GAMMA REMOTE SENSING

GAMMA Portable Radar Interferometer
Model: GPRI-II

User Manual

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1. Read First

This is the user manual for the GPRI-II hardware that uses the Gamma developed azimuthal scanner, and Instrument Computer running Ubuntu Linux 14.04 LTS. If you have feedback please do not hesitate to contact us gamma@gamma-rs.ch.

1.1 Regulatory Notices

NOTICE (FCC 15.19/RSS-GEN):

This device complies with Part 15 of the FCC Rules [and with Industry Canada license-exempt RSS standard(s)].
Operation is subject to the following two conditions:

(1) this device may not cause harmful interference, and
(2) this device must accept any interference received, including interference that may cause undesired operation.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio
exempts de licence. L'exploitation est autorisée aux deux conditions suivantes:

(1) l'appareil ne doit pas produire de brouillage, et
(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

NOTICE (FCC 15.21):

Changes or modifications made to this equipment not expressly approved by Gamma Remote Sensing AG may void the FCC authorization to operate this equipment.

NOTICE (FCC 15.105):

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

Notice (FCC 2.1091 / 2.1093 / KDB 447498 / RSS-102)
Radio frequency radiation exposure Information:
This equipment complies with FCC and IC radiation exposure limits set forth for an uncontrolled environment. This equipment should be installed and operated with minimum distance of 100 cm between the radiator and your body. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Cet équipement est conforme aux limites d'exposition aux rayonnements IC établies pour un environnement non contrôlé. Cet équipement doit être installé et utilisé avec un minimum de 100 cm de distance entre la source de rayonnement et votre corps.

Notice (IC RSS-Gen 7.1.2):
This device has been designed to operate with the antennas listed below, and having a maximum gain of 32 dB. Antennas not included in this list or having a gain greater than 32dB are strictly prohibited for use with this device. The required antenna impedance is 50 ohms. The 3 identical antennas used with the instrument are custom manufactured for Gamma Remote Sensing AG and only available from Gamma:

GPRI-II-2 Antennas:

Model:	*ANT0235-0100*
Type:	*Slotted Waveguide*
Frequency:	*17.1 to 17.3 GHz*
Polarization:	*Vertical*
Maximum Gain:	*32 dB*

To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that permitted for successful communication.

Cet appareil a été conçu pour fonctionner avec les antennes énumérées ci-dessous, et ayant un gain maximal de 32 dB. Antennes pas inclus dans cette liste ou présentant un gain supérieur à 32 dB sont strictement interdits pour une utilisation avec cet appareil. L'impédance requise de l'antenne est 50 ohms. Les 3 antennes identiques utilisés avec l'instrument sont fabriqués sur mesure pour Gamma Remote Sensing AG et uniquement disponible à partir de Gamma

GPRI-II-2 Antennes:

Modèle:	*ANT0235-0100*
Type:	*Slotted Waveguide*
Fréquence:	*17.1 to 17.3 GHz*
Polarisation:	*Vertical*
Gain Maximum:	*32 dB*

Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

1.2 Electrical Safety

There are no user serviceable parts in the RF Assembly, Instrument Controller Enclosure, or Azimuthal Scanner

1. The mains socket outlet must be close to the equipment and easily accessible. It must be provided with a protective earth. Depending on national safety regulations, a double pole circuit breaker is required.
2. The auxiliary output provides a voltage of 22 to 30 VDC. The maximum current is 4A.
3. Disconnect all power by turning off the power and unplugging the power cable before installing or removing a chassis or working near power supplies.

1.3 General Safety

- Keep the working area clear during installation and instrument operation.
- Wear safety glasses if you are working under any conditions that might be hazardous to your eyes.
- Do not perform any action that creates a potential hazard to people or makes the equipment unsafe.
- Do not work alone if potentially hazardous conditions exist.
- Never assume that power is disconnected from a circuit; always check the circuit.
- Electrical equipment generates heat. Ambient air temperature may not be adequate to cool equipment to acceptable operating temperatures without additional measures.
- Ensure that the Tripod, Tower, Antennas, RF assembly and Instrument Controller are mechanically secure, especially in high wind situations. All components should be securely fixed to prevent them from falling over.

1.4 Introduction

The Gamma Portable Radar Interferometer (GPRI) development at Gamma is based on the benefits of in-situ measurement of deformation using differential radar interferometry. Our extensive experience with satellite differential interferometry has demonstrated successful application of this technique for measuring deformation due landslides, subsidence due to pumping of oil and water, slope failures in open-pit mining, and glacier and tectonic motion.

However, when the deformation between repeat observations exceeds wavelength/4 the usefulness and interpretation of the data rapidly become difficult. A ground-based instrument can be rapidly deployed and obtain data with both high spatial and temporal resolutions that are particularly well suited to measuring rapid deformation.

Unlike orbital SAR systems, in-situ measurement permit flexibility in the selection of the observation geometry. The geometry can be selected to give maximum sensitivity to deformation along the line of sight. Observations from multiple aspect angles can be combined to resolve the deformation into components along different look vectors.

Path delay variation due to tropospheric water vapor is the most significant cause of error in deformation using differential interferometry. A stationary instrument has the ability to acquire multiple observations for mitigation of path delay variations. Note that ground measurements have a shorter path through the atmosphere than orbital observations also leading to reduced error from this source.

Multiple observations acquired over short time intervals have the advantage that decorrelation is minimized by the shorter time intervals. Successive measurements can be processed to track non-linear deformation within the scene.

This manual shall help the user to setup and use the instrument but also provides background information on the instrument. Section 2 describes how to setup the instrument in the Field. Section 3 describes the software interface to the system and how to operate the instrument using secure shell (ssh). Section 4 gives more detailed information on the instrument hardware and operation. Section 6 describes the instrument software for data acquisition and processing as well as lower-level utility programs for instrument control. Section 7 describes some of the programs in the GAMMA software that are used for processing the GPRI data to obtain deformation maps. Section 8 has the instrument specifications and the Appendix (section 9) contains a sample form used for recording system parameters during a field campaign.

2. Mechanical Setup for Measurement

The installation needs to be stable and reproducible (if repeat measurements from a given position are foreseen). The GPRI can be installed either on a heavy duty tripod or on a concrete or metal pier. In either case there must be sufficient free room for the instrument to rotate (about 2.5 meters). There should not be any obstacles in the direct path of the antennas such as trees, bushes, fences, or buildings. Large structures such as buildings or towers should not be in the line of sight in the region of interest.

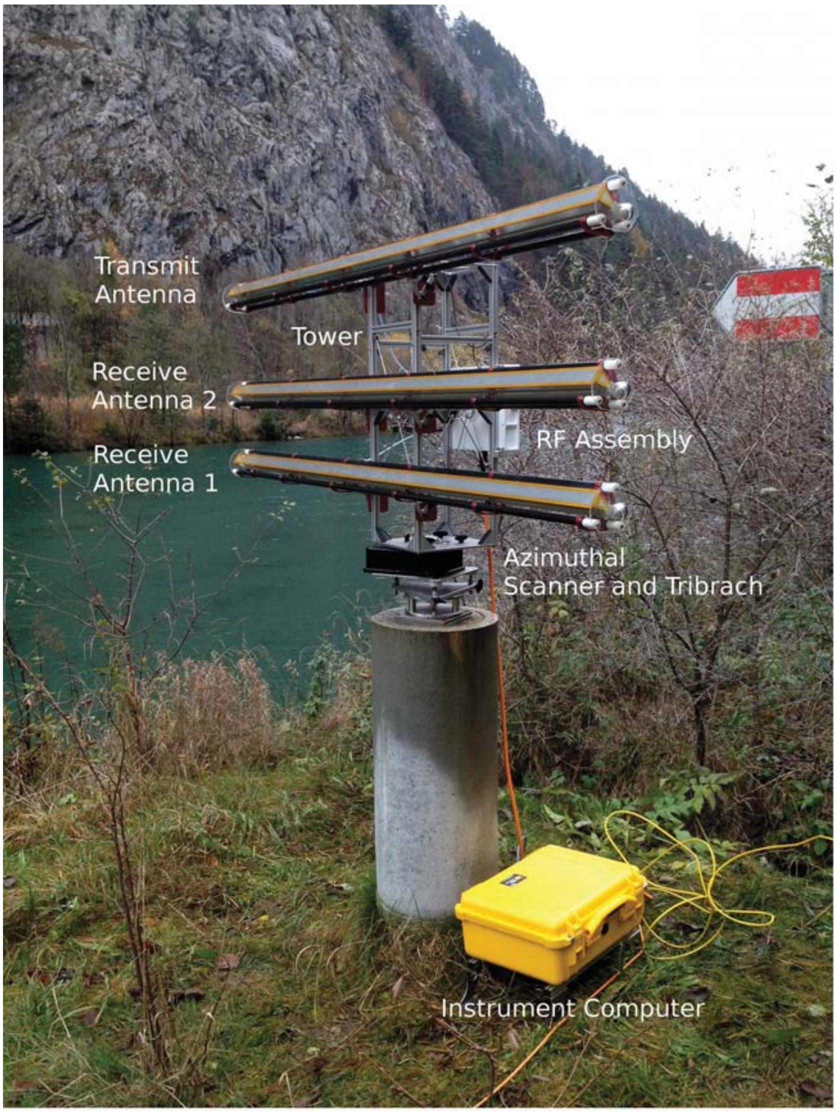


Figure 1: GPRI-II installed on a pedestal with adapter plate and spacer

2.1 Tripod Mounting

Installation of the tripod is the first step in setting up the GPRI-II. The tripod legs should be initially fully retracted. Make sure that you have a clear view of the region of interest in the scene and that there are no large obstacles in front of the radar such as walls or power towers. Radar backscatter from near targets can saturate the radar receiver. Nothing should get in the way of the antenna rotation and any objects such as bushes should be at least a few meters away from the antennas.

Take the tripod out of the canvas transport bag and take out the 3 stainless steel rods.

1. Install the stainless steel support rods to the tripod to maintain the legs at a fixed 60 degree angle. These rods fit into the attachments at the bottom of each leg. The end of the rod is shaped to fit into the slots on the attachment points. A small locking arm on each attachment point must be rotated to permit insertion of the rod. Once the rod is attached, rotate the arm back over the rod ends and it will lock into place.
2. The tripod legs are numbered 1,2, and 3 with label. Make sure that you note the location of each leg so that when you return to the site, the orientation of the tripod is identical. One leg of the tripod should remain fully retracted and this should not change. In sloping terrain, this leg should be the leg with the highest elevation. The zero degree look direction of the radar is in the direction of leg 2 and should point to the center of the region of interest.
3. Using the bubble level on top of the tripod, extend the other 2 feet of the tripod until the tripod top surface is horizontal as seen in the small bubble level. Remember to keep one leg of the tripod fully retracted and only extend the other 2 legs.
4. Screw the feet through the hole in the tip to the ground using anchor screws (6mm anchors).
5. Measure and note the extension of the legs for future repositioning if you intend to return to the same position for repeat pass observations.

Figure 2: Stabilization rods for the tripod. These snap into the rod brackets mounted on the tripod legs.

Figure 3: Tripod feet that permit screwing down the legs at fixed positions

Figure 4: Tripod leg extent measurement. Only required for repeat measurements.

Figure 5: Interface Plate of the Tripod with level and 5/8" hollow screw. The small level is used to ensure that the tripod is level after the feet are locked.

2.2 Mounting of the GPRI-II on a Pedestal or Mounting Plate

Figure 6: Mounting Plate and Tribrach Spacer

The GPRI can also be mounted on a pier using a stainless steel plate and spacer included with the GPRI. The plate should screwed down to the pier using anchor screws. The tribrach spacer (shown in Figure 6) is attached to the plate and to the tribrach using four M8 x 20 mm socket screws. The mounting plate can also be used on rock surfaces using anchors for attachment. The tribrach is attached to the spacer using 4 M8 x 20 mm socket screws. Stainless steel hardware should be used throughout. Additional plates are available from Gamma.

2.3 Azimuthal Scanner, Tribrach and Tower

1. Mount the rotary positioner and leveling assembly on the tripod using the black 5/8” screw interface of the tripod. The positioner has labels with the numbers 1 and 3. Position this edge of the positioner +leveler between tripod legs 1 and 3. Rotate the positioner and leveler assembly such that the edge of the positioner plate is parallel with the tripod stainless-steel rod between legs 1 and 3.
2. Make the antenna tower interface perfectly level using the tribrach level adjustment screws. Note, the screw on side 1 is fixed and should never be loosened. The large bubble level on the positioner should be used to determine if the tower mounting plate is level. Be sure to look down from directly above the level to make sure the bubble is centered. Alternately you can look from 2 sides and make sure that the bubble is in the center of the black ring.
3. If you intend to perform repeat observations from the same point, then power on the laser plummet using the battery pack. If this is the first measurement, mark the position of the laser on the ground for future repositioning. This point is precisely on the rotation axis of the tower. If you are returning to the site, adjust the positioner and leveler so that the laser beam hits the previously marked rotation center
4. Remove the 4 wing screws on the tower mounting plate, and mount the tower on the plate. There is an alignment pin on the plate that makes sure that there is only one way to position the tower. Screw the tower to the mounting plate. When you remove the tower, be sure to screw the 4 screws back on to the plate for future use and storage.
5. Define the antenna elevation angle and set all six antenna holders accordingly. The antenna illuminates about 60 degrees in elevation, Set the elevation angle so that the beam center aims at the area of interest. If there are areas that are significantly farther away, adjust the beam to be centered on these areas.

