Journal of Engineering Science and Technology
ICIST2022, Vol. 18, No. 1 (2023) 60 - 70

NARROW WALL BEAMWIDTH SLOTTED WAVEGUIDE ANTENNA FOR PORTABLE COASTAL RADAR COMMUNICATION

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Abstract

This research project was developed to determine the effect of increasing the number of slots on a narrow wall-slotted waveguide for portable coastal radar applications. Coastal radar is a vital device for monitoring the border security of Indonesian territory. Since 2019, Indonesia has already had 11 maritime radar points installed in several parts of Indonesia. However, this amount is still insufficient to cover the Indonesian ocean, especially in border areas. The radar consists of several components, one of which is an antenna. Usually, slot antennas are used in navigation radar from an array fed by a waveguide. This paper discusses a design and simulation of the effect of adding the number of slots on a narrow wall waveguide antenna at 9.3 GHz. The simulation showed that increasing the slot number would narrow the beamwidth and increase the gain. The simulation results of a narrow wall-slotted waveguide with 6 slots produce a beamwidth of 12° with a gain of 13.8 dBi. The simulation results of a narrow wall-slotted waveguide with 12 slots produce a beamwidth of 5.9° with a gain of 17 dBi, while the simulation results of a narrow wall slotted waveguide with 18 slots produce a beamwidth of 3.9° with a gain of 18.8 dBi.

Keywords: Beamwidth, Narrow wall, Portable coastal radar, Slotted waveguide antenna.

1. Introduction

Indonesia is a maritime country with very large coastal waters with about 17.504 islands, and two-thirds of Indonesia's territory is the sea. Therefore, a lot of equipment and devices are required to guard and monitor the islands of Indonesia. In addition, the navy and police have very limited enforcement of the Republic of Indonesia's territorial waters, leaving it vulnerable to fish theft, territorial encroachment by foreign vessels, vessel hijacking, and smuggling [1]. Therefore, they need coastal radars to improve security and surveillance systems in monitoring and protecting Indonesia's coastal waters. Coastal radar is an electronic navigation device that detects and measures distance and speed, maps objects, and monitors foreign vessels violating its territory in Indonesian waters. It also monitors vessel movements to avoid collisions when moored in port [2].

In the 2019 presidential election debate, President Jokowi stated that 19 air radar points and 11 maritime radar points were installed in several parts of Indonesia. With this radar system, Jokowi guarantees that anyone who enters Indonesian territory will be detected. But in reality, this amount is still not enough to cover the Indonesian ocean, especially in border areas. Because radar is essential for sea and air transportation, it is necessary to develop Indonesia's domestic capabilities to provide radar independently. Therefore, a portable coastal radar system is needed with the limited number of radars and many ocean areas that must be monitored [3]. In addition, portable coastal radar has advantages in the ease of observing (monitoring) ocean areas by moving locations according to the observation data. This radar is designed using Frequency Modulated Continuous Wave (FMCW) technology, which is a radar technology that transmits signals continuously and uses two separate antennas for the transmitter and receiver. FMCW radars are often called radars of the future. This is because almost every radar X-Band and higher uses this technology [4]. FMCW radars achieve extremely high-range resolution radar detection and have a low SNR [5]. However, an independent system generates communication and radar signals separately, resulting in the wastage of hardware resources [6].

The antenna is one of the important subsystems of coastal radar. Antennas have transmitter and receiver functions for electromagnetic waves. Therefore, narrow beamwidth and significant gain are the most important specifications in designing a coastal surveillance radar antenna [7]. The purpose of getting a narrow beam width is not only to increase the gain value in the main lobe but also to reduce the interference of the beam signal to distinguish two adjacent objects at the time of radar detection [8]. Therefore, a high-tower coastal radar is needed to cover large areas of the Indonesian ocean. The type of antenna used is a slotted waveguide antenna with linear polarization, large enough gain, and narrow beam width. The benefits of slotted waveguide antennas over the advantages of microstrip patch antennas are that one module antenna can have multiple slots. Therefore, no power combiner is required for module-to-module coupling. Thus, loss can be eliminated by using a power combiner with a waveguide slot antenna as a radar antenna. The slotted waveguide antenna has been extensively researched and developed. Some have worked out techniques to calculate slot dimensions for longitudinal slots for horizontal linear polarization and develop transverse slots for vertical polarization [9].

