# A SIMMWIC 76 GHz Front-End with High Polarization Purity

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## ABSTRACT

An integrated active antenna with a polarization purity better than 28 dB and a radiated power of 8 dBm at 75.7 GHz is presented. The linearly polarized radiator consists of a planar resonant antenna and a transit-time diode monolithically integrated on a silicon substrate. This active antenna finds various applications in low-cost multi-channel sensor systems, e.g. for object classification. Guidelines for the design are discussed. The characterization of the fabricated SIMMWIC devices includes measurements of output power, polarization purity, and far-field pattern. Moreover, the oscillation frequency of the devices has been successfully stabilized using subharmonic injection locking. The FM noise behavior of the locked oscillator has been characterized. The measured results are presented and compared to theoretical calculations.

## INTRODUCTION

Monolithic millimeter wave integrated transmitters and receivers are key elements of sensor systems for automotive applications. Monolithic implementation of the sensor system's complete mm-wave front-end provides the possibility of low-cost production, improved reliability, small size, light weight, and easy assembly. Some multi-channel sensor systems are based on polarization multiplexing, e.g. systems for object classification. These systems require monolithically integrated oscillators radiating with high polarization purity.

## RESULTS

The transmitters consist of an active element and an integrated resonant structure. In order to minimize the required chip dimensions, the resonator simultaneously acts as an antenna. Since no additional microstrip lines for connecting the oscillator to an external antenna are needed parasitic losses are reduced to a minimum [1]. On silicon so far only transit-time diodes are available as active elements in the frequency band around 76.5 GHz allocated to industrial applications. Matching of the diode's low-impedance in a planar configuration is critical and requires careful optimization of diode structure, geometry, resonator layout, and a precise knowledge of the diode's impedance. The impedance of the employed quasi Read double drift diode (QRDD) was determined by on-wafer measurements of various diodes (Fig. 2). By aid of this measurements the impedance of the resonator can be matched precisely to that of the QRDD diode [2]. The resonator satisfying the requirements of impedance matching and polarization purity is based on a planar dipole [3] as depicted in Fig. 1. This structure represents the complete passive part of the SIMMWIC (silicon mm-wave integrated circuit) front-end.

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We calculated the impedance seen by the QRDD diode using a full wave analysis based on the method of moments in the spectral domain [4]. In this analysis all the relevant loss phenomena, such as dielectric and ohmic losses, radiation, and surface waves, have been included. The solution of the resulting complex system matrix delivers all interesting properties of the examined antenna, namely input impedance, gain, radiation pattern and radiation efficiency. A symmetric dipole (Fig. 1)

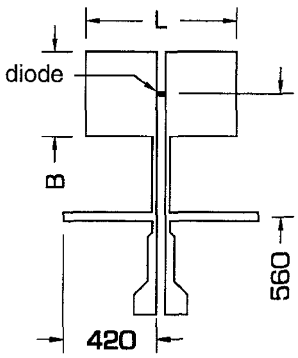


**Fig.** 1: Dipole layout, unit: $\mu$m

with L=680 $\mu$m and B=380 $\mu$m was found to match the requirements of the QRDD diode resulting in a polarization purity better than 28 dB normal to the linearly polarized radiator. The negative calculated input impedance of the symmetric dipole seen by the QRDD diode vs. frequency is depicted in Fig. 2. Since matching is obtained for $Z_{diode} + Z_{dipole} = 0$, the intersection between the negative reactance of the dipole and the reactance of the diode determines the oscillation frequency.

Dipole antenna and QRDD diode have been monolithically integrated on high resistive silicon with a thickness of 125 $\mu$m and backside metallization. This small substrate thickness results in high thermal stability of the oscillator and a calculated radiation efficiency of $\eta$ = 44 % of the planar antenna. The complete layer sequence of the QRDD diode was

