CPW-급전 3중-주파수 대역 사각 슬롯 안테나 설계
Design of Triple-frequency Band CPW-Fed Rectangular Slot Antennas

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Key Word : broadband antenna, coplanar waveguide (CPW)-fed, rectangular slot antenna

ABSTACT : A new broadband coplanar waveguide (CPW)-fed rectangular slot antenna is presented in this study. The rectangular slot waveguide with a tuning patch inside is excited to perturb triple-frequency band antenna operations. This antenna has an impedance bandwidth (VSWR≤2) of 12.8GHz~35.8GHz, 94.7% and a radiation bandwidth of 42% at 24.3GHz the center frequency, compared to the 12-46% impedance bandwidth of the standard CPW-fed square slot antenna. The impedance bandwidth can be adjusted with the ratio of width and length of the rectangular slot. Simulated and measured results for different ratios of the proposed antenna are presented. The rectangular slot antenna has broad applications in wireless technologies and medical equipments.

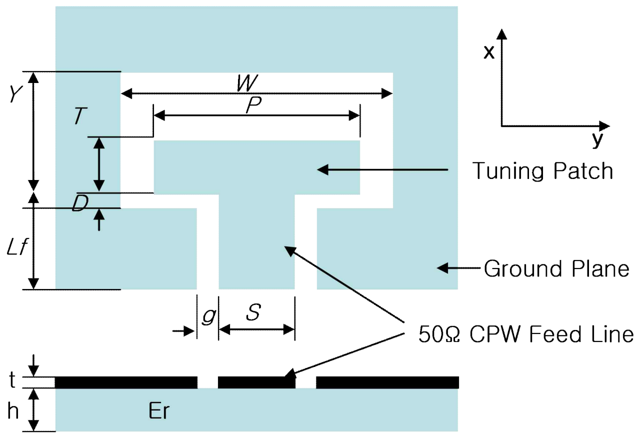
요약 : 본 논문에서는 새로운 광대역 CPW-급전 사각 슬롯 안테나를 제시하였다. 사각 슬롯 웨이브가이드 안쪽의 주파수 조절 패치를 조절하여 3개의 주파수 대역에서 동작하도록 설계하였다. 설계된 안테나는 기존의 12~40%의 임피던스 대역폭의 일반적인 사각슬롯 안테나에 비해 12.8GHz ~ 35.8GHz 영역에서 94.7%의 VSWR≤2 임피던스 대역폭과 중심주파수 24.3GHz에서 42%의 방사 대역폭을 갖는다. 임피던스 대역폭은 사각슬롯의 길이와 폭의 비율로써 조절되며, 제안된 안테나에서 다양한 폭과 길이의 조합을 시뮬레이션과 측정치를 통해 살펴보았다. 제시된 사각 슬롯 안테나는 무선 기술 및 의료용 장비에 폭넓게 적용할 수 있다.

1. Introduction

PLANAR slot antennas with broadband characteristics have received lots of attention recently due to much demand for high capacity wireless K-band applications. They have several advantages in terms of antenna size, cost, and easy integration with monolithic microwave integrated circuits (MMICs) compared to the microstrip patch antennas [1, 2]. A few attempts to increase the bandwidth to the CPW (coplanar waveguide)-fed slot antennas have been conducted employing a square slot [3, 4], a bow-tie slot [5], a circular slot [6] or a half-wavelength capacitively coupled hybrid slot [2]. For the reported design that uses a capacitively coupled CPW feed [1], there have been a lot of limitations in the design of high performance antennas, such as surface wave losses and feeding transmission line losses. Typical CPW-fed antennas, however, have shown the limitation of their narrow bandwidth of 10-20% [8], which is not enough to cover the demand of wireless communication systems at K-band and medical application bands. To overcome these limitations, it is necessary to develop a new slot antenna design.
In this paper, a novel and simply designed CPW-fed rectangular slot antenna that operates in triple-frequency bands is presented. The means of exciting triple-frequency modes and

broadband operation is to adjust the ratio of the width and the length of the rectangular slot. Its impedance bandwidth is also optimized with the size of a tuning patch. Experimental results are compared with the simulation data generated with a HFSS (high frequency simulation structure) software tool and other published results.

