

Single-Chip 77GHz Radar Sensor and its Automotive Applications

Akihiko Hyodo, Shigeru Oho and Toshiyuki Nagasaku
Hitachi Ltd.

ABSTRACT

This paper describes the development of a compact and low cost millimeter wave Doppler radar sensor (77GHz band), which can measure the vehicle ground speed precisely. The sensor has three unique features: First, all the radio frequency components are integrated into a single chip, including a millimeter wave transceiver and an on-chip antenna. Then, the chip package is made of plastic resin without use of expensive ceramic. Finally, a tiny dome-shaped resin lens is attached to the chip to collimate waves. These technologies enable the sensor to measure $53 \times 71 \times 65 \text{ mm}^3$, to weight 115 grams. Compared to a conventional optical measuring instrument for example, the sensor weights only about fifteenth and is one-fifth of the size, while the measurement accuracy is almost comparable. So this sensor seems to have a variety of potential applications.

In this paper, we also considered the feasibility of some other applications than just measuring ground speed. One is the yaw rate detection by using two sensors mounted on both sides of the vehicle. It can be calculated from differential speed between sensors. From the experimental results, we found that the detection was possible and the limit of sensitivity depended on the speed measurement accuracy which is under 2% variation. The other possible application is detecting obstruction. Although it was difficult to cover from 0 meters to far side with one sensor because of its narrow beam shape, we confirmed from experiments that the sensor was able to detect vehicles in the next lane in the range from at least 10 to 60 meters.

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INTRODUCTION

Millimeter wave (MMW) radar sensors are becoming the essential part of automotive safety, comfort and convenience systems, such as ACC (Adaptive Cruise Control) and pre-crash safety systems. It is well known that MMWs have several advantages over microwaves and infrared sensors in most applications. MMWs can offer better resolution than lower frequency microwave sensors, and can penetrate dust, fog, smoke and other obscurants better than infrared sensors. However, the high cost of MMW devices has so far limited their use to a wide range of applications. So we have developed a novel MMW sensor more suitable for general purpose applications, which can achieve low cost, compact and lightweight by implementing full radar function into single-chip MMIC, in contrast with sophisticated and high cost radar sensors. The developed sensors enable many existing and potential users to use MMW technology more freely. In this paper, we present the realization of a single-chip MMW radar module and a prototype sensor, and also discuss the feasibilities of some automotive applications, such

as non-contact measurement of speed, yaw rate, and obstacle detection.

OVERVIEW OF MILLIMETER WAVE SENSOR

SINGLE-CHIP REALIZATION OF COMPLETE RADAR

The [Figure 1](#) shows the photograph of single chip radar MMIC (Monolithic Microwave Integrated Circuits) and a complete radar module with a dome shaped lens [1] [2]. The MMIC contains all necessary MMW functional blocks for radar sensor, such as a LO oscillator, amplifiers, a mixer and a TX/RX antenna on a single GaAs substrate. We employed a single microstrip patch antenna with a dielectric lens for cost effectiveness compared to an array antenna, which could improve the sensitivity, but at the cost of increased chip area. As seen in the photograph, a dome shaped lens is attached to the top of the package, which collimates radiation beam and compensates for lack of gain obtained only from the single

