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Slotted waveguide antenna design for maritime radar system

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Abstract
Waveguide structures have got popularity because of its extensive application in radar system of naval ships and aircrafts. Waveguide models provide high probability of small target detection and reduce rate of false target detection. There are a large number of studies on the waveguide slotted in the wide wall. Researches concerning the narrow wall of the waveguide are much less known. An edge slotted waveguide antenna array based on semicircular end of inclined slots radiating waveguide is proposed. Length of the inclined slot is extended to the adjacent broad wall with semicircular cutting. This extended length increases the resonant length and hence higher gain is obtained. Semicircular cutting at the end of the slot reduces cross-polarization component hence side lobe level obtained are low. Narrow wall inclined slotted waveguide is analyzed and designed to operate in X-band. The radiating slots are etched and rotated alternatively on the broadened top plate with semicircular cutting into the adjacent walls. This technique deletes the radial component of the propagating wave and adds the axial component of the propagating wave. Semicircular cutting increases the resonant length and enhances the gain of the antenna. Designed waveguide structure provides high gain, and cross-polarization component is minimized. Gain of 26 dB is obtained from the simulation results obtained in HFSS (High frequency Software Simulation) and side lobe level obtained is around 20 dB while hardware design provides the gain of 24.5 dB measured on VNA (Vector Network Analyzer) keeping the side lobe level minimum.

Keywords
slotted waveguide, gain, radiation pattern, return loss, inclined slots, X-band frequency, narrow wall

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Конструкция волноводной антенны с прорезями для морской радиолокационной системы

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Аннотация
Волноводные конструкции приобрели популярность благодаря широкому применению в радиолокационных системах кораблей и самолетов Военно-морского флота. Волноводные модели обеспечивают высокую

вероятность обнаружения мелких целей и снижают вероятность обнаружения ложных целей. Существует большое число исследований по широкой стенке щелевого волновода. Исследования, касающиеся узкой стенки волновода, известны много меньше. В работе предложена краевая волноводная щелевая антенная решетка на основе полукруглого конца наклонных щелевых излучающих волноводов. Длина наклонной прорези расширена до прилегающей широкой стенки полукруглой вырезки. Увеличенная длина повышает резонансную длину. Таким образом достигается более высокое усиление. Полукруглая вырезка в конце щели уменьшает составляющую кросс-поляризации, поэтому получаемый уровень боковых лепестков низкий. Проанализирован и спроектирован узкостенный наклонный щелевой волновод для работы в X-диапазоне. Излучающие щели выполнены и поочередно повернуты на уширенной верхней пластине с полукруглой врезкой в соседние стенки. Этот метод позволяет удалять радиальную составляющую распространяющейся волны и добавляет осевую составляющую распространяющейся волны. Полукруглая нарезка увеличивает резонансную длину и увеличивает коэффициент усиления антенны. Разработанная волноводная структура обеспечивает высокий коэффициент усиления, а кроссполяризационная составляющая сведена к минимуму. В результате высокочастотного программного моделирования (High frequency Software Simulation, HFSS) получено усиление 26 дБ, уровень боковых лепестков составил около 20 дБ. Исследование реальной конструкция модели обеспечило усиление 24,5 дБ, измеренное на векторном анализаторе цепей (Vector Network Analyzer, VNA) при сохранении минимального уровня боковых лепестков.

Ключевые слова
щелевой волновод, коэффициент усиления, диаграмма направленности, обратные потери, наклонные щели, частота X-диапазона, узкая стенка

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Introduction

Waveguides are being utilized to transmit the electromagnetic energy via waveguides to detect the target and the target location. Waveguides are considered to be compact and robust to tolerate the roll of aircrafts and ships [1]. Waveguides are made in workshop from copper metal 1.25 mm thick. Waveguide slots can be made in both broad and narrow wall of the waveguide. Different shapes and position of slots produce varying effects in the output radiation pattern and their characteristics in terms of gain and side lobe levels [2]. WR90 waveguide is chosen for use in X-band applications like submarines and aircrafts. Waveguide antennas generally employ array of slots to produce high gain and to get high probability of correct target detection. Choice of etching the slot in either broad wall or narrow wall depends on the researcher and manufacturer as on the requirement of the application [3]. A good waveguide array should have very low cross-polarization component and low side lobe levels so that the false target detection rate decreases. High frequency software simulation (HFSS) is used as a tool to detect the effectiveness of the designed waveguide and the various radiation parameters. Radiation parameters like lobe gain, far field, near field, return loss 3D radiation pattern are analyzed in the HFSS version 15.0 [4]. To give an effective output, the design should be employed with the aim of increasing the radiation in the direction of the target and reducing the radiation in the direction other than target as shown in Fig. 1. It helps increasing the main lobe and reducting side lobe of waveguide.

Two components which are responsible for the high side lobe levels are effective aperture offset of the waveguide and the component of the cross-polarization of the antenna. To work efficiently as a radar antenna, waveguide must have some characteristics; for example, the radiated energy must be focused on the target, or radiated return energy from the target only must be taken into account [5]. It should have high gain and low side lobes because the energy radiated from the side lobes increases the loss and reduces the gain. The causes of side lobes are the offset of the waveguide structure aperture and cross-polarization component. HFSS is used to simulate the designed structure, and results are obtained for the return loss gain, far field and near field radiation pattern [6].

