Review of Fast, Efficient and Bendable Radio-Frequency Integrated Receivers for the Wireless Communication Systems of the Future

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***Abstract*— This paper focus on the review of leading-edge integrated radio frequency (RF) receiver chips for the wireless communication systems of the future. A 190 GHz silicon germanium bipolar complementary metal oxide semiconductor (SiGe BiCMOS) transceiver chip with 47 dB gain and power consumption of only 122 mW is presented. Moreover, a 2.4 GHz SiGe BiCMOS receiver with aggressive duty cycling is presented which can be operated with a power consumption down to 3 µW. Last but not least, a 20 MHz receiver with 15 dB gain is presented which is fully integrated in a bendable plastic substrate and does not need any rigid components.**

Keywords—high-speed integrated circuits, receiver, flexible electronics, wireless communications

I. Introduction

The wireless communication technologies of the future will improve our quality of life. However, the challenges for RF circuits will massively increase. Advanced approaches are needed to make the required integrated circuits (ICs) much faster and much more energy-efficient. If we succeed in making wireless communication systems also bendable or even stretchable, a further unique selling point can be created. This will enable novel applications for communications, transportation, industry and medicine.

SiGe BiCMOS technology is very well suited for lower power consuming as well as high frequency circuits [1]. Compared to CMOS circuits [2, 3], SiGe BiCMOS technologies provide better performance. For our fast 190 GHz wireless receiver, as well as our ultra-low power consuming wireless 2.4 GHz receiver, we use an IHP 0.13 µm SiGe BiCMOS technology with a transit frequency (f_t) of around 300 GHz.

Moreover, we present a receiver, which is fully integrated in a bendable plastic foil using Indium Gallium Zink Oxide (IGZO) thin film transistor (TFT) technology providing a f_t of up to 300 MHz [4].

II. High-Speed Receivers

We have designed a SiGe millimeter-wave transceiver at 190 GHz, which provides 50 Gb/s [5] using binary phase shift keying (BPSK). Since no amplitude levels are needed, no analog to digital or digital to analog converters are required. This is one reason why the power consumption is very low. The power consumption of the transceiver frontend amounts only 154 mW, which is the lowest of its class.

In table 1, the measured results of our transceiver are summarized and compared with a recent state of the art work operating around 200 GHz as well. The other work provides higher data rates but consumes much more power. In comparison, our transceiver needs much less power per bit. We apply compact bond-wire antennas with 4.9 dBi gain, a 360° azimuthal coverage and a radiation efficiency of up to 92 % [7].

We focus in this paper on receivers. Hence, we would like to present now details of the receiver frontend. The schematics, chip photo, measured conversion gain and measured compression behavior are shown in Figs. 1-4. The receiver has a center frequency of 190 GHz, a bandwidth of at least 35 GHz, a high gain of up to 47 dB and a minimum double-side-band noise figure of 10.7 dB. The receiver requires a moderate local oscillator input power of -20 dBm and consumes only 122 mW.

TABLE I. BiCMOS Transceivers Around 200 GHz

Parameter	This work [5]	[6]
Operation frequency	170-210 GHz	225-255 GHz
Modulation	BPSK	QPSK
Data rate	50 Gb/s	65 Gb/s
Power consumption	154 mW	1960 mW

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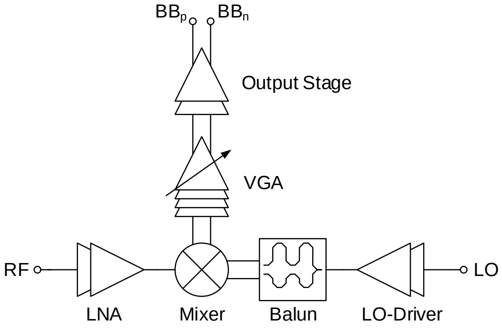

