A New Two-Terminal Feeding Active Leaky-Wave Antenna

Chien Jen Wang, Christina F. Jou, and Jin Jei Wu

***Abstract*— A new two-terminal feeding active-integrated leaky-wave antenna design is demonstrated. The X-band microstrip two-terminal feeding leaky-wave antenna is integrated with an active high-electron mobility transistor (HEMT) oscillator to produce a two-beam radiation pattern. The antenna is fed asymmetricly at both sides to excite the first higher order mode. This configuration, as compared to a single-terminal feeding leaky-wave antenna, has the advantage of the multidirection and the reduction of the reflected wave caused by the open end of the radiating element. Measured results show that the radiation directions of two beams are approximately at 34° and 140°, the effectively isotropic radiated power (EIRP) is close to 17.5 dBm, and the return loss is almost less than −10 dB between 9 and 11.5 GHz.**

***Index Terms*—Leaky-wave antennas.**

Active planar antennas are important components in microwave and millimeter wave systems. Many prototypes such as patch antennas [1], circulator antennas [2], and leaky-wave antennas [3], have been demonstrated. They combine the solid-state devices or the signal sources with the passive radiating elements on the same substrate.

Recently, leaky-wave antennas have become popular and there is growing interest in the active-integrated leaky-wave antennas as frequency scanning elements. Due to their narrow beam and good scanning ability, much investigation of the leaky-wave antenna has been made [3], [4]. The leaky-wave antennas are operated in the first higher order mode; therefore, the space wave dominates most of the leakage and radiates away at some angle. Thus, a pencil beam can scan in the elevation plane. As the result of the finite length of the leaky-wave antenna, the reflected wave resulting from the mismatch of the open load of the microstrip antenna will leak from the end.

In this paper, a new configuration of the leaky-wave antenna, a compact two-terminal feeding leaky-wave antenna, is demonstrated. An active signal source, the high-electron mobility transistor (HEMT) oscillator, is integrated with a passive radiating element and the signal is fed from both ends of the leaky-wave antenna. This active leaky-wave antenna is designed to achieve a two-beam radiation pattern in the elevation plane. Because the signal is fed from both sides of the open end of the antenna, the effect of the reflected wave can be reduced.

An active two-terminal leaky-wave with a HEMT oscillator, is designed to operate at 10.4 GHz. The HEMT used here is a package type NEC NE42484A. The overall circuit is fabricated on a 20-mil (0.0508-cm)-thick Rogers RT-Duroid 5880 substrate with a dielectric constant of 2.2. The HEMT oscillator is designed using a small signal iterative procedure utilizing a commercially available CAD tool HP-EE's of Libra. The signal of the microstrip leaky-wave antenna is fed from both sides through a T divider (see Fig. 1).

The dimension of the antenna is chosen empirically in such a way that the first higher order mode can be excited. Fig. 2 shows the variations of phase constant β and attenuation constant α as functions of frequency. The circuit is operated at 10.4 GHz, in

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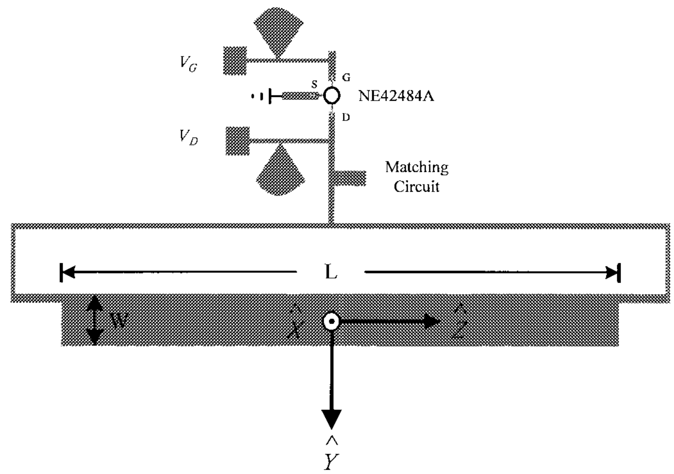

Fig. 1. The configuration of the active microstrip two-terminal leaky-wave antenna. $W = 11$ mm, $L = 150$ mm.

