W-Band ARM Cloud Radar

System Description and Operations Manual

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Prepared for

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1. Introduction

This document describes the W-Band ARM Cloud Radar (WACR) system, built by ProSensing Inc. of Amherst, MA for the ARM Mobile Facility (WACR AMF). The WACR AMF system is designed for dual polarization measurement of Doppler spectral moments in clouds and precipitation in a vertically pointing configuration.

2. System Description

WACR AMF consists of the following subsystems:

RF Unit Environmental Enclosure, houses the RF unit and peripherals. The enclosure is liquid cooled in order to stabilize its interior temperature and to minimize contamination by dust and airborne contaminants.

Antenna Housing, containing a 48” diameter dual polarized Cassegrain antenna. The housing mounts to the top of the environmental enclosure and includes a radome, heaters and a connection for dry air purging to prevent interior moisture accumulation.

A photograph of the Environmental Enclosure and antenna is shown in Figure 1.

Data System Rack, includes the host PC computer, chiller, and computer controlled power strip, shown in Figure 2.

Dry Air Compressor, wall mount unit, shown in Figure 3.

A signal interconnection diagram for WACR AMF is presented in Figure 4. All of the subsystems in WACR operate on 120 VAC 50/60 Hz.

Figure 1. WACR AMF RF unit environmental enclosure and antenna housing.

Figure 2. Data system rack.

Figure 3. Wall-mountable dry air compressor.

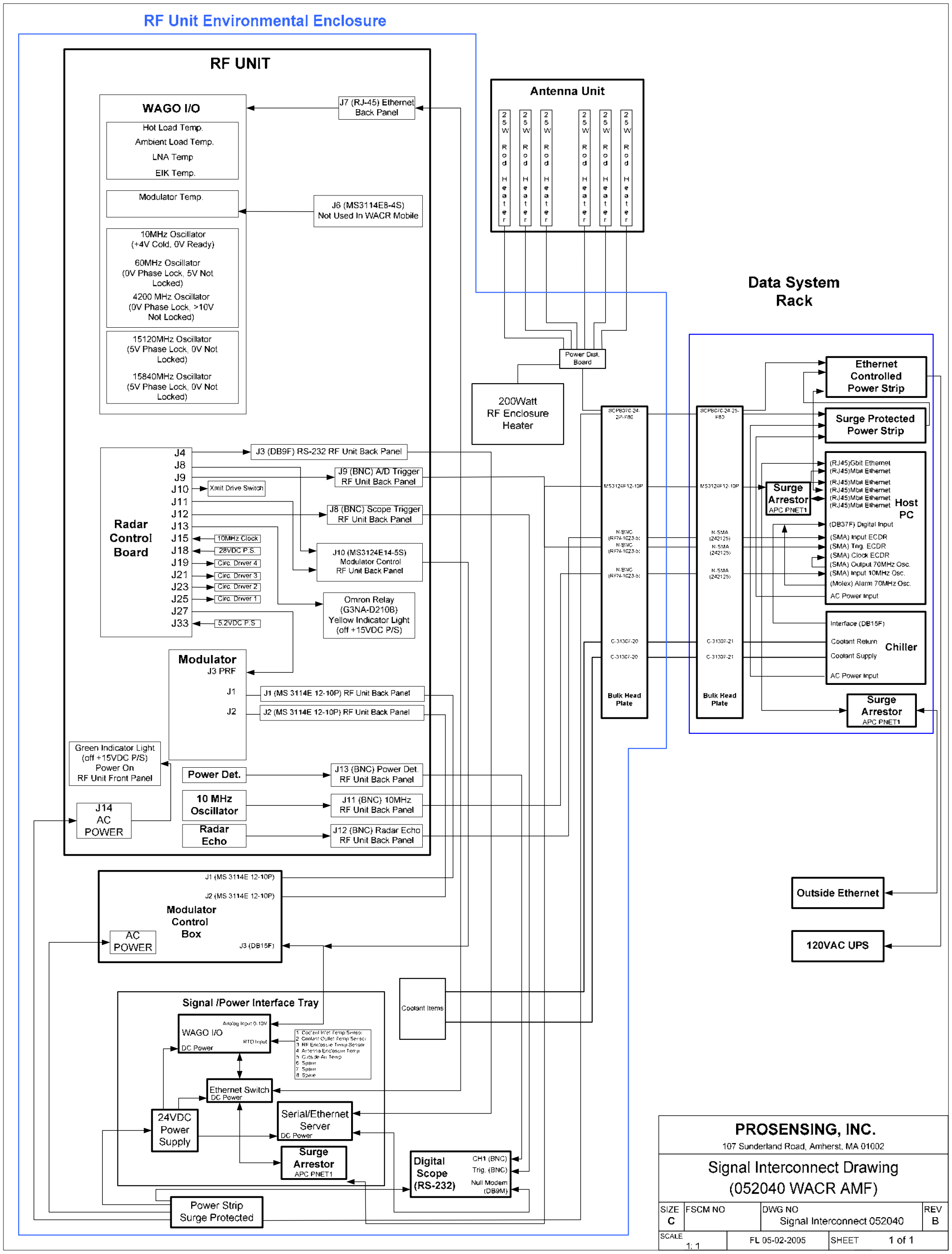

Figure 4. WACR system interconnect diagram.

Descriptions of the various subsystems are presented below.

Antenna and radome.

A 48" diameter Cassegrain antenna, built by Millitech Corporation, is housed in a sheet metal enclosure, shown in Figure 5 and Figure 6. The antenna includes a removable plastic radome, shown in Figure 7 and an optional heat shrink radome described below. Two systems are employed to prevent moisture buildup on the antenna and the interior of the radome. A set of six self-regulating heaters are installed beneath the antenna. These can be used in cold weather to maintain the temperature of the antenna to minimize condensation. Secondly, a fitting that connects to a 40' hose connected to a dry air compressor is provided on the outside of the antenna enclosure. The dry air source should be used in hot, humid environments to reduce the humidity of the air inside the antenna housing, especially the air between the antenna surface and the radome.

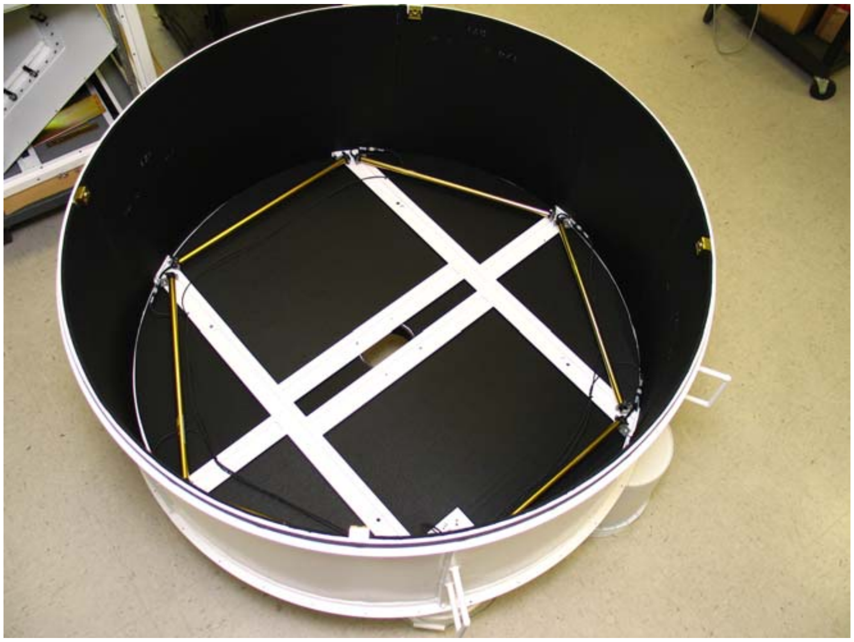

Figure 5. Housing for 48" Cassegrain Antenna showing ring of six self regulating heaters.

Figure 6. Antenna installed in housing showing fiberglass struts used to support the radome. Dry air fitting is located above the housing handle on the left.

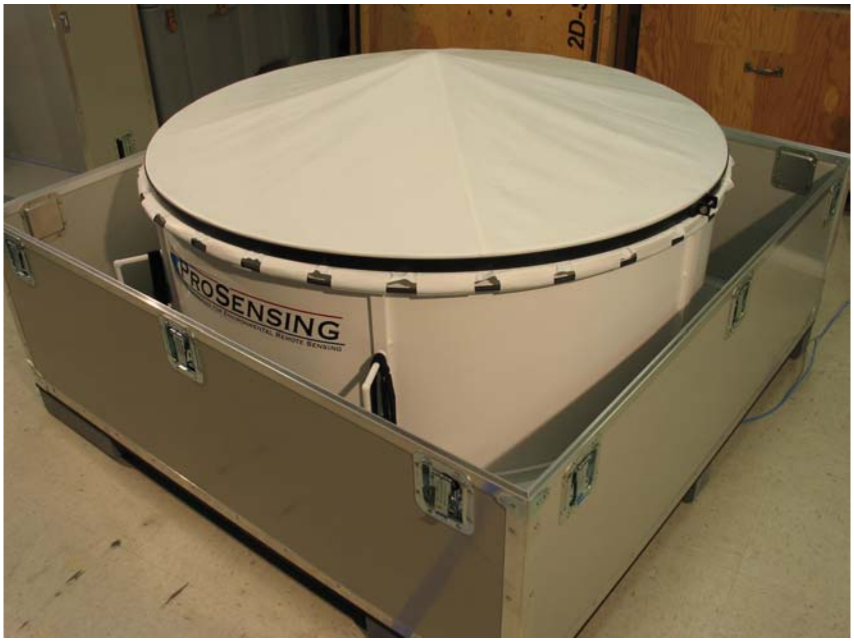

Figure 7. Removable plastic radome secured by black metallic clamp.

RF Unit

Photographs of the RF unit are shown in Figure 8 and Figure 9, along with a detailed block diagram (Figure 10). The RF unit is functionally identical to the RF unit in the WACR system installed at the SGP site. Specifications for the RF unit are provided in Table 1.

RF Unit Subsystems:

LO Section. This section generates the various phase-locked reference signals necessary for signal generation and detection. A dual down-conversion design will be employed, resulting in a final IF frequency of 120 MHz.

