Experimental X-Band Automotive SAR System for Land Observation Application

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***Abstract*— In this paper, an experimental X-band automotive-Synthetic Aperture Radar (SAR) system for land observation application is proposed with the obtained SAR images. In order to develop and validate simply, Commercial Off-The-Shelf (COTS) technology is partially employed especially for standard horn antenna, arbitrary waveform generator, and digital signal processor. In order to validate the system performance, SAR image quality is evaluated by using corner reflector. In this paper, the feasibility of the automotive-SAR system for land application is demonstrated by presenting the SAR images of several kinds of ground areas.**

Keywords-Synthetic aperture radar (SAR); Ground-based SAR system; land application; system development.

I. Introduction

Recently, ground-based Synthetic Aperture Radar (SAR) systems have been proposed as observation and monitoring tool for land application such as landslides monitoring, terrain elevation mapping, and environmental study of vegetation cover. Because a ground-based SAR system has great advantage of stable motion effect, SAR formation processing can be very simple. Therefore many researchers employ the ground-based SAR system for its research purpose [1]-[7]. Pieraccini et al. [2][3] suggest simple interferometric system based on ground rail system for topographic mapping application. And Luzi et al. [4] demonstrate the potential of ground-based SAR system for landslides monitoring. Recently, Lingua el al. [5] employ the Terrestrial Laser Scanning (TLS) technique to improve the ground-based interferometric SAR system for remote sensing of landslide monitoring. Recently, Zhou, et al. [6] and Sato et al. [7] suggest ground-based SAR systems for ground-truth validation in polarimetric SAR remote sensing of vegetation cover. Most of a ground-based SAR system is based on rail system, so its observation area is very limited. We have developed a high resolution experimental automotive-SAR system for land application. Unlike rail-based SAR systems, an automotive-SAR system provides large observation area of ground cover and can be used in various kinds of land applications.

This paper is organized as follows. In Section II, the automotive-SAR system is described. Section III describes the development and the evaluation of the system. Section IV addresses the SAR image results which are conducted during SAR data acquisition campaign to show the feasibility for land application.

II. System Description

The system described in Figure 1 consists of arbitrary waveform generator (AWG) module, amplifier (AMP) module, receiver (RCV) module, signal processor (PRC) module, antenna module, and power module.

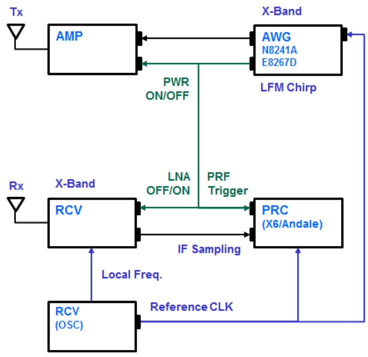

Figure 1. Block diagram of automotive-SAR system.

We employ an arbitrary waveform generator (N8241A) for the generation of baseband I/Q signal and the baseband signal is up-converted by vector signal generator (E8267D). Utilizing commercial off-the-shelf technology, operating frequency can be easily varied for other applications. The signal waveform of this system is Linear Frequency Modulation (LFM) chirp pulse with wide bandwidth. Therefore, very high resolution SAR image of sub-meter in range direction can be obtained. AWG also provides stable trigger signal for ON/OFF control of AMP and RCV module and for sampling timing of PRC. Because of low power level of AWG module, we develop an AMP module with the high power level to extend the maximum detection range. As mentioned earlier, the AMP module is controlled by ON/OFF trigger signal to avoid amplification of noise level during the receiving window time.

In order to avoid I/Q imbalance problem, we adapt Intermediate Frequency (IF) sampling, and Digital Down Conversion (DDC) scheme is used to obtain I/Q signals. The

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sampling rate is more than gigahertz with high bit resolution, and as a result, the recorded data rate is also gigahertz.

Figure 2 shows the overall SAR system. In order to avoid internal leakage, bi-static type is considered. Due to the short period of time for development and validation, we need to make use of standard horn type antenna with the high gain and the feed and adaptor type provides linear polarization.

