

# E-면 결합을 이용한 구형 마이크로스트립 안테나에 관한 실험적인 연구 : 마이크로스트립 선로 급전

正會員 洪 在 杓\*\* 正會員 趙 榮 基\* 正會員 孫 鉉\*

## Experimental Study on the E-plane Coupled Rectangular Microstrip Patch Antennas : Microstrip Line Fed Case

Jae Pyo HONG\*\*, Young Ki CHO\*, Hyon SON\* *Regular Members*

**要 約** 본 논문에서는 복사면 가장자리가 결합된 두 구형 마이크로스트립안테나에, 패치사이의 복사면 가장자리의 결합을 특성화하는 REC 모델을 적용하여 여러가지 결합간격에 대해 산란계수  $|S_{11}|$ 과  $|S_{22}|$ 를 구하였으며, 이를 실험치와 비교하였다. 그리고 복사면 가장자리에서의 결합을 이용한 기생소자를 갖는 구형 마이크로스트립 안테나에, REC 모델을 적용하여 계산 손실을 구한 뒤 실험치와 비교하였다. 여기서 각각의 안테나는  $50\Omega$  마이크로스트립 선로에 의해 급전한 결과를 다루었으며, 이는 REC 모델을 이론적으로 제시하여 동축선로로 급전한 결과<sup>(10)</sup>와 비교하기 위한 논문이다.

**ABSTRACT** In this paper, applying the REC model which characterizes the coupling between the radiating edges to two coupled rectangular microstrip patch antennas, we obtain scattering parameters  $|S_{11}|$  and  $|S_{22}|$  for the various coupling separations,  $S_e = 0.5\text{mm}, 1.0\text{mm}, 1.5\text{mm},$  and  $2.0\text{mm}$ . The calculated values are compared with the measured values. For the rectangular microstrip patch antenna with a parasitic element which is gap-coupled to the radiating edges of the rectangular patch, calculated return losses using the REC model are compared with measured values. Here, the each microstrip antenna is fed by a  $50\Omega$  microstrip line. The purpose of the paper is to compare a  $50\Omega$  microstrip line fed case with a coaxial fed case treated in Ref.<sup>(10)</sup>

### I. INTRODUCTION

Rectangular microstrip patch antennas have been used in recent years in a broad spectrum of applications. This popularity is due to their inherent advantages such as simple geometry,

\*慶北大學校 電子工學科  
Dept. of Electronic Engineering, Kyungpook National  
University, Daegu 635, Korea.

\*\*順天工業專門大學  
Sunchun Technical Junior College Dept. of  
Electronics  
論文番號 : 89-08(接受 1988. 11. 8)

low profile, light weight, ease of production, and conformality to a given surface. But these antennas have a major disadvantage in that they have a very small bandwidth. Broader bandwidth in rectangular microstrip patch antenna has been experimentally achieved by use of a log-periodic structure<sup>(1-2)</sup> or a gap-coupled microstrip patch antenna<sup>(3-4)</sup>.

An equivalent model (E-plane coupling model) representing the gap coupling between radiating edges is initially proposed by Krown<sup>(5-6)</sup>. And several authors<sup>(7-9)</sup> have experimentally shown that the narrow bandwidth of the rectangular microstrip antenna can be improved by using parasitic elements, or multi-resonators which are coupled to the radiating edges of the patches.

In this paper, applying the Radiating Edges-Coupling (REC) model<sup>(10)</sup> and the radiation admittance<sup>(11)</sup> to two coupled rectangular microstrip patch antennas fed by a 50 Ω microstrip line, we obtained the numerical results in terms of S-parameter values  $|S_{11}|$  and  $|S_{12}|$  for the various separations,  $Se = 0.5\text{mm}, 1.0\text{mm}, 1.5\text{mm},$  and  $2.0\text{mm}$ . The calculated values are compared with measured values for each case.

Rectangular microstrip patch antenna which is coupled to a parasitic element and fed by a 50 Ω microstrip line is also considered. Return losses as a function of frequency are calculated and measured for the various coupling separations. Here, experiments had been performed in the frequency range of 2.5-3.5 GHz. The antennas were fabricated in Teflon substrate with relative dielectric constant  $\epsilon_r = 2.6$  and thickness  $h = 0.155\text{cm}$ . Measurements were carried out with HP-8746B S-parameter Test Set. And this paper is presented to compare a 50 Ω microstrip line fed case with a coaxial fed case treated in Ref<sup>(10)</sup>, which proposed theoretically the REC model.

