HCR Calibration - HowTo Documentation

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1. Lab setup

The HCR is calibrated on the bench in the lab. Figure 1 shows a schematic of the lab setup.

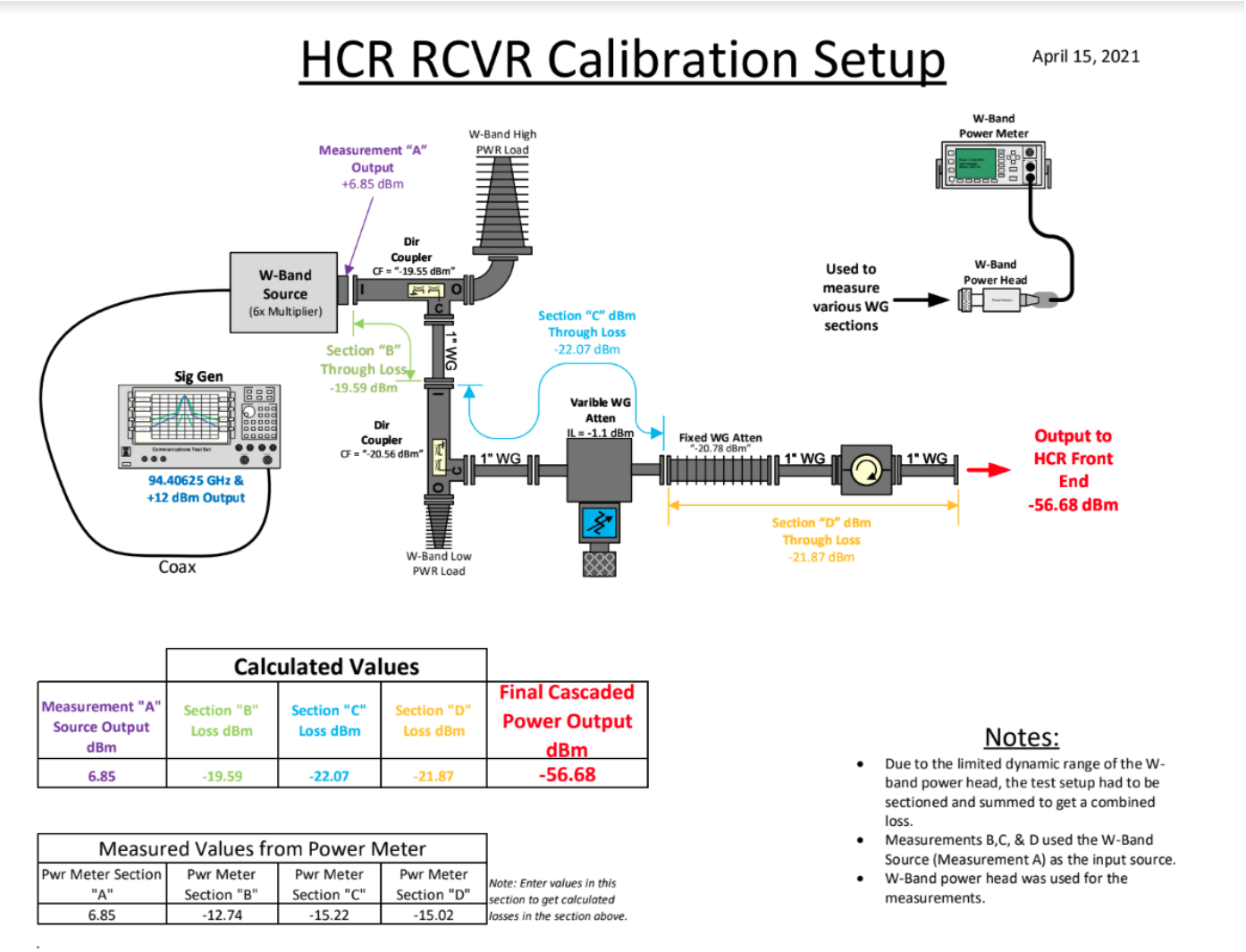


Figure 1: Connections and losses for the HCR calibration setup

NOTE: calibrations are run with the LNA heaters on.

