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Research Article

Printed Antenna Arrays with High Side Lobe Suppression

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The problem of side lobe suppression (SLS) in printed antenna arrays has been investigated in the paper. Influence of several factors that make difficult design and realization of antenna arrays with relatively high SLS has been analyzed. We introduced a new type of printed antenna array with symmetrical pentagonal dipoles and symmetrical tapered feed network with Chebyshev distribution enabling SLS better than 34 dB in E-plane. Agreement between simulated and measured results is very good. The antenna is suitable for integration with other microwave circuits. Presented antenna is low cost and very simple for realization.

1. INTRODUCTION

Microwave antenna arrays are usually used in telecommunication systems such as indoor and outdoor wireless LANs, point to point and point to multipoint and also in radar microwave and millimeter systems. One of the main antenna characteristics is SLS in radiation patterns which is defined for telecommunication systems (usually for microwave links) by international standards and recommendations [1]. In conventional radar systems, requirements for SLS are much severe since responses from side lobes practically are false targets. Depending on the antenna class, required SLS in telecommunications systems is about 20 to 40 dB. For example, in AWACS and F-16 radar systems, this suppresion is better than 50 dB.

Such impressive SLSs are hardly achievable with conventional microstrip antenna arrays (with patches). In microstrip antenna arrays presented in literature, side lobe levels are suppressed 25 dB (related to main lobe) at best. A relatively small number of publications dealing with this issue are available [2–4].

2. LIMITING FACTORS IN REALIZATION OF PRINTED ANTENNA ARRAYS WITH HIGH SIDE LOBE SUPPRESSION

There are several problems in realization of printed antenna arrays with relatively high SLS. The main of them are tolerances in fabrication, mutual coupling between radiating elements, limitations in feasibility of feed network realization, and surface wave effect as well as parasitic radiation from a feeding network.

Due to effects mentioned above, it is quite difficult to obtain sidelobe suppression better than 25 dB in microstrip antenna arrays [2]. Tolerances affect various parameters on which sidelobe suppression depends are as follows: (1) dimensions of radiating element, (2) dimensions of feeding lines (width and length) including branches that represent impedance transformers, and (3) distance between radiating elements.

(1) and (2) influence tolerances of phase and amplitude of radiating elements on which SLS depends directly. As it is known, microstrip patches have relatively narrow bandwidth, that is, quick change of impedance with its dimensions change. The consequence of this is notable phase as well as amplitude deviation from optimized values. Another factor is tolerance of feed network dimensions (microstrip lines and impedance transformers) on which amplitude and phase deviations depend directly.

Another group of factors that affect side lobe suppression includes (4) surface wave effect, (5) parasitic radiation from a feed network, especially when the feed network is printed on the same dielectric substrate as the antenna elements, and (6) mutual coupling between radiating elements. However, mutual coupling effect can be easily incorporated into design of the feed network. The above factors are the most noticeable in conventional microstrip antenna arrays with patches as radiating elements that are printed on a dielectric

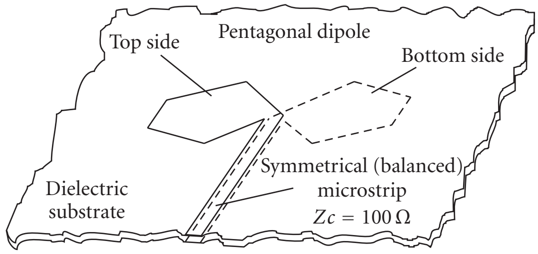

FIGURE 1: Pentagonal dipole as a basic element of the antenna array printed on dielectric substrate.

substrate and are fed by conventional (unbalanced) microstrip lines.

3. SIDE LOBE SUPPRESSION

In order to decrease side lobe levels, various tapered distributions are used in antenna arrays: cosine, cosine-squared, Gaussian, Taylor, and Chebyshev. These distributions are being chosen depending on required side lobe attenuation, possible pedestal in distribution ($I_{\max}/I_{\min}$ ratio), desired position of radiating elements, desired position, that is, distribution of side lobes, distance between radiating elements, number of radiating elements, and expected tolerances in realization.