Transmitter Section. This section includes the multiplier chain to generate the 95.04 GHz pulsed drive signal and the Extended Interaction Klystron Amplifier (EIKA) to amplify the 95.04 GHz signal to a level of 1.67 kW peak power. The VKB2461T24 EIKA is rated at 3 percent duty cycle, which is ten times the requirement for the WACR system (300 ns pulse at 10 kHz PRF=0.3% duty). The EIKA requires 4 mW (6 dBm) drive to achieve its full output power. The frequency response of the EIKA is plotted in Figure 11. A 20 dB directional coupler samples the transmitter output and a detector is used to monitor the transmit power over time.

The transmitter driver consists of a Ku-band switch for generating the proper pulse width, followed by a x6 multiplier, preamp, variable attenuator and 20 dB directional coupler. The x6 multiplier output power is 4.1 dBm. This signal is boosted to 12 dBm by a W-band preamp, which provides several dB of excess drive power. This allows the input to the EKIA to be trimmed using a variable attenuator to maximize output. The 20 dB coupler in the driver chain samples a small portion of the drive signal. This sample is directed to the receiver to monitor the stability of the transmit drive signal as well as confirming that the receiver operates properly in the upper end of its dynamic range.

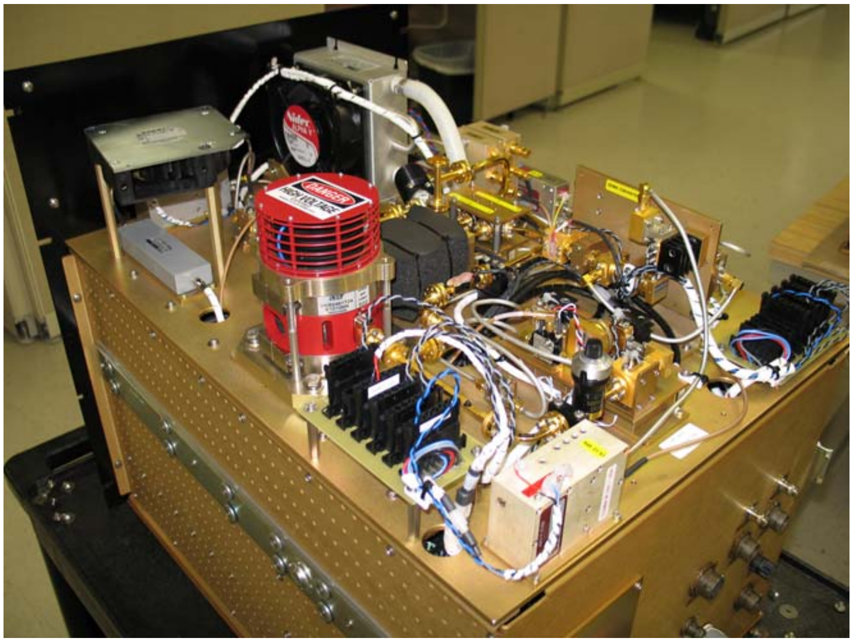

Figure 8. RF unit interior, top plate showing RF components.

Figure 9. RF unit mounted in the Environmental Enclosure underneath the antenna.

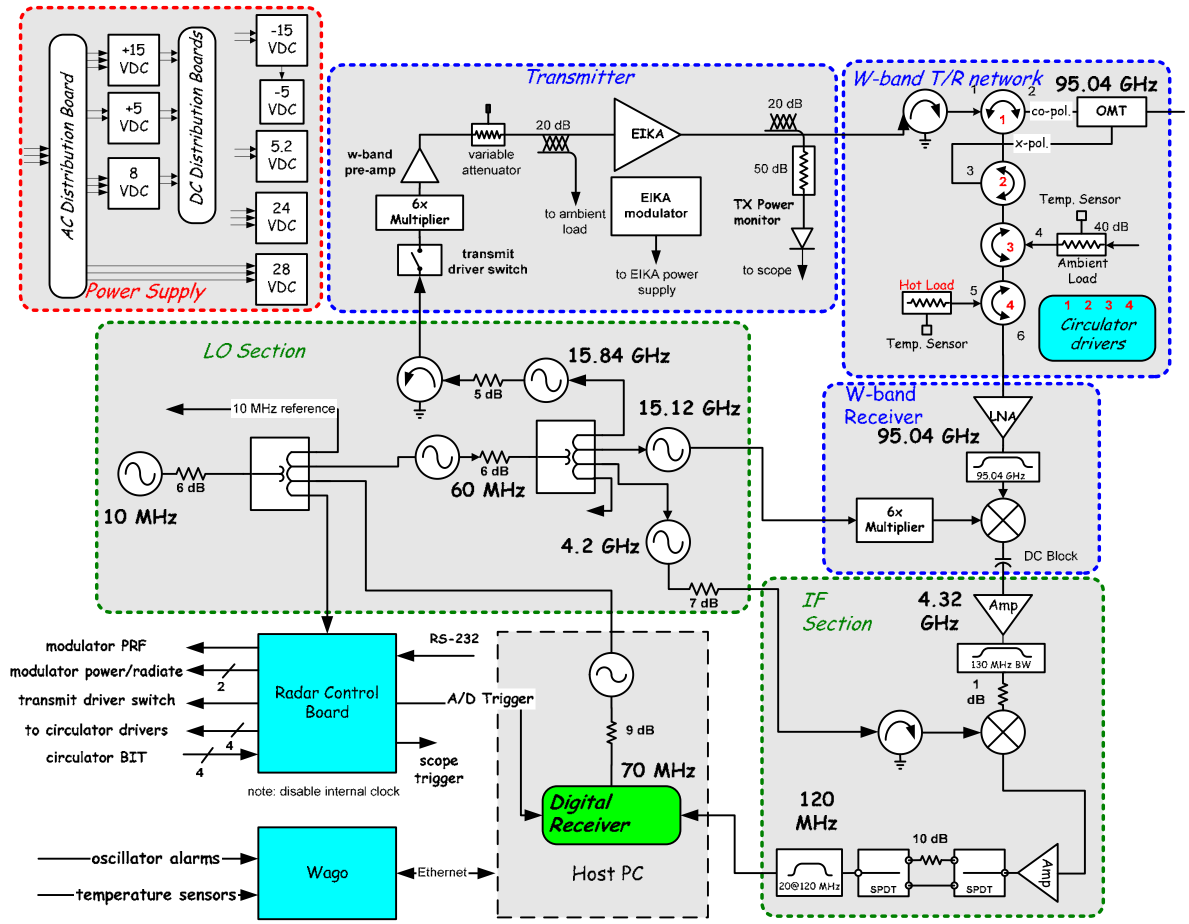

Figure 10. RF unit block diagram

Table 1. Summary of key RF unit parameters. Additional data is presented in the WACR AMF Test Report.

Parameter	Value
RF output frequency	95.04 GHz
Peak transmit power from EIKA	1.6 kW
Transmitter duty cycle	1% max (15 kHz max. PRF).
Pulse widths (selectable)	100, 300, 600 ns
Transmit polarization	Linear
Receiver polarizations	Selectable Co- or Cross-polarization linear
Transmitter front-end losses (EIKA output through radome, assuming 1.1 dB antenna +radome loss)	3.4 dB
Receiver front-end losses (assuming 1.1 dB antenna + radome loss, and including OMT, and receiver protection components)	V: 3.7 dB H: 3.7 dB
Receiver noise figure (from LNA through digital rx)	4.9 dB
IF output to digital receiver	120 MHz

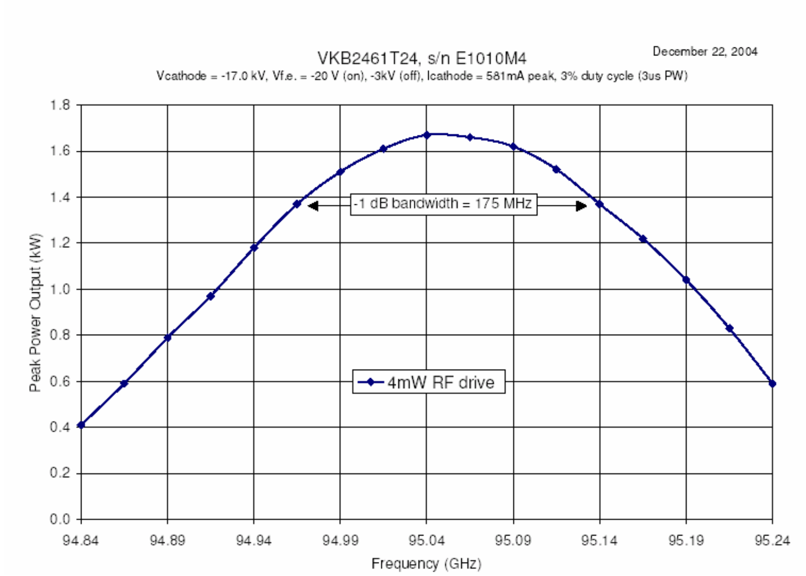

Figure 11. VKB2461T24 EIKA output power versus frequency.

The modulator, built by Pulse Systems Inc., is separated into two sections: a rack-mounted Power Supply Module (PS-1938), shown in Figure 15, and the Modulator System (MG-1376) located in the lower section of the RF unit. The modulator has a maximum duty cycle of 1 percent. The Power Supply Module has a TTL interface that allows the Host PC to turn on the modulator, and to set the modulator into the standby and radiate states. Also, this same TTL interface reports various modulator fault conditions used to determine the cause of potential faults in the circuitry or its operation. These faults include: HV Power Supply Fault, Body Over Current, Over Duty Cycle, Collector Temperature, Deck Fault, and Deck Temperature.

Millimeter-Wave T/R Network. This section, which lies under the gold-colored plate in Figure 12, provides the latching circulator network and orthomode transducer (OMT) necessary for dual-polarization operation and receiver protection. Each latching circulator has a typical loss of 0.5 dB per junction, and can handle power levels of 2 kW peak, 20 W average[1]. The receiver small signal gain and noise figure is monitored using hot (90° C) and cold or ambient[2] (about 25° C) loads connected to the two receiver protector circulators. After each data block is gathered (approximately 2 seconds) the data system switches to internal calibration mode, where the hot and ambient loads are sampled as well as the transmit drive level. Internal calibration is discussed in more detail

[1] The circulator network in the WACR SGP RF Unit has a rating of 10 W average, which is sufficient for all of its operating modes. Both RF units have EIKA port isolators with 20 W average power rating.

[2] The ambient load also serves as an attenuator for the drive signal injection.

in the Calibration section of this document.