## II. TWO COUPLED RECTANGULAR MICROSTRIP PATCH ANTENNAS

Geometry of two coupled rectangular microstrip patch antennas is shown in Fig.1. Here  $W$  and  $L$  are the width and length of single patch, respectively.  $Se$  is the coupling separation between the radiating edges. The each microstrip patch is fed by a 50 Ω microstrip line.  $X$  is the distance of the feed point from the corner,  $h$  is the substrate thickness and  $\epsilon_r$  is a dielectric constant.

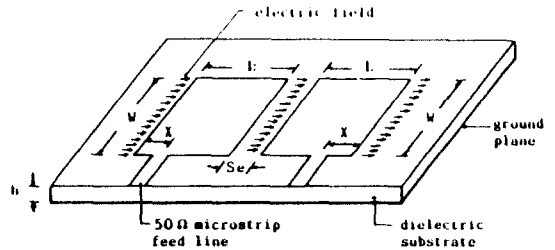


Fig. 1. Geometry of two coupled rectangular microstrip patch antennas.  
(for a 50 Ω microstrip line fed case)

Applying the REC model and the radiation admittance to two coupled rectangular microstrip patch antennas, we obtain an equivalent circuit, as shown in Fig.2. In Fig.2, the radiation admittance of the rectangular microstrip patch antenna is composed of a parallel combination of a radiation conductance and a capacitance given in [11-12]. The REC model which char-

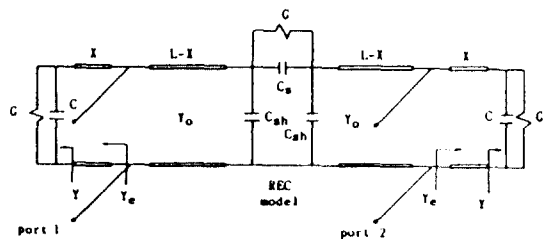


Fig. 2. Equivalent circuit of two coupled rectangular microstrip patch antennas. (for a 50 Ω microstrip line fed case).

acterizes the coupling between the radiating edges is composed of the radiation conductance, series and shunt capacitances proposed in [10].

$Y_0$  is the characteristic admittance in the patch and is given by<sup>(10,13)</sup>

$$Y_0 = \frac{W \alpha \sqrt{\epsilon_{eff}}}{\eta_0 h} \quad (1)$$

where

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 10 \frac{h}{W} \right]^{-\frac{1}{2}}$$

$$\alpha = 1 + 1.393 \cdot \frac{h}{W} + 0.667 \cdot \frac{h}{W} \cdot$$

$$\ln \left[ \frac{W}{h} + 1.444 \right]$$

and  $\epsilon_{eff}$  is the effective dielectric constant,  $\eta_0$  is intrinsic impedance in the free space.

The equivalent circuit shown in Fig.2 is a two-port network cascading seven successional transmission matrices from port 1 to port 2.

The entire transmission matrix [T] is represented as<sup>(14)</sup>

$$[T] = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = [T_{ve}] [T_{L-x}] [T_{sh}] [T_s] [T_{sh}] [T_{L-x}] [T_{ve}] \quad (2)$$

where  $[T_{ve}]$  and  $[T_{L-x}]$  represent the transmission matrix of the equivalent radiation admittance and transmission line L-X, respectively.  $[T_{sh}]$  and  $[T_s]$  represent the shunt and series element matrices of the REC model, respectively.

Each transmission matrix is expressed as follows :

$$[T_{ve}] = \begin{bmatrix} 1 & 0 \\ Y_e & 1 \end{bmatrix}$$

$$[T_{L-x}] = \begin{bmatrix} \cos \beta (L-X) & j \frac{1}{Y_0} \sin \beta (L-X) \\ j Y_0 \sin \beta (L-X) & \cos \beta (L-X) \end{bmatrix}$$

$$[T_{sh}] = \begin{bmatrix} 1 & 0 \\ j \omega C_{sh} & 1 \end{bmatrix}$$

$$[T_s] = \begin{bmatrix} 1 & \frac{1}{G + j \omega C_s} \\ 0 & 1 \end{bmatrix}$$

and  $\beta = \frac{2\pi}{\lambda_0} \sqrt{\epsilon_{eff}}$  is the propagation constant in the patch,  $\lambda_0$  is the free space wavelength and an equivalent radiation admittance  $Y_e$ , transforming the radiation admittance through distance X, is

$$Y_e = Y_0 \cdot \frac{Y + j Y_0 \tan \beta X}{Y_0 + j Y \tan \beta X} \quad (3)$$

Scattering matrix [S] which characterizes the coupling of two rectangular microstrip patch antennas can be obtained by transforming the entire transmission matrix [T]. Here,  $|S_{11}| = |S_{22}|$  and  $|S_{12}| = |S_{21}|$  because of symmetrical network.

