Comparison Analysis of Small and Large Bandwidth Indoor SAR Multi-Object Imaging at Low Terahertz Spectrum

Aman Batra[1], Michael Wiemeler[1], Diana Goehringer[2], Thomas Kaiser[1]
[1]Institute of Digital Signal Processing, University of Duisburg-Essen, Campus Duisburg, Germany,
[2]Chair of Adaptive Dynamic Systems, Technische Universitaet Dresden, Dresden, Germany

Abstract— **Indoor THz Synthetic Aperture Radar (SAR) is an emerging research domain. It expands the conventional SAR applications to sub-mm resolution imaging and localization due to high available bandwidth and compact antennas at this spectrum. In general, high resolution is always preferred but it comes with the cost of complexity of the radio front-end chain. Therefore, in this paper three SAR systems with different carrier frequency f_c and bandwidth B_w are studied. These systems are set-up with $f_c =$ 230 GHz and $B_w =$ 20GHz, $f_c =$ 245 GHz and $B_w =$ 50 GHz and lastly, $f_c =$ 275 GHz and $B_w =$ 110 GHz. The paper presents the comparison between these systems w.r.t. the focused SAR image quality associated with the spatial resolution.**

I. INTRODUCTION

Synthetic aperture radar (SAR) is a remote sensing technology and most commonly used for 2D and 3D imaging. It was developed for military surveillance in the 1950s and since then its application has been extended to various domains such as meteorology, land observation, traffic mobility management, and much more [1-2]. Based on the altitude and radar sensor carrying platform, this technique is usually classified as space-borne, air-borne, and ground-based SAR and typically operating in the region of microwave and radio spectrum. These regions are preferred in terms of penetration property but they lack spatial resolution as the range resolution r_x is proportional to bandwidth and azimuth resolution r_{az} is proportional to antenna diameter. Therefore, to achieve sub-mm spatial resolution, higher spectrums are being investigated. Visible and Infrared region offers very high resolution but they are non-penetrating whereas the THz spectrum possesses both the property of penetration and high resolution. The THz spectrum extends the SAR applications in sub-mm resolution imaging/localization and material characterization. However, the spectrum suffers from high atmospheric absorption that limits the propagation range but it is suitable for short-range applications.

Many testbeds are developed for sub-300 GHz SAR but they differ with the system bandwidth [3-4]. In this paper, we analyze and summarize the difference in using small and large bandwidth at the low-THz spectrum in multi-object environment. Therefore, to study this technology, a THz SAR testbed has been set-up and due to the unavailability of commercial THz RF front-end with large bandwidth up to 110 GHz, a vector network analyzer (VNA) with a frequency extender is used as a SAR sensor.

The remaining paper is organized as follows. In section II, SAR signal processing and testbed are explained. Further section III, presents the measurement results and lastly, a conclusion is provided.

II. SAR SIGNAL PROCESSING AND MEASUREMENT SETUP

SAR technique synthesizes large antenna aperture to provide high resolution along cross-range and works on the principle of real aperture radar. In this approach, the sensors are mounted on a mobile platform and transmit electromagnetic (EM) waves towards target at each aperture position. To form an image of the target, the backscattered echoes are recorded and processed with an image reconstruction algorithm in time or frequency domain [1-2]. In the paper, the recorded data known as raw data is processed with *Backprojection Algorithm* [2]. Moreover, the platform moving direction is defined as azimuth or cross-range and the EM waves propagate along range directions.

The sketch of the measurement setup and an optical picture of the targets are shown in Fig. 1 (a), (b) respectively. It consists of a VNA that operates up to a frequency range of 67 GHz and the extender up-converts the generated RF signal from the VNA up to the frequency range of 220-330 GHz. Further, a horn antenna of aperture size 6×8 mm is connected to the extender waveguide. For a multi-object scenario, three different sized metal screws are taken as targets/objects and mounted on a white foam as shown in Fig. 1 (b). The targets are placed at a reference range $R_0 = \sim 39$ cm. To form a synthetic aperture, the sensor is moved along the azimuth or y-axis in a stop-and-go approximation manner with a step size of around 1 mm and radiate EM waves along the x-axis.

