

Reconfigurable L-Band Radar

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Abstract— The reconfigurable L-Band radar is an ongoing development at NASA/GSFC that exploits the capability inherently in phased array radar systems with a state-of-the-art data acquisition and real-time processor in order to enable multi-mode measurement techniques in a single radar architecture. The development leverages on the L-Band Imaging Scatterometer, a radar system designed for the development and testing of new radar techniques; and the custom-built DBSAR processor, a highly reconfigurable, high speed data acquisition and processing system. The radar modes currently implemented include scatterometer, synthetic aperture radar, and altimetry; and plans to add new modes such as radiometry and bi-static GNSS signals are being formulated. This development is aimed at enhancing the radar remote sensing capabilities for airborne and spaceborne applications in support of Earth Science and planetary exploration. This paper describes the design of the radar and processor systems, explains the operational modes, and discusses preliminary measurements and future plans.

I. INTRODUCTION

This paper discusses a new technological development that combines state-of-the-art radar technologies, on-board processing, and advances in the signal processing techniques in order to enable new remote sensing capabilities applicable to Earth science and planetary applications.

The development builds upon two ongoing efforts at the NASA Goddard Space Flight Center (GSFC). The first one is the development of the L-Band Imaging Scatterometer (LIS), a phased-array radar designed for the development and testing of digital beamforming radar techniques. The second effort is the development of a multi-channel, reconfigurable data acquisition and real time processing system customized for LIS. The two developments form the basis for the Digital Beamforming Synthetic Aperture Radar (DBSAR) system. DBSAR migrates many of the radar functions to the digital domain which combined with the reconfigurable hardware yields maximum system flexibility and portability.

The ability to implement multimode remote sensing techniques by reconfiguring the radar provides great benefits to Earth science and planetary exploration missions. The reconfigurable modes currently being implemented in DBSAR include scatterometer, synthetic aperture radar, and altimetry; and plans to implement new modes are being formulated.

In Earth Science applications, the scatterometer mode can provide accurate estimates of ocean or land surface roughness (as well as the presence of vegetation, in the case of land) which when coupled with passive radiometric measurements can be used to retrieve ocean salinity and soil moisture, important components of the global water and energy cycle. The SAR mode higher resolution imaging provides information about vegetation and forests types and extents,

important in the study of carbon cycle. It also allows the monitoring the dynamics of ice sheets, or snow accumulation and melt, important drivers of sea-level change and water cycle. The altimeter mode provides Earth surface mapping applicable to cryospheric, hydrospheric and oceanographic applications.

Many of the techniques employed in the remote sensing of the Earth are also applicable to planetary exploration. The modes implemented in the reconfigurable radar could provide observations of planetary surface, and geological processes critical for understanding the dynamics of bodies such as Mars, Venus, Europa, Titan, and Enceladus. Enhancing the capability of a radar with multi-mode capability is also very attractive in planetary exploration since it is costly and inefficient to send more than one radar mission to other planets in the solar system.

The next sections will describe the design of the radar and processor systems, explain the operational modes, and discuss preliminary measurements and future plans.

II. RADAR ARCHITECTURE

The radar is a phased array system consisting of eight transmit/receive (T/R) channels connected to a micro-strip antenna, as shown in Figure 1. The transmit channels share a 1.26 GHz phase-locked oscillator (PLO) and a pulse modulator. Each transmit channel incorporates a solid state power amplifier (SSPA), as well as digital amplitude and phase controllers that enable across track beam steering. The attenuators, phase shifters, and calibration switches are digitally controlled by the radar control card (RCC) on a pulse by pulse basis. Calibration of the transmit channels is achieved by an internal calibration loop that routes the transmit signal into to the down-converter.