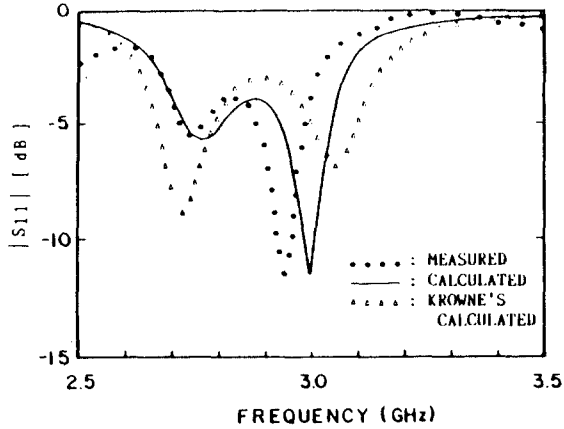
Table I. Specifications of two coupled rectangular microstrip patch antennas.

Patch Length L [cm]	Patch Width W [cm]	Substrate Thickness h [cm]	Dielectric Constant $\epsilon_r$	Feed Point X [cm]
3.02	3.7	0.155	2.6	0.894

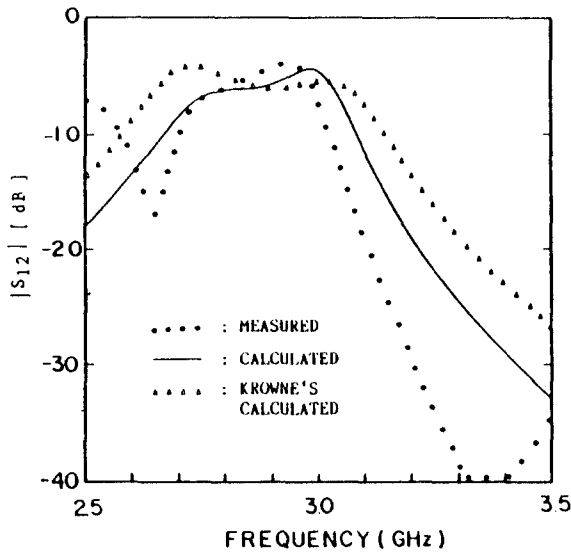
Specifications of the antennas considered here are listed in Table I. X means a 50  $\Omega$  feed point whose input impedance of the rectangular microstrip patch antenna is equal to 50  $\Omega$ . The antennas are fabricated in Teflon substrate 'CGP-512' with relative dielectric constant  $\epsilon_r = 2.6$  and thickness  $h = 0.155$ cm. Measurements are carried out with HP-8746B S-parameter Test Set in the frequency range of 2.5-3.5 GHz.

The calculated values of  $|S_{11}|$  and  $|S_{12}|$  are compared with measured values for the coupling

separations,  $Se = 0.5\text{mm}$ ,  $1.0\text{mm}$ ,  $1.5\text{mm}$ . and  $2.0\text{mm}$ , respectively.



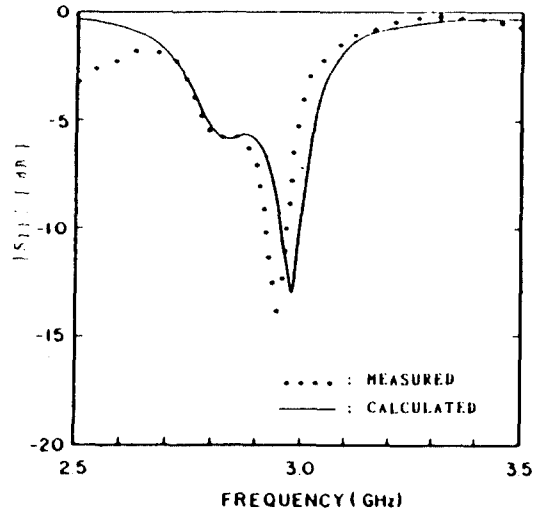
(a)



