



A New Wideband Unidirectional Antenna Element

Kwai-Man LUK, *Fellow, IEEE* and Hang WONG, *Member, IEEE*

Department of Electronic Engineering, City University of Hong Kong
83 Tat Chee Avenue, Kowloon Tong, Hong Kong SAR, China
Email: ekmluk@cityu.edu.hk; hangwong@ieee.org

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 \leq 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 \sim 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 \leq 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.

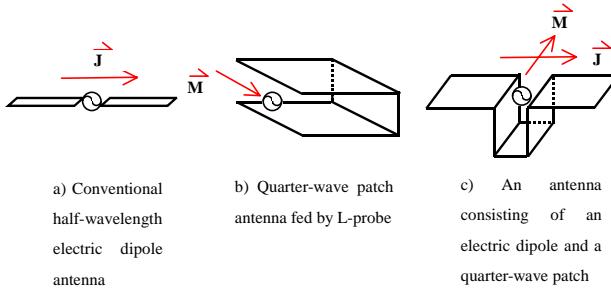


Fig.1 Principle of operation of the antenna.

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 $W=60\text{mm}$ (0.5λ), and a length $L=30\text{mm}$ (0.25λ). The shorted patch antenna has a length $H=30\text{mm}$ (also close to 0.25λ), where $\lambda=2\pi f$. For wideband operation, the separation of the two vertical plates, $S=17\text{mm}$, of the shorted patch antenna should be close to 0.14λ and the width of the dipole and the patch W should be around 0.5λ . The size of the ground plane can be used to adjust the back radiation. The optimum dimensions of the ground plane are $120\text{mm} \times 120\text{mm}$ (1λ by 1λ).

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.

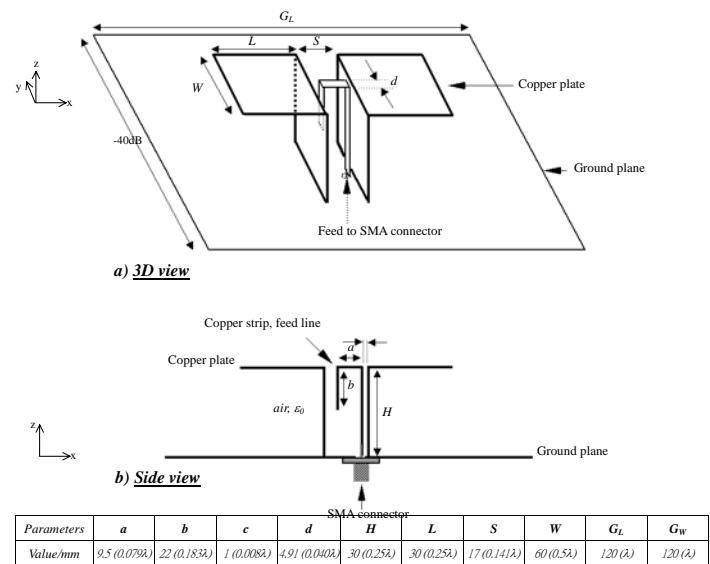


Fig. 2 Configuration of a wideband antenna composed of a planar dipole and a quarter-wavelength patch.

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 very 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