Pozar and Kaufman in [2] show that variation in frequency of 1% causes, in patch antenna arrays, the phase change of 12.5° which dramatically decreases SLS from 40 dB (in ideal case) to 26 dB. Only due to parasitic radiation from a microstrip feeding line, SLS decreases from 40 dB to about 30 dB. Other parasitic factors that degrade side lobe suppression in patch antenna arrays such as surface wave effect and difraction are also significantly influenceable, so one cannot expect SLS better than 25 dB. The exception is case when each radiating element is fed through a separate tunable phase shifter and atennuator and when the feed network is not on the same dielectric substrate with elements [2].

Beside conventional printed antenna arrays with patches fed by conventional asymmetrical microstrip line, there are printed antenna arrays with printed dipoles, usually of pentagonal shape (one half of them on one side and another half on the opposite side of the substrate). These dipoles operate on the second resonance and are fed by a symmetrical (balanced) microstrip line, Figure 1, [5].

Behind the array, there is a reflector plate [6] or the linear array is placed between two plates which form a corner reflector [5]. Figure 2 shows real and imaginary parts of pentagonal dipole impedance versus frequency, printed on dielectric substrate of 0.254 mm thickness end $\varepsilon_r = 2.1$. It is obvious that impedance variation with frequency is very slow which is of crucial importance for arrays with high SLS. Also, due to the fact that feed network is symmetrical and consists of symmetrical microstrip lines, parasitic radiation from it is practically eliminated. Majority of factors that make difficult realization of printed antenna arrays with high side lobe suppression has been eliminated in these printed arrays.

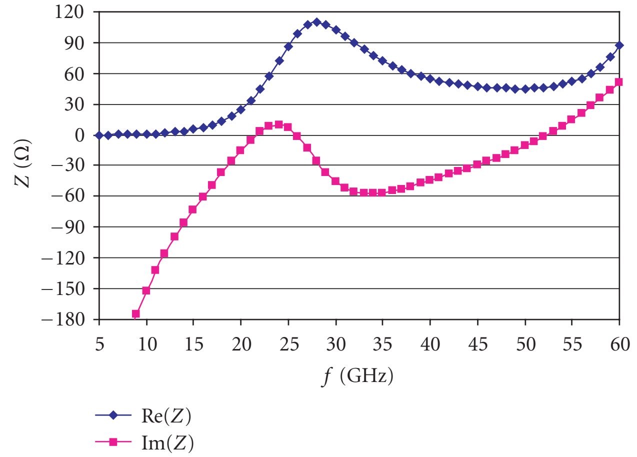

FIGURE 2: Real and imaginary part of pentagonal dipole impedance versus frequency ($\varepsilon_r = 2.1$, $h = 0.254$ mm, and $S = \lambda_0/4$) when aperture angle (α) is 180°.

Because of tolerances in photolithographic process as well as dilatations caused by temperature change, deviations from projected values of position, amplitude, and phase of radiating elements in the array occur. We will investigate influence of these tolerances in the case of printed antenna array with 8 broadband pentagonal dipoles operating on second resonance and with mutual distance of $0.85\lambda_0$. Dipoles are fed by feed network enabling Dolph-Chebyshev distribution of the second order with pedestal ($I_{\max}/I_{\min}$) of 17 dB.

Realizable values of relative tolerances have been assumed at operating frequency of 26 GHz:

(i) *deviations in distances between radiating elements in the array:* 1% or 2% of λ_0,

(ii) *amplitude deviations along tapered lines:* 1 dB or 2 dB,

(iii) *phase deviations:* 2° or 4° (corresponds to about 40 μm and 80 μm tolerances in length of the feeding line).

Using [7], SLS has been calculated: (a) in ideal case; (b) in case of higher deviation only in position of radiating elements; (c) in case of greater amplitude errors only; (d) in case of greater phase errors only; (e) in real cases when all minor errors exist; and (f) when all existing errors are of greater value. Results are presented in Table 1. Errors were randomly distributed in the simulation process (Monte Carlo method).

