- J. Ren, O.P. Gandhi, L.R. Walker, J. Fraschilla, and C.R. Boerman, Floquet-based FDTD analysis of two-dimensional phased array antennas, IEEE Microwave Guided Wave Lett 4 (1994), 109–111.
- P. Harms, R. Mittra, and W. Ko, Implementation of the periodic boundary condition in the finite-difference time-domain algorithm for FSS structures, IEEE Trans Antennas Propagat 42 (1994), 1317–1324.
- M.E. Veysoglu, R.T. Shin, and J.A. Kong, A finite-difference time-domain analysis of wave scattering from periodic surfaces: Oblique incidence case, J Electromag Waves Appl 7 (1993), 1595–1607.
- J.A. Roden, S.D. Gedney, M.P. Kesler, J.G. Maloney, and P.H. Harms, Time-domain analysis of periodic structures at oblique incidence: Orthogonal and nonorthogonal FDTD implementations, IEEE Trans Antennas Propagat 46 (1998), 420–427.
- A. Reinex and B. Jecko, A new photonic band gap equivalent model using finite difference time domain method, Ann Télécommun 51 (1996), 656-662.
- A. Alexanian, N.J. Kolias, R.C. Compton, and R.A. York, Threedimensional FDTD analysis of quasi-optical arrays using Floquet boundary conditions and Berenger's PML, IEEE Microwave Guided Wave Lett 6 (1996), 138–140.
- J.P. Bérenger, Three-dimensional perfectly matched layer for the absorption of electromagnetic Waves, J Comput Phys 127 (1996), 363–379.
- T. Kashiwa, O. Chiba, and I. Fukai, A formulation for surface impedance boundary conditions using the finite-difference timedomain method, Microwave Opt Technol Lett 5 (1992), 486–490.
- S. Kellali, B. Jecko, and A. Reinex, Surface impedance boundary conditions at oblique incidence in FDTD, Ann Télécommun 48 (1993), 268–276.
- E. Takagi, B. Houshmand, and T. Itoh, Practical metal loss implementation for a microstrip line structure using SIBC in FDTD simulation, IEEE MTT-S Dig, June 1997, pp. 1531–1534.

© 1999 John Wiley & Sons, Inc. CCC 0895-2477/99

SCANNING LEAKY-WAVE ANTENNA INTEGRATED WITH SELF-OSCILLATING DOUBLER

Chien-Jen Wang,1 Christina F. Jou,1 and Jin-Jei Wu2

 Institute of Communication Engineering National Chiao Tung University Hsinchu, Taiwan, R.O.C.
 Department of Electric Engineering Kao Yuan College of Technology & Commerce Luchu, Kaohsiung, Taiwan, R.O.C.

Received 12 January 1999

ABSTRACT: A new method which can enhance the scanning angle and elevate the operating frequency for active scanning leaky-wave antennas is proposed in this paper. We know that the characteristics and performance of scanning leaky-wave antennas are strongly dependent on the variation of the operating frequency within the leaky-mode region. The self-oscillating doubler without external oscillator sources provides double-frequency variation at the second-harmonic frequency instead of one-frequency variation at the fundamental frequency. Therefore, the antenna scanning range can be enhanced and the operating frequency can be elevated. The measured scanning angle of this antenna is 13°, which agrees well with the predicted 13.7°, and the data show that the frequency-scanning ability of the leaky-wave antenna using a self-oscillating doubler increases as predicted. This self-oscillating doubler design is very simple, and it not only can improve the scanning capability of the active leaky-wave antenna, but it is also very suitable for millimeter-wave active antenna design. © 1999 John Wiley & Sons, Inc. Microwave Opt Technol Lett 22: 108-111, 1999.

Key words: beam scanning; leaky-wave antenna; self-oscillating doubler

I. INTRODUCTION

Active scanning antennas have attracted increased interest during the past years [1-2]. Compared to the large area and high cost of phase antenna arrays, leaky-wave antennas are efficient, simple, low cost, low weight, and have a frequencyscanning capability. In order to reduce the size, passive leaky-wave antenna elements are integrated on the same substrate with active signal sources, such as oscillators [3], amplifiers, and varactor-tuned oscillators [4]. It is known that the range of the antenna-scannable angle is strongly dependent on the operating frequency range of the active sources, and the microwave and millimeter-wave solid-state devices become expensive as the frequency increases. Frequency multipliers can provide multiple-frequency variation, which contributes to an enhanced scanning angle at the harmonics of the fundamental frequency. Hence, the leaky-wave antenna integrated with a frequency multiplier, such as a frequency doubler, is a novel and excellent combination. A self-oscillating doubler is an even better choice because it need not be injected by external oscillator sources; therefore, it can effectively reduce the circuit size and cost.

