10. E. Costamagna, Integration formulas for numerical calculation of the Schwarz–Christoffel conformal transformation, Microwave Opt Technol Lett 15 (1997), 219–224.
11. E. Costamagna, Error-masking phenomena during numerical computation of Schwarz–Christoffel conformal transformations, Microwave Opt Technol Lett 20 (1999), 223–225.
12. J. Meixner, The behavior of electromagnetic fields at edges, IEEE Trans Antennas Propagat AP-20 (1972), 442–446.
13. J. Van Bladel, Singular electromagnetic fields and sources, Clarendon, Oxford, England, 1991, chap. 4, 5.
14. E.A. Guillemin, The mathematics of circuit analysis, Wiley, New York, 1950, chap. VI, art. 25.
15. K.J. Binns and P.J. Lawrenson, Analysis and computation of electric and magnetic field problems, Pergamon, Oxford, England, 1963, chap. 8, 10.
16. E. Costamagna, A. Fanni, and P. Gamba, ISTET'97, Int Symp Theoretical Elect Eng, Palermo, Italy, June 1997, pp. 462–465.
17. H.E. Green, The numerical solution of some important transmission line problems, IEEE Trans Microwave Theory Tech MTT-13 (1965), 676–692.
18. J.H. Mason, Breakdown of solid dielectrics in divergent fields, IEE Monograph 127 M, 1955, pp. 254–263.
19. S.S. Bamji, A.T. Bulinski, and K.M. Prasad, Electric field calculations with the boundary element method, IEEE Trans Elect Insulation, 28 (1993), 420–424.

A BACK-TO-BACK DUAL-BEAM ACTIVE MICROSTRIP LEAKY-WAVE ANTENNA ARRAY WITH MODE-SWITCHING CAPABILITY

Cheng-Chi Hu,[1] Christina F. Jou,[1] Jin-Jei Wu,[2] and Song Tsuen Peng[1]
[1] Institute of Communication Engineering
National Chiao Tung University
Hsinchu, Taiwan, R.O.C.
[2] Department of Electric Engineering
Kao Yuan College of Technology & Commerce
Luchu, Taiwan, R.O.C.

Received 18 August 1999

ABSTRACT: *An X-band two-element back-to-back coupled-oscillator-driven spatial power-combining microstrip leaky-wave antenna array is developed, which has a dual-beam radiation pattern and mode-switching capability. Two Gunn diode CPW oscillators are placed on the back side of the substrate, each driving two back-to-back microstrip leaky-wave antenna pairs in opposite directions for dual-beam operation. This active antenna array is able to produce sum and difference patterns between the in-phase and 180° out-of-phase mode by controlling the bias voltages of the Gunn diodes.* © 2000 John Wiley & Sons, Inc. Microwave Opt Technol Lett 24: 195–197, 2000.

Key words: *leaky-wave antennas; active antennas; spatial power combining*

I. INTRODUCTION

Active integrated antennas consisting of a microstrip radiator and an integral oscillator have been an area of growing interest in T/R modules and quasioptical power combiners. They have the advantage of low profile, light weight, easy fabrication, and suitability for mass production. In coupled oscillator arrays, mutual coherence is achieved by the bilateral injection locking of each oscillator to its nearest neighbors. The mode-switching phenomenon of two different oscillation modes of a two-element coupled active antenna array has already been verified theoretically and experimentally [1–4]. These active antenna arrays can produce sum and difference patterns between mode switching. These sum and difference patterns are suitable for possible application in microwave systems such as wireless communication, smart antenna design, and collision-warning radars.

