New type of millimeter wave antenna with high gain and high lobe suppression

ALEKSANDAR NEŠIĆ, IVANA RADNOVIĆ*
IMTEL Komunikacije, Bulevar M. Pupina 165b, 11070 Beograd, Serbia

Concept, simulation, design and realization of the printed tapered antenna array with a subreflector and a cylindrical-parabolic reflector is presented. This antenna is intended for microwave and millimeter wave ranges and is characterized by many advantages such as efficacy, compactness and possibility of integration with other passive and active microwave circuits. Antenna gain is nearly 26 dBi and aperture efficiency is almost 50% due to very low loss tangent (tg δ) of the dielectric substrate the antenna is printed on. The antenna operates in the frequency range from 24 GHz to nearly 30 GHz. Measured results are in good accordance with those obtained by a simulation.

(Received July 29, 2009; accepted September 29, 2009)

Keywords: Millimeter wave antennas, Printed antenna arrays, Side Lobe Supression, Printed subreflector, Cylindrical-parabolic reflector, Extremely low loss tangent materials

1. Introduction

Microwave and millimeter wave printed antenna are usually used in telecommunication and radar systems. Main advantages of printed antennas are simple fabrication, low cost and possibility of integration with other passive and active microwave circuits. However, problem with printed antennas is obtaining the following characteristics: (1) high gain, (2) relatively wide bandwidth, and (3) high side lobe suppression (SLS). We have proposed some effective solutions for mentioned problems, especially for millimeter wave printed array antennas. In our case, high gain is obtained by using practically hybrid antenna with cylindrical-parabolic reflector (which is usually used in VHF, UHF and lower microwave ranges) [1,2], and by introducing a printed subreflector. Wideband is obtained using pentagonal printed dipoles that operate on the second resonance and by feeding the antenna with symphase network [3]. High SLS is achieved with tapered axial array [4].

Radiating elements, subreflector, tapered feed network, BAL-UN [3] (or transition from a symmetrical microstrip to a waveguide [5]), and potentially other microwave circuits are printed on the same dielectric substrate.

1.1 Concept

The antenna consists of a linear tapered axial array of printed pentagonal dipoles with printed subreflector and a cylindrical-parabolic reflector. One half of each dipole is placed on one side and another half on the opposite side of the dielectric substrate, Fig. 1, Detail B. The dipoles operate on the second resonance (antiresonance) and their impedances are about 100Ω. The strip printed ahead of the array plays a role of a subreflector [6], Fig. 1. Dipoles are fed through the printed feed network realized with symmetrical (balanced) microstrip lines, like in [4]. Impedance transformers in the feed network enable tapered distribution which results in high side lobe suppression in E-plane (better than 30 dB). We have chosen Dolph-Chebyshev distribution of the second order with dynamic I_{max}/I_{min}=17dB. Distribution coefficients (Table 1), are calculated by LINPLAN program package [7].

Table 1. The calculated distribution coefficient.

Dipole No.	1	2	3	4	5	6	7	8
I*	0.146	0.418	0.759	1	1	0.759	0.418	0.146

(I* is excitation intensity)

With calculated distribution coefficients, feeding network with λ/4 transformers in symmetrical microstrip has been preliminary designed on flexible dielectric substrate of h=0.254mm, ε_r=2.1 and tgδ=$4x10^{-4}$ by using TEM analysis. Then, the full-wave analysis has been carried out in the frequency range (24–30) GHz. Based on results of the full-wave analysis, obtained phase errors have been corrected by slightly changing the lengths of particular branches in the feed network in order to achieve symphase feeding of all dipoles. Correction of amplitude errors has been omitted because of their negligible influence on side lobe suppression. Calculated transformed impedances, symmetrical microstrip line widths and lengths are shown in Table 2. In order to provide a transition from conventional to a symmetrical microstrip structure, there is a BAL-UN (transition from balanced to unbalanced microstrip) inserted between the feed line and the antenna [3]. All the elements of this antenna system, except the cylindrical-parabolic reflector, are placed on the same dielectric substrate.

Table 2.The calculated impedances, line widths and lengths.