Fig. 1. Architecture of 190 GHz receiver

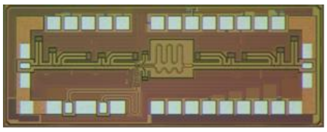

Fig. 2. Chip foto of 190 GHz BiCMOS receiver, chip area is 1.24 mm^2

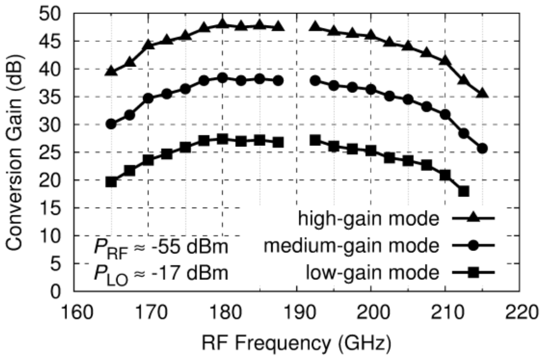

Fig. 3. Measured conversion gain of 190 GHz receiver versus radio frequency

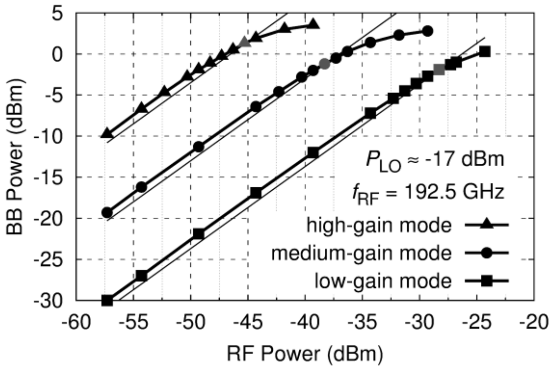

Fig. 4. Measured baseband power versus radio frequency power to extract compression bahavior

III. LOW POWER RECEIVERS

To reduce the power consumption, we exploit the fact that maximum performance is typically only needed during a fraction of time. The adaptive tuning of parameters such as the transmit power, bandwidth, on-times, number of antenna paths and antenna beamforming characteristics [8, 9] can massively save energy.

A wireless receiver with an ultra-low power consumption of only 3 µW is presented [10]. Aggressive duty cycling can strongly reduce the power consumption in wireless receivers. The duty cycling describes the fraction of time a circuit is on. The smaller this on-time, the lower the power consumption but also the possible data rate. In Fig. 5, the typical architecture of an on/off keying receiver is shown. Our chip implementation in BiCMOS is depicted in Fig. 6. The corresponding measured power consumption is plotted in Fig. 7 versus data rate. At an ultra-low power of 3 µW, a data rate of 60 bit/s is measured. Such low data rates are e.g. sufficient for wake-up receivers to receive an activation signal. A data rate of 8 kbit/s is measured at a power consumption of 100 µW. To maximize the time during which data can be received, our frontend is optimized for minimum on-times, which are below 60 ns.

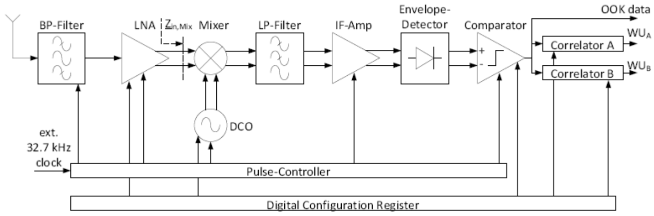

Fig. 5. Architecture of a typical on/off keying receiver which is also suited as wake-up receiver

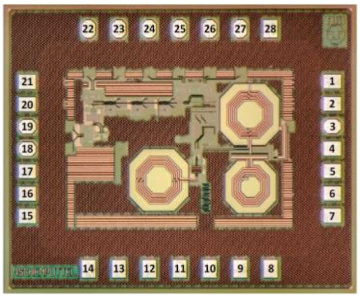

Fig. 6. Chip foto of ultra-low power on/off and wake-up receiver in BiCMOS

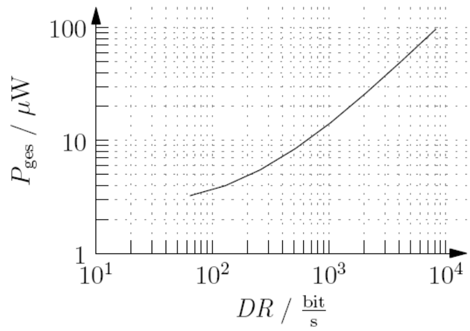

Fig. 7. Meassured power consumption of on/off and wake-up BiCMOS receiver

IV. BENDABLE WIRELESS RECEIVERS

Moreover, the world's first fully integrated bendable thin-film transistor (TFT) based wireless data receiver frontend using mechanically flexible IGZO TFT technology is presented [11]. This work shows that bendable and stretchable wireless communication receivers can be designed on a thin piece of plastic and do not require rigid chips (e.g. on silicon) any more. Such bendable wireless communication chips are e.g. very well suited for textile integration, medical applications and wearable computing.

