論文 89-26-2-5

Improved Method for Calculating Radiation Admittance of a Rectangular Microstrip Patch Antenna

(구형 마이크로스트립 안테나의 개선된 복사 어드미턴스 계산방법)

洪 在 杓,* 趙 榮 基,* 孫 鉉*

(Jae Pyo Hong, Young Ki Cho and Hyon Son)

要 約

본 논문에서는 균일한 유전체로 채워져 있고 윗면에 슬릿이 있는 평행평판 도파로의 π-등가회로로부터 구형 마이크로스트립 안테나의 복사 컨덕턴스와 서셉턴스를 동시에 구하는 새로운 방법을 제시하였다. 계산된 결과를 기존의 이론치와 비교하였다. 또한 등가전송선로를 이용하여 반사손실(return loss) 및 공진주파수를 계산하여 실험치와 비교한 결과 양호한 특성을 얻었다.

Abstract

In this paper, a new method which simultaneously gives the radiation conductance and susceptance of the rectangular microstrip patch antenna. This solution is derived from the load admittance of the equivalent π-network circuit of the slitted parallel-plate waveguide filled with homogeneous dielectric. Our theoretical results for the radiation admittance are compared with other theoretical results. Also, our theoretical return loss and resonant frequency which are calculated by use of the equivalent transmission line model are in fairly good agreement with the experimental results.

I. Introduction

Microstrip antennas have the advantage of small size, light weight, ease of construction, and compatability with solid-state microwave devices. As practical applications of microstrip antenna increase, the need for more exact solutions is growing. Although several approximate expressions for the radiation admittance of a rectangular microstrip patch antenna have been described by several authors, no rigorous expressions have been found yet. The aperture admittance for a parallel-plate waveguide into a half space[1] is commonly used as the radiation admittance of the rectangular microstrip patch antenna. Derneryd[2] and Bahl[3] analyzed the radiation admittance using the aperture theory and concept of the line extension $\Delta\ell$. Recently, Sengupta[4] obtained the radiation admittance by use of the image principle

*正會員, 慶北大學校 電子工學科

(Dept. of Elec. Eng., Kyungpook Nat'l Univ.)

接受日字 : 1988年 8月 9日

and the results for a semi-infinite parallel-plate waveguide radiating into free space.

In this paper, a new method is presented which simultaneously gives the radiation conductance and susceptance of the rectangular microstrip patch antenna. These calculations are derived from the equivalent π-network circuit [5],[6] of the slitted parallel-plate waveguide filled with homogeneous dielectric. Our computed results for the radiation admittance are compared with other theoretical solutions. Also, from the knowledge of the radiation admittance, return loss is calculated and compared with the measured result. Here the antenna is fabricated in Teflon substrate with relative dielectric constant ϵ_r=2.6 and thickness h=0.155cm. The experimental results are in fairly good agreement with the calculated results.

II. Calculation of Radiation Admittance

The geometry of the slitted parallel-plate waveguide filled with homogeneous dielectric is shown in Fig.1(a), where the slit width 2a is parallel to Y axis and the waveguide height is h.

When only a TEM wave whose electric field component has +X direction can propagate along +Z direction, the slitted parallel-plate waveguide shown in Fig.1(a) is represented by the equivalent π-network circuit [5],[6] shown in Fig.1(b).

In Fib.1(b), the TEM magnetic field reflection coefficient Γ_H is defined as the ratio of reflected to incident magnetic field at a reference plane located at z=-a, and the transmission coefficient T_H as the ratio of transmitted field at z=+a to incident field at the reference. Therefore Γ_H and T_H can be written as[5],[6]

$$\Gamma_H = \frac{H_{yI.ref}(z)\,|_{z=-a}}{H_{yI.inc}(z)\,|_{z=-a}} \qquad (1)$$

$$T_H = \frac{H_{yI.tran}(z)\,|_{z=+a}}{H_{yI.inc}(z)\,|_{z=-a}} \qquad (2)$$

where $H_{yI.ref}(z)$, $H_{yI.tnc}(z)$, and $H_{yI.tran}(z)$ are incident, reflected, and transmitted magnetic field in the region I, respectively.

