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DESIGN AND DEVELOPMENT OF A C-BAND RF TRANSCEIVER FOR UAVSAR

Y. K. Chan*, V. C. Koo, C. Y. Ang, K. S. Yee, and M. Y. Chua

Faculty of Engineering & Technology, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang, Melaka 75450, Malaysia

Abstract—An experimental Unmanned Aerial Vehicle (UAV) Synthetic Aperture Radar (SAR) Sensor has been designed and developed at Multimedia University, Malaysia. This airborne system is an inexpensive C-band, single polarisation, linear FM airborne radar sensor. The system will be used for monitoring and management of earth resources such as paddy fields, oil palm plantation and soil surface. A series of field measurements and flight test has been conducted to verify the performance of the RF transceiver. This paper highlights the design and development of the SAR RF transceiver, as well as its evaluation result.

1. INTRODUCTION

Radar is the abbreviation for "Radio Detection and Ranging". It operates by radiating electromagnetic energy through a transmitting antenna and detects the reflected or scattered signal from the target [1]. Radar has long been used for military and non-military purposes in a variety of applications such as imaging, guidance, remote sensing and global positioning [2]. The history of radar development can be traced back to 1886 where Heinrich Hertz successfully conducted an experiment on propagation of electromagnetic waves. The radar system was comprehensively developed and operated during World War II. The requirement of the military battle field has become an enormous motive for development of radar technology. However, the image formed by conventional radar (so-called real aperture radar, RAR) was poor in azimuth resolution.

SAR is a technique which uses signal processing to improve the resolution [3, 4]. In SAR, forward motion of the actual antenna is

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* Corresponding author: Yee Kit Chan (ykchan@mmu.edu.my).

used to "synthesise" a very long antenna. The concept of SAR can be traced back to the 1950s. In June 1951, Carl Wiley of Goodyear Aerospace Co, United States proposed the Doppler beam sharpening system which can be used to improve the azimuth resolution of the radar. Meanwhile, the Control Systems Laboratory of University of Illinois independently conducted a non-coherent radar experiment which confirmed that the Doppler frequency analysis method can really improve the azimuth resolution of the radar. This effort was continued by experimenting coherent radar with non-focused aperture synthesis methods and produced the first SAR image in July 1953 [5]. During the summer of 1953, American scientists presented a new concept of synthesis the real radar antenna to form a larger aperture by linear antenna array [3].

Since then, the principle of synthetic aperture and SAR have been recognized and supported with continuous development at research laboratories in various countries. In short, synthetic aperture technologies have greatly promoted the development of high-resolution imaging radars. The initial function of radar as a target detector has been migrated to the target imaging. SAR has its unique advantages in comparison with optical imaging, and it can provide a complementary and useful information to the optical sensor. With continuous development and improvement of the SAR technology, SAR resolution is finer and is approaching an optical sensor resolution. SAR as an active microwave remote sensor is able to extract a wide range of terrain and surface features. Its high resolution, large area of coverage, and all weather capability has aroused great interest of remote sensing scientists.

The use of SAR for remote sensing is particularly suited for tropical country such as Malaysia. By proper selection of operating frequency, the microwave signal can penetrate clouds, haze, rain precipitation with very little attenuation, thus allowing operation in unfavourable weather condition that preclude the use of visible-light/infrared system [1]. Since SAR is an active sensor, which provides its own source of illumination, it can therefore operate day and night, illuminate the earth surface at variable look angle, and wide area coverage can be selected. In addition, the topography change can be derived from phase difference between measurement using radar interferometry. For national monitoring and management of earth resources, limited number and untimely supply of the required SAR images have been a major problem. Therefore the need for developing our own SAR technology and sensor system is apparent.

Microwave remote sensing is one of the major research areas conducted by a research group in Multimedia University (MMU), Malaysia, for the past 12 years or so [6–8]. Theoretical modelling and image processing technique on SAR images have been developed. However, the main limitation is the dependence on overseas institution to supply the measurement data and SAR images. For national monitoring and management of earth resources, limited number and timely supply of the required SAR images have been a major problem. Therefore, there is an urgent need to develop our own SAR sensor system.