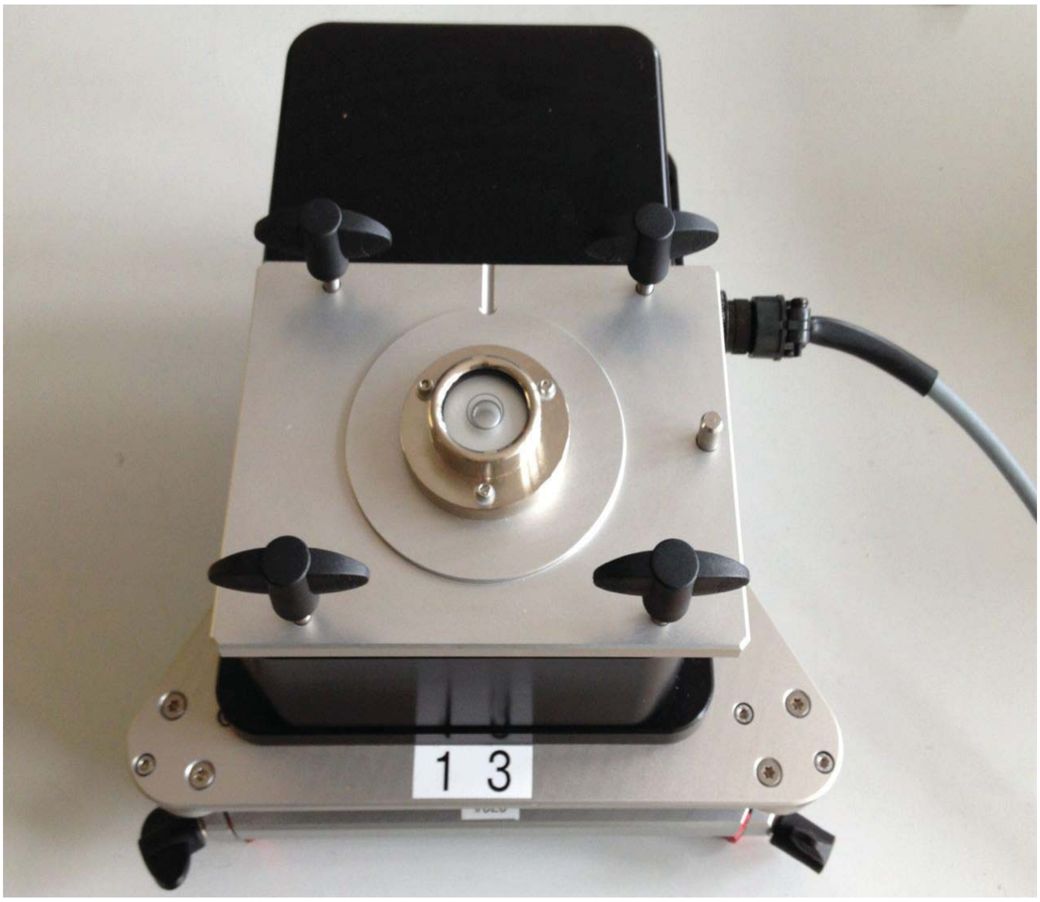


Figure 7: Azimuth Positioner with Tribrach. The 4 wing screws are used to secure the tower to the positioner. The bubble level is used to level the tower. Note the pin on the right side of the positioner plate for accurate repositioning of the tower. The front of the positioner (top of image) should point towards the center of the region that is azimuthally scanned.

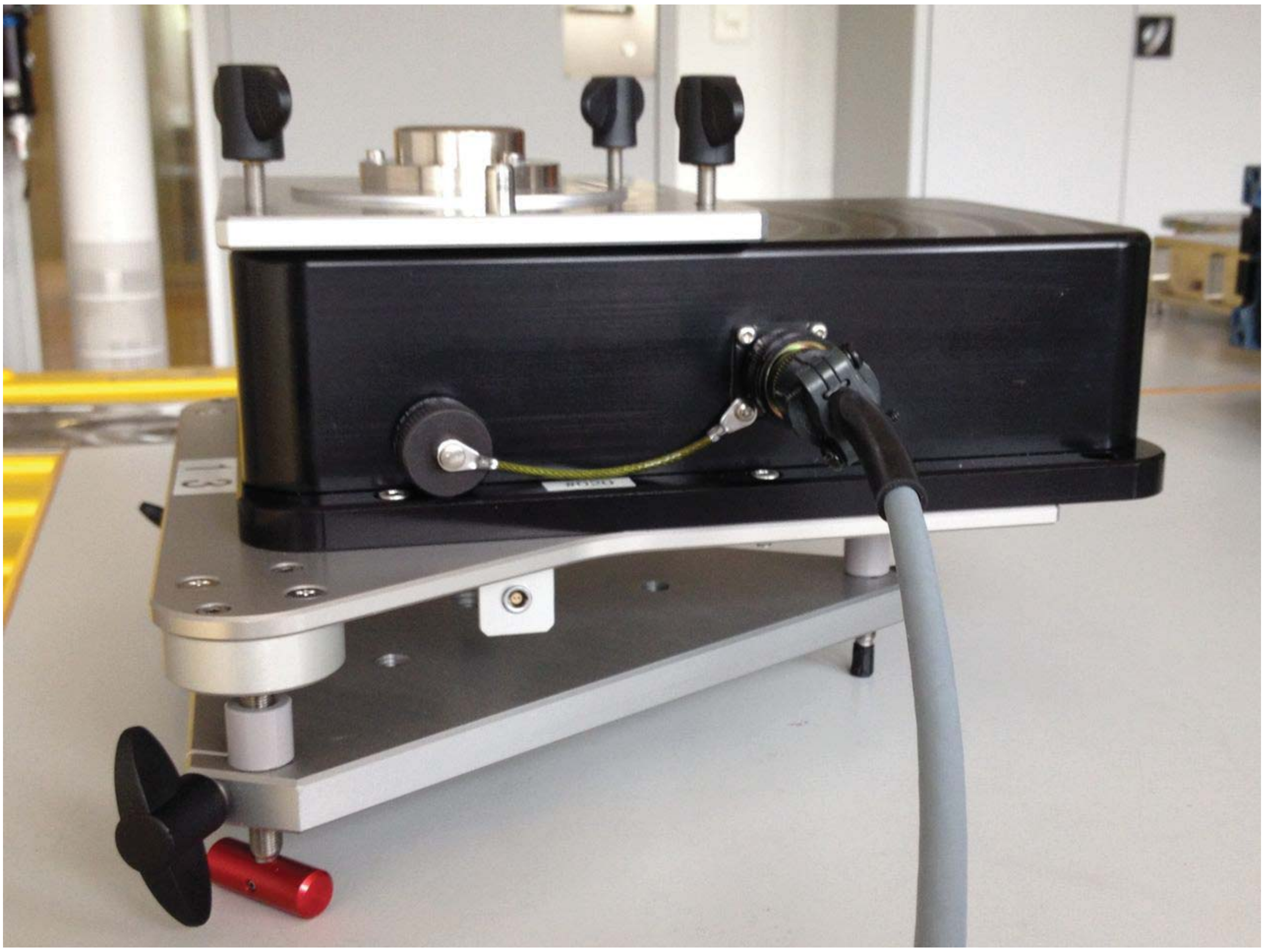


Figure 8: Side view of the tribrach and azimuth positioner. The tribrach is leveled by rotating the two red knobs that are locked by the black wing screws. The power connector for the laser plummet is below the azimuth positioner.

2.4 Mounting the RF Assembly (RFA) on the Tower

1. Mount the RF Unit on mounting brackets at the back of the Antenna Tower. Use the 2 wing screws on the back to secure the RF unit to the tower.
2. Attach the GPS Antenna cable to the BNC connector on the side of the RFA. The GPS antenna is located on top of the tower centered on the tower rotation axis.

Figure 9: RF Assembly antenna connectors. The three antennas connect to the SMA coaxial connectors using the 8mm torque wrench.

Figure 10 : RF Assembly mounted on the antenna tower. On the left side is the BNC GPS antenna connector.

2.5 Antenna Mounting

These have been precisely positioned on the tower to insure that the antennas are parallel. The elevation angles must be set to the same value on both sides of the tower. **The antenna can be severely damaged if the elevation angles of the bracket are are not the same angle for both sides of the antenna!** There are 5 degree detents where you can insert the pins so that the elevation angle can be set in 5 degree increments. The antenna has a half-power elevation beamwidth of about 30 degrees and a null-to null beamwidth of about 60 degrees. The elevation angle is usually selected so that the center of the antenna beam points towards the far range of the region of interest. Since the gain of the antenna is maximum at the center of the beam, the beam center should point near to the farthest area in the region of interest to get a stronger radar echo. For example if you are looking at a mine pit from the edge, the antenna is pointed in elevation slightly down, perhaps -5 or -10 degrees from horizontal. As an other example, if looking at a mountain slope, where the crest is at +35 degrees elevation, select the antenna elevation to a value near +25 degrees.

The antenna elevation (Tilt Angle) must be set BEFORE mounting the antennas on the brackets. To adjust the brackets to a specific elevation angle loosen the center butterfly screw 1 turn and pull out both locking pins. The bracket should then be able to rotate about the screw axis. Select the elevation angle such that you are pointing approximately at the farthest point in the region of interest near the center of the beam and insert the locking pin at that angle. The antenna elevation beamwidth is about 30 degrees, so make sure that the region of interest lies within the beam. The elevation angle can be set in steps of 5 degrees. The positions alternate between the two pins in 5 degree steps, such that only one of the pins can be inserted at a time. After the appropriate pin is inserted at the desired tilt angle, tighten the wing screw (do not over-tighten!).

1. Take each antenna out of the tube by loosening the thumb screw at the end of the tube. NOTE it is important that you slide out the antenna with getting the antenna cable caught between the tube and the antenna. For that reason pull out the end of the antenna with the desiccator. The clear plastic end-plates have a hole that you can grasp to pull out the antenna.
2. Mount the antennas one by one on the corresponding antenna brackets. Make sure you use a fixed order for the antennas (TX, RX1, RX2) to avoid phase effects due to slightly different antenna characteristics. The antennas are marked TX, RX1 and RX2. Typically the TX antenna is on top and RX1 and RX2 are above one another. But in the case of the radome, the TX antenna is at the tower center and RX1 and RX2 are at the top and bottom respectively.

   NOTE: When using a radome, the transmit antenna should be the center antenna on the tower to reduce reflections.

3. Connect the 3 antennas to the appropriate SMA connect jacks on the side of the RF assembly using the 8 mm torque wrench. **Do not over-tighten the SMA coaxial connectors**! Rotate the torque wrench until it clicks. Inspect the connector before each use to make sure the pin is straight and not damaged and that connector is clean.
4. **Never move or adjust location of the antenna brackets on the tower.** These have been carefully positioned on the tower. The spacing between the top brackets and the center bracket is 35 cm. The distance between the center and lower brackets is 25 cm. Hence if you are using the center antenna for the transmitter, the interferometric baseline between the receive antennas is 60 cm.

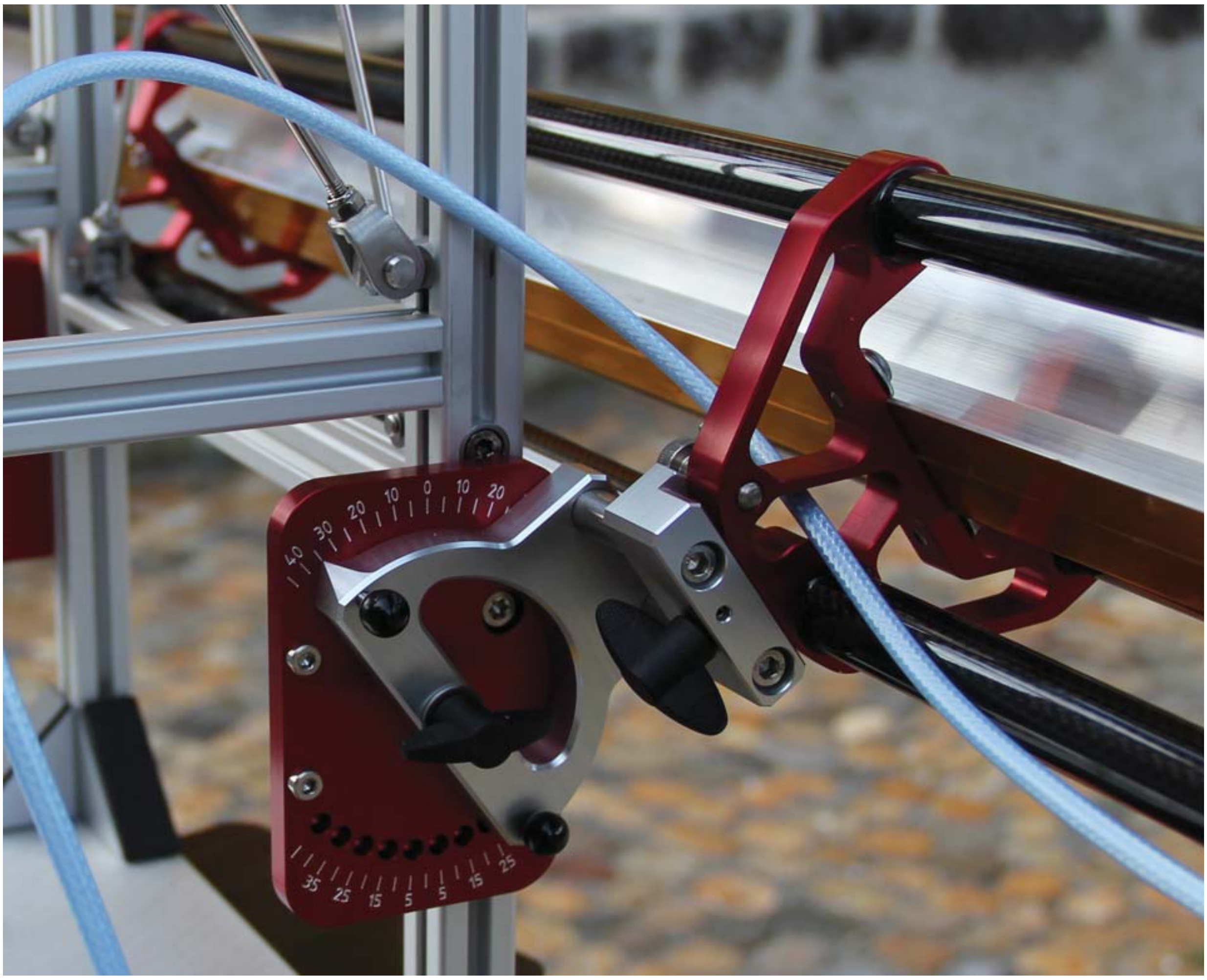


Figure 11: Closeup of the antenna bracket with elevation setting. Here an elevation angle of 35 degrees has been selected. Note that the angles in 10 degree steps are for the upper pin, and the angles offset by 5 degrees are on the lower circle.