The normalized series admittance $\bar{Y}_1$, shunt admittance $\bar{Y}_2$, and load admittance $\bar{Y}_L$ of the equivalent π-network circuit are given by the following expressions[5],[6] in terms of the coefficients Γ_H and T_H:

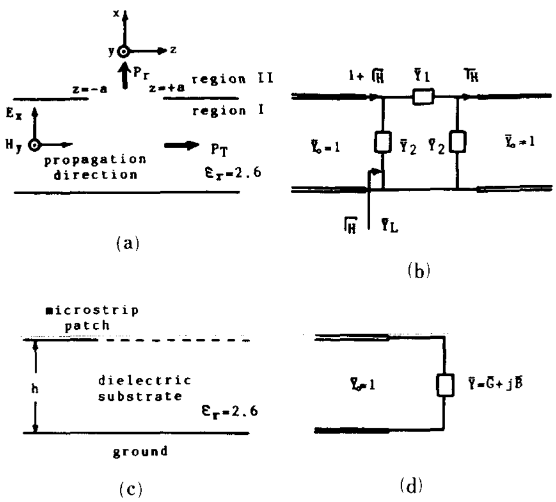


Fig.1. (a) Geometry of a slitted parallel-plate waveguide filled with homogeneous dielectric.
(b) Equivalent π-network.
(c) Reduced geometry of a radiating edge.
(d) Equivalent circuit of the radiating edge in Fig.1(c).

$$\bar{Y}_1 = \bar{G}_1 + j\,\bar{B}_1 = \frac{(\bar{Y}_2+1)\;(\bar{Y}_L-\bar{Y}_2)}{2\bar{Y}_2+1-\bar{Y}_L} \qquad (3)$$

$$\bar{Y}_2 = \bar{G}_2 + j\,\bar{B}_2 = \frac{1+\Gamma_H-T_H}{1-\Gamma_H+T_H} \qquad (4)$$

$$\bar{Y}_L = \bar{G}_L + j\,\bar{B}_L = \frac{1+\Gamma_H}{1-\Gamma_H} \qquad (5)$$

In Fig.1(a), 1(b), it was found[5],[6] that:

1) for ka>0.1, the normalized load conductance $\bar{G}_L$ and susceptance $\bar{B}_L$ are constant, independently of the slit width, and $\bar{G}_L$ is almost the same as $\bar{G}_1$ for ka<0.2. Here k is the propagation constant of the free space.
2) for ka<0.2, i.e., narrow slit width, $\bar{G}_1$ is identical to the normalized radiation conductance of the microstrip radiating edge calculated by the method of Bahl[3].

When the ratio of the normalized transmitted power P_T to the normalized radiated power P_r approaches to an extremely small value, i.e., one percent, then the slit width 2a is equivalent to about $0.56\lambda_g$[7]. Here λ_g is the wavelength in the waveguide. In this case, the transmitted power is nearly negligible so that the geometry of the slitted parallel-plate waveguide shown in Fig.1(a) reduces to the geometry with the upper plate removed beyond z=+a in Fig.1(a), as shown in Fig.1(c). Therefore the load admittance in Fig.1(b) can be interpreted physically as the radiation admittance of the edge in Fig.1(d). In addition it has been well taken that two dimensional parallel-plate result is valid for the rectangular microstrip patch application. From the load admittance discussed aobve, we obtain the radiation admittance of the rectangular microstrip patch antenna.

III. Theoretical and Experimental Results

1. Radiation Admittance

Fig.2 shows the geometry of the rectangular microstrip patch antenna fed by a 50-Ω microstrip line, where the feed point location is X. The substrate used here is copper-clad 'CGP-512' with a dielectric constant of 2.6. The antenna dimensions are listed in Table 1.

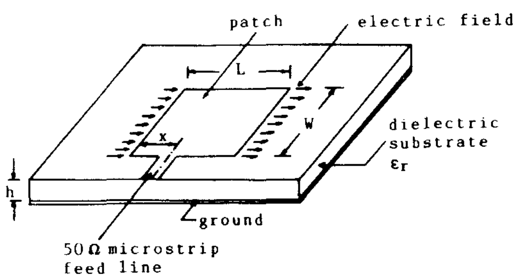


Fig.2. Geometry of a rectangular microstrip patch antenna.

Table 1. Specification of a rectangular microstrip patch antenna.

