A New Configuration for Circularly Polarized Waveguide Slot Antenna

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***Abstract* — A new structure to radiate circularly polarized electromagnetic waves based on the slotted waveguide antenna is proposed. A combination of a slotted rectangular waveguide and a cavity is used to created waves with circular polarization with very low axial ratio. In an array of the proposed structure, slot spacing close to λ/2 is achievable. Therefore, a planar array with presented waveguide slot antenna can designed with only one main lobe and a directive pattern with circular polarization.**

***Index Terms* — Array waveguide slot antenna, circular polarization, slotted waveguide antenna, V-slot.**

I. Introduction

Waveguide slot antennas because of their low profile, geometric simplicity, polarization diversity and their high physical resistance have extensive use in linear and two-dimensional (2-D) arrays that are used in missile, spacecraft and airborne radars. Various configurations have been proposed to radiate linear polarization [1], [2] and circular polarization [3]-[7] from the slotted rectangular waveguides. Cutting a circular hole or a pair of crossed slots into the broad wall of a rectangular waveguide at a proper point is a convenience method to radiate a circularly polarized wave [4]. The difficulty of this configuration is that for a 2-D array there is no way to reduce the slot to slot spacing to the half free space wavelength in either direction. Thus, more than one main lobe with equal amplitudes can appear in the radiation pattern of the array. Radiation from the narrow walls of a rectangular waveguide is a convenient method to get round this difficulty. The proposed configuration in [5] is a circularly polarized waveguide narrow wall slot array with a single layer dipole array mounted on it as a polarization converter and can be used to radiate circular polarization from waveguide narrow walls. Using an array of dipoles in front of the narrow wall slots result in a circularly polarized antenna that does not have a low profile structure. In this paper a novel configuration to radiate a circularly polarized wave from the rectangular waveguide narrow walls is proposed that has a low profile structure and has no secondary maxima in its radiation pattern.

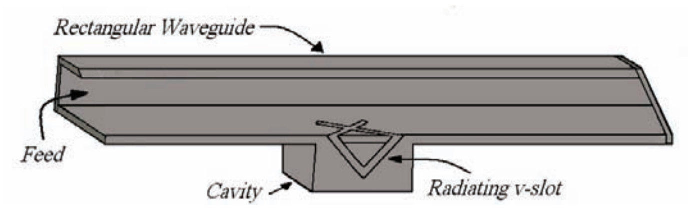

Fig. 1. Proposed waveguide sot antenna configuration.

II. Slotted Waveguide Structure

Fig. 1 shows the proposed configuration that consists of a rectangular waveguide and a cavity that involves the radiating v-slot. The center of the x-slot is at a point on the interior broad wall on the waveguide which the transverse and longitudinal current distribution components of the TE_{10} mode are equal in magnitude and in phase quadrature. The x-slot branches are excited by the circularly polarized current, so that the electric fields produced in the x-slot branches are equal in magnitude and in phase quadrature. Unlike the proposed method in [4], this x-slot is not a radiating element and acts as a transmission line and guides the electric fields to the radiating v-slot. The v-slot consists of a pair of narrow slots crossed at right angles and is excited by a circularly polarized electric field; therefore this slot radiates a circularly polarized wave. To obtain a broadside radiation in an array structure of this radiating element, all of the slots must be excited in phase. This can be achieved by spacing the slots one guided wavelength, λ_g, apart. On the other hand, in order to avoid more than one main lobe in the radiation pattern, the slot spacing must be close to $\lambda/2$ for a broadside array, where λ is free space wavelength. In a conventional unloaded rectangular waveguide, λ_g is larger than λ. So, the λ_g slot spacing yields a radiation pattern with more than one main lobe. Here in the proposed structure, the waveguide and the cavity heights can be selected in a way that their total is less than half free space wavelength. In this case, it is possible to stack linear arrays with the spacing close to $\lambda/2$ so that the effective spacing between slots in the planar array is equal to $\lambda_g/2$. This slot spacing yields a planar array with one main lobe in its radiation pattern. Fig. 2 shows how the linear

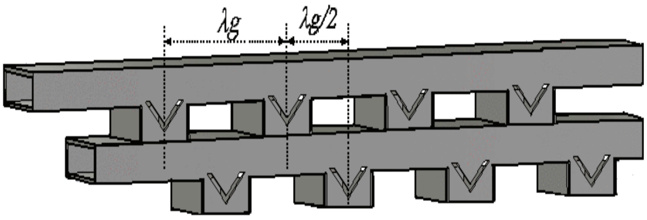

Fig. 2. Planar array with the effective slot spacing equal to $\lambda_g/2$ and close to λ/2.

