Active SIMMWIC-Antenna for Automotive Applications

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ABSTRACT

An active SIMMWIC-Antenna (**Si**licon **M**onolithic **M**illimeter**w**ave **I**ntegrated **C**ircuit) for vehicular technology in the frequency range around 76.5 GHz is presented. This active antenna acts as a transceiver and is well suited for low-cost integrated sensor systems for automotive applications. The monolithic active antenna embedded in a synchronization network requires only 3.2×2.6 mm^2 chip size. Using subharmonic injection locking frequency tuning and stabilization is realized. With an injection power of 0 dBm we measured a tuning range of 300 MHz. To our knowledge, this is the first synchronizable monolithic integrated active antenna suited for automotive applications in the frequency band around 76.5 GHz.

INTRODUCTION

The suitability of silicon for M^{3}IC's has been demonstrated in numerous examples [1]-[3]. SIMMWIC's provide new solutions for low cost near-range sensor [4] and communication applications in the frequency range above 50 GHz. Particular advantages are the capability of the very easy monolithic integration, a high degree of technological reproducibility, small size and thus low costs. The active antenna concept, where the antenna acts simultaneously as a resonator of a millimeterwave oscillator and the active element of the oscillator (in our case an IMPATT diode) is integrated in the antenna structure, provides the highest degree of integration and, thus, lowest costs.

The bandwidth in the millimeterwave band allocated for automotive and industrial applications [5] is very small (below 1 %). Thus, the required spectral purity demands frequency stabilization and precise modulation of the active antenna. Usually a phase-locked-loop is employed to stabilize the oscillation frequency and to improve the phase noise behavior. However, many millimeterwave components such as frequency dividers, mixers and phase/frequency comparators are required resulting in an expensive and complex multichip system. As an alternative, subharmonic injection locking is a very effective and low-cost solution as long as the tuning range and frequency modulation depth are small. The signal of a tunable low noise reference oscillator, e.g. a Si/SiGe-hetero-bipolar-transistor oscillator [6], is injected at a subharmonic frequency into the active antenna. The active element in the antenna generates harmonics of the injected signal and the active antenna locks onto one of the harmonic, if this harmonic lies in the vicinity of the oscillation frequency of the free running oscillator. The tuning range is usually very small (depends on the power of the injected signal) [7]. But, due to the bandwidth restrictions only very small frequency variations are allowed. Thus, subharmonic injections locking is ideally suited to stabilize active millimeterwave antennas.

As an example, Fig. 1 shows an integrated low-cost sensor system for automotive applications. The system consists of three devices, the synchronizing

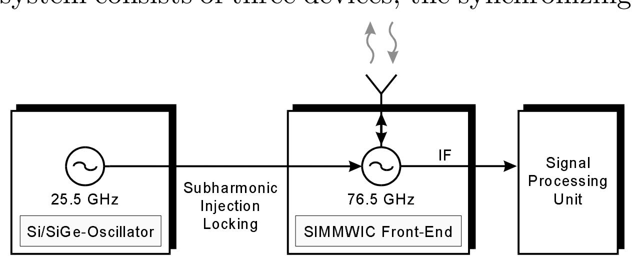

Fig. 1: Millimeterwave sensor system on Silicon

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oscillator at 25.5 GHz, the front-end at 76.5 GHz, and the signal processing unit at IF band. Due to the self-mixing properties of the integrated front-end IF is generated automatically and no additional mixer components are required.
Last year we presented a robust monolithically integrated active antenna at 76.5 GHz for free-running sensor applications [3]. This design has now been completed with a balun for subharmonic injection locking and an integrated bias network resulting in a front-end for system applications. Compared to [3] the antenna performance has not been deteriorated by the additional network components. To our knowledge, this is the first synchronizable monolithic integrated active antenna suited for automotive applications in the frequency band around 76.5 GHz.

DESIGN AND FABRICATION

For low power requirements of the subharmonic oscillator ($< +5\,\text{dBm}@25.5\,\text{GHz}$) the synchronizing network has to inject the subharmonic signal into the diode with low reflections. The monolithically integrated diode provides a symmetric port for the injection signal. Since due to compatibility reasons the front-end should feature an asymmetric port for the injection signal, symmetric power splitting with a phase difference of 180° is necessary for the synchronizing signal. DC decoupling from the synchronizing oscillator is achieved by use of a MIM capacitor at the input port. For bias and IF two additional isolated ports are required.

