RADAR TOMOGRAPHY USING MIMO NOISE RADAR AND ANTENNA WITH BEAM SYNTHESIS

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ABSTRACT

Conventional SAR generates 2D image using combination of range compression and 1D aperture synthesis. The range resolution of such approach is determined by the signal spectrum width, while cross-range resolution is defined by the synthetic aperture length. 2D aperture synthesis implies movement of antenna along 2D aperture and cross-range compression technique in both dimensions to obtain resolution along two angular coordinates. In combination with pulse compression it gives 3D resolution. We suggest using MIMO principle in combination with SAR approach to generate 3D coherent radar images. For that, two linear synthetic apertures used – one for transmit antenna and another for receive one. Spatial scanning with those antennas is performed in the way which provides data similar to the ones obtained from 2D scanner. The paper describes the approach and presents results of its experimental test using Ka-band noise waveform ground based SAR.

Index Terms— Radar Tomography, MIMO, SAR, Noise Radar, 3D Imaging

1. INTRODUCTION

Radar imaging and radar tomography systems can be used in many applications, such as: intrusion detection, concealed weapons detection, monitoring of large objects: bridges, buildings, towers, etc. 3D microwave or millimeter wave imaging of partially transparent objects may be implemented via generation of a series of 2D images as cross-range slices at different range gates provided application of a high resolution radar, for instance, Ka-band Ground Noise Wave Radar [1, 2]. Actually this technique is a realization of 2D aperture synthesis at each range bin of high range resolution radar.

The paper is devoted to investigation and implementation of *novel* approach to millimeter wave tomography which consists in combining of Multiple-Input-Multiple-Output (MIMO) radar and Synthetic Aperture Radar (SAR) principles. Radar tomography is based on the fact that microwaves can penetrate through many artificial and natural media which are optically opaque. Dielectric materials such as plastics and organic materials will cause partial reflection of the waves and partial transmission so they will be seen as partially transparent. Actually the approach suggested may be implemented with the help of any type of high resolution coherent radar. However, unlike any earlier work, in the paper the millimeter wave tomography is implemented with the help of noise signals and antenna of a new type: Antenna with Beam Synthesizing [3]. To demonstrate implementation of millimeter wave tomography with the help of Ka-band Ground Based Noise SAR [4] we have carried out indoor experiments aimed on obtaining of 3D tomography images of a laboratory room interior. The approach suggested opens up a new direction in microwave tomography which may be applied for design of millimeter wave tomography systems for content inspection of closed boxes, hidden monitoring of a closed room [5], etc.

2. MIMO SAR 3D IMAGING USING NOISE WAVEFORM

The principle of tomographic 3D imaging consists in illumination of transparent /semitransparent area of interest with a wideband signal enabling the required range resolution and in formation of 2D aperture for providing the specified angular resolution. Having the reference signal as a sampled copy of the transmitted signal one can vary its delay and thereby perform range focusing which enables generation of 2D images (tomographic slices) related to the given range inside a transparent area of interest. In this

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way, application of noise waveform with wide enough power spectrum bandwidth enables layer-by-layer visualization of a semitransparent object and, therefore, generation of its tomographic 3D image.

Conventional approach to 3D SAR imaging is implemented via movement of Tx-Rx antennas over a planar synthetic aperture and performing of radiation and reception of signals at every node of equidistant grid. Usually, positioning system for such 2D movement of Tx-Rx unit is rather complex and expensive. We propose generation of equivalent of 2D synthetic aperture via linear moving of two antennas along orthogonal directions. The scan for that is done in the following way: Tx antenna takes the first position, Rx antenna performs synthetic aperture scan along linear aperture. After that, the Tx antenna takes the next position and the new scan is performed by the Rx antenna. Each scan of the Rx antenna enables generation of a 2D image in the plane of Rx synthetic aperture. Those images for different Tx antenna positions will contain information on phase shift of the signal due to movement of the Tx antenna phase center which may be used for compressing of the image along the second angular coordinate.

