Planar Arrays for Indoor and Outdoor Millimeter Wave Systems
- Tokyo Tech Wireless Fiber Project -

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Abstract

Novel planar arrays using single layer waveguides are proposed and fabricated. Based upon the high gain, high efficiency and low cost arrays, millimetre wave test system is under planning .

1. INTRODUCTION

Four types of single layer waveguide arrays are developed in Tokyo Tech. Key features as well as the advantages in terms of fabrication costs have been demonstrated. Millimetre wave test systems, utilizing these antennas are now proposed in Tokyo Tech where base band CMOS chip will be developed.

2. SINGLE-LAYER WAVEGUIDE SLOT ARRAYS FOR MILLIMETER WAVE

The authors have developed single mode waveguides and oversized waveguides for potentially mass producible planar arrays [1]. Fig.1 presents four types of single-layer waveguides as well as their performance. The antenna gain and efficiency in terms of frequency reported in the literature are summarized in Fig.2. These arrays can cover very high gain ranging up to 35 dBi which is not attainable by planar arrays using microstrip and triplate with larger line loss. From Fig.2, the high potential of the single-layer waveguide arrays in high gain and high frequency applications is fully demonstrated. Four types in Fig.1 are briefly characterized as:

(Co) Only two components that are a slotted plate and a base plate with corrugation are the parts of this array. The electrical contact between the narrow walls on the bottom plate and the slot plate should be perfect. The multiple-way power divider for single-mode waveguides with co-phase excitation consist of series of π -junctions spaced by a wavelength. The peak gain of 35.9 dBi and the efficiency of 75.6 % at 22.15 GHz were realized [2]. The 76GHz band arrays for automotive radar are also tested and 35.5dBi with 64% efficiency was reported.

(Alt.) In alternating phase fed arrays, the power divider with series of T-junctions separated by half the wavelength excites adjacent waveguides out of phase by 180degree; electrical contact between the narrow walls and the slot plate is not necessary. So, drastic reduction of loss as well as cost for fabrication has been realized. The leakage at the periphery of the aperture was suppressed by the choke in realistic arrays. No less than 60% efficiency and 32.4 dBi gain was reported in 26GHz band antenna with mechanical contact by simple screws [3]. The alternating-phase-fed waveguide array has realized 57% efficiency with 34.8dBi gain at 76.5GHz in measurement.

(RLSA) Parallel plate structure operating in TEM cylindrical wave excitation has no side-walls. It is already commercially mass-produced in the form of circular radial line slot antennas (RLSA) fed by a coaxial cable for 12GHz DBS reception. For millimeter wave application, 52% efficiency at 32 dBi was accomplished in 60GHz band [4].

(Post-Wall WG) The "post wall waveguide" antenna with plane TEM wave generator is fabricated using a thick grounded dielectric substrate and densely arrayed metalized via-holes (posts; 0.3mm diameter) which replace conducting narrow walls. It can be easily made at low cost by conventional PCB (print circuit board) fabrication techniques such as via-holing, metal-plating and etching. Car radar antennas in 70GHz band are now tested and 25-34 dBi are covered with the efficiency 40-50% while about 60% was realized in 60GHz band [5]. Millimeter wave RF modules using a 21 dB post-wall array are realized [6].

3. MILLIMETER-WAVE MEDIA CONVERTERS

Cost-effective millimeter-wave media converters were developed for gigabit home-link systems. The converter is composed of a packaged MMIC(Microwave Monolithic Integrated Circuit) mounted on the PTFE-based printed circuit board and a post-wall planar antenna formed on the backside of the board. The post-wall planar antenna will be precisely described later. The converters have two types of the transmitter and the receiver.

One example of the converters with a relatively high gain array is shown in Fig. 3. The printed circuit board with the size of 75 x 32 x 1.2 mm^3 is inserted into the card-edge connector to feed the IF signal and the DC power. The antenna gain was 20 • 1.5 dBi at the frequency range of 60 ~ 62.5 GHz as shown in Fig 4. The converter can be characterized to have no mm-wave terminals.

The transmission experiment was done at the distance D = 10 m between the transmitter and the receiver. The post-wall planar antenna of the transmitter was boresighted at the center of the aperture in that of the receiver. Fig. 5 shows measured transmission characteristics from the IF input power P_{IF1} in the transmitter to the IF output power P_{IFout} in the receiver. The novel self-heterodyne scheme was used [6]. The input frequency f_{IF1} and the frequency f_{IF2} of the non-modulated signal IF_2 were 4.5 GHz and 3.5 GHz, respectively, and then the f_{IFout} of 1 GHz was obtained at the IF output port of the receiver. The power P_{IF2} of the non-modulated signal IF_2 was constant to be -13 dBm.