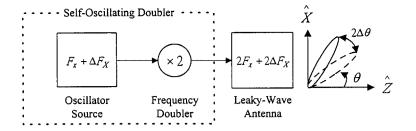
In this paper, we demonstrate an asymmetrically feeding leaky-wave antenna integrated with a self-oscillating doubler on an RT/Duroid substrate. Figure 1(a) shows the block diagram and the characteristics of the equivalent module, which include an oscillator doubler and an antenna element; Figure 1(b) shows the module diagram and the coordinate system of the active scanning leaky-wave antenna. We utilize the self-oscillating doubler to directly excite the signal source at the second-harmonic frequency. The operating frequency, the second-harmonic frequency $2F_x$, and the double-frequency variation $2\Delta F_x$ at the second-harmonic frequency are twice ΔF_x at the fundamental band. This feature, combined with the advantage of no external injection power, is very useful for millimeter-wave applications of the leaky-wave antenna and to obtain a wider scanning angle.

II. DESIGN OF SELF-OSCILLATING DOUBLER

The circuit configuration of the 5 double to 10 GHz self-oscillating doubler as the active source is illustrated in Figure 2. Figure 2 includes a fundamental oscillator, a rejection circuit for the fundamental frequency F_x , a matching circuit for the second-harmonic frequency $2F_x$, and the frequency-tuned circuit. A commercially available Fujitsu FHX35LG low-noise GaAs HEMT device is employed. Since rich harmonic generation is shown to result from Class B operation, where V_{es} is biased at the pinch-off voltage V_p [5]; therefore, our selfoscillating doubler uses the common-source topology and Class B operation to excite the higher second-harmonic power. The simple $\lambda_x/4$ microstrip-line stub is useful as the rejection circuit for the fundamental frequency. The matching circuit for the second-harmonic frequency $2F_r$ is designed to reduce the return loss and raise the radiated efficiency. The frequency-tuned circuit includes a varactor and a varactor bias circuit. The frequency can be varied electronically by changing the bias voltage of the varactor.

III. DESIGN OF LEAKY-WAVE ANTENNA

In order to excite the first higher order mode, the leaky-wave antenna is asymmetrically fed [6]. A rigorous (Wiener-Hopf) solution mentioned in [7] is utilized, and we obtain the variation of the normalized complex propagation constant



 F_{\star} : the oscillating frequency

 ΔF_x : the original tuning frequency variation $2F_x$: the operating frequency of an antenna

 $2\Delta F_r$: the tuning frequency variation of an antenna

 θ : the main-beam direction

 $2\Delta\theta$: the frequency-scanning angle range

Self-Oscillating Doubler

Microstrip Leaky-Wave Antenna \hat{X} \hat{Y} \hat{Y} (b)

(a)

Figure 1 (a) Block diagram and characteristics of the equivalent module, which includes an oscillator doubler and an antenna element. (b) Module diagram and coordinate system of the active scanning leaky-wave antenna on a RT/Duroid substrate with 0.0508 cm thickness and relative permittivity of $\epsilon_r = 2.2$

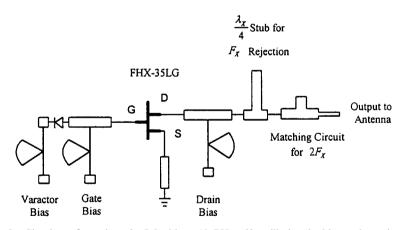


Figure 2 Circuit configuration of a 5 double to 10 GHz self-oscillating doubler as the active source

 $\beta - j\alpha$, where β is the phase constant and α is the attenuation constant, in Figure 3. With the relationship between the normalized propagation constant (β , α) and the dimension (W, H) of the leaky-wave antenna, the empirical dimension is chosen so that the space wave dominates the radiating power, and the first higher order mode can be excited within the operating frequency.