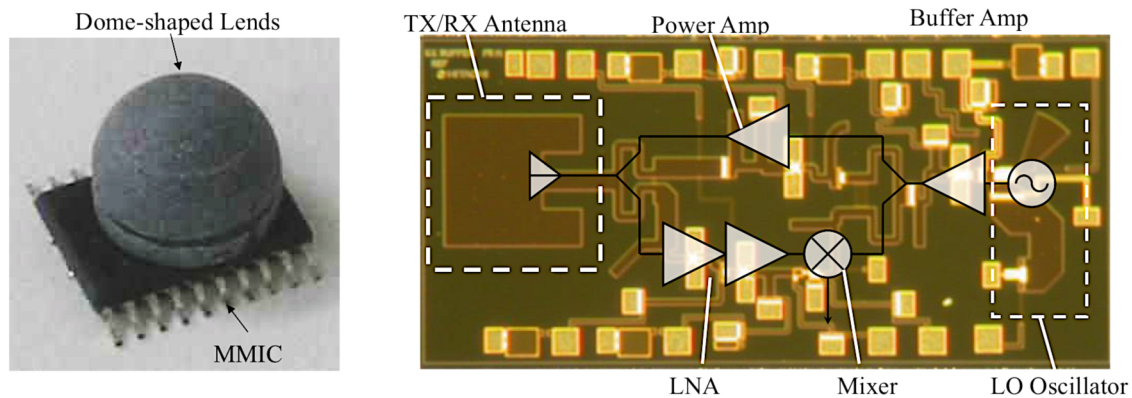


Figure 1. Photograph of single-chip radar MMIC and complete radar module

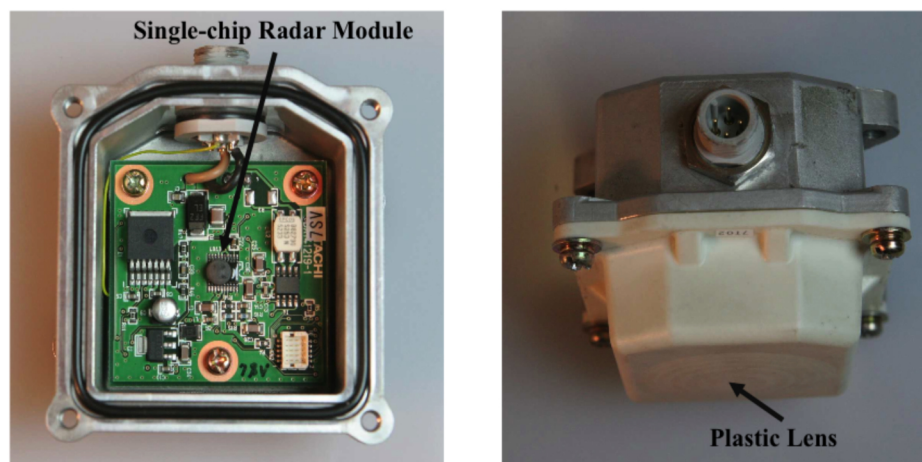


Figure 2. Prototype of millimeter wave sensor

patch antenna. The lens collimates the MMW beam to about 40 degrees with 10 dB of gain. The MMIC is fabricated on a GaAs pHEMT process with 30.15um gate length and substrate thickness of 100um. The MMIC measures $2.7 \times 1.3 \text{ mm}^2$ and the completed radar module including the dielectric lens measures $6.5 \times 4.4 \times 6.0 \text{ mm}^2$.

SPECIFICATIONS OF SENSOR UNIT

Figure 2 shows the photograph of prototype sensor unit, which measures $53 \times 71 \times 65 \text{ mm}^3$. The sensor unit contains single-chip radar MMIC and power supply circuits on the upper side of the board, a microcontroller as a signal processing module on the flip side of the board (not in the figure) and has CAN-bus (Controller Area Network) interface. In order to narrow down the beam width of radiation, a second dielectric lens is embedded within radome structure. Table 1 lists the specifications of the sensor.

Table 1. Sensor specifications

Items	Specifications
TX Power (EIRP)	24 dBm
TX Signal Frequency	76.5 GHz
-3dB Beam Width	6 degrees
Module Size	$53 \times 71 \times 65 \text{ mm}^3$
Weight	115 grams

GROUND SPEED MEASUREMENT

METHOD OF MEASURING GROUND SPEED

Measuring vehicle ground speed is the most straightforward and promising usage of developed sensors [3] [4]. Conventional vehicles calculate their speed from the rate of wheel rotations. So they could misread when all wheels are locking up or skidding by acceleration. However, the developed sensor can measure the vehicle speed correctly even in these situations. So the sensor is expected to be useful