In late 2007, the project to develop a UAVSAR system was initiated with joined collaboration between MMU and Agency Remote Sensing of Malaysia (ARSM). The main objective of this project is to design and construct an imaging radar system with UAV as the platform. Thus, an UAVSAR RF transceiver has been developed at Faculty of Engineering and Technology, Multimedia University. It will serve as a test-bed for demonstrating SAR technology and acquiring data for the development of radar processing techniques and applications. This RF system will be employed in a UAV based, C-band, single polarization, linear FM SAR. The construction and testing of the RF transceiver was completed in early 2010. A series of indoor and outdoor experiments has been conducted to verify the capability of the RF transceiver.

Table 1 summarizes the system-level requirements of the UAVSAR. The center frequency of our system is selected at C-band (5.3 GHz). Single polarization mode has been utilized for

Table 1. System level requirements.

Operating frequency	5.3 GHz (5 cm)
Polarization	VV, single polarization
Modes of operation	Stripmap
Waveform type	Linear FM
Bandwidth	80 MHz
Incident angle	30°
Target types	Distributed targets with σ° between 0 dB and −30 dB
Altitude	$\sim$ 1 km
Azimuth 3-dB bandwidth	3°
Elevation pattern width	24°
Operating platform	Airborne, UAV
Platform speed	$\sim$ 32 m/s

simple classification and multi-temporal change detection. VV-polarization (Vertical transmit-Vertical receive polarization) is the preferred configuration since it is sensitive to the vegetation's vertical canopy structure, and thus providing the opportunity for crop type and growth stage discrimination. The system will operate in stripmap mode with incidence angle of 30 degree. It can produce SAR imagery of all classes of terrain with scattering coefficient, σ°, between 0 and -30 dB. In order to obtain reliable and accurate data, the UAV SAR platform should maintain a constant-velocity straight-and-level flight. Preferably, the aircraft flies at an altitude of 1000 m above sea level.

2. SYSTEM DESCRIPTION

Based on the system requirements discussed in pervious section, technical specifications of the RF system can be summarised as in Table 2. Basically, radar subsystem can be divided into three assemblies, namely transmitter, receiver and antenna. For RF subsystem, it consists of a transmitter and a receiver. Connectorised coaxial hardware implementation approach is employed in our design. The advantages of this approach are lower cost, fastest development and convenient for testing and trouble shooting. It is also easy to be modified when improvement is required. Most of the RF components are selected with SMA connector. Semirigid and flexible coaxial cables are used for interconnecting between components.

The block diagram of RF transceiver of SAR system is shown in Figure 1. Basically it can be sub-divided into two subsections: the transmitter and the receiver. The main functions of the transmitter

Table 2. Technical specifications for the RF transceiver.

Operating frequency	5.3 GHz (5 cm)
Bandwidth	80 MHz
Input Chirp Signal	I, Q
Input Reference Clock	10 MHz
Output Peak Power	~ 50 W
Input Control Signal	Transmitting Window, receiving window
Output Down-converted Baseband Signal	I, Q
Supplier voltage	+15 V, +28 V (for HPA only)

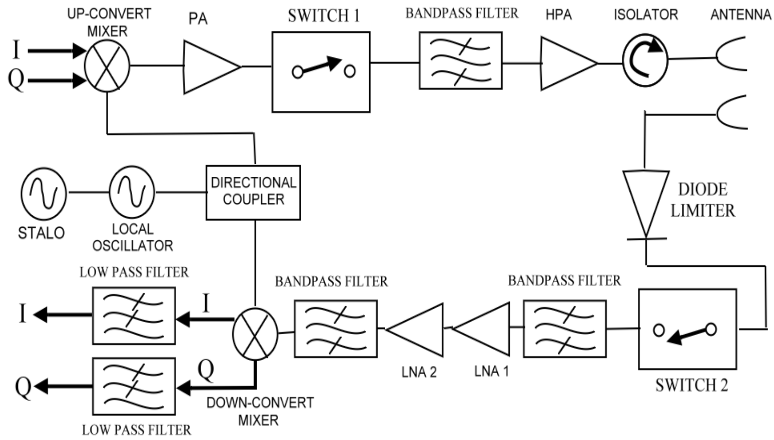

Figure 1. Diagram of UAVSAR RF system.