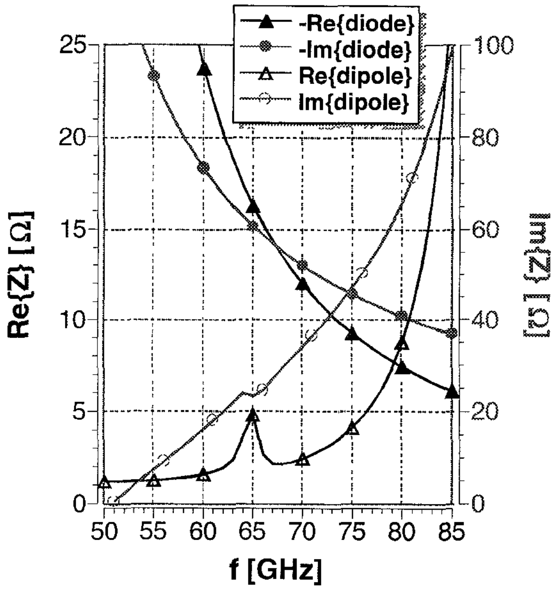


**Fig.** 2: Impedance of QRDD diode and dipole

grown by silicon molecular beam epitaxy (Si-MBE). The device with a diameter of 22 $\mu$m is processed following a published SIMMWIC process [5]. The measured oscillation frequen-

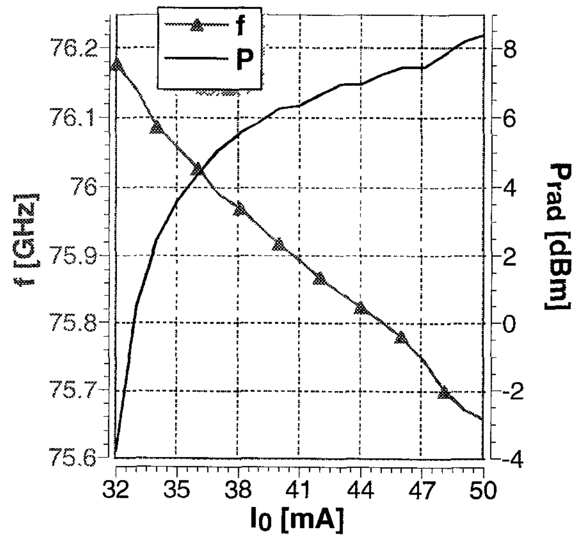


**Fig.** 3: $P_{rad}$ an $f$ vs. $I_0$

cy $f$ = 75.8 GHz for a bias current of 45 mA deviates by only 1.5 % from the predicted 74.6 GHz. Additionally, the radiated power $P_{rad}$

and the oscillation frequency vs. the bias current $I_0$ are depicted in Fig. 3. The maximum radiated output power $P_{rad} = 8.2$ dBm at 75.66 GHz was measured for an applied bias current of 50 mA and a voltage of 22.8 V. Hence the power $P_{gen}$ generated by the IMPATT diode is determined to

$$P_{gen} = \frac{P_{rad}}{\eta} = 11.7 \text{ dBm}$$

resulting in an DC to RF conversion efficiency of the QRDD diode of 1.3 %. The measured

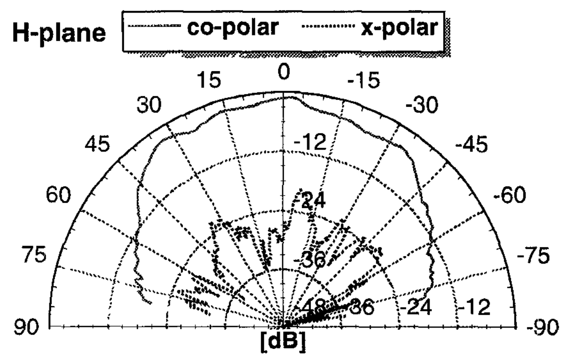


**Fig.** 4: H-Plane radiation Pattern at 75.8 GHz

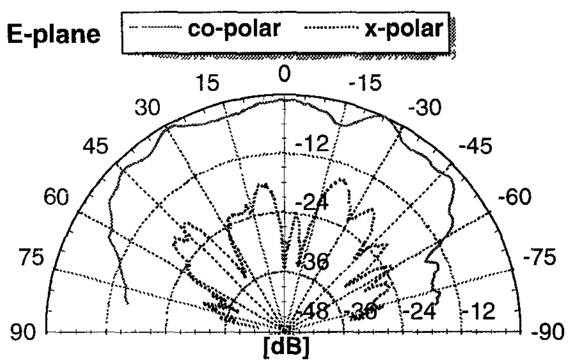


**Fig.** 5: E-Plane radiation Pattern at 75.8 GHz

radiation pattern of the oscillator is depicted in Fig. 4 and in Fig. 5. The ripple most distinct in the co-polar E-plane pattern is induced by the finite extent of the substrate. The orthogonal polarization state in E-plane and H-plane is suppressed by more than 28 dB at 0.

