Design of Trihedral Corner Reflector for Shipboard Navigation Systems

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Abstract

A trihedral corner reflector is proposed to be designed numerically and applied as part of shipboard navigation systems. The design reflector takes into two shapes, square trihedral and quarter-circle trihedral corner reflector. It has dimension of 300mm x 300mm x 300mm for square trihedral corner reflector and radius of 300mm for quarter-circle trihedral corner reflector. The reflectors are designed to work whereby at the frequency around 3GHz with the radar cross section at least of $10m^2$.

Keywords: radar cross section, trihedral corner reflector, square trihedral, quarter-circle trihedral

1. Introduction

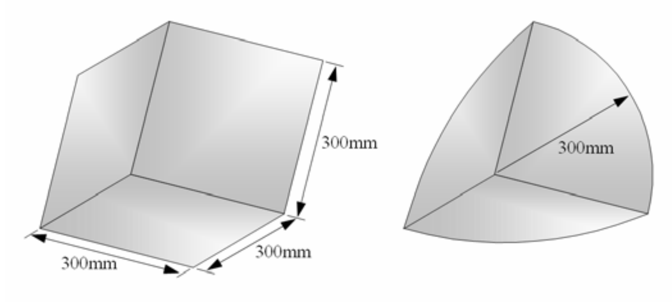
As is well-known, reflector that is usually applied as a radar target is a device that can reflect an electromagnetic wave incident into reflector toward to the sender signal. Some applications of reflector as a radar target are often founded in many aspects such as on the border of some country, as a geographic mapping tool for helping somewhere, as a tool for object detection, and as a means for vehicle navigation [1]-[3]. As a vehicle navigation device, the reflector serves to guide a vehicle such as shipboard, etc. to follow a predetermined path or provide position location information. There are 2 kinds of a reflector commonly used for the navigation system, namely active and passive reflector. Passive reflector is a reflector that can only reflect the incoming electromagnetic signal into the sender, whilst active reflector is similar to the passive one with the capability to amplify the incoming signal before being transmitted [4].

Basically, reflectors take a variety of forms such as planar reflector, dish reflector and corner reflectors [5]-[6]. Here, the last form will be focused for the design in this paper. Similar to other reflector forms, as navigation device the corner reflector aims to maintain a moving vehicle to avoid unwanted accidents, in which the navigation mechanism is using a reflection process from corner reflector utilizing electromagnetic waves generated by the reflector. Hence, from the mechanism it will be obtained about the vehicle information distance and position relative to the reflector where the information can be used by the crew, for example, to drive the shipboard in avoiding accidents.

In this paper, a design of trihedral corner reflector as part of shipboard navigation systems is investigated numerically. The proposed reflector that is designed to work whereby at the frequency around 3GHz takes into 2 shapes, square trihedral and quarter-circle trihedral corner reflector. Some basic parameters such as return loss, gain, radar cross section (RCS), and radiation pattern are intensively investigated as performance indicators of the designed reflector. In addition, the discussion and analysis related the design parameters will be consecutively presented.

2. Design of Trihedral Corner Reflector

Trihedral corner reflector is one of the simplest forms of corner reflector. According to an international regulatory bodies, SOLAS (Safety of Life at Sea), there is a set regulations related to the use of square trihedral corner reflector such as the working frequency is around 3GHz or 9GHz and RCS should be of $10m^2$ for the frequency of 3GHz or 9GHz with a maximum weight of 5kg. The regulations are established for the reflector that is used as target radar for navigation systems on shipboard or boat [5].



(a) square trihedral (b) quarter-circle trihedral

Figure 1: Structure of proposed trihedral corner reflector design.

As theoretically described in [6], the maximum radar cross section of trihedral corner reflector is expressed in equation (1),

$$\sigma = \frac{12\pi a^4}{\lambda^2} \tag{1}$$

where a is the length of square trihedral side of corner reflector (m), λ is the wavelength used for radar transmitters (m) and σ is the radar cross section of reflector (m^2). As illustrated in Fig. 1, the structure of designed reflectors takes into 2 shapes of trihedral corner reflector, i.e. square trihedral corner reflector and quarter-circle trihedral corner reflector. The shape of quarter-circle trihedral is proposed in the design as its shape is more aesthetic than the counterpart one. The reflectors are designed to work whereby at working frequency of 3GHz and have radar cross section of at least $10m^2$. To obtain σ of at least $10m^2$ at 3GHz (λ = 0.1m), based on equation (1) the minimum value of a should be 226.94mm, therefore in the design the dimension of 300mm x 300mm x 300mm for square trihedral corner reflector and the radius of 300mm for quarter-circle trihedral corner reflector are taken to accomplish the minimum requirement. The material used in the design is copper with the conductivity of 5.8 x 10^7S/m. Although the required thickness of copper at the frequency of 3GHz is very thin due to its skin dept, therefore for the realization purpose the thickness of 1mm is used to obtain the robust corner reflector.

