Conceptual Design of A High Resolution, Low Cost X-Band Airborne Synthetic Aperture Radar System

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Abstract — This paper describes the conceptual design of a low cost airborne Synthetic Aperture Radar (SAR) capable to obtain high-resolution image. The proposed system is an X-band, single polarization, high bandwidth linear FM radar and high resolution airborne SAR system. The system can be used as monitoring and management of earth resources such as paddy field, oil palm plantation and soil surface. First of all, the high level design will be discussed and detail design parameters are presented. It followed by radar electronics design, which outlined the detail in radar transmitter and receiver.

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1. INTRODUCTION

Radar has long been used for military and non-military purposes in a wide variety of applications such as imaging, guidance, remote sensing and global positioning [6]. Development of radar as a tool for ship and aircraft detection was started during 1920s. The first imaging radar, developed during World War II, used the B-Scan, which produced an image in a rectangular format. In the 1950s, the Side Looking Airborne Radar (SLAR) was developed. Scanning had been achieved with the SLAR by fixed beam pointed to the side with aircraft’s motion moving the beam across the land.

However, the image formed by SLAR is poor in azimuth resolution. For SLAR the smaller the azimuth beamwidth, the finer the azimuth resolution. In order to obtain high-resolution image one has to resort either to an impractically long antenna or to employ wavelengths so short that the radar must contend with severe attenuation in the atmosphere. In airborne application particularly the antenna size and weight are restricted. Another way of achieving better resolution from radar is signal processing. Synthetic Aperture Radar (SAR) is a technique which uses signal processing to improve the resolution beyond the limitation of physical antenna aperture [8]. In SAR, forward motion of actual antenna is used to ‘synthesise’ a very long antenna. SAR allows the possibility of using longer wavelengths and still achieving good resolution with antenna structures of reasonable size.

There are many applications or potential applications such as biomass estimation, crops monitoring, vegetation cover mapping, mineral exploration, ice dynamics modelling, forest fire, oil spill and biological water monitoring. Some of these have not yet been adequately explored because lower cost electronics are just beginning to make SAR technology economical for smaller scale uses. This paper describes the conceptual design and the proposed X-band airborne SAR system.

2. DESIGN CONSIDERATION

The primary goal of this project is to develop a low cost airborne X-band SAR system capable to illuminate a small size terrain and construct the high-resolution image of scanned area. 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 1 to 30 GHz is normally used. In the 1–10 GHz range, the transmissivity through air approaches 100%. Thus, a SAR 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 X-band (9.6 GHz or 3 cm wavelength), which is within the allowable spectrum (9.5G–9.8 GHz) defined by International Telecommunication Union (ITU) for Earth Exploration Satellite System (EESS) [4].

The size of an X-band antenna is considerably small and suitable to be used in airborne platform. In this frequency band, incident wave tends to be reflected by the surface layer. Potential application

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of X-band SAR included high-resolution land imaging, and ocean observation. In our design, single polarisation will be utilized. The VV polarization is chosen because it is more suitable for remote sensing of earth terrain. Change detection and simple classification can be done by VV polarization.

2.2. Modulation and Mode of Operation
Modern radar uses Linear Frequency Modulation (LFM) waveform or Chirp to increase range resolution when long pulses are required to get reasonable signal to noise ratio (S/N). The same average transmitting power as in a pulse system can be achieved with lower peak amplitude. The LFM configuration is employed in this project since it gives better sensitivity without sacrificing range resolution and ease of implementation. The lower peak power allows for the use of commercially available microwave components that have moderate peak power handling capability.

Stripmap is standard mode of SAR operation, widely used by airborne SAR sensors where a strip (swath) to the side of the aircraft is imaged. The radar antenna pattern is oriented towards the ground, orthogonal to the flight track and to one side of aircraft. As the aircraft moves, a swath is mapped out on the ground by antenna footprint. In our design, stripmap mode will be used.

2.3. Resolution and Swath Width
Typical resolution of airborne SAR range from 1 m to 20 m [1]. It depends mostly on the application requirements. Since our main objective is to establish high-resolution airborne SAR system, resolution of $1 \times 1$ m for both range and azimuth direction is chosen. A swath width of 1 Km is used in our design for small terrain coverage.

2.4. Operation Platform and Antenna
A small aircraft flying at low altitude will be used in the design in order to achieve the low cost SAR design. The SAR system should support true ground speed at 100 m/s and operating altitude about 1000 m. Typical airborne SAR antenna has the gain of 17 dB to 28 dB. The 25 dBi gain microstrip patch antenna will be used in this system design.

2.5. Range of Incident Angle
From the open literatures, the incident angle from $0^\circ$–$80^\circ$ is utilised by present airborne SARs. The backscattering coefficient of nature targets such as soil, grass and vegetable are maintained almost constant over the incident angle of $40^\circ$ to $60^\circ$ [6, 7]. Base on the swath width requirement and operating altitude, $50^\circ$ incident angle with $24^\circ$ elevation angle is chosen in our SAR system.

