Bistatic Radar Manual:

Instructions for Building Hardware, Conducting Experiments and Processing Data

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Version 1
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Contents

Overview

This manual contains information for building a bistatic radar centered at 320 MHz with a bandwidth of 15.36 MHz, 1 second chirp length, and intermittent 8 second receiver recordings.

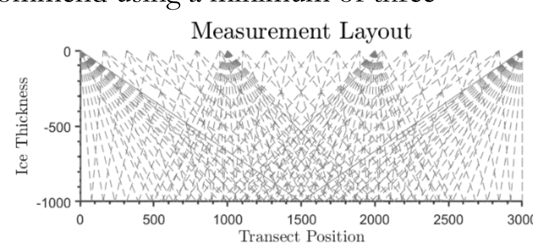
Important Reminders

Some devices in this experiment are sensitive and can easily be damaged. Most issues are easily avoided by following the reminders below.

- PRES
    - Do not run the PRES without either an antenna or 50 ohm load connected to the RX side of the PRES. An antenna should always be connected to the TX side of the PRES.
- LNA
    - Do not power the LNA unless both its ports are connected to either an antenna, the SDR, or a 50ohm load.
    - Do not touch a piece of metal to the + and case of the LNA. The case is grounded and it will shock you.
- SDR
    - The maximum input power to the SDR = 0dBm. [1,41]
        - When using the LNA and the default internal gain of 62dB, do not turn on the SDR until you are 200m from the PRES transmitter.
    - Do not run the SDR unless the RX port is plugged into an antenna.
    - The SDR cannot be left charging longer than 12 hours.

Experiment Planning

For a tomography experiment we recommend developing the inversion model and performing a sensitivity study to determine the number of data points you need for testing your hypothesis. However, in the absence of sensitivity analysis, we recommend using a minimum of three transmitter positions (preferably 4), with 10 receiver positions per transmitter location, and a transect length three times the length of your ice thickness. For example, the figure to the right shows the use of 4 transmitter positions, 20 receiver locations, and a transect length 3x the ice thickness. Each receive location will require a different number of coherently summed chirps to recover the basal reflection, depending on the accumulated signal attenuation for a given measurement. For example, an 800m antenna offset on 1km thick ice only requires 1s of measurement time to detect the bed, while longer offsets require more measurement time.



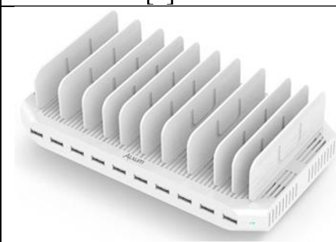
Materials List

Required Materials

Below are the minimum materials required to simultaneously run two redundant SDR receivers in a bistatic experiment. Tools for building are not included on the list. A set of two receivers as listed in the required materials costs $10,068 at the time of writing, excluding the ApRES unit.

Type	Item	Qty	Shopping Link	Purpose	Lead Time	Image
Device	Ettus Research E312	2	https://www.ettus.com/all-products/usrp-e312/ [1]	Radar Receiver	4 mo	 [1]
	ApRES	1	Contact Keith Nicholls at BAS (kwni@bas.ac.uk)	Radar Transmitter	6 mo	 [2]
	LNA (20 dB gain, 0.5 dB NF, centered @ 330MHz)	2	Special order: http://www.advancedreceiver.com/page3.html [3]	Amplify received signal	2 mo	
	Bowtie Antennas	3	Contact Keith Nicholls at BAS (kwni@bas.ac.uk)			
	4Tb Hard Drive	1	https://www.amazon.com/gp/product/B07CRGSR16/ref=ppx_yo_dt_b_asin_title_o05_s02?ie=UTF8&psc=1 [4]	Store data		 [4]

	Electric hand warmers	4	https://www.amazon.com/OCOOPA-Rechargeable-10000mAh-Handwarmer-Motorcycling/dp/B08GQ1HHKQ/ref=sr_1_2_sspa?dchild=1&keywords=electric+hand+warmer&qid=1630350836&refinements=p_72%3A1248957011&rnid=1248955011&s=sporting-goods&sr=1-2-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEyUFFBMFVQTUExVlZLJmVuY3J5cHRlZElkPUEwNzE4NDI4M0RIWVhZNEI4TEsxNiZlbmNyeXB0ZWRBZElkPUEwMTU3NjA5MVlLWVVTUVFFNE5QVCZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ1NsaWNrPXRydWU= [5] https://www.human-creations.com/product-page/energyflux-g3-5200mah-rechargeable-hand-warmer-external-battery-pack [6]	Heating element to keep radar receiver warm		 [6]
	SanDisk 32GB SD card	1	https://www.amazon.com/SanDisk-Ultra-UHS-I-Memory-SDSDUN4-032G-GN6IN/dp/B08GYG6T12/ref=sr_1_4?dchild=1&keywords=sandisk+32GB+SD&qid=1626217291&s=electronics&sr=1-4	Note: Not all brands work in the PRES		 [7]

	PNY Pro Elite 256GB Flash Drive	4	https://www.pny.com/pro-elite-usb3?sku=P-FD256PRO-GE [8]	The SDR writes data to a flash drive. PNY was found to have the fastest write speeds of flash drives tested		 [8]
	Hand warmer charging dock	1	https://www.amazon.com/Alxum-Charging-Station-Multiple-Organizer/dp/B01K7F51VU/ref=sr_1_1?crid=3BEYJX7TZH57C&dchild=1&keywords=ipad+charging+station+96w+10-port+alxum+usb+charging+station&qid=1619127437&sprefix=ipad+charging+station+96W+%2Celectronics%2C205&sr=8-1 [9]	Recharge electric hand warmers		 [9]
	3V GPS antenna	2	https://www.amazon.com/Trimble-66800-52-SP-Magnetic-Antenna-connector/dp/B072NYQPH7 [10] https://www.ettus.com/all-products/gps-ant-3v/ [11]	Required for SDR to stamp data with GPS location		 [10]
RF	N-type male to SMA male	1	https://www.amazon.com/DZS-Elec-Connecting-Coaxial-Extender/dp/B072C6CJBC/ref=sr_1_5?dchild=1&keywords=N+type+to+SMA+cable+6+in&qid=1630350622&sr=8-5 [12]	Connecting PRES to SDR		

	SMA Male-Male 6in	1	https://www.amazon.com/Coaxial-Antenna-Extension-Security-Pigtail/dp/B091TFR9WC/ref=sr_1_10?dchild=1&keywords=SMA+Male-Male+6in&qid=1626217731&sr=8-10 [13]	Used for bypassing LNA for reference chirp recording		 [13]
	SMA female-female adapter	1	https://www.amazon.com/gp/product/B07FDHBS19/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1 [14]	Required for reference chirp test		 [14]
	Sma male-TNC male Cable	3	https://www.amazon.com/15FT-LMR195-cable-SMA-Male-TNC/dp/B004WL9TIC/ref=sr_1_1?dchild=1&keywords=sma+MALE+TO+tnc+MALE+CABLE+15+ft+LMR195&qid=1626217960&s=electronics&sr=1-1 [15]	Connect antenna to SDR receiver and ApRES		 [15]
	N-type 50 ohm load	1	https://www.digikey.com/en/products/detail/amphenol-rf/202109-10/1011850 [16]	Connect to ApRES transmit port to prevent damage to system	1 wk	 [16]

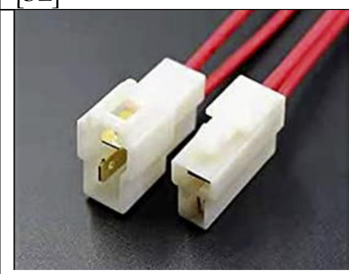
	TNC 50 ohm loads	15	https://www.digikey.com/en/products/detail/amphenol-rf/202117/1011794?s=N4IgTCBcDaIIGEAaBGNB2AtAOQCIgF0BfIA [17]	If MIMO is used instead of SISO, used to prevent damage	1 wk	 [17]
	40 dB attenuator SMA female - male	1	https://www.amazon.com/BECEN-10W-attenuator-3GHz-40db/dp/B07MZLVY9T/ref=sr_1_4?dchild=1&keywords=40db+attenuator&qid=1626218199&sr=8-4 [18]	Reference chirp		 [18]
	SMA-SMB adapters	4	https://www.amazon.com/Maxmoral-Female-Connector-Coaxial-Adapter/dp/B071SDXWFW [19]	Adapters for SDR ports		 [19]
	N-type M – SMA F adapter	1	https://www.amazon.com/RFaha-Female-Adapter-Coaxial-Connector/dp/B0932LQB4R/ref=sr_1_17_sspa?dchild=1&keywords=N-type+M+to+SMA+F+adapter&qid=1626218264&s=electronics&sr=1-17-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzQUFBSlJOTTUwV1pEJmVuY3J5cHRlZElkPUEwOTE4Mjc2M1ZTTktETFdZVzE4RiZlbmNyeXB0ZWRBZElkPUEwNTYwOTEzMTY0T1BXVFhGN1dOWSZ3aWRnZXROYW1lPXNwX210ZiZhY3Rpb249Y2xpY2tSZWRpc			 [20]

			mVjdCZkb05vdExvZ0NsaWNrPXRydWU= [20]			
Cables	E312 Power Cable	2	Comes with SDR	Charging SDR receiver overnight		 [1]
	12V battery charger	1	https://www.amazon.com/gp/product/B001G8AIMU/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 [21]	Charge batteries overnight		 [21]
	Hard drive cables	2	Comes with hard drives			
	Ethernet cable	1	https://www.amazon.com/AmazonBasics-RJ45-Cat-6-Ethernet-Patch-Cable-5-Feet-1-5-Meters/dp/B00N2VILDM/ref=sr_1_1_sspa?dchild=1&keywords=ethernet+cable&qid=1626218419&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzSUpFNThDQVg5VVFEJmVuY3J5cHRlZElkPUEwODI1NzY5M0dQN09CRjVPVlhYRyZlbmNyeXB0ZWRBZElkPUEwMDM2NDMzTUFTTzNIRTJBUVQ4JndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ== [22]	Communicate with SDR via ethernet		 [22]

	USB-USB cable to connect to heated box	1	https://www.amazon.com/gp/product/B00P0E39CM/ref=ppx_yo_dt_b_asin_title_o07_s00?ie=UTF8&psc=1 [23]	Connecting computer to SDR without opening heated box		 [23]
	USB-micro usb cable for hand warmers	4	Included with hand warmers	Charging heating element		
Tools	12V 4.5A battery	2	https://www.amazon.com/gp/product/B00A82A4N8/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 [24]	Extend battery life of SDR during experiments		 [24]
	permanent marker	1		Useful in the field		
	Electrical tape	1		Just in case		
	Zip ties	1		Useful in the field		
	Dell Rugged Extreme 7424 laptop	1		Laptop – wouldn't recommend	2 wk	
	Rugged laptop charger	1		Charging laptop		
	Precision 7730 laptop	1		Back up laptop – wouldn't recommend due to issues with cold weather	2 wk	

	Precision laptop charger	1		Charging back up laptop		
Heated Box	SMA Male-male flexible 2.5 in Cable	4	http://www.crossrf.com/cable-assemblies/flexible-cables/rg-316-cable-assembly [25]	Used in heated box for receiver		
	SMA Male-male rigid 2.5in Cable	2	https://www.digikey.com/en/products/detail/crystek-corporation/CCSMA-MM-086-3/2433482 [26]	Used in heated box for receiver		
	Right angle SMA Male-Female adapters	2	https://www.amazon.com/gp/product/B00VHAZ0KW/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1 [27]	Used in heated box		

	USB-micro usb cable for/in heated boxes	2	https://www.amazon.com/gp/product/B07GGTZG2V/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1 [28]	Connecting SDR to heated box port		 [28]
	Battery Terminal Clips	1 kit	https://www.amazon.com/gp/product/B07T6CLGL2/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 [29]	Connecting battery to SDR		 [29]
	1400 Pelicase	2	https://www.pelican.com/us/en/product/cases/protector/1400?sku=1400-000-150 [2]	Heated box shell	2 wk	 [2]
	Foam glue	1	https://www.amazon.com/gp/product/B011XWDTOW/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1 [30]	Gluing pelicase foam		 [30]

	SMA female-female waterproof bulkhead	4	https://www.amazon.com/gp/product/B07B8F5XYD/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1 [31]	Waterproof SMA ports		 [31]
	USB bulkhead waterproof	2	https://www.amazon.com/gp/product/B07RPW5XGB/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1 [32]	Waterproof connection of SDR to outside of case		 [32]
	LNA connectors	1 kit	https://www.amazon.com/gp/product/B07X3K32DC/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1 [33]			 [33]
	DC plugs	1 kit	https://www.amazon.com/gp/product/B01LX51QHN/ref=ppx_yo_dt_b_asin_title_o02_s01?ie=UTF8&psc=1 [34]			 [34]
	Plumbers Caulk	1		waterproofing		
	16 or 18 AWG wire	1 spool				

Optional Materials

These are additional items that our team takes to the field. We typically take spares of all cables on the required materials list.

Category	Item	Qty	Shopping Link	Purpose
Devices	Spectrum analyzer	1		Test instrument to confirm radar is transmitting
	Multimeter	1		Tool for debugging
RF Cables	SMA Male-Male 3ft	6	https://www.amazon.com/gp/product/B00MA50Q16/ref=ppx_yo_dt_b_asin_title_o08_s00?ie=UTF8&psc=1 [35]	Just in case
	SMA Male-Female 6 in	2		Just in case
	30dB, 30dB, 20dB, 10dB attenuators	4		Just in Case
	TNC M-SMA M, TNC F – SMA M, SMA F – TNC M, N M-SMA M adapters	3		Just in Case
	SMA Male-Male adapter	3		Just in Case
Tools	Alligator clips	4		Just in Case
	Spare Dell Precision Laptop Battery	1		Back up Laptop battery
	9V batteries for multimeter	2		Back up multimeter batteries
	Philips head screw drive	1		opening multimeter or precision laptop
	Allen Key	1		Opening SDR for debugging
	paracord	1		Just in case
	Wire Snippers	1		Just in case

Linux Cheat Sheet

The linux terminal is used throughout this experiment, and you may find the below commands useful.

Fix ethernet on host laptop

  sudo ifconfig enx9cebe839911f 192.168.10.1 netmask 255.255.255.0 up

Scroll up terminal

  Ctrl + a

  Esc

  Now you can scroll up with the arrow keys.

  When done hit esc

Using Vim

  To find a word

  To find a word in Vi/Vim, simply type the / or ? key, followed by the word you're searching for.

  Once found, you can press the n key to go directly to the next occurrence of the word.

Terminal not working printing all outputs

  reset -c

  Plug in SDR

  echo -e "\033c"

Hardware Configuration

SDR

Calibrate device: https://files.ettus.com/manual/page_power.html

This experiment uses an Ettus Research E312 as the radar receiver. The radio can be purchased from https://kb.ettus.com/Knowledge_Base. Full instructions can also be found on this website, and the material presented here is only intended to supplement the official instructions.

The SDR configuration instructions presented here are split into two categories. “Out of the Box” provides the easiest instructions and is intended for users that do not need to modify the SDR code we provide. “Code Developer” provides instructions for setting up the SDR and host computer for modifying our code.

Out of the Box

Download the SDR image and flash it to the microSD card. These instructions require a linux operating system for your computer.

1. Download the SDR image
   The image, `bienert_SDR_image_fc320_bw15_rec8.image.gz` from https://stanford.box.com/s/kon0nm0u3dpajoaicnex3uwzep2q9ag4

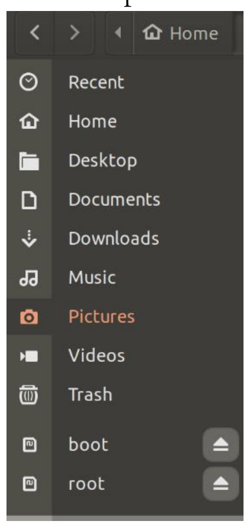
   ```
   bienert_SDR_image_fc320_bw15_rec8.image.gz
   ```
2. Eject the microSD card from the Ettus E312 SDR.
3. Identify the name of the microSD card.

Type lsblk without the microSD card inserted. You will see a list of devices including you computer's internal storage. Here, my laptop's SSDs are nvme1n1 and nvme0n1.