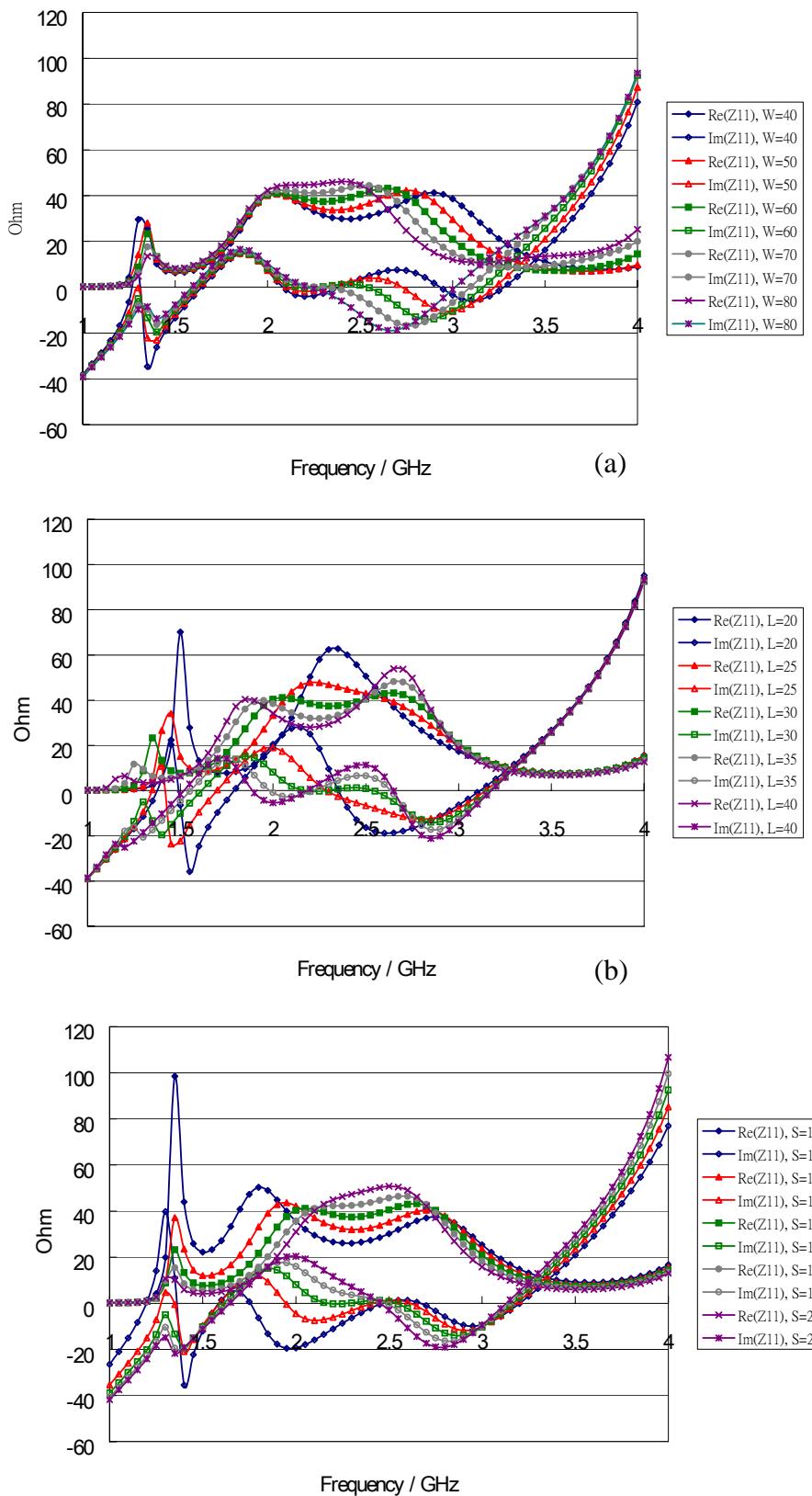
Fig. 3 shows the dependance of input impedance, $Re(Z_{11})$ and $Im(Z_{11})$, on various parameters L , S and W . In Fig. 3a, shows the study of varying the antenna width, W . It can be observed that there are two local maxima in the curve of $Re(Z_{11})$ within the frequency range from 2GHz to 3GHz. 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.

