CALCULATION OF IMPEDANCE VARIATIONS AT THE TRANSCEIVERS IN ELECTRONICALLY BEAM-STEERED ACTIVE LENS ANTENNAS FOR SPACE BASED RADAR

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Summary

Design specifications require estimates to be made of the impedances presented to the monolithic microwave transceivers being investigated for use in electronically beam-steered active lens antennas for space based radar systems. A method of calculation is explained and applied to active lenses composed of large planar arrays of dipoles on either side of a screening plane upon which the transceivers are mounted and connected by parallel wire lines to the dipoles.

Introduction

Much of the current stimulus for developing technology for fabricating monolithic microwave integrated circuit modules (MMICM) arises from proposals for building space based radars that would use large numbers of these modules in high gain active lens-type antennas. Such an antenna, as shown in Figure 1, would be composed of a focal-region phased-array of dipoles feeding an active lens formed of a planar-array of dipoles on either side of a screening plane upon which MMIC transceivers would be placed equal in number to the dipoles in each array and connected by parallel wire lines at input and output to the dipole elements. The transceivers incorporate a phase shifter which can be set under microprocessor control as shown in Figure 2, to yield beam formation in a desired direction relative to the physical axis of the antenna structure.

Design specifications for these transceivers include the impedances presented at each port as a function of such factors as the position of the module relative to the axis of the lens, the beam-steering angle, the beam shape and the mode of operation (transmit or receive). The insertion phase of the module, and to a lesser extent its amplification is affected by mismatch between the module output and its load impedance and the module input and its source impedance.

The problem of determining these impedances in large aperture structures has been solved by first identifying realistic simplifications in an otherwise large and complex assembly and then using solutions for infinite uniform arrays of dipoles.

The results of this solution can be used to calculate antenna patterns and their dependence on beam-steering or to design adjustable matching structures in the MMICM's so that mismatch effects are automatically kept within desired limits.

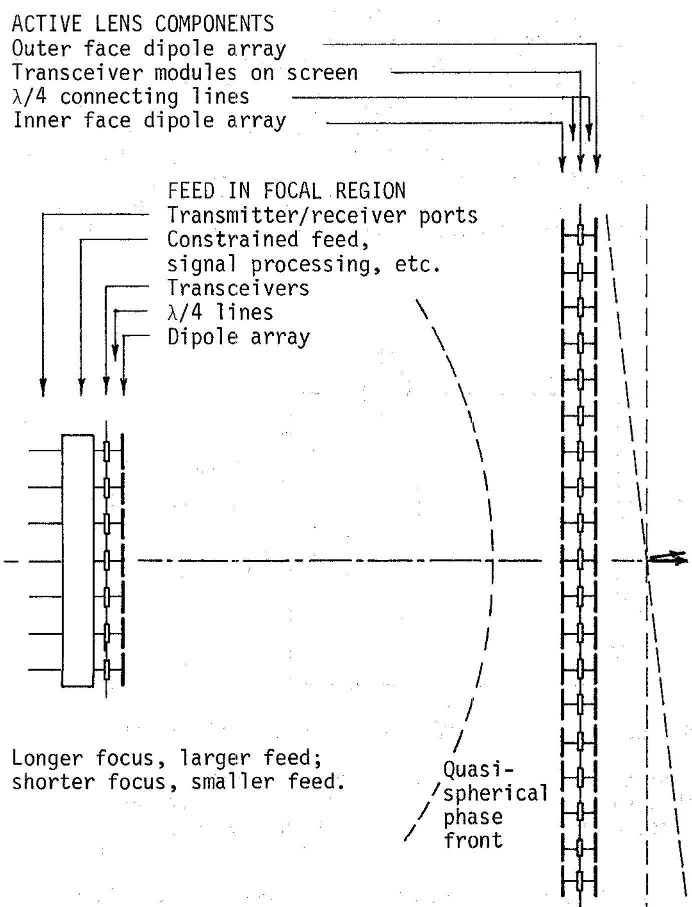

Figure 1. Schematic of a space-fed active phased-array lens antenna (SFAPALA).

