Balanced Topology to Cancel Tx Leakage in CW Radar

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***Abstract*—Balanced topology in radar front-end is presented, which can reduce Tx leakage to receiver drastically. The balanced radar front-end which is composed of a differential cross-coupled oscillator, two Lange couplers, and a Wilkinson combiner is implemented using commercially available InGaP/GaAs heterojunction bipolar transistor technology. The tuning range of voltage control oscillator is 320 MHz from 25.307 to 25.627 GHz. The peak output power is 0.8 dBm. Average Tx-to-Rx isolation is about 40.5 dB. Since the isolation of the Lange coupler is 19 dB, the additional cancellation due to balanced topology is expected to be 21.5 dB. The chip size is 1.05 $\times$ 1.70 mm^2.**

***Index Terms*—Balanced radar topology, small radar, Tx leakage canceller.**

I. Introduction

RECENTLY, the demands of small radar systems such as automotive collision avoidance radar, traffic control sensor, and motion detector, are increased. So, low cost and high performance radar is required [1], [2]. Continuous wave (CW) radar is very simple to be implemented because it requires fewer components compared to pulsed radar [3]. This, therefore, allows small size and low cost solutions. However, CW radar has some inherent problems when single antenna is used to transmit and receive the signal. The large leakage signal from transmitter due to the low isolation of circulator or the reflection from the antenna can reduce the sensitivity of the receiver, and even saturate the receiver components, so that the dynamic range of the receiver is reduced. Therefore, most of CW radars separate the transmitting antenna and the receiving antenna to improve Tx-to-Rx isolation [3]. However, in this case, the radar size becomes doubled, since the antenna determines the size of radar. To achieve good Tx-to-Rx isolation performance using single antenna, reflected power canceller (RPC) has proposed [4]–[6]. It has been reported good Tx-to-Rx isolation performance up to X-band. However, it is difficult to implement RPC in mm-wave frequency because it needs high performance vector modulator. Also, it is very complex to be implemented. This paper presents a new method to reduce TX leakage with simple structure in single antenna radar system.

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II. Balanced Radar Topology

Fig. 1 shows the block diagram of the proposed balanced radar system. The system is composed of a balanced oscillator, two Lange couplers, and a Wilkinson combiner. A balanced oscillator instead of a balun with an oscillator was used to generate the balanced signals which have equal amplitude and anti-phase. This is because baluns show more imbalance in mm-wave frequency. Lange coupler was used rather than circulator, because it can be integrated with other MMICs. One coupled port of the Lange coupler (A1) is connected to the antenna which is matched to 50 Ω, the other coupled port (A2) is terminated with 50-Ω terminator. In this case, because the system uses a single antenna to transmit and receive signals, the size of radar can be reduced by half. The isolation ports of the two Lange couplers are combined with Wilkinson combiner (B).

Tx leakage signal can be suppressed by the two steps. At the first, balanced Tx leakage signals are reduced due to the isolation of the Lange coupler, and, then, canceled out when they are combined with Wilkinson combiner because the leakage signals are balanced. Thus, Tx leakage signal can be suppressed much more than only one Lange coupler is used. As a result, we can increase the gain of LNA without the saturation and then the noise figure of the receiver can be improved. The proposed balanced radar topology can also reduce Tx leakage noise because it operates in a fully balanced structure. The topology uses only passive components such as Lange coupler and Wilkinson combiner compared to the RPC. Therefore, it is very simple to be implemented and has broadband performances.

III. Circuit Design and Device Technology

To generate balanced signals, differential cross-coupled oscillator was used. LC tank of the voltage control oscillator (VCO) was implemented using microstrip line inductor and MIM capacitor. Since the microstrip line inductors have higher quality factor and self-resonant frequency than on-chip spiral inductors in mm-wave band, low-phase noise performance can be achieved. VCO core current is controlled by current mirror. To reduce the frequency pulling, the output buffer is used. The base-collector junction capacitance of heterojunction bipolar transistor (HBT) is used as a varactor for the frequency tuning. Lange coupler and Wilkinson combiner are designed using Agilent ADS.

Balanced radar front-end was fabricated using 6-in InGaP/GaAs HBT HS process at Knowledge $*$ on foundry. The large signal model of the transistor was performed using vertical bipolar inter-company (VBIC) model. One finger 2×4 μm^2

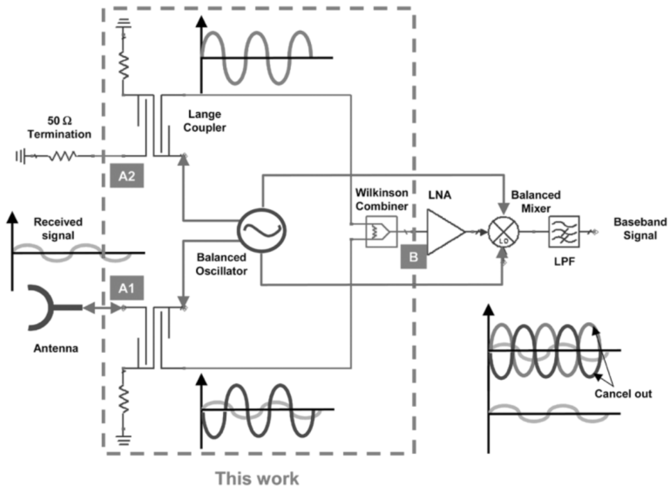


Fig. 1. Balanced radar topology.

