# Narrow Beam Ka-band Slotted Waveguide Array for Tracking Radars

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***Abstract*— A narrow beam slotted waveguide array antenna operating in Ka-band is proposed for high performance tracking application. High resolution tracking demands for a radiation pattern with narrow beam having low sidelobes. Taylor's distribution of -40 dB has been provided for low sidelobe excitation. The antenna is accurately designed by providing slot offset from the center line for appropriate power distribution in order to achieve low sidelobes throughout. The error in displacement leads to sidelobes similar to grating lobes. The array consist of longitudinal slots milled on to the broad wall of a non-standard waveguide provided with machining tolerances. The adjacent slots are displaced on either side of the center line with half guided wavelength inter element spacing.**

**Initially, a linear waveguide array of 10 slots with -30 dB Taylor's distribution operating at Ka-band has been designed and optimized in order to explain the methodology. The linear array is divided into two symmetric sub-arrays by shorting at the center at a distance of $\lambda_g/4$ from the nearest slots and fed at both ends. A non-standard waveguide of dimension a = 5.62 mm and b = 2.81 mm provides sufficient bandwidth at the operating range of frequencies. A linear array of 150 elements has been designed to provide a narrow beam having HPBW = 0.4˚ and gain 26 dBi. The antenna exhibits a broadside radiation with sidelobe level -40 dB and low cross-polarized radiation throughout theta.**

***Keywords—slots; waveguide array; sidelobes***

## I. INTRODUCTION

Slotted waveguide arrays are attractive candidate in high frequency radar applications due to high efficiency and simplicity in the geometry. The other main advantages of these kind of antennas are their power handling capability and mechanical strength. These antennas are often used in airborne radar applications because of their ability to be conformal on the mounting surfaces. High frequency narrow beam antennas are used in high performance tracking radar applications. A planar slotted waveguide array antenna exhibits linear polarization in the broadside direction. The optimization and analytical techniques to design a planar slotted waveguide array has been reported in [1]-[4]. The two types of slotted waveguide arrays are standing wave array (resonant array) and travelling wave array (non-resonant array). The design procedure of travelling wave slotted waveguide array is given in [5]. A center-fed slotted waveguide array using Surface Integrated Waveguide (SIW) is shown in [6]. A compact resonant slot array design using partial H-plane waveguide is given in [7]. The mathematical formulas for designing a slotted waveguide array is reported in [8].

The present paper indicates the methodology of designing a Ka-band planar slotted waveguide array with the help of a 1x10 linear array. A non-standard waveguide has been finalized for the design purpose such that spacing between two linear arrays needs to be compensated. The assignment was to design a high performance linear array antenna having HPBW 0.5˚ and sidelobe level -40 dB. The goal was achieved with the help of linear array having 150 elements.

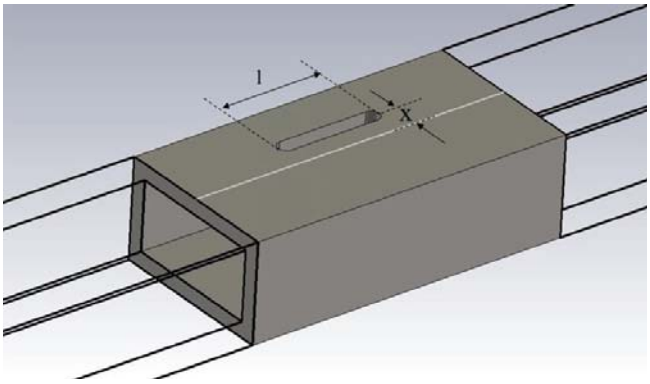
## II. ANTENNA DESIGN

The initial step in the design of a waveguide array include selection of appropriate waveguide for providing sufficient bandwidth. A non-standard waveguide of dimensions a = 5.62 mm, b = 2.81 mm and thickness 0.625 mm have been chosen such that distance between the slots of two linear arrays should be half guided wavelength ($\lambda_g/2$). The Babinet's principle relates the impedance and radiated fields of a slot radiator to that of a dipole antenna. The electric field vector of a slot radiator is perpendicular to the longitudinal axis. The slots behave as a radiating element for a displacement x from the center line of the waveguide. The slots are half wavelength long and typically thin (less than $0.1\lambda_0$). Increase in slot width improves bandwidth, however cross-polarization is a limiting factor.

