Characterization of a Monolithic Slot Antenna Using an Electro-Optic Sampling Technique

Kenji Kamogawa, *Member, IEEE,* Ichihiko Toyoda, *Member, IEEE,*
Kenjiro Nishikawa, *Associate Member, IEEE,* and Tsuneo Tokumitsu, *Member, IEEE*

***Abstract*—The first electro-optic measurement of a monolithic antenna near-field is presented. A 10-GHz monolithic slot antenna is designed and precisely characterized by Electro-Optic Sampling (EOS). The fringing effect of a shorted slot and the influence of undesirable modes on the antenna's near field can be measured accurately. Therefore, the EOS technique is very effective for on-wafer measurement and the development of monolithic antennas.**

I. Introduction

MMIC/ANTENNA integration will be a key technology for future personal and radio access systems. Integrating RF/IF circuits and antennas into one chip will provide an excellent means for receiving/transmitting signals in an extremely compact and cost-effective way. Several monolithic antenna circuits in which circuits and antennas are integrated have been reported recently [1]–[5]. However, the reports failed to directly relate antenna design and measurement to the design of the MMIC because no thorough study was done on how to effectively perform on-wafer measurements for monolithic antennas.

Slot antennas are one of the most suitable antennas for integration with uniplanar and multilayer RF circuits. However, it is not yet clear how such circuits can be accurately designed and analyzed. Therefore, on-wafer near-field measurements are necessary for the rapid development of monolithic antennas and also for optimizing MMIC/antenna integration.

This paper proposes the use of Electro-Optic sampling (EOS) [6], [7] to characterize monolithic antennas. The near-field amplitude and phase of a 10-GHz monolithic slot antenna were measured. As a result, the electro-magnetic behavior at points just above the slot antenna has been precisely characterized.

II. Monolithic Slot Antenna

The 10-GHz monolithic slot antenna shown in Fig. 1 was fabricated on a GaAs substrate using a semiconductor process. The chip size is 6.5 × 1.5 × 0.6 mm. The slot length, L, is 5.87 mm and the width, w, is 0.1 mm. This slot antenna is fed by a coplanar waveguide through an air-bridge at a point offset from the center. The offset is roughly calculated to be 1.65 mm using the Moment method for 50-Ω impedance matching. The slot width is half the value of w at the feeding point. The slot antenna can be easily combined with uniplanar circuits on the chip.

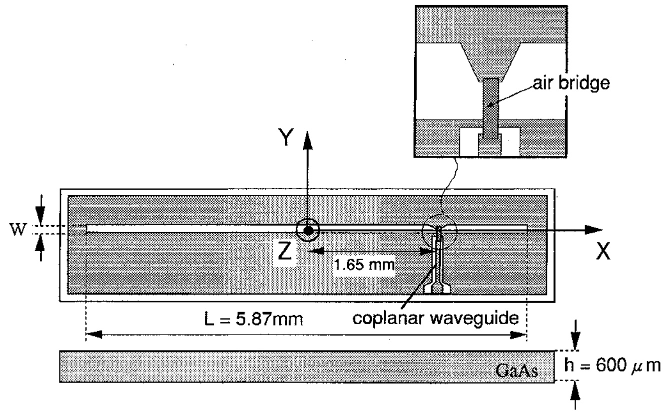

Fig. 1. Layout of the 10-GHz monolithic slot antenna (chip size: 6.5 mm × 1.5 mm × 0.6 mm).

III. Electro-Optic Sampling System

The external Electro-Optic sampling (EOS) system [6] shown in Fig. 2 utilizes the Pockels effect [8] in an EO material: the electric field radiated from the antenna changes the material's refraction in according to the field's strength. A change in the index simultaneously changes the polarization of the probing beam passing through the EO material, and all polarization changes are detected. A gain switched-diode laser with a 150-ps pulsewidth and a 100-MHz repetition rate is used for the pulse source, achieving the measurement up to 20 GHz. The EO probe tip (100–200 μm in diameter) is brought close to the circuit during measurement. The EO materials are $LiTaO_3$ and GaAs. These materials are used for measuring the transverse and the normal electric field, respectively. The probes are flat at the bottom as shown in the figure, and the bottom is a dielectric mirror coated to reflect the probing beam with high efficiency. The probing beam focused using a 20× microscope objective lens into a 2-μm spot on the dielectric mirror of the probe tip assures the accuracy of the measurement. The EOS measurement is performed as follows: while keeping the EO probe at the same height above the antenna, the system automatically controls the probe position through a workstation to survey the entire plane. Therefore, measurement accuracy is extremely good.

Manuscript received August 3, 1994.
The authors are with NTT Wireless Systems Laboratories, Kanagawa 238-03, Japan.
IEEE Log Number 9406700.

