Ku-Band Demonstrator of Microwave Video Camera

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Abstract – Conceptual design and implementation of demonstrator of microwave video camera for real-time imaging of moving objects in the Ku band are briefly explained. Main algorithms for two-dimensional (2D) image formation in real time and first experiments are described. The 10 mS frame rate was demonstrated for the 2D imaging mode.

1. Introduction

Microwave imaging of moving objects is still a challenge for radar engineers. The microwave video camera (MVC) will be in great demand in many applications, such as all-weather radar, day and night monitoring of moving objects, border protection in harsh environments, and transport security. We are working on a microwave three-dimensional (3D) imaging system based on two-dimensional (2D) aperture synthesis for angular resolutions and noise signal (NS) with wide enough power spectral density (PSD) for range resolution capability. As an alternative, we may use a stepped frequency (SF) NS covering the required frequency span [1–8]. For 3D microwave imaging, we suggested a microwave imaging system compound of two orthogonally oriented one-dimensional (1D) ground SF noise synthetic aperture radars (SAR). One such SAR may be used for 2D SAR image formation and is much easier to implement. In this article, we present preliminary results on elaboration of the concept, design, and laboratory tests of Ku-band MVC in a single-input multiple-output (SIMO) configuration based on ground noise SAR.

When designing a MVC, microwave imager operating in real-time, one has to meet contradictory requirements of the system: On the one hand, one has to provide high 3D spatial resolutions performance, which requires both wide enough PSD of the transmitted signal sufficient for providing specified radial and range resolution, and a large enough aperture of a 2D antenna array for specified angular resolutions. On the other hand, reception and processing of radar returns in real time, as well as formation of 3D or 2D images and visualization, require fast handling of large-scale data flow. This challenge being straightforwardly solved would be a serious challenge even now for dedicated signal processors.

In the following, we briefly describe one of the possible ways to go around the aforementioned difficulties, using SIMO radar concept, the simplified option of multiple-input multiple-output (MIMO) radar concept and SF method for transmit (Tx) signal formation.

2. Architecture of SIMO Ground Noise 2D Imager

Code division method in MIMO radar was provided by generation of orthogonally coded (in particular, wideband random waveform) signals. This approach enabled the fastest scan, but it required use of as many transmitters as the number of Tx antennas to be used. To avoid that constraint, we preferred a simpler architecture, the SIMO radar architecture, meaning radar with a single Tx channel and multichannel receiver (Figure 1).

In addition, the Tx noise waveform with PSD bandwidth, *B,* was digitally generated in the noise generator unit, converted up to the central frequency in the transmitter unit, and transmitted with the help of the transmit antenna into the scene. Part of this signal was used as the reference for every receive channel of the multichannel receiver. However, in this case, every receive channel should contain a fast analog-to-digital converter (ADC) with a minimal sampling frequency that equals *2B*, making the design very complicated and expansive. This will also require coping with processing of a huge amount of data, which will make implementation of such a system impossible. That is why we adopted another approach to the imager design; the SF technique, modified for the NS case. A block diagram of the suggested imager is shown in more detail in Figure 1. In SF noise radar (NR), a narrowband random signal was transmitted, while its central frequency was sequentially increased at fixed time intervals by a fixed frequency step, and this frequency step should not exceed the PSD width of the transmitted random signal. We briefly describe the general design and validation of the SIMO SF NR, with a single transmit channel and 32 receive channels used as a real-time 2D imager, the MVC. The main performance of the SF random signal generator (based on voltage-controlled oscillator (VCO) and direct digital synthesis), with stepped switching of its central frequency, was evaluated and found suitable for this MVC. Performance of the designed data acquisition and signal processing unit based on a truly