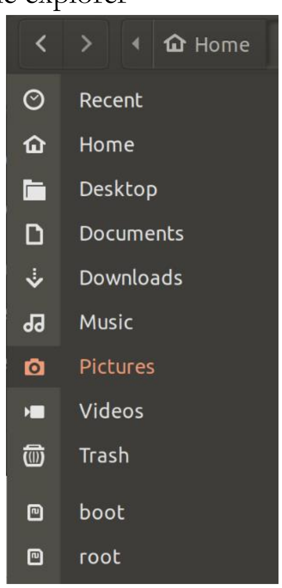
```
nvme0n1      259:0    0 238.5G  0 disk
├─nvme0n1p1 259:1    0   512M  0 part /boot/efi
└─nvme0n1p2 259:2    0   238G  0 part /
nvme1n1      259:3    0 931.5G  0 disk
├─nvme1n1p1 259:4    0 931.3G  0 part
├─nvme1n1p2 259:5    0   100M  0 part
└─nvme1n1p3 259:6    0   128M  0 part
```

Now, plug in the microSD card into your laptop and type lsblk again. A new device will appear. In the example below, the microSD card has the name mmcblk0. You will use the microSD card name in step 6 – be certain that you have properly identified the microSD card.

The microSD card also appears in the file explorer as `boot` and `root`.



4. Eject `boot` and `root` from the file explorer



5. Use lsblk to check that the microSD card in no longer mounted. In step 3, my device mmcblk0 was mounted to /media/bienert/boot and /media/bienert/root. After ejecting, the device mmcblk0 no longer has a mount point.

```
mmcblk0       179:0    0   7.4G  0 disk
├─mmcblk0p1 179:1    0  17.7M  0 part
└─mmcblk0p2 179:2    0     7G  0 part
nvme0n1       259:0    0 238.5G  0 disk
├─nvme0n1p1 259:1    0   512M  0 part /boot/efi
└─nvme0n1p2 259:2    0   238G  0 part /
nvme1n1       259:3    0 931.5G  0 disk
├─nvme1n1p1 259:4    0 931.3G  0 part
├─nvme1n1p2 259:5    0   100M  0 part
└─nvme1n1p3 259:6    0   128M  0 part
```

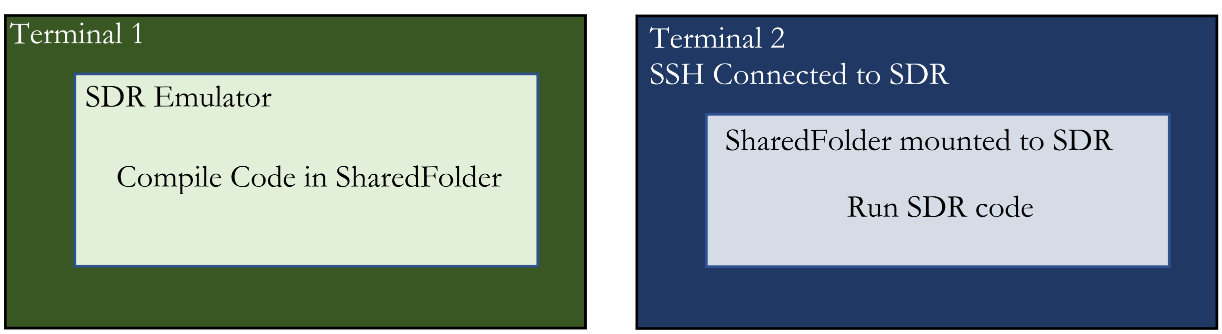
6. CAUTION: the dd command can overwrite your hard drive if you use it incorrectly. From the terminal change directories (using cd) to the folder containing the SDR image downloaded in step 1. Use the dd command to flash the image onto the microSD card with the following command. Change yourDeviceName to the device name given with lsblk. Be certain that you have identified the name of the microSD card and not your computer's SSD.

   gunzip -c bienert_SDR_image_fc320_bw15_rec8.image.gz | sudo dd of=/dev/yourDeviceName bs=64k

```
bienert@bienert-ThinkPad-X1-Extreme-2nd:~/Desktop$ sudo gunzip -c bienert_SDR_image_fc320_bw15_rec8.image.gz  |sudo  dd of=/dev/mmcblk0 bs=64K
```

Code Developer

While the SDR code can be modified on the device after following the "Out of the Box" directions, compiling code directly on the SDR is very slow due to the limited capabilities of the onboard processor. Code development is much faster if it can be compiled on a host laptop for testing then moved to the SDR for deployment. This is made possible using an SDK which allows a host computer to emulate the operating system of the SDR. While working with the SDK, two terminals will be open on the host computer – one connected to the host computer emulating the SDR for writing and compiling code, and another terminal connected to the SDR which mounts to the host computer's file system (essentially using the host laptop as a flash drive), allowing the SDR to run code stored on the host computer. Below is a graphic depicting the roles of each terminal:



Please note that these directions are written for and tested on Linux operating systems.

Update SDR

1. Obtain an updated SD card image from: https://files.ettus.com/binaries/cache/e3xx/meta-ettus-v3.15.0.0/e3xx_e310_sg3_sdimg_default-v3.15.0.0.zip

2. Flash the SD card image to the SDR's SD card using the dd command. Instructions on using the dd command can be found here: https://kb.ettus.com/Writing_the_USRP_File_System_Disk_Image_to_a_SD_Card#Writing_the_SD_Card_Image Be sure to use the SD card image downloaded in step 1.

3. Connect to the SDR over micro usb and change the ip address of your computer and the SDR such that the first 3 numbers match. Set the IP address of computer and SDR to be 192.168.10.X, netmask: 255.255.255.0 and gateway (to be a slight variant on the IP address) as 192.168.10.Y. You chose the values of X and Y.

   On the SDR….
   V4.0.0.0:

   Vim /etc/systemd/networkd
   Add Address=192.168.10.2 below the [Network] title

   Other versions before v4.0.0.0

   cd /etc/network
   vim interfaces
   change the ip address, netmak, gateway then restart the SDR

   Make sure that the ethernet is connected now: From the laptop type ping 192.168.10.X

4. Updating the FPGA code can be completed easily using the UHD code, but this requires that UHD is installed on the host computer outside of the SDK. Install UHD version 3.15.0.0 following the directions from https://kb.ettus.com/Building_and_Installing_the_USRP_Open-Source_Toolchain_(UHD_and_GNU_Radio)_on_Linux.

5. After installing UHD, download the FPGA images and load them onto the device:

   uhd_images_downloader

   uhd_image_loader -a type=e3xx,addr=192.168.10.X

Set up emulator environment on the host laptop

1. Follow the instructions "Preparing the Development Machine: Preparation from Source" from: https://kb.ettus.com/Software_Development_on_the_E310_and_E312. However, use the sdk downloaded in step one above because the one listed on this web page is out of date and not compatible with our code.

2. Follow the instructions for "Compiling and Installing UHD," however after the git clone step, type

```
git checkout v3.15.0.0
```

to checkout the same UHD version as the SDK downloaded in step 1.

Run emulator environment on the host laptop

1. Every time you want to emulate the SDR for compiling code, you will need to follow the instructions for "Running the new UHD via sshfs." In summary, you should have two terminals open

   Terminal 1: Host computer configured to mimic SDR

   ```
   cd ~/prefix
   source ./environment-setup-cortexa9t2hf-neon-oe-linux-gnueabi
   ```

   This sets up the terminal to mimic the SDR. From here, modify code in prefix, and build it with:

   ```
   mkdir build
   cd build
   cmake ../
   make
   ```

   Terminal 2: SDR mounted to folder on host computer

   ```
   ssh root@192.168.10.2
   sshfs bienert@192.168.10.1:prefix/ usr/
   ```

   Now you can run whatever code you compiled

Install receiver code on SDR

1. From the github, go to the folder `SDR_Code` and download the folder `cpp_code` and the code `run_me_GPS_Thwaites_2020.sh`.
2. Move these two files to ~/prefix on the host computer.
3. Open a terminal and type

   ```
   cd ~/prefix
   mkdir build
   cd build
   cmake ../
   make -j8
   ```

   The number after make -j indicates the number of computer cores to use for compiling the code. If your computer has fewer than 8 cores, use a smaller number.

ApRES

Any LFMCW chirp generator with sufficient bandwidth may be used as the transmitter. Many field going teams take a Single Input Single Output (SISO) or Multiple Input Multiple Output (MIMO) ApRES to the field for other measurements, so we use one of these systems as the transmitter. Be sure that all ports are connected to either an antenna or 50 ohm load to avoid damaging the system. The unit is transmitting when the red LED indicator is on. The code shown here will make the ApRES transmit continuously until the battery is drained. The data stored on the SD card is just noise since the receive port is covered, so I recommend deleting it between measurements to ensure that the ApRES has sufficient storage capacity for an experiment.

SISO ApRES

Required Materials

- 1x SISO ApRES
- [1x N-Type 50 ohm load]
- 1x SanDisk 32GB SD card

SISO SD Card Code – 15.36 MHz Bandwidth

The ApRES reads the SD card's config.ini file for instructions. The config file tells the aPRES to take instructions from the host computer if anything is plugged into the ethernet port, but if there is nothing plugged in the PRES will take measurements automatically following the config instructions. The supplied SD card has a config file on it which tells the PRES to transmit continuously. Below is the config.ini code. The config file must be called config.ini. Any other name or extension won't work.

```
; IMPORTANT: THIS CODE HAS NOT BEEN TESTED
; Author: Nicole Bienert
; Purpose: Configuration file for Bistatic Transmitter using SISO PRES unit (2 port)
; Last update: 10/5/2021
;***********************************
;
; Number of sub-bursts in a burst (>=0)
; Default=10
;
NSubBursts=2000
;
; Whether to average all chirps in a burst. Saves memory. IGNORED IN ATTENDED MODE.
; 1 = average chirps; 0 = no average
Average=0
;
;Burst repetition period (integer seconds) (>0). Interpretation depends
; on IntervalMode. If IntervalMode = 0 (default), RepSecs is time from
; start of one burst to the start of the next. If IntervalMode = 1,
; RepSecs is interval between end of one burst and start of next.
; We want this to be 1, so that when it is done with 2000 subBursts,
; it will start transmitting 1 second later.
RepSecs=1
;
;
; IntervalMode = 0 means RepSecs is time from start of first burst to start of next
; IntervalMode = 1 means RepSecs is time from end of one burst to start of next
IntervalMode=1
```

```
;
17; Attenuator settings for attenuator 1 and 2 (dB) (>=-1, <=31.5)
; Number of chirps in a burst = NSubBursts x nAttenuators
; Defaults=30dB
nAttenuators=1
Attenuator1=31,0,0,0
;
; Gain setting for deramp (AF, or audio frequency) amplifier
AFGain=-14,0,0,0
;
; Maxiumum depth to graph when doing Trial SubBurst. It doesn't affect data collection
; in any way.
MaxDepthToGraph=1000
;
; Maximum length of data file before another one started (>=1,000,000)
; Default=10,000,000
MAX_DATA_FILE_LENGTH=10000000
;
;*****************************************************************************************************
;
; Number of samples per burst (>=20000)
; Default=40,001
N_ADC_SAMPLES=40001
;
Housekeeping=0
SyncGPS=0
Iridium=0
ANTENNA_SELECT=0
LOGON=0
;
; WatchDog task behaviour. Time in seconds of operation after which;
; radar will be reset. Assumption is that a fault has occurred if radar
;is active for longer than this time. Watchdog does not operate in
; attended mode. If Watchdog time is set to 0, then the default of 3600
; seconds is used. If set to -1, then Watchdog task is disabled.
; WATCHDOG_TASK_SECS=-1
;
; Check for an Ethernet connection of powerup (0=no; 1=yes)
; Default=1
;
CheckEthernet=1
;
;
; End of configuration file
; ***************************
; DDS programming strings
Reg00=00000008
Reg01=000C0820
Reg02=0D1F41C8
Reg0B=53F7CED94FDF3B64
Reg0C=0000055E0000055E
Reg0D=13881388
```

Why the config file makes the PRES transmit continuously:

The number of subBursts is set to 2000, so that the PRES transmits 2000 chirps. The watchdog timer is defaulted to 3600seconds, so if the PRES has not done anything different for about 2180 chirps, then the timer will run out and the radar will reset itself. The watchdog is intended to restart the system in the event of errors. This is why we limit the number of bursts to 2000 and set RepSecs to *1* so that the PRES starts transmitting another batch of sub bursts *1* second after it finishes the first 2000 chirps. The IntervalMode is set to 1 so that the PRES starts the RepSecs timer once it finishes transmitting a batch of chirps. Another (untested) way to accomplish the same would be to disable the watchdog by setting NsubBursts to a very large number and WATCHDOG_TASK_SECS=-1 so that the PRES doesn't restart.
How the config file avoids damaging the PRES receiver:
The transmit power of the PRES is fixed to +20dB, but the receiver has both attenuators and amplifiers to adjust the received signal. Power can couple from the transmit circuitry to the receive circuitry, so we adjust the attenuator and gain settings to dampen the signal as much as possible to avoid damaging the receiver. nAttenuators is set to one, and Attenuator1= Attenuator1=31,0,0,0 so that only one attenuator/amplifier setting is used, and the attenuator dampens the received signal at the maximum value (31dB.) The AFGain is set to the minimum value (-14dB) so that it also dampens the signal rather than increasing it.

MIMO ApRES

A MIMO ApRES can be used as the transmitter, but 7/8 of the transmit ports need to be terminated and all 8 receive ports must be terminated to prevent damage to the system and undesired EM noise. The code must also be modified to instruct 7/8 of the transmit ports to not transmit. The code shown below instructs TX Port 1 to transmit and all others to be off, which requires the connection shown below:

Required Materials

- 1x MIMO ApRES
- [15x TNC 50 ohm load]()
- 1x SanDisk 32GB SD card

MIMO SD Card Code – 15.36 MHz Bandwidth

Here is the config file to turn the MIMO into a transmitter. All the ports need to be covered with 50 ohm loads (15 ports) except for tx1 which is connected to the bowtie antenna.

```
; ***********************************************
; Author: Nicole Bienert
; Purpose: Configuration file for Bistatic Transmitter using MIMO PRES unit (16 port)
; Last update: 10/5/2021
; *********************************
; ***********************************************
;*******************************************************************************
; Configuration settings relevant for Attended Mode
;
; Always start the Web Server (ie always go into Attended Mode), regardless
; of an active Ethernet connection. Default 0.
AlwaysAttended=0
;
; Check for an Ethernet connection on power-up (1=yes; 0=no)
; Default=1
CheckEthernet=1
;
; When used in attended mode, and doing a Trial Sub-Burst, the maximum
; depth that is displayed on the FFT (A-scope) display. This can be
; overwritten from the browser
maxDepthToGraph=1500
;
;*******************************************************************************
;*******************************************************************************
; Configuration settings relevant for both Attended and Unattended modes
;
; Number of samples per burst (>= 40,001; default=40,001)
N_ADC_SAMPLES=40001
;
;
;
;
; WatchDog task behaviour. Time in seconds of operation after which;
; radar will be reset. Assumption is that a fault has occurred if radar
; is active for longer than this time. Watchdog does not operate in
; attended mode. If Watchdog time is set to 0, then the default of 3600
; seconds is used. If set to -1, then Watchdog task is disabled.
WATCHDOG_TASK_SECS=-1
;
;
; Number of sub-bursts in a burst (>=0)
; Default=10
NSubBursts=2000
;
; Are all the chirps from this burst to be stored individually (0),
; averaged (1) or stacked (2) (Should not be used if nAttenuators>1 or
; if using in MIMO mode)
Average=0
;
; Burst repetition period (integer seconds) (>0). Interpretation depends
; on IntervalMode. If IntervalMode = 0 (default), RepSecs is time from
; start of one burst to the start of the next. If IntervalMode = 1,
; RepSecs is interval between end of one burst and start of next.
; 21600 = 6 hours; Alternating between qMono and MIMO every other burst.
```

```
RepSecs=1
20IntervalMode=1
;
; Maximum length of data file before another one started (>=1,000,000)
; Default=10,000,000
MAX_DATA_FILE_LENGTH=10000000
;
; Whether a logging file is to be maintained (default = no (0)).
LOGON=1
;
; Number of combinations of attenuator settings to be used
nAttenuators=1
;
; Attenuator setting sequences (dB) (>0, <=31.5)
; Defaults=30dB.
Attenuator1=30,0,0,0
Attenuator2=30,0,0,0
;
; In unattended mode, does the radar sleep between bursts (default, 0),
; or does it wait (1). In the sleep case the system is powered down
; between bursts and draws a low current (<200uA). Otherwise system
; remains powered and draws ~1 Amp.
SleepMode=1
;
; Time out for GPS receiver for each burst (0-255 seconds)?
; Default is 0 - do not attempt to obtain fix before each burst.
GPSon=0
;
; Undertake daily housekeeping (GPS clock check, Iridium exchange and
; memory card check? (1 = yes, 0 = no)
Housekeeping=1
;
; If GPS fix obtained during daily housekeeping, synchronise radar clock
; to GPS time (only if Housekeeping=1)? (1 = yes, 0 = no)
GPSsync=0
;
; If Housekeeping=1, is Iridium messaging enabled? (1 = yes, 0 = no)
; Default = 0
Iridium=0
;
;
TxAnt=1,0,0,0,0,0,0,0
RxAnt=1,0,0,0,0,0,0,0
;
; Very much for the advanced user. The DDS programming strings.
; These strings are set by defaults in the instrument and, like the
; rest of the parameters in the config file, do not need to be set here.
; They are included for completeness. See main text.
;
; End of configuration file
; *************************

; DDS programming strings
Reg00=00000008
Reg01=000C0820
Reg02=0D1F41C8
Reg0B=53F7CED94FDF3B64
Reg0C=0000055E0000055E
Reg0D=13881388
```

