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AN ASYMMETRIC FEEDING X-BAND ACTIVE FREQUENCY-SCANNING LEAKY-WAVE ANTENNA

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Abstract

An asymmetric feeding X-band active leaky-wave antennas is developed, to excite the first high order mode of the microstrip leaky wave antenna. One is the asymmetric feeding leaky-wave antenna which integrated with a HEMT oscillator, and the other is the frequency-tuned leaky-wave antenna which integrated with a varactor-tuned HEMT VCO. The microstrip leaky-wave antenna is operated in the first higher mode. To excite the first higher mode, the microstrip leaky-wave antenna is fed asymmetrically. The dominant mode excitation has been successfully suppressed by adding a sequence of covered wire in the center of the microstrip leaky wave antenna. The design of these active leaky-wave antennas is discussed and the beam scanning phenomena of the antenna is presented. The HEMT oscillator frequency is controlled by tuning the varactor DC bias and the beam scanning is demonstrated. The measured scanning angle agree with prediction, it is close to 30°as the VCO frequency tuned from 8.06 GHz to 9GHz.

Key Words:

asymmetric feeding; leaky-wave antenna; frequency scanning; varactor-tuned VCO

I. Introduction

The active antennas are an area of recent research which offer much potential applications, these include low cost phased array radar [1], spatial power combining system [2],[3] and beam-scanning array, [4]. In these active antenna arrays, many individual oscillators are synchronized through mutual coupling, or by an external signal injection. In most of the phased array presented until now, beam steering is obtained by different types of phase shifters distributed through the feed work, or by tuning the free-running frequency of the outermost array elements [4]. But increasing the number of oscillators in the arrays decrease the maximum phase difference between each oscillator, and the scanning range is limited for modest size arrays.

Frequency scanning is a effective technique for providing antenna beam steering which has been implemented with microstrip technology in recent years. Frequency scanning can be a cost-effective alternative to phase scanning in certain applications because phase shift elements and their associated drivers are not required to steer the antenna beam. Recently, there is a growing interest in active antenna integration using microstrip leaky-wave antenna as frequency scanning elements[5],[6]. Microstrip leaky-wave antenna is not a low-loss element. However, it has the advantage of low profile, simple structure, easy fabrication, easy matching, frequency scanning, narrow beam, and it is very suitable for active integrated antenna application. In this paper, the microstrip leaky-wave antenna is fed asymmetrically to excite the first higher mode[7] and leaks in the form of space wave. In addition, by introducing a sequence of covered wire in the middle of the microstrip leaky-wave antenna (see Fig. 1.), the excitation of the dominant mode can be successfully suppressed and the radiation efficiency can be improved. The characteristic of the microstrip line antenna is determined by its complex propagation constant. Here, an attempt is made to accomplish an active phase-shifterless frequency scanning antenna by integrating a varactor-tuned VCO with microstrip leaky-wave antenna. The radiation main beam depends on its operating frequency, and the frequency is varied by a varactor in the oscillator resonant circuit, the beam direction is controlled by adjusting the varactor DC bias. Therefore, it can be used as a frequency-scanning antenna.

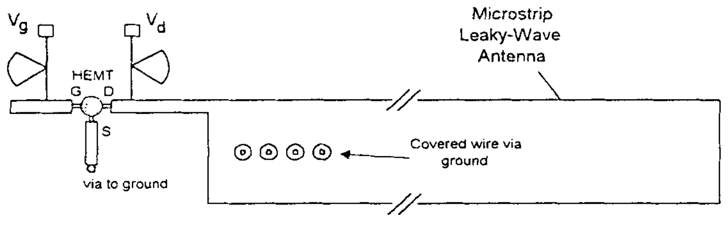

Fig. 1. Configuration of the asymmetric feeding active microstrip leaky-wave antenna.

In this paper, we start with a asymmetric feeding leaky-wave antenna integrated with HEMT oscillator and then using the frequency-scanned characteristic of the leaky-wave antenna to design a frequency-tuned beam-scanning leaky-wave antenna integrated with voltage controlled HEMT oscillator. The theoretical results and the experimental results of these active leaky-wave antennas are compared and agree well with prediction.

