*	42.00%; 8.32; 1.90 – 2.91
60	49.47%; 8.15; 1.78 – 2.95	*17*	49.47%; 8.15; 1.78 – 2.95	*30*	49.47%; 8.15; 1.78 – 2.95
70	47.08%; 8.15; 1.77 – 2.86	*19*	45.38%; 8.08; 1.84 – 2.92	*35*	53.85%; 8.02; 1.71 – 2.97
80	43.71%; 8.17; 1.77 – 2.76	*21*	41.34%; 8.03; 1.90 – 2.89	*40*	55.48%; 7.91; 1.68 – 2.97
**Fixed S=17mm and L=30mm*		*^Fixed W=60mm and L=30mm*		*+Fixed W=60mm and S=17mm*	

Table 2. Summary of simulated gain versus parameters *L, S* and *W*.

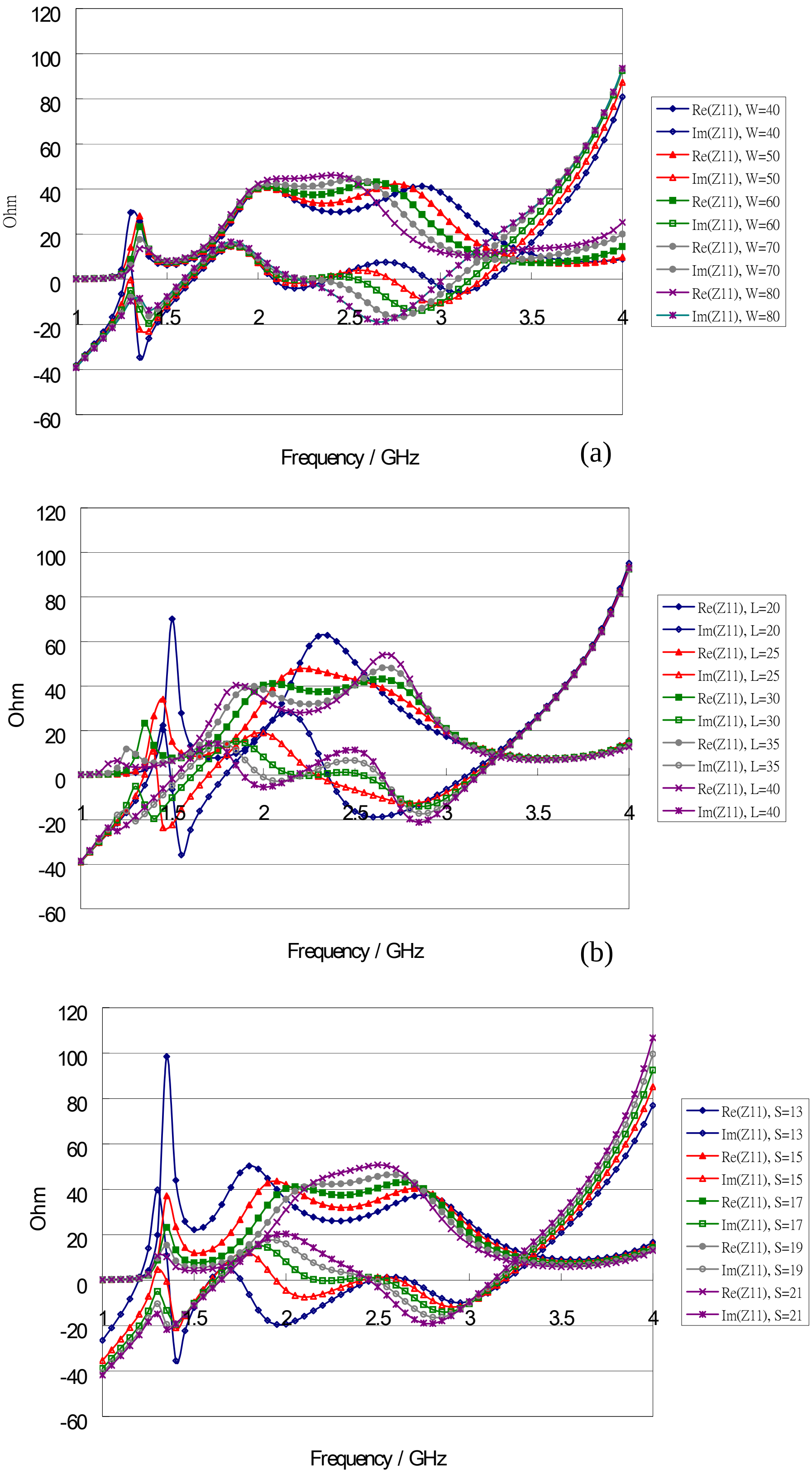


Fig.3 Impedance response with versus parameters *L*, *S* and *W*

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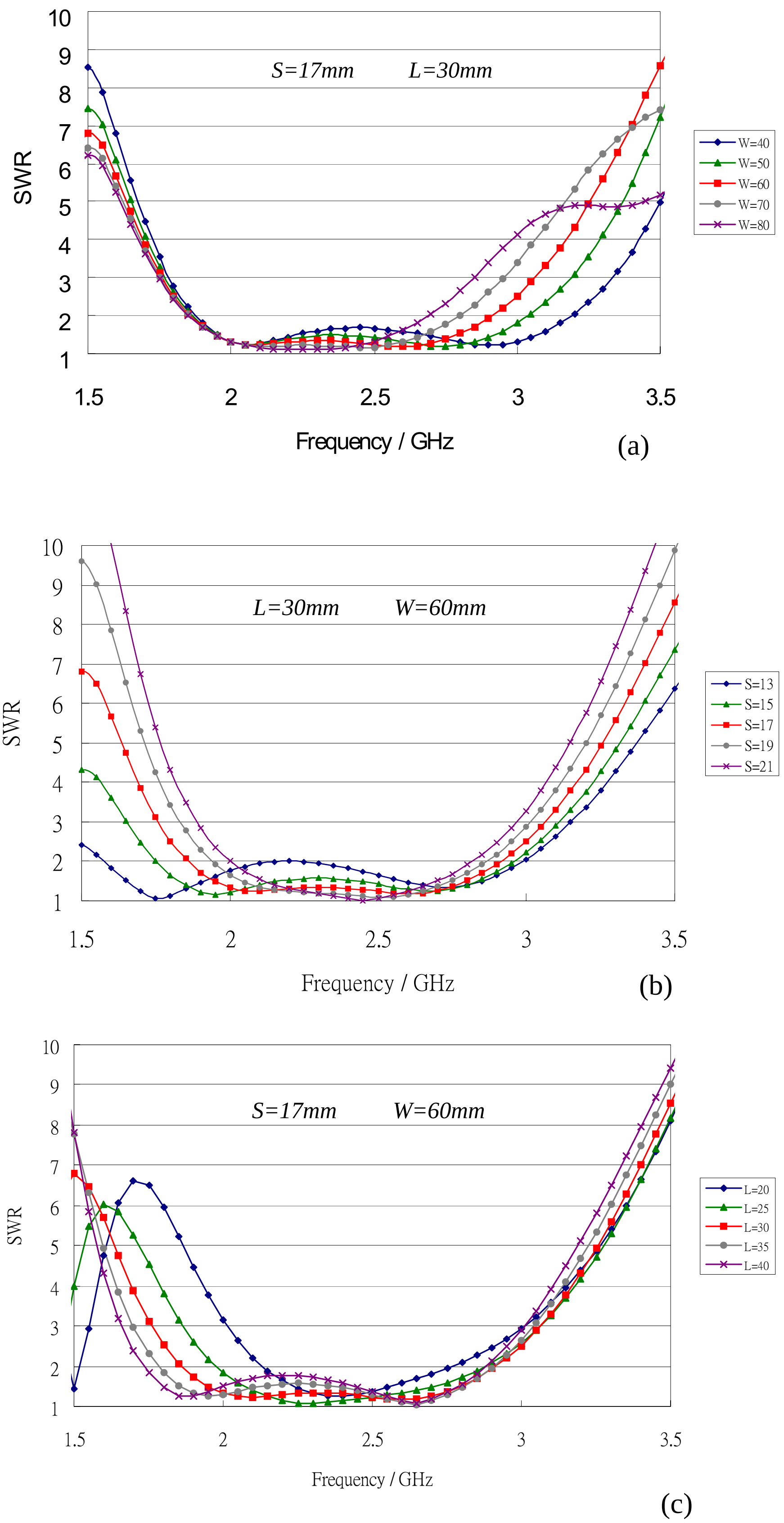

