CPW Feed Wideband U-slot Microstrip Antenna

Jong In Lee[1] · Byoung Moo Lee[2] · Young Joong Yoon[2]

Abstract

In this paper, we have proposed the new configuration of wideband antenna using CPW feed lines. The proposed antenna has CPW feed lines and U-slot to achieve wide bandwidth with good impedance matching. The use of CPW feed line can decrease the number of substrates. It is compared with the conventional antenna fed by a microstrip feed line. The parameters of CPW feed lines were studied by using the quasi-static approximation which is based on the conformal mapping method. The analysis of CPW discontinuities such as the tapered-step structure and the open ended gap were studied by using the quasi-static approximation which is based on the boundary element method. Also, the equivalent circuit model of multi-layer antenna were proposed using the cavity model. Experiment results of the proposed antenna show wide-bandwidth characteristics and good radiation patterns in passband.

Key words : wideband, U-slot, CPW feed line, microstrip antenna.

Ⅰ. Introduction

The Coplanar Waveguide (CPW) has been researched due to the several attractive features in comparison with microstrip lines. These have wide bandwidth, better impedance matching, easy integration of solid state active devices and low radiation losses[1],[2]. Especially, in microwave and millimeter wave applications, slot coupling fed by CPW has the several useful properties. In this paper, the U-slot microstrip antenna using CPW feed is proposed. The proposed antenna has the wide bandwidth characteristics and can decrease the number of substrate, comparing with an antenna with the microstrip feed line. Antenna designs and the details of experimental results are discussed.

Ⅱ. Quasi-static Parameters of CPW Feed Line

The parts of CPW feed line are described by uniform transmission lines for which the characteristic impedance Z_L (Ω) and the effective dielectric constant $\varepsilon_{r,eff}$ are determined by quasi-static formulas based on the conformal mapping technique[3]. These parameters can be written as

$$Z_L = Z_{L0}/\sqrt{\varepsilon_{r,eff}} = \eta_0 K(k')/[\,4\sqrt{\varepsilon_{r,eff}}K(k)] \quad (1)$$

$$\varepsilon_{r,eff} = (\varepsilon_r + 1)/2 \quad (2)$$

where Z_{L0} is the characteristic impedance of CPW in free space and $K(k)$ is the complete elliptical integral equation of the first order.

In equation(1), k' and k can be defined as

$$k' = \sqrt{1-k^2} \text{ and } k = w/d \quad (3)$$

Therefore, the CPW characteristic impedance Z_L is approximated from k' of equation (3).

Ⅲ. Discontinuities of CPW Feed Line

The CPW discontinuities such as bends, T-junctions, step-in-width, short and open stubs bring about the different path lengths. These discontinuities cause slot mode which is occured to disturb proper transmission of the quasi-TEM mode. Therefore, it is necessary to model the CPW discontinuities for optimum antenna design. In this paper, the discontinuities are characterized open circuits, series gaps in the center conductor, and symmetric steps in the center conductor.

The CPW open circuit as shown in Fig. 1 is formed at a gap between the end of the center strip and the slot. The capacitive reactance is caused by the terminated center strip and the surrounded ground conductor, which is seen at a plane coincident with the open end of the center strip. Thus the apparent position of the open circuit is beyond the physical end of center strip. The open circuit capacitance is the parallel combination of the capacitance due to the fringing field effect across the gap, g, and those across the slot, s, in Fig. 1. The dependance of slot on capacitance is constant and the dependance of gap on capacitance is proportional to 1/g[4].

The step changes in the width of the center conductor of CPW is shown in Fig. 2. The step discontinuity perturbs the normal CPW electric and magnetic fields in additional to the reactances. These additional reactances are assumed to be

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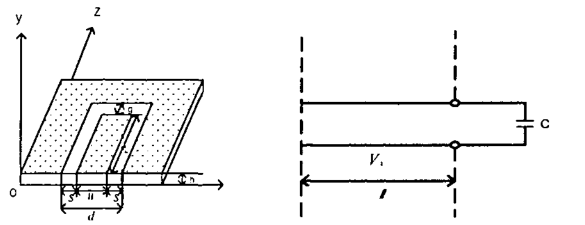
lumped and located in the plane of the step discontinuity, which can be modeled as a shunt capacitance. The influence of this capacitance is to lengthen effectively the lower impedance CPW line toward the higher impedance CPW line[4]. Also, the tapered line is applied at step CPW line easily to match impedance[5].