According to the regulation made by the Ministry of Communications and Information of the Republic of Indonesia, number 13 of 2018 on the Indonesian radio frequency allocation table, spectrum radio navigation is described as being on frequencies 9200 MHz - 9800 MHz [10]. These regulations include the frequency limit in the X-Band designation band, which has a frequency range of 8 - 12 GHz for military applications [11]. Lubis et al. [1] presented the design of a slotted waveguide antenna with 12 narrow wall slots for X-band applications. The copper antenna produces an S11 of -22.076 dB, a gain of 16.90 dBi with a bandwidth of 159 MHz, and a beamwidth of 6.7°. However, these results need to be improved to get better parameter results. Therefore, this study will describe the effect of increasing the number of slots in a slotted waveguide antenna for portable coastal radar at 9.3 GHz frequency to achieve narrow beamwidth and high gain. The frequency of 9.3 GHz follows the portable coastal radar developed by PT. Indonesian Telecommunications Radar (industry).

2. Narrow Wall Beamwidth Antenna Design

This study begins with designing the antenna in three dimensions, calculating the antenna parameters, and performing simulations. In this study, the antenna design uses Aluminium material. Theoretically, the best antenna is an antenna with a low standing wave ratio (SWR), antenna impedance close to 50 Ohms, and the strongest received signal. Thus, the author uses aluminium material because it has a low SWR, strong signal reception, light-weight, and easy to form [12]. Then, the next step is to determine the type of slotted waveguide antenna. The slotted waveguide antenna design is WR-90, with waveguide dimensions of 22.86×10.16 mm [13], as shown in Fig. 1. The material specifications and the type of waveguide used are shown in Table 1.

Table 1. Type and specification of waveguide material.

Waveguide type	Waveguide Dimension	Material	Material Thickness
WR-90	22.86×10.16 mm	Aluminium	1.27 mm

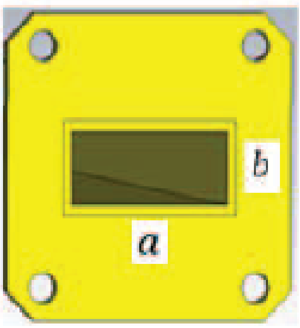


Fig. 1. The dimension of rectangular waveguide WR90.

When designing an antenna, some necessary specifications are used as parameters for target simulation results in addition to material specifications [14]. The target specifications for the antenna simulation results in this study are shown in Table 2.

Table 2. Antenna parameter specification.

Frequency	9.3 GHz
S11	≤ -10 dB
VSWR	≤1.5
Bandwidth	>30 MHz
Beamwidth	<4°
Gain	≥15 dBi
Radiation pattern	unidirectional

After determining the material and target antenna parameters, the next step is calculating the antenna dimensions based on the theory. For example, to get the dimensions for a narrow wall-slotted waveguide antenna can be calculated using the following equations:

To calculate the wavelength of the waveguide by using Eq. (1):

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \tag{1}$$

The dimensions of the slot width and the distance between the center of the antenna slots [15] it is calculated using the following Eqs. (2) and (3):

$$Ws = \lambda_0/20 \tag{2}$$

$$c = \lambda_g/2 \tag{3}$$

The angle rotation of the slot located on the side of the waveguide wall [16] is calculated using the following Eq. (4):

$$\theta = \frac{\lambda_0}{\lambda_g} \tag{4}$$

For the depth dimension of the slot that intersects the top and bottom of the waveguide wall [17], it can be calculated by the following Eq. (5):

$$d = \left(t + \left(Lr - \left(\frac{\frac{b}{coscos\left(\frac{\theta}{180}\right)}}{2}\right)\right)\right) \tag{5}$$

