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WIDE SCANNING PHASED ARRAY ANTENNA USING PRINTED DIPOLE ANTENNAS WITH PARASITIC ELEMENT

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Abstract—A active phased array antenna has been developed that is capable of wide scanning angle with small deviation in antenna gain using printed dipole antennas with parasitic element, which may have the capability of adjusting the influence of mutual coupling in the array element pattern. The design of the parasitic element is examined and the effect of its shape on pattern characteristics is confirmed. Beam scanning angles of 58 degrees in the $\varphi = 0^\circ$ plane were obtained for each array antenna pattern.

1. INTRODUCTION

Microstrip array antennas are widely used for radars [1–3]. There are several advantages to using microstrip array antennas: A high gain antenna with a narrow beamwidth and high resolution is achieved when identical aperture dimensions are a requirement.

Phased array antennas using printed dipole antennas are required to scan large angles. Therefore, we have tried to develop an array antenna capable of electronic beam scanning with small deviation in antenna gain at large angles. For the antenna element, notch [4], dipole, slot line [5–7], and patch antennas [8] have been compared because they require limited mounting space and crosspolarisation. The dipole antenna was selected.

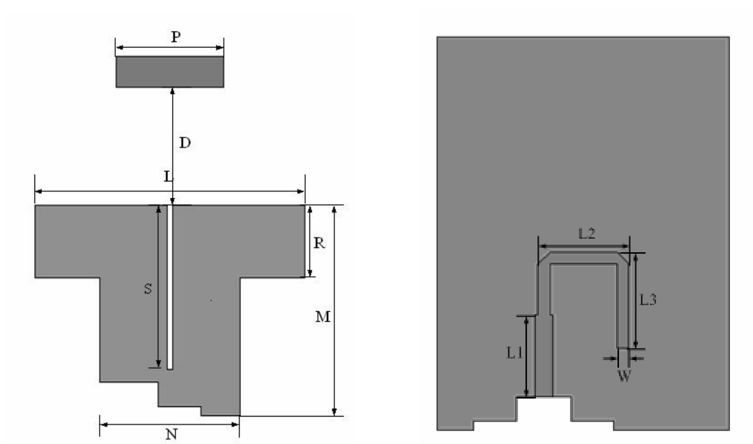
However, if the spacing between element antennas is dense in order to obtain large angle scanning, mutual coupling between elements is so strong that the antenna gain deviates from changing monotonically with angle in the array element pattern. Thus, when the beam is made to scan electronically, the antenna pattern will be composed of all array element patterns, leading to fluctuation in antenna gain with directional angle. This deviation or ripple in antenna gain will affect the precision of angle measurement when searching for an object using the angular difference in the strength of reflected signals, and thus cause deterioration in object search or tracking performance.

In order to solve the above problem, we have used a printed dipole antenna [9, 10] with parasitic element capable of adjusting the influence of mutual coupling in the array arrangement and correcting deviations or fluctuations in the array element pattern without losing any emission energy [11, 12].

The paper examines how to design the parasitic element and confirms the effect of its shape on pattern characteristics. Details of the proposed antenna design and experimental results are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the structure and dimensions of the array element, whose conductor is fabricated on an inexpensive substrate with the effective dielectric constant of 2.65 and the substrate thickness of 1 mm. The printed dipole antenna is defined by its Length $L = \lambda_0/2 = 50$ mm, $R = 12$ mm, $M \approx \lambda_0/4 = 25$ mm, $S = 27$ mm, $N = 0.4L \times 0.5L = 23$ mm, $P = 27$ mm and $D = 24.3$ mm. For the parasitic element, $P = 0.271\lambda$ and $D = 0.243\lambda$ as the centre values for design, we decided to change P and D by $\pm 20\%$.



(a) front side (b) reverse side

Figure 1. Geometry of the microstrip printed dipole antenna with parasitic element.

The form of coupling feed is used at the reverse side of substrate. For achieving efficient excitation and good impedance matching, the length of the protruded strip is denoted as $l1$, $l2$, $l3$ and w of which the optimal length are found to be 14 mm, 15 mm, 14 mm and 2 mm. By varying the length of $l1$, $l2$, $l3$ and w, the wideband operation of the microstrip printed dipole antenna can be excited with good impedance matching. The maximum impedance bandwidth (2.5–4.0 GHz) is formed.

The maximum gain of an isolated element is shown in Fig. 2. From these results, the gain as a dipole antenna alone show that the difference caused by a $\pm 20\%$ change in D was small enough to be negligible. However, when P was increased from -20% to $+20\%$, the antenna gain is changed, revealing the strong effect of the parasitic element.

