Design and Development of A FMCW Ground Based Imaging Radar System

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Abstract— This paper describes the design and development of a ground based Frequency Modulated Continuous Wave (FMCW) radar system in Multimedia Univeristy (MMU), Malaysia. In this project, a ground-based fully polarometric, C-band, high bandwidth linear FM-CW and real time imaging radar system is to be designed and constructed. The system should have the capability to measure the complex scattering matrices of distributed targets using FMCW system and obtained fully polarimetric signals which can be used to provide more accurate identification and classification of the geophysical media.

The purposed system hardware consists of four major sections: an antenna system, a radio frequency (RF) subsystem, an intermediate frequency (IF) electronic, and a data acquisition unit (DAU). The RF section is constructed in-house from several RF components, which include voltage-controlled oscillator, high power amplifier, directional coupler, RF switches, band-pass filter, isolators, and mixers. In RF section, the received signal is mixed with a portion of the transmitted signal to produce low frequency IF signals. The IF signals are pre-processed in IF section, before they are digitised in DAU. A mobile personnel computer with analog to digital converter card is used to store the measurement data and process the data on real time basics.

In paper, the high level design will be discussed and detail design parameters will be presented. It followed by radar electronics design, which outlined the detail in radar transmitter and receiver.

1. INTRODUCTION

When an earth terrain is illuminated by an electromagnetic wave, the characteristics of the scattered wave are found to be related to the physical properties of the terrain. The wave received by a radar, commonly known as the backscattered signal, is therefore the information carrier from which the dielectric and geometrical properties of the terrain may be retrieved. In recent years, polarimetric technique has proven to be a promising tool for geophysical remote sensing [1–5]. Fully polarimetric radar signals carry additional phase information of the backscatterer and thereby provide more accurate identification and classification of terrain types.

A device which measures the full polarisation response of the scattered wave is called a polarimeter. Polarimetric radar systems differ from conventional radar system in that they are capable of measuring the complete scattering matrix of the remotely sensed media. The complete scattering matrix consists of four vector (amplitude and phase) quantities that may be determined from four different polarization combinations of the transmitting and receiving antennas. Typically, horizontally and vertically polarized antennas are employed to achieve the necessary polarisation diversity. However, any two orthogonally polarised antennas could be used [6]. By having the knowledge of the complete scattering matrix, it is possible to calculate the backscattered signal for any given combination of the transmitting and receiving antennas. This process is called the polarisation synthesis, which is an important technique used in terrain classification [1, 3].

Radar polarimetry deals with full polarimetric information of scattered waves from a target. It has been attracting attention in many application areas such as observation of the earth [1, 2], surveillance system for disaster, and highly advanced radar sensing. Therefore a polarimetric FMCW radar system is purposed to realize classification of various targets.

2. DESIGN CONSIDERATION

The primary goal of this project is to design and development of a ground based high bandwidth linear FMCW, fully polarometric and real time imaging radar system. High-level system design and subsystem level requirements have been carefully considered. High-level design consideration include:

2.1. Operating Frequency and Polarization

For remote sensing applications, frequency range from 1G to 30G Hz is normally used. In the 1 GHz to 10 GHz range, the transmissivity through air approaches 100%. Thus, a radar operating in this frequency range is always able to image the earth's surface independent of the cloud cover or precipitation. Our system is designed to operate at C-band (5.3 GHz or 0.057 cm wavelength), which is within the allowable spectrum defined by International Telecommunication Union (ITU) for Earth Exploration Satellite System (EESS) [7].

Full polarization is chosen because a fully polarimetric radar signals carry additional phase information of the backscatterer and thereby provide more accurate identification and classification of target.

2.2. Modulation and Measurement Range

In radar remote sensing, there are two widely used configurations, i.e pulse and FM-CW radar. The FM-CW configuration is employed due to its simplicity in design and construction. In addition, by using the FM-CW arrangement, it is possible to obtain large independent samples within a single illumination footprint — which is the key to improve the precision of the measurement. This radar system will be used for near range measurement which range from 20 m to 100 m.

2.3. Operation Platform and Antenna

A simple ground based radar system is to be designed in this project. Thus a simple mobile unit utilized a trolley will be employed in the field measurement. Typical radar system antenna has the gain of 17 dB to 28 dB. Four 25 dBi gain horn antenna with single polarization will be used in this system design for ease of implementation and increasing isolation between the transmitting antenna and receiving antenna; and between two cross polarization.