II. Analysis, Design, and Characteristic of a Microstrip Leaky-Wave Antenna

The dominant mode on a uniform microstrip line is a slow wave relative to free space, so that the dominant mode cannot furnish a way to archive a uniform leaky-wave antenna. To create a uniform leaky-wave antenna based on microstrip line, we employing a higher mode in an appropriate range of operation. The most convenient higher mode is the first higher mode. In contrast to the dominant mode, the first higher order mode has a nonzero cutoff frequency which depends on the guide width. There are two forms of leakage. One is the surface wave another is the space wave. But the surface TM_0 wave with zero cutoff frequency is often weakly excited. This is desirable since most electromagnetic energy will propagate in the intended direction rather than dissipating in the form of a surface wave on the dielectric layer outside the strip region.

A. Dispersion Characteristic of the Leaky-Wave Antenna

In order to 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 by employing rigorous (Wiener-Hopf) solution mentioning by Ref. [8]. Fig.2 shows the variations of phase constant β

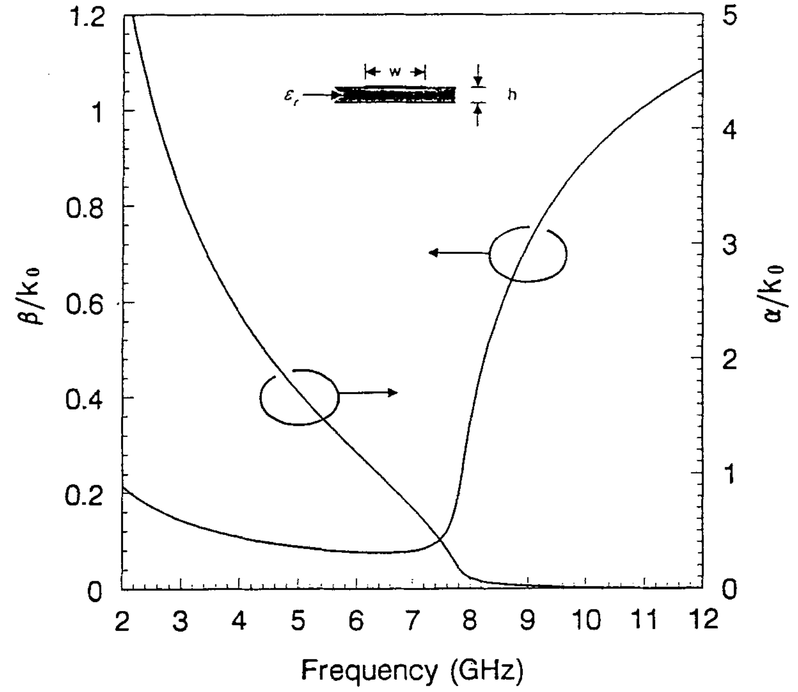

Fig. 2. Normalized complex propagation constant of the first higher mode for the particular microstrip leaky-wave antenna. h=.508 mm, w = 12mm, and $\varepsilon_r = 2.2$. k_0 is the free-space wave number.

and attenuation constant α as a function of frequency. In our structure, the microstrip leaky-wave antenna is open at the top. For values of $\beta < k_o$, power will leak into a space wave 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 $\theta_m = \cos^{-1}(\beta / k_o)$, where θ_m is the angle of the beam maximum measured from the z-axis direction, we can predict the main beam position

B. Radiation Pattern

Using the field equivalence principle, we can derive the far field radiation pattern of the microstrip leaky-wave antenna. The geometry and coordinate system of the microstrip leaky-wave antenna structure is shown in Fig.3. The antenna consists of two slots, each of width w,

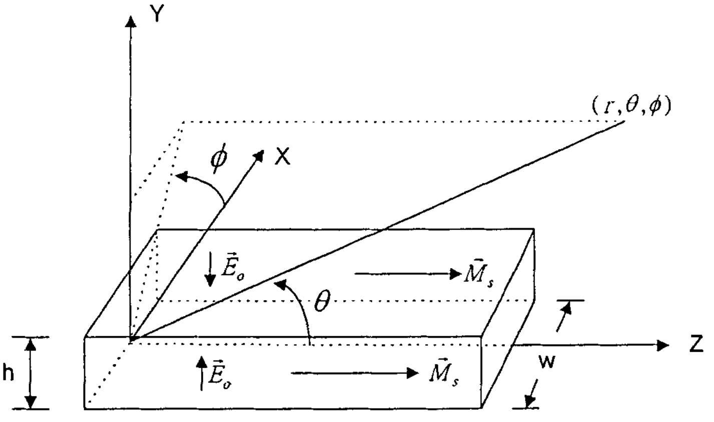

Fig. 3. Geometry and coordinate system for the microstrip leaky-wave antenna.