T	Z_T	Z_{CT}	W [mm]	L [mm] (λ/4)
T_1	459.9	214.65	0.0885	2.25
T_2	56.1	74.9	0.597	2.124
T_3	136.69	116.91	0.2979	2.35
T_4	78.84	88.81	0.459	2.317
T_A	452.45	212.71	0.090	2.25
T_B	56.21	74.97	0.597	2.124

Z_T – Transformed dipole impedance
Z_{CT} – Characteristic impedance of the λ/4-transformer line
W – Width of the symmetrical microstrip λ/4-transformer line
L – Length of the symmetrical microstrip λ/4-transformer line

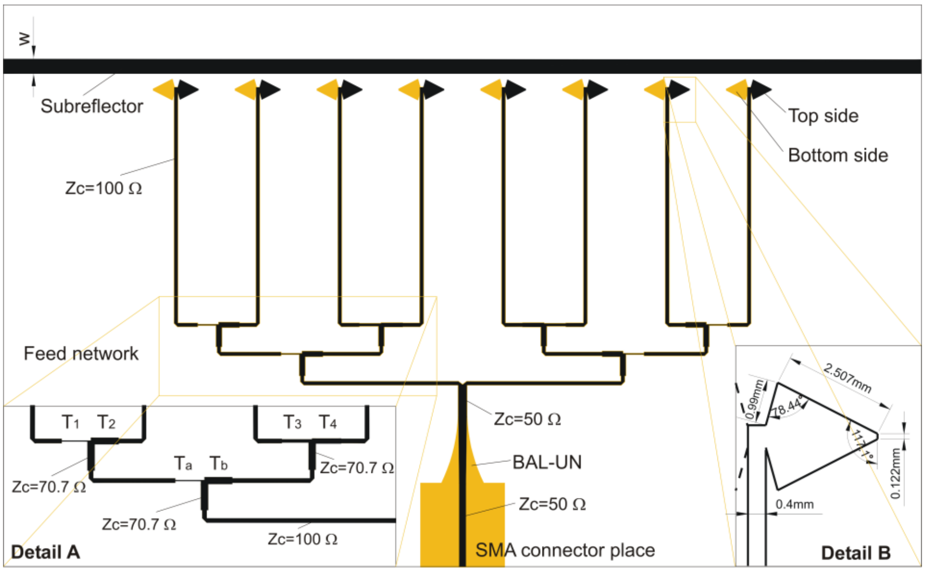

Fig. 1. Printed antenna array and tapered feed network integrated on the same dielectric substrate. (Detail A: tapered feed network, Detail B: dipole with its dimensions).

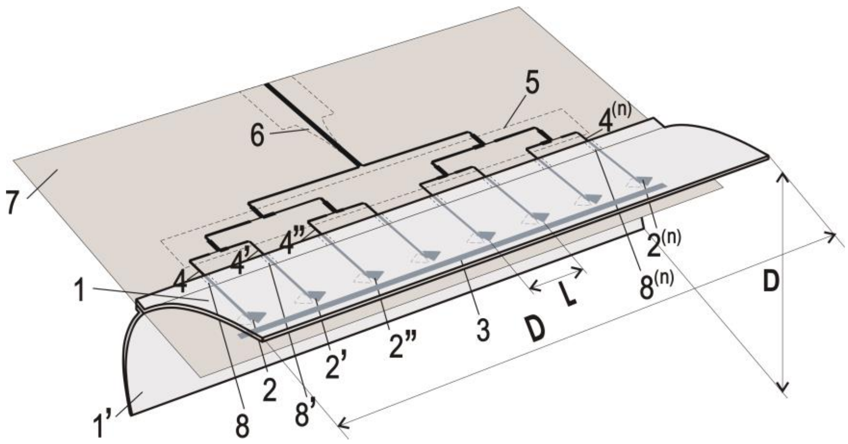

Fig. 2. Layout of the printed antenna array with subreflector placed in the parabolic reflector: 1 and 1': two halves of the parabolic reflector; 2-2$^{(n)*}$: printed pentagonal dipoles; 3: subreflector; 4-4$^{(n)*}$: 100Ω-lines of the feed network; 5: tapered feed network; 6: BAL-UN; 7: dielectric substrate;8-8$^{(n)*}$: holes in the cylindrical-parabolic reflector (n= number of dipoles in the array).*

2. Experimental

2.1 Design and realization

Linear array: Radiating elements in the linear array are pentagonal dipoles axially placed in the focal line of the cylindrical-parabolic reflector and operating on the second resonance, Fig. 2. The dipoles, feed network, and the subreflector (printed on both sides of the dielectric), are realized on the dielectric substrate of h=0.254mm, ε_r=2.1 and tgδ=4x10^{-4}. Distance between the subreflector's axis and dipole's axis is $\lambda_0/4$ at the central frequency, while width of the subreflector (w=1.7 mm) is optimized so to obtain better SLS as well as increased gain. Dimensions of the pentagonal dipoles are optimized so to obtain impedance of about (100+j0) Ω at the central frequency of 26 GHz.