Figures 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f) show simulated radiation patterns for the cases given in the table above.

For the purpose of better insight in the assumed values resulting from tolerances in realization, we give the absolute values of assumed errors at 26 GHz: tolerances in radiating elements positioning are 230 μm Figures 3(b), 3(f); phase errors result from tolerances in feed lines' lengths that are 40 μm Figure 3(e) and 80 μm Figures 3(d), 3(f). Amplitude

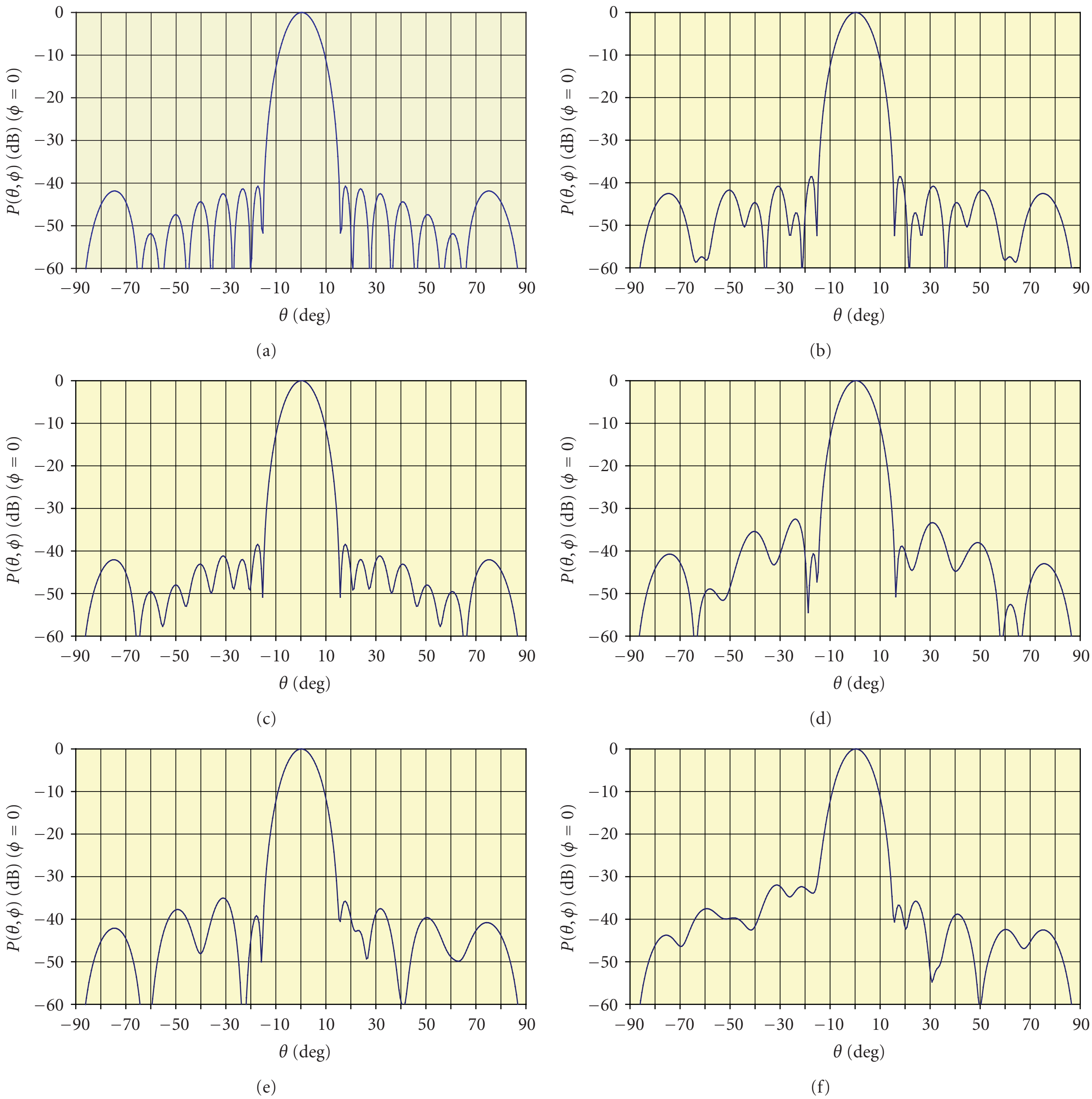

Figure 3: (a), (b), (c), (d), (e), and (f) Simulated radiation patterns for several cases of deviations (amplitude, phase, and radiating elements positioning deviations).

errors occur as a consequence of tolerances in impedance transformer lines widths.

4. CONCEPT, DESIGN, AND REALIZATION OF PRINTED TAPERED LINEAR ANTENNA ARRAY WITH CORNER REFLECTOR

Proposed antenna array consist of three parts: (1) axial array of eight printed pentagonal dipoles (Figure 4, Detail B) (2) feeding network printed on the same dielectric substrate with the pentagonal dipoles (Figure 4, Detail A) and (3) corner reflector consisting of two metal plates. Distance between the dipoles (at the center frequency) is chosen in such a way to obtain relatively high-array gain