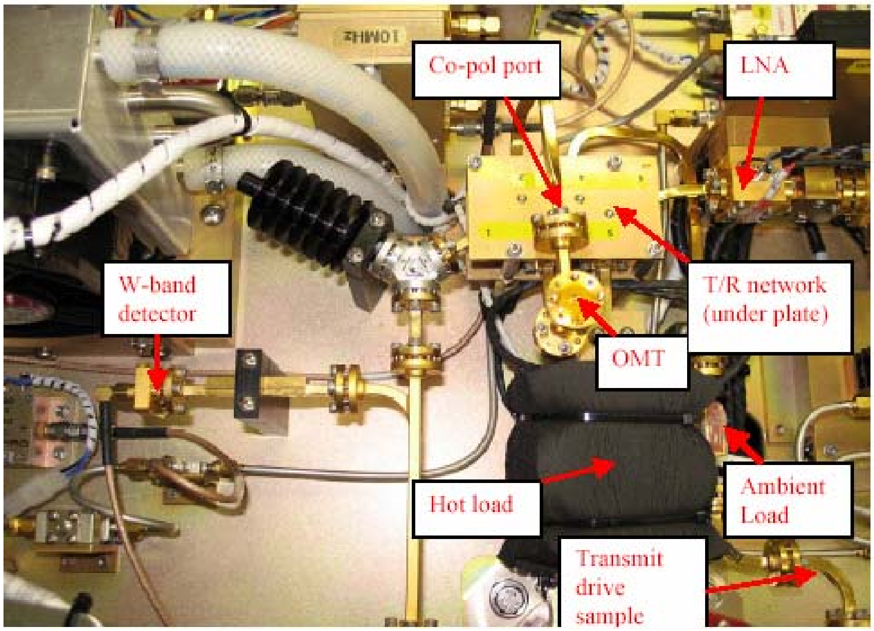

Figure 12. W-band front end components.

W-Band receiver section. A single receiver channel is provided for pulse-to-pulse measurement of the co- and cross-polarized received signal. The receiver employs a 4.9-dB noise figure W-band low noise amplifier, followed by a highpass filter, having 1.2 dB loss at 95 GHz, and greater than 50 dB loss below 88 GHz. This assures that the lower sideband at 86.4 GHz is rejected and does not contribute to the system noise floor. The filter is followed by a W-band mixer which downcoverts the received signal to 4.32 GHz. A DC block is used at this point to isolate the biased mixer from the 4.3 GHz LNA.

IF section. In the IF section, the 4.32 GHz output of the W-band receiver is amplified, then filtered by a bandpass filter which provided greater than 25 dB rejection of the lower sideband. The signal is then downconverted to 120 MHz. The signal is amplified and filtered to a 20 MHz bandwidth before input to the digital receiver. A pair of SPDT switches are used to switch a 10 dB pad into the receiver chain during the transmit pulse and extending out to approximately 200 m range to prevent damaging the digital receiver by the main bang or strong near range returns.

Radar Control Board. The radar control board (RCB) generates all of the timing and control signals needed to run the radar. The operating state of the radar (PRF, pulse width, polarization switching mode, etc.) is downloaded to the RCB via an RS-232 interface from the host PC via a serial to Ethernet server. The RCB has a watchdog timer that disables the PRF turns the modulator into the standby state if the host PC is not responding.

Power Supply Section. This section provides all of the DC voltages required by the RF and IF subsystems.

Digital I/O module. A Wago digital I/O module, shown in Figure 13 and Figure 14, is used to monitor lock alarms of phase locked oscillators, and interfacing to temperature sensors in the RF unit.

Digital Oscilloscope. A two-channel digital oscilloscope, shown mounted in the Environmental Enclosure in Figure 15, is used to monitor the detected RF pulse from the EIKA. The current value of the maximum level of the detected pulse is sampled by the data system after each averaging period (approximately once every two seconds).

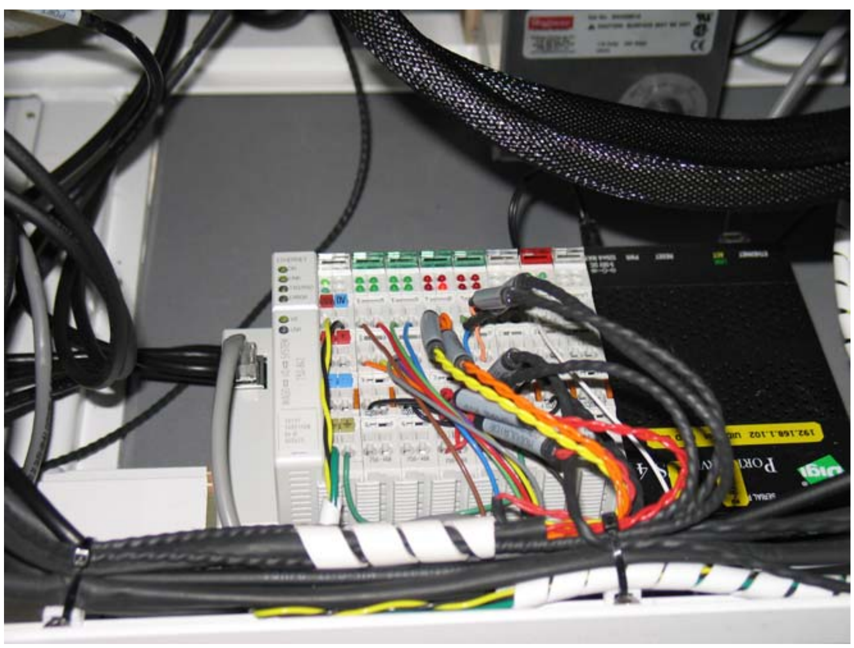

Figure 13. Wago controller accessible from the removable panel the Environmental Enclosure opposite the cable attachment area.

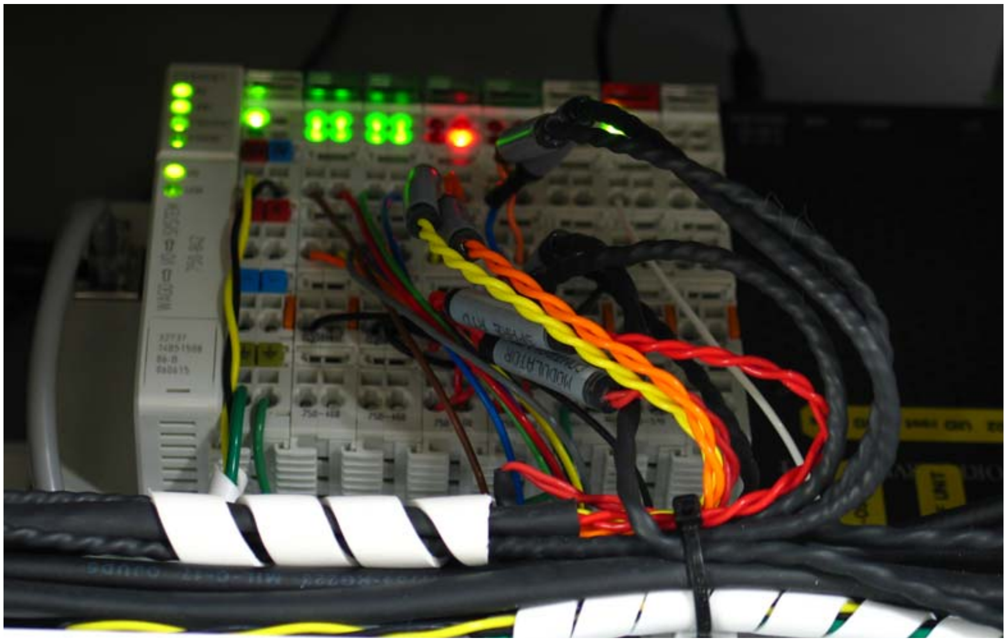

Figure 14. Wago controller, showing LED pattern during normal operation.

Figure 15. Digital oscilloscope, modulator power supply unit, and power strip mounted in RF Unit Environmental Enclosure.

Host Computer

The rack mounted host PC includes a dual Intel Xeon 2.66 GHz processor, with 160 GByte hard drive (130 GBytes available for storage of moment data), 1 GByte RAM, and a single CDRW drive, and a SeaLevel digital input module. A Lacie external 512 Gbyte hard drive connects to the host PC via a Firewire interface. The host computer also houses the digital receiver, described below.

Digital Receiver

An Echotek digital receiver, model ECDR-2-12210-PMC is used to sample the radar output. This PMC-based card contains a 12-bit digitizer sampling at 70 MS/s and a FPGA processor programmed to perform I & Q demodulation and decimation filtering. The analog input to the digitizer supports IF signals at frequencies up to several hundred MHz. By operating the sample clock at F_s=70 MS/s, the 120 MHz IF output of the radar will alias to 20 MHz, thus the 120 MHz IF signal can be demodulated by programming a 20 MHz digital LO frequency. The ECDR-2-12210-PMC also includes a fast FIFO output buffer ensuring uninterrupted streaming of I & Q samples for further processing. A fast PCI interface (66MHz, 64 bit wide) is employed that supports continuous data transfers without data gaps.

Chiller

Temperature stabilization of the RF Unit is achieved through a radiator on the main plate of the RF unit, and a cold plate on the base of the modulator. The K-O Concepts DMC-7.5 Recirculating Water Chiller is rated to supply coolant to an 800 Watt heat load. It includes a PID temperature controller that maintains the coolant to +/-0.1 degrees C over a range of 5-35 degrees C. The chiller is set to maintain the coolant at 25 degrees C, which should maintain the interior of the RF unit to a temperature of less than 35 degrees C, excepting the modulator which reaches temperatures of approximately 43 degrees C. The host PC monitors and records the temperature of the coolant supply and return where the lines enter and exit the environmental enclosure. The difference of these two temperatures is used to compute heat extraction, using the measured coolant flow rate of 0.098 liters/s, and knowing the coolant heat capacity (4.186 J/gram/degree C).

Coolant.

A 25% Propylene Glycol/75% distilled water mix should be used for the coolant during cool weather operation. Pure distilled water may be used during summer months when there is no chance that the temperature inside the shelter will drop below freezing. The chiller should be topped off with coolant at regular intervals.

Switched Rack PDU

An Ethernet controlled power distribution unit is used to control the turn-on sequence for the chiller and the environmental enclosure. All of the equipment in the environmental enclosure is powered simultaneously.