2.6 Power Requirements

The GPRI-II can be powered either using AC in the range of 100 to 240 VAC 50-60 Hz at 2.0 Amperes, or DC power at 22-30 VDC at 7.5 Amperes. The instrument is supplied with a power cable for AC. The DC power cable uses different wiring at the Instrument Computer power plug to differentiate between AC and DC. A power cable configured for DC is provided with an available Lithium-Ion Battery pack. A DC power cable is available from Gamma if this is required for DC operation without the battery pack.

Connect the GPRI power cable to the AC or DC power source only after the RFA has been connected to the Instrument Computer with the RFA Multi-Function cable.

2.7 Instrument Controller Installation

The instrument controller inclosure contains the instrument computer, power supplies, and software defined radio (SDR) used for digitization of the radar signals.

1. Place the Instrument Computer case close to the tripod in a dry location. The usual location

is close to the tripod so that there is sufficient slack for the cable to wrap ¾ turn around the tripod.

2. Make sure the Instrument Controller is switched off before connecting any cables
3. **The RFA can be damaged if the RFA Multi-Function cable is connected or disconnected when the Instrument Controller is powered ON!**
4. Connect the Instrument Controller with the RF Unit (orange cable).
5. Connect the Instrument Controller with the azimuthal scanner using the grey cable.
6. Connect the Instrument Controller to the computer network using an Ethernet cable at the LAN port.
7. Switch on the power to the Instrument Controller.

Figure 12: GPRI Connector Plate: Ethernet LAN, RFA, Power, USB, Scanner, Auxiliary Power for the radome fan connection

3. Instrument Operation

Communication with the instrument in the field is through TCP/IP over Ethernet. The easiest solution is to connect the instrument to a laptop computer. Modern laptops automatically check on the direction of the signal and crossed Ethernet cable is not required. For maintenance it is also possible to connect screen and keyboard directly to the video port and USB ports. This would be a way to change the IP address of the instrument or to set the instrument to obtain an IP address via DHCP.

The GPRI-II supports two communication layers, SSH (Secure Shell) and HTTPS (Secure Web). It is good policy to have also a logbook for the instrument and take pictures for documentation. A list of items to record is given in Appendix A.

3.1 Field Measurement Setup Procedure

When setting up the instrument at a new site the following parameters must be set up to ensure a successful measurement campaign after the instrument has been installed. The parameters for a measurement are stored in a GPRI-II profile described in Section 5.7.1. An example of a measurement profile is shown below for a 2 ms FM-CW chirp:

```
RF_center_freq:     1.720000e+10
IMA_atten_dB:   48
CHP_freq_min:   100.0e6
CHP_freq_max:   300.0e6
CHP_num_samp:   12500
STP_antenna_start:  -80
STP_antenna_end:    70.0
STP_gear_ratio:       72
STP_rotation_speed:  10.0
TX_power: on
TX_mode: None
ADC_capture_time: 0.0
ADC_sample_rate:   6.25000e+06
antenna_elevation:       10
```

Table 1: Measurement Profile for a 2ms chirp. The azimuth scan starts at -80 degrees and ends at +70 degrees. The nominal rotation rate is 10 deg./second. The chirp lasts 2ms, equivalent to 12500 samples as specified by the CHP_num_samp keyword.

The usual procedure is to copy one of the default profiles from the $GPRI2_HOME/profiles into the directory where you will be storing the data on the disk and edit this profile using a text editor such as *gedit or pico.* You can also use a previous created profile and adapt it.

mkdir /data/RoboNorth
cd /data/RoboNorth
cp /home/gpri2/GPRI2-2/profiles/gpri_2ms.prf robonorth_2ms.prf

#edit the profile using a text editor
gedit robonorth_2ms.prf

The parameters in the profile in keyword:value format determine the azimuth sweep starting and ending angle (degrees), sweep speed in degrees/second, the FM-CW chirp length (samples), and the radar attenuation.

The FM-CW chirp length is the number of samples the radar acquires during the transmission time of the chirp. The radar samples the data at 6.25 MHz or equivalently 6250 samples/millisecond. A 1 ms chirp has 6250 samples, 2ms 12500, and a 4ms chirp 25000 samples.

The radar attenuation is the opposite of gain and is specified in decibels (dB). The higher the attenuation, the lower the gain. The nominal default value of the attenuation is 44 dB. Generally when looking at targets close to the radar, the attenuation can be higher. It has valid values that are even, ie 40,42,44... in the range of 0 to 60 dB. When operating in a radome, the default value is +48 dB due to the additional reflections within the radome.

The radar image will cover a slightly smaller span than the actual scan due to the time required to accelerate the radar to the constant scan speed. The raw data collected by the radar is processed to produce 2 SLC images, one image from each of the receiving antennas. The Single-Look complex image metadata (SLC_par) generated from the raw data contains the actual start and end azimuth angles and the angular spacing between image lines.

The RAW_par metadata file for the raw data is similar to the measurement profile but includes additional information such as the GPS coordinates, exact start time of the data acquisition, and the exact frequencies and FM-CW chirp rate. An example RAW_par file is shown below and described in detail in Section 5.7.2:

```
time_start: 2010-11-05 10:57:06.025627+00:00   #UTC time at s tart of data
geographic_coordinates:  46.6809900000, 7.6398266667 613.00 47.3
RF_center_freq: 1.72000000000e+10
RF_freq_min:    1.71000578460e+10
RF_freq_max:    1.72999421541e+10
RF_chirp_rate:  9.99425537884e+10
CHP_num_samp:   12500
TX_mode:        None
IMA_atten_dB:   48
ADC_capture_time:   9.50679
ADC_sample_rate:    6.25000e+06
STP_antenna_start:  -80.0
STP_antenna_end:    70.000
STP_rotation_speed: 10.00000
STP_gear_ratio:     72
antenna_elevation:  10.00000
CHP_temperature:  23.500
TSC_temperature:  28.400
```

Table 2: RAW_par meta-data file is generated for each raw data file

3.1.1 Determine the Field of View for the Azimuth Scan

When you turn on the radar and have made a connection using SSH, the first thing that must happen is that you calibrate the azimuthal scanner by entering the *home_run.py* command:

home_run.py

When this command is completed, the antenna will be in the home position that corresponds to an azimuth angle of 0.0. The antenna can rotate from -270 degrees to + 270 degrees. Positive rotation is to the right when looking at the antenna tower, standing behind the antennas. It is good practice to orient the antenna mount so that azimuth angle 0.0 is close to the center of the azimuthal scan, such that for a scan of 120 degrees, you would set the azimuth scan angles from -60.0 to +60.0 degrees.

You can move the azimuth position from the command line using the move_abs.py command

move_abs.py -30

will move the azimuth antenna position to -30 degrees. You can then determine the azimuth scan starting and ending azimuth angles.

3.1.2 Selection of the FM-CW Chirp

Select the FM CW chirp duration based on the maximum distance that will be recorded in the image and background. See Section 5.7.1.

Acquire the initial radar image and adjust the radar gain to avoid saturation. Check and possibly modify the azimuth field of view to ensure that the radar. View a plot of the radar echoes using the *-g* option when acquiring data with *gpri2_capture_utc.py*. Alternately call the program *gpri2_raw_plot.py* to examine the raw data that have been written to disk.

3.2 Operating the GPRI-II through SSH

To control the instrument through SSH a SSH client program is necessary. Preferred is to access from a Linux system that also permits using the X-Windows graphics supported by the Linux OS running on the instrument. There are X-Windows servers that run on Windows (e.g. Cygwin). See the Cygwin web page for an open-source X-server and SSH client that can be installed. It is easiest to have a laptop running Linux for communication but not essential. Under Linux, be sure to install the Linux SSH client *openssh.*

Please refer to Section 5 for the detailed instrument software reference. Program parameters are provided for easier reading but need to be adjusted for each case.

1. Login to instrument:
   ssh -X gpri2@192.168.1.xx *where xx = 70+GPRI-II Serial Number*

2. Check available disk space for data. The data are stored in the */data directory.* This directory is in its own partition on the disk.
   df /data

   and then set your current directory to be /data:
   cd /data

3. Initiate home run of the positioner (make a visual check that instrument can move freely and the RFA cable has enough room when it rotates!):
   home_run.py

4. The instrument is now looking at 0 degrees local instrument azimuth angle. Angles increase clockwise. Negative to the left, positive to the right when standing behind the instrument looking in the illumination direction of the antennas. This would be a good time to measure the azimuth heading of the instrument using a compass (there is one in your iPhone or other smart phone). The azimuth heading of the radar is the angle relative to true North when at the home position. If the radar is facing East the heading is +90 degrees, West is -90 degrees, and south is 180 degrees from North. Furthermore you may want to check system and GPS status to make sure these components are working properly:
   chupa_status.py
   tscc_status.py
   gps_message.py
   The CHUPA and Instrument Computer interior temperatures should be below 65° C. The program *tscc_status.py* prints the interior temperature of the instrument computer to the screen. *gps_message.py* will print several lines of the GPS NEMA messages to the screen.

5. Create a directory for your site, e.g. the location name, and move into:

```
mkdir -p /data/mysite/20140625
cd /data/mysite
```

6. Define the measurement parameters and setup the corresponding measurement profile. The profile contains information on the transmitter chirp, angular scan, speed, and receiver attenuation. See Table 3 for a description.

   You can copy a template preference file from ~/GPRI2-2/profiles for several different chirps. Its a good idea to give it a descriptive name (site, name), especially if you do repeat measurements.

   ```
   cp /home/gpri2/GPRI2-2/profiles/gpri_2ms.prf mysite_2ms.prf
   ```

7. Determine the start and stop azimuth angles for the scan. Be aware that approximately 2 degrees are needed on both sides of the scan for acceleration and deceleration. To determine the starting and stoping azimuth angle use the *move_abs.py* command to move to the angle desired.
   ```
   move_abs.py -30
   ```

8. Edit the profile to reflect your settings for *IMA_atten_dB, STP_antenna_start, STP_antenna_end* and *antenna_elevation*. The setting *TX_power* must be "on" for measurements, or "off" for listen only. The -g option generates a screen plot that can be examined for saturation. Description of the profile parameters is given in Section 5.7.1.

   ```
   gpri2_capture_utc.py mysite_2ms.prf 20140625\
   1 now 60 -p 20140625 -m 20140625 -g -d 5 -R 2000 -s .35 -e .35
   ```

9. Then display the processed data:
   ```
   eog 20140625/*.bmp
   ```

   Check signal levels by plotting the raw data signals with *gpri2_raw_plot.py* to make sure there is no saturation. If there is saturation (signal above 0.75 volts) then increase the attenuation value in the profile by 6 dB and repeat until there is no saturation in any echo. Nominal values for attenuation are between 44 and 50 dB. If the signal is below 0.1 volt you might consider decreasing the attenuation level by 6 dB.

10. A long series of SLC images can be acquired using the *gpri2_capture_utc.py* script by specifying the number of scenes and the time interval parameters (see documentation on *gpri2_capture_utc.py*). If a long series of differential interferograms for deformaton analysis is required then use the script *gpri2_capture_ts6.py*.

11. **Backup** data. e.g. with *rsync* to a network attached disk. Use *ionice* to avoid disk timeouts while acquiring data at the same time that a backup is being performed:
    ```
    ionice -c2 n7 rsync -av mysite 192.168.1.1:/backup
    ```

    Alternately use an external USB disk and mount it. To find out the device id of the disk, most likely */dev/sdb1*:
    ```
    dmesg | tail -n 50
    ```
    and look out for lines such as
    ```
    [1295858.275037] sd 16:0:0:0: [sdb] Assuming drive cache:
    [1295858.275046] sdb: sdb1
    ```

    Mount the device on /mnt for user GPRI-II with:
    ```
    sudo mount -o gid=1000,uid=1000,user /dev/sdb1 /mnt
    ```

The data can now be copied to and from /mnt.
ionice -c2 -n7 rsync -av mysite /mnt
Make sure you unmount the device when finished:
sudo umount /mnt

12. **Always** do a positioner home-run before you switch off the instrument:
    home_run.py

13. Shut down the GPRI instrument computer properly:
    sudo poweroff
    and press the power switch into the off position. Next unplug the radar at the power source.