Heated Box

Required Materials

List of materials to build 1 box:

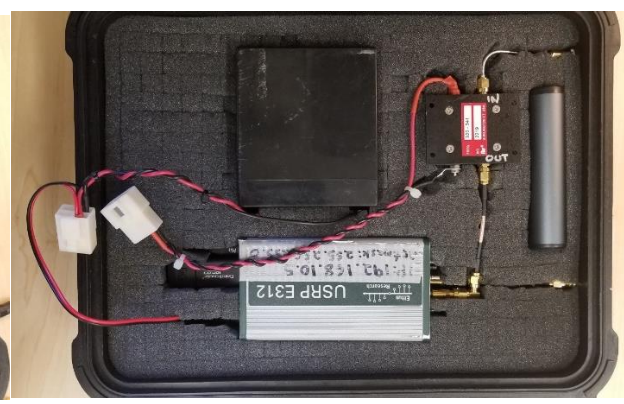
- 1x 1400 Pelican Case
- 1x DC Power Plug
- 2x Electrical Wire Connectors
- 1x Battery Terminal Connector
- 1x Waterproof USB Port
- 2x SMA Jack
- 1x Foam Glue
- 1x USB – micro USB cable
- 1x Plumbers Caulk
- 16 or 18 gauge wire

Required Tools

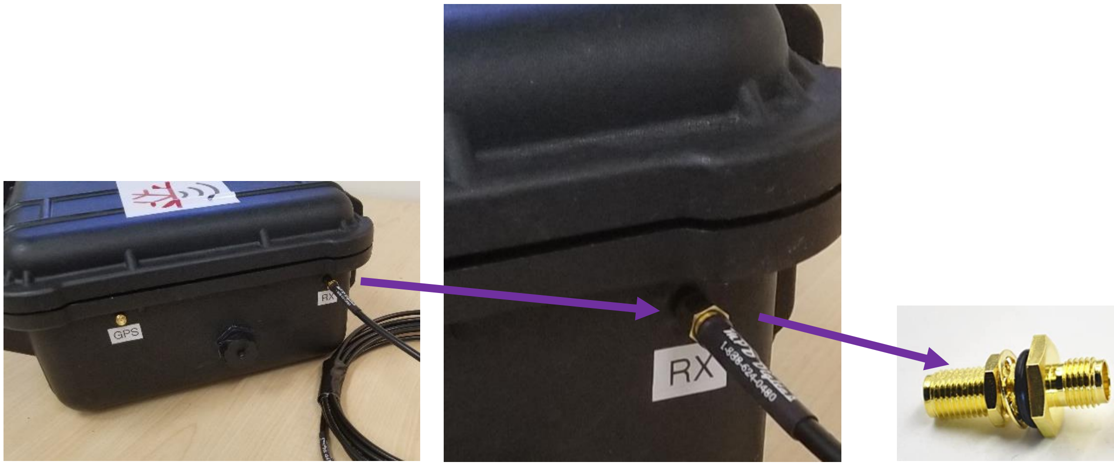
- Wire cutters
- Crimpers
- Soldering iron
- Drill
- Dremel

Building the Case

1. Cut out the foam to hold all the parts.



2. Remove foam from the box.
3. Drill two holes on the right side of the box for the RX and GPS SMA ports. Drill holes just wide enough that the female part of the SMA jack fits through the hole but the nut does not.

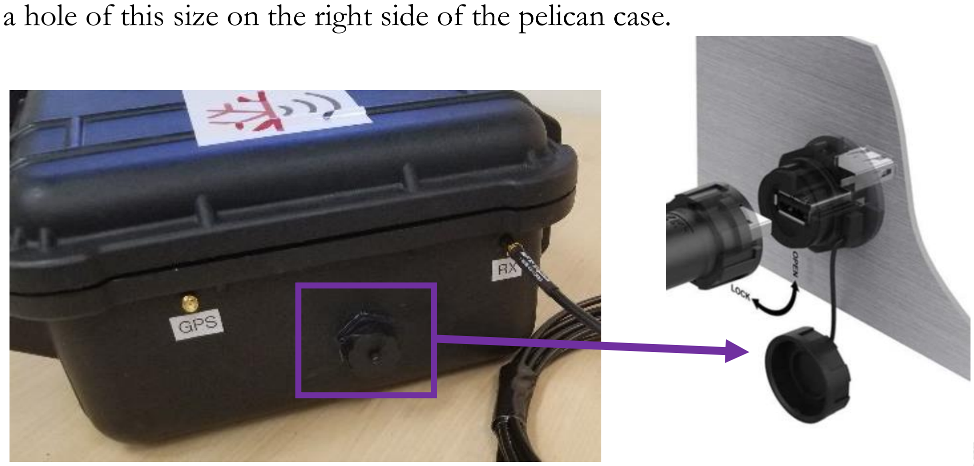


[31]

4. Remove the nut and washer from the SMA jack but leave the O-ring. Lightly dab plumbers caulk onto the longer side of the SMA jack.

[31]

5. Insert SMA jack into drilled holes in the pelicase with the O-ring on the outside of the case. Put the lock washer and nut on the SMA jack and tighten to fasten the SMA jack to the pelicase. Fill gaps with plumbers caulk to waterproof the port.
6. Repeat for second SMA port.
7. Next the USB jack is connected to the right side of the case. To begin, unscrew the plastic nut on the waterproof USB port and measure the width of the threaded part of the port. Drill a hole of this size on the right side of the pelican case.



[32]

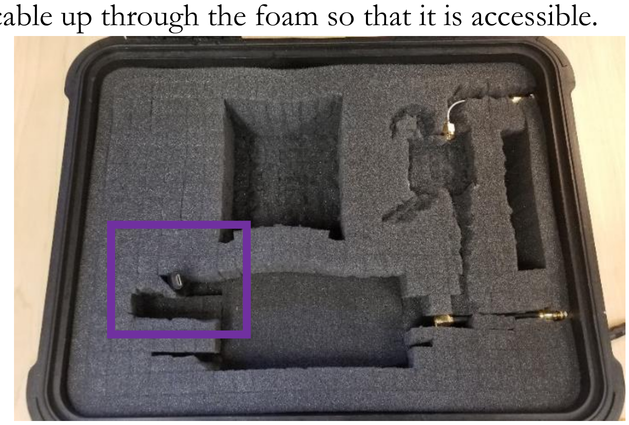
8. Dab plumbers caulk onto the plastic threaded part of the USB jack.

[32]

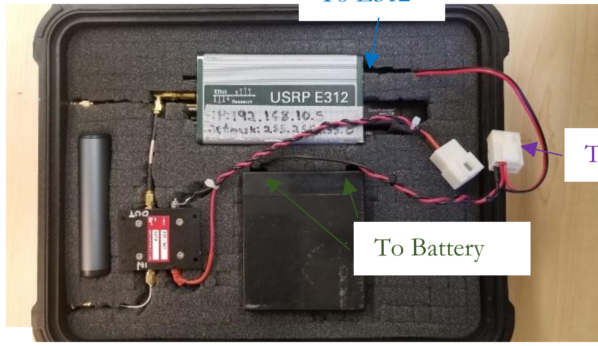
9. From the inside of the case, insert the USB jack through the drilled hole.
10. Screw the plastic nut on from the outside of the case to fasten the USB port. Wipe off excess plumber caulk.

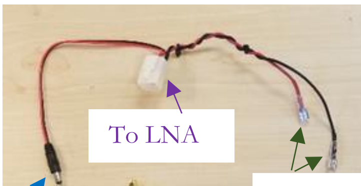
[32]

11. Plug in USB-micro USB cable to the USB port inside the pelican case. This will be used to connect a laptop to the SDR without opening the heated case.
12. Insert foam into pelican case.
13. Thread micro-USB cable up through the foam so that it is accessible.

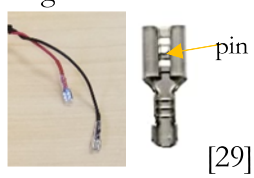


Constructing the Power Cable





1. Cut the red and black wire to length.
2. Crimp on medium female battery terminals connectors to the end of both red and black wires. They should fit tightly on the battery terminals. There is a little pin on the terminal connectors which will need to be flattened to allow the terminal connectors and battery terminal to separate. I recommend using a flat head screwdriver to flatten the pin.



[29]

Female Battery Terminal Connector

3. Using the red wire from last step, crimp this wire and red wire of the DC power plug to a female wire connector. Repeat this with the black wires.


[33]

Female Wire Connector

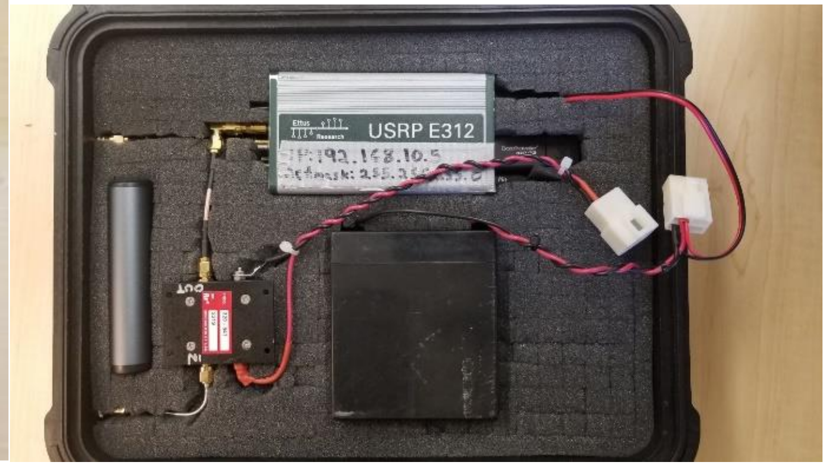
4. Optional: Add solder to the cimped wire connectors.
5. Insert both female wire connectors into the plastic clip as shown below, which will be used to power the LNA.

Wire Connector Plastic Clip

6. Use a multimeter to check connectivity of all wires. Spin the multimeter dial to the arrow symbol. In this mode, the multimeter will beep if current can flow between the two probes. Touch one probe to the inside of the DC power plug and the other to the red (positive) terminal connectors – the multimeter should beep. To check the negative connections, touch

one probe to the outside of the DC power plug and the other probe to the black terminal connectors.

Soldering the LNA Power Cable

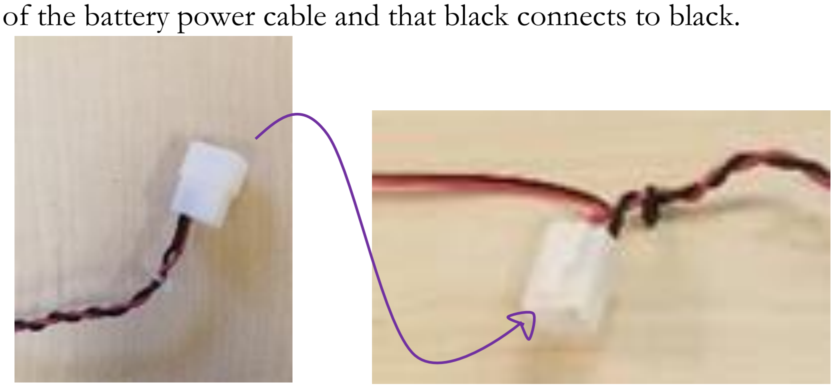


1. Cut red and black wire to length.
2. Solder the red wire to the positive terminal of the LNA.
3. Solder the black wire to the negative terminal of the LNA.
4. Solder male [wire connectors](#) to the end of both red and black wires.

 [33]

Male Wire Connector

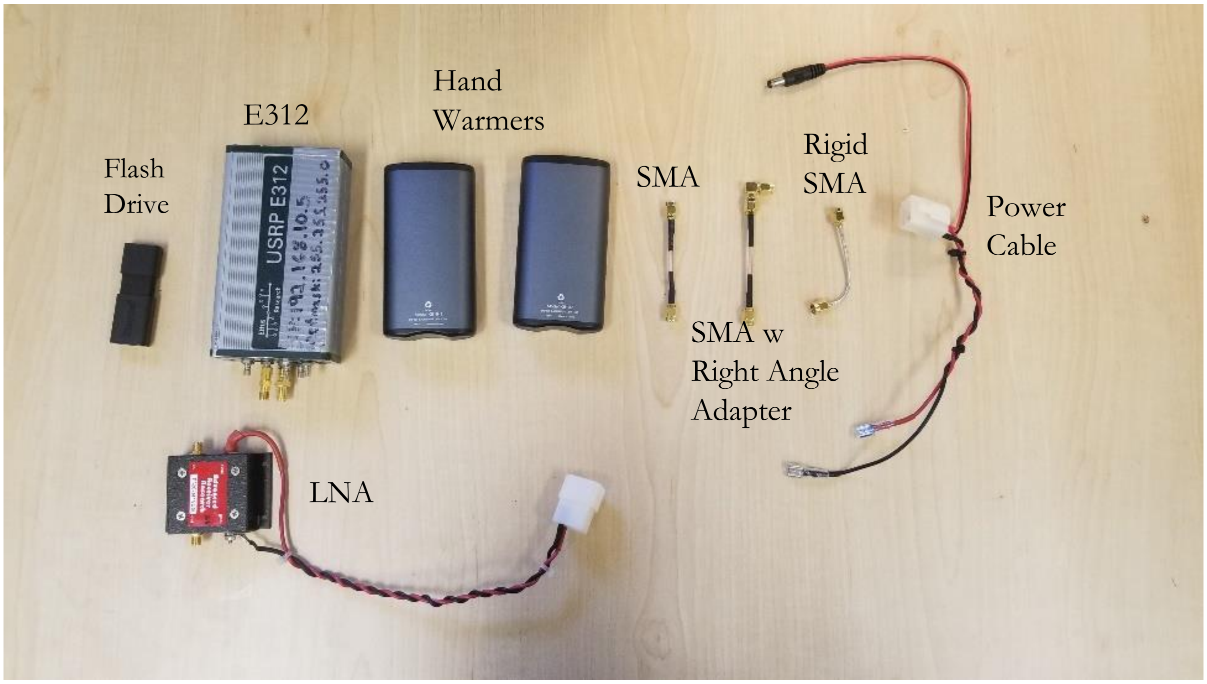
5. Optional: Reinforce the crimp with solder.
6. Insert male wire connectors into plastic clip. Be sure to use the appropriate clip that connects with the clip on the power cable. Double check that the red LNA wire connects to the red wire of the battery power cable and that black connects to black.



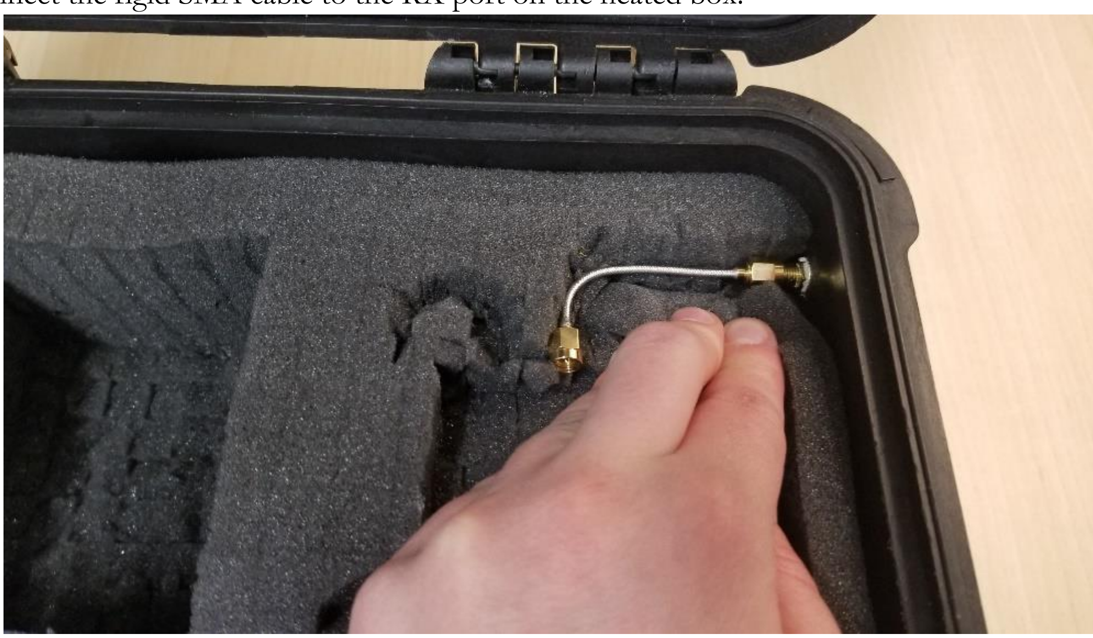
Field Instructions

When you get to the field, the heated box can be hooked up.