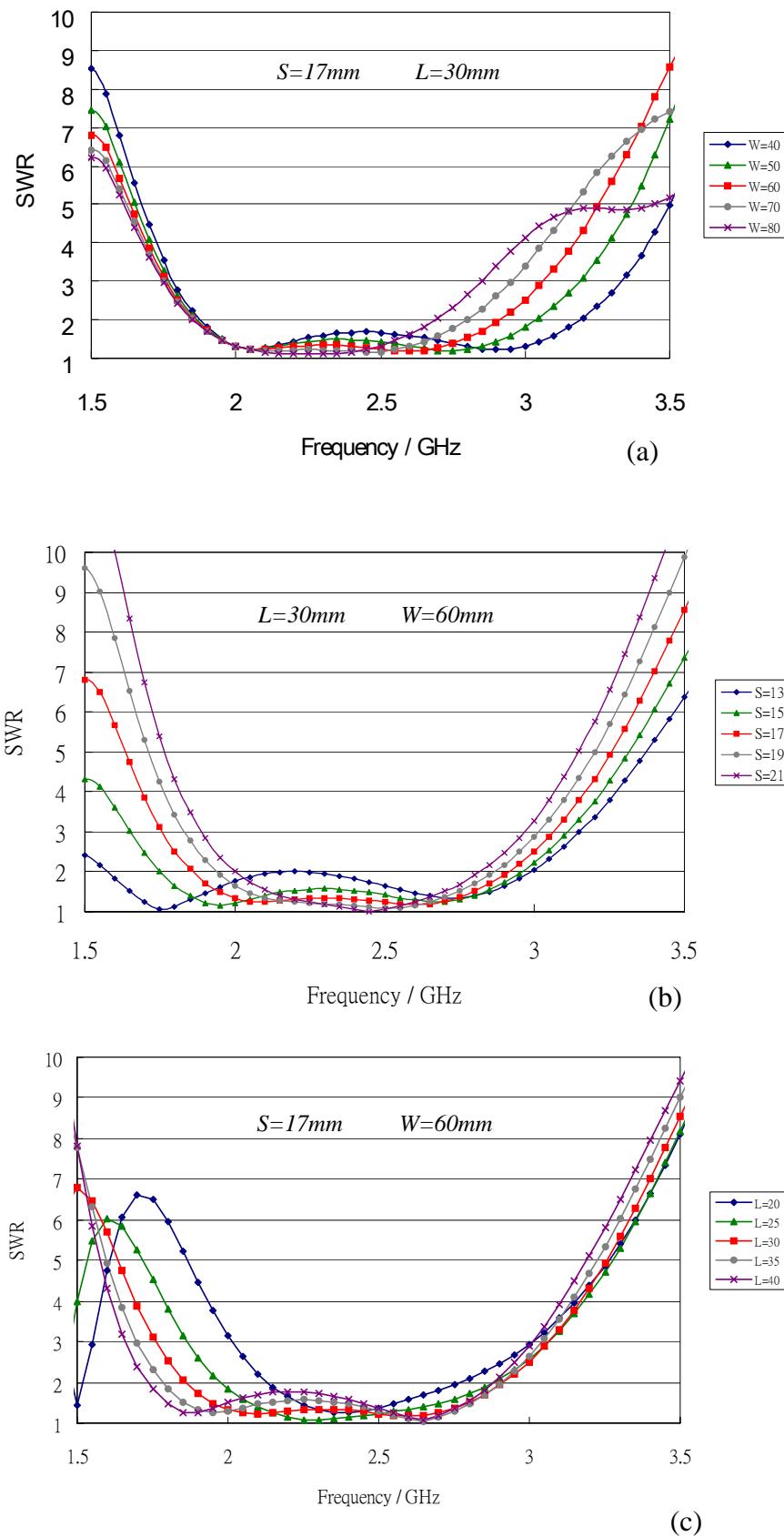
Antenna Width, W^*		Aperture Width, S^*		Length of Dipole, L^+	
$W(mm)$	$BW\%, SWR \leq 1.5 \text{ GHz}$	$S(mm)$	$BW\%, SWR \leq 1.5 \text{ GHz}$	$L(mm)$	$BW\%, SWR \leq 1.5 \text{ GHz}$
40	13.4%, 1.95-2.23	13	14.0%, 1.65-1.90	20	13.5%, 2.23-2.56
50	39.9%, 1.94-2.92	15	17.5%, 1.82-2.17	25	26.6%, 2.07-2.70
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 $S=17\text{mm}$ and $L=30\text{mm}$		[*] Fixed $W=60\text{mm}$ and $L=30\text{mm}$		[*] Fixed $W=60\text{mm}$ and $S=17\text{mm}$	