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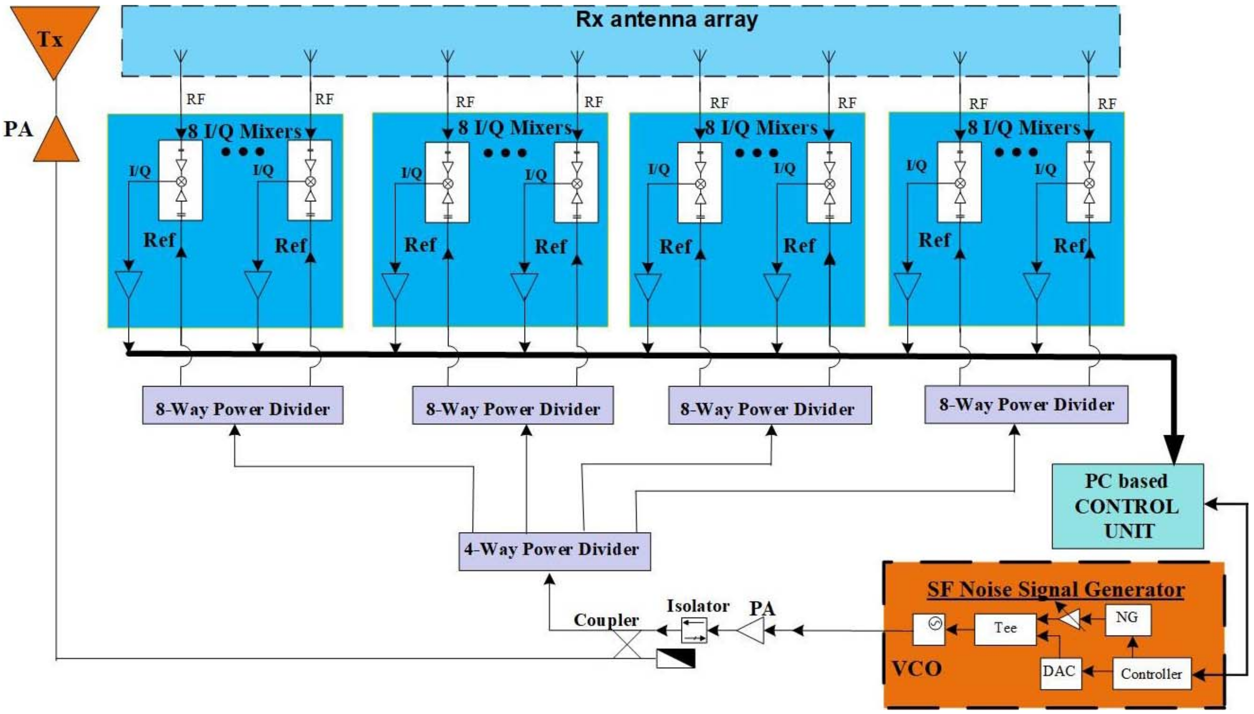

Figure 1. Block diagram of SIMO 2D imager.

parallel multichannel ADC were validated, as well. The SF or noise SF signal was generated in VCO by applying a proper voltage waveform to the VCO control electrode. Digital random voltage was formed either in a personal computer (PC) or in a field-programmable gate array device and converted to an analog signal. The random voltage was mixed with the DC voltage that defined the central frequency of the VCO signal for implementing a steplike increase of the central frequency of the transmitted NS. The frequency of the transmitted signals was within 12 GHz to16 GHz that provided range resolution of about 4 cm. In case we needed to transmit a sinusoidal signal, the random component was omitted. Full-chain dataflow was studied and bottlenecks identified. Implementation optimization was performed, and the timing performances achieved were coherent with the operational requirements. SF ground SAR for 2D imaging in the SIMO operational mode was fabricated and tested.

