ARRAY OF HIGH DIRECTIVE ENDFIRE ELEMENTS

Harish A.R. and M. Sachidananda
Department of Electrical Engineering
Indian Institute of Technology
Kanpur - 208 016 India

1 Introduction

Printed planar arrays using microstrip or stripline feed is very attractive at higher microwave frequencies because of low profile, low cost, ease of fabrication, light weight etc. As the frequency of operation increases, the physical space between the elements decreases, but the width of the feeder line for a specified characteristic impedance remains same. Therefore, the space available for the feeder network is reduced. Due to the decreased space between the elements, the interaction of the feeding lines with the radiating elements and the coupling between the feeding lines has to be taken into account while designing the antenna array. In a practical array it is necessary to make space for the feeder lines, which essentially involves increasing the spacing between elements. The result of this would be a lower aperture efficiency and appearance of grating lobes when the spacing is greater than about a wavelength. In this paper, we consider arrays with inter-element spacing greater than one wavelength. This reduces the number of elements in the array for a given aperture size, as well as enough room for the feed lines. To compensate for the decrease in aperture efficiency, higher directive endfire elements are used as radiators and the grating lobes are suppressed via appropriate element pattern.

In the arrays of high directive elements addressed by many authors [1..4], the inter-element spacing is less than a wavelength to keep the grating lobes out of visible region. High directive elements have been used only to improve the aperture efficiency. Yen [5] gives a qualitative description of suppression of grating lobes by placing the nulls of the element pattern in the direction of grating lobes.

In this paper, a technique of suppressing the grating lobes has been presented, and is useful for antenna arrays operating in the frequency range of 15-30GHz.

2 Array Design

The array pattern is a product of array factor and the element pattern. In an array of dipoles or slots, the element pattern is assumed to be isotropic and the final pattern depends only on the array factor. The conventional design is aimed at deciding the excitation coefficients so that the array factor meets the design goals.

When the inter-element spacing is greater than a wavelength, the array factor has grating lobes in the visible region. By a proper choice of the element pattern, the final pattern can be designed so that the radiation in the direction of grating lobe is within the acceptable limits. The element is so chosen that it also has the necessary directivity, so that the overall aperture efficiency does not deteriorate.

To get an insight into the array design procedure, consider an array of 8 isotropic elements, spaced 1.15λ apart. The elements are excited to generate a Taylor pattern of -20dB sidelobe level. As the inter-element spacing is greater than 8/9 wavelength, grating lobe appears in the visible region (Fig.1). The array meets the design specifications of -20dB sidelobe level, if the grating lobe appearing between 50° and 90° can be suppressed by a proper choice of element pattern.

This can be achieved either by using a small array of dipoles or slots (sub-array) or by using high directive element radiating in the endfire direction as array elements. The radiation pattern of the sub-array can be controlled by changing the excitation coefficient of the individual elements of the sub-array. However, the problem of feeding the elements of sub-array is the same as the original problem we sought to address in this paper. Therefore, the choice of element is limited to endfire type which can give higher directivity while occupying space in front of the array.

The High Directive Endfire element (HiDE element) is a high directivity antenna radiating in the endfire direction with a capability to shape the radiation pattern. HiDE element can be an array of serially fed dipoles radiating in the endfire direction, Yagi-Uda array, Log-periodic array, helical antenna, dielectric rod or a horn antenna. These structures have a single feed point. The radiation pattern of these elements can be shaped according to the requirement by modifying the geometry of the structure and the excitation coefficients.

Literature available on most HiDE elements is oriented towards maximising the endfire gain. The HiDE element for the array configuration under consideration must have capability to shape the radiation pattern. In order to achieve this, it may be necessary to sacrifice certain amount of endfire gain. Therefore, the element design criteria is different from the usual endfire element design.

The feed arrangement of the HiDE element used in the array under consideration may be different from the conventional feed configuration. This is necessary to facilitate a transition from the microstrip/stripline feed used to excite the planar array. The HiDE elements project out of the plane containing the feed network. Though this projection is couple of wavelengths long, in 15-30GHz frequency range this amounts to few centimetres. Therefore, this is not a very serious disadvantage.