Meanwhile, controlling the beam scanning of the active antennas using the microstrip leaky-wave antenna has received much attention in recent years [5–6]. The microstrip leaky-wave antenna has the characteristic of narrow-beam frequency scanning. It is also suitable for radar systems and communication applications. Besides, by feeding a microstrip leaky-wave antenna at its center, a dual-beam pattern can be obtained [7]. Therefore, it has high potential in automotive applications for side-looking sensors [8]. In this letter, a new spatial power-combining active antenna array using a microstrip leaky-wave antenna as a radiating element has been developed (see Fig. 1), which possesses a dual-beam pattern and two switching radiation modes. The active leaky-wave antenna array is comprised of a CPW Gunn diode oscillator circuit, the CPW-to-slot-line feeding structure, and a microstrip leaky-wave antenna as a radiating element. Control of the mode switching is achieved by tuning the Gunn diode dc bias voltages, which has no need to change the element spacing of the couple oscillators or switches at the center of the coupling network [4].

II. DESIGN AND MEASUREMENT RESULTS

Figure 2 shows the realization of a two-element back-to-back CPW-slot-line-fed microstrip active leaky-wave antenna structure. On the top side of the dielectric substrate, the microstrip leaky-wave antennas are placed back to back for dual-beam operation. The coplanar waveguide (CPW), slot lines, dc block, and the CPW–slot-line transition are etched on the opposite side. Each back-to-back microstrip leaky-wave antenna pair is driven by a coplanar waveguide (CPW) Gunn oscillator. The slot line excites the higher order leaky-mode radiating from the microstrip leaky-wave antenna, and the entire feeding structure is of the uniplanar type. In order to

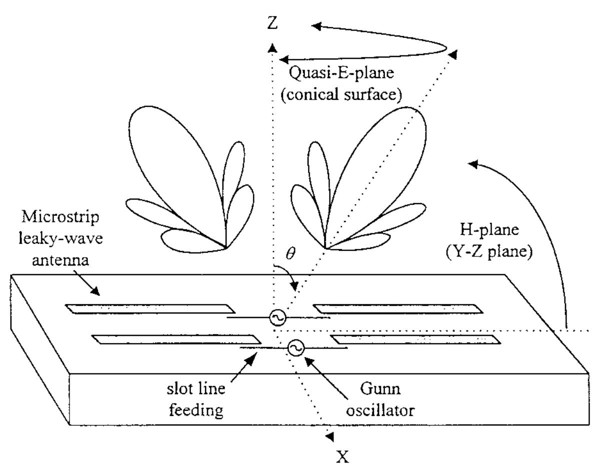

Figure 1 Schematic of the back-to-back dual-beam active microstrip leaky-wave antenna array

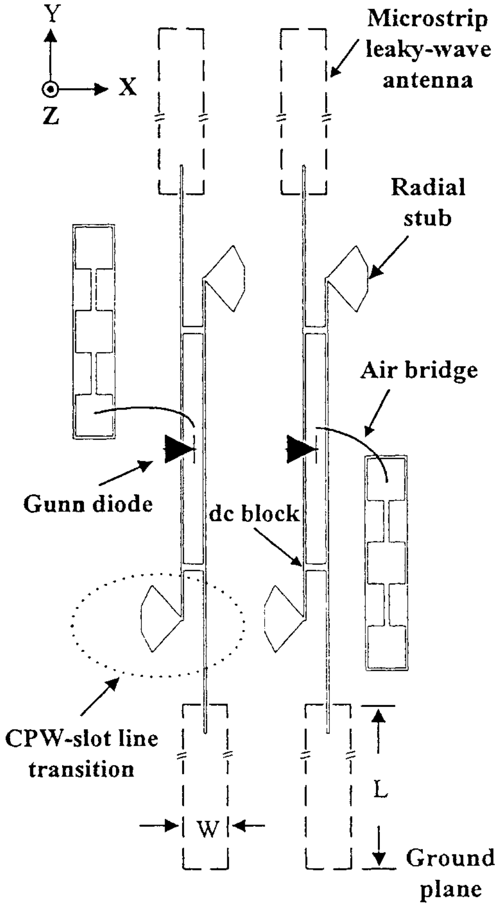

Figure 2 Proposed two-element dual-beam back-to-back active microstrip leaky-wave antenna array. $W = 4.47$ mm, $L = 50$ mm

