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Automotive In-Cabin Object Detection and Passenger Monitoring with Sub-THz Radar System

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Summary

In this paper, an H-band radar system is built, and measurement of in-cabin object detection and passenger monitoring is demonstrated to better understand the in-cabin propagation environment at sub-THz frequencies.

1. Introduction

Sub-THz frequency radar systems have great potential to be used in in-cabin monitoring for their compact size and high accuracy [1-2]. It is essential to understand the in-cabin propagation condition at sub-THz frequencies for designing such radar systems. Such data is not widely available and needs to be obtained through measurements due to this unusual use case. In this paper, an H-band radar system is built with a micromachined-waveguide based planar slot array antenna. Measurements of in-cabin object detection and passenger monitoring are demonstrated. The H-band radar system uses range-domain processing to eliminate peripheral reflection points and multipath, enabling measurements in an enclosed environment such as an automobile. Furthermore, a power-deviation joint analysis is proposed to detect the in-cabin objects and passengers. To the best of the authors' knowledge, this is the first work that demonstrates an H-band radar for in-cabin detection measurement.

2. H band radar system and measurement setup

(a) (b) (c)

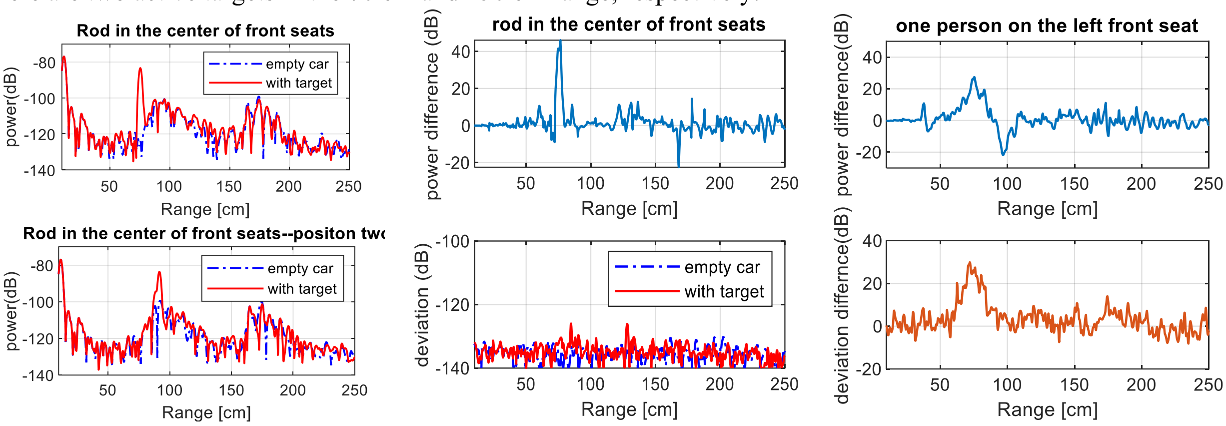
Figure 1. (a) H-band radar system structure, (b) measurement setup in the car cabin, and (c) microscope picture of the fabricated antenna array with micromachined-waveguide distribution network

The proposed H-band radar system structure is shown in Fig. 1(a). A picture of the in-cabin measurement setup is shown in Fig.1(b). A vector network analyzer (VNA) and two extenders from VDI were used in this setup, which operate at frequencies from 238 GHz to 248 GHz. One of the antennas is a commercial antenna SGH-15-WR03 from Anteral. The other antenna is a planar slot array antenna with an amplitude tapered corporate waveguide feed network and is designed and manufactured by silicon micromachining. The slot array antenna is composed of sixteen apertures, forming a 2×8 array as shown in Fig. 1(c).

