HIGH-ALTITUDE IMAGING WIND AND RAIN AIRBORNE RADAR (HIWRAP)

Lihua Li[1], *Gerald Heymsfield*[2], *James Carswell*[3], *Dan Schaubert*[4], *Justin Creticos*[4], *Manuel Vega*[2]

[1]University of Maryland Baltimore County, Baltimore, MD
[2]Goddard Space Flight Center, Greenbelt, MD
[3]Remote Sensing Solutions, Barnstable, MA
[4]University of Massachusetts, Amherst, MA

ABSTRACT

This paper describes the development of the High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) which is funded under the NASA Instrument Incubator Program (IIP) [1]. HIWRAP is a dual-frequency (Ka- and Ku-band), dual-beam (30^0 and 40^0 incidence angle), conical scan, Doppler radar system designed for operation on the high-altitude (65,000 ft) Global Hawk Unmanned Aerial System (UAS). It utilizes solid state transmitters along with novel pulse compression scheme that will result in a system that is considerably more compact in size, lighter in weight, less power consumption, and ultimately cost significantly less than radars currently in use for precipitation and Doppler wind measurements. By combining measurements at Ku- and Ka-band, HIWRAP will be able to image winds by measuring volume backscattering from clouds and precipitation.

Index Terms— HIWRAP, wind, high altitude, dual frequency, conical scan

1. INTRODUCTION

Extreme weather events including tropical storms pose significant natural threats to costal areas and maritime interests. Forecasts for these weather events depend on numerical weather models that assimilate various types of atmospheric measurements. In the case of tropical cyclones and severe ocean storms, often measurements of the atmospheric and tropospheric winds are sparse. Satellite scatterometers (e.g., QuikScat) and radiometers (e.g., WindSat) have provided ocean surface wind measurements in precipitation-free regions, but as yet, remote measurements of atmospheric winds have utilized surface-based or aircraft Doppler radars because there are still technical challenges for the spaceborne Doppler wind retrievals [2][3]. Furthermore, spaceborne sensors have resolutions that are too large and revisit times that are too infrequent for providing critical information on rapidly developing weather events such as hurricanes in coastal regions. Aircraft radar-measured atmospheric winds have filled this critical data gap and have been essential for understanding of various weather events such as tropical storms, and the subsequent improvement of parameterizations in forecast models [4]. Tropical storms are often located in remote regions of the ocean making manned aircraft impractical because of their limited endurance. Along with the development of new technologies, NASA's interests have more recently focused on UAS, especially high altitude, long endurance platforms (HALE UAS) such as the Northrop Grumman RG-4A Global Hawk. Wind and precipitation measurements from high-altitude aircrafts, especially long-duration UAS are highly desirable since they provide focused measurements with higher spatial and temporal sampling.

2. MEASUREMENT CONCEPT

HIWRAP is designed to measure the tropospheric winds by collecting multi-look Doppler profiles from cloud and precipitation volume backscattering measurements. With the combination of Ku/Ka-band, HIWRAP is significantly more sensitive to cloud particles than lower frequency radars, enabling it to measure the mean cloud particle velocity and thus map the 3D tropospheric winds. In addition, its dual-wavelength operation enables it to map the full atmospheric boundary layer winds from Doppler-precipitation volume backscatter measurements, derive information about the drop-size distribution of the precipitation and estimate the ocean surface wind field using ocean wind scatterometry techniques similar to that employed by the NASA SeaWinds. As shown in Figure 1, HIWRAP will produce two antenna beams (30^o and 40^o) at Ku-band and two at Ka-band, simultaneously. Conically scanning, these beams will sweep through the volume beneath the aircraft, while simultaneously measuring the Doppler/reflectivity profiles from each beam. For any given volume cell within the inner swath, HIWRAP will view this cell at Ku and Ka-band from two different incidence angles and four different azimuth angles, from which the 3 components of the wind will be derived. The unique sampling and phase correction strategy implemented by HIWRAP (RSS' frequency diversity Doppler processing technique) [5] will enable the Doppler measurements to be unfolded. The measurement requirements for HIWRAP are given in Table 1 for wind retrievals in 1 km x 1 km x 60m pixels. The actual line-ofsight wind measurement accuracy is much smaller than the retrieved wind accuracy.

