Novel Design of a Wideband Improved U-slot on Rectangular Patch Using Additional Loading Slots

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ABSTRACT

This paper presents a novel design of wideband improvement of a U-shape on rectangular patch antennas using additional loading slots. The new technique uses a slot load coupled to both vertical arms of U-slotted patch antenna. The proposed structure is simulated using IE3D™ commercial software packages, and implemented using an air substrate (ε_r=1). Measurement and simulation results for substrate thickness of 0.1 wavelength are presented. An impedance bandwidth of 53.85 % for return loss less than -10 dB are obtained at a center frequency of 5.25 GHz. A good radiation pattern is observed.

Keywords: Wideband patch antenna, U-slot patch antenna, Bandwidth widening

1. INTRODUCTION

Generally, bandwidth improvement techniques have been extensively investigated by many researchers. These include using a multilayer structure consisting of several parasitic radiating elements with slightly different sizes above the driven element as stacked configuration or a planar patch antenna surrounded by closely spaced parasitic patches in a coplanar configuration. The stacked patch antenna increases the thickness of the antenna while the coplanar configuration increases the lateral size of the antenna. In 1995, T. Huynh and K.F. Lee [1] presented new kind of wideband patch antennas with an impedance bandwidth about 47% at centre frequency around 900 MHz. The antenna has a structure which is fed at centre of internal patch inside a U-shape slot with unity permittivity substrate. In 1997, U-slot patch antennas was introduced in [2] and both experimental and simulation results were obtained at a high frequency band, with bandwidth of 32.4% at centre frequency of 4.5 GHz. In 2002, [3] proposed an enhancement bandwidth using a stack patch and an improved driven patch form . It use slits radiation edge to base of U-slot with bandwidth of 38.41% for driven patch.

This paper presents an enhance bandwidth improvement based on the U-slot patch as introduced in [2], by using an additional slot load coupled vertical arms of U-slot. Three obvious advantages include using the single patch, single layer and simple fed using probe. The new structure can be used in various applications such as in a C-band communication.

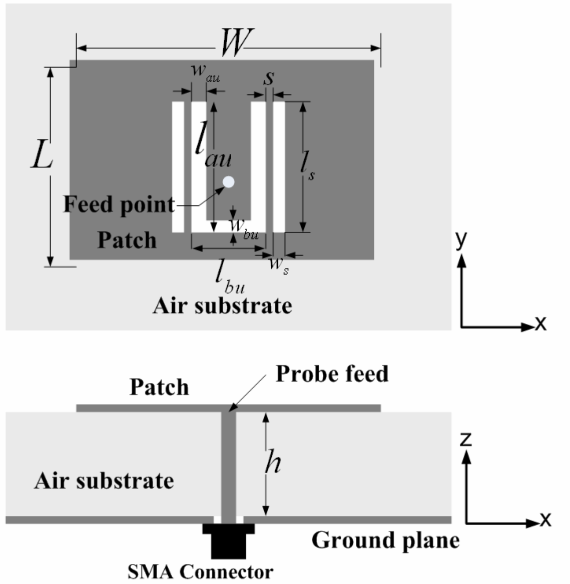


Fig. 1: *Configuration of proposed slot coupler vertical arms of U-slot patch antenna design*

2. ANALYSIS

A simple model of the rectangular patch antennas can be represented by a parallel RLC resonator. The new technique using a slot load coupled to vertical arms of U-slot is shown in Fig.1. It can considerably be seen as three resonators as shown in Fig.2. The three lumped resonators can be associated with patch resonance, interior U-shape slot and the resonance of the coupling slot. Both first and second resonance frequencies for TM_{10} mode can be approximated as [4, ε_{eff} equal ε_r].

$$2\Delta L_1 = 0.824h\frac{(\varepsilon_r + 0.3)(W/h + 0.262)}{(\varepsilon_r - 0.258)(W/h + 0.813)} \quad (1)$$

$$f_{res1} = \frac{v_o}{2(L + 0.5l_{bu} - w_{bu} + 2\Delta L_1)\sqrt{\varepsilon_r}} \quad (2)$$

