RADAR SENSORS TO DETERMINE POSITION AND PHYSIOLOGICAL PARAMETERS OF A PERSON IN A VEHICLE

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Abstract - Two different sensor concepts based on the impulse radar principle are proposed to determine position and physiological parameters (heartbeat and breath frequency) of a person in the interior of a vehicle. In this paper, the sensor concepts are presented as well as first measurement results collected in both laboratory and vehicle environment.

I. INTRODUCTION

In the last years, much effort has been spent to develop radar systems to measure physiological parameters of the human body [1-7] ? but none of them has been designed for automotive applications.

Compliance with increasing safety requirements in motor vehicles necessitates continuous improvement of the safety for passengers. Therefore, different strategies and system concepts are pursued:

On the one hand, minimising consequences of vehicle crashes can be achieved e.g. by adaptively inflating the airbag in dependence of the position of a passenger ? for unfavourable conditions a full airbag blow may cause significant injuries. In the past, the realisation of this concept failed due to lack of precision determining a passenger's position inside the vehicle.

On the other hand, the avoidance of serious vehicle crashes can be achieved e.g. by the assistance of a driver's state recognition system. In this case, the physical state of the driver is determined continuously ? e.g. to keep him awake when tired or drowsy.

Different technologies are available for each system concept and first realisations are currently under investigation: For example by use of video or ultrasonic sensors, the interior of a vehicle can be scanned. Applying a suitable image processing, the position of a passenger can be determined. With these concepts, however, obstacles between the sensor and a passenger (e.g. a newspaper in front of the person) may prevent a successful detection of the "target". Recognition of the driver's state needs a sensor technology to determine physiological parameters under automotive conditions, which is not yet available. Tests have shown that the evaluation of driving performance only (e.g. the lane behaviour) is not sufficient for an unambiguous state recognition. Radar sensors offer solutions applicable for both system concepts as demonstrated in the following.

II. DRIVER MONITORING WITH RADAR SENSORS

In this paper, two different radar-based sensor concepts are introduced for systems to monitor a person's position and physiological parameters to find out the physical state of a driver, respectively. By means of the first sensor concept, the distance between the dashboard and the driver or a front-seat passenger can be determined, the second one is used to measure their heart beat and breath frequency. Both concepts use the principle of an impulse radar, which operates at different frequencies according to the application. In both cases, short impulses are radiated and reflected by the "target" ? strongly depending on the penetration depth into the human body (which itself is a function of frequency and the tissues irradiated). Distance and movement of the "target" can be determined from the travel time of the impulse between transmission and reception or from the evaluation of the Doppler effect, respectively.

II.1. POSITION MONITORING

The first sensor system ? to determine a passenger's position ? delivers both information on the position of a person (e.g. relative to the location of the airbag) and the direction of movement. The latter can be used to predict the position with regard to an "area of danger" ? defined in dependence of the blowing door of the airbag (so-called "keep-out zone", see **Fig. 1**). The objective is to reduce injuries caused by an airbag blow in the close proximity to the passenger. To obtain the necessary resolution, the sensor operates in the mm-wave range at 24GHz, where electromagnetic waves are mainly reflected by the surface of the human body.

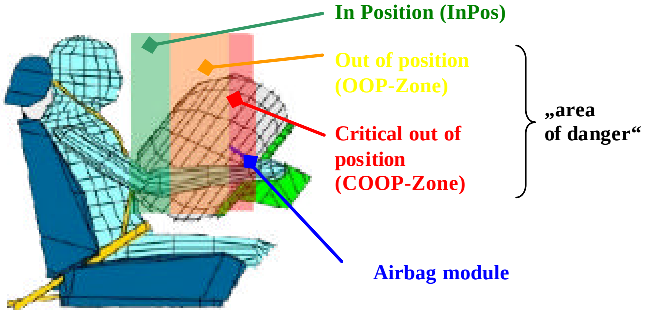

Fig. 1: *Classification of zones in front of the airbag module*

II.2. HEART BEAT AND BREATHING MONITO-RING

The second sensor system developed for recognition of heartbeat and breath frequency operates at a lower frequency (2.45GHz) to obtain the penetration depth necessary for signal reflection at different organs inside the human body (e.g. the heart). The system allows to evaluate the "quality" (intensity) of the heartbeat as well as the heart frequency. The collected sensor signals can be used for different purposes: The detection of the heartbeat indicates the presence of a living being on the seat worth for protection in contrast to lifeless objects. Moreover, the evaluation of the heart and breath frequency supports a better classification of passengers. Both parameters (and also their variability) are fundamentally higher for a child or a younger person in comparison to an adult (e.g. for a 5 year old child the heart frequency is in the range of 110 beats per minute, for an adult it is about 60 beats per minute). Furthermore, the comparison of the present value and the average over a longer period gives information about the physical and emotional status of a driver.