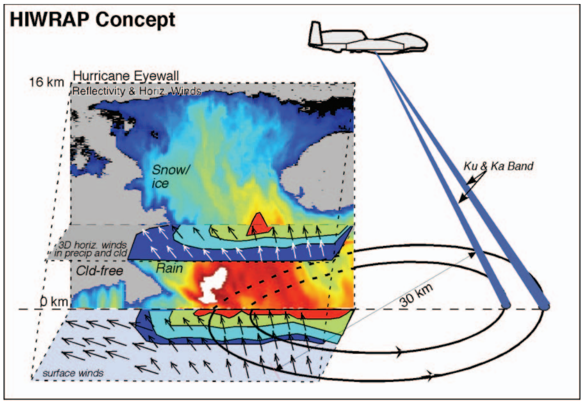

Figure 1. HIWRAP Measurement Concept

TABLE 1 HIWRAP MEASUREMENT REQUIREMENTS

	Parameters	Range	Accuracy
Retrieval Products (resolution cell: 1km x 1km x 60m)	Horiz. Wind Speed (ms^{-1})	0-100	2.0
	Horiz. Wind Direction (°)	0-360	15
	Surface Wind Speed (ms^{-1})	0-60	2.0
	Surface Wind Direction (°)	0-360	15
	Vertical Wind Speed (ms^{-})	± 20	2.0

3. SYSTEM DESCRIPTION

The design of HIWRAP involves a compromise in order to address the scientific requirements and hardware limitations imposed by the size, power, and weight constraints of the aircraft platform. A number of factors, such as the high altitude environment, limited space, weight and power pose challenges to system design. The entire radar system must have the capability to operate in a "turnkey" autonomous operation mode. Table 2 provides performance specifications for HIWRAP and Figure 2 shows HIWRAP system block diagram. The radar IF/LO, RF transceivers and the digital receiver and processor subsystems will be mounted on a rotating structure that will typically spin at about 10 rpm (Figure 3). These enclosures will not be pressurized and cooling of the high heat producing power amplifiers will be dealt with using heat pipes. The data system, power distribution, navigation unit and the scanner controller will be installed in the stationary payload area. This configuration avoids the usage of long waveguides and a multi-channel RF rotary joint, which is lossy and difficult to build and maintain at HIWRAP frequencies. Figure 4 shows HIWRAP scanner assembly installed in Global Hawk radome area. HIWRAP has several subsystems and the following provides a brief description of the key subsystems.

TABLE 2 HIWRAP SYSTEM SPECIFICATIONS

Parameters	Specifications	
	Ku-band	Ka-band
RF Frequency (GHz)	Inner Beam: 13.910 Outer Beam: 13.470	Inner Beam: 35.560 Outer Beam: 33.720
Tx Peak Power (W)	30	8
3 dB Beam Width (°)	2.9	1.2
Polarization	V (inner beam), H (outer beam)	
Minimum Detect. Reflectivity (dBZ_e, 60 m range res., 10 km range and 3 km chirp pulse)	0.0	-5.0
Dynamic Range (dB)	> 65	
Doppler Velocity (ms^{-1})	0-150 (Accuracy < 1.5 ms^{-1} for SNR>10)	
Scanning	Conical Scan, 10-30 rpm	

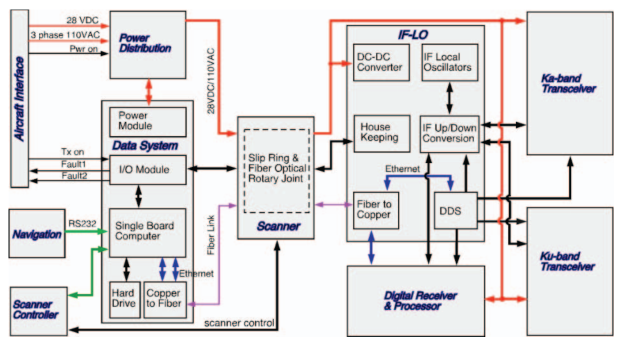

Figure 2. HIWRAP System Block Diagram

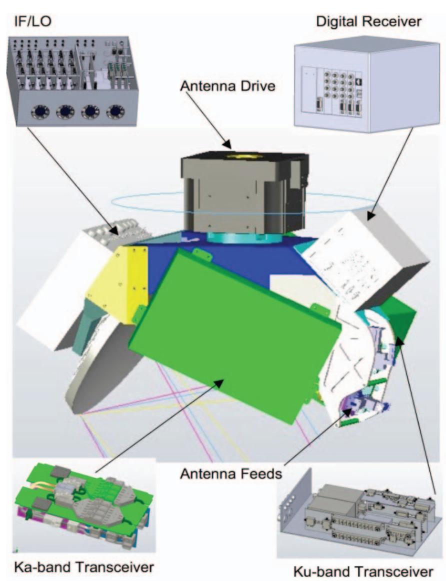

Figure 3. HIWRAP scanner assembly.