Heaters

For cold weather operation, the Environmental Enclosure and Antenna Enclosure are equipped with heaters. The 200 W heater in the base of the Environmental Enclosure (Figure 16) has a thermostat which turns off the heater once the temperature reaches the set point. This is typically set well below the desired operating temperature and is primarily intended to warm the enclosure before turning on the system in cold weather. The antenna includes six self regulating heaters that draw approximately 150 W. These heaters are intended to aid the dry air purge system in reducing the relative humidity of the air in the antenna enclosure to minimize condensation.

Figure 16. Environmental Enclosure heater.

On-site Radar Installation

Tools required for installation

3/32 Ball driver
#2 Phillips screw driver
5/16" wrench
7/16" wrench
9/16" wrench
1 1/8" wrench
Wire cutters
Cable ties
Carpenter's level or digital level
Scissors or knife for trimming radome cover
Flashlight

Siting the RF Unit Environmental Enclosure

The RF Unit Environmental Enclosure is packed in the shipping container shown in Figure 17. Under normal circumstances, the RF Unit and all subsystems that are normally located inside the Environmental Enclosure will be installed in the enclosure before shipment.

The Shipping container for the RF unit Environmental Enclosure (Figure 17) and its associated base (Figure 18) should be moved close to the point of installation for the radar. Remove the mounting rails from their container and set them in place. The cables passing between the Environmental Enclosure and the data system rack are 30 feet long. Thus, the mounting rails should be placed within 20 feet of the operations shelter containing the data system.

Adjust the feet so that the rails are level to within 0.1 degree.

Remove the top lid of the shipping container. Remove all boxes and other equipment packed around the enclosure and set them aside. The RF Unit Environmental Enclosure, which weighs 315 lbs may be removed by four strong personnel. Place the Environmental Enclosure on the rails and secure with four ¼-20 x .75L bolts, as shown in Figure 19. The bolts are contained in a plastic box, shown in Figure 20, which is secured to the reverse side of the waveguide access panel.

Figure 17. Shipping case for the RF Unit Environmental Enclosure.

Figure 18. Base for Environmental Enclosure (top). Shipping box for mounting rails shown below.

Figure 19. ¼-20 x .75" bolt fastening Environmental Enclosure to mounting rails.

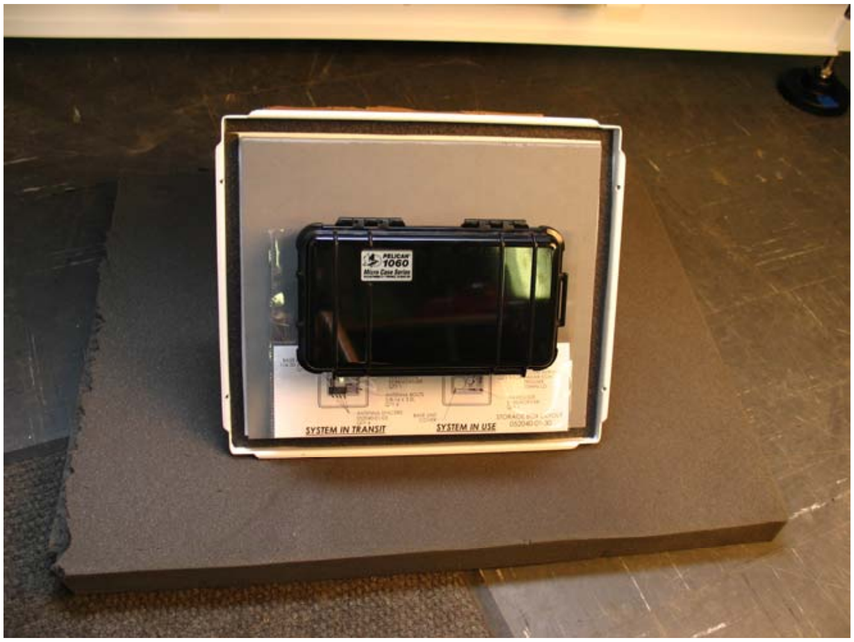

Figure 20. Storage box containing antenna spacers, mounting bolts, cylindrical waveguide and other hardware.

Under normal circumstances, the RF Unit will be shipped inside its Environmental Enclosure. If so, the following section on installing the RF Unit may be skipped.

Installing RF Unit into Environmental Enclosure

The RF Unit is first connected to rack slides as shown in Figure 21. The RF unit should be supported using a fork lift or pallet lift or equivalent so that the slides may be engaged with the tracks attached to the side of the RF Unit. When the slide first engages the track, the release buttons must be depressed to allow the track to fully enter the slide. After a few inches, the release buttons will snap into place. Before the RF Unit can be fully inserted, the release buttons must be depressed, as shown in Figure 22. The RF Unit is supported by the slides as well as by two plastic runners underneath the RF Unit, and should slide easily into place. The last ½ inch of engagement requires a little extra force.

WARNING: when removing the RF Unit from the environmental enclosure, be sure to remove the cylindrical waveguide connecting the RF Unit to the antenna.

Figure 21. RF Unit on rack slides before insertion into Environmental Enclosure.

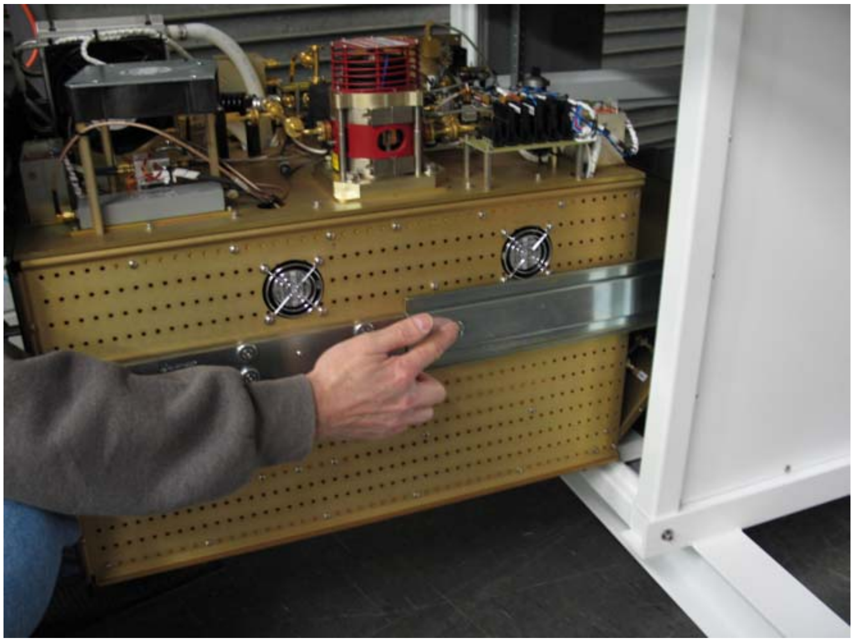

Figure 22. Depressing release on slides.

Installing the Optional Insulation Blanket.

An optional insulation blanket to cover the RF unit environmental enclosure is included for operation in very hot or cold environments. This blanket, shown in Figure 23, should be installed before the antenna is installed and cables are connected.

Figure 23. Temporary insulation blanket installed on RF unit environmental enclosure.

Installing the Antenna and Waveguide

The antenna is shipped in the large box shown in Figure 24. Remove the top lid of the box. The antenna enclosure, which weighs 153 lbs., can be removed by lifting on the handles on the side of the antenna enclosure.

The white plastic protective plates covering the mating rings on the base of the antenna and on the top of the RF unit environmental enclosure (Figure 25) should be removed and stored along with their associated fasteners.

The antenna should be lifted above the mating ring on the Environmental Enclosure, rotated such that the arrows indicating “line up” are aligned (Figure 26), then dropped into place. There are pins on the mating rings that will engage to provide exact alignment.

Installing the Waveguide

The cylindrical waveguide and feed horn connecting the OMT on the RF Unit to the antenna is also stored in the plastic box shown in Figure 20. Figure 27 shows the access point for waveguide installation. Installing the waveguide requires three people, as shown in Figure 28. Two people lift the antenna slightly, approximately 0.5”, while a third person inserts the waveguide (Figure 29), into the waveguide collar at the base of the antenna (Figure 30). The antenna is the dropped back into place. The base of the cylindrical waveguide should mate with the top of the OMT. There should be a few thousandths of an inch of vertical play in the waveguide between the OMT and the mating surface in the antenna’s waveguide collar.

The cylindrical waveguide should be rotationally aligned such that the screw holes line up. Two 1” long removable waveguide pins are provided in the plastic box shown in Figure 20 to line up the waveguides before tightening the waveguide screws. These pins will pass through one pair of waveguide alignment holes, 180 degrees apart, but not the other pair. After the pins are in place, tighten the four waveguide screws using the 3/32” ball driver, provided in the plastic box shown in Figure 20.

Figure 31 shows the appearance of the waveguide after installation.

Securing the Antenna to the Environmental Enclosure

(Complete this step immediately after installing waveguide).

The four spacers and bolts that support and secure the antenna to the top of the Environmental Enclosure are contained in the plastic box, shown in Figure 20. The spacers should be inserted between the lower surface of the antenna enclosure and the mounting tabs on the Environmental Enclosure as shown in Figure 32.

After securing the antenna, connect the antenna heater power cable as shown in Figure 33. Secure the protective cap on the dummy bulkhead connector at the right of the bulkhead power connector.

Figure 24. Antenna shipping container.

Figure 25. Protective plate covering mating rings on antenna and RF unit environmental enclosure.

Figure 26. Proper rotational alignment of the antenna.

Figure 27. Access panel providing access for installing the waveguide between the RF Unit and Antenna.

Figure 28. Lift antenna approximately 0.5" to slide waveguide into place (antenna lifted 3" in this picture).

Figure 29. Cylindrical waveguide with permanently attached feed horn.