HBTs were used in the VCO core circuit. This device shows a cut-off frequency (f_T) of 55 GHz and a maximum oscillation frequency (f_{MAX}) of 100 GHz. A turn-on voltage of HBT is 1.21 V. The technology provides a SiNx MIM capacitor with 600 pF/mm^2, a 50 $\Omega/\square$ NiCr resistor and two metal layers of which thickness are 1.3 and 4 μm, respectively. All circuits are passivated by polyimide. The wafer is thinned to 95 μm with backside via. Fig. 2 shows the microphotograph of the fabricated balanced radar front-end. The chip size is 1.05×1.70 mm^2.

IV. Measurement Results

The spectra were obtained from HP 8564E spectrum analyzer. The losses of the microprobe and the cable and the connectors are about 5 dB at K-band. The free running oscillation frequency of 25.627 GHz is achieved. It provides the output power of 0.4 dBm. Fig. 3 illustrates the oscillation frequency and the output power characteristics as the varactor control bias is varied from 0 to 5 V. The frequency tuning range is 320 MHz from 25.307 to 25.627 GHz. The output power variation is less than 1 dBm in the tuning range. The total current consumption is 24 mA at 5 V. Fig. 4(a) shows the output spectrum of the coupled port of Lange coupler which shows the output power of -4.6 dBm without the loss compensation of the measurement setup. Fig. 4(b) shows the output spectrum of Wilkinson combiner which shows the output power of -43.1 dBm. Tx leakage suppression was 38.5 dB at 25.627 GHz. Fig. 5 shows the Tx leakage suppression for the tuning frequency of the VCO. Average Tx leakage suppression of about 37.5 dB was achieved. The Lange coupler distributes the input power equally to two output ports of a through port and a coupled port, so that the total Tx leakage suppression is about 40.5 dB which is 3 dB higher than that at the coupled port of Langer coupler. The Lange coupler isolation is measured using HP 8560C VNA. The isolation of Lange coupler is about 19 dB within tuning range of the VCO. It is shown that the additional suppression of Tx leakage due to the balanced radar topology is 21.5 dB.

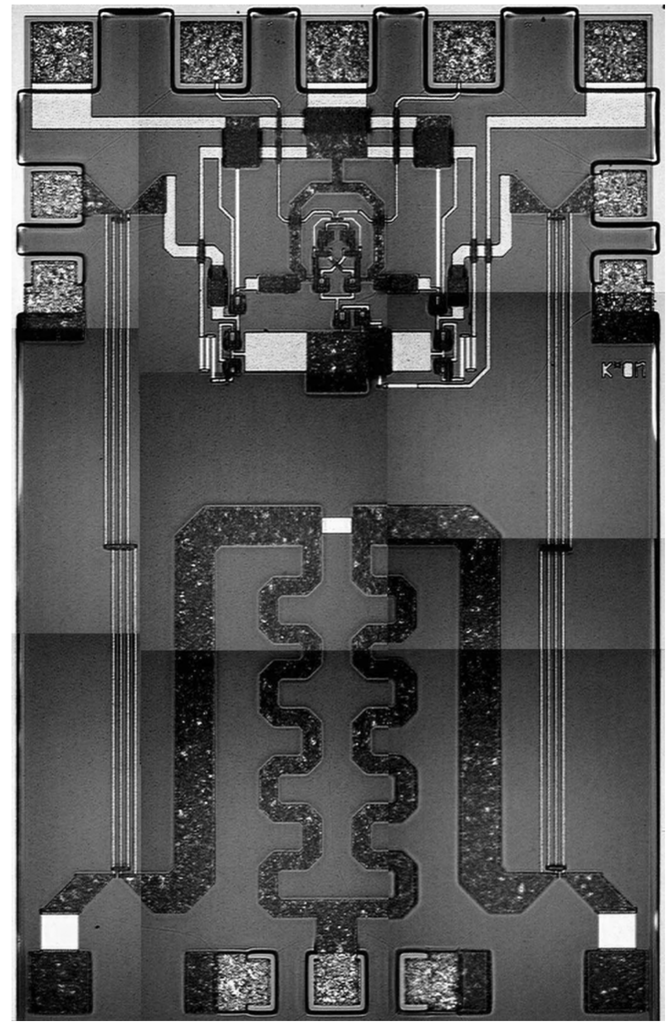


Fig. 2. Microphotograph of the fabricated balanced radar front-end (chip size: 1.05×1.70 mm^2).

