Wide-Band T-Shaped Microstrip-Fed Twin-Slot Array Antenna

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A numerical simulation and an experimental implementation of T-shaped microstrip-fed printed slot array antenna are presented in this paper. The proposed antenna with relative permittivity 4.3 and thickness 1.0mm is analyzed by the finite-difference time-domain (FDTD) method. The dependence of design parameters on the bandwidth characteristics is investigated. The measured bandwidth of twin-slot array antenna is from 1.37 GHz to 2.388 GHz, which is approximately 53.9 % for return loss less than or equal to -10 dB. The bandwidth of twin-slot is about 1.06 % larger than that of single-slot antenna. The measured results are in good agreement with the FDTD results.

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I. INTRODUCTION

As microwave equipments require low profile and lightweight to assure reliability, an antenna with these characteristics is essentially required and a microstrip antenna satisfies such requirement. Microstrip antennas have conformal structure, low cost, and ease of integration with solid-state devices as well as low profile and lightweight. But the microstrip antennas have a narrow bandwidth which is about 10-20 %. In the last decade, many researchers have studied the bandwidth widening technique of microstrip antennas [1]-[3]. A popular method is the use of parasitic patches, either in another layer (stacked geometry) [4] or in the same layer (coplanar geometry). However, the stacked geometry has the disadvantage of increasing the thickness of the antenna, and the coplanar geometry has the disadvantage of increasing the lateral size of the antenna [5]. Most microstrip-fed structures of the printed slot antenna have been used by making the microstrip-fed structures [5] across the center of slot [7], [8]. The conventional center-fed transverse slot antennas have a large value of radiation impedance, so that it is very difficult to match in practice. To solve these problems, short-tuning and open-tuning stubs which offset from the center of a slot to the end were proposed [9]. Narrow slot width is good for impedance matching [10] but with wide slot width, a special matching circuit at the feeding port is needed for good impedance matching.

This paper presents the characteristics of single-slot and twin-slot antennas with T-shaped feed line. A T-shaped microstrip feed line is proposed to match the input impedance for narrow as well as wide slot antennas. When the T-shaped feed line is used, we can extend the bandwidth in proportion to the slot width. In this case, the proposed antenna leads to the impedance matching in a wide frequency band. I also analyzed the excited slot antenna with T-shaped feed line using finite-difference time-domain (FDTD) method and calculated return loss by transforming the time domain results to the frequency domain. The design of a T-shaped microstrip-fed, twin-slot antenna for a broad bandwidth was optimized by FDTD method. The optimal feeding position for good impedance matching was determined through a full-wave analysis using the FDTD method. With these optimal parameters, the proposed antenna was fabricated and measured.

II. FDTD FORMULATION

FDTD method is formulated by discretizing Maxwell's curl equations over a finite volume and approximating the derivatives with central difference approximations. These FDTD approximate equations contain the second order error in both the space and time steps. According to the Yee's notation [11], the space point in the FDTD cell is denoted by (iΔx, jΔy, kΔz), the time increment by nΔt, and the arbitrary function by F(iΔx, jΔy, kΔz, nΔt). In analyzing the microstrip slot antenna design [10], we applied Mur's absorbing boundary condition [12].

The response value of the frequency domain can be calculated by Fourier-transforming the time domain value [13]. As the microstrip feed-line is an open stub, the microstrip antenna is a 1-port circuit. So the reflection coefficient S_{11} of the microstrip antenna is

$$S_{11} = \frac{F[V_1^{ref(t)}]}{F[V_1^{inc(t)}]}, \tag{1}$$

where $V_1^{ref(t)}$ is a reflected voltage, $V_1^{inc(t)}$ is an incident voltage, and F is a Fourier transform notation. From the calculated reflection coefficient, voltage standing wave ratio (VSWR) can be calculated as

$$\text{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1+|S_{11}(w)|}{1-|S_{11}(w)|}. \tag{2}$$

