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Effective Analysis of Waveguide Slot Array

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bstract— Waveguide slot arrays are useful in different radar applications due to their compactness several vorks are reported in the open literature on such structures. However, most of the works are confined using he conventional techniques and hence computationally expensive and they are not exact. In view of these, ntensive and investigation are carried out to bring out the results of effective analysis in the present work. The arrays of present interest are 4 slotted arrays. These slots are cut in the broad-wall of rectangular waveguide and they are displaced for its central line. The slots are separated by a resonant spacing and the slots have a finite width. The present analysis is based on CST Microwave studio which is basically a 3D electromagnetic simulator.

Keywords- *Slotted waveguides, CST, Array antenna, S11, VSWR.*

I. INTRODUCTION

Metallic rectangular waveguides are popular as transmission lines, radiators, and filter circuits in microwave range of frequencies. They can be designed for required polarizations [1]. Depending on the frequency of operation S-band are X-band waveguides are used. As single waveguide does not provide required directivity, arrays of waveguide are used. For high directivity of radiated gain such arrays, become heavy and bulky while occupying more space [2]. Hence slot arrays in the waveguide structures become viable and compact per such requirements [3].

The slots can be fabricated either the narrow wall or broad wall of a rectangular waveguide. It all depends on polarization requirements. The slots can be uniforming space or non-uniformly space. the second port of a waveguide is usually matched terminator in order to obtain required VSWR.[4]

The design of a resonant SWA is generally based on the procedure described by Stevenson and Elliot[5-6] For several military applications, the slotted waveguide array (SWA) are preferred due to their obvious advantages. They are known for their large power handling capability and hence can provide large gain too [7]. Due to this, they are more efficient and robust to work.Moreover, they are even capable of redundant pattern features essentially required for higher spectrum. These applications require high directivity and preferably need to maintain a very low profile. Single element radiation systems are not capable of producing patterns with required level directivity[8]: Hence array of radiating elements is used. Slots produced on the Waveguide (WG) serve as radiating elements and hence array of slots are obvious choice of high directive applications [9].

Slots are etched or removed portions on the walls of the WG. As a result, they are responsible for the discontinuity on the surface of the WG. This certainly leads to characteristic impedance variations as well as the conductivity. This in turn impacts the magnitude of the current and hence results in reasonable radiation from the WG walls. [10-11]

With reference to the propagation characteristics these SWAs can be classified as resonant type or travelling wave (TW) type. The resonant wave type is also known as standing wave (SW) type. In order to produce the SW patterns, the respective WG has to be shorted thereby providing a zero-impedance termination[12]. As a result, the forward travelling wave is completely reflected back and overlaps with the forward wave to generate the so-called SW pattern. On the other hand, in TW WGs the termination should be a matching load such that no wave is reflected back and completely absorbed at the terminal end. There is a considerable difference in the power-efficiency by which, the SW are termed as more efficient as the WG loses no power. Hence, the SW WGs are generally preferred.[13-14]

The physical properties of the WG have a significant impact on its radiation characteristics. Some of the physical properties are its width and length[15]. Especially, the resonant features can be directly mitigated using the slot properties like, its dimensions and position. For example, the slot placed on the axis of the WG cannot radiate as there is no significant corresponding density of current along the axis[16]. The radiation initiates as the slot position is moved from the axis to one of the edges. This is due to the corresponding variation in the field along the circumference of the slot[17].

Using SW patterns, it is possible to provide unbiased excitation to the slots. Hence, the SW excitation is preferred.

II. ANALYSIS

Consider 4 element slotted waveguide of figure 1. These slot and array parameters listed in table 1 are considered for the analysis.

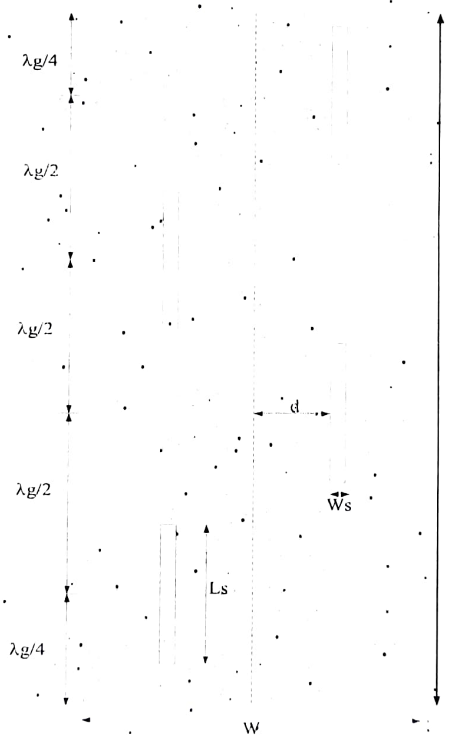

Fig.1: Structure of 4 element SWG

Table 1: Dimensions of slot array parameters

S.No	Parameter	Value in mm
1	L (Waveguide Length)	280
2	W (Waveguide Width)	72
3	Ws (slot width)	0.8
4	Ls (slot length)	49.3
5	d (slotted displacement)	12
6	a (size of the broad wall wave guide)	72.136
7	b (size of the narrow wall waveguide)	34.036

Using the above parameters CST Microwave studio is used to obtain different parameters for 4 slot waveguide structure.