The calculation of probe length on the coaxial probe can be calculated using the following Eq. (6):

$$g = \frac{71{,}3232}{f} \tag{6}$$

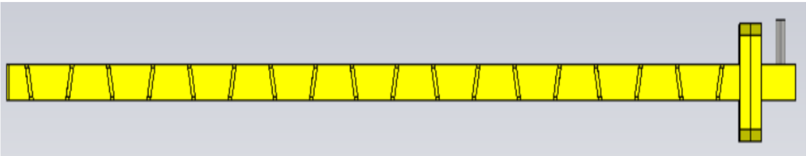
And the maximum range that radar can detect a target [4] can be calculated using the following Eq. (7):

$$R_{Rmax} = \left[\frac{P_{CW}\, G_t\, G_r \lambda^2 \sigma_T L_2}{(4\pi)^3 (\delta_R) L_{RT} L_{RR} SRF}\right]^{\frac{1}{4}} \tag{7}$$

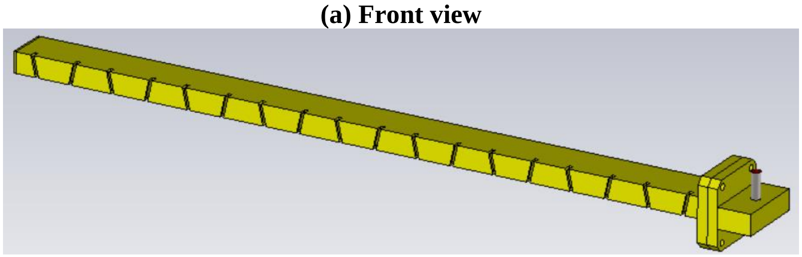
After calculating the parameters, the antenna is designed based on the dimensions obtained from the above formula. Figure 2 shows the design of a narrow wall-slotted waveguide antenna with 18 slots. The optimal parameter of antenna simulation is shown in Table 3.

Table 3. Optimal parameter of antenna.

Parameter	Description	Value
a	Waveguide width	22.86 mm
b	waveguide height	10.16 mm
c	The distance between the center of the slot	22.78 mm
d	Slots that cut the top and bottom of the waveguide	4.12 mm
e	Distance from the port to the nearest slot	11.39 mm
f	End spacing	11.39 mm
g	Probe length	7.6 mm
t	Waveguide thickness	1.27 mm
Ws	Slot width	1.913 mm
Tetha (Θ)	Slot angle	12.575°



(a) Front view



(b) perspective view

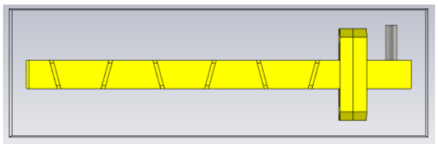
Fig. 2. Design of narrow wall slotted waveguide antenna with 18 slots.

A parametric study was performed to obtain the optimal dimensions of the proposed antenna. In the parametric study, we change the dimensions of the slot width, tetha, and depth of the slot that intersects the top and bottom of the waveguide and add an antenna slot. In this research, the design of a narrow wall-slotted antenna is varied with 6 slots, 12 slots, and 18 slots to evaluate the effect of the increasing number of slots, particularly on the beamwidth and gain of the antenna. The limited number of slots aims to make the simulation more structured. The authors have performed a simulation with 6 slots, 12 slots, and 18 slots. With the 18 slots designed on the antenna, it has met the desired parameter targets, as listed in Table 2. The slot in this antenna is very influential on the S11, whereby an increasing number of slots will produce a good beamwidth and gain value. Figure 2 shows the designed antenna's final dimensions after the parametric study.

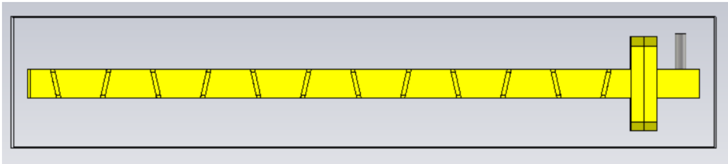
3. Numerical Simulations

3.1. Parametric study

The antenna proposed in this research is designed at a working frequency of 9.3 GHz for portable coastal radar. The material used is aluminium with a thickness of 1.27 mm. The feeding technique on the slotted waveguide antenna uses coaxial probe feeding. The most efficient place to put the probe is in the center of wall "a" (broad wall), parallel to wall "b" (edge wall), and at a quarter-wavelength (λg/4) distance from the termination of the short-circuit waveguide [18]. The geometry of 6 slots, 12 slots, and 18 slots of the proposed antenna is shown in Fig. 3.