III. BASIC CONSIDERATIONS

Reflection (and transmission) of the electromagnetic waves at the boundaries of a "target" are the basic effect used by a radar systems. Numerical calculations show that the main part of the power is reflected by the following boundary layers:

Frequency of 2.45GHz:

- First reflection at the boundary between air and skin (relevant for the measurement of breath),
- second reflection at the boundary of fat and heart tissue (relevant for the measurement of heartbeat), see **Fig. 2**.

Frequency of 24GHz:

- Reflection at the boundary between air and skin.

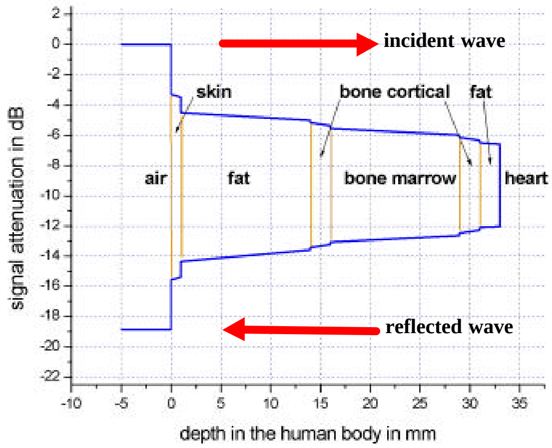

Fig. 2: *Signal attenuation inside the human body*

Simplifications:

- *Path with maximum signal level is considered only,*
- *multiple reflections are not considered, since their attenuation inside the tissue is very high.*

For 24GHz, additional boundaries are not necessary to be considered, since the loss inside the tissue is very high.

IV. SENSOR DESIGN AND MEASUREMENT RESULTS

For both concepts (**Fig. 3** shows the system operating at 24GHz, **Fig. 4** that of 2.45GHz), test sensors have been developed and realized. Herewith, the basic functionality can be demonstrated. Measurement results prove the requirements to be fulfilled both in laboratory environment as well as inside a motor vehicle.

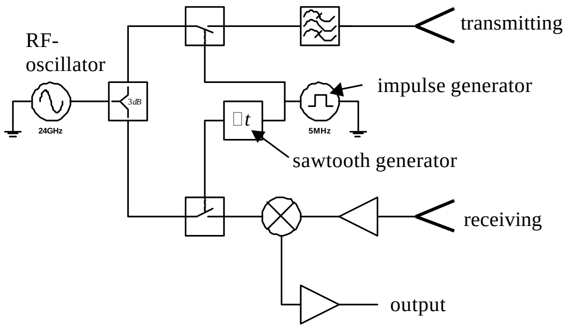

Fig.3: Block diagram of the 24GHz sensor (RF-part)

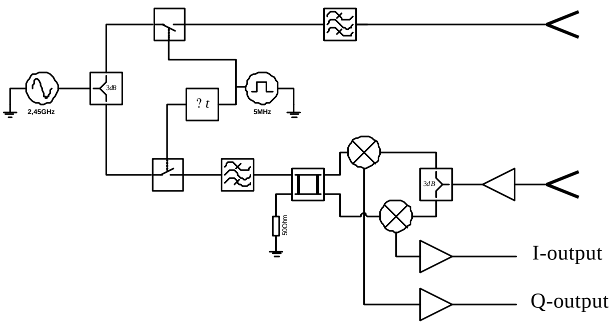

Fig.4: Block diagram of the 2.45GHz sensor (RF-part)

IV.1. MEASUREMENT RESULT FOR POSITION MONITORING

For the signal analysis the reflected signal is mixed with the time-delayed transmit signal. The time delay is controlled by a sawtooth generator. The IF signal is generated only when the propagation time of the signal is equal to the delay. As a consequence, the propagation time of the signal and the distance to the "target" are proportional to the sawtooth voltage, see **Fig. 5**:

$$X_{target}\,[m] = \frac{X_{sawtooth}\,[m] \cdot U_{target}\,[V]}{U_{sawtooth}\,[V]} \qquad (1)$$

Measurements have shown that it is possible to achieve a distance information with a precision of ±1..2cm and a multi target resolution of about 15cm.