4. Instrument Description

4.1 Instrument Components / Package List

The instrument consists of the following components:

- 3 Ku-band slotted waveguide antennas
- 1 RF Assembly RFA (Radio Frequency electronics that are mounted on the rotating tower)
- 1 Instrument Computer (Yellow Instrument Computer Case)
- 1 Power Cable
- 1 Instrument cable (thicker 2m orange cable with military connectors)
- 1 Antenna Tower with GPS antenna on top
- 1 Tripod with 3 stainless rods (orange bag)
- 1 Azimuth Positioner with Tribrach (Leveler)
- 1 Laser Plummet Battery Pack
- Tool kit
  - socket screw key (socket screw key provided in toolkit)
  - 8mm SMA torque wrench

Additional items necessary for field work

- Power generator with spare fuel or Lithium-Ion battery pack
- Laptop computer with SSH and X-Server software
- USB backup disk
- Power Drill fo and screws, washers, anchors to fix the tripod to the ground (4 mm screws in 6mm anchors should be fine)

4.2 GPRI-II Electronic Description

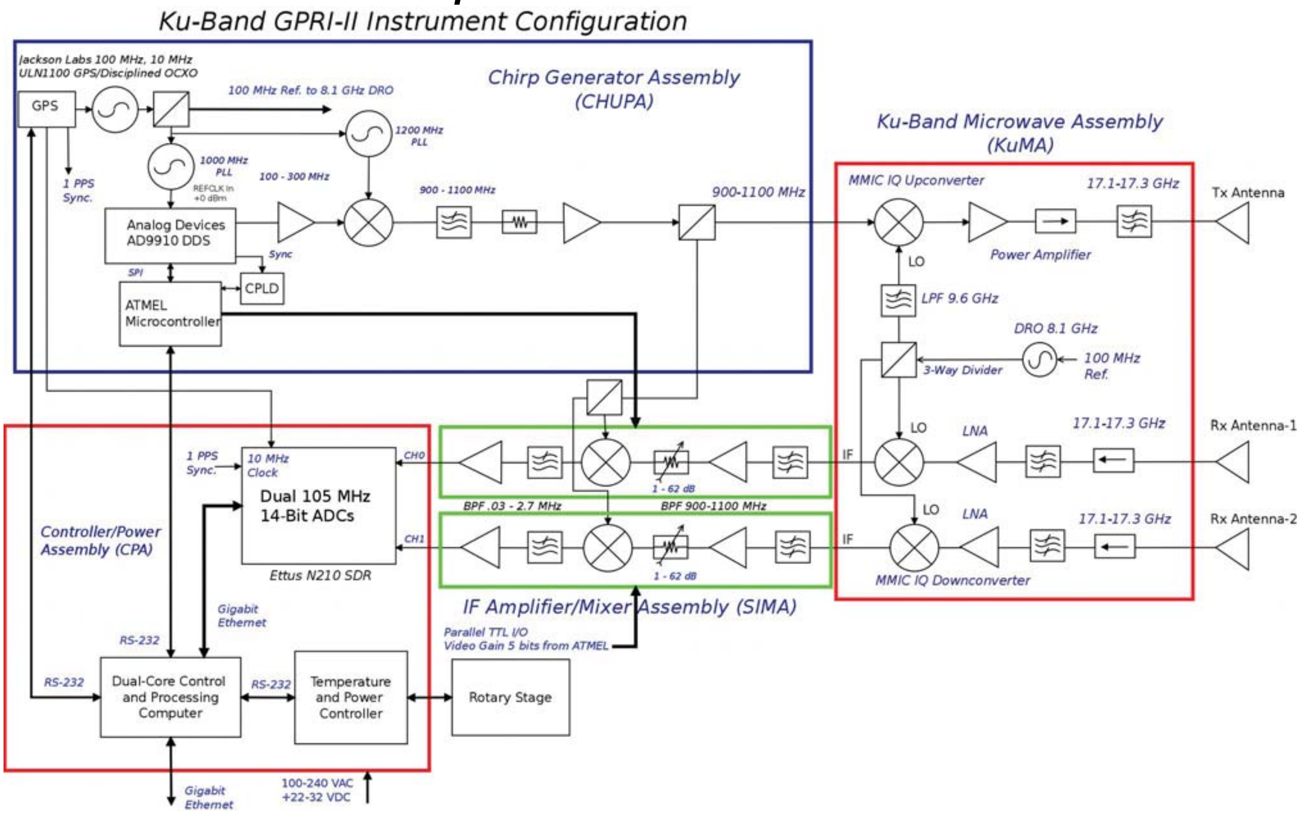


Figure 13: GPRI-II System Level Design

The high-level block design of the GPRI-II is shown above. The main elements in the electronics are the Chirp Generator Assembly (CHUPA), Single Channel IF Amplifier/Mixer Assembly (SIMA), Ku-Band Microwave Assembly (KuMA), and the Instrument Computer (IC). The GPRI acquires data within a the duration of the chirp minimizing the effects of temporal decorrelation on image focus.

The use of a built-in computer permits autonomous operation and recording of data with the need for an external lap-top. Data acquisition speed is increased substantially because data acquired during continuous rotation of the motor avoiding stop/start motion and the associated mechanical settling time.

The computer, power-supply, and dual ADC digitizer are all within the controller/power assembly enclosure. Temperature and power regulation are steered by a controller on the TSCI (Temperature and Power Controller) board. It is responsible for ensuring that the temperature within the enclosure is within operational limits and can provide functionality for implementation of a low-power sleep mode.

The RF electronics assembly is connected to the Computer/Power enclosure using a single multi-conductor cable with 19-pin MIL-C26582 connectors. These connectors are weather resistant (IP-65) and rugged. The receiver output goes directly to the input of the ADCs of the SDR

4.3 Antenna Characteristics

The GPRI-II antenna is an end-fed slotted-waveguide antenna. The azimuth antenna sidelobes remain constant over the entire operational bandwidth from 17.1 to 17.3 GHz at an acceptable level (-20 dB). The slotted waveguide antenna is designed with an aluminum flare that determines the elevation beam-width of approximately 32 deg. The elevation pattern is shown in Figure 14.

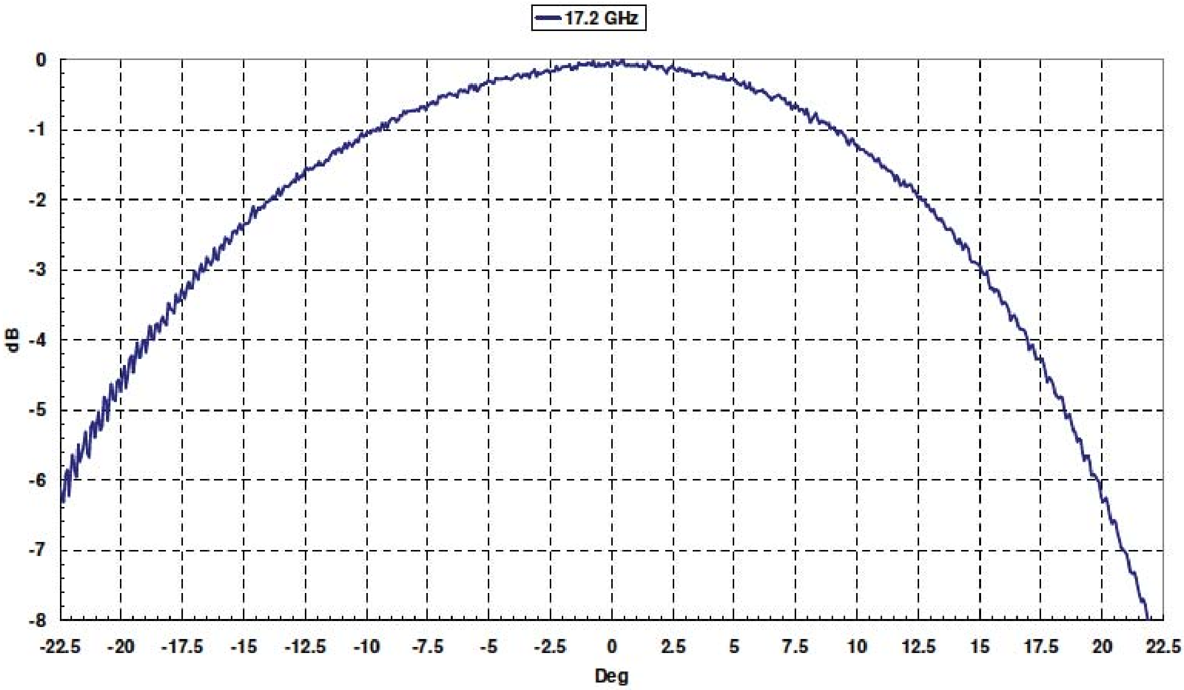


Figure 14: Antenna elevation pattern at 17.2 GHz, The half-power beam width varies between 31.4 and 33.8 degrees depending on the particular antenna unit

A thin plastic radome over the flare opening to seal the antenna against moisture. The GPRI-II antennas support is designed to fit in a 125 mm PVC tube for protection. These tubes fit in a custom shipping case for shipping by a commercial shipping company.

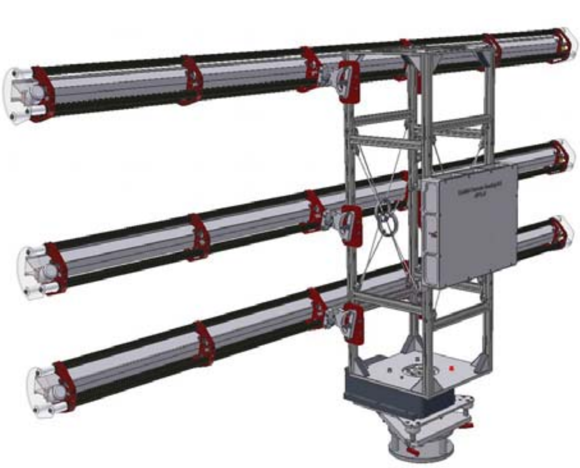
4.4 GPRI-II Mechanical Description

4.4.1 GPRI-II Antenna Tower

The antenna support tower has a height of 80 cm and a square cross-section of 28 x 28 cm and is constructed using ITEM aluminum extrusion. The tower is further stiffened on each face through the use of stainless-steel rods under tension connected to a central stainless-steel ring as shown in Figure 15. These cross-struts stiffen the tower to reduce torsional deformation.

4.4.2 Tripod, Positioner and Tribrach Leveler

The tripod supporting the scanner and antenna tower is a heavy duty fiberglass tripod. It comes with a 5/8” threaded screw that is standard and is adjustable to permit repeatable positioning. A small bubble level embedded in the tripod mounting plate has been added to allow initial leveling of the tripod.. The tripod can be leveled approximately by moving out the legs. An aluminum foot has been added to the end of each tripod leg that permits fixed mounting of the legs using screws and anchors. This arrangement facilitates accurate repositioning of the GPRI-II for later data acquisitions. A laser plummet on the scanner rotational axis projects the rotational axis on the ground. Additional metal struts have been added at the tripod base to improve the rigidity and to permit precise repositioning of the tripod on preexisting anchors.



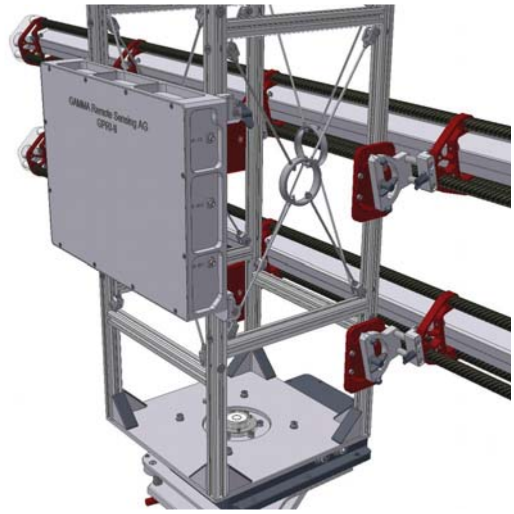


Figure 15: GPRI-II Tower with RF electronics Assembly (RFA).

A rugged custom tribrach supports the tower and is used to adjust the axis of rotation to be vertical. A stainless steel spacer is also provided to mount the tribrach and azimuthal scanner on a pier or rock outcrop or other structure.

Figure 16: Tripod mounting adapter for screw anchor mounting.

Figure 17: Tribrach with azimuthal scanner and tower. Adapter for pier mounting is shown attached to the tribrach. Red knobs adjust the tilt of the azimuthal scanner mounting plate.

4.4.3 Azimuthal Scanner

The GPRI-II uses a custom designed intelligent azimuthal scanner. This positioner has a repeatability of 5 arc-sec, and a resolution of 0.36 arc-seconds. The scanner has dual thrust bearings eliminating any measurable wobble in the axis and permits a load up to 100 kg. The internal scanner micro-controller supports smooth ramp-up and ramp-down of the rotational velocity It also remembers the current position even if power is lost suddenly and this prevents subsequent wrapping of the RFA cable. The scanner memory has a duration of up to 10 days. It is essential whenever powering up the GPRI to perform a home-run of the azimuthal positioner using the *home_run.py* program.

The range of angles that the tower can rotate is +/- 270 degrees relative to the home position after running *home_run.py*. The home position azimuthal angle is 0.0 degrees. The rotation velocity can be set in steps of approximately 0.1 degree/sec from 0 to 15 degrees/sec. The controller can be queried to determine the time and angle required for acceleration to a constant velocity or to stop rotation.

4.5 Radio Frequency Assembly (RFA)

The radar RF electronics are mounted in an aluminum enclosure made of single aluminum slab 56mm thick with a 6 mm central plate dividing the enclosure into two 22 mm deep cavities. . A gasket for the top and bottom plates makes the RF enclosure watertight. A gas-permeable membrane prevents accumulation of condensate in the enclosure. A single 19-pin MIL C26582 connector is used for baseband radar signals and power to the Radio Frequency Assembly (RFA). The cable connecting the RFA and Instrument Controller carries power, serial communication, and the analog receiver output. SMA microwave connectors for the TX output and 2 RX inputs are mounted on the side of the RFA.

The RFA is powered by +22-28 volt DC that is then converted to the various voltages used by the

RFA modules in the power distribution module inside the RFA enclosure. The 24 VDC used to power the RFA comes from the Instrument controller enclosure.

The RFA contains the linear FM chirp generator and up-converter assembly (CHUPA) that generates a programmable chirp in the 900-1100 MHz frequency range. This FM chirp signal is used both to drive the transmitter up-converter and to deramp the received radar echo in the dual receivers.

The receiver IF amplifier assemblies (SIMA) amplify the output of the Ku-Band (KuMA) RX down-converters and deramp the echo to obtain a range compressed radar echo in slant range geometry. Communication and control of the RFA is via a microprocessor located in the CHUPA. The CHUPA configures the chirp parameters, receiver gain, and controls the power to the different modules. Each of the different modules in the CHUPA can be powered up or down by software command. The entire RFA can be powered on or off by command of the TSCI in the Instrument controller enclosure.

