High Gain and High Efficiency Planar Antennas for Various Wireless Systems in Millimeter Wave Bands

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ABSTRACT

Four types of planar slotted waveguide arrays have been developed and applied for various millimeter-wave wireless systems. Key features for these are, single-layer and mass producible, high efficiency and high gain. State-of-the-art design/analysis techniques for novel structures as well as the characteristics in millimeter-wave band are reviewed. Beam switching, connectors to RF circuits and the use of PCB substrate are mentioned on demands from systems. The latest application in the systems is demonstrated, such as FWA, LAN and TV-video link etc.

INTRODUCTION

For real popularization of millimeter wave systems, cost reduction and miniaturization of the system is indispensable. Key components of these systems are millimeter wave RF modules, circuits and antennas as well as connectors. Fig.1 presents the frequency and the antenna gain for various wireless systems. Authors have developed high-efficiency and mass producible planar arrays using unique four kinds of single-layer waveguide structures as are shown in Figs.2 and 3. Low loss characteristics of waveguides make these the leading candidates for high gain antennas in millimeter wave wireless systems. The latest design of single-layer waveguide arrays are directed toward the applications such as fixed wireless access (FWA), local area network (LAN), video home link, automotive radars and road monitors in ITS and mobile communication base stations and so on. This paper first summarizes the state-of-the-art performances of the single-layer waveguide arrays. Various types of antenna input ports are being designed for the compact interface to millimeter wave RF circuits. Low sidelobe design as well as the beam scan/switch capability is also developed. Finally, the latest millimeter-wave wireless systems with these antennas, to appear on the market, are demonstrated.

SINGLE-LAYER WAVEGUIDES

Authors have developed four kinds of waveguides, which are potentially mass producible [1]. The potential for millimeter wave frequency has already been confirmed in each structure. The state-of-the-art efficiency of these antennas is presented in Fig.4 in the same coordinate as Fig.1. The waveguide arrays are surpassing other planar antennas. In “Co-phase feed waveguide”, only two components, that are a slotted plate and a base plate with corrugation, are the parts of this array. For antennas with resonant shunt slots, the peak gain of 35.9 dBi and the efficiency of 75.6 % at 22.15 GHz was realized [2]. The 76GHz band arrays for automotive radar are also tested and 35.5dBi with 64% efficiency was reported[3][4]. One difficulty of co-phase feed arrays as applied for high frequency is that the electric contact between the narrow walls on the bottom plate and the slot plate should be perfect. This difficulty is removed by “Alternating phase feed waveguide”. Adjacent waveguides are out of phase by 180degree and electrical contact between the narrow walls and the slot plate is not necessary. So, drastic reduction of loss as well as cost for fabrication would be expected. 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. [5] The 76GHz model antennas are being manufactured as well. The above techniques are for single mode waveguides. In terms of loss and cost, oversized waveguide arrays are more advantageous. Authors have been studying “Radial Line Slot Antennas(RLSA)” in this category. Parallel plate structure operating in TEM cylindrical wave excitation has no sidewalls and assures the lowest transmission loss. It is already commercially mass-produced for 12GHz DBS reception. For millimeter wave application, stacking of two plates and one spacer is replaced with a thick substrate for accurate alignment of the plates[6]: the substrate thickness is ten times larger than that of microstrip and triplate. In 60GHz band, 55% efficiency at 33.4 dBi was accomplished. The new version of rectangular aperture antennas are also developed using plane TEM wave generator called "Post-wall Waveguide" [7]. The antenna is fabricated using a thick-grounded dielectric substrate and densely arrayed plated via-holes, 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[8].

