A SENSOR SYSTEM BASED ON SIGE MMIC'S FOR 24 GHZ AUTOMOTIVE APPLICATIONS

C.N. Rheinfelder[1], S. Lindenmeier[1], J.-F. Luy[1], C. Willner[2], and A. Schüppen[3]

[1]DaimlerChrysler Research Center Ulm, Germany
[2]DaimlerChrysler Corporation Rochester Hills, MI, USA
[3]Temic Semiconductors Heilbronn, Germany

***Abstract* — A near-range sensor for an electronic automotive cocoon from concept to realization is presented. Based on the commercial TEMIC SiGe technology on high and low resistivity Si substrate the DSSS- (direct sequence spread spectrum) concept allows a simplified all-round approach while maintaining high resolution below several millimeters with simultaneous compliance to ISM and cost requirements.**

I. INTRODUCTION

Up to now, the market for RF applications in the ISM (industrial, scientific, and medical) band (24.0 GHz to 24.25 GHz) is dominated by III/V semiconductors. Due to cost requirements of the III/V technology and incompatibility issues with prevailing silicon base-band applications the use of GaAs, InP, and their derivatives in cost sensitive mass products is often prohibitive. But, for a higher market penetration of future applications in the automotive and communications field low-cost mm-wave systems are required. Therefore, we describe a sensor system for near-range perception in a future premium-class vehicle that is capable to keep the area around 20 m under surveillance.

The paper is organized as follows: In the first paragraph we inspire the concept of this safety-critical sensor. Particularly, the immunity to jammers and the reliability of the detection of objects are crucial. Then we explain the basing technology and give some examples of the realizations. This approach will be supported by measurements of the SiGe MMIC's, the patch antenna triplets, and the overall performance.

II. SYSTEM CONCEPT

To guarantee an all-around covering of the electronic cocoon we provide two active sensors at the front of the vehicle and a multitude of partially active and passive low cost sensors around the car. In fig.1 the sensor system for the electronic cocoon is shown. In front direction it is of high importance to localize objects early as can be seen in fig.1 for scatterer 1. Hence a radar for distance measuring is required for a distance range of at least 20m. For the localisation of objects in the side and backside area of the car small low cost sensors are sufficient having a distance range of approximately 7m. In this case the localisation of the objects can be performed by detecting the direction of the scattered signals in the horizontal plane at different points on the car. The distance of the objects can be derived then by triangulation. For this purpose there are positioned two patch antenna triplets at each side of the car near to the edges which are connected to each other via a bus system.

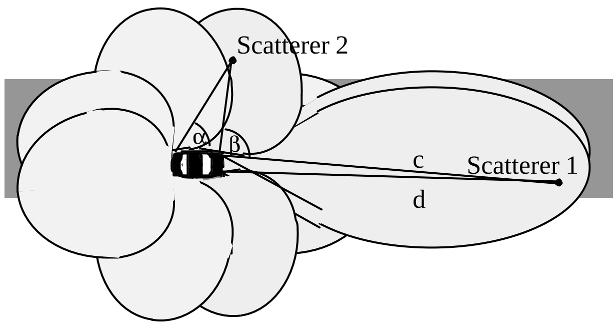

Fig.1: Sensor system of the electronic cocoon

The antenna triplets represent small patch antenna arrays where the antennas are located in a distance of $\lambda/2$ to each other. The direction of the received signal is detected via the phase difference between the patch antennas. The decoupling of transmitting antennas and receiving antennas is obtained in a transmission multiplex. In one sequence of the multiplex each of the sensors is active for 0.1ms one after the other, while the other sensors are receiving the signals scattered by the objects (Fig.2).