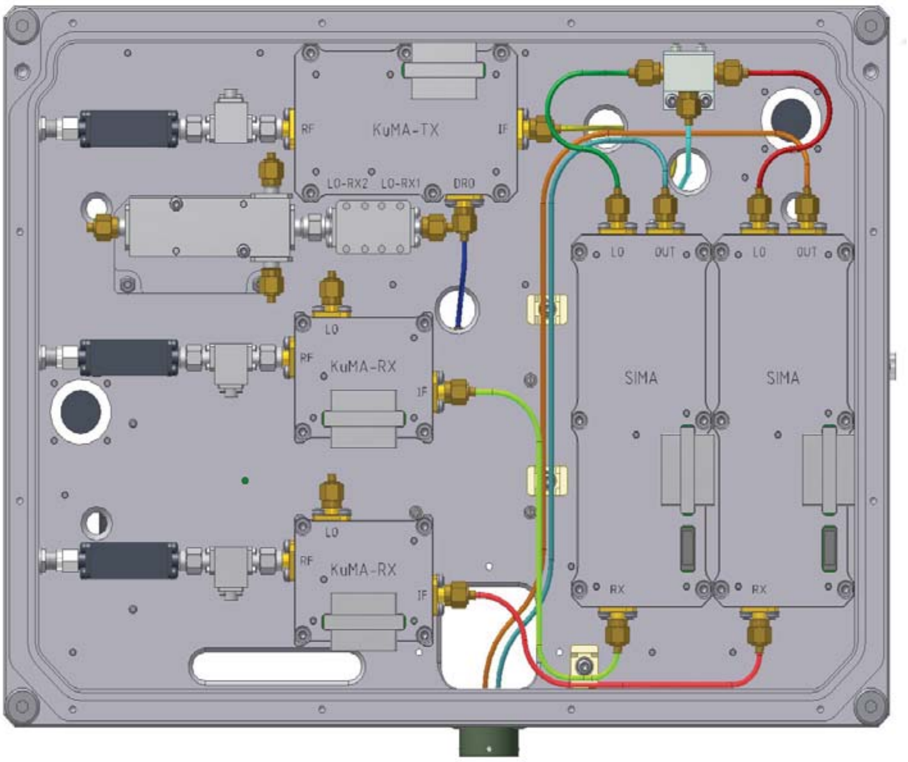


Figure 18f: RF Electronics Assembly Interior showing KuMA-TX and KuMA-RX modules along with the dual SIMA modules. The compartment on the other side of the RFA contains the CHUPA, GPS and DISTRI modules

The microwave up- and down converters and SIMA are located on one side and the GPS receiver, CHUPA and DISTRI on the opposite side of the enclosure.

4.6 Instrument Controller and Power Unit

The instrument computer is located in the Instrument Controller and Power Unit. The computer is a

Mini-ITX board and uses a 3rd generation Core I5 processor with 8 GB RAM. A solid-state disk (SSD) with 1 TB capacity is used for the operating system and data buffer.

The Instrument Controller and Power Unit also contains the power supplies that convert 100-240 VAC or 22-28 V DC to the voltages required by the radar. The power input connector can either have AC or DC input power. An internal switch can be used to select the input power source. Output connectors are provided for the RF electronics and the azimuthal scanner. Additional ports for Ethernet and USB interfaces are also available.

An internal fan circulates air to transfer heat to the baseplate in the case. The internal fan speed is regulated to provide control of the internal temperature. An external fan cools the external heat sink. An external fan draws air over the external heat sink to allow operation at high ambient temperatures. There is also built in heater for operation at temperatures below 0 C. The GPRI can operate over the temperature range of at least -20 to +50 C.

5. Instrument Software

The instrument has different levels of software. The instrument controller is running Ubuntu Linux as the operating system. On top of that different system services such as *openssh* and *lighttpd* and tools that are provided through the Ubuntu software repository. User Interface

The GPRI-II instrument can be accessed through TCP/IP over the Ethernet connection provided at the Instrument Controller, or by opening the Instrument Computer case and connecting a computer display and keyboard/mouse. The latter allows access in case the IP address of the instrument is unknown or any other communication problem occurs.

5.1 Local Terminal Access

To have local access to the Instrument computer requires opening the Pelican case to attach a video terminal (DVI interface) and a keyboard and mouse using USB. These interfaces are on the connector panel of the instrument computer. After booting up the instrument computer, the Ubuntu login screen appears and the user can login as user **gpri2** with password **gpri2**.

A Ubuntu desktop is is then presented on the video screen. In this configuration, there is access to all system settings, most importantly the network configuration. Right-clicking on the network configuration icon on the top taskbar reveals a menu with various options including “Settings” at the bottom. Selecting this option brings up the configuration window for network interfaces. One of the system Ethernet interfaces (eth0) is the system external connection. The other interface (eth1) is connected to the Ettus N210 Software Defined Radio using a fixed IP of 192.168.10.2. **Do not change the configuration of this interface**. The other interface has a fixed IP set to 192.168.1.xx where xx is determined from the serial number of the radar+70. As an example, the IP of GPRI-II-20 is 192.168.1.90. This IP can be changed if required to your desired network configuration.

5.2 Terminal Access via SSH

The instrument computer terminal can be accessed through secure shell (ssh). The export of the X11 windows is supported through the ssh -X option:

```
ssh -X gpri2@192.168.1.x
```

In this section the command line tools are described grouped by functionality. Furthermore at the end of the section the parameter and data file formats are given. Section 6.5 shows the list of auxiliary tools that are not needed for every day use but can be helpful in case of instrument problems.

5.3 Radar Data Acquisition

The basic program to acquire data is gpri2_capture_uhd.py. However, usually it is much more convenient to use gpri2_capture_utc.py or gpri2_capture_ts4.py. gpri2_capture_utc.py can acquire a time-series of SLC images and MLI images derived from them. gpri2_capture_ts4.py goes several steps further and can optionally generate a series of interferograms, correlation maps, unwrapped interferograms, filtered interferograms, and the time-series from adding the sequential unwrapped and filtered interferograms.

5.3.1 gpri2_capture_ts8.py

This script acquires a series of radar images and generates the interferogram time series from sequential series of acquisitions AB, BC, CD.. This sequence of interferograms can be optionally unwrapped and integrated to create the time series. The user can specify the start time, number of acquisitions, and time interval between acquisitions. The image region can be specified in terms of the starting and ending slant range. The user can also specify the channel (RX1, or RX2) data that will be used for generating a series of differential interferograms.

```
usage: gpri2_capture_ts.py  <profile> <nraw> <start_T> <delta_T> <DATA_dir> [-d decim] [-
j channel] [-r rmin] [-R rmax] [-h heading] [-u] [-z "x y"] [-c cthres] [-p pthres] [-m
mask] [-f radius] [-t] [-x] [-k] [-w days] [-s scale] [-e exp]
  profile      GPRI2 profile for raw data acquisition
  ndata        number of raw data acquisitions to perform
  start_T      starting time in UTC of the first acquisition in ISO-8601 format,
               enter "now" for immediately
               (YYYY-MM-DDTHH:MM:SS, example: 2011-06-25T13:00:00)
  delta_T      time in seconds between start of each acquisition, interval includes
                acquisition time
  DATA_dir     main data directory, data will be stored in subdirectories organized
               by date and time
  -d decim     raw data decimation factor (default: 5)
  -j channel   channel specification for creation of differential interferograms
               (1:lower-RX1  2:upper-RX2 (default))
  -r rmin      starting slant range (default: 50 meters)
  -R rmax      maximum slant range enter, default is maximum determined from chirp
                duration (meters)
  -h heading   radar heading at the center of the azimuth sweep (deg., default = 0.0)
  -u           unwrap interferogram phase and generate 2 column list of unwrapped
               interferograms and delta_T values in decimal days
  -z "x y"     reference point for phase unwrapping and phase reference for stacking,
               x and y arguments must be in quotes (default: image center)
  -c cthres    interferometric correlation coefficient threshold used for selection
               of points for phase unwrapping (default: 0.7)
  -p pthres    relative radar image intensity threshold used for selection of points
               for phase unwrapping, (default: .01)
  -m mask      mask to apply to interferometric phase after phase unwrapping (BMP or
               Sun raster format)
  -f radius    apply fast GPRI spatial filter to the unwrapped phase for atmospheric
               phase suppression (nominal: 160 samples)
  -t           generate time-series of interferograms in the TS_dir directory,
               files are named ts_nnnn, -u option is required
  -x           delete raw data after processing to generate SLC images
  -k           do not generate raster format images
  -w days      delete output directories older than the specified number of days,
               value must be 1 or greater
  -s scale     display scale factor (default = .4)
  -e exp       display exponent (default = 0.35)

   Note: All data are stored in sub-directories in DATA_dir.
         Subdirectory names are organized by date with suffix YYYYMMDD
         SLC data files are listed in SLC_tab1_YYYYMMDD and SLC_tab2_YYYYMMDD
         MLI data files are listed in MLI_tab1_YYYYMMDD and MLI_tab2_YYYYMMDD
         unwrapped phase data files are listed in DIFF_tab_YYYYMMDD
         time-series data files are listed in TS_tab_YYYYMMDD

        -u option is specified then the differential interferograms are unwrapped
           and DIFF_tab and when time series are generated
        -z option is used to specify the required phase reference point coordinates
           for unwrapping and integrating the phase
```

Interferograms and correlation maps are generated by default. To specify that the interferograms should be unwrapped, enter the -u option on the command line with the name of the file that will contain a list of differential interferograms.

The GPRI data products are stored in subdirectories created by the script in the DATA_dir directory. Each subdirectory is named with the current date in the form YYYYMMDD. When a new day begins, a new subdirectory is created and the interferometric time-series continues.
Data products stored in the subdirectory include raw data files and raw data parameter files (raw, raw_par), SLC images and their parameter files (slc, slc.par), multi-look intensity images and associated parameter files(mli, mli.par), interferograms (diff), adf filtered interferograms (adf.diff), interferometric coherence (cc), unwrapped phase (unw), and integrated time series (ts).

It is important to specify the phase reference point in the interferogram for unwrapping and stacking using the -z option. The argument of the -z option are the x and y coordinates of the center of the reference region contained within double quotes: **-z "x y"**.

Other options relate to unwrapping the phase of the differential interferogram. These options are thresholds for the interferometric correlation and intensity that must be exceeded for a point to be unwrapped:

```
-c cthres     interferometric correlation coefficient threshold used
              for selection of points for phase unwrapping (default: 0.7)
-p pthres     relative radar image intensity threshold used for selection of\
              points for phase unwrapping, (default: .01)
-m mask       mask to apply to interferometric phase after unwrapping
```

Points with low interferometric correlation will have noisier phase values. Similarly, dark regions or regions in shadow will also have noisy phase values. Typically, the value of *cthres* is set to be 0.7 or greater, while the intensity threshold parameter *pthres* is usually set to values < 0.05. The **-m** option lets you specify a mask file that is applied to the image after unwrapping the phase. The -f option is used to switch on or off the fast spatial filter used for atmosphere suppression. This script requires the Gamma software to generate the interferometric and multi-look intensity products.

Options that are related to data management are -x, -k, and -w. The -x option specifies that the raw data files be deleted after SLC images have been produced. These raw data files are up to 1 Gb in size and deleting them is a good idea to delete these if you are sure that you have the right area covered in the processed images. The -k option specifies that most of the raster images (BMP or Sun Raster format) will not be created, also saving space. The most important parameter for data management is the -w option.

5.3.2 gpri2_capture_utc.py

This is a script to capture a series of raw data sets and process these data to form SLC images at fixed time intervals starting at a specific UTC time-stamp. A time-stamp of "now" can also be specified to begin acquisition immediately. This script requires the Gamma software for generation of MLI images:

```
*** GPRI ground-based radar data capture and processing UTC time reference ***
*** Copyright 2011, Gamma Remote Sensing, v1.5 8-Aug-2011 clw ***

usage: gpri2_capture_utc.py  <profile> <RAW_dir> <nraw> <start_T> <delta_T> [-p slc_dir]
[-m mli_dir] [-x] [-d] [-r rmin] [-R rmax] [-h heading] [-a] [-s scale] [-e exp]

  profile      GPRI-II profile for raw data acquisition
  RAW_dir      directory to store raw data acquisitions and raw data parameter files
  ndata        number of raw data acquisitions to perform
  start_T      starting time in UTC of the first acqusition in ISO-8601 format, enter
```

```
"now"
              for immediately
              (YYYY-MM-DDTHH:MM:SS, example: 2011-06-25T13:00:00)
  delta_T     time in seconds between start of each acquisition, interval includes
              acquisition time
  -p slc_dir  process data to SLC and store in directory slc_dir
  -m mli_dir  generate MLI images and store in directory mli_dir
  -x          delete raw data after processing
  -d decim    raw data decimation factor (default = 5)
  -r rmin     starting slant range, default: 50 meters
  -R rmax     maximum slant range enter, default is maximum determined from
              chirp duration
  -h heading  radar heading at the center of the azimuth sweep (deg., default = 0.0)
  -a          process using ati option for gpri2_proc.py, turn off
              azimuth interpolation
  -s scale    display scale factor (default = .4)
  -e exp      display exponent (default = 0.35)
```

This program is the general purpose data acquisition program for the GPRI-II instrument. It has the option to process the data to SLC and MLI image products immediately after acquisition using the -p and -m options. If the user desires, the raw data can then be deleted (-x option) in order to save disk space. The SLC images are typically about 10% the size of the raw data due to data decimation performed by the processor.

The raw data files include the UTC time in the file name in the format YYYYMMDD_HHMMSS.raw For each RAW data file there is also a RAW_PAR file with the same root name and the extension “raw_par”. The time-stamp for data acquisition in the command line must be provided in ISO-8601 format as THH:MM:SS (example T10:11:58) where the letter T precedes the time in HH:MM:SS. Alternately there is the option to type “now” to specify that the scan should start immediately.

Important to note is the -a option. Nominally the processor performs a frequency dependent azimuth interpolation to compensate for the antenna frequency dependent squint angle. This option turns off this interpolation step for data acquired with a constant azimuth angle.