IV. EXPERIMENTAL RESULT

An asymmetrically feeding leaky-wave antenna integrated with a Class B HEMT self-oscillating doubler is designed and fabricated. The bias voltages are -1.14 V for the gates and 5.2 V for the drain, which is a Class B bias condition. The fundamental frequency is measured to be 4.83–5.05 GHz; therefore, the second-harmonic frequency can be tuned from

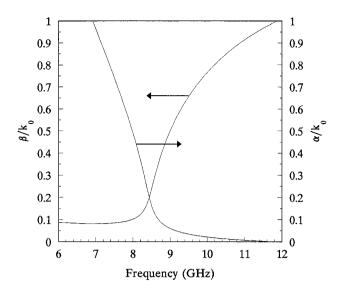


Figure 3 Variation of the normalized phase constant β and the normalized attenuation constant α

9.66 to 10.1 GHz. The frequency variation ($\Delta F_x = 220 \text{ MHz}$) of the fundamental frequency is half of the frequency variation $(2\Delta F_r = 440 \text{ MHz})$ of the second-harmonic frequency that we designed. The calculated scanning angle obtained by using the equation $\theta = \cos^{-1}(\beta/k_0)$ under the frequency variation ($\Delta F_x = 220$ MHz) of the operating frequency is 6.85°; in other words, the calculated scanning angle under the double-frequency variation ($2\Delta F_x = 440 \text{ MHz}$) is the double scanning angle 13.7°. Figure 4 shows the theoretical radiation patterns of the leaky-wave antenna integrated with the selfoscillating doubler at 9.66 and 10.1 GHz. The measured radiation patterns of this antenna at 9.66 and 10.1 GHz are shown in Figure 5. The total measured scanning angle is 13°, which is close to the theoretical scanning angle of 13.7° shown in Figure 4. A comparison of the theoretical and measured radiation patterns at 9.66 GHz is presented in Figure 6; both the theoretical elevation angle 49.8° and the measured elevation angle 50° agree well. The effective

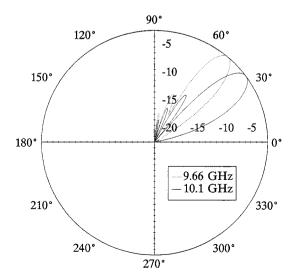


Figure 4 Theoretical radiation patterns of the leaky-wave antenna at 9.66 and 10.1 GHz

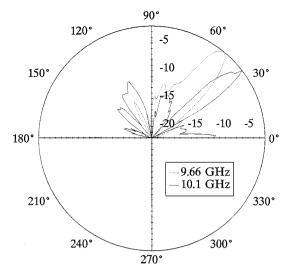


Figure 5 Measured radiation patterns of the leaky-wave antenna integrated with a self-oscillating doubler at 9.66 and 10.1 GHz

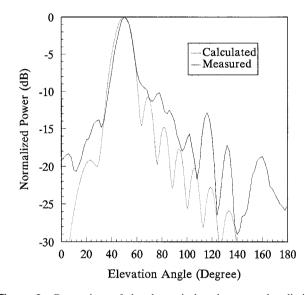


Figure 6 Comparison of the theoretical and measured radiation patterns at 9.66 GHz

isotropic radiated power (EIRP) under the far-field condition is approximately 12 dBm.

V. CONCLUSION

A scanning leaky-wave antenna integrated with a self-oscillating doubler is developed. This paper utilizes the frequency-scanning capability of the leaky-wave antenna and the technique of the self-oscillating doubler to demonstrate the method for reaching a wider scanning angle and a higher operating frequency. For example, it is unnecessary to directly implement a *Ka*-band circuit using high-cost *Ka*-band solid-state devices; instead, low-cost *Ku*-band solid-state devices can be utilized. The self-oscillating multiplier without external injection sources can effectively reduce the size and cost of the whole circuit, and it has wider frequency variation at the harmonic frequencies than that of the fundamental frequency. This design of the combination of scanning leaky-wave antennas and multipliers will be interesting for millimeter-wave applications.

REFERENCES

- P. Liao and R.A. York, A six-element beam-scanning array, IEEE Microwave Guided Wave Lett 4 (1994), 20–22.
- J. Lin, S.T. Chew, and T. Itoh, A unilateral injection-locking type active phased array for beam scanning, IEEE MTT-S Dig, 1994, pp. 1231–1234.
- 3. G.J. Jou and C.K. Tzuang, Oscillator-type active-integrated antenna: The leaky-mode approach, IEEE Trans Microwave Theory Tech 44 (1996), 2265–2272.
- C.J. Wang, J.J. Wu, C.C. Hu, and C.F. Jou, Asymmetric feeding active leaky-wave antenna arrays, Microwave Opt Technol Lett 18 (1998), 14–17.
- 5. G. Dow and L. Rosenheck, A new approach for mm-wave generation, Microwave J (Sept. 1983), 147–162.
- W. Menzel, A new traveling wave antenna, Proc 8th European Microwave Conf, 1978, pp. 302–306.
- 7. D.C. Chang and E.F. Kuester, Total and partial reflection from the end of a parallel-plate waveguide with an extended dielectric loading, Radio Sci 16 (1981), 1–13.

