Single Layer Waveguide Slot Arrays for Ultra-Low Cost Wireless Access Systems

Makoto Ando* and Jiro Hirokawa
Tokyo Institute of Technology
Department of Electrical and Electronic Engineering
Tokyo, Japan
mando@antenna.ee.titech.ac.jp, jiro@antenna.ee.titech.ac.jp

Abstract: *High efficiency and low cost planar waveguide arrays have been proposed and developed by using four kinds of single-layer waveguides. Among the four, alternating phase fed arrays are recently applied for commercial fixed wireless access(FWA), where the cost and the size of the wireless terminals are drastically reduced to 1/10 and 1/5. Post wall waveguide arrays as another type of the four, are applied for millimetre wave RF modules for Gigabit Home-link systems. These planar arrays bring about "low cost" and "high gain" in the systems as the key features.*

1. Introduction

For decades, authors have developed high-efficiency and mass producible planar arrays using unique single-layer waveguide structures. Four types of planar waveguides, all belonging to single-layer waveguide, are structurally quite simple and low cost while they inherit low loss characteristics from waveguides. They are leading candidates for high gain antennas in high frequency wireless systems. Recent studies are directed to system integrations for microwave and millimeter wave systems. This paper reviews the state-of-the-art performances of the single-layer waveguide arrays. Then two examples of system integration are described. Alternating phase waveguide arrays have realized the drastic cost reduction of fixed wireless access systems in 26 GHz band while post-wall waveguide arrays have been implemented in 60GHz band RF modules for Gigabit Home-link systems.

2. Single Layer Waveguide Arrays

Authors have developed single mode waveguides and oversized waveguides for potentially mass producible planar arrays [1] [2]. Figure 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 Figure 2, the high potential of the single-layer waveguide arrays in high gain and high frequency applications is fully demonstrated. In Fig.1, four types are briefly characterized as:

(Co) The multiple way power divider for single-mode waveguides with co-phase excitation consist of series of π-junctions spaced by a wavelength. 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 peak gain of 35.9 dBi and the efficiency of 75.6 % at 22.15 GHz were realized [3]. 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. [4]

(RLSA) Parallel plate structure operating in TEM cylindrical wave excitation has no side-walls and assures the lowest transmission loss among the three. 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 (M). For millimeter wave application, 52% efficiency at 32 dBi was accomplished in 60GHz band. [5]

(**Post-wall Waveguide**) The new version of rectangular aperture antennas are also developed using plane TEM wave generator called "post wall waveguide" [6]. The antenna 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.[7] Millimeter wave RF modules using

21 dB post-wall array are realized.[8]

3. Compact wireless terminal for wireless IP access systems (WIPAS)

As an commercial application of alternating phase fed arrays, a compact wireless terminal (WT) with a high gain planar array has been developed for the 26GHz Wireless IP Access System (WIPAS), which is a point-to-multipoint FWA (fixed wireless access) system in Fig.3 and Tab.1. [9] Drastic cost reduction and downsizing are realized by using an alternating phase fed single layer waveguide array antenna and MMIC (Microwave Monolithic IC) technologies. This terminal is 190x190x55mm^3 in volume and less than 2.0kg in weight which accommodates over 31dBi very high efficiency antenna with radome, RF module, IF modules, ASIC(Application Specific IC) for modem, TDMA(Time Division Multiple Access) equipment control, and MAC(Medium Access Control). Only an Ethernet cable with 24 DC power supply is attached on the terminal. The antenna serves both as the radiating element and the housing accommodating all the circuits such as RF, IF and MAC processing modules as in Fig.4. A RF module is mounted on the back of the antenna. Fig. 5 shows the newly developed MMIC for the up and down converter [10]. To satisfy the space availability, the size of the up converter is 2.9x2.9 mm^2, and that of down converter is 1.4x2.4 mm^2. The newly developed converter integrates IF balun, multiplicate, RF amplifier, and frequency converter in one chip, while converters on the market usually acts as only frequency converter. This technology greatly contributes to the cost reduction of RF module.