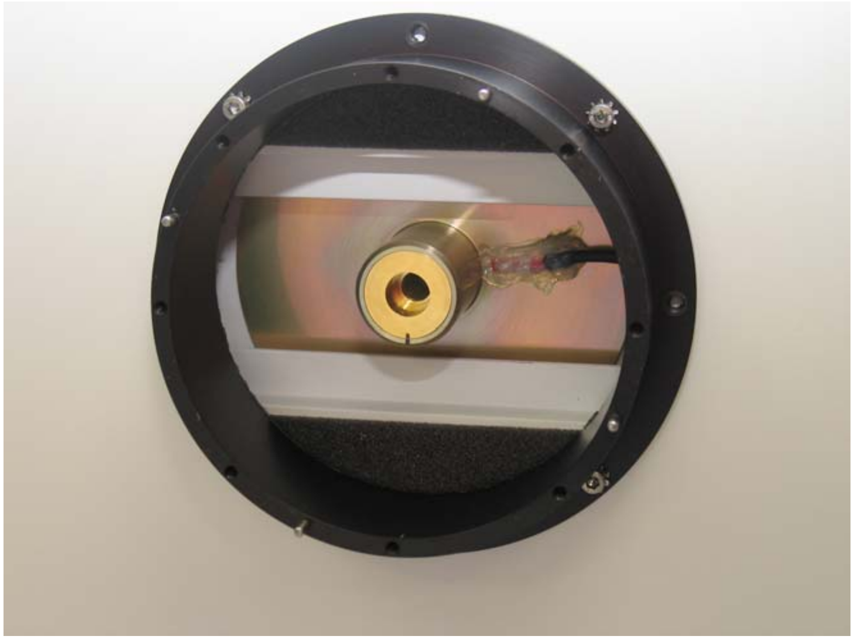

Figure 30. Feed horn inserts into cylindrical waveguide collar (gold) on base of antenna.

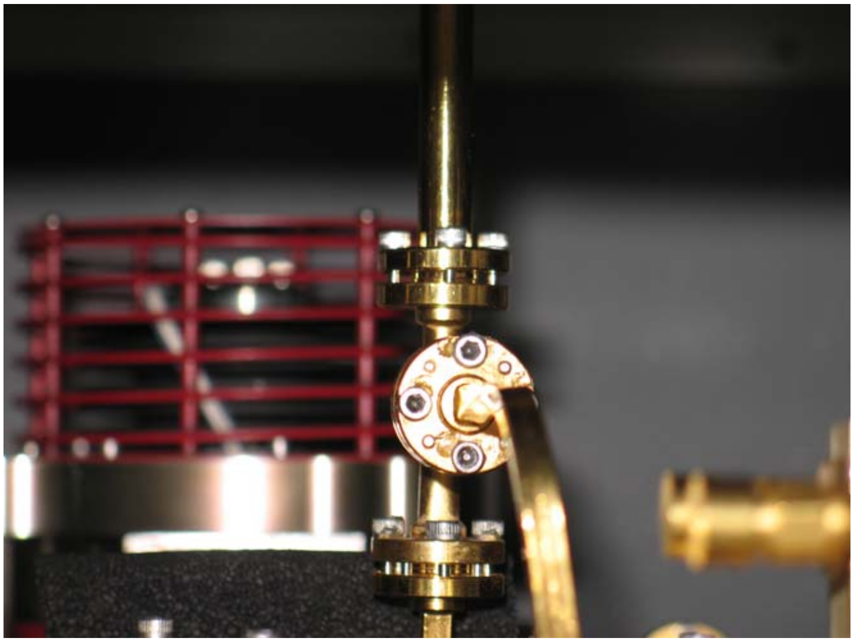

Figure 31. Waveguide connection at the OMT.

Figure 32. Spacer and mounting bolt (one of four).

Figure 33. Antenna heater power connection.

Connecting External Cables and Hoses

WACR AMF was designed to use a small number of cables between the data system rack and the RF Unit Environmental Enclosure. There are three coaxial cables, Radar Echo, Data System Trigger, and 10 MHz LO. These cables are labeled and color coded to minimize the chance of them being misconnected. The two remaining electrical connections are the AC POWER and SYSTEM INTRANET. All of the electrical cables are bundled together and covered with a polyester/velcro sleeve which can be removed if necessary.

In addition to the electrical connections, there are two quick release coolant lines, labeled Coolant Supply and Coolant Return. These connections are shown in Figure 34. Short sections of plastic insulation have been provided to cover these lines to minimize heat loss to the environment.

After making these connections, the cable should be run to the operator shelter inside a trench or laid on the ground with some type of protective shielding to minimize the chance of cable damage.

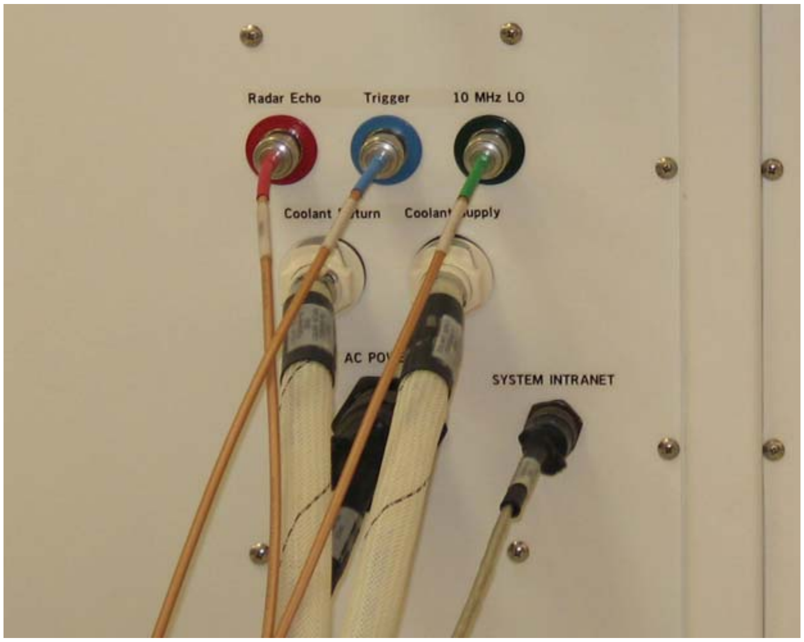

Figure 34. Connections between RF Unit Environmental Enclosure and Data System Rack.

Connecting Cables to Data System Rack

Figure 35 shows the five electrical cables and two chiller lines from the Environmental Enclosure connected to the Data System rack. Additional cables that should be attached at this time are the Ethernet cable connection to the site's Local Area Network (blue cable at right) and the firewire cable to the removal Lacie disk. A close up photo of the connections to the host PC is shown in Figure 36.

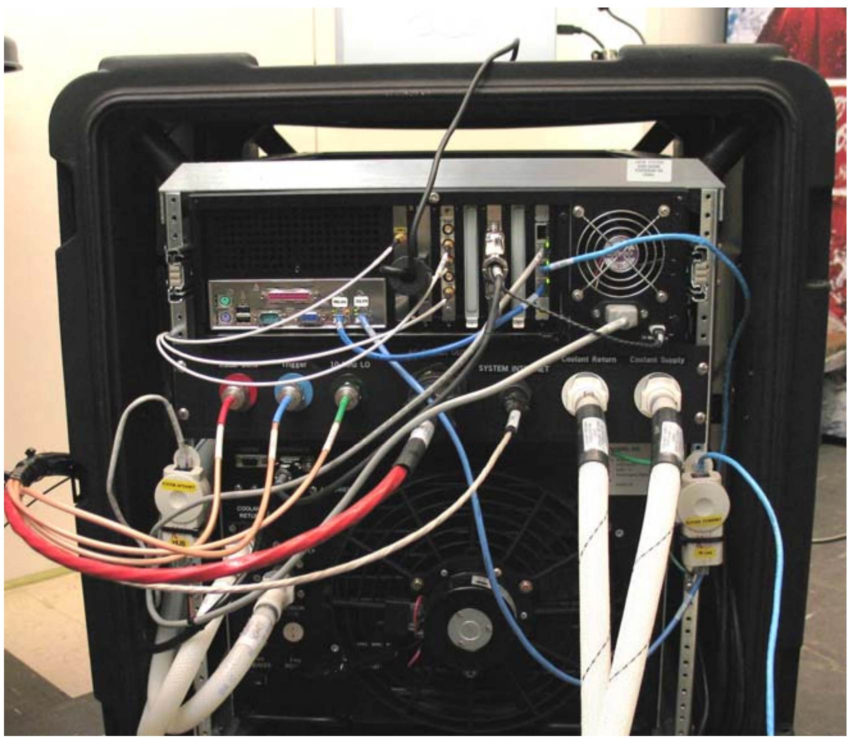

Figure 35. Connections from the RF Unit Environmental Enclosure are connected directly below the data system computer.

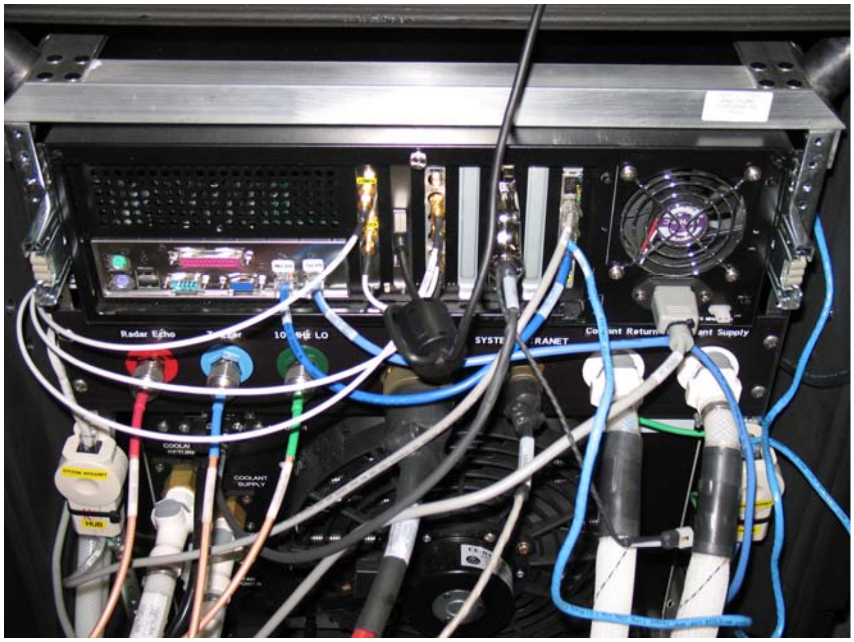

Figure 36. Connections to host PC.

AC Power Connections

There are two AC power cords in the rack, one labeled ‘TRIPLITE POWER’ and a second labeled ‘HEATER POWER’. The ‘TRIPLITE POWER’ cable provides all system power, except for the antenna heaters and the 200 W heater internal to the environmental enclosure. The heater cord does not need to be plugged in during warm weather operation.

Adding Coolant

Coolant must be added before operating the radar system.