The Noise Radar system uses the illumination by random signal and coherent detection (both amplitude and phase) of the back scattered wave. Noise waveform with a variable power spectrum width enables controlling the resolution along the range, the 3rd coordinate of the 3D Imaging. The range resolution is defined by the power spectrum bandwidth, as

$$\Delta z = {c}/{2\,\Delta f},$$

where Δf is power spectrum bandwidth, c is the velocity of light.

Use of random waveform delivers such benefits as absence of range ambiguity and improving immunity against external electromagnetic interferences [1-4]. In this way, imaging with MIMO aperture synthesis and noise waveform enables tomographic 3D imaging through the range resolution of the wideband radar

3. 3D INDOOR IMAGING USING NOISE SAR WORKING IN MIMO REGIME

Experiment was carried out using Ka-band (36 - 36.5GHz) Ground Based Noise Waveform SAR [3]. Noise CW signal with 480MHz power spectral bandwidth and 1mW transmit power was used as a sounding signal. Special type of millimeter wave antennas, the antenna with beam synthesizing [5], was used for 2D and 3D radar imaging (fig.1). In those antennas, a half-lambda transmit/receive slot antenna moves along real aperture of the antenna when transmitting/receiving signals. Further application of 1D or 2D aperture synthesis along with range compression

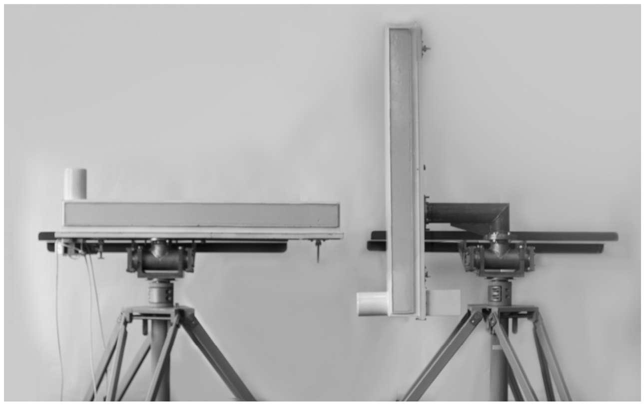

Fig.1. Picture of the antenna system. Tx and Rx antennas with beam synthesizing are oriented in mutually orthogonal fashion which enables data acquisition in VH cross-polarized MIMO mode.

technique enables generation of 2D SAR images and 3D tomographic images, respectively. One antenna of that type has been oriented vertically for signal transmission while another antenna with beam synthesizing was oriented horizontally for the radar returns reception. Each antenna has synthetic aperture length of 0.7m, which defined angular resolution along elevation and azimuth. In this way, the designed experimental setup allowed obtaining tomographic images in VH cross-polarization MIMO mode.

Radar returns and reference signals were down converted to the baseband and digitized with a fast ADC from GaGe Company having two 1 GHz instant pass band channels with 1Gs/s sampling rate and 8bit depth resolution. The sampled radar returns and reference signals are processed in a PC using special algorithms for standard mode of 2D SAR imaging via range compression and azimuth compression. Tomographic imaging has been implemented via range compression and 2D aperture synthesis via MIMO operational mode for each range bin. Dynamic range of the generated 2D and tomographic images reaches 42dB which is determined by 7 bit effective depth resolution of the used ADC. The measurements were carried out in the LNDES laboratory room with concrete walls, ceiling and floor. A polyethylene sphere covered with aluminum foil was placed in the middle of the room and was used as the reference target. At the same time, inside the room there were several laboratory tables with electronic devices and equipment, PCs, metal chairs and multiple metal objects. Fig. 2 shows sketch of the scene for 2D and 3D imaging carried out.

