VARACTOR CONTROLLED SCANNING MICROSTRIP TRAVELLING-WAVE ARRAY

J. R. James*, G. Evans*, A. Henderson* and A. Fray†.

* Royal Military College of Science, Swindon, Wiltshire SN6 8LA, England.

† Royal Signals and Radar Establishment, Great Malvern, Worcs, WR14 3PS, England.

INTRODUCTION

Much of the research in antennas today is directed towards highly sophisticated phased arrays [1] but there is also considerable interest in simpler techniques offering limited beam scanning but possibly lower costs along with other advantages. The utilisation of ferrite material for electronically controlled beam scanning continues to be investigated [2, 3] but progress here is also dependent upon the development of improved ferrite material. In this present paper a novel approach is investigated which relies on the varactor diode control of a microstrip line designed to serve the dual role of phase shifter and feeder for the microstrip array. Such a dual role is possible for microstrip travelling-wave arrays, Fig 1, having a central microstrip line feeder [4]. This present paper highlights some of the main factors arising from this new beam scanning technique and although the computed and measured results are confined to comb-line and electromagnetically coupled patch-arrays, the principles could be extended to other travelling-wave antenna types as in Fig 1.

MICROSTRIP PHASE-SHIFTER CONFIGURATIONS

The deployment of switching diodes in circuits and lines to produce phase shifters is well known [5, 6] but in the present application we are seeking continuous control brought about by the variable capacitance of a varactor diode. Parasitic components associated with the diode package need to be allowed for along with the dissipative losses in the diode.

There are numerous ways of arranging the diodes in a line to trade-off phase-shift, loss and bandwidth but for this antenna application we choose the simple configuration, Fig 2, with the radiating elements coupled in some way at approximately $\lambda_g/4$ to $\lambda_g/2$ intervals, where λ_g = line wavelength. The diode package elements and generalised line equivalent circuit are given in Fig 3. If the diodes are spaced approximately $\lambda_g/4$ then G_R (the microstrip radiation conductance) will typically be coupled in every $\lambda_g/2$. Under certain conditions twice the number of radiating elements will be used at $\lambda_g/4$ spacing [ref 4, pp 119-123]. The generalised equivalent circuit in Fig 3b embodies the action of the different types of travelling-wave antennas in Fig 1 under varactor feed control but in order to design each case the appropriate element coupling parameters must be established. It is instructive however, to show results in Fig 4 for the circuit in Fig 3b for a commercially available diode and an assumed G_R. The relative excitation phase and amplitude at each element or node are given as a function of control bias. In this case C_V varies from 0.4 to 1.8 pF and 25^o phase shift is obtained with a variation along the array of about $\pm 6^o$. Over this range the array efficiency varies from 60.4% to 48.8%. Computations for higher capacity diodes show a greater phase shift but at the expense of lower efficiency and less uniformity in the excitation along the array.

This simple model also gives important details about the bandwidth of the scan system. In practice the coupling of the radiating elements to the line would be designed for a desired aperture distribution. An experimental result, Fig 5, illustrates the scanning concept and utilises diodes having larger capacity which necessitates a low impedance feeder line. A dissipation loss of 2 dB is assessed on scanning and this together with mismatch losses are evident in Fig 5.

COMPUTED PERFORMANCE OF COMB ARRAY

The precise performance of a varactor controlled array depends to a large extent on parameters such as the element coupling to the line and to some extent on mutual effects. The comb-line linear array has been extensively modelled [4] and we use these parameters here to illustrate pattern behaviour, scan and loss, in Fig 6. A 30^{0} beam scan is predicted without excessive pattern corruption but a lower capacitance diode would result in more practical values of stub width.

CONCLUSIONS

The concept of varactor phase control along a microstrip line feeding a travelling-wave antenna has been demonstrated. A variety of arrangements are possible but the major design issue is increased dissipative loss and our findings to date indicate that a beam scan of 20^{0} is feasible for a loss of 3 dB. The embedding of the varactors in the line requires a substrate of compatible thickness if additional parasitic series inductance is to be avoided and overlaid patches offer more design freedom than other configurations. The exploitation of other types of diodes is under consideration together with possible limitations due to harmonic generation and additional noise due to the diode dissipation. These effects are application dependent.

ACKNOWLEDGEMENTS

This research programme was partially funded by RSRE, Malvern, UK.

REFERENCES

[1] James, J. R., "What's new in antennas", *6th Proc. Int. Conf. Antenna and Prop.*, Warwick, 1989.

[2] Henderson, A., James, J. R. and Fray, A.: "Magnetised microstrip antenna with pattern control", *Electron. Lett.*, Vol 24, No 1, Jan 1988, pp 45-47.

[3] Maheri, H., Tsutsumi, M. and Kumagi, N.: "Experimental studies of magnetically scannable leaky-wave antennas having a corrugated ferrite slab/dielectric layer structure", *IEEE Trans. AP-6*, No 7, July 1988, pp 911-917.

