# Fully Polarimetric FMCW Instrumentation Radar at 228 GHz

*Adib Y. Nashashibi*, Badeea Alazem, and Kamal Sarabandi*
*Radiation Laboratory, Electrical Engineering and Computer Science Department*
*The University of Michigan, Ann Arbor, Michigan, USA*
*nuha@umich.edu, bazem@umiche.edu, sarband@umich.edu*

***Abstract*—The paper reports on a new fully-polarimetric instrumentation radar operating at 228 GHz. The radar is designed to operate in FMCW mode and enjoys high angular and range resolutions and fast data acquisition.**

***Keywords—Instrumentation radar; millimeter-wave; polarimetry;***

## I. Introduction

Over the past decade, there has been a significant increase in use of millimeter-wave (MMW) radars in sensing applications, such as high resolution imaging [1], assistive landing of aircraft [2], vehicular intelligent cruise control [3], and concealed weapons detection [4-5]. The majority of these systems thus far has been operating at frequencies centered around 35, 77, and 95 GHz. The proliferation of MMW radars is expected to continue as the demand for compact, lightweight, high range resolution, and all-weather sensors continue to expand into new applications. Examples of newly envisioned applications include robotic navigation and autonomous vehicles. More compact MMW systems and/or finer angular resolutions are among the constraints imposed by these newly emerging technologies.

The ability to accurately sense the environment surrounding the vehicle is a critical requisite of autonomous vehicles. For this application to be reliable and successful, sensors on the vehicle should be able to detect and track other vehicles (their location, speed, and size), assess the road-surface conditions, detect and classify hazards on the road (location and size), and distinguish between on-road and off-road objects over a wide range of distances from the vehicle. The fact that the functionality of MMW radars is not hampered by day/night or inclement weather conditions, make them an essential sensor in forthcoming autonomous vehicles. Compact 77-GHz radar sensors are already in use in the vehicular intelligent cruise control applications with angular beamwidths on the order of $2^{o}$ to $3^{o}$. A promising approach to achieve finer angular resolution needed in autonomous vehicles is to design its MMW radar to operate at 230 GHz (3 times the 77-GHz) whereby an antenna of size equal to that of 77-GHz sensor becomes electrically larger at 230 GHz with narrower antenna beamwidth and higher gain. The phenomenology of radar backscatter from vehicles and road surfaces at near-grazing incidence have not been investigated before.

In this paper, we report on the development of a new fully polarimetric instrumentation radar operating at 228 GHz. The new design circumvents limitations in existing commercially available RF components at 228 GHz to create a unique instrumentation radar with high resolution, full-polarimetry, and fast data acquisition capabilities. The new system will be used in phenomenological studies that support the use of 230 GHz radars for autonomous vehicles and other applications.

## II. Radar Design

The conventional approach in constructing a polarimetric instrumentation radar at frequencies below 100 GHz is to generate the modulated radar signal (e.g. LFM, step-frequency) at low microwave frequencies, translate its frequency to the desired radar frequency range using an up-converting mixer and a local oscillator operating near the RF frequency (e.g. Gunn oscillator), amplify the RF signal, and send the signal to the transmit antenna assembly. The transmit antenna assembly includes an antenna, an orthomode transducer (OMT) and a fast RF SPDT switch to select between two transmitted orthogonal polarizations [6]. The received signal is passed through an OMT, low-noise amplifier, and is down-converted to low microwave frequencies for detection. Unfortunately, many of the RF components needed in this conventional design are not commercially available at frequencies above 110 GHz. This includes efficient up-converters, power and low noise amplifiers, OMT, RF SPDT switch, and Gunn oscillators. An alternative approach has been reported in [7] whereby an instrumentation radar operating at 222 GHz was constructed using two sub-harmonic mixers (used to up- and down-convert the modulated radar signal that had been generated at 7-9 GHz), a local oscillator operating at 107 GHz, and mechanically controlled polarization cards placed inside the antennas. This results in a system with very low transmit power (-13.5 dBm) and long data acquisition time.

