New Printed Antenna Structures Suitable for Millimeter–Wave Ranges

Aleksandar Nešić, and Ivana Radnović

***Abstract*—The paper presents a new class of printed antenna structures that have numerous advantages over conventional microstrip antennas: dipoles operating on or near the second resonance, printed pentagonal dipoles whose shape enables broadbandedness, obtaining wide range of impedances, and reducing parasitic couplings and losses to a great extent due to balanced feeding structure. Various feeding structures are also presented: symmetrical microstrip, coplanar strips (CPS), coplanar waveguide (CPW) as well as the new feeding method of slots on dielectric substrates. Moreover, the paper gives an overview of realized 3D printed antennas: printed antenna structures placed in cylindrical-parabolic or corner reflector. All presented structures are realized on a prototype level and have great number of citations. They could be designed for operations in millimeter-wave ranges which is of great significance due to rising development of 5G radio-communication systems and devices.**

***Keywords*—Microstrip antennas; printed antenna structures; symmetrical microstrip line; coplanar strips (CPS); coplanar waveguide (CPW); printed antenna arrays with 3D reflector surfaces.**

I. Introduction

In the last few decades research, development and application of printed antennas are in great expansion due to a number of advantages over conventional 3D antennas such as low weight, small dimensions, compactness, easiness of fabrication and high reproducibility (owing to use of photolithographic processing), as well as suitability for integration with other passive or active microwave circuits on the same printed board.

Microstrip antennas with patches as radiating elements are the most common type of printed antenna, Fig. 1. Although they are characterized by advantages listed above, patch antennas have several drawbacks: very narrow impedance bandwidth, high losses in feed networks, i.e. low efficiency (especially in antennas with great number of radiating elements), low crosspolarization attenuation and poor possibility of forming antenna arrays with high side lobe suppression.

In order to diminish these disadvantages various techniques have been developed. For example, by modification of the patch shape or the feeding technique narrowbandedness and tolerances effect on the operating frequency can be reduced. Also, feed structures with suitable branching may be used to obtain desired antenna array characteristics. However, some flaws of patch antennas cannot easily be eliminated.

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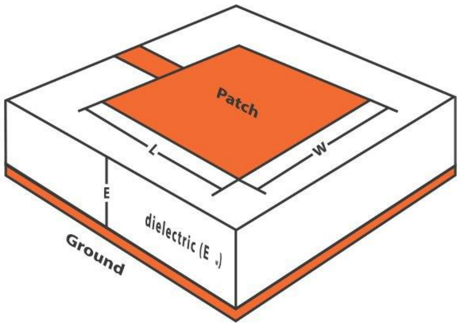

Fig.1. Mcrostrip patch antenna.

II. Antenna Structures with Printed Dipoles

In the late seventies of the last century, in IMTEL Komunikacije (former Institute for Applied Physics) extensive research of printed radiating elements of various shapes was in progress. Different printed waveguide structures – symmetrical microstrip, coplanar waveguides (CPW) and coplanar striplines (CPS) as well as impedance transformers realized with these printed waveguide structures - were investigated also.

The first significant enhancement of conventional microstrip antennas was introducing printed dipoles that operate near the second resonance, [1]. In this way, obtaining of considerably broader bandwidth was enabled (even 10 times broader than with microstrip patch antennas). Generally, impedances of such dipoles are much higher (at their operating frequencies) which can also be beneficial in many applications.

Results of these researches were antenna structures that have not been applied until then and were characterized by wider bandwidth, lower loss and lesser parasitic couplings. One of them is the linear array, realized in 1981, [1], with strip dipoles that operate on the second resonance (antiresonance) and are fed by coplanar strips, Fig. 2. The main feed line is realized as a symmetrical (balanced) microstrip that extends to a symmetrical microstrip-to-

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waveguide transition, Fig. 3, and terminates with a waveguide connector.

