# SYSTEM INTEGRATIONS OF PLANAR SLOT ARRAY ANTENNAS FOR MILLIMETER WAVE WIRELESS SYSTEMS

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## 1. INTRODUCTION

The authors have developed high-efficiency and mass-producible planar slot array antennas 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 planar antennas in high frequency wireless systems. Recent studies are directed to system integrations for microwave and millimeter wave systems. This paper describes two examples of the system integrations using the single-layer waveguide arrays as well as their state-of-the-art performances. Alternating-phase-fed waveguide arrays have realized drastic cost reduction of fixed wireless access systems in 25 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

The authors have developed single mode waveguides and oversized waveguides for potentially mass producible planar arrays [1][2]. 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. 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 $\pi$-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]. 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 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. 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 a 21 dB post-wall array are realized [8].

## 3. COMPACT WIRELESS TERMINAL FOR WIRELESS IP ACCESS SYSTEMS

As an commercial application of the alternating phase fed arrays, a compact wireless terminal with a high gain planar array has been developed for the 25GHz Wireless IP Access System (WIPAS), which is a point-to-multipoint FWA (fixed wireless access) system in Fig.3 and Table 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 a 31dBi-gain high-efficiency antenna with a 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 24V 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. 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 an IF balun, a multiplicator, a RF amplifier, and a frequency converter in one chip, while converters on the market usually acts as only a 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 in 60 GHz band transmitting video signals need a high rate of several giga bits per second (Gbps). Moreover, it requires drastic cost reduction of millimeter-wave hardware. High performances such as phase-noise less than -90 dBc/Hz at 100 kHz off-carrier frequency and wide band characteristic 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 a resonator of the VCO, a filter, an antenna and a 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]. A novel self-heterodyne system technology is proposed [10][11]. The completed cost-effective 60-GHz module with a post-wall planar antenna is shown in Fig.5. A 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 DC power supply and IF signals are placed at the edge of the board and are inserted to a connector. The post-wall planar antenna is formed on the backside of the print-circuit board [7]. It has an aperture size of 26 x 23 mm$^2$. Measured frequency characteristic of the gain is shown in Fig.6. The thickness of the print-circuit board is 1.2 mm. A gain of 20 ± 1.5dBi is obtained in a frequency range of 60 - 62.5GHz.

## 5. CONCLUSIONS

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

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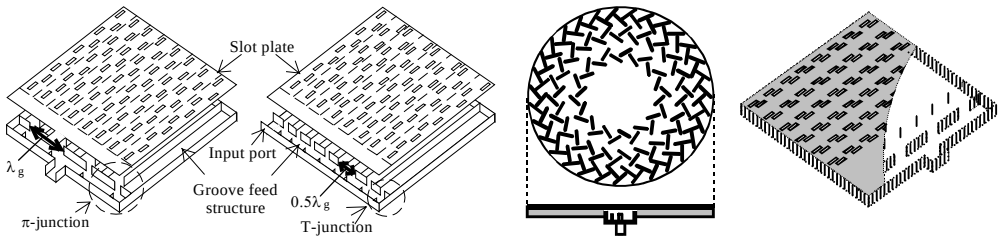


| Modes | Single-mode | | Oversize | |
|---|---|---|---|---|
| Structure | Co-phase(Co) | Alternating-phase(Alt) | Stacking Substrate RLSA | Post-wall Waveguide |
| Applicability for millimeter wave | ○ 76GHz 35.5dBi, 64% | △ 26GHz 32.4dBi, 60% | ○ 60GHz 32dBi, 55% | ○ 60GHz 27dBi, 59% |
| Antenna input 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