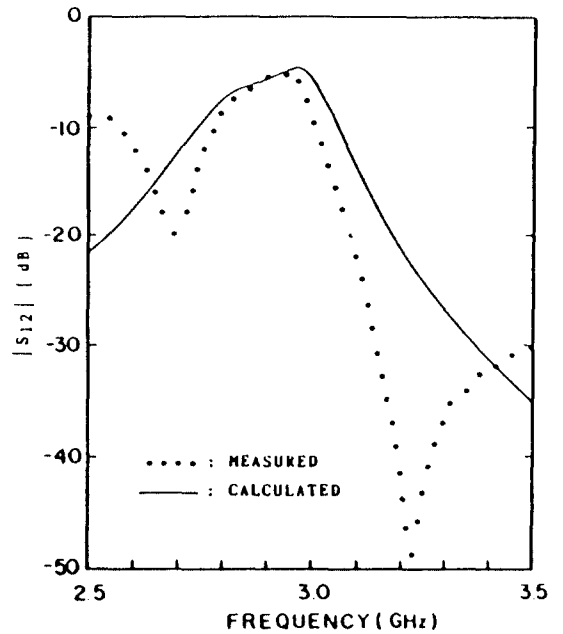
(b)

Fig. 3. Measured and calculated S-parameter values as a function of frequency for  $Se = 0.5\text{mm}$ , (for a  $50\Omega$  microstrip line fed case)  
(a)  $|S_{11}|$  (b)  $|S_{12}|$

Figs. 3 (a) and (b) illustrate the calculated and measured values of  $|S_{11}|$  and  $|S_{12}|$  for  $Se = 0.5\text{mm}$ . From these results, it is observed that the



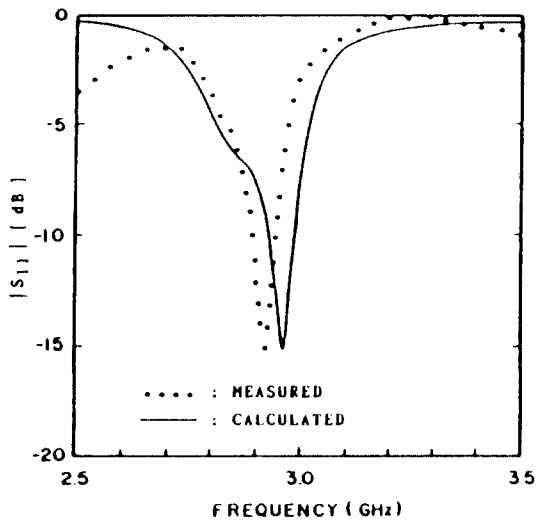
(a)



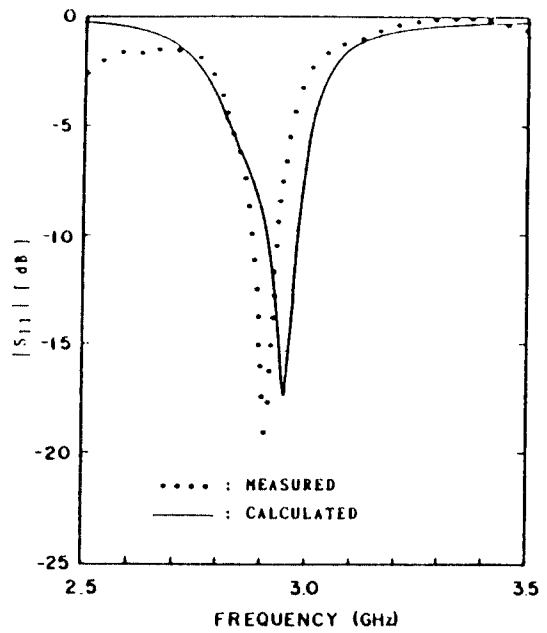
(b)

Fig. 4. Measured and calculated S-parameter values as a function of frequency for  $Se = 1.0\text{mm}$ , (for a  $50\Omega$  microstrip line fed case)  
(a)  $|S_{11}|$  (b)  $|S_{12}|$

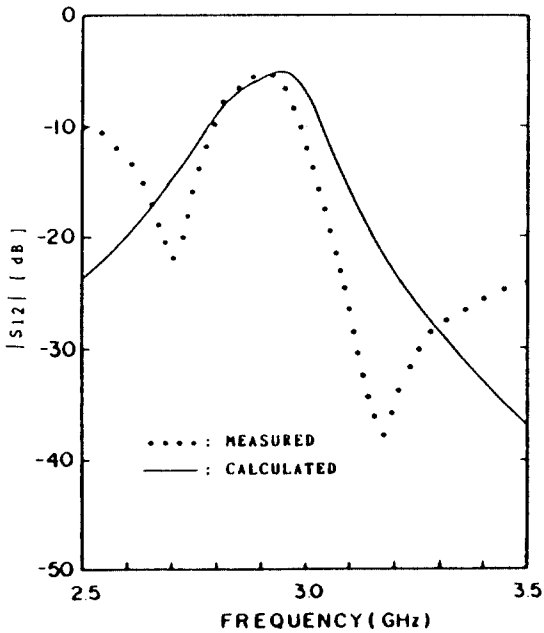
REC model is more accurate than the previous E-plane coupling model proposed by Krowne<sup>(6)</sup>. In Figs. 4-6, it is also observed that calculated