© 1999 John Wiley & Sons, Inc. CCC 0895-2477/99

CHARACTERISTICS OF CIRCULAR POLARIZATION OF ELLIPTICAL MICROSTRIP ANTENNA WITH FULL-WAVE ANALYSIS CONSIDERING THE ATTACHMENT MODE

Hooin Jung1 and Chulhun Seo1

¹ Department of Information and Telecommunication Engineering Soongsil University Seoul, Korea

Received 15 December 1998

ABSTRACT: In this paper, we present the characteristics of circular polarization of an elliptical microstrip patch fed by a coaxial probe through the method of moments in conjunction with the reaction integration method. After obtaining the general Green's function, the input impedance was calculated by superposition of two circular patches whose radii pertain to the major and minor axes of the elliptical patch, respectively, and then the characteristics of circular polarization are shown. The attachment mode was contained to ensure the continuity and singularity of the currents at the patch–probe conjunction point, and plays a role in accelerating the convergence for solving matrix equations. Results showed that the elliptical patch can be used to generate circular polarization characteristics with one probe feed, and attachment modes also should be contained in the formulation to obtain the exact impedance. © 1999 John Wiley & Sons, Inc. Microwave Opt Technol Lett 22: 111–113, 1999.

Key words: method of moments; microstrip antenna

I. INTRODUCTION

Printed circuit antennas such as microstrip or strip line have been popular for a few decades thanks to their merits, such as light weight, small size, and low cost in manufacturing. However, they have some disadvantages, such as low efficiency, low power, poor polarization purity, very narrow bandwidth, etc., and it is very difficult to overcome these drawbacks in designing microstrip antennas by conventional methods [1]. A circular polarization can be easily obtained by exciting the elliptical patch rather than the rectangular or circular one by means of the proper selection of both the feed position and the eccentricity of the ellipse. That is, the feed point should be on a radial line of $\pm(\pi/4)$ relative to the major axis, in which the positive sign yields LHCP while the negative one yields RHCP to generate circular polariza-

tion [2]. It is, however, complicated to analyze elliptical patch geometry because of its unique elliptical characteristics.

There have been several methods to analyze this elliptical patch, such as using the resonant equivalent circuits consisting of the R, L, and C [3] or using the same method as the circular patch geometry [4]. Although these methods are relatively accurate and simply, they did not consider effects such as the thickness variation of the substrate, the relative permittivity, and attachment modes [5], and had a shortcoming of degrading the accuracy as the thickness of the substrate increases. We analyze the characteristics of the circular polarization of this elliptical patch considering the attachment modes for accelerating the convergence with the reaction integration method and the method of moments [6]. As a result, the property of circular polarization is shown, and the impedance characteristics of the elliptical patch are also presented and compared with the experimental values.

II. THEORY AND FORMULATION

Figure 1 illustrates an analytical model of the elliptical microstrip which is excited by a coaxial probe extending through the ground plane and substrate. In this model, the current distribution of the probe can be modeled as follows:

$$\mathbf{J}_{s} = \hat{z}I_{o}/\pi d_{o} \tag{1}$$

where I_o is the total current flowing in a cylinder of diameter d_o .

The elliptical patch is modeled with two circular patches whose radii pertain to the major and minor axes of the elliptical patch, respectively, so the total currents on the patch can be expressed as the sum of the currents on the two circular patches:

$$\mathbf{J_{I}}(\rho,\phi) = \sum_{n=1}^{\infty} I_n^1 \Psi_n^1(\rho,\phi)$$
 (2)

$$\mathbf{J_2}(\rho,\phi) = \sum_{n=1}^{\infty} I_n^2 \Psi_n^2(\rho,\phi)$$
 (3)

where $\Psi_n^1(\rho, \phi)$ and $\Psi_n^2(\rho, \phi)$ are the basis functions of the unknown currents on each circular patch and I_n^1 and I_n^2 are complex coefficients of the unknown currents on each circular patch. The basis functions can be expressed in terms of

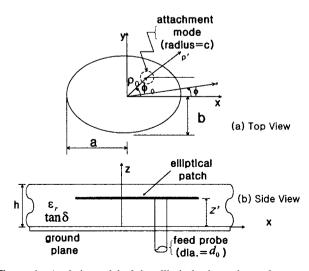


Figure 1 Analytic model of the elliptical microstrip patch antenna