2. Geometry of Rectangular Slot Antennas



[Fig. 1] Configuration of a CPW-fed broadband rectangular slot antenna

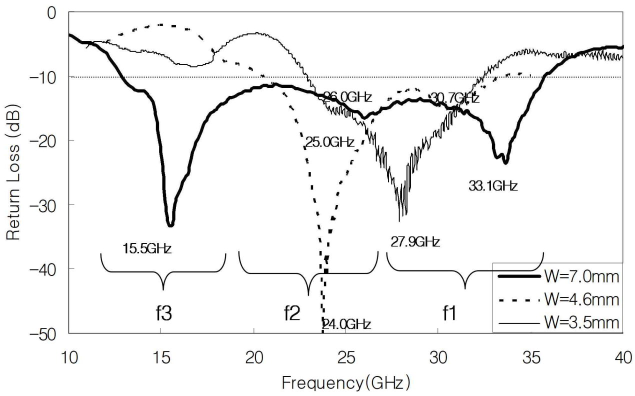
Figure 1 shows the basic configuration of a broadband CPW-fed rectangular slot antenna with a wide radiating slot and its cross-sectional geometry. This antenna is composed of two components: a rectangular slot acting as a radiating antenna and a rectangular tuning patch as an internal tuning stub for feeding the antenna. The present design in Fig. 1 is denoted as a CPW-fed rectangular slot antenna.

The rectangular slot has a width of W and a length of Y (3.5㎜ fixed in this study) for the proposed antenna printed on a Rogers 4003^{TM} substrate of thickness h=0.5mm, a dielectric constant=3.38, and metal thickness t=18㎛. The rectangular tuning patch ended to the signal strip of a 50Ω CPW should be inside the rectangular radiation slot near the bottom edge of the slot on the same layer and centered with respect to the center line of the slot.

A 50Ω CPW feed line, with a metal center conductor of width S of 1.6㎜ and gap spacing g of 0.12㎜ between the signal strip and the coplanar ground plane, is used to capacitively excite the proposed antenna.

3. Results and Discussion

Figure 2 shows the measured return loss curves of the proposed CPW-fed rectangular slot antennas. Each data shows return losses for three different sizes of the rectangular slot: W = 3.5㎜, 4.6㎜, and 7.0㎜ with Y=3.5㎜. For a square slot (antenna 1), the resonant frequency f1 is measured at 27.9 GHz which is excited along the slotline Y, 3.5㎜. When the slot width is increased from 3.5㎜ to 7.0㎜ with the slot length Y fixed at 3.5㎜, three resonant modes are excited. The first excited frequency f1 is shifted to 33.1GHz. The second resonance mode of a radiating frequency f2 appears at 26.0GHz. The third frequency f3 is also generated at 15.5GHz as shown in Fig. 2.



[Fig. 2] Measured return losses against the frequency for the proposed antenna: Y=3.5㎜.

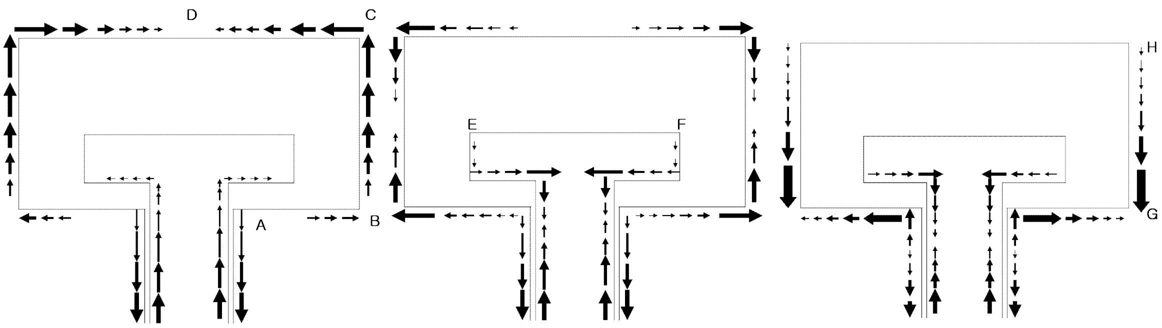
In order to visualize the broad bandwidth operation, a structural effect of the rectangular slot has been investigated. The increase of the aspect ratio W/Y to 2 (i.e., $W=2Y$) makes the slot wider, enhancing its operation bandwidth through the generation of a third resonant frequency f3. As the return loss curve of Fig. 2 shows, the bandwidth approaches to 23.0 GHz (12.8GHz~35.8GHz), which is 94.7% for 10 dB return loss level at the center frequency of 24.3 GHz. This is due to the proposed approach that uses a wide CPW-fed rectangular slot as a radiating waveguide. For the purpose of the analysis of the excitation behavior, simulations about the surface current distribution were carried out. Surface current distribution of Fig. 3 depicts the behavior of the excitation of three different resonant frequencies at 15GHz, 26GHz, and 33GHz as for antenna 3 in Table I.