Fig.4 SWR response with versus parameters *L*, *S* and *W*

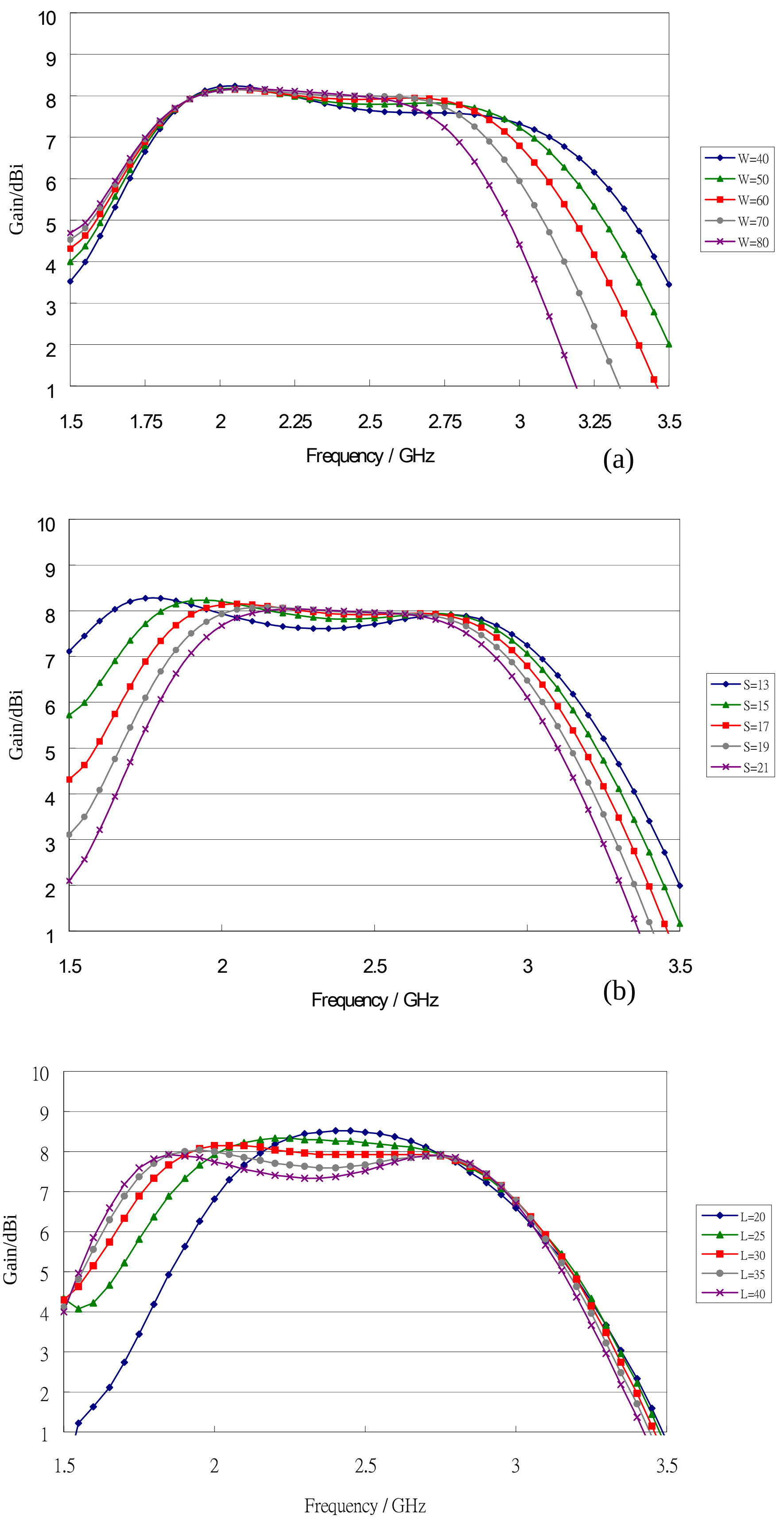

Fig. 5 Antenna gain versus parameters *L*, *S* and *W*

Fig. 3b demonstrates that the aperture width, *S*, can control the lower resonant frequency. It can be observed that the lower resonance occurs at 1.8GHz when *S*=13mm. When *S* is increased from 13mm to 21mm, the lower resonance shifts up to the frequency of 2.1GHz. On the other hand, the upper resonant peak shifts down slightly from 2.7GHz to 2.5 GHz. The reactance curve $Im(Z_{11})$ also shifts down accordingly when *S* is increased from 13mm t o 21mm.