CHALLENGES FOR MILLIMETER WAVE SYSTEMS

The latest studies for implementation in millimeter wave systems are reviewed. It includes, the use of thick substrate, adaptor between the antennas and the millimeter wave RF circuits, low sidelobe design and the beam scan/switch capability. Original interface of single-layer waveguide arrays are waveguide for single-mode type, coaxial cable for RLSA and waveguide for post-wall antennas, respectively. In order to enhance the applicability for the systems, alternative interfaces are under developing. Coaxial feed for post-wall waveguide array has the loss about 0.5dB and the crossed slot waveguide feed for RLSA in Fig.5 has less than –15dB reflection with excellent symmetry[9][10]. Sidelobe suppression is required for some applications. Tayler distribution has already been introduced in the power dividing structures in Co-phase type[11] and post-wall types[12]. Beam switch is attractive but most challenging functions for car radars and intelligent base station antennas. Here, single-mode post-wall waveguide arrays with four ports Butler matrix shown in Fig.6 is designed for reconfigurable, switchable or shaped beams in 26GHz band FWA. These arrays are now used in the systems. <LAN>CRL Japan has developed 38GHz 156Mbps MM-wave LAN named BRAIN and RLSAs are used for 200m-link user terminals by OKI, as in Fig.7[13]. <FWA>26GHz fixed wireless access named WIPAS will provide 60Mbps point-to-multi point service and alternating-phase arrays in Fig.8 as well as RF and IF circuitary is enclosed in a unit 180mmx180mmx100mm by JRC. <TV-video home link>A 60GHz wireless link for video proposed by Fujitsu Quantum uses the post-wall waveguide array as a user terminal in Fig.9.

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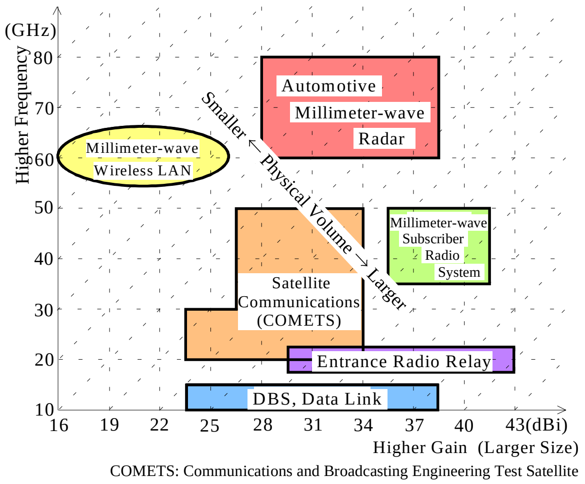


Fig. 1 Millimeter-Wave and High-Gain Applications

Fig. 2 MWE (in Yokohama)

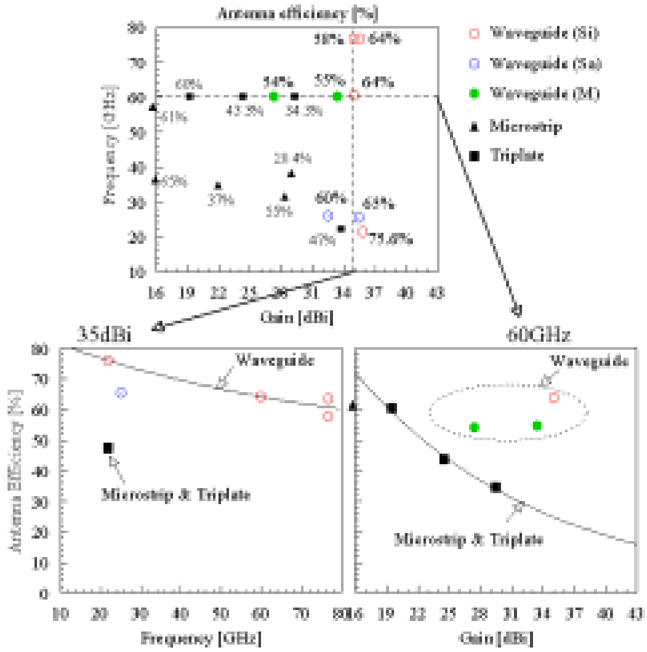
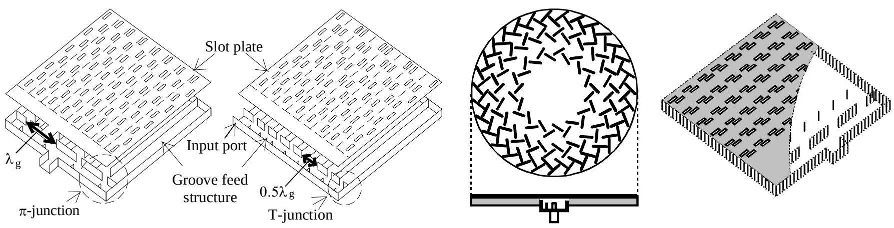