2.4. Signal Processor

There are many polarimetric systems that utilise vector network-analyser as the signal conditioner and processor. With the advancement in computer technology, however, computer-based systems are getting popular in recent years. A typical example is the C/X-band system developed by Gogineni et al. [8], which is an inexpensive polarimetric scatterometer. Another interesting design is the C/X-band helicopter-borne scatterometer [9] that uses a digital signal processor, together with a microcomputer for real-time signal processing. In our project, a personal computer (PC) is used as the signal processor and storage device. Compared to the network analyser based system, the PC-based system is more flexible in handling various sources of data.

2.5. Dynamic Range of Backscattering Coefficient σ°

The radar system sensitivity is determined based on the various categories of earth terrain to be mapped such as man made target, ocean, sea-ice, forest, natural vegetation and agriculture, geological targets, mountain, land and sea boundary. From the open literatures, the typical value of σ° falls in the range of +20 dB to −40 dB [10, 11]. For vegetation the typical value of σ° vary from +0 dB to −20 dB. In our system, a dynamic range of 50 dB is targeted from +20 dB to −30 dB in order to facilitate the measurement of various types of target.

The design considerations are summarised in Table 1:

Table 1: Design considerations.

System Parameter	**Design Considerations**
System configuration	FM-CW
Operating frequency	C-band
Quantities measured	Magnitude and phase of the received signal in full polarisation capability
σ° dynamic range	Adequate dynamic range for targets of interest > 50 dB
Signal Processor	PC-based system
Operating platform	Ground base (using trolley)

3. DESIGN PARAMETER

This C-band radar system is proposed to operate at 5.3 GHz. The FMCW waveform with bandwidth of 400 MHz is selected in our design.

Since the radar system is planned to operate within the range of 20 m to 100 m, and assuming a signal to noise ratio of 10 dB is sufficient for detection of various target, for the lowest value of backscattering coefficient, $\sigma_o = -30\,\text{dB}$ and the system losses is assume as 6 dB, the minimum average power required to be transmitted will be 0.023 watt. Therefore a high power amplifier that has a 1-dB compression level larger than +20 dBm can be employed.

The Nyquist Criterion states that in order to construct a band-limited signal from its samples, the signal must be sampled at least twice the highest frequency. In practice, the signal is over-sampled at a rate higher than the Nyquist by 25% in order to account for non-ideal filter behaviour. From the minimum and maximum operation range, the beat signal from both range will be 6.4 KHz and 32 KHz respectively. Therefore in our design, sampling rate of 100 KHz is chosen. The data rate for single ADC channel (assuming 12 bits per sample for greater dynamic range) will be 1.2 Mbits/second. Therefore the total data rate can be calculated by multiplying the data rate for single channel with the number of receive channels which is equal to 150 kbyte/second. Design Parameters of the FMCW Polarimetric radar system is listed in Table 2.

Table 2: Design parameters of the polarimetric radar system.

System Parameter	**Selected Value**
System configuration	FM-CW
Operating Frequency	5.3 GHz (C-band)
Transmit power, P_t	20 dBm
Measurement range	20 to 100 m
σ°dynamic range	+20 dB to −30 dB
Received power, P_r	−41 dBm to −107 dBm
IF bandwidth	100 KHz
Minimum signal-to-noise ratio	10 dB

4. PROPOSED RADAR SYSTEM

The proposed block diagram of the fully polarometric, C-band, high bandwidth linear FM-CW imaging radar system is shown in Fig. 1. The system is based on a superheterodyne design. It consists of antenna system (2 horn antennas with vertical polarization, 2 horn antennas with horizontal polarization), a radar electronics subsystem and a data acquisition system.

The microwave source is generated from a voltage control oscillator (VCO). VCO is used to generate the required FM-CW signal. Portion of the signal from VCO is couple to the down-converter mixer to act as the reference signal for return echo. The major portion of VCO output is routed to a solid-state high power amplifier with 20 dB gain. The amplified signal is then radiated