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

Antenna Width, W^*		Aperture Width, S^*		Length of Dipole, L^+	
$W(mm)$	$1\text{-dB Gain BW} (\%), \text{Max. Gain (dBi); Freq. Range(GHz)}$	$S(mm)$	$1\text{-dB Gain BW} (\%), \text{Max. Gain (dBi); Freq. Range(GHz)}$	$L(mm)$	$1\text{-dB Gain BW} (\%), \text{Max. Gain (dBi); Freq. Range(GHz)}$
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 $S=17\text{mm}$ and $L=30\text{mm}$		[*] Fixed $W=60\text{mm}$ and $L=30\text{mm}$		[*] Fixed $W=60\text{mm}$ and $S=17\text{mm}$	

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

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

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

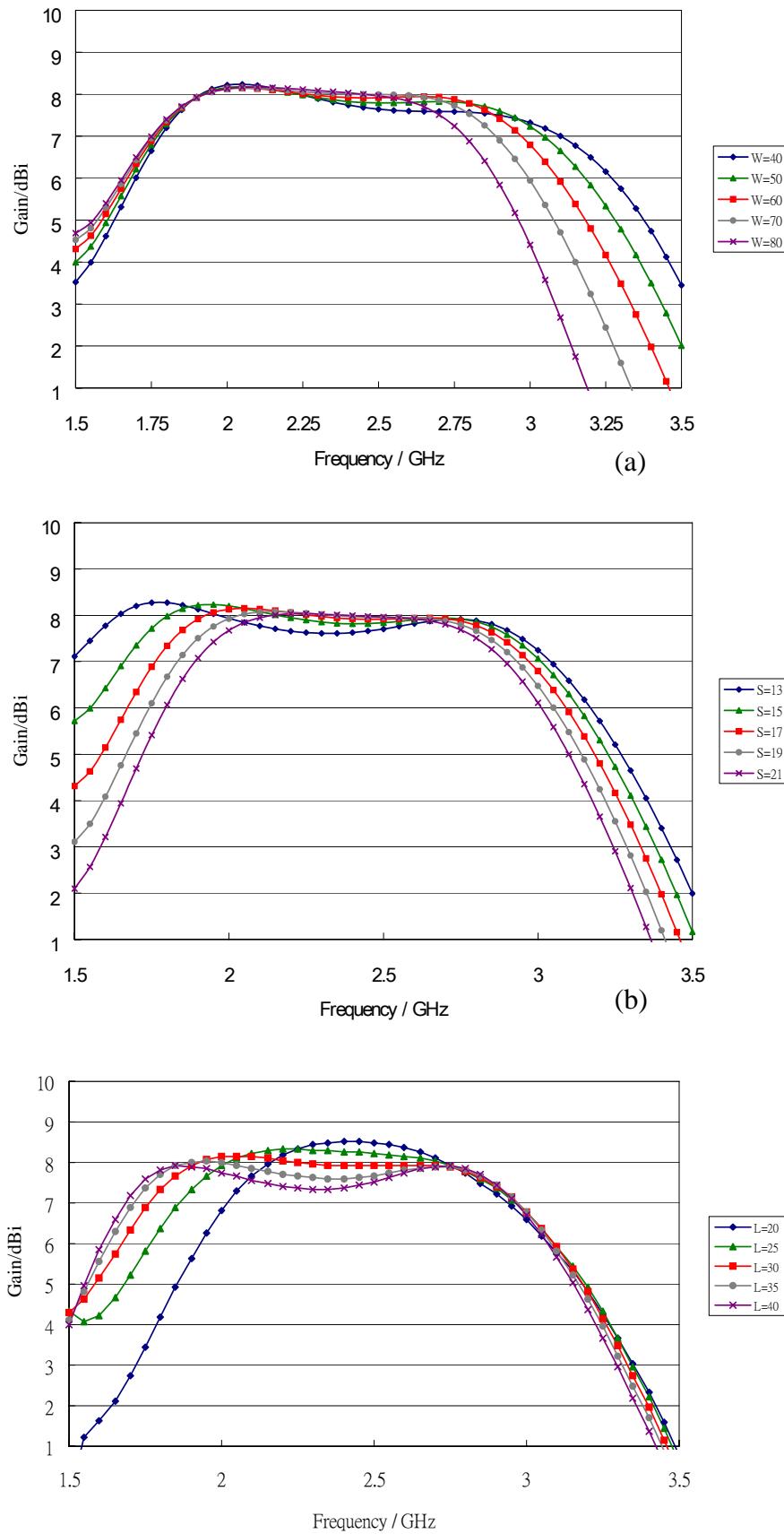
Fig. 5 Antenna gain versus parameters L , S and W