With presented antenna structure almost all weaknesses of conventional patch antennas are avoided: the bandwidth of the antenna has been broadened due to relatively slow dipole impedance variation with frequency when they operate on the second resonance; losses in coplanar strips are significantly lower (especially dielectric loss) than in microstrip lines, and higher crosspolarization attenuation has been obtained owing to ideally balanced (symmetrical) structure. Maximum measured gain of the presented antenna is 20.5 dB, while side lobes are suppressed around 14 dB in respect to the main lobe.

Also, when operate on the second resonance, dipoles' impedances can be varied within a very wide range of values by changing the strip width and thus enabling design of arrays with relatively high tapering ratio i.e. achieving high side lobe suppression.

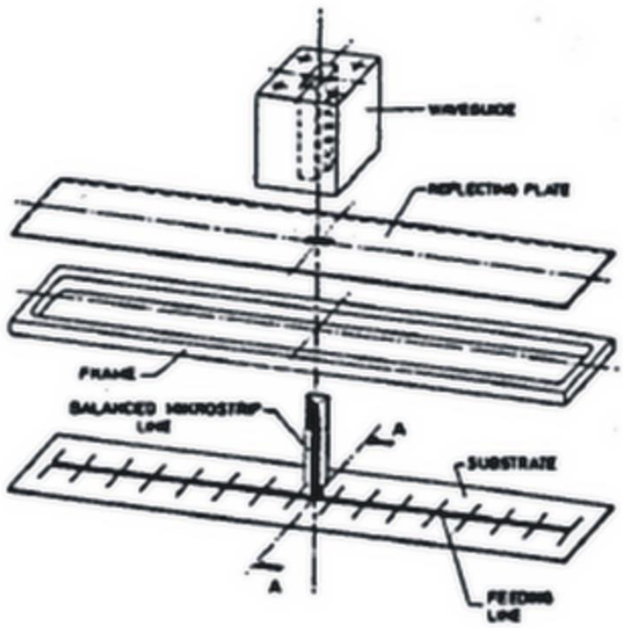

Fig. 2. Linear array of strip dipoles fed by a coplanar strip.

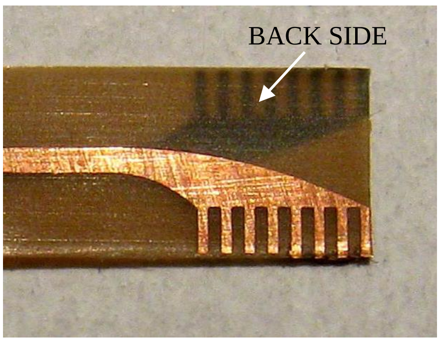

Fig. 3. Symmetrical (balanced) microstrip-to-waveguide transition.

Using the same concept, the two-dimensional (10x10) array of printed dipoles (10 subarrays, each having 10 antiresonant dipoles as radiating elements) was designed in 1984, [2], Fig. 4.

Subarrays are fed through the power divider realized in symmetrical microstrip on teflon dielectric substrate (ε_r=2.17) 0.254 mm thick, while the antenna array is realized on 0.508 mm teflon. The power divider has a meander-like form to provide required distance between its branching points. Its ends are soldered to coplanar strips at the subarrays feed points. As the tapered distribution ($\cos^2$) has been applied in both planes, obtained side lobe suppression is better than 20 dB at the central frequency of 17 GHz. Measured gain and VSWR at f_c are 28 dB and 1.1, respectively. The best feature of the presented antenna array is exceptionally high efficiency (74%) owing to symmetrical microstrip feed network and dipoles' subarrays feeding realized in CPS with extremely low losses..

Furthermore, printed dipoles of various shapes have been extensively investigated – triangular, triangular with cap and trapezoidal. Best results, in terms of broadbandedness and wide range of realizable impedances' values, have been obtained with trapezoidal dipoles. These dipoles are often realized in such a way that one dipole's half is printed on one