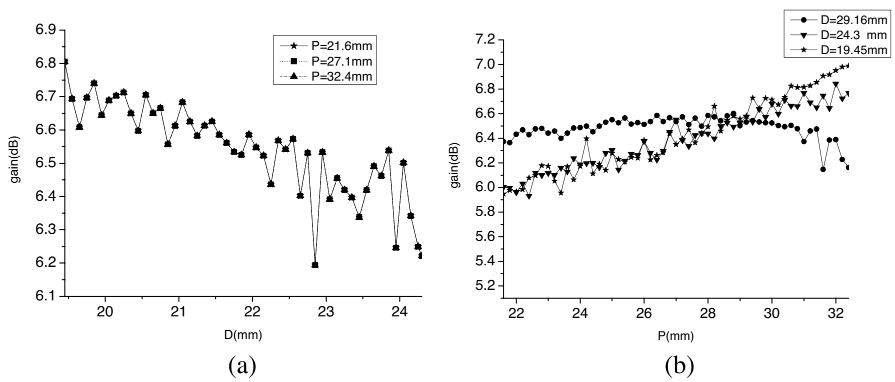


Figure 2. Isolated element pattern using parasitic element.

Comparison of design centre values for an isolated element in $\varphi = 0°$ plane pattern and $\varphi = 90°$ plane pattern when using the parasitic element is shown in Fig. 3. In the $\varphi = 0°$ plane pattern, the beamwidth for a dipole antenna with parasitic element became approximately 90% of the value of the beamwidth without parasitic element. A similar phenomenon is seen in the $\varphi = 90°$ plane pattern, in which beamwidth for a single element is approximately 70% of the value of the beamwidth without the parasitic element. Therefore it is surmised that the addition of the parasitic element has reduced the effect of mutual coupling.

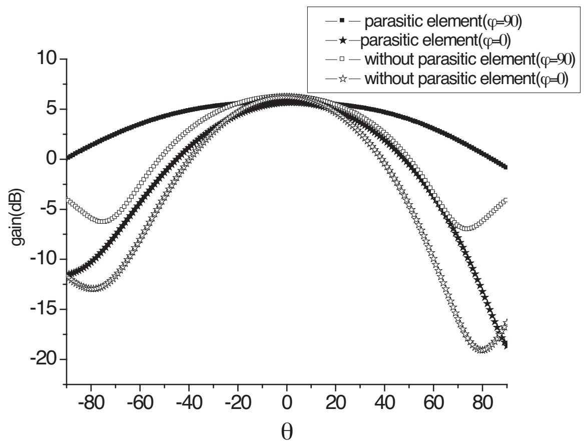


Figure 3. Isolated element pattern with parasitic element and without it.

3. EVALUATION OF BEAM FORMATION AND SCANNING CHARACTERISTICS OF PHASED ARRAY ANTENNA

In general, the array element pattern $E_{an}(\theta)$ is known to differ from the isolated element pattern $E_{in}(\theta)$ due to effects of mutual coupling.

$$E_{an}(\theta) = \frac{1}{G_0} \sum_{m=1}^{n} E_{in}(\theta) \left(\delta_{mn} + S_{mn}\right) \exp\left(jk\left(m-n\right) d \sin\theta\right) \tag{1}$$

Here d, k, θ, $E_{an}(\theta)$, G_0, $E_{in}(\theta)$, and S_{mn} represent array spacing, wavenumber, angle from array bore site, array element pattern when only the nth antenna element is active, the others loaded for impedance matching, real part of admittance, isolated element pattern when nth antenna element is placed independently from the array, and the (m, n)th element of the scattering matrix S, respectively.

In order to design an array antenna which performs beam scanning without generating a grating lobe in a phased array antenna, element distance must satisfy:

$$\frac{d}{\lambda} = \frac{1}{\left|1 + \sin\theta_{\max}\right|} \tag{2}$$

Here, d, λ, and $\theta_{\max}$ represent array spacing, wavelength, and maximum scanning angle, respectively.

When frequency is fixed, scanning a wider angle means having a smaller element distance. However, having a smaller distance between antenna elements will increase mutual coupling between antenna elements, which generates deviations such as ripple or fluctuation in antenna gain. The element distance from the desired scanning angle, $\theta_{\max}$ and wavelength were calculated using (2). Next, the dimensions of the parasitic element and the distance between the parasitic element and dipole antenna were changed and the deviation in element pattern measured for ripples or fluctuations in the amplitude of the array element pattern. Based on the results, the following requirements need to be satisfied when determining adjustment of the parasitic element.

(i) The beamwidth of the array element pattern necessary for scanning the beam over a large angle is maximised.

(ii) Improvement in gain from the array element pattern is maximized.

(iii) Deviation in array element pattern with angle (range of angle which reduces gain by 3 dB) is minimised.