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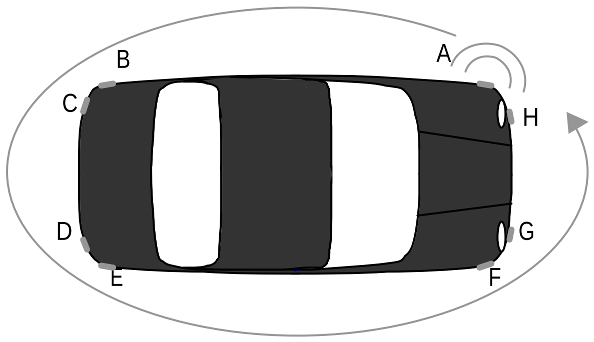

Fig. 2: multiplex transmission of the radar sensors

In table 1 one sequence of the transmission multiplex is shown. In the first 0.8ms of the sequence the sensors A to H are transmitting one after the other while the other sensors are detecting the directions of the scattered signals. In the last 0.1ms of the sequence no sensor is transmitting in order to detect only signals which are generated by other car sensor systems.

Time	Transmit:	Receive:
0.1ms	Sensor A	B,C,D,E,F,G,H
0.2ms	Sensor B	A, C,D,E,F,G,H
	⋮	⋮
0.8ms	Sensor H	A,B,C,D,E,F,G
0.9ms	no Sensor	A,B,C,D,E,F,G,H

Tab.1: Sequence in the transmission multiplex

To ensure highly accurate distance resolution the front sensors continuously sample the area in front of the car while the angular sensors at the side and back of the vehicle alternately work as transmitter or receiver. Consequently, we achieve very high resolution without impairing the ISM restrictions.

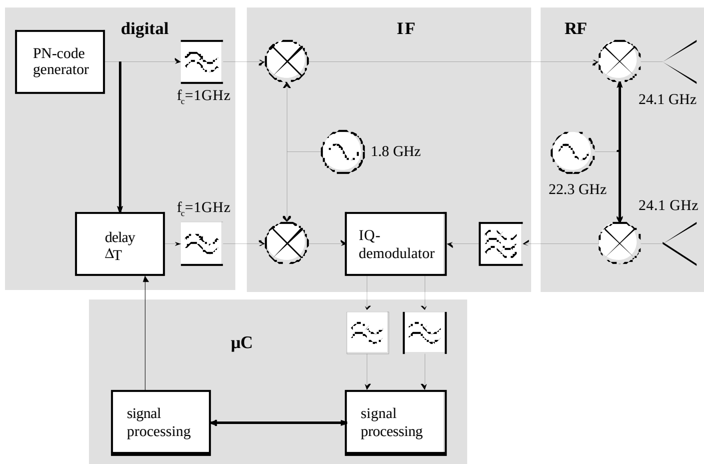

Fig 3: Block diagram of the 24.1 GHz automotive multifunctional near-range sensor for pre-crash detection.

The system under consideration comprises of a ECL base-band block at 112.5, 225 or 450 MHz, an IF-stage at 1.8 GHz, and the RF-frontend at 24.125 GHz. Additionally, a host in the trunk of the car completes the harness. Fig. 3 shows the block diagram. A 10-bit 450 MHz pseudo-noise (DSSS) signal source in ECL technology together with a programmable delay in pico-seconds form the basis of the system [1]. The clock reference is generated by a 1.8 GHz synthesizer and programmable frequency dividers in the IF section. The signal is amplitude modulated on top of a 22.3 GHz microwave source and transmitted via patch arrays. The scattered signal is received by another portion of the antenna and downconverted in the 1.8 GHz band.

The correlation of the reflected signal together with the delayed source is performed in I-Q mixers. Therefore, it is possible to scan the range cells with ps resolution. This corresponds to a distance of only a few millimeters. Although not optimized in this regard, a complete scan of a range cell takes place below 5 ms due to the switchable bandwidth. The signal includes the distance and doppler-frequency in every range gate and is therefore called cVr (closing velocity and range). The unambiguous range is beyond 300 m. This allows the analysis and evaluation of the relative speed and the distance in every single range cell and enables the application of special tracking procedures taking the history into account.

