MILLIMETRE-WAVE INSULAR GUIDE FREQUENCY SCANNED ARRAY

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Abstract

The paper describes the design construction and experimental evaluation of a novel frequency scanning linear array. Dielectric image-line is used to provide a compact low-loss feed network which is integrated with dielectric-rod antenna radiators to produce arrays which are well suited for applications at frequencies above 20GHz.

Introduction

With the present upsurge of interest in the millimetre-wave band many system applications have been identified which could benefit from an application of the low-cost, lightweight features of integrated-circuit techniques. The high fabrication costs and special problems associated with scaling microstrip microwave circuits to operate at these frequencies has led to the investigation of alternative guiding structures and the emergence of millimetre-wave image-line integrated circuits (MILIC). This paper examines the feasibility of applying "insular guide"[1] (a variant of the MILIC technology) to low-loss feed networks, where the highly dispersive nature of the transmission lines may be exploited to produce compact frequency-scanned arrays.

A cross-section of a typical insular-guide transmission line is shown in Figure 1. It consists of a rectangular high permittivity (ε_r = 10 - 100) line separated from a metal ground plane by a thin layer of low permittivity material. This layer serves a dual purpose in that it both reduces conductor losses in the ground plane and eases fabrication tolerances. A theoretical model[2] has been developed which predicts the dispersion characteristics of such structures and provides the necessary data for ensuring single-mode operation and designing passive components such as directional couplers and ring filters. In general, good correlation has been observed between theory and experiment with individual components[3,4]. Here attention is focused on investigating the feasibility of the technology to produce somewhat more complex systems such as the frequency-scanned array[5].

System description

The frequency-scanned dielectric linear-array concept is illustrated in Figure 2. Alternate dielectric-rod radiating elements are fed from the main insular guide transmission-line via proximity-line directional couplers. The array circuit is repeated on the reverse side of the ground plane and each array half is excited from a waveguide input with an E-plane power splitter, which is integrated into a pair of standard horn-type surface-wave transducers (not shown in the figure). This arrangement was chosen to accommodate the directional couplers (whose radii of curvature are limited to prevent excessive radiation from the curved sections) while maintaining the close element spacing necessary in wide-angle scanning arrays. The incorporation of directional couplers in the feed network is required to avoid the build-up of large mismatches in the main feed-lines as the beam is steered through broadside. To facilitate construction the curved sections are identical in shape and the required amplitude aperture distribution is established by adjusting the line spacing at each directional coupler position. These spacings are predetermined using a computer-aided design procedure for the couplers.

The particular example shown in Figure 2 was a design exercise performed for an array operating at a nominal frequency of 20GHz with a half power beamwidth of 5°. If a high permittivity material such as Barium Tetratitanate (ε_r = 37, tan δ <.0005) is employed, the insular guide is highly dispersive and, for the network shown in Figure 2, a scan sector of $\pm$ 30° can be attained with a $\pm$ 5% frequency bandwidth. The associated feed loss would be in the region of 2dB. A comparable system in microstrip would require a meander feed line to obtain the above frequency sensitivity, with feed losses typically of the order of 15 - 20dB. Thus the low-loss characteristics, compact form and potential low-cost combine to make the insular-guide approach extremely attractive.

Experimental array section

An eight-element array section which retains the essential features of the full array has been constructed for operation about a centre frequency of 30GHz. An outline drawing of the layout is presented in Figure 3. In the first prototype the directional coupler dimensions were computed to provide uniform excitation of the radiating elements. To simplify fabrication and testing, each half of the array was mounted on a separate base plate. The material used for the dielectric guides was Custom Material's High-K 707L, which is a styrene-based ceramic which is machineable and more readily lends itself to laboratory-prototype work than true ceramic. It has, however, a lower dielectric constant (approximately 10) and higher loss tangent than Barium Tetratitanate, which results in a reduction in the achievable scanning range and increased feed losses. The insular-guide lines were accurately positioned with the aid of locating jigs which are relatively easy to construct, because of the periodic nature of the feed network. The structure was bonded together with a thin polyethelene film which also serves as the insulating layer.