To perform the measurements, the VNA is calibrated with 1-port short technique to normalize cable losses and one port reflection coefficients S_{11} are measured at each aperture position [5]. The measurements are performed for three configurations (Config.) and from the input system parameters point of view they mainly differ w.r.t. carrier frequency f_c and bandwidth B_w. The essential parameters of these Config. are summarized in Table I.

In 2D imaging, the spatial resolution is defined by r_x and r_y. For r_x, the B_w plays a crucial role in SAR image quality as the $r_x = c/2B_w$ is directly dependent on the B_w and here, c is the

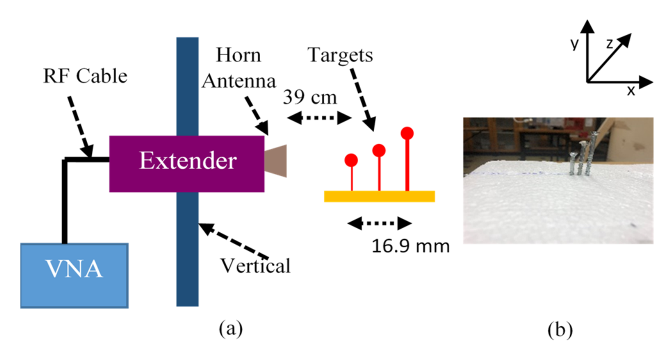

Fig. 1 (a) Testbed sketch, (b) camera picture of targets speed of light in vacuum. Moreover, in consideration with synthetic aperture length equals to -3 dB beamwidth of real aperture antenna or antenna diameter L_a, the $r_y = L_a/2$ [1, 2].

Table I System Parameters

Parameter	**Config. 1**	**Config. 2**	**Config. 3**
Carrier Frequency	230 GHz	245 GHz	275 GHz
Bandwidth	20 GHz	50 GHz	110 GHz
Aperture Length	8.7 cm	8.7 cm	8.7 cm
Range Resolution	7.5 mm	3 mm	1.36 mm
Azimuth Resolution (approx. real aperture/2)	3 mm	3 mm	3 mm
No. of Frequency Points	201	501	1101

III. RESULTS

The measured 2D raw data of all the three Config. is processed with the *Backprojection Alogithm* to generate a 2D image of the target and the results are summarized in Fig. 2. For the Config. 1, the focused SAR image and the image contour is shown in Fig. 2 (a) and (b). The three targets are visible but their separation is difficult to distinguish and also the pixel spread is large. Further, Fig. 2 (c) and (d) shows the focused image and contour for the Config. 2. In this, the objects are clearly distinguishable and the image is much sharper that reveals more accurate information about the targets such as height and thickness in comparison to Config. 1. Lastly, the results for Config. 3 are shown in Fig. 2 (e) and (f) respectively. Due to the highest resolution than the other two configurations, the image offers very sharp visibility of target edges and lowest pixel spread. In comparison to other two, it provides better image quality in terms of target shape and dimensions. However, as of the lowest penetration depth or the smallest carrier wavelength, no useful information is obtained for the second and third screw length/body that is hidden behind the first screw, whereas some details are observed in the other two Config. 1 and 2 results. Furthermore, it is observed that the backscattered power is highest in the Config. 3 because of the smallest beamwidth and the same can also be seen in the normalized magnitude scale in Fig. 2 (a), (c) and (e).

IV. CONCLUSION

The paper has presented the measurement results for three configurations to define the impact of small and large bandwidth at the THz spectrum. It can be generalized that the higher the bandwidth the better will be the image quality but as of high carrier frequency, the penetration and absorption losses will also be higher.

ACKNOWLEDGMENT

This research work is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project-ID 287022738 – TRR 196 for associated project M01 – THz Channel Measurements for Material Characterization and Localization.

REFERENCES

[1] I. G. Cumming and F. H. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2005.

[2] Mehrdad Soumekh, Synthetic Aperture Radar Signal Processing with Matlab Algorithms, A WileyInterscience Publication, 1999.