In Fig. 3c, the result indicates that the length of the dipole, *L* is very effective to adjust the location of lower and upper resonant peaks. When the value of *L* is small, (e.g. *L*=20mm), the electric dipole is weakly excited such that only one resonant peak of $Re(Z_{11})$ can be found within the operating bandwidth, which is due to the excitation of the vertically-oriented quarter-wave patch antenna. Since the height of the vertical-oriented patch antenna is chosen as 30mm which is equal to quarter of a wavelength at frequency of 2.5GHz.

This result provides a good physical insight on the principle of operation of the proposed antenna.

A. SWR

Fig. 4 shows the effect of various parameters *L*, *S* and *W* on the bandwidth response. The simulated result was summarized and reported in Table 1. For SWR≤1.5, the largest BW is 39.9% when *W*=50mm, *S*=17mm and *L*=30mm.

B. Gain

When selecting a wideband antenna for a practical application, it is necessary to consider the gain performance in addition to the impedance bandwidth. From the pervious result in *(b) SWR*, the proposed antenna has a good wide impedance characteristic. The antenna gain against frequency with different values of *L*, *S* and *W* is shown in Fig. 5. A summary of the 1-dB gain bandwidth is reported in Table 2. The result shows that the antenna gain changes only slightly with variation of *W* and *S*. The length of the planar dipole, *L*, cannot be too small; otherwise, the gain bandwidth will be reduced dramatically, only 30.89% 1-dB gain bandwidth for the case of *L*=20mm with *W*=60mm and *S*=17mm. Table 2, summarizes the simulated gain with various values of *L*, *S* and *W*. The average gain for all cases is around 8dBi. And the 1-dB gain bandwidth ranges from 30.89% to 65.19%. It is worth mentioning that the antenna has a very stable antenna gain across the operating bandwidth.

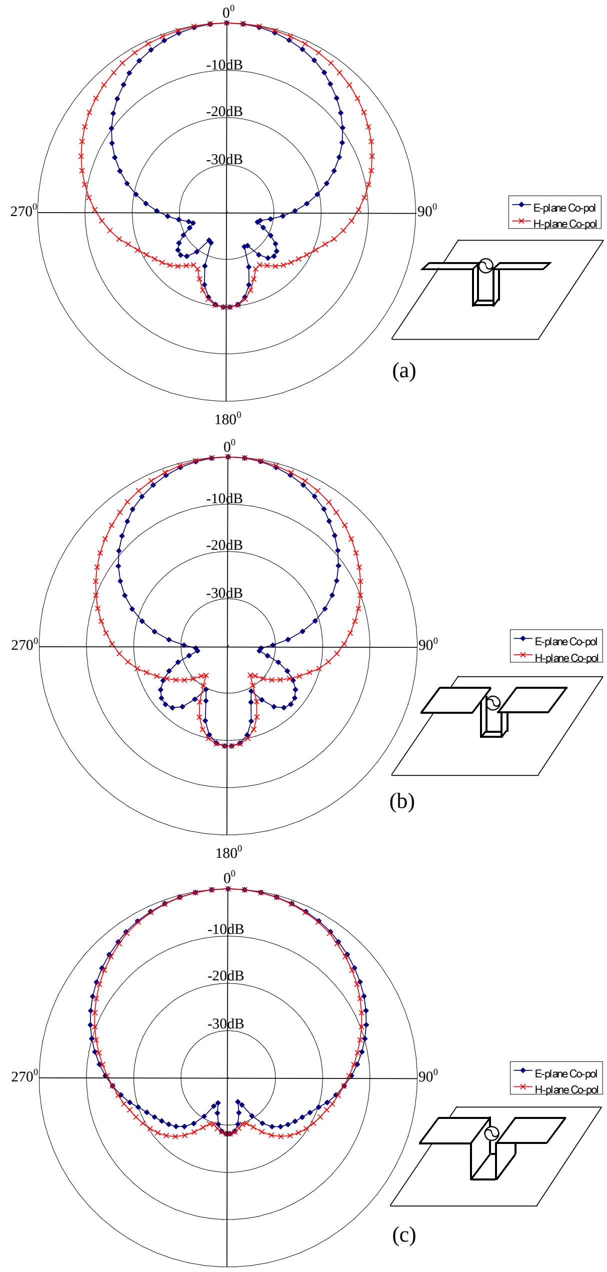

Fig. 6 Radiation patterns comparison of a) thin dipole, b) planar dipole and c) proposed antenna