In this paper, as a specific example, an array of dipoles radiating in the endfire direction has been used to demonstrate the grating lobe suppression.

3 HiDE element Design

The HiDE element used to demonstrate the concept of grating lobe suppression is a linear array of printed dipoles kept in front of a reflector and radiating in the endfire direction. The dipoles, if printed on either side of a dielectric substrate, can be fed in shunt by a two-strip transmission line. The radiation pattern of the array can be shaped by changing the excitation coefficient of each of the dipoles. To establish the required excitation on the dipoles, it is necessary to use matching structures like transformers and stubs. Since the radiation is in the endfire direction, the spurious radiation from the matching sections interact with the dipoles and is very difficult to predict this interaction. It is, therefore, necessary not to use any matching structures with discontinuities in the feeding network to establish the currents on the dipoles. The only variables under control, viz., the dipole lengths and the inter-dipole spacing, can be used to design the array. This restricts the current distribution which can be established on the dipoles. Therefore, a slightly modified design methodology is followed to design the HiDE element.

The design starts by assuming certain dimensions for the dipoles and the inter-dipole spacing. With this initial condition, the currents on the dipoles and hence the radiation pattern is computed. The dimensions are adjusted iteratively till the desired pattern is obtained. The desired pattern should have a peak sidelobe below the design value in a specified range of angles ($50° - 90° forthisproblem$). The task at hand is to analyse the array of certain dimensions and compute the cost function, which is the peak sidelobe level in a specified range of angles.

Admittance matrix approach is used to analyse the array. The reflector is replaced by N image dipoles by invoking image theory. An admittance matrix is written for the system of 2N dipoles. The elements of the admittance matrix are obtained by carrying out measurements on the dipoles fed by two strip transmission line. The feeding line is now introduced into the system by connecting the corresponding feed line admittance matrices in between the dipoles. Upon enforcing the current continuity at each of the nodes, we arrive at a matrix equation, whose solution yields the voltage at all the nodes from which the current into each dipole and hence the cost function can be computed.

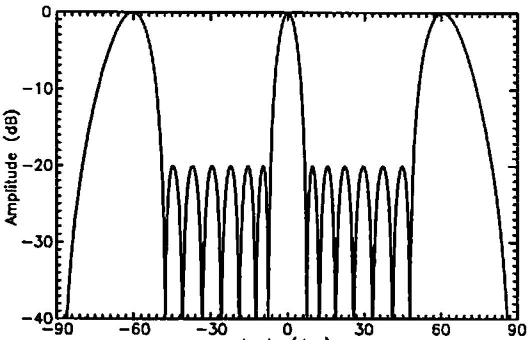

Fig. 1 Computed Radiation pattern of array of 8 isotropic radiators spaced 1.15λ apart.

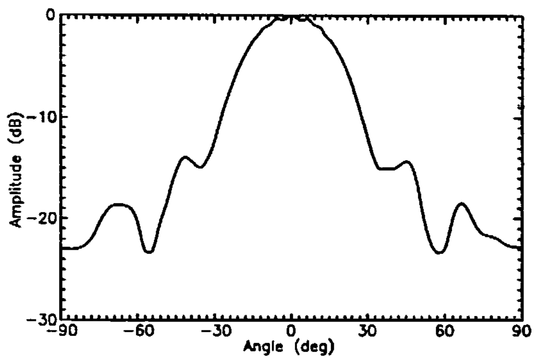

Fig. 2 Measured E-plane Radiation pattern of HiDE element. Frequency of operation: 15GHz. HiDE element: endfire array of 4 dipoles.