[4] James, J. R., Hall, P. S. and Wood, C.: "Microstrip antenna theory and design", (*Peter Peregrinus Ltd.*, London 1981), Chapter 5.

[5] Garver, R. V.: "Broadband diode phase shifters", *IEEE Trans. MTT-20*, No 5, May 1972, pp 314-323.

[6] Wilson, K., Nicholas, J. M. C., McDermott, G. and Burns, J. W.: "A novel MMIC X band phase shifter", *IEEE Trans. MTT-33*, No 12, December 1985, pp 1572-1578.

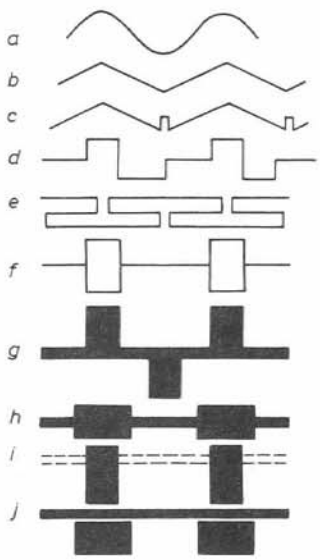

Fig 1: Travelling-wave array microstrip antennas: (a) serpent (b) triangle (c) CP chain (d) rampart (e) Franklin (f) LP chain (g) comb (h) series patch (i) overlaid patch (j) coupled patch.

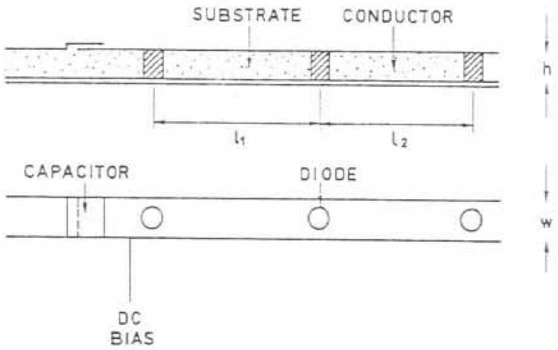

Fig 2: Elevation and plan views of microstrip line with varactor diodes embedded with spacing l_1 or l_2 together with control voltage connection and blocking capacitor.

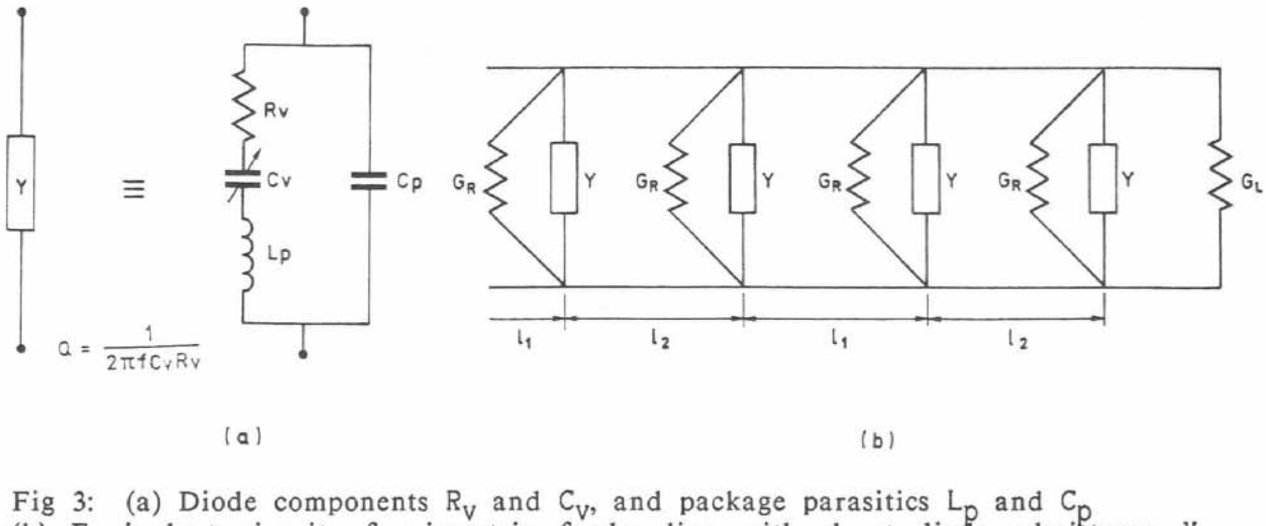

Fig 3: (a) Diode components R_V and C_V, and package parasitics L_p and C_p (b) Equivalent circuit of microstrip feeder line with shunt diode admittance Y and radiating element radiation conductance G_R. G_L = feeder line load. In general $l_1 \neq l_2$ and alternate G_R are omitted.