5.3.3 gpri2_capture_uhd.py

This program acquires a single GPRI-II raw data set and is called by both *gpri2_capture_utc.py* and *gpri2_capture_ts6.py*. Input used to specify the operating parameters of the acquisition are stored in a parameter file called a “profile”. This profile is organized as keyword value pairs and described in Section 5.7.1. There are template profiles (*.prf) for different duration chirps (250us, 500us, 1ms, 2ms, 4ms, and 8ms) in the /home/gpri2/GPRI2-2/profiles directory:

```
$ gpri2_capture_uhd.py
linux; GNU C++ version 4.8.1; Boost_105300; UHD_003.006.002-rc2

*** GPRI data capture program with UHD v2.5 30-Jan-2014 ***
Usage: gpri2_capture_uhd.py: [options] -p profile -o output_filename

Options:
  -h, --help            show this help message and exit
  -a DEVICE_ADDR, --device-addr=DEVICE_ADDR
                   se USRP at specified device-address which can be IP
                        address (-a addr=192.168.10.2), serial (-a
                        serial=1234567) or name (-a name=name). There is no
                        mac-address support. [default=None]
  -f FREQ, --freq=FREQ  set frequency to FREQ
  -d DECIM, --decim=DECIM
                        set fgpa decimation rate to DECIM [default=16]
```

```
-g GAIN, --gain=GAIN  set USRP gain in dB (default is midpoint)
-K SCALE, --scale=SCALE
                      set rx input scaling of usrp2, scale_iq  (default is
                      1024)
-S SHIFT, --shift=SHIFT
                      set rx output shifting of usrp2, shift_iq  (default is
                      0). Allowed values 0, 1, 2 and 3
--lo-offset=LO_OFFSET
                      set daughterboard LO offset to OFFSET [default=hw
                      default]
-N NSAMPLES, --nsamples=NSAMPLES
                      number of samples to capture [default=+inf]
-T CAPTURE_DURATION, --capture-duration=CAPTURE_DURATION
                      number of seconds to capture [default=+inf]
-o OUTPUT_FILENAME, --output-filename=OUTPUT_FILENAME
                      output filename for captured samples [default=None]
-s, --output-shorts   output interleaved shorts instead of complex floats
-M, --lock-masterclock-to-SMA
                      lock usrp2 100 Mhz master clock to external 10 Mhz
                      reference clock on SMA input
-P, --sync-to-first-1PPS
                      reset the usrp2 samplecounter on the first PPS
                      received on the PPS SMA input
-j RX_START_TIMESTAMP, --rx-start-timestamp=RX_START_TIMESTAMP
                      set start_at time of first RX packet in usrp2 100 Mhz
                      clockpulses (long) [default=-1 start immediately]
-k RX_START_TIME_SECONDS, --rx-start-time-seconds=RX_START_TIME_SECONDS
                      set start_at time of first RX packet in seconds
                      (float) [default=-1.0 start immediately]
-C EXTERNAL_PROGRAM, --external-program=EXTERNAL_PROGRAM
                      give a programname to start this as external program
                      just before streaming starts (string) [default=None do
                      not start an external program]
-v, --verbose         verbose output
-p GPRI_PROFILE, --gpri-profile=GPRI_PROFILE
                      GPRI acquisition profile [default=None]
--nosemaphore         Dont check and set measurement semaphore (used if
                      called from a master measurement script that sets the
                      flag)
```

5.4 Quality Control of Raw Data

The *gpri2_raw_plot.py* program plots the raw data records and plots the range compressed radar echoes. When first setting up the radar at a new location. This program is required to see if the gain has been set correctly to avoid saturation of the radar.

It is recommended that that the initial acquisitions of data when using the command line interface be preformed using *gpri2_capture_utc.py (see below).* This program can optionally generate SLC and MLI images that are required to determine if the region of interest in the scene has been adequately covered.

5.4.1 gpri2_raw_plot.py

```
Usage: gpri2_raw_plot.py v1.6 30-Sep-2011: [options] raw_par raw_data

Takes a GPRI raw data set and raw data acquisition parameters and displays the
two channels and the slant range echo.  The start position in the file can be
set by specifying -o or --offset and defaults to 0 (the start of the file). A
specified number of points can be set to zero using the -z option

Options:
  -h, --help            show this help message and exit
  -d DATA_TYPE, --data-type=DATA_TYPE
                        Specify the data type (float32, int16 [default=int16])
  -o OFFSET, --offset=OFFSET
                        Specify record offset to begin display [default=10]
  -z ZERO, --zero=ZERO  number of samples to set to 0 at the start of the
                        echo: [default=0]
  -s STRIDE, --stride=STRIDE
                        spacing between successive display records:
                        [default=100]
  -y YMAX, --ymax=YMAX  maximum value for range-profile magnitude:
                        [default=20.0]
  -r RMAX, --rmax=RMAX  maximum slant range for plot: [default=0.0]
  -n, --no_range_wgt    turn off range weighting of the echo
  -b, --dB              plot echo with dB scale
  --png                 generate PNG output image
```

This program takes a GPRI raw data set and instrument profile and displays the two channels and the slant range echo. The start position in the file can be set by specifying -o or --offset and defaults to 0 (the start of the file). A specified number of points in the echo can be set to zero using the -z option to remove transients at the start of the echo.

5.5 Processing of GPRI raw data to SLC

5.5.1 gpri2_proc.py

Takes a GPRI-II echo data set and processes to generate SLCs for receivers with inputs RX1 and RX2. The SLC acquired from RX1 is called the upper (u) and RX2 the lower (l) SLC.

```
Usage: gpri2_proc.py: [raw_data] [raw_par] [slc1] [slc2] options

Process GPRI-II raw data to SLCs v2.7 29-May-2014 clw

Options:
  --help                show this help message and exit
  -F DATA_TYPE, --data-type=DATA_TYPE
                        Specify the data type (float32, int16)
                        [default = int16]
  -z ZERO, --zero=ZERO  Number of samples to weight at the start of the echo
                        [default=300]
  -d DEC, --decim=DEC   Raw data decimation factor to apply [default=1]
  -R RMAX,--rmax=RMAX   Maximum SLC slant range (meters), default is 0.9 of
                        the aliasing slant range for the chirp
  -r RMIN,--rmin=RMIN   Minimum SLC slant range (meters) [default=50.0]
  -a, --ati             Turn off azimuth interpolation, required for Along-
                        Track Interferometry [default=False]
  -e, --little_endian   Generate little-endian SLCs, Gamma Software default is
                        big-endian [default=False]
  -h HEADING            Heading of radar boresight clockwise from North (deg.)
                        [default=0.0]
  -k KBETA              Kaiser Window beta parameter [default=3.0]
  -t TX_ANTENNA         Specify TX antenna for C-band data acquired in HV mode
                        (H,V): [default=V]
```

Input to the program are the **raw** data and **raw_par** parameter files. Output are the SLC images **slc1** and **slc2** from each of the two channels. The user enters the names of the SLCs as the parameters slc1 and slc2. Two SLC meta data files are also created with extension **.par.**

```
20110715_105720u.slc  20110715_105720u.slc.par
20110715_105720l.slc  20110715_105720l.slc.par
```

The starting slant range RMIN for the SLC images is by default 50 meters. The **-r** parameter command line parameter can be set to a minimum value of 5 meters, . The maximum slant range in the SLC is given by th**e -R** *RMAX* command line parameter. The maximum slant range possible for a particular chirp is determined by the chirp length, the ADC sampling rate and the chirp bandwidth. Since we are using the full 200 MHz bandwidth for each chirp, the pixel spacing is fixed at ***delta_r = 0.75m***. The maximum possible range ***R_MAX*** for a particular chirp duration ***t_c*** is given by:

*R_MAX = 0.9 * t_c * 3.125e6 * delta_r*

Hence for a 2 ms chirp the maximum possible slant range is 4.218 km.

The decimation factor **-d** DEC is an azimuth averaging parameter and specifies the number of echoes averaged to improve the Signal to Noise Ratio (SNR). The aim is to set the DEC factor such that the azimuth spacing is 0.1 degrees. Hence given a 2ms chirp and rotation rate of 10 deg/sec, the decimation factor should be set to 5. Similarly, if rotating at 5 deg/sec with a 4 ms chirp, *DEC* should remain 5.

Data input can either be as floating point or short integer data format. All data collected by the GPRI-II is in short-integer format. The **-F** parameter specifies the data input format.

There is a transient signal at the start of the raw data due to the sudden change in the put signal frequency when restarting the chirp. This transient is attenuated using a weighting function at the beginning of the raw data. The width of the section (in samples) of the section that is weighted is specified by the **-z** parameter that is by default 300 samples. To further reduce range sidelobes, this window is also applied at the end of the received data.

The **-e** parameter sets the endian format for the floating point data with big-endian standard for Gamma software.

The heading parameter ***-h*** *HEADING* is used for terrain geocoding and is the nominal heading of the radar clockwise from North for the center of the radar scan. This parameter is copied to the SLC_par parameter file associated with the SLC image.

The *-k beta* parameter sets the Kaiser window BETA parameter. Larger beta values result in lower range sidelobes at the cost of reduced range resolution. The default value the beta parameter is 3.0 that results in range sidelobes < -35 dB.

5.5.2 gpri2_proc_all.py

Script to process a series of raw GPRI-II data files to produce SLC images using gpri2_proc.py:

```
usage: gpri2_proc_all.py  <RAW_list>  <SLC_dir> [-m mli_dir] [-d] [-r rmin] [-R rmax]
                          [-h heading] [-a] [-s scale] [-e exp] [--png]

  RAW_list   (input) list of raw data files (2 columns):
               1. GPRI-II raw data file (*.raw)
               2. GPRI-II raw data parameter file (*.raw_par)
  SLC_dir    directory to store output SLC images and SLC parameter files profile
  -m mli_dir generate MLI images and store in directory mli_dir
  -d decim   raw data decimation factor (default = 5)
  -r rmin    starting slant range, default: 50 meters
  -R rmax    maximum slant range enter, default is maximum determined from chirp duration
  -h heading radar heading at the center of the azimuth sweep (deg., default = 0.0)
  -a         process using ati option for gpri2_proc.py, turn off azimuth interpolation
  -s scale   display scale factor (default = .4)
  -e exp     display exponent (default = 0.35)
  --png      convert output to PNG format
```

This script is used to process an entire stack of raw data to produce SLC images. The script generates the arguments to call the processing program *gpri2_proc.py.* The input to the script is a list containing the raw data files and the raw_par parameter files as a two column list. This list is generated using the *mk_tab* script.

Output from running the script is a pair of SLC images from each raw data file. The images from the CH-1 lower antenna has an “l” at the end of the name. Images from CH-2, upper channel have a “u” at the end of the name. Important parameters are the directory where the processed data are placed <SLC_dir> and the maximum slant range for the SLC.

The maximum slant range possible for a particular chirp is determined by the chirp length, the ADC sampling rate and the chirp bandwidth. Since we are using the full 200 MHz bandwidth for each chirp, the pixel spacing is fixed at delta_r = 0.75m. The maximum possible range R_MAX for a particular chirp duration t_c is given by:

R_MAX = 0.9 * t_c * 3.125e6 * delta_r

Hence for a 2ms chirp the maximum possible slant range is 4.218 km.

The starting slant range for the SLC images is by default 50 meters. The **-r** parameter command line parameter can be set to about 5 meters.

The decimation factor is an azimuth averaging parameter and specifies the number of echoes averaged to improve the Signal to Noise Ratio (SNR). The aim is to set the decimation factor such that the azimuth spacing is 0.1 degrees. Hence given a 2 ms chirp and rotation rate of 10 deg/sec, the decimation factor should be set to 5. Similarly, if rotating at 5 deg/sec with a 4 ms chirp, *dec* should remain 5.

The heading parameter **-h** *heading* is used for terrain geocoding and is the nominal heading of the radar clockwise from North for the center of the radar scan. This parameter is copied to the SLC_par parameter file associated with the SLC image.

There is a transient signal at the start of the raw data due to the sudden change in the put signal frequency when restarting the chirp. This transient is attenuated using a weighting function at the beginning of the raw data. The width of the section (in samples) of the section that is weighted is specified by the **-z** parameter that is by default 300 samples. To further reduce range sidelobes, this window is also applied at the end of the received data.

The transmit antenna parameter **-t** *channel* is used only for processing of data acquired with the C-band RFA that supports 2 transmit channels H and V. By default the transmit channel is V since the Ku data are all acquired with V transmit polarization. For data acquired with alternating transmit polarization (e.g. C-Band), the channel value determines the data processed in the raw data set. The SLCs are t hen generated from the data with the selected transmit channel.

5.6 GPRI-II Software Utility Programs

5.6.1 get_pos.py

Get current positioner angle in degrees

5.6.2 home_run.py

Execute home run of the positioner to find the 0 position. Should be performed at startup and also before power-down of the instrument! It is very important to do this before power-down, or else there is a significant chance that the RFA power cable will be wrapped around the tower.

5.6.3 move_abs.py

Move the antenna the a absolute motor angle.

```
*** Move antenna positioner to an absolute angle ***

    Usage: move_abs.py <angle> [rate] [--nosemaphore]
    angle  relative angle (deg.)
    rate   rotational velocity (deg/s 0.5 --> 10., default: 10.)
    --nosemaphore do not check measurement semaphore before moving
```

5.6.4 move_rel.py

Move the antenna the given angle from the current position.

```
*** Move antenna positioner a relative angle ***

  Usage: move_rel.py <angle> [rate]
    angle  relative angle (deg.)
    rate   rotational velocity (deg/s 0.5 --> 10., default: 10.)
```

5.6.5 stop_scan.py

Immediately stop motion of the tower, even in the middle of an acquisition.

5.6.6 chupa_status.py

Get current CHUPA software version, voltages, and temperature. The CHUPA is located in the RFA enclosure.

5.6.7 gps_poweron.py

Turn on power to GPS receiver located in the RFA.

5.6.8 gps_poweroff.py

Turn off power to GPS receiver located in the RFA.

5.6.9 ima_poweron.py

Turn on power to SIMA located in the RFA.

5.6.10 ima_poweroff.py

Turn off power to IMA located in the RFA.

5.6.11 rfa_poweron.py

Turn on RFA power supplied by the DISTRII to the chirp generator (CHUPA), IF amplifiers (SIMA), and microwave electronics (except for the transmitter).

5.6.12 rfa_poweroff.py

Turn off RFA power supplied by the DISTRI to the chirp generator (CHUPA), IF amplifiers (SIMA), and microwave electronics (except for the transmitter).

5.6.13 rx_poweron.py

Turn on power to the Ku-Band receiver front-ends located in the RFA.

5.6.14 rx_poweroff.py

Turn off power to the Ku-Band receiver front-ends located in the RFA.

5.6.15 tscc_status.py

```
#program to print current TSCC status, voltage input and temperature

TSCC Software version: SW V1.02
```

```
TSCC Voltage: ['U1 23.8']
TSCC Temperature (C):  ['T1 31.3']
```

5.6.16 tx_poweron.py

```
Turn on power to the Ku-Band up-converter and transmitter amplifiers.
```

5.6.17 tx_poweroff.py

```
Turn off power to the Ku-Band up-converter and transmitter amplifiers
```

5.6.18 usrp_poweron.py

```
Turn on power to the USRP software defined radio in the Instrument computer
enclosure. USRP power consumption is about 10 Watts.
```

5.6.19 usrp_poweroff.py

```
Turn on power to the USRP software defined radio in the Instrument computer
enclosure. USRP power consumption is about 10 Watts.
```

5.7 GPRI-II File Formats

Meta data and measurement data are kept separate. The meta data is stored in text files in a "keyword : value" format. The data itself is stored as plain binary without headers.