Figures 2a to 2d show images of the lab setup.

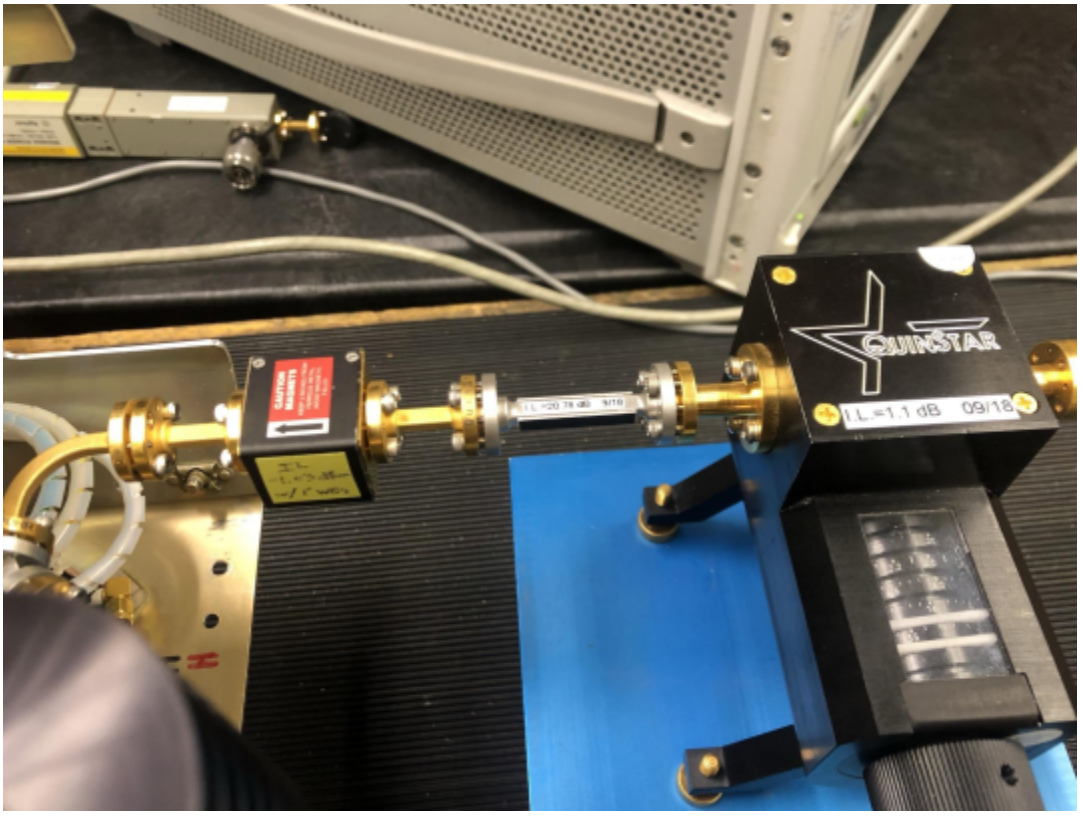


Figure 2a: manual attenuator, fixed attenuator, isolator

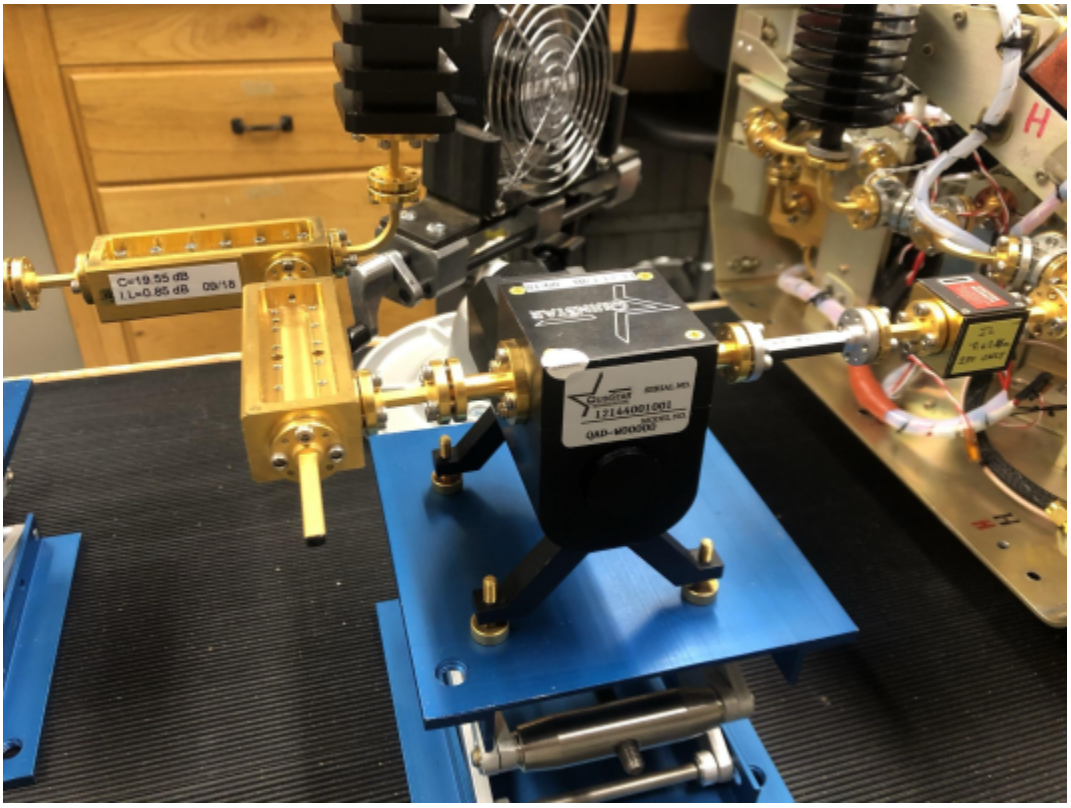


Figure 2b: coupler, manual attenuator, fixed attenuator, isolator

