ACTIVE INTEGRATED LEAKY-MODE ANTENNA

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Abstract

The complexity involved in the design of active integrated antennas or arrays can be simplified by a new approach employing the leaky modes of planar or quasi-planar guided structures. This paper describes the recent advances in the active integrated leaky-mode antennas, showing very promising results for active array system integration.

I. Introduction

In the past two decades researchers recognized that simple scaling of low-frequency active microwave circuits and antennas did not provide satisfactory solutions for millimeter-wave applications. Thus alternative quasi-optical techniques emerged and replaced the conventional designs in numerous radio communication front-end circuit modules [1]. Since these new approaches integrated the active circuits and passive antennas on the same substrate, they were in fact examples of active integrated antennas. This paper reports how a new class of active integrated leaky-mode antennas emerge from the existing (traveling wave) leaky-wave type designs while not only possessing all the above-mentioned features but maintaining the inherent unique characteristics such as high gain, negligible cross polarization, no blind spots and no grating lobes [2]. Here the leaky-mode antenna is a terminology describing a class of leaky-wave antenna with uniform cross-section that slow leakage (radiation) of power takes place along a planar or quasi-planar waveguide.

II. Generic Microstrip Leaky-Mode Antenna

Fig. 1 illustrates a generic microstrip leaky-mode antenna from which a proximity coupling structure using the slotline underneath the microstrip can efficiently excite the first higher mode [3]. The supporting substrate can be either dielectric or gyromagnetic materials[4]. When the slotline is at the same length with the microstrip, the antenna is like a microstrip with tuning septum [5] except that the antenna now operates at the odd mode [6]. On the other hand, both measured and theoretic results showed that an approximately half wavelength long shorted slotline was efficient for exciting higher order leaky-mode [7]. Despite the length of slotline, Fig. 2 shows open microstrip's typical modal characteristics. Besides the well-known even-symmetric microstrip mode, two higher-order leaky modes and one leaky dominant mode (LDM) are present. The leaky dominant modes could be excited accompanying with the even microstrip mode [8, 9]. Therefore we focus on the active integrated antenna design applying the higher order leaky modes. The observed leaky-mode phenomena also appear in a microstrip on gyromagnetic substrate, where both higher-order leaky modes and leaky dominant modes were found [4, 10].

The knowledge of complex propagation constant ($\gamma=\beta-j\alpha$) directly determines the far-field antenna radiation pattern, of which the main lobe points to $\theta = \cos^{-1}(\beta/k_o)$ in a fan beam manner [11]. The symbols β, α and k_o represent phase constant, leakage (attenuation) constant and free-space wavenumber, respectively. Fig. 3 shows the radiation contour of a microstrip first higher leaky-mode antenna using the Fourier transform of the scanned near-field data [Nearfield Systems, Inc.]. The measured fan beam agreed with the theoretic prediction with its maximum located at $\phi = 0°$ plane, i.e., the H-plane of the antenna. If the active integrated antenna is printed on gyromagnetic substrate, the main beam can be steered by DC magnetization field. Fig. 4 illustrates how the fan beam scans in elevation by simply varying the external DC magnetic field [4]. If we replace the single microstrip leaky-mode antenna by an array properly spaced and phased, a pencil-beam in a conical manner will scan in both elevation and azimuth.

III. Active Integrated Antenna Source Module

It turned out that the generic microstrip leaky-mode configuration facilitated very compact and flexible packaging scheme for active integrated antenna, on which one side of the suspended substrate resided *the leaky-mode (array) antenna* whereas the other side distributed the *uniplanar (monolithic) microwave integrated circuits ((M)MICs)*, which had been widely adopted in microwave community [12,13]. Accordingly the array antenna design on one side of the substrate will not interfere with the microwave circuits on the other side, and vice versa [14]. The uniplanar (M)MIC incorporates coplanar waveguides (CPW), slotlines and airbridges for interfacing external ports and active microwave circuit designs. The CPW and slotline naturally merge into the backside of the generic microstrip leaky-mode antenna.

