Two-dimensional Microwave and Millimeter Planar Antenna Arrays with Circular Polarization and High Gain

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Abstract – **A new concept of the two-dimensional planar antenna arrays with circular polarization is introduced with practically application in the whole microwaves and in millimeter waves up to 110 GHz. Dipoles (radiation elements), feeding network and connector are on the same dielectric substrate. Symmetrical microstrip is used instead of the classical microstrip to form radiation elements on both sides of the substrate. It also obtains wider frequency band and smaller losses as results of suppression of coupling of the feeding network. Simulations were done for arrays 4x4 and 6x6. Array 4x4 around 15 GHz and array 8x8 around 60 GHz were fabricated and measured. Fabrications were done in standard photolithographic process for printed circuit board. Axial ratio (AR) < 3 bandwidth is 17% with gain around 16 dBi and 25% with gain near 20 dBi respectively for 15 GHz and 60 GHz array. Simulations are in a relative agreement with measurement.**

Keywords – **Planar Printed Antenna, Circular polarization, Symmetrical microstrip, High gain, Millimeter waves.**

I. Introduction

Last two decades there is a serious work in research of antenna arrays with circular polarization in microwaves and millimeter waves [1]. It is a solution for a rapid development of mobile communication (the fifth generation (5G) mobile network), satellite and military communication and radar systems [2-4].Recent results in the field of circularly polarized millimeter wave antenna arrays are described in [5-8].

Circular polarized antennas with dipoles in the shape of rings were early reported in [9,10]. However, they have the drawback not to be applicable for high gain application and in the case of [9] not planar feeding. One of the most useful antenna solutions with rings will be described here. It is a new idea and a same specific unusual concept in wide frequency range, from UHF to millimeters around 110 GHz. The concept is a planar structure realized in technique of symmetrical microstrip (also known as double sided or balanced microstrip) that avoids ground metallization in the classical microstrip. Avoiding ground metallization and symmetrical structure obtain smaller parasitic coupling. Impedance transformers are tapered symmetrical microstrip lines that produce smaller loses than in classical microstrip.

The concept was developed from a simple dipole and spreading from 2x2 to 8x8 two-dimension (matrix) antenna array with an idea to extend to 16x16 and 32x32. Simulation results are presented for 4x4 and 6x6 cases. Detailed measured results are presented for matrix array 4x4 around 15GHz and for 8x8 around 60 GHz. In order to test reproduction of smaller tolerances for millimeter wave structures three 8x8 same matrix arrays were fabricated [11]. Three antenna arrays with the same initial dimensions were fabricated. They are measured for identical antenna parameters from 50 GHz to 70 GHz. The measured parameters are in an agreement between all three samples.

Unlicensed band around 60 GHz is chosen according to a rising interest in the band with more than 7 GHz of spectrum. It has a rising application in the short (indoor) communications as announced in standard IEEE 802.11ad (WiGig) and 5G wireless communications [12-15]. It has also many aspects of the industrial applicaton, including machine vision, surveillance and medical equipment [16]. The reason of two-dimensional (matrix) array is using beamforming to form narrow beams in 60 GHz spectrum, allowing for other products to use even the same channel at the same time [12, 14].

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II. Concept

A. The Basic Dipole

The basic antenna dipole, Fig. 1, consists of two open rings on the opposite sides of a dielectric substrate. Feeding lines are in the symmetric microstrip technique with lines on both side of the substrate. Metal reflector is located approximately on distance $\lambda_0/4$ from the substrate, as presented in Fig. 1.