understand the radiation properties of such a microstrip leaky-wave antenna, we obtained its complex propagation constants $\beta - j\alpha$ of the first higher microstrip mode in its leaky range, where β is the phase constant and α is the attenuation constant. The complex constants are obtained rigorously by the spectral-domain approach. Such complex propagation constants represent a forward leaky wave radiating into the space at an angle $\theta_m = \sin^{-1}(\beta/k_0)$, where θ_m is the angle of the beam maximum measured from the z-axis. In addition, the scanning angle θ_m can be varied with frequency.

The microstrip leaky-wave antenna array is fabricated on a 25 mil (0.635 mm) thick RT/Duroid 6010 substrate with a dielectric constant of 10.2. The width of the microstrip is properly chosen such that efficient leaky-mode radiation can be attained. The negative resistance of the Gunn diode in stable oscillation is matched to the input impedance of the back-to-back microstrip leaky-wave antenna through the coplanar waveguide (CPW), dc block, CPW–slot-line transition, and shorted slot-line feeding structure. The injection locking is fulfilled through free-space mutual coupling and the surface waves in the substrate. The element spacing d was chosen to be 12.7 mm ($d \cong 0.4\lambda_0$, with λ_0 being the free-space wavelength at 9.4 GHz). From [3], the operating mode of the symmetric coupled array is 180° out of phase for an element spacing of about $0.4\lambda_0$, which provided a sum radiation pattern. During our experiment, when both of the Gunn diodes are biased at 11.87 V simultaneously, the oscillating frequency of the array is at 9.329 GHz and the phase delay between the adjacent antennas should be locked at 180°. However, because of the opposite orientations between the slot antennas in [1] and our microstrip leaky-wave antennas, the actual radiation pattern of our active leaky-wave antenna array is a different one. This different radiation pattern (solid line) is shown in Figure 3, which was measured in the quasi-E-plane at $\theta = 35°$ (see Fig. 1). The measure H-plane radiation pattern is shown in Figure 4; two maxima (dual beam) are observed. Reverse switching, i.e., from out-of-phase mode operation to in-phase mode operation, can be achieved as the dc bias voltage of one of the Gunn diodes is