At the input power to the transmitter P_{IF1} = -13 dBm, the IF output power of the receiver P_{IFout} was -37dBm, which suggested the capability of the transmission with the bandwidth of 2.5 GHz and C/N of 25 dB in the home-link systems[6]. The linearity between P_{IF1} and P_{IFout} is kept in the wide dynamic range.

Fig. 6 summarizes various types of transitions between the coaxial line and a post-wall waveguide [J1]. Fig. 7 shows the measured frequency characteristics of the reflection for the structure (a)-(d). The structure (c) and (d) fulfill the required bandwidth of 7.0 GHz for the reflection less than −15 dB and can be candidates for millimeter-wave band wireless systems.

4. TOKYO TECH WIRELESS FIBER PROJECT

Wireless group in Tokyo Institute of Technology, proposes a “Wireless Fiber Project”, which is defined as the construction of millimeter-wave communication test network using the line of sight transmission. The target of the project covers the base-band CMOS chip which can offer the transmission of several Gbps. The networks which have the span of several hundred meters to one kilo-meter is planned to be constructed in the Tokyo Institute of Technology Ookayama campus. To demonstrate the high speed data transmission in millimetre wave, the orthogonal polarization will also be utilized for Polarization duplex, where frequency is fully re-used utilizing polarization isolation only [8]. As Fig. 8 presents two center-feed single layer slotted waveguide arrays used and with orthogonal polarization in exactly the same frequency band used for transmission and reception. In order to completely reuse the frequency two times, about 100dB transmission-reception isolation is required. The antenna has a gain more than 30 dBi. This antenna size is 18.4 lambda (218mm) x 33.3 lambda (394mm) at the design frequency of 25.3GHz. We simulate this model using HFSS. The simulated result shows the isolation more than 80dB at 25.3GHz. Fig. 9 shows the measured and simulated results. Good agreement is seen.

Fig. 10 is the block diagram of the 8-way Butler matrix. The numbers in circles are phase shifters and they correspond to the amount of the phase shift in units of $-\pi/8$. The Butler matrix consists of quadrature hybrid couplers and fixed phase shifters. The Butler matrix with 4 or more input ports generally needs three-dimensional crossings where two transmission lines intersect; this is well known difficulty for realizing a planar structure. A completely planar crossing structure of waveguide, called ``cross coupler", is realized here using a short-slot coupler . We fabricate the single-layer hollow-waveguide 8-way Butler matrix [9]. The total size of the matrix is 303.14mm by 106.54mm which corresponds to 17.1λ by 6.0 λ at the design frequency of 22~GHz. The patterns are measured with a large ground plate of 810mm by 500mm. An electromagnetic wave radiates directly from the edge of the waveguide port of the Butler matrix. The calculated patterns are derived from ideal power division of the Butler matrix as in Fig. 11. A TE10 mode distribution waveguide aperture on the infinite ground plane is used as a radiating element. The element pattern becomes a cosine-like distribution. The element spacing is 12.268mm and corresponds to 0.90 λ (the wavelength in free space).

5. CONCLUSION

Millimeter wave planar antennas developed in Tokyo Tech. as well as the test systems utilizing them are reviewed.

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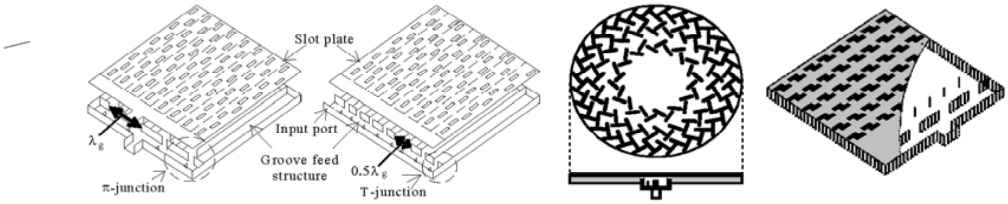


