Antenna Solution for Future Communication Devices in mm-Wave Range

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Abstract - **Different type of printed antennas for millimeter ranges like: high gain (narrow beam) with linear and circular polarization, sector antennas with azimuth angle of 60^0, 90^0 and 180^0, omnidirectional antennas are proposed. All type suitable for integration with active microwave and millimeter wave like amplifiers, down and up convectors. Also, proposed sector and omnidirectional antennas are practically applicable for lower microwave range of 5 GHz that is included in new generation of communication systems for 60 GHz range.**

Keywords–**antennas, linear polarization, circular polarization, omnidirectional antennas, antenna arrays**

I. Introduction

The recent user demands for broadband wireless communications are tracing a new era, of future commercial communication devices in mm-wave range. 60 GHz non-licence frequency band offers world-wide wideband operation. Due to the spectrum availability (5-7 GHz) a variety of the short range high data rate applications may be targeted, in the scope from analog wideband transmission, up to digital GBit/s system solutions. Possible application scenarios in Fig. 1(a,b,c) are setting functional requirements on antenna systems. In Fig.1d [7,8] vision of the future high data rate communication system in mm-range in combination with microwaves (about 5 GHz) is presented. Related antennas have to be capable to offer both wide-angle and high gain operations, depending of the application. In past mm-wave metal antennas, dielectric lens antennas are elaborated in references [1-3], respectively. However the chance to integrated the chips with this antenna for forming active antenna systems was hardly offered. In this paper solutions for both wide angle antennas and high gain antennas are presented.

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Linear and circular polarised antennas are addressed providing specific properties like low cost technologies and ability to be easy integrated with front end on the same substrate. Proposed technologies may be easily applied for any other low cost application in microwave and mm-wave range. As a result we may conclude that classic high gain antennas [4], shaped uniform coverage low gain antennas, omnidirectional antennas [5], high gain with narrow beam in elevation and wideangle in azimuth antennas may be required [6]. Circular polarisation may be in specific cases advantageous. Concepts for linear polarized 60 GHz antennas with high gain, circular polarized antennas with conical beam characteristic, high gain circular polarized antennas, and wideangle high gain antenna with 60, 90 and 180^0 coverage in azimuth are explained. Concepts are verified by simulation and prototyping. Bandwidths up to 40% are measured enabling tolerance insensitive low cost manufacturing. Proposed approaches may be good step for the future low cost mass production sub-systems in different mm-frequency range, specially in 60 GHz range, enabling high data rate short range in-door and out-door applications.

II. Linear polarized high gain printed antennas

In the Fig.2a prints (upper side of the substrates) of the 60 GHz linear polarized printed antenna are presented [4]. Symmetrical prints are provided at the lower part of the substrate, which is around one forth distance from reflector. The key features of the proposed approach are:

- Wideband radiation pentagonal dipole like radiation elements
- Usage of the tapered balanced microstrip feed lines instead of quarter-wave transformers, in order to ensure non frequency selective behaviour
- Radiation quality almost not depended on substrate where the prints are, enabling integration of the microwave and millimeter wave active and passive circuit directly on the same substrate.

Fig, 2b shows measured input reflection loss, showing around 40% operation bandwidth, which allows very low cost tolerance independent manufacturing process. In the figure Fig. 2c, measured antenna diagrams may be observed. Side-lobs are due to the uniform feed 13 dB less than main beam. Antenna gain remain almost the same (+/- 1 dB) in the region 50 to 75 GHz. Classic photolithographic process is used on 17μm metalization, on ε_r=2.17, h=0.127 mm soft substrate. Table shows measured antenna gains for 64 and 256 antenna elements. Please note that transition to the WR-15 waveguides, and mechanical flange were realised only for testing purposes and they were not sufficiently optimised. So for actual antenna with integration with front end, we may expect around 2 dB more gain. Waveguide transitions may be hardly acceptable for commercial low cost applications. Measured cross polarisation is for both kind of prototypes in the range of –29 dB to –37 dB. The actual size of the prototypes were (3.5 X 3.5 cm, 7 X 7 cm) for 64 and 256 elements, respectively. After detailed analyses, it was confirmed that losses in dielectric are 3-4 dB. Smaller losses, 2-3 dB higher gain than in Table 1. are expected, using pure teflon dielectric substrate (tg $\delta<4\cdot10^{-4}$).

TABLE 1
GAIN

Freq. [GHz]	8x8 elements [dBi]	16x16 elements [dBi]
59.05	19.7	23.8
61.50	19.7	24.0
63.95	19.6	24.3

III. ULTRA-WIDE AND MEDIUM-ANGLE HIGH GAIN ANTENNA

This antenna has to provide ideally 180, 90 or 60 degree coverage in azimuth plane and simultaneously narrow angle in elevation. The basic outlook of the proposed antenna concept may be observed in the Fig.3. We are proposing a piece of dielectric substrate with printed antenna elements (two side print) placed between the bended reflector plane. Each dipole has an input impedance of around 100 Ohm, so that the feeding network has to provide (taper like) transition from microstrip line to balanced microstrip line of the 50 Ohm impedance. In the end of feeding network there are bal-un for transmission between balanced and unbalanced microstrip line. It should be denoted that one half of the pentagonal dipoles are printed at one side of the dielectric and opposite side of dielectric back. Distance between dipoles is 0.85 λ. Design has to include gaps (holes in bended reflector). This is required in order to suppress possible discontinuities by changing impedance of the balanced microstrip line by passing from one to another side of the bended reflector. From another prospective those holes has to be small enough not to influence radiation diagram, so trade of has to be applied. The main design feature is that changing angle of the reflector bend azimuth antenna coverage is influenced, so we are able to design different antenna. Approximately following may be considered:

