A Novel Design for Microwave Linear Lossy Arrays

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ABSTRACT

With the advent of microstrip technology, planar strip line and microstrip line array have started to gain more confidence in applications, although there are some reservations due to the ohmic losses where appear higher than the waveguides. An improved analysis method is presented in this paper which can evaluate the conductance of the array elements for any form of lossy transmission line loaded periodically with radiating elements of a given efficiency.

INTRODUCTION

Advantages of size, weight and cost have risen the interest for planar printed arrays in recent years. Narrow band and side-lobe level are of the most severe problems the designers have met so far. They are due to secondary effects such as coupling, surface waves, but also due to the transmission line losses. Flat triplate stripline arrays[1] were the most successful of all since they produce side-lobe level as low as -30dB, while conventionally designed microstrip arrays have shown side-lobe levels typically of the order of -20dB[2,3]. The design appoach for microstrip arrays[3] is similar to that employed in waveguide arrays[4,5,6].

Figure 1 shows a piece of transmission line loaded periodically with shunting elements at equal intervals. The discrete shunting elements may be regarded as the radiating elements of the array resulting in a relatively simple design procedure for both resonant and traveling wave arrays, assuming that the ohmic and dielectric losses associated with the feeder and elements are negligible. Defining $P_1, P_2, P_3, \ldots P_n$ to be the power distribution for an N-element array, the normalized radiation conductance $\overline{Gr}_n$ of the nth element is given by the expression:

$$\overline{Gr}_n = P_n \Big/ \left[\sum_{s=n}^{N} P_s + t \sum_{s=1}^{N} P_s \right]$$

Equation (1) is based on the assumption of small reflections ($\overline{Gr}_n \ll 1$). The expression $t\sum_{s=1}^{N} P_s$ is some fraction of the radiated power absorbed by the load of the traveling wave array. The normalized radiation conductance $\overline{Gr}_n$ is the ratio of the radiation conductance of the nth element over the conductance of the feeder line.

Whilst ohmic and dielectric losses are neglected in the design procedure for microwave arrays with few elements, the effect of such losses in the evaluation of the conductance values is likely to be considerable for large element microwave array. Waveguides have a relatively low attenuation but in microstrip and stripline triplates, attenuation is of the order of 0.1 dB / wavelength. In addition to the above assumption the reflection of the feeder due to the elements is neglected in the above analysis. In the following a new design approach overcoming the shortcomings of the above procedure is developed.

DESIGN APPROACH

Consider a circuit where the radiating element shunt periodically a lossy feeder line. Let $P_1, P_2, P_3, ...P_n, ...P_{n+1}$ be the required power distribution of the linear array. Let P_{n+1} be the power dissipated in either the matched load of an N-element traveling-wave array or the last element of an (n+1)-element resonant array. The shunt conductances required to achieve the given power distribution may be found by any optimization procedure. Therefore let $Gr_1, Gr_2, ...Gr_n, ...Gr_{(n+1)}$ be a set of conductance values for the elements, and the corresponding power distribution evaluated as $P'_1, P'_2, P'_3, ...P'_n ... P'_{n+1}$. The optimization is completed when the normalized mean squared error defined as:

$$\epsilon = \sum_{n=1}^{N+1} \left(\frac{P_n - P'_n}{P_n} \right)^2$$

is a very small quantity.

Refering to figure 1 the power absorbed by the nth element, the feeder and all the elements to the right of it is Q_n:

$$Q_n = \frac{1}{2} G_f /V+/^2 (1-/\rho_n/^2)$$

Where G_f is the characteristic conductance of the feeder and $\rho_\eta = V_\eta^- / V_\eta^+$ is the reflection coefficient of the feeder at the location of the nth element. Excluding the power P'_n absorbed by the nth element Q_n is given by:

$$Q_n - P'_n = \frac{1}{2} G_f /V^+_{n+1}/^2 e^{2\alpha\lambda_f} (1-/\rho_{n+1}/^2 \; e^{-4\alpha\lambda f})$$

Where α and λf are the attenuation constant and wavelength of the feeder respectively. From (3) and (4) it is apparent that the power radiated by the nth element is:

$$P'_n = G_f [/V_n/^2 (1-/\rho_n/^2) - /V_{n+1}/^2 e^{2\alpha\lambda_f} (1-/\rho_{n+1}/^2 e^{-4\alpha\lambda f})] re_n$$

Where re_n represents the radiation efficiency of the nth radiating element and the recurrence relation for the reflection coefficients is given by:

$$\rho_{n+1} = \left[\frac{1 - \frac{Gr_n}{G_f} - \frac{1-\rho_n}{1+\rho_n}}{1 - \frac{Gr_n}{G_f} + \frac{1-\rho_n}{1+\rho_n}} \right] * e^{2\kappa\lambda f}$$

The above expression is derived by noting the input conductance at the location of the nth element. Also a recurrence relationship for the incident voltages at the element locations is obtained by noting that continuity of voltage holds for a shunt loaded transmission line:

$$/V^+_{n+1}/ = \frac{/V^+_n/ \; /1+\rho_n/}{/1+\rho_{n+1} e^{-2\alpha\lambda f}/ e^{\alpha\lambda f}}$$

Choice of initial values for ρ and $/V^+/$ depend on whether the array is of the resonant or travelling wave type.