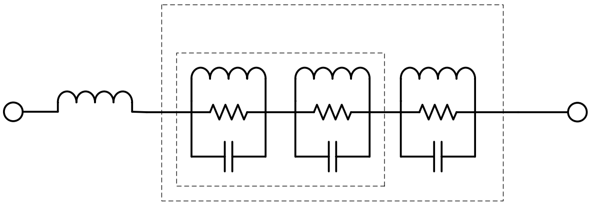
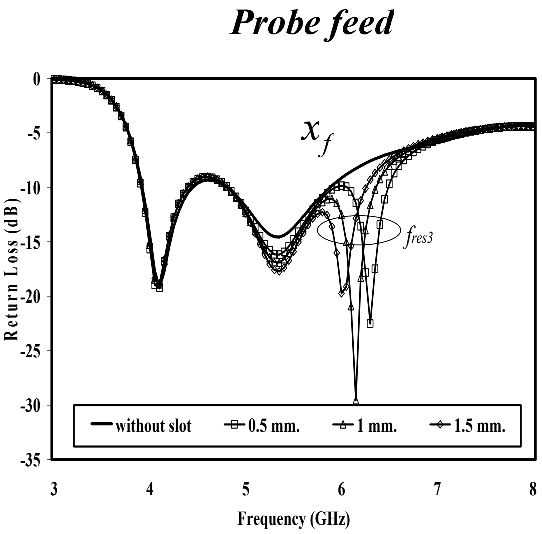
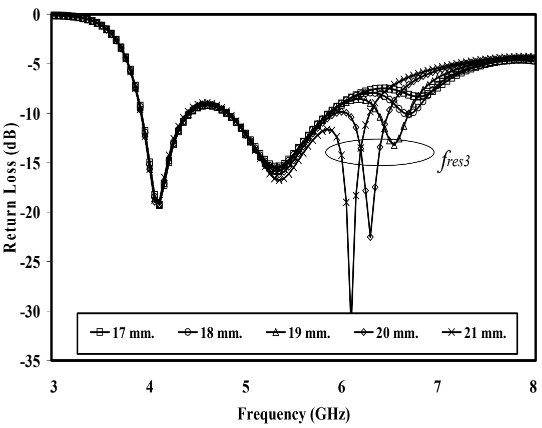


Fig. 2: *Lumped element equivalent circuit*



(a)



(b)

Fig. 3: *Simulation return loss for wideband patch antennas with*
(a) different gap spacing between the slot load and vertical arm of U-slot when selected slot side both length 20 mm and width 1 mm, varied from 0.25, 0.5, 1 and 1.5 mm
(b) different slot length when selected gap spacing 0.5 mm and slot width 1 mm, varied from 17 to 21 mm in 1 mm steps

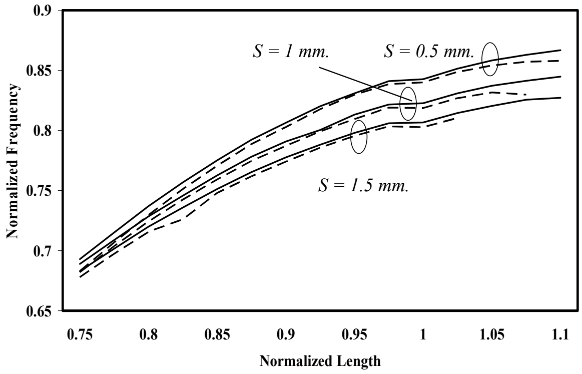


Fig. 4: *Simulated 3rd resonant frequency (f_{res3}) normalized with half-wavelength of slot length (f_o^{slot}) and slot length normalized with length of vertical arms of U-slot*

Table 1:

Dimensions of the initial of the conventional U-slot patch antennas antenna in millimeter W = 36 mm, L = 26 mm, h = 6.2 mm

l_{bu}	w_{bu}	l_{au}	w_{au}	d_p	Offset feed	Offset U-shape
12	2	20	2	1	(0,-2)*	(0,0)*

** (0,0) is a centre of patch*

$$2\Delta L_2 = 0.824h\frac{(\varepsilon_r + 0.3)\left(\frac{l_{bu} - 2w_{au}}{h} + 0.262\right)}{(\varepsilon_r - 0.258)\left(\frac{l_{bu} - 2w_{au}}{h} + 0.813\right)} \tag{3}$$

$$f_{res2} = \frac{v_o}{(2l_{au} + l_{bu}) + (0.5L + 0.5l_{au} - 0.5w_{bu} - y_u + 2\Delta L_2)\sqrt{\varepsilon_r}} \tag{4}$$

Where v_o is the velocity of light which equals $3x10^8$ *m/s*, *(0,y_u)* is offset point of the centre of U-shape.