are to generate the desired waveform, amplify it to the appropriate amplitude and transmit via an antenna. The transmitter consists of a up-convert mixer, a power amplifier (PA), a SPST switch, bandpass filter, a high power amplifier (HPA), a 10 MHz stable local oscillator (STALO), a 5.3 GHz local oscillator, and some RF accessories such as RF cables and isolators. The coherent radar signal originates in the STALO. 10 MHz STALO is used as reference signal for local oscillator (LO) and Field-Programmable Gate Array (FPGA) board to maintain the coherence of SAR system. The I (In-phase) and Q (quadrature phase) chirp signal are generated by FPGA board. These signals are mixed with carrier frequency at C-band (5.3 GHz) via an up-converted mixer. The signal from the mixer is amplified by the PA to a range suitable for transmission. The switch will then turn on and off the transmission according to the transmitting window which will increase isolation and reduce unnecessary signal leakage. After that, the signal will be fed to the bandpass filter to reject unwanted signal outside the desired band of frequency. The signal is then amplified by the HPA to gain the sufficient power for long range transmission. A circulator is used for signal routing of signal antenna configuration.

Dual antenna system is employed to provide higher isolation between the transmitter and receiver. Dual antenna configuration reduces the leakage signal from transmitter to receiver via circulator in monostatic configuration. The receiver consists of a switch, diode limiter, two low noise amplifiers (LNA), two bandpass filters, a down-convert mixer and two low pass filter. The receiver front end diode

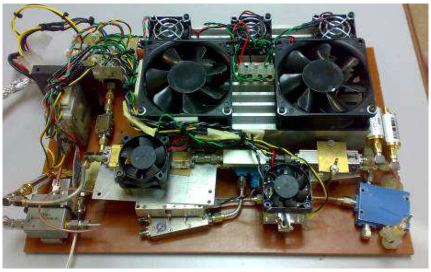

Figure 2. SAR RF transceiver.

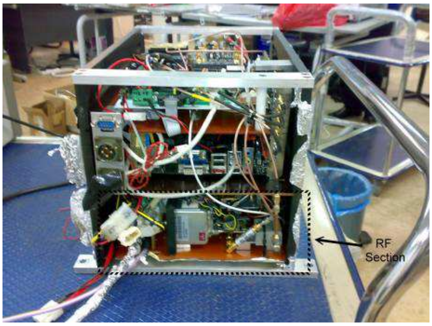

Figure 3. RF transceiver with chassis.

limiter is to provide protection for any sudden peak power spikes from the transmission. A pin diode switch is to provide a correct receiving window for the receiving channel. Bandpass filter is used to reject any frequencies outside the desired band. Two low noise amplifiers are cascaded to provide sufficient amplification of return echo and improves the sensitivity of the system. Finally the mixer down converts the received signal to I and Q signal. The output of the mixer is passed through two low pass filters to eliminate high frequency noises. The complete RF transceiver is shown in Figure 2. Figure 3 shows the integration of RF transceiver with others module of SAR system. The RF transceiver is fitted in the third layer of the sensor chassis.

3. CALIBRATION AND VERIFICATION

The RF transceiver of UAVSAR system has been tested in laboratory and outdoor environment. Subsystem performance test and internal calibration are done in the laboratory to verify the performance of transmitter and receiver. Outdoor experiments are carried out to demonstrate the capability of the system in range detection. The detail descriptions of measurements are explained in the following sections.

3.1. Subsystem Performance Test and RF Feedback Calibration

In subsystem performance test, the transmitted power is monitored and signal waveform is verified. For the receiver chain, the receiver gain is determined. A chirp waveform with centre frequency of 5.3 GHz and 80 MHz bandwidth is generated by the LO and FPGA board respectively. The linearity of transmitted chirp is monitored and

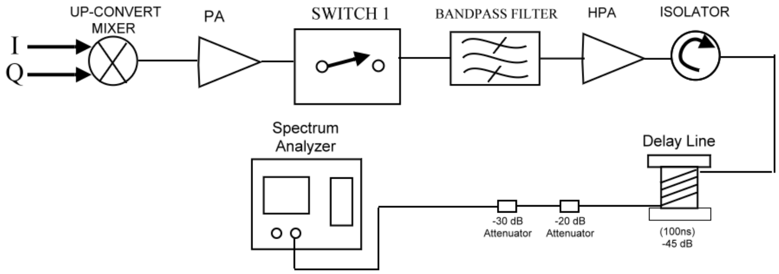

Figure 4. Measurement setup for transmitter testing.