Related work

Slotted waveguide narrow wall antenna was simulated [7] and, after analyzing the radiation pattern in CST simulation software, they found that when two waveguides with 32 slots in narrow wall were combined, the combined structure would have 64 slots. The authors designed three such narrow wall waveguides and combined the waveguide with and without flange connectors. The simulation of

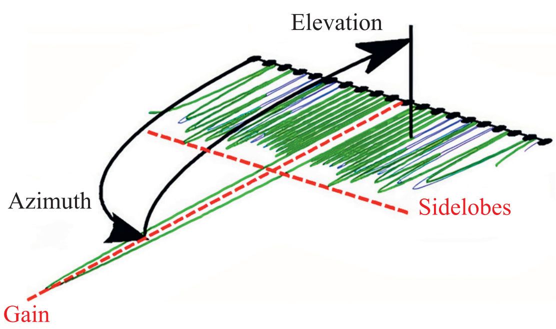


Fig. 1. Radiation pattern suitable for waveguide

these three structures was performed in CST simulation software and their radiation characteristics were analyzed. The maximum they could achieve by combining two waveguides with total 64 slots was 23 dB. They analyzed the effect of flange connector on the radiation pattern and found that the gain increases by combining two waveguides but the impact of flange connector causes side lobe level of the waveguide to increase. This is not suitable for the waveguide since it increases the false detection rate of the target primary antenna in which etching of 64 slots was developed and its radiation pattern and slot parameters are analyzed [8]. Secondary, waveguide is structured with 32 slots and two such structures are attached together to get the complete structure. Third one was formulated using trimmed flange connector and the design was simulated which shows that the maximum gain with low side lobe is achieved in case of the first designed structure. Second structure shows the good increment in gain but side lobe levels are also raised due to flange connector. Trimmed flange connector provides low gain and high side lobes [9]. The maximum gain achieved using flange connector was 23 dB.

Researchers [10] formulated a waveguide with slots etched in the broad wall and attached a reflector to get the higher gain. They etched 16 slots in the broad wall of the waveguide and a reflector was used along with the waveguide structure. This arrangement was simulated in HFSS with transmitted TE10 electromagnetic wave through broad wall slotted WR90 waveguide structure. They analyzed radiation pattern in simulation software and achieved the gain of 22.5 dB. The structure is simulated for the frequency of 9.4 GHz and the adding horizontal polarization increased the reflector gain to 22.5 dB [11]. The structure was simulated with and without reflector and found that the use of reflector increases the gain of the waveguide but the gain side lobe level also increases. The gain of the waveguide without reflector was calculated as 16 dB [12], by incorporating reflector gain increases to 22.5 dB.

Researcher [13] worked on the Planar Structure of the waveguide and formulated several branch feed waveguide structures and calculated weight of the element by incorporating Taylor aperture. They compared the calculated and simulated results. They calculated the gain in the Taylor's aperture in E plane by transmitting electromagnetic wave at 9.37 GHz [14]. The designed waveguide along with the branch feed waveguide was simulated in the Microwave CST Software and its return loss, radiation pattern, far field and near field patterns are analyzed; the gain of 25 dB was achieved [15]. They represented the feed current of the designed structure in simulation and showed that as the feed point is moved away from the center of the structure, surface current starts decreasing [16].

Contributions

A thorough examination of the manuscripts discussed in the preceding section shows that the vast majority of authors have primarily concentrated on the broad wall of the antenna and neglected the advantage of narrow walls of the waveguide. In this research, narrow wall side of the antenna is analyzed for array of slots. The contribution to the research article is as follows.

We present a new design model for the waveguide having slots in the narrow wall of the waveguide. Waveguide is analyzed for various array and slot inclinations. The simulation was performed in HFSS.

Hardware model of the waveguide was manufactured and tested in the laboratory on VNA (Vector Network Analyzer) to verify and compare the simulation results.

Gain and side lobe level of the designed waveguide was estimated for both simulation model and hardware model.

The performance of the designed model was compared with the latest findings by the researchers and their proposed models.

Finally, advantages and disadvantages of the designed model are compared with the previously proposed models.

No extra component is incorporated in the waveguide structure to achieve higher gain to keep the structure less complex, durable and robust to cope with the roll of the ship and aircraft.

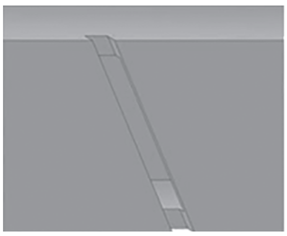
Mathematical Model

In the designed structure, WR90 waveguide is used with slots etched in the narrow wall side of the waveguide. Three structures are designed with two groups of four and ten slots with the help of HFSS. The slots initially remain vertical and are simulated in the software, but these vertical slots run parallel to the current flow because these vertical slots do not interrupt the current flow, the structure does not radiate and practically very low gain is obtained. Then slots are etched in the horizontal direction and structure is analyzed by transmitting electromagnetic wave at 9 GHz. Horizontal slots alter the current flow but it increases the side lobe level which leads to the detection of false target hence inclination of 45 degree is used for the slots [17].

These inclinations are kept opposite to each other for the nearby slots in order to cancel the one component as shown in Fig. 2 and to get the maximum gain for the other component. Slot parameters are calculated using the structure shown in Fig. 3 and equations shown are employed to get the slot parameters resonant length which is calculated as 14.35 mm.

These slots are extended from the top broad wall to the bottom broad wall. Slots are further extended by 2 mm in the broad walls by etching slots in semicircular shape.

a



b

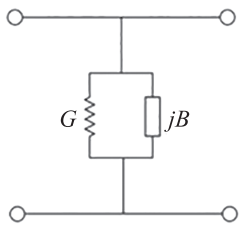


Fig. 2. Inclined slots in narrow wall with semicircular cutting: inclined slot (*a*); admittance of the slot where G is the conductance and jB is the susceptance (*b*)

Table. Parameters for simulation

Parameters	Specification
X-band Frequency, GHz	9
Slot size, mm	16.67
Slot width, mm	2.4
Gap between the slots, mm	24.35
Distance of last slot from, mm	12.18
Inclination of the slot, deg	45

These semicircular shaped slots increase radiation by altering the current flow, thereby increasing the gain of the antenna in desired direction while reducing the gain in the side lobes of the antenna. Width of the slot is calculated as 2.4 mm and spacing between the nearby slots is calculated as 24.35 mm. Waveguide is short circuited at one end and the gain is calculated at the 90°. The distance of the first slot from the short-circuited end is calculated as 12.18 mm. The structure is designed using copper metal plate with the thickness of 1.25 mm. In the first designed structure slots are etched in the one of the narrow wall sides of the antenna.