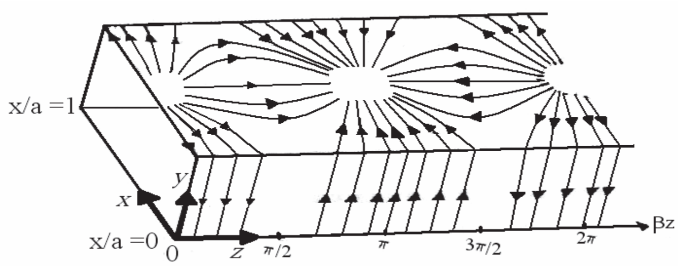

Fig. 3. The current distribution on the interior walls of the waveguide.

arrays must be stacked to construct a planar array with the effective slot spacing close to $\lambda/2$.

III. Design Procedure

The transverse and longitudinal current distribution components of the TE_{10} mode on the interior broad wall of the rectangular waveguide are given by:

$$J_x = J_0(\lambda/2a)\cos(\pi x/a) \quad (1)$$

$$J_z = J_0[1-(2a/\lambda)^2]^{0.5}\sin(\pi x/a). \quad (2)$$

Fig. 3 shows the current distribution on the interior walls of the waveguide. Two values of *x* can be found for which $|J_x|=|J_z|$. At the following point, the transverse and longitudinal components of the current distribution are equal in magnitude and in phase quadrature:

$$x = (a/\pi)\tan^{-1}\left(1/[(2a/\lambda)^2-1]^{0.5}\right) \quad (3)$$

If an x-slot be cut at the *x* point, the produced electric fields in the x-slot branches are equal in magnitude and in phase quadrature. As proposed in [4], this x-slot can be used as a radiating element to produce electromagnetic waves with circular polarization. The broad dimension of a rectangular waveguide must be considerably greater than $\lambda_g/2$ to avoid operation too close to the cut-off frequency. In a conventional unloaded rectangular waveguide, λ_g is larger than λ. Therefore, a planar array with a close to $\lambda/2$ sub array spacing is not practical with these radiating elements. In our new configuration, the x-slot acts as a transmission line and guide the electromagnetic fields into the branches of the v-slot. The v-slot radiates the electromagnetic fields into the free space.

Here as an example, the operating frequency is considered equal to *10 GHz* and the center of the x-slot is chosen halfway between side wall and the center line of the waveguide, i.e. $x = a/4$. So, the waveguide width, *a*, must satisfy the following relationship to have a circularly polarized radiation:

$$a = \lambda/4 \quad (4)$$

If the waveguide and the cavity heights are chosen so that their total are less than $\lambda/2$, it is possible to stack the linear arrays with the spacing close to $\lambda/2$. This condition is achieved if the waveguide height, i.e. *b*, and its thickness, i.e. *t*, satisfy the following relationship (equal waveguide and cavity heights are considered).

$$2b + 3t \le \lambda/2 \quad (5)$$

with a value of *t=1 mm* for the waveguide thickness, relationship (5) yields that:

$$b \le 6\,mm \quad (6)$$

Here, *b=6 mm* is chosen for the waveguide height.

The center of x-slot is placed at the x point and its branches are cut at ±*45*° with respect to the z axis. The v-slot branches that start from the end of the x-slot branches are cut at ±*45*° with respect to the y axis in the cavity wall. The v-slot branches are at right angles to each other and their electric fields are equal in magnitude and in phase quadrature so that radiate a near circularly polarized wave. As mentioned, the x-slot can be considered as a transmission line with short circuit termination at one end. The other end of the x-slot branches terminates in v-slot branches. In the other hand, each of the v-slot branches is as a load at the end of the x-slot branches. The v-slot branches width and the distance from the center of the x-slot to the end of its branches affect the electric fields distribution in the slots and also antenna axial ratio. Values close to half free space wavelength and waveguide thickness are appropriate initial values for the x-slot branches length and the v-slot width, respectively. These parameters can affect the circular polarization considerations. In the example, the x-slot branches length and the v-slot width are assumed to be equal to *13.5 mm* and *1 mm*, respectively.