length L, and height h. Each slot will radiate the same fields as a magnetic dipole[6],[9] with magnetic current density $\vec{M}_S = -\hat{n} \times \vec{E}$ which can be assumed to be exponential decaying functions with an attenuation constant α and can be expressed as

$$\vec{M}_S = \hat{z}E_0 e^{-j(\beta - j\alpha)z} \tag{1}$$

where E_0 is an arbitrary constant. The total field will be the sum of the two element array with each element representing one of the slots. Thus, the far-zone fields can be written as

$$E_r \cong E_\theta \cong 0$$

$$E_\phi \cong -jE_o \frac{khe^{-jkr}}{\pi r} \left\{ \sin\theta \left[\frac{\sin(X)}{X} \right] \left[\frac{e^{ZL} - 1}{Z} \right] \right\} \cdot \cos\left(\frac{kw \sin\theta \sin\phi}{2} \right) \tag{2}$$

where

$X = kh \sin\theta \cos\phi$
$Z = j(k\cos\theta - \beta) - \alpha$
and $k = 2\pi / \lambda$ are the wave number.

The H-plane normalized radiation patterns derived from (2) are plotted in Fig.4 for operating frequencies at 8.06 GHz, 8.86 GHz, and 9 GHz.

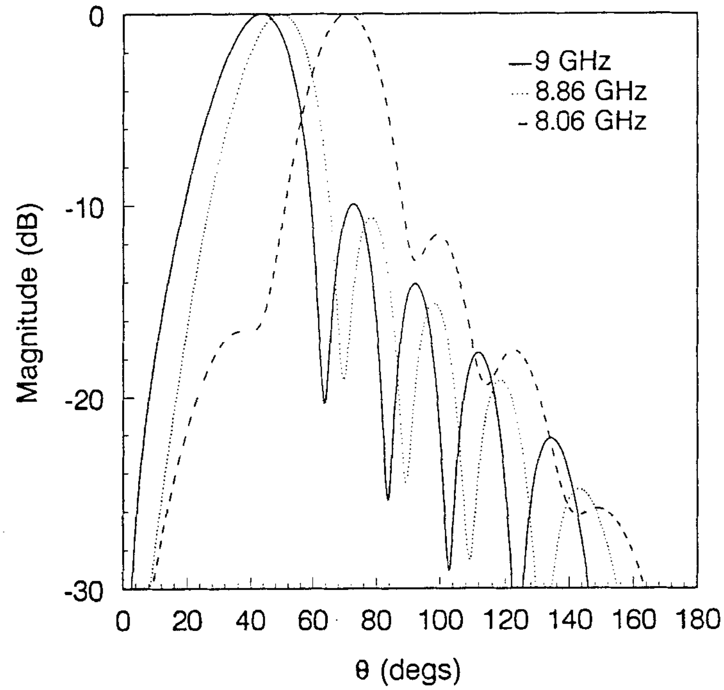

Fig.4. Theoretical H-plane (y-z plane) radiation patterns of the microstrip leaky-wave antenna for three different frequencies.

III. The Asymmetric Feeding Active Microstrip Leaky-Wave Antenna

Figure 1 shows the asymmetric feeding active leaky-wave antenna configuration. The circuit consists of a microstrip leaky-wave antenna integrated with a HEMT oscillator. To excite the first higher order mode, the microstrip leaky-wave antenna is fed asymmetrically. A sequence of covered wire was inserted in the center of the antenna to suppress the propagation of the dominate mode (whereas the longitudinal current would be zero for the first higher mode). The HEMT oscillator was designed using a small signal iterative procedure utilizing a commercially available CAD tool HP-EEsof Libra. A short-circuited microstrip feedback is used in series with the source to provide the device negative resistance. The leaky-wave antenna is connected to the drain to compensate the negative resistance under steady state operation. The circuit is designed and fabricated on RT/Duroid substrate with a dielectric constant of 2.2 and thickness of 20 mils. The low dielectric constant of 2.2 allows efficient antenna radiation. NEC NE32484 low noise HEMT is used, and the Drain is biased at 2.0 Volt with a drain current of 10 mA.

