Fan-Beam Microstrip Array Antenna for X-B and Radar

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***Abstract*— In this study, a fan-beam microstrip array antenna for an X-band radar was designed and fabricated using a novel technique. A microstrip array structure was used to obtain a high-gain and narrow horizontal beam-width. The feeding point is located at the center of the antenna because of its 360° rotational characteristic. The measured results indicate a gain of 23dBi, and a horizontal and vertical beamwidth of 3.57°, 26.12°, respectively. The proposed antenna performed adequately and managed to meet the specifications.**

***Index Terms*— fan-beam, bandwidth, radar, matching**

I. INTRODUCTION

RADAR(radio detection and ranging) is a technology that uses electromagnetic waves to detect the distance and direction of a target by bouncing these waves off the target and receiving the echo signal. Radar is a very important tool in shipping, where it is used for locating ships and preventing collisions [1].

The antenna for an X-band marine radar has characteristics similar to that of a fan-beam[2-4]. Among the antennas used in marine radars, a microstrip array antenna is popular because of its weight and price advantages [5]. In spite of these advantages, there has been little research and development in this field domestically. Therefore, X-band marine radar, with fan-beam characteristics, was designed by a new technique using a microstrip array. The characteristics of the fabricated antenna have been found to surpass design specifications.

II. MICROSTRIP PATCH ANTENNA

THE practical length and width of the resonant patch determines the operating frequency thus it is a critical factor because it is narrow band patch. Fig. 1 shows the single rectangular patch antenna. For a dielectric substrate of thickness h, permittivity ε_r, and antenna operating frequency f_r , the practical width is given by,

$$W = \frac{c}{2f_r}\sqrt{\left(\frac{2}{\varepsilon_r + 1}\right)} \tag{1}$$

Where c is the velocity of light.

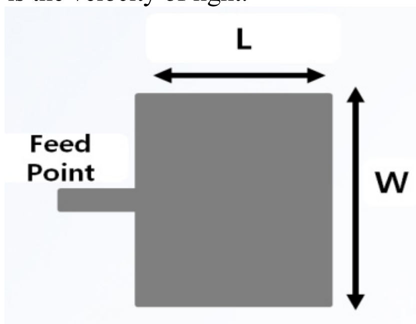

Fig. 1. Rectangular patch antenna

Because of the small length and width of the resonant patch, a fringing effect is observed along the edges of the patch. The total fringing effect, which is a function of the patch size and substrate thickness, must be considered because it affects the resonant frequency. Effective permittivity is used to calculate the wave propagation and fringing effect along the edges. For W/h > 1, the effective permittivity, ε_{re}, is given by,

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

Because of the fringing effect, the resonant patch of microstrip antenna looks larger than its actual size. In a basic E-plane, the length of the resonant patch is extended as much as ΔL at one end. The extended length ΔL is given by,

$$\Delta L = 0.412\frac{(\varepsilon_{re} + 0.3)(W/h + 0.264)}{(\varepsilon_{re} - 0.268)(W/h + 0.8)} \tag{3}$$

The length (L) of the patch is determined in terms of effective permittivity, ε_{re} as,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{re}}} - 2\Delta L \tag{4}$$

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For rectangular patch, the length (L) is generally $\frac{\lambda_0}{3} < L < \frac{\lambda_0}{2}$.

The resonant frequency of the microstrip patch antenna is given by,

$$f_r = \frac{c}{2(L + 2\Delta L)\sqrt{\varepsilon_{re}}} \qquad (5)$$

The resonant frequency is generally expressed in terms of the electrical length $L + \Delta L$, effective permittivity, and thickness of the substrate.

III. MICROSTRIP ARRAY ANTENNA

Table 1 lists the design specifications of the X-band radar antenna.

TABLE I
DESIGN SPECIFICATION

Center frequency	9410MHz
Bandwidth	30MHz
Horizontal beam-width	≤ 4°
Vertical beam-width	≥ 25°
Gain	≥ 23 dBi
Side lobe level	Within 20°≤ -18° beyond 20°≤ -23°

Fig. 2 shows the layout of the designed 3×24 array antenna for X-band radar.

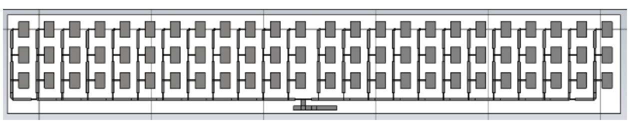

Fig. 2. Layout of designed antenna.

