Low-cost array antenna design for S-Band maritime radar by using sparse array method

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Abstract. In this paper, compact design and high aperture efficiency S-band maritime radar antennas are proposed. To obtain an antenna design with high efficiency elements and a smaller aperture size, the sparse array method approach is used. The antenna design uses a stretching strategy approach based on the Taylor line source algorithm. The design simulation results show a good performance with high efficiency of elements and antenna size compared to conventional array design with uniform spacing between elements λ/2.

1. Introduction

This study aims to develop a prototype of low-cost planar array antenna for S-band maritime radar application. The development of more cost-efficient radar devices is the main objective of developing radar systems. Antennas are an important part of the radar system that determines the efficiency of a radar system. To achieve the required radar specifications, an array antenna with a large number of elements is needed. This consequence will make the antenna and radar equipment systems expensive. Thus the antenna design with high element efficiency is the main target for the development of radar antenna design.

Maritime radar is one type of surveillance radar that is widely applied to marine navigation systems. Development of maritime radar with a compact and mobile system is a breakthrough to improve efficiency and operational costs [1]. This radar system requires a more efficient antenna design and low-cost, especially for radars that operate at S-band frequencies that have large array antenna sizes as a consequence of S-band frequency usage [2]. Thus the S-band radar antenna design with high efficiency and low-cost is needed to be developed.

In this paper array antenna design with low-cost is proposed. This design applies the design sparse array concept to improve element efficiency and size of array antenna [3].

2. Antenna Design Method

2.1. Single Array Design

The proposed single microstrip antenna is designed numerically by using CST microwave studio software to operate at 3 GHz S-band radar frequency. Design of microstrip antennas used FR4-Epoxy substrate and thickness of 1.6 mm. The Overall microstrip antenna dimensions resulting from design optimization are 61.42 mm x 46.36 mm for substrate material and 37.31 mm x 23.3 mm for patch antennas as shown in Figure 1.
2.2. Sparse Array Design
Array antenna design is intended to obtain antenna gain and radiation patterns according to maritime radar specifications. Based on ITU standards for radar antennas (Rec. ITU-R M.1460-2) about technical and operational characteristics and protection criteria of radiodetermination radars in the frequency band 2 900-3 100 MHz [4], the specification of the beamwidth antenna required are 2° in azimuth and 26.5° in elevation and 27.5 dB antenna gain. To achieve these specifications, conventional array designs with uniform spacing λ/2 between elements require 64 elements for azimuth and 4 elements for elevation. Consequently the dimensions of the antenna that are needed become large and require a large space for antenna clearance in the radar scanning process. Therefore the sparse array solution is needed to achieve the required specifications with reduce number of elements and smaller dimensions.

In this paper, the proposed design sparse array for S-band radar antennas uses a stretching strategy approach and spacing coefficient between elements by using Taylor’s line-source distribution [5], [6]. This approach is the development of a deterministic synthesis to produce a sparse array design configuration [7], [8], [9].

To calculate the distance between elements that are not uniform, an opposite relation of Taylor line-source distribution [6] is used. Thus the approach used to calculate the distance between elements as following relation [6]:

\[
d_n = \frac{1}{I_n}
\]

(1)

Where,
- \(d_n\) : Distance between elements for \(n\) element
- \(I_n\) : Excitation for \(n\) element

\[
I_n = J_0 \left[ j \pi B \sqrt{1 - \left( \frac{2z_n}{p} \right)^2} \right]; \quad -\frac{p}{2} \leq z_n \leq \frac{p}{2}
\]

(2)

Parameter \(z_n\) is the position of the \(n^{th}\) element from center of array configuration and total number of elements is \(p\) (odd or even) [6]. The distance for each element is obtained by multiplying the distance coefficient \(d_n\) with the standard distance between elements \(\lambda/2\).

The difference of this research with previous research regarding the development of linear sparse array method based on Taylor line source distribution [6] are the design of 3 GHz antenna frequency, antenna feeding system and settings to obtain planar antenna configuration. The antenna feeding system in this
study uses a single input signal source for 32 array elements, while the previous research was designed for each single source element. A planar configuration design is needed to meet the radar antenna's elevation beamwidth specifications.

To achieve the required maritime radar antenna specifications, the sparse array configuration is designed with 32 elements for azimuth beamwidth and 4 elements for elevation beamwidth. The sparse-array configuration was developed with 32 elements for as shown in Figure 2. The distance between elements was calculated by using element distance coefficients based on Taylor line source (1) and (2). The SLL reference was characterized in -30 dB to obtain \( I_n \) parameter. The propose S-band array antenna for maritime radar as shown in Table 1.