1. Assemble all the items you need.

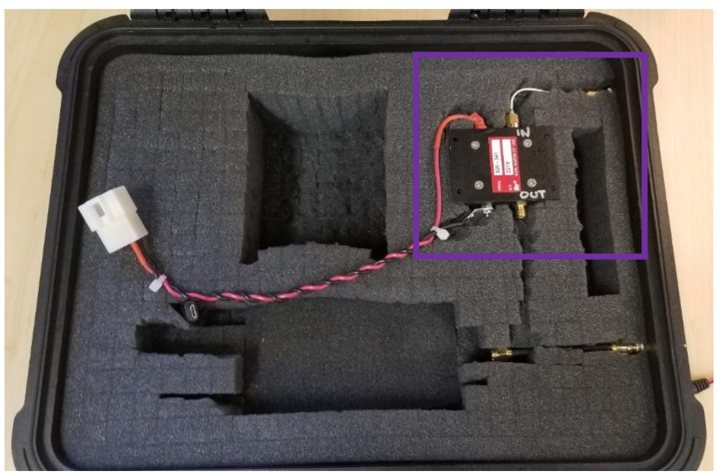


2. Connect the rigid SMA cable to the RX port on the heated box.



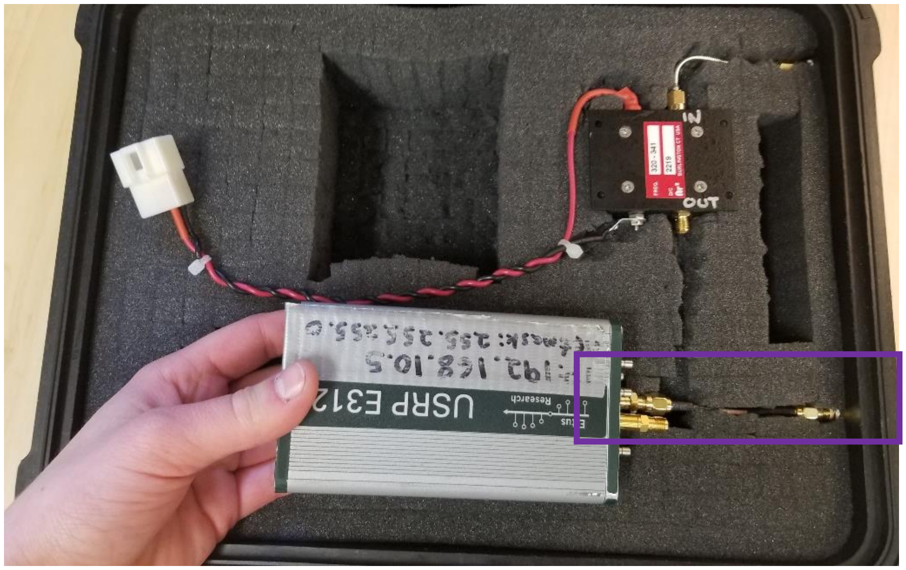
3. Connect the flexible SMA to the GPS port on the heated box.

4. Plug in the RX SMA cable on the heated enclosure to the input side of the LNA. Make sure it is the input. Do not connect the output yet, because the LNA will not be used in the first experiment.



5. Insert a hand warmer in the compartment below the E312. Place a piece of foam on top of the hand warmer so that the E312 is not rattling against metal.

6. Connect the GPS port on the E312 to the GPS port on the heated box.



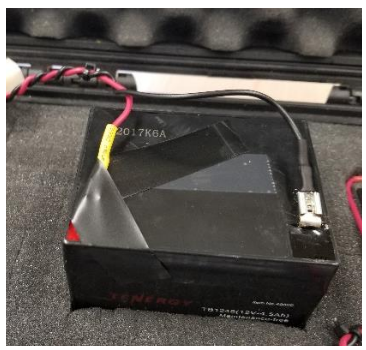
7. Connect the flash drive to the top slot of the E312.

8. Connect the micro-USB cable to the E312 SDR.

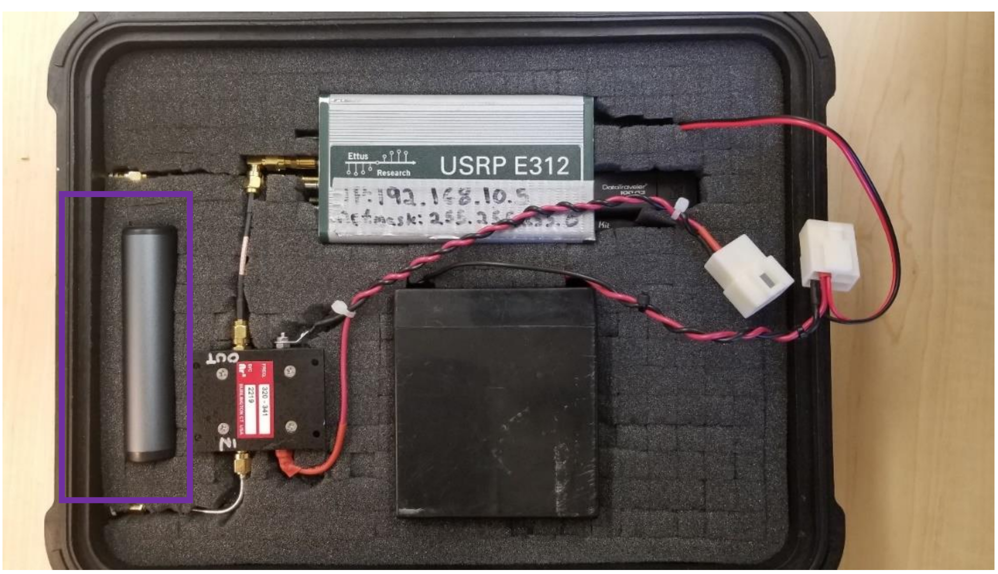
9. Insert the battery and connect it. Red goes to red and black to black. The clips should clip into place.

If you push on the back of the clips they will unclip and you can unplug them.

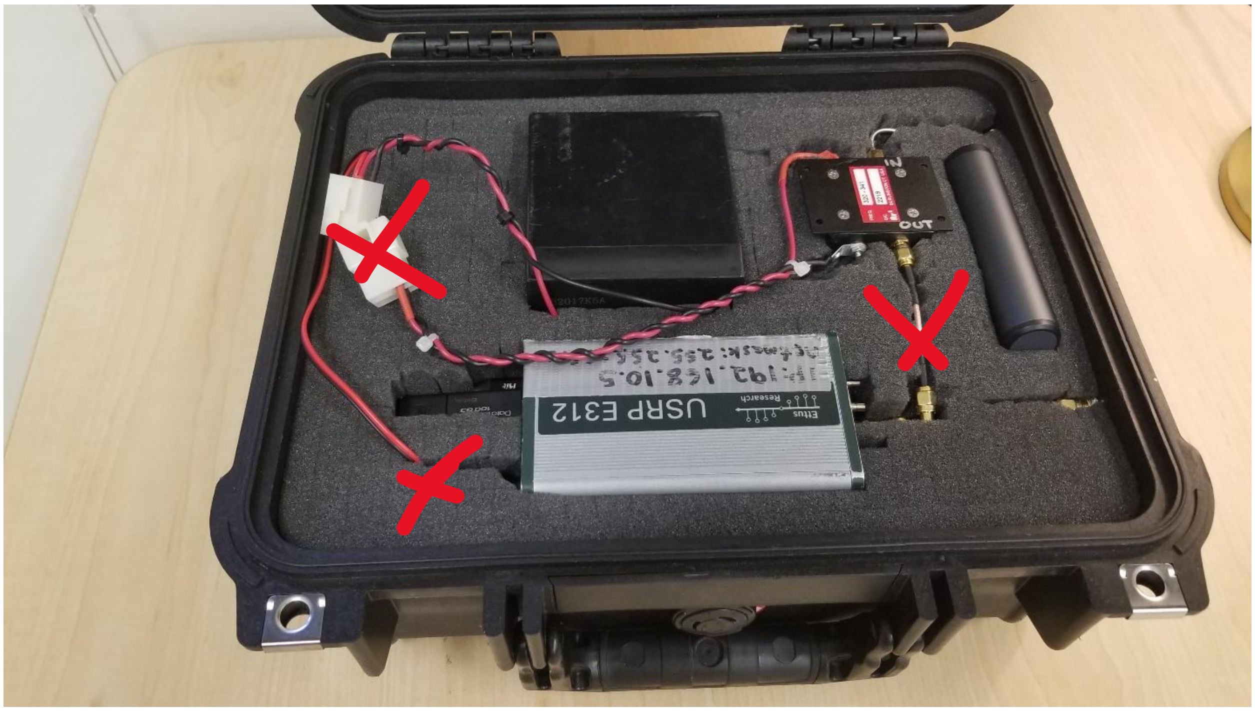
We don't want the clips to come undone during an experiment due to pressure on the back of the clips, so electric tape should be applied in a way that doesn't apply pressure to the back of the clips.



10. Insert the 2nd hand warmer in the slot next to the LNA.



11. Everything should be all connected now, except that the LNA shouldn't be connected to power or to the E312 and the E312 shouldn't be plugged in yet. The LNA needs to have either a 50 ohm load, antenna, or the E312 connected to both ends before it is powered otherwise it will damage the LNA. The LNA shouldn't be plugged into the E312 yet, because it will need to be unplugged for the first experiment. The E312 cannot be connected to the battery indefinitely because it will overcharge. It can only be plugged in for 12 hours.



Experiment

SDR Recording

Purpose: Both the reference chirp and bistatic experiment require an operator to connect a laptop to the SDR and execute the appropriate code so that the SDR begins recording data. We recommend practicing this connection in the warmth before moving to the field and having commands ready to be copied and pasted into the terminal to avoid cold hands.

Quick Start:

Micro-USB from Linux/Mac	Ethernet from PC
1. Type **sudo screen /dev/ttyUSB0 115200** 2. Login with username **root** and hit enter for the password 3. Type **mount -t vfat /dev/sda1 /media/usb0** 4. Type **./run_me_GPS.sh -n folderName -i numOfMeasurements** 5. Make sure the code never prints an overflow error! 6. Unplug computer if desired during measurements. Plug it back in later 7. Type **umount /media/usb0** 8. Type **shutdown -h 0**	1. In PuTTY, type **root@169.254.0.177** in the box titled "Host Name (or IP address)" then click open. 2. Login with username **root** and hit enter for the password 3. Type **mount -t vfat /dev/sda1 /media/usb0** 4. **screen** (or screen -r to reconnect to old shell) 5. Type **./run_me_GPS.sh -n folderName -i numOfMeasurements** 6. Make sure the code never prints an overflow error! 7. Click **ctrl** + **a** then **ctrl** + **d**, then the then unplug computer 8. Plug in computer, reconnect through PuTTY, then type **screen -r** 9. Type **umount /media/usb0** 10. Type **shutdown -h 0**

Start Recording:

1. Connect to the SDR
   a. Decide which computer you want to control the radio with and follow the corresponding connection settings in Laptop – SDR Connection Options. You can disconnect your computer from the SDR and it will continue to run, so it shouldn't matter what computer you use.
2. Connect the Flash Drive
   a. Plug in the flash drive to the top USB slot
   b. Type **lsblk** to find the flash drive name
      - The flash drive is usually called sda1, but may also be called sdb1or sdc.
      - If nothing shows up, try a different flash drive. Some flash drives don't work with this version of linux.

No flash drive

flash drive name

flash drive connected

```
root@ettus-e3xx-sg3:~# lsblk
NAME         MAJ:MIN RM  SIZE RO TYPE MOUNTPOINT
mmcblk0      179:0    0  7.4G  0 disk
|-mmcblk0p1 179:1    0 17.7M  0 part /media/FAT
`-mmcblk0p2 179:2    0    7G  0 part /
root@ettus-e3xx-sg3:~# lsblk
NAME         MAJ:MIN RM   SIZE RO TYPE MOUNTPOINT
sda            8:0    1 115.3G  0 disk
`-sda1         8:1    1 115.3G  0 part
mmcblk0      179:0    0   7.4G  0 disk
|-mmcblk0p1 179:1    0  17.7M  0 part /media/FAT
`-mmcblk0p2 179:2    0     7G  0 part /
root@ettus-e3xx-sg3:~#
```

c. If your flash drive is called sda1, type **mount -t vfat /dev/sda1 /media/usb0**. If it isn't called sda1, replace sda1 with the name of your flash drive.

- This connects the flash drive to the folder /media/usb0. If you type **lsblk**, you should see that the flash drive is mounted.

Flash drive sda1 is now connected to /media/usb0

```
root@ettus-e3xx-sg3:~# mount -t vfat /dev/sda1 /media/usb0
root@ettus-e3xx-sg3:~# lsblk
NAME         MAJ:MIN RM   SIZE RO TYPE MOUNTPOINT
sda            8:0    1 115.3G  0 disk
`-sda1         8:1    1 115.3G  0 part /media/usb0
mmcblk0      179:0    0   7.4G  0 disk
|-mmcblk0p1 179:1    0  17.7M  0 part /media/FAT
`-mmcblk0p2 179:2    0     7G  0 part /
root@ettus-e3xx-sg3:~#
```

- If you get an error, it is probably because the flash drive was previously disconnected incorrectly. Remember to always unmount the flash drive before unplugging it by typing **umount /media/usb0**.
  1. Fix on windows: Unplug the flash drive and plug it into your windows computer. On your computer it will tell you that there was an issue with the flash drive. Click this warning and then the button that says it will fix the flash drive.
  2. Fix on Linux: Plug the flash drive into your linux laptop and move all data off the flash drive. To reformat the flash drive, open the disk utility tool and select the flash drive. Double check that you are selecting the flash drive and not your computer's hard drive! Right click, select format partition. Uncheck the button for erasing the drive, and select the format to be FAT32 or alternatively NTFS. xw

3. If using original run_me scripts, empty tmp folder
   - The new run_me and run_me_GPS do this step automatically
   - **cd /tmp**
   - Type **ls** to identify files that shouldn't be there. oprofileui.socket and screens stays in that folder, but everything else should be deleted
   - **rm filename**

```
root@ettus-e3xx-sg3:~# cd /tmp
root@ettus-e3xx-sg3:/tmp# ls
E312_SipleDome2019_wGPS_buff10000_freq330_gain0_BW15_10  screens
oprofileui.socket
root@ettus-e3xx-sg3:/tmp# rm E312_SipleDome2019_wGPS_buff10000_freq330_gain0_BW1
5_10
```

• Anytime you stop the code before it transfers the data to the flash drive, the data gets left in memory where it consumes all of the SDR's internal memory. The code won't throw any errors, but won't be recording data since the memory is full.