The total size of antenna is limited to 56×9 cm, because of the limited space in a radome

TABLE Ⅱ
CHARACTERISTICS DIELECTRIC

Permittivity	2.5
Height	1.6mm
Loss tangent	0.0019

Table 2 lists the characteristics of the dielectric. The most favorable characteristics are obtained at a central frequency of 9410MHz with a patch size of W=14.2mm and L=8.89mm. The simulation result of the input return loss is shown in Fig.3.

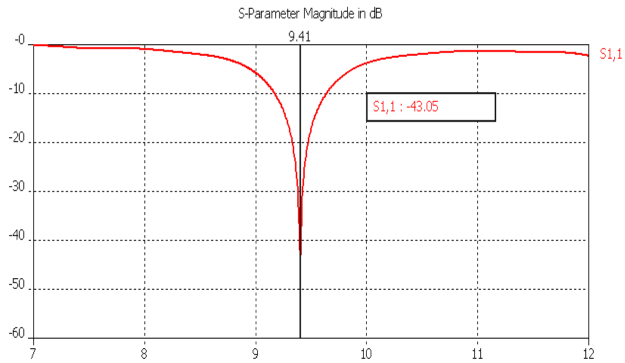

Fig. 3. The input return loss of single patch antenna.

Three patch elements were arrayed in the vertical direction to broaden the vertical beam-width. The number of optimum elements was decided using the PCAAD 3.0 simulator. The 3 × 24 array satisfies the design specification for both the size and the gain of the antenna. The line of the antenna was designed using a non-uniform feeding structure. Figs. 4 and 5 show the characteristic graph of the phase and transmission coefficients in a vertical and horizontal line, respectively.

For the vertical line, the power ratio of the top and bottom patches was the same. Most of the power was transferred to the central patch and the phase difference of all the ports approached zero. The horizontal line is designed to reduce the power ratio further away from the center of the graph. In addition, a uniform feeding structure is used to minimize the side lobe level and to obtain a sharp beam-width at the center

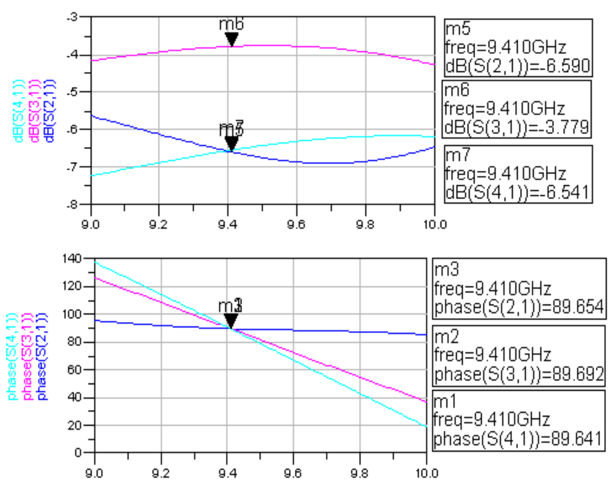

Fig. 4. Characteristics of phase and transmission coefficients in a vertical line.

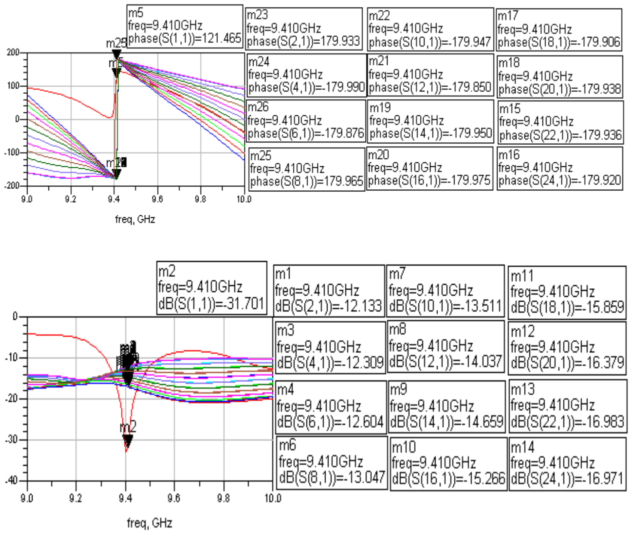

Fig. 5. Characteristics of phase and transmission coefficients in a horizontal line

Because of the 360° rotational characteristic of the radar antenna, the feeding point is located at structural center and not the geometric center. Hence, stub matching is required. Using the same design process, the simulation results showed different characteristics along the stub length. The simulation result showed good characteristics when the left length and right length were 11mm and 6.8mm, respectively, at 9410MHz.