- For angle of around 45 degrees, diagram is around 60 degrees
- For plane reflector 180 degrees, diagram is around 90 degrees
- For angle of around 270 degrees, diagram is around 180 degrees

The concept is verified at scaled frequency in 2.4 GHz and 10.5 GHz, due to the easier measurement for version with beamwidth of 180^0, gain of 10 dBi is confirmed as well as operation bandwidth of 37%, for VSWR less than 2. There is almost no significant variation of the gain in the whole frequency range. Simulated radiation pattern in azimuth plane and in elevation plane is presented in Fig.4a and Fig.4b. The measured results for radiation pattern is practically same as simulated. Prototype VSWR measurements is presented in Fig.4c. Verification of the concept and obtained bandwidths confirm possibility of low cost 60 GHz application capabilities with integration of the frond end at the same substrate. Included radome, antenna diameter may be around 0.5 cm at 60 GHz

IV. CIRCULAR POLARIZED ANTENNAS

The circularly polarized antennas are particularly interesting for communication scenarios where. Besides that there is no need for the antenna orientation, the special advantage of the circularly polarized antennas is their feature of additional physical attenuation of reflected waves (due to polarization direction changing) which makes propagation channel much better and the overall system more resistant in the case of multipath propagation. There are two major application areas where circularly polarized antennas with conical antenna characteristics are required:

- Uniform coverage problem (base station or remote station antenna for indoor application. In this case, varied attenuation which is due to different communication distances is compensated by antenna pattern.
- Outdoor application where land mobile platform communicates with stationary satellite (land mobile platform antenna Fig.5), where the maximum gain in the specific direction targets geostationary satellite.

V. OMNIDIRECTIONAL ANTENNA WITH CONICAL RADIATION PATTERN

We have presented a printed antenna with circular polarization having a conventional radiation pattern (maximum at θ=0°) in [9]. This antenna consisted of two crossed dipoles, (1) and (2), (Fig.6) whose impedances were complex-conjugated: $Z_{D1}=(50\text{-}j50)\Omega$ and $Z_{D2}=(50+j50)\Omega$, so the pure circular polarization was obtained (AR=0 dB). Dipoles were fed in parallel (Fig.7), so the total impedance of the antenna was $Z_A=(50+j0)\Omega$. Distance between the dipoles and the reflector plate was λ/4, so the conventional radiation pattern with a maximum at θ=0° was obtained in [9]. However, it is possible to achieve conical radiation pattern with a minimum at θ=0° by increasing the distance between the reflector plate and printed crossed dipoles. Depth of the minimum increases with increase of this distance up to λ/2 when the minimum theoretically becomes infinite, Fig.8. Certainly, it is necessary to make corrections of dipoles' dimensions for each distance of the reflector plate as well as of the feeding line length l_2 that enters between the strip of dipole (2) in order to obtain required values of complex impedances of crossed dipoles (1) and (2), i.e. pure circular polarization and minimal VSWR.

We have obtained radiation patterns in horizontal and vertical planes by simulation at frequency of 4.5 GHz (Fig.9a and Fig.9b) for the required minimum depth (at $\theta=0°$) of about 12 dB (for indoor application, Fig. 1a) and maximums at $\theta\approx\pm 60°$. Parameter S_{11} is shown in Fig.10a, while axial ratio (AR) is presented in Fig.10b. Crossed dipoles are realized on a thin dielectric substrate of Teflon-fiberglass (ε_r=2.17, h=0.127 mm). Feeding line-balanced microstrip is also realized on the dielectric substrate of the same characteristics. Under the antenna plate, at the distance of 0.47λ, there is a reflector plate and polyurethane foam between them. Measured VSWR and radiation pattern of the realized antenna are presented in Fig.11a and Fig.11b, respectively. Axial ratio is less than 2dB in (4-5) GHz frequency range.