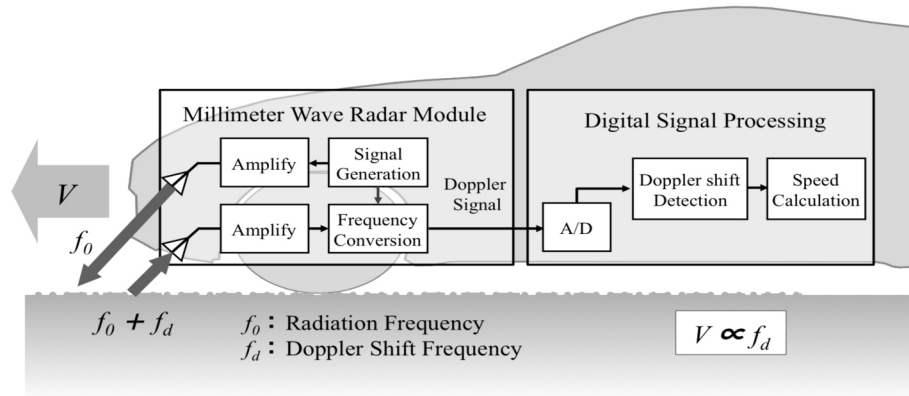


Figure 3. Block diagram of ground speed sensor

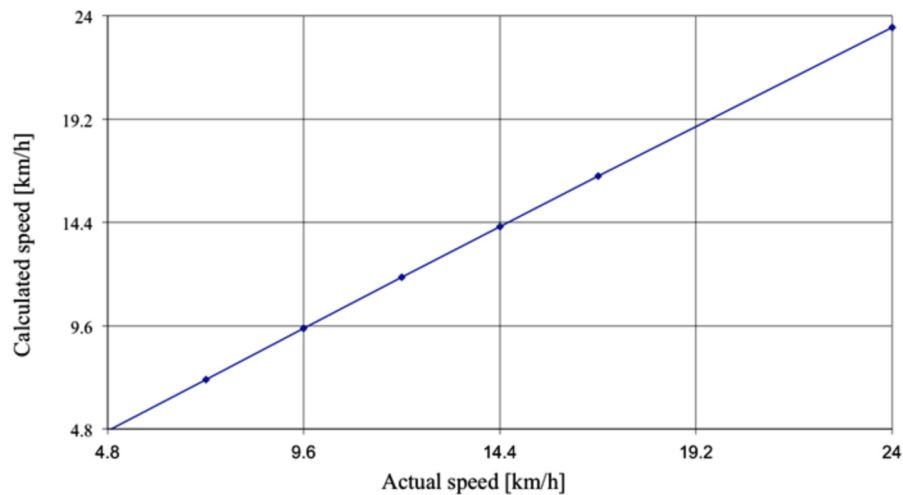


Figure 4. Comparison of measured speed with actual speed

for applications that need high accuracy vehicle speed such as advanced vehicle control and safety systems.

The measuring principle is as follows. The sensor is aimed downward typically at 45 degree to sense the relative movement of a vehicle to the ground surface, as shown in Figure 3. Actual ground speed is derived from the measured speed v according to the following equation:

$$v = f_d \frac{c}{2f_i \cos \theta} \quad (1)$$

where f_d is the Doppler frequency, f_i is the frequency of radiation signal, θ is the angle between the wave direction and the ground surface, and c is the speed of the light.

Figure 4 shows the test result of measuring speed on the test bench, which includes a drive belt of chassis dynamometer and an optical resolver that detects its rotational speed. The X-axis shows the actual speed, which means the outputs of the optical resolver and the Y-axis shows the measured speed of MMW sensor. Good linearity was obtained from the result.

ROAD TESTING OF GROUND SPEED SENSOR

Skidding is often caused by hard acceleration or braking driving on slippery roads. A conventional speed sensor, which measures the rotation rate of a vehicle wheel, cannot detect vehicle speed correctly under such conditions. On the other hand, the ground speed sensor using MMW sensor can never be affected by wheel skidding. We conducted road tests with a car, mounting the ground speed sensor on the front bumper to assess the effectiveness of this non-contact measurement approach.

Figure 5 shows the speed measurement results in the case of accelerating and braking on a snowy road. As can be seen in these figures, the detection error of the wheel speed sensor, which means the speed difference between the wheel rotation and the true ground speed, occurred greatly during a traction slip or a wheel lock. However, the developed ground speed sensor was able to detect the actual vehicle speed precisely. Comparing with the GPS as a reference, the detected speeds of both sensors were almost overlapped.