The output power P_0 was calculated using the Friss transmission equation:

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

where

P_r = Power received.

P_o = Power transmitted from the active leaky-wave antenna.

λ_o = Wave length in free space.

R = Antenna separation.

G_t = Gain of the transmit antenna.

G_r = Gain of the receive antenna.

If the active antenna gain is unknown, the Equivalent Isotropic Radiation Power ($EIRP$) defined below should be used.

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

A EIRP of 20 dBm was observed at 8.86 GHz for the active leaky-wave antenna. Figure 5 shows the measured H-plane radiation pattern which agree well with the prediction data.

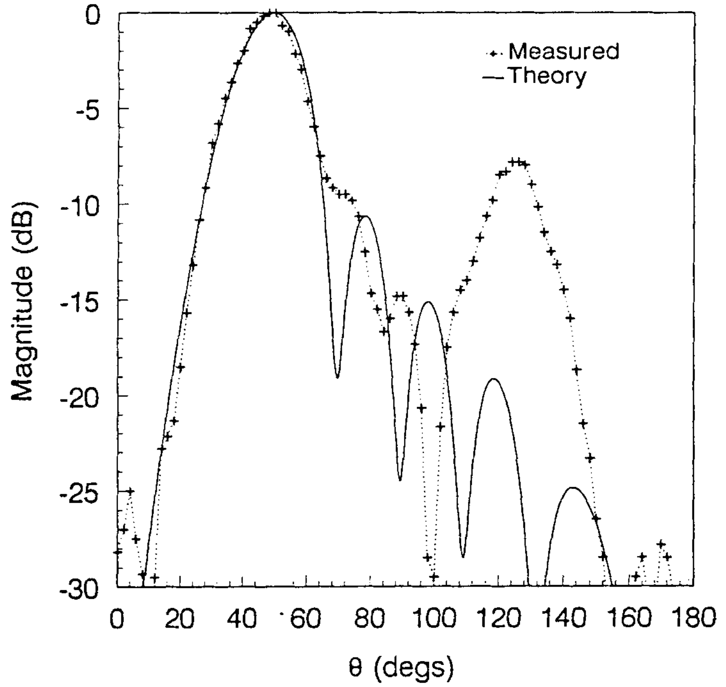

Fig. 5. The H-plane radiation pattern of the asymmetric feeding active leaky-wave antenna measured at 8.86 GHz.

IV. The Frequency-Scanning Active Leaky-Wave Antenna

Figure 6 shows the microstrip realization of the varactor-tuned frequency-scanning active leaky-wave antenna structure. The circuit is designed and fabricated on RT/Duroid substrate with a dielectric constant of 2.2 and thickness of 20 mils. NEC NE32484 low noise HEMT is used, and the Drain is biased at 2.0 Volt with a drain current of 10 mA. GaAs beam lead varactor (M/A-COM MA46585) is used as a tuning varactor, which has a capacitance ratio of 10:1 and a capacitor of 0.5 pF at 4 V. For a tuning voltage of 1.0 V to 10 V, the active leaky-wave antenna exhibits a tuning bandwidth of 8.06 to 9 GHz. This equivalent to over 10 % electronic tuning bandwidth. The variation of scanning angle as a function of frequency is shown in Fig.7, where the beam scanning angle is close to 30^{o}. Figure 8 shows the experiment results of the H-plane pattern for operating frequency at 8.06 GHz and 9 GHz. We can see from Fig.8 that as the operating frequency is lower, the beam swings up from z-axis. This phenomena can be referred to Fig.2 where it shows that the attenuation constant decrease as the operating frequency increases, resulting in the observed narrower beamwidth in Fig.8. The EIRP of this active antenna is about 18 dBm ± 2 dBm throughout the frequency tuning range. The difference in power level of the main beam is caused mainly by the varied impedance of the microstrip leaky-wave antenna.

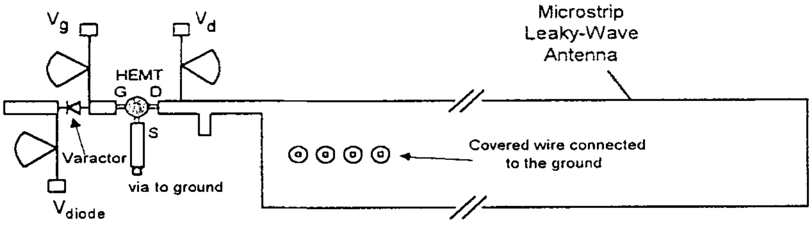

Fig. 6. Configuration of the varactor-tuned frequency scanning active leaky-wave antenna.