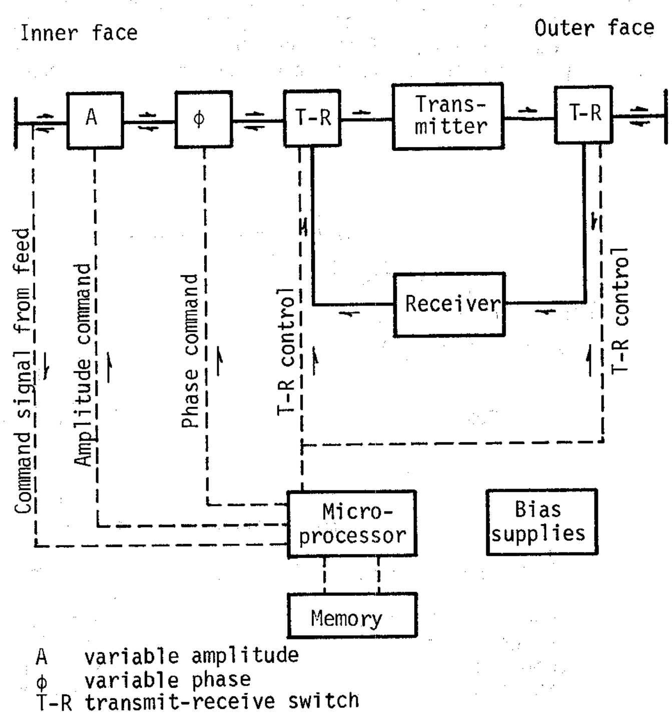

Figure 2. Block diagram showing monolithic microwave integrated circuit module (MMICM) functions when used in an active lens antenna element.

Impedance behaviour of the active lens

Transmit mode, inner face.

In Figure 1 for the transmit mode the angle of incidence of the excitation wave from the feed onto the inner face of the lens increases with the distance of the lens element from the antenna system axis. The group of dipoles near the axis will receive waves created by the feed from the broadside direction. The MMICM input matching structure will probably be designed so that the signal from each dipole that is close to the axis is absorbed without reflection. The mutual coupling effects amongst these dipoles will be governed by the fact that excitation from the feed comes from the broadside direction and is therefore in-phase for all dipoles of significance. The lenses envisaged for space based radar applications may be a hundred or more wavelengths in diameter and for qualitative discussions and quantitative calculations may be regarded as infinite arrays. Specific to such large arrays is the feature that phase and amplitude changes per element spacing are quite small for all realistic types of excitation and sufficient elements to take account of mutual coupling effects can be grouped and associated with a reasonable approximation to a plane wave. Thus groups of dipoles at various distances from the antenna axis can be selected and their effective impedances calculated assuming incident excitation waves at angles from broadside corresponding to the angle at which the feed array sees the group of dipoles. The effective source impedance of the dipoles will change with distance from the axis and a radially graded mismatch results. No previous reference to this effect in active lens antennas has been found in the literature.

Transmit mode, outer face.

The outputs from the MMICM's are fed to the inputs of the dipoles on the outer face of the lens. Amplitude and phase changes per element spacing would be small enough for each dipole to experience approximately the same coupling effects and therefore exhibit the same input impedance. That impedance will be a function of the angle from broadside to which the transmitted beam is steered. The matching network between the final power amplifier and the dipole in each module would probably be designed for a match when all elements are fed in phase for a broadside main beam.

Receive mode.

In the receive mode the role of the dipoles on either side of the lens and in the feed is reversed and the amplifier in the module is changed to a low noise receiver. Similar realistic simplifications are possible. For example the array of dipoles on the inner face of the lens focuses the received signals in a fixed way onto the feed array. The elements of the inner face array near the axis have to be fed in phase so that they radiate broadside along the axis to the feed. By contrast a group of elements near the edge of the inner face array have to be fed with a linear phase gradient designed to steer the beam by the angle from broadside that is sufficient to direct it at the feed. The mutual coupling effects for the edge group will be different from those for the near-axis group and therefore the load impedance presented by the dipoles to the MMICM's will vary with distance from the antenna axis. This is similar to the effect identified in the discussion of the transmit mode of operation.

