A CPW-to-Slotline Active Gunn Diode Leaky Wave Antenna

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Abstract

A X-band coplanar waveguide (CPW) to slotline couple feeding active microstrip leaky wave antenna using Gunn-diode oscillator as source is demonstrated. The method to excite the first higher order mode of the microstrip leaky wave antenna is to put the CPW-to-slotline transition underneath the middle of the microstrip line, and the oscillator circuit and radiating element are separated by a ground plane. The measured angle of the maximum beam direction of active antenna is at 72° for the active Gunn oscillator frequency of 11.218GHz. This prototype of active leaky wave antenna feeding by Gunn diode oscillator with CPW-to-slotline structure can be easily scaled up to millimeter wave frequency region.

I. Introduction

Since 1979, Menzel found the traveling-wave phenomenon, numerous studies have been carried out using leaky wave antenna element [1]. Oliner and Lee clarified the confusion of properties of microstrip line higher-order modes and divided the leakage modes into two forms, surface wave and space wave [2]. Then Oliner proposed a linear antenna-array integration using leaky wave antenna elements [3]. Recently, there is a growing interest in active-integrated antennas [4][5] using microstrip leaky-wave antenna as radiating elements. In 1996, C. K. Tzuang et al [4] proposed an active antenna source module utilizing a microstrip as a radiating element while adopting uniplanar technology for active circuit design. Because the radiation main-beam of micostrip leaky wave antenna depends on the operating frequency, it can be used as a frequency-scanning antenna [4]. In 1997, C.C.Hu et al [5] demonstrate an active frequency scanning microstrip leaky wave antenna using HEMT voltage control oscillator at X band. Their scanning angle is close to 30 degrees as the VCO frequency tuned from 8.06GHz to 9 GHz.

In this paper, a CPW-to-slotline feeding to a backside microstrip leaky wave antenna is demonstrated. This antenna feeding source is a Gunn diode oscillator. The active leaky wave antennas comprised of an coplanar Gunn diode active oscillator circuit, the coplanar-to-slotline feeding structure and a microstrip leaky wave antenna radiating element The active CPW circuits have several attractive features[4][6][7][8]: (1) reduced cross coupling, (2) without via holes to

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form ground connection, (3) easily to mount devices in series or parallel, (4) low radiation loss, and (5) easy for completely monolithic process. Furthermore, it is a resonator circuit for the oscillator, and a good heatsink because of its large ground plane.

As for this antenna feeding topology, it is feeding on one side of the substrate to excite the microstrip's first higher order leaky mode, while retaining all the merits of the uniplanar microwave-integrated circuits on the other side [3][8], it became quite natural when a slotline underneath the middle of the microstrip line is employed as an efficient antenna feed. Thus, the oscillating circuit and radiating element are separated by a ground plane and isolated from each other.

In our paper, a prototype of a CPW-to-slotline active microstrip leaky-wave antenna is demonstrated by composing a microstrip leaky-wave antenna with a Gunn diode oscillator using coplanar waveguide circuit. Furthermore, by adding a varactor in this Gunn diode CPW oscillator circuit, this active-integrated antenna can become a frequency scanning antenna.

II. A X-band CPW-to-Slotline Leaky-wave antenna Design

Figure 1. Show the configuration of our CPW-to-slotline Leaky wave antenna. It is composed of three parts, coplanar waveguide oscillator circuit, CPW-to-slotline transition feeding structure, and a backside microstrip leaky wave antenna.

To determine the size of such a microstrip leaky-wave antenna, we obtained its complex propagation constant β-jα of the first higher microstrip mode in its leaky range, where β is the phase constant, and α is the attenuation constant. The complex constant is obtained by employing rigorous (Wiener-Hopf) solution mentioned by Ref [9]. Figure.2 shows the variations of phase constant β and attenuation α as a function of frequency. The width of this leaky wave microstrip antenna designed to be 3.5 millimeter, the substrate dielectric constant is 10.2 and substrate thickness is 0.635milimeter. In our structure, the microstrip leaky-wave antenna is open at the top. For values of $\beta<k_0$, power will leaky into space and exist in a space wave form in addition to the surface wave. The space wave actually corresponds to radiation at some angle θ, the value of this angle changes with frequency. By using the approximate relationship $\theta m=Cos^{-1}(\beta/k_0)$ where θm is the angle of the beam maximum measured from the end fire direction, we can predict the main beam position.

In order to obtain the Gunn diode admittance, we designed a planar Gunn diode oscillator using microstrip line circuit. Using this admittance value and utilizing a commercially available CAD tool HP-EEsof Libra, the coplanar waveguide oscillator was designed at 11GHz. C&K W2420 Gunn diode is used in the Gunn diode oscillator. A CPW-to-slotline transformer is used between CPW Gunn oscillator and the microstrip leaky wave antenna and it is a part of the matching circuit. To excite the first higher order mode for better efficiency, the slotline must be put directly under the backside at the middle of the leaky wave antenna.