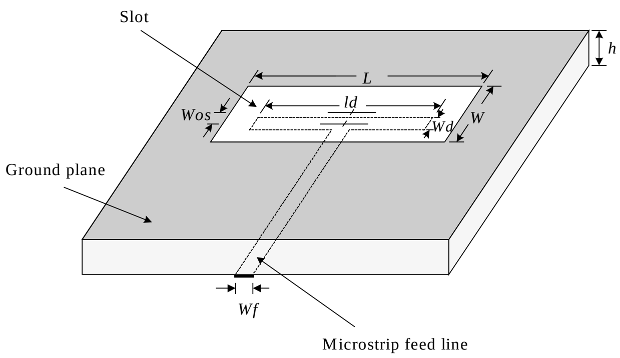
The percent bandwidth of the antennas was determined from the impedance data. For ease of notion, the term bandwidth refers to percent bandwidth unless otherwise specified. Bandwidth is normally defined as

$$percent\ \ \text{BW} = [(f_{r2} - f_{r1})/f_r] \times 100, \tag{3}$$

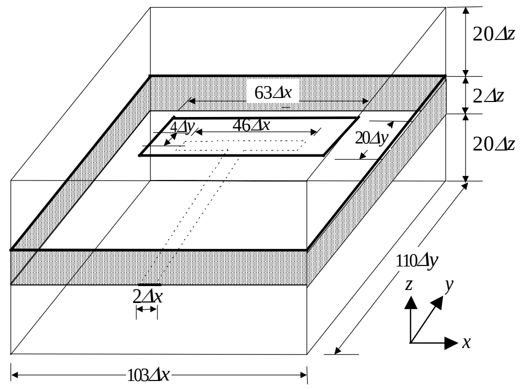
where f_r is the resonance frequency, while f_{r1} and f_{r2} are the frequencies between which reflection coefficient of the antenna is less than or equal to 1/3, which corresponds to VSWR≤ 2. At the far-field area, the electric field can be calculated as follows:

$$E_\Phi = \frac{-jke^{-jkr}}{4\pi\gamma} E_m WLF(\theta,\phi)\cdot \tag{4}$$

where k is the propagation constant, E_m is the electric field at the slot, W is slot width, and L is slot length.



(a) Geometry and design parameters



(b) FDTD analysis structure

Fig. 1. One-element microstrip slot antenna with T-shaped feed line.

III. NUMERICAL RESULTS

The geometry and FDTD analysis structure of single-slot microstrip antenna are shown in Figs. 1(a) and 1(b), respectively. The geometry structure of twin-slot microstrip array antenna is shown in Fig. 2. This antenna is designed by adding three open stubs to microstrip line. The relative permittivity of the substrate is 4.3 and the thickness of the substrate is 1.0 mm. Where L is slot length, W is slot width, l_d is horizontal component length, W_{os}*(offset)* is the interval between slot center and horizontal component feed-line center, W_d is the width of horizontal feed line, and W_f is the width of feed-line. To analyze

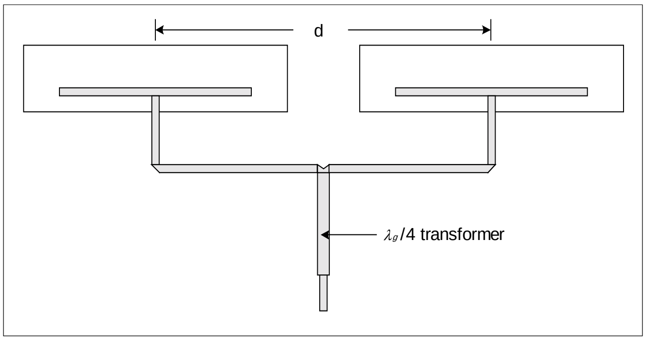


Fig.2. Geometry and design parameters of twin-slot antenna with T-shaped feed line.

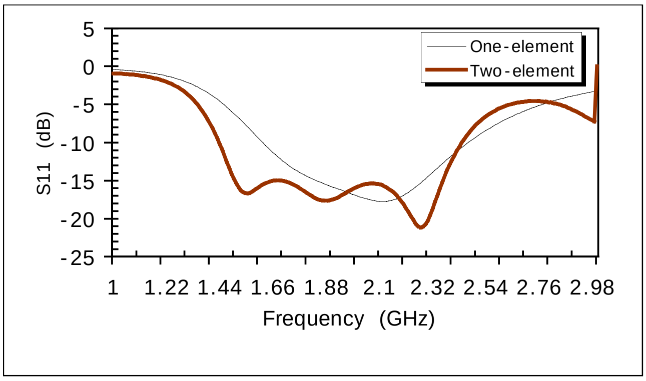


Fig. 3. Comparison of calculated return losses of one-element and two-element slot antennas.