Width W [cm]	Length L [cm]	Dielectric constant ϵ_r	Substrate thickness h [cm]
3.7	3.02	2.6	0.155

Teflon substrate : CGP-512

For the antenna given in Table 1, the radiation admittance computed by using the present method is compared with the theoretical results by the method of Harrington[1], Derneryd[2], and Sengupta[4] at 3GHz, respectively. Comparative results are given in Table 2. Our theoretical radiation admittance Y ($Y=\bar{Y}\cdot Yo$: Yo denotes the characteristic admittance), as mentioned in section II, is given by the load admittance Y_L in the region of ka>0.1.

Table 2. Comparision of the radiation admittance for the antenna specified in Table 1 at 3GHz.

Method	Radiation conductance G [mho]	Radiation susceptance B [mho]
Harrington[1]	0.3082×10^{-2}	0.7648×10^{-2}
Derneryd[2]	0.1359×10^{-2}	0.8829×10^{-2}
Sengupta[4]	0.3083×10^{-2}	0.9009×10^{-2}
Ours	0.3259×10^{-2}	1.4597×10^{-2}

As shown in Table 2, our computed radiation conductance is almost the same as Harrington's[1] and Sengupta's[4] theoretical results except for Derneryd's[2] theoretical result. But our computed radiation susceptance is much greater than other theoretical values[1],[2],[4].

In order to confirm the validity of our results for the radiation admittance, the theoretical results of the present method are compared with Chang's results[8] obtained by the Wiener-Hopf techniques and with Sengupta's results[4].

Fig.3 shows that the normalized radiation conductance $\bar{G}$ and susceptance $\bar{B}$ are plotted as a function of kh for ϵ_r=2.56. In Fig.3, our results for $\bar{G}$ and $\bar{B}$ are in agreement with the theoretical results of Chang's[8], respectively. Also, it is observed that our normalized susceptance and Chang's values are much greater than Sengupta's theoretical values.

2. Feed Point

The rectangular microstrip patch antenna shown in Fig.2 is represented by the equivalent transmission line model, as shown in Fig.4. Here X is a 50-Ω microstrip line feed point location. Y_o is the characteristic admittance of the microstrip patch. Y_{in} and Y are the input admittance

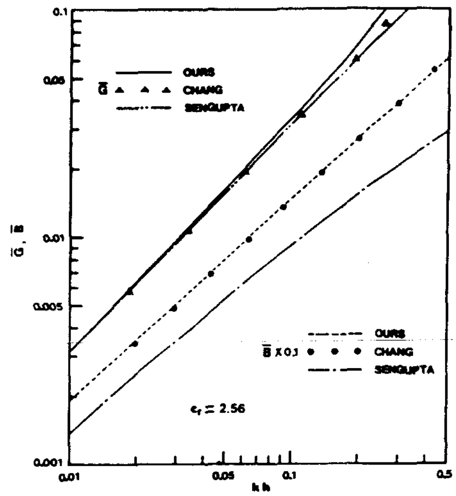


Fig.3. Normalized radiation admittance as a function of dimensionless thickness kh.

$$Y_o = \frac{W\,\alpha\,\sqrt{\epsilon_{eff}}}{\eta_o h} \qquad (7)$$

where

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

$$\alpha = 1 + 1.393\frac{h}{W} + 0.667\frac{h}{W}\,\ell_n\left[\frac{W}{h} + 1.444\right]$$

and η_o is the intrinsic impedance of the free space.

From (6) and (7), it is seen that the input admittance of the antenna varies with the feed point location. Therefore, the feed point should be accurately chosen so as to provide a good match between the antenna and the feed line. A 50-Ω microstrip line feed point location can be determined by the input admittance locus for the feed point location.

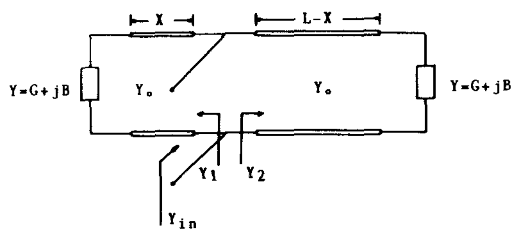


Fig.4. Equivalent circuit of the rectangular microstrip patch antenna.