VI. HIGH GAIN CIRCULAR POLARIZED ANTENNA

Array of slot like antennas with microstrip line feeding systems with reflecting plate seems to be a good candidate 60 GHz applications. Due to the fact that feeding is on opposite side of the metalized structure between substrate and reflector, feeding network theoretically may not disturb the radiation pattern. Two type of the slot structures are investigated, one with double spiral like type of the elements and second with V type of the slot elements. In Fig.12a typical spiral like slot element (scheme and 10x down scaled prototype) and in Fig.12b V-slot elements (outlook and 10x down scaled prototype) are presented. Note that down scaling is performed in order to ensure dielectric thickness of 0.127 mm for 60 GHz antenna. Approximately both of the approaches are providing according to the simulation between 15-20% of the bandwidth (VSWR less than 2) and about 8% for axial ratio better than 3 dB. In the Fig.13 simulation results of radiation pattern for ϕ=0. 30, 60 and 90^0 for array of the 4 X 4 spiral elements at 60 GHz are presented. Radiation pattern looks approximately the same in the whole frequency range from 55 to 66 GHz. Antenna diagram is slightly rotated from zero to 90 degrees showing that axis in the main antenna beam are remaining the same (satisfactory axial ratio). Side lobes at specific positions for angle relatively far from the main beam are mainly with relatively high AR, which is not significant issue for the system performance. The typical solutions bottlenecks are that circular polarized structures if they are realized by slots may need to have larger tolerance dependency compared to liner polarized solution presented in this paper. In Fig.14 realized array of 8x8 (64) double slot spiral antennas is shown.

VII. CONCLUSION

Results of research on antennas and antenna systems for future mobile communication systems with high capacity in millimeter (around 60 GHz) and microwave range (around 2.4 GHz and around 5 GHz) are presented. Results include: antennas and antenna systems with linear and circular polarization, omnidirectional antennas with conventional and conical characteristic, sector antennas with various beam widths (60, 90 and 180^0) and high gain antenna arrays (8x8 and 16x16 elements) with linear or circular polarization. Measured results for most realized models are in good agreement with the simulation.

Special research was done to integrate metioned antennas with other millimeter and microwave circuits (low noise amplifier, down- and up-converter, power amplifier etc).

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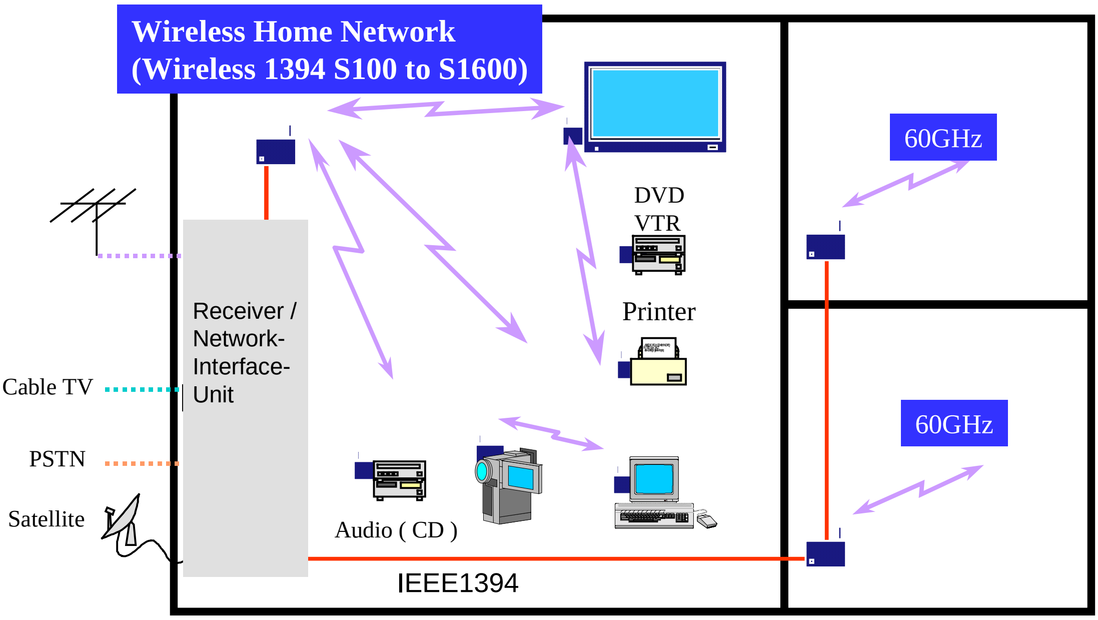


Fig.1a Possible in-door home application scenario for both analog and digital application