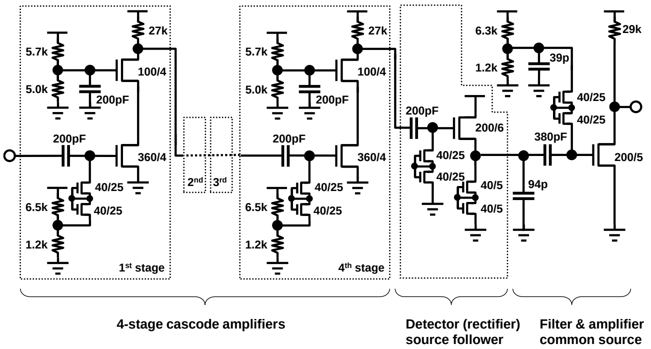

Fig. 8. Schematics wireless bendable TFT receiver

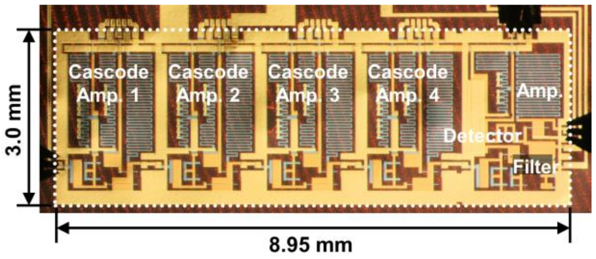

Fig. 9. Chip photo of wireless bendable TFT receiver

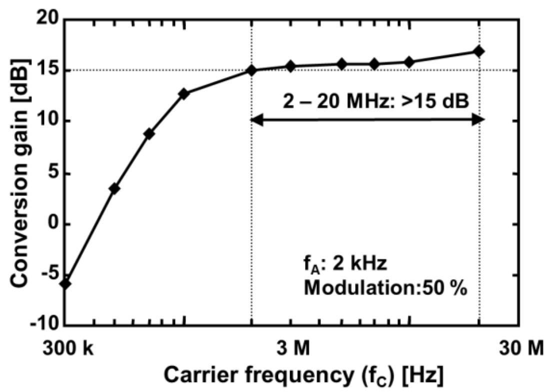

Fig. 10. Measured conversion gain of wireless bendable TFT receiver

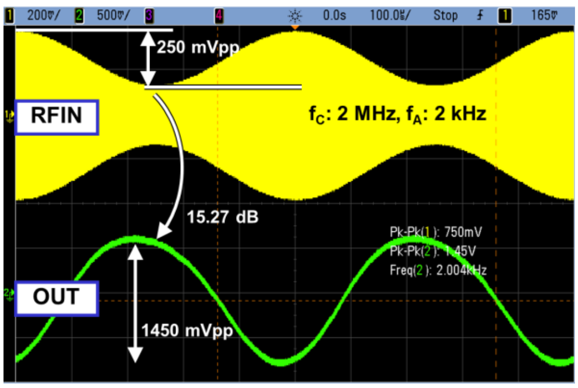

Fig. 11. Schematics, photo and measurements of wireless bendable TFT receiver

In Fig. 8, the schematics of the bendable receiver applying amplitude modulation is shown. At a carrier frequency ranging from 2 to 20 MHz, we measured a conversion gain of at least 15 dB. The 3 dB-bandwidth of the baseband signal ranges from 400 Hz to 10 kHz. The receiver draws a moderate current of 7.2 mA from a 5 V supply. It requires a plastic foil area of 3 × 9 mm^2. A tailored textile integrated loop antenna based on woven metal wires was designed [12].

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