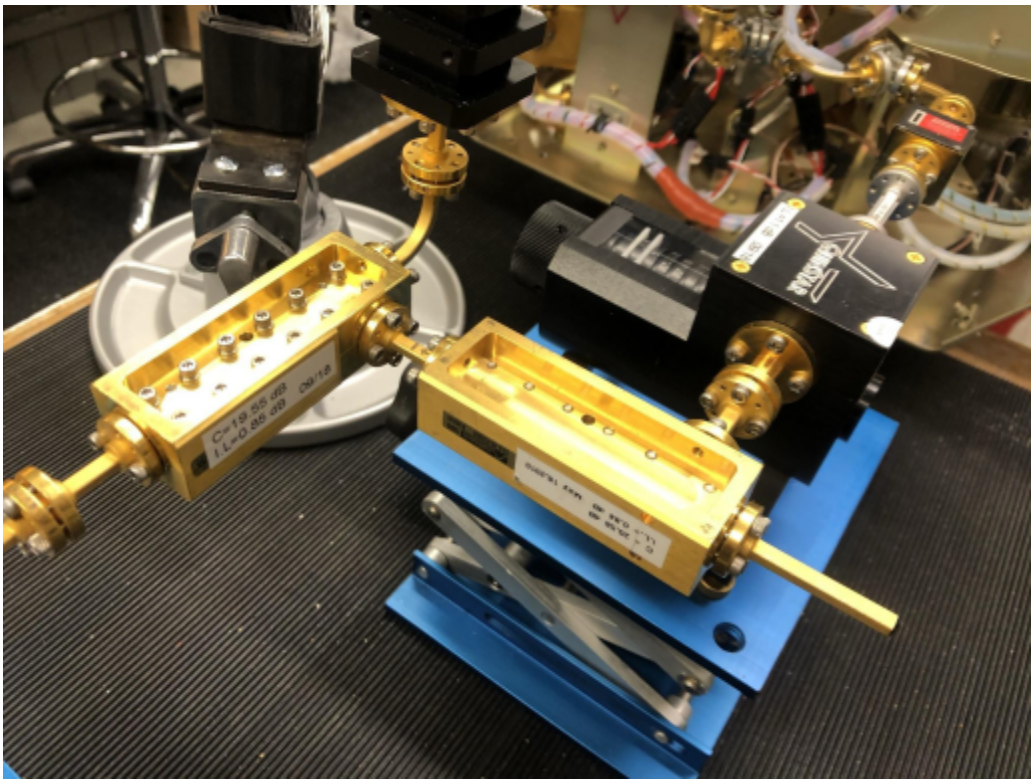


Figure 2c: couplers

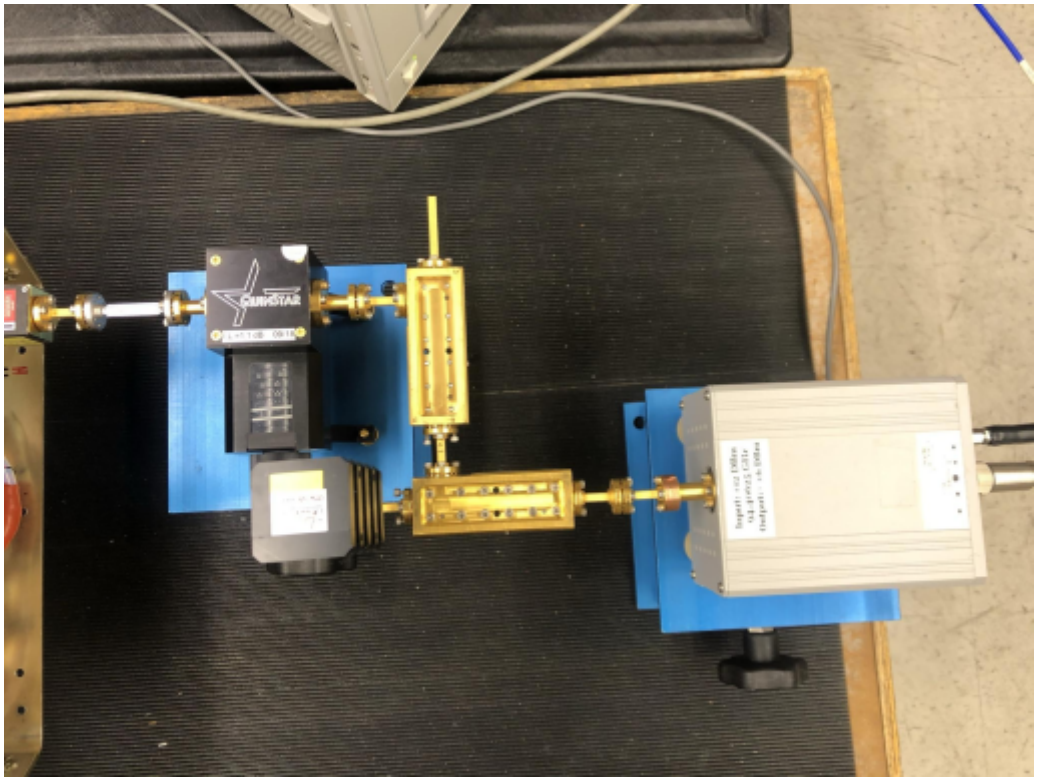


Figure 2d: top view

2. Calibration procedure outline

We have to calibrate the H and V channels separately. We also have to split the calibration of each channel into two parts: we calibrate the higher powers first - i.e the upper half of the calibration curve. We then insert the ~20dB fixed attenuator into the circuit, and calibrate the lower half of the curve, down into the noise.