Fig. 4 Gain and Efficiency of Slotted Waveguide Arrays



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<-18dB
System mouting	Automotive radar FWA	Automotive radar FWA	FWA Wireless LAN Plasma processing	Automotive radar FWA Mobile base station

Fig. 3 Four types of waveguide arrays

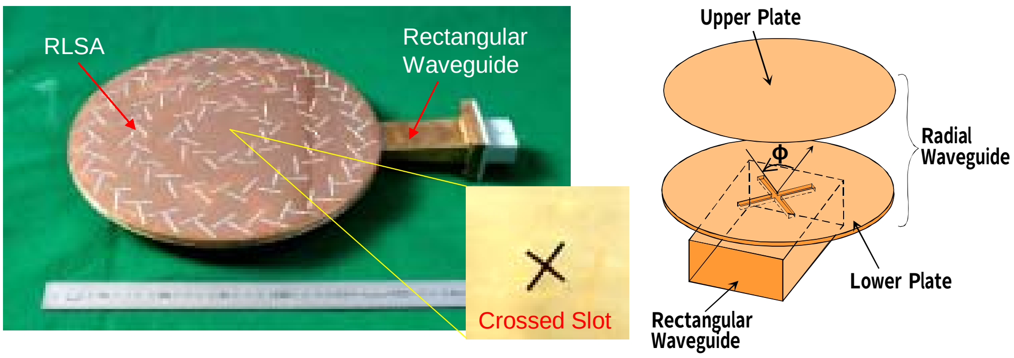


Fig. 5 RLSA Fed by Rectangular Waveguide through a Crossed Slot

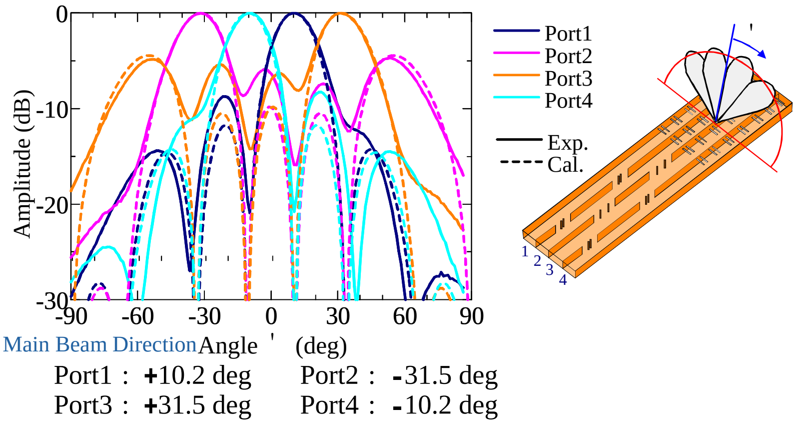


Fig. 6 A 4-Way Planar Butler Matrix for Beam Switching of a Slot Array

Fig. 8 Alternating-phase Arrays for 26GHz FWA

Fig. 7 38GHz 156Mbps MM-wave LAN and RLSAs

Fig. 9 Post-wall Waveguide Array for 60GHz TV-video home link