The Ecosystems SAR (EcoSAR)
An airborne P-band Polarimetric InSAR for the measurement of vegetation structure, biomass and permafrost

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Abstract— **EcoSAR is a new synthetic aperture radar (SAR) instrument being developed at the NASA/ Goddard Space Flight Center (GSFC) for the polarimetric and interferometric measurements of ecosystem structure and biomass. The instrument uses a phased-array beamforming architecture and supports full polarimetric measurements and single pass interferometry. This Instrument development is part of NASA's Earth Science Technology Office Instrument Incubator Program (ESTO IIP).**

I. Introduction

Climate change constitutes the greatest environmental problem of this century and is destined to significantly impact all societies. Quantifying the carbon (C) cycle accurately is the most important element in understanding climate change and its consequences, yet our current C estimates vary greatly[1][2]. In effect, forests store 85% of terrestrial biomass, yet the amount of C contained in the Earths biomass is not known to even one significant figure, with estimates ranging from 385 to 650 10^{15} g carbon [3][4]. Moreover, in the past 60 years, the Arctic has been one of the fastest warming regions on Earth [5]. As warming occurs, permafrost soils containing over 1,670 billion tons (Pg) of carbon -twice the amount of C stored in the atmosphere- are thawing and degrading with little understanding of the spatial extent of degradation and the amount of carbon dioxide (CO_2) and methane (CH_4) being released[6][7]. Both Terrestrial Carbon storage and Pan-Arctic permafrost thaw need be quantified accurately, regularly, and at large scales to account for changes from both natural and human-induced disturbances. These needs have been stressed by both the Intergovernmental Panel on Climate Change [8] and the National Reserch Council Decadal Survey [9].

In this paper we introduce the EcoSAR instrument, an airborne Polarimetric and "single pass" Interferometric P-band Synthetic Aperture Radar (SAR) instrument for the measurement of measurements of terrestrial ecosystem structure, biomass, and permafrost.

EcoSAR's P-band measurements can penetrate vegetation structure and sense the entire canopy volume and woody density. Such measurements provide the unique capability of mapping the forest cover, disturbance from deforestation and degradation, forest recovery, wetland inundation, and aboveground biomass. EcoSAR's wavelength of is also desirable for several critically important science measurements of permafrost. The EcoSAR InSAR measurements of arctic soils will allow the modeling of the thickness of the 'active layer', which in turn can be used to estimate methane emissions into the atmosphere [10] and assess other hazards related to permafrost thawing [11].

II. Instrument Description

The EcoSAR instrument is an airborne Digital Beamforming SAR [12] [13] that operates at a center frequency of 435 MHz (P-band) and uses a reconfigurable architecture to select and adjust important parameters including number of beams, beam direction, pulse duration, signal bandwidth, and waveform type, among others. Table I lists some of the main characteristics of the EcoSAR instrument.

TABLE I. EcoSAR main characteristics

Center Frequency	435 MHz	Pulse Length	1 usec–50 usec
Bandwidth	6 MHz - 200 MHz	Array Peak Power /polarization	40 Watts
Polarization	HH,HV, VH,VV	PRF	100 Hz – 10 KHz
Polarization Isolation	> 30 dB	Swath	4 km *
Noise Equivalent σo	- 41 dB *	Finest Range Resolution	0.75 m
Total Number Channels	36	Single Look Azimuth Resolution	0.5 m
Interferometric baseline	25 m	Vertical Accuracy	< 5 m
Antenna size (2)	3 m x 1.2 m	Antenna element	Stack patch

* from 8km altitude, 35 º incidence angle

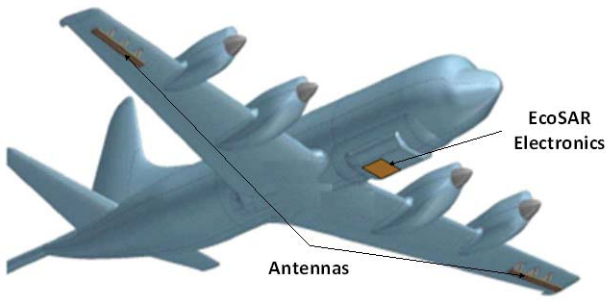

Figure 1. EcoSAR will employ advanced technology and techniques in order to enable polarimetric and interferometric measurements of biomass and ecosystem structure.