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 $S=13\text{mm}$. 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 $\text{Im}(Z_{11})$ also shifts down accordingly when S is increased from 13mm to 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. $L=20\text{mm}$), the electric dipole is weakly excited such that only one resonant peak of $\text{Re}(Z_{11})$ 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 $\text{SWR} \leq 1.5$, the largest BW is 39.9% when $W=50\text{mm}$, $S=17\text{mm}$ and $L=30\text{mm}$.

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 previous 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

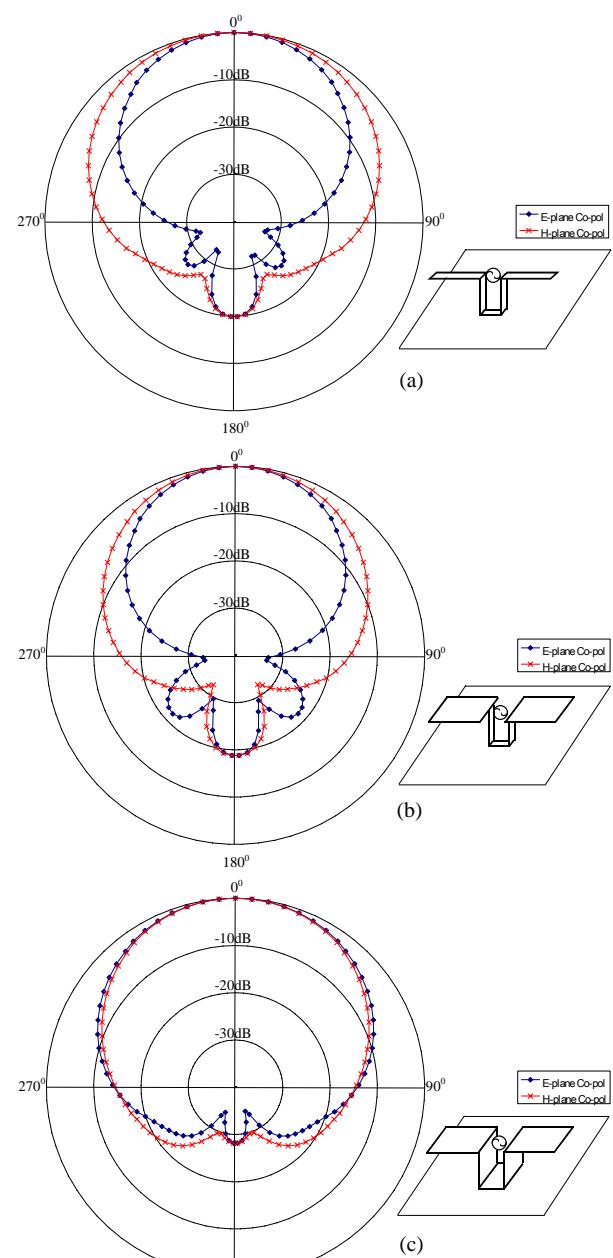


Fig. 6 Radiation patterns comparison of a) thin dipole, b) planar dipole and c) proposed antenna

bandwidth for the case of $L=20\text{mm}$ with $W=60\text{mm}$ and $S=17\text{mm}$. 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.