To have a circularly polarized electric field distribution in the v-slot and x-slot branches, it is necessary to have a traveling wave in the waveguide. But, the x-slot perturbs the initially traveling wave, and therefore the circularly polarized electric fields. The effect of this perturbation can be

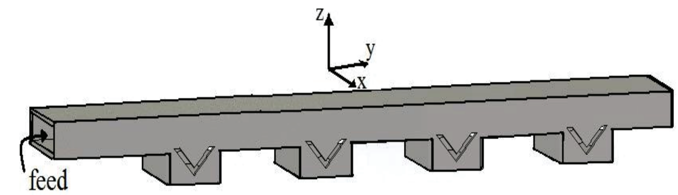

Fig. 4. Linear array with four radiating v-slots.

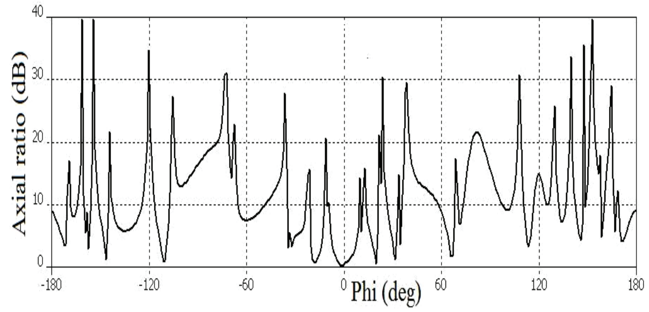

Fig. 5. Axial ratio of the linear array versus φ in the *xy* plane.

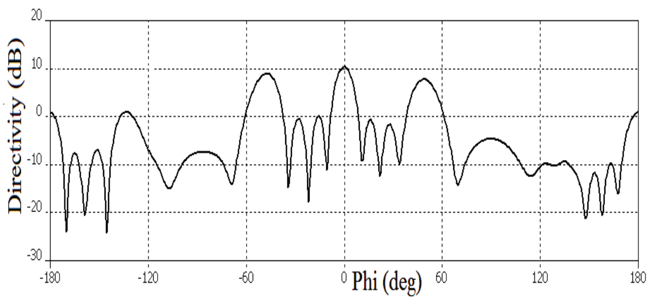

Fig. 6. Directivity of the linear array versus φ in the *xy* plane.

compensated by varying the reflection from the waveguide end. The value of the reflection coefficient depends on the number and dimensions of the slots. Increasing the radiation from the slots decreases the delivered power to the waveguide end. Therefore to compensate the effect of this perturbation it is necessary to have a higher reflection from the end of the waveguide.

IV. Simulation Results

A linear array with 4 slots and a planar array that consists of 5 such linear arrays are considered. The simulations were made in the CST microwave studio environment. Fig. 4 shows a linear array that is feed from one waveguide end and another end of the waveguide is terminated in a certain load. This load is adjusted so that a circular polarization is

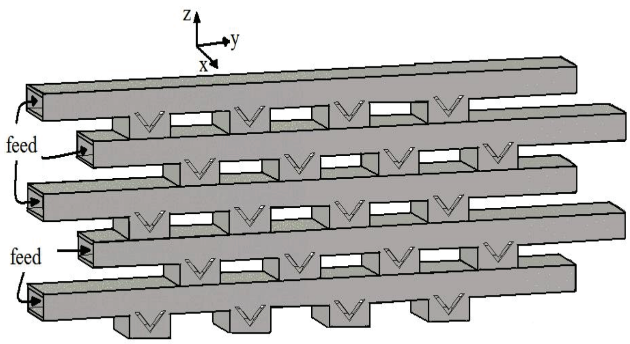

Fig. 7. Planar array configuration.

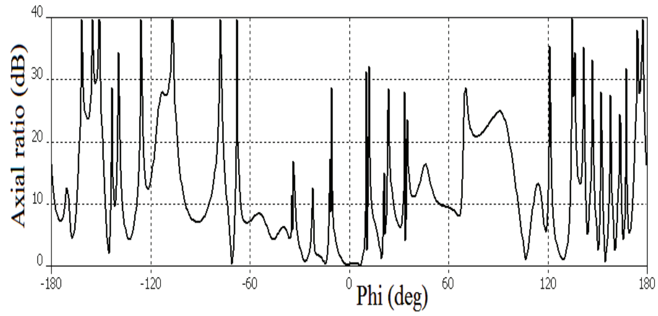

Fig. 8. Axial ratio of the planar array versus φ in the *xy* plane.