2.6. Dynamic Range of Backscattering Coefficient $\sigma^0$
The required 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 $\sigma^0$ falls in the range of $+20$ dB to $-40$ dB [3, 5]. For vegetation the typical value of $\sigma^0$ 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 earth terrain.

3. DESIGN PARAMETER
In this Section, the calculation associated with the design and hardware implementation of airborne SAR system is presented. The analysis of data rate and data volume are also illustrated. Fig. 1 shows a sketch of the operating condition.

Figure 1: Operating condition of airborne SAR system.
This X-band SAR system is proposed to operate at 9.6 GHz. The LFM waveform with bandwidth of 200 MHz is selected in our design. The theoretical range resolution of this system is 0.75 m. Assuming a 0.8 m length of antenna will be used in this system, the theoretical azimuth resolution of 0.4 m can be achieved.

The upper limit of Pulse Repetition Frequency (PRF) is attained from a consideration of the maximum mapping range and the fact that the return pulse from this range should come within the interpulse period [2]. In order to adequately sample the Doppler bandwidth, the radar must be pulse with a PRF greater or equal to this bandwidth. Combination of lower and upper limit, and assuming antenna length of 0.8 m is used, a medium PRF of 1000 Hz is chosen.

Since the radar system is planned to operate at altitude of 1000 m, the first return from the target will be at 8.46 µs. Therefore the transmitted pulse-width is pre-selected as 8 µs. Assuming a S/N of 10 dB is sufficient for mapping of earth terrain, for the lowest value of backscattering coefficient, σ₀ = −30 dB and the system losses is assume as 6 dB, the minimum average power required to be transmitted will be 0.208 watt. Thus the peak power requirement is 26 watts. Therefore a high power amplifier that has a 1-dB compression level larger than 26 watts (+44 dBm) can be employed.

System design and performance can be impacted by limitation on data rate and data volume. The impacts of limitation include smaller swath, fewer receiver channels, reduce range resolution, fewer bits per sample and reduce pulse duration. Refer to Fig. 1, the far range and near range is 1269 m and 2130 m respectively and the swath width of 1099 m can be obtained. The time delay for far range and near range can be calculated, there are 8.46 µs and 14.2 µs respectively.

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. In our design, sampling rate of 500 MHz is chosen. In order to capture all the data during the flight mission for geometry given in Fig. 1, the Data Acquisition Unit (DAU) needs to start range sampling at time of return from near-range of swath and stop sampling at end of return from edge of swath.

Assuming the aircraft flies at the constant height of 1000 m, the data window is given by time of flight far range minus time of flight near range plus pulse duration, and is equal to 13.74 µs. Thus the data rate for single ADC channel (assuming 8 bits per sample) will be 54.96 M bits/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 6.87 M byte/second. Assuming an image length of

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**Figure 2:** Proposed block diagram of X-band SAR system.
100 km will be taken for each flight mission, the data volume required for each data take is about 6.87 GB.

The data rate of at least 6.87 M bytes per second is required to record all the information captured during the data window. In addition, the data storage of more than 6.87 G bytes are needed for recording an image length of 100 km. Thus for a flight time of one hour, the storage required for raw data storage is 24.73 G bytes.

4. PROPOSED AIRBORNE X-BAND SAR

The proposed block diagram of the X-band SAR system is shown in Fig. 2. The system is based on a superheterodyne design. It consists of a microstrip antenna, a radar electronics subsystem and a data acquisition system.

The microwave source is generated from an ovenized Stable Local Oscillator (STALO). The frequency plan of this X-band SAR is shown in Fig. 3. The entire reference signal phase-locked to 100 MHz STALO to preserve the coherency of received signal. An arbitrary waveform generator (AWG) is used to generate the required LFM chirp signal. The timing circuit provides the control signal to switch the chirp mode gate so that the chirp pulse width is properly control. The output of the chirp mode gate is routed to a solid-state high power amplifier with 40 dB gain. The amplified signal is then radiated through the antenna via a circulator. The transmitted waveform is centered at 9.6 GHz with 200 MHz bandwidth. The first stage of the receiver is a low noise amplifier (LNA) and followed by a band-pass filter.

![Figure 3: X-Band SAR frequency plan.](image)

The first down-converter mixer is used to convert the received signal to an intermediate frequency (IF) centered at 600 MHz. This IF signal is filtered and amplified by Auto-Gain Control (AGC) Amplifier before feed into second mixer. The signal from second mixer will be routed to IF section which consists of IF filter and amplifier. The X-band SAR system is proposed to employ a PC-based digital signal processing system for data acquisition. It consists of a high-speed 8-bits 500MHz analogue-to-digital converter (ADC). The ADC is capable of converting the down-converted SAR echoes into digital signals and stores them into high-density digital disk for future processing.

5. CONCLUSIONS

The conceptual design of a low cost X-band airborne SAR system has been presented. This airborne SAR system can be used as a tool for monitoring and management of earth resources. This low cost system can be achieved by using simple RF subsystem, commercial component for chirp generation, PC based data acquisition and processing system.

REFERENCES


