Researches and Applications of Monolithic Millimeter-Wave Integrated Circuits at National Taiwan University

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Abstract

The recent research efforts of monolithic millimeter-wave integrated circuits at National Taiwan University are presented in this paper. The scope of our researches includes III-V compound based HEMT and HBT MMICs, as well as the silicon-based (CMOS and SiGe BiCMOS) RF/MMICs. State-of-the-art results have been achieved and some of the applications are also addressed.

Introduction

Microwave and millimeter-wave (MMW) technologies are very important in both civil and military applications. Monolithic microwave/MMW integrated circuits (MMICs) play an important role in modern microwave/MMW systems and have been developed using high-speed III-V (GaAs or InP) semiconductor technologies. The recent evolution of silicon-based IC technologies enabled the development of RFICs in microwave frequency range with low cost, and even MMW RF/MMICs were reported.

In this paper, the research accomplishments of monolithic microwave and millimeter-wave integrated circuits at National Taiwan University in the past few years are presented. The circuits include low noise amplifiers (LNAs), mixers, power amplifiers (PAs), switches, frequency multipliers and voltage control oscillators (VCOs). The highlights cover GaAs-based broadband MMICs, modulators, mixers, as well as several silicon-based (CMOS and SiGe BiCMOS) broadband circuits and VCOs. In addition, we have successfully developed a highly integrated 60-GHz single-chip receiver, which includes an antenna integrated with a mixer and an on-chip local oscillator. These accomplishments are expected to have significant impacts for future research works.

GaAs-based HEMT and HBT MMICs

The traveling-wave concept was used to implement a number of broadband MMICs using the GaAs 0.15- μm PHEMT MMIC process. Broadband single-pole-double-through (SPDT) and single-pole-single-through (SPST) traveling-wave switches operated to 135 GHz were developed and achieved low loss and high isolation performances [1]-[2]. A miniature broadband balanced frequency doubler using a reduced size rate-race hybrid, with good performance to convert frequency from 15-25 to 30-50 GHz was demonstrated [3]. In addition, in order to develop the high gain and wide bandwidth amplifiers, an approach using combination of conventional distribution amplifier (CDA) and cascaded single stage distributed amplifier (CSSDA) was proposed and achieved 20-dB gain over dc-40 GHz in a single chip [4].

We have also developed MMW BPSK and IQ modulators using GaAs-based 1- μm HBT technology. These modulators are based on the reflection type vector modulators and can be

operated from 60 to 110 GHz with very low LO power (about -10 dBm) [5]. MMW HEMT mixers were also implemented, including a miniature uniplanar Q-band (35-40-GHz) active mixer using a novel multi-function transition [6], a sub-harmonically pumped resistive W-band mixer using a new MMW transformer balun [7], and a very compact wide-band diode mixer using a modified Marchand balun [8].

Silicon-based RF/MMICs

Owing to the recent advances in silicon-based CMOS and SiGe HBT technologies, we further exploit to implement the RF/MMICs using the standard CMOS and SiGe BiCMOS processes with impressive results achieved. The highlights for CMOS broadband amplifiers include dc-14 and dc-22-GHz distributed amplifiers [9], a miniature CMOS 0.3-25-GHz amplifier implemented using CSSDA approach [10], a CSSDA broadband SiGe HBT amplifier using loss compensation technique [22], and a novel design of cascaded multi-stage distributed amplifier (CMSDA) using 90-nm bulk CMOS demonstrating 7-dB gain from dc to 70 GHz [11]. A novel loss-compensation technique was proposed to enhance the gain of a CSSDA using SiGe HBT and achieved 15-dB gain from dc to 28 GHz [21]. We also developed a broadband reflect-type BPSK modulator using 0.13- μm CMOS cover 15-75 GHz [12]. Another highlight is the push-push VCOs at 63 and 131 GHz [13]-[14] using CMOS cross-couple pairs. The first CMOS MMW switch is also demonstrated with 3-4 dB insertion loss [15].

Integrated Design and System Applications

We also extended the research efforts to further integrate our developed components into a V-band single-chip receiver using GaAs PHEMTs [16]. This chip has a receiving antenna comprising a pair of folded slots and a pair of diodes to form a singly balanced mixer imbedded in the antenna in order to reduce the chip area. The on-chip V-band local oscillator was designed in conductor-back CPW (CBCPW) and feed to the folded slot via a miniature CPW-to-slotline transition. The success of this demonstration indicates the feasibility of the system-on-chip (SOC) concept at MMW frequency.

The research efforts of our MMIC development also supported a real system application, that is, the receiver of the 85-105-GHz radio telescope "Array for Microwave Background Anisotropy" (AMiBA) system [17]. The MMIC components include a W-band InP-based HEMT LNA [18], a W-band singly balanced GaAs-based gate HEMT diode mixer [19]. Several wide-band analog multipliers covering dc-20 GHz are also developed for the correlators, including a GaAs HBT Gilbert-cell mixer [20], a broadband CMOS Gilbert-cell mixer with LC ladder [21], and a SiGe HBT Gilbert-cell mixer using loss-compensation technique with LC ladder networks to

achieve 19-dB conversion gain from 0.1 to 23 GHz and superior low frequency noise figure [22].

Summary

We have presented the recent research efforts on microwave and millimeter-wave integrated circuits at National Taiwan University. It is apparent that these research results will have significant impact for future research work in this area.

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