A 243 GHz Direct-Conversion FMCW Transceiver for Radar Moving Target Signature Measurements

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***Abstract*— A prototype single-channel V-transmit V-receive (VV) frequency modulated continuous wave (FMCW) instrumentation radar operating near a center frequency of 243 GHz has been developed. The primary motivation for development of the radar is to support micro-Doppler signature measurements of moving targets at millimeter-wave frequencies. The transceiver employs a commercially available synthesizer evaluation module that directly drives both the transmitter and receiver x24 frequency multiplier assemblies. The receiver is a simple direct conversion architecture feeding a modest 5 MS/s data acquisition card or fast oscilloscope (up to 2 GS/s). The design and operation of the transceiver is presented in this paper along with measurement results of a reconfigurable multi-blade rotor assembly used to demonstrate system performance.**

Keywords—FM, FMCW, Micro-Doppler, Millimeter-Wave, Radar, Radar Cross Section, Radar Scattering, Range-Doppler, Spectrogram, Time-Frequency Analysis.

I. Introduction

The measurement of radar signatures of moving targets at millimeter-wave frequencies is of ever increasing interest to the radar and signature analysis communities [1, 2]. Millimeter-wave frequency radars require generation of very short duration frequency sweeps in order to simultaneously resolve high target velocities as well as target range. In this paper the design and operation of a prototype instrumentation radar operating near 243 GHz is presented. This particular frequency band straddles the upper-portion of the mm-wave and lower THz regions of the electromagnetic spectrum which has been targeted recently for real-time imaging applications [3].

II. System design

The 243 GHz FM transceiver was constructed at the University of Massachusetts Lowell Submillimeter-Wave Technology Laboratory (STL). The x24 millimeter-wave transmitter and receiver multiplier assemblies were constructed to operate as a 240 GHz transceiver. The transceiver provides an output power of ~1 mW and receiver noise temperature of ≤1,200 Kelvin double side-band (DSB) [4]. The synthesized source driving the multiplier assemblies is a PC-controlled Texas Instruments (TI) LMX2492 phase-locked loop (PLL)-based X-band synthesizer evaluation module (EVM) [5]. This prototype design necessitated the implementation of a direct conversion homodyne receiver architecture without an I/Q demodulator (Fig. 1).

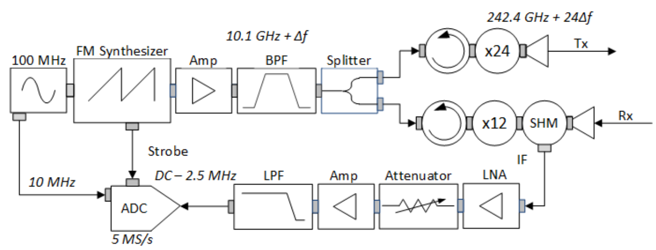

Fig. 1. 243 GHz FMCW Transceiver Direct Conversion Architecture

The mm-wave receiver IF signal is amplified and low-pass filtered prior to being captured by a National Instruments NI-6110 12-bit data acquisition (DAQ) card, or a Keysight Technologies MSO-X 2024A 200 MHz oscilloscope. The NI DAQ card operates at a modest sampling rate of 5 MS/s, while the Keysight oscilloscope provides sampling rates as high as 2 GS/s but has limited memory depth. The oscilloscope was used primarily for system characterization purposes and the DAQ card for target data acquisition. The 20 MHz clock of the NI DAQ card was derived from the 100 MHz PLL reference oscillator's 10 MHz output reference signal. The two corrugated feeds of the mm-wave transceiver, one for transmit and one for receive, were positioned at the focal point of a 250-inch focal length, 45-inch diameter, aluminum diamond-turned spherical reflector, creating a 25-inch diameter FWHM 2-way quiet zone. Targets were located within the quiet zone for micro-Doppler signature measurements approximately 400 inches from the transceiver.

III. System performance

A high-range-resolution (HRR) plot of a 1" metal trihedron (~-5.4 dBsm @ 243 GHz) mounted upon a serrated foam pylon is provided in Fig. 2. The results employ a single 100 µs period 1.2 GHz wide linear FM waveform (sawtooth) at a center frequency of 243 GHz. The low-pass-filtered intermediate frequency (IF) signal was Hanning-windowed prior to application of a Fourier Transform. Subtraction of the complex-averaged background system response was found to reduce contributions arising at low IF frequencies due to system nonlinearities and various sources of leakage (DC in Fig. 2), as well as due to scattering off of the collimating reflector. The noise floor and spurious response in the vicinity of the trihedron is below ~-35 dBsm and varies with system configuration (waveform period, bandwidth, and PLL charge pump gain).