Equivalent circuit of active lens element

We can set down the equivalent circuit of Figure 3 to represent a lens element when transmitting and a similar circuit when receiving. The inner face element is associated with quasi-spherical waves to and from the focal region and the calculation of the mutually induced voltages must take account of this. The outer face element on the other hand is associated with plane waves to and from targets in the radar case, and therefore the calculation of the mutually induced voltages will be different from that for the inner face element. Equivalent circuits for the dipole to transmission line terminal regions are shown followed by quarter-wave long parallel wire lines connecting the dipoles to the ports of the MMICM. Despite the

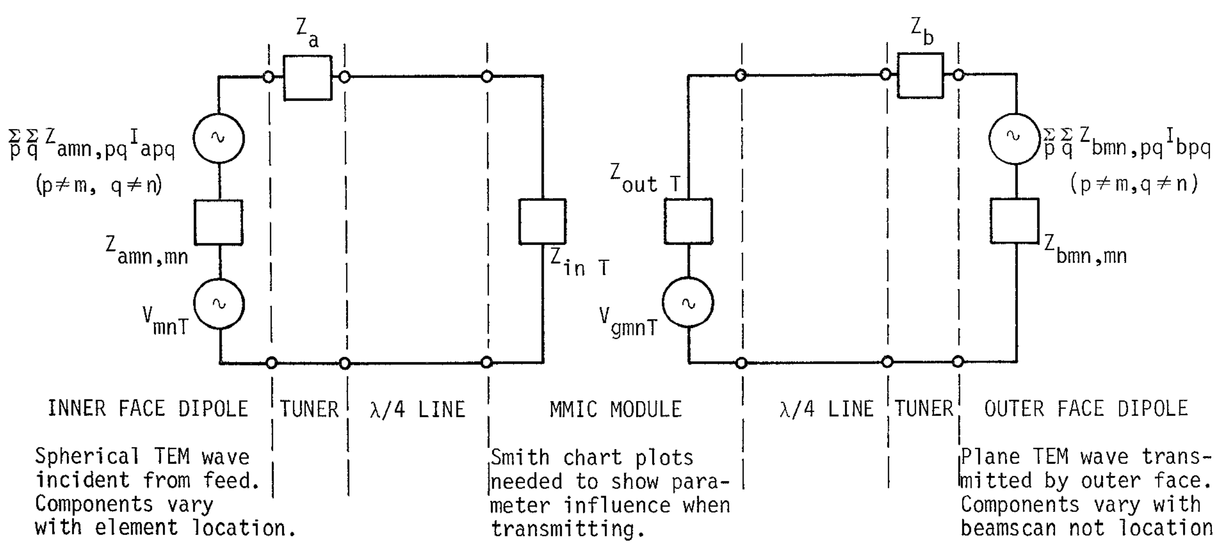

Figure 3. Network representation of a typical element (mn) of an active lens when transmitting

internal complexity expected in the modules and the likely dependence of behaviour on operational parameters, for the purposes of estimating phase and amplitude errors due to mismatch effects the module is represented by an input impedance and an equivalent output source and output impedance.

Because of the opportunities that exist for calculating dipole impedances using the work of Stark[1], behaviour at the dipole terminals, not the module terminals, will be discussed in detail below. Mismatch then refers to the impedance presented by the dipole in its phased array environment compared with the impedance seen looking at the module termination through the terminal region equivalent circuit and the transmission line.

The radiation impedance of a dipole in an infinite uniform planar phased array for an angle of beam-maximum relative to the broadside direction has been evaluated by Stark[1] and resistance and reactance components are shown in Figure 4 as a function of scan angle in E-, H- and D- (diagonal) planes. a and b are the dipole element spacings in the plane of the array and s is the distance to the ground screen.

Calculation of impedance variations at the transceivers

The significance of these results is best understood by reference to the lens element equivalent circuit of Figure 3. The impedance of the dipoles associated with either transmitted or received waves of either planar or quasi-spherical TEM form is represented by a self-impedance component, e.g. $Z_{amn,\,mn}$, together with (N_T-1) voltage generators, e.g. $\sum_p \sum_q Z_{amn,pq} I_{apq}$ with $p \neq m$ and $q \neq n$. The graphical results of Figure 4 are effectively these equivalent circuit components subject to assumptions that are a close approximation to the conditions that prevail in the large but finite active lens adopted for studying module design problems. The impedance presented to the transceiver by the inner face dipoles is obtained from Figure 4 by interpreting the scan angle as the angle θ_1 subtended by an inner face dipole P at the focal point F_1 of the lens as illustrated in Figure 5. This impedance is a function of distance OP. The impedance presented to the transceiver by the outer face dipoles is also obtained from Figure 4 by interpreting the scan angle conventionally as the angle relative to the antenna axis at which the main beam is steered.