3. Test results analysis and discussion

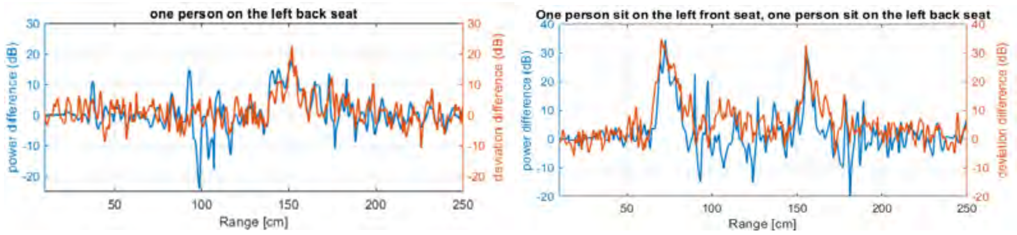
In-cabin measurements were made with a metal rod and a person at different positions inside the cabin. For each test, ten times measurements were made with 1 second interval time between each measurement. Reference tests were made when the car is empty. Then tests were made with objects inside the car. All measurements were made with doors closed. The windows are closed as well except for the right back side window which is half closed to let the cables from the VNA come into the car. First, a metal rod was placed in the middle of two front seats. Then the metal rod was moved toward the backseat by around 20 cm. Fig. 2(a) shows the S21 in the range domain. The blue dash curve represents the reference test. The red solid curve represents the test with a metal rod. It can be clearly seen that the metal rod gives a strong reflection which leads to a peak in the S21 plot as compared to the reference test. Besides, from the positions of the peak in the plots, 75.5 cm and 91 cm, the position difference of the metal rod can be detected. Besides the metal rod, a person was also measured as a target. First, the target person was sitting in the left front seat. In addition to the power of S21, the standard deviation of S21 over ten times measurement is also derived to detect the movement of the target. For a stationary target, such as a metal rod, the deviation of

S21 is expected to be zero in the ideal case, which also applies to the reference tests where all objects inside the cabin are stationary. Fig. 2 (b) shows the power difference of S21 and its standard deviation when the target is a metal rod. The S21 deviation of both the reference test and test with the metal rod is very small, which means there was almost no movement detected. Then, the deviation difference between the test with a target and the reference is studied. Fig. 2 (c) shows the power difference and the deviation difference of S21 with the reference when a target is a person. Compared to a metal rod, a person sitting on the left front seat gives less reflection power. On the other hand, its natural movements cause a large deviation in S21 which makes it detectable by the radar system. It is worth emphasizing that the person was trying to sit as still as possible during the 10 seconds measurement time. The movement is mainly due to breath and heartbeat which introduce very small movements. Thus, when combining the power data relative to reference measurements and the deviation difference data, more information on the in-cabin scenario can be provided. Stationary targets and active targets can be distinguished. The power difference plots in Fig. 2 (b) (c) show a big negative value at some range points. This is due to the blockage by the target. In Fig. 2 (b), the blockage appears at around 170 cm range, this should be the part of the back seat being blocked by the metal rod. In Fig. 2 (c), the blockage appears at around 100 cm range, this should be the part of the front seat being blocked by the person. Fig. 3 (a) shows the test result of a person sitting on the left back seat. From the deviation difference curve, it can be seen that an active target is around 150 cm away from the radar, the power difference curve also supports that. There is another peak at around 90 cm in the power difference curve while the deviation is negligible at this range. Besides, a negative peak is at around 100 cm in the power difference curve. Since there is no other target other than the person, this might be due to a small movement of in-cabin built-in objects when a person sits inside the car. The measurement results indicate that this is a stationary target or environmental change at the 90 cm range while there is an active (moving) target at the 150 cm range. Fig. 3(b) shows the test result of two people sitting in the car. One sits on the left front seat, another sits on the left back seat. The power difference curve and the deviation difference curve both show peaks at the range where a person sits. This measurement result indicates that there are two active targets in the 70 cm and 150 cm range, respectively.



(a) (b) (c)

Figure 2. (a) Range domain S21 measurement results of a metal rod at two positions, test results of (b) a metal rod in the center of front seats, and (c) a person sit on the left front seat.



(a) (b)

Figure 3. Test result of (a) a person sit on the left back seat, and (b) two person sit in the car: one sit on the left front seat while another sit on the left back seat.

References

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