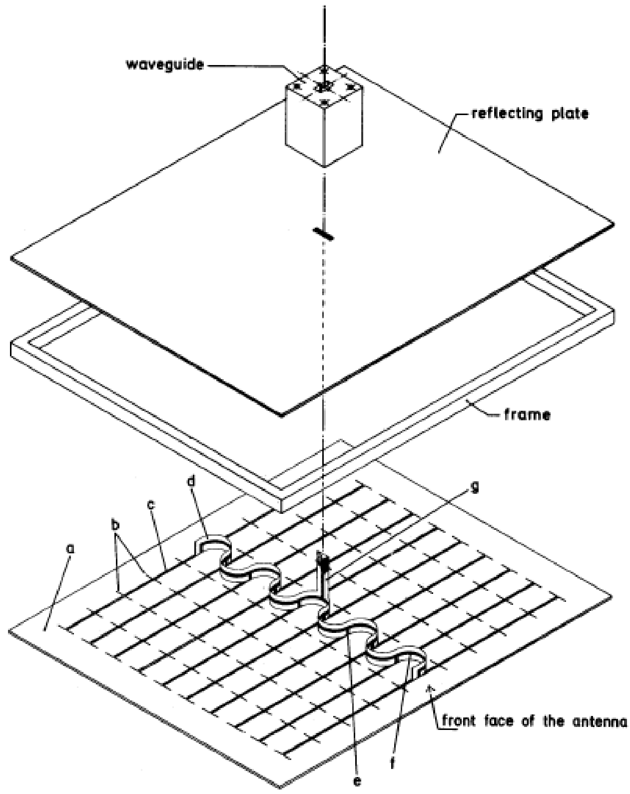

Fig. 4. Two-dimensional printed strip dipoles array with tapered distribution.

a: Dielectric substrate; b: antiresonant dipoles; c: coplanar strip (CPS); d: power divider; e: subarray feed point; f: balanced (symmetrical) microstrip; g: balanced microstrip-to-waveguide transition.

side and the other half on the opposite side of the dielectric substrate, and are fed by a symmetrical (balanced) microstrip line, Fig. 5. If there is a need to include impedance transformers in the feeding network, they can be realized as a symmetrical microstrip, too. Coplanar strips (CPS) may be used as a feeding structure when both dipole's halves are printed on the same side of the dielectric material, Fig. 6, but in this case mounting process requires application of soldering or bonding.

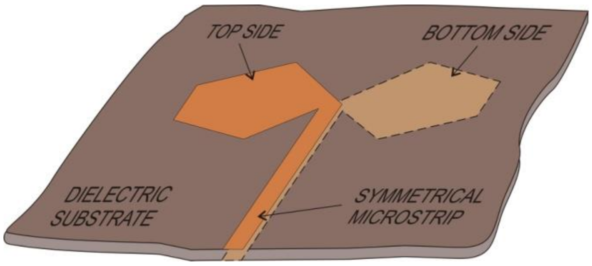

Fig. 5. Pentagonal dipole fed by symmetrical microstrip line.

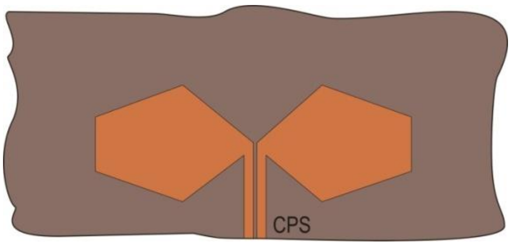

Fig. 6. Pentagonal dipole fed by coplanar strips (CPS).

III. Slotted Antenna Structures

Along with antenna structures with printed dipoles, their complementary structures – printed slots – have been investigated also. Arrays with such radiating elements are usually fed with a microstrip line on the opposite side of the dielectric substrate and electromagnetically coupled with a slot, Fig. 7.

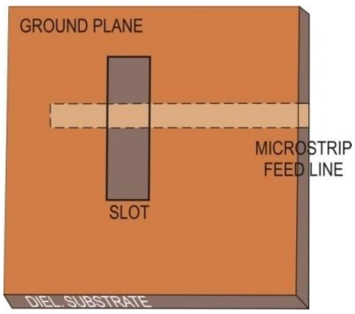

Fig. 7. Microstrip-fed slot.