The structure is simulated in the Ansys HFSS, the electric field component is assumed to be vertical, and the perfect E is assumed for the entire structure. Frequency range is selected for X-band ranging from 8 to 12 GHz as specified in Table. The model is simulated in HFSS and the gain of the antenna, far field and near field radiation pattern and return loss are analyzed. Return loss is found to be greater than 10 dB and gain of 16 dB is achieved for the frequency of around 90°. The side lobe levels are at 10 dB level. Frequency is increased with the step of 0.2. In Fig. 3 *Yin* is the input admittance, *L* is the inductance, *Y* is the admittance, *d* is the slot distance.

$$Hx = -\frac{Eo}{4\pi f\mu} B\sin\frac{\pi x}{a} e^{-\mathbf{j}\beta z} \qquad Hz = \mathbf{j}\frac{Eo}{2\pi f\mu}\cos\frac{\pi x}{a} e^{-\mathbf{j}\beta z}$$

$$Jx = -\mathbf{j}\frac{Eo}{2\pi f\mu} B\cos\frac{\pi x}{a} e^{-\mathbf{j}\beta z} \qquad Jz = -\frac{Eo}{2\pi f\mu} B\sin\frac{\pi x}{a} e^{-\mathbf{j}\beta z}$$

$$L = \lambda g/4$$

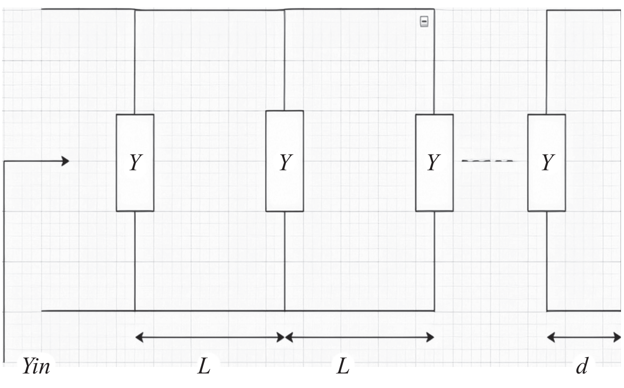


Fig. 3. Calculation of parameters for waveguide

Where *Hx* is magnetic field intensity in *x* direction; *Hz* is magnetic field intensity in *z* direction; *L* is resonant length = 0.465λ; β is propogation constant; *Eo* is maximum amplitude of electromagnetic wave; *B* is magnetic flux density; *f* is frequency of electromagnetic wave; *a* is width of the waveguide; λ*g* is guided wavelength in waveguide; μ is permiability of the medium; *J* is current density; **j** is unit vector in the direction of propogation; *z* is *z* axis direction; *x* is *x* axis direction.

Simulated and Designed Structure

Waveguide structure designed in this research and analysis is less complex as compared to the structure designed by the researchers earlier for high gain and low side lobes. No additional component is incorporated in the waveguide structure which makes waveguide structure robust and less complex as shown in Fig. 4. This type of waveguide structure is very well suited for aircrafts, ships & submarines to tolerate the roll of aircraft or ship.

If slots are cut into the walls, current flow is affected more or less depending on the location of a slot. Slots *B* and *C* cause little disruption to current distribution and produce less or no radiation. Slots *A* and *D* create barriers for current flow hence radiation occurs. Working of slot can be explained using Babinet's Principle. It relates the radiated fields and impedance of slot antenna to that of the field of a dipole antenna. The fields of the slot antenna are the same as in the dipole antenna but the field components are interchanged. As vertical slots alter the current flow, the higher radiation is obtained for vertical slots but with the gain cross-polarization component also increases simultaneously. Hence, an inclination of 45° is given to the slots so that the altered current will have two components: a vertical and a horizontal. Inclination of the adjacent slots is kept opposite to each other so that vertical component gets cancelled and horizontal component gets added and helps in achieving high gain.

Side lobes are undesirable. They are produced due to the diffraction effects in the air. Diffraction occurs in the antenna array due to sharp edges. When the edges end abruptly, diffraction effects are produced. One can minimize these effects by softening edges of the antenna array. Hence, in the designed model, slots are extended with

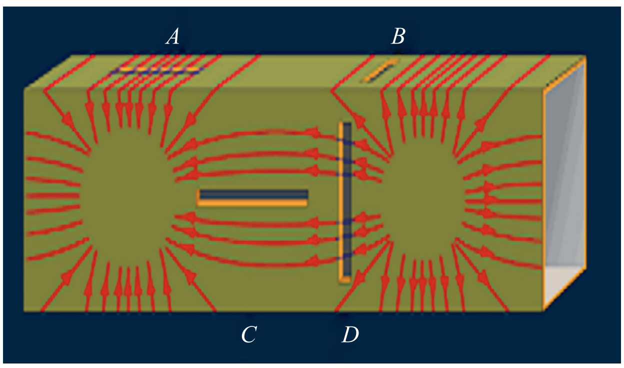


Fig. 4. Typical slots over rectangular waveguide:

A — horizontal slot in narrow wall; *B* — vertical slot in narrow wall; *C* — horizontal slot in broad wall; *D* — vertical slot in broad wall semicircular cutting. These semicircular cutting softens the edges and minimizes diffraction effects. This reduction in diffraction effects results in reduction of the cross-polarization component of electromagnetic wave. Hence, average power distributed in all the directions decreases and gain in the desired direction of the target increases. Gain G of the waveguide is calculated using the formula

$$G = E_{ant}D,$$

where D is directivity of the antenna; E_{ant} is the antenna efficiency. The formula for directivity is shown here as denominator component which represents the average power radiated over all the directions. The expression is the ratio of the peak value of the radiated power to the average power radiated over all the directions. Thus, with decrease in the average power distributed over all the directions, the gain of the antenna increases. Directivity D of the antenna is

$$D = \frac{1}{\frac{1}{4}\int_0^{\pi}\int_0^{2\pi}|F(\theta, \varphi)^2|},$$

where θ is azimuth angle; φ is elevation angle; F is normalized radiation pattern.