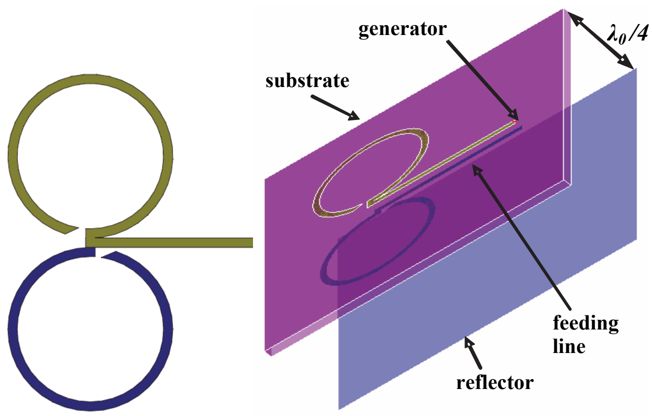


Fig. 1. The basic antenna dipole and reflector

B. Two-dimensional Antenna Array and Feeding Network

Two-dimensional antenna array is needed to generate relatively high gain narrow radiation pattern with central axial-symmetry. An example of a simple two-dimensional 2x2 antenna array is presented in Fig. 2. Feeding now needs to transform to a feeding network. In the introduced antenna concept feeding network is realized as a symmetrical microstrip, like feeding line in Fig. 1. It has smaller parasitic coupling according to the symmetrical structure.

Impedance transformation is realized using tapered symmetrical microstrip lines as impedance transformers, Fig. 3. It produces smaller loses than in the classical microstrip tapered transformers.

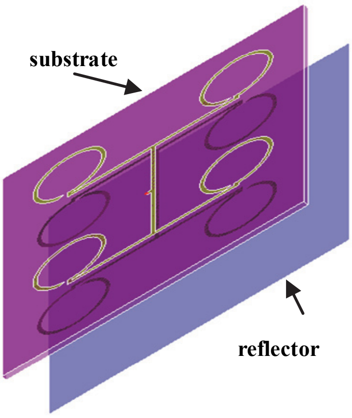


Fig. 2. Basic concept of a simple 2x2 two-dimensional antenna array with a reflector

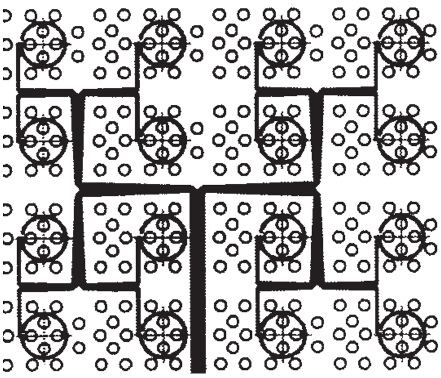


Fig. 3. An example of the feeding network: Upper side. Impedance transformers as tapered symmetrical microstrip lines

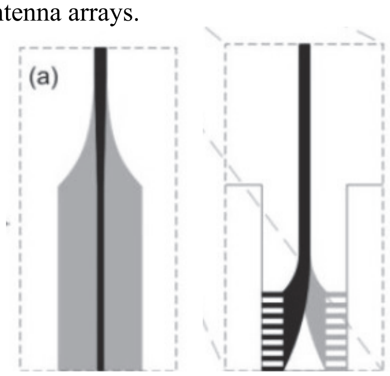
C. Differences in Structure According to Working Frequency

The same basic concept is for all frequencies and it is the main advantage of the introduced concept. Some differences, beside dimensions, are according to desire frequency band: thickness of the substrate and transition to generator. Lower dielectric constant is desirable to fit appropriate distance between radiation elements.

Higher frequencies need thinner substrates to suppress unwanted higher modes and surface waves. Lower frequencies use bal-un transition from symmetrical microstrip to classical microstrip and to SMA connector, Fig. 4a. Millimeter frequencies, over 30 GHz, need special transition from symmetrical microstrip to waveguide, Fig. 4b.