with sufficient SLS in tapered array. In our case, the distance between axial dipoles is $0.85\lambda_0$. Also, with such distance between axial dipoles, mutual coupling is very low making the design and optimization of the antenna array relatively easy. Pentagonal dipoles' dimensions were optimized with program package WIPL-D [8] so to obtain impedance of 100 Ω at the center frequency of 26 GHz. During the optimization the influence of symmetrical microstrip feeding line of $Zc = 100\,\Omega$ was taken into account. In this case, we have adjusted dimensions of pentagonal dipoles in printed array to obtain impedance

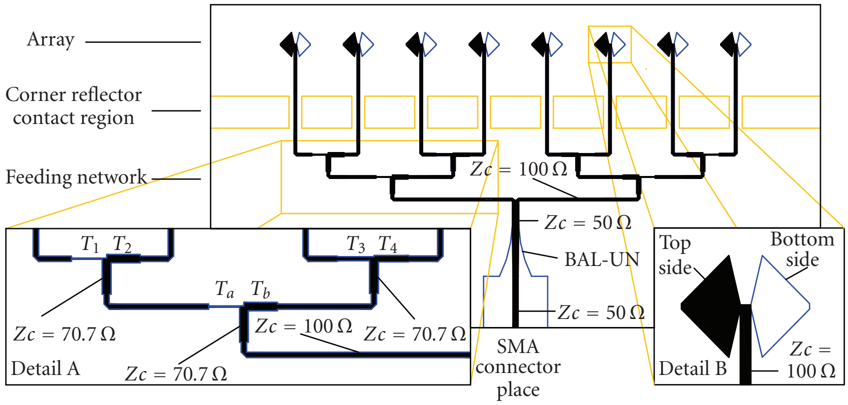

FIGURE 4: Printed antenna array and tapered feeding network integrated on the same dielectric substrate ($\varepsilon_r = 2.1$, $h = 0.254$ mm, and tgδ = 4×10^{-4}). Detail A: tapered feeding network. Detail B: Pentagonal dipole with a symmetric microstrip feeding line of $Zc = 100\,\Omega$.

FIGURE 5: Realized antenna array with corner reflector compared to US quarter.

of $100\,\Omega$ at the center frequency of 26 GHz, taking into consideration the reflector influence. Since the dipoles are electrically symmetrical elements, the feeding network with tapering is realized with symmetrical (balanced) microstrip lines.

