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AN INVESTIGATION OF SIDE LOBE SUPPRESSION IN INTEGRATED PRINTED ANTENNA STRUCTURES WITH 3D REFLECTORS

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Abstract. *The paper discusses the problem of side lobe suppression in the radiation pattern of printed antenna arrays with different 3D reflector surfaces. The antenna array of eight symmetrical pentagonal dipoles with corner reflectors of various angles is examined. All investigated antenna arrays are fed by the same feeding network of impedance transformers enabling necessary amplitude distribution. Considering the different reflector surfaces, the influence of parasitic radiation from feeding network on side lobe suppression is studied to prevent the reception of unwanted noise and to increase a gain.*

Key words: *Printed antenna array, Reflector antennas, Side lobe suppression, Symmetrical pentagonal dipole*

1. INTRODUCTION

Modern wireless communication systems establish strong antenna requirements relating to theirs size, weight, cost, performance and ease of installation. Printed (microstrip) antennas can meet the most requests set by many government and commercial applications (mobile radio and wireless communications), high-performance aircraft, spacecraft, satellite, and missile applications. Printed antennas feature low profile and low weight, simple and inexpensive production using standard photolithographic technique, great reproducibility and the possibility of integration with other microwave circuits [1].

Major disadvantages of microstrip antennas are spurious feed radiation, tolerances in fabrication, very narrow frequency bandwidth and surface wave effect [2]. The printed antenna arrays with symmetrical pentagonal dipoles can mostly overcome mentioned limitations of printed antenna. The antenna array is an assembly of radiating elements in an electrical and geometrical configuration improving the majority of antenna parameters.

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The symmetrical pentagonal dipole operates on the second resonance (antiresonance) enabling both much slower impedance variation with frequency and useful wide bandwidth than in case of operation on the first resonance [3]-[7]. Consequently, proposed antenna array has lower sensitivity to fabrication's tolerances enabling the use of low-cost photolithography printing process for its manufacture. Further, the feeding network is also symmetrical printed structure causing the reduction of parasitic radiation and surface wave effect. However, spurious radiation from the feed network has a very substantial, although indirect, effect on side lobe level [2].

International standards and recommendations define side lobe suppression (SLS) for modern communication systems between 20 dB and 40 dB. Moreover, the radar systems that are employed to control civil and military object, have more serious SLS requirements. Side lobe should be minimized to avoid false target indications through the side lobes that can cause catastrophic consequences. Also, insufficient SLS indicates that more power is radiated in side lobes resulting in a low antenna gain.

The proposed antenna array of eight symmetrical pentagonal dipoles uses Dolph-Chebyshev distribution of the second order with 19 dB pedestal (I_{max}/I_{min} ratio) in order to achieve SLS of 44 dB in ideal case without realization errors. Besides realization deviations that can reduce SLS, the parasitic radiation from feeding network may influence on antenna parameters, especially SLS. The reflector plates can be good tool to overcome undesired effect by feeding structure's radiation. Furthermore, they can improve gain and control radiation pattern that is desirable for many modern wireless applications.

2. Printed Antenna Arrays with High Side Lobe Suppression

The investigated printed antenna consists of array of eight symmetrical pentagonal dipoles (labelled as D_1-D_8), feeding network, balun and 3D reflector surface (Fig. 1). The array, feeding network and balun are printed on the same dielectric substrate of 0.508 mm thickness with ε_r=2.1. The vertex of corner reflector with angle α is at distance *h* from the antenna array.

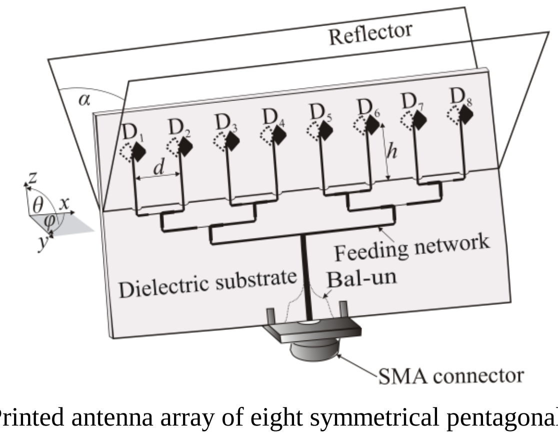


Fig. 1 Printed antenna array of eight symmetrical pentagonal dipoles with feeding network, balun and reflector

2.1. Antenna array

The eight symmetrical dipoles form the antenna array. They have pentagonal shape whose one half is on one side and another half, contrariwise turned, is on the opposite side of the substrate. The single pentagonal dipole has very large bandwidth regardless used reflector plate. Considering their impedance variation in desired frequency range, its bandwidth (VSWR is bellow 2) is more than 35% of central frequency [8]. However, mostly antenna parameters of single pentagonal dipole are hardly controlled. Therefore, pentagonal dipoles associate in array to achieve higher gain, better SLS and other required parameters.