(a)



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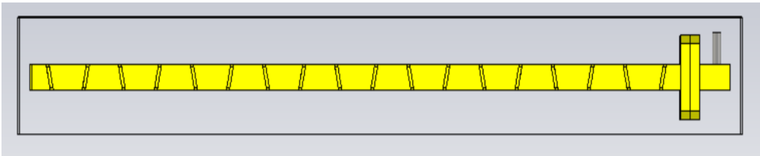


(c)

Fig. 3. Design of narrow wall slotted waveguide antenna (a) with 6 slots (b) 12 slots (c) 18 slots.

Figure 4 shows the comparison of S11 for 6, 12, and 18 narrow walls slotted waveguide antenna. The red line shows the simulated S11 of 6 narrow wall slots. The antenna works well at a frequency of 9.3 GHz, with an S11 value of -31.8 dB and a bandwidth of 165.5 MHz. The green line shows the simulated S11 of 12 narrow wall slots with a frequency of 9.3 GHz, an S11 value of -18.07 dB, and a bandwidth of 74.399 MHz. Finally, the blue line shows the simulated S11 of 18 slots. Again, the antenna works at a frequency of 9.3 GHz, with an S11 value of -17.9 dB and a bandwidth of 45.199 MHz.

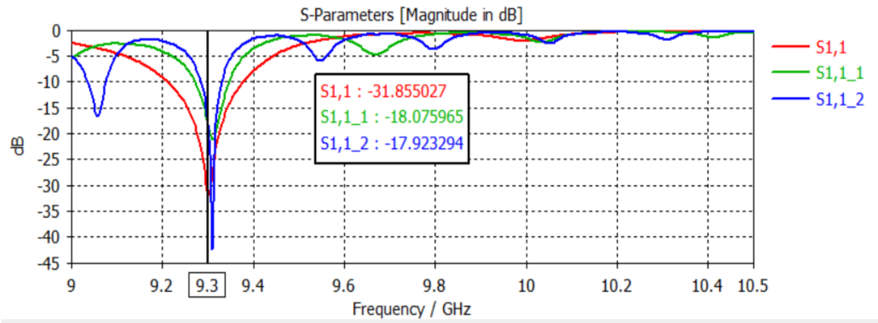
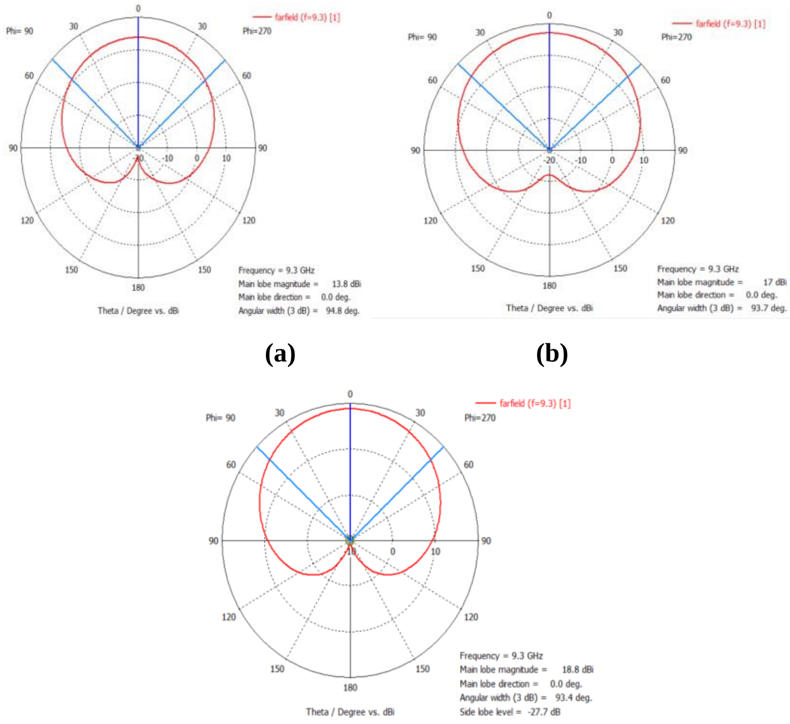