In the next step, an array of 8 dipoles has been modeled. The distance between the dipoles is chosen in such a way as to obtain relatively high array gain and sufficient side lobe suppression [7]. In our case, the distance between axial dipoles is $L=0.85\lambda_0$. Tapered feed network realized in symmetrical (balanced) microstip is shown in Fig. 1 (Detail A). Feeding lines for dipoles penetrate the junction of two reflector halves. In the place of this junction there are holes with diameter d=2mm through which symmetrical microstrip lines of the feed network pass. Software package WIPL-D [8] has been used in these analyses.

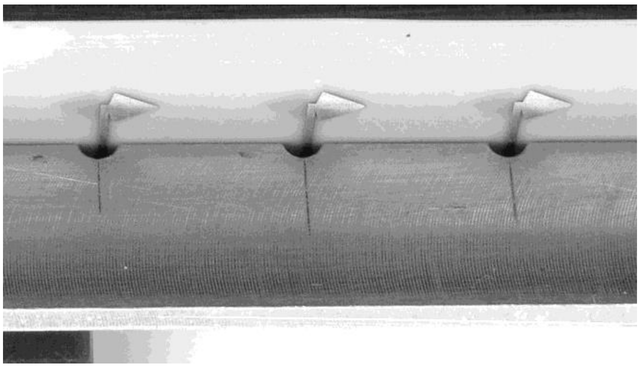

Fig. 3. Holes in the cylindrical-parabolic reflector through which microstrip lines of the feed network pass.

Cylindrical-parabolic reflector: Cylindrical-parabolic reflector is assembled of its two halves. Dielectric substrate with printed radiating elements, subreflector, feed network and BAL-UN is positioned between the reflector's halves, Fig. 2. Length of the cylindrical-parabolic reflector (D=100mm) is practically defined by the linear array's length.

Focal length (L_f) is 7λ/4 (20.19mm at f=26 GHz). Thus, L_f/D is around 0.2 that makes the depth of the cylindrical-parabolic reflector smaller. Owing to the subreflector, more suitable illumination distribution, i.e. higher gain and better side lobe suppression in H-plane has been achieved, Fig 5.

3. Obtained results and discussion

E- and H-plane radiation patterns of the array, with and without a subreflector, obtained by a simulation are shown in Fig. 4 and Fig. 5, respectively. There is a significant improvement of about 10 dB in the side lobe suppression in H-plane and in the antenna gain of about 1.5 dB in the case with a subreflector. Also, the SLS in E-plane is slightly worse in this case, but still sufficiently low. Figs. 6 and 7 show simulated and measured E- and H-plane radiation patterns of the array.

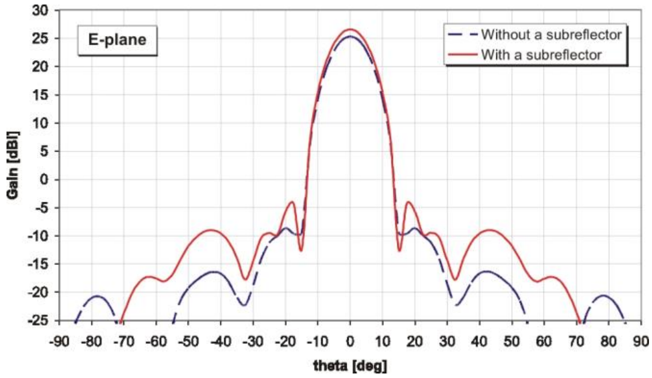

Fig. 4. Simulated E-plane radiation patterns of the printed array with and without a subreflector, in cylindrical-parabolic reflector (@26GHz).