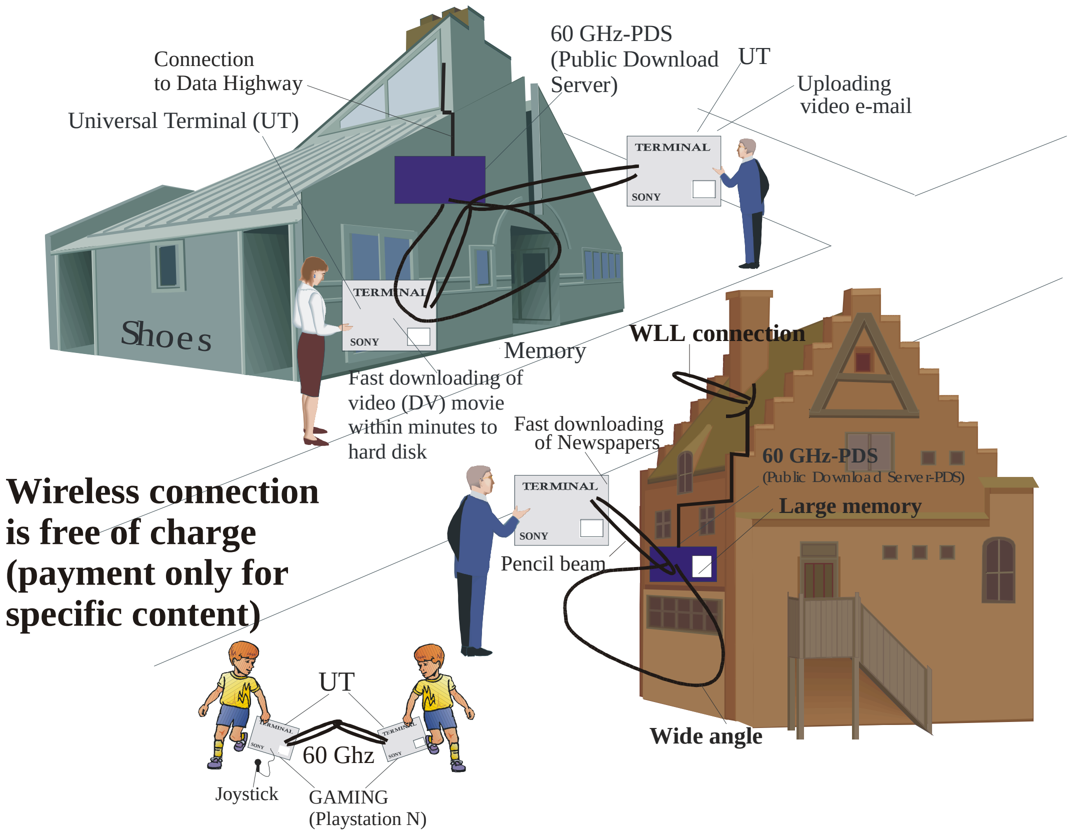


Fig.1b Possible out-door application scenario for fast downloading and uploading and free of charge broadband internet in urban areas

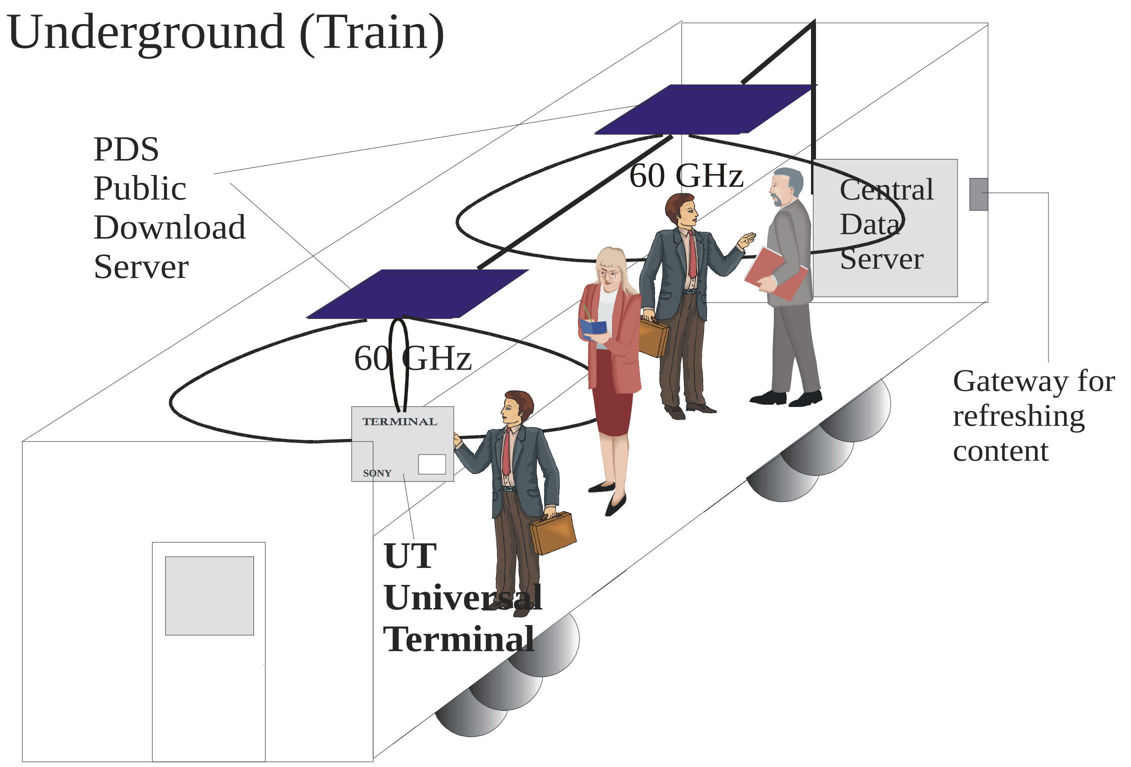


Fig.1c Semi-out-door application for underground. Note that the same approach is for airport, large halls and corporate office scenario