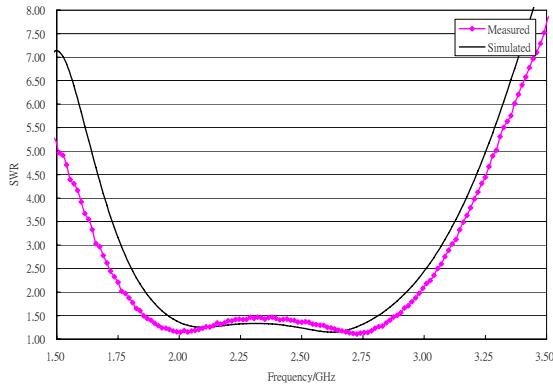


Fig. 7 Measured and simulated SWR against frequency for a quarter-wave L-probe patch fed rectangular planar dipole antenna.

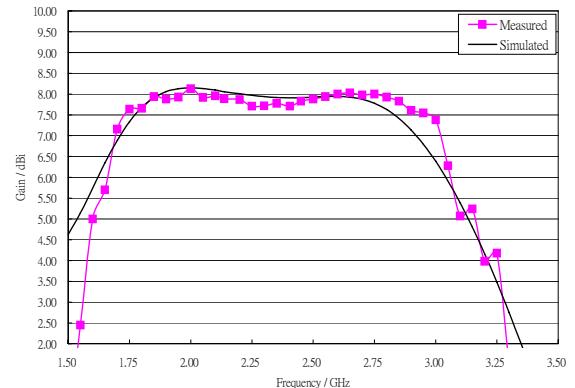


Fig. 8 Measured and simulated gain against frequency for a quarter-wave L-probe patch fed rectangular planar dipole antenna.