TABLE 1. Design parameters and measured bandwidths of proposed rectangular slot antennas: (*Simulated data)

	W (㎜)	Y (㎜)	P (㎜)	T (㎜)	D (㎜)	f_c (㎓)	BW (%, ㎓)
Antenna 1 (Square slot)	3.5	3.5	2.1	0.9	0.3	27.65	34.4, 22.9~32.4
Antenna 2	4.6	3.5	3.1	1.0	0.3	27.5	45.8, 21.2～33.8
Antenna 3	7.0	3.5	4.3	1.0	0.5	24.3	94.7, 12.8～35.8

Table1 shows experimental data of three different structures measured by a HP8722ES network analyzer. Each data is compared with the simulation data by a HFSS.

At f3=15GHz, the surface current path makes one cycle along the path A-B-C-D. Here, the slot width W and the slot length Y are a dominant contributor to the resonant radiation. However, at f2=26GHz, the tuning patch width P induces the horizontal path of the surface current along the tuning patch width E-F. The related equivalent surface current path along the ground plane is strongly meandered.



(a)f3 = 15GHz (b)f2 = 26GHz (c)f1 = 33GHz

[Fig. 3] Simulated surface current distribution on the proposed antenna (antenna 3).

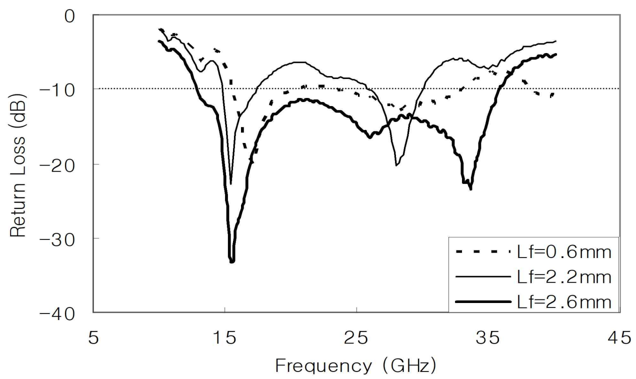
The tuning patch width P can be considered as an excitation medium to induce the radiation mode of a half-wavelength antenna. On the other hand, at f1=33GHz, the vertical path of surface current distribution of Fig. 3 (c) shows maximum intensities at point G and nulls at point H. There, the surface current path becomes parallel to the slotline length Y, showing a half-wavelength radiation following the path G-H.

From the results, the slot shape of the proposed design is considered as a slotline resonator shorted at two ends and capacitively fed by a CPW feed line.[3] The slotline of the rectangular slot length Y is used to excite the current of the resonant frequency f1 like the behavior of a half-wavelength slot waveguide antenna [3]. Similarly, the tuning patch width P is used for another resonant frequency f2. On the other hand, the loop shape ($W\times Y$) of the slot structure itself shows the relation to the resonance at the lower frequency f3, as observed in the surface current distribution of Fig. 3 (a). This result illustrates that the expansion of the slot width W directly corresponds to the excitation of the lower resonant frequency f3 and contributes to the expansion of the impedance bandwidth to 94.7%.