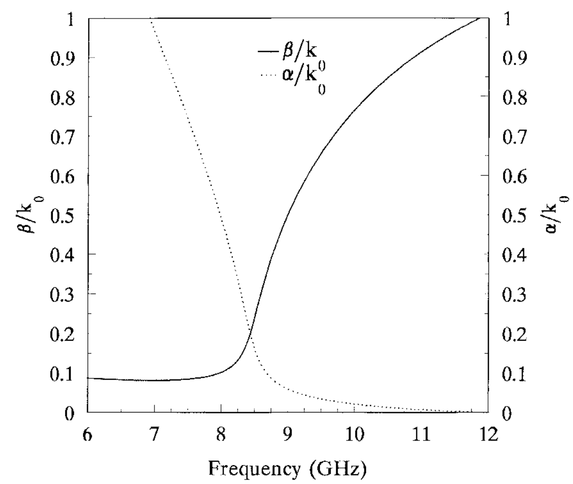

Fig. 2. Normalized complex propagation constant of the first higher order mode for the particular microstrip leaky-wave antenna. $H = 0.508$ mm, $W = 11$ mm, and $\varepsilon_r = 2.2$. k_0 is the free-space wave number.

radiation region, and the scanning angle θ can be calculated using the equation $\theta = \cos^{-1}(\beta/k_0)$, where θ is the elevation angle between the main-beam direction and the end-fire, i.e., the Z-axis direction. According to the value of Fig. 2, we calculate the theoretical angle of the main beam which is close to 34.5°. The length of the antenna is 150 mm $(5.20\lambda_0)$. To reduce the mismatch of the impedance, 50 Ω line is the better choice for the feeding line.

The measured S parameter of this configuration of the leaky-wave antenna is shown in Fig. 3. The parameter S_{21} shows that much of the incident power leaks from the antenna. Because between 9 and 11.5 GHz, the reflection loss S_{11} is approximately less than -10 dB, therefore, the leaky-wave antenna is a broad-band antenna and it is suitable to be used as a high-performance frequency-scanning radiator.

Under far-field condition, the radiation pattern of this two-terminal feeding active leaky-wave antenna was measured (see Fig. 4). The angle of the right beam is about 35° and the angle of the left beam is close to 140°. Excellent agreement between the theoretical angle and the measured angle of the right beam for this two-terminal feeding active antenna is obtained. For the left beam, there is approximately

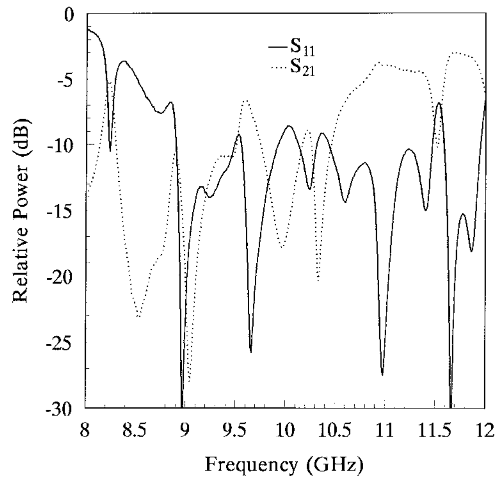

Fig. 3. Measured S parameter of the microstrip two-terminal leaky-wave antenna.

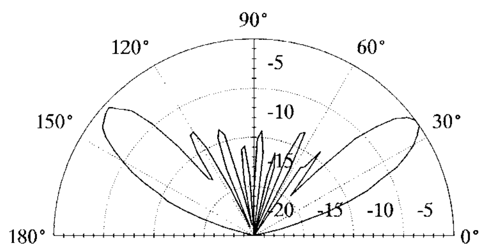

Fig. 4. The measured radiation pattern (X-Z plane) of the active two-terminal leaky-wave antenna.

a 5° error. The 3-dB beamwidth of the right beam is 15°, and the 3-dB beamwidth of the left beam is 14°. The measured effective isotropic radiated power (EIRP) of this antenna is 17.5 dBm for the right beam. The EIRP of the left beam is 16.83 dBm, 0.67 dB lower than the right beam.