The pentagonal dipoles in array are axially positioned at distance *d*. The array is mirror symmetrical whose line of symmetry passes through the middle of array. Consequently, dipoles D_1 and D_8 have the same dimensions and parameters, as well as dipoles D_2 and D_7, D_3 and D_6, and D_4 and D_5. Each array's dipole is fed by symmetrical feeding line that penetrates through the holes at the contact between two reflector metal surfaces. The holes must be sufficient diameter (2.3mm) to minimize the influence of the metallic plates.

The previous researches [8-10] have showed that reflector plate influences the antenna parameters like SLS, gain, bandwidth, etc. The planar reflector plates [8-10] enable that antenna array can apply in a wide frequency range, although its gain and SLS are not satisfactory for many modern communication systems. Unlike planar reflector plates, the antenna array with corner reflectors [8-9] can achieve greater gain and SLS but narrow bandwidth. The improvement in a gain and SLS is more noticeable when the angle of corner reflector is smaller. Even though the antenna array with corner reflector of 90° and 60° angle [8-9] have been examined, their SLSs are not satisfactory for many wireless applications. Further investigations should optimize the angle of corner reflector to obtain satisfactory SLS and gain. Furthermore, the antenna array with optimal parameters is planned to be realized and measured. The radiation patterns in H plane will be also investigated.

2.2. Feeding network

The feeding network, also symmetrical printed structures, enables the amplitude distribution calculated by LINPLAN software [11]. It begins with balun that is used for transition from conventional printed to symmetrical printed structure. After it, there are impedance transformers, T- junctions, and feeding lines (Fig. 2).

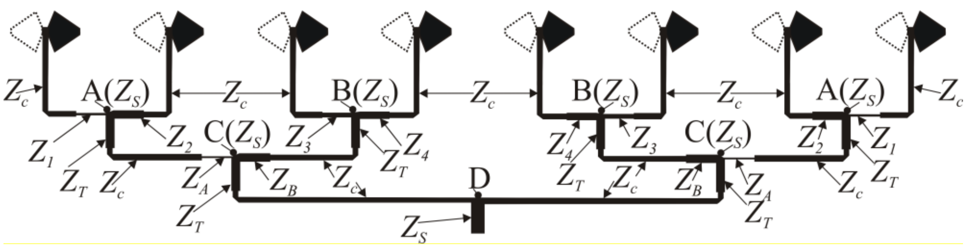


Fig. 2 Feeding network of impedance transformers for antenna array with high side lobe suppression

Feeding lines with impedance $Z_c = 100\ \Omega$ correspond the dipoles with the same impedances $Z_d = 100\ \Omega$. There are a few T-junctions (one in the first stage, two in the second stage and four in the third stage of feeding network). The T- junctions are marked by points A, B, C, and D (Fig. 2). The impedance in separating points A, B, C, and D is $Z_S = 50\ \Omega$. The impedance transformer $Z_T = 70.7\ \Omega$ is used to transform impedance of feeding line $Z_c = 100\ \Omega$ into impedance in separating point $Z_S = 50\ \Omega$. The other impedance transformers (Z_1, Z_2, Z_3, Z_4, Z_A, and Z_B) are employed to obtain a requested amplitude weight for every array's radiating elements obtained by LINPLAN software [11]. LINPLAN software enables the adjustment of an antenna array's parameter in order to achieve optimal value of SLS, gain and HPBW (Half-Power Beamwidth) [8]. Also, the distance d between radiating elements should have optimal value to prevent oversizing of their mutual impedance. Furthermore, the value of pedestal determine the width of impedance transformers in feeding network that should be moderate due to easier realization by photolithographic printing. Considering all requests, the pedestal of 19 dB and distance between array's elements $d = 0.77\lambda_0 = 19.25$ mm (λ_0 is wavelength in vacuum at centre frequency f_c=12 GHz) are chosen [8]. The amplitude distribution is shown in Table 1.