EcoSAR employs a multi-channel architecture, including a highly capable multi-channel digital waveform generator and data acquisition/processor system, and two dual-polarization phased-array antennas. The instrument is designed to fly on board of a P3 aircraft with the antennas mounted under the wings forming an interferometric baseline of 25 m [Fig. 1]. This architecture allows considerable measurement flexibility such as post processing synthesis of multiple beams, simultaneous measurement over both sides of the flight track, and variable incidence angle [14].

EcoSAR features a fully programmable bandwidth from 6 MHz to 200 MHz. This capability allows the adjustment of the range resolution according to mission requirements in a heavily used P-band environment. An operational mode with 5 m to 25 m resolution (6 MHz -30 MHz) is used as a nominal mode for most areas, and a science mode with meter resolution (up to 200 MHz) for selected sites.

III. Architecture

EcoSAR consists of three main subsystems: 1) The wideband, dual-polarization array antennas, 2) The Radar Electronics Unit (REU), and a Radar Digital Unit (RDU).

The antennas are based on a stacked patch design that permits polarimetric radar operation with bandwidths up to 200 MHz. Ten subarrays make up each EcoSAR antenna. The antennas (see Fig. 2) are installed under the wing of the aircraft using aircraft pylons.

Figure 2. The EcoSAR antennas support single pass interferometry and full polarimetric operation with bandwidths up to 200 MHz.

The REU consists of 32 transmit/receive (T/R) modules which reside in aircraft racks inside the aircraft fuselage. Each T/R module featuress a 20-Watt solid state power amplifier (SSPA), low noise amplifier (LNA), circulator, coupler, filters, and control switches. The T/R modules also include closed loops for robust calibration, dynamic beam control and adaptive waveform generation. The transmit path was designed accounting for dynamic range, impedance matching and signal levels. The receive path was designed in a similar fashion but noise figure and out-of-band rejection had to be considered. The T/R modules are installed on a aircraft racks for operation on the fuselage of a P3 aircraft, as shown in Fig 3.

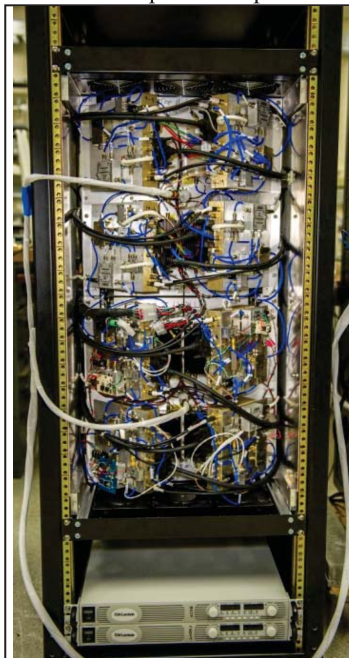

Figure 3. EcoSAR aircraft rack containing 16 transceivers.

The RDU features a FPGA-based programmable digital waveform synthesizers system with 32 time-synchronous and phase-locked digital waveform generators (with independent amplitude and phase control), and a reconfigurable data acquisition and real-time processor with 32 independent receive channels, as illustrated in Fig 4. The waveform synthesizers and data acquisition processor are controlled by custom Graphical Unit Interface which performs real-time configuration, monitoring, and data archiving.

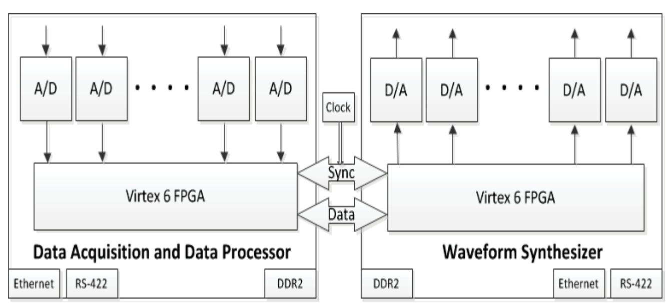

Figure 4. EcoSAR's Radar digital Unit digital consisting of a waveform generator, data acquisiton, and processor system.

IV. Concluding Remarks

EcoSAR's digital beamforming, polarimetric, and "single pass" interferometric operation makes this system a first of its kind, providing unprecedented two- and three-dimensional fine scale measurements of terrestrial ecosystem structure and biomass. These measurements directly support science requirements for the study of the carbon cycle and its relationship to climate change, recommended by the National

Science Foundation's Decadal Survey (2007) and highlighted in NASA's Plan for a Climate-Centric Architecture (2010).

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