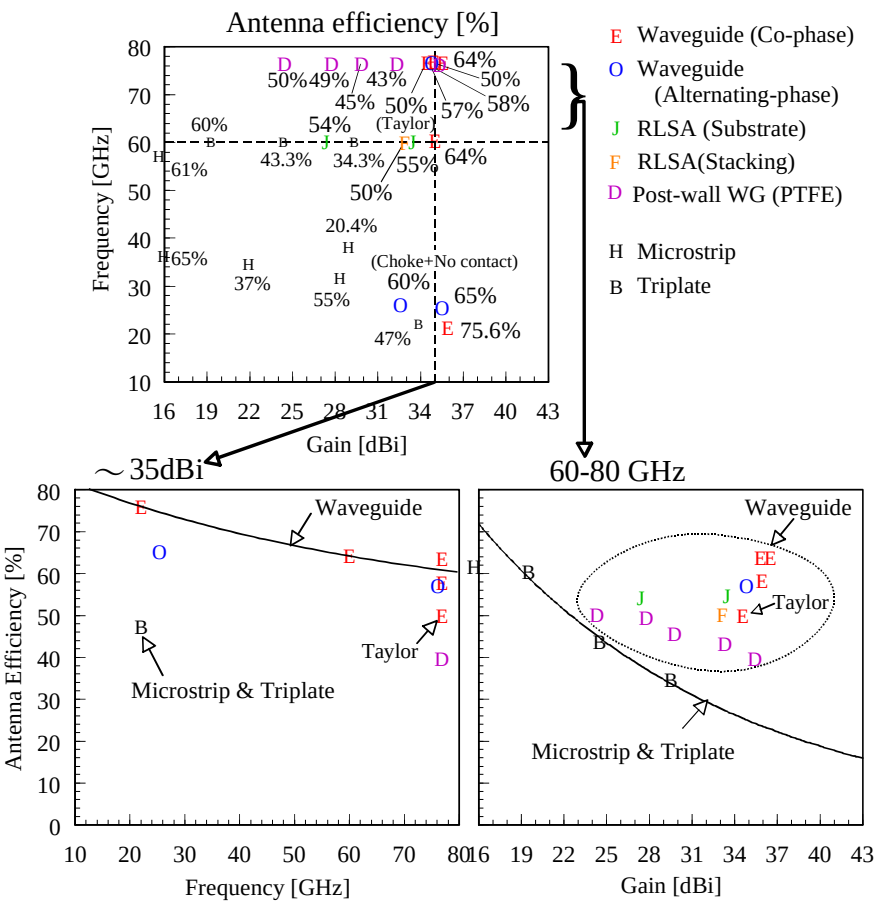


**Fig.2** Efficiency of four-types of single-layer slotted waveguide arrays VS. frequency and gain

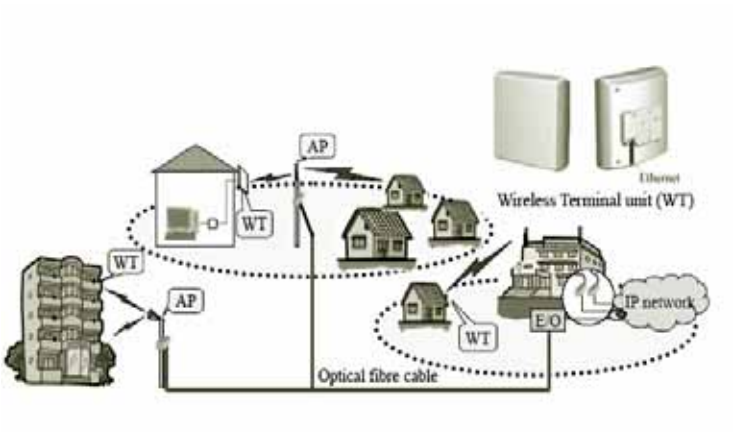


**Fig.3** Configuration of Wireless IP Access System (WIPAS)

Table 1 WIPAS main specifications.

| | | |
|---|---|---|
| Frequency band | | 26 GHz band |
| Transmission | | TDD/TDMA |
| Modulation | | QPSK or 16QAM |
| Transmission capacity | | QPSK: 40 Mbit/s<br>16QAM: 80 Mbit/s |
| TX power | | QPSK: 14 dBm<br>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)<br>Sector (90 degrees, 12.0 dBi)<br>Horn (90x90 degrees, 5.5 dBi) |
| | WT | Planar (31.5 dBi) |