Remove the cap covering the chiller fill point (see Figure 37). Using the watering can provided, fill the chiller reservoir with distilled water[3] until full. The reservoir is now full, but not the hoses.

Remove the hoses from the RF Unit environmental enclosure and connect the small (2 foot long) double female section of hose between the hose ends near the RF unit. The host computer should be turned on as described in the power up sequence section of this

[3] A 25% Propylene Glycol/75% distilled water mix should be used for the coolant during cool weather operation.

document. After logging into the host computer (step 4), type SNMP.sh ON to turn on the power to the chiller and RF unit. You may need to turn the chiller on using the rocker switch on the chiller front panel. The chiller will now pump the fluid through the hoses. Continue adding water for a few minutes until the level in the reservoir stabilizes.

Stop the chiller using the rocker switch. Remove the short section of hose and reconnect the hoses to the RF Unit Environmental Enclosure. Restart the chiller and continue adding water for several more minutes until the level in the reservoir stabilizes. The coolant system, including the chiller, hoses and RF unit should now be filled with coolant.

Figure 37. Chiller fill point shown with red arrow.

System Maintenance

Chiller: The chiller fluid level should be checked periodically and topped off with water or the water/propylene glycol mix. The data system will shut the radar down if the coolant level falls below a nearly-full level.

The coolant should be drained from the chiller and from the hoses and RF unit once every six months. Draining should be carried out with the pump turned off. Short sections of hose have been included with connectors on only one end to allow the hoses and RF unit to be drained. A drain is provided on the chiller unit located at the lower right of the chiller front panel. Refill the chiller, hoses and RF unit using the procedure described in the previous section.

The filter on the front of the chiller should be periodically checked for contamination by dust and dirt. If the filter is dirty, it should be removed, cleaned, and replaced.

Antenna Radome: The radome should be checked periodically for dirt accumulation and any punctures. A thin layer of dirt is acceptable, as long as the white material is still visible through the dirt. The polyethylene heat-shrink radome is easily punctured, but can be repaired using the polyethylene tape shipped with the system. If the radome is free of punctures, it may be washed clean of dirt by hosing the radome with water or using a damp sponge.

If the polyethylene is torn, it may be replaced using the procedure described below, or the heavy-duty radome made of Gore architectural plastic may be installed in its place.

Dry Air Compressor: The cartridge in the dry air compressor needs to be changed approximately every 5000 hours of operation. Refer to the documentation provided with the compressor for instructions on changing the cartridge.

Installing heat-shrink radome

Six sheets of polyethylene shrink wrap material were shipped with WACR AMF. This material has very low loss (0.2 dB) and should be used if possible. A second, heavy duty radome with 0.6 dB loss has been included with the system as a backup.

First secure the polyethylene material to the antenna shroud using the large black metal clamping ring. Tighten the ring and pull the excess material outward so the radome material is snug, as shown in Figure 38. Attached the heat gun to the propane tank. The heat gun operates with a trigger control and should be kept at least 18” away from the material while heating. Heat the radome material with the heat gun, while constantly waving the heat gun from side to side and up and down. If the gun is held in one area for more than a second, the radome will melt and a hole will form. Continue heating the radome while walking around the antenna. The radome material will first loosen when heated, but will later shrink substantially when cooled off.

When completed, the radome should fit very tightly, as shown in Figure 40. The excess radome material should be trimmed using scissors, leaving about 0.5” of material below the clamping ring.

Figure 38. Heat shrinking radome.

Figure 39. Heat gun and propane tank.

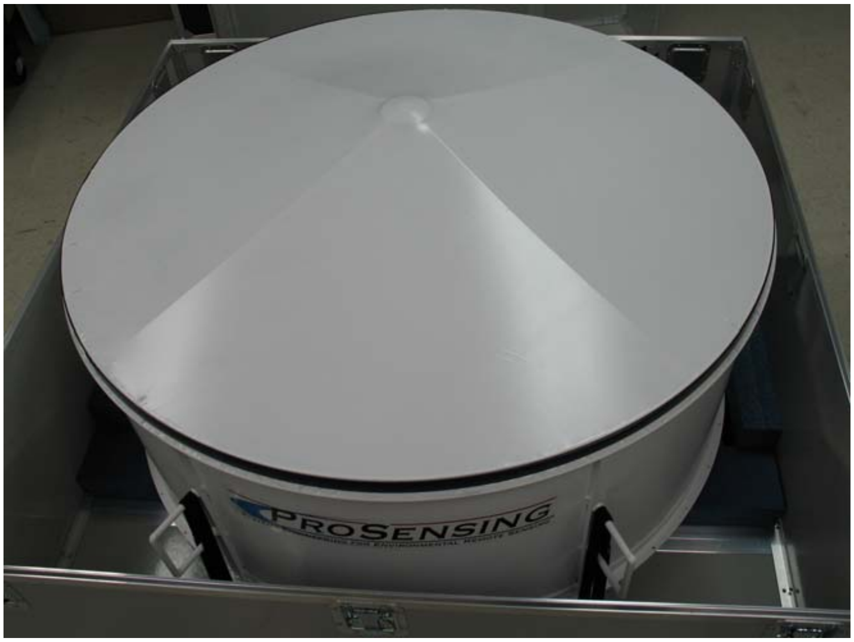

Figure 40. Final appearance of polyethylene radome.

Shipping

Table 2 summarizes the equipment shipped to Niamey, Niger.

Packing RF Unit Environmental Enclosure: Use straps to lift the enclosure by its handles as shown in Figure 41 and Figure 42. The enclosure should fit into the foam supports without interference. No strapping is required. Additional equipment, as summarized in Table 2, is packed in the spaces between the foam supports.

Packing the Antenna: The antenna is light enough to be lifted into its shipping container by two or three people. The antenna is secured to the base by four velco straps as seen in Figure 40. 20 sections of coolant line foam insulation are also placed in the base of the antenna shipping crate.

Packing the RF Unit Environmental Enclosure Base: The base for the environmental enclosure, shown in Figure 44, is packed in a pasteboard box, and strapped to the top of the antenna's shipping container, as shown in Figure 45. The temporary insulating blanket was also packed in the pasteboard box.

Packing the Data System: The data system is permanently housed in its shipping container, with the lids removed for operation. Reinstall the lids for shipping and place the container on a pallet, as shown in Figure 46.

Figure 41. Straps are passed through handles on the end of the environmental enclosure when moving the enclosure into and out of the shipping container.

Figure 42. RF unit being lowered into shipping container by overhead hoist.

Figure 43. Environmental enclosure inside shipping container.

Figure 44. RF Unit Environmental Enclosure Base

Figure 45. Environmental enclosure base and external insulation blanket are shipped in the pasteboard box secured to the top of the antenna shipping container.

Figure 46. Data system in black shipping container, dry air compressor and heat shrink radomes in pasteboard boxes.

Table 2. Summary of equipment shipped to Niamey, Niger.

Antenna Shipping Crate Weights and Measures: 577Lbs. 64" L x 64" W x 52" H
262.3 Kg. 1.63m (L) x 1.63m (W) x 1.32m (H)

#1 **Antenna Shipping Crate includes:**

Qty.	Description	Model #	S/N
1	Antenna Enclosure	PS052040-4A	US001
20	Chiller Hose Insulation	N/A	N/A
1	RF Unit Enclosure Base Stand	PS052040-1A	US001
1	RF Unit Enclosure Insulation Wrap	N/A	N/A

RF Enclosure Shipping Container Weights and Measures: 625 Lbs. 85" L x 44" W x 48" H
284.1 Kg. 2.16m (L) x 1.12m (W) x 1.22m (H)

#2 **RF Enclosure Shipping Container Includes:**

Qty.	Description	Model #	S/N
1	RF Enclosure	PS052040-2A	US001
2	Lifting Straps	N/A	N/A
1	Gore Radome	N/A	N/A
1	Spare Hardware & Aluminum Tape	N/A	N/A
1	Chiller Filling Can	N/A	N/A
2	LaCie Hard Drives	300794U	154608630
		300794U	154608777
2	Chiller Hoses	PS052040-9A	US001
		PS052040-9A	US002
1	Cable Assembly	See Note 1	
1	Antenna Heater Power Cable	PS052040-12A	US001
1	Gore Radome	N/A	N/A
Maintenance Kit for Chiller			
1	Chiller Drain Hose (OEM)		
1	Funnel (OEM)		
1	Chiller Filter Pad (OEM)		
2	Coolant Drain Hose (1' of 1/2" hose w/Cole Parmer# A-31307-11)		
2	Coolant Drain Hose (1' of 1/2" hose w/Cole Parmer# A-31307-46)		
1	Coolant Drain Hose (2' of 1/2" hose with two Cole Parmer# A-31307-11)		

Data System Pallet Weights and Measures: 315 Lbs. 48" L x 40" W x 36" H
143.2 Kg. 1.22m (L) x 1.02m (W) x 0.92m (H)

#3 **Data System Enclosure & Pallet Includes:**

Qty.	Description	Model #	S/N
1	Data System Enclosure	PS052040-5A	US001
1	Auto DeHydrator	PMT200A-82015	0511PMT0349M
1	Shrinkfast Heat Tool	N/A	N/A
6	Spare Shrink Radomes w/Repair Tape	N/A	N/A

3. System Operation

The following paragraphs describe system power up sequences, Host PC reboot and power outage recovery. Details of the software and graphical user interface are provided in a separate document (WACR AMF Software Operations Manual).

Power Up Sequence

1. Begin by turning on the main circuit breaker.
2. Turn on the host PC by pressing the rocker switch on the PC behind the PC's protective panel.
3. After approximately 1 minute, log into the host PC from a client computer using putty or equivalent program.
4. Login: **username**: radarop. **Password:** ******* (ask local system administrator or contact ProSensing).
5. Mount firewire disk, by becoming super user by typing: su (enter), then enter super user password (enter). Temporarily disconnect firewire connection to removable disk, reconnect firewire connection, then type /etc/init.d/firewire start (enter). The disk should now be mounted. Type exit to return to user radarop.
6. cd to /data1/radarop (data1 is the main data partition on the removable disk).
7. To start the main program, type insectd. Type insectd –h to see run time options.
8. The PC will check the ambient temperature in the RF unit. If this temperature falls within a 0-45 degree C window, the PC will send a command to the system power strip to turn on power to the RF unit, modulator controller, chiller, blower, and digital scope. If the temperature is below 0 C, check that the AC power cord for the Environmental Enclosure heaters is plugged into an active AC outlet.
9. The PC places the radar control board (RCB) in the idle mode.
10. The Host PC checks all critical status bits. This will take at least 2 minutes and as long as 5 minutes, due to the time delay required for the "standby ready" signal from the modulator and for the oscillator lock alarms to show that the RF unit oscillators are locked.
11. When the system is ready to run, the host will print a message: "waiting for a connection on port 2000".
12. Start the client program "insect" from an icon on the client PC.
13. Press "connect" on the client GUI to connect to the host.
14. Press "configure" to set the operating parameters of the radar.
15. Press "run" to begin taking data, "record" to begin running and taking data.
16. The client may be disconnected while the radar is running and recording. Also,

other clients may log in, but are not able to change the radar settings.