4. 60GHz RF module for Gigabit home-link systems

The broadband home-link systems which transmit the video signals need the bit-rate of the Gigabit per second order. Moreover, it requires the drastic cost reduction of millimeter-wave hardwires. High performances such as the phase-noise less than -90 dBc/Hz at 100 kHz off-carrier frequency and the wide band characteristics more than 2.5 GHz must be maintained in the millimeter-wave range. In addition, the cost and size of millimeter-wave passive components such as the resonator of the VCO, the filter, the antenna and the package, have to be drastically reduced as well as those of MMIC. Cost-effective 60-GHz modules with a post-wall planar antenna have been developed. [8] The authors proposed the novel self-heterodyne system technology.[11][12] The completed cost-effective 60-GHz module with a post-wall planar antenna is shown in Fig.6. The packaged MMIC is mounted on the upper side of a PTFE-based print-circuit board. The size of the board is 75 x 32 x 1.2 mm^3. The terminals for the DC power supply and the IF signals are formed at the edge of the board and are inserted to the connector as shown in Fig.1.The post-wall planar antenna is formed on the backside of the print-circuit board [7]. It has the aperture size of 26 x 23 mm^2. The thickness of the print-circuit board is 1.2 mm. Measured frequency characteristic of the gain is shown in Fig.7. The gain of 20 ± 1.5dBi was obtained in the frequency range of 60 ~ 62.5GHz

The local oscillator of the transmitter is composed of the low cost 14-GHz VCO and the multiplier(x 2). The anti-parallel diode pair (APDP) harmonic mixer (Humid) is utilized for reducing the responsibility of the filter. A small size planar band pass filter is developed to reject the local signal of 57 GHz and the image signal of 54 GHz. The antennas of 20 dBi are used for both the transmitter and the receiver. The input power to the antenna of the transmitter was 8 dBm when the input power P_{IF1} was -13 dBm. The output power P_{IFout} of -37 dBm was obtained at IF_{out} of the receiver when the distance between the transmitter and the receiver was 10 m. 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. Measured transmission characteristics is shown in Fig. 8. The f_{IFout} of 1 GHz was obtained at the IF output port of the receiver. The 2nd IF input power P_{IF2} was constant to be -13 dBm. At the P_{IF1} = -13 dBm, the IF output power of the receiver P_{IFout} was -37dBm.The linearity between the 1st IF input power of the transmitter P_{IF1} and the P_{IFout} is kept in the wide dynamic range.

5. Conclusions

Four types of single layer waveguide slot arrays are reviewed. Typical systems for high gain and high frequency applications are demonstrated.

6. Acknowledgement

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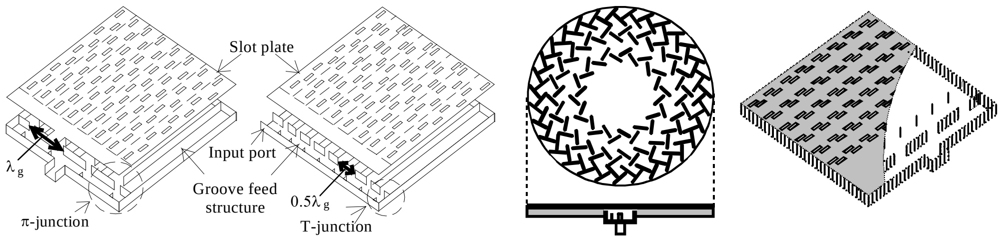

Modes	Single-mode		Oversize	
Structure	Co-phase(Co)	Alternating-phase(Alt)	Stacking Substrate RLSA	Post-wall Waveguide
Applicability for millimeter wave	○ 76GHz 35.5dBi, 64%	△ 26GHz 32.4dBi, 60%	○ 60GHz 32dBi, 55%	○ 60GHz 27dBi, 59%
Antenna input ports(Adaptor)	Single-layer WG — Std. WG	Single-layer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

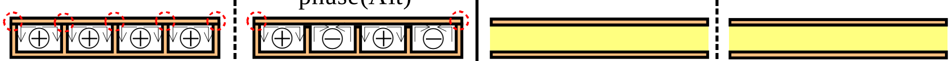

Fig. 1 Four types of single-layer slotted waveguide arrays, interfaces and applications

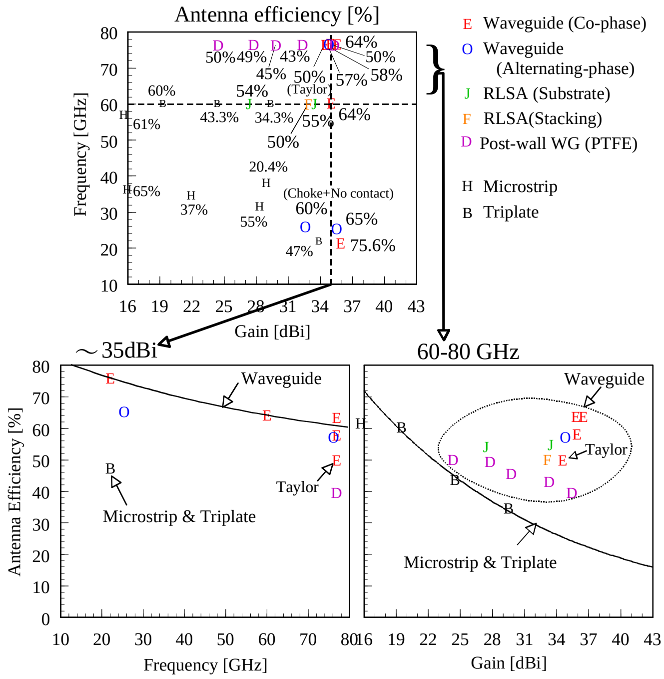

Fig.2 Efficiency of four-types of single-layer slotted waveguide arrays VS. frequency and gain

