Fully Polarimetric E-Band Instrumentation Radar in Support of Autonomous Vehicle Research

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***Abstract*—This paper reports on the development of a new fully polarimetric and wideband instrumentation radar operating at a center frequency of 79.6 GHz. This FMCW radar features high angular, range, and Doppler resolutions and supports continuous data acquisition of radar returns from complex traffic scenes. The system is suitable for use in phenomenological studies that support the use of E-band radars for autonomous vehicles and other applications.**

***Keywords*— polarimetry; radar; automotive; millimeter-waves;**

I. INTRODUCTION

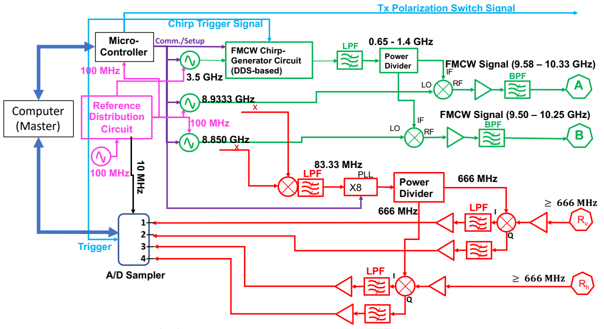
Automotive radars, operating at millimeter-wave frequencies (MMW), have become a standard sensor on the majority of new vehicles. They serve in various assistive roles such as collision-warning, adaptive cruise-control, and blind-spot detection. Car manufacturers are actively pursuing the development of autonomous vehicles, whereby expanded sensor capabilities that include fine angular resolution for precise navigation, road debris detection, and road surface condition assessment are needed. For the near future, the E-band automotive radar (76-81 GHz) will remain an indispensable sensor for autonomous driving due to its long-range (> 200 m) and all-weather capabilities compared to optical and laser sensors. These radars are compact, lightweight, capable of both high range and high Doppler resolution measurements of road scenes, and optimizable according to the needs of autonomous driving. Current automotive radars are singly polarized radars of modest range resolution of 0.3 m (Bandwidth = 500 MHz) and modest angular resolution of 4^o. Adding polarimetric measurement capability to an automotive radar will allow it to assess the road surface conditions in front of the vehicle [1] and discriminate between different objects on/off the road. In addition, enhancing range resolution (e.g. 0.03 m which corresponds to signal bandwidth of 5 GHz) allows the radar to accurately determine the location and extension of objects on the road, such as vehicles and hazardous debris.

While early work on automotive radars has focused on detecting large moving objects on the road, little work has been devoted to examining the polarimetric response of road surfaces and objects [2-5]. In this paper, we report on the development of a new fully polarimetric instrumentation radar operating at 79.6 GHz. The details of the radar design are first presented and are followed by preliminary test results.

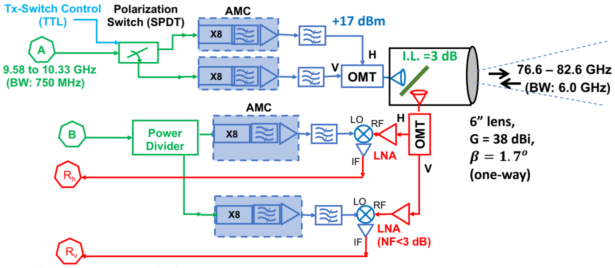
II. RADAR DESIGN DETAILS

The vertical (V) and horizontal (H) polarization basis is selected for the radar design. The radar can be programmed to transmit V or H polarizations while simultaneously detecting both V and H components of the received radar signal. Hence, in two consecutive FMCW transmissions (V- then H-polarized transmitted signals) the entire scattering matrix of the target can be measured.