III. Design and Fabrication

Antenna structure is fabricated in planar technology on one substrate. Both metalized sides, upper and down, are etched to follow symmetrical microstrip technology. Metal reflector is located approximately on distance $\lambda_0/4$ from the substrate. Distance between dipoles is chosen according to the optimal radiation pattern. Dielectric substrate is teflon fiberglass with ε_r = 2.17 or teflon ε_r = 2.1. The thickness of the substrate depends on the frequency band. Higher frequencies need thinner substrates to suppress unwanted higher modes and surface waves. In order to obtain better suppression of the surface waves dielectric substrate is perforated [17] for both fabricated antenna arrays.



a) b)

Fig. 4. Transition from symmetrical microstrip according to frequency (Black-upper side, Gray-down side): a) Bal-un transition; b) Transition to waveguide

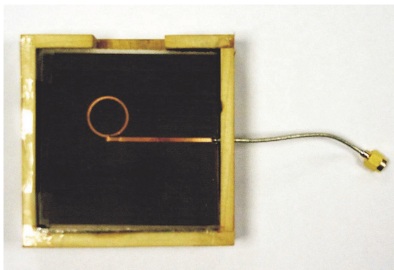


Fig. 5. Fabricated one dipole antenna around 5 GHz (upper side) with SMA connector

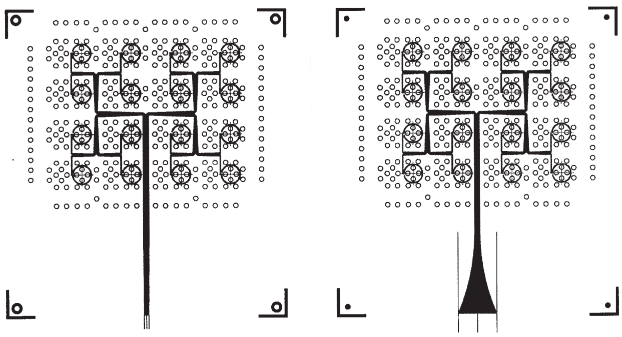


Fig. 6. Lay-out of both sides of 4x4 two-dimensional antenna array around 15 GHz with a bal-un transition

Fabrication of the 4x4 two-dimensional antenna array around 15 GHz was realized on dielectric substrate teflon fiberglass with ε_r = 2.17 and h = 0.508 mm. Dimensions are 6.75 x 8.5 mm. Lay-out is depicted in Fig. 6.

Fabrication of the 8x8 two-dimensional antenna array around 60 GHz [11] is realized in the conventional planar technology on dielectric substrate teflon with ε_r = 2.1. Lay-out is in Fig. 7. The substrate is thinner, h = 0.127 mm, to suppress unwanted higher modes and surface waves. As can be seen in Fig. 8, polyurethane foam (ε_r =1.04) is between the antenna substrate and the reflector. As mentioned earlier, millimeter frequencies need special transition from symmetrical microstrip to waveguide as presented in Fig. 4b (transition to waveguide WR-15 in Fig. 8). Assembled structure in the plastic case and the waveguide connector are shown in Fig. 9.

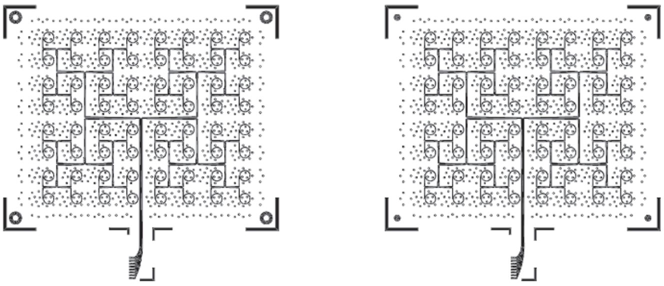


Fig. 7. Lay-out of both sides of 8x8 two-dimensional antenna array around 60 GHz with transition to waveguide