By adding semicircular radius cutting of 1.2 mm to the slot, diffraction is reduced. Hence, average power distributed over all the directions is reduced. As denominator component decreases, directivity increases. Improved directivity helps in achieving high gain. To achieve high gain for the antenna array, the directivity should be increased and it can be increased by increasing the effective area of the array given by the expression.

$$Ae = \left(\frac{\lambda^2}{4\pi}\right)D,$$

where Ae is effective area of the array; λ is wavelength.

In the designed structure, slots are extended to the broad walls increasing the resonant length of the antenna. This increase in the length increases effective area of the array which helps to improve directivity of the antenna. Improved directivity results in higher gain of the designed slotted waveguide. These expressions allow us to estimate the increase in the amplification of the fundamental radiation and the suppression of its cross-polarization component. Rodrigi Keinj Enjio [2] designed a slotted waveguide using a WR90 waveguide with inclined slots in narrow wall having 12 slots (without semicircular cutting in the end of the slots) and achieved gain of 16 dB with cross-polarization component of around 13 dB and side lobe level of –21.9 dB.

The expression for the effective area of array helps in discrediting the surface with initial conditions:

1) Gain > 16 dB
2) Polarization: Horizontal
3) Frequency = 9 GHz
4) Scanning beam should be narrow in azimuth plane and wider in elevation plane to compensate the roll of the ship.

To have a narrow beam in azimuth plane and wider beam in elevation plane horizontal polarization is required. Slots are etched in the narrow wall to get the horizontal polarization. For fundamental TE10 mode, longitudinal slots etched in the broad wall generate vertical polarization. Transverse slots etched in narrow wall produce horizontal polarization.

Designed model is very well suited for the application involving TE10 mode of the electromagnetic wave propagation. Slots are designed for three waveguides in such a way that the induced current flows from the top wall of the waveguide to narrow wall of the waveguide vertically, and the slots are etched in one of the narrow walls. These slots alter the current flow and result in radiation into the air. Radiated power by the slot is a function of angle phi by which the slot is rotated. In this design, the slot is rotated at the angle of 45°, therefore radiated power will be function of sin45°. Radiation from the z component of waveguide will be responsible for output gain and radiation characteristics, whereas x component will get distributed and results in cancelling out the radiation. Waveguide is fed by a coaxial feed from one end, and other end is short circuited. The last slot is at a distance of λ/4 from the short-circuited end of the waveguide whereas distance between the slots is λ/2. Calculated slot distance is 24.35 mm and the last slot distance from the short-circuited end is 12.18 mm. Width of the slot is calculated as 2.4 mm. Pencil type of beam is obtained from this waveguide structure.

Waveguide structure is designed using a copper plate with thickness of 1.25 mm, the length of the designed waveguide is 22.86 mm and the width of the waveguide is 10.16 mm as shown in Fig. 5. The hardware is designed for the array of 10 slots and one end of the waveguide is short circuited by the copper plate and the other end is closed by epoxy with coaxial feed to transmit X-band frequency ranging from 8 to 12 GHz and analyzed on VNA.

A bridge circuit is used to transmit and receive the electromagnetic waves in TE10 mode of operation and to analyze the co- and cross-polarization component of the wave. The designed structure shown in Fig. 6 is simulated as well as tested on hardware for the 10 slots array but only for the four- and two-slot structure simulation is carried out. Results of the 10-slot array model are compared for both

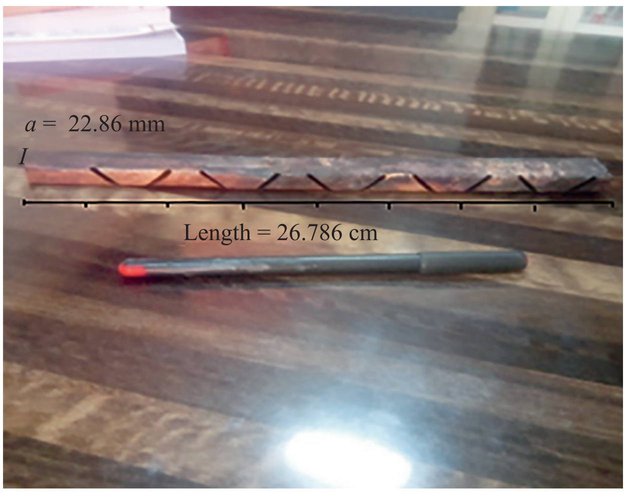


Fig. 5. Designed waveguide with 10 inclined slot

Fig. 6. Designed waveguide with semicircular slots in broad wall

simulation and hardware model. Slots are etched using CNC machine with precise measurement in the workshop. The designed hardware model is tested in the laboratory on VNA machine.

Results and Discussion

Simulation is carried out for the structures designed for two & ten slots. Simulation results obtained for the structure show that the designed waveguide radiates at 9 GHz and the radiation gain obtained is 18 dB with side lobe level of 15 dB. Here side lobe levels are quite high. This should be reduced by increasing the array gain of the structure to the optimum level.

As the number of slots is increased, gain of the waveguide increases due to array of slots as shown in Fig. 7; they all radiate and transmit electromagnetic waves towards the target. The maximum gain obtained for the narrow wall slotted waveguide with two inclined slots without semicircular cutting extending to the broad wall is 10 dB. This number of slots also causes cross-polarization component of the waveguide to increase. Cross-polarization component increases the side lobe levels which cause polarization of the radiated energy and this is not suitable for the waveguide operating as radar antenna in ships, aircrafts or submarines.