3. Numerical Analysis and Discussions

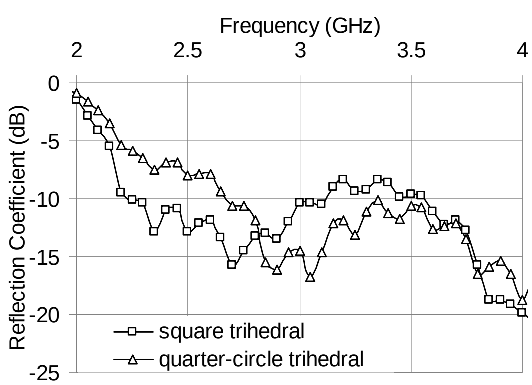


Figure 2: Numerical results of return loss.

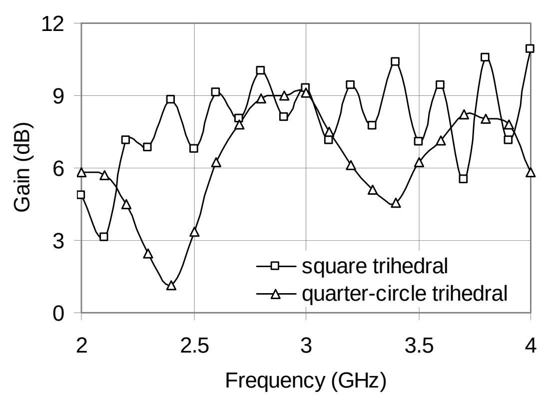


Figure 3: Numerical results of gain.

In the numerical analysis, the trihedral corner reflector structures shown in Fig. 1 are illuminated by the electromagnetic wave signal sourcing from a wave transducer of WG10. To obtain a plane wave of signal, the reflector is normally positioned in far-field region of the source. Some parameters including return loss, gain, radar cross section (RCS), and radiation pattern are investigated as performance indicators. The results are plotted in Figs. 2-6 for return loss, gain, RCS, and radiation patterns, respectively.

From Fig. 2, it is shown that for the frequency range of 2.8GHz–3.7GHz the quarter-circle trihedral corner reflector has a lower return loss over the square trihedral corner reflector, whilst out of the range, i.e. below 2.8GHz and above 3.7GHz, the return loss of each shape shows in contrary response. It can be figured out that the incoming energy from the source is reflected more by the square trihedral shape than by the quarter-circle trihedral shape as the cross-sectional area of square trihedral shape is wider than of the quarter-circle trihedral shape. However, around the frequency of 2.8GHz, both reflectors show similar response of return loss indicates that the reflectors can substitute each other. Whilst from Fig. 3, it is shown that the gain is proportional to the cross-sectional area of reflector and has similar response to the return loss for the frequency range below 2.8GHz. Here, the gain is obtained when the reflectors are separated away of 800mm from the source. On the other hand, for the frequency range above 2.8GHz, the trend of gain differs to the return loss in which the gain of square trihedral shape is higher than of quarter-circle trihedral shape.

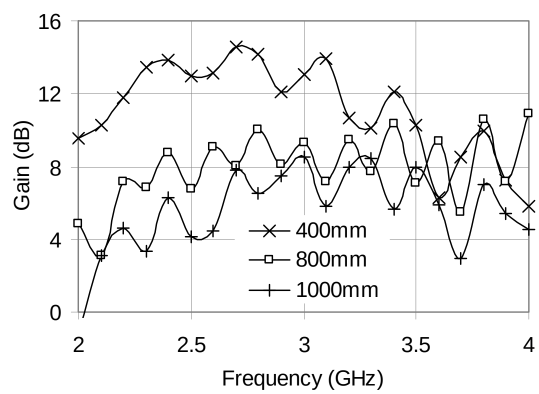


Figure 4: Gain of square shape for different distance.

