Design of Arrays using Twisted Arm Slot Coupled Waveguide Junction

Dr. SrivalliGundala[1], Dr. Srinivasa Baba VSSN[2]

[1]*Associatet Professor, Dept. of Electronics & Communication Engineering, GNITS, Shaikpet,Hyderabad - 500104India*

[2]*Dept. of Electronics & Communication EngineeringACE Engineering College ,Ankushapur(V), Ghatkeswar(M), R RDist, Telangana 501301 India*

Abstract- Inclined slots in a narrow wall are usually attractive for using in linear slot arrays, as the machining of these slots is relatively easy. However, when the resonant slot arrays are required to be designed where in each individual slot should be at resonant, it is not possible to accommodate the resonant length of each slot entirely in the narrow wall because of the limited wall dimension. As a result they are protruded into the broad wall exhibiting a depth of cut in the broad wall. This additional length of the slot in the broad wall disturbs the desired polarization. Moreover, the inclination of the slot also creates cross-polarized fields when horizontally polarized fields are desired. In this work, a typical junction is proposed in which T-arm is properly inclined to make it suitable for the design of square grids. The main objective of the present work is to design linear arrays in which the radiating element is a tilted arm rectangular slot coupled waveguide junction. The conductances of the radiating junctions in the array are evaluated by taking internal reflections into account. The design also takes care of the fraction of the power dissipation in the matched load. The design of the linear array is unique in the sense that the above two factors are not conventionally taken into account. In addition, this type of array in which twisted armed waveguide junctions are used as a radiating element are not investigated earlier.

Keywords- Waveguides, Shunt Tees, Admittance Loading, H-Plane Tee, Slot coupled Tee Junctions

I. INTRODUCTION

E plane and H plane T-junctions in which the power is coupled through rectangular slots are well known [1-15]. As these junctions have limited applications, there is a need to evolve new type of junctions. In the design of an array antenna, the desired array pattern characteristics are essentially specified. In the case of linear array design the radiation pattern is a function of θ alone and is independent of ϕ. This means the patterns are always computed as a function of θ. In fact, the specifications of complete radiation pattern through analytical expression are complex and involved. As a result, these specifications are usually centered around the specification of first side lobe level and the null to null main beam width.The array design consists of mainly the following.

1. Design of amplitude distribution.
2. Design of phase distribution if required.
3. Design of space between the radiating elements.
4. Design of type of element.

Out of the above four factors, the design of amplitude distribution plays major role for non-scan application. The second factor is optional and is included different type of application and type of radiation beam. The third and fourth factors are usually specified and fixed depending again on applications.However, there is a need to design the radiating elements, which are characterized by the designed conductance values satisfying the amplitude distribution, which yield the desired radiation patterns.When the slot arrays are fed through a waveguide, the design is very complex as the active admittance of each slot is defined in terms of propagating mode.

II. DESIGN METHODOLOGY

The conductances of the radiating junctions in the array are evaluated by taking internal reflections into account. The design also takes care of the fraction of the power dissipation in the matched load. The design of the linear array is unique in the sense that the above two factors are not conventionally taken into account. In addition, this type of array in which twisted armed waveguide junctions are used as a radiating element are not investigated earlier. The design procedure is given in the proceeding sections.

The design methodology involves the following steps

1. Design of a suitable amplitude distribution, which results in a radiation pattern with prescribed side lobe levels
2. To determine power distribution.
3. To sample the continuous amplitude distribution to find out the discrete levels at the location of the radiating element.
4. To determine the normalized conductances that each element should offer.
5. From the conductances evaluated, the junction parameters are determined.

III. DETERMINATION OF EXCITATION LEVELS FOR THE ARRAY

When uniform distribution is used for the array it results radiation pattern with higher side lobe levels, which are unacceptable. It gives rise to first side lobe level of –13.5dB. In view of this, the optimally tapered amplitude distributions are needed to reduce the side lobe levels.These tapered distributions can be cosine or pedestal. It is possible to find out such functions by the use of the popular methods suggested by Taylor [19]. Taylor's method specified radiation pattern consists of the prescribed number of side lobes with equal height and the respective side lobes decay exponentially. It is up to the designer, to choose number of side lobes, which have equal heights.