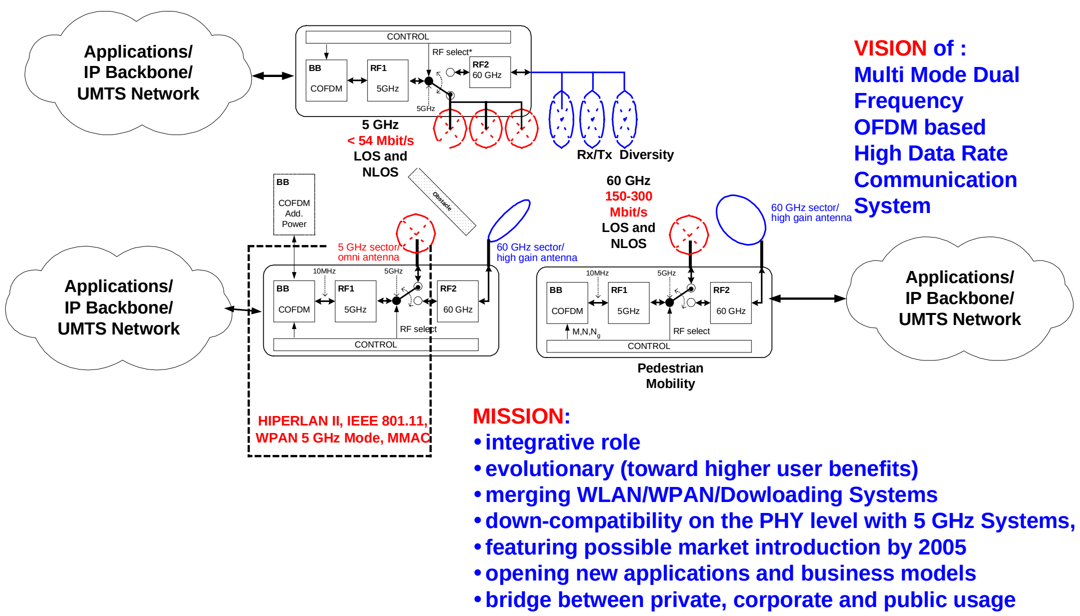


Fig.1d Vision of 60 GHz communication system as evolution of current WLAN and WPANs in 5 GHz range, allowing their next generation. The system is able to operate in both RF and IF range according to preferences

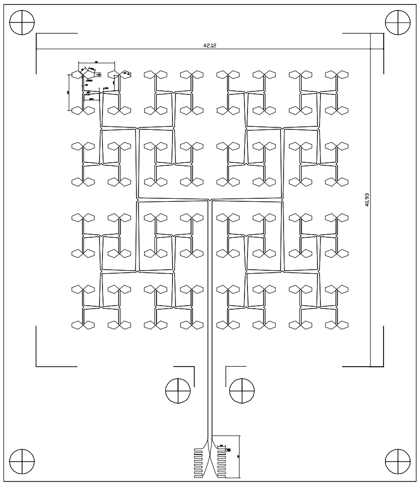


Fig.2a Projection of the linear polarized high gain antenna array prototype prints for 60 GHz range

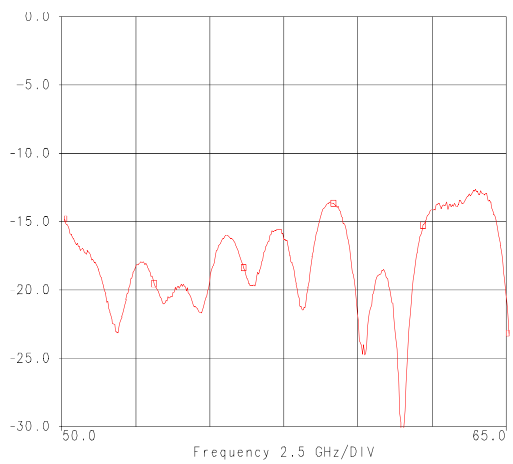


Fig.2b Measured input reflection loss of linear polarized high gain antenna array for 60 GHz range