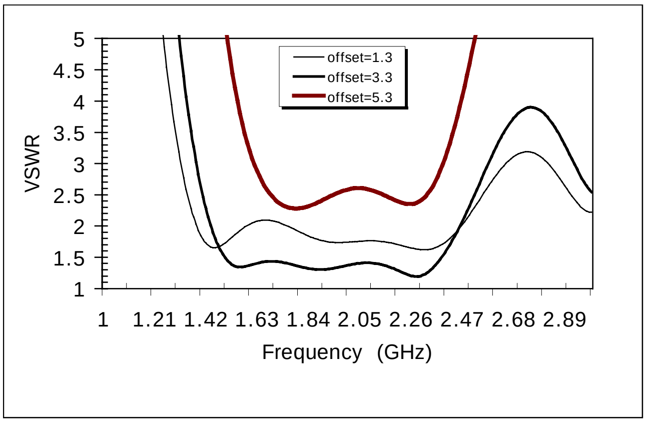


Fig. 4. Calculated VSWR of twin-slot microstrip array antenna as a function of offset length.

the antenna correctly, Δx and Δy are chosen so that an integral number of nodes fit the feed-line and slot exactly. Δz is chosen so that an integral number of nodes fits the thickness *h* of the substrate exactly.

The spatial step sizes used are Δx =0.97 mm, Δy =0.82 mm and Δz = 0.50 mm. The thickness of substrate, h, is $1\Delta x$; the length of slot, *L*, is $65\Delta x$; the width of slot, *W*, is $16\Delta y$; the length of horizontal component feed-line, l_d, is $46\Delta x$; and the, W_{os}*(offset)*, the length of horizontal component feed-line center interval from slot center is $4\Delta y$. To calculate the far-field pattern, 20 free space mesh cells are added to the top and bottom of substrate. The total mesh dimensions of single-slot antenna are $103\Delta x \times 110\Delta y \times 42\Delta z$ and those of twin-slot antenna are $230\Delta x \times 121\Delta y \times 42\Delta z$. One time step is 1.9ps. The antenna is excited by a Gaussian pulse just underneath the dielectric interface. The pulse width is 32 time steps. In order to calculate the input S-parameter for the antenna, a standard technique of time-stepping the signal on the microstrip line is used to separate the incident and reflected waveform. From Fourier transforms of these waveforms, the required S-parameters are obtained. The simulation continues until energy traveling back toward the source from the resonant cavity subsides to a negligible level. Stopping the run results in ripple on the calculated S-parameters.

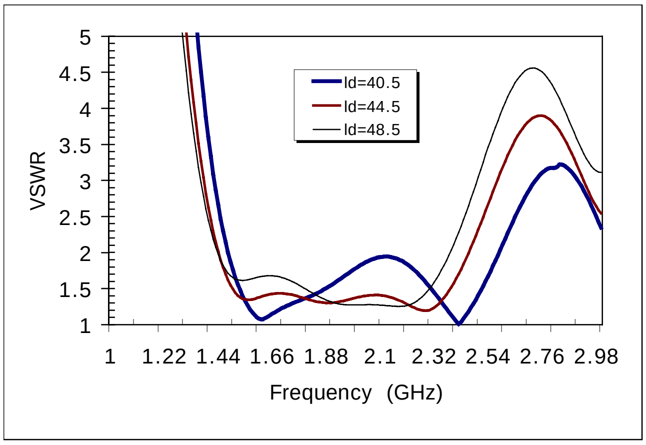


Fig. 5. Calculated VSWR of twin-slot microstrip array antenna as a function of the horizontal component feed-line length (l_d).

Figure 3 shows the comparison of calculated return loss of single-slot with that of twin-slot antenna. A frequency is usable if the return loss of antenna is less than -10 dB. In a single-slot antenna, the usable frequency band is from 1.58 GHz to 2.38 GHz, which gives 0.80GHz of bandwidth; in twin-slot array antenna, the usable frequency band is from 1.47 GHz to 2.47 GHz as shown in Fig. 3, and the bandwidth is 1.00 GHz, accordingly. The bandwidth of the twin-slot is 0.20 GHz wider than that of the single-slot antenna.