Measured results show that our leaky-wave antenna not only has a wide bandwidth, but also produces two symmetric beams with respect to the normal direction of the antenna. Because of its wide bandwidth and multidirectional radiation pattern, this active two-terminal leaky-wave antenna can be used in systems such as the front-end transceiver of the mobile-collision avoidance system or the satellite communication system. Because it is planar, it is also suitable for monolithic circuit integration. Furthermore, in the future, a voltage-controlled oscillator (VCO) can be integrated with this configuration of the passive antenna element in order to control the two-side symmetric-beam angle electronically by varying the operating frequency.

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Electromagnetic Scattering by Weakly Lossy Multilayer Elliptic Cylinders

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***Abstract*—The analytic solution to the electromagnetic scattering due to a multilayer elliptic cylinder is generalized to the case of weakly lossy materials by using a first-order truncation of the Taylor expansion of each Mathieu function.**

***Index Terms*—Electromagnetic scattering, nonhomogeneous media.**

I. Introduction

The analytic solution to the two-dimensional scattering problem due to a single lossless homogeneous dielectric cylinder was obtained by Yeh in terms of Mathieu functions [1]. The extension to the case of several confocal lossless elliptic cylinders has recently been proposed by the authors [2]. Even though this problem has been considered to be "relatively intractable" [3], the series solution proposed in [2] exhibits a computational efficiency similar to that of the Yeh solution.

In this letter, the above series solution is generalized to the scattering by weakly lossy multilayer elliptic cylinders. Since software for Mathieu functions of complex arguments is not available, a first-order approximation, based on their analytical properties and on the first-order Taylor formula is developed. This allows the treatment of weakly lossy materials by making use of the available subroutine for the calculation of Mathieu functions of real arguments. To the best of our knowledge it is the first time that analytic results are provided concerning scattering by lossy elliptic cylinders.

II. Mathematical Formulation

Let us consider a TM plane wave illuminating an elliptic cylinder made up of N dielectric layers. In the i-th layer, $i = 1, \cdots, N$, the electric field can be expressed as

$$\begin{aligned} E_z^i(u,v) = &\sum_{m=0}^{\infty} \left[e_{m,1}^i Mc_m^{(1)}(q_i,u) + e_{m,2}^i Mc_m^{(2)}(q_i,u)\right] ce_m(q_i,v) \\ &+ \sum_{m=1}^{\infty} \left[o_{m,1}^i Ms_m^{(1)}(q_i,u)\right. \\ &\left. + o_{m,2}^i Ms_m^{(2)}(q_i,u)\right] se_m(q_i,v) \end{aligned} \quad (1)$$

where ce_m, se_m, $Mc_m^{(1)}$, $Ms_m^{(1)}$, $Mc_m^{(2)}$, and $Ms_m^{(2)}$ denote angular and radial Mathieu functions [1]; (u,v) are the elliptic coordinates and $q_i = (\frac{k_0 d}{2})^2 \varepsilon_{r_i}$ where $k_0 = \omega\sqrt{\varepsilon_0 \mu_0}$ and $\varepsilon_{r_i} = \varepsilon_i' - j\varepsilon_i''$ is the complex relative dielectric permittivity. This scattering problem can be solved in a quite efficient way by the procedure proposed in [2].

Since the generic Mathieu function $\xi(q_i, \eta)$, $\eta = u$, or v, is an analytic function of the complex variable q_i for $q_i \neq 0$ from the theory of complex functions, the derivative $\frac{\partial \xi}{\partial q_i} = \lim_{\Delta q_i \to 0} \frac{\Delta \xi}{\Delta q_i}$ can be calculated independently of the path along which Δq_i tends to

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