Figure 4 shows the radiation-pattern of one half of the array at the broadside frequency of 29.25GHz. Excellent correlation may be noted between theory and experiment. In Figure 5 the radiation pattern of the complete eight element array is presented. The higher sidelobe levels are attributed to small distortions in the styrene-based material. These distortions arose during fabrication, and result in different phase tapers in the two halves of the array. In Figure 6 sample radiation-patterns are shown over a ± 5% frequency bandwidth. As expected there is an increase in side-lobe level as the beam is steered away from broadside. This effect is associated with the shape of the element radiation pattern and the onset of grating lobes. In a full array the performance may be improved by tapering the aperture distribution and decreasing the element spacing. The variation of scan-angle with frequency is plotted in Figure 7. It can be seen that a uniform scan characteristic is obtained with a shift in centre frequency, and a small change of slope, due to the fabrication errors described above.

Work is now proceeding with a second array employing a tapered aperture distribution to provide improved sidelobe suppression. Improvements are being made to the line locating jigs to eliminate the distortions noted in the first array, and alternative directional coupler configurations are being examined to further compact the feed network.

Conclusions

The prototype array section described, demonstrates the feasibility of the Insular-guide technology for use in small frequency-scanned arrays. A uniform scan performance more than $\pm 20^{o}$ was obtained with a 10% frequency bandwidth, a performance which is unlikely to be matched using alternative technologies without considerable added complexity. The results obtained also suggest that the technology may have applications for other array configurations operating at frequencies above 20GHz.

References

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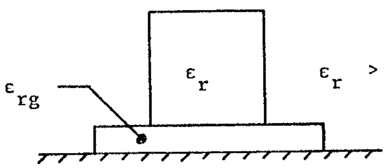

Fig 1. Typical cross section of insular guide

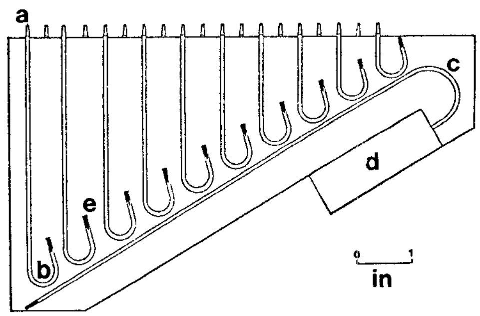

Fig. 2 19 element K band frequency scanning array
a - dielectric rod antenna
b - proximity line coupler
c - main feed line
d - input unit
e - matched load

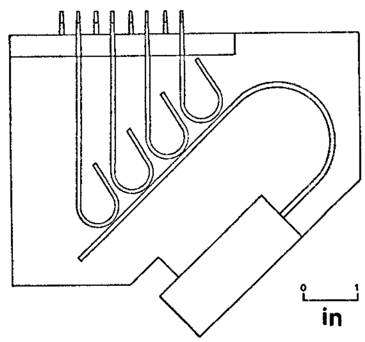

Fig 3 8 element prototype array section

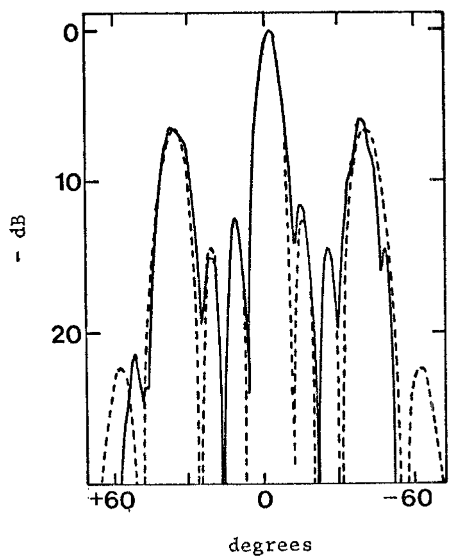

Fig 4. H plane radiation pattern of one half of the array. f = 29.25GHz
—— experiment - - - - - theory