Figure 4 shows the calculated VSWR of twin-slot array antenna as a function of offset length. When the offsets are 1.3 mm and 3.3 mm, the bandwidths are about 1.09 GHz and 1.01

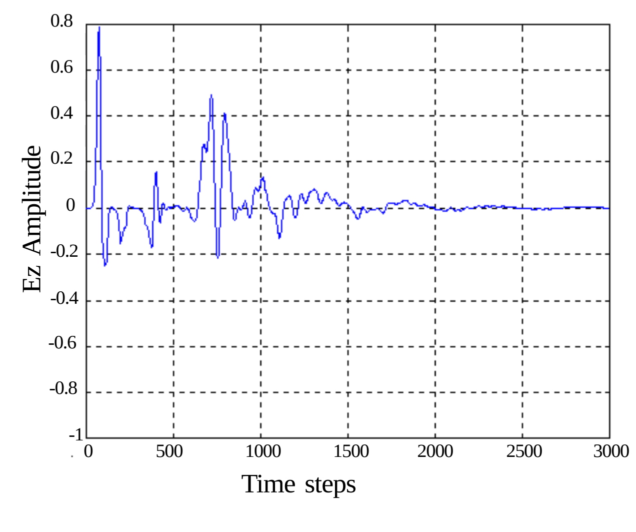


Fig. 6. Total waveform on the time-steps (two-slots array antenna).

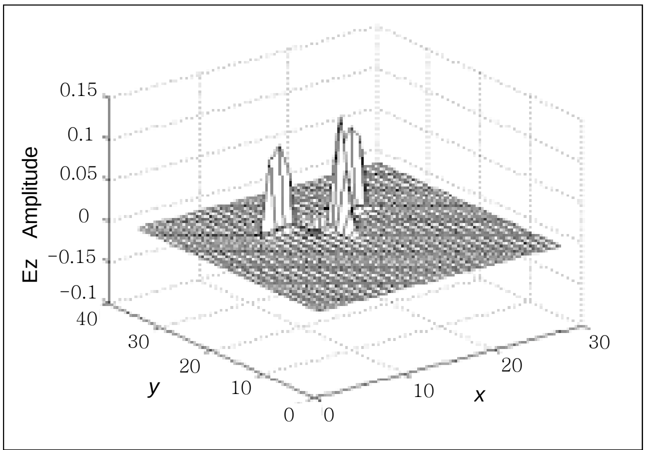


Fig. 7. Ez(x, y, t) distribution of one-element microstrip slot antenna just underneath the dielectric interface at 1000th timestep.

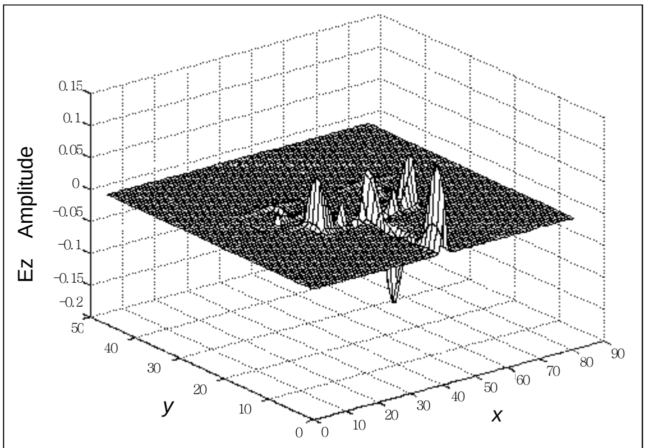


Fig. 8. Ez(x, y, t) distribution of two-element microstrip slot array antenna just underneath the dielectric interface at 1000th time step.

GHz, respectively.

Figure 5 shows the calculated VSWR of twin-slot array antenna as a function of the horizontal component feed-line length, l_d, where all other parameters are set to the fundamental values. When l_d is 35 mm, the bandwidth is about 1.08 GHz, when l_d is 31 mm, the bandwidth is about 1.08 GHz, and when l_d is 27 mm, the bandwidth is about 1.05 GHz.

The total waveform of two-slot array antenna versus the time steps is shown in Fig. 6. Figure 7 shows $E_z(x, y, t)$ distribution of the single-slot microstrip antenna just underneath the dielectric interface at 1000th time step. Figure 8 shows $E_z(x,y,t)$ distribution of the twin-slot array antenna measured at the same environment.

IV. EXPERIMENTAL RESULTS

The proposed antenna was fabricated using FR-4 substrate whose relative permittivity, ε_r , is 4.3 and the thickness, *h*, is 1.0 mm. The ground plane size of twin-slot array antenna is 230 mm × 120 mm. Measurement was made on the HP8510B network analyzer.