However, by forming a structure that is complementary to dipole fed by coplanar strips (CPS), it is obvious that newly obtained structure is slot fed by a coplanar waveguide (CPW), Fig. 8 and Fig. 9. This idea lead to realizations of slotted arrays excited by coplanar waveguide located on the same side of the substrate along with radiating slots, [3]. This characteristic is very desirable in active integrated – monolithic antenna structures. Since the structure is uniplanar, all components of the integrated structure are placed on the same side of the dielectric material together with radiating slots, so there is no need to drill holes in the substrate to provide connections between components and/or components and ground plane. Coplanar lines (CPS, CPW) provide easiness of mounting components in series and shunt configuration (while microstrip lines are suitable only for series mounting and slotlines only for shunt mounting), [4].

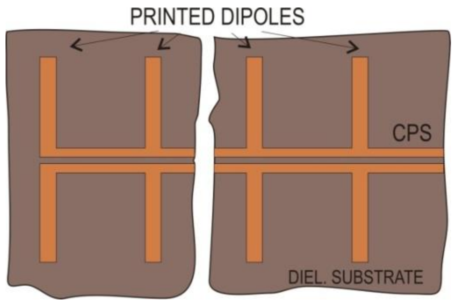

Fig. 8. Array of printed dipoles fed with CPS.

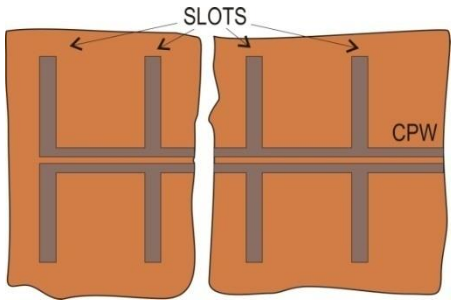

Fig. 9. Array of slots fed with CPW.

Concerning the range of realizable impedances (in a sense of minimal strip (or slot) width, CPW and slotlines are suitable for obtaining high impedance, whereas microstrip lines can be used for low impedances. Comparing conductor losses in microstrip line and CPW [4], it can be seen that high impedance CPW can be designed to have lower loss, while low impedance microstrip line is less lossy than high impedance microstrip. Also, comparing losses in slotline and CPW [4], one can see that high impedance lines have lesser conductor loss when they are realized as slotlines. Besides, slotline is the least sensitive to fabrication tolerances.

IV. PRINTED ANTENNA ARRAYS WITH 3D REFLECTOR SURFACES

In conventional microstrip antennas, planar reflectors are usually used. However, it is suitable to use corner reflectors with linear printed arrays, Fig. 10, [5]. Introducing a corner reflector in the antenna structure enables obtaining several advantages over conventional 2D antenna structures. Some other benefits can also be achieved by use of a cylindrical-parabolic reflector with a linear printed array placed at its focal axis. Keeping in mind that in some applications printed antennas suffer from certain limitations – in high power transmitters, in high gain antennas as well as in antennas with very high side lobe suppression – involving 3D reflectors is the way to overcome them.

Besides, realization of antennas with corner or cylindrical-parabolic reflector surfaces that operate at ranges around 100 GHz is possible while keeping equally good radiation characteristics as in the case of antennas realized for lower frequency ranges. One of the required conditions is to use low loss dielectric substrates with metallization thicknesses below 10 μm.

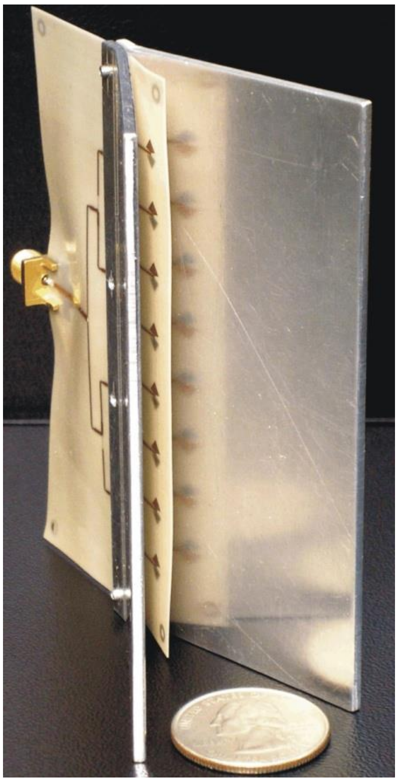

Fig. 10. Photo of the 26 GHz 8-element antenna array with tapered feed distribution placed in 45° corner reflector (compared to US quarter).