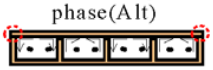
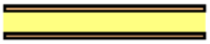
Modes	Single-mode		Oversize	
Structure	Co-phase(Co) 	Alternating-phase(Alt) 	Stacking Substrate RLSA 	Post-wall Waveguide 
Applicability for millimeter wave	● ● 76GHz 35.5dBi, 64%	● ● 26GHz 32.4dBi, 60%	● ● 60GHz 32dBi, 55%	● ● 60GHz 27dBi, 59%
Antenna input ports(Adaptor)	Single-layer WG —— Std. WG	Single-layer WG —— Std. WG	Radial WG —— Std.WG/Coax	Post-wall WG —— Std.WG/Coax
Planar circuits	•	•	• •	•
Low side lobe	● ● SLL<•25dB	● ●	● ●	● ● SLL••18••••
System mouting	Automotive radar FWA	Automotive radar FWA	FWA Wireless LAN Plasma processing	Automotive radar FWA Mobile base station

Fig. 1: Four types of single-layer slotted waveguide arrays, interfaces and applications

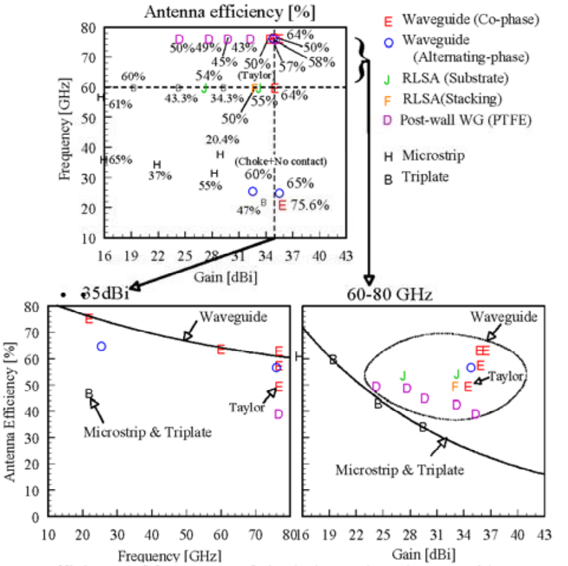


Fig. 2: Efficiency of four-types of single-layer slotted waveguide arrays VS. frequency and gain

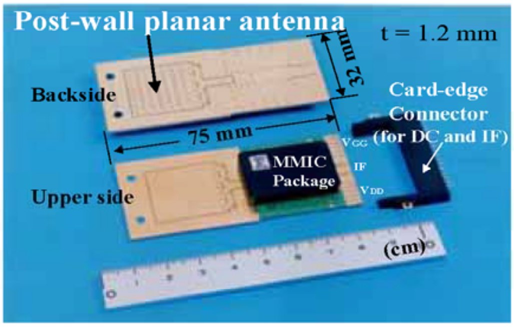


Fig. 3 Completed millimeter-wave media converter with a post-wall planar antenna. The MMIC package is made of plastic materials and the size is 30 x 21 x 6 mm^3. The antenna is formed on a PTFE-based print-circuit board with the size of 75 x 32 x 1.2 mm^3.

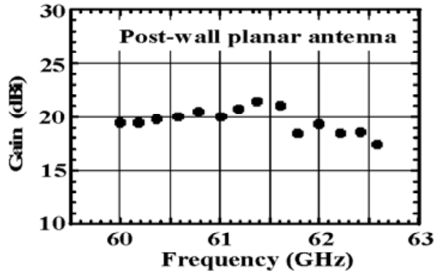


Fig. 4 Measured frequency characteristics of the antenna gain. The gain of 20 ± 1.5 dBi was obtained at the frequency range of 60 ~ 62.5 GHz.

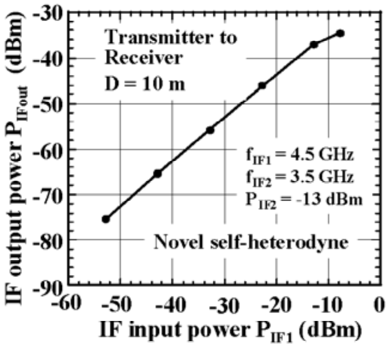
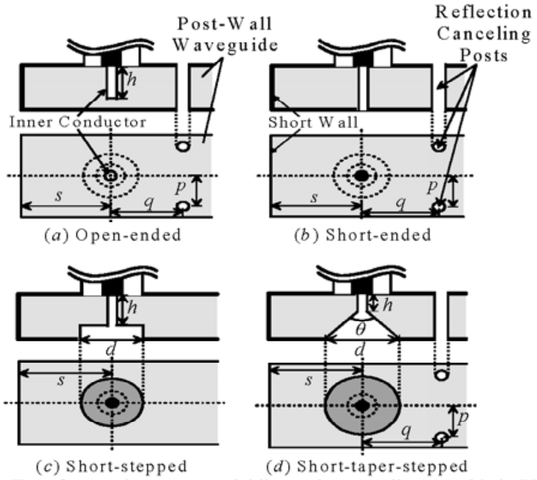