IV.2. MEASUREMENT RESULTS FOR HEART BEAT AND BREATHING MONITORING

For monitoring heart beat and breathing, the following scenario is considered: A person is sitting in a car-seat, while the antennas of the sensor system are mounted in front of the person (e.g. at the location of the airbag). The distance between the antennas and the person is about 30..40cm. The signal recording and processing is carried out on a PC applying a Fourier analysis. Herewith, the frequency of the breathing can be determined (see **Fig. 6**).

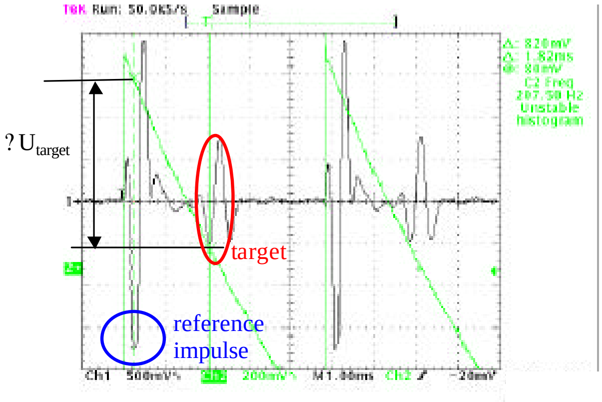

Fig. 5: Measurement result for position monitoring:

*Distance of **85cm** (24GHz sensor) vs. **84.5cm** (conventional determination of distance as a reference)*

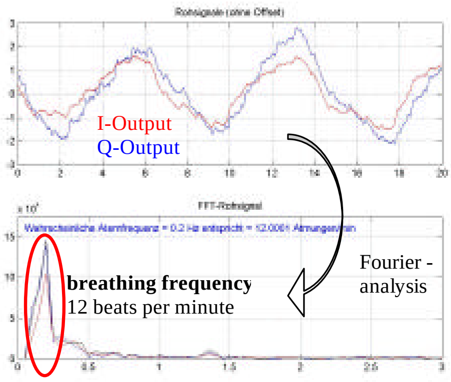

Fig. 6: Measurement result for breath monitoring (2.45GHz sensor and FFT)

With an additional high pass filter (cut-off frequency of 0.2Hz), the breathing signal can be eliminated. By means of a second FFT, information on the heartbeat frequency can be achieved (see **Fig. 7**). With a pressure sensor at the wrist of the person, a reference signal can be generated.

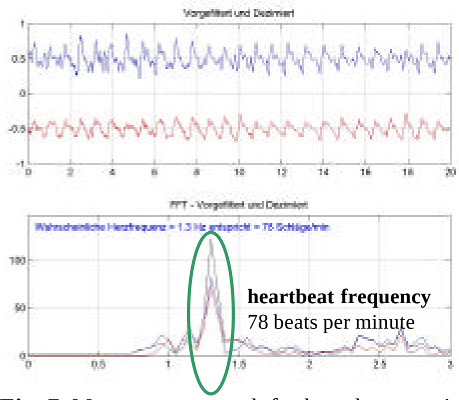

Fig. 7: Measurement result for heartbeat monitoring (2.45GHz sensor, FFT, high pass, add. FFT)

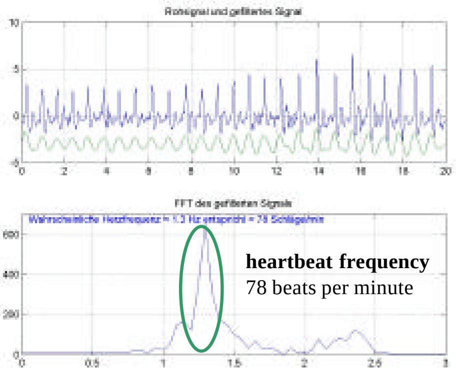

***Fig. 8**: Measurement result for heartbeat monitoring (pressure sensor on the wrist and FFT) as a refernce*

V. CONCLUSIONS

Two radar-based sensor systems have been presented for contact-free determination of position and physiological parameters (i.e. heartbeat and breath frequency) of a person in the interior of a vehicle. By means of test systems, functionality has been proved by comparing results to reference values achieved by conventional technologies. Further investigations will focus on integration of the systems with respect to automotive requirements as well as additional interpretation of the results (e.g. comparison with ECG of a person).

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