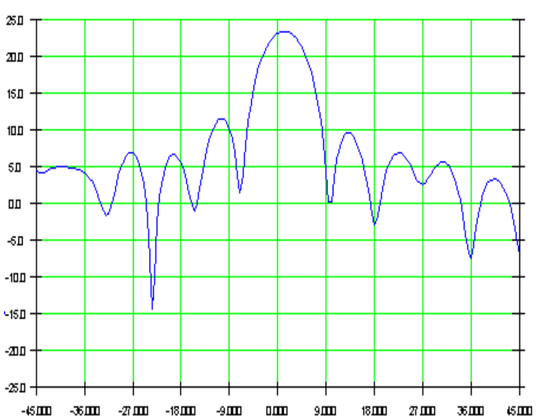


Fig.2c Measured antenna diagram (60 GHz), dBi

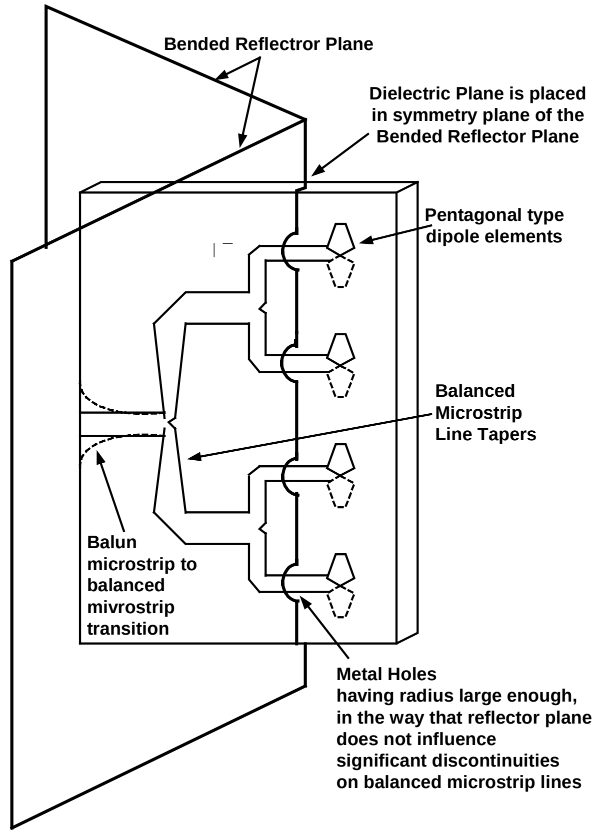


Fig.3 Side outlook of the antenna structure with beam width of 180^0 in azimuth plane

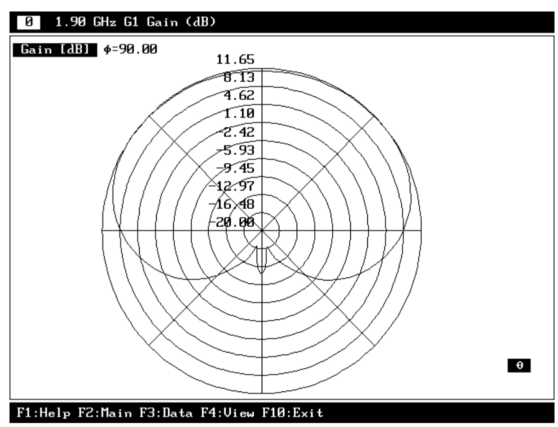


Fig.4a Simulated antenna diagram in azimuth plane, dBi (no loss)

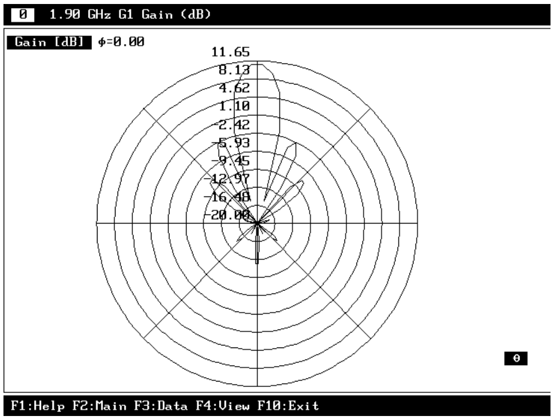


Fig.4b Simulated antenna diagram in elevation plane, dBi (no loss)