The steps for the H channel are:

- set up for H channel, no fixed attenuator
- calibrate H channel top half
- insert fixed attenuator
- calibrate H channel bottom half

followed by the V channel:

- set up for V channel, no fixed attenuator
- calibrate V channel top half
- insert fixed attenuator
- calibrate V channel bottom half

The manually-variable attenuator has a range of 0 to 60 dB.

For the top half, we start with it set to 0, and then apply 5 dB increments up to 40 dB.

We then insert the fixed attenuator, which has a value of 20.95 dB. (It is marked as 20.78 dB, but our measurements show it to be 20.95.)

For the lower half, we start with the variable attenuator set to 25 dB. That gives an effective attenuation of 25 + 20.95 = 45.95 dB. We then use 5 dB increments up to 60 dB, for effective attenuation of 45.95 up to 80.95 dB.

After the measurement at 60 dB (effective 80.95 dB) we turn off the siggen to take measurements of the noise.

Remember to turn on the LNA heaters.

We run the entire procedure for the 256 ns pulse width.

If the radar will also be run using the 512 ns pulse width, we repeat the procedure for the 512 ns case.

In this document we are assuming a 256 ns pulse width.

For the H channel, the siggen waveguide must be attached to the port at the edge of the instrument. For the V channel use the port at the center of the instrument.

3. Running the software

The calibration software is run on the archiver.

3.1 Start the system

Start the full system, except for the transmitter. The hcrdrx must be running on the rds.

Generally this will be done on desktop 1.

3.2 Monitoring the receive channel powers and LNA temperatures

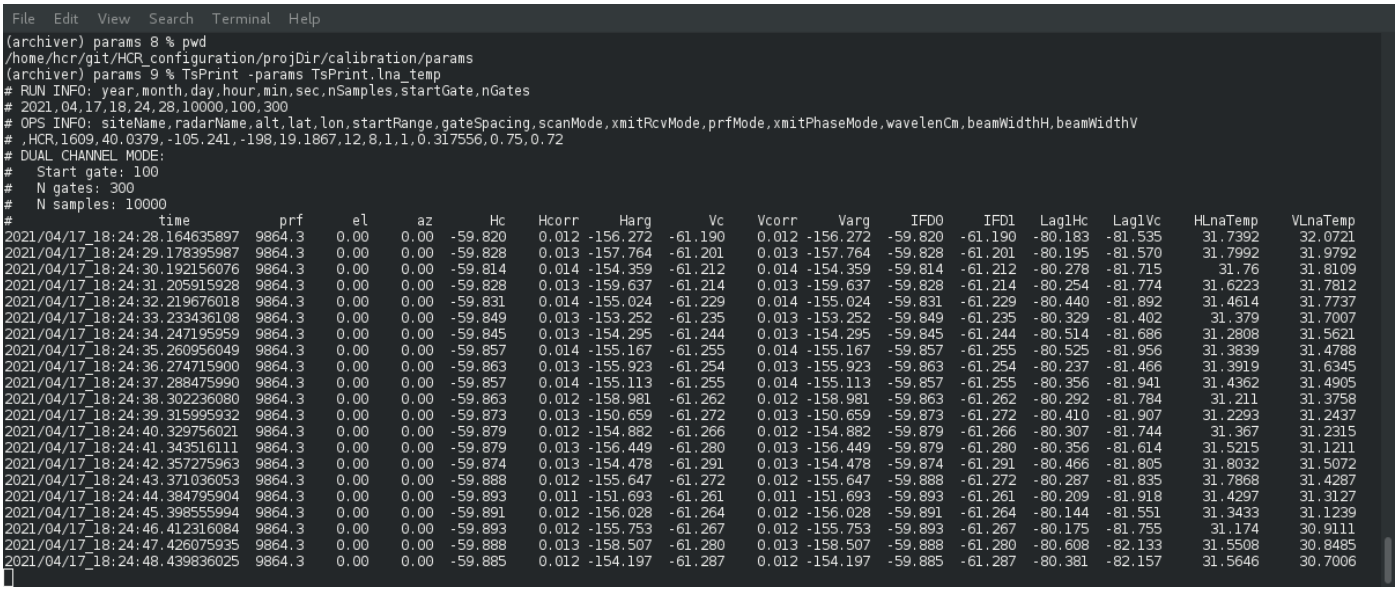
It is a good idea to run the calibration on a clean desktop, say desktop 2.