In this paper, we report on the design and construction of new fully-polarimetric Frequency-Modulated Continuous-Wave (FMCW) radar with effective beamwidth of $\beta_{3dB} = 1^{o}$, 6-GHz in generated signal bandwidth (resulting in 2.5 cm in range resolution), fast switching speeds (10 ns) between vertically and horizontally polarized transmitted signals, short chirp period (< 100 μs), and +6 dBm in transmit power. The FMCW-

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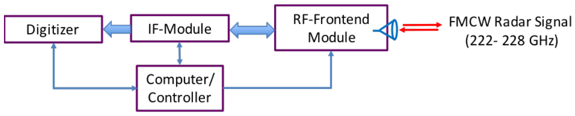


Fig. 1: Major modules comprising the new radar.

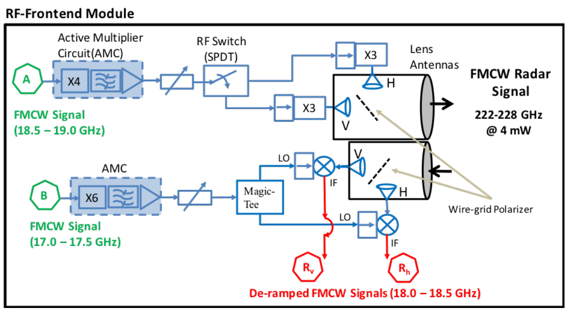


Fig. 2: Block diagram of the RF-frontend module.

based approach is used in many short-range radar applications [4-5, 8]. It has the following advantages: (a) low peak power requirements, (b) its wideband radar signal is de-chirped on receive and the detected signal is narrow band resulting in low sampling requirements on the digitizer, and (c) reduced radar hardware complexity and cost.

The radar consists of two primary modules, an RF-frontend module and an IF module, as depicted in Fig. 1. The function of the IF module is to generate the FMCW signal and to down-convert the received signal from the RF-module to baseband for detection by the digitizer. The FMCW signal is generated at S-band using a custom PLL circuit. Then, the FMCW signal is split into two, each is up-converted using two coherent LO signals operating at different frequencies. The up-converted signals are sent to the RF module. At the RF-frontend module, shown in Fig. 2, the two FMCW signals are frequency multiplied differently using active multiplier circuits (AMC), however each signal path ends with a total frequency multiplication factor of 12. On the transmit path and after multiplying the FMCW signal by factor of 4, resulting in a signal between 74 and 76 GHz, an RF SPDT switch is used to select between two dedicated transmit channels. The transmit signal is then fed to triplers to create the radar signal at 222-228 GHz, which in turn is transmitted using a dual-polarized antenna. A $2^{nd}$ dual polarized antenna is used for receiving the backscattered signal from the target. The received signal is mixed-down with a copy of the FMCW signal using a subharmonic mixer (the FMCW signal is de-chirped at this stage) and the de-chirped signal is sent back to the IF-module for additional down-conversion and detection. Details of the radar design will be presented at the conference.

## III. Validation

The performance of the IF- and RF-frontend modules have been validated separately. Their performance conforms to design specifications. In addition, the IF-module was also tested as a stand-alone radar. The IF transmit FMCW signal was passed

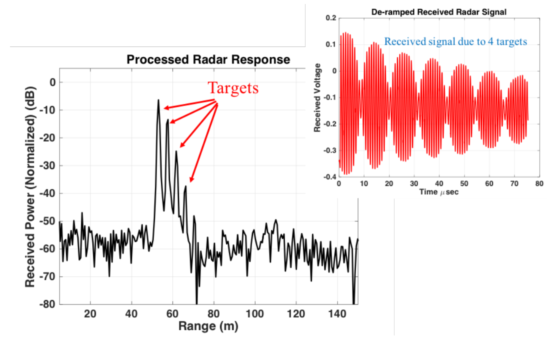


Fig. 3: De-chirped time-domain signal of 4 targets and the corresponding processed radar response as function of range.

through a long delay line and mixed with a copy of it using an external mixer (de-chirped). The delay line had also a built-in T-junction that allowed for multiple reflections to occur mimicking the presence of multiple targets in the radar scene. Fig. 3 shows the de-chirped time domain signal of 4 targets as well as the processed radar signal as function of range. Additional data charactering the performance of the entire radar system will be presented at the conference.

## IV. Conclusions

A one-of-kind, FMCW fully-polarimetric, high-resolution instrumentation radar operating at 228 GHz has been designed and constructed. The radar will be used to accurately measure the scattering matrix of different targets at this frequency and characterize the radar response of complex scenes in support of autonomous vehicles and other emerging applications.

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