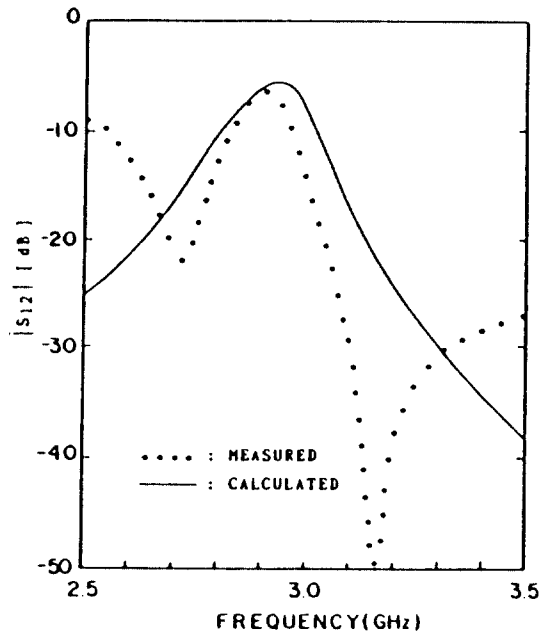
(a)



(a)



(b)



(b)

Fig. 5. Measured and calculated S-parameter values as a function of frequency for  $Se = 1.5 \text{ mm}$ , (for a  $50 \Omega$  microstrip line fed case)  
(a)  $|S_{11}|$  (b)  $|S_{12}|$

Fig. 6. Measured and calculated S-parameter values as a function of frequency for  $Se = 2.0 \text{ mm}$ , (for a  $50 \Omega$  microstrip line fed case)  
(a)  $|S_{11}|$  (b)  $|S_{12}|$

values using the REC model are in fairly good agreement with measured values. From the calculated and measured results of  $S_{11}$  in Figs. 3-6, it is obvious that the wider the coupling separation becomes, the smaller the swelling diminishes, the sharper the dip becomes, and the lower the dip frequency shifts. Therefore it can be deduced that when the coupling separation is sufficiently increased,  $|S_{11}|$  of the two coupled rectangular microstrip patch antenna is interpreted physically as the return loss of the single rectangular microstrip patch antenna. Then, the Dip frequency approaches the resonant frequency  $f_0=2.910$  GHz of the single rectangular microstrip patch antenna, given in [11]. In Figs. 3-6, the discrepancy between the measured and calculated values in the vicinity of 2.5 GHz and 3.5 GHz, respectively, may be caused by the discontinuity between the patch and the microstrip feed line. Meanwhile, when the patch was fed by a coaxial line instead of a 50Ω microstrip line, respectively, the measured values were in fairly good agreement with the calculated values in the whole frequency range of 2.5-3.5GHz, as described in [10].

### III. RECTANGULAR MICROSTRIP PATCH ANTENNA WITH A PARASITIC ELEMENT

Rectangular microstrip patch antenna with a parasitic element, which is coupled to the radiating edges between the patch and a para-

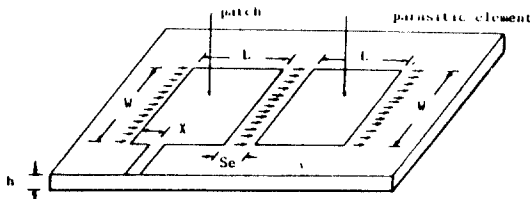


Fig. 7. Geometry of the rectangular microstrip antenna with a parasitic element. (for a 50Ω microstrip line fed case)

sitic element, is shown in Fig.7. Here  $Se$  is the coupling separation between the patch and the parasitic element. The antenna is fed by a 50Ω microstrip line and  $X$  is the same as given in Section II.

The antenna with the parasitic element shown in Fig.7 is represented by the equivalent transmission line model<sup>(15)</sup>, as shown in Fig.8. The REC model<sup>(10)</sup> represents the gap coupling between the radiating edges, and  $Y$  is the radiation admittance of the radiating edges<sup>(11-12)</sup>.