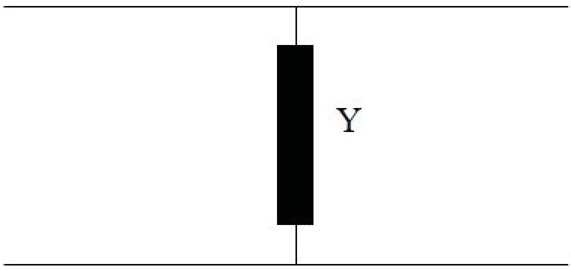
A simple slot radiator with an offset x from the center is given in Fig. 1 (a). The surface currents on the waveguide are disturbed with the displaced slot, thus forcing to go around the slot. This results in coupling the power from the waveguide to free space through these slots. The equivalent circuit of the slot is shown in Fig. 1 (b).

### *A. 10 Element Linear Array*

A 10 element linear array of -30 dB Taylor's distribution has been designed and optimized using CST STUDIO SUITE. The antenna is shorted at the center which is $\lambda_g/4$ away from the $5^{th}$ and $6^{th}$ slot. The array with short at the center is fed at both the ends in fundamental $TE_{10}$ mode, thus divide into two sub-arrays. The inter element spacing of the antenna is $\lambda_g/4$ with alternate slots displaced on either sides of the center line as shown in Fig. 2. This ensures equal phase in all the slots and radiates in broadside direction. The overall dimension of the antenna is 66.865 mm x 6.87 mm.




(a)




(b)

Fig. 1 Single slot radiator (a) Simulated model (b) Equivalent circuit.

The equivalent circuit of the slot radiator is represented by a transmission line shunted by a lumped admittance Y. The slot admittance Y is directly proportional to the power coefficient.

The relation between slot admittance and return loss of the antenna has been derived from [10], given as

$$|S_{11}| = 20\log\left(\frac{Y}{Y+2}\right) \qquad (1)$$

where $S_{11}$ is the return loss and Y is the slot admittance.

The 10 element Taylor's distribution of -30 dB and corresponding slot length and offset has been given in Table I. A waveguide of length $\lambda_g$ with a slot at the middle of longitudinal axis and two ports at each end was simulated with the help of CST STUDIO SUIT. The slot length and offset x has been adjusted according to the magnitude and phase of return loss. The arrangement is in such a way that the phase transition of return loss from -180˚ to 180˚ happens at the center frequency. Fig. 3 shows the magnitude and phase of $S_{11}$ for a single slot.

TABLE I. CHARACTERISTICS OF RADIATING SLOTS

| Radiating Element | Power Coefficient | $S_{11}$ [dB] | Slot Offset- x [mm] | Slot Length- l [mm] |
|---|---|---|---|---|
| **Slot 1** | 0.0160 | -42.0 | 0.39 | 3.94 |
| **Slot 2** | 0.0608 | -30.6 | 0.40 | 4.20 |
| **Slot 3** | 0.1710 | -22.1 | 0.58 | 4.29 |
| **Slot 4** | 0.3200 | -17.2 | 0.80 | 4.34 |
| **Slot 5** | 0.4318 | -15.0 | 0.92 | 4.37 |