Bring up a terminal window, and widen it out.

The run the following:

```
cd projDir/calibration/params
TsPrint -params TsPrint.lna_temp
```

Figure 3a shows us starting TsPrint:



```
File  Edit  View  Search  Terminal  Help
(archiver) params 8 % pwd
/home/hcr/git/HCR_configuration/projDir/calibration/params
(archiver) params 9 % TsPrint -params TsPrint.lna_temp
# RUN INFO: year,month,day,hour,min,sec,nSamples,startGate,nGates
# 2021,04,17,18,24,28,10000,100,300
# OPS INFO: siteName,radarName,alt,lat,lon,startRange,gateSpacing,scanMode,xmitRcvMode,prfMode,xmitPhaseMode,wavelenCm,beamWidthH,beamWidthV
# ,HCR,1609,40.0379,-105.241,-198,19.1867,12,8,1,1,0.317556,0.75,0.72
# DUAL CHANNEL MODE:
#   Start gate: 100
#   N gates: 300
#   N samples: 10000
#                time          prf      el      az       Hc    Hcorr     Harg       Vc    Vcorr     Varg     IFD0     IFD1   LaglHc   LaglVc   HLnaTemp   VLnaTemp
2021/04/17_18:24:28.164635897  9864.3    0.00    0.00  -59.820  0.012 -156.272  -61.190  0.012 -156.272  -59.820  -61.190  -80.183  -81.535    31.7392    32.0721
2021/04/17_18:24:29.178395987  9864.3    0.00    0.00  -59.828  0.013 -157.764  -61.201  0.013 -157.764  -59.828  -61.201  -80.195  -81.570    31.7992    31.9792
2021/04/17_18:24:30.192156076  9864.3    0.00    0.00  -59.814  0.014 -154.359  -61.212  0.014 -154.359  -59.814  -61.212  -80.278  -81.715      31.76    31.8109
2021/04/17_18:24:31.205915928  9864.3    0.00    0.00  -59.828  0.013 -159.637  -61.214  0.013 -159.637  -59.828  -61.214  -80.254  -81.774    31.6223    31.7812
2021/04/17_18:24:32.219676018  9864.3    0.00    0.00  -59.831  0.014 -155.024  -61.229  0.014 -155.024  -59.831  -61.229  -80.440  -81.892    31.4614    31.7737
2021/04/17_18:24:33.233436108  9864.3    0.00    0.00  -59.849  0.013 -153.252  -61.235  0.013 -153.252  -59.849  -61.235  -80.329  -81.402     31.379    31.7007
2021/04/17_18:24:34.247195959  9864.3    0.00    0.00  -59.845  0.013 -154.295  -61.244  0.013 -154.295  -59.845  -61.244  -80.514  -81.686    31.2808    31.5621
2021/04/17_18:24:35.260956049  9864.3    0.00    0.00  -59.857  0.014 -155.167  -61.255  0.014 -155.167  -59.857  -61.255  -80.525  -81.956    31.3839    31.4788