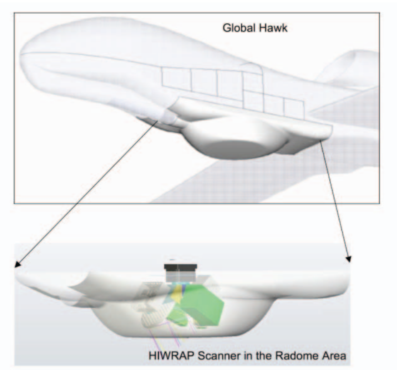

Figure 4. HIWRAP configuration in Global Hawk

3.1. ANTENNA

HIWRAP's antenna consists of a single offset parabolic reflector and two dual-frequency feed horns to form the 30° and 40° beams. The University of Massachusetts was responsible for the antenna subsystem. The completed antenna reflector and feeds were mounted on a temporary frame for testing antenna patterns in an anechoic chamber (Fig. 5a). One of the dual-frequency feeds using a novel design to improve performance at the two frequencies is shown in Fig. 5b. Figure 5c and 5d show the antenna main reflector and antenna patterns for Ku-band at two incidence angles.

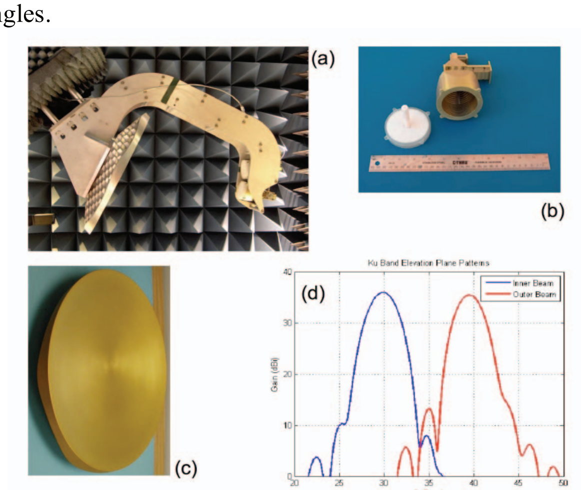

Figure 5. HIWRAP antenna (a) mounted in test frame at Goddard compact range; (b) dual frequency feed.; (c) main reflector; (d) antenna pattern at Ku-band for two incidence angles.

3.2. TRANSCEIVER

HIWRAP utilizes a dual-wavelength compact transceiver that is modular in design. This transceiver supports digital pulse compression through the use of inexpensive direct digital synthesizer (DDS) chips in order to obtain 50% of the average power of the Ku and Ka-band power amplifiers. The design supports simultaneous operation at two wavelengths and multiple incidence angles in order to maintain high temporal and spatial resolution. Innovative approaches are being taken to enhance independent sample rates and utilize the full average power that the power amplifiers can deliver. This design takes advantage of mixing products in the RF upconversion stage to produce the two RF channels at each band necessary to form the two beams. As such, this design only needs one RF LO for each band, and thus saves on space, power consumption and weight.

HIWRAP uses commercial power amplifiers that deliver 30W at Ku-band and 8W at Ka-band through power combining. A custom board is used to produce the transmit waveform and timing control signals. The combination of DDS and field programmable gate array (FPGA) technologies enable the software controlled, versatile waveform generation, such as frequency diversity and amplitude modulation, as well as timing control from a single board. An internal calibration loop also provides an accurate measurement of the total transceiver gain to within 0.2 dB or better and samples the transmit waveform so that pre-distortion techniques can be used to improve range sidelobe performance. Figure 6 shows a typical HIWRAP transmit and receive waveform cycle. Figure 7a and 7b show the test assembly for the Ka- and Ku-band transceivers. These subsystems will be remounted in a flight enclosure after testing is completed. Figure 7c shows the custom DDS/timing board under test.

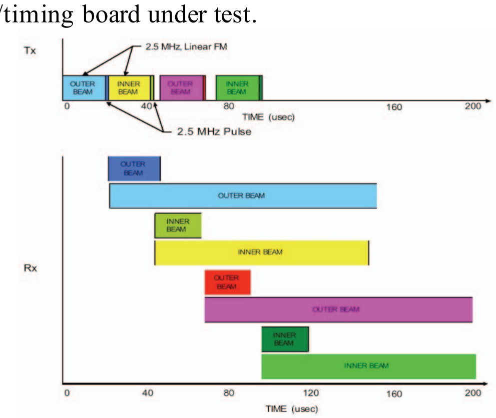

Figure 6. HIWRAP transmit and receive waveform

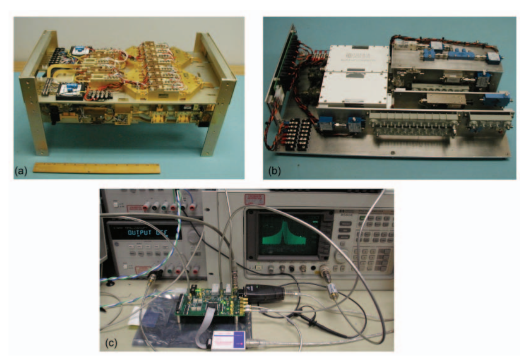

Figure 7. (a) Ka-band transceiver and (b) Ku-band transceiver mounted on the test frames (c) DDS/timing control board under test.