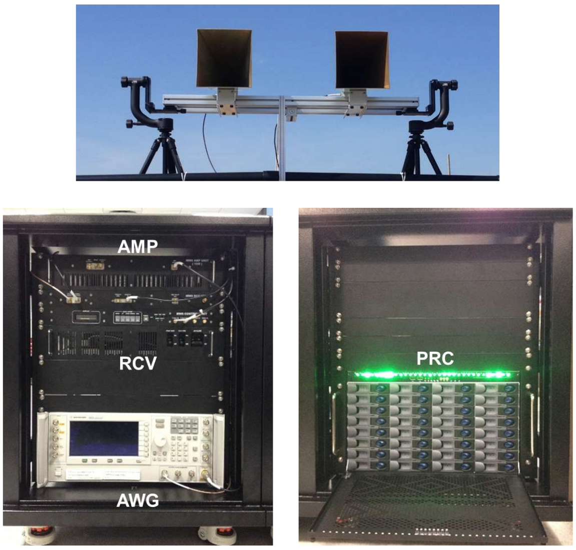

Figure 2. Automotive-SAR system.

By change of feed direction, dual or quad polarization can be supported. The receiving channel can be expanded up to 4 channels by additional ADC board in PRC module. Therefore, this system can be used for interferometric SAR (InSAR) and/or polarimetric SAR (PolSAR) application.

III. Development and Validation of Automotive-SAR System

The SAR system, as shown in Figure 3, is installed in vehicle which provides power supply utilizing vehicle battery and invertor. Antenna module is mounted on top of vehicle. The elevation of antenna can be easily controlled by using tripod. The system is controlled by laptop notebook which means that the system could be operated in the moving vehicle.

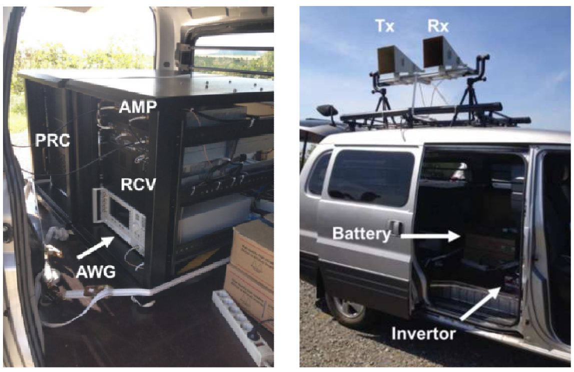

Figure 3. Installation of automotive-SAR system.

The system operation frequency in the experiment is 10 GHz. The bandwidth of LFM chirp is 500 MHz, so the ideal range resolution of 0.3 meter can be expected. The velocity of vehicle is about 80 km/h, and the antenna beam width is approximately 4 deg. Therefore, Doppler bandwidth can be obtained about 104 Hz and the expected resolution is 0.2 m in azimuth. The PRF is set to 1 KHz so that the processing gain in azimuth direction can be very high after aperture synthesizing.

In order to validate the system performance, some of experiment results are presented. The height of the road is normally more than 20 m. Also, the road condition is very important. The road should be flat and straight. The SAR image from first field work is described in Figure 4. The system has no squint angle and beam width is narrow. Therefore, Doppler centroid is close to zero and Doppler estimation can be very simple. Because the road condition is very flat and straight, the motion factor of automotive-SAR system is very stable. Therefore, a motion compensation process can be relatively simple compared to airborne SAR case. Contrast-based autofocusing is used for velocity estimation.

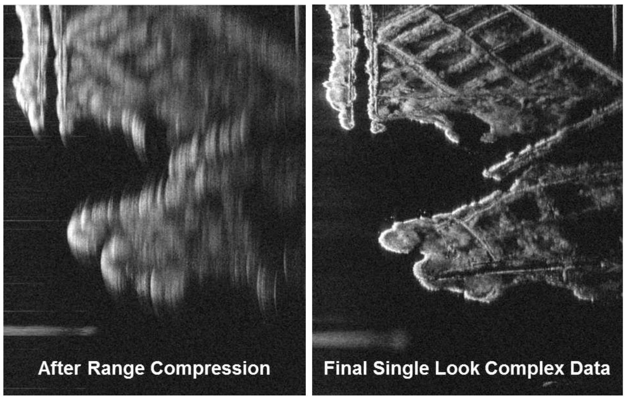

Figure 4. First SAR image.

In order to verify the system performance, we do calibration field work using passive calibrator as shown in Figure 5 and Figure 6.

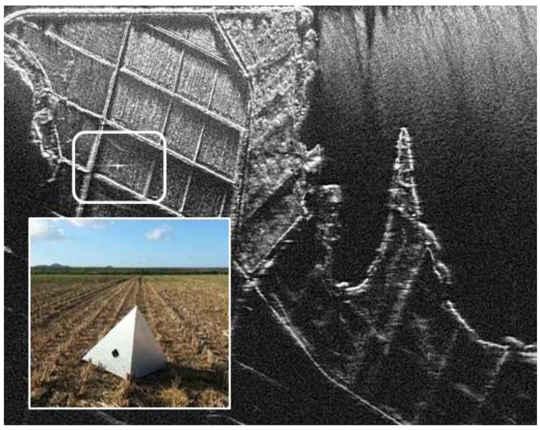

Figure 5. SAR image of calibration field.