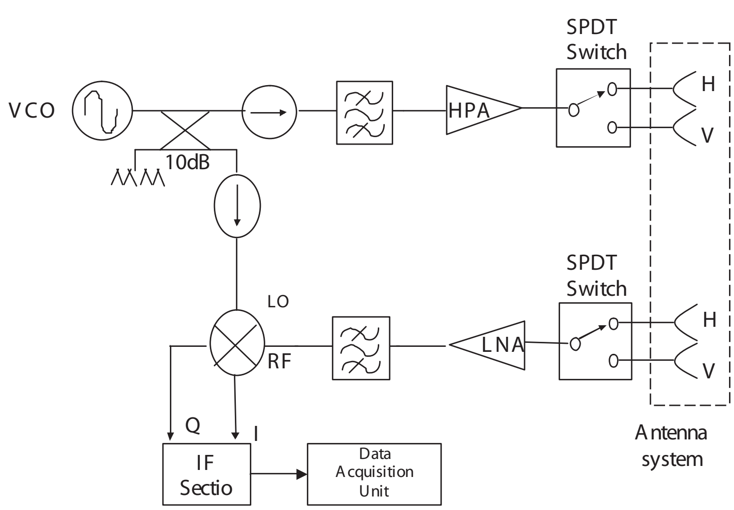

Figure 1: Proposed block diagram of C-band radar system.

through the antenna via a SPDT switch. The SPDT switch will determine the polarization of the transmitted signal. Thus a timing control is needed to ensure the full polarimetric signal is being received. The transmitted waveform is centered at 5.3 GHz with 400 MHz bandwidth.

The first stage of the receiver is a low noise amplifier (LNA) and followed by a band-pass filter. The down-converter mixer is used to convert the received signal to an intermediate frequency (IF). The signal from the mixer will be routed to IF section which consists of IF filter and amplifier. This radar system is proposed to employ a PC-based digital signal processing system for data acquisition. It consists of a high-speed 12-bits 100 KHz analogue-to-digital converter (ADC). The ADC is capable of converting the down-converted radar echoes into digital signals and stores them into high-density digital disk for future processing.

5. CONCLUSION

The conceptual design of a FMCW, fully polarometric imaging radar system system has been presented. This radar system can be used as a tool for monitoring and classification of simple target. This low cost system can be achieved by using simple RF subsystem, commercial component for chirp generation, PC based data acquisition and processing system.

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REFERENCES

1. Nghiem, S. V., M. Borgeaud, J. A. Kong, and R. T. Shin, "Polarimetric remote sensing of geophysical media with layer random medium model" *Progress In Electromagnetics Research*, PIER 3, 1–73, 1990.
2. Ulaby, F. T. and C. Elachi, *Radar Polarimetry for Geoscience Applications*, Artech House, California, 1990.
3. Zebker, H. A., J. J. van Zyl, and D. Held, "Imaging radar polarimetry from wave synthesis," *Journal of Geophysical Research*, Vol. 92, No. B1, 683–701, 1987.
4. Boerner, W. M., B. Y. Foo, and H. F. Eom, "Interpretation of polarimetric co-polarization phase term in radar images obtained with JPL airborne L-band SAR system," *IEEE Transactions on Geoscience and Remote Sensing*, GE-25, 77–82, 1987.
5. Winebrenner, D. P., L. D. Farmer, and I. R. Joughin, "On the response of L-band polarimetric SAR signatures at 24 cm wavelength to the thickness of arctic sea ice in leads," *Radio Science*, 1994.
6. Boerner, W. M., M. B. El-Arini, C. Y. Chan, and P. M. Mastoris, "Polarization dependence in electromagnetic inverse problems," *IEEE Transactions on Antennas and Propagation*, Vol. 29, 262–271, 1981.
7. International Telecommunication Union's (ITU) World Radiocommunication Conference (WRC-97), 1997.
8. Gogineni, S., F. A. Hoover, and J. W. Bredow, "High performance, inexpensive polarimetric radar for in-situ measurements," *IEEE Transaction Geoscience and Remote Sensing*, Vol. 28, No. 4, 450–455, 1990.
9. Hallikainen, M., J. Hyyppa, J. Haapanen, T. Tares, P. Ahola, J. Pulliainen, and M. Toikka, "A helicopter-borne eight-channel ranging scatterometer for remote sensing: Part I: System description," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 31, No. 1, 161–169, 1993.
10. Hyyppa, J., J. Pulliainen, K. Heiska, and M. T. Hallikainen, "Statistics of backscattering source distribution of boreal coniferous forests at C- and X-band," *Proceeding of the 1986 International Geoscience and Remote Sensing Symposium*, Vol. 1, 241–242, 1986.
11. Pulliainen, J. T., K. Heiska, J. Hyyppa, and M. T. Hallikainen, "Backscattering Properties of boreal forests at the C- and X-bands," *IEEE Trans. on Geosc. and Remote Sensing*, Vol. 32, No. 5, 1041–1050, 1994.