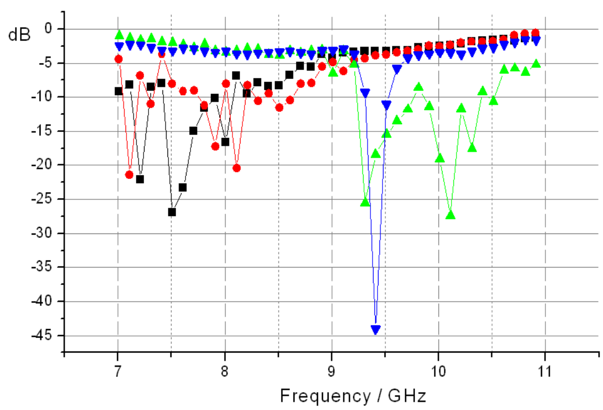

Fig.6 Characteristics of S-parameter along Stub length

IV. FABRICATION AND MEASUMENT RESULTS

Fig. 7 shows the fabricated antenna. The optimized antenna is fabricated using photolithography. Its size is 56×9 cm. The line shield connects to prevent spurious radiation on the line. The measured results of the fabricated antenna shown in Figs. 8, 9 and 10. The radiation pattern is measured using a five frequency band.

Fig. 7. Fabricated 3×24 array antenna.

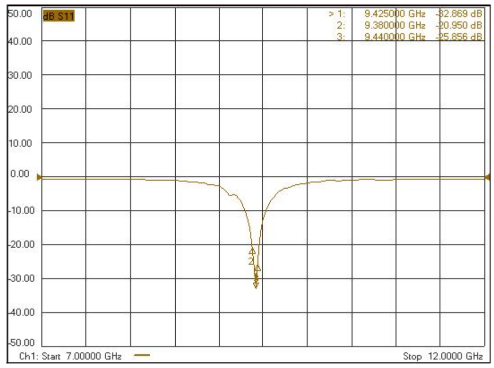

Fig. 8. The input return loss of fabricated antenna

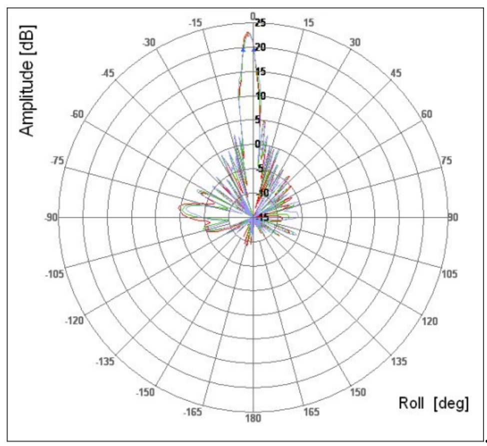

Fig. 9. Horizontal radiation patter of antenna

The measured input return loss is -32dB at 9,425MHz; this exceeds the design specifications by approximately 15MHz. The measured radiation pattern show that the gain is higher than 23dBi, and the horizontal and vertical beamwidth are 3.57°, and 26.12°, respectively. The gain characteristic of the sidelobe level within 20° of the main lobe is -18.09°dB whereas that beyond 20° of main lobe is -23.07dB.

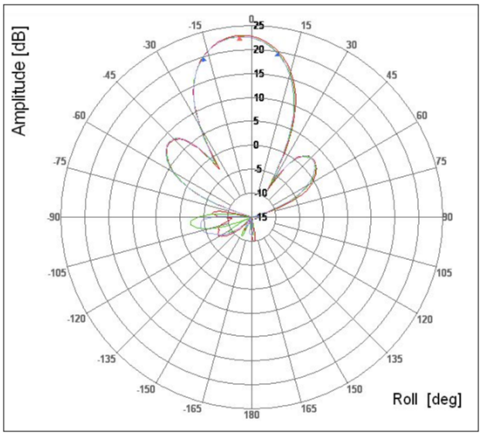

Fig. 10. Vertical radiation patter of antenna

TABLE III
MEASUREMENT RESULTS

frequency (MHz)	Gain (dBi)	Horizontal beamwidth (°)	Vertical beamwidth (°)
9,350	22.19	3.26	26.29
9,380	22.64	3.42	26.24
9,410	23.09	3.57	26.16
9,440	22.87	3.52	26.02
9,470	22.83	3.47	25.98

IV. CONCLUSIONS

In this paper, a fan-beam microstrip array antenna is designed and fabricated for an X-band radar. A non-uniform feeding structure with a series feed is used to reduce the antenna size and to simultaneously obtain characteristics such as high-gain and low side lobe level. The tilt of the main beam in the horizontal radiation pattern is due to incomplete setup equipment when the radiation pattern is measured. The characteristics of the proposed antenna exceed the design specification. Therefore, this antenna is suitable for the X-band radar application. The proposed antenna not only has very simple structure but also is very easily constructed with a very low cost.

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