According to the Taylor's method, the general array factor is given by

$$E(\theta)=\int_{-L}^{+L} A(x)\ e^{j\beta x\sin\theta}\,dx \qquad (1)$$

here E(θ) is specified which is the desired pattern, ; A(x) is the specified amplitude distribution to be found out, 2L is array length,; x is a variable on the array axis

$\beta=2\pi/\lambda$, θ is the angle between the line of observer and broad side

When $A(x)=Be^{-j\beta x}$ (2)

where B is constant, the antenna array factor becomes

$E(\theta)=2BL\sin(\beta L\cos\theta) / (\beta L\cos\theta)$ (3)

If an integer $\bar{n}$ is chosen in such a way that for $|u|\geq\bar{n}$, the nulls of the pattern occur at integer values of u. E (u)=

$$\frac{\sin\pi n}{\pi n}\,\frac{\prod_{n=1}^{\bar{n}-1}\left(1-\frac{u^2}{u_n^2}\right)}{\prod_{n=1}^{\bar{n}-1}\left(1-\frac{u^2}{n^2}\right)} \qquad (4)$$

The new null positions are determined from [19] the expression.

$$u_n = \bar{n}\left[\frac{D^2+(n-\frac{1}{2})^2}{D^2+(\bar{n}-\frac{1}{2})^2}\right]^{\frac{1}{2}} \qquad (5)$$

where **D** represents the side lobe level(SLL) and is defined as

$$\mathbf{D}=\cosh^{-1}(b/\pi)$$

and **b** is defined as $\mathbf{b=10^{SLL/20}}$ (6)

The patterns are usually represented in dB and the side lobe level in dB is given by

SLL= 20 $\log_{10}$b dB (7)

Using the expressions (3-5), it is possible to find out the required aperture distribution from eqn.(1) and it is given by

$$A(x) = \sum C_i \cos\frac{i\pi x}{L} \qquad (8)$$

With the substitution of eqn. (8) in eqn (1), we get

$$E(u)=\sum_{i=0}^{\infty} C_i \int_{-L}^{+L} \cos\frac{m\pi x}{L}.e^{ju\pi xL}\,dx \qquad (9)$$

As a result, the Fourier series represented by eqn. (8) becomes finite. The continuous aperture distribution is therefore given by

$$A(x)=\frac{e^{-j\beta x}}{2L}\left[\delta(0)+2\sum_{i=1}^{\bar{n}-1}\delta(i)\cos\frac{m\pi x}{L}\right] \qquad (10)$$

From the expression (10), amplitude distribution is numerically computed as a function of x for the following cases.

1. SLL= -28 dB, $\bar{n}$ =5
2. SLL= -30 dB, $\bar{n}$ =5

In the present work, it is of interest to design an array of slot coupled twisted armed junctions. There is a need to find out the excitation levels of the individual radiating elements from the above continuous distribution. This is possible if the distribution is sampled at the location of the elements. Instead of considering a discrete array to calculate the excitation levels separately, the above procedure becomes very simple.

A few typical such excitation levels of small arrays where number of radiating elements, N=20 are presented in the Tables (1-2).

IV. DESIGN OF AN ARRAY

A linear array of slot coupled twisted armed waveguide junction is shown in fig.1. Array of slot coupled waveguide junction differs from two wire fed slot arrays. In two wire fed slot arrays, voltage waves on two wire lines, which feed the slots, are used to find out the conductance of the slots and directional characteristics of the array. However, it is more complicated with slot coupled waveguide fed slot array. It is evident from the literature, inclined slots in a narrow wall are more attractive for various applications to use in linear slot arrays. On the other hand, two-dimensional arrays of slots are not very popular due to overall slot array configuration.

It is well known that H-plane and E-plane slot coupled waveguide junctions are very common and they are used for varied applications. It is difficult to construct a specified grid structure by using either H-plane or E-plane junction.In view of this, slot coupled twisted armed waveguide junction is proposed in order to use it in a square grid, for different radar applications. In this work, the design of an array of such junctions is presented to produce radiation patterns presented in the preceding section.

As mentioned earlier, the design of such a slot array demands the data on amplitude distribution for an array of junctions, which can produce the specified radiation pattern.