The design of WG is guided by a set of rules which determine the radiation features of the WG and its other electrical characteristics. The guidelines followed for the 4 slot waveguide structure are listed as follows:

1. The position of the Slot-1 is multiples of λg/4 distance from the feed point
2. The position of the last slot also is placed at distance of multiples of λg/4 from the load.
3. The spacing between the two slots is λg/2.

Here λ and λg refers to wavelength and guide wavelength. Whereas the λ_g refers to the spacing between the peaks of similar phase planes..The operating frequency is determined using the λ_g. The λ_c refers to the cut-of wavelength and is determined using

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_{cutoff}}\right)}} = \frac{c}{f} \times \frac{1}{\sqrt{1-\left(\frac{c}{2a\cdot f}\right)}} \qquad (1).$$

Here, $\lambda_o$is the free-space wavelength corresponding to principle wave calculated at 3 GHz, and c refers to the velocity of light.N= number of slots.Also, λg= 138.5 mm. Similarly, the slot displacement refers to the distance between the centre of a slot and the axis of the WG broad face, as illustrated in Fig. 1.The value of the uniform slot displacement that leads to a good reflection coefficient is given by

$$d_u = \frac{a}{\pi}\sqrt{\arcsin\left[\frac{1}{N\times G}\right]} \qquad (2)$$

$$G = 2.09\times\frac{a}{b}\times\frac{\lambda_g}{\lambda_0}\times\left[\cos\left(0.464\pi\times\frac{\lambda_0}{\lambda_g}\right)-\cos(0.464\pi)\right]^2$$

For rectangular slots, the length is usually $0.98\times\lambda 0/2 = \lambda 0/2$. [5-6] .

The 4-element slotted WG(4SWG) as shown in figure 1. Following the rules mentioned above, the design of the 4SWG has been carried. The slots are arranged on either side of the axis line. A set of two slots are visible on either side of the axis. The two slots are on a straight oriented one after the other. This pattern is followed with the both the sets of slots. However, the slots on the left side of the axis are much closer to the WG edge than the other set of slots on right side.

The dimensions of the four slots are uniform and same. The width (W_s) and the length (L_s) are the dimensions of the slot and gap between the set of slots on either side of the axis is 2*d. This means d is the distance between the axis line and the slot.

III. RESULTS

For the slot and array parameters presented above, the variation of S-parameters, VSWR are numerically obtained as a function of frequency over the S-band frequency range and presented in the figures. The variation of slot length (Ls) and slot width (Ws) and displacement (d) are consider as variables for the above results. The exact values of these parameters as shown in the respective figures. The simulation studies are also made to obtain 3D patterns gain and directivity are also obtained and they are presented in the figures 2 to figure 12.

The design of the 4-SWG is carried out on CST and the simulated designs are presented and analysed here. Moreover, the simulated design has been thoroughly analysed using parametric analysis. The physical dimensions and the positions of the slots can be varied with different intervals and several values. The radiation characteristics of the SWG varies with the dimensions and greatly dependent on the them.[17] Hence, the parametric analysis is necessary to understand the dependency of its working and features on the location and dimensions of the slot.

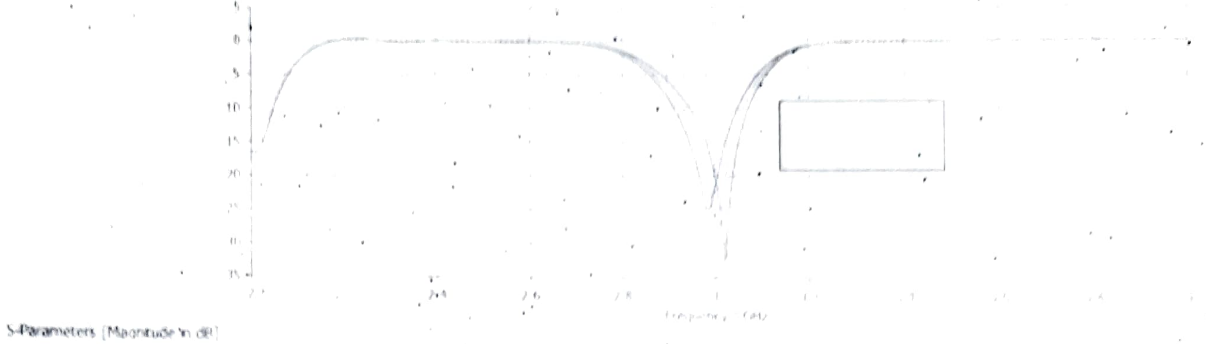

Fig.2: Return loss parameter by varying length of the slot (Ls)

The simulation of the SWG is carried out with 4 slots. The 4SWG designs and analysis are presented and discussed in this Section as two cases. Further, the results in terms of S11 and VSWR plots are initially used for parametric analysis to arrive at the optimized parameters. Further gain, directivity and 3D radiation pattern plots are generated for analysis.