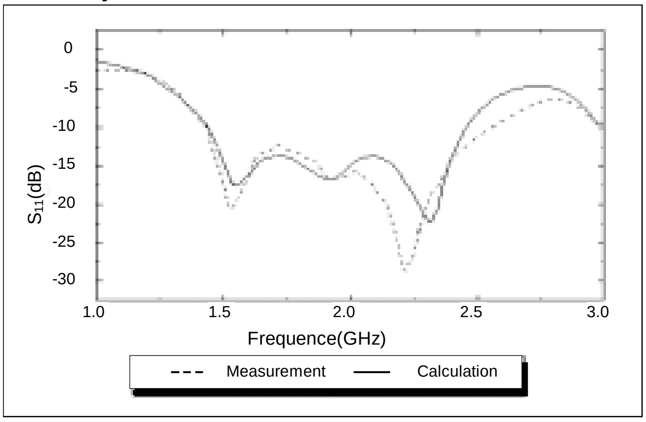


Fig. 9. Comparison of measured and calculated return losses of the twin-slot antenna.

In Fig. 9, the measured and calculated return losses of the twin-slot antenna are compared. The measured result is in good agreement with the FDTD result. The measured bandwidth of the antenna is from 1.37 GHz to 2.388 GHz, which is approximately 53.9 % ($S_{11} \leq$ -10 dB) at the center frequency 1.89 GHz. The resonance frequencies are 1.6 GHz with return loss of 22.3 dB and 2.2 GHz with 28.5 dB, respectively. The measured bandwidth (54%) is wider than the simulated result (52.9 %).

Figure 10 shows the impedance locus of the twin slot microstrip antenna exhibiting three-looped characteristic, which is in contrast with the conventional microstrip-fed structure slot

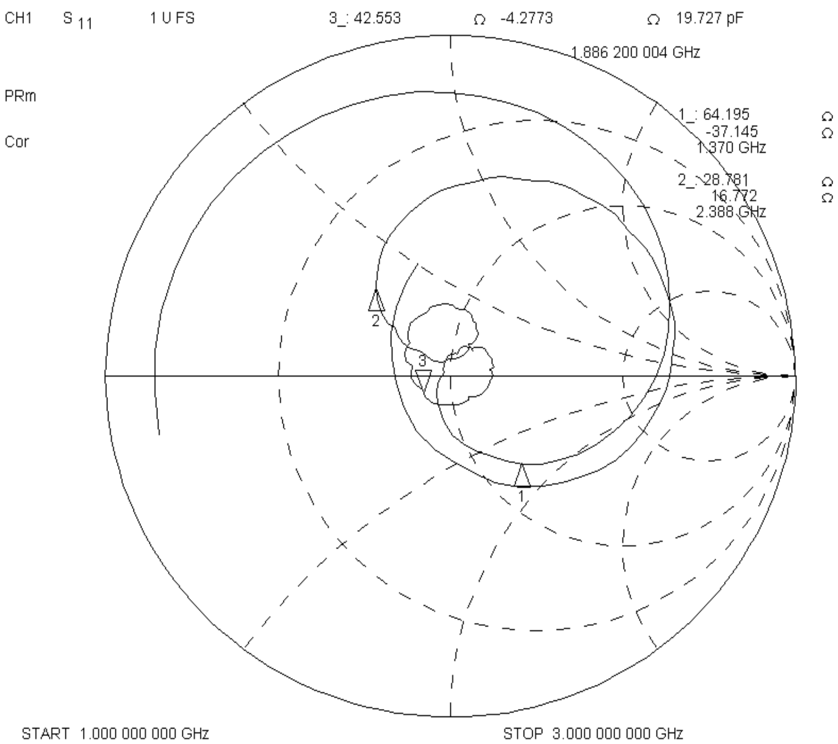


Fig. 10. Measured input impedance of the twin-slot antenna.

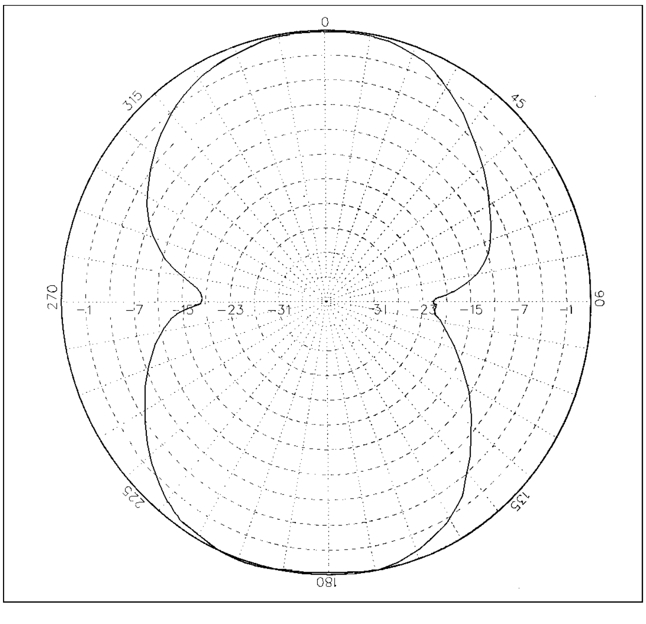


Fig. 11. Measured radiation pattern of the twin-slot antenna in x-z plane.