(a) CPW end-gap structure (b) CPW end-gap equivalent circuit

Fig. 1. CPW open ended structure and equivalent circuit.

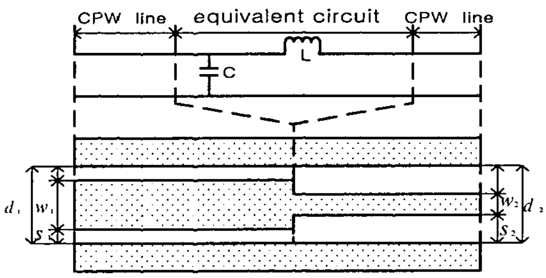


Fig. 2. CPW step structure equivalent circuit.

Ⅳ. Equivalent Circuit Model for Proposed Antenna

In Fig 3 and 4, The analytical model of the proposed multi-layer antenna is based on the cavity model. Fig. 3 (a) shows the proposed multi-layer antenna structure and Fig. 3 (b) shows the equivalent structure of the lower patch. Fig. 3 (c) shows the physical structure of upper patch and Fig. 3 (d) is the equivalent structure of that.

In Fig. 3 (b), the input admittance is from the CPW feed line to the lower patch can be written as

$$Y_{in1} = \left[\frac{1}{Y_{10}} + \frac{1}{Y_{01}} + \frac{1}{Y_{11}} + \frac{1}{Y_{21}} + \frac{1}{Y_{12}} \right]^{-1} \tag{4}$$

In Fig. 3 (c), the input admittance is from the CPW feed line to the upper patch can be written as

$$Y_{in2} = \left[\frac{1}{Y_{10}} + \frac{1}{Y_{01}} + \frac{1}{Y_{11}} + \frac{1}{Y_{21}} + \frac{1}{Y_{12}} \right]^{-1} \tag{5}$$

Also, the admittance to consider the mutual coupling between the upper patch and the lower patch can be written as follows [7]

$$Y_{12}^{P} = Y_c \frac{Y_{12}^{S} + jY_c \tan(\beta_c L_{1L})}{Y_c + jY_{12}^{S} \tan(\beta_c L_{1L})} + Y_c \frac{Y_{12}^{S} + jY_c \tan(\beta_c L_{1R})}{Y_c + jY_{12}^{S} \tan(\beta_c L_{1R})} \tag{6}$$

Therefore, the total input impedance Z_{in} of multi-layer antenna can be written as follows [6]