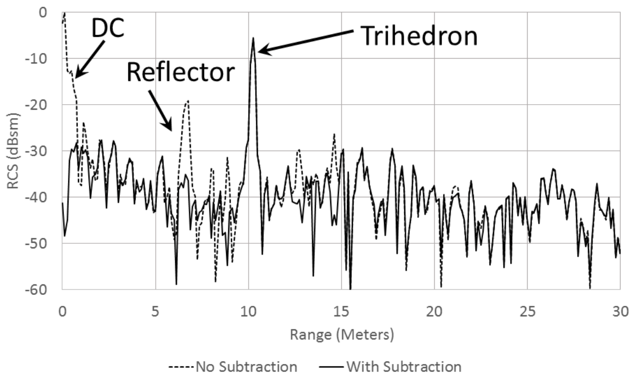

Fig. 2. Range Response - Trihedron with/without Background Subtraction fc=243 GHz, 100 µs Period, 1.2 GHz BW.

To determine the capabilities of the millimeter-wave system to capture moving target signatures over a wide range of Doppler frequencies a reference moving target was required. A three-blade rotor with a sphere, flat plate, and truncated pyramid mounted on blade ends was design and constructed at STL. The rotating reference target is shown mounted on a user controllable servo-motor in Fig. 3. A section of STL-designed THz radar absorbing material (RAM) is employed to reduce the radar return of the target and motor mounting assembly.

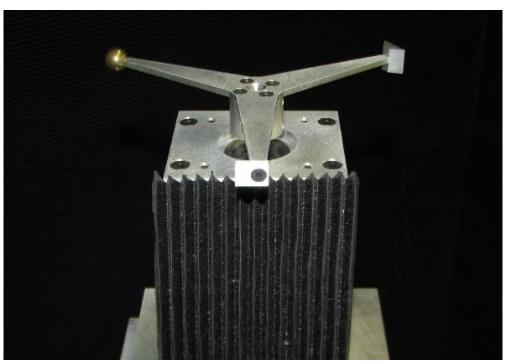

Fig. 3. Rotating Reference Target - Three-Blade Rotor Assembly

The acquired real IF data were Hilbert transformed to create an analytic signal allowing signal phase estimation for waveform linearization. Spectrogram and Range-Doppler images of the rotating three-blade reference target are provided in Figures 4 and 5. The sphere RCS is -39 dBsm indicating a spectrogram noise floor slightly below -40 dBsm. Each rotor and target are identifiable within the spectrogram.

The Range-Doppler image of Fig. 5 was captured near 220 milliseconds (compare to Fig. 4), using a window 100 chirps wide to provide a Doppler resolution of 100 Hz. The specified targets are clearly resolved with a processed noise floor below -50 dBsm.

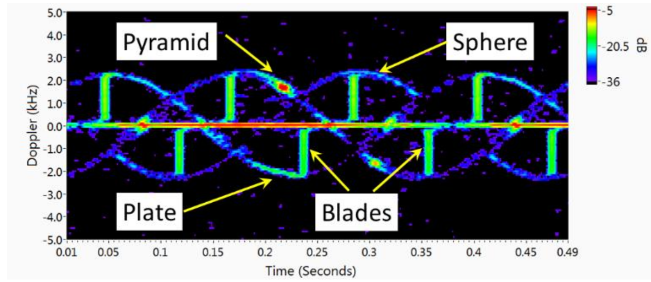

Fig. 4. Normalized Spectrogram fc=243 GHz, 100 µs Period, 1.2 GHz BW – Rotation Rate of 3 rot/s (1.5 m/s).

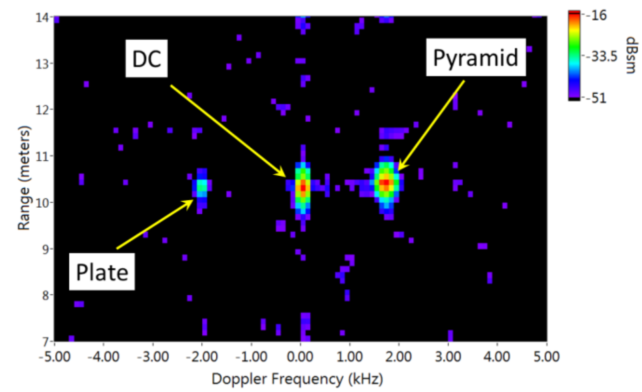

Fig. 5. Range-Doppler Image fc=243 GHz, 100 µs Period, 1.2 GHz BW – Rotation Rate of 3 rot/s (1.5 m/s).

IV. Conclusion and Future Work

A prototype 243 GHz FMCW single-channel direct-conversion transceiver for moving target signature investigations has been demonstrated. The system was designed and constructed at the UMass Lowell Submillimeter-Wave Technology Laboratory (STL). To improve system performance, the transceiver may be redesigned with a super-heterodyne I/Q receiver possibly using a direct digital synthesizer (DDS) in place of the PLL-based EVM. Micro-Doppler measurements of moving targets of interest to the radar community will also be acquired and analyzed.

References

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