In general, an array antenna pattern is represented as a multiple of the array element pattern and an array factor. Therefore, it is evident that the change in gain in the forward direction during beam scanning by the array antenna changes at the same rate as the beam shape of the array element pattern

$$F(\theta) = \sum_{n=1}^{N} E_{an}(\theta) i_n \exp\left(jknd \sin\theta\right) \tag{3}$$

Here, i_n represents the incident wave on the nth element.

Figure 4 shows the change in main beam direction when the beam is scanned by applying the Taylor distribution [13, 14] with sidelobe level -30 dB and $\bar{n} = 5$ on the 30×30 plane array. As a result, the beam scanning range (half value width) obtained was $\pm 58°$.

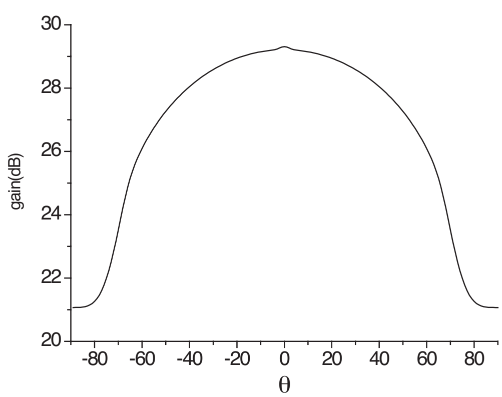


Figure 4. Array scanning gain pattern.

4. CONCLUSIONS

The paper discusses one method to determine the element antenna shape for an array antenna to perform beam scanning over a wide angle. Applying a dipole antenna with parasitic element on an element antenna enabled increase in the beamwidth of the array element pattern and reduced gain fluctuation. With results it was confirmed that the design was capable of forming wide angle beam scanning and shaping as well as performing satisfactory pattern scanning and forming. This design method has been demonstrated to be applicable to dipole antenna arrays.

REFERENCES

1. Eldek, A. A., "Design of double dipole antenna with enhanced usable bandwidth for wideband phased array applications," *Progress In Electromagnetics Research*, PIER 59, 1–15, 2006.
2. Edward, B. J., D. R. Helms, R. S. Webb, and S. Weinreb, "W-band active transmit and receive phased array antenna," *IEEE MTT-S Int. Microw. Symp. Dig.*, 1095–1098, 1995.
3. Kim, D., M. Kim, M. Tanaka, and K. Matsugatani, "A microstrip antenna using patch array resonator," *Microwave and Optical Technology Letters*, Vol. 49, No. 12, December 2007.
4. Butterworth, J. C., "A high power coherent 95 GHz radar (hipcor-95)," *IEEE MTT-S Int. Microw. Symp. Dig.*, Vol. 1, 499–502, 1987.
5. Pazoki, R. and J. Rashed-Mohassel, "Bandwidth enhancement of resonant slot array antennas," *Microwave and Optical Technology Letters*, Vol. 21, No. 9, 1177–1189, December 2007.
6. Sayem, A. M. and M. Ali, "Characteristics of a microstrip-FED miniature printed Hilbert slot antenna," *Progress In Electromagnetics Research*, PIER 56, 1–18, 2006.
7. Chair, R., A. A. Kishk, K.-F. Lee, C. E. Smith, and D. Kajfez, "Microstrip line and CPW FED ultra wideband slot antennas with U-shaped tuning stub and reflector," *Progress In Electromagnetics Research*, PIER 56, 163–182, 2006.
8. Wei, W.-B., Q.-Z. Liu, Y.-Z. Yin, and H.-J. Zhou, "Reconfigurable microstrip patch antenna with switchable polarization," *Progress In Electromagnetics Research*, PIER 75, 63–68, 2007.
9. Chen, K., X. Chen, and K. Huang, "A novel microstrip dipole antenna with widerband and end-fire properties," *Microwave and*

Optical Technology Letters, Vol. 21, No. 12, 1679–1688, December 2007.

10. He, Q.-Q. and B.-Z. Wang, "Radiation patterns synthesis for a conformal dipole antenna array," *Progress In Electromagnetics Research*, PIER 76, 327–340, 2007.
11. Mizutani, H., M. Funabashi, and M. Kuzuhara, "GHz small-size HJFET MMIC switch for high power applications," *IEEE AP-S Symp. Digest*, Vol. C-50, 949–952, 1995.
12. Kuwahara, Y., Y. Kadowaki, and K. Matsumoto, "Array element pattern shaping by a parasitic element," *IEEE AP-S Symp. Digest*, Vol. 2, 934–937, 1995.
13. He, Q.-Q. and B.-Z. Wang, "Design of microstrip array antenna by using active element pattern technique combining with Taylor synthesis method," *Progress In Electromagnetics Research*, PIER 80, 63–76, 2008.
14. Yuan, H.-W., S.-X. Gong, X. Wang, and W.-T. Wang, "Scattering analysis of a printed dipole antenna using PBG structures," *Progress In Electromagnetics Research B*, Vol. 1, 189–195, 2008.