# AN I-Q MIXER AT 76.5 GHZ USING FLIP-CHIP MOUNTED SILICON SCHOTTKY DIODES

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### ABSTRACT

**Silicon Schottky diodes show the advantages of low 1/f noise combined with low cost. We use these diodes in hybrid flip-chip configuration to build a novel I-Q mixer at 76.5 GHz for automotive applications. The realized mixer shows promising features such as 10 dB conversion loss @ 100 kHz IF, LO-to-RF isolation better than 25 dB, and average IF noise power of –80 dBm.**

### I. INTRODUCTION

With an average of more than 50 million vehicles produced every year and an increasing share of electronics within these cars, a growing number of car manufacturers deals with advanced security systems such as automotive radars. Fig. 1 shows the present and future global market volume for vehicle electronics systems [1].

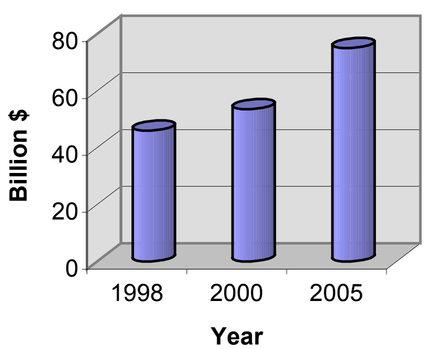


Fig. 1 Global demand for vehicle electronics systems.

As can be seen, there is a big demand for low cost, reliable, and easy to manufacture RF front-ends. These needs can be satisfied with waveguide [2]-[3], hybrid integrated [4] or monolithic integrated circuits [5]. Though there are many works dealing with monolithic mixers [6]-[8], only few consider the hybrid approach [9]. The combination of discrete active devices together with low-cost passive substrates combines the advantages of excellent reproducibility of the device with easy processing of the substrate. Additionally, different device technologies can be used and defective components can be replaced easily. The devices are mounted on the substrate using flip-chip technology suitable for automatic pick and place operation.

Actually, automotive radar systems are used as safety features (e.g. collision warning [10]) and it is expected that they will be applied in the future increasingly as comfort features (e.g. autonomous cruise control). In these systems, fast and faultless target recognition, classification and tracking is inevitable.

Automotive FMCW radar systems are usually operated with homodyne receivers. From that follows that the IF is generated in the audio frequency range making the system sensitive to $1/f$ noise contributions from the receive mixer.

Using a one-channel receiver, the target velocity sign can be deduced by comparing the Doppler shifts in the FMCW up- and down sweep. If a quadrature I/Q receiver is utilized instead, the velocity sign information can be easily derived from the phase between I and Q channels [11].

In this paper, we present a 76.5 GHz I-Q mixer realized in hybrid technology. Microstrip technique is used to connect the mixer diodes. In contrast to earlier published works [9], we use silicon diodes, showing superior $1/f$ noise properties compared to GaAs diodes. The design was performed in two steps. In a first step, the passive circuits were modeled and measured to prove the accuracy of the used full-wave approach. In a second step, the mixer was designed and characterized.

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## II. NONLINEAR DEVICE DESCRIPTION

We use Schottky medium barrier diodes from Infineon Technologies as nonlinear mixer devices. These silicon diodes have gold-bumps allowing flip-chip mounting using thermal compression bonding. To examine the influence of the package we use two different diode packages. The dimensions of the larger package are 520 µm × 330 µm (Fig. 2) compared to 260 µm × 220 µm of the smaller one. The diameter of the active diode region is in both cases 5 µm.

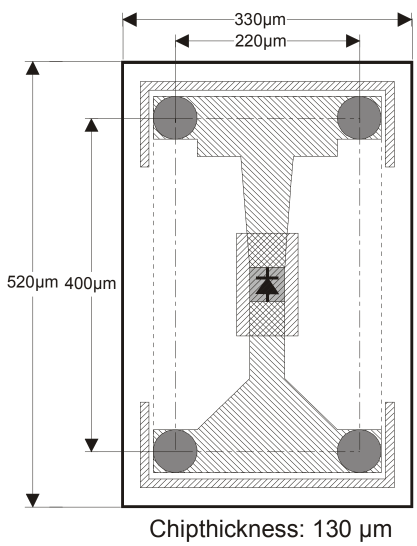


Fig. 2 Silicon Flip Chip Schottky Diode.

Compared to active GaAs-HEMT mixers or discrete GaAs mixer diodes, silicon Schottky diodes show much lower 1/f noise. This is an important feature in homodyne receivers with very low IF.