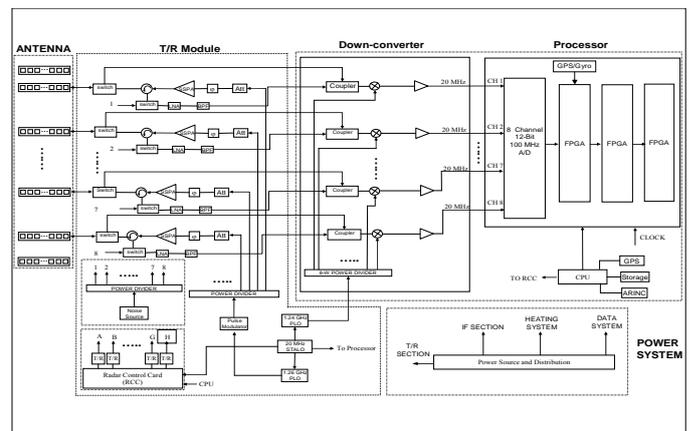


Fig. 1 Radar architecture showing antenna subarrays, RF hardware, and processor.

Each receiver channel consists of a low noise amplifier (LNA), a band pass filter, and a down-conversion unit. The channels share a noise source to monitor and calibrate amplitude and phase fluctuations on the receive chains. The down-converters share a 1.24 GHz phase-locked oscillator (PLO) used to translate the microwave RF signals to an intermediate frequency of 20 MHz. After down-conversion the signals are routed to the data acquisition section of the processor. All the RF components exhibit phase linearity over a wide bandwidth.

The Radar Control Card (designed by ProSensing Technologies) receives the control signals from a host PC over an RS-422 cable and generates all the timing signals. The RCC includes a fan out board to connect the RCC to the T/R modules on each of the channels. Each T/R module controls an attenuator and a phase-shifter, as well as several switches. The T/R module holds a table of values containing attenuation and phase settings. At each pre-trigger, T/R module sets the attenuator and phase shifter with the current value and updates the current value with the next value.

The antenna is a corporate fed microstrip patch-array centered at 1.26 GHz with a 20 MHz bandwidth. The patch elements have a separation of one-half wavelength, and are printed on .125" thick Teflon-fiberglass substrate, as shown in figure 2. Although only one feed is used with the present configuration, a provision was made for separate corporate feeds for vertical and horizontal polarization.

The radar was designed to fly on the NASA P3 aircraft. The radar mounts on the aircraft bomb-bay with the antenna pointing at nadir. The radar processor and power supplies are mounted on a rack which seats directly above in the fuselage. The signal and power cables run between the radar hardware and rack through a bulkhead interface. Figure 3 shows the radar during testing in the laboratory, and integrated to the P3 aircraft before test flights (inset). Table I lists some important radar characteristics.

TABLE I
RADAR CHARACTERISTICS

Frequency	1.26 GHz
PRF	50 Hz to 10 KHz
Pulse Width	1 to 1000 μ s
Number of Transmitters	8
Total Output Power (Nominal)	16 W
Beam Steering Angles	\pm 45 degrees
Bandwidth (10 dB return loss)	20 MHz
Polarization	Horizontal
Total antenna Gain	> 20 dB
3 dB Beamwidth (Nadir, along track)	13.6 Degrees
Side Lobes	Better than - 18 dB
Total System Power	350 W
Total System Weight	235 Lbs



Fig. 2 Dual-polarization micro-strip patch antenna



Fig 3 Radar assembly in laboratory and mounted on P3 aircraft (inset).

III. THE DBSAR PROCESSOR

DBSAR is a reconfigurable data acquisition and processor system capable of real-time, high-speed data processing. DBSAR uses an FPGA-based architecture to implement digitally down-conversion, in-phase and quadrature (I/Q) demodulation, and subsequent radar specific algorithms. The processor architecture was a custom design for the implementation SAR algorithms. The core of the processor board consists of an analog-to-digital (A/D) section, three Altera Stratix field programmable gate arrays (FPGAs), an ARM microcontroller, several memory devices, and an Ethernet interface, as shown in figure 4. The processor also interfaces with a navigation board consisting of a GPS and a MEMS gyro.