III. SIGE CIRCUITS AND TECHNOLOGY

In order to serve the high volume automotive market with its stringent price targets, a high level of monolithic integration is necessary. Virtually all radar system currently being produced for the commercial market in the 10 to 100 GHz range are based upon GaAs materials technology. Despite years of development, GaAs-based heterostructures are still relatively expensive to produce due to a lack of a technique for producing high density circuitry in a planar configuration. As a result, GaAs are generally produced either as discrete devices or primitive sub-circuits which must then be 'integrated' at the circuit board level. Although these systems can generally achieve higher power levels, the need to fabricate transmission-lines and match components at the circuit-board level becomes a very expensive concession. Advantages of silicon-based, SiGe devices include a lower generation of 1/f noise. The lattice mismatch between single-crystal silicon and sc-Germanium is only about 4 %. Thus SiGe epitaxial layers can be monolithically grown on sc-Si substrates, thereby enabling planar microcircuit fabrication of high-frequency front-end circuitry on standard 0.5 µm to 0.1 µm CMOS, IF signal processing circuitry. The cost of GaAs based systems is in the \$50 to \$ 100 range per sensor head - SiGe based technology is currently projected in the \$ 10 to \$ 20 range per sensor head (ultrasonic devices currently cost ~ \$ 15 per sensor head). In Fig. 4 we show the adoption of the front-end of the sensor-system in SiGe technology.

The complete front-end has the dimensions of 4 by 4 mm^2 and comprises of a 22.3 GHz voltage controlled oscillator with buffer amplifier, an active power divider, active up- and downconverters, and a low-noise amplifier. These chips are processed in the TEMIC/ATMEL SiGe1 production LOCOS technology with selectively implanted collector and differential growth of the SiGe layer on high- and low-resistivity substrates. The SiGe HBTs exhibit cutoff frequencies beyond 50 GHz with self-aligned emitter areas of 30 μm^2. All circuits are designed in a coplanar environment. The whole range of components like MIM's, spiral inductors, poly resistors, and bridges to suppress unwanted modes in the CPW are available in this technology.

TEMIC´s SiGe1 technology has a nearly box shaped Ge profile with above 20% Ge in the base [2]. This contrasts other companies, as e.g. IBM [3] and Infineon [4], which prefer a triangular Ge profile with only up to 15% Ge in their low doped base.

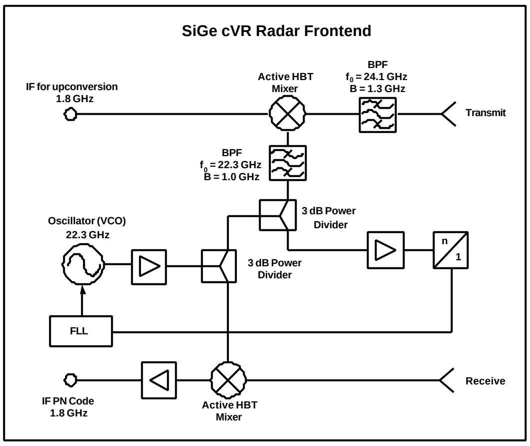

Fig.4: General architecture for the 24GHz NR radar, RF section

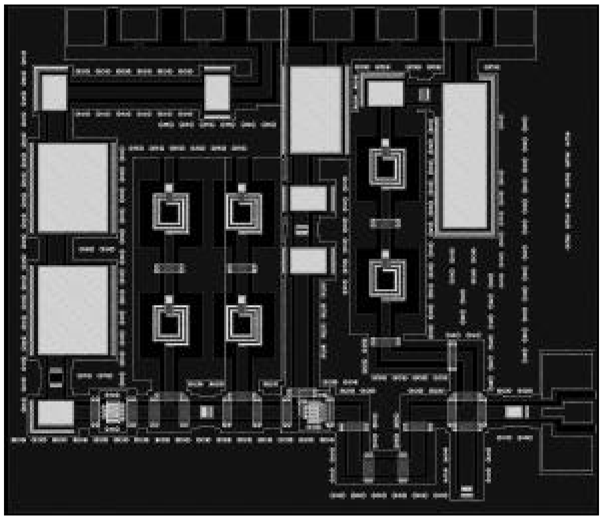

Fig. 5: Layout of the 22.1 GHz oscillator in coplanar environment. The extensive use of lumped elements together with massive DC stabilization is visible. Morover, the underpasses at all discontinuities can be observed.