Table 1 The distribution coefficients for Dolph-Chebyshev distribution of the second order with pedestal of 19 dB

Dipoles number i	1/8	2/7	3/6	4/5
Distribution coefficients u_i	0.121	0.387	0.742	1

All impedance transformers are $\lambda_g/4$ length (λ_g is wavelength at the centre frequency f_c for the dielectric substrate whose thickness is 0.508 mm and dielectric constant is 2.17). Their characteristics and dimensions have been calculated [9]-[10] using values u_i $i = 1,2,3,4$ from Table 1 for dielectric substrate of 0.508 mm thickness, 2.17 relative dielectric permittivity, 41 MS/m conductivity of metal, insignificantly small values of loss tangent and conductor thickness (Table 2).

Table 2 The impedance transformers of the feeding network

Impedance transformer	Z_1	Z_2	Z_3	Z_4	Z_A	Z_B
Width [mm]	0.152	1.232	0.615	0.97	0.147	1.245
Characteristic impedance [Ω]	236.95	74.08	118.66	88	228.37	74.36

Moreover, expected tolerances in standard photolithographic process have been assumed in order to estimate the SLS degradation, due to amplitude, phase and radiating elements positioning deviations from optimized values at the operating frequency of 12 GHz. Besides ideal case without realization errors, two more cases have been considered:

- the real case when deviations in distances between radiating elements in the array are 1 percent of λ_0, phase deviations are 0.908° (approximately 40 μm tolerances in the length of the feeding line) and amplitude deviations along feeding lines are 1dB;
- the worst case when deviations in distances between radiating elements in the array are 2 percent of λ_0, phase deviations are 1.835° (approximately 80 μm tolerances in the length of the feeding line) and amplitude deviations along feeding lines are 2 dB.

The radiation patterns simulated by LINPLAN [11] for all three cases show that the proposed antenna array in ideal case has SLS of 44.8 dB at 12 GHz and that the expected SLS is 39.8 dB (in the real case) and 36.2 dB (in the worst case) at the same frequency. Further, LINPLAN [11] works with abstract radiating elements and it can expect that real antenna arrays with real elements would have bigger degradation.

3. Side Lobe Suppression of Printed Antenna Array

Initially, all dipoles are fed by singular generators and their dimensions are adjusted in order to obtain all dipoles' impedance of $Z_d = 100\Omega$ at the centre frequency ($f_c = 12$ GHz) taking into consideration mutual coupling and reflector influence. Afterwards, the array of dipoles with optimized dimensions is connected with feeding network of impedance transformers.

3.1. Simulation results

The first investigated antenna array is situated in corner reflector with angle of 90° whose vertex is at distance $h = \lambda_0/2 = 12.5$ mm from centres of dipoles. Both reflector plates have 308mm x 60.8mm dimensions. Its simulated radiation patterns, run by WIPL-D software, in both E and H plane are presented in Fig. 3 and Fig. 4, respectively. First simulated model when dipoles are fed by single generators has side lobe suppression 40.6 dB in E plane (Fig. 3). The second model is generated by integration antenna array with feeding network. Its SLS is 36.65 dB. It can suppose that the unwanted radiation from feeding network degrades the SLS.

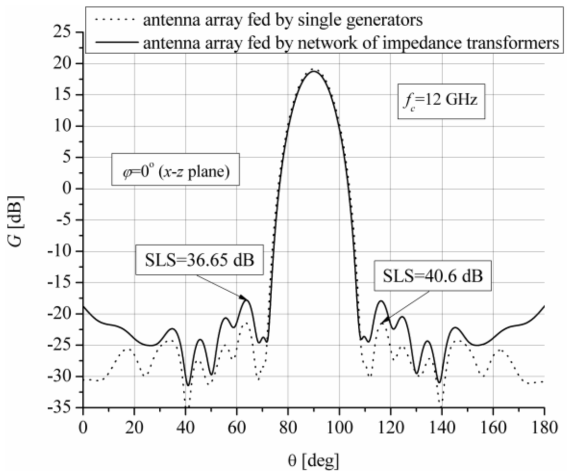


Fig. 3 Radiation pattern of printed antenna array in corner reflector with angle of 90° in E plane