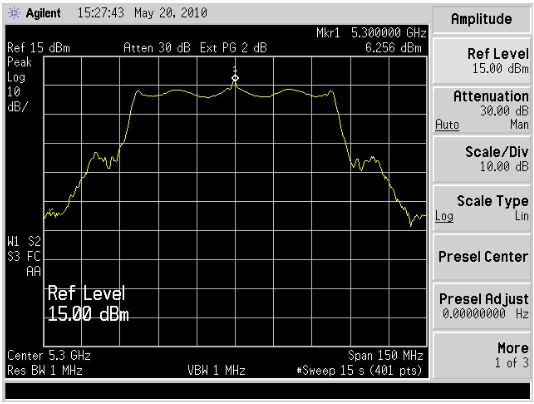

Figure 5. Output waveform of the transmitted chirp signal at the transmitter.

verified using the Agilent E4407B Spectrum analyser. Figure 4 shows the measurement setup for transmitter testing and Figure 5 shows the output waveform of the transmitted chirp signal by the transmitter.

Figure 6 shows the measurement setup of the RF feedback calibration. The transmitted signal is fed into the receiver via a delay line. The delay line is used to delay the transmitted signal for simulating a single point target. A chirp signal with 80 MHz bandwidth is mixed with a 5.3 GHz signal from local oscillator using an up-converter mixer. The signal is circulated through the transmitter, a 100 ns delay line and the receiver. The power level of the down-converted mixer is been measured and the output waveform is been verified as in Figure 7 below.

Figures below show some of the snapshots captured with an oscilloscope. Figure 8 shows the output waveform of the RF subsystem

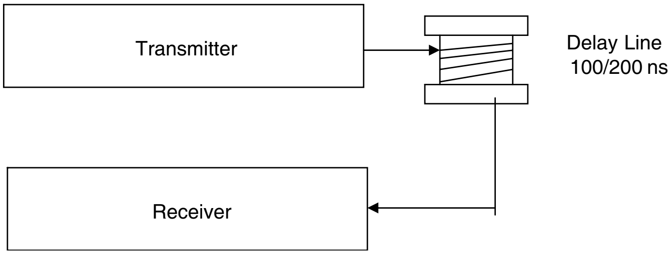

Figure 6. Measurement setup of RF feedback calibration.

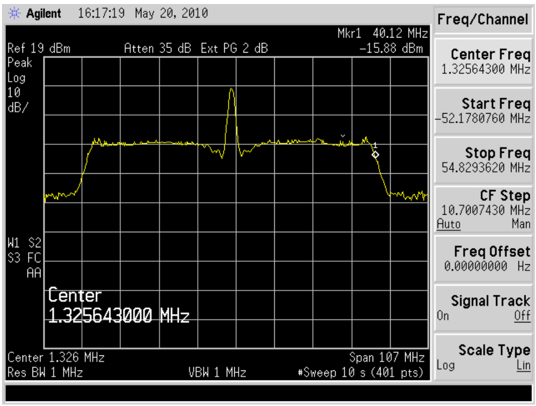

Figure 7. Output waveform of the transmitted chirp signal at the receiver.

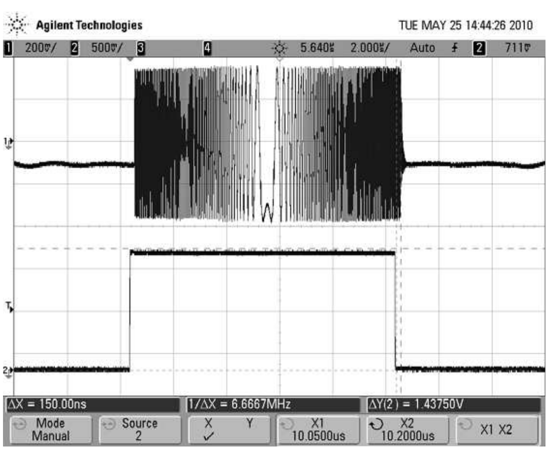

Figure 8. Output waveform of the RF subsystem using a 100 ns delay line.