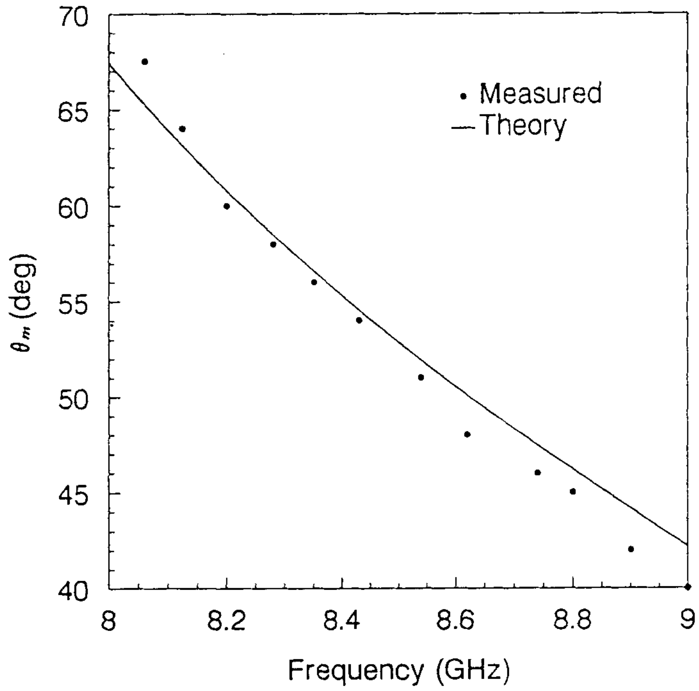

Fig. 7. Beam position angle θ_m versus operating frequency of the active microstrip leaky-wave antenna.

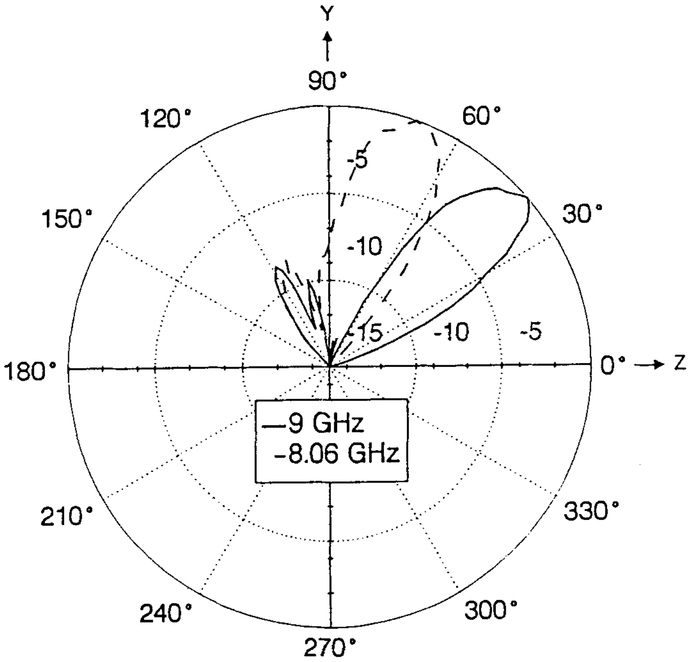

Fig. 8. H-plane (y-z plane) frequency scanned radiation patterns of the varactor-tuned active leaky-wave antenna measured at 8.06 GHz and 9 GHz

V. Conclusion

Two types of asymmetrical feeding X-band active leaky-wave antenna has been developed. In our active leaky-wave antenna, the first high order mode can be successfully excited by asymmetrical feeding. The present work demonstrated the operation principle for electronic beam control where such as phase shifters do not enter into the concept. Instead, we utilize the frequency scanning antenna, the microstrip leaky-wave antenna, as the beam scanning active antenna. By tuning the varactor DC bias, beam scanning control of close to 30^o is achieved. The measured beam scanning angle agrees to the predicted data. The circuit offers a small, simple, lightweight, low cost tunable source for many microwave application. And since it is planar, therefore it is suitable for monolithic circuit integration.

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