By using LINPLAN program package [7], we calculated distribution coefficients that could be achieved with a printed feeding network. Dolph-Chebyshev distribution of the second order with $I_{\max}/I_{\min}$ of 17 dB has been chosen. Distances between dipoles are $0.85\lambda_0$. Under these conditions, we have obtained distribution coefficients enabling highest SLS of 40.72 dB (@ $\Theta = \pm 18^\circ$). In order to attain desired distribution, we designed feeding network in symmetrical microstrip technique with $\lambda/4$ transformers, T_{1-4} and $T_{\mathrm{a,b}}$ (Figure 4, Detail A). With obtained structure, we carried out full-wave analysis [9] in the frequency range from 24 GHz to 28 GHz. Corrections of phase deviations were accomplished by changing the lengths of particular branches in the feeding network, while amplitude deviations remained uncorrected. After these corrections, we achieved symphase feeding of all dipoles in the array.

Corner reflector is designed using the results from [10], which contains very detailed experimental results obtained by variation of length (L), width (W), aperture angle between corner reflector plates (α), and distance of radiating element from apex (S). Suitable radiation pattern with relatively high gain and high SLS in H-plane is obtained with $L = W = 4\lambda_0$, $\alpha = 45^\circ$, and $S = 0.7\lambda_0$.

Axial array with feeding network and BAL-UN [11] is placed between two metallic plates forming a corner reflector with $\alpha = 45^\circ$. Beamwidth in H-plane (azimuth) depends mainly on the angle between the metallic plates and length of the reflector plates (L), while SLS in E-plane depends only on the linear antenna array, Figure 5.

Feeding lines for dipoles penetrate the junction of two reflector plates. In the place of this junction, there are holes through which symmetrical microstrip lines of the feeding network pass. Influence of the metallic plate on the microstrip lines is minimized by selecting the sufficient holes' diameter (2 mm).

5. OBTAINED RESULTS AND COMMENTS

Simulated and measured results are presented in Table 2 and Figures 6–8. The discrepancy between simulated and measured SLS is due to tolerances in photolithography and mounting process because relatively small inaccuracies can significantly influence precise distribution. The return loss measured at SMA connector is presented in Figure 8. The measured gain of the antenna is about 1 dB smaller than the simulated because the feeding network, BAL-UN, and transition from microstrip to SMA connector were not taken into account. Photograph of the realized antenna array with tapered distribution and 45° corner reflector operating in 26 GHz range is shown in Figure 5.

Table 1

	Radiating elements positioning error	Amplitude error	Phase error	Side lobe suppression of the highest lobe [dB]
a	0	0	0	40.72
b	$0.02\lambda_0$	0	0	38.56
c	0	2 dB	0	38.87
d	0	0	4°	32.66
e	$0.01\lambda_0$	1 dB	2°	35.05
f	$0.02\lambda_0$	2 dB	4°	32.02

Table 2: Simulated and measured results at 26 GHz. G: gain; HSLS^{E}, HSLS^{H}: highest side lobe suppression (E-plane, H-plane); F/B: front to back ratio; HPBW^{E}: E-plane 3 dB beamwidth, HPBW^{H}: H-plane 3 dB beamwidth.

	G [dBi]	HSLS^{E} [dB]	HSLS^{H} [dB]	F/B [dB]	HPBW^{E} [°]	HPBW^{H} [°]
Simul.	21.4	38.4	35	32	10.5	23.8
Meas.	20.8	34.7	32.6	35.4	10.7	23.8

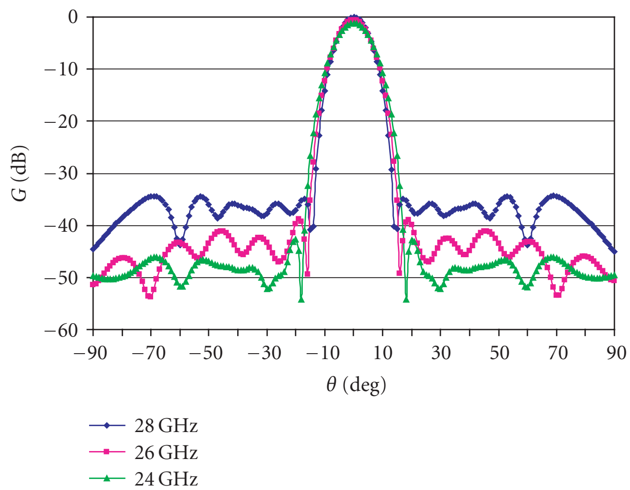

Figure 6: Normalized simulated E-plane radiation pattern at 24 GHz, 26 GHz, and 28 GHz.