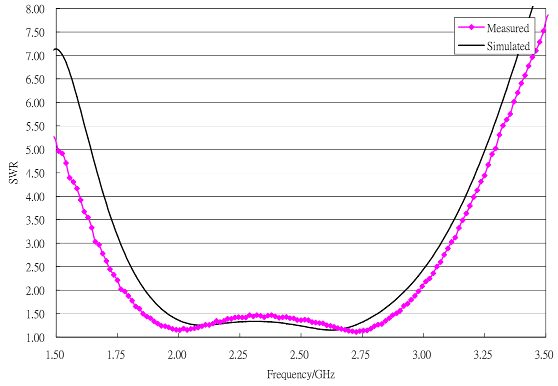

Fig. 7 Measured and simulated SWR against frequency for a quarter-wave L-probe patch fed rectangular planar dipole antenna.

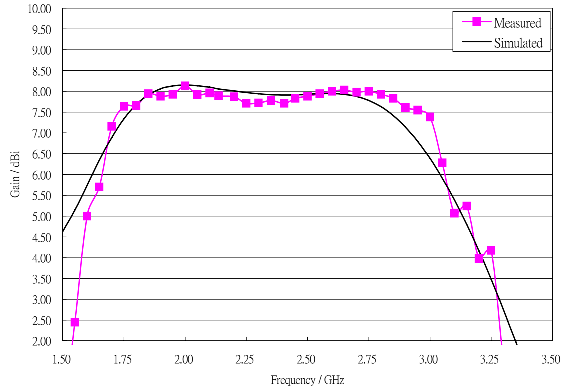

Fig. 8 Measured and simulated gain against frequency for a quarter-wave L-probe patch fed rectangular planar dipole antenna.

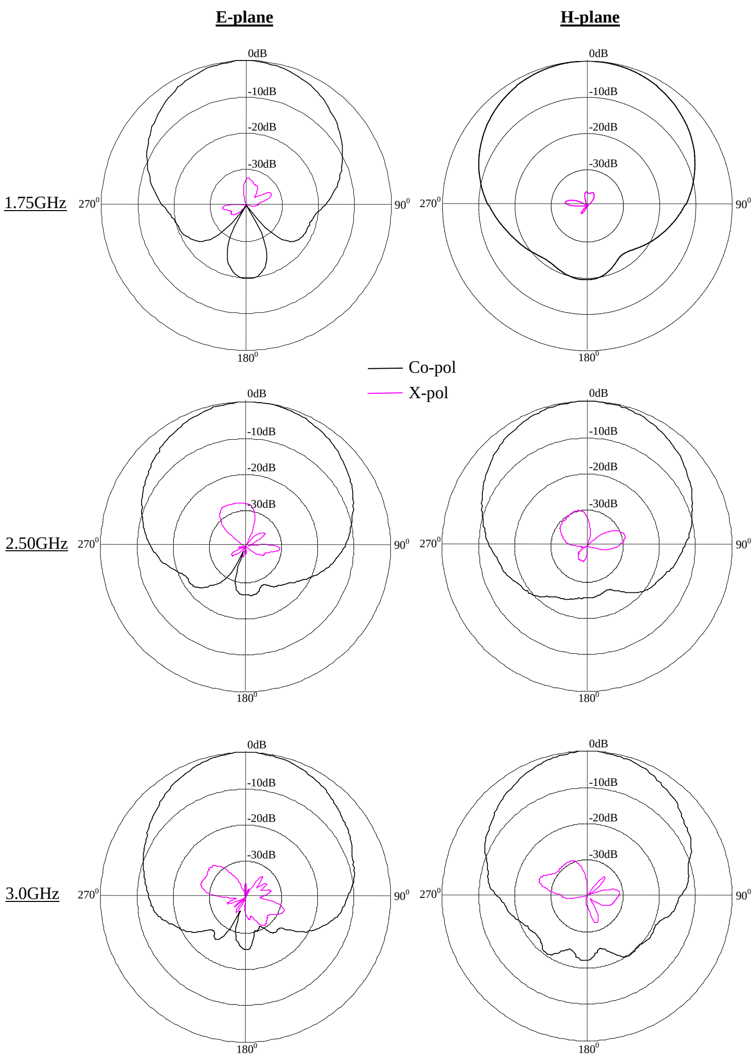

Fig. 9 Measured radiation pattern at 1.75, 2.5 and 3.0 GHz.