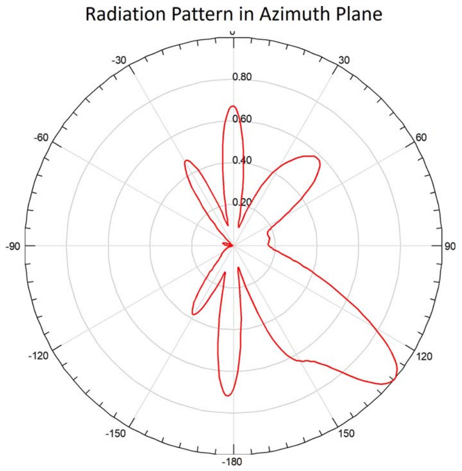

Figure 2. Antenna pattern of four Vivaldi antennas arranged in linear order: azimuth plane for vertical E-polarization mode.

At the first stage, we designed and fabricated a 32-element Vivaldi antennas array for the SAR multichannel receiver and formed the SIMO configuration for the 2D imager. For 3D imaging, the MIMO geometrical configuration was suggested, based on the two such SIMO systems mounted as L-shape sparse antenna array. In our design, Vivaldi-antennas were arranged in a checkerboard pattern to suppress undesirable coupling between them, as we had to keep half-lambda spacing to avoid antenna array diffraction lobes. To illustrate the right choice of the antenna array arrangement, we compared antenna patterns of four Vivaldi antennas (in azimuth plane for vertical E polarization mode) arranged in linear (Figure 2) and in checkboard order (Figure 3). Comparison of antenna patterns in Figures 2 and 3 shows that the checkboard arrangement has an advantage of sidelobe reduction due to suppression of lateral coupling of the Vivaldi antennas. A single Vivaldi antenna has about 8 dBi gain. The checkerboard arrangement of Vivaldi antennas in the quasilinear antenna array allowed us to obtain a single-beam antenna pattern, with no diffraction lobes and acceptable level of the sidelobe level.

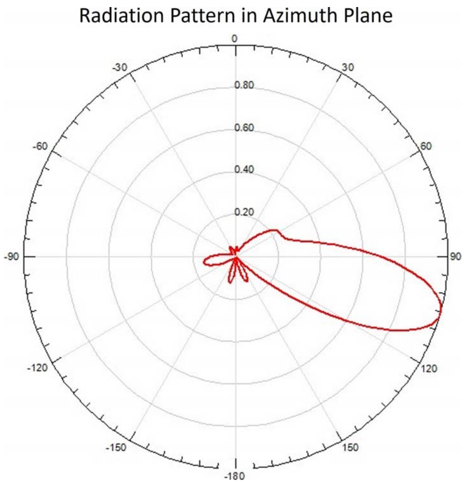

Figure 3. Antenna pattern of four Vivaldi antennas arranged in checkerboard order: azimuth plane for vertical E-polarization mode.

3. Algorithms for 2D SAR Image Formation

As seen from Figure 1, the first step of the signal processing, which is the estimation of the cross correlation between radar returns and the reference signal for each frequency, was performed in in-phase quadrature (I/Q) mixers of the multichannel receiver. In this case, the in-phase, I , signals from the quadrature detectors outputs of the receive channels were assigned to the real part of a data array, while the quadrature, Q , signals from the receive channels were assigned to the imaginary part.

In the code developed, the data array was formed in such a way that each separate column represented all samples obtained for every frequency step, numbered via $k <$ K, in the SF mode of the SAR for each individual antenna channel, numbered as $n <$ N. In other words, we formed a complex data N by K array containing 32 columns related to 32 receiver channels, and each column contained 128 . . . 512 samples, representing I/Q signals at the output of the quadrature detector for all K frequency steps. Application of the inverse fast Fourier transform to the data of each column gave the corresponding range profiles. Knowing the geometry of the antenna system, one has the complete information set for generation of the SAR image, performing azimuth compression for all range bins.

Figure 4 shows laboratory demonstrator of SIMO ground SF noise SAR with a horn transmit antenna and multichannel Vivaldi antenna array on receive. With this SIMO ground SF noise 2D imager, we carried out a series of indoor SAR imaging experiments for several scenes containing various objects in it [6, 7]. The transmitted power of about 0.1 mV was transmitted through the horn antenna with 20 dB gain. For example, it was shown that the SAR image of the assault rifle AK47 sample contained its details with a high-range resolution (4 cm), while azimuth (cross-range) resolution (15 cm at the range 2.4 m) was not sufficient to show the cross-range details.