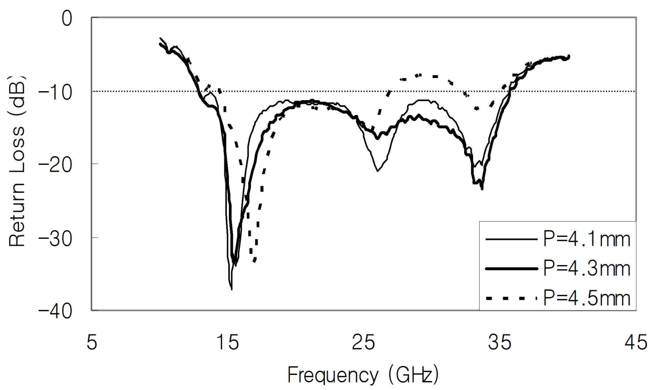
The behavior of the impedance matching to a 50Ω CPW feed line has been investigated with the design variables of an internal tuning stub for the proposed antenna. The effect of the feed line length (Lf) on the impedance matching of the antenna is examined (W=7.0㎜, Y=3.5㎜, P=4.3㎜, T=1.0㎜, and D=0.5㎜). When Lf=0.6㎜, three resonant modes are excited at 17 GHz, 28 GHz, and 38 GHz. However, the overall return losses show above 10dB, indicating irrelevant impedance matching conditions.

When Lf is increased to 2.6㎜, f1 and f3 shift toward the lower frequencies, the overall return losses improve below 10dB. The increase of the feed line Lf generates the broad bandwidth of 24GHz, down shifting the resonant points of f1, f2, and f3 as shown in Fig. 6.

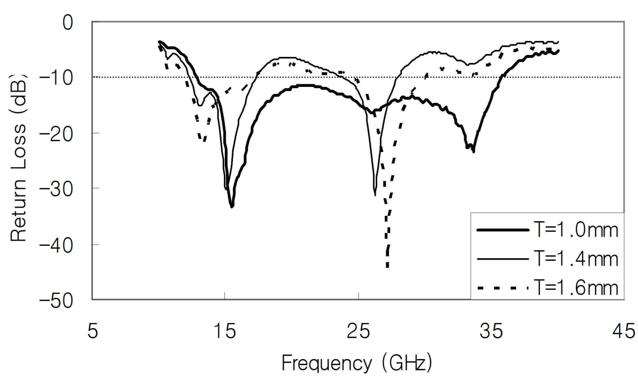
The impedance bandwidth in the proposed design can be further improved by adjusting the tuning patch dimension (P, T) and the space between the patch and the ground plane (D) as shown in Fig. 5~7. The tuning patch width P affects mainly the higher resonant frequency f1 and f2. The variation of patch width affects the coupling between the tuning patch and the slot length Y. The good impedance matching for higher frequency regions can be enhanced by controlling the tuning patch width. In this case, the optimal patch width of P=4.3㎜ is considered to perform the broadband operation.



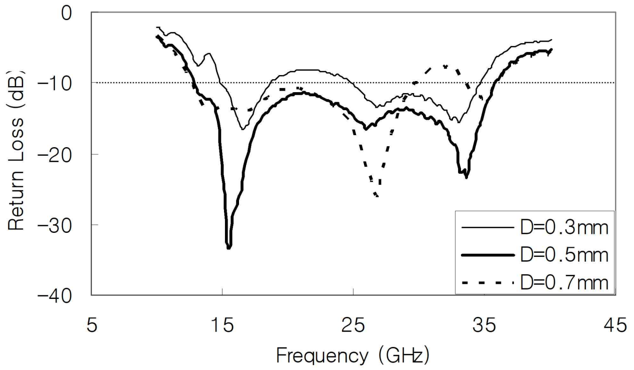
[Fig. 4] Measured data due to the variation of resonant frequencies respect to feed line length (L_f): W=7.0㎜, Y=3.5㎜.



[Fig. 5] Variation of resonant frequency respect to tuning patch width (P) with fixed slot length: W=7.0㎜ Y=3.5㎜

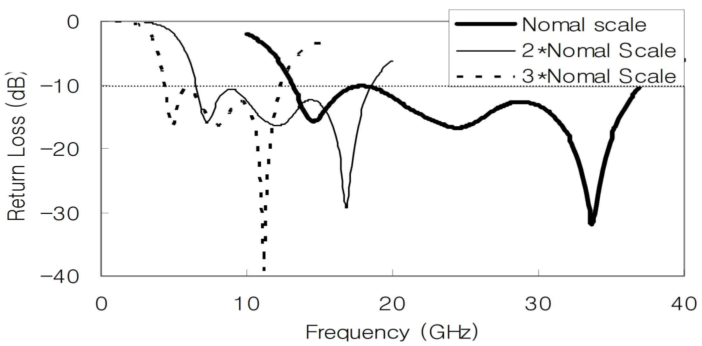


[Fig. 6] Variation of resonant frequencies respect to feed line length (T): W=7.0㎜, Y=3.5㎜.