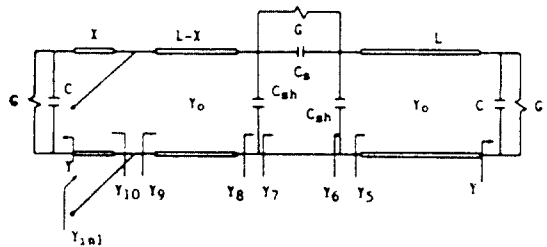


Fig. 8. Equivalent circuit of the rectangular microstrip antenna with a parasitic element. (for a 50Ω microstrip line fed case)

In Fig.8, the input admittance of the antenna can be written as<sup>(15)</sup>

$$Y_{in1} = Y_9 + Y_{10} \tag{4}$$

where

$$Y_5 = Y_0 \frac{Y + j Y_0 \tan \beta L}{Y_0 + j Y \tan \beta L}$$

$$Y_6 = Y_5 + Y_{sh}$$

$$Y_e = \frac{Y_s \cdot Y_6}{Y_s + Y_6}, \quad Y_{sh} = j \omega C_{sh}$$

$$Y_8 = Y_7 + Y_{sh}, \quad Y_s = G + j \omega C_s$$

$$Y_9 = Y_0 \frac{Y_8 + j Y_0 \tan \beta (L - X)}{Y_0 + Y_8 \tan \beta (L - X)}$$

$$Y_{10} = Y_0 \frac{Y + j Y_0 \tan \beta X}{Y_0 + j Y \tan \beta X}$$

The return loss of the antenna is defined as

$$RL = 20 \log \left| \frac{1 - \bar{Y}_{in1}}{1 + \bar{Y}_{in1}} \right| \quad (5)$$

where  $\bar{Y}_{in1}$  is the input admittance normalized to  $1/50\Omega$ .

Specifications of the patch and the parasitic element considered here are given in Table I.

Figs. 9-12 give comparisons of the calculated and measured return losses for the various coupling separations. In Fig.9, the return losses calculated by using the REC model<sup>(10)</sup> are compared with the measured results and with those calculated by using the previous E-plane coupling model<sup>(6)</sup> for  $Se=0.5\text{mm}$ . It is observed in Fig. 9 that the measured values are better agreement with the calculated values using the REC model than the calculated values using

previous E-plane coupling model. Fig. 10-12 compare calculated results using the Rec model with measured results for  $Se=10\text{mm}$ ,  $1.5\text{mm}$ , and  $2.0\text{mm}$  respectively. It is observed from Figs. 10-12 that the calculated values are fairly good agreement with the measured values.

As discussed in Section II, the calculated results are also not in good agreement with the measured results in the vicinity of 2.5 GHz and 3.5 GHz, respectively.

#### IV. CONCLUSION

In this paper, applying the REC model to two coupled rectangular microstrip patch antennas fed by a  $50\Omega$  microstrip line, we obtained the calculated values of  $|S_{11}|$  and  $|S_{12}|$  for the various coupling separations,  $Se = 0.5\text{mm}, 1.0\text{mm}, 1.5\text{mm}, 2.0$

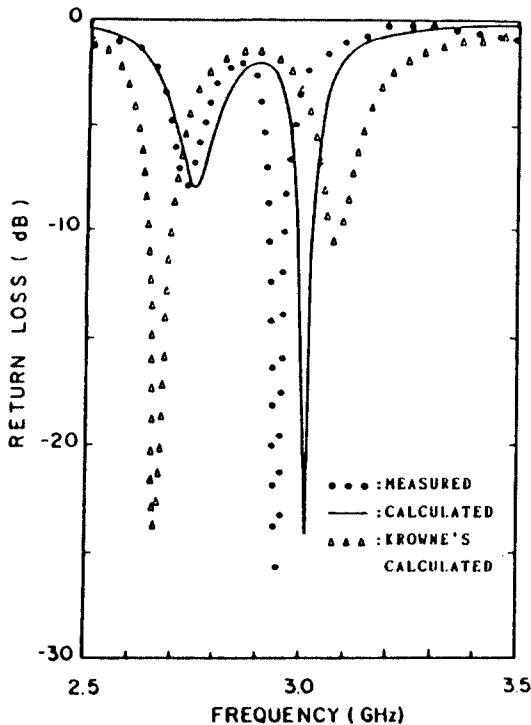


Fig. 9. Measured and calculated return losses as a function of frequency for  $Se = 0.5\text{mm}$ . (for a  $50\Omega$  microstrip line fed case)