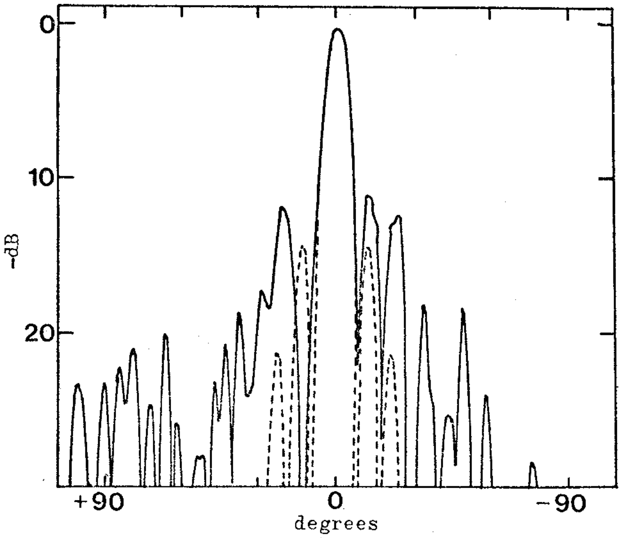

Fig 5. H plane radiation pattern of complete array. f = 29.25 GHz

——— experiment ----- theory

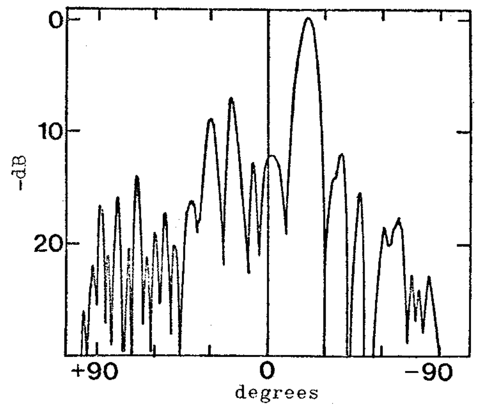

Fig 6. (a) H plane radiation pattern of complete array. f = 27.75GHz

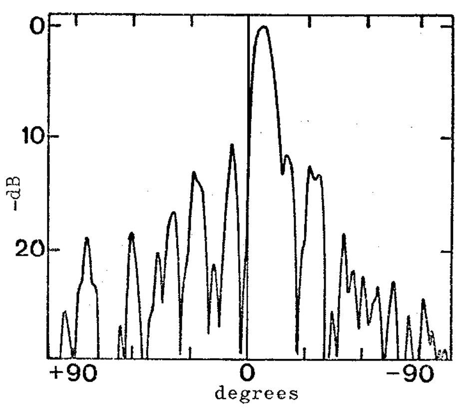

Fig 6. (b) H plane radiation pattern of complete array f = 28.5GHz

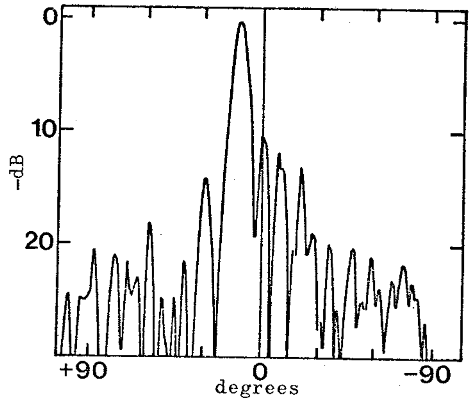

Fig 6. (c) H plane radiation pattern of complete array f = 30.0GHz

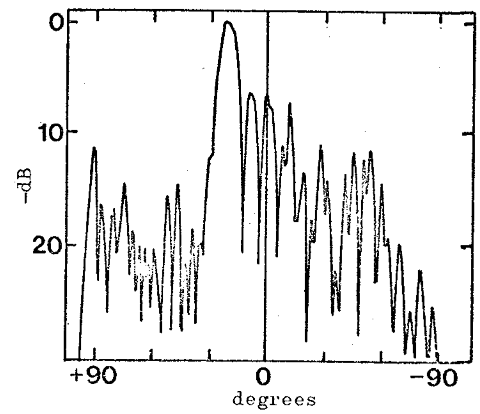

Fig 6. (d) H plane radiation pattern of complete array f = 30.75GHz

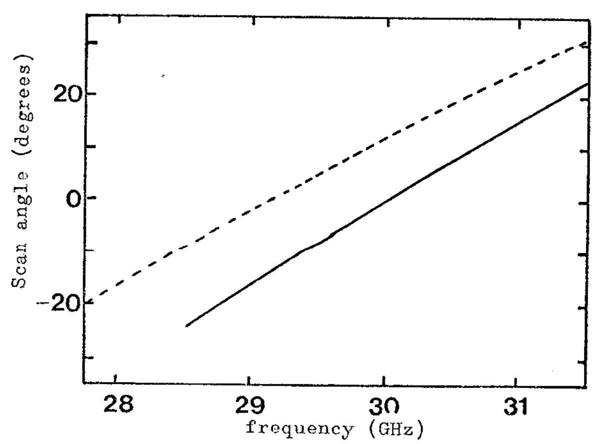

Fig 7. Scan angle versus frequency

——— predicted ----- experiment