A HiDE element operating at 15GHz having a peak sidelobe of -20dB between 50° – 90° is designed with $0.7mm$ wide dipoles printed on either side of a $0.8mm$ thick substrate with 2.2 dielectric constant. After carrying out the design, it was found that 4 dipoles, with inter-dipole spacing of $8.5mm$, kept in front of a reflector, having lengths $8.4mm$, $8.0mm$, $8.0mm$, $8.4mm$ yield a peak sidelobe level of -23dB in the desired direction. An open circuit stub is used to match the array to a 100Ω two-strip transmission line. A smooth balun is used to transform 100Ω two-strip line into a 50Ω microstrip line. Since the matching stub and the balun are placed behind the reflector, they do not interfere with the dipoles, and hence the pattern is not affected. Fig. 2 shows the E-plane pattern of the HiDE element.

4 Array of HiDE elements

Comparing Figures 1 and 2, we find that the HiDE element can be used to suppress the grating lobe of the 1.15λ spaced 8 element array. Corporate feeding network in microstrip configuration is designed to excite the 8 elements with Chebyshev excitations. Since the entire feed network is situated behind the reflector. this does not interfere with the main radiation. Fig. 3 shows the E-plane pattern of the array of HiDE elements.

5 Conclusions

The feeding problems of printed planar arrays working in the range of 15-30GHz has been addressed in this paper. Due to lack of space between the elements, the layout of feed line for such an array becomes difficult. By increasing the interelement spacing, it is possible to accommodate the feeding network. This approach results in a different kind of problems viz., appearance of grating lobes and reduction in aperture efficiency.

The grating lobes in the array factor are allowed to enter the visible region. These are suppressed to the desired levels by properly shaping the element pattern. The aperture efficiency is improved by using high directive elements to construct the array.

The design of element pattern and array factor depend of each other. Therefore, the design procedure should make use of the flexibility available in both the patterns. Since the elements are widely spaced, the mutual coupling between the elements may be neglected [4].

In this paper a linear array of dipoles has been used as HiDE element to demonstrate the practicality of shaping the element pattern and hence the suppression of grating lobes in the final pattern. A method has been proposed to design the feed lines to the dipoles in the HiDE element to obtain the required element radiation pattern.

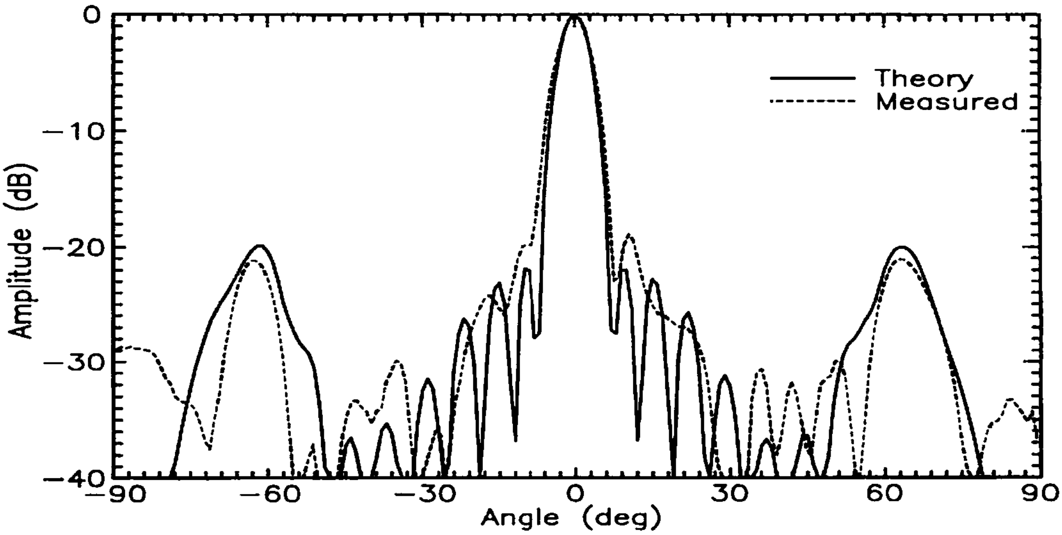

Fig. 3 E-plane radiation pattern of 1.15λ spaced array of 8 HiDE elements.

6 References

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