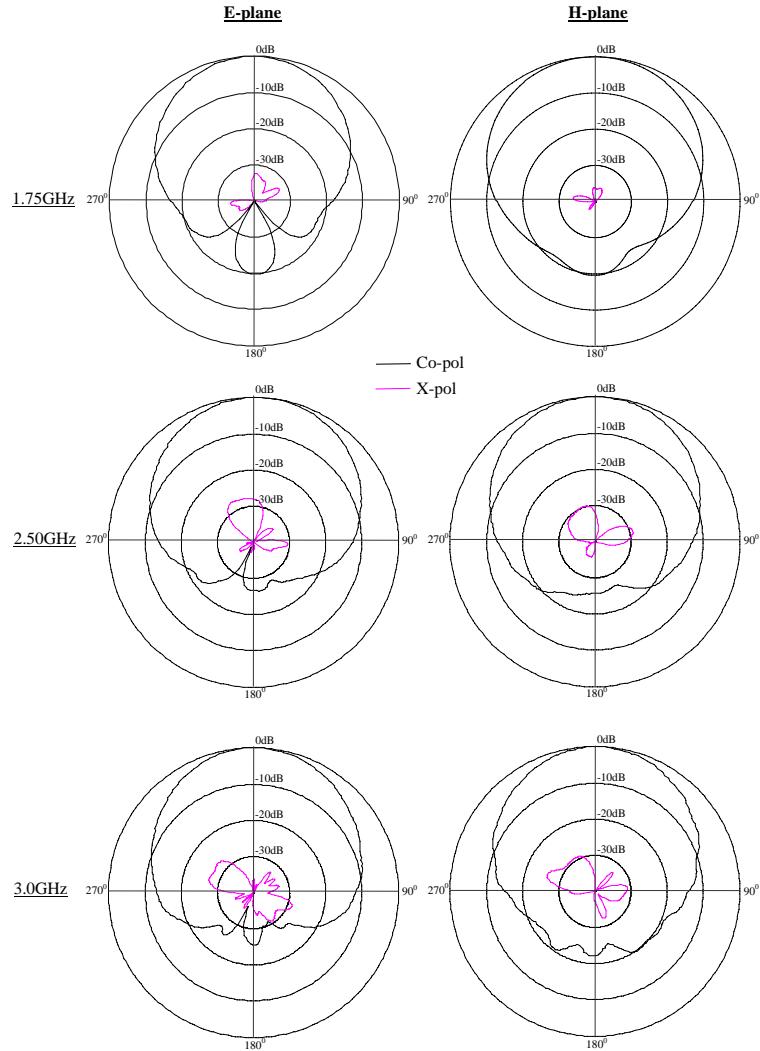


Fig. 9 Measured radiation pattern at 1.75, 2.5 and 3.0 GHz.

IV. RADIATION PATTERN COMPARISON

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% ($SWR \leq 1.5$) from 1.85 to 2.89 GHz. Fig. 8 illustrates the measured and simulated gain curves of the antenna. It can be observed that

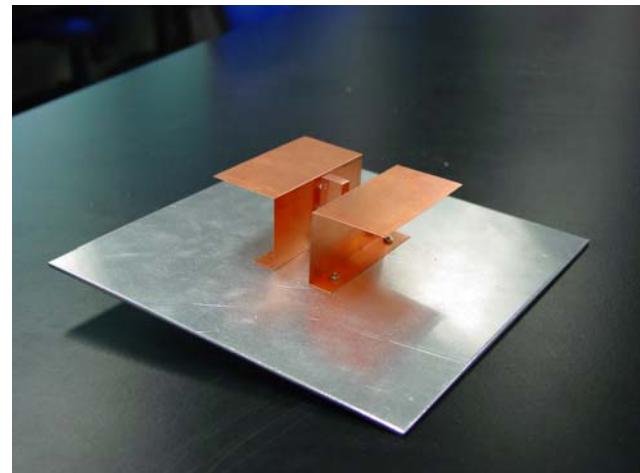


Fig. 10 Photo of the wideband antenna composed of a planar dipole and a quarter-wavelength patch.

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° , which is slightly larger than the beamwidth at E-plane which is about 75° . 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.

ACKNOWLEDGEMENT

The work described in this paper was fully supported by a grant from the Research Grants Council of the Hong Kong Special Administration Region, China.