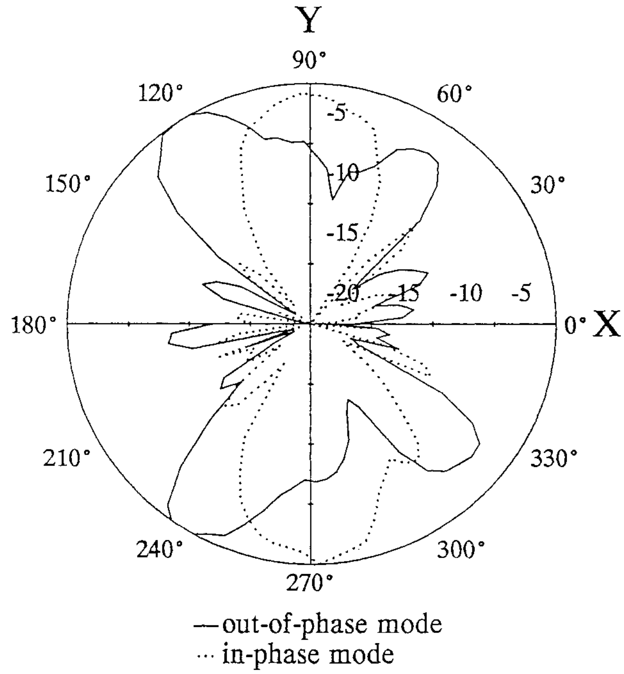

Figure 3 Measured quasi-E-plane patterns for two different mode operations

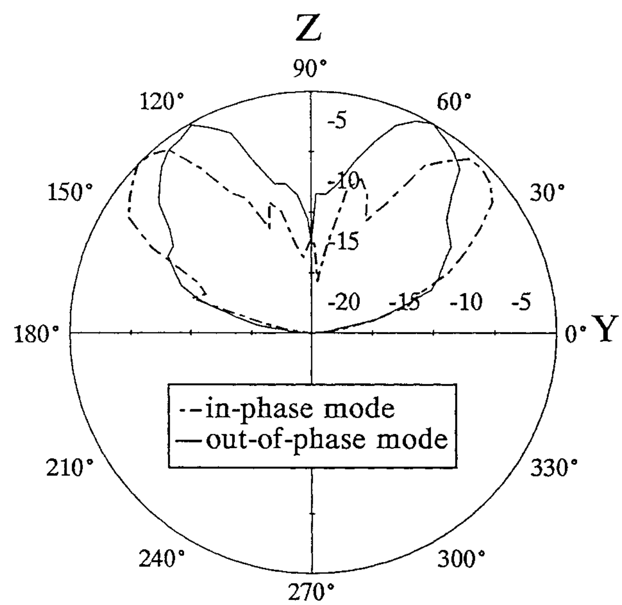

Figure 4 Measured H-plane radiation patterns for two different mode operations

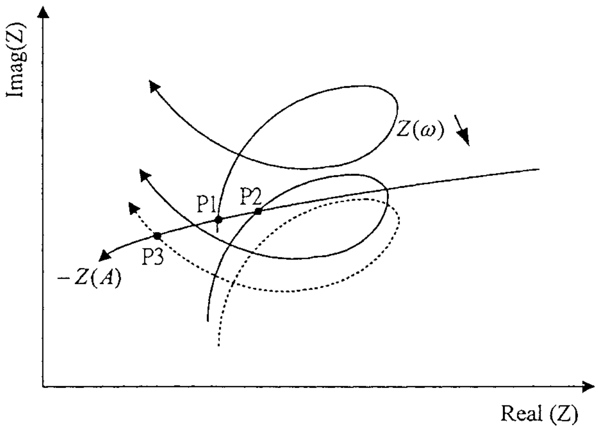

Figure 5 Variation of the operating point as the circuit impedance locus changes its location [11]

decreased to less than 9.45 V and the oscillating frequency is then jumped to 9.465 GHz. The measured in-phase mode radiation patterns (dotted line) in the quasi-E-plane and H-plane are also shown in Figures 3 and 4.

The reason why two-way switching is achieved by changing the bias voltages of the Gunn diode may be the following. According to the multiple loops that can potentially occur in an active antenna circuit impedance locus induced by the effects of distant reflections [9], Figure 5 shows the circuit impedance and the device impedance on the complex plane. $Z(\omega)$ is the circuit impedance seen from one of the Gunn diodes, and $-Z(A)$ is the Gunn diode device impedance. The device impedance is a function of the RF current amplitude A. Suppose that decreasing the bias voltage of the Gunn diode changes the location of the impedance locus with a loop downward, as shown in Figure 5. The operating point $P1$ first moves to the right, as indicated by operating point $P2$; as soon as the upper edge of the loop separates from the device line, the operating point jumps to point $P3$, thereby giving rise to a mode jump.

III. CONCLUSION

A two-element dual-beam back-to-back CPW–slot-line-fed active microstrip leaky-wave antenna array was demonstrated. Injection locking was achieved by using free-space mutual coupling. The CPW slot has been shown to be a correct feeding structure for the excitation of the leaky mode. A dual beam is achieved in the H-plane radiation patterns. Also, the two-way switching phenomenon of the radiation patterns in the quasi-E-plane was achieved by controlling the dc bias of one of the Gunn devices. The circuit offers a possibility for completely monolithic millimeter-wave integrated circuits. The initial results shows the good potential for using this circuit for low-cost transmitters, spatial power combiners, and collision-warning radar applications. The active CPW oscillator circuits have several attractive features: reducing cross coupling, without using via holes to form a ground connection, low radiation loss, and ease for a completely monolithic process. Furthermore, two-terminal devices, for example, the Gunn diodes, have advantages over three-terminal devices such as a higher cutoff frequency, a simpler bias circuit, and suitability for monolithic millimeter-wave integration circuits.