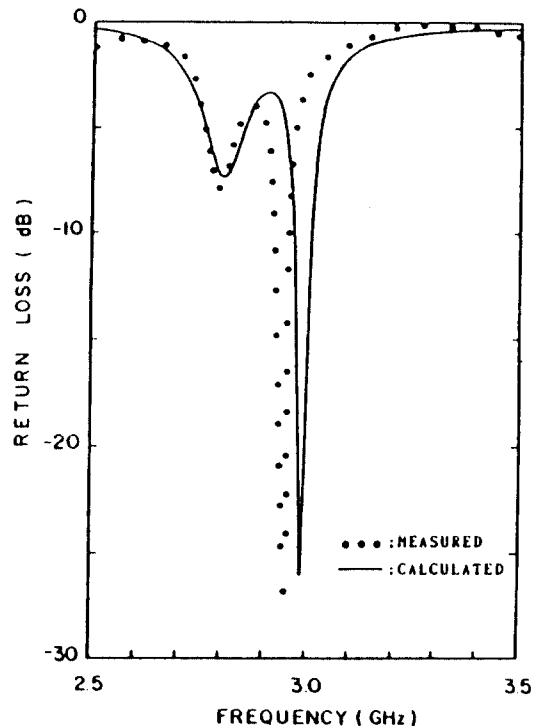


Fig.10. Measured and calculated return losses as a function of frequency for  $Se = 1.0\text{mm}$ . (for a  $50\Omega$  microstrip line fed case)

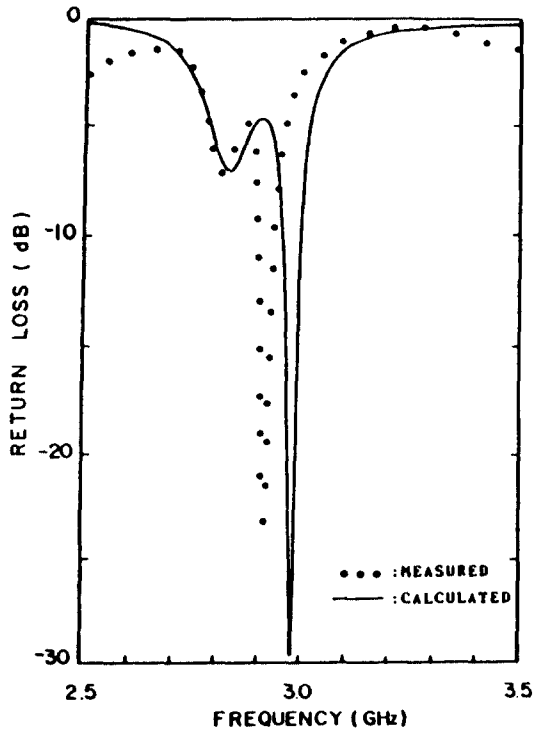


Fig.11. Measured and calculated return losses as a function of frequency for  $\epsilon_r = 1.5$ mm. (for a  $50\Omega$  microstrip line fed case)

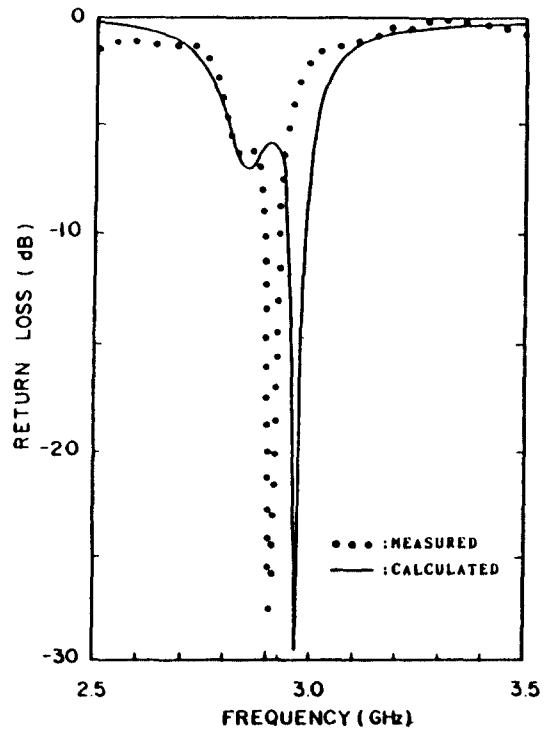


Fig.12. Measured and calculated return losses as a function of frequency for  $\epsilon_r = 2.0$ mm. (for a  $50\Omega$  microstrip line fed case)

mm. And the calculated values were compared with the measured values for each case. For a  $50\Omega$  microstrip line fed case considered here, the calculated results were not in good agreement with the measured results in the vicinity of 2.5 GHz and 3.5 GHz, respectively.