IV. RADIATION PATTERN COMPARISION

A comparison of the simulated radiation patterns of a dipole, a planar dipole and the proposed antenna is depicted in Fig. 6. The three antennas have the same ground plane size (120mm x 120mm) as well as the same antenna's height (30mm, 0.25λ). The length of the dipole, *L*, for three cases is chosen to be 60mm which is equal to 0.5λ at the operating frequency of 2.5GHz. For cases (a) and (b), the antennas are excited by a conventional coaxial cable with a balun; and the case (c), the antenna is excited by a Γ-shaped strip feed.

The simulated results demonstrate that when the conventional thin dipole, Fig. 6a, becomes a planar dipole, Fig. 6b, the radiation pattern does not change much. However, when the planar dipole is combined with the open end of a vertically-oriented shorted patch antenna as shown in Fig. 6c, the beamwidth in both E- and H-planes becomes similar. Moreover, the level of back radiation is also smaller than the cases without the shorted patch antenna by about 10dB. In addition, the three antennas also have low cross-polarization due to the symmetric architecture of the antennas. The level of the cross-polarization among the three cases is less than -40dB, thus they did not appear on the graphs presented in Fig. 6.

V. EXPERIMENTAL VERIFICATION

To verify the simulated results, a prototype of the proposed antenna was built and tested. Dimensions of the antenna are listed in the table inserted in Fig. 2. and the picture of fabricated antenna is shown in Fig. 10. Experimental results of SWR was obtained by an HP8510C network analyzer and radiation patterns and the antenna gain were measured by a compact range with an HP85103C antenna measurement system. Fig. 7 shows a comparison of the measured and simulated SWRs of the proposed antenna. As seen from the SWR curves, the antenna has wide impedance bandwidth of 43.8% (SWR≤1.5) from 1.85 to 2.89 GHz. Fig. 8 illustrates the measured and simulated gain curves of the antenna. It can be observed that

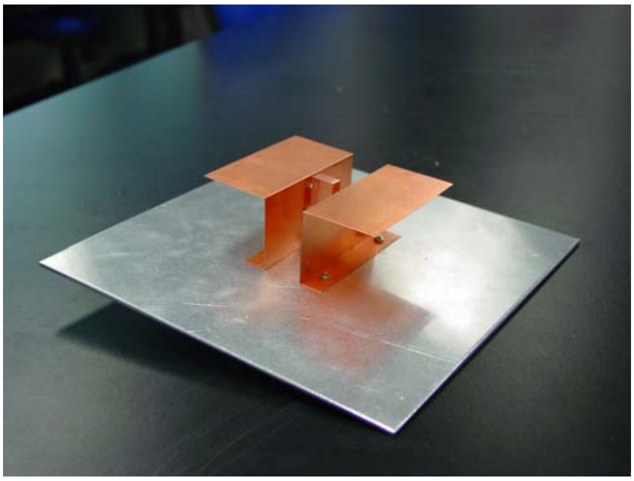

Fig. 10 Photo of the wideband antenna composed of a planar dipole and a quarter-wavelength patch.

the proposed antenna has an average gain of 8dBi approximately, varying from 7.5dBi to 8.2dBi across the operating bandwidth. Radiation pattern at frequencies of 1.75, 2.5 and 3 GHz were measured and shown in Fig. 9. For both E and H-planes, the broadside radiation patterns are stable and symmetric across the operating bandwidth, and the beamwidth for the center frequency of 2.5GHz at the H-plane is 79^0, which is slightly larger than the beamwidth at E-plane which is about 75^0. Low cross-polar radiation level as well as low back radiation are achieved across the entire operating bandwidth.

VI. CONCLUSION

A new wideband antenna composed of a planar dipole and a vertically-oriented quarter-wavelength patch is introduced. It is simply excited by a Γ-shaped strip line. More than 43.8% impedance bandwidth for SWR<1.5 and 8dBi maximum gain has been achieved. This new design antenna has many advantages, including simple structure, wide bandwidth, low cross polarization, symmetrical radiation pattern, and in particular, very low back radiation. Moreover, the gain and beam width of the antenna are almost constant over the operating band. The antenna will find many applications in modern wireless communications.

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