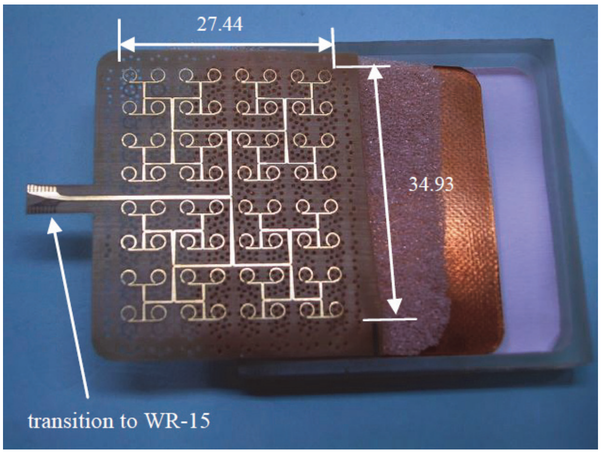


Fig. 8. Fabricated 8x8 two-dimensional antenna array around 60 GHz in parts. From up to down: antenna substrate, polyurethane foam, reflector and plastic case. Opposite open rings and feeding network are on the opposite side of the antenna substrate

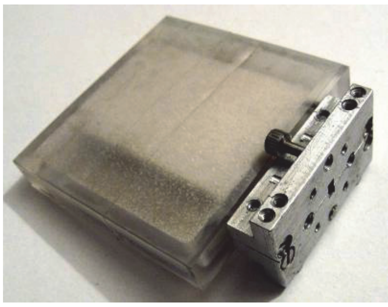


Fig. 9. Assembled 8x8 antenna array around 60 GHz: Plastic case and waveguide connector for WR-15

In order to test reproduction of smaller tolerances for millimeter wave structures three 8x8 same matrix arrays were fabricated [11]. Three antenna arrays with the same initial dimensions were fabricated. They are measured for identical antenna parameters from 50 GHz to 70 GHz. The measured parameters are in an agreement between all three samples. Measured results of one antenna is presented in section IV.

IV. Simulation and Measurement

Measured WSVR and gain of the one dipole antenna around 5.5 GHz, Fig. 5., are presented in Fig. 10. Position of antenna package during measurement is in Fig. 11.

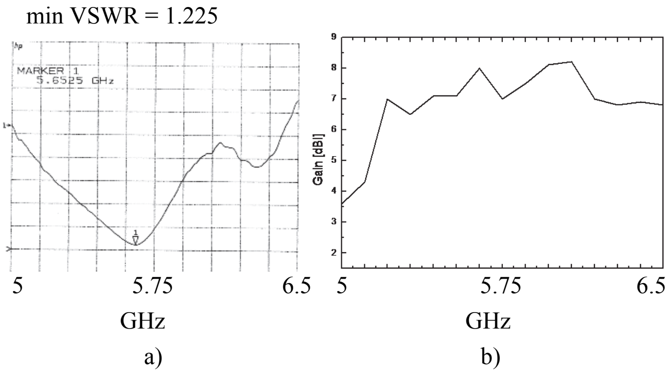


Fig. 10. Measured a) VSWR and b) gain vs frequency of the scaled realized model of the double open ring tapes around 5 GHz

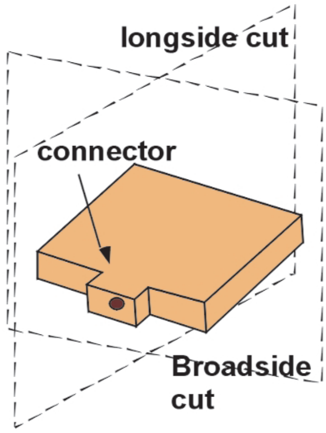


Fig. 11. Position of the antenna package during measurement.

Measured characteristics of the 4x4 two-dimensional antenna array around 15 GHz are presented in Figs. 12-14.