1051–8207/94$04.00 © 1994 IEEE

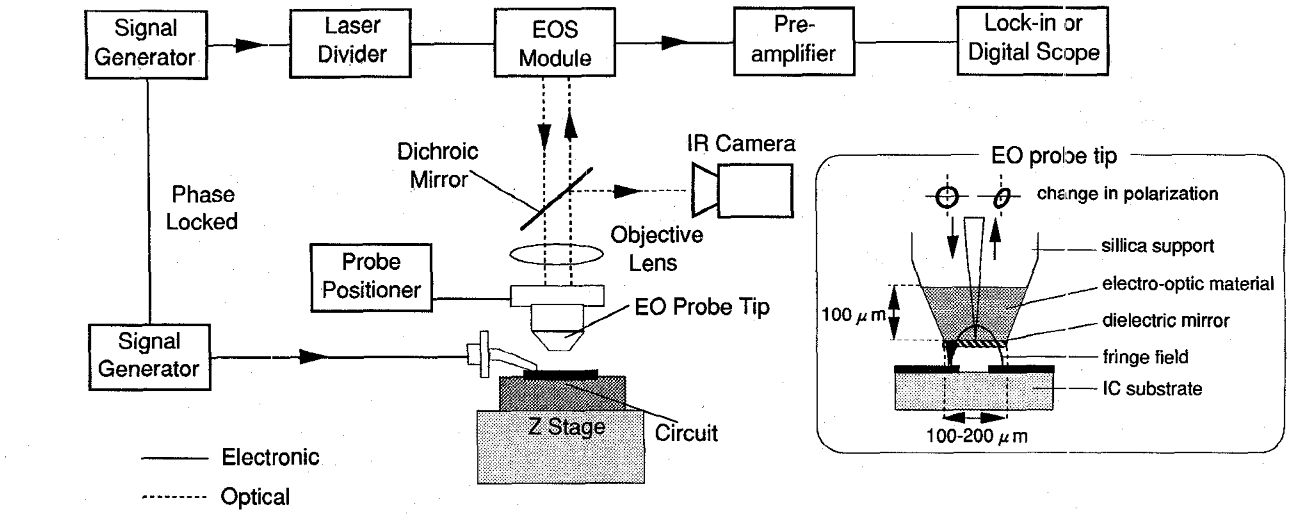

Fig. 2. The external EOS system configuration.

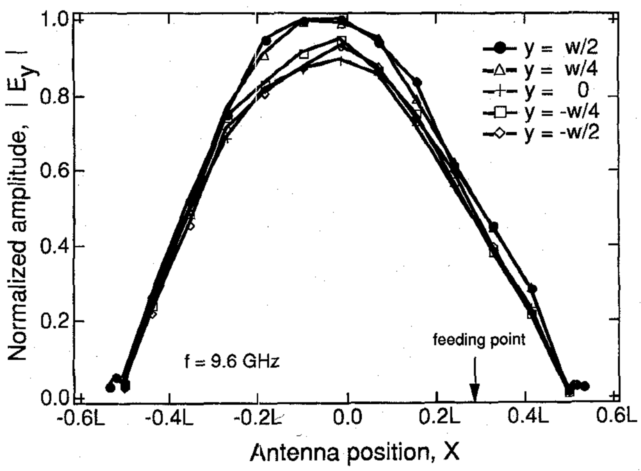

Fig. 3. Measured transverse-electric field (E_y) amplitude just above the aperture.

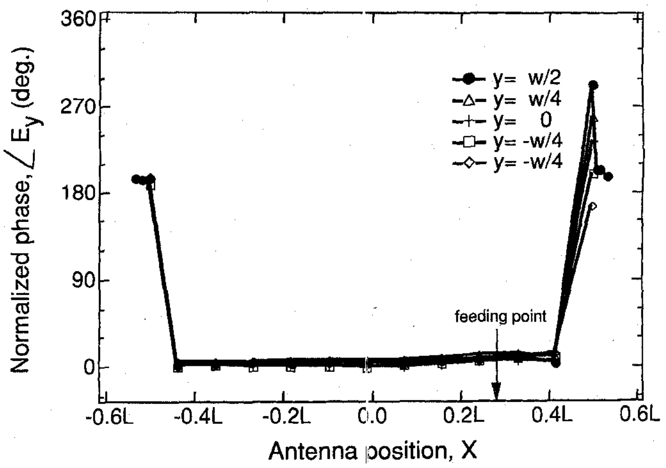

Fig. 4. Measured transverse-electric field (E_y) phase just above the aperture.

IV. Measured Results

The electric field of the monolithic slot antenna shown in Fig. 1 was measured using the external EOS method. Figs. 3 and 4 show the normalized amplitude and the phase of the transverse component of the electric field (E_y), respectively, just above the slot as a function of the antenna position. The measured E_y amplitude, which includes the very small scattering effect of the probe, is sinusoidal along the antenna-length direction, X, and nearly uniform across the antenna-width, Y. The distance between the substrate and the EO probe is set in 0.5 μm to measure the E_y field, which is also the magnetic current on the monolithic slot antenna. The radiation field can be easily calculated using the measured magnetic current distribution [9]. Therefore, the EOS makes it possible to characterize the normalized far-field pattern.