4. If using ethernet, type **screen**
5. Run the code

a. You should be in the home directory which you can navigate to by typing **cd ~** or **cd $HOME**. If you type **ls** to see what is in your directory, you should see something like:

```
root@ettus-e3xx-sg3:~# ls
grc  run_me.sh  rx_samples_to_file  rx_samples_to_file_cp
```

b. Type **./run_me.sh -n folderName -i numberFiles**

```
root@ettus-e3xx-sg3:~# ./run_me.sh -n 70-563800N_50-058266W -i 6
Counter 0
linux; GNU C++ version 4.9.2; Boost_105700; UHD_003.009.002-0-unknown


Creating the usrp device with: master_clock_rate=61440000...
-- Loading FPGA image: /usr/share/uhd/images/usrp_e310_fpga_sg3.bit... done
-- Detecting internal GPSDO .... found
-- Initializing core control...
-- Performing register loopback test... pass
-- Performing register loopback test... pass
-- Performing register loopback test... pass
-- Performing CODEC loopback test... pass
```

• While the code is running the radio will give you periodic updates about how fast it is sampling. It should say 15.36 Msps. Make sure that the code never prints an overflow error. If it does, something went very wrong. Hit ctrl and c at the same time to terminate the program. Go to the tmp folder by typing **cd /tmp**. Type **ls** to see what is in the folder. If anything shows up, delete it by typing **rm -r filename.fileExtension.**

BAD!

```
Press Ctrl + C to stop streaming...
OGot an overflow indication. Please consider the following:
  Your write medium must sustain a rate of 61.440000MB/s.
  Dropped samples will not be written to the file.
  Please modify this example for your purposes.
  This message will not appear again.
        15.294670 Msps
        15.359893 Msps
        15.359955 Msps
        15.360123 Msps
        15.360814 Msps
```

Ensure that the code doesn't throw an overflow error, because the data is useless if this error is thrown. One reason it may throw the error is if the flash drive is full. Empty the flash drive, ensuring that the hidden trash folder is empty, or simply reformat it as FAT.

b. Wait until code is finished, which is indicated when it prints the directories you just saved to.

```
dirfix_DV2018_1012_freq330_gain62_BW15_0
dirfix_DV2018_1012_freq330_gain62_BW15_1
dirfix_DV2018_1012_freq330_gain62_BW15_2
dirfix_DV2018_1012_freq330_gain62_BW15_3
dirfix_DV2018_1012_freq330_gain62_BW15_4
dirfix_DV2018_1012_freq330_gain62_BW15_5
/media/usb0/70-563800N_50-058265W
root@ettus-e3xx-sg3:~#
```

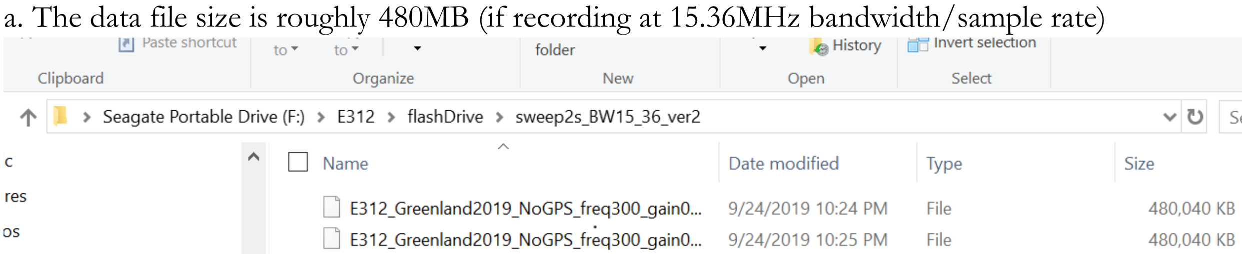
6. Disconnecting the laptop

   When you are taking measurements, you could leave and do something else for a few hours. You can unplug your computer, but you will have to reconnect it to check if the SDR is done and shut it down properly. If you chose to unplug your computer, you can check that the SDR is still receiving by looking at the RX2A LED to see if it continues lighting up 8s per minute (when it is recording). When it is transferring data, the LED on the flash drive will light up.

   a. USB connection: If you are using a USB connection, simply disconnect the cable.
   b. Ethernet: If you are using ethernet, the code will stop running if you simply disconnect it. The code needs to be running in a screen shell to prevent this. Type screen before running the code, and when you want to disconnect hit the **ctrl** and **a** buttons at the same time, then **ctrl** and **d** buttons at the same time. This should return you to the terminal before you ran the code. Now you can close putty and disconnect the ethernet cable. When you want to check the SDR's progress, reconnect through Putty the usual way, then type **screen -r**. This reconnects you and you should once again see the output of the code.

7. Simple check that data is okay

   a. The data file size is roughly 480MB (if recording at 15.36MHz bandwidth/sample rate)



   b. This can be checked on the flash drive by changing to the folder you just wrote to with **cd /media/usb0/filename** then typing **ls -al** to see all file sizes including the hidden ones.

```
root@ettus-e3xx-sg3:/media/usb0/11819TestRunMeGPS# ls -al
total 480096
drwxr-xr-x 2 root root     32768 Sep 25 00:19 .
drwxr-xr-x 5 root root     32768 Sep 25 00:19 ..
-rwxr-xr-x 1 root root 491520100 Sep 25 00:19 E312_Greenland2019_wGPS_buff10000_
```

   c. If the file size is too small this is generally caused by there being files left in the /tmp folder which are consuming the internal memory of the SDR. Return to step 3.
   d. Another possibility is that the flash drive is full. When you delete files from the flash drive, they aren't actually gone until you empty the trash on your computer or reformat the flash drive. If you need to reformat the drive, use the disk utility on a Linux system to re-format the drive as

FAT32, which is the only filesystem that works with the SDR (the SDR is Xilinx brand Linux, not full Ubuntu Linux).

Stop Recording

1. Type **umount /media/usb0** to eject the flash drive. You must do this or else you will get an error next time you try to use the flash drive. Type **lsblk** to make sure that sda1 is no longer attached to /media/usb0.
    a. If you turn off the SDR without ejecting it, you will need to reformat it on your computer before the next experiment.
2. Connect the flash drive to your computer and check that the files exist and have data in them.
3. Turn off the radio
    - Type **shutdown -h 0**
    - The lights on the radio's power button should turn off.

Laptop – SDR Connection Options

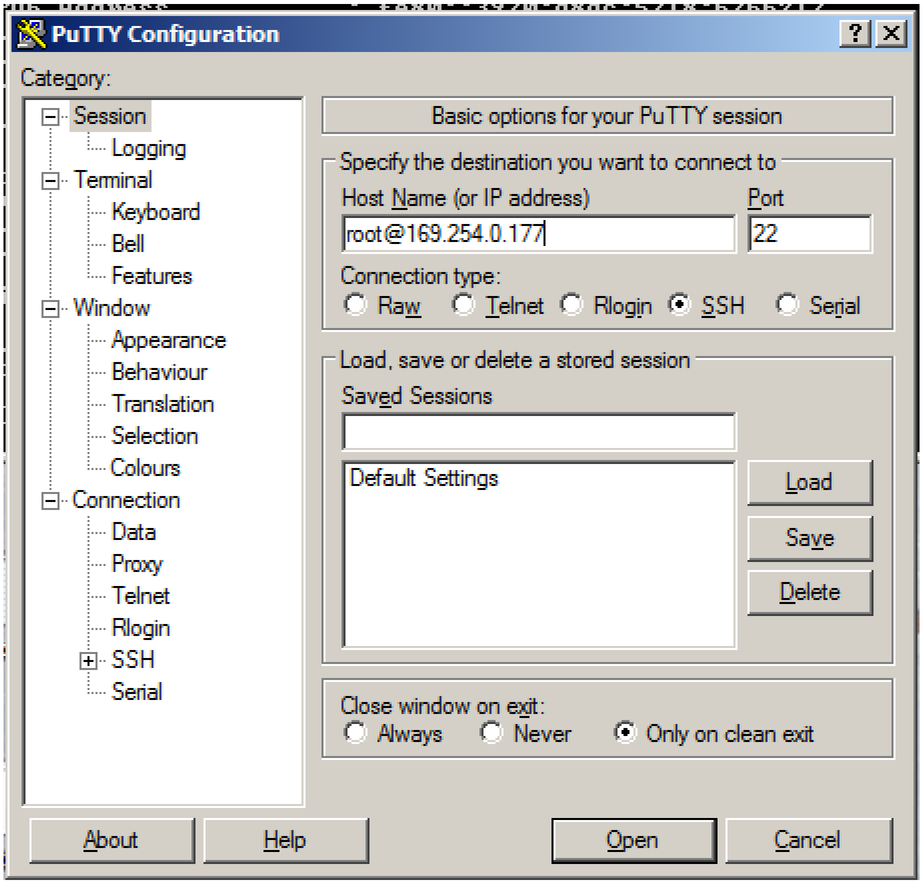
The SDR can be controlled over either USB or Ethernet, but USB encounters fewer issues. Linux and Mac systems are easiest (see option 3). On a PC, you must have putty installed. If you are using a PC other than the Toughbook, then it is easiest to connect over USB (see option 2). If you are using the Toughbook, then you either need to install the UART drivers to communicate over USB or the computer's IP address must be compatible with the radio's address to communicate over Ethernet. I set up the radio's IP address to be compatible with the group's Toughbook, so if you want to use the Toughbook I'd try the ethernet connection before pursuing other options.

1. Windows via Ethernet
    a. Connect your computer and the radio through an ethernet cable or the USB cable.
    - When using an ethernet cable, a green light should turn at the ethernet port on the radio. If it isn't on, then there is a connection issue.

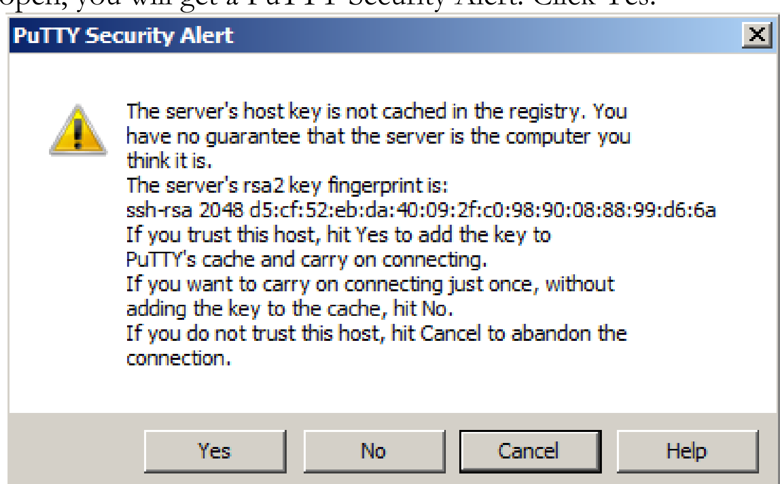
    b. Turn on the radio.
    - Once you press the power button, the power button will be dimly illuminated green.

    c. From the start menu, type PuTTY and open the program
    - Putty is how you control the radio's computer. It should be pre-installed.

    d. In the box titled "Host Name (or IP address)" type **root@IPaddr** then click open. The IP address should be labeled on the SDR.
    - SSH should be checked under connection type.



e. After clicking open, you will get a PuTTY Security Alert. Click Yes.



f. When the radio's terminal opens it may ask for a username. If so, type root. If it asks for a password, just hit enter. It probably won't do this.

g. Troubleshooting: If it does not open the radio's terminal, then check that the radio is on. If it is on, then there was most likely a problem caused by ethernet address mismatch. In this case, either install the USB drivers and connect over USB (see option 2 below), use a different computer, or you will need to make the IP addresses compatible. Devices can only communicate if the first three numbers of the IP address and netmask are the same.

• Change IP address of computer:
You can check your computer's ethernet ip address by typing **ipconfig** from the command prompt and looking at the values in "Ethernet adapter Local Area Connection." If you need to change the IP address type:

netsh
interface ip show config
interface ip set address name="Ethernet adapter Local Area Connection" static 169.254.0.176 255.255.0.0 169.254.1.1

This will change the address to 169.254.0.176, the netmask to 255.255.0.0, and default gateway to 169.254.1.1. I haven't had to do this myself, so I am more confident in the method outlined below.

• Change IP address of the radio:
This method is redundant because you need to connect over usb with a different computer following instruction option 2 or 3. Once connected you can change its address and netmask to match your computer. To do so, in the radio's terminal type:

cd /etc/network
vim interfaces

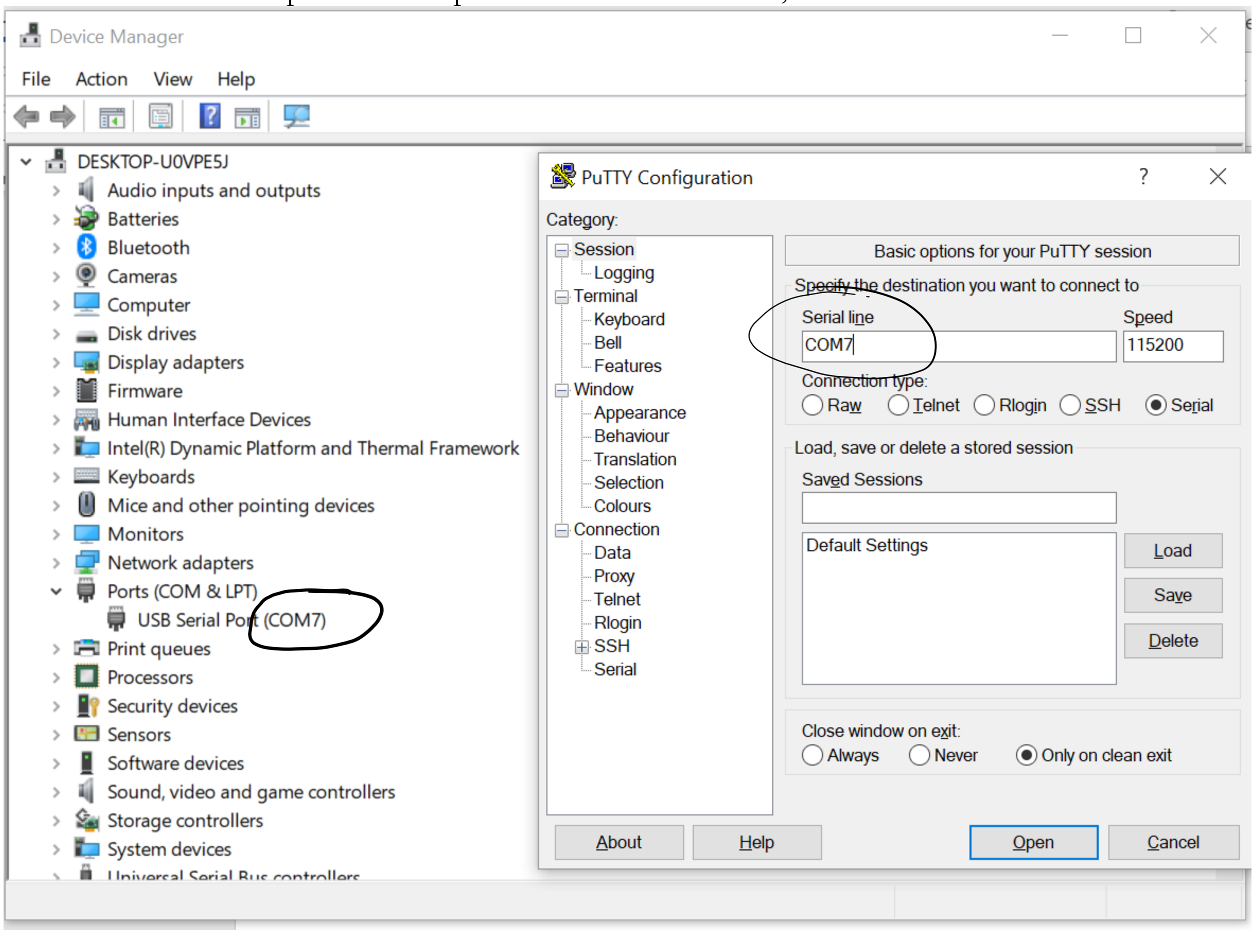
Now you are in the vim editor. Type **i** to enter edit mode. Hit the **esc** button to exit edit mode. Type **:w** to save once you are out of edit mode, and **:wq** to save and quit or **:q!** to quit without saving changes. You will need to alter the values of eth0 to be compatible with your computer. In the command prompt on your computer, you can check the ip address by typing **ipconfig**.

h. Disconnecting computer and keep the code running:

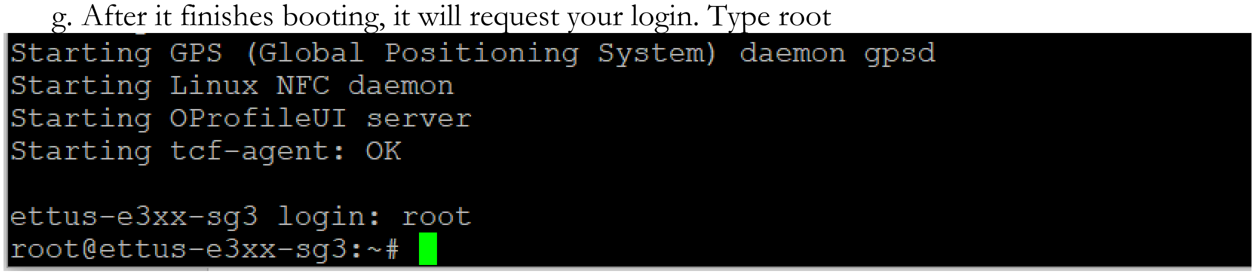
• When you need to disconnect your computer, it is not as easy as the USB interface, because ethernet will shut down all related functions (including your code) when ethernet is disconnected. Therefore, you will need to run the code in a screen shell.

1. Start the screen shell before the ./run_me command by typing **screen**.
2. Before unplugging your computer click the ctrl + alt buttons simultaneously before disconnecting your computer.
3. Close PuTTY.
4. When reconnecting to check if the code is still going, connect to through putty in the usual way.
5. Type **screen -r** to reconnect to your previous session.

