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.

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 im-
pedance 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 an-
tenna 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 ap-
proximate 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 $(i \Delta x, j \Delta y, k \Delta z)$, the
time increment by $n \Delta t$, and the arbitrary function by $F(i \Delta x, j \Delta y,$
$k \Delta z, n \Delta t)$. 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 calcu-
lated 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 micro-
strip antenna is

$$S_{11} = \frac{F[V_{\text{ref}}]}{F[V_{\text{inc}}]}$$

where $V_{\text{ref}}$ is a reflected voltage, $V_{\text{inc}}$ is an incident voltage,
and $F$ is a Fourier transform notation. From the calculated re-
fection coefficient, voltage standing wave ratio (VSWR) can be calculated as

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

The percent bandwidth of the antennas was determined from
the impedance data. For ease of notion, the term bandwidth re-
fers to percent bandwidth unless otherwise specified. Band-
width is normally defined as

$$\text{Percent BW} = \left( \frac{f_2 - f_1}{f_r} \right) \times 100$$

where $f_r$ is the resonance frequency, while $f_1$ and $f_2$ are the frequencies between which reflection coefficient of
the antenna is less than or equal to 1/3, which corresponds to
VSWR $\leq 2$. At the far-field area, the electric field can be cal-
culated as follows:

$$E_\theta = \frac{-jke^{-j\phi}}{4\pi\gamma} E_\phi WLF(\theta, \phi)$$

where $k$ is the propagation constant, $E_\phi$ is the electric field at
the slot, $W$ is slot width, and $L$ is slot length.

![Diagram](image)

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

III. NUMERICAL RESULTS

The geometry and FDTD analysis structure of single-slot mi-
crostrip 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 sub-
strate is 4.3 and the thickness of the substrate is 1.0 mm. Where
$L$ is slot length, $W$ is slot width, $L_2$ is horizontal component
length, $W_{ob}(offset)$ is the interval between slot center and hori-
zontal component feed-line center, $W_d$ is the width of hori-
tzontal feed line, and $W_f$ is the width of feed-line. To analyze
The antenna correctly, \( \Delta x \) and \( \Delta y \) are chosen so that an integral number of nodes fit the feed-line and slot exactly. \( \Delta z \) is chosen so that an integral number of nodes fits the thickness \( h \) of the substrate exactly.

The spatial step sizes used are \( \Delta x = 0.97 \) mm, \( \Delta y = 0.82 \) mm and \( \Delta z = 0.50 \) mm. The thickness of substrate, \( h \), is \( 1.\Delta z \); 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, \( W_{\text{os}}(\text{offset}) \), 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.

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 the horizontal component feed-line length \( (l_d) \).
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, $\varepsilon_r$, is 4.3 and the thickness, $h$, is 1.0 mm. The ground plane size of twin-slot array antenna is 230 mm $\times$ 120 mm. Measurement was made on the HP8510B network analyzer.

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 GHz, respectively.
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


Yong-Woong Jang received the B.S. and the M.S. degrees from Myongji University, Seoul, Korea, in 1989 and 1991, respectively, and the Ph.D. degree from Ajou University, Suwon, Korea, in 1999, all in electronics engineering. Since 1994, he joined the Department of Electronics & Communication Engineering at College of Keukdong, Eumsung, Korea, as a faculty member, where he is now an associate professor. His research interests include antennas, RF systems, and numerical methods in solving electromagnetic problems.