Some of the specified patterns are presented in the preceding section and corresponding amplitude distributions are numerically computed precisely. Moreover, the design of an array further demands an appropriate equivalent circuit of the array, so that the internal reflections can be taken into account. This is possible as the equivalent circuit of each junction is a shunt element.

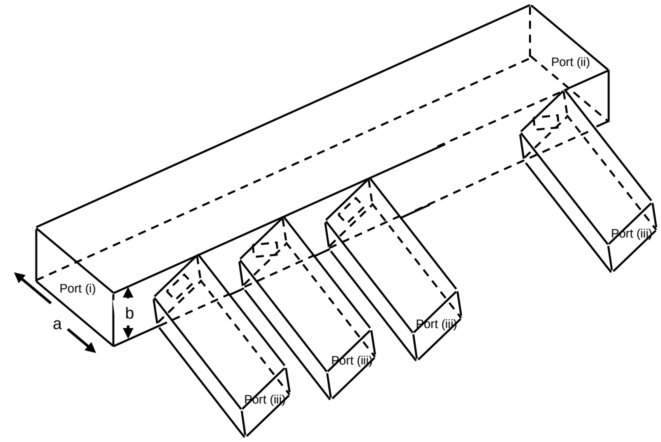

Fig. 1 Array of slot coupled twisted armed waveguide junction

The equivalent transmission line circuit for an array of above mentioned junction is shown in fig. 2. Here, g_{n1}, g_{n2}……represents normalized conductance and d represents spacing between junctions which has equivalent electrical length given by

$$\alpha_d = \frac{2\pi}{\lambda g} d + \pi \qquad (11)$$

where λ_g is guide wavelength.

It is evident that the equivalent input conductance is the sum of all individual slot conductances i.e.

$$g_{ne} = \sum_{i=1}^{N} g_i \qquad (12)$$

when the equivalent voltage across the equivalent circuit is represented by V. The power radiated by the slot i be $\frac{1}{2} V^2 g_{ni}$. Hence the relative excitation level of i^{th} slot is proportional to $(g_i)^{1/2}$.

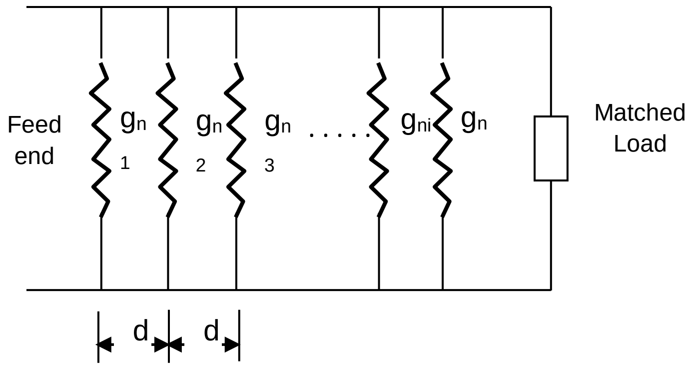

Fig.2: Equivalent circuit of array of junctions with matched termination

If there is no loss in radiation and if all the available power is radiated, the equivalent array conductance g_{ne} is equal to unity.

As a result, g_{ni} can be expressed as

$$g_{ni} = KA^2(x_i) \quad (13)$$

As $g_{ne} = 1$, we get

$$K\sum_{i=1}^{N} A^2(x_i) = 1 \quad (14)$$

It is possible to determine K, for the specified amplitude distribution levels.

V. RADIATION PATTERNS OF THE ARRAYS

The radiation patterns corresponding to the amplitude distributions of section (5.2) are numerically computed and are presented in figs. (5.1-5.9). The computations of radiation patterns for a line source and for an array of discrete radiators are made form the following expressions.

For a continuous line source, the radiation pattern is given by

$$E(\theta) = \int_{-L}^{L} A(x)\, e^{j\frac{2\pi L}{\lambda} x \sin\theta} \quad (15)$$

where $\frac{2L}{\lambda}$ = normalized array length

A(x) = amplitude distribution

x = variable point on the line source

λ = wave length

θ = angle between the line of observer and broadside

However, for discrete array, the pattern is given by

$$E(\theta) = \sum_{i=1}^{N} A(x_i)\, e^{j\frac{2\pi L}{\lambda} x_i \sin\theta} \quad (16)$$

where x_i is the location of i^{th} element and $A(x_i)$ is the excitation level for i^{th} element. It is well known that uniform amplitude distribution results in radiation pattern with the first side lobe level of -13.5 dB.