REFERENCES

1. K.D. Stephen and S.L. Young, Mode stability of radiation coupled interinjection-locked oscillators for integrated phased arrays, IEEE Trans Microwave Theory Tech 36 (1988), 921–924.
2. Z. Ding and K. Chang, Modes and their stability of a symmetric two-element coupled negative conductance oscillator driven spatial power combining array, IEEE Trans Microwave Theory Tech 44 (1996), 1628–1636.
3. J. Lin, S. Nogi, and T. Itoh, Mode switch in a two-element active array, 1993 IEEE AP-S Int Symp Dig, June 1993, vol. 2, pp. 664–667.
4. M. Minegishi, J. Lin, T. Itoh, and S. Kawasaki, Control of mode-switching in an active antenna using MESFET, IEEE Trans Microwave Theory Tech 43 (1995), 1869–1874.
5. C.-C. Hu, J.-J. Wu, and C.F. Jou, An active frequency-tuned beam scanning leaky-wave antenna, Microwave Opt Technol Lett 17 (1998), 43–45.
6. W. Menzel, A new traveling wave antenna, Proc 8th European Microwave Conf, 1978, pp. 302–306.
7. C. Luxey and J.-M. Laheurte, Simple design of dual-beam leaky-wave antennas in microstrip, Proc Inst Elect Eng 144 (1997), 397–402.
8. B. Zimmermann and W. Wiesbeck, 24 GHz microwave close-range sensors for industrial measurement applications, Microwave J 39 (1996), 228–238.
9. K. Kurokawa, Injection locking of microwave solid state oscillators, Proc IEEE 61 (1973), 1386–1410.

CCC 0895-2477/00

A NOVEL WAVEGUIDE FILTER FOR REDUCING CROSSTALK IN OPTICAL CROSS CONNECTION AND SWITCHING IN ALL-OPTICAL NETWORKS

Lee Zhengbin,[1] Jeffrey S. Fu,[2] Fen Engxin,[1] and Fu Jumei[1]
[1] Electromagnetic and Communication Laboratory
Electronics and Information School
Xi'an Jiaotong University
Xi'an 710049, P.R. China
[2] School of Electrical and Electronic Engineering
Nanyang Technological University
Singapore 639798

Received 24 August 1999

ABSTRACT: *A novel filter structure is presented in this paper to reduce the crosstalk in cross connection and switching in all-optical networks based on dense wavelength-division multiplexing (DWDM). Following the principle of an optical film filter, the filter is constructed by a dielectric waveguide with the waveguide boundary or the waveguide itself discontinuous in the transmitting direction. As the propagation phase constant β does not change in the wave propagating direction z, the waveguide system can be considered as a homogeneous dielectric medium with effective refractive index n_e in this direction. Because the effective refractive index n_e changes with the thickness or parameters as n_i of the waveguide at a given field mode, we arrange different n_e alternately as an optical film filter. After proving this kind of waveguide's filtering properties, the design principle and an example are given, which will be very useful to reduce the crosstalk in optical cross connection and switching in all-optical networks based on DWDM. This kind of filter can be easily connected to other related components.* © 2000 John Wiley & Sons, Inc. Microwave Opt Technol Lett 24: 197–202, 2000.

Contract grant sponsor: Graduate School, Xi'an Jiaotong University, P.R. China
Contract grant number: DFXJU-11
Contract grant sponsor: NNSFC
Contract grant number: 69671017