The parametric analysis of the 4SWG is performed initially in terms of length(L_s), width(w_s) spacing (d), and material properties. Initially, the length is varied from 49.1mm to 49.5mm at 0.2mm interval. The corresponding S11 and VSWR plots are presented in figure 2.and figure 3 respectively. It is possible to notice that the resonant frequency diminishes with the increase in the length.

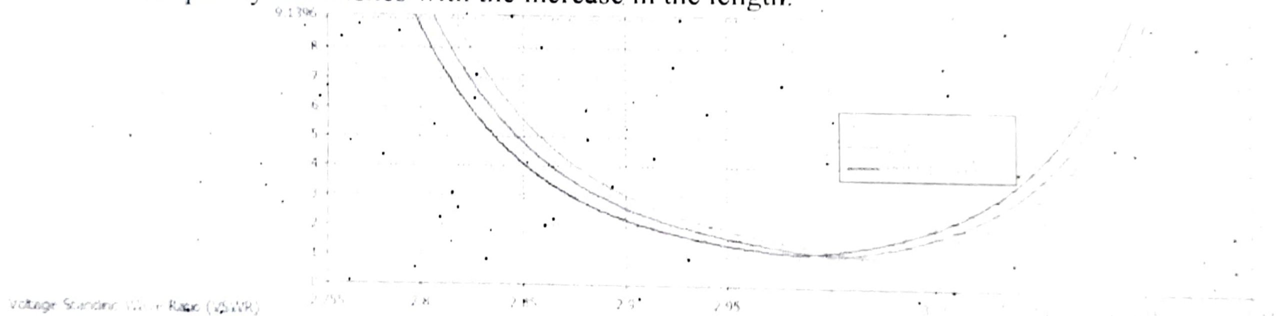

Fig.3: VSWR parameter by varying length of the slot (Ls)

Similarly, in figure 4 and figure 5, the results pertaining to the parametric analysis of width of the slot (Ws) are presented. It is possible to mention that the effect of the width in such a small interval of 0.1mm within the range of 0.7mm to 1mm is ignorable. The S11 parameter of by varying width of the slot is represented in figure 4 and the figure 5 represents the VSWR parameter of the 4-element slot antenna by varying the width of the slot (Ws).

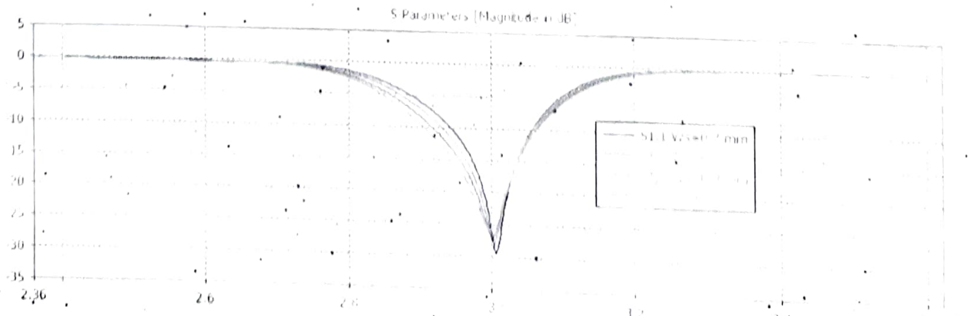

Fig.4: Return loss parameter by varying width of the slot (Ws)

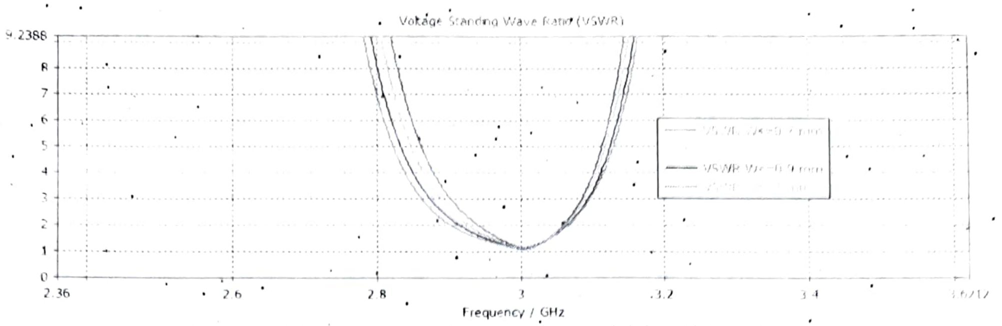

Fig.5: VSWR parameter by varying width of the slot (Ws)

Similarly, the spacing between the axis and slot lines is optimized. The parametric analysis is carried out for d=10mm to 14mm in 2mm interval. The shift of resonant frequency is noticed using the plots of S11 and VSWR presented in figure 6 and figure 7 respectively.