antenna [7]-[10]. Figure 11 presents the experimental radiation pattern of x-z plane at f=1.89 GHz. After the calibration using a horn antenna, we measured the radiation pattern at the far field. The beam width of twin-slot array antenna was measured to be approximately 66 degrees.

V. CONCLUSION

In this paper, the characteristics of the wide-band microstrip slot antenna are investigated by using the FDTD method. I fabricate and test the twin-slot slot array antenna, which shows good impedance matching in wide frequency band. The measured bandwidth of the proposed twin-slot antenna is from 1.37 GHz to 2.388 GHz, which is approximately 53.9 %.

As this antenna has wide bandwidth, low profile and lightweight, it may find applications in PCS, IMT-2000, mobile communications, satellite communication, and wide-band communication system, and so on.

REFERENCES

[1] S. H. David, “A survey of broadband microstrip patch antennas,” *Microwave J.*, Sep. 1996, pp. 60-84.

[2] A. Sangiovanni, J.Y. Dauvignac and C. Pichot, ” Embedded dielectric antenna for bandwidth enhancement,” *Electronics Letters*, Vol.33, No.25, Dec. 1997, pp. 2090-2091.

[3] Zhang-Fa Liu, Pang-Shyan Kooi, Le-Wei Li, Mook-Seng Leong, and Tat-Soon Yeo, “A Method for Designing Broad-Band Microstrip Antenna in Multilayered Planar Structures,” *IEEE Trans. Antennas and Propagat*., Vol.47, No. 9, Sep. 1999, pp. 1416-1420.
[4] B.L. Ooi, C.L. Lee, “Broadband air-filled stacked U-slot antenna,” *Electronics Letters*, Vol. 35, No. 7, Apr. 1999, pp. 51-52.
[5] T. M. Au , K.F. Tong and K.M. Luk, “Analysis of offset dual-patch microstrip antenna,” *IEE Proc. Microwave. Antennas Propagat*., Vol.141, No.6, 1994, pp. 523-526.
[6] Bandwidth enhancement of insert-microstrip-line-fed Triangular microstrip antenna,” *Electronics Letters*, Vol.34, No.23, Nov. 1998, pp. 2184-2185.
[7] A. Axelrod, M. Kisliuk and J. Maoz, “Broadband microstrip-fed slot radiator,” *Microwave J*., June 1989, pp. 81-94.
[8] M. Kahrizi, T.K.Sarkar and Z.H.Maricevic, " Analysis of a wide radiating slot in the ground plane of a microstrip line," *IEEE Trans. Microwave Theory Tech*., Vol. MTT-41, Jan. 1993, pp.29-37.
[9] Y. Yoshimura, “A microstrip slot antenna,” *IEEE Trans. Microwave Theory Tech*., Vol. MTT-20, Nov. 1972, pp. 760-762.
[10] D. M. Pozar, “Reciprocity method of analysis for printed slot and slot-coupled microstrip antennas,” *IEEE Trans. Antennas and Propagat.*, Vol. AP-34, Dec. 1986, pp. 1439-1446.
[11] K.S. Kunz, R.J. Luebbers, “The Finite Difference Time Domain Method for Electromagnetics,” *CRC Press, Inc.*, 1993, pp. 11-26.
[12] G. Mur, “Absorbing boundary conditions for the finite difference approximation of the time domain electromagnetic field equations,” *IEEE Trans. Electromag. Compat.*, Vol. EMC-23, Nov. 1981, pp. 377-382.
[13] D. M. Sheen, S. M. Ali, M. D. Abouzahra and J. A. Kong, “Application of the Three-Dimensional Finite-Difference Time Domain Method to the Analysis of Planar Microstrip Circuits,” *IEEE Trans. Microwave Theory and Tech.*, Vol. MTT-38, No.7, Jul. 1990, pp. 849-857.

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