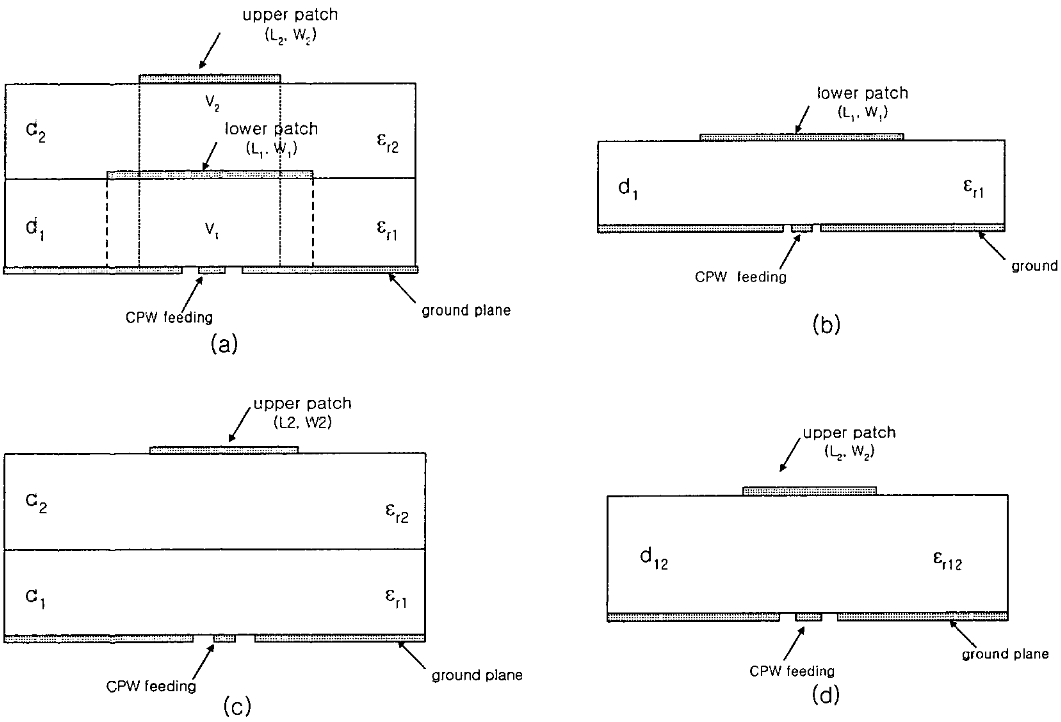


Fig. 3. Multi-layer antenna structure and equivalent structure.

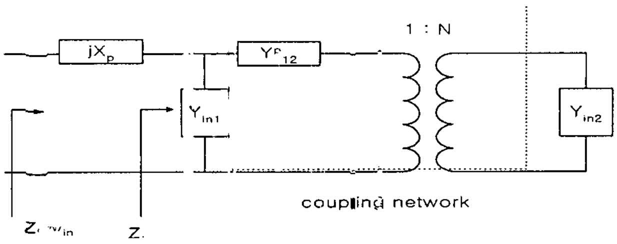


Fig. 4. Equivalent-circuit model of proposed antenna.

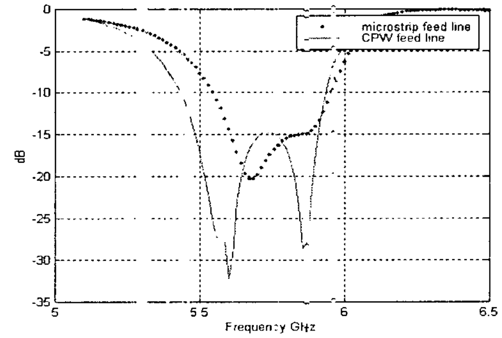


Fig. 5. Simulated S_{11} of the proposed antenna.

$$Z_{in}=\frac{Y_{12}^{P}+N^2 Y_{in2}}{Y_{in1}(Y_{12}^{P}+N^2 Y_{in2})+N^2 Y_{in2} Y_{12}^{P}} \tag{7}$$

where N^2 is the power ratio of the transformer and can be expressed as

$$N^2=\frac{V_2}{V_1}=\frac{d_1+d_2}{d_1}.$$

In equation (6), Y_{12}^{S} can be expressed as

$$Y_{12}^{S}=-2j\omega\varepsilon_{r12-eff}\varepsilon_0\frac{(W_2 W_1)}{(d_2+d_1)}\frac{(\triangle L_2)}{(L_2)}\frac{(2\pi)}{(W_2 L_2)(K^2-K_{01}^2)}\cdot$$