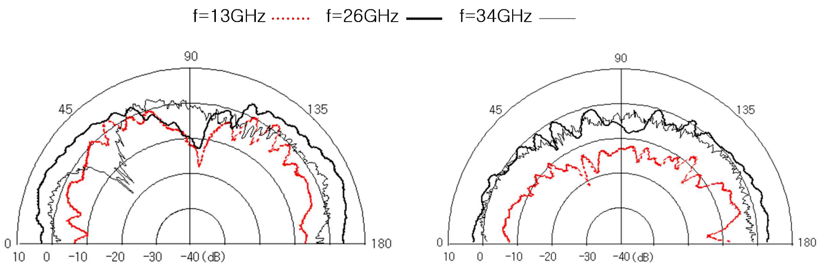
[Fig. 7] Variation of resonant frequencies respect to feed line width (S): W=7.0㎜, Y=3.5㎜.

The tuning patch length T is related to the low resonant frequencies, f2 and f3, as shown in Fig. 6. The variation of tuning patch length affects the coupling between the tuning patch and the top slot width W. When the length T is larger than 1.0㎜, the return losses dramatically degrade and the frequency f3 shift to the lower range. As a result, return losses between f2 and f3 are enhanced to less than -10 dB.
Similarly, the impedance matching for low resonant frequency f3 can be improved by adjusting the space D between the bottom side of radiation slot and the tuning patch inside. By carefully selecting the other tuning parameters (S and g) of the CPW feed line, two resonant frequencies, f1 and f2, of the proposed antenna are shifted close to each other as in Fig. 7.
The proposed design is applied to the different frequency band and various sizes as shown in Fig. 8.[4] When the antenna is scaled twice the size of the proposed antenna, the center frequency is shifted from 25.1GHz to 12.6GHz while maintaining the impedance bandwidth of 95% as shown in Fig. 8.



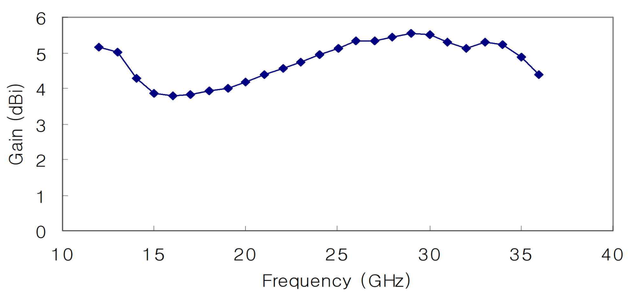
[Fig. 8] Simulated return losses for various scaled sizes of proposed antenna (antenna3).

The radiation characteristics and the antenna gain are also studied as shown in Fig. 9. The E plane (x-z plane) and the H plane (y-z plane) radiation patterns at 13 GHz, 26GHz, and 34 GHz for antenna3 show omni-directional broadside radiation and similar behavior.[10, 11] The half power beam width (HPBW) angle in the E plane at 20.5GHz and 30.7GHz is 79 degrees. The cross-polarization radiation in the E-plane is seen to be less than 40 dB below the co-polarization level throughout the bandwidth, whereas relatively larger cross-polarization in the H-plane is observed. The radiation bandwidth of the wideband antenna is 72 %.



E-plane H-plane

[Fig. 9] Measured E plane and H plane gain patterns for various frequencies (antenna3): (a) f=13GHz. (b) f=26GHz). (c) f=34GHz.



[Fig. 10] Measured antenna gain of antenna3.

4. CONCLUSION

A new design for a broadband CPW-fed rectangular slot antenna for broadband operation has been designed and successfully implemented in this study. When the slot width is twice its length, the rectangular slot antenna with a tuning patch inside excites triple-frequency broadband operation showing the properties of an impedance bandwidth (VSWR≤2) of 12.8GHz~35.8GHz, 94.7% and a radiation bandwidth of 72% at the center frequency of 24.3GHz. This result shows that a CPW-fed slot antenna can be easily implemented with a simple rectangular slot structure which includes a tuning patch inside in the wireless technologies and medical applications.

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