2021/04/17_18:24:36.274715900  9864.3    0.00    0.00  -59.863  0.013 -155.923  -61.254  0.013 -155.923  -59.863  -61.254  -80.237  -81.466    31.3919    31.6345
2021/04/17_18:24:37.288475990  9864.3    0.00    0.00  -59.857  0.014 -155.113  -61.255  0.014 -155.113  -59.857  -61.255  -80.356  -81.941    31.4362    31.4905
2021/04/17_18:24:38.302236080  9864.3    0.00    0.00  -59.863  0.012 -158.981  -61.262  0.012 -158.981  -59.863  -61.262  -80.292  -81.784     31.211    31.3758
2021/04/17_18:24:39.315995932  9864.3    0.00    0.00  -59.873  0.013 -150.659  -61.272  0.013 -150.659  -59.873  -61.272  -80.410  -81.907    31.2293    31.2437
2021/04/17_18:24:40.329756021  9864.3    0.00    0.00  -59.879  0.012 -154.882  -61.266  0.012 -154.882  -59.879  -61.266  -80.307  -81.744     31.367    31.2315
2021/04/17_18:24:41.343516111  9864.3    0.00    0.00  -59.879  0.013 -156.449  -61.280  0.013 -156.449  -59.879  -61.280  -80.356  -81.614    31.5215    31.1211
2021/04/17_18:24:42.357275963  9864.3    0.00    0.00  -59.874  0.013 -154.478  -61.291  0.013 -154.478  -59.874  -61.291  -80.466  -81.805    31.8032    31.5072
2021/04/17_18:24:43.371036053  9864.3    0.00    0.00  -59.888  0.012 -155.647  -61.272  0.012 -155.647  -59.888  -61.272  -80.287  -81.835    31.7868    31.4287
2021/04/17_18:24:44.384795904  9864.3    0.00    0.00  -59.893  0.011 -151.693  -61.261  0.011 -151.693  -59.893  -61.261  -80.209  -81.918    31.4297    31.3127
2021/04/17_18:24:45.398555994  9864.3    0.00    0.00  -59.891  0.012 -156.028  -61.264  0.012 -156.028  -59.891  -61.264  -80.144  -81.551    31.3433    31.1239
2021/04/17_18:24:46.412316084  9864.3    0.00    0.00  -59.893  0.012 -155.753  -61.267  0.012 -155.753  -59.893  -61.267  -80.175  -81.755     31.174    30.9111
2021/04/17_18:24:47.426075935  9864.3    0.00    0.00  -59.888  0.013 -158.507  -61.280  0.013 -158.507  -59.888  -61.280  -80.608  -82.133    31.5508    30.8485
2021/04/17_18:24:48.439836025  9864.3    0.00    0.00  -59.885  0.012 -154.197  -61.287  0.012 -154.197  -59.885  -61.287  -80.381  -82.157    31.5646    30.7006
```