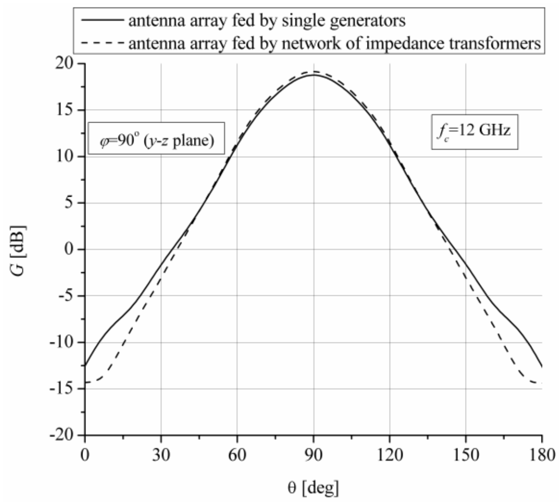


Fig. 4 Radiation pattern of printed antenna array in corner reflector with angle of 90° in H plane

However, it does not influence gain and radiation pattern in H plane (Fig. 4). Gain in E plane for both antenna simulation models is 19 dBi.

The second investigated antenna array is located between two metallic plates of 308mm x 76mm dimensions joined at 60° angle. The distance between array and vertex of corner reflector is $h = \lambda_0/2 = 12.5$mm. The antenna array fed by eight single generators has SLS = 43.7 dB and gain $G = 20.5$ dBi in E plane (Fig. 5). When feeding network of impedance transformers is integrated with antenna array, SLS decreases to 37.3 dB while gain stays approximately the same.

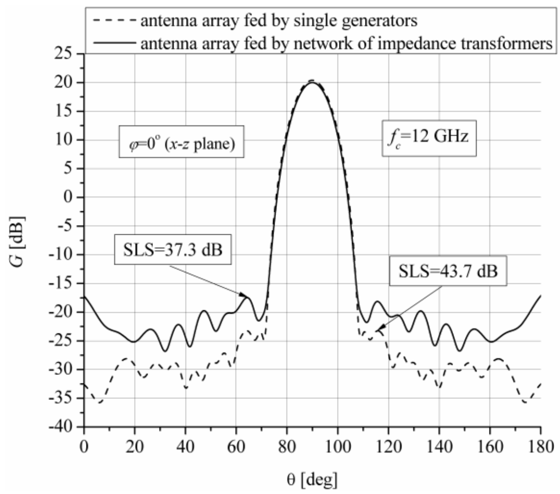


Fig. 5 Radiation pattern of printed antenna array in corner reflector with angle of 60° in E plane

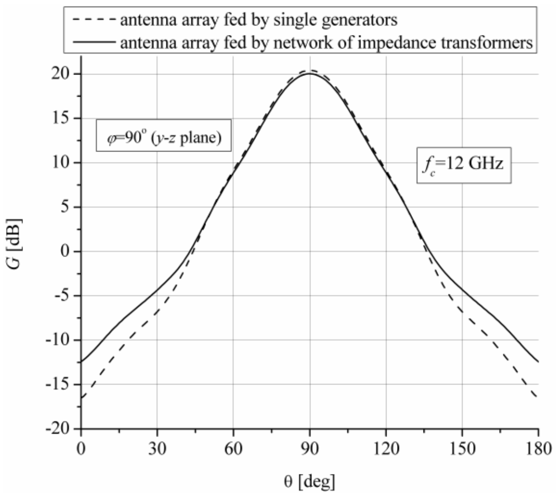


Fig. 6 Radiation pattern of printed antenna array in corner reflector with angle of 60° in H plane

The simulated radiation pattern in H plane, run by WIPL-D software, does not change using the different feeding method (Fig. 6). Meanwhile, it is significantly narrower than the simulated radiation pattern in H plane of antenna array with corner reflector with 90° angle.

The last examined antenna array is with corner reflector of angle of 45°. The dimensions of each reflector plate are 308mm x 106 mm. The smaller angle of corner reflector requests greater distance between its vertex and antenna array. Therefore, the distance $h = 0.6\ \lambda_0 = 15$ mm is selected. The first WIPL-D simulation model when dipoles in array are fed by single generators has SLS = 41 dB (Fig. 7). The second model, that integrates antenna array of eight dipoles with feeding network of impedance transformers, has SLS = 38.8 dB (Fig. 7). Due to the simulation results are satisfied for both WIPL-D models, the proposed antenna has been realized. Fig. 9 shows a photograph of a fabricated antenna in such a way that Fig. 9 a is a view of antenna array in corner reflector with angle of 45° and Fig. 9.b is a view of antenna array with one metallic plate and with feeding network.