5.7.1 GPRI-II Measurement Profiles

The measurement profile dataset, contains the instrument and observation geometry parameters used for a given observation. The format is self describing, an example is shown below:

```
RF_center_freq:    1.720000e+10
IMA_atten_dB:   38
CHP_freq_min:   100.0e6
CHP_freq_max:   300.0e6
CHP_num_samp:   12500
STP_antenna_start:  90
STP_antenna_end:    180.0
STP_gear_ratio:       72
STP_rotation_speed:  10.0
TX_power: on
TX_mode: None
ADC_capture_time: 0.0
ADC_sample_rate:   6.25000e+06
antenna_elevation:       10
```

Table 3: GPRI-II Measurement Profile

The keywords identify the chirp generator (CHP), transmitter (TX), Intermediate Frequency Amplifiers (SIMA), Stepper motor driver (STP), and Analog to Digital Converter (ADC). The parameter *RF_center_freq* is the center frequency of the RFA and cannot be changed. The Ku-band radar has a nominal center frequency of 17.2 GHz.

The IF amplifier attenuation (*IMA_atten_dB*) can be set between 2 and 60 dB. Nominal system values are between 40 and 46 dB. Increasing the attenuation decreases the signal level at the input to the analog to digital convertor (ADC). It is essential that the receiver ADCs do not saturate. A test data acquisition followed by examining the data with *gpri2_raw_plot.py* should be performed. Saturation of the ADC output is observed as clipping of the input level at approximately +/- 1.0 volts. If this is the case, increase the *IMA atten_dB* value in steps of 2 dB (always even) to attenuate the signal. Increasing the attenuation by 6 dB will cut the amplitude of the digitized signal level in half.

The start and stop frequency of the baseband chirp are specified by the *CHP_freq_min* and *CHP_freq_max* parameters. These values are approximate and should normally not be changed.

The number of samples in the chirp *CHP_num_samp* determines the chirp duration. The ADC sampling rate is 6.25 MHz (6250 samples/millisec). Hence a chirp with 12500 samples is a 2ms chirp, 25000 samples is a 4 ms and so forth. The radar uses chirps between 250 us and 8 ms.

The chirp length determines the maximum range that can be imaged. Longer chirp rates are also required for longer range imaging. Below is a table showing the recommended combinations of chirp-length and rotational velocity as a function of the maximum observation range:

Maximum Slant Range	***Chirp duration***	***Rotational Velocity deg./sec.***	***Decimation Factor***
< 1 km	500 us	10	20
1 → 2.0 km	2 ms	10	5
2.0 → 5 km	4 ms	5	5
>5 km	8 ms	2.5	5

Table 4: Recommended Chirp Duration, Rotation Rate, and Decimation Factor as a function of maximum distance

The transmitter power can be turned on or off using the TX_power option. The data acquisition program itself turns the transmitter on only during data acquisition.

TX_mode is only used when there are multiple transmit output channels. In the POL-GPRI, the TX_mode can be set to *TX_RX_SEQ*. For the standard GPRI this keyword should be set to *'None'*

In the nominal case where the antenna will be scanned in azimuth, the start and stop azimuth angles can be specified with the *STP_antenna_start* and *STP_antenna_end* keywords. The SLC image produced by the scan will have a slightly smaller azimuth span due to the acceleration and deceleration of the antennas.

The rotational velocity specified in the profile is approximate. The controller in the azimuthal scanner selects a velocity very close to the specified value derived from the gear reduction ratio and the possible rates derived from the quartz crystal reference clock. Velocities can be selected in steps of about 0.1 degree/sec. The exact value for the velocity in deg/sec is stored in the metadata file (*.raw_par) that is associated with the raw data and created by *gpri2_capture_uhd.py*. The *.raw_par files are also organized by *keyword:value* and described below.

If the start and end angles are the same, then the duration of the ADC capture is specified by the *ADC_capture_time* parameter. (seconds). The value of capture time should be set to 0.0 otherwise if performing an azimuth scan.

The ADC sample rate (*ADC_sample_rate*) parameter is a fixed value in the profile and should not be changed since it is related to the analog filters in the SIMA.

Finally, the *antenna elevation* parameter is a value placed in the profile by the user and documents the physical elevation angle of the antenna. The elevation angle is set manually when the radar is installed. The elevation angle should be selected to illuminate the center of the farthest region to be imaged by the GPRI instrument.

5.7.2 Raw Data Metadata: RAW_par

The raw data is stored in a binary file of integers in little endian format. The raw data metadata are stored in the *.*raw_par* text file:

```
time_start: 2010-11-05 10:57:06.025627+00:00   #UTC time at s tart of data
geographic_coordinates:  46.6809900000, 7.6398266667 613.00 47.3
RF_center_freq: 1.72000000000e+10
RF_freq_min:    1.71000578460e+10
RF_freq_max:    1.72999421541e+10
RF_chirp_rate:  9.99425537884e+10
CHP_num_samp:   12500
TX_mode:        None
IMA_atten_dB:   38
ADC_capture_time:   9.50679
ADC_sample_rate:    6.25000e+06
STP_antenna_start:  90.00000
STP_antenna_end:    180.00000
STP_rotation_speed: 10.00000
STP_gear_ratio:     72
antenna_elevation:  10.00000
CHP_temperature:  23.500
TSC_temperature:  28.400
```

Table 5: RAW_par meta-data file generated for each raw data file

The time is specified in UTC time the +00:00 is the offset in Hours and Minutes relate to UTC. Geographic coordinates are in latitude and longitude in the WGS84 horizontal data in decimal degrees. The geographic_coordinates string format is:

latitude	decimal degrees WGS84 horizontal datum
longitude	decimal degrees WGS84 horizontal datum
altitude	altitude (m) above the geoid. This will be generally be close to the value of the height you would read on a map in the local
Geoid height	Height of the geoid relative to the WGS84 ellipsoid (vertical datum)

The radar center frequency is used for reference and is copied from the GPRI-II profile. The values of *RF_freq_min, RF_freq_max,* and *RF_chirp_rate* are exact values required for processing the raw data to produce SLC images, The frequencies are in Hz and the chirp rate in Hz/sec. The number of samples in the chirp is recorded in the *CHP_num_samp* parameter. The transmit cycle uses 1 more sample to return to the chirp start frequency as required by the Direct Digital Synthesizer used to generate the chirp.
The *TX_mode* parameter specifies the transmitter mode. The value *None* is used for the current Ku-band GPRI.

The I*MA_atten_dB* value is value using for IMA attenuation an is copied from the GPRI-II profile.

The *ADC_capture_time* parameter is the actual time that samples are recorded by the Analog-to-digital converters (ADCs) in the digitizer.

The *STP_antenna_start, STP_antenna_end* are the starting and ending used in the antenna scan. The image covers a slightly smaller angular range that is documented in the SLC_par meta data file produced by *gpri2_proc.py*.

5.7.3 SLC (Single-Look Complex) Data

The detected radar data is store in the SLF file with accompanying slc_par. The data type is indicated in the slc_par text file. In general the data is in big endian format to be compliant with the standard byte order in the GAMMA Software. The slc file format is compatible with the GAMMA Software:

```
Gamma Interferometric SAR Processor (ISP) - Image Parameter File
title: 2010-11-05 10:57:06.025627 CH1 upper
sensor: GPRI 2.0
date:  2010 11 05
start_time:     39426.500665  s
center_time:    39430.776007  s
end_time:       39435.051349  s
azimuth_line_time: 1.008147e-01  s
line_header_size:      0
range_samples:    2667
azimuth_lines:    856
range_looks:           1
azimuth_looks:         1
image_format:          FCOMPLEX
image_geometry:        SLANT_RANGE
range_scale_factor:    1.0
azimuth_scale_factor:  1.0
center_latitude:       0.00000000  degrees
center_longitude:      0.00000000  degrees
heading:               0.000000  degrees
range_pixel_spacing:   0.749912  m
azimuth_pixel_spacing: 0.000000  m
near_range_slc:        0.000000  m
center_range_slc:  1000.000000  m
far_range_slc:     2000.000000  m
first_slant_range_polynomial:  0.0 0.0 0.0 0.0 0.0 0.0
center_slant_range_polynomial: 0.0 0.0 0.0 0.0 0.0 0.0
last_slant_range_polynomial:   0.0 0.0 0.0 0.0 0.0 0.0
incidence_angle:       0.0  degrees
azimuth_deskew:        OFF
azimuth_angle:         0.0 degrees
radar_frequency:       1.720000e+10  Hz
adc_sampling_rate:     1.998851e+08  Hz
chirp_bandwidth:       1.998843e+08  Hz
prf:                   9.919192  Hz
azimuth_proc_bandwidth: 0.0  Hz
doppler_polynomial:     0.0 0.0 0.0 0.0
doppler_poly_dot:       0.0 0.0 0.0 0.0
doppler_poly_ddot:      0.0 0.0 0.0 0.0
receiver_gain:          22.000  dB
calibration_gain:        0.000  dB
sar_to_earth_center:             0.0000  m
earth_radius_below_sensor:       0.0000  m
earth_semi_major_axis:     6378137.0000  m
earth_semi_minor_axis:     6356752.3141  m
number_of_state_vectors:   0
GPRI_az_start_angle:     93.33750  degrees
GPRI_az_angle_step:       0.10081  degrees
GPRI_ant_elev_angle:     10.00000  degrees
GPRI_ref_north:      46.68099000 #GPS lat/lon in the WGS84 horizontal datum
GPRI_ref_east:        7.63982667
```

```
GPRI_ref_alt:              453.0  m      #geoidal height of reference point
GPRI_geoid:                47.000 m      #geoid height relative to WGS84 ellipsoid
GPRI_scan_heading:         90.00000  degrees  #rel. to N. at image azimuth center
GPRI_tx_coord:    0.2218   0.0000  -0.3694  m m m
GPRI_rx1_coord:   0.2218   0.0000  -0.0194  m m m
GPRI_rx2_coord:   0.2218   0.0000   0.2306  m m m
GPRI_tower_roll:   0.00000  degrees
GPRI_tower_pitch:  0.00000  degrees
GPRI_phase_offset: 0.00000  radians
```

The SLC parameter file contains metadata related to processing the GPRI raw data. A number of the keyword:value parameters are GPRI specific. The keywords of these parameters are all prefixed with GPRI. Most significant of these parameters are the starting azimuth rotation angle for the image and the spacing between image lines.

The positional information for the GPRI position are contained in the *GPRI_ref_north* (latitude in decimal degrees), *GPRI_ref_east* (longitude in decimal degrees) and GPRI_ref_alt (geoidal height in meters) parameters. The height of the geoid relative to the WGS84 ellipsoid is in the *GPRI_geoid* parameter. The reference position is the location of the GPS antenna on the top of the antenna tower. The *GPRI_tx_coord, GPRI_rx1_coord,* and *GPRI_rx2_coord* are the positions of the antenna phase centers in the local tower coordinate system. The origin of the tower coordinates is the intersection of the rotation axis and the central plane of the tower, 40 cm from the bottom mounting plate. The *GPRI_scan_heading* is the heading angle clockwise from north of the center azimuth line of the SLC image.

6. Gamma Software used for GPRI-II Processing

The processing strategy is to bring GPRI data in an SLC format as supported by the GAMMA Software. This has the advantage that a very broad functionality becomes available for the further processing. As a consequence it is required that at least licenses for the GAMMA ISP/DIFF&GEO modules are required to process the GPRI data.

Within the Gamma Software there is special provision for reading and processing GPRI-II data. Included with each GPRI-II data set are specific meta data that describes the GPRI-II imaging geometry, and GPS data. Gamma software programs that work directly with the GPRI-II data recognize and use these meta-data as required. There are also special programs for terrain geocoding of GPRI-II data.

The following is a concise overview of the GAMMA Software. For detailed documentation on processing sequences or individual programs the user is referred to the GAMMA Software documentation.

GAMMA Software supports the entire processing from SAR raw data to products such as digital elevation models, displacement maps and landuse maps. The software is grouped into five packages:

(3) Modular SAR Processor (MSP / not required for GPRI data processing)
(4) Interferometric SAR Processor (ISP)
(5) Differential Interferometry and Geocoding (DIFF&GEO)
(6) Land Application Tools (LAT)
(7) Interferometric Point Target Analysis (IPTA)

Each of the packages is very modular and can therefore be used in the way the user prefers. Programs can be run individually on the command line or they can be called from scripts that permit running often used processing sequences in a more operational and efficient way.

The Gamma software is written in ANSI-C. Many of the computationally intensive programs have been parallelized using OPENMP for multiple core processors. Standard binary distributions are available for:

- Intel/AMD processor Linux OS (e.g. Ubuntu, Debian, CentOS, Fedora) 64-bit
- Intel/AMD processor Microsoft Win7, Win8 64-bit OS systems
- Mac OS-X 10.9 Mavericks (64-bit binaries)

Distributions for other platforms may be provided on demand.

Besides GPRI data processing the software supports processing of a wide range of spaceborne and airborne SAR data, including data of the following space-borne SAR instruments:
ERS-1, ERS-2, ENVISAT, Radarsat-1, Radarsat-2, TerraSAR-X, Tandem-X, Cosmo-Skymed, KOMPSAT, JERS-1, ALOS PALSAR, and RISAT

The main processing software is complemented by quality control and display programs. The display of the final and intermediate products is supported with display programs and programs to generate easily portable images in SUN raster or BMP format. Data can also be exported in GeoTIFF format.

6.1 Interferometric SAR Processing Software (ISP):

The Gamma Interferometric SAR Processor (ISP) encompasses a full range of algorithms required for generation of interferograms, height and coherence maps. The processing steps include baseline estimation from orbit data, precision registration of interferometric image pairs, interferogram generation (including common spectral band filtering), estimation of interferometric correlation, removal of flat Earth phase trend, adaptive filtering of interferograms, phase unwrapping using either a branch cut algorithm or an approach based on a triangular irregular network with a minimum cost flow optimization technique, precision estimation of interferometric baselines from ground control points, generation of topographic height, and image rectification and interpolation of interferometric height and slope maps. Absolute radiometric calibration of ESA PAF processed SLC and PRI data is also supported. Offset tracking techniques starting from SLC pairs are also supported by the ISP. Importing TerraSAR-X SLC and interferometry with these SLCs is supported.