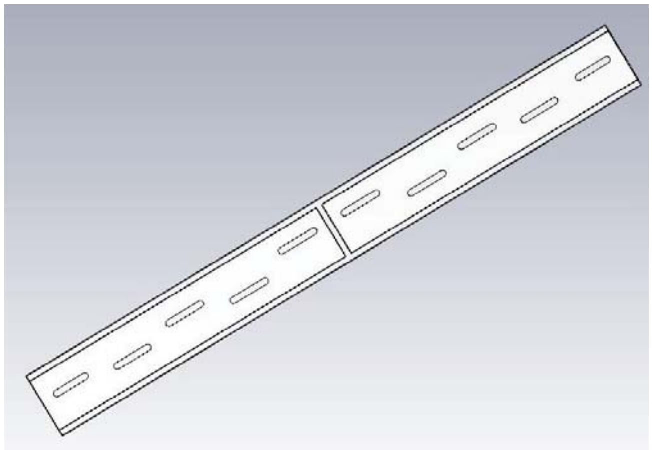
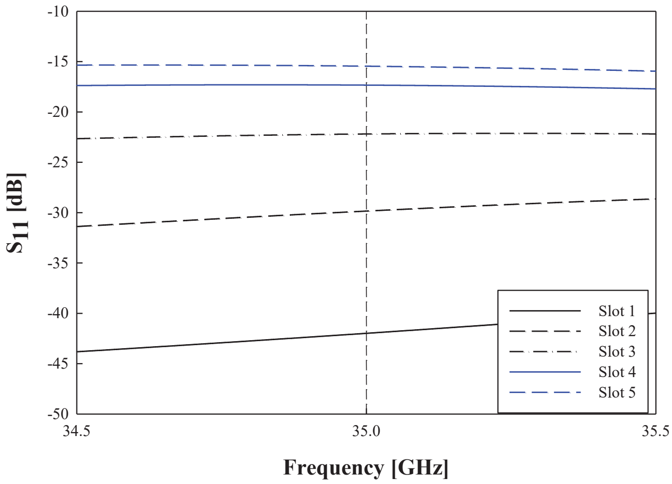
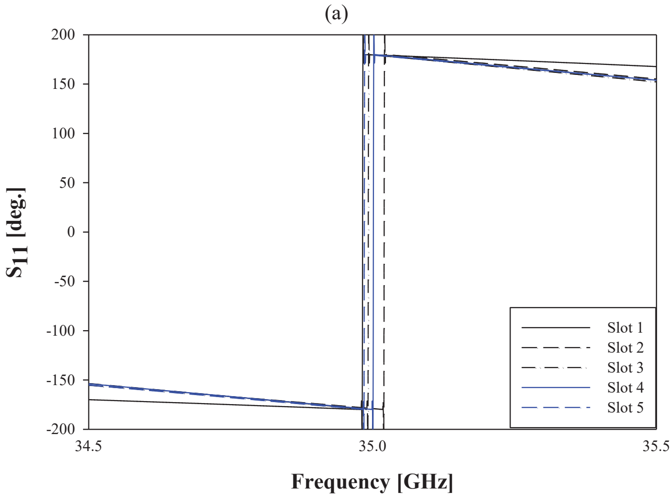


Fig. 2 Top view of 1x10 linear slotted waveguide array.




(a)




(b)

Fig. 3. Return loss of individual slot radiators (a) Magnitude in dB (b) phase in degree.

## *B. 150 Element Linear Array*

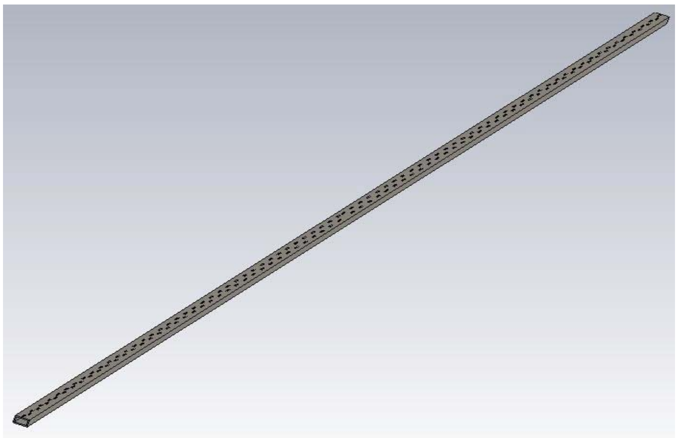
The similar method has been adopted to design a waveguide array of 150 elements in order to achieve a narrow beam width of 0.5˚. The total number of slots are calculated using the gain and beamwidth formula given in [9]