With cylindrical-parabolic reflector surfaces combined with printed antenna arrays, we can affect the radiation pattern as well as levels of side lobes in H-plane. There is also a possibility of adding a subreflector realized as a symmetrical microstrip line in front of dipoles' array, [6,7], Fig. 11 and Fig. 12. Aperture blockage of the antenna structure by this subreflector is negligible.

By varying its width, one can optimize illumination distribution of the cylindrical-parabolic reflector and achieve higher gain and better side lobe suppression. More, owing to the presence of printed subreflector, the depth of the cylindrical-parabolic reflector can be reduced and so the overall size of the antenna structure.

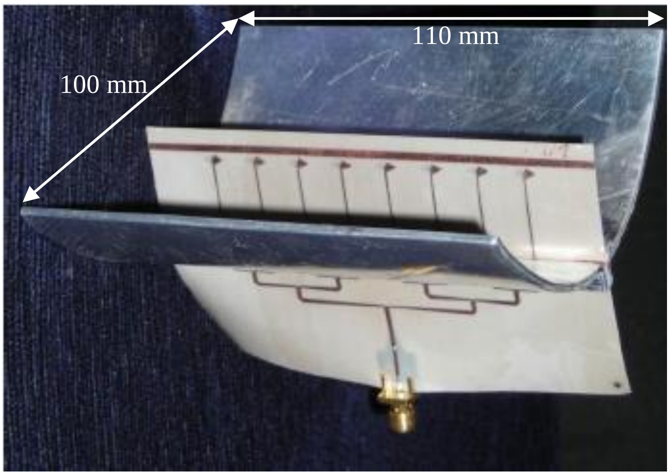

Fig. 11. Photograph of the 8-element antenna array with uniform feed distribution placed in the cylindrical-parabolic reflector (26 GHz).

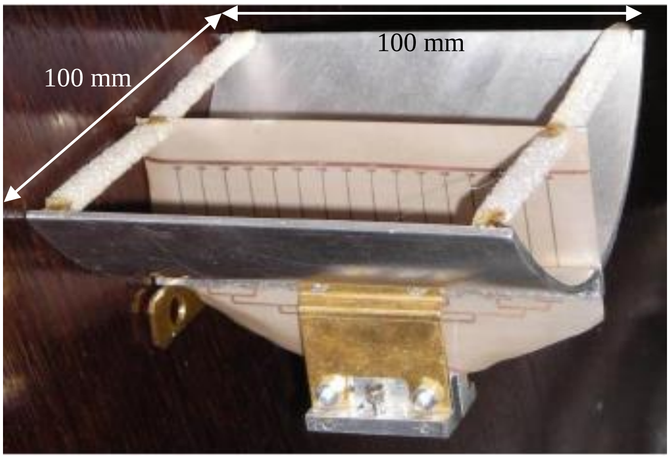

Fig. 12. Photo of the 16-element antenna array with uniform feed distribution in the cylindrical-parabolic reflector (60 GHz).

Efficiencies of such antenna structures are also increased comparing to printed antenna arrays with flat reflectors. The only drawback of corner or cylindrical-parabolic reflector antennas is their depth i.e. the third dimension that these reflectors introduce in the antenna structure. However, this is less noticeable at millimeter-wave frequencies where wavelengths become very small. Presented antenna structures are very convenient for research and developing of phase scanning antennas.

Measured reflection coefficients S_{11} and VSWRs of three presented arrays are shown in Fig. 13, 14 and 15 while their relevant characteristics are given in Table 1.