Measured results are presented in Fig. 7 and Fig. 8. The gain in E plane of realized antenna is about 21 dBi which is the value obtained by WIPL-D software for both simulated models (Fig. 7). However, SLS is smaller than value expected by WIPL-D simulations. SLS of realized antenna is 32 dB that is about 6.8 dB smaller then simulated SLS of antenna array with feeding network. The possible reasons for SLS degradation of realized antenna can be: an accidental reflection during measuring, tolerances in fabrication of very thin impedance transformers (Z_1 and Z_A), the influence of corner reflector metallic plates on feeding structure, etc. Although all these influences are hardly investigated and some of them cannot be solved, the measured SLS is appropriate for many commercial wireless services. Furthermore, the realized antenna has very good gain of 21 dBi which is very important for applications where all potential users request wireless signal of good quality.

Fig. 8 presents the simulated and measured radiation pattern in H plane for antenna array in corner reflector with 45°angle. It is obvious that it is the narrowest beam in H plane among the examined antennas.

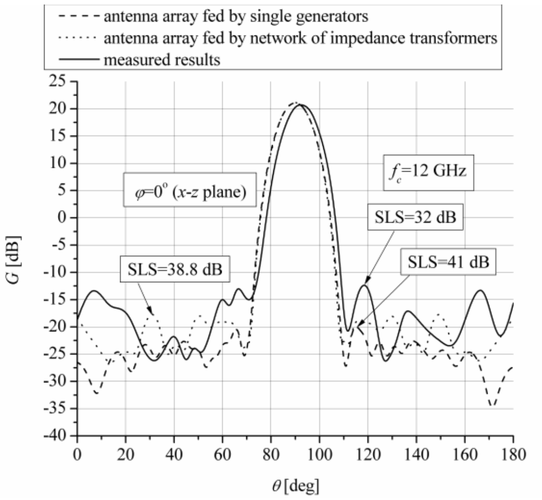


Fig. 7 Radiation pattern of printed antenna array in corner reflector with angle of 45° in E plane

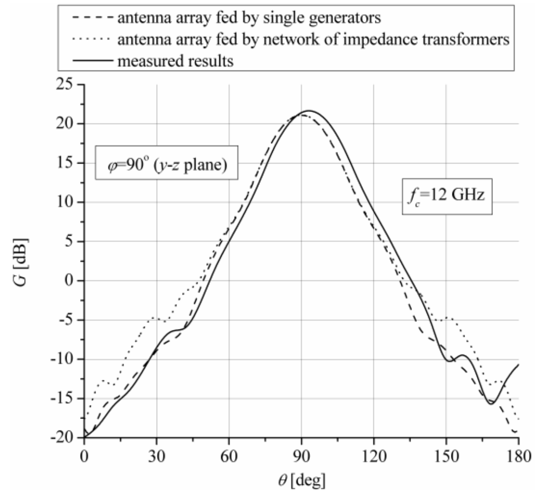
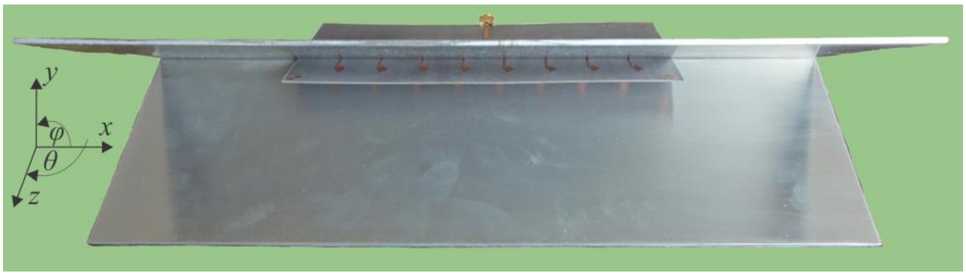
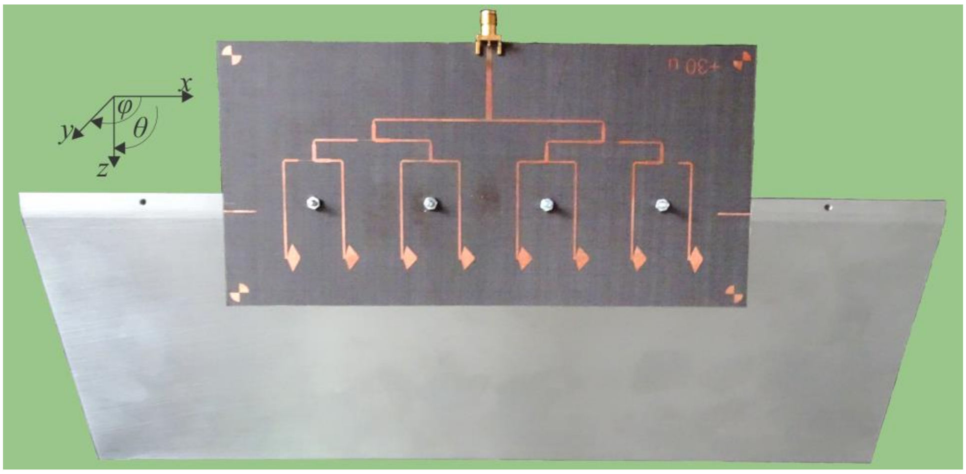