3.3. DIGITAL RECEIVER

The HIWRAP digital receiver and signal processor subsystem will be responsible for implementing digital I&Q detection, match filtering (i.e. pulse compression), spectral and/or Pulse-Pair processing and data reduction through coherent and/or non-coherent averaging. The subsystem is currently under development by RSS. It uses a combination of FPGAs and low power consumption processors, which provide the most compact solution without a requirement for pressurization. To reduce risk, the system is network based so that the data can be easily ingested by a PC-based system where further processing algorithms may be applied. As the algorithms are tested and validated, they can be transferred to the FPGA-based processors with minimum impact.

Another novel feature of the FPGA-based digital receiver is that each IF channel will support up to eight independent sub channels. With more than 90 dB of rejection and a 1.5 filter shape factor. HIWRAP will be able to utilize frequency diversity to improve its independent sampling rate and implement an advanced phase correction scheme for unfolding its Doppler measurements. The primary digital receiver characteristics are:

- Two IF channels per board and independent sub channels per IF channel.
- 500 KHz to 20 MHz bandwidth per subchannel.
- 40 MHz aggregated bandwidth per IF channel.
- Greater than 80 dB SNR.
- 14 bit A/D resolution.
- Matched Filter supports up to 30 dB pulse compression gain per subchannel
- Supports up to 1000 range gates.

3.4. HOST COMPUTER, NAVIGATION SYSTEM AND SCANNER CONTROLLER

HIWRAP uses a Compact PCI (CPCI) bus based single board computer (SBC) to run radar control program and to capture processed data from the digital receiver through a high-speed fiber optic link. The HIWRAP scanner is a DC powered, brushless, commercial off-the-shelf (COTS) unit with a superior mechanical design and flexible configuration. It communicates with the host computer system through either RS232 or Ethernet. HIWRAP also utilizes a dedicated high-speed navigation system to provide precise platform position information. Radar status information, scanner position and high-speed navigation data will be collected and saved by the host computer along with radar data.

4. STATUS AND FUTURE PLAN

HIWRAP hardware and software are currently under development. System integration and lab test is scheduled in late Fall 2008. The long term HIWRAP plans are to fly long duration flights over hurricanes with the NASA Global Hawk based at NASA Dryden Flight Research Center. Because of Global Hawk availability and that HIWRAP will have a number of new technologies to test, the WB-57 aircraft based at NASA Johnson Space Center will be used for initial instrumental and measurement concept test. The WB-57 provides an excellent simulator for the Global Hawk operating environment since both planes fly at similar altitudes. Figure 8 shows a concept drawing for HIWRAP installation in a 6-foot pallet on the WB-57.

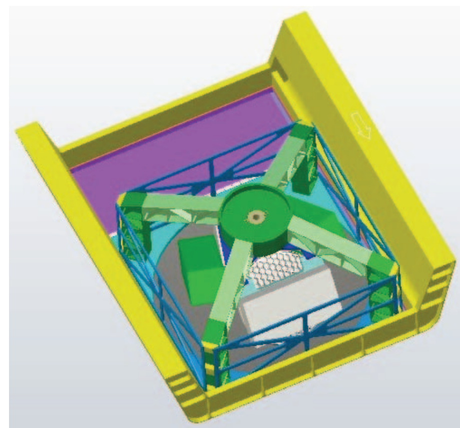

Figure 8. HIWRAP mounted in a WB-57 6-foot pallet.

ACKNOWLEDGMENT This work is being conducted under NASA Instrument Incubator Program funding.

5. REFERENCES

[1] G.M. Heymsfield, J. Carswell, *High Altitude Imaging Wind and Rain Radar (HIWRAP).* , NASA Science Technology Conference 2008 (NSTC2008).

[2] Marks, F. D., Houze R.A., *Inner core structure of hurricane Alicia from airborne Doppler radar observations*, Journal of the Atmospheric Sciences, vol. 44, no. 9, pp. 1296-1317, May 1987

[3] G.M. Heymsfield, S. Bidwell, *et al*., "The EDOP Radar System on the High Altitude NASA ER-2 Aircraft.", *J. Atmos. Oceanic Tech*., 1996, pp 795-809.

[4] Marks, F.D., Shay, L.K and PDT-5, *USWRP PDT-5 Report, 1998: Tropical Cyclones: Forecast problems and associated research opportunities*. Bull. Amer. Met. Soc., Vol.79, No.2 , 305-323.

[5] Carswell, J.R., "Final Report: A Revolutionary Wind and Rain Airborne Profiler for Unmanned Aircraft Vehicles", NASA STTR Final Report, Contract No. NNG05CA96.