Simulation is carried out for 10-slot structures of the waveguide. Return loss, gain and side lobed levels are calculated. Co-polarization & cross-polarization components are determined by simulating the structure with last slot at a distance of 12.18 mm from the short-circuited end of the waveguide as shown in Fig. 8.

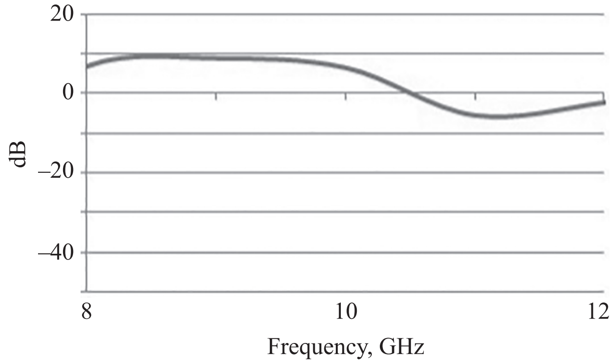


Fig. 8. HFSS result for gain of two inclined slots in narrow wall (without semicircular cutting)

The length of the slots is extended into the broad walls of the waveguide in both upper and bottom plate which increases the resonant length of the antenna. The length without extension is 14.35 mm, and after extension slot length increases to 16.35 mm which helps in achieving higher gain as shown in Fig. 9. Semicircular cutting in the broad walls also keeps the cross-polarization component low. With low cross-polarization component the side lobe levels are also low. This makes it possible to get the high gain keeping side lobe level at minimum.

With 10 slots HFSS shows good result for the gain. Simulation results for the co-polarization & cross-polarization components show gain of 26 dB and cross-polarization component – around 20 dB as shown in Fig. 10. The beam is obtained in X–Z plane at 90 for the wave propagating with the frequency of around 9 GHz.

Maximum gain obtained for 10 slots without semicircular cutting extended to the broad wall is 13 dB. Radar is an important component of modern navigation and radar antennas. It needs to be designed for the exact specifications. Antennas used on ships need to be of high gain with tightly controlled beam width. Antenna should be robust, compact, and resistant to the effects of roll and motion. Designed slotted waveguide antenna matches all these criteria. Fig. 11 shows the simulation results obtained for the gain of the waveguide antenna without semicircular cutting. The maximum gain achieved is 13 dB at resonant frequency of 9 GHz, whereas Fig. 12 shows the simulation results obtained for the waveguide antenna with semicircular cutting. The maximum co-polarization gain achieved is 26 dB. This value is almost double to the gain obtained without semicircular cutting.

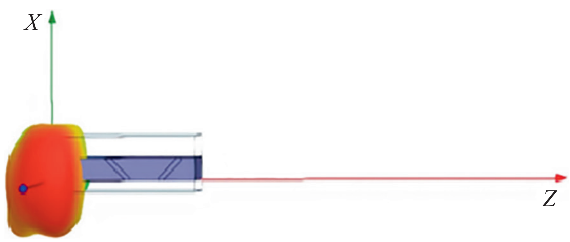


Fig. 7. HFSS simulation for two inclined slots in the waveguide

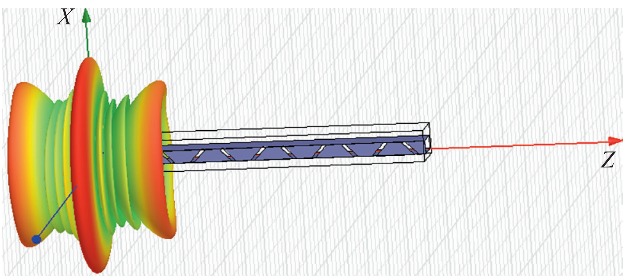


Fig. 9. Waveguide designed for ten slots

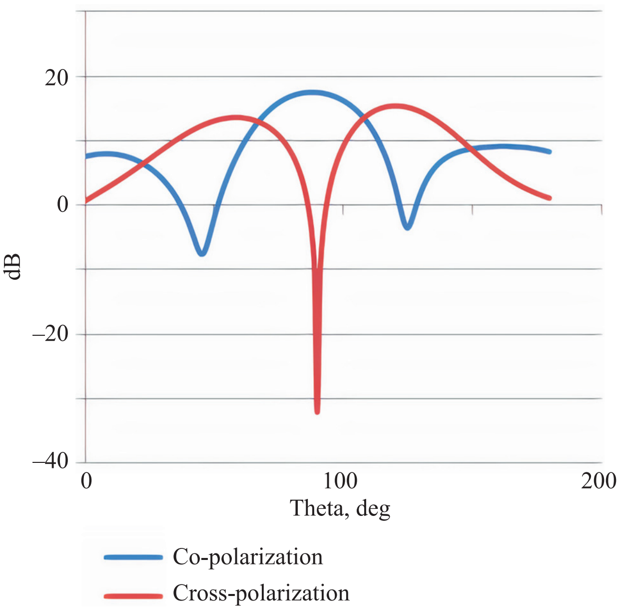


Fig. 10. HFSS simulation result for two inclined slots in narrow wall (with semicircular cutting)

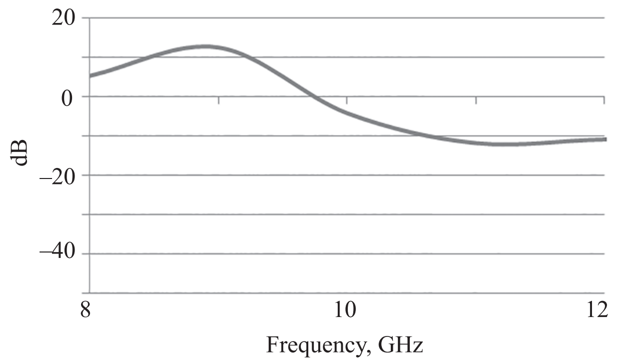


Fig. 11. HFSS result for ten inclined slots in narrow wall without semicircular cutting

