A 4-by-4 Slotted Array Antenna Employed in WiMAX Base Station

*Cheng-Yuan Chin, Yen-Jung Tseng, and R. B. Hwang
Department of Communication Engineering, National Chiao Tung University
1001 University Road, Hsinchu, Taiwan 300, ROC
Corresponding author: raybeam@mail.nctu.edu.tw

Abstract

In this paper, a 4-by-4 two-dimensional slotted array antenna was designed, fabricated and measured. Such an array antenna consists of four series-fed sub-array antennas and a metal reflector for achieving single-side radiation. Moreover, the four sub-array antenna is fed by a 4-way power divider made up of three 2-way power dividers. By the antenna theory, adjusting the progressive phase delay angle, the main-beam angle can be steered toward any desired direction. In this research, the progressive phase delay angle is designed at 0 degree for obtaining the radiation main-beam toward broadside direction (perpendicular to the plane of slots). Additionally, the slot inclines 45 degree with respect to the micro-strip line for generating two polarized electric-field along two orthogonal directions. It may enhance the receiving performance in a complex environment. Due to the advantages of easy fabrication, robustness and low-cost issue, such an array antenna can be a potential candidate for serving a point-to-point planar array antenna in WiMAX applications around 3.5GHz.

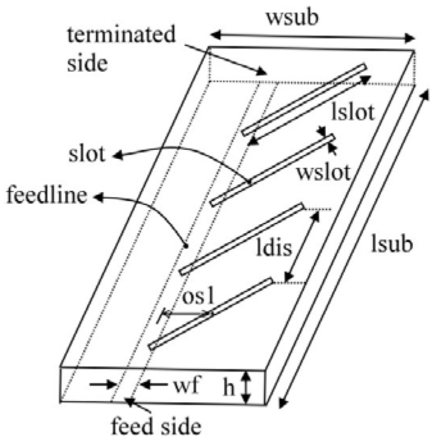
1. Introduction

Array antennas have been intensively investigated for many years; especially for the military application, such as phase array antennas applied in radar system. Many types of array antennas comprised of slot elements have been studied thoroughly [1-5]; to mention a few: a 45-degree-inclined slotted array is investigated for linear polarization by Itoh [3]; the slot element etched on top of metallic surface of the substrate integrated waveguide (SIW) to form a slotted array was presented [4]. In this paper, we developed an array antenna consisting of a 4-way power divider, as well as 16 crossed slots etched directly on the back of 4 parallel-fed micro-strip lines. The numerical simulation based on the finite element method was employed to carry out the calculation for the electrical properties of the feeding network and radiation pattern of the slotted array antenna. Besides, the radiation far-field pattern was measured to validate the design procedure of this array antenna.

2. Description of the antenna

As shown in Fig. 1(a), a 50 Ω micro-strip line implemented on a FR4 substrate with relative dielectric constant 4.4 and thickness 0.8 mm, has periodic placement of slots on its ground plane. The length of the slot is 34.3 mm corresponding to half free-space wavelength at 3.5 GHz. Moreover, the width of slot is 2 mm, and the period of the slotted array is 46 mm designed for obtaining a zero phase delay between adjacent slots. The slot performed on the ground plane serves as a radiating element to leak guided-wave energy in the micro-strip line into the air region, becoming an antenna. Specifically, the slots are performed to cross the micro-strip line for interrupting the returning current on the ground plane. Furthermore, the slot inclines 45 degree with respect to the micro-strip line to obtain electric-field components along the two directions. Such a scheme may improve the receiving efficiency in a complex wave-propagating environment.

After completing the design of a 4 elements slotted-array, we start to integrate a 4-by-4 array antenna using a 4-way power divider. As demonstrated in Fig. 1(b), a 4-way power divider consisting of two identical 2-way power splitters was designed to feed the 4 series-fed slotted arrays shown in Fig. 1(a). Moreover, the center-to-center distance between two sub-arrays is designed around half wavelength in free-space at 3.5 GHz to avoid generating grating lobes.