$$\text{Gain [dBi]} = 10\log\left(\frac{N\frac{\lambda_g}{2}}{\lambda}\right) \tag{2}$$

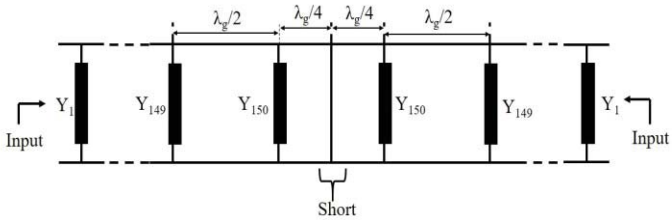
$$\text{Beamwidth [deg.]} = 50.7\left(\frac{\lambda}{\frac{N}{2}\cdot\frac{\lambda_g}{2}}\right) \tag{3}$$

where N is the number of radiating elements, λ is the free space wavelength.

Taylor's distribution for -40 dB sidelobe level has been realized by offsetting the slot from the waveguide center with appropriate slot length. The wall thickness of the non-standard waveguide is 0.625 mm, thus made easy to design a planar array. The bandwidth of the array is directly proportional to the wall thickness and slot width. However, slot width are typically less than 0.1λ so as to maintain low cross-polarization. The slot width of the proposed antenna is 0.66 mm and the overall dimension of the antenna is 994.225 mm x 6.89 mm. The model of 150 element linear array and equivalent circuit is shown in Fig. 4 (a) and Fig. 4 (b).



(a)




(b)

Fig. 4. Linear 150 element array (a) Simulated model (b) Equivalent circuit.

## III. RESULTS AND DISCUSSION

The 10 element linear array exhibits broadside radiation with better matching of -17.3 dB at 35 GHz. The impedance bandwidth of the antenna is 3.23 GHz at $S_{11}$ =-10 dB as shown in Fig. 5.

The radiation pattern of 10 element linear array at 35 GHz is shown in Fig. 6. The antenna exhibits broadside radiation having gain 15.8 dBi and HPBW 8.9˚. The maximum sidelobe level of the antenna is -24.3 dB. The cross-polarization of the antenna is very low with a null at theta = 0˚, with maximum level -58.6 dB at theta = 44˚.

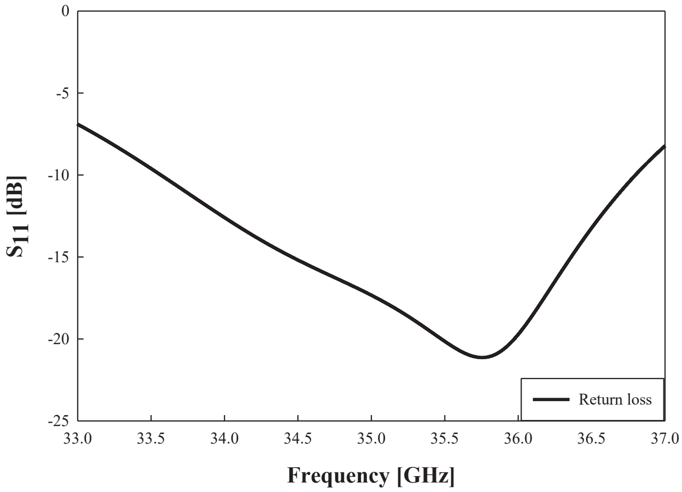



Fig. 5 Return loss characteristic of slotted waveguide array.