**Table 1** WIPAS main specifications

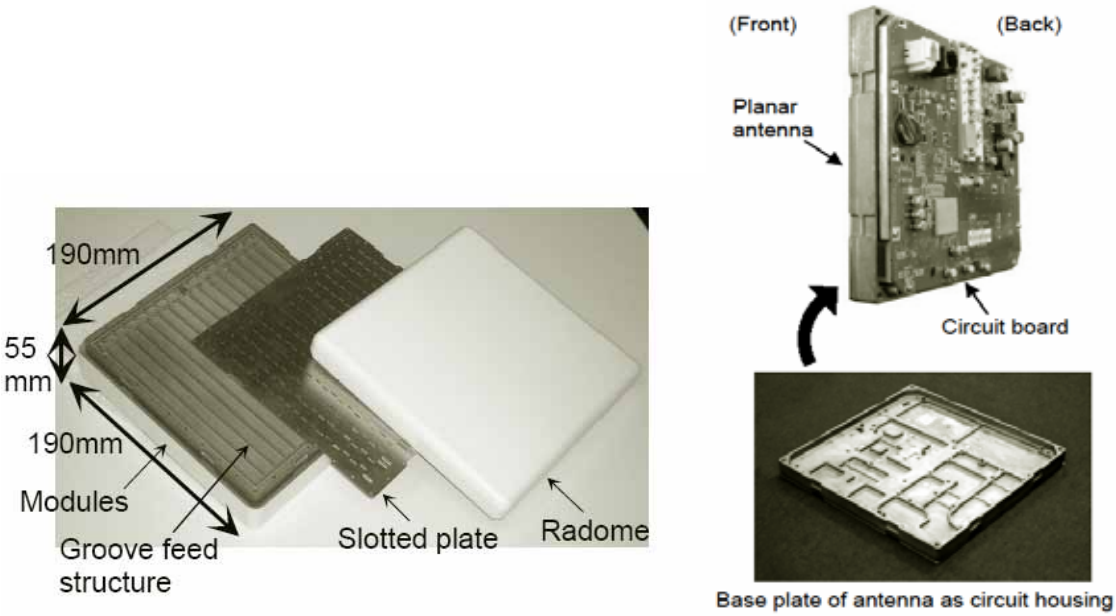


**Fig.4** Assembly of Wireless Terminal (WT) and an alternating-phase fed single-layer slotted waveguide array

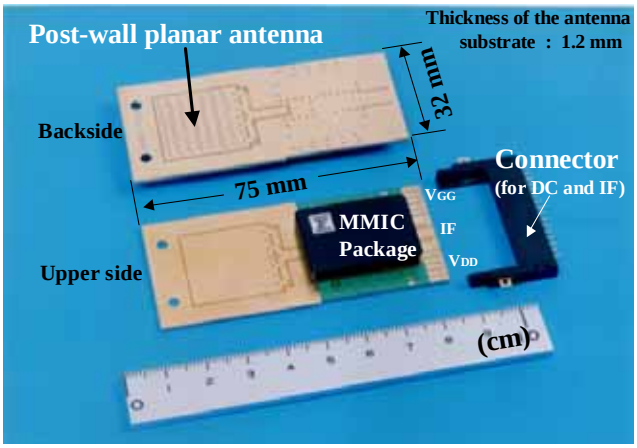


**Fig.5** Completed cost-effective 60-GHz module with a post-wall planar antenna.

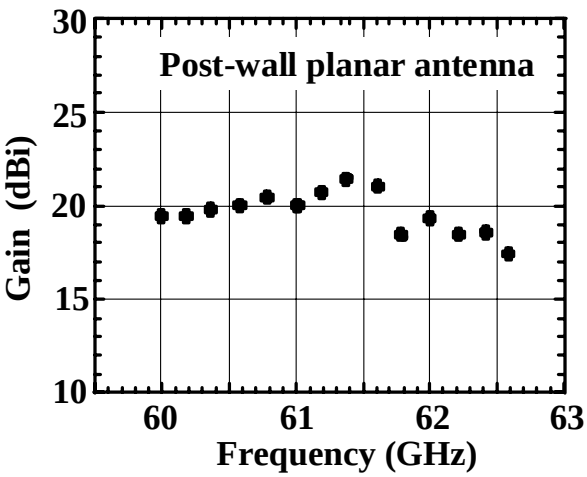


**Fig.6** Measured frequency characteristics of the antenna gain