Attempting to develop a pencil-beam quasi-optical power combiner, Fig. 5 shows the layout of an X-band active integrated antenna source module of an array system, comprising an input injection-locked circuit, an HEMT oscillator with DC biasing circuits, a CPW-to-slotline transition circuit and a generic microstrip leaky-mode antenna. When the spatial injection is desired, one may illuminate the HEMT oscillator directly by a horn antenna without interfering the microstrip leaky-mode antenna [14]. The phase noise of -100 dBc/Hz at 100 KHz from the carrier (9.17 GHz) was obtained in the locked situation. The measured minimum input power for locking the transmission-type injection-locked source module was -10 dBm, -5 dBm and 0 dBm for 1.63%, 2.4% and 4.79% bandwidth operation, respectively. In practice the locking bandwidth should be kept wide enough for broad frequency scanning coverage.

By using the Friis transmission equation, the measured data indicated that 8.6 dBm output power emitted from the microstrip leaky-mode antenna, inferring that the DC-to-RF conversion efficiency was 11%. Under the condition that the complete active integrated antenna source module was placed in the near-field antenna testing system , the measured H-plane co-polarization and cross-polarization data against the elevation angle θ were plotted in Fig. 6, showing that the theoretic co-polarization profile agreed very well with the measured data while the measured cross-polarization profile was kept about -15 dB below the peak radiated power. The latter manifested that the cross-polarization of the microstrip leaky-mode antenna should be low. The reported performance assessment based on a series of measurements shows that the new active integrated microstrip leaky-mode antenna is a viable approach for quasi-optical (M)MIC design.

IV. Quasi-Optical Oscillator: the Frequency-Selective Feedback Approach

The leaky-wave antenna employing the periodic structure exhibited two unique features, namely, very high VSWR (high Q) at stopband and broadside radiation. Such phenomena had been genuinely applied to a quasi-optical transceiver design [15], incorporating a periodic microstrip antenna as a leaky-wave antenna operated at two regions, the stopband for the frequency-selective feedback of a self-oscillating FET mixer and the passband for the same receiving antenna.

For the generic microstrip leaky-mode antenna, the operation of frequency selective feedback can be different, owing to the non-periodic modal characteristics as shown in Fig. 2. To this end a self-oscillating mixer intended for FMCW sensor application is depicted in Fig. 7, showing the role of the microstrip leaky-mode antenna as a two-port device in the positive feedback loop for sustaining the oscillation [16]. The Barkhausen criterion determined the desired oscillation frequency. The power loss from the radiated leakage of the leaky-mode antenna was compensated by the amplifying stage, yielding a high-Q device as desired for any microwave source module.

V. Conclusion

This paper reviews the progress of active integrated microstrip leaky-mode antennas, explaining how such new technology emerged from two fields of studies, namely, the uniform leaky-mode waveguides and uniplanar (M)MICs , and demonstrating that the new technology is an attractive approach and a viable alternative to the development of active integrated (array) antennas. Good measured data from various quasi-optical source modules suggested that the merits of microstrip leaky-mode antenna and uniplanar (M)MIC were well retained by the new technology without compromising the electrical performance. This paper also reports three additional features that are unique to the new technology, the first enabling radiation pattern synthesis from a single leaky-mode antenna element, the second utilizing the complex characteristic impedance for matching within the active integrated antennas and the third allowing the second higher-order leaky-mode generation. Consequently the proposed design approach of active integrated leaky-mode antennas may result in a new linear N-element array wrestling with advantages over the available planar N^2-element arrays in performance, cost and ease of integration.

Acknowledgment

This work was supported by Taiwan National Science Council under contracts NSC85-2213-E009-003 and NSC84-2622-E009-011.

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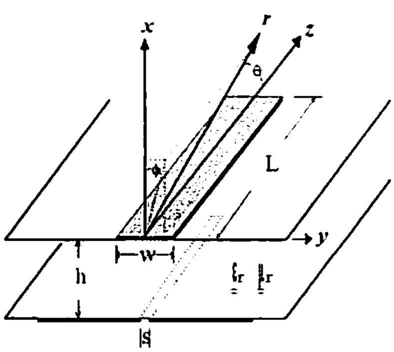
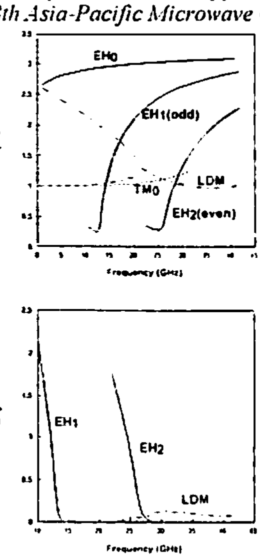


Fig. 1 Schematic of a generic microstrip leaky-wave antenna.