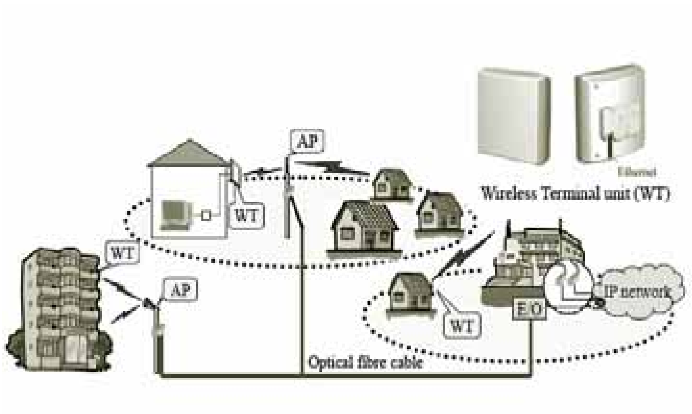

Fig. 3 Configuration of Wireless IP Access System (WIPAS)

Table 1 WIPAS main specifications

Frequency band		26 GHz band
Transmission		TDD/TDMA
Modulation		QPSK or 16QAM
Transmission capacity		QPSK: 40 Mbit/s 16QAM: 80 Mbit/s
TX power		QPSK: 14 dBm 16QAM: 11.5 dBm
Max number of WTs		239 WTs per AP
Network interface		100BASE-FX
User interface		100BASE-TX / 10BASE-T
Antenna	AP	Omni (6.0 dBi) Sector (90 degrees; 12.0 dBi) Horn (90x90 degrees; 5.5 dBi)
	WT	Planar (31.5 dBi)

Table 1 WIPAS main specifications .

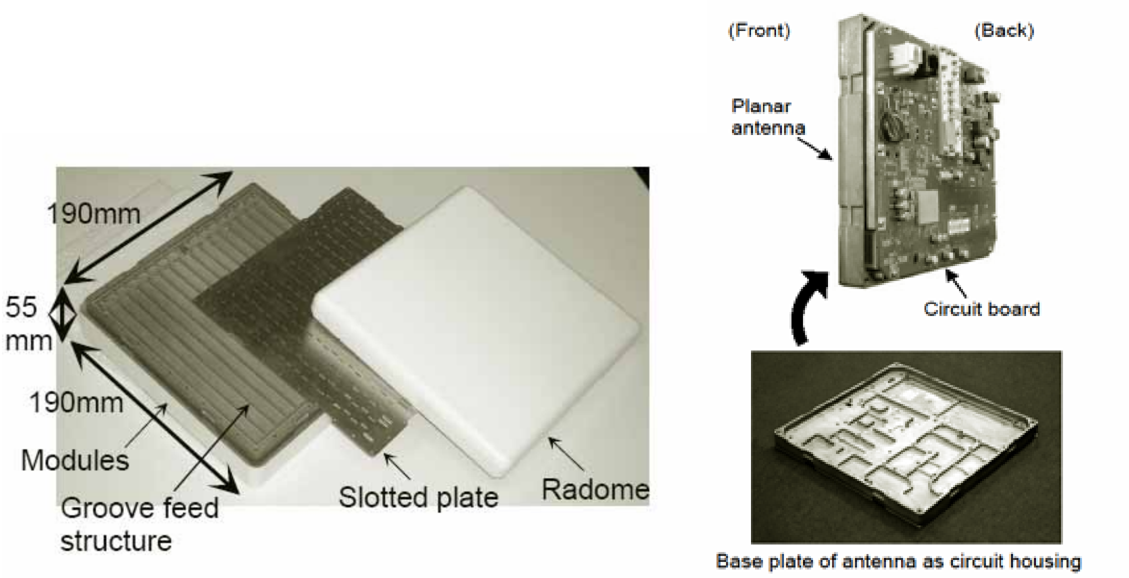

Fig. 4 Assembly of Wireless Terminal (WT) and an alternating-phase fed single-layer slotted waveguide array..