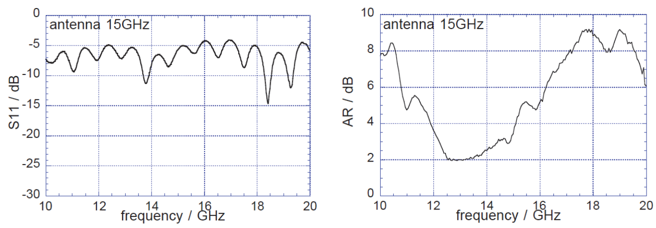


Fig. 12. Measured reflection (S_{11}) and axial ratio (AR) of the 4x4 antenna array around 15 GHz

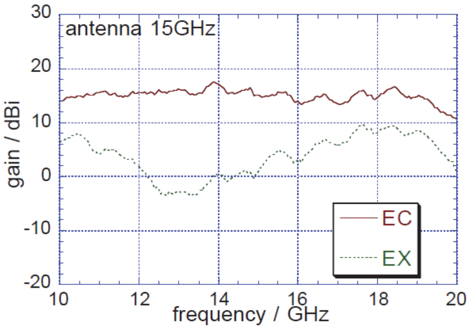


Fig. 13. Measured Gain (copolarization) and attenuation of x-polarization (opposite circulation) of the 4x4 antenna array around 15 GHz

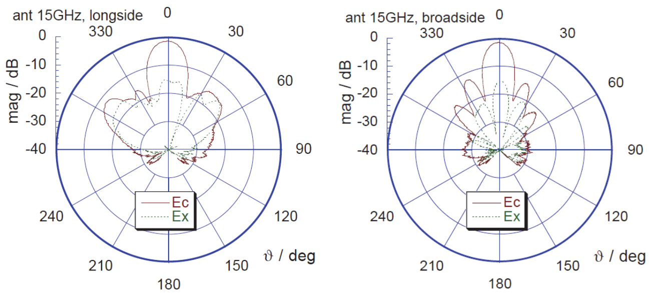


Fig. 14. Measured radiation pattern: long side and broad side cut of the 4x4 antenna array around 15 GHz

Simulated characteristics of the 4x4 and 6x6 two-dimensional antenna arrays around 60 GHz are presented in Figs. 15 and Fig. 16, respectively.

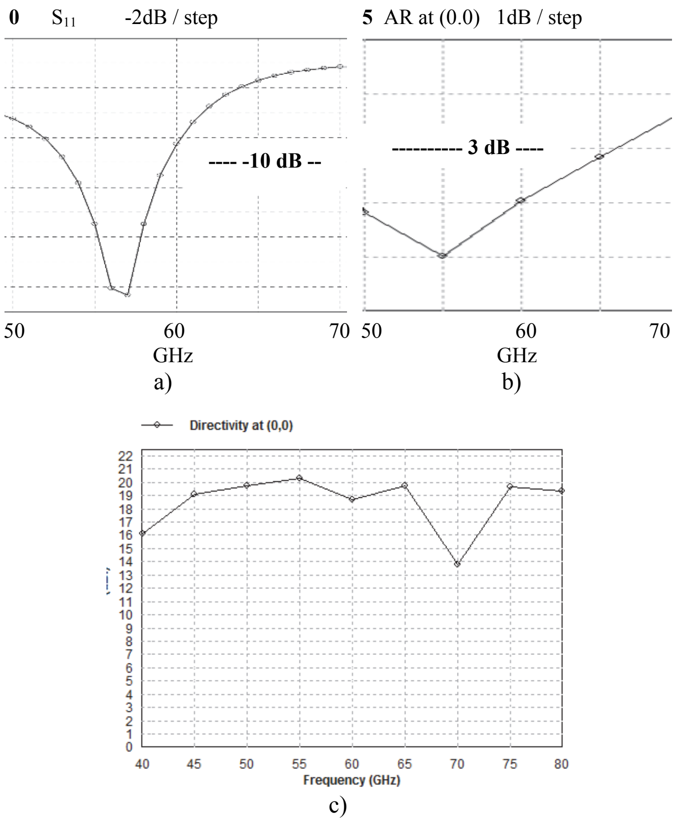


Fig. 15. Simulation results for 4x4 antenna array around 60 GHz: a) S_{11}, b) AR and c) Directivity