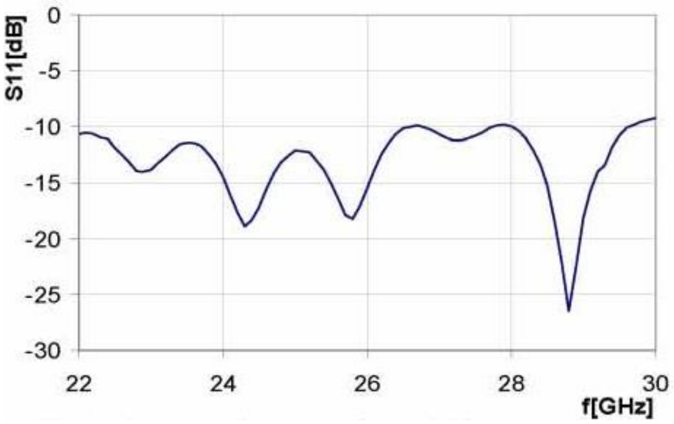

Fig. 13. Measured S_{11} of the 8-element antenna array in 45° corner reflector (tapered feed distribution, 26 GHz).

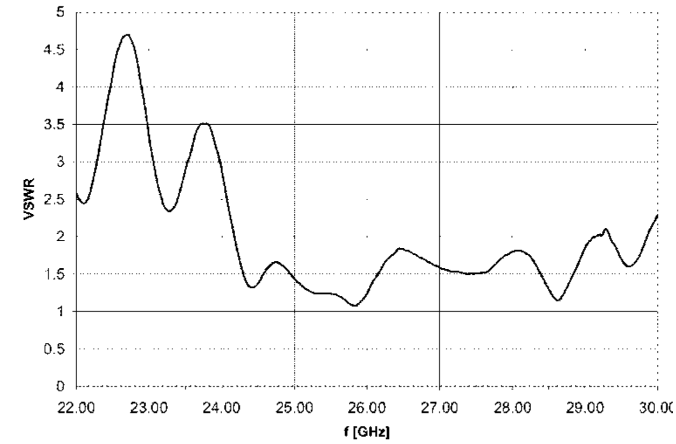

Fig. 14. Measured VSWR of the 8-element antenna array in the cylindrical-parabolic reflector (uniform feed distribution, 26 GHz).

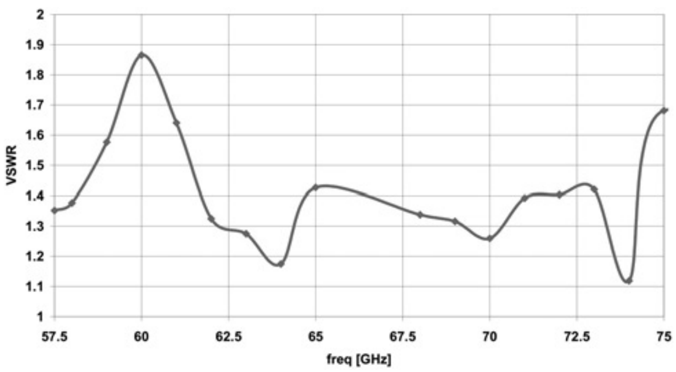

Fig. 15. Measured VSWR of the 16-element antenna array in the cylindrical-parabolic reflector (uniform feed distribution, 60 GHz).

TABLE I

MEASURED ELECTRICAL CHARACTERISTICS OF THREE PRINTED ARRAYS IN 3D REFLECTORS

	Corner reflector array 26 GHz	Cylindrical-parabolic reflector array 26 GHz	Cylindrical-parabolic reflector array 60 GHz
Measured gain at f_c	20.8 dBi	27.5 dBi	34 dBi
Measured FSLSE/FSLSH*	34.7 dB/32.6 dB	13 dB/20 dB	13 dB/17 dB
Bandwidth (VSWR<2)	30%	21%	26%
Aperture efficiency	~ 50%	54.1%	54.2%

*FSLSE/FSLSH – First Side Lobe Suppression in E/H-plane

V. CONCLUSION

A new class of printed antenna structures is presented in the paper. Along with antennas, various feeding printed waveguide structures, with their advantages and disadvantages, are shown. Priority has been given to mm-wave antennas due to increasing usage of the millimeter wave spectrum with rising development of 5G radio-communication systems and devices.

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