Fig. 8 Radiation pattern of printed antenna array in corner reflector with angle of 45° in H plane

Entire symmetrical printed structure composing eight dipoles array in corner reflector, feeding network and balun are simple and easy to fabricate by printing on the unique substrate. In particular, it is fabricated by cheap and simple photolithographic process satisfying the requirements of mass productions.



a)



b)

Fig. 9 a) Realized antenna with corner reflector b) antenna array, feeding network and one metallic plate of corner reflector

The simulated and measured VSWR is presented in Fig. 10. The simulated VSWR of the antenna array is less than 2 in wide frequency range for every considered corner reflector: between bellow 9 GHz and 13.9 GHz for reflector with 90° angle, between 10.4 GHz and 13.4 GHz for reflector with 60° angle and between 10.3 GHz and 13.7 GHz for reflector with 45° angle. However, the realized antenna array in corner reflector with 45° angle is characterized by VSWR, measured by Agilent N5227A Network Analyzer, below 2 for range of frequencies between 11.13 GHz and 13.11 GHz. While realized antenna is less wideband than simulation models, possibly due to fabrication tolerance and losses introduced by connectors, it still demonstrates good bandwidth of 1.98 GHz (16.5% of central frequency).

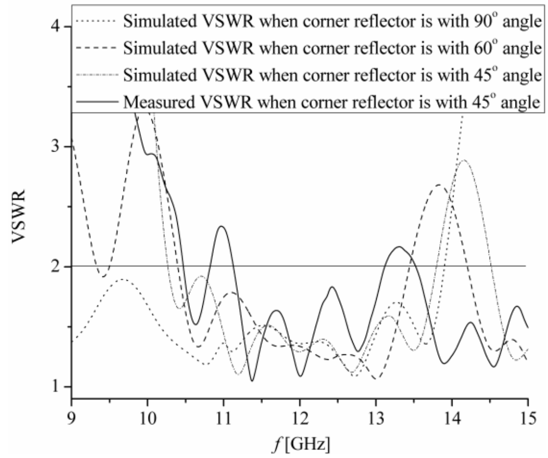


Fig. 10 VSWR of antenna arrays in corner reflector with different angles

The presented results show that the corner reflector can significantly influence both radiation patterns in E and in H plane. Using corner reflector of smaller angle can increase gain and SLS of antenna array (Fig. 11). In order to confirm the advantages of corner reflector, the antenna array with the same parameters as investigated arrays (distribution, feeding network, distance between elements, dielectric, frequency, etc.), although without any reflector plate, is studied. The simulation results of antenna array without reflector are presented in Fig. 11.