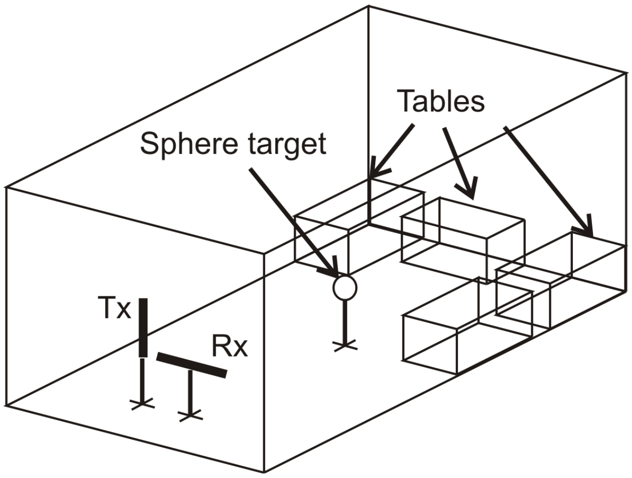

Fig.2. Sketch of the scene of imaging and antennas placement.

Multiple reflections from all the above objects in the room, as well as from the room walls, floor and ceiling created a harsh condition for precise phase preserving measurements. Nevertheless, application of Noise signals with wide enough power spectral density and coherent reception of the noise radar returns enabled performing radar coherent imaging and millimeter wave tomography inside the room in the above harsh conditions. As an example, Fig. 3 shows a horizontal slice of 3D image obtained. Response from the sphere reflector may be seen in the center of the image. Besides, responses from the side walls of the room, as well as those from tables and chairs could be readily recognized in the image as well. Range and angular resolutions obtained are close to their theoretical values.

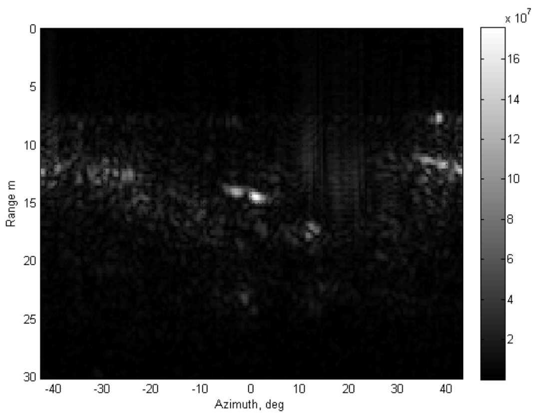

Fig.3. Horizontal slice of 3D image of the laboratory room with sphere reflector in the middle.

Combination of MIMO approach and antennas with beam synthesizing [3] enabled tomographic coherent imaging using noise signals. Experimental results have shown high stability and repeatability of the measurements carried out.

4. CONCLUSIONS

A *novel* approach for generation of tomographic millimeter wave and microwave 3D images based upon MIMO, Aperture Synthesis and Noise Radar Technology has been considered and validated experimentally. We have carried out experiments on generation of 3D tomographic imaging using Ka-band continuous waveform noise radar [4] and two antennas with beam synthesizing [3]. In these experiments we have shown generation of 3D tomographic images and capability of focusing the scene targets responses in 3D space using the proposed approach. The method enabled implementation of Noise Radar Tomography which is promising in many applications, in particular, for homeland security, covert detection of terrorists inside and outside buildings and others.

5. REFERENCES

1. Lukin, K.A. "Noise Radar Technology", *Telecommunications and Radio Engineering,* Vol.55, No. 12, pp.8-16, 2001.
2. Lukin, K.A. "Noise Radar Technology: the Principles and Short Overview", *Applied Radio Electronics,* Vol. 4, No. 1, pp. 4-13, 2005.
3. K.A. Lukin, "Sliding Antennas for Noise Waveform SAR", *Applied Radio Electronics,* Vol. 4, No.1, pp. 103-106, April 2005.
4. Lukin, et. al. "Ka-band Bistaic Ground-Based Noise Wavefom SAR for Short-Range Applications", *IET Proc. Radar Sonar & Navigation*, Vol.2, pp 233-243, August 2008.
5. Lukin K.A. et. al. "2D and 3D imaging using S-band noise waveform SAR", *Proc. of the 3rd International Asia-Pacific Conference on Synthetic Aperture Radar* (APSAR-2011), pp. 1-4, 2011.