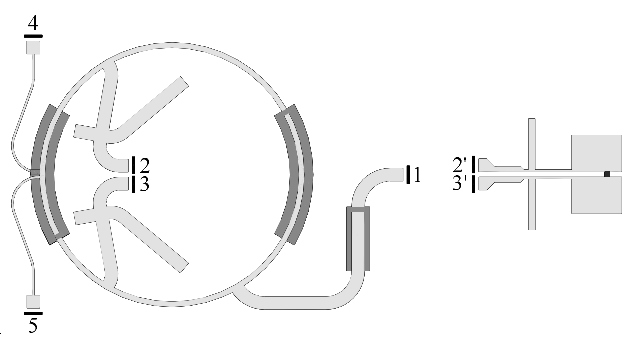

Fig. 2: To facilitate the design process synchronizing network and active antenna have been separated. In the final layout ports 2 and $2'$ as well as ports 3 and $3'$ are directly connected and the active antenna is located inside the rat-race coupler

As synchronizing network we chose an integrated travelling wave rat-race coupler (Fig. 2). With second order subharmonic injection locking at 25.5 GHz the square dimensions of the integrated circuit decrease to a minimum, since the active dipole antenna can be located in the center of the rat-race coupler resulting in 3.2×2.6 mm^2 chip size.
Active antenna and rat-race coupler have been monolithically integrated on 125 μm thick high resistivity silicon with backside metallization. This small substrate thickness features low thermal resistance resulting in high thermal stability of the oscillator [7]. The diode with diameter of 22 μm is processed by means of a state-of-the-art SIMMWIC process [1].
With a coupler diameter of 1980 μm the input signal at port 1 is split into two parts with phase difference of 180° and the same amplitude in the frequency range from 24 to 27 GHz (S_{12}, $S_{13} \approx -3.8$ dB). Four open ended stubs in the coupler provide matching between the output ports of the coupler (2 and 3) and the input ports of the antenna ($2'$ and $3'$) for the subharmonic signal. For biasing the diode two additional ports (4 and 5) are necessary. DC decoupling is realized by a couple of MIM capacitors of 1050 μm length (Fig. 2, darkgray underlay). Port 4 is connected to the bottom metalization of the MIM and port 5 to the top metalization, respectively (Fig. 3). The

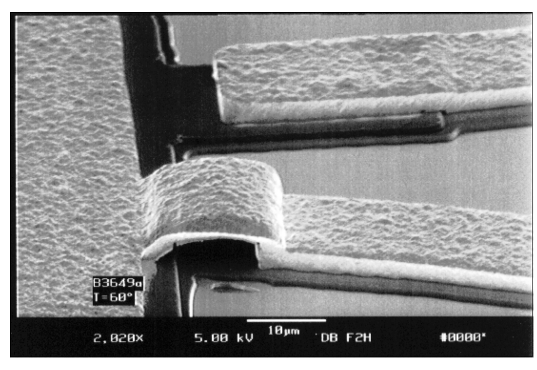

Fig. 3: MIM capacitor with coupled biaslines

thickness of the isolator is about 200 nm. With this configuration the isolation S_{14}, S_{15} is better than -35 dB between 24.5 and 26.5 GHz.
Knowledge about the input impedance of the

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structure at diode's location, the radiation efficiency and the radiation pattern can only be gained by means of a full-wave analysis [2]. To achieve matching between diode and antenna, the dipole length and width has to be chosen to 620 μm and to 380 μm, respectively. In Fig. 4 the intersection at 76.5 GHz between negative diode reactance and the reactance of the antenna identifies the oscillation frequency. The slight resonances at 55 GHz,