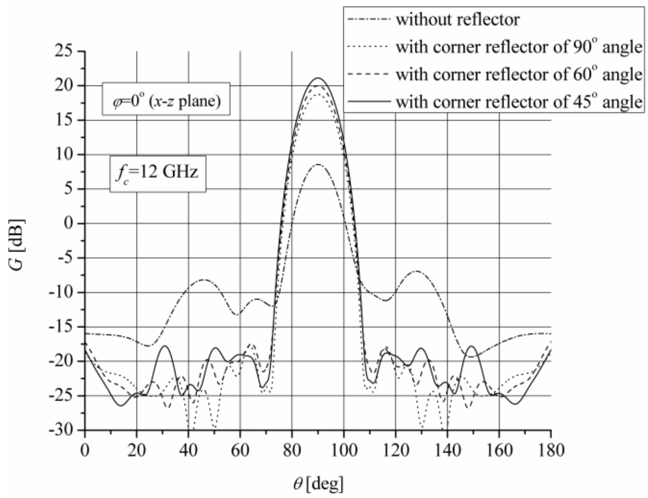


Fig. 11 Simulated radiation pattern in E plane of antenna arrays without reflector and with corner reflector with different angles

It is obvious that its simulation results are far worse than all results of antenna array in corner reflectors. Its gain is 8.6 dBi while its SLS is 15.5 dB. Even if its simulation results are not satisfactory for communication system that require high SLS, thanks its planar form and optimal dimensions (185mm x 50mm), the printed antenna array without reflector is suitable for many other applications: IoT equipment [12], portable devices, RFID systems, etc.

The distance h between the corner reflector's vertex and the dipoles must increase as the angle α of the reflector decreases [1]. Furthermore, for reflectors with smaller angles, the dimensions of reflector plates must be larger [1] increasing the size of entire antenna. Although a gain increases as the angle between the reflector plates decreases, there is an optimum dipoles-to-vertex distance h for the angle α of corner reflector. If the distance h becomes too small, antenna can be inefficient. For very large distance h, the system produces undesirable multiple lobes and it loses its directional characteristics [1]. Consequently, the corner reflector whose plates are set at the 45° angle has the distance $h = 0.6\lambda_0$ between its vertex and dipoles in array and the satisfactory simulated and measured results. Even though the using a corner reflector with a smaller angle can increase antenna gain and SLS, also it will result in larger entire antenna dimensions as well as inadequate radiation pattern.

4. CONCLUSION

Side love suppression is one of the most important antenna parameters whose value must be sufficient to minimize false target indications through the side lobes. Side lobe levels of −20 dB or smaller are usually not desirable in most applications. Antennas with side lobe suppression bigger than 30 dB or 40 dB (mostly radar systems) must be carefully designed and realized.

Furthermore, modern wireless systems request compact, light and simple antennas that are easy to implement. Microstrip (printed) antennas satisfy all listed requirements although they have several limitations to achieve high side lobe suppression: tolerances in fabrication, mutual coupling between radiating elements, surface wave effect as well as parasitic radiation from a feeding network. The symmetrical printed antenna array of pentagonal dipoles can overcome mostly obstacles to achieve great side lobe suppression.

The presented simulated and measured results show that symmetrical printed antenna arrays can achieve great SLS. But, there are several factors that must be considered for their design. The appropriate choice of used distribution determines maximum SLS that can be obtained but also and the parameters of impedance transformers in feeding network. If tapered distribution with great pedestal is used, the transformers with the greatest and the smallest impedance will have the smallest and the biggest width. The impedance transformers with the smallest width are mechanically unreliable; they can easily be broken. The impedance transformers with the biggest width can have high modes. Also, the technical tolerances of photolithographic realization must be considered because deviations from projected values in width and length of impedance transformers can lead to change in amplitude and phase of radiating elements causing SLS degradation.

An unwanted radiation from the feeding structure has significantly influence on side lobe level. Although the feeding network of symmetrical impedance transformers features less radiation than standard microstrip feeding structures, it cannot be completely eliminated. The simulated results show that use of corner reflector with different angle can partially solve the problem of parasitic radiation from feeding network. The corner reflector with smaller angle better prevent the spurious radiation from feeding network and greater SLS can be achieved. Moreover, the greater gain can be obtained using corner reflector with smaller angle. Furthermore, the corner reflector with different angle influences on width of beam in H plane.

Besides all mentioned advantages of corner reflector, the side lobe suppression of realized antenna array in corner reflector of 45° is less about 6.8 dB than expected value obtained by simulation. The reason for measured SLS degradation can be in weakness of measuring condition and in tolerances of realization. However, the gain of realized antenna is 21 dBi that is optimal value for many modern wireless applications.

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