A third resonance frequency could be adjusted by moving the coupler slot load position away from the vertical arms of U-slot on rectangular patch. The position of the coupler slot load is in the interior of the patch with parameters: *s*, the gap spacing between the slot load and vertical arm of U-slot, l_s, the slot length and , w_s, slot width. In the parametric studies, only one parameter is changed while other parameters are fixed. The initial geometric parameters are provided in Table 1 and a probe diameter was varied from 1 to 2mm. The dimensions of coupler slot were varied: *s* ; from 0.5, 1 and 1.5 mm, l_s; from 17 to 21 mm in 1 mm steps while w_s, was selected to be 1 mm all case in this study. The typical results of the simulated return loss for adjusted gap spacing case shows in Fig. 3(a) and adjusted slot length shows in Fig. 3(b). These parameters had effect only on the third resonance frequency. The third resonance frequency increases as both gap spacing and slot length are reducing. Fig. 4 shows the relationship between the normalized frequency and the normalized length as the gap spacing is varied from 0.5 to 1.5 mm in 0.5 mm steps, slot length was varied from 15 to 22 mm in 0.5 mm steps. The normalized frequency is ratio of third resonant frequency (f_{res3}) and the half-wavelength resonator slot dipole as

$$f_o^{slot} = \frac{v_o}{2\sqrt{\varepsilon_r}\, l_S} \qquad (5)$$

Where v_o is speed of velocity of $3x10^8$ m/s .The normalize length is the ratio of slot length (l_s) and a vertical arms length of U-slot (L).

Table 2: *Physical dimensions of the proposed antennas in millimeterW = 36 mm, L = 26 mm, h = 6.2 mm,* l_{au} *= 20 mm,*w_s *= 1mm*

	l_{bu}	w_{bu}	w_{au}	l_s	s	d_p	Offset feed	Offset U-shape
Ant.A	12	2	2	20	0.5	2.2	(0,-2)*	(0,-1)*
Ant.B	14	1	1	18	1	3	(0,-3.3)*	(0,0)*

** (0,0) is a centre of patch*

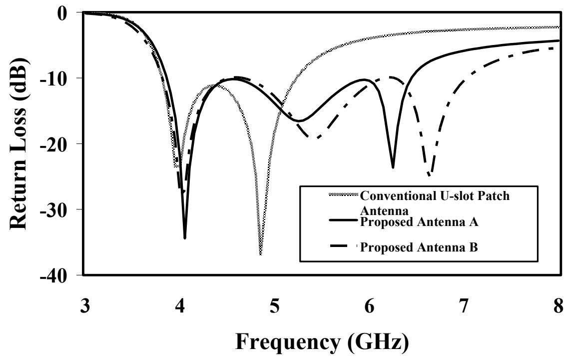


Fig. 5: *The comparison of the return loss simulated result of proposed antenna and conventional U-slot patch antenna*

3. ANTENNAS DESIGN AND EXPERIMENTAL RESULT

The proposed antenna is depicted in Fig.1. The rectangular patch has a dimension of LxW and is printed on a air substrate (ε_r= 1) of thickness h. The U-slot is discussed in terms of its bass (width w_{bu}, length l_{bu}) and its vertical arms (width w_{au}, length l_{au}). A coupler slot load is denoted as length l_s, and width w_s. The vertical probe for feeding denoted with diameter d_p. The conventional U-slot patch antenna were based on antenna designed in [2], with l_{au} = 20 mm and h = 6.2 mm]. The dimension of antenna was adjusted to good impedance matching for large bandwidth. The dimension can be seen from Table 2. The centre frequency is designed at around 5 GHz and the height of the substrate is approximately equal to 0.1λ. A simulation is performed using a IE3D [5]. The obtained bandwidth of the antenna is shown in Fig. 5, determined by -10 dB return loss. The implementation of proposed antenna was obtained using antenna A shown in Fig. 8. The patch and ground plate ware constructed with 0.5 mm brass plate and 0.5 mm copper plate respectively. The return loss of the proposed antennas is measured using Agilent 8719ES network analyzer. Measurement and simulation results were shown in Fig. 6**.** In Fig. 7, the Smith chart was shown using input impedance results from measurement of the proposed Antenna A. The results are based on five resonances occur as defined by $jx = 0\ \Omega$ axis crossings on the Smith chart. Resonance loops are shown as three such small loops located very near to the centre of Smith