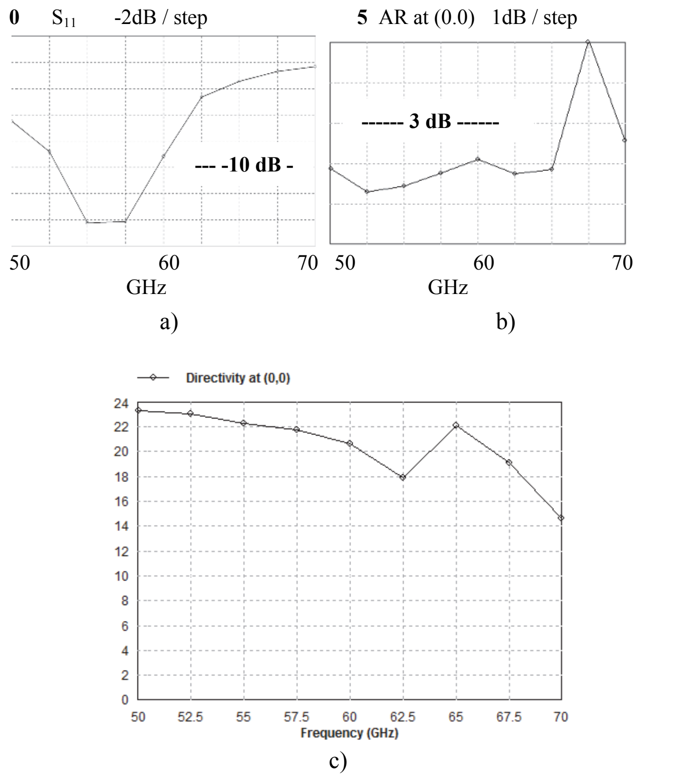


Fig. 16. Simulation results for 6x6 antenna array around 60 GHz: a) S_{11}, b) AR and c) Directivity.

Simulation characteristics of the 8x8 two-dimensional antenna array around 60 GHz are presented in Figs. 17.

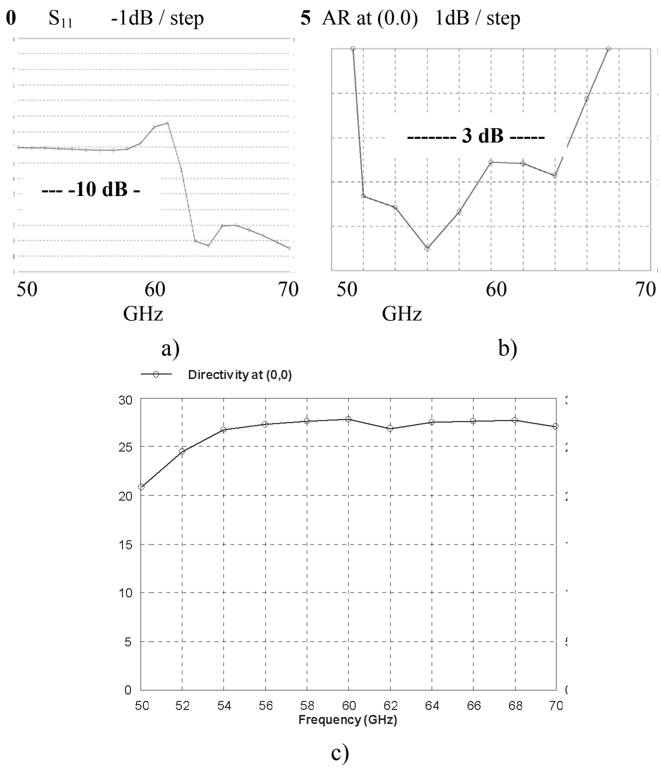


Fig. 17. Simulation results for 8x8 antenna array around 60 GHz: *a*) S_{11}, b) AR and c) Directivity

Measured characteristics of one 8x8 two-dimensional antenna array around 60 GHz are presented in Figs. 18-20.

