Preliminary Results of Narrowband Doppler Radar Imaging Using Real Data in the 0.5 THz Frequency Band

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Abstract — **In this paper preliminary results of radar imaging measurements using a narrowband signal in the low terahertz band are presented. Measurement system architecture as well as the narrowband imaging technique are also discussed. Verification of the theoretical method of acquiring images by the use of narrowband signal through its application to real radar data is presented. Additionally, the results obtained are compared with the results acquired using the Inverse Synthetic Aperture Radar (ISAR) technique utilizing a bandlimited signal.**

I. INTRODUCTION

IN this paper a radar system used to acquire radar data samples for proofing the concept of narrowband Inversed Synthetic Aperture Radar (ISAR) [1] imaging in the terahertz (THz) band is briefly described. A concept of using a single frequency sinusoidal signal for radar imaging appeared in the 2000s and was described in [2], [3] and [4] among others. In [2] real test data was synthesized from a stepped frequency wideband system, while in [3] single frequency measurements of two targets were conducted; in both cases the systems worked in the X band. In [4] simulations in the bistatic case were presented, while real narrowband measurements and results obtained with bistatic passive system using GSM signals – in [5]. To the authors' knowledge, there have been no other works published about applications of this technique to multiple target real data measurements in the millimeter-wave and terahertz band.

II. NARROWBAND DOPPLER IMAGING

Presented narrowband Doppler imaging technique works well with single frequency sinusoidal signal, although it is possible to apply the same processing for other narrowband signals with similar effects [2]. Provided the path of the scatterer is perpendicular to the antenna's heading direction and its velocity is known, it is possible to obtain the position of the scatterer in both range and azimuth, due to only the Doppler frequency shift change in time. Two scatterers moving with the same velocity could be distinguished in range because the radial velocity of the closer one is changing faster than the other one as it spends less time within the beam of the antenna passing the radar. For the geometry described above the point target response phase related component can be defined as [2], [3]:

$$W_{\varphi}(x) = \exp\left(j \cdot \frac{4\pi}{\lambda} \cdot \sqrt{(R^2 + x^2)}\right). \qquad (1)$$

Imaging of the scene is done by computing the cross-correlation between the received echo and the template signal synthesized for each specified distance based on equation (1). Effective bandwidth is dependent only on the Doppler frequency shift, thus allowing for low sampling rate and small data storage even in the terahertz range.

III. MEASUREMENT SYSTEM

The system used comprises of transmitter (TX) and receiver (RX) modules working in the 325-500 GHz frequency band, and two signal generators: Keysight E8257D analog and E8267D vector signal. The modules are commercial-of-the-shelf (COTS) equipment produced by Radiometer Physics GmbH. The E8267D vector signal generator is capable of generating an arbitrarily programmed complex signal with bandwidth up to 100 MHz. The up/down conversion in the TX/RX modules is done using frequency multipliers. In the 325-500 GHz system the overall multiplication factor is 36, therefore the final bandwidth of the described Frequency Modulated Continuous Wave (FMCW) version of the system is 3.6 GHz.

The targets of the imaging are moving on a motorized optical table. This table is equipped with X, and Y axis positioners allowing the target platform to move along and perpendicular to the TX/RX modules' viewing direction. In addition, the target platform can be freely rotated in either direction. The radar system can also use TX and RX modules for two lower frequency ranges: 75-110 GHz and 110-325 GHz.

The signal can be recorded with various recording devices. For the presented setup, the measurement signal in the narrowband system was recorded using Keysight's VSA 89600-series Vector Signal Analyzer, while on the bandlimited system the Ettus Research USRP N210 series device was used.

IV. MEASUREMENT SCENARIO AND RESULTS

The sounding signal used has the frequency of 396 GHz. As the Doppler frequency shift is proportional to the carrier frequency this signal is very well suited for narrowband processing so high resolution is possible.

Two sets of the measurements were designed. In case of the first one the narrowband system with various radar scenes with one, two and three targets placed on the moving platform was arranged. The second set of the measurements was set up with the FMCW wideband system and recreated radar scenes of the selected narrowband measurements. In each measurement as the measurement target one metallic can was used out of three possible: two smaller ones, approximately 8 cm in diameter and 11 cm in height and a larger one approximately 10 cm in diameter and 17 cm in height.

Fig. 1 presents the result of narrowband measurement and image processing of a single target.