Fig.5 IF output power P_{IFout} in the receiver module vs. IF input power P_{IF1} in the transmitter module. The distance D between the transmitter and the receiver was 10 m. The novel self-heterodyne scheme was used. The power P_{IF2} of the non-modulated signal IF_2 was constant to be -13 dBm.



(a) Open-ended (b) Short-ended

(c) Short-stepped (d) Short-taper-stepped

Fig. 6: Transformers between coaxial line and post-wall waveguide in PTFE substrate (post-walls are replaced with conducting walls at the equivalent position in the analysis)

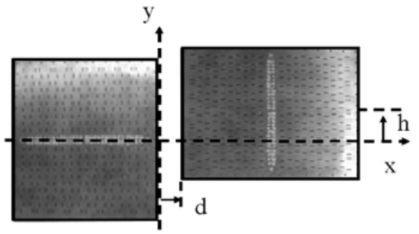


Fig. 8 Orthogonally polarized slot arrays in side-by-side arrangement with distance d and position h.

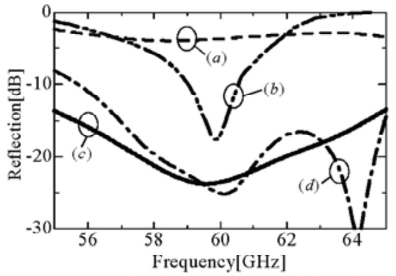


Fig. 7: Experimental results of reflection characteristics of coaxial line to post-wall waveguide transformers in PTFE substrate

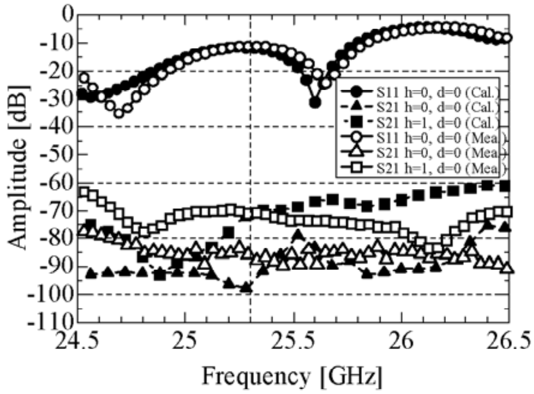


Fig. 9 Experimental results of Reflection and isolation characteristics between two center-feed waveguide arrays

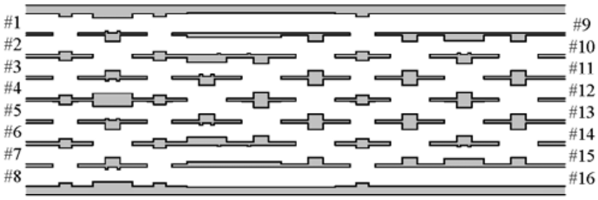


Fig. 10: Single-Layer Hollow-Waveguide 8-Way Butler Matrix

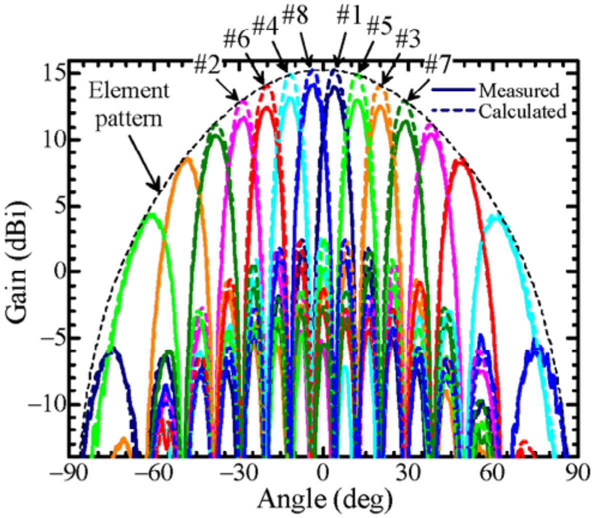


Fig. 11 Radiation Patterns