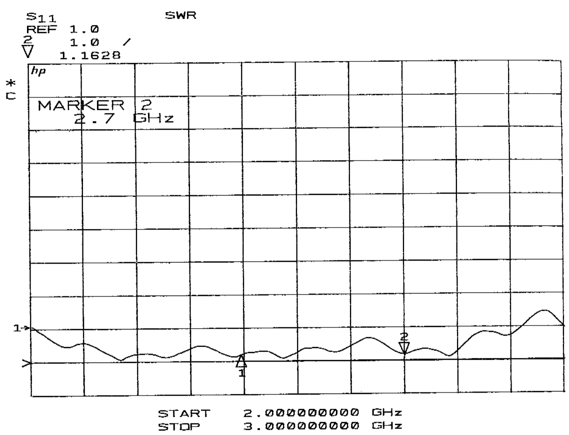


Fig.4c Measured VSWR of antenna with beam width of 180^0 In azimuth plane

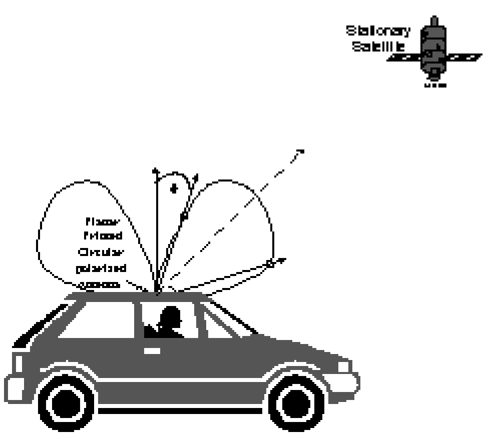


Fig.5 Targeting a geostationary satellite

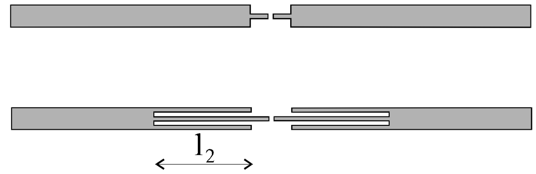


Fig.6 Pair of dipoles with conjugated impedances

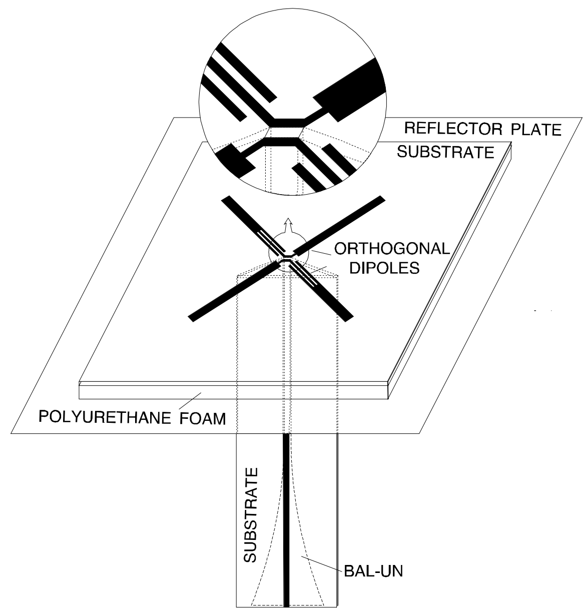


Fig.7 Two orthogonal dipoles fed by balanced (symmetrical) microstrip which form antenna for circular polarization

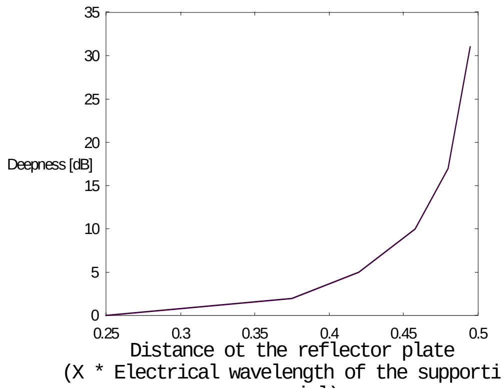
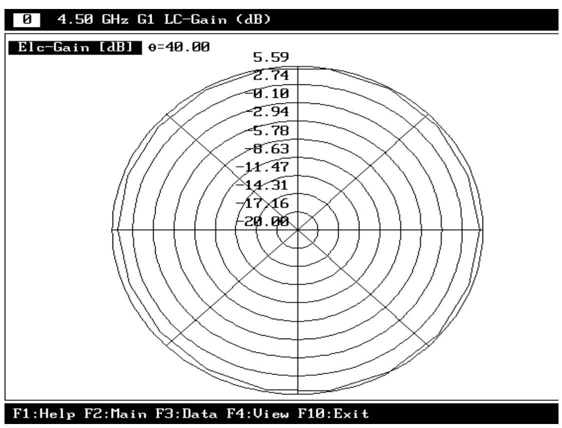
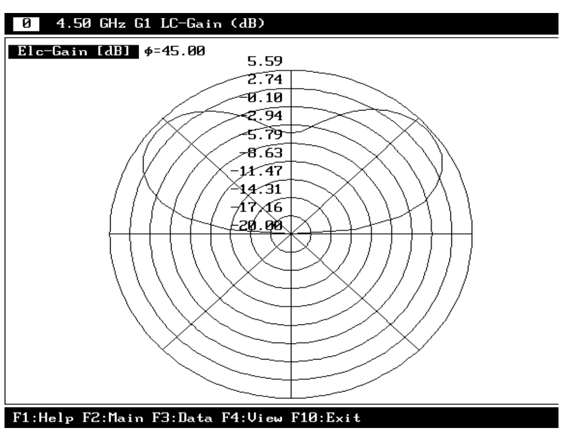


Fig.8 Deepness of the radiation pattern vs. distance of the reflector for omnidirectional antenna with circular polarization



a) in horizontal plane



b) in vertical plane

Fig.9 Simulated radiation pattern with depth of the minimum of 12 dB at θ=0° for omnidirectional antenna with circular polarization and conical radiation pattern

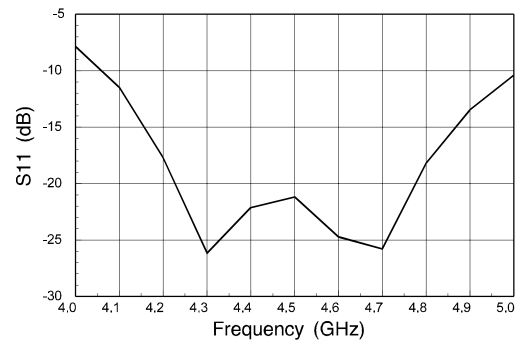


Fig10a Simulated S_{11} vs. frequency for omnidirectional antenna with circular polarization and conical radiation pattern

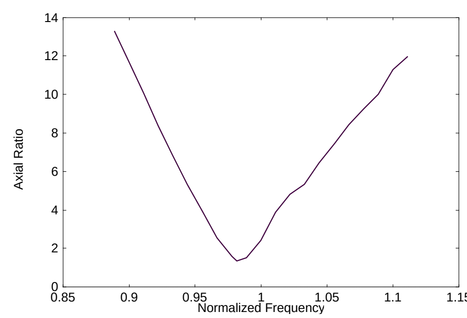


Fig.10b Simulated axial ratio vs. frequency for omnidirectional antenna with circular polarization and conical radiation pattern