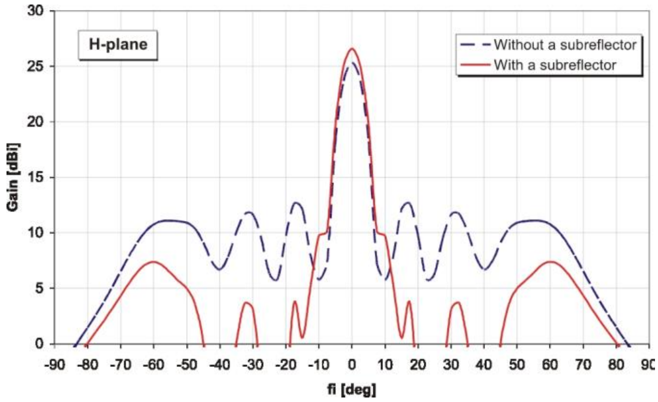

Fig. 5. Simulated H-plane radiation patterns of the printed array with and without a subreflector, in cylindrical-parabolic reflector (@26GHz).

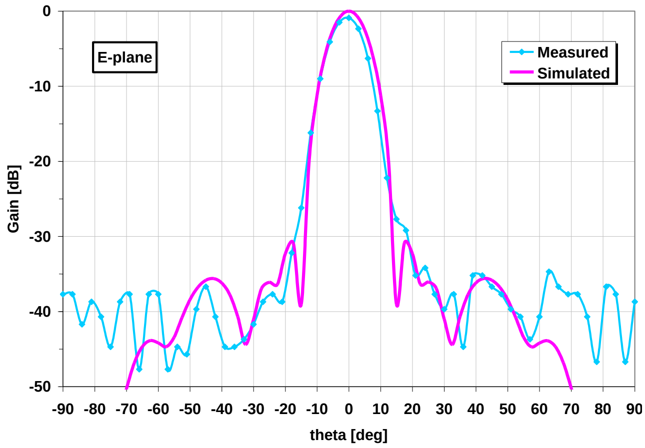

Fig. 6. Normalized simulated and measured E-plane radiation patterns of the printed array with a subreflector, in cylindrical-parabolic reflector (@26GHz).

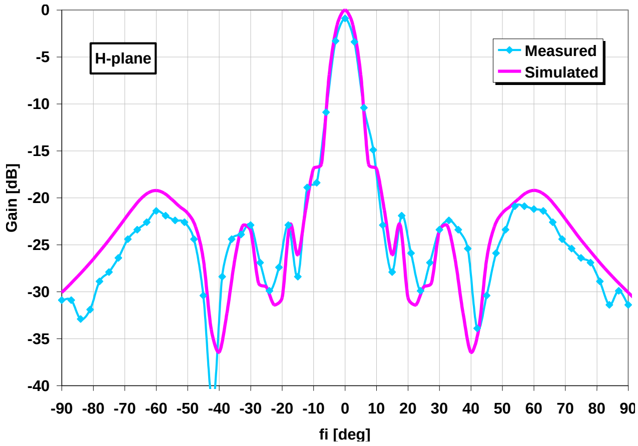

Fig. 7. Normalized simulated and measured H-plane radiation patterns of the printed array with a subreflector, in cylindrical-parabolic reflector (@26GHz).

Measured gain at 26 GHz is 25.7 dB which is about 1 dB lesser than the gain obtained by a simulation where losses in the dielectric substrate and microstrip lines were not taken into account. Losses in dielectric substrate are calculated afterwards using known expression [9] and are about 0.4 dB, while losses in microstrip lines don't exceed 1 dB. SLSs in H-plane and E-plane are better than 20 dB and 30 dB, respectively. There is a very good accordance between measured and simulated results.

Measured VSWR and gain vs. frequency are given in Fig. 8 and Fig. 9, respectively. VSWR of the array is lesser than 2 in the range from 24.2 GHz to nearly 30 GHz.

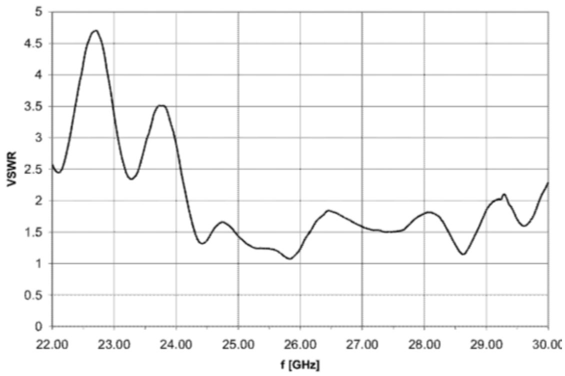

Fig. 8. Measured VSWR of the printed array against frequency.