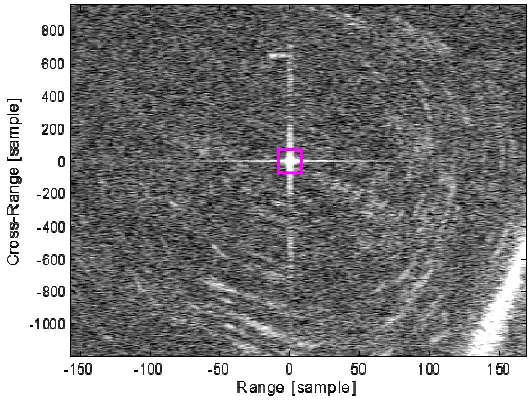

Figure 6. Response of passive calibrator.

Several corner reflectors with diameter of 1 m and 0.5 m are used as passive calibrator. These are located in rice field with very low backscattering. Figure 7 shows the profile of the corner reflector response in range and azimuth direction.

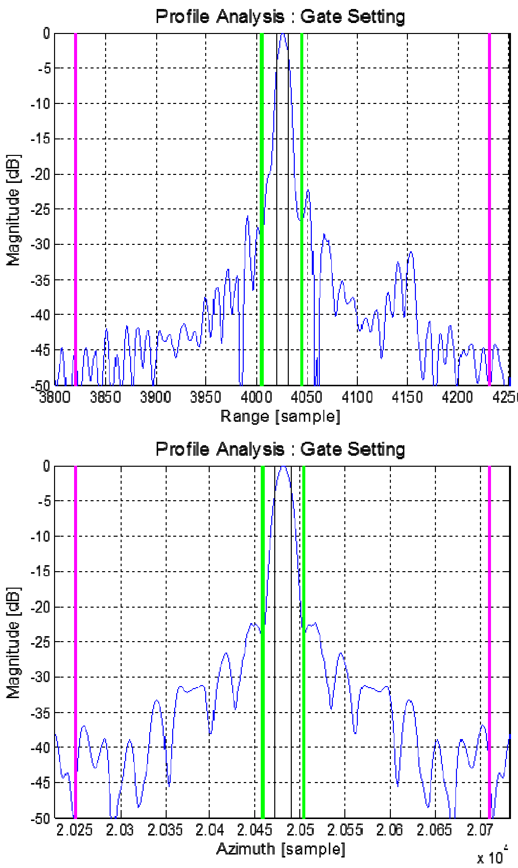

Figure 7. IRF Profile in range and azimuth direction.

Because of wide bandwidth LFM chirp waveform, slant range resolution can be 0.3 m in theory. Actual resolution of 0.4 m can be obtained. Azimuth resolution of 0.2 m, depending on Doppler bandwidth, can be also obtained.

TABLE I. IRF PERFORMANCE

Range Profile	Resolution	0.4	[m]
	PSLR	-22.1	[dB]
	ISLR	-20.2	[dB]
Azimuth Profile	Resolution	0.2	[m]
	PSLR	-22.3	[dB]
	ISLR	.17.1	[dB]

For evaluation of SAR systems, Impulse Response Function (IRF) is recognized as the basic and most representative performance parameter in SAR community. The experiment result of IRF performance, consisting of resolution, peak to sidelobe ratio (PSLR), and integrated sidelobe ratio (ISLR), is shown in Table 1.

IV. SAR IMAGES FOR LAND APPLICATION

For land observation application, several SAR images were obtained during SAR data acquisition campaign. The first SAR image obtained by the automotive-SAR system is depicted in Figure 8. By changing the horn antenna, we can get the full polarization SAR images. The image scene area is nearby seawall area. There are various kinds of scatterer scene such as water area, rice field, wet land and reed grass. Scene size is 4 km x 1.5 km.