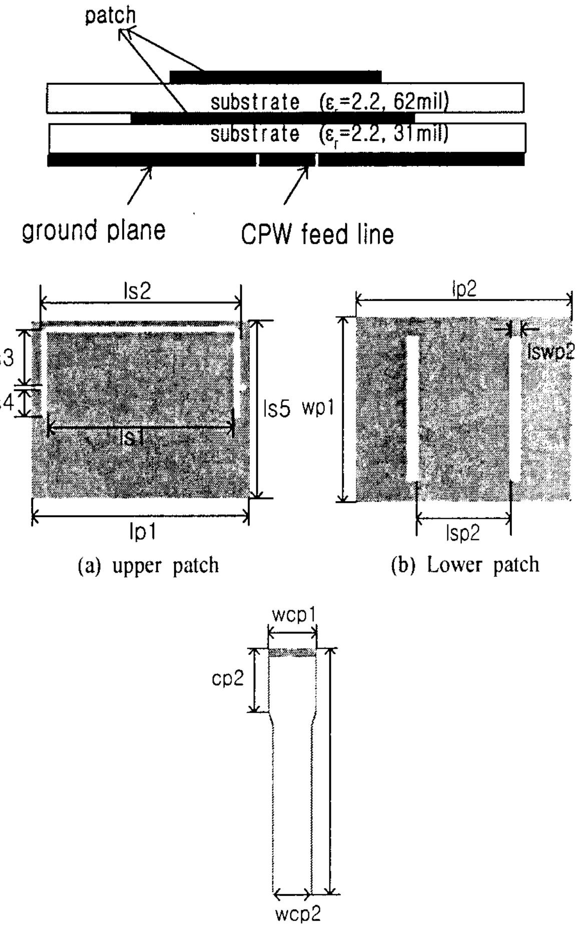
$$J_0\left(\frac{\pi\triangle L_1}{2L_2}\right)J_0^2\left(\frac{\pi\triangle L_2}{2L_2}\right)\times\cos\left\{\frac{\pi}{2L_2}(L_1+\triangle L_1)\right\} \tag{8}$$

where ε_{r12}, d_{12}, L_{1R} and L_{1L} can be written as equation (9), equation(10).

$$\varepsilon_{r12}=\frac{(d_1+d_2)\varepsilon_{r1}\varepsilon_{r2}}{d_2\varepsilon_{r1}+d_1\varepsilon_{r2}},\ d_{12}=d_1+d_2 \tag{9}$$

$$L_{1R}=L_1-y_f+\frac{\triangle L_1}{2},\quad L_{1L}=y_f+\frac{\triangle L_1}{2} \tag{10}$$

Fig. 4. shows the equivalent-circuit model of the proposed antenna. The proposed equivalent circuit model uses the cavity model and leads to the expression of input impedance as a function of antenna parameter and frequency[7]. In Fig. 4, X_p is the inductance of the CPW feed line.



(a) upper patch (b) Lower patch

(c) CPW fed line

Fig. 6. Geometry of the proposed antenna.

Table 1. The designed antenna parameters.

Division	Classfication	Length(mm)
Upper patch (U-slot type)	Width (wp1)	16.56
	Length (lp1)	20.92
	Inner gap of slot (ls1)	18
	Outer gap of slot (ls2)	19
	Upper length of slot (ls3)	5
	Lower length of slot (ls4)	2.5
	Total length of slot (ls5)	8
Two slot coupling patch	Width (wp2)	16.56
	Length (lp2)	28
	Inner gap of slot (lswp2)	1
	Length of slot (lsp2)	13
	Gap of slot (swp2)	9
Tapered step cpw-feed line	CPW feed line length (lcp1)	35.38
	CPW open stub length (lcp2)	9.18
	CPW open stub width (wcp1)	7.4
	CPW 50ohm line width (wcp2)	5.69
	CPW 50ohm line gap	0.2

V. Antenna Designs

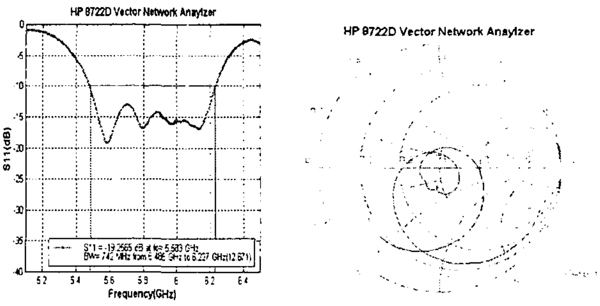
The proposed antenna structure consists of the upper patch, lower patch and CPW feed line. The upper patch has U-slot as shown in Fig. 6 (a), which tunes resonant frequency through the truncated corner with the stub for impedance matching. In Fig. 6 (b), the lower patch has two slots for coupling between the upper patch and the CPW feed line. Especially the distance between two slots is related to control the impedance matching and the coupling. This antenna is etched on RT/duroid 5880 substrate with ε_r=2.2 and thicknesses are 62 mil for the upper substrate and 31 mils for the lower substrate. Respectively, This antenna is simulated by Ansoft HFSS 6.0, and the results are shown in Fig. 5 with comparison between microstrip line fed and CPW fed microstrip antenna. It shows the improvement of bandwidth about 3.2 % on VSWR < 2.