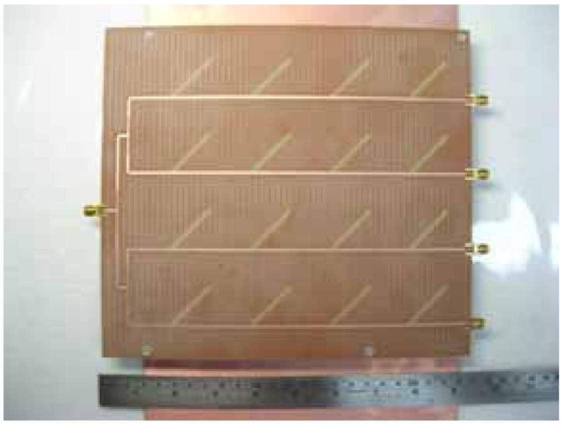


Figure 1: (a) Structure configuration of the 1×4 slotted array, and (b) photo of the 4-by-4 slotted array antenna

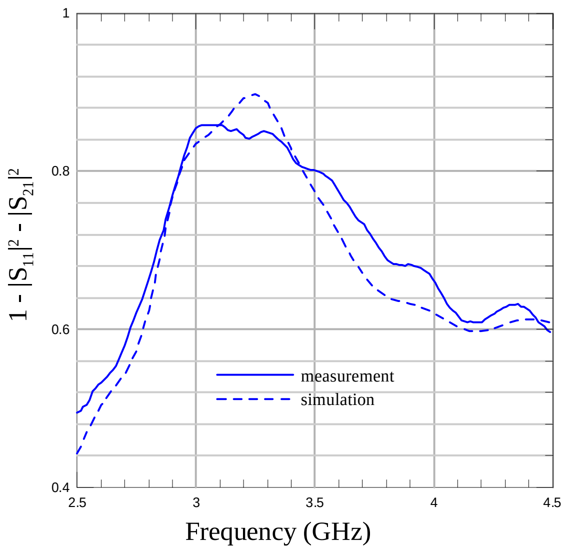


Figure 2: Distribution of absorption power versus frequency

3. Numerical and measured results

Before demonstrating the numerical simulation and measurement for the overall 4-by-4 slotted array antenna, we first measured the return- and insertion- loss of the slotted micro-strip line. Although not shown here, the return- and insertion- loss at 3.5 GHz is 9.6dB and 10.4dB respectively. It allows us to believe that most of the input power can be transformed into leaky-wave radiating into the air region. Furthermore, we assess the absorption efficiency by calculating $1-|s_{11}|^2-|s_{21}|^2$ from the calculated and measured scattering parameters versus the operation frequency, as shown in fig. 2. From this figure, we found that the absorption efficiency of such a radiating structure is more than 70% around 3.5 GHz. Since the loss-tangent is insignificant in this frequency range, we believe that most of the energy will be converted into leaky-wave rather than being absorbed in the FR4 substrate.

We are now in a good position to design, fabricate and measure the 4-by-4 array antenna. In general, a slot antenna radiates toward both sides. To improve its directivity, a metal reflector was added to direct the backward radiating wave to the forward side. However, due to the interference between the two waves mentioned previously, the distance between the reflector and fed-line should be carefully designed to obtain a constructive interference in the frequency band of operation. Here, the distance is deigned at 20 mm corresponding to quarter wavelength at 3.5 GHz.

Fig. 3 shows the radiation pattern of the slotted array antenna. As depicted in the inset of Fig. 3, the *z* axis is in the direction perpendicular to the transverse plane. Furthermore, since the slot inclines 45 degree with respect to the micro-strip, the electric field in the two orthogonal directions (the *x*- and *y*- axis) denoted as E_x and E_y, respectively, should be taken into account. Figures 3(a) and (b) indicate the radiation pattern along the XZ and YZ planes respectively, it is apparent to observe that the radiation main beam is in the direction perpendicular to the transverse plane. The measured directivity are listed in Table 1. It is noted that the back lobe is considerable; particularly in the measurement. We may conjecture that it is due to the re-radiation of the current induced on the metal reflector.