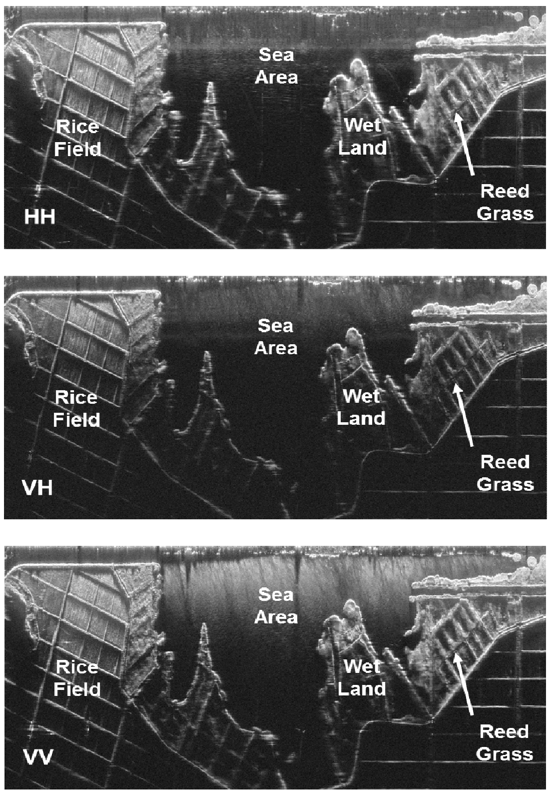

Figure 8. Polarization SAR image.

For land observation, another SAR image of rice field is presented in Figure 9. Image scene size is 1 km x 400 m and polarization is VV. The vehicle is moving up on the left of image scene. As shown in Figure 9, some of rice field is already under cultivation and the cultivated direction is well described in SAR image. In this image, radar shadow is visible because the data is acquired with low altitude. In right middle of image, there is very bright object nearby dark scene because of man-made object and water bank for fish hatchery.

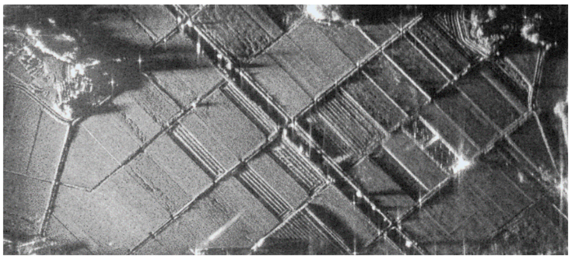

Figure 9. SAR image – rice field.

For another image, Figure 10 shows the rice field and image scene size is 500 m x 1 km. In this image, radar shadow is visible because of rice terrace. In this case, the test site is middle of mountain and the vehicle is moving right on the top of the image scene. The ground based SAR system is near range system so there is no offset from imaging vehicle.

Figure 10. SAR image – rice terrace area.

The last SAR image is acquired from mudflats area, as shown in Figure 11. This image can be used for biomass study.

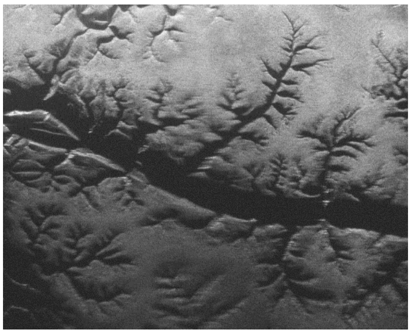

Figure 11. SAR Image - mudflats.

As mentioned in the introduction, almost all ground-based systems are based on rail system. Therefore, the observation area, such as Swath width and detection range, is very limited. In rail system, the synthetic aperture is realized by moving the antenna system along a linear rail. So, image size in azimuth is limited by physical length of rail. Tarchi et al. [1] suggest the ground-based InSAR system for landslide monitoring. But, its resolution is 4 x 4 meter and observation length is 2.8 meter in azimuth. Sato et al. [7] propose a ground-based SAR system with resolution of 1 x 5 meter. But, its observation area is still limited in 500 x 500 meter. We developed an automotive-SAR system which is installed on the top of vehicle, so we could take the image of wide area by moving the long distance up to 4 km. The resolution performance is also better than the previous ground-based SAR systems.

V. CONCLUSION

In this paper, an automotive-SAR system for land observation was proposed with various scenes of SAR image. The system is equipped in a vehicle, so motion effect is very stable compared to airborne SAR system. Unlike most of the other ground-based SAR systems, the proposed automotive-SAR system takes advantage of large observation coverage. In order to validate the system performance, calibration field work is performed using passive corner reflector. Finally, various kinds of scenes are presented to verify the possibility for land applications.

Because receiving channel can be easily expanded up to 4 channels, this system could be used for along-track and across-track interferometry SAR applications. Furthermore, PolSAR and PolInSAR applications can be also possible with a minor modification of antenna module.

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