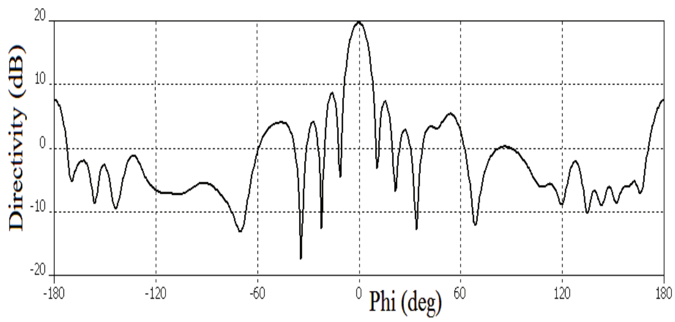

Fig. 9. Directivity of the planar array versus φ in the *xy* plane.

achieved. The axial ratio may be made close to unity by varying the reflection coefficient of the load. The axial ratio of the designed linear array is less than *1.7 dB* over the main beam of the radiation pattern. Figs. 5 and 6 show the axial ratio and the directivity of the linear array, respectively. The axial ratio is less than *0.5 dB* in the maximum radiation direction. Since, in the array structure the slot spacing is equal to λ_g, the linear array has more than one main lobe in its radiation pattern and has too high side lobe level (SLL).

The designed planar array consists of 5 linear arrays. As shown in Fig. 7, the linear arrays can be stacked side-by-side

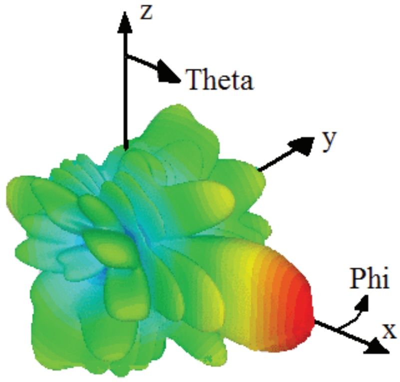

Fig. 10. 3-D radiation pattern of the planar array designed using the proposed configuration in this paper.

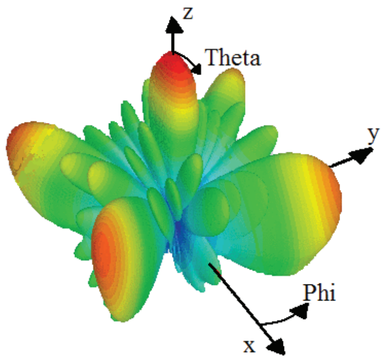

Fig. 11. 3-D radiation pattern of the planar array designed using proposed configuration in [4].

with the spacing close to $\lambda/2$ in the z direction. Moreover, shifting the sub arrays in the y direction can provide a planar array with the effective slot spacing close to $\lambda/2$. This planar array has only one main lobe in its radiation pattern. Figs. 8 and 9 show the axial ratio and the directivity of the planar array versus in the xy plane. The axial ratio is close to $0.3\,dB$ in the maximum radiation direction, which is too close to the ideal circular polarization. As shown in Fig. 9, the planar array has only one main lobe in its radiation pattern. Figs. 10 and 11 show the three-dimensional (3-D) radiation patterns of our configuration and the proposed configuration in [4], respectively. As mentioned before, to avoid more than one main lobe in the radiation pattern, the slot spacing must be close to $\lambda/2$. The slot spacing in our planar array is close to $\lambda/2$, therefore has only one main lobe in its radiation pattern. As shown in fig.11, the planar array designed using the proposed method in [4], has 4 main lobes except the desired main lobe in its radiation pattern.

V. Conclusion

A new configuration is introduced to radiate circularly polarized electromagnetic fields in the slotted waveguide antennas. A combination of an x-slot and a v-slot is used to achieve circular polarization. By using this configuration it is possible to make a planar array with close to $\lambda/2$ slot spacing which can have only one main lobe and directive pattern.

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