17. If a problem occurs, and a stale session is running, cd /tmp/ and remove insectd_pid (rm insectd_pid).

Power Down Sequence

1. Press “configure” on the client PC, then put the radar in “idle” mode.
2. Disconnect the client.
3. In the putty window, press “cntl c” to stop the insectd program.
4. Shut down host by logging in as super user (**username**: su, **password:** ask system administrator or contact ProSensing) and typing “halt”
5. The radar may be closed from another putty session by using the utility insectl (final character is the letter l). Type insectl –h to see options.

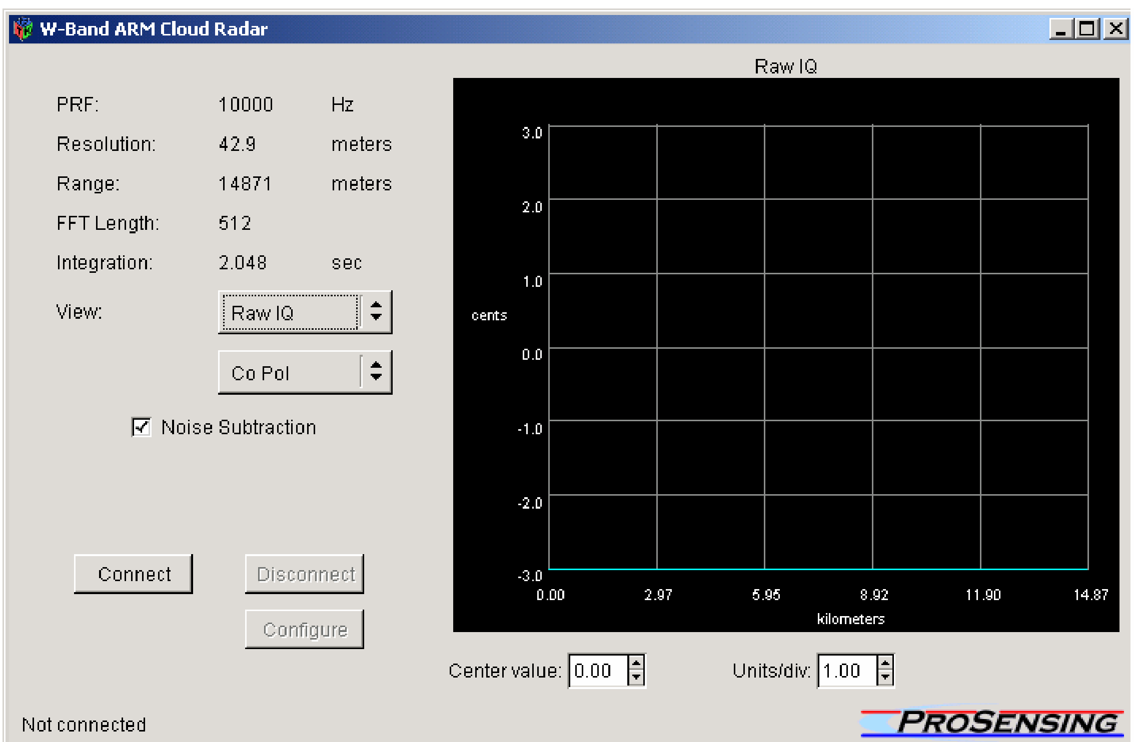

Figure 47. Client GUI.

PC Reboot

1. If the PC hangs up, a watchdog timer in the RCC, in the absence of a periodic message from the Host PC, will inhibit the radar trigger signals going to the Ku-band upconverter and modulator, and will put the modulator into standby mode.
2. The PC may be manually rebooted by holding the power switch in the on position for 5 seconds.

Radar Operating Modes

WACR has the following operating modes:

1. FFT Mode, Co-polarized.
2. FFT Mode, Cross-polarized.
3. FFT Mode, Alternate Co-/Cross-polarized.
4. Internal Calibration Mode.

Mode descriptions.

1. ***FFT Mode, Co-polarized***. In this mode, the radar pulses continuously with the receiver switched to receive co-polarized signals only. The data system computes FFT's of length N_{FFT} which are averaged N_{AVE} times before storage.

2. ***FFT Mode, Cross-polarized***. In this mode, the radar pulses continuously with the receiver switched to receive cross-polarized signals only. The data system computes FFT's of length N_{FFT} which are averaged N_{AVE} times before storage.

3. ***FFT Mode, Alternate Co-/Cross-polarized***. In this mode, the radar pulses N_{FFT} times with the receiver switched to the co-polarized channel, then switches to the cross-polarized channel for N_{FFT} pulses. This pattern repeats continuously. The data system computes FFT's of length N_{FFT} for both polarizations, which are averaged separately N_{AVE} times before storage.

4. ***Internal Calibration Mode.*** In this mode, the radar samples N_{CAL} samples from the hot load, N_{CAL} samples from the cold load (both cases with the W-band up-converter switched off); then N_{CAL} samples from the cold load with the W-band up-converter switched on. The modulator trigger is disabled during internal calibration mode. This mode is automatically run at the end of each averaging period.

Appendix A. Radar Calibration

The calibration routine involves solving for several unknown factors in the range equation, including the transmitted power, system loss, and antenna gain. This analysis assumes that the target is in the far field of the antenna, which includes all ranges greater than R_{FF}:

$$R_{FF} = \frac{2D^2}{\lambda}$$

where D is the diameter of the antenna and λ is the radar wavelength. For the present application, D=.61 m, λ=.003154 m, thus, R_{FF}=235 m. Data calibration for targets at closer ranges will require a separate analysis to account for the near field gain and beam pattern of the antenna.

Following the development presented in section 5-14 of [1], the radar cross section, σ, is given by

$$\sigma = \sigma_v V_w = \frac{(4\pi)^3 R^4 P_r}{G_0^2 \lambda^2 P_t} \qquad \text{(A.1)}$$

where P_r is the received power at the antenna terminals, P_t is the transmit power, G_o is the peak antenna gain, R is the target range. The radar cross section is equal to the backscattering cross section per unit volume, σ_v, times the weighted volume, V_w, illuminated by the radar:

$$V_w = \frac{c\tau}{2} \iint_{\theta,\phi} g(\theta,\phi)^2 d\phi d\theta$$

where $g(\theta,\phi)$ is the normalized antenna gain pattern in azimuth (θ) and elevation (ϕ), and $\frac{c\tau}{2}$ is the pulse length in meters[4]. Assuming a symmetric, Gaussian antenna beam pattern, V_w can be approximated by [2]

$$V_w = \pi \cdot \frac{c\tau R^2 \theta_{3dB}^2}{16 \ln 2} \qquad \text{(A.2)}$$

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[4] Since the receiver filter weights are uniform in the time domain (matched filter for a rectangular pulse) there is no correction factor needed in the range dimension to account for a non-rectangular impulse response, as is often the practice when using an analog filter.

where θ_{3dB} is the antenna's one-way half power beamwidth. Substituting A.2 into A.1 yields

$$\sigma_v = \frac{1024 \ln 2 \pi^2 R^2 P_r}{c \tau G_0^2 \lambda^2 \theta_{3dB}^2 P_t} \qquad \frac{m^2}{m^3}. \qquad \text{(A.3)}$$

The radar range equation for a point, or corner, reflector is given by

$$\sigma_c = \frac{(4\pi)^3 R_c^4 P_{rc}}{G_0^2 \lambda^2 P_t} \qquad \text{(A.4)}$$

where the subscript "c" refers to a corner reflector.

Equation A.4 can be rearranged as follows:

$$\frac{G_0^2 \lambda^2 P_t}{(4\pi)^3} = \frac{R_c^4 P_{rc}}{\sigma_c} \qquad \text{(A.5).}$$

Equation A.1 can also be rearranged to pull out the same constants:

$$\frac{G_0^2 \lambda^2 P_t}{(4\pi)^3} = \frac{R^4 P_r}{\sigma_v V_w} \qquad \text{(A.6).}$$

Equating A.5 and A.6 and substituting A.2 for V_w yields the following expression for σ_v:

$$\sigma_v = \frac{16 \ln 2 R^2 \sigma_c}{\pi c \tau R_c^4 \theta_{3dB}^2} \left(\frac{P_r}{P_{rc}} \right) \qquad \text{(A.6).}$$

Note that both P_r and P_{rc} are scaled by the receiver gain and the transfer function of the digital receiver.

From section 5.11.3 in [1], σ_v is related to the cloud reflectivity factor, Z in $\frac{mm^6}{m^3}$, by

$$\sigma_v = 10^{-18} \frac{\pi^5}{\lambda^4} |K|^2 Z \qquad \text{(A.7)}$$

where K is a function of the complex index of refraction, n:

$$K = \frac{n^2 - 1}{n^2 + 2}$$

For liquid water at 95 GHz, $0^\circ C$, $|K| = 0.84$.

Combining A.6 and A.7 gives Z as:

$$Z = \frac{16 \ln 2 \lambda^4 \sigma_c}{10^{-18} c \tau \pi^6 |K|^2 \theta_{3dB}^2} \frac{R^2}{R_c^4} \frac{P_R}{P_{RC}} \qquad \frac{m^2}{m^3} \qquad \text{(A.5).}$$

This derivation assumes no appreciable atmospheric attenuation between the radar and the corner reflector, or between the radar and the cloud.

Incorporating Internal Calibration Data

The radar cross-section determined using A.5 assumes minimal system drift between observations of the corner reflector and observations of the target. The current data may be corrected for system drift by tracking system drifts as recorded by the internal calibration loop. The internal calibration signals include:

P_d = transmit driver power sampled by the receiver.

P_t = transmit power sampled at output of EIKA.