Due to the relatively short coherence lenght of the free running active antenna an unstabilized SIMMWIC front-end finds only short range applications [6]. For a larger operation range a frequency stabilization of the oscillator is required, which is advantageously realised using subharmonic injection locking. We locked the oscillator with a third order subharmonic signal generated by a synthesizer and measured the FM noise behavior for power levels of the injected signal between -14 dBm and +5 dBm. Fig. 6 shows the results. For a frequency offset

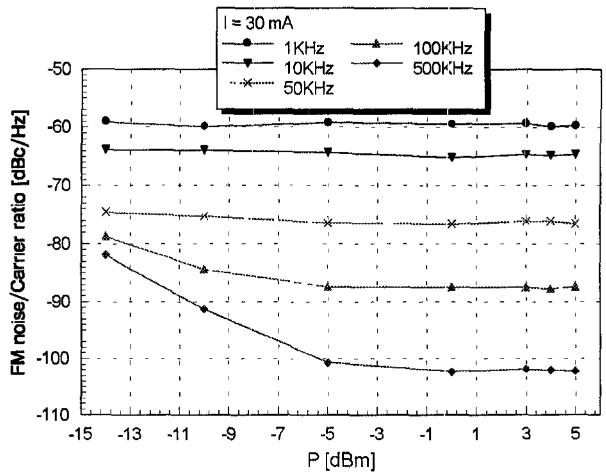


**Fig.** 6: FM noise behavior of the subharmonically injection locked SIMMWIC

of 50 kHz or less the FM noise level does not depend on the injection power level. For larger offset the FM noise decreases with increasing injection power level and remains constant above a certain power level. This behavior is due to the fact that the synchronization bandwidth increases with increasing power of the injected signal. Our measurements show that an injection power level of -3 dBm is sufficient for a synchronization bandwidth of about 1 MHz, which is sufficent for long range applications of the SIMMWIC front-end.

## CONCLUSIONS

Monolithically integrated active antennas for the frequency-range around 76.5 GHz have been manufactured. Because of reduced size and easy manufacturing this kind of monolithic integrated transmitter is well suited for low cost sensor systems in automotive applications requiring high polarization purity. By exploiting the resonant characteristics of a planar antenna and directly locating the active element in the planar structure a integrated active antenna has been fabricated. Space requirements and parasitic losses of the presented transmitter are reduced to a minimum while at the same time the suppression of the orthogonal polarization state is enhanced to 28 dB. The maximum radiated output power $P_{rad} = 8.2$ dBm was achieved at 75.66 GHz. Even with a small injection power level of -3 dBm efficient injection locking with the third subharmonic has been demonstrated.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] J.F. Luy, K.M. Strohm, J. Buechler, "Monolithically integrated coplanar 75 GHz silicon IMPATT oscillator", *Microwave and Optical Technollogy Letters,* pp. 117-119, Vol. 1, June 1988

[2] J.F. Luy, K.M. Strohm, J. Buechler, "Silicon Monolithic Millimeter Wave IMPATT Oscillator", *Proc. 18th Europ. Microwave Conf.,* pp. 364-369, 1988

[3] A. Stiller, M. Singer, K.M. Strohm, E.M. Biebl, "Characterization of Planar Resonators by Means of Integrated Schottky Diodes," in *1995 IEEE MTT-S Int. Microwave Symp. Digest,* (Orlando), pp. 1151-1154, 1995

[4] P. Russer, E.M. Biebl, "Fundamentals" in *Silicon-Based Millimeter-Wave Devices,* (J.F. Luy, P. Russer, Eds.) Berlin: Springer 1994, pp. 1-46

[5] K.M. Strohm, "Silicon Millimeter-Wave Integrated Circuit Technollogy" in *Silicon-Based Millimeter-Wave Devices,* (J.F. Luy, P. Russer, Eds.) Berlin: Springer 1994, pp. 241-281

[6] M. Gupta, R.J. Lomax, G.I. Haddad, "Noise Considerations in Self-Mixing IMPATT-Diode Oscillators for Short-Range Doppler Radar Applications," *IEEE Trans. on MTT,* pp. 37-43, Vol. 22, No. 1, 1974