The SiGe base is highly boron doped with $4x10^{19}$ cm^{-3}, which is grown by a single wafer CVD machine and has a real advantage over the drift HBTs due to the approximately 10 times smaller base sheet resistance. Values of 1.5kΩ/sq are achieved. Even with emitter stripes up to 2 µm, f_{max} values of 50 GHz for power HBTs and noise figure NF_{min} down to 1 dB at 2 GHz are measured.

Fig. 5 depicts a segment of the front-end chip system: It shows the layout of the 22.3 GHz VCO (without buffer amplifier). Due to an active power-divider the buffer is not mandatory. Because of the use of lumped elements this circuit has dimensions of only 1.2* 0.9 mm^2.

Fig. 6 shows the measured output power. A maximum output power at 3V Vce is measured to 8.5 dBm. Phase-noise measurements exhibit a phase-noise of –75 dBc/Hz at 100 kHz off-carrier. The frequency tuning spans about 900 MHz. A comparison of oscillators on high- (4 kΩcm) and low- (20 Ωcm) resistivity Si substrates didn't show up significant differences. This could be explained by a thick oxide layer to shield the CPW's from the substrate, the use of mainly lumped elements, and extensive substrate contacts.

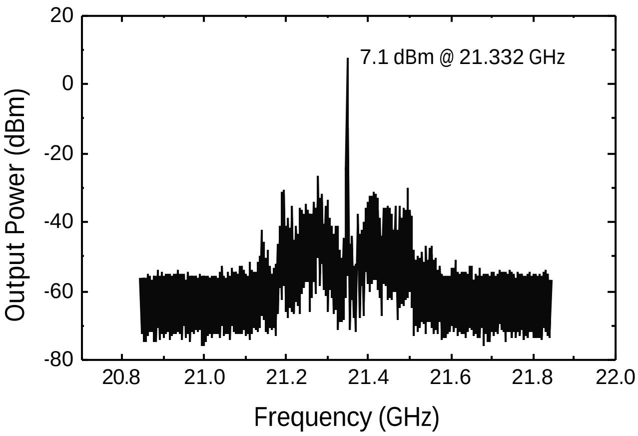

Fig. 6: Measured output spectrum of the SiGe VCO. A maximum output power of 8.5 dBm at 3V collector-emitter voltage could be obtained. The phase-noise at 100 kHz offset is identified to 100dBc/Hz.

IV. MEASUREMENTS

An important feature of the overall system is the multi-target capability and the object classifcation possibility.
Fig. 5 shows the target response as value of the autocorrelation function of a car "only" and a car and a pedestrian. It can be seen , that (i) the person causes a different shape and amplitude of the autocorrelation function compared to the car and (ii) that the pedestrian can be clearly distinguished from the car.
Due to the radar concept, the backscattered signal can be analyzed in each range gate in the spectral domain. Spectral estimation is considered to be an important analysis method for future implementation of object classification algorithms.

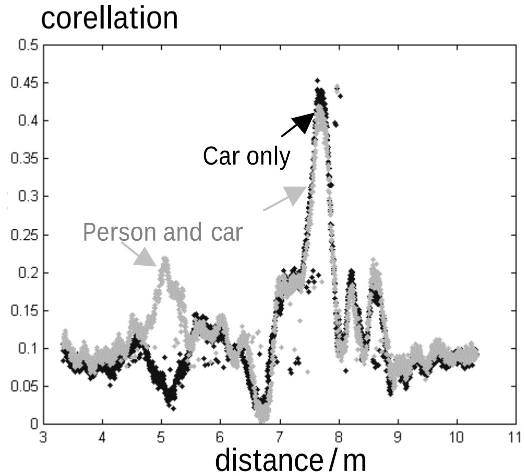

Fig. 4: Autocorrelation voltage as a function of the target distance. Two different measurements: "Car only" and "Person and Car".

V. CONCLUSION

The pseudo-noise code architecture is the basis for the realization of a near range sensor system for safety critical applications. The realization of the 24 GHz front-end components in a commercial SiGeMMIC technology enables the multiple sensor configuration around a car in order to form an electronic cocoon. Multi target capability and the potential for the implementation of object classification algorithms are demonstrated.

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