Fig. 2 presents the result of narrowband imaging of two identical targets. In the measurement depicted in Fig. 2 a) both small cans were offset in azimuth, while in Fig. 2 b) – in range.

A scene geometry of one of the more complex measurements with three targets with the target dimensions marked is presented in Fig. 3.

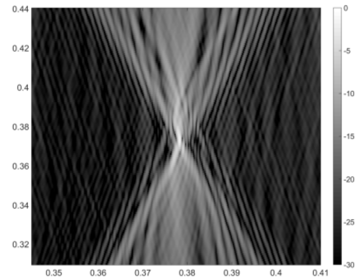

Fig. 1. Narrowband Doppler image of a single target

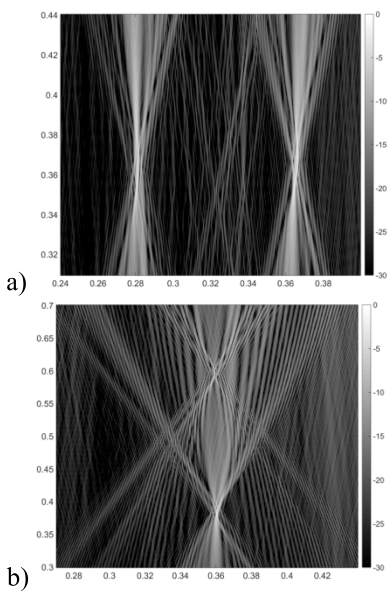

Fig. 2. Narrowband Doppler image of two identical targets offset in a) azimuth b) range.

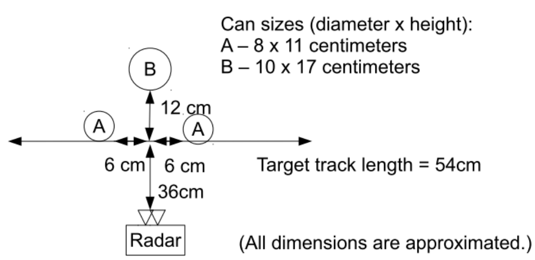

Fig. 3. Scene geometry containing radar and three measured targets.

Fig. 4 a) below presents the image of the described scene processed with the narrowband Doppler imaging method. Obtained resolution is very high in both range and azimuth. The image is distorted by a series of ambiguities and demonstrates the effect of concealing weaker scatterers by the stronger ones (two front cans are clearly visible with the third one in the back blurred, even though it is much bigger than the others).

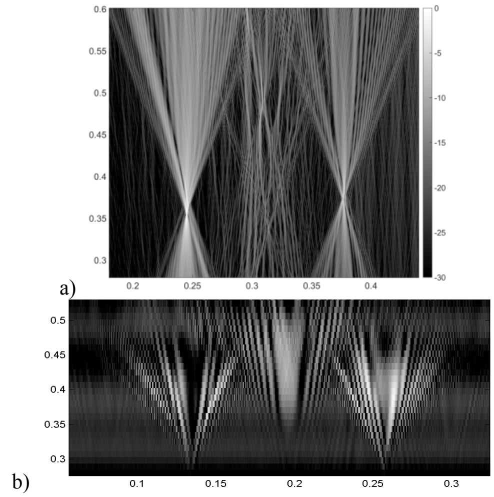

Fig. 4. Results of radar imaging of the described scene: a) using the narrowband Doppler technique and b) using the bandlimited FMCW waveform

Fig. 2 b) presents the image acquired with a bandlimited (3.6 GHz bandwidth) FMCW radar. All three cans are visible in the FMCW ISAR picture. Due to the carrier frequency as well as because of the signal bandwidth and cans' dimensions in the FMCW ISAR scenario, the cans cannot be considered point targets anymore. Due to this, the FMCW ISAR image becomes somewhat harder to read. Despite the aforementioned, the amount of information coming from both images is similar.

V. CONCLUSIONS AND FUTURE WORKS

In this paper the technique for obtaining radar images with the use of a single frequency narrowband signal has been presented. The described technique was applied to the real data measurements conducted with the experimental radar system working in the lower terahertz band.

As presented, the narrowband Doppler technique is simple, easy to implement and well suited for radar imaging of the simple scenes. Nevertheless, additional processing algorithms should be devised to cope with masking weaker targets by the strong ones in the scene as well as other ambiguities. In the next step the authors intend to apply an additional clean processing for removing echo from the strong targets, which should help in improving visibility of the weak targets [4]. Further research on applications of narrowband Doppler imaging to more complex scenes will be continued.

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