The radar consists of two primary modules, an IF-module and an RF-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 ADC. The FMCW signal is generated near baseband using a programmable direct digital synthesizer (DDS). This saw-tooth FMCW signal, which spans up to 750 MHz in bandwidth, is split into two. The two split FMCW signals are up-converted to X-band using two coherent LOs operating at slightly different frequencies (83.33 MHz offset). The up-converted signals are sent to the RF module, where they are used to feed four x8 active multiplier circuits (AMC). Along the transmit path, denoted by symbol A in Fig. 1b, an X-band SPDT switch is used to channel the FMCW signal between the V- and H-polarization ports of the Orthomode Transducer (OMT) feeding the transmit antenna horn. Along the receive path, denoted by symbol B in Fig. 1b, the X-band FMCW signal is divided between two x8 AMC modules that provide the LO signals for the two E-band mixers in the receiver as depicted in Fig. 1b. The V- and H-polarized components of the received radar signal reaching the receiver horn are separated using the receiver OMT, amplified via an E-band low-noise amplifier (LNA), and then fed to the E-band mixers where de-chirping of the FMCW signal is done. The V- and H-polarized de-chirped signals consist of CW signals above 666.6 MHz with frequencies proportional to the distances to different targets. The de-chirped signals are fed back to the IF-module where they are I-Q demodulated and fed to an ADC for detection. A common reference signal and synchronization clock are used to maintain phase coherence during measurements.



(a) IF-Module



(b) RF-Module

Fig. 1: Block diagram of new polarimetric radar (a) IF- and (b) RF-modules.

The x8 AMC units are commercial modules featuring an 18 dB unwanted harmonic signals suppression. Despite the fact that these harmonic signals are weak, their presence will result in “ghost targets” and elevated noise floor. Custom E-band, waveguide-based, bandpass filters were constructed and placed at the output of the AMC units to ensure these harmonics are suppressed by more than 50 dB [6]. A single lens antenna (0.15 m diameter) for both transmit and receive was developed for this radar [7]. In this antenna, a polarization-independent power-divider plate is placed between the transmit and receive feed-horns with over 45 dB isolation between the feeds [7]. Overall, the radar can be operated over a maximum bandwidth of 6-GHz centered around 79.6 GHz with transmit power of 13 dBm, cross-polarization isolation > 25 dB, and antenna beamwidth of 1.7° (one-way). The DDS can be programmed to repeatedly generate very short saw-tooth FM chirps (> 5 µsec each) to enable high-resolution Doppler measurements of fast moving objects. In principle, any chirp duration and bandwidth within the specifications provided above can be used provided that the required sampling rate of demodulated baseband signals can be accommodated by the ADC. The ADC used in the system is capable of 100 MSamples/Channel in block-segmented mode (i.e. On/Off mode) and 50 MSamples/Channel in continuous streaming mode (i.e. non-stop data collection and transfer to multi-core computer for storage and processing) which is sufficient for most phenomenological experiments of interest.

III. VALIDATION

The performance of the IF- and RF-modules were validated separately, and their performance conformed to design specifications. In addition, the entire radar was placed in a cluttered room with a corner reflector placed close to the absorbing back wall and the VV-polarized radar response of the scene was measured. In Fig. 2, the coherently-averaged responses of 100 chirp periods is compared with the response due to a single chirp. This figure demonstrates system coherence, a critical feature in generating the Doppler-range map of a target. Additional measurements characterizing the performance of the entire radar system under different measurement modes will be presented at the conference.

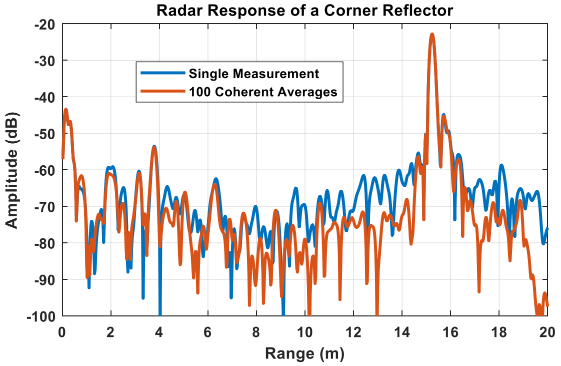


Fig. 2: Comparison between a single measurement and 100 coherently averaged data acquisitions

IV. CONCLUSIONS

A one-of-a-kind, fully-polarimetric, high-resolution FMCW instrumentation radar operating at 76.6 - 82.6 GHz has been designed and constructed. The radar will be used to accurately measure the scattering matrix of different targets at this frequency band and characterize the radar response of complex road scenes in support of autonomous vehicles and other emerging applications.

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