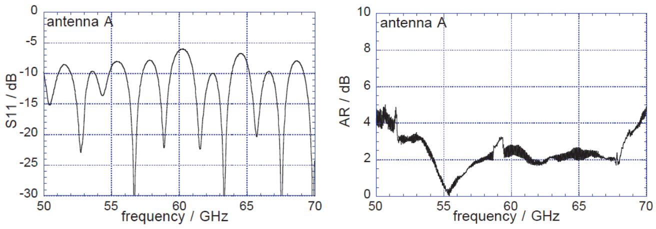


Fig. 18. Measured reflection (S_{11}) and axial ratio (AR) of the 8x8 antenna array around 60 GHz

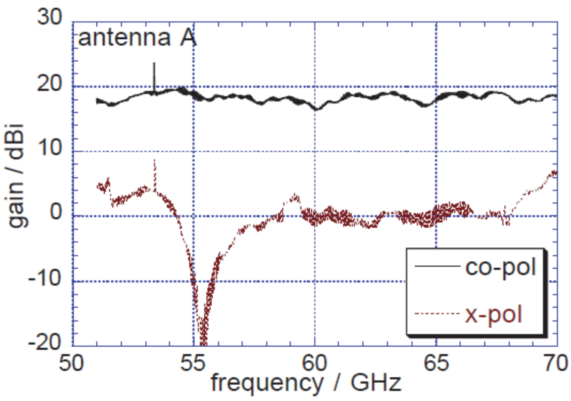


Fig. 19. Measured Gain (copolarization) and attenuation of x-polarization (opposite circulation) of the 8x8 antenna array around 60 GHz

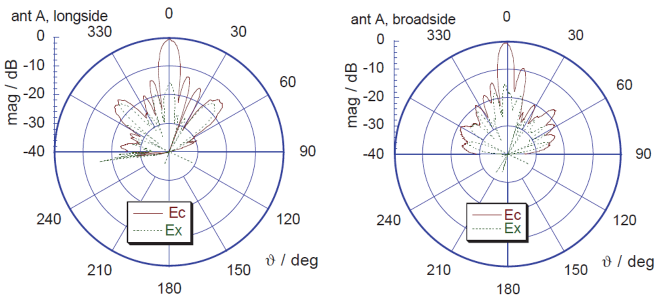


Fig. 20. Measured radiation pattern: long side and broad side cut of the 8x8 antenna array around 60 GHz

V. Conclusion

The concept of the introduced two-dimensional antenna arrays with circular polarization is practically applicable in the whole microwaves and in millimeter waves up to 110 GHz.

All part of the mentioned antenna arrays are fabricated in planar technology on one dielectric substrate. Dipoles, feeding network and connector are on the same dielectric substrate. Symmetrical (double sided or balanced) microstrip is used instead of classical microstrip to suppress coupling and obtain wider frequency band. Impedance transformation is realized using tapered symmetrical microstrip lines as impedance transformers.

Thickness of substrate and connection to generator are different for microwave and millimeter waves. Higher frequencies, millimeter, need thinner substrates to suppress unwanted higher modes and surface waves. The millimeter frequencies need special transition from symmetrical microstrip to waveguide instead of bal-un transition to classical microstrip and SMA connector.

Some, relatively small, disagreements between simulation results are effects of surface waves, polyurethane foam between antenna and reflector, plastic case surrounding the whole array and tolerances in fabrication. The surface waves are suppressed using perforations in the dielectric substrate.

In the field of commercial application it is promising in (5G) mobile network, satellite communication and industry.

Acknowledgement

This work was funded by Serbian Ministry of Education and Science, project TR-32052.

The authors are grateful to I. Radnovic, S. Fizensan and M. Tasic for their help. The authors are also grateful to *Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe*, Germany for high quality measurements.

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