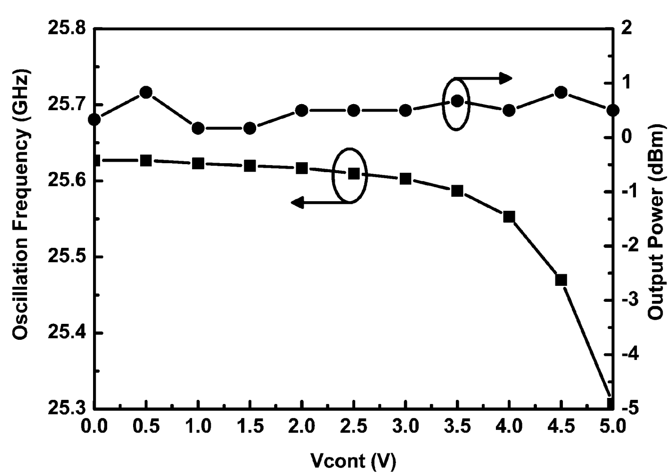
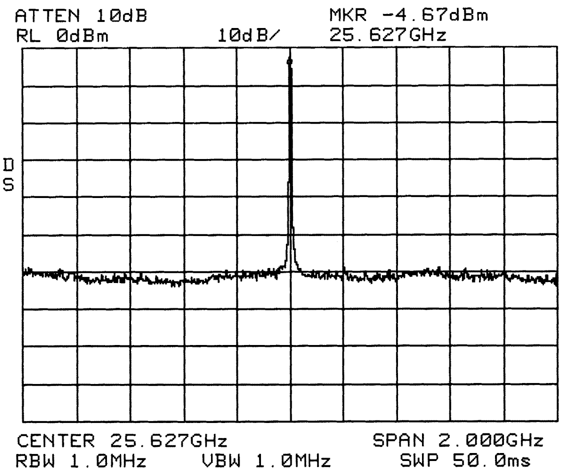


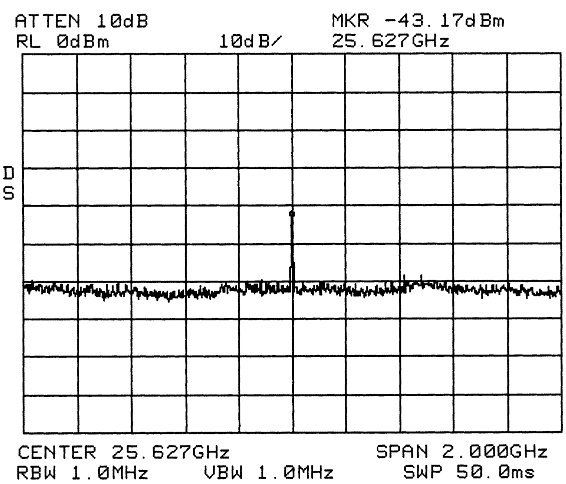
Fig. 3. Oscillation frequency and the output power of the VCO as varying the varactor control voltage bias.

V. Conclusion

We have present a new method to suppress the Tx leakage which reduces the sensitivity of the receiver by using balanced radar topology. The balanced radar front-end was implemented



(a)



(b)

Fig. 4. (a) Measured spectrum of the coupler port of Lange coupler. (b) Measured spectrum of the output of Wilkinson combiner.

using commercially available InGaP/GaAs HBT technology. A differential cross-coupled VCO, two Lange couplers and a Wilkinson coupler were implemented to have a balanced

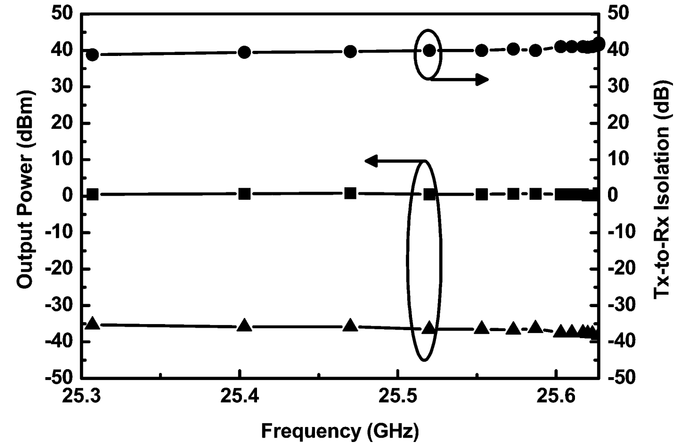


Fig. 5. Tx leakage suppression as the tuning frequency of VCO. (■) Output power of the coupled port of lange coupler. (▲) Output power of the combined port of wilkinson combiner. (●) Tx-to-Rx isolation.

radar front-end. The tuning range of VCO is 320 MHz from 25.307 to 25.627 GHz. The peak output power is 0.8 dBm. Average Tx-to-Rx isolation of about 40.5 dB was achieved at K-band although it is very simple. This result is comparable to two antennas system, where the transmitting and the receiving antenna are separated. The small chip size of 1.05×1.70 mm^2 is achieved.

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