2. Windows through USB
   a. Open Device Manager to figure out which COM port the radio is connected to.
      - For me it shows up under “Ports (COM & LPT).”
   b. Open Putty
   c. Select Serial
   d. Change speed to 115200
   e. Enter the COM port which represents the radio. For me, that is COM7



   f. You may turn on the radio either before or after opening the serial connection
   g. After it finishes booting, it will request your login. Type root



   h. If it asks for a password, jut hit enter

3. Mac/Linux through USB
   a. Ensure that the radio is off

b. Open a terminal
c. Type **cd /dev**
d. Type **ls**
e. Look for something that starts with tty and looks like it could be the radio. For the group mac, that is tty.usbserial-DQ004C4T. It could also be something like ttyUSB0.

- Precision 7730 = ttyUSB0
- Group mac = tty.usbserial-DQ004C4T
- Latitude Rugged Extreme = ttyUSB0

f. Type **sudo screen /dev/ttyUSB0 115200**
g. Turn on the SDR. The booting notifications will appear on screen.
h. If it asks you for a username type **root**. Otherwise, hit ener.

Reference Chirp

Purpose: When process the data, the time domain data is match filtered with a pre-recorded reference chirp. The transmitted chirp's shape may change when the PRES is in colder temperatures than the lab, so a chirp recorded in the field is optimal for match filtering.

<u>PREP</u>

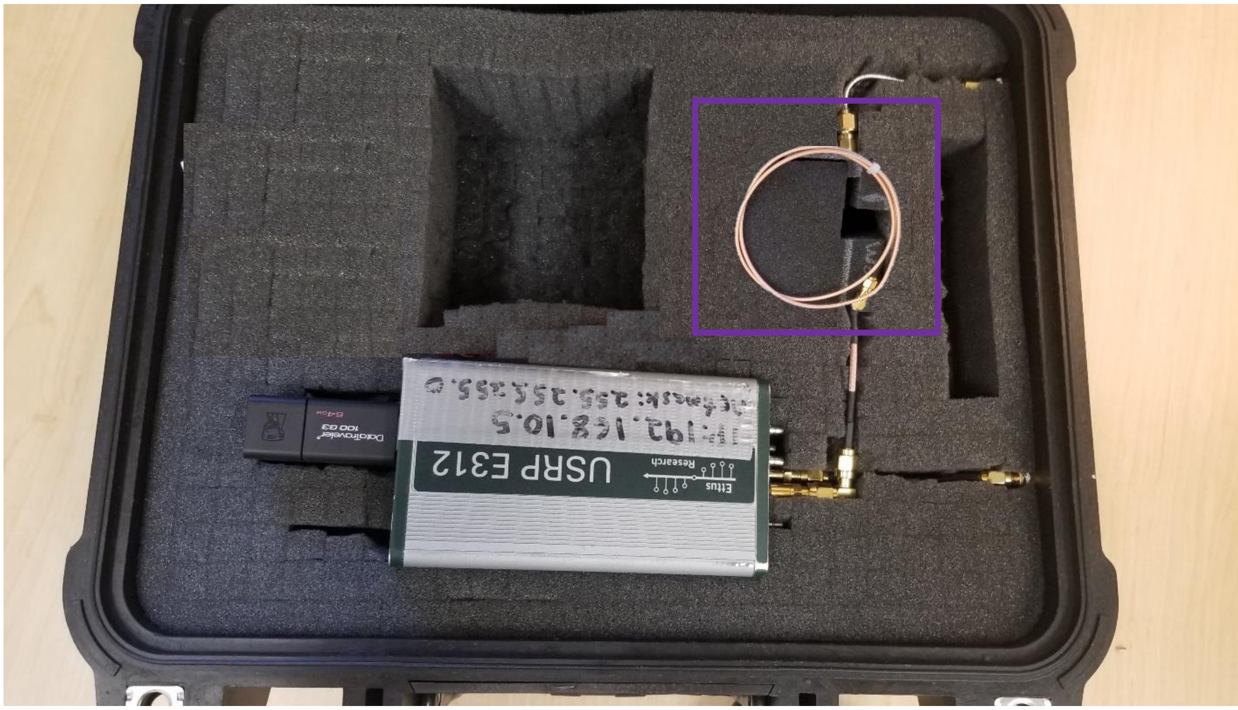
1. Charge the E312. It cannot be left plugged in longer than 12 hours.
2. Empty the flash drive.
3. Charge the electric hand warmers.

<u>HEATED BOX SET - UP</u>

1. Turn on hand warmers and place them in the heated case.


2. Insert flash drive into the top USB port of the SDR.

3. Plug in the RX SMA cable from the inside of the heated box to the RX2A port on the SDR, bypassing the LNA. This can be done by disconnecting the LNA coaxial cables and replacing the connection with a female – female SMA cable or a male – male SMA cable and two female-female adapters. DO NOT connect the battery when the LNA coaxial ports are disconnected.



[14]

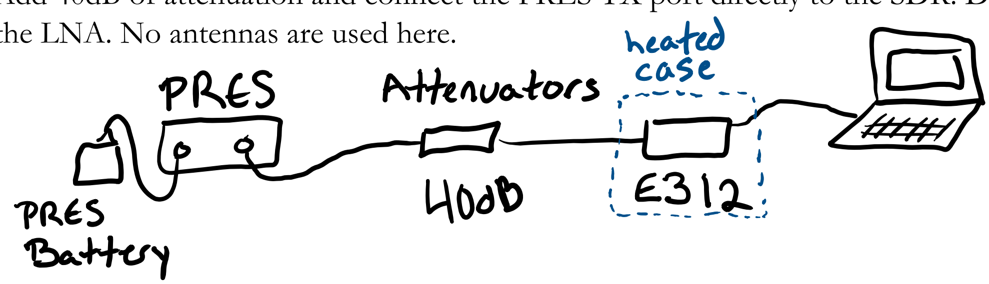
RX2-A Port on the SDR

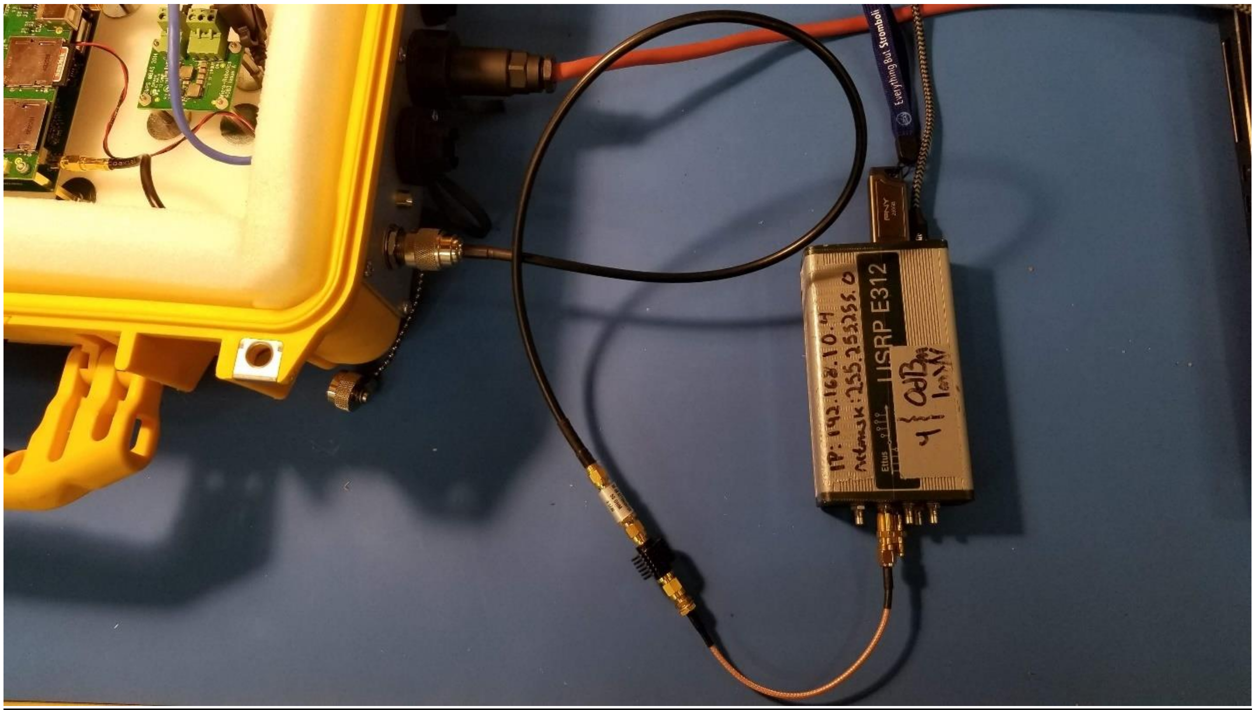
Female -Female SMA Adapter

4. Close the case and let the SDR warm up while you set up the PRES.

<u>Quick Set Up</u>

- Add 40dB of attenuation and connect the PRES TX port directly to the SDR. Do not connect the LNA. No antennas are used here.

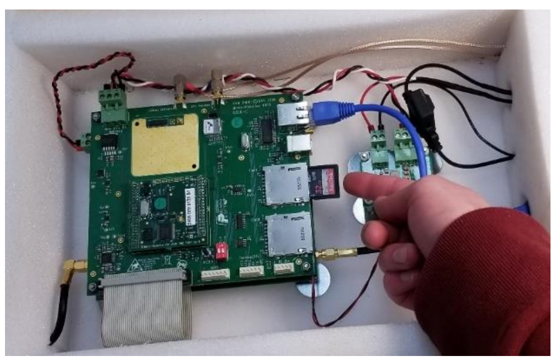




Experimental Set-Up without Heated Case

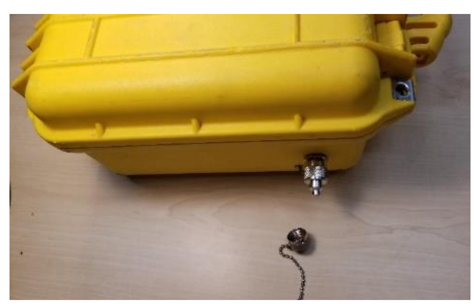
Full Set Up Instructions

1. Plug in the SD card with the config file into slot 1 as discussed in the ApRES Hardware Configuration section.



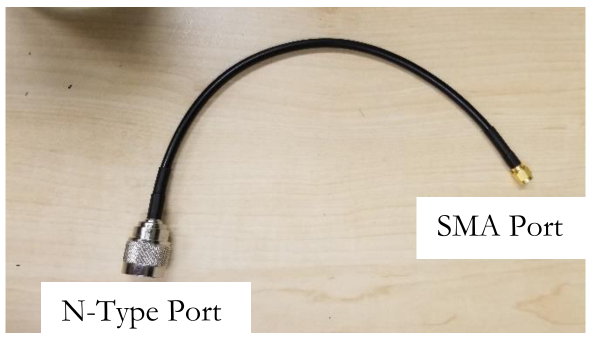
2. Connect the 50 ohm terminator to the RX side of the aPRES.
   - The transmitted signal couples to the receiver circuitry and can reflect off the RX port and can damage the receiver. The 50 ohm terminator absorbs energy that would otherwise reflect back into the receiver circuitry.

[16]



3. Connect the power terminal of the PRES to a 12V battery. Use a multimeter to check that the battery has above 12V.

4. Connect a N-type to SMA cable to the TX port of the PRES or an N-type to SMA adapter and an SMA cable.

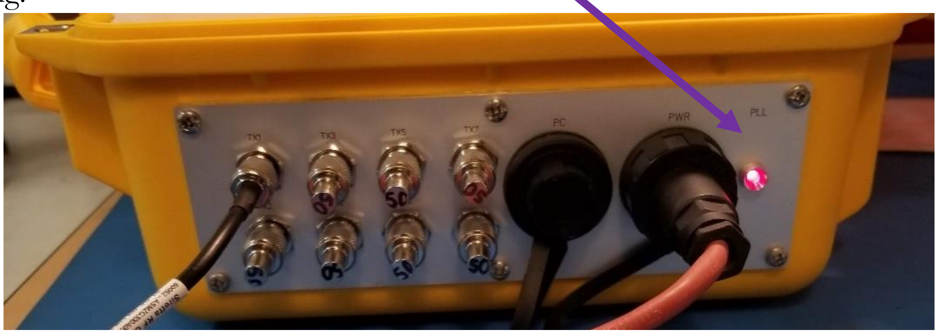


N-Type to SMA cable

5. Add **40dB of attenuation** to the SMA part of the ApRES cable.
    a. This prevents damage to the SDR because the output of the PRES is 25dBm and the max input to the SDR is 0dBm. DO NOT connect the LNA.

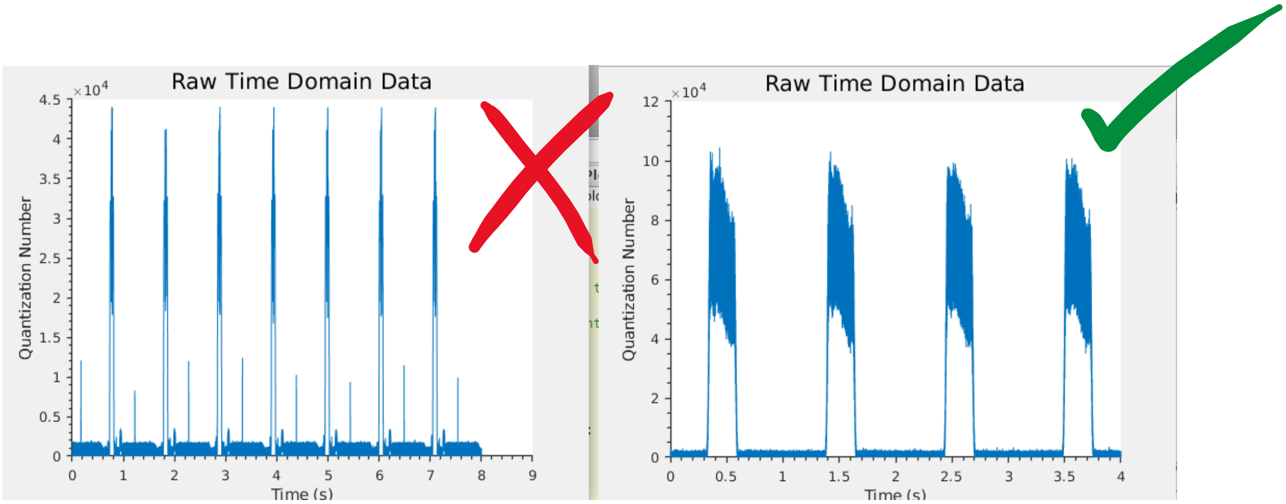
6. Connect the attenuators to the RX port of the enclosure using an SMA cable.

7. Turn on the aPRES. The light on the PRES labeled PLL should turn on to indicate that it is transmitting.



<u>Experiment Instructions</u>

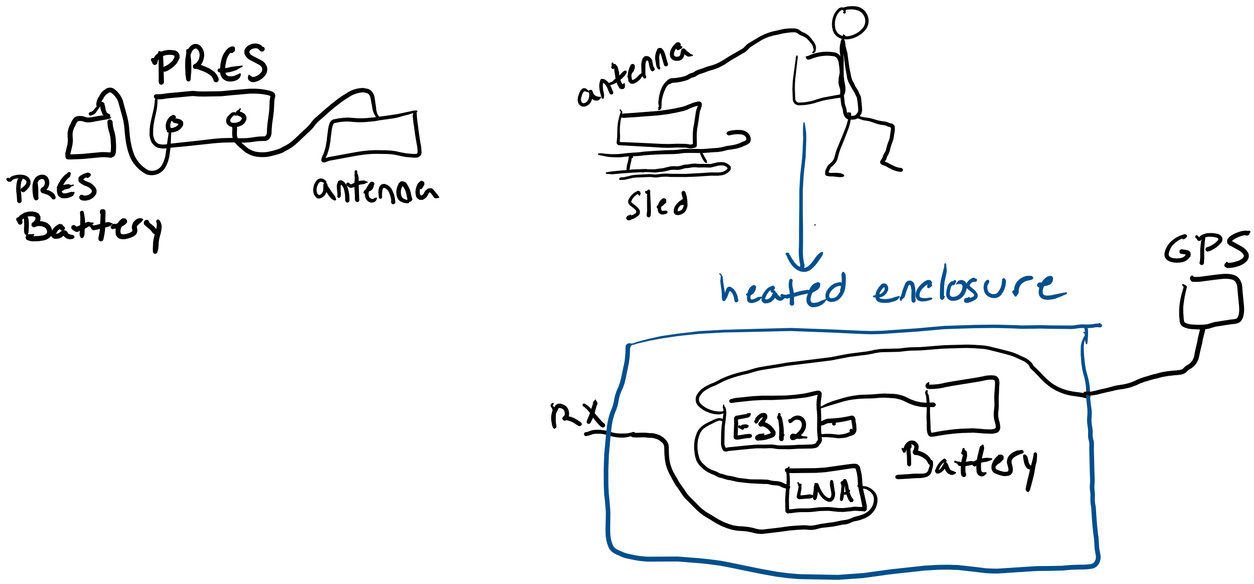
8. Follow the radio instructions and run the non-GPS stamping code with gain set to 0.
   run_me_GPS.sh -n E312referenceDateGreenland -i 5 -g 0
9. Record in your notebook how much attenuation was used.
10. Open matlab and look at the data using Processing_Scripts\Simple_Processing\Plot_Freq_and_Time_Domain_Single_File/E312_NoGPS_plotFreqTime.m. You will need to add the extension '.dat' to the file you want to process.
11. You should see peaks in the data that look like the image to the right: If the shape of the peaks looks odd, or you get tiny peaks like those to in the left image, add more attenuation and repeat the experiment. Ensure that when running the SDR, you include the parameter -g 0. This sets the gain to 0dB and prevents the signal from saturating or coupling into circuitry where it shouldn't go (like the image to the left).