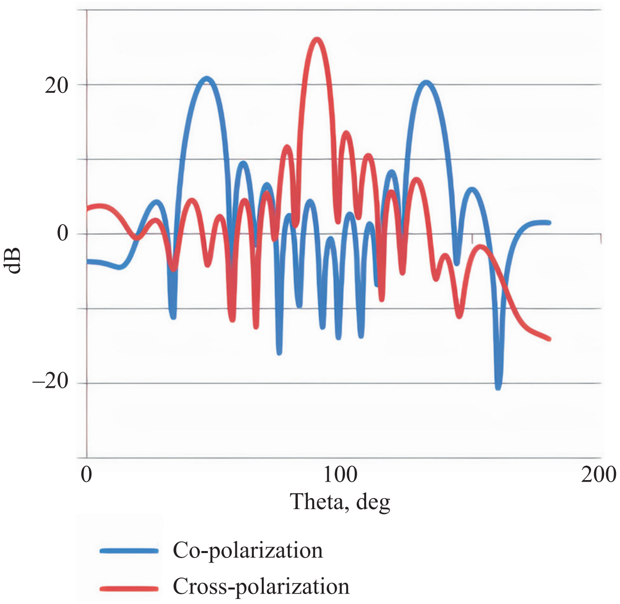


Fig. 12. HFSS result for 10 inclined slots in narrow wall (with semi-circular cutting)

Simulation results are compared with the hardware results measured using VNA as shown in Fig. 12. Hardware prepared according to the designed and simulated structure in the workshop is tested in the laboratory for the X-band frequency from 8 to 12 GHz using a bridge circuit which allows both input and output wave to pass through it without interfering. VNA provides insight of the microwave waveguide. It helps in analyzing cross-polarization component, side lobe level, gain in the direction of target, and voltage standing wave ratio of the waveguide. Results obtained from vector network analyzer for X-band frequency, ranging from 8 to 12 GHz for TE10 mode of operation, are compared with the simulation results obtained from ANSYS HFSS.

HFSS results for the simulation and calculated results on vector network analyzer shown in Fig. 13 are compared. The simulation results seemed to be promising after comparison with the actual hardware results. Simulation results show the maximum gain of 26 dB with side lobe level of around 20 dB for the designed waveguide array of 10 slots. Hardware results obtained from vector network analyzer give the maximum gain of 24.5 dB with the side lobe level of 18 dB. The results prove that the designed structure provides optimum gain for the structure which can be effectively utilized in the aircraft, maritime radar, having robust and compact model with low side lobe level.

Horn antenna is used for receiving the signal transmitted by the waveguide antenna. With the help of horn antenna, receiving signal gain and radiation pattern for co- and cross-polarization is calculated. Slots etched in WR90 waveguide are extended in broad wall by 2 mm and the shape of these extended slots is kept semicircular in order to get the higher gain and reduced co-polarization component. We could achieve higher gain in comparison with previous research made work by researchers [1] where authors could achieve gain of 23 dB by adding two waveguides with the help of a flange connector. Each waveguide has 32 slots and the combined structure has total 64 slots. The

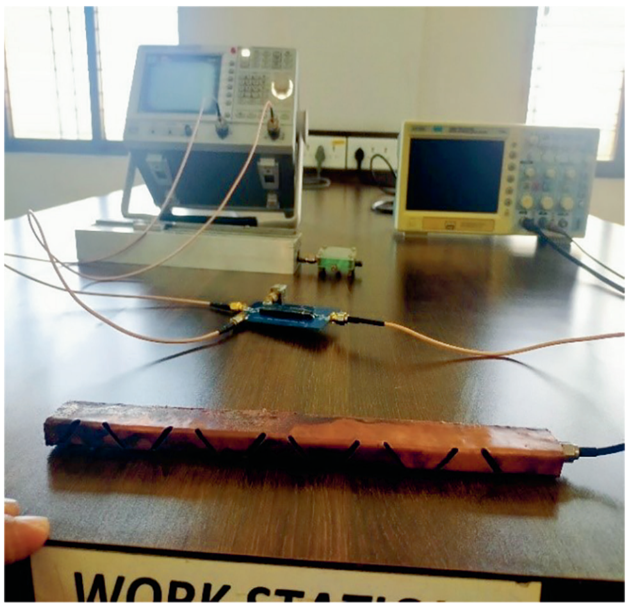


Fig. 13. Hardware model analysis experimental setup

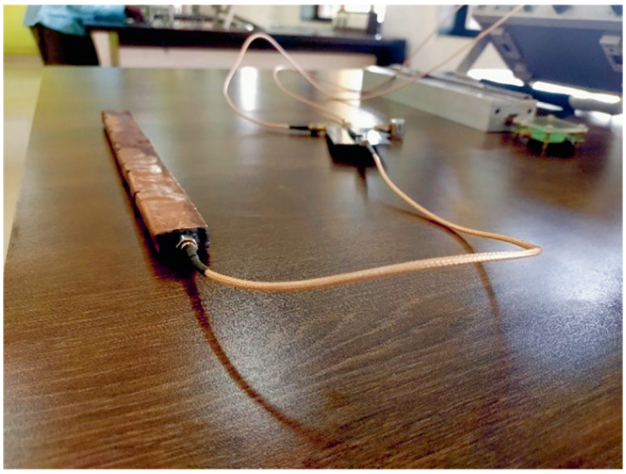


Fig. 14. Gain measurement using bridge circuit

construction looks bulky, has increased complexity and decreased reliability to employ it effectively in aircrafts or submarines.