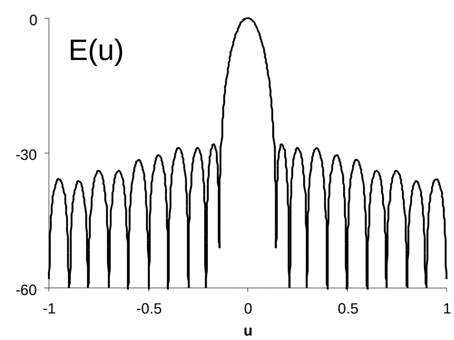

Fig.3: Radiation Pattern in u-domain for amplitude distribution of SLL=-28dB, $\bar{n}$ =5

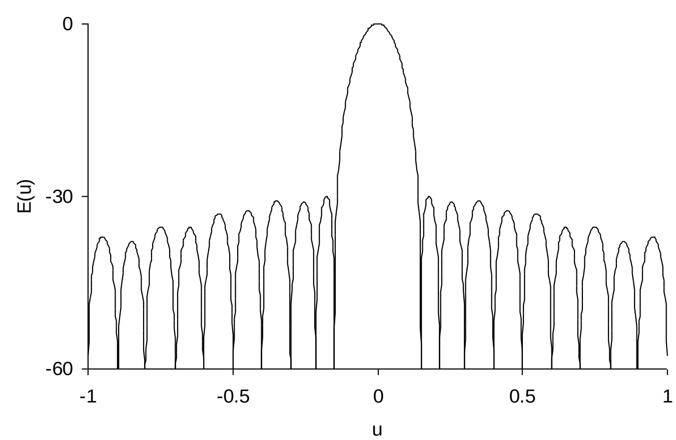

Fig.4: Radiation Pattern in u-domain for amplitude distribution of SLL=-30dB, $\bar{n}$ =5

This is not acceptable in most of the applications. As a result, it is required to taper amplitude distribution (fig. 5) to reduce the side lobe heights. As mentioned in preceding sections, the side lobes are controlled with the help of computed distributions using Taylor's method.

The expression containing the summation can be recognized as Fourier series. When the spacing between the elements is made smaller and smaller while keeping array length constant, a large number of elements can be accommodated.

Under these conditions, the series in the limit can be replaced by Fourier Transform and hence the antenna is no longer a array of discrete radiations but it is a continuous aperture.

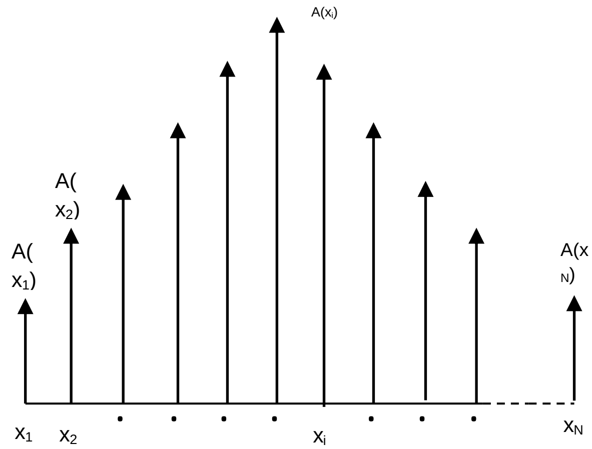

Fig. 5. Tapered amplitude distribution

VI. RESULTS AND CONCLUSIONS

From the amplitude distributions, presented in figs. (3-4), the normalized conductance values of the slot coupled junctions are determined for number of junctions in the array equal to 20 and are presented in Tables (1-2).

For the conductance values so computed, the design junction parameters are also presented in the same Tables (1-2). The parameters are computed for a fixed slot width of 0.1 cm.

It is found from the results that the required slot conductance values for a specified radiation pattern are small for large array and are large for small arrays.