Raw Time Domain Data
×10^4
Quantization Number
Time (s)
Raw Time Domain Data
×10^4
Quantization Number
Time (s)

Bistatic

Set Up Overview

What's different? Plug in the GPS antenna, LNA, 12 V battery, and bowtie antennas.



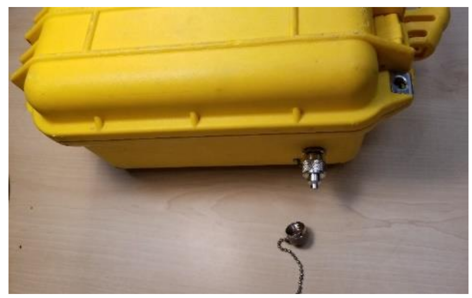
Experiment Instructions

1. Open the E312 case and connect the LNA to the E312 and the RX SMA port on the inside of the heated case. It will be connected for the remainder of all other experiments.

2. Plug in the PNY 256GB flash drive to the E312. This one is the fastest of the flash drives we tested.
3. Turn on the hand warmers so that the box heats up and close the lid.

4. Do a normal PRES ice thickness measurement and log the filename and GPS coordinates. The measured bed depth is useful.
5. Plug in the SD card with the config file (discussed in section ApRES Hardware Configuration) into slot 1.

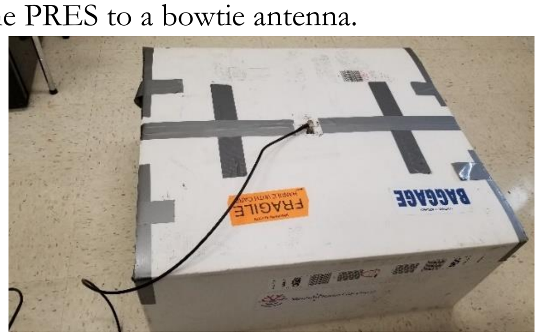
6. Connect the 50 ohm terminator to the RX side of the aPRES.
    - The transmitted signal couples to the receiver circuitry and can reflect off the RX port and can damage the receiver. The 50 ohm terminator absorbs energy that would otherwise reflect back into the receiver circuitry.



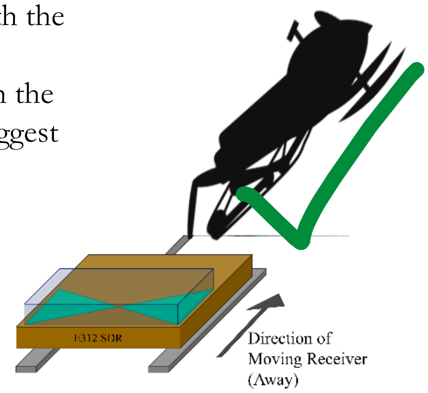
[16]

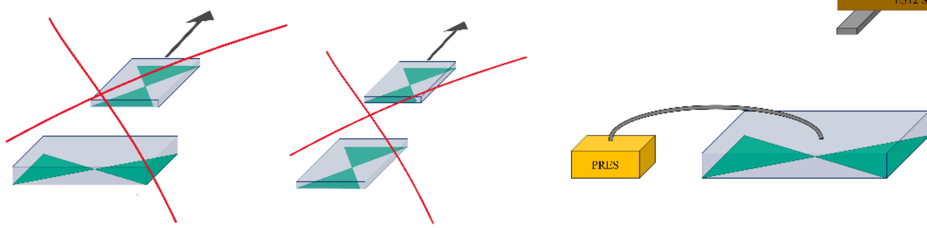
7. Connect the power terminal of the PRES to a 12V battery. Use a multimeter to check that the battery is fully charged and will last the whole day (~13.5V).

8. Connect the TX port of the PRES to a bowtie antenna.

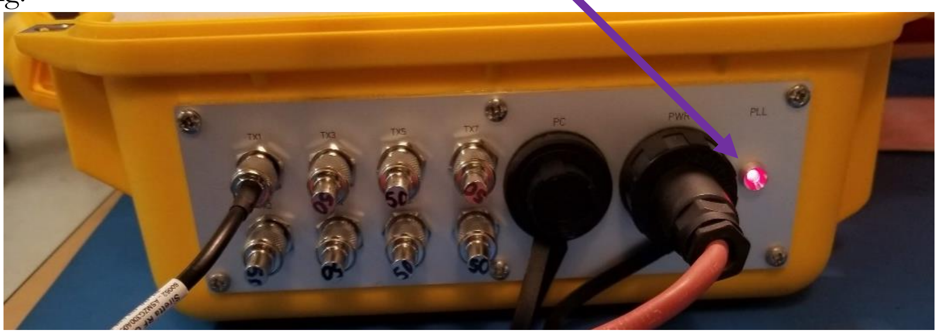


9. Log the gps coordinates for the PRES antenna. Align your GPS with the center of the antenna.
10. It is crucial that the antennas are oriented in the same direction with the electric field parallel to the bed-ice interface as depicted below. I suggest using permeant marker to draw on the antennas arrows that point towards each other so that they don't get flipped the wrong way by mistake. Take a photo or otherwise log how the antennas are oriented because you will get very different results depending on the orientation.





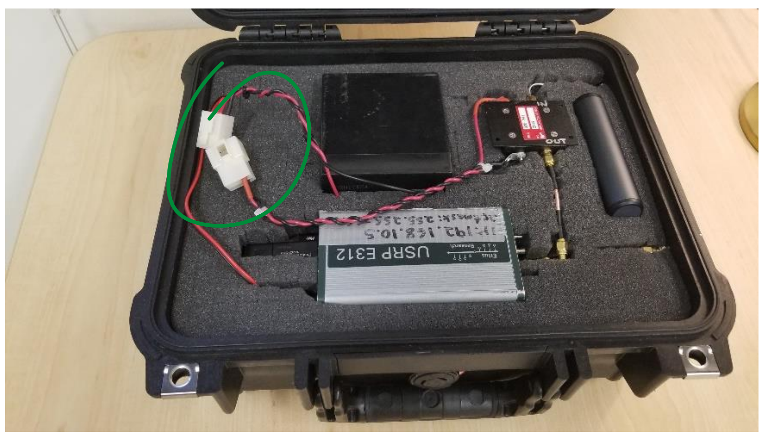
12. Turn on the aPRES. The light on the PRES labeled PLL should turn on to indicate that it is transmitting.



11. Move ~200m away from the PRES before setting up the SDR.
    - The amplification from the LNA and internal amplifiers may increase the signal beyond the maximum input power for the SDR at less than 200m. If you need to do shorter transects, reduce the internal SDR gain.
12. Connect the bowtie antenna to the RX port of the heated enclosure using the SMA-TNC cable. Do not use adapters.

13. Connect the 3V GPS antenna to the GPS port.

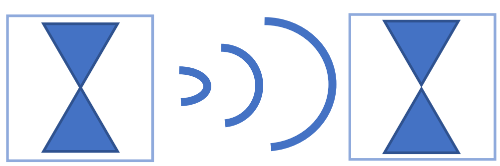
14. Open the heated enclosure and connect the LNA to a 12V battery.
    - Connect the negative side of the battery to gnd and the positive side of the battery to +vdc. Do not power the LNA before its in/out ports are connected. Be careful not to touch the LNA case (which is grounded) and vdc terminal at the same time with an alligator clip or other metal. It will shock the LNA and maybe you.



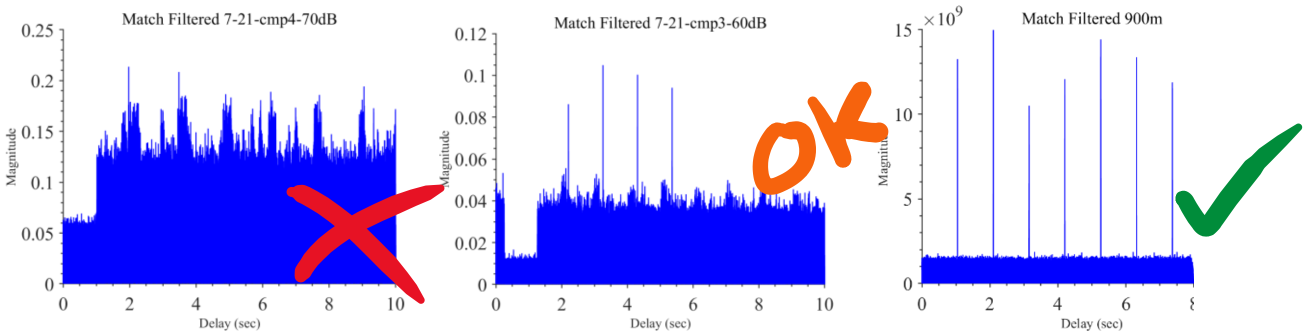
15. Connect the SDR to the battery.
    - The LED indicator on the power button will toggle on and off every 2 seconds to indicate charging.
    - Both the LNA and SDR operate off 12V. The LNA draws 25mA, and the SDR draws up to 0.5A. The battery can provide 1.35A, so this is fine. Remember that the SDR cannot be plugged in longer than 12 hours.

16. Turn on the SDR.
    - The lights above the ports will briefly flash to indicate that the system is booting. The LED indicator on the power button will begin toggling on and off every 1 second.
17. Connect the laptop to the USB port on the heated enclosure.

18. Check that the antennas are mounted on the sled properly.
    - The GPS antenna needs to point up and the bowtie needs to maintain the same orientation as the ApRES antenna. Technically, if the antennas are oriented orthogonally, then they will not transmit any signal to each other. Also, mathematically, if the GPS antenna is oriented vertically, it won't receive signal from the satellites.



19. Log the starting GPS coordinates of the SDR RX antenna.
20. Do a quick test that the SDR can see the PRES chirps. Follow the instructions in the [SDR Recording]() section. When you run the code to record data, use this command instead: **run_me_GPS.sh -n E312bistaticTestDateFieldLocation -i 1**
21. Open matlab and look at the data using Processing_Scripts\Simple_Processing\Matched_Filter_Single_File/ plotTimeMatchFilt_wGPS_E312_singleFile.m.
22. The PRES chirps should be clearly visible.



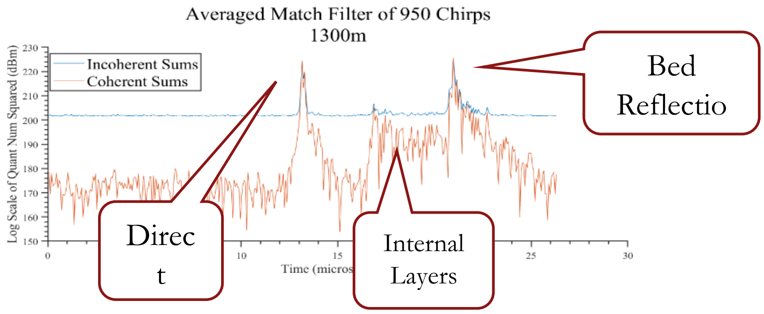
BAD OKAY GOOD

23. Check that the variable gpsData has something displayed before the N/S and the W/E indicating that it got the GPS coordinates.
24. If you saw chirps in the previous step, then you can begin the experiment. We want to GPS stamp the data and record 2hrs worth of files, so when running the code, use: **run_me_GPS.sh -n E312bistaticDateFieldLocation**
25. If using ethernet, type **ctrl** + **a** then **ctrl** + **d** to disconnect the screen shell.
26. Close putty or the terminal and unplug your computer. The SDR will continue recording data. Close the lid of the heated enclosure and if desired, put it in your backpack. Check that the SDR is still receiving by looking at the RX2A LED to see if it continues lighting up 8s per minute (when it is recording). When it is transferring data, the LED on the flash drive will light up.
    - The SDR will not continue recording if you are using ethernet unless you use the screen command
27. It is okay to stop and start the experiment, just log the start/stop GPS coordinates.
28. The SDR will fill up the 256GB PNY flash drive after about 4 hours. So every four hours, empty the flash drive. The battery will last 8 hours on a full charge. The code will terminate and the RX2A light will stop lighting up if the flash drive is full. Using the faster hard drives (the 128GB San Disk and 256GB PNY) the drives fill at a rate of about 58.7GB per hour. Because this drive is the fastest, chirps are recorded more frequently than the other slower drives (like the DataTraveler), so avoid using the Kingston DataTraveler if possible.

7.68e6 ~~Samps~~	4 Bytes	8 ~~Sec of data~~	60 ~~Secs of recording time~~	60 ~~mins~~
1 ~~Sec data~~	1 ~~Samp~~	15 ~~Sec of recording time~~	1 ~~min~~	1 hr

=58.7GB per hour

29. Upon completion of the experiment, log the ending coordinates of the SDR RX antenna.
30. Unplug the LNA from power before disconnecting the antenna.
31. Unplug the SDR from power.
32. Open matlab and look at the data using: Processing_Scripts\Simple_Processing\Matched_Filter_Single_File/plotTimeMatchFilt_wGPS_E312_singleFile.m. Check if you can see the bed in a few of the small distance files. Below is an image of what the parts of the data look like. Note that the plot is in dB, and without coherent summation you probably won't see the internal layers.



33. If the data looks okay, run the moving coherent summation code called quasi_radargram. Be sure to change the user input variables.

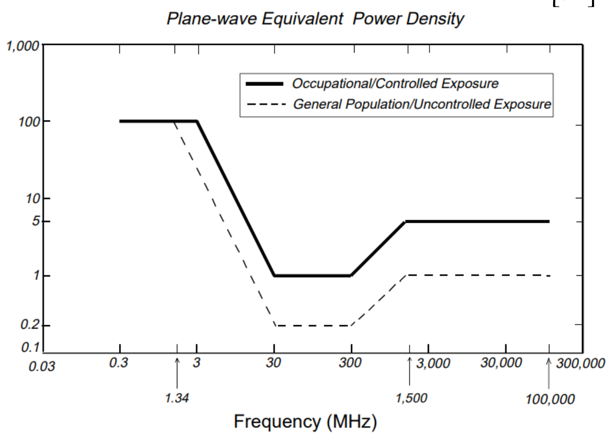
Operational Considerations

Summary— For use in permitting, we evaluate the ApRES's compliance with FCC and IEEE regulation. While we estimate that the ApRES system transmits a power density lower than the FCC and IEEE regulations, we recommend that operators maintain at least a 5-inch distance from the transmitting antenna. At distances beyond 1.18m the power density can be accurately assessed as 0.0026 mW/cm^2 at that distance, which is below the safe exposure limits of 0.2 mW/cm^2 and 1.0mW/cm^2 for uncontrolled and controlled environments respectively [35,36]. At distances less than 1.18m, the FCC recommends a near field approximation which produces a maximum power density of 0.07mW/cm^2. This is roughly three times below the uncontrolled exposure limits and 14 times below the controlled exposure safety limits.

Introduction

The ApRES transmits a total of 20dBm, which is 100mW in linear units [37,38]. This is six times less power than the lower of the two transmit powers used in cell phones, 0.6 watts and 3 watts [40]. However, cell phones transmit in the 900-1900MHz band, while the PRES operates from 200-400MHz. This is important, because human tissue is most absorbent of radio waves in the frequency range of 30-300MHz so the maximum permissible exposure levels are lower in this range.

Figure 1. FCC Limits for Maximum Permissible Exposure (MPE)[37]



Maximum Permissible Exposure (MPE) is the amount of power a person can be exposed to without any harmful effects, and the value includes a safety factor [35,36]. The Federal Communications Commission (FCC) and Institute for Electrical and Electronics Engineers issue regulations on MPE which include two standards. The controlled exposure standards are intended for people who are aware of the radio wave transmitter and the uncontrolled exposure limits are intended for bystanders who are unaware of the radio waves.