Semicircular shape of these slots increases radiation by altering the current flow, thereby increasing the gain of the antenna in desired direction, while reducing the gain in the side lobes of the antenna. Radar system needs the antenna with highly directional characteristics having high gain in the direction of the target location and small amount of energy should be radiated in all other directions. Radiation pattern of the antenna in Fig. 15 above shows evidence of the goal achievement. Main lobe of the antenna shows the gain of around 26 dB while side lobes are below 20 dB. Width of the slot is calculated as 2.4 mm and spacing between the nearby slots is calculated as 24.35 mm. Waveguide is short circuited at one end and the gain is calculated at the 90°. The distance of the first slot from the short-circuited end is calculated as 12.18 mm.

The structure is designed using copper metal plate with the thickness of 1.25 mm. In the first designed structure, slots are etched in the one of the narrow wall side of the antenna. 2 mm of length is extended in the inclined slot which causes it to extend in the broad side wall of the waveguide. This increase in the inclined slot length increases resonant length and helps in achieving higher gain, and semicircular shape keeps the cross-polarization component low and reduced side lobe levels. Fig. 16 shows 3D radiation pattern in HFSS.

Fig. 17 shows hardware model experimental result for co-polarization and cross-polarization gain. Slotted waveguide narrow wall antenna was designed and simulated by researchers in [1]. After simulating the radiation pattern in CST simulation software, they found that by adding two waveguides with 32 slots in narrow wall the combined structure will have 64 slots. They designed three narrow wall waveguides and combined the waveguide with and without flange connectors. The authors simulated these three structures in CST simulation software and analyzed their radiation characteristics. The maximum they could achieve by combining two waveguides with total 64 slots was 23 dB. They analyzed the effect of flange connector on the radiation pattern and observed that the gain increases by adding two waveguides but the impact of flange connector causes side lobe level to increase.

Electromagnetic field distribution of the designed waveguide using HFSS is shown in Fig. 18. The HFSS system of electrodynamics modeling is used effectively to get the E-Field and H-Field distribution. The gain of the waveguide is increased which is not suitable for the waveguide as it increases the false detection rate of the target. Primary antenna was designed by etching 64 slots and its radiation pattern was analyzed. The use of flange connector makes the system bulky, less robust and also complex in terms of installation and maintenance as compared to the designed structure. Designed waveguide structure does not include any extra component like flange connector or reflector which makes the designed waveguide compact, robust, and can easily tolerate the roll of the aircraft or ship. Gain of 26 dB in simulation and gain of 24.5 dB in hardware is achieved with side lobe level of 20 dB in simulation and 18 dB for the hardware model. It seems to be better than the designed slotted narrow wall waveguide of the researchers in [1]. The designed structure

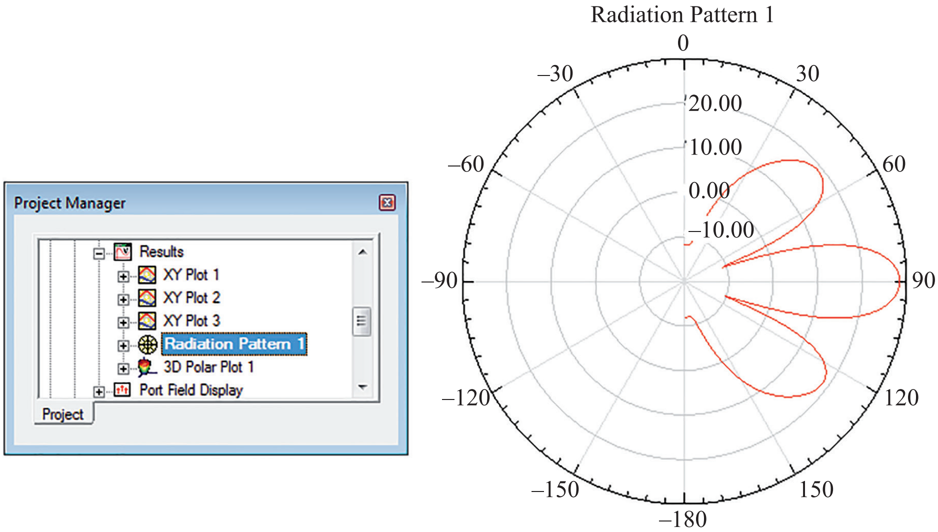


Fig. 15. Radiation pattern in HFSS

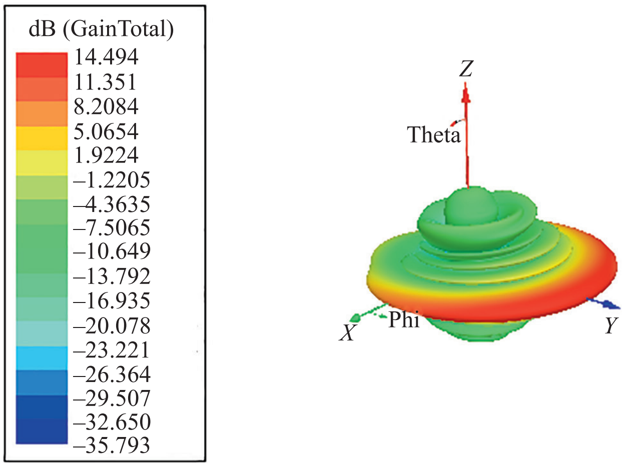


Fig. 16. 3D radiation pattern in HFSS

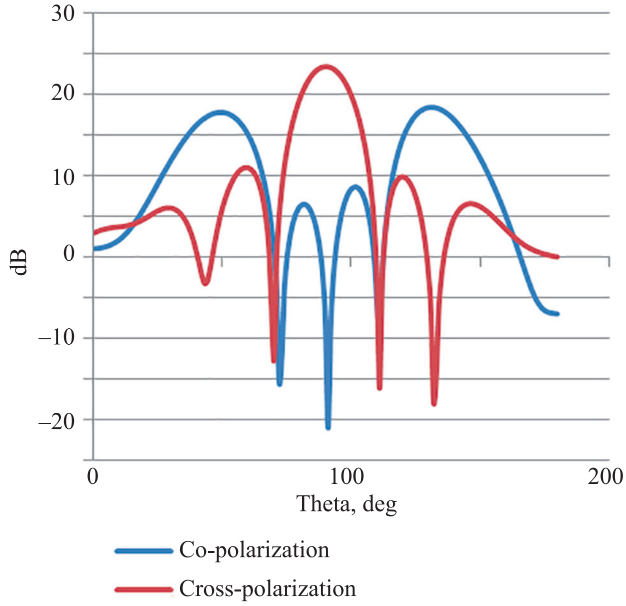


Fig. 17. Hardware model experimental result for co-gain & cross-polarization gain

shows multiple advantages as compared to the previous simulations presented and the models proposed.