The length of the slot is found to vary between 1.5 to 1.6 cm to obtain the desired conductance values. In this work, there is a lot of flexibility in the design as there exists more number of parameters available to the designer.

When $\bar{n}$ is 5, there exists 4 side lobes of equal height The rest of the side lobes are found to decay exponentially as evident from the presented results.

When T-arm is twisted by 45^0 from broadside, it is possible to fabricate square grid for radar applications. For other than the present junctions, it is not possible to construct square grids because of unsuitable junction geometry. In fact, the present method is extendable to any type of array.

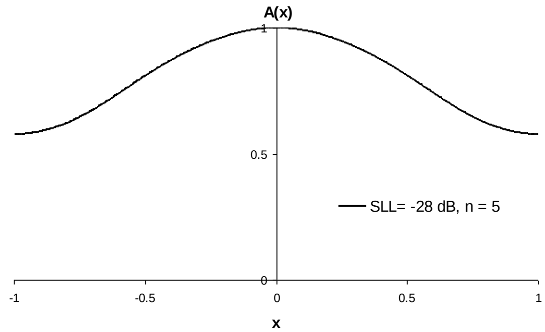

Fig.6: Amplitude distribution for continuous line source

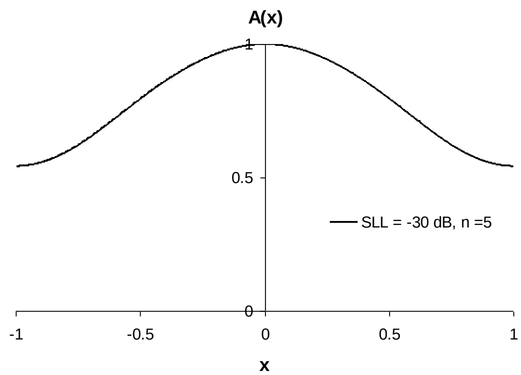

Fig.7: Amplitude distribution for continuous line source

Table 1 Array design parameters for desired radiation pattern (N = 20, SLL = -28dB, $\bar{n}$ =5)

N	Required conductance g_r	Realized Slot Conductance g_n	Slot inclination $\theta_{s(deg)}$	Feedguide inclination $\theta_{g(deg)}$	$2L_{cm}$
1	0.15031	0.1500	31.00	10	1.544
2	0.19604	0.1960	35.00	15	1.554
3	0.30115	0.3010	42.00	30	1.592
4	0.48073	0.4800	51.00	40	1.600

5	0.73175	0.7320	55.00	50	1.620
6	1.02520	1.0300	59.70	60	1.620
7	1.32138	1.3200	63.00	60	1.620
8	1.58739	1.5900	65.70	65	1.620
9	1.79475	1.8000	66.50	65	1.620
10	1.91131	1.9100	68.00	65	1.620

Table 2 Array design parameters for desired radiation pattern

(N = 20, SLL = -30dB, $\bar{n}$ =5)

N	**Required conductance g_r**	**Realized Slot Conductance g_n**	**Slot inclination $\theta_{s(deg)}$**	**Feedguide inclination $\theta_{g(deg)}$**	**$2L_{cm}$**
1	0.12650	0.1300	29.00	10	1.544
2	0.17340	0.1730	33.00	15	1.554
3	0.28130	0.2810	41.00	30	1.556
4	0.46460	0.4650	50.00	40	1.600
5	0.71970	0.7200	54.50	50	1.620
6	1.02010	1.0200	59.20	60	1.620
7	1.32810	1.3300	63.20	60	1.620
8	1.60860	1.6100	65.30	65	1.620
9	1.82760	1.8300	66.30	65	1.620
10	1.95010	1.9500	6.710	65	1.600

VII. CONCLUSIONS

The arrays are designed to produce the specified radiation patterns. Amplitude distributions using Taylor's method are computed and the radiations patterns are produced for the specified side lobe levels.In order to produce the desired such radiation patterns, the array of junctions are designed and required conductance, slot inclination, guide inclination, slot length and slot width are determined. The designed data for arrays containing 20 elements are presented in the form of tables. Since the specified radiation patterns are symmetric, the array elements are also symmetric in terms of their dimensions.

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