Reference

1. Stark, L., "Radiation impedance of a dipole in an infinite planar phased array", Radio Science, 1 (new series), 361-377, 1966, March.

Acknowledgement

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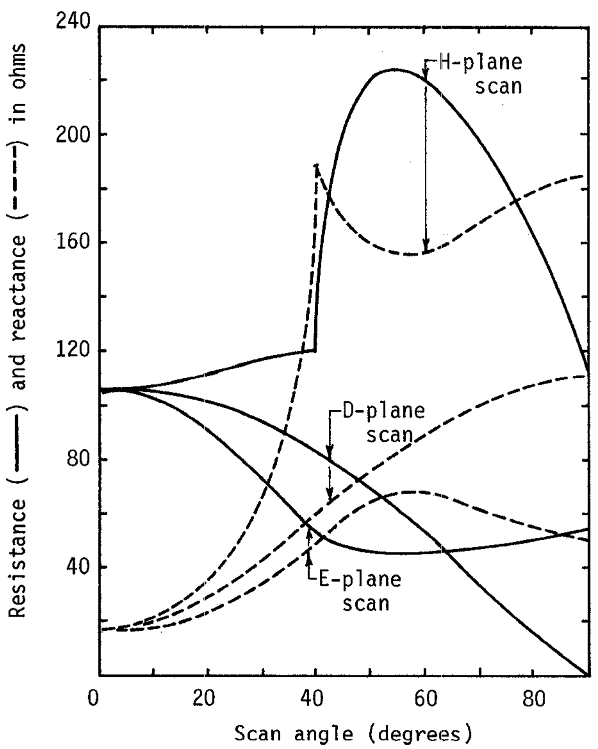

Figure 4. Element driving impedance versus scan angle for an infinite planar phased array of λ/2 dipoles. a=b=0.6λ, s=0.25λ.

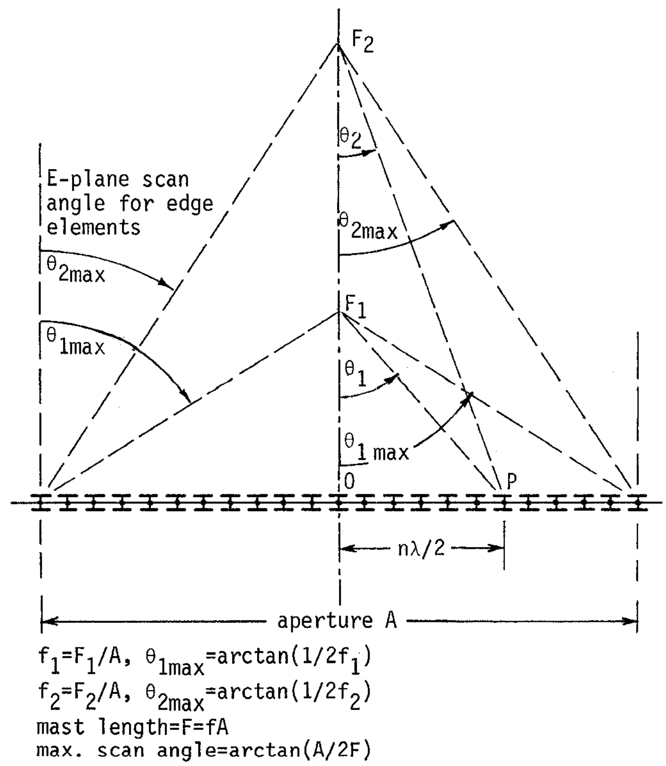

Figure 5. Inner face dipole position P can be measured as a scan angle θ_1 or θ_2 at the feed position F_1 or F_2.