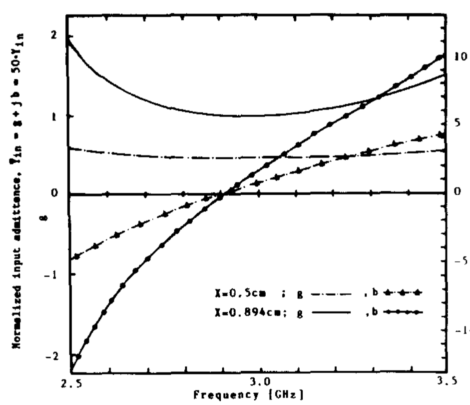


Fig.5. Normalized input admittance loci as a function of frequency for X=0.5cm and X=0.894cm.

and the radiation admittance of the rectangular microstrip patch antenna, respectively.

In Fig.4 the input admittance of the antenna Y_{in} is calculated by

$$Y_{in} = Y_1 + Y_2$$
$$= Y_o\frac{Y + jY_o\tan\beta X}{Y_o + jY\tan\beta X} + Y_o\frac{Y + jY_o\tan\beta(L-X)}{Y_o + jY\tan\beta(L-X)} \qquad (6)$$

where $\beta = \frac{2\pi}{\lambda_o}\sqrt{\epsilon_{eff}}$ is the propagation constant of the transmission line, λ_o is the free space wavelength, and ϵ_{eff} is the effective dielectric constant.

The characteristic admittance Y_o [9] of the rectangular microstrip patch antenna is given by

Fig.5 shows the input admittance loci normalized to 50 Ω, i.e., $\overline{Y}_{in}$=g + jb=50·Yin, as a function of frequency for different feed point location, 0.5 and 0.894cm, respectively. Here the detailed specification of this antenna is given in Table 1. It is observed that for the case of 0.894cm, when g=1, the frequency where the imaginary part of the normalized input admittance is nearly zero exists. This implies that for X= 0.894cm, the input admittance of the antenna is equal to the characteristic admittance of the feed line at the frequency. Also, in Fig.5 the resonant frequency is observed to be 2.910 GHz.

3. Return Loss

The return loss RL is defined as

$$RL = 20 \log |\Gamma_{in}| = 20 \log \left| \frac{1-\bar{Y}_{in}}{1+\bar{Y}_{in}} \right| \qquad (8)$$

where Γ in is the input reflection coefficient of the rectangular microstrip patch antenna.

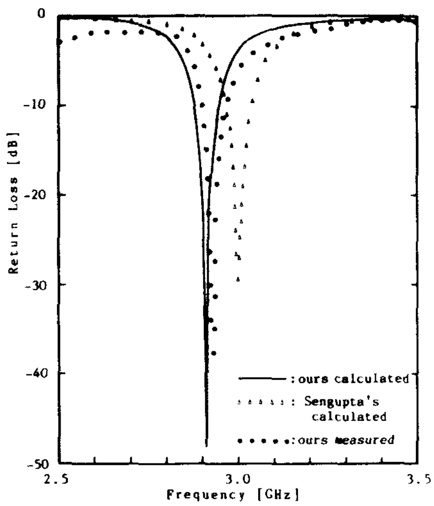


Fig.6. Measured and computed return losses as a function of frequency for the antenna specified in Table 1 at X=0.894cm.

In Fig.6, the computed and measured return losses are illustrated and compared with the theoretical results by the method of Sengupta[4]. The detailed specification of the antenna is given in Table 1. The feed point location proved to be 0.894cm. As shown in Fig.6, the experimental results are in better agreement with our theoretical results than Sengupta's theoretical results. Also, it is observed in Fig.6 that our computed and measured resonant frequency of the rectangular microstrip patch antenna are 2.910 and 2.937GHz, respectively, whereas the Sengupta's theoretical value is 3.000GHz. Therefore, the frequency discrepancy between our measured and calculated resonant frequency is smaller than that between our measured and the Sengupta's theoretical value.

4. Resonant Frequency

From the resonant condition: Im(Yin)=0, the resonant frequency f_0 of the rectangular microstrip patch antenna can be obtained by use of the following expression in terms of the radiation admittance:

$$\tan\left(\frac{2\pi f_0 L}{c}\sqrt{\epsilon_{eff}}\right) = \frac{2BY_0}{B^2+G^2-Y_0^2} \qquad (9)$$

where c is the light velocity of the free space.