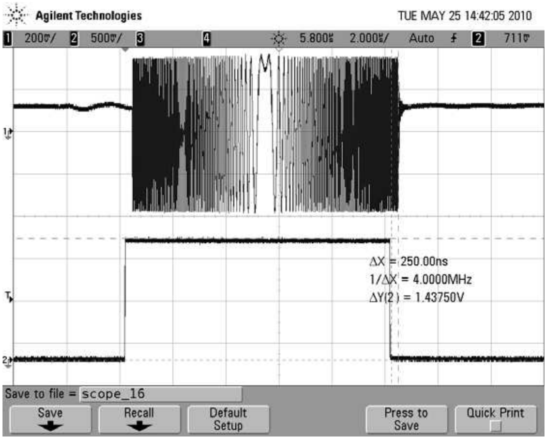

Figure 9. Output waveform of the RF subsystem using a 200 ns delay line.

using a 100 ns delay line and Figure 9 shows the output waveform of the RF subsystem using a 200 s delay line. The measurements' output shows a good agreement with the expected results.

3.2. Field Measurement and Evaluation

A series of field experiment has been conducted in year 2010 to verify the performance of the RF transceiver. These include ground based SAR measurement using a ground based moving platform. Flight missions were finally conducted to perform the RF transceiver functional test.

3.2.1. Ground Based SAR Measurement

Ground experiments have been conducted to verify the performance of the SAR RF transceiver. The main test site is a housing area at distance more than 1 km. The SAR system was mounted onto a truck which travelled at a constant speed for approximately 1 km to perform SAR imaging. Figure 10 shows the setup of the SAR RF system together with the microstrip antenna.

Figure 11 show the processed image for the test site. It is clearly shown that multiple strong targets are observed at distance more than 1 km. The arrangement of the targets is consistent with the locations of the houses. This preliminary ground experiment has successfully verified the imaging capability of the SAR sensor.

Figure 10. Measurement setup with microstrip array antenna.

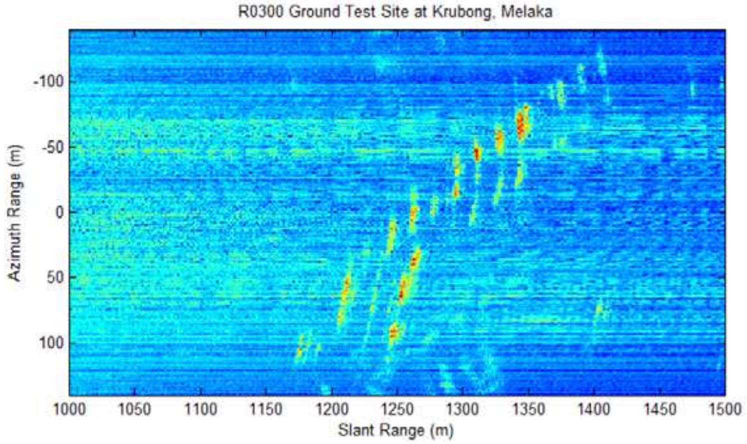

Figure 11. Processed image of ground test site.

3.2.2. Fight Mission

Flight measurements have been successfully conducted end of 2010 at Mersing, Malaysia with primary objective is to verify the capability of UAVSAR system. During the Mersing Flight Mission, 6 flight measurements were successfully conducted. A total of about 200 sets of SAR raw data were collected.

Figure 12 shows one of the samples of SAR images captured on 5th Dec 2010, respectively, with comparison to the Google Earth map of the same site. Clear signatures of river, roads, urban and forested areas are observed.

Figure 12. (a) Google earth map. (b) SAR image at mersing site.

4. CONCLUSION

In this research project, receiver C-band RF transceiver for UAVSAR have been successfully designed and constructed. Various design parameters have been carefully studied and determined in the high-level system design. The detailed consideration of each transmitter and receiver assembly has been carried out before actual hardware implementation. The new modified RF transceiver have been integrated and successfully attached to the final chassis. Integration with other subsystems has been done. Indoor testing and a series of outdoor measurements have been conducted to verify the performance and capability of RF transceiver. The results show good agreement with the theoretical calculation and the matched with the outdoor measurement field.

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