[3] M. Caris, S. Stanko, S. Palm, R. Sommer, A. Wahlen and N. Pohl, "300 GHz radar for high resolution SAR and ISAR applications," 2015 16th International Radar Symposium (IRS), Dresden, 2015, pp. 577-580

[4] T. Bryllert et al., "A 600 GHz imaging radar for concealed objects detection," 2009 IEEE Radar Conference, Pasadena, CA, 2009, pp. 1-3.

[5] A. Batra et al., "Experimental Analysis of High Resolution Indoor THz SAR Imaging," WSA 2020; 24th International ITG Workshop on Smart Antennas, Hamburg, Germany, 2020, pp. 1-5.

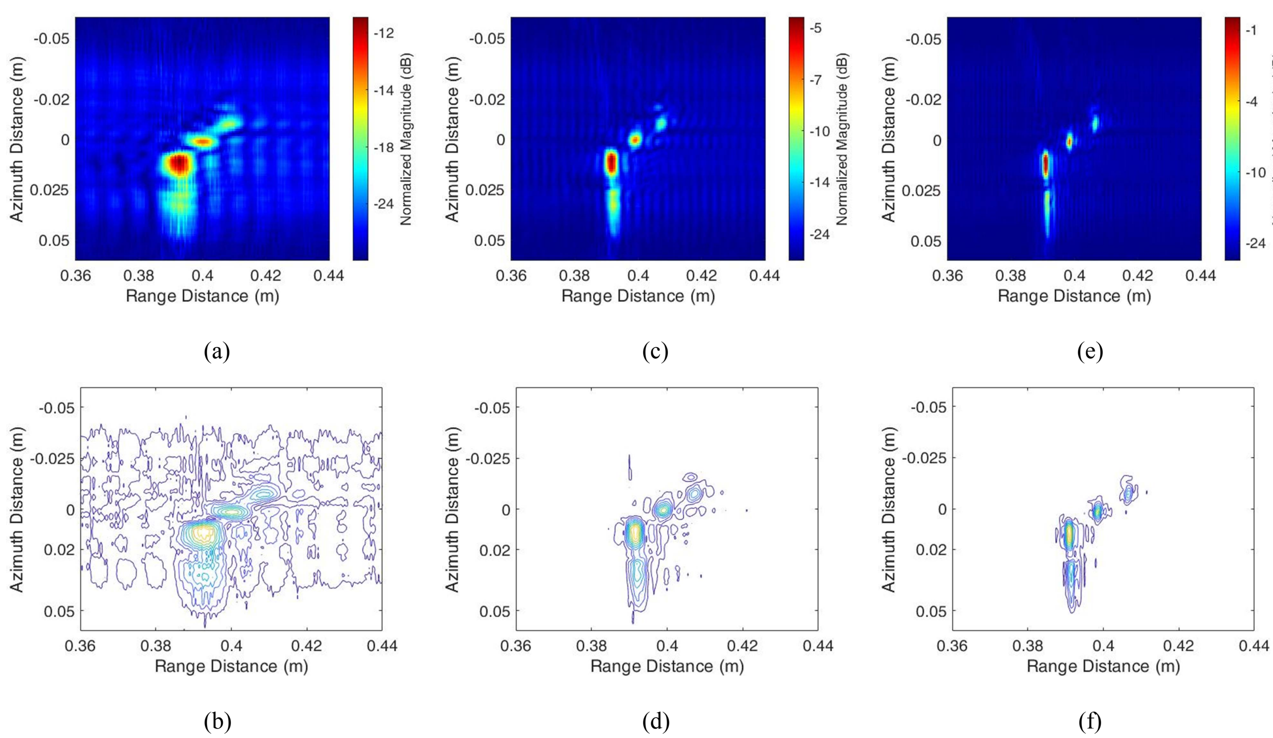

Fig. 2 Focused SAR image and contour (a) and (b) $B_w = 20$ GHz, (c) and (d) $B_w = 50$ GHz, and (e) and (f) $B_w = 110$ GHz