A simplex optimization procedure is utilized to obtain final conductance values of the elements. The initial values are obtained by the simplified procedure described here where the ohmic and dielectric losses in the array are neglected. The simplex routine optimization method was used to evaluate the radiation conductance values of 19 element resonant array with power following the chebycheff distribution. The two sets of normalized radiation conductances obtained by the simplified (loss-free array) and the complete analysis are given in figure 2. The second set of conductances is used to calculate the power distribution from the complete circuit analysis, then the radiation pattern of the array is evaluated. The rise in the sidelobe level may be as much as 6 dB. The radiation pattern of a 9-element resonant array, where the elements follow a chebycheff distribution and expect side-lobe level as low as -28dB gives no better than -24dB if in the design analysis a loss free model is considered.

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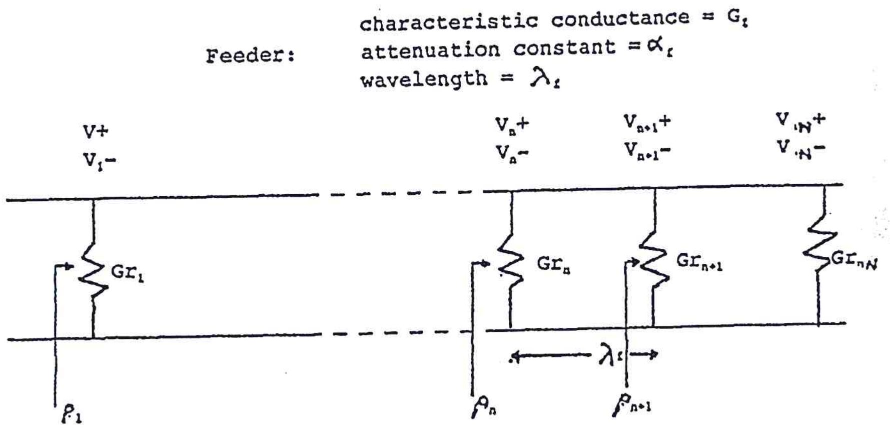

Figure 1: V_n+ = incident voltage at nth element
V_n- = reflected voltage at nth element

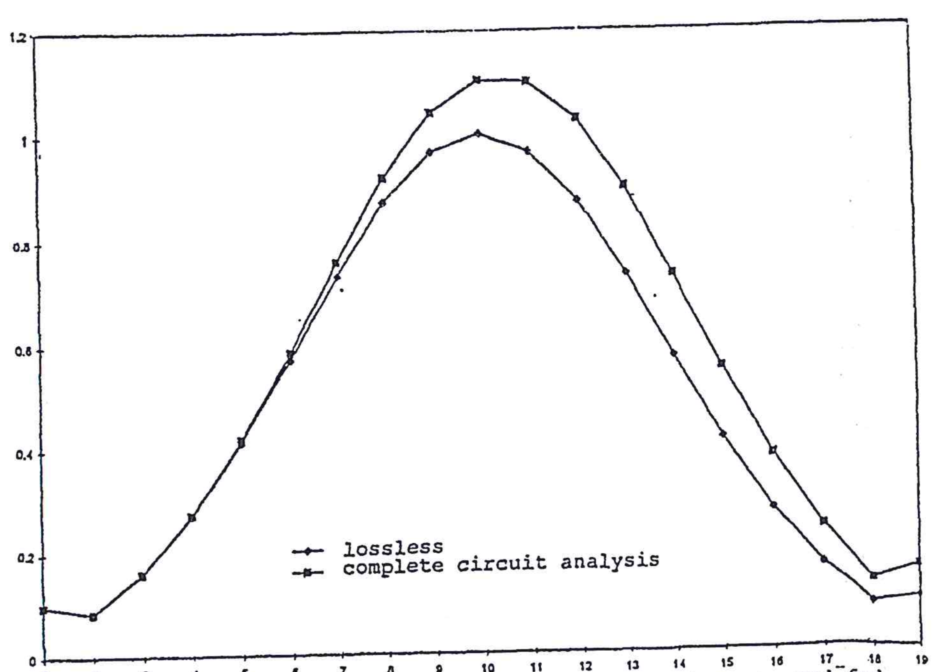

Figure 2: Sets of normalized conductances of 19 elements, end fed array, showing the deviation of the values obtained from a lossless and a complete circuit analysis.