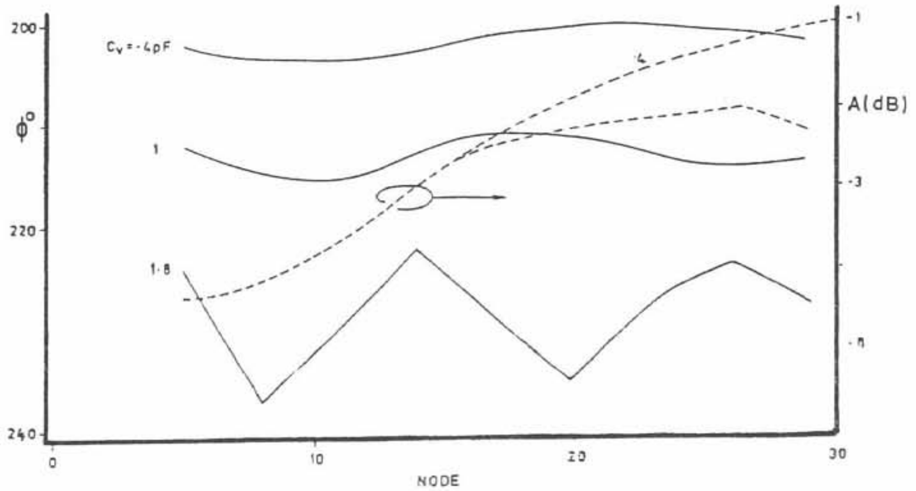

Fig 4: Phase shift ϕ° and attenuation A(dB) along a varactor controlled feeder line with $G_L = 0.02S$, $G_R = 0.002S$, $C_p = 0.18pF$, $L_p = 0.5nH$, $l_1 = 0.28\lambda_g$, $l_2 = 0.25\lambda_g$. G_R radiating elements are spaced every $(0.2 + 0.25)\lambda_g$, frequency = 1 GHz and Q = 240.

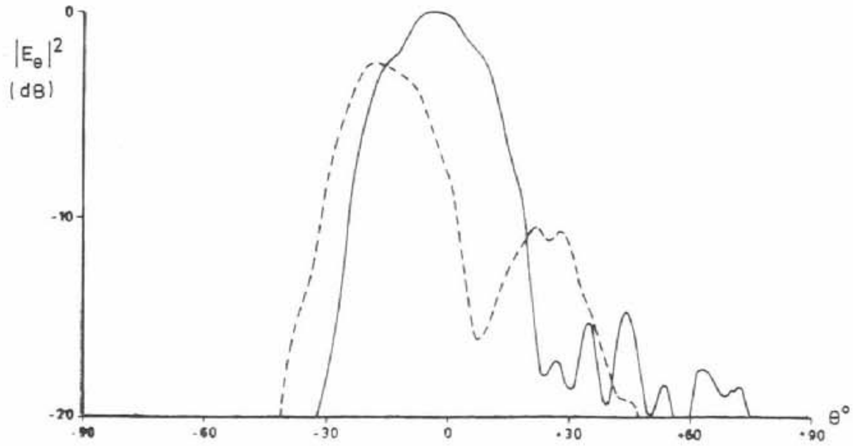

Fig 5: H-plane radiation patterns for a 4-element capacitively coupled travelling-wave array with implanted diodes at 1.05 GHz. h = 1.59 mm, $\epsilon_r = 1.05$, $L_p = 0.5nH$, $C_p = 0.18pF$, $G_L = 0.2S$, $G_R = 0.075S$, element spacing = $0.53\lambda_g$, diode spacing = $0.25\lambda_g$.

——— 30 v DC bias (C_V = 4pF) - - - - 10 v DC bias (C_V = 10pF)

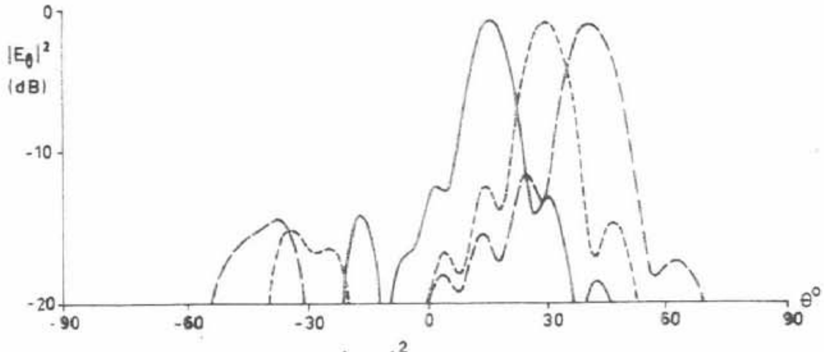

Fig 6: H-plane radiation pattern $|E_\theta|^2$ of 20 element comb antenna with $G_L = 0.02S$, h = 27mm, $\epsilon_r = 2.33$ normalised to main beam. Diodes were mounted in radiating stubs which were separated by $0.53\lambda_g$. Antenna efficiency varies from 80.3% to 49.9% as C_V increases. Diode Q = 250, frequency = 1 GHz

——— C_V = 4pF - - - - C_V = 15pF — — — C_V = 26pF