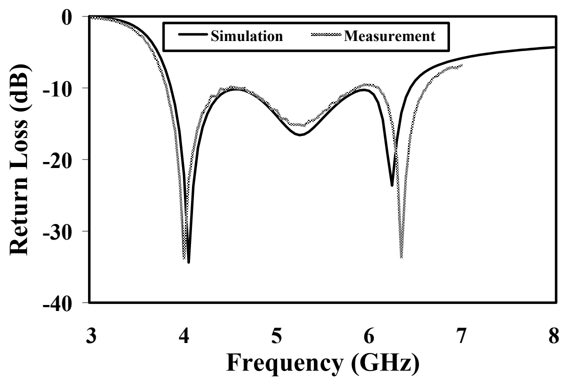


Fig. 6: *Measurement and Simulation return loss of proposed Antenna A*

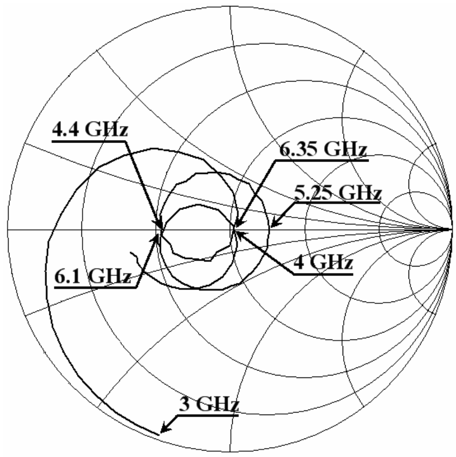


Fig. 7: *The measured result of input impedance of proposed Antenna A. Frequency rang :* f_{start} *= 3 GHz,* f_{stop} *= 7 GHz, and* f_{step} *= 50 MHz.*

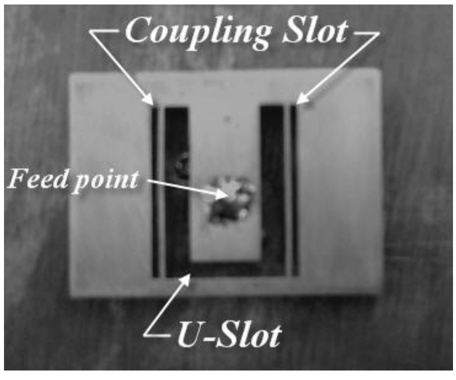


Fig. 8*: Prototype of proposed Antenna A.*

Table3: *The bandwidth of antenna design for Return loss less than 10 dB*

Antenna design		BW (GHz)	%BW
Conventional U-slot patch antenna	simulated	1.45	32.04
Antenna A.	simulated	2.60	50.49
	measured	2.80	53.85
Antenna B	simulated	3.25	59.91

chart with size no more than VSWR ≤ 2. The photo of a proposed Antenna A is shown in Fig. 8. The bandwidth results of antennas design are listed in Table 3.

The far-field radiation characteristics of the operation frequency within the antenna bandwidth are also investigated. Typical pattern in two orthogonal planes at the three resonant frequencies at 4 GHz, 5.1 GHz and 6.4 GHz are presented in Fig.9.

4. CONCLUSION

A novel technique for enhancing bandwidth of wideband patch antennas is successfully demonstrate in this paper using slot load coupled both vertical arms of U-slot technique. The operating frequency band has three nearly resonance frequencies. The impedance bandwidth result is more then 50 % for the designed antenna example. For example, with a centre frequency about 5.25 GHz , it has 53.85 % bandwidth.

5. REFERENCES

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[5] IE3D Software is trademark Zeland Software Inc,

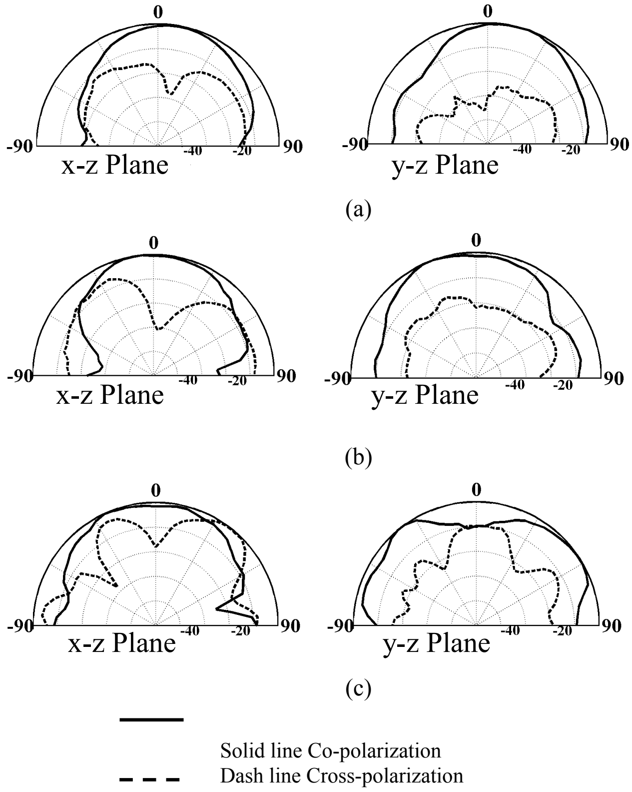

Fig. 9: *Measured radiation patterns of proposed Antenna A H-Plane (x-z Plane) and E-Plane (y-z Plane) at frequency*

(a) 4 GHz (b) 5.1 GHz (c) 6.4 GHz