REFERENCES

- [1] S. Dey, P. Venugopalan, K.A. Jose, C.K. Aanandan, P. Mohanan and K.G. Nair, "Bandwidth enhancement by flared microstrip dipole antenna", *IEEE Antennas and Propagation Society International Symposium*, 1991. AP-S. Digest , 24-28 June 1991, vol.1, pp. 342 – 345.
- [2] Y. D. Lin and S. N. Tsai, "Coplanar waveguide-fed uniplanar bow-tie antenna", *Electron. Lett.*, 1997, 45, pp. 305-306.
- [3] E. Levine, S. Shtrikman and D. Treves, "Double-sided printed arrays with large bandwidth," *IEE Proceedings – Part H*, vol.135, no.1, pp.54-59, 1988.
- [4] K. M. Luk, C. L. Mak Y. Chow and K. F. Lee, "Broadband microstrip patch antenna," *Electron. Lett.*, vol. 34, pp.1442-1443, 1998.
- [5] F. Croq, and D. M. Pozar, "Millimeter wave design of wide-band aperture-coupled stacked microstrip antennas," *IEEE Trans. Antennas Propogat.*, vol. 39, pp. 1770-1776, Dec 1991.
- [6] R. B. Waterhouse, "Design of probe-fed stacked patches," *IEEE Trans. Antennas Propogat.*, vol. 47, no. 11, pp. 1780-1784, Nov. 1999.
- [7] K. F. Lee, K. M. Luk, K. F. Tong, S. M. Shum, T. Huynh and R. Q. Lee, "Experimental and simulation studies of the coaxially fed U-slot rectangular patch antenna," *IEE Proc.-Microw. Antenna Propag.*, vol. 144, no.5, pp. 354-358, Oct. 1997.
- [8] A. Petosa, A. Ittipiboon and N. Gagnon, "Suppression of unwanted probe radiation in wideband probe-fed microstrip patches," *Electron. Lett.*, , vol. 35, no.5, pp. 355-357, 1999
- [9] C. L. Mak, H. Wong and K. M. Luk, "High-gain and wide-band single-layer patch antenna for wireless communications, " *IEEE Trans. on Vehicular Technology*, vol. 54 no. 1, Jan. 2005.
- [10] H. W. Lai and K. M. Luk, "Design and study of wide-band patch antenna fed by meandering probe," *IEEE Trans. Antennas Propogat.*, vol. 54, no. 2, Feb. 2006.
- [11] A. Clavin, "A new antenna feed having equal E- and H-plane patterns," *IRE Trans. Antennas Propogat.*, vol.AP-2, pp.113-119, 1954.
- [12] A. Clavin, D. A. Huebner, and F. J. Kilburg, "An improved element for use in array antennas," *IEEE Trans. Antennas Propogat.*, vol.AP-22, no.4, pp.521-526. Jul. 1974.
- [13] R. W. P. King and G. H. Owyang, "The slot antenna with coupled dipoles, " *IRE Trans. Antennas Propogat.*, vol.AP-8, pp.136-143, Mar. 1960.
- [14] W. W. Black and A. Clavin, "Dipole augmented slot radiating element," *U. S. Patent 3594806*, Jul. 1971.
- [15] K. Itoh and D. K. Cheng, "A novel slots-and-monopole antenna with a steerable cardioid pattern," *IEEE Trans. on Aerospace and Electronic Systems*, vol. AES-8, no.2, pp.130-134, Mar. 1972.
- [16] Zealand IE3D version 10.0.

如何学习天线设计

天线设计理论晦涩高深，让许多工程师望而却步，然而实际工程或实际工作中在设计天线时却很少用到这些高深晦涩的理论。实际上，我们只需要懂得最基本的天线和射频基础知识，借助于 HFSS、CST 软件或者测试仪器就可以设计出工作性能良好的各类天线。

易迪拓培训(www.edatop.com)专注于微波射频和天线设计人才的培养，推出了一系列天线设计培训视频课程。我们的视频培训课程，化繁为简，直观易学，可以帮助您快速学习掌握天线设计的真谛，让天线设计不再难…



HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程，可以帮助你快速学习掌握如何使用 HFSS 软件进行天线设计，让天线设计不再难…

课程网址: <http://www.edatop.com/peixun/hfss/122.html>

CST 天线设计视频培训课程套装

套装包含 5 门视频培训课程，由经验丰富的专家授课，旨在帮助您从零开始，全面系统地学习掌握 CST 微波工作室的功能应用和使用 CST 微波工作室进行天线设计实际过程和具体操作。视频课程，边操作边讲解，直观易学；购买套装同时赠送 3 个月在线答疑，帮您解答学习中遇到的问题，让您学习无忧。

详情浏览: <http://www.edatop.com/peixun/cst/127.html>



13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…



详情浏览: <http://www.edatop.com/peixun/antenna/116.html>

关于易迪拓培训:

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，一直致力于专注于微波、射频、天线设计研发人才的培养；后于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

我们的课程优势:

- ※ 成立于 2004 年，10 多年丰富的行业经验
- ※ 一直专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求
- ※ 视频课程、既能达到了现场培训的效果，又能免除您舟车劳顿的辛苦，学习工作两不误
- ※ 经验丰富的一线资深工程师主讲，结合实际工程案例，直观、实用、易学

联系我们:

- ※ 易迪拓培训官网: <http://www.edatop.com>
- ※ 微波 EDA 网: <http://www.mweda.com>
- ※ 官方淘宝店: <http://shop36920890.taobao.com>