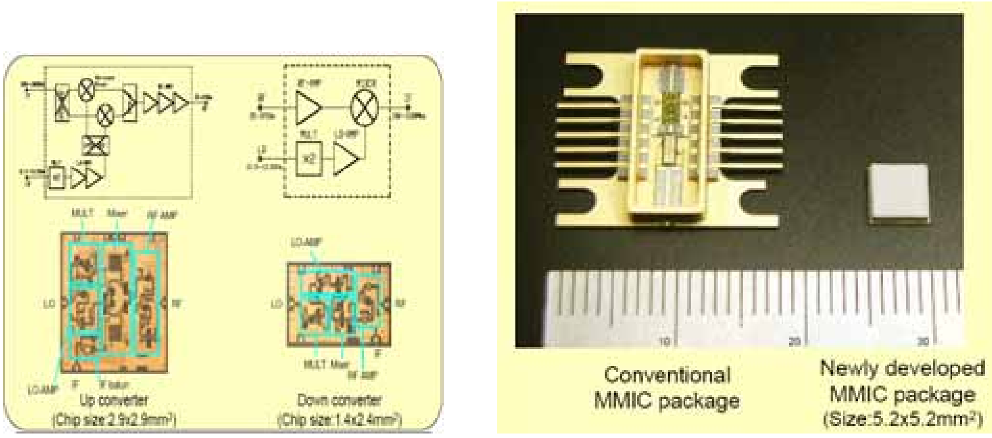

Fig. 5 Block diagram of the up and down converter and down-sized MMIC package.

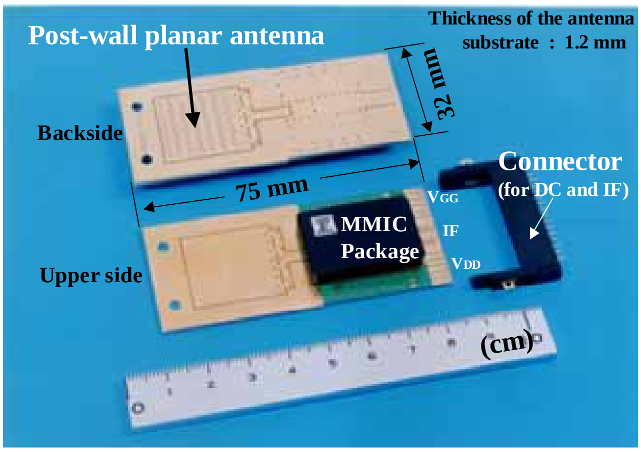

Fig.6 Completed cost-effective 60-GHz module with a post-wall planar antenna. MMIC package 30 x 21 x 6 mm^3. The total size of the module 75 x 32 x 1.2 mm^3.

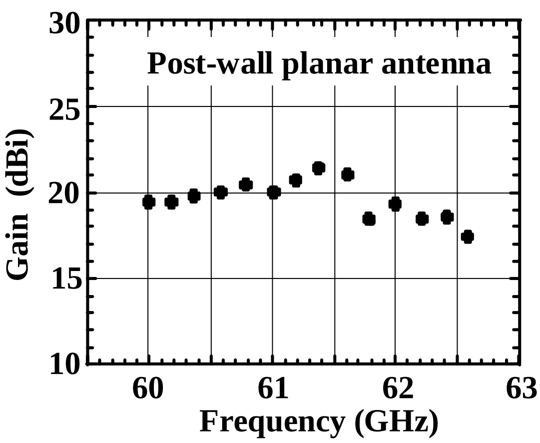

Fig.7 Measured frequency characteristics of the antenna gain.

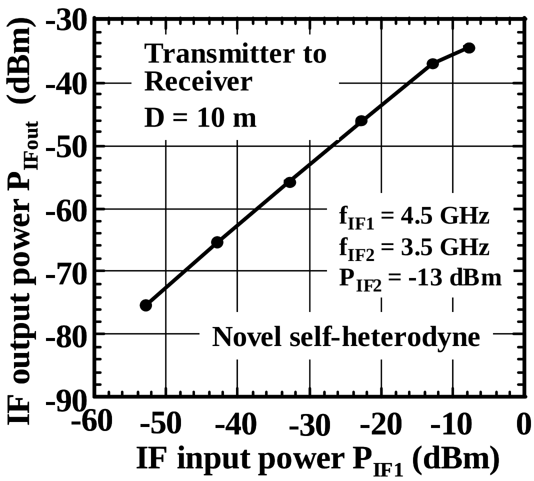

Fig.8 IF output power P_{IFout} in Rx vs. IF input power P_{IF1} in Tx.