## III. PASSIVE STRUCTURE DESIGN AND MEASUREMENTS

Before designing the entire mixer, passive circuits consisting of a 3-dB Wilkinson divider (to split the LO signal), a 90° hybrid (to generate the I and Q channel by phase-shifting one half of the RF signal), and the mixer ring were calculated with HP ADS. The components are produced on a low-cost 5 mil $Al_2O_3$ substrate ($\varepsilon_r$=9.9) in 50 Ohm microstrip technique. The rat-race coupler is used to pump the two mixer diodes of each channel with the LO signal 180 degrees out of phase. The benefits of this balanced configuration comprise reduction of the LO-AM-noise influence, rejection of some spurious LO signals, and good LO-to-RF isolation [12]. Different rat-races (without diodes) were measured using CPW on-wafer probe tips. Because the network analyzer can measure only two ports simultaneously, we designed five test structures with the surplus ports terminated with a 50 Ohm impedance connected to a λ/4 radial stub.

## IV. MIXER DESIGN

Four diodes are used in the circuit design, consisting of two balanced mixers. The diodes are serially DC biased so that only one DC voltage must be applied for either the I or Q channel leading to the same operating point for both diodes. This balance is important for an efficient rejection of LO AM noise. A typical mixer layout (10 × 12 mm) is shown in Fig. 3.

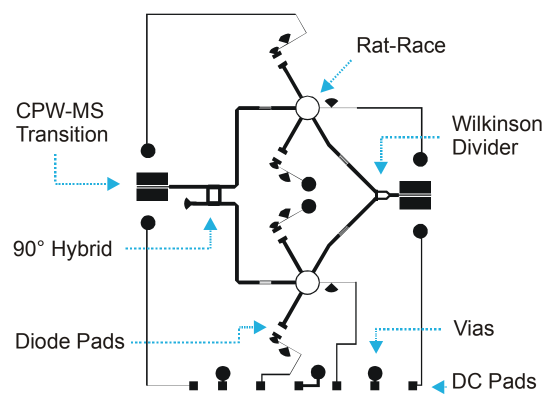


Fig. 3 Mixer layout.

To allow mixer measurements with CPW on-wafer probe tips, a CPW-microstrip transition is realized both at the LO and RF port of the circuit. Isolation of I and Q channels with regard to the IF and DC voltages is realized via quarter wavelength interdigital capacitors. The IF filter is a simple low pass structure with radial stubs. To increase the design robustness with respect to diode impedance variations, the diodes are driven avoiding narrow-band compensation using a 50 Ohm source impedance.

Alternatively, inductive matching circuits are developed to compensate for capacitances caused by the diode package. However, compensation networks are narrowband and therefore sensitive to variation of diode parameters and manufacturing tolerances.

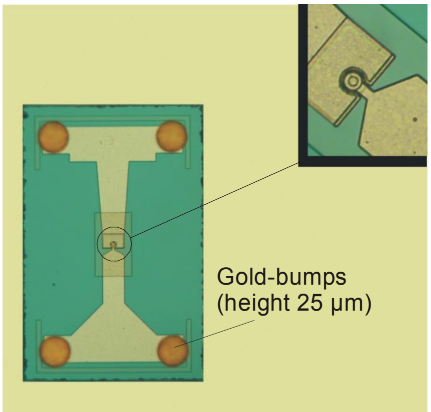


Fig. 4 Silicon Flip Chip Schottky Diode with gold-bumps.

After simulation, all circuits were realized on 5 mil alumina substrate with via-holes. The diodes were flip-chip mounted on the substrate using gold-bumps and thermal compression bonding. A photograph of the diode with these gold bumps and the magnified active region is shown in Fig. 4.

## V. MIXER MEASUREMENTS

The operation frequency of the mixer is 76.5 GHz. The LO power level was assumed to be 6 dBm and a typical RF power level was selected to be -20 dBm. Each diode was biased with 0.4 V being equivalent to 0.8 V per channel. Resulting typical IF power levels are -38 dBm (@ 300 Ohm load impedance, $\Delta f = 100$ kHz) and -33 dBm (@ 50 Ohm load impedance, $\Delta f = 100$ MHz).

The conversion gain, measured with a 50 Ohm load impedance, is depicted in Fig. 5. Two different diode packages were used. It can be seen that the smaller diode (a) leads to much better conversion gain than the larger diode (b). The reason for this behavior is that the larger diode package has more parasitics. It must be noticed that the conversion gain is defined as the ratio between the complete RF input power to the IF power available at the each IF load impedance. As our mixer concept features two channels, only half of the RF and LO power is available at each channel, resulting in an a-priori decrease of the conversion gain by 3 dB.