Fig. 4. Simulated S11 of 6 slots, 12 slots, and 18 slots.

Figure 5 shows the unidirectional radiation patterns obtained for 6, 12, and 18 narrow wall slot antenna designs. Figure 5(a) presents a unidirectional radiation pattern of 6 narrow wall slots antenna with a gain of 13.8 dBi. Figure 5(b) shows a gain of 17 dBi for 12 slots, and Fig. 5(c) shows a gain of 18.8 dBi for 18 slots.



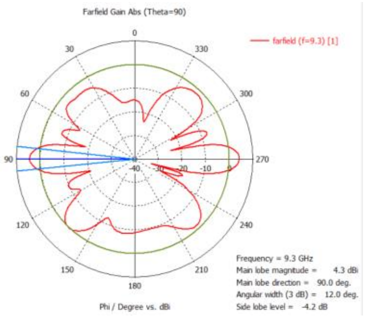
(a) **(b)**

(c)

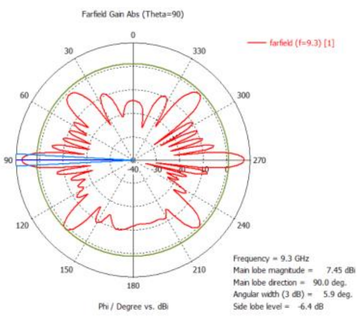
Fig. 5. Gain and radiation pattern antenna (a) 6 slots (b) 12 slots (c) 18 slots.

Figure 6(a) describes the beamwidth of 12° for 6 narrow wall slots antenna with a side lobe level of -4.2 dB. Figure 6(b) shows the beamwidth of 5.9° for the antenna with 12 slots and a side lobe level of -6.4 dB. Figure 6(c) presents a beamwidth of 3.9° with a side lobe level value of -6.8 dB for 18 slots. Chou et al. [19] also improve the antenna gain by having ultra-low side lobes. Alhuwaimel [20] presented that the smaller the sidelobe level, the narrower the beamwidth.

Figure 7 shows the surface current densities on the slotted antenna at resonant frequencies of 9.3 GHz from the first slot to the surrounding slots. The antennas have a high current density flow on each slot. The current plot shows that the proposed slotted waveguide antenna resonates at a multifrequency band because of the different locations of the small resonating slots. Since these resonant frequencies are close to each other and the increasing number of slots, antennas with narrow beamwidth can be achieved [21]. The maximum E-field flowing in the 6 narrow wall slots antenna element is 145.462 dB (mV/m), as shown in Fig. 7(a). The maximum E-field flow is 144.525 dB(mV/ m), as described in Fig.7 (b) for 12 slots, and for the18 slots, the maximum flowing E-field of 144.574 dB(mV/m) is presented in Fig. 7 (c).



(a)