2(a) Normalized phase constants

2(b) Normalized attenuation constants

Fig. 2 Dispersion curves of a typical open microstrip line.

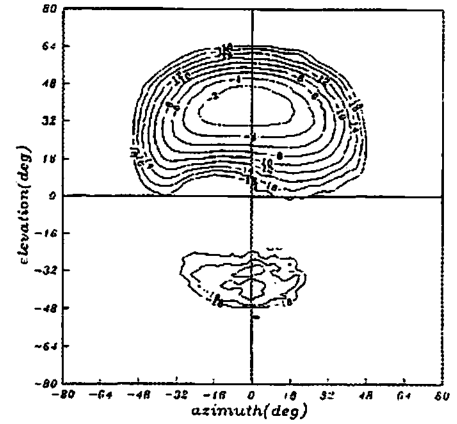


Fig. 3 Measured radiation contour of a microstrip leaky-mode antenna as shown in Fig. 1.

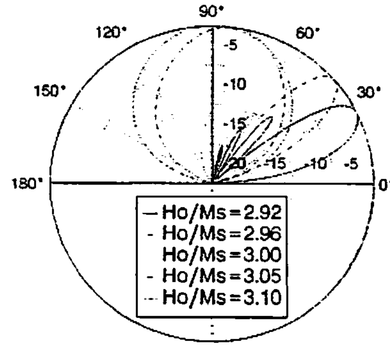


Fig. 4 The theoretic bias-dependent H-plane radiation patterns of a leaky-mode antenna on gyromagnetic substrate.

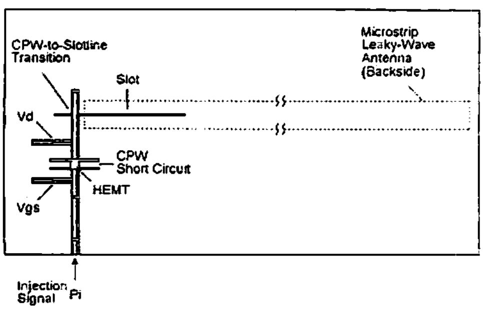


Fig. 5 Layout of the active integrated microstrip leaky-mode antenna source module.

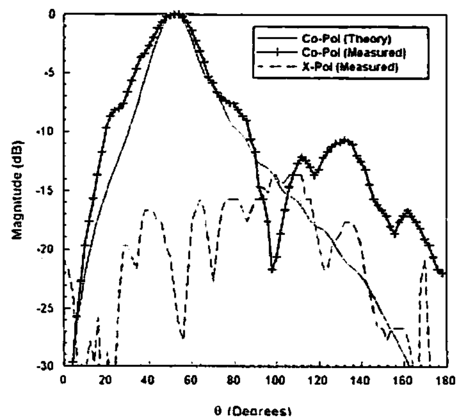


Fig. 6 H-plane pattern of the active integrated microstrip leaky-mode antenna source module at 9.17 GHz.

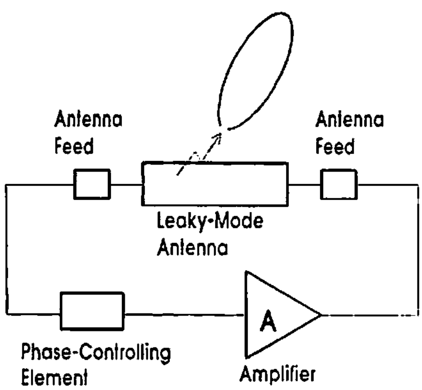


Fig. 7 Schematic of active integrated antenna source module incorporating the leaky-mode antenna as a feedback circuit.