Researchers had proposed a waveguide with slots etched in the broad wall and added a reflector to get the higher gain. They made 16 slots in the broad wall of the waveguide and a reflector was used along with the waveguide structure. This arrangement was simulated in HFSS. The authors transmitted TE10 electromagnetic wave through broad wall of the slotted WR90 waveguide structure. They found radiation pattern in simulation software and got the gain of 22.5 dB. The structure was simulated for the frequency of 9.4 GHz and the polarization utilized was horizontal. By adding the reflector, gain was increased to 22.5 dB. They simulated the structure with and without reflector and found that the use of reflector increases the gain of the waveguide but, along with the gain, side lobe level also increases. The gain of the waveguide without reflector was calculated as 16 dB and by incorporating reflector gain increases to 22.5 dB. The designed structure shows the good gain as compared to the slotted waveguide without using reflector which makes the arrangement complex and costly as well. The design structure provides cost effective way to achieve higher gain and reduce the probability of false target detection [3].

Researchers [4] worked on the Planar Structure of the waveguide and formulated several branch feed waveguide structures and calculated weight of the element by incorporating Taylor's aperture. They compared the calculated and simulated results. They calculated the gain in the Taylor's aperture in E plane by transmitting electromagnetic wave of 9.37 GHz [4]. The designed waveguide, along with the branch feed waveguide, was simulated in the Microwave CST Software and its return loss, radiation pattern, far field and near field patterns are analyzed; the gain of 25 dB was achieved. They represented the feed current of the designed structure in simulation and showed that as the feed point is moved away from the center of the structure then surface current starts decreasing.

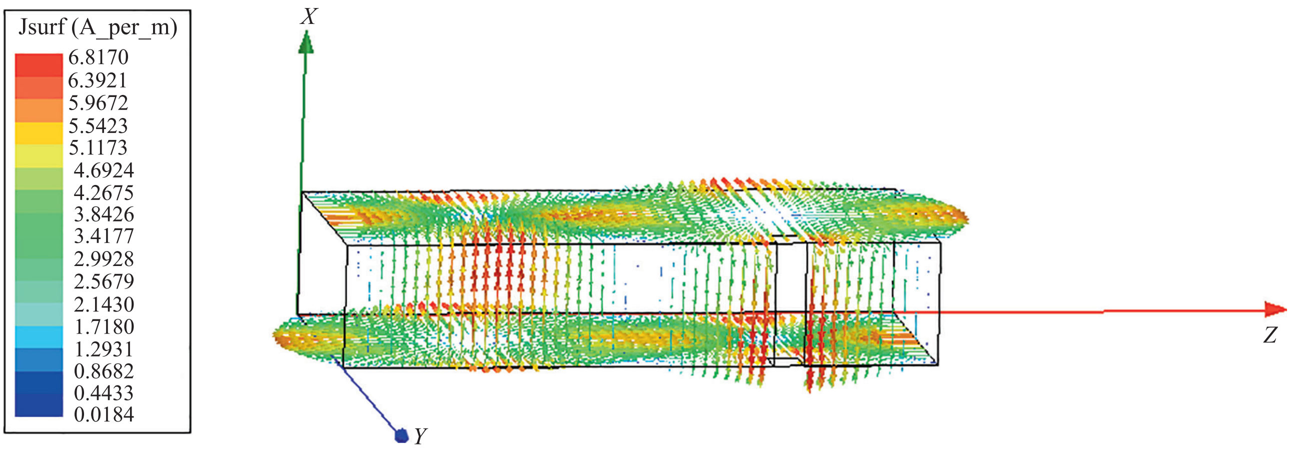


Fig. 18. Software simulation model of electromagnetic fields (using HFSS)

Fig. 19. Gain measurement for the hardware

The designed simulated structure is fabricated in the workshop and tested in the laboratory for the evaluation of the simulation results. The designed slotted waveguide is tested for the gain and cross-polarization component by using a VNA.

Horn antenna is used for receiving the signal transmitted by the waveguide antenna as shown in Fig. 19. With the help of horn antenna receiving signal gain and radiation pattern for co- and cross-polarization is calculated. Slots etched in WR90 waveguide are extended in broad wall by 2 mm and shape of these extended slots is kept semicircular in order to get the higher gain and reduced co-polarization component.

We could achieve higher gain in comparison with previous research work by researchers [1] who could achieve gain of 23 dB by adding two waveguides with the help of a flange connector, each waveguide having 32 slot and combined structure have total 64 slots. This makes it bulky, increases its complexity and decreases reliability to employ it effectively in aircrafts or submarines.

Conclusion

Simulation results for the designed models of 2 and 10 inclined slots in the narrow wall of the waveguide antenna provide the gain of 18 dB and 26 dB respectively. The result is better as compared to the proposed models by earlier researchers. Advantage of the designed model is that it does not incorporate any additional device like reflector or flange connector which makes the structure robust and increases its reliability. The designed structure is cost-effective and less complex, so it can be effectively used as a radar antenna for aircrafts and ships. Hardware model analysis provides the gain of 24.5 dB and verifies the simulation results.

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