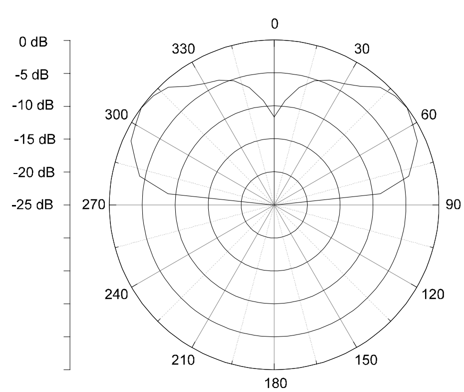


Fig.11a Measured radiation pattern for omnidirectional antenna with circular polarization and conical radiation pattern

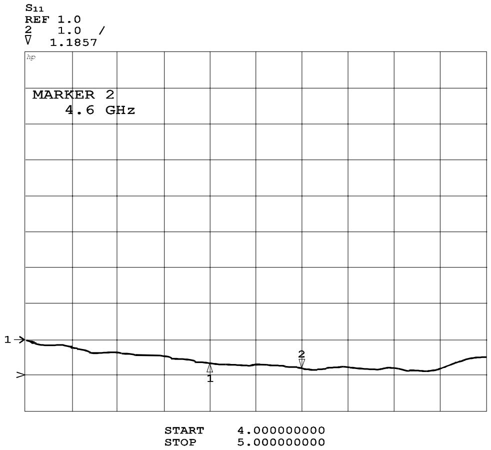


Fig.11b Measured VSWR vs. frequency for omnidirectional antenna with circular polarization and conical radiation pattern

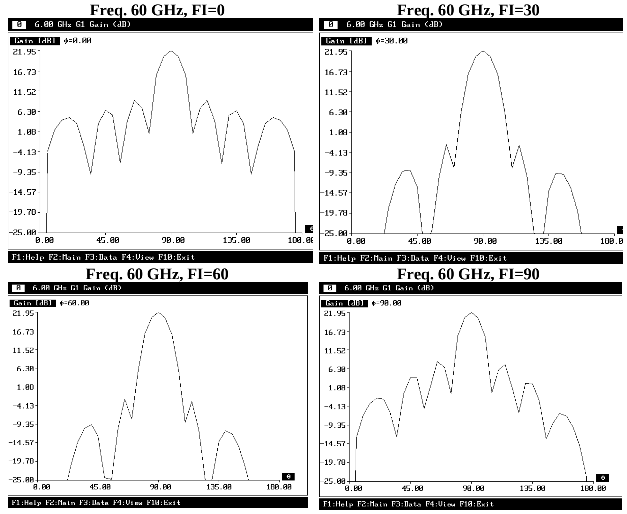


Fig.13 Simulation of 60 GHz 4x4 elements circular polarization antenna diagram, having spiral slot elements of Fig.12a

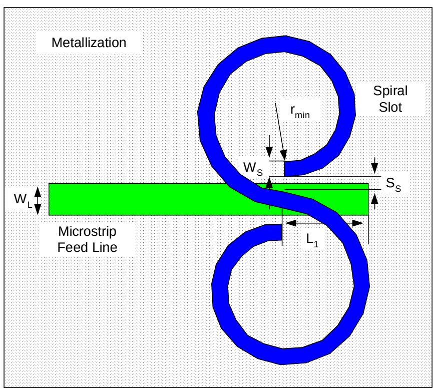


Fig.12a Spiral slot antenna prototype for circular polarization

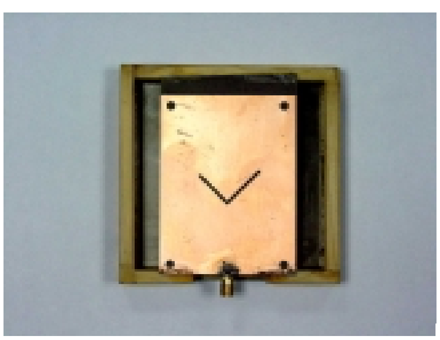


Fig.12b V-slot antenna prototype for circular polarization

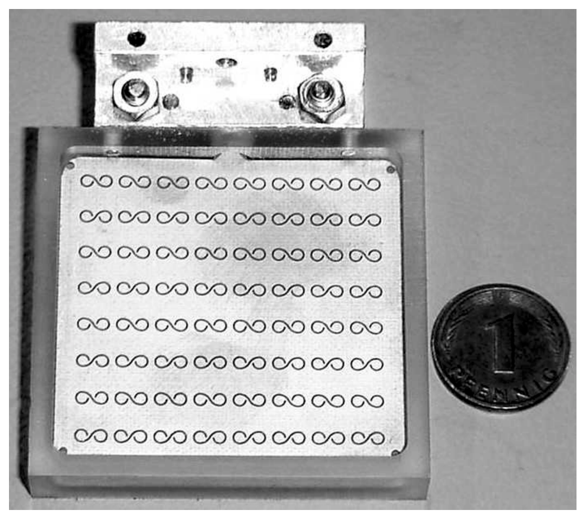


Fig.14 Antenna array with 8x8 slot radiating elements with circular polarization for 60 GHz band