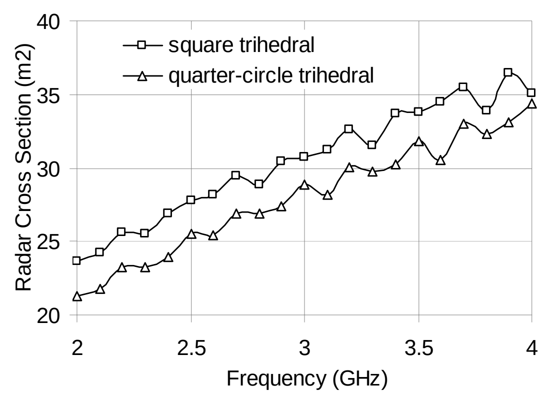
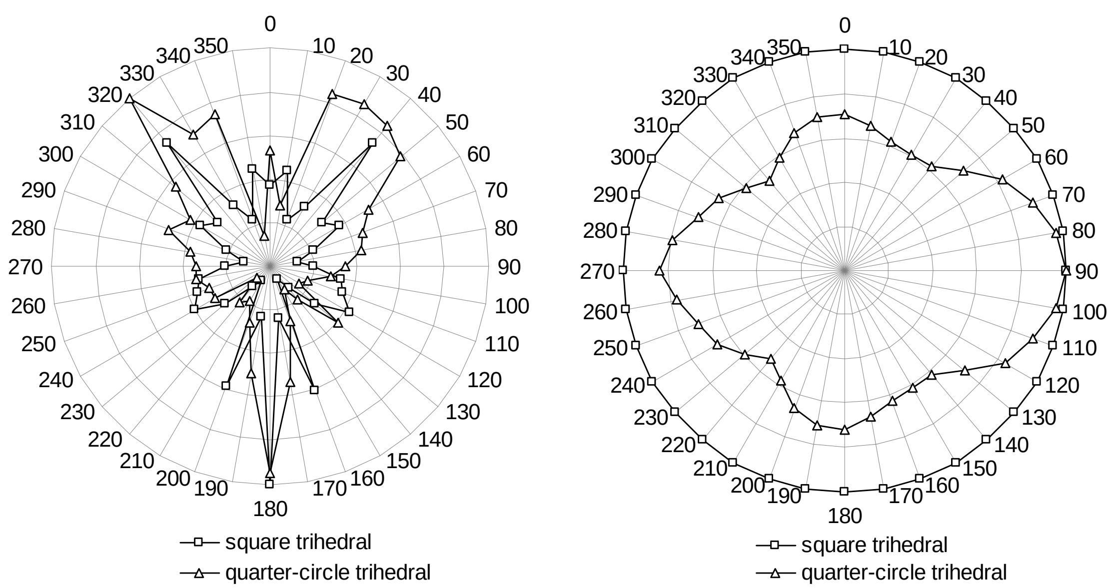


Figure 5: Numerical results of RCS.



(a) *E*-plane (b) *H*-plane

Figure 6: Numerical results of radiation patterns.

Furthermore, as shown in Fig. 4, the different distances between the square trihedral corner reflector and the source, i.e. 400mm, 800mm and 1000mm, varies to the gain particularly for the frequency range below 3.3GHz; however it still shows a proportional trend to the distance. It can be understood as the distance is bigger the power of reflected signal is lesser; thus the overall gain decreases. Hence, from Fig. 5, the radar cross section of square trihedral corner reflector is greater than of the quarter-circle trihedral corner reflector due to the wider cross-sectional area of square trihedral shape. It should be noted that the radar cross section of square trihedral corner reflector is 30.73dB or11.84m^2 around the frequency of 3GHz, whilst the quarter-circle corner reflector has radar cross section of 29dB or 8m^2. From the result, it can be concluded that the square trihedral corner reflector with the dimension of 300mm x 300mm x 300mm accomplishes the international regulations established by SOLAS related to the requirement of radar cross section.

The radiation patterns of both reflectors shown in Fig. 6 indicate that the square trihedral corner reflector has a narrower beamwidth and smaller back lobes for *E*-plane compared to the quarter-circle trihedral corner reflector, whilst the side lobes are quite similar each other. Again, this is mostly caused by the cross-sectional area of square trihedral shape that is wider than the counterpart corner reflector. It should be noted that the radiation pattern shown in Fig. 6 is obtained when the gain of each reflector is highest at the frequency of 3GHz. From the figure of *H*-plane, it shows that the type of *H*-plane radiation pattern for square trihedral corner reflector is a broadside and is different with the quarter-circle trihedral corner reflector that has unidirectional type.

4. Conclusions

The design of trihedral corner reflector has been demonstrated numerically. The reflector that intended to be applied as part of shipboard navigation systems took into 2 shapes, square trihedral corner reflector with the dimension of 300mm x 300mm x300mm and quarter-circle trihedral corner reflector with the radius of 300mm. From the numerical results, in general it can be concluded that due to the wider cross sectional area the square shape of trihedral corner reflector shows better performances compared to the quarter-circle trihedral shape in terms of return loss, gain and radiation pattern in the frequency range of 2.9GHz–3.1GHz. The radar cross section of the square shape is 30.73dB or 11.84m^2 whereas the quarter-circle shape is 29dB or 8m^2. Further, the realization of both shapes of corner reflector is still under progress in which the experimental characterization will be reported later.

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Acknowledgments

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