	XZ-plane					
4×4 slot array	Max gain (dBi)		Max gain angle (degree)		3dB beam width (degree)	
	Ex	Ey	Ex	Ey	Ex	Ey
3.4GHz	9.87	9.4	1	3	14	16
3.5GHz	9.74	8.1	1	2	13	17
3.6GHz	9.75	6.39	0	1	13	16
	YZ-plane					
4×4 slot array	Max gain (dBi)		Max gain angle (degree)		3dB beam width (degree)	
	Ex	Ey	Ex	Ey	Ex	Ey
3.4GHz	9.81	8.92	10	8	24	23
3.5GHz	9.52	8.89	2	2	22	18
3.6GHz	9.69	8.35	2	-1	22	20

Table 1: Directivity of the 4-by-4 slotted array antenna

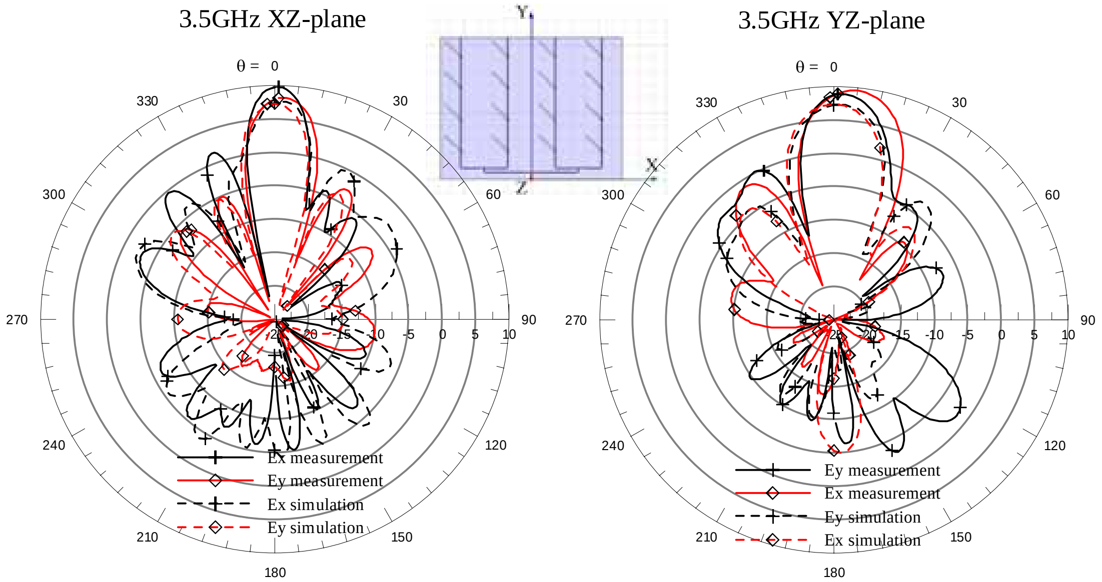


Figure 3: Radiation Pattern of complete array antenna system at 3.5 GHz

4. Conclusion

In this paper, we demonstrate a 4-by-4 slotted array antenna consisting of a 4-way power divider and 4 series-fed slotted array antennas. The distance between slots was designed at one guided-wave wavelength to have zero phase delay angle between slots, enabling the radiating main-beam toward the direction perpendicular to the antenna array. In addition to the numerical simulation, we have designed, fabricated and measured the radiation pattern of the antenna array. Due to the two-dimensional placement of slots, the radiation pattern exhibits a cone beam with average beam-width around 24.4 and 23.4 degrees along the YZ and XZ plane respectively. Last but not the least, owing to the low-cost and easy fabrication of this antenna array, it may be a potential candidate of a directional antenna in 3.5GHz WiMAX application.

References

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