The eight A/D converters are 12-bit devices with sampling rates of up to 170 MSPS that provide 65.6 dB of dynamic range. The three Altera Stratix FPGAs are capable of high computation power and clock frequencies up to 400 MHz. The processor architecture can perform up to 66 Giga-multiply-accumulate (GMAC) operations per second. Six 72-Mbit 200-MHz SRAMs are used for signal processing and can store up to 4 million 18-bit words each. The system

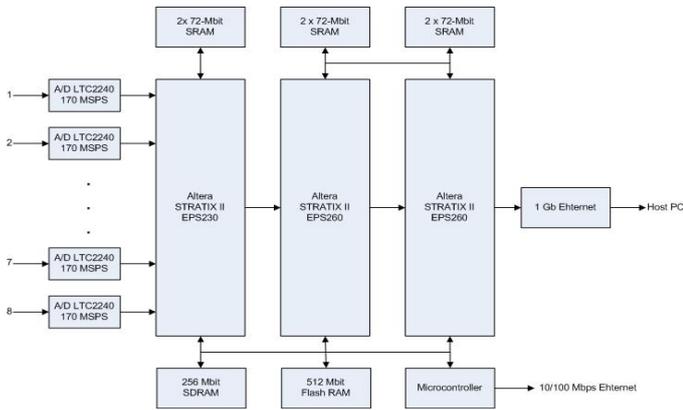


Fig. 4 DBSAR processor diagram showing main components.

control and interfacing is managed by an on-board ARM micro-controller which uses a 256-Mbit SDRAM. A 1-Gigabit Ethernet interface provides communications with a host PC for data transfers and house keeping. The processor board has dimensions 17 cm x 24 cm x 4 cm, and a power consumption of less than 94 Watts.

The several modes implemented on the processor are based on digital beamforming which is a digital process that generates the far-field beam patterns at various scan angles from voltages sampled in the antenna array. This technique allows steering the received beam and controlling its beamwidth and sidelobe. DBSAR can operate in several beam forming modes, each characterized by unique strengths and weaknesses, and each applicable to different measurement scenarios.

IV. OPERATIONAL MODES

The processor has been configured to operate in scatterometer, Synthetic Aperture Radar (SAR), and altimeter modes.

A. Scatterometer Mode

In this mode, the radar is capable to generate a wide beam or scan a narrow beam on transmit, and to steer the received beam on processing while controlling its beamwidth and side-lobe level. The radar can operate in the beamforming modes, each characterized by unique strengths and weaknesses, and each applicable to different measurement scenarios. The scatterometer operational modes are as follows:

- Simultaneous transmission and reception on all subarrays: In this mode, the beam is electronically scanned across the field of view. A sequence of focused beams is formed on transmission, with amplitude tapering and beam steering achieved by adjusting the gain and phase of the individual transmit modules. Similar amplitude and phase tapering is applied to the digitized signal to steer the received beam and control its sidelobe structure. The two-way sidelobe levels for such an array approach 50 dB, since the sidelobes are determined by the product of the transmit and receive power levels, which are around 25 dB. This mode of operation has the dual advantages that the transmitted

power is highest and the beam is the narrowest of the different modes of operation.

- Transmission on a single subarray, simultaneous reception on all subarrays: In this mode, the central subarray is energized, illuminating the entire field of view on each pulse of the radar. The signals received at all of the subarrays are sampled, then a digital beamforming algorithm is executed which forms simultaneous beams at various scan angles. For a given amplitude taper, the simultaneous illumination mode has have sidelobes which are twice that for beam steering, giving a practical sidelobe level of ~25 dB. The primary advantage of this type of beamforming is that it provides simultaneous imaging on all beams, which is advantageous in comparison to the ESTAR radiometer measurements, and that a greater number of samples are provided, thus providing the opportunity to improve SNR in some situations. The disadvantage is the lower transmitted power and the higher sidelobe levels.

The scatterometer mode was successfully flight tested in May 2006 and in January 2007 on board of the NASA P3 aircraft over the Delmarva Peninsula, VA using an earlier version of the beamforming processor. In scatterometer mode, the new processor will be able to generate 32 beams at a pulse repetition frequency as high as 10 KHz.

B. SAR Mode

In this mode the radar can achieve fine resolutions over large swaths without degrading image quality as in the case of conventional Synthetic aperture Radar (SAR) systems. Conventional SAR systems are inherently narrow swath because of imposed ambiguity limitations.