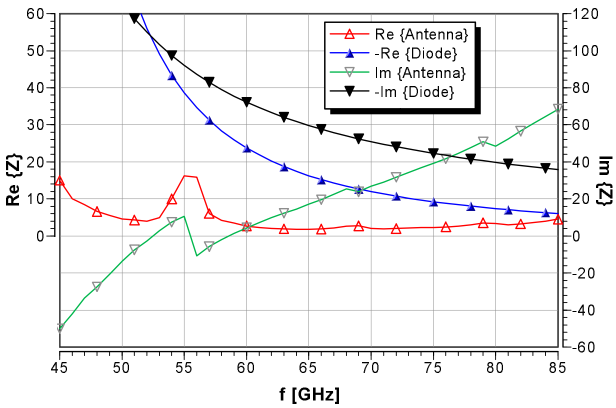

Fig. 4: Impedance of antenna and diode

68 GHz and 79 GHz are caused by the rat-race coupler and the four open ended stubs. The calculated radiation efficiency of the planar structure is $\eta = 21$ % and the directivity $D = 4.6$ dBi. For an active antenna without any feeding network we obtained only slightly higher values. Thus, the synchronizing and feeding network shows no relevant interaction with the millimeterwave signal.

RESULTS

At first we determined the radiated power P_{rad} and oscillation frequency of the free running active antenna depending on the DC current I through the IMPATT diode. With $I = 22.4$ mA oscillation starts at 76.594 GHz. Varying the current in the range from 23 to 33 mA tunes the frequency from 76.56 to 76.45 GHz (Fig. 5). At $I = 30$ mA we measured a diode voltage of $U = 19.8$ V resulting in a DC to RF conversion efficiency of $\eta_{DC \rightarrow RF} = P_{rad}/(\eta U I) = 2.42$ %.

To lower the power requirements for the synchronizing oszillator, the input port of the active antenna must provide low reflections. Fig. 6 shows

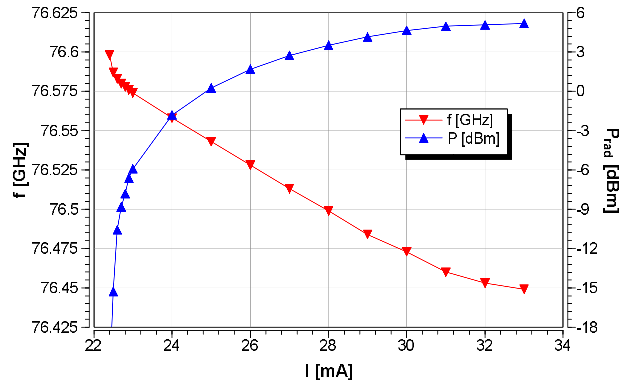

Fig. 5: f and P_{rad} depending on diode current I

the measured reflection coefficient S_{11} of the frontend at the synchronization port for different diode currents in the frequency range from 22 to 29 GHz. For $I = 0$ mA the injected power is almost totally reflected. But at the operation current $I = 27$ mA the IMPATT diode provides the proper impedance resulting in correct termination of the coupler with low reflections. From 24.8 to 26.4 GHz the reflection coefficient is almost $S_{11} \approx -8$ dB. This low reflection coefficient results in a maximum tuning range for the active antenna of 600 MHz with $P_{inj} = +3$ dBm. With $P_{inj} = 0$ dBm a frequency tuning of almost 300 MHz is possible. For automotive applications this tuning range is sufficient.

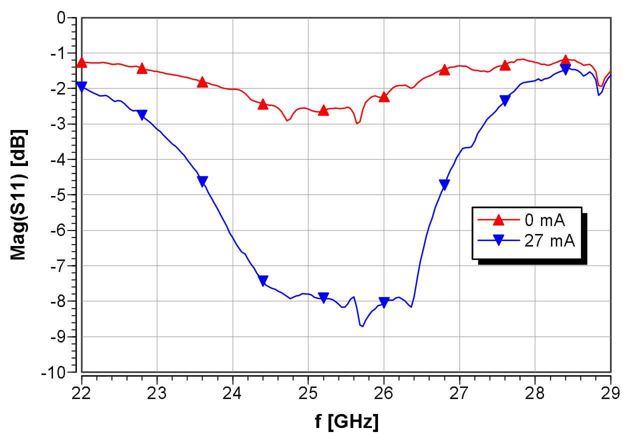

Fig. 6: Injection behavior

Finally we determined the radiation pattern of the active antenna (Fig. 7). Compared with [3] no relevant degradation due to the additional synchronization network is observed. The orthogonal polarization state in H-plane and in E-plane