In addition, similar results were obtained for the rectangular microstrip patch antenna with a parasitic element, which is coupled to the radiating edges between the patch and the parasitic element, and fed by a  $50\Omega$  microstrip line. This is probably due to the fact that the discontinuity between the patch and a  $50\Omega$  microstrip feed line occurred. In the case of a coaxial line feed, as described in [10], the measured values were in good agreement with the calculated values for the whole frequency range of 2.5-3.5 GHz. Therefore, we think that for the

microstrip line fed case an equivalent circuit model for the discontinuity between the non-radiating edges of the patch and the microstrip feed line is required.

## REFERENCES

1. P.S. Hall and A. Sparrow, "Microstrip log-periodic antenna array with endfire beam", *Elect. Letters*, vol. 23, no. 17, pp. 912-913, Aug. 1987.
2. P.S. Hall, "New wideband microstrip antenna using log-periodic technique", *Elect. Letters*, vol. 16, no. 4, pp. 127-128, Feb. 1980.
3. C.K. Aanandan and K.G. Nair, "Compact broadband microstrip antenna", *Elect. Letters*, vol. 22, no. 20, pp. 1064-1065, Sept. 1986.
4. H. Entschladen and U. Nagel, "Microstrip patch array antenna", *Elect. Letters*, vol. 20, pp. 931-933, 1984.



5. C.M. Krowne, "E-plane coupling between two rectangular microstrip antennas", *Elect. Letters*, vol. 16, no. 16, pp. 635-636, July 1980.
6. C.M. Krowne, "Dielectric and width effect on H-plane and E-plane coupling between rectangular microstrip antennas", *IEEE Trans. Antennas Propagat.*, vol. AP-31, no. 1, pp. 39-47, Jan. 1983.
7. G. Kumar and K.C. Gupta, "Broad-band microstrip antennas using additional resonators gap-coupled to the radiating edges", *IEEE Trans. Antennas Propagat.*, vol. AP-32, no. 12, pp. 1375-1379, Dec. 1984.
8. G. Kumar and K.C. Gupta, "Nonradiating edges and four edges gap-coupled multiple resonator broad-band microstrip antennas", *IEEE Antennas Propagat.*, vol. AP-33, no. 2, pp. 173-178, Feb. 1985.
9. C. Wood, "Improved bandwidth of microstrip antennas using parasitic elements", *IEE Proc. Pt. H*, vol. 127, no. 4, pp. 231-234, Aug. 1980.
10. Jae Pyo Hong, Young Ki Cho, and Hyon Son, "New radiating Edges-Coupling (REC) model for the gap between two rectangular microstrip patch antennas", *Journal of KITE*, vol. 26, no.2, Feb. 1989.
11. Jae Pyo Hong, Young Ki Cho, and Hyon Son, "Improved method for radiation admittance of a rectangular microstrip patch antenna", *Journal of KITE*, vol. 26, no.2, pp. 35-40, Feb. 1989.
12. Jae Pyo Hong, Young Ki Cho, and Hyon Son, "Radiation admittance calculation of the rectangular microstrip antenna", *KITE conference at Kyunghee University in Soowon*, pp. 430-432, July 1988.
13. D.L. Sengupta, "Approximate expression for the resonant frequency of a rectangular patch antenna", *Elect. Letters*, vol. 19, no. 20, pp. 834-835, Sept. 1983.
14. R.E. Collin, *Foundations for Microwave Engineering*, McGraw-Hill, 1966.
15. Jae Pyo Hong, Young Ki Cho, and Hyon Son, "Analysis of the rectangular microstrip antenna with parasitic element", *KITE conference at Kyunghee university in Soowon*, pp. 433-434, July 1988.



洪在杓(Jae Pyo HONG) 正會員  
 1958年 8月17日生  
 1981年 2月: 慶北大學校 電子工學科 卒業  
 1983年 2月: 慶北大學校 大學院 卒業 (工學碩士)  
 1988年 2月: 慶北大學校 大學院 卒業 (工學博士)  
 1983年 4月~1986年 8月: 慶北大學校助教

1989年 9月~現在: 順天工業專門大學 專任講師



趙榮基(Young Ki CHO) 正會員  
 1954年 9月12日生  
 1978年 2月: 서울大學校 電子工學科 卒業  
 1978年 : 大榮電子 開發室勤務  
 1981年 8月: 韓國科學院 卒業(工學碩士)  
 1981年 9月~現在: 慶北大學校電子工學科 助教授



孫 鉉(Hyon SON) 正會員  
 1935年 5月27日生  
 1960年 9月: 延世大學校 電氣科 卒業  
 1972年 8月: 漢陽大學校 大學院 卒業  
 1960年 9月~1977年 4月: 駐韓美陸軍戰略通信大 勤務  
 1977年 4月~現在: 慶北大學校 電子工學科 副教授(工學博士)