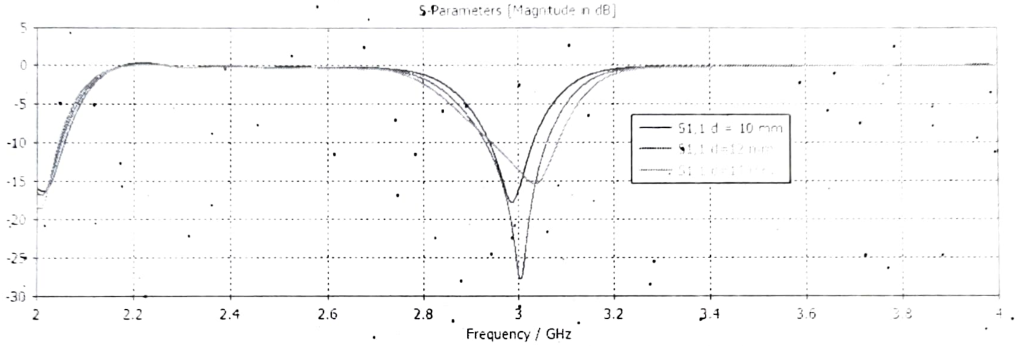

Fig.6: Return loss parameter by varying slot displacement (d)

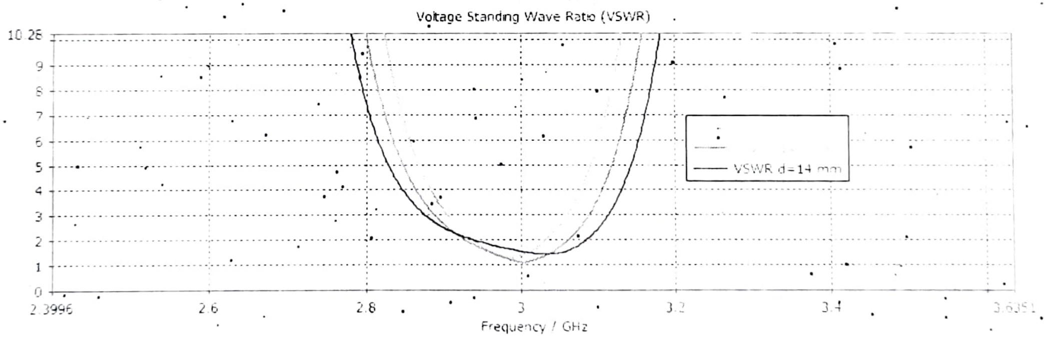

Fig.7: VSWR parameter by varying slot displacement(d)

On the other hand, the material of the aluminium, brass and copper are suggested for parametric analysis based on materials. However, there no change in the resonant features of the 4SWG with change in the material listed above. This is evident from the plots mentioned in figure 8 and figure 9.

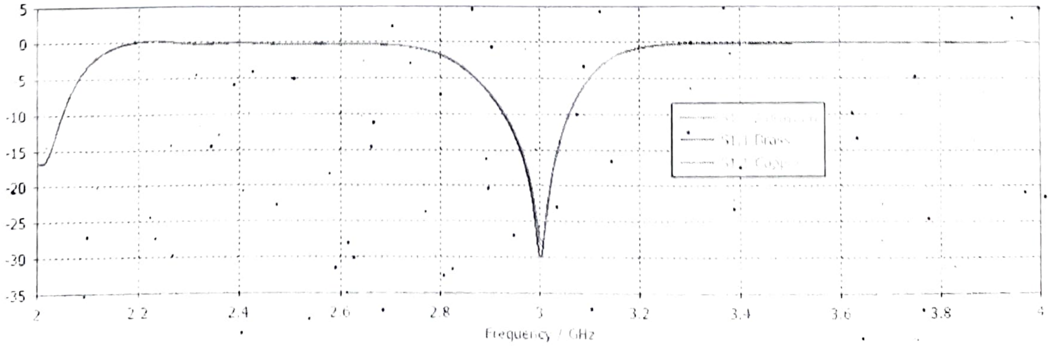

Fig.8: Return loss parameter by varying waveguide material