FCC and IEEE Standards

The IEEE regulations can be found on page 5 of [36] and the FCC regulations can be found on page 67 of [37]. The IEEE standard is recognized as an American National Standard, so the limits are identical between the two documents and are listed below for the ApRES frequency range.

Limits for Controlled Exposure	
Frequency (MHz)	Power Density (S) (mW/cm^2)
30-300	1.0
300-1500	frequency/300
Limits for Uncontrolled Exposure	
30-300	0.2
300-1500	frequency/1500

The ApRES frequency ranges from 200MHz to 400MHz. The power density limits are constant to 300MHz, then linearly increase. The controlled exposure limits increase to 1.33 mW/cm^2 at 400MHz, while the uncontrolled exposure limit is 0.27mW/cm^2 at that frequency.

Near Field Maximum Power Density

The total power transmitted by the ApRES is 100mW, but the power spreads out spherically and decays with distance at a rate of 1/distance^2. However, the power density very close to the antenna cannot be described this simply. Therefore, FCC offers an approximation for the maximum power density close to the antenna [37] (in the near field) which is:

$$S_{NF} = \frac{16 e_a P}{\pi D^2}$$

Where

S_{NF}	=	Maximum near field power density ($\frac{W}{m^2}$)
e_a	=	Aperture efficiency
P	=	Power fed to antenna (W)
D	=	Maximum antenna length, diagonal (m)

The aperture efficiency describes how efficient of a radiator the antenna is given the area of the antenna.

$$e_a = \frac{A_e}{\pi D^2/4} = \frac{G\lambda^2}{4\,\pi} \bigg/ \frac{\pi D^2}{4}$$

Where

e_a	=	Aperture efficiency
G	=	Gain
λ	=	Wavelength (m)
D	=	Maximum antenna length , diagonal (m)

The diagonal length of the antenna is 0.943m, the gain is 6.56dB or 4.52 in linear units, the largest wavelength is 1.5m, and the power fed to the antenna is 100mW. With this information, the maximum power density in the near field calculated to be 0.664W/m^2, or 0.07mW/cm^2. The power density close to the antenna is significantly below both the controlled and uncontrolled exposure limits.

Far Field Power Density

To ensure an accurate safety assessment, the far field power is also evaluated. The power in the far field (far from the antenna) is given by the equation:

$$S = \frac{GP}{4\pi r^2}$$

Where

P	=	Power fed to the antenna (W)
G	=	Gain
r	=	Distance from antenna (m)

This equation only applied to the far field when the terms with a higher power of r have decayed sufficiently to be neglected. The area of validity for this equation is:

$$r_{far} = \frac{2D^2}{\lambda}$$

Using D=0.943m and the largest wavelength of 1.5m, the region of validity for the power decaying at a rate of $1/r^2$ is 1.18m. At the boundary for the region of validity, the power density is 0.0026 mW/cm^2, which is well below the limits for both controlled and uncontrolled exposure.

Below the limits of validity, the far field power equation is a significant over-estimate of the power density. However, it is a useful safety factor and can be compared with the near field calculation. The distance at which the safe power density is exceeded can be found by re-arranging the far field power equation:

$$r = \sqrt{\frac{GP}{4\pi S}}$$

By plugging in G=4.52, P=0.1W, S=0.2mW/cm^2=2 W/m^2 for uncontrolled exposure, the distance is found to be 0.134m. This equation predicts that at 5.3 inches the power density would exceed safe limits; however, the equation used does not apply for distances less than 1.18m and is a significant over-estimate. The over-estimate for controlled exposure suggests that 0.06m or 2.4 inches is safe for someone who is aware of radio wave exposure. These distances are very small, and significant over-estimates since they are well outside the region of validity.

Conclusion

The power density radiated by the antenna is difficult to calculate close to the antenna, so two approaches were used to evaluate if the power is within safe limits. The FCC offered an approximation for calculating the maximum power density close to the antenna, which is 0.07mW/cm^2, and is well below the FCC and IEEE limits for controlled and uncontrolled exposure of 1mW/cm^2 and 0.2mW/cm^2 respectively. The far field power density equation is more accurate, but only applies at distances beyond 1.18m at which the power density is 0.0026 mW/cm^2. At smaller distances, the far field power density equation becomes a significant over-estimate of the power. The safe regions for controlled and uncontrolled exposure were found using this equation as 2.4 and 5.3 inches. This suggests that as an over-estimate of safety, it is safe to be anywhere near the antenna except for touching it. Because the overestimated safe distances are very small, the calculation supports the near field approximation of a maximum power density of 0.07mW/cm^2 near the antenna. Therefore, we expect that people are safe anywhere around the ApRES system. However, for extra caution we recommend that an operator does not touch the transmitting antenna and maintains at least a 5 inch distance.

References

[1] “USRP E312,” Ettus Research, Product ID 784421-01, Oct. 8, 2021. [Online] https://www.ettus.com/all-products/usrp-e312/

[2] “1400 Protector Case,” Pelican, Oct 8, 2021. [Online] https://www.pelican.com/us/en/product/cases/protector/1400?sku=1400-000-240

[3] “High Performance Receive Only Comercial Preamplifiers,” Advanced Receiver, Oct 8, 2021 [Online] http://www.advancedreceiver.com/page3.html

[4] “Seagate Portable 4TB External Hard Drive HDD – USB 3.0 for PC, Mac, Xbox, & PS4 - 1-Year Rescue Service (STGX4000400),” Segate, Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07CRGSR16/ref=ppx_yo_dt_b_asin_title_o05_s02?ie=UTF8&psc=1

[5] “OCOOPA Rechargeable Hand Warmers, 10000mAH Electric Handwarmer Winter Warm 15 Hours Portable Hands Heater for Men and Women, Outdoor Indoor Camping/Fishing/Cycling/Motorcycling/Skiing (Fire Orange),” Ocoopa via Amazon, Oct 8, 2021. [Online] https://www.amazon.com/OCOOPA-Rechargeable-10000mAh-Handwarmer-Motorcycling/dp/B08GQ1HHKQ/ref=sr_1_2_sspa?dchild=1&keywords=electric+hand+warmer&qid=1630350836&refinements=p_72%3A1248957011&rnid=1248955011&s=sporting-goods&sr=1-2-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEyUFFBMFVQTUExVlZLJmVuY3J5cHRlZElkPUEwNzE4NDI4M0RIWVhZNEI4TEsxNiZlbmNyeXB0ZWRBZElkPUEwMTU3NjA5MVlLWVVTUVFFNE5QVCZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=

[6] “EnergyFlux G3 Series 5200mAh Rechargeable Hand Warmer / External Battery Pack,” Human Creations, Oct 8, 2021. [Online] https://www.human-creations.com/product-page/energyflux-g3-5200mah-rechargeable-hand-warmer-external-battery-pack

[7] “SanDisk 32GB Ultra SDHC UHS-I Memory Card - 120MB/s, C10, U1, Full HD, SD Card - SDSDUN4-032G-GN6IN, SanDisk via Amazon, Oct 8, 2021. [Online] https://www.amazon.com/SanDisk-Ultra-UHS-I-Memory-SDSDUN4-032G-GN6IN/dp/B08GYG6T12/ref=sr_1_4?dchild=1&keywords=sandisk+32GB+SD&qid=1626217291&s=electronics&sr=1-4

[8] “PRO Elite USB 3.0 Flash Drive,” PNY, Oct 8, 2021. [Online] https://www.pny.com/pro-elite-usb3?sku=P-FD256PRO-GE

[9] “iPad Charging Station 96W 10-Port Alxum USB Charging Station Multiple Device USB Charger with Smart IC Tech, Organizer Stand for iPhone X, Xs Max,8,7,6, Samsung Google Nexus LG, Tablets, White,” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/Alxum-Charging-Station-Multiple-Organizer/dp/B01K7F51VU/ref=sr_1_1?crid=3BEYJX7TZH57C&dchild=1&keywords=ipad+charging+station+96w+10-

port+alxum+usb+charging+station&qid=1619127437&sprefix=ipad+charging+station+96W+%2Celectronics%2C205&sr=8-1

[10] "Trimble 66800-52-SP: 3 Volt Magnetic Mount GPS Antenna with SMA connector," Trimble via Amazon, Oct 8, 2021. [Online] https://www.amazon.com/Trimble-66800-52-SP-Magnetic-Antenna-connector/dp/B072NYQPH7

[11] "3-Volt Active GPS Antenna for N Series," Ettus Research, Oct 8, 2021. [Online] https://www.ettus.com/all-products/gps-ant-3v/

[12] "DZS Elec 2pcs RG316 Wire Jumper 15cm SMA Male to N Male with Connecting Line RF Coaxial Coax Cable Antenna Extender Cable Adapter Jumper," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/DZS-Elec-Connecting-Coaxial-Extender/dp/B072C6CJBC/ref=sr_1_5?dchild=1&keywords=N+type+to+SMA+cable+6+in&qid=1630350622&sr=8-5

[13] "SMA Cable RG316 6inch (15cm) TUOLNK SMA Male to SMA Male Coaxial Cable WiFi Antenna Extension Cable for WiFi Radios Security System SMA RF Pigtail Coax Cable 2 Pack," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/Coaxial-Antenna-Extension-Security-Pigtail/dp/B091TFR9WC/ref=sr_1_10?dchild=1&keywords=SMA+Male-Male+6in&qid=1626217731&sr=8-10

[14] "exgoofit SMA Male to SMA Male Plug Connector 5-Pack + SMA Female to SMA Female 5-Pack Jack RF Coaxial Adapter Connector," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07FDHBS19/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1

[15] "15FT--LMR195 cable SMA Male to TNC Male," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/15FT-LMR195-cable-SMA-Male-TNC/dp/B004WL9TIC/ref=sr_1_1?dchild=1&keywords=sma+MALE+TO+tnc+MALE+CABLE+15+ft+LMR195&qid=1626217960&s=electronics&sr=1-1

[16] "202109-10," Digi-Key, Oct 8, 2021. [Online] https://www.digikey.com/en/products/detail/amphenol-rf/202109-10/1011850

[17] "202117," Digi-Key, Oct 8, 2021. [Online] https://www.digikey.com/en/products/detail/amphenol-rf/202117/1011794?s=N4IgTCBcDaIIIGEAaBGNB2AtAOQCIgF0BfIA

[18] "BECEN 10W SMA RF attenuator, DC to 3GHz, 40dB," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/BECEN-10W-attenuator-3GHz-40db/dp/B07MZLVY9T/ref=sr_1_4?dchild=1&keywords=40db+attenuator&qid=1626218199&sr=8-4

[19] "Maxmoral 2PCS SMA Female to SMB Female Connector RF Coax Coaxial Adapter," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/Maxmoral-Female-Connector-Coaxial-Adapter/dp/B071SDXWFW

[20] "RFaha 2pcs N Male to SMA Female RF Coax Adapter N to SMA Coaxial Connector(F41-2)," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/RFaha-Female-Adapter-Coaxial-Connector/dp/B0932LQB4R/ref=sr_1_17_sspa?dchild=1&keywords=N-type+M+to+SMA+F+adapter&qid=1626218264&s=electronics&sr=1-17-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzQUFBSlJOTTUwV1pEJmVuY3J5cHRlZElkPUEwOTE4Mjc2M1ZTTktETFdZVzE4RiZlbmNyeXB0ZWRBZElkPUEwNTYwOTEzMTY0T1BXVFhGN1dOWSZ3aWRnZXROYW1lPXNwX210ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=

[21] "UPG D1724 Sealed Lead Acid Battery Charger (6V/12V Switchable Single-Stage With Alligator Clips)," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B001G8AIMU/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

[22] "Amazon Basics RJ45 Cat-6 Ethernet Patch Internet Cable - 5 Feet (1.5 Meters)," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/AmazonBasics-RJ45-Cat-6-Ethernet-Patch-Cable-5-Feet-1-5-Meters/dp/B00N2VILDM/ref=sr_1_1_sspa?dchild=1&keywords=ethernet+cable&qid=1626218419&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzSUpFNThDQVg5VVFEJmVuY3J5cHRlZElkPUEwODI1NzY5M0dQN09CRjVPVlhYRyZlbmNyeXB0ZWRBZElkPUEwMDM2NDMzTUFTTzNIRTJBUVQ4JndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==

[23] "UGREEN USB to USB Cable, USB 3.0 Male to Male Type A to Type A Cable for Data Transfer Compatible with Hard Drive, Laptop, DVD Player, TV, USB 3.0 Hub, Monitor, Camera, Set Up Box and More 3FT," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B00P0E39CM/ref=ppx_yo_dt_b_asin_title_o07_s00?ie=UTF8&psc=1

[24] "ExpertPower EXP1245 12V 4.5 Amp Rechargeable Battery for Security Systems," ExpertPower via Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B00A82A4N8/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

[25] "RG-316 Cable Assembly," Cross RF, Oct 8, 2021. [Online] http://www.crossrf.com/cable-assemblies/flexible-cables/rg-316-cable-assembly

[26] "CCSMA-MM-086-3," Digi-Key, Oct 8, 2021. [Online] https://www.digikey.com/en/products/detail/crystek-corporation/CCSMA-MM-086-3/2433482

[27] "RF Coax Adapter SMA Male to Female RF FPV Antenna Adapter WiFi Antenna Cable Connector Right Angle 90-Degree Adapter for FPV Race RX5808 Fatshark Goggles Pack of 2," Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B00VHAZ0KW/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1

[28] “Short Micro USB Charger, iSeeker 3Pack 1.5ft/50cm High Speed Micro-USB to USB 2.0 Cable Sync & Charge Cord Compatible for Samsung Galaxy S7 Edge/S6, Nexus, Motorola, Android Smartphone, Camera,” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07GGTZG2V/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1

[29] “ 360Pcs Quick Splice 6.3/4.8/2.8mm Male Female Wire Spade Connector, Crimp Terminal with Insulating Sleeve Assortment Kit,” Amazon, Oct 8, 2021. [Online] ttps://www.amazon.com/gp/product/B07T6CLGL2/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

[30] “Bob Smith Industries BSI-142 Clear Foam-Cure, Craft Glue, 4 oz.,” Bob Smithy Industries via Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B011XWDTOW/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1

[31] “SMA Jack Female to Female Coupling nut Basket Hole Waterproof Bulkhead Straight O-Ring to Standard Polarity 50 Ohm SMA Jack Female Hole RF Coaxial Adapter Standard Polarity 50 Ohm, 2 pcs,” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07B8F5XYD/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1

[32] “Anmbest 2PCS Electrical USB2.0 IP67 Waterproof Connector Industrial Standard Double Head Coupler Adapter Female to Female Socket Plug Panel Mount with Waterproof/Dust Cap,” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07RPW5XGB/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1

[33] “Swpeet 120Pcs 6.3MM 1 Pin Automotive Electrical Wire Connectors, Automotive Electrical Wire Connectors Pin Header Crimp Wire Terminals for Car Motorcycle,” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B07X3K32DC/ref=ppx_yo_dt_b_asin_title_o03_s01?ie=UTF8&psc=1

[34] “DC Power Plug Pigtail Cable (Male Power Plug Pigtail Cable / 19.68 inches/Pack of 10),” Amazon, Oct 8, 2021. [Online] https://www.amazon.com/gp/product/B01LX51QHN/ref=ppx_yo_dt_b_asin_title_o02_s01?ie=UTF8&psc=1

[35] “DHT Electronics RF coaxial Coax Assembly SMA Male to SMA Male 3ft,” Amazon, Oct 8. 2021. [Online] https://www.amazon.com/gp/product/B00MA50Q16/ref=ppx_yo_dt_b_asin_title_o08_s00?ie=UTF8&psc=1

[36] IEEE Standards Coordinating Committee 28 on Non-Ionizing Radiation Hazards, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," The Institute of Electrical and Electronics Engineers, Inc. New York, NY, American National Standard. Library of Congress Number 92-8054, Nov. 1991.

[37] R. Cleveland, D. Sylvar, J. Ulcek, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," Federal Communications Commission Office of Engineering & Technology, Washington, D.C. OET Bulletin 65. Ed. 97-01, Aug. 1997.

[38] P. Brennan, et al. "Phase-sensitive FMCW radar system for high-precision Antarctic ice shelf profile monitoring." *IET Radar, Sonar & Navigation*, vol. 9, Iss. 7, pp 776-786, 2014. Doi: 10.1049/iet-rsn.2013.0053

[39] L. Lok, P. Brennan, K. Nicholls, H. Corr, "ApRES: Autonomous PhaseSensitive FMCW Radar, for Basal Monitoring and Imaging of Antarctic Ice Shelves," IET Colloquium on Antennas, Wireless and Electromagnetics, London, UK. 27 May. 2014.

[40] S. Bhatti, W. Mohiuddin, "Overview of Cell Phone Technology," *ucsb.edu*, n.d. [Online]

[41] AD9361, "Analog Devices," [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/AD9361.pdf.