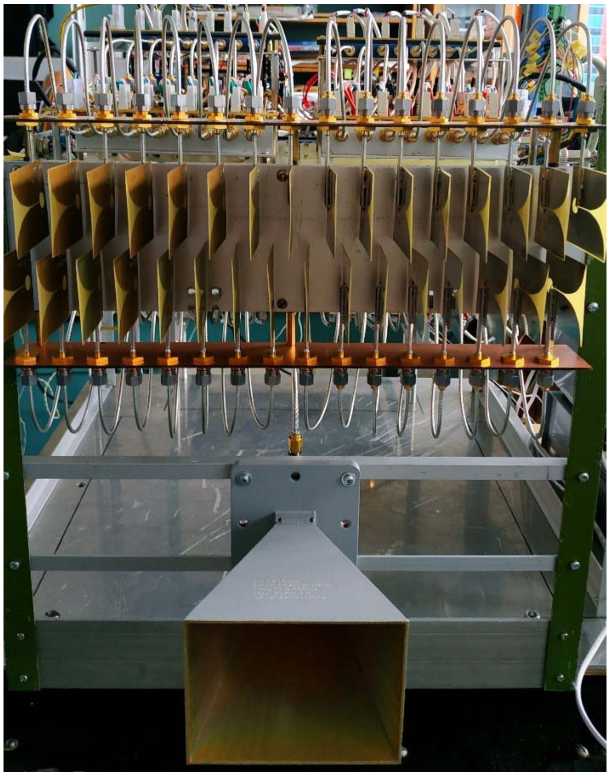

Figure 4. Laboratory model of SIMO ground SF noise imager with 1 transmit and 32 receive channels (front view).

4. MVC Mode

With mplementation of the MVC mode, we had to enable real-time SAR image formation. There were still several bottlenecks in the data acquisition and signal processing parts, as well as in the displaying of the image obtained. The signal processing chain is briefly described in the following.

The acquired data were directly transferred from the multichannel ADC to RAM memory. After that, the threading technique was applied, aiming to reduce the time of data acquisition and processing: the code was split into two asynchronous threads to implement parallel operation of different parts of the required processing. The first thread was used for acquisition of the backscattered signals by the acquisition board. The second thread was used for data processing and image visualization.

The main parts of the radar receiver code operated as follows: the first thread performed the ADC of the signals from 32 I/Q mixers of the radar receivers and transfer the data acquired to the RAM memory. The second thread contained the code for digital processing of the acquired data and displaying of the radio image obtained.

The SIMO SF radar time schedule is as follows. The data acquisition boards wait for a trigger signal from the PC-based radar control unit. The trigger signal initiates sampling in the 32-channel ADC boards. After the ADC, the code waits for the next trigger signal.

In parallel, the second thread code performed digital processing and visualization of the data acquired at the previous stage: calculation of the range profiles for each of the radar receiver channels; performing the azimuth compression for every range bin; and finally, radio image formation, and its displaying as a single frame of the microwave video. One can repeat the previously mentioned operations according to the prescribed number of the required frames.

We performed imaging of moving persons. The system designed was able to detect the moving objects within the range of few meters (1 m to 5 m) from the antenna array in real time (i.e., producing the microwave video) and estimated frame rate of 10 mS to 70 mS for 128 to 512 frequency steps, respectively [9].

5. Conclusion

The first SIMO subunit of MIMO ground SF noise SAR was assembled and tested. Capability of the designed and fabricated SF ground SAR in SIMO configuration to produce high-resolution 2D SAR images and microwave videos were experimentally approved in the Ku band. The next stage may focus on the azimuth resolution enhancement and fabrication of the second instance of SF ground SAR to produce 3D SAR images and microwave videos.

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