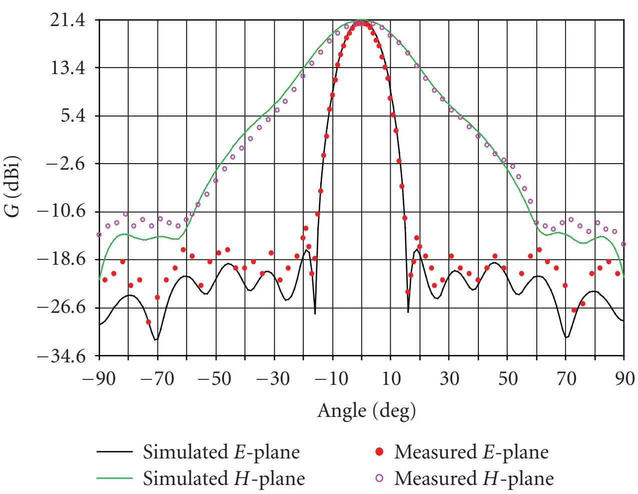

Figure 7: Simulated and measured radiation pattern in H- and E-plane at 26 GHz (highest side lobe is suppressed about 35 dB in relation to the main lobe).

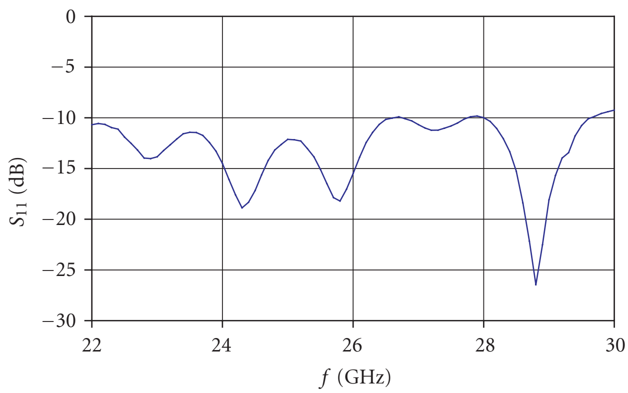

Figure 8: Measured return loss of the antenna array.

6. CONCLUSION

The paper investigates possibilities and limitations in printed arrays side lobe suppression. All relevant factors on which SLS depends are particularly analyzed: phase deviations, amplitude deviations, radiating elements positioning deviations, mutual coupling between elements, and parasitic radiation from the feed network. It is shown that SLS, satisfactory for most microwave telecommunication and especially radar systems, is hardly achieveable with conventional microstrip antenna arrays with patches due to their narrow bandwidth that is, quick variation of impedance with dimensions change, parasitic radiation from the feed network, and surface wave effect.

Antenna structure with printed pentagonal dipoles forming the array is proposed. The dipoles operate on the second resonance and are fed by a symmetrical (balanced) microstrip line. Array consisting of 8 axially placed dipoles is fed through the feed network with impedance transformers enabling Chebyshev distribution with pedestal $I_{\max}/I_{\min} = 17$ dB. We have analyzed effects of particular parameters with assumed tolerances on which SLS depends. Linear antenna array realized in this way is placed between two metallic plates forming a corner reflector which enables achieving relatively high SLS and narrow beamwidth even in H-plane. Measured beamwidth in E-plane at 26 GHz is 10.7°. Experimentally obtained E-plane SLS at 26 GHz, which depends only on the antenna array, is better than 34 dB and is, to the authors' knowledge, the best result published so far. The array is realized using standard photolithographic process with moderate precision of $\pm 10\,\mu$m. Simulated and measured results are in very good accordance.

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