The ISP is also the base for the differential interferometry software.

6.2 Differential Interferometry and Geocoding (DIFF&GEO):

The differential interferometry module (DIFF&GEO) is designed to be very flexible with respect to separating topographic and displacement effects. If you have a DEM available from another source you can use this to simulate an interferogram and use that to subtract the topographic phase effects (that's probably the best solution in this case). The precision registration between the simulated interferogram and the true interferogram (due to uncertainties in the orbit data for example) can be done automatically.

Other approaches, which are independent of a DEM, are 3 and 4-pass interferometry. In this case an interferogram, preferably one without differential effects, is used as reference to subtract the topographic phase effects. It is necessary to unwrap this reference interferogram
(putting some limitations with respect of steep terrain and low coherence over forests and water).

In addition the DIFF&GEO package provides a complete set of programs for precision geocoding. Terrain and ellipsoid corrected geocoding from range-Doppler to map coordinates and vise versa are supported. Interpolation algorithms are applied for the resampling step. Due to inaccurate orbit information the geocoding requires a fine registration step. In order to automate this step a SAR image is simulated (based on the DEM) and used to automatically determine the fine registration using cross correlation analyses. The geocoding of images in ground-range geometry is also supported.

The DIFF&GEO also supports SLC co-registration considering terrain topography effects. Furthermore, offset tracking techniques starting from detected images are supported.

6.3 Land Application Tools (LAT)

The land application tools support filtering, parameter extraction, simple classification schemes, mosaicking, and additional data display tools.

Filtering tools include spatial filters (moving average, median, Frost, Lee, Enhanced Lee, Gamma Map) as well as multi-temporal filtering tools (based on Quegan et al). Data of specified polygon regions and lines can be extracted and investigated (mean values, standard deviations, histograms). Adaptive coherence, texture, and effective number of looks estimation programs as well as programs to conduct simple calculations with image data are included. Single or multiple classes can be classified based on one or several registered input data sets using a hierarchic thresholding scheme. Mosaicking of multiple data sets in map geometry is supported. Tools to generate RGB and HIS composites and tools to exchange the image intensity of one image with that of another image are also provided.

6.4 Interferometric Point Target Analysis (IPTA):

Instead of a full two-dimensional analysis of a stack of interferograms only the phases of selected points are analyzed. For points which correspond to point targets the geometric decorrelation observed for distributed targets does not occur, permitting to interpret interferometric phases even for pairs with baselines above the critical baseline. Consequently, a more complete interpretation of the SAR data becomes possible. More interferometric pairs can be included in the analysis, leading to an increase of the accuracy and temporal coverage achieved.

In the IPTA much of the data are kept in vector data format, in so-called point data stacks, which permits to dramatically increase the processing efficiency and reduce the disk and memory requirements. Another important element are programs for a systematic use of the temporal dimension of the data.

A typical IPTA processing sequence starts by co-registering multiple repeat-pass SLCs. Then, an important step is the identification of point targets. For the selected point targets the interferometric phases are further investigated. The physical models describing the dependence of the interferometric phase on system and target parameters are exactly the same as used in conventional interferometry. An iteration concept is used for the optimization of the information retrieval from the multi-temporal set. Parameters that are improved include the topographic heights of the scatterers, the deformations, the atmospheric path delays, and the baselines. Different phase terms can be discriminated based on its differing spatial, temporal, and baseline dependencies. The atmospheric phase delay, for example, is relatively smooth in the spatial dimension, but uncorrelated in the temporal dimension. The topographic phase shows a linear dependence on the perpendicular baseline component and the deformation can in many cases be assumed to be relatively smooth (or low-pass) in the spatial and temporal dimensions.

The main results derived with the IPTA are topographic heights, average deformation rates, deformation histories, and relative atmospheric path delays.

The IPTA is fully compatible with the other GAMMA software. Programs for conversion between the vector data used in the IPTA and the normal 2D raster formats used are included. For a convenient use of the IPTA access to the GAMMA ISP and DIFF&GEO modules is required.

The IPTA package also includes support for calculation of time-series from a set of unwrapped differential interferograms that form a 2-D graph with respect to baselines and time-intervals. This interferogram network can be solved for deformation phase, and height correction. In addition the solution can be optimized with respect to a set of smoothing constraints that can be useful for suppression of noise due to changes in the troposphere.

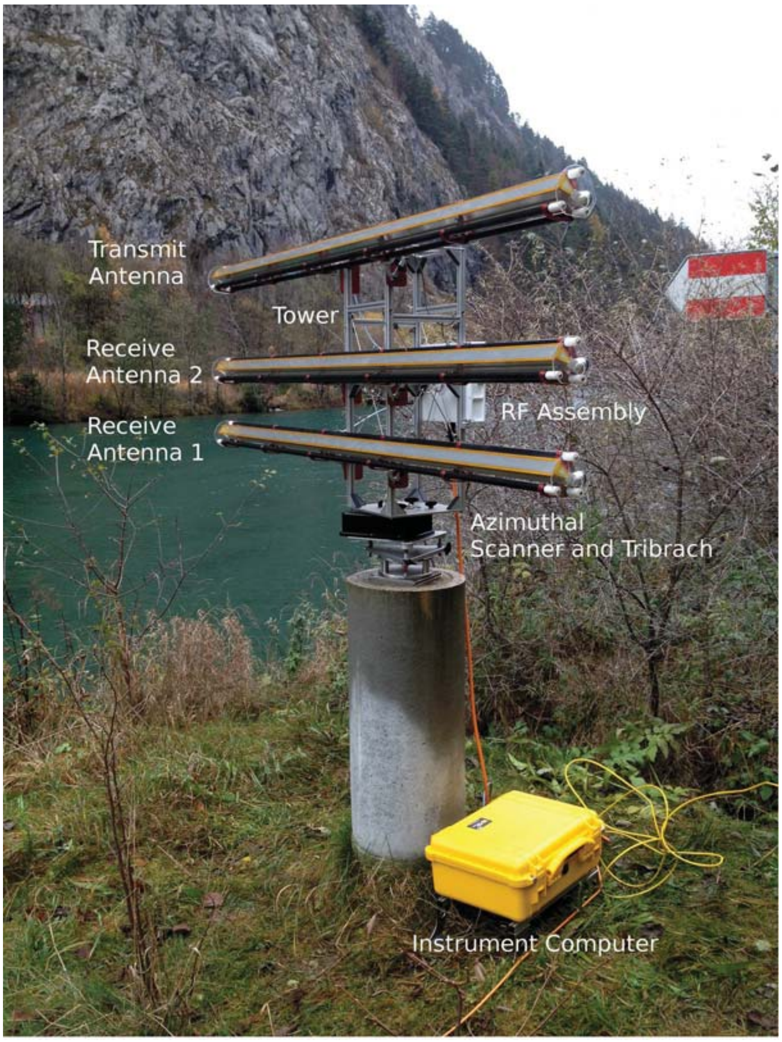
6.5 Maintenance and Support:

Gamma uses it's software for it's own research and development activities, which also means that the software is kept up-to-date with the newest developments. Your contacts for the support are those persons who developed the software and who use it regularly for their own work!

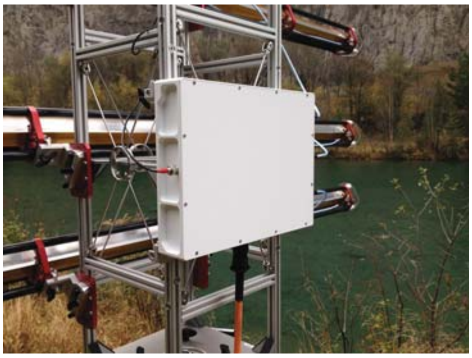
Additional information is available at GAMMA’s homepage http://www.gamma-rs.ch.

7. Instrument Specifications

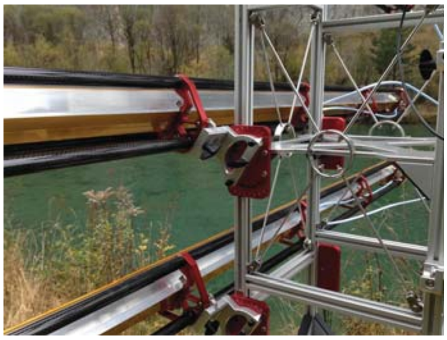
Frequency Range	17.1 to 17.3 GHz, 200 MHz BW Frequency accuracy < 100 Hz
GPRI Antenna Pattern	0.385 deg -3 dB azimuth beamwidth (2-way) 35 deg. -3 dB elevation beamwidth (2-way)
GPRI Transmitter Modulation	FM-CW chirp duration 250 microsec. to 16 millisec. 200 MHz max. bandwidth (programmable)
GPRI Measurement Range	50 m to 10 km
Time and Frequency Reference	100 MHz GPS-disciplined crystal oscillator
Range sample spacing and resolution	0.75 m sample spacing, 0.95 m -3 dB peak width -26 dB peak range sidelobe
Azimuth Resolution (-3 dB)	6.8m at 1 km range, -3 dB peak-width -30 dB peak azimuth sidelobe
Deformation Measurement Precision and Accuracy	Deformation Measurement Precision 0.03 mm at 30 dB SNR 0.125 mm at 20 dB SNR Deformation Measurement Accuracy Typically less than 1 mm at 1 km, dependent on variability of atmospheric water vapor
Receiver Channels	2 independent receiver channels, dual 14-bit ADC dual receive channels, 6.25 MHz ADC sample frequency
Power Requirements	115 W average with 21-32 VDC input 125 W average with 110-240 VAC input
Instrument Computer and Operating System	Industrial mITX PC, Multi-Core I5 CPU, 8 GB RAM, 1 TB Disk Storage, Ubuntu Linux OS
Computer Interfaces	USB2, Gigabit Ethernet. Communication via HTTPS and SSH
Azimuth Scan Time	Nominal 10 deg/s Azimuth sweep rate is programmable in steps of 0.5 deg/s
Operation Temperature Range	-20 C to +50 C
Instrument Weight	Instrument Computer 16.3 kg, RF Assembly 5.5 kg, Tower 9.9 kg, Tribrach leveler and azimuth scanner 8.9 kg, Antennas 3 x 2.7 kg, Tripod 8.9 kg.
Instrument Dimensions	Tower: 80x28x28 cm, RF assembly: 30x26x6 cm Controller/Power: 52x42x30 cm Antennas: 210x12.5x12.5 cm



GPRI Radar on Pedestal



RF Assembly

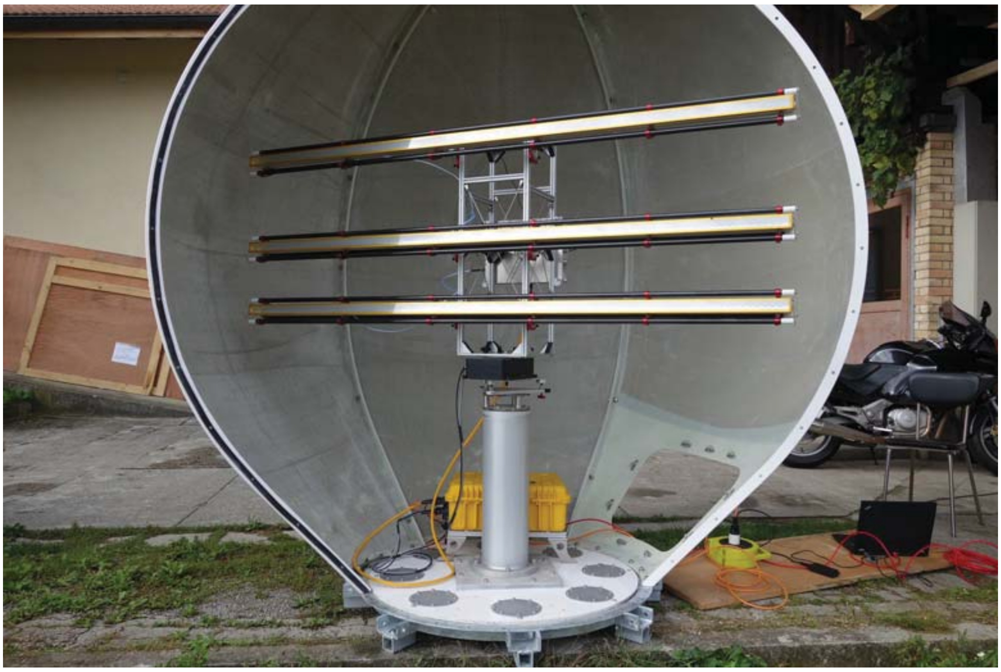


Elevation Adjustment

GPRI Tripod Mount

1. *Rapid Deployment: 15 Minutes*
2. *Tripod or Pedestal mounting*
3. *Modular construction*
4. *Precision design and fabrication for repeat measurement campaigns*
5. *Self-contained data acquisition, data storage and processing*
6. *Optional Lithium battery pack for 6 hr operation*

1. *Optional 2.5 m diameter radome with aluminum pedestal provides environmental protection for long-term observations. Designed for winds up to 150 km/h*
2. *Excellent environmental protection permits operation of radar possible in high winds*
3. *Radome attenuation < 2 dB, constant phase delay*
4. *Temperature control with active ventilation of radome interior*
5. *Radome can be trailer or truck-mounted for mobile deployment*
6. *1.2 meter galvanized steel base can be mounted on concrete pad*
7. *Optional extended base supports available for deployment without concrete pad*



8. Appendix A

Measurement Protocol

It is also recommended to take photos of the installation including the Antenna Elevation angle, radar location, and the region of interest.

Campaign Name	
Customer	
Site Name and Coordinates	
Date	
Weather (Temp, Wind)	
Antenna elevation angle	
Heading Angle at Scene Center (deg.)	
GPS Coordinates	
Power Source	
Chirp Waveform	
TX_mode (C-Band)	
RX Channel Attenuation	
Start Azimuth angle	
Stop Azimuth angle	
Azimuth Scanrate (deg/s)	
Start/End Time	
Acquisition Time Interval	
Dataset Names	
Pictures	
Remarks	