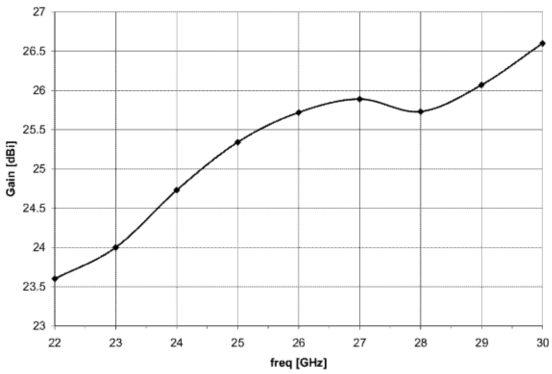

Fig. 9. Measured gain of the printed array against frequency.

Photograph of the realized printed antenna array in the parabolic reflector is presented in Fig. 10.

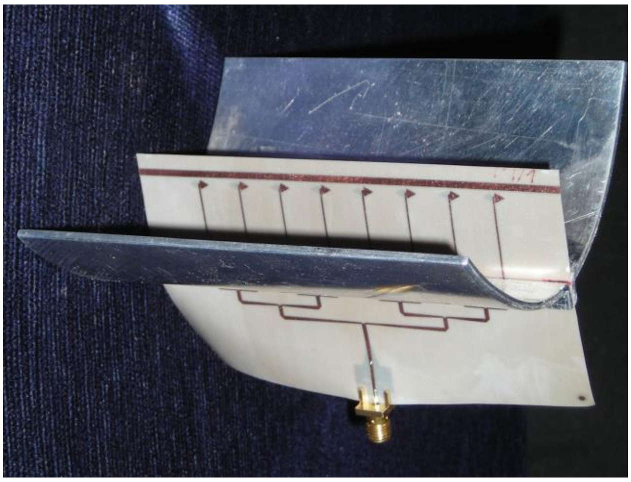

Fig. 10. Photograph of the realized antenna array with a subreflector in cylindrical-parabolic reflector.

4. Conclusions

The paper presents a new type of printed tapered antenna array with a subreflector, placed in a cylindrical-parabolic reflector. In front of the array, in the parabolic reflector's direction, there is a printed strip that acts as a subreflector. Radiating elements, subreflector, tapered feed network and the BAL-UN (or transition from a symmetrical microstrip to a waveguide) are on the same flexible dielectric substrate with very low loss tangent (tgδ=4x10^{-4}). The whole structure, except the cylindrical-parabolic reflector, is realized using simple photolithographic process with tolerances of printed lines' widths of about 10µm, thus the reproducibility of the antenna is quite high.

Proposed concept of the cylindrical-parabolic antenna with a printed primary feed can be used in millimeter ranges up to 110 GHz.

Acknowledgments

Authors would like to thank Ms. M. Marjanovic and Mr. M. Tasic for their help in realization of the experimental model. This work has been carried out and supported within the Project of Technological Development of the Serbian Ministry of Science and Technological Development.

References

[1] J. D. Kraus, Antennas, McGraw-Hill Book Company, 572, 1988.
[2] P. S. Kildal, IEEE Transactions **32**(6), 541 (1984).
[3] A. Nešić, Z. Mićić, S. Jovanović, I. Radnović, D. Nešić, IEEE Antennas & Propagation Magazine **49**(1), 113 (2007).
[4] A. Nesic, Z. Micic, S. Jovanovic, I. Radnovic, Proc. IEEE AP-S Int. Symp., (ISBN: 1-4244-123-2, CD ROM Edition: 0717.pdf), Albuquerque, USA, 9-14

July 2006, p. 3051.
[5] A. Nesic, I. Radnovic, V. Brankovic, Antennas and Propagation Society International Symposium, IEEE., Digest **2**(13), 1272 (1997).
[6] A. Nesic, D. Nesic: patent pending No. P-2007/0738, 24th Sep. 2007.
[7] M. Mikavica, A. Nesic, CAD for linear and planar antenna array of various radiating elements, Artech House, Norwood, MA, 1992.
[8] WIPL-D Pro v5.1, Branko Kolundzija, Jovan Ognjanovic, Tapan K. Sarkar.
[9] K. C. Gupta, R. Garg, I. Bahl, P. Bhartia, Microstrip Lines and Slotlines, Second Edition, Artech House, 1996.

*Corresponding author: ivana@insimtel.com