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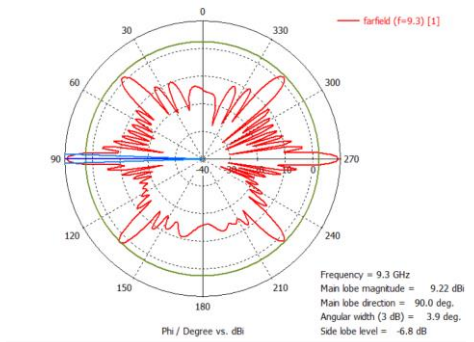
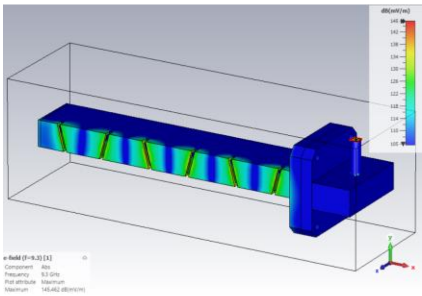
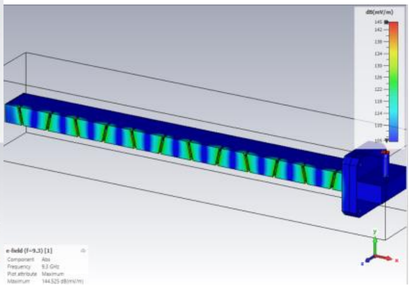


(c)

Fig. 6. Beamwidth comparison of the antenna (a) with 6 slots (b) 12 slots (c) 18 slots.



(a)



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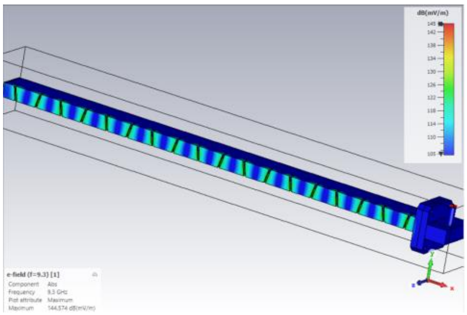

(c)

Fig. 7. Simulated E-field (a) 6 slots (b) 12 slots (c) 18 slots.

3.2. Design comparison

Table 4 compares the effect of increasing the number of slots on a narrow wall-slotted waveguide antenna with 6, 12, and 18 slots. The antenna parameters for the narrow wall-slotted waveguide antenna are obtained from Eq. (1). It is shown that the increased number of slots will increase the gain and narrow the beamwidth [22]. The highest gain value is obtained on the antenna with 18 slots, 18.8 dBi, with the narrowest beamwidth of 3.9°. The purpose of getting a narrow beamwidth antenna is to get a strong directional beam signal; thus, the antenna is able to detect two or more objects that are closer in the distance.

Table 4. The comparison of the effect of an increasing number of slots.

Number of Slots	Frequency (GHz)	Beamwidth (°)	Gain (dBi)	Bandwidth (MHz)
6 slots	9.3	12	13.8	165.5
12 slots	9.3	5.9	17	74.399
18 slots	9.3	3.9	18.8	45.99

4. Conclusions

An investigation has been made into the effects of increasing slots on a narrow wall-slotted waveguide antenna. Some concluding observations from the investigation are given below.

- The simulation results of a narrow wall-slotted waveguide antenna with increasing the slot number were presented. The antenna beamwidth and gain showed significant improvement. The more the number of slots, the beamwidth obtained is getting narrower.
- From the simulation result, it can be concluded that the more the number of slots, the greater the gain value, where the highest gain value is obtained on the antenna with 18 slots, which is 18.8 dBi.

Acknowledgments

This project is financially supported by Kedai Reka under the Matching Fund project 2022. In addition, the authors would like to thank the Research and Innovation Agency, Indonesia, for its research facility and the research and community service agency of Universitas Riau for its research management service.

Nomenclatures

a	Waveguide width, mm
b	Waveguide height, mm
c	Speed of light in free space, 3×10^8 m/s
d	Depth of slot that cuts the top and bottom of the waveguide, mm
e	Distance from the port to the nearest slot, mm
f	End spacing, mm
g	Probe length, mm
L_r	Length resonant, 0.4625 λ_0 mm
R_{Rmax}	Maximum range radar
t	Waveguide thickness, mm

Ws	Slot width, mm
Greek Symbols	
λ_g	Wavelength in cut-off frequency, 2×*a*, mm
λ_0	wavelength in free space, $\left(\lambda_0 = \frac{c}{f}\text{ mm}\right)$
ϑ	Angle slot
Abbreviations	
FMCW	Frequency Modulated Continuous Wave
SNR	Signal-to-Noise Ratio
SWR	Standing Wave Ratio

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