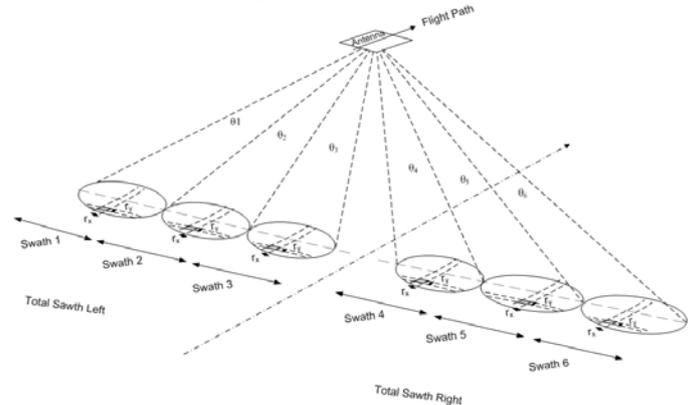


Fig. 5 Digital beamforming SAR operational mode

As shown in figure 5, a wide beam is generated by energizing a small section of the antenna, as explained in the scatterometer mode. The transmitted beam illuminates entire field of view. DBSAR synthesizes simultaneously multiple cross-track beams using digital beamforming techniques, and processing each beam using SAR techniques, all in real-time. Each beam can be synthesized with different beam widths and side lobe levels so as to maintain constant swath widths and minimize side lobe contamination. Furthermore, the DBSAR

system is able to synthesize beams on both sides of the track using a single nadir-looking antenna, thus doubling the coverage area.

The onboard real-time processing capability of DBSAR allows the implementation of data reduction techniques (e.g., data averaging or data compression), as well as to dynamically update firmware parameters (e.g., beam pointing angle or match-filter coefficients).

C. SAR Altimeter Mode

This mode is currently being implemented in which altimetry is performed on the Nadir beam of the Scatterometer mode or SAR mode, as shown in figure 6. The Delay/Doppler technique (Keith Raney, 1998) is employed to reduce the altimeter foot print along track and provide better speckle reduction and precision than conventional altimeters. In this mode, the onboard processing enables high data reduction, making this technique very suitable for spaceborne applications.

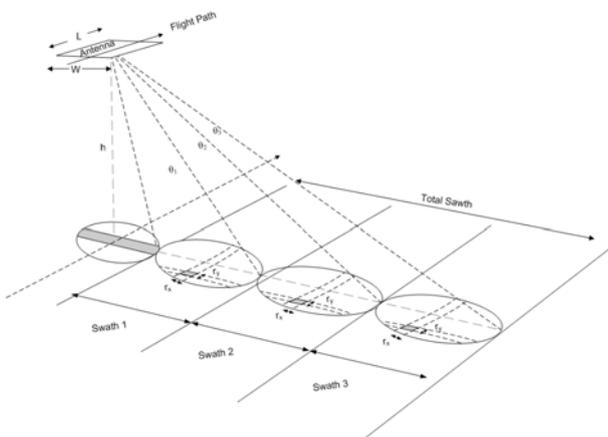


Fig. 6 Altimeter and SAR operational mode

V. CONCLUSION

The reconfigurability inherent in the DBSAR architecture can provide great benefits to Earth science and planetary exploration missions by enabling more measurements in a single platform.

The multimode operation of scatterometry, SAR, and altimetry, can be implemented as separate modes or can be combined into a single mode (simultaneous or time multiplexing), providing greater flexibility particular useful in spaceborne applications.

The onboard processing capability also yields reduction in the data rates that make these techniques possible from space platforms.

The DBSAR modes will be tested on board of the NASA P3 aircraft based at the Wallops Flight Facility (WFF). The flight tests will take place in the fall 2008 when radar will gather data over areas of the Delmarva Peninsula and Virginia.

Future plans include increasing the DBSAR system bandwidth in order to implement wideband algorithms, and to incorporate bi-static GPS (GNSS-R) retrievals.