For the comparision of the resonant frequency of the rectangular microstrip patch antenna for various values of W, our theoretical results, Sengupta's computed results[4] and the experimental results reported in [10] are shown in Table 3, from which the experimental results[10] are seen to be in better agreement with our computed values than Sengupta's calculated values[4].

Table 3. Calculated and measured values of the resonant frequency for rectangular microstrip patch antennas.

Width W [cm]	Length L [cm]	Resonant frequency, f_0[MHz]		
		Measured	Calculated	
		Howell[10]	Sengupta[4]	Ours
4.100	4.140	2228	2248	2200
6.858	4.140	2200	2228	2179
10.800	4.140	2181	2216	2166

$h=0.1524cm$, $\epsilon_r=2.5$

IV. Conlusion

This paper presents a new method which simultaneously gives the radiation conductance and susceptance of the rectangular microstrip patch antenna. This solution is derived from the load admittance of the equivalent π-network of the slitted parallel-plate waveguide filled with homogeneous dielectric. Our theoretical results for the radiation admittance are compared with other theoretical results. Also, applying the radiation admittance in the equivalent transmission line model, we observed that our theoretical return loss and resonant frequency are in fairly good agreement with the experimental results. Further, it is concluded that these are more accurate than previous theoretical results[1]-[4].

References

[1] R.F. Harrington, Time-Harmonic Electromagnetic Fields, New York: McGraw-Hill, 1961.

[2] A.G. Derneryd, "Linearly polarized microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-24, no. 6, pp. 846-851, Nov. 1976.

[3] I.J. Bahl, "Build microstrip antennas with paper-thin dimensions," Microwaves, vol. 18, pp. 50-63, Oct. 1979.

[4] 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.

[5] Seung Gak Kim and Young Ki Cho, et al., "Equivalent circuit description for a parallel-plate waveguide with a transverse slit in its upper plate," *Journal of KITE,* vol. 25, no. 4, pp.11-16, Apr. 1988.

[6] 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.

[7] Young Ki Cho, "On the equivalent circuit representation of the slitted parallel-plate waveguide filled with a dielectric," *to be published IEEE Trans. Antennas Propaga., in future issue.*

[8] D.C. Chang, "Analytical theory of an unloaded rectangular microstrip patch," *IEEE Trans. Antennas Propagat,* vol. AP-29, no. 1, pp. 54-60, Jan. 1981.

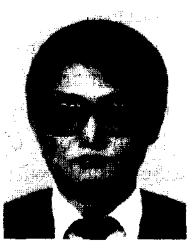
[9] T.C. Edwards, Foundations for Microstrip Circuit Design, Chichester: John Wiley & Sons, 1981.

[10] J.Q. Howell, "Microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-23, no. 1, pp. 90-93, Jan. 1975. *

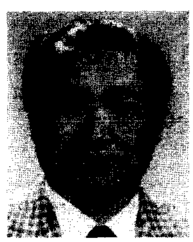
著 者 紹 介

洪 在 杓(正會員)
1958年 8月 17日生. 1981年 2月 경북대학교 전자공학과 졸업. 1983年 2月 경북대학교 대학원 전자공학과 졸업 공학석사학위 취득. 1983年 3月 경북대학교 대학원 박사과정 입학. 1983年 3月～1986年 8月 경북대학교 조교. 1986年 9月～현재 순천공업전문대학 전자과 전임강사. 주관심분야는 마이크로파 및 안테나공학 등임.

●



趙 榮 基(正會員)
1954年 9月 12日生. 1978年 2月 서울대학교 전자공학과 졸업. 1981年 8月 한국과학기술원 전기 및 전자공학과 공학석사학위 취득. 1981年 9月～현재 경북대학교 전자공학과 조교수. 주관심분야는안테나 이론 및 마이크로파공학 등임.



孫 鉉(正會員)
1935年 5月 27日生. 1960年 8月 연세대학교 전기과 졸업. 1984年 8月 경희대학교 대학원전자과 공학박사학위 취득. 1960年 9月～1977年 4月 주한 미육군 전략통신단 대구지역 기술부장역임. 1985年 3月～1987年 8月 한국통신학회 대구경북 지부장역임. 1977年 4月～현재 경북대학교 전자과 재직중. 주관심분야는 마이크로파 및 안테나공학 등임.