Figure 2. 33 Element sparse array design for 3 GHz S-band frequency: (a) Front view linear array; (b) Side view linear array; (c) Planar array 4 x 32 elements.
### Table 1. Design parameter for 32 elements sparse array

| Elemen Number $(n)$ | Line-source Taylor coefficients $(L_p)$ | Spacing coefficients $(d_p)$ | Elemen Spacing $(\lambda)$ |
|---------------------|----------------------------------------|-----------------------------|---------------------------|
| 1                   | 0.11                                   | 9.09                        | 4.58                      |
| 2                   | 0.16                                   | 6.25                        | 3.15                      |
| 3                   | 0.22                                   | 4.55                        | 2.29                      |
| 4                   | 0.29                                   | 3.45                        | 1.74                      |
| 5                   | 0.36                                   | 2.78                        | 1.40                      |
| 6                   | 0.44                                   | 2.27                        | 1.14                      |
| 7                   | 0.52                                   | 1.92                        | 0.97                      |
| 8                   | 0.59                                   | 1.69                        | 0.85                      |
| 9                   | 0.67                                   | 1.49                        | 0.75                      |
| 10                  | 0.74                                   | 1.35                        | 0.68                      |
| 11                  | 0.81                                   | 1.23                        | 0.62                      |
| 12                  | 0.87                                   | 1.15                        | 0.58                      |
| 13                  | 0.92                                   | 1.09                        | 0.55                      |
| 14                  | 0.96                                   | 1.04                        | 0.52                      |
| 15                  | 0.98                                   | 1.02                        | 0.51                      |
| 16                  | 1.00                                   | 1.00                        | 0.50                      |
| 17                  | 1.00                                   | 1.00                        | 0.50                      |
| 18                  | 0.98                                   | 1.02                        | 0.51                      |
| 19                  | 0.96                                   | 1.04                        | 0.52                      |
| 20                  | 0.92                                   | 1.09                        | 0.55                      |
| 21                  | 0.87                                   | 1.15                        | 0.58                      |
| 22                  | 0.81                                   | 1.23                        | 0.62                      |
| 23                  | 0.74                                   | 1.35                        | 0.68                      |
| 24                  | 0.67                                   | 1.49                        | 0.75                      |
| 25                  | 0.59                                   | 1.69                        | 0.85                      |
| 26                  | 0.52                                   | 1.92                        | 0.97                      |
| 27                  | 0.44                                   | 2.27                        | 1.14                      |
| 28                  | 0.36                                   | 2.78                        | 1.40                      |
| 29                  | 0.29                                   | 3.45                        | 1.74                      |
| 30                  | 0.22                                   | 4.55                        | 2.29                      |
| 31                  | 0.16                                   | 6.25                        | 3.15                      |
| 32                  | 0.11                                   | 9.09                        | 4.58                      |

3. Results and Discussion
The simulation result of the return loss at the frequency 3 GHz and the radiation pattern of the proposed sparse array antenna are shown in Figure 3 and Figure 4. The radiation performance of 32-element sparse array antenna was a 3dB beamwidth (half power beamwidth) 1.7° and the peak sidelobe (PSL) performance is -17.15 dB.
Figure 3. S-parameter of proposed antenna design

Figure 4. The radiation pattern of the proposed sparse array

The overall performances comparison of the proposed array antenna by using sparse array method with conventional uniform array is shown in Table 2. These results show that using 32 elements can achieve the beamwidth needed for the S-band maritime radar specifications. This is a significant efficiency for the size of the antenna dimensions on radar application. However, the directivity performance is still lower when compared to conventional uniform arrays as the effect of reducing the number of elements. In the further development, it is necessary to add more antenna elements to achieve the required gain specifications.

Table 2. Performances Comparison

| No. | Array Configuration       | Element Configuration | Aperture (λ) | Radiation Performances |
|-----|--------------------------|-----------------------|--------------|------------------------|
|     |                          |                       |              | Directivity (dB) | 3 dB Beamwidth (°) | PSL (dB) |
| 1   | Sparse Array Design      | 4 x 32                | 64.92        | 23.80                  | 1.7               | -17.15   |
| 2   | Uniform Array λ/2        | 4 x 64                | 80.27        | 27.79                  | 0.7               | -13.50   |
4. Conclusion
The compact and high efficiency array antenna design for S-band maritime radar has been demonstrated. The proposed antenna design by using sparse array method was shown significantly efficiency of antenna dimension compare to conventional array antenna design. This antenna design can be used as a reference for developing high efficient and low-cost S-band radar antenna.

5. References
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