The imbalance mode, i.e., the coplanar waveguide mode is not perfectly transformed into the slot mode, causes the E_y amplitude along the Y-axis, which is not completely equal as shown in Fig. 3. This situation makes the imbalance mode noteworthy in the design of monolithic antennas. At the resonant frequency (9.6 GHz), magnetic currents just above the aperture do not have the phase component and a standing wave exists on the slot antenna. However, it is clear from Fig. 4 that the phase of E_y changes 180° at the ends.

Fig. 5 shows the measured amplitude of the normal component of the electric field (E_z) just above the aperture. It can be clearly seen in the figure that E_z on the feeder edge ($y = +w/2$) disrupts the normal component distribution, while on the other side ($y = -w/2$) it does not. This is caused by the slot discontinuity at the feed position, i.e., the slot width at the feed point is reduced by half. The measured E_z amplitude at the ends is not zero because of the fringing effect. Experimental characteristics of a short-end slotline have been reported by J. B. Knorr and J. Seanz [10]. Although they characterized the fringing effect using VSWR measurement, it is very difficult to accurately analyze the fringing effect under such radiation conditions. The EOS technique, however, makes it possible to precisely measure the effect.

V. Conclusion

The near field of a monolithic slot antenna fabricated on GaAs has been measured and characterized for the first time using an external EO probe. It was found that the phase of the transverse component of the electric field is turned 180 deg. at the ends. The EOS technique makes it possible to characterize

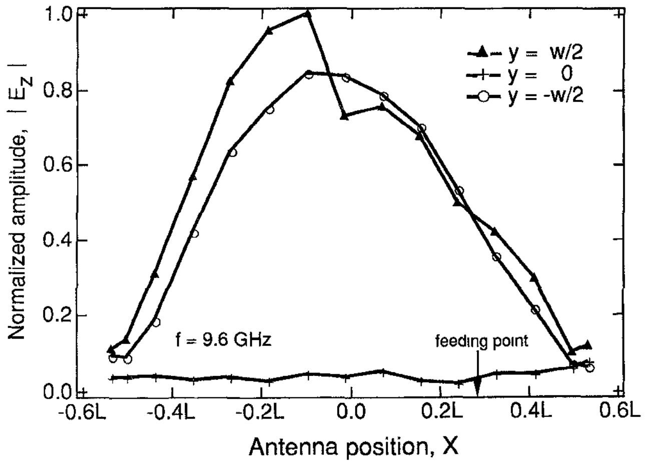

Fig. 5. Measured normal-electric field (E_z) amplitude just above the aperture.

the fringing effect under any condition. Therefore, the EOS technique is very effective for the on-wafer measurement of monolithic antennas and is expected to become a powerful tool for MMIC/antenna integration.

Acknowledgment

We would like to thank Drs. K. Morita and M. Aikawa of NTT Wireless Sys. Labs. and Drs. K. Takeya, T. Nagatsuma, and M. Shinagawa of NTT LSI Labs. for their continuous support and encouragement.

References

[1] D. M. Pozar and D. H. Schaubert, "Comparison of architecture for monolithic phased array antennas," *Microwave J.*, pp. 93–104, Mar. 1986.

[2] J. F. Millvenna, "Monolithic phased arrays for EHF communications terminals," *Microwave J.*, pp. 113–125, Mar. 1988.

[3] S. Kawasaki and T. Itoh, "Active integrated antenna based on slots with FETs," *1992 URSI Int. Symp. Signal, Systems and Electronics*, Sept. 1992, Paris, France, pp. 584–587.

[4] Z. B. Polovic, R. M. Weikle, Jr., M. Kim, and D. B. Rutledge, "A 100-MESFET planar grid oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-39, pp. 193–200, Feb. 1991.

[5] H. Ohmine, T. Kashiwa, T. Ishikawa, A. Iida, and M. Matsunaga, "An MMIC aperture-coupled microstrip antenna in the 40-GHz band," in *Proc. ISAP '92*1992, Sapporo, Japan, vol. 4.

[6] M. Shinagawa and T. Nagatsuma, "An automated optical on-wafer probing systems for ultra-high-speed ICs," in *Proc. Int. Test Conf.*, 1992, pp. 834–839.

[7] J. A. Valdmanis and G. Mourou, "Subpicosecond electrooptic Sampling: Principles and Apprications," *IEEE J. Quantum Electron.*, vol. QE-22, no. 1, Jan., 1986.

[8] F. Pockels, *Lehrbuch der Kristalloptik.* Leipzig: Teubner, 1906.

[9] I. J. Bahl and P. Bhartia, *Microstrip Antennas.* Dedham, MA: Artech House Inc., 1980.

[10] J. B. Knorr and J. Sesnz, "End effect in a shorted slot," *IEEE Trans. Microwave Theory Tech..*, vol. MTT-21, pp. 579–580, 1973.