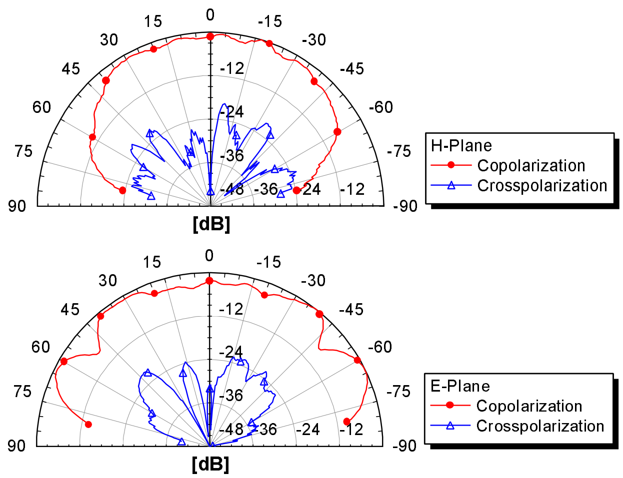

Fig. 7: Radiation pattern of the active antenna

is suppressed by more than 28 dB normal to the substrate orientation.

CONCLUSIONS

Integrated active antennas on silicon well suited for system applications for vehicular technology at 76.5 GHz have been designed and manufactured. This one-chip front-end features a high millimeter-wave output power up to 5 dBm, highly decoupled ports for bias and subharmonic injection locking at 25.5 GHz, low injection power of $P_{inj} = +0$ dBm for a frequency tuning range of 300 MHz, and very small chip size of only 3.2×2.6 mm^2 (Fig. 8).

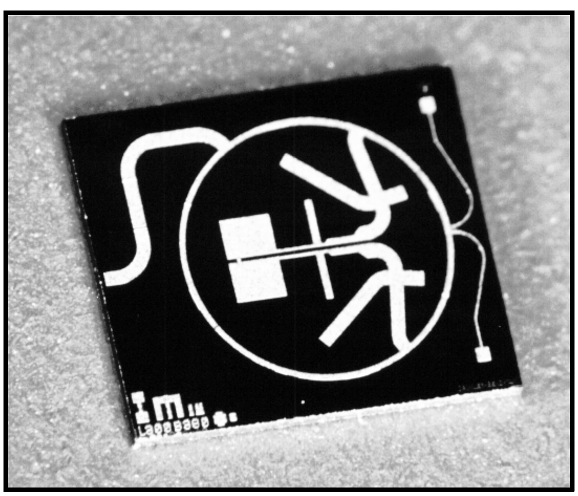

Fig. 8: Active SIMMWIC-Antenna for system applications

With this active antenna low-cost sensor systems are feasible.

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REFERENCES

[1] J.-F. Luy, P. Russer, eds., *Silicon-Based Millimeter-Wave Devices*, Springer Verlag: Berlin Heidelberg 1994.

[2] A. Stiller, E.M. Biebl, J.-F Luy, K.M. Strohm, J. Büchler, “A Monolithic Integrated Millimeter Wave Transmitter for Automotive Applications,” *IEEE Trans. on Microwave Theory Tech.*, pp. 1654-1659, vol. 43, no. 7, 1995.

[3] M. Singer, A. Stiller, K.M. Strohm, J.-F. Luy, E.M. Biebl, “A SIMMWIC 76 GHz Front-End with High Polarization Purity,” *1996 IEEE MTT-S Int. Microwave Symp. Digest,* pp. 1079-1082, 1996.

[4] R.H. Rasshofer, E.M. Biebl, “A Low Cost W-Band Multi-Beam Doppler Radar for Automotive Applications,” *1997 IEEE MTT-S Int. Microwave Symp. Digest,* 1997.

[5] N.P. Morenc, “MMICS for Automotive Radar Applications,” *1996 IEEE MTT-S Int. Microwave Symp. Digest,* pp. 39-41, 1996.

[6] F. Beißwanger, U. Güttich, C. Rheinfelder, “Microstrip and coplanar SiGe M-MMIC oscillators,” *Proc. of the 26th Europ. Microwave Conf.,* pp. 588-592, 1996.

[7] M. Singer, J.-F. Luy, A. Stiller, K.M. Strohm, E.M. Biebl, “FM Noise and Synchronization Behaviour of a SIMMWIC 76.5 GHz Front-End,” in: *Directions for the Next Generation of MMIC Devices and Systems,* N.K. Das, H.L. Bertoni, eds., Plenum Press: New York 1996.

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