The output power P_0 was calculated using the Friss transmission equation in the far field condition:

$$P_o = P_r\left(\frac{4\pi R}{\lambda_0}\right)^2 \frac{1}{G_o G_r}$$

where P_r = Power received. P_o = Power transmitted from the active leaky-wave antenna. λ_c =

Wave length in free space. R = Antenna separation. G_t = Gain of the transmit antenna. G_r = Gain of the receive antenna. The radiation pattern is measured at a distance of R=86 centimeters between horn and active leaky wave antenna. The radiation power received (EIRP) is about 4.17 dBm at a radiation angle of 72 degree while Gunn diode is biased at 8.34Volts, 0.09Amperes.

The dc-to-RF conversion efficiency is 0.56%. Figure 3 shows the measured H-plane radiation pattern at 11.218GHz which agrees well with the theory. Figure 4 shows the measured and theoretical H-plane radiation patterns in polar chart. The radiation pattern is derived from ref [4]. The reason of our choice in using high dielectric constant substrate (ε_r=10.2) to fabricate active leaky wave antenna is that it can produce a larger corresponding angle at the same feeding frequency than low dielectric constant, and also because it is closer to the dielectric constant of GaAs substrate (ε_r=13), thus, it can be easily implemented to monolithic millimeter circuits. The slightly deviation between measurement and theory may be due to the rigorous Wiener-Hopf mode chart in using high dielectric constant substrate (ε_r=10.2) and CPW-to-slotline transition circuit.

IV. Conclusions

A X-band CPW-to-slotline active leaky-wave active antenna using Gunn-diode oscillator as source is developed. This is a prototype of leaky wave antenna using Gunn diode by coplanar waveguide circuit structure, which is demonstrated at X band, and it can be easily scaled up to millimeter wave frequency region. The method to excite the first higher order mode of the microstrip leaky wave antenna is to put the CPW-to-slotline transition underneath the middle of the microstrip line. The measured angle of the maximum beam direction of active antenna is at 72 degree as the Gunn diode oscillator frequency is at 11.218GHz.

The measured beam angle agrees very well with the predicted data. The circuit offers a possibility for completely monolithic millimeter wave circuits which is small, simple, light weight, low cost, a frequency scanning source for many application. According to this demonstration of single frequency leaky-wave antenna, the goal of frequency scanning antennas and arrays may attain.

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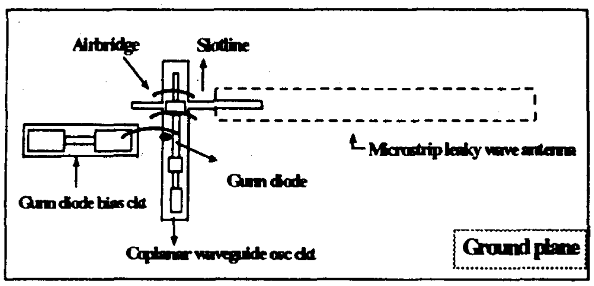

Fig. 1. Configuration of the CPW-to-slotline transition feeding Gunn diode active microstrip leaky wave antenna designed at 11GHz.

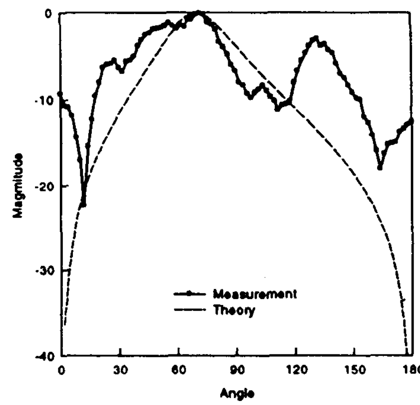

Fig. 3. The H-plane radiation pattern of the asymmetric feeding active leaky-wave antenna measured at 11.218 GHz.

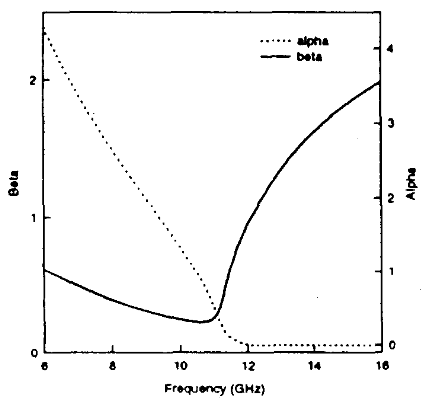

Fig. 2. Normalized complex propagation constant of the first higher mode for the microstrip leaky-wave antenna. h=.635 mm, w = 3.5mm, L=12.7cm, and Er=10.2. k_0 is the free-space wave number.

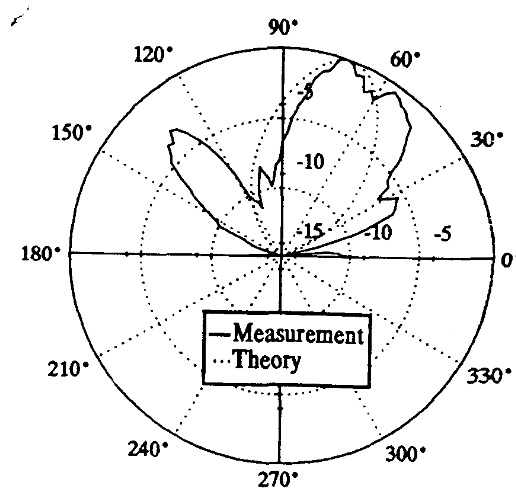

Fig. 4. Polar chart of H-plane frequency radiation patterns at 11.218GHz.