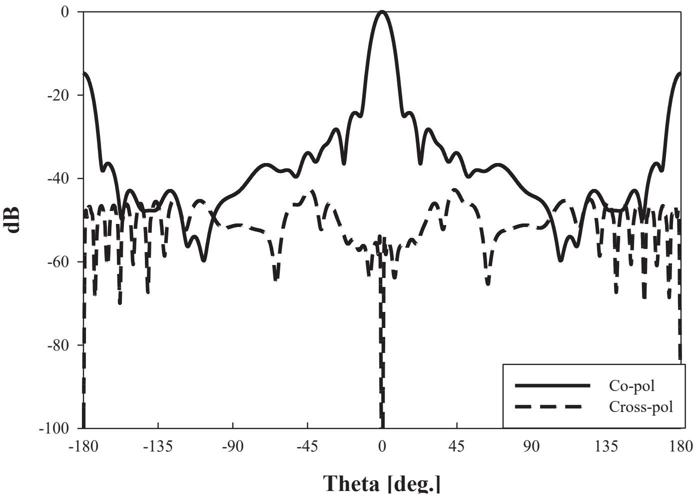



Fig. 6. Radiation pattern of 10 element array.

The radiation pattern of high performance slotted waveguide array of 150 elements has been depicted in Fig. 7. A high resolution tracking radar antenna demands a high frequency narrow beam radiation pattern. The proposed antenna provides a narrow beam pattern with HPBW 0.4˚ with a peak gain 26.5 dBi and Front to Back ratio (F/B) 14.9 dB. The antenna exhibits exponentially decaying sidelobes with maximum -40 dB. The cross-polarization radiation of the antenna is very low having maximum level -51.7 dB and with a null at the center. The performance characteristics of the proposed antenna is depicted in Table II.

TABLE II. PERFORMANCE COMPARISON OF WAVEGUIDE ARRAYS.

| Antenna Array | Gain (dBi) | HPBW (deg.) | Max. SLL (dB) | Max. Cross-pol (dB) | F/B (dB) |
|---|---|---|---|---|---|
| **1x10** | 15.8 | 8.9 | -24.3 | -58.6 | 14.8 |
| **1x150** | 26.5 | 0.4 | -40 | -51.7 | 14.9 |

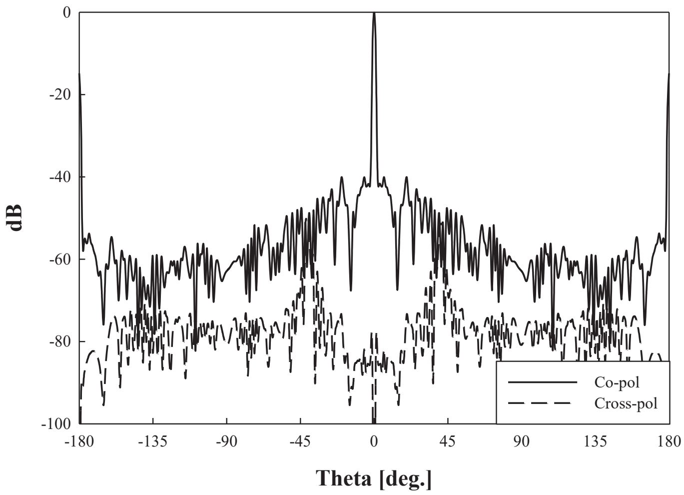



Fig. 7. Radiation pattern of 150 element linear array.

## IV. CONCLUSION

An efficient methodology for the design of a slotted waveguide array antenna was presented. A high performance slotted waveguide array operating at Ka-band having very low sidelobe is designed. The aperture distribution was realized by displacing the slots from longitudinal center line of the waveguide. The proposed array with machining tolerances reduced the complexity of mechanical design and milling. Thus the array is applicable in high resolution tracking radars.

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