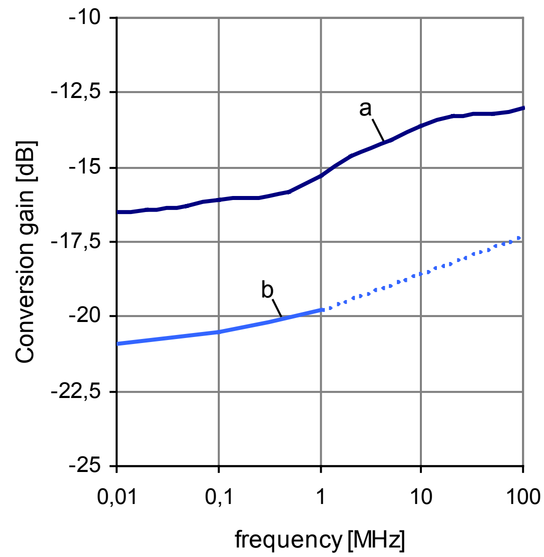


Fig. 5 Conversion gain vs. frequency for large (a) and small (b) diode packages.

As can be seen from Fig. 5, the conversion gain of the mixer shows IF dependency. We blame this on frequency dependence of the diode IF impedance. A simple model for the IF diode impedance is a parallel resistor capacitor configuration. Therefore, at higher IF frequencies, the output impedance becomes lower and – given a constant IF voltage - the voltage drop at the load resistor increases.

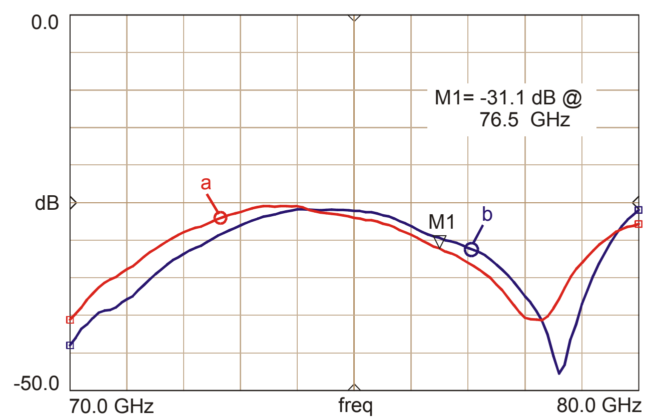


Fig. 6 LO-to-RF isolation vs. frequency for biased mixer (a) and zero-biased mixer (b).

LO-to-RF isolation was also characterized. Fig. 6 shows the results for both externally DC biased diodes (a) and the zero biased case (b). For a bandwidth larger than 10 GHz, isolation is better than 25 dB.

To prove the excellent noise characteristics of the silicon diode, the IF noise of the mixer was measured. The mixer noise was characterized without any RF signal (Fig. 7a) and with LO power applied (Fig. 7b). It can be seen that the 1/f-noise of the diodes is negligible compared to the noise produced by the LO. As LO driver, we used an HP 83640A synthesizer with a high-power frequency quadrupler.

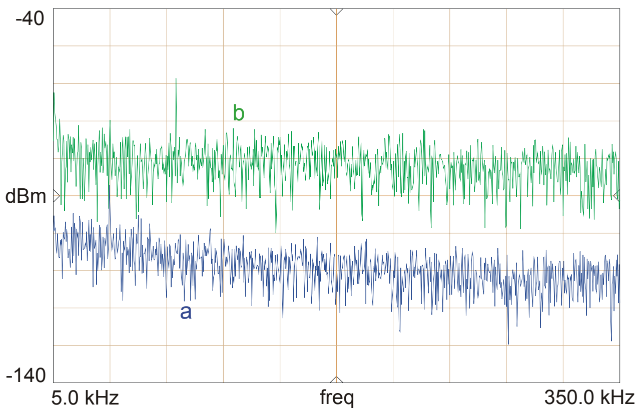


Fig. 7 IF noise power vs. IF frequency for the mixer w/o LO (a) and w/ LO (b).

## VI. Conclusion

A novel balanced I-Q mixer at 76.5 GHz based on flip-chip mounted silicon Schottky diodes was simulated and built on 5 mil alumina substrate. Conversion gain up to -10 dB (one channel) and a LO-to-RF isolation better than 25 dB could be achieved. These results prove the feasibility of this simple concept for high-volume, low-cost applications.

## Acknowledgement

The authors especially like to thank Dr. H.-J. Siweris and Mr. T. Meier, Infineon Technologies GaAs concept engineering/auto-motive radar products, for their support.

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