P_h = hot load power.

P_c = ambient load power.

Each of these signals is sampled every acquisition period, typically once every 2 seconds. A small number of samples of P_d and P_t are made each acquisition cycle, since the signals have a high signal to noise ratio. A large number of samples are required to accurately estimate the mean value of P_h and P_c, since the signals represent a Gaussian white noise process. 16K samples of P_h and P_c will be gathered each acquisition cycle.

Knowing P_h and P_c, we compute the receiver noise temperature from the LNA input through the digital receiver as:

$$T_{sys} = \frac{T_h^{'} P_c - T_0 P_h}{P_h - P_c} \quad \text{(A.6)}$$

where

$$T_h^{'} = T_h L_h + T_0 (1 - L_h)$$

T_h = the hot load physical temperature

T_0 =the ambient temperature of the radar front end components (equal to the temperature of the ambient load), and

L_h = the loss between the hot load and the LNA front-end.

The overall system noise temperature, $T_{sys}^{'} = T_{sys} / L_{FE}$, where L_{FE} equals the sum of all front-end losses from the radome to the LNA input. Note that L_h and L_{FE} vary between 0 and 1, 0 being infinite loss, 1 being no loss (e.g., $L_h = 10^{-L_h(dB)/10}$). We estimate that L_h =0.83 (0.8 dB) and L_{FE} =0.4 (4.0 dB).

Once T_{sys} is found, the receiver gain is computed by

$$G = 0.5\left[\frac{P_h}{k(T_h^{'} + T_{sys})B} + \frac{P_c}{k(T_0 + T_{sys})B} \right] \quad \text{(A.7)}$$

where B is the receiver noise bandwidth, and k is Boltzmann's constant=$1.38 \cdot 10^{-23} J / K$.

Simulations of the estimation of T_{sys} and G were made for the following conditions: T_{sys} =813K (6 dB noise figure), T_h =360K, L_h =0.83, G=1000 (30 dB), number of samples of the cold load and hot load power =16,384. The standard deviation of the T_{sys} estimate was approximately 500K, while the standard deviation of the gain estimate was approximately 1.5 dB. Since the system noise temperature should be a slowly varying function of time, the power data P_h and P_c can be smoothed for several minutes when estimating T_{sys}. With a smoothing interval of 6 minutes, the standard deviation of the T_{sys} estimate was reduced to around 6K. The standard deviation of the gain estimate made using (A.7) with the smoothed estimate of T_{sys} (but without smoothing P_h and P_c) was 0.03 dB. The gain estimate can be further stabilized by assuming that T_{sys} is constant for much longer time period (hour or day scale).

The reported reflectivity value can be adjusted to account for variations in receiver gain and transmit power using the following method.

Let $G^{current}$ be the current estimate of the receiver gain, and G^{cal} be the receiver gain corresponding to time of the last corner reflector observation. Also, let $P_t^{current}$ be the current estimate of the transmit power, and P_t^{cal} be the transmit power corresponding to time of the last corner reflector observation.

The value of P_r used in A.5 is given by

$$P_r = \frac{P_r G^{cal} P_t^{cal}}{G^{current} P_t^{current}} .$$

Thus, if the transmit power or receiver gain has increased since the time of the last external calibration, the received power used in A.5 is reduced to maintain a constant Z value.

References

Ulaby, F.T., R.K. Moore, and A.K. Fung, Microwave Remote Sensing, Active and Passive, Volume I, Artech House, Norwood, MA, 1986.

J.R. Probert-Jones, “The radar equation in meteorology,” J. Royal Meteor. Soc., vol. 88, pp. 485-495, 1962.

Appendix B. Digital Receiver Filter Weights

The Echotek ECDR-1-1480-PMC digital receiver utilizes a Graychip GC2011A digital filter chip which allows the user to download custom digital filters with up to 127 taps. With digital filtering, a true matched filter can be implemented for a given IF pulse shape. Given the fast rise time of the transmitted wave form, and the relatively wide bandwidth of the IF section (20 MHz) the IF pulse shape will be approximately rectangular. A matched filter for this waveform is achieved by convolution with a filter kernel equal to the complex conjugate of the signal itself. Since the signal is real-valued, the kernel is equal to the scaled replica of the signal.

Initial tests using the true matched filter showed an unacceptably high image in the Doppler spectrum, which was due to the poor frequency domain response of the matched filter. The matched filter was slightly modified by convolving the weights with a 5-element Hanning filter. This smoothes the leading and trailing edges of the filter, improving its frequency response, while only slightly degrading the impulse response and SNR.

The Graychip GC2011A implements a discrete-time convolution, with sample spacing equal to $1/F_c$ where F_c is the clock rate. The number of taps in the filter is selected such that N_{taps} divided by F_c is as close as possible to the pulse width. The receiver is set up to force the filter to be symmetrical, with an odd number of taps. After filtering, the output is decimated (subsampled) by a factor of 4 to 60 in steps of 4. The resultant range gate spacing is given by

$$\Delta R_g = \frac{cF_d}{2F_c}$$

where the decimation factor, F_d =4, 8, 12…60, and c is the speed of light. Because the digital receiver clock rate is fixed at 70 MHz, the range gate spacing must occur in multiples of 8.56 meters. The range resolution is determined by the pulse width, T:

$$\Delta R = \frac{cT}{2}.$$

The decimation factor is selected to make the range gate spacing as close as possible to the range resolution. For a given decimation factor, the maximum error in the peak return from a point target is given by:

$$\Delta P_{\max} = 20\log\left[\frac{N_{taps} - F_d/2}{N_{taps}}\right].$$

For example, if F_d =4, then ΔP_{max} =2.92 dB for 100 ns pulse, .87 dB for a 300 ns pulse, and .41 dB for a 600 ns pulse. Table 3 summarizes the filter parameters for the three pulse widths used in the WACR system.

Table 3. Pulse width, range resolution, and filter parameters for selected pulse lengths.

Pulse width	Range resolution	Range gate spacing for cloud sampling	Decimation factor for cloud sampling	Matched Filter 3 dB bandwidth	N_{taps}	Filter weights
100 ns	15 m	17.1 m	8	8.92 MHz	9	[0, 1132, 4095,7059, 3x8191,7059, 4095, 1132, 0]
300 ns	45 m	42.8 m	20	2.95 MHz	23	[0, 1132, 4095,7059, 17x8191,7059, 4095, 1132, 0]
600 ns	90 m	85.6 m	40	1.43 MHz	45	[0, 1132, 4095,7059, 39x8191,7059, 4095, 1132, 0]

The impulse response of the 300 ns filter is plotted in Figure 48 for F_d =4 and in Figure 49 for F_d =20. Figure 49 shows that the range sidelobes for the matched filter are below –25 dB in the range gates on either side of a given range cell.

In order to measure the exact peak of the corner reflector, a decimation factor of one must be used. This cannot be achieved using the hardware filter on the digital receiver. Instead, a raw data mode is employed, which uses a software version of the digital receiver mixing and filtering process to implement the same filter, with a decimation factor of one.

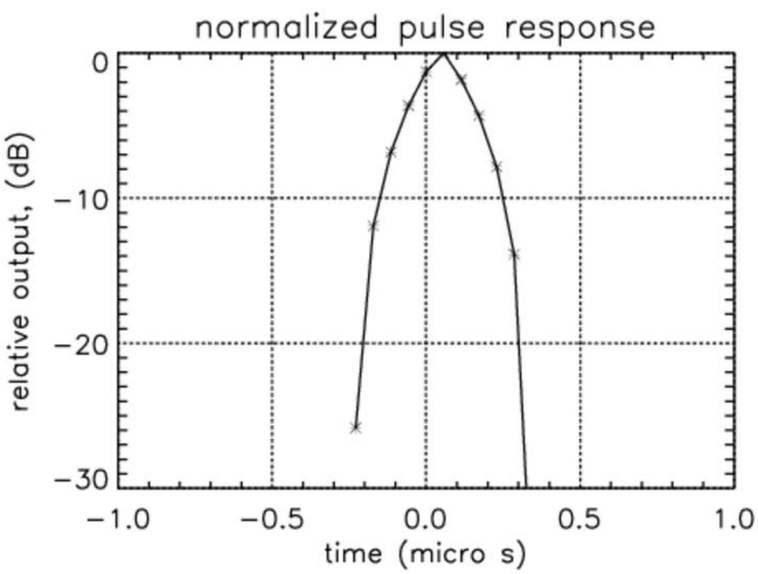

Figure 48. Impulse response for 300 ns matched filter, with F_d =4.

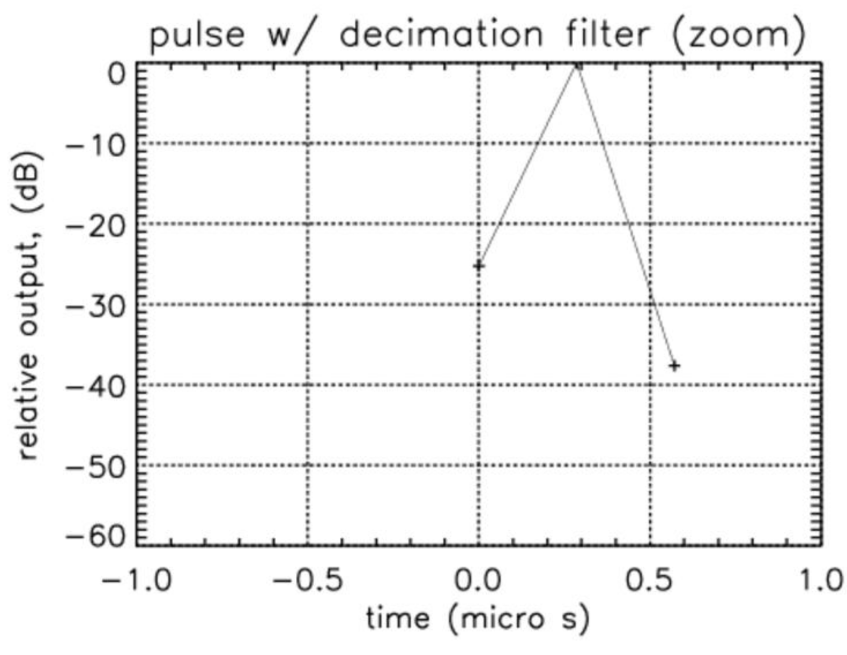

Figure 49. Impulse response for 300 ns matched filter, with F_d =20.