Ⅵ. Impedance-matching Techniques using CPW Feed Line

In the slot coupled microstrip antenna, the most common method to control the coupling from the feed line is to vary the size of the slot[7]. But its size cannot be varied independently and the coupling from the feed line must be controlled in other manners since the slot is used as a radiator in this kind of antenna. In this paper, the use of a radiating slots results in high level of coupling and the size of slots must be reduced for the proper impedance matching to the antenna. Therefore, the wide-centered CPW feed line of Fig. 6 (c) achieve this through the fact that the coupling decreases with feed line width[5].

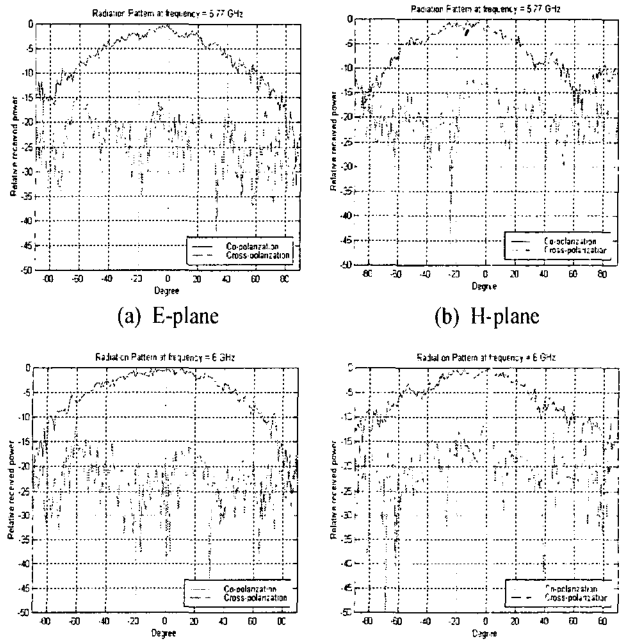
Ⅶ. Experimental Results

The experimental results of the return loss and radiation characteristics for the proposed antenna are presented. Fig. 7 (a) and (b) show the measured return loss and impedance loci on the smith chart of the proposed antenna, respectively. The impedance loci on the smith chart shows a looped characteristic inside VSWR = 2 circle. It means the various wideband method compensating for the rapid frequency variations of the input impedance. The measured impedance bandwidth is 742 MHz (12.67 %, VSWR < 2), from 5.485 GHz to 6.227 GHz. The measured co-polar and cross-polar radiation patterns in the E and H-plane of the proposed antenna are illustrated in Fig. 8. The radiation patterns are measured at lower and upper bound frequencies of the bandwidth. Two radiation patterns of the each type have the similar broadside radiation characteristics and the cross-polarization has a higher level in the H-plane than the E-plane. It results from the slots cut on the patch. The introduction of the slots on the patch definitely alters the distribution of the induced electric currents. The increased cross-polarization levels partly stem from the equivalent magnetic currents in the arms of U-slot.



(a) Return loss (b) Impedance loci

Fig. 7. Measured return loss and impedance loci versus frequency for the proposed antenna.



(a) E-plane (b) H-plane

(c) E-plane (d) H-plane

Fig. 8. Measured E- and H-plane radiation patterns for the proposed antenna, (a) and (b) @ f = 5.77 GHz, (c) and (d) @ f = 6 GHz.

Ⅷ. Conclusions

The proposed antenna using CPW feed and CPW open-ended stub provides wideband bandwidth (12.67 %). In addition, the impedance matching can be easily obtained through the tapered-step CPW line. The proposed antenna can decrease the number of substrate, compared with the conventional microstrip feed line. However, the reason back-lobe shows in the radiation pattern is that the ground plane is finite, and correction and adjustment of this factor is necessary.

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