Figure 3a: TsPrint output showing LNA temperatures

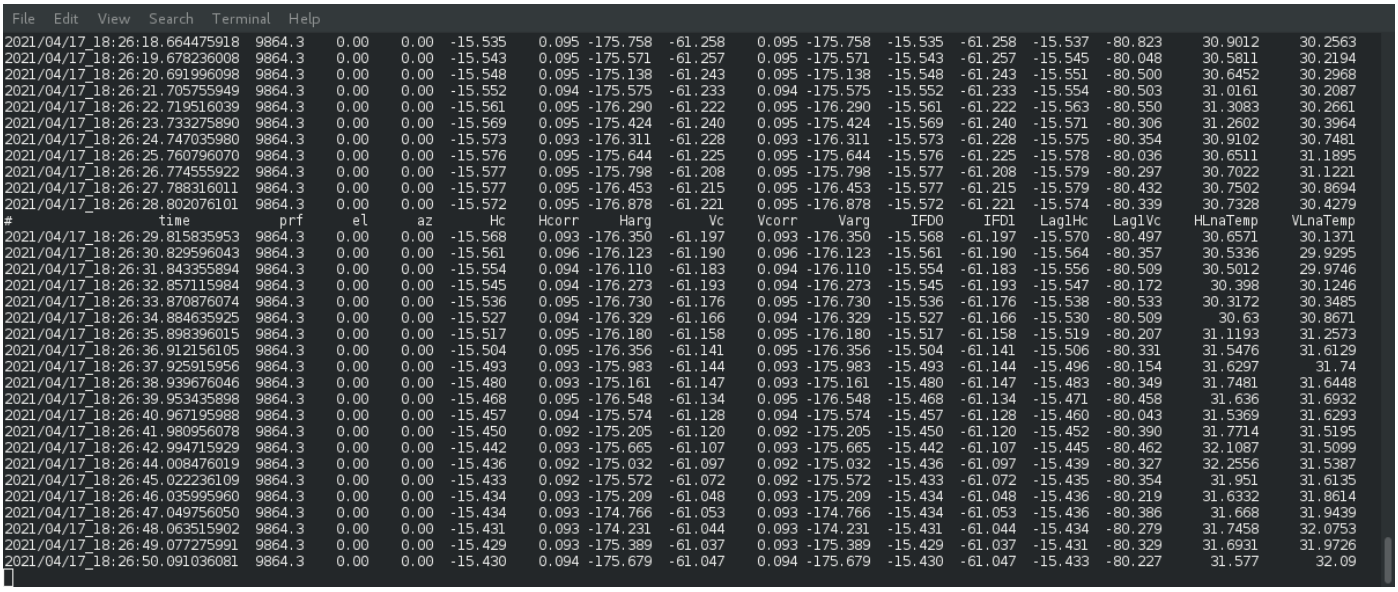
The LNA temperatures are in the right-hand 2 columns. These temps should be between 30 and 32 C. That shows that the heaters are on. Check the LEDs on the heater boards, to ensure the heaters are cycling.

The H power, in dBm, shows up under headings 'Hc' and 'IFD0'.
The V power, in dBm, shows up under headings 'Vc' and 'IFD1'.

In Figure 3a, both H and V are showing noise: -59 dBm for H and -61 dBm for V.

In contrast, Figure 3b shows a power of -15 dBm in the H channel, and noise in the V channel.

In Figure 3b, note that the LNA temperatures are varying as the heaters cycle on and off.



```
File  Edit  View  Search  Terminal  Help
2021/04/17_18:26:18.664475918  9864.3  0.00  0.00  -15.535  0.095 -175.758  -61.258  0.095 -175.758  -15.535  -61.258  -15.537  -80.823  30.9012  30.2563
2021/04/17_18:26:19.678236008  9864.3  0.00  0.00  -15.543  0.095 -175.571  -61.257  0.095 -175.571  -15.543  -61.257  -15.545  -80.048  30.5811  30.2194
2021/04/17_18:26:20.691996098  9864.3  0.00  0.00  -15.548  0.095 -175.138  -61.243  0.095 -175.138  -15.548  -61.243  -15.551  -80.500  30.6452  30.2968
2021/04/17_18:26:21.705755949  9864.3  0.00  0.00  -15.552  0.094 -175.575  -61.233  0.094 -175.575  -15.552  -61.233  -15.554  -80.503  31.0161  30.2087
2021/04/17_18:26:22.719516039  9864.3  0.00  0.00  -15.561  0.095 -176.290  -61.222  0.095 -176.290  -15.561  -61.222  -15.563  -80.550  31.3083  30.2661
2021/04/17_18:26:23.733275890  9864.3  0.00  0.00  -15.569  0.095 -175.424  -61.240  0.095 -175.424  -15.569  -61.240  -15.571  -80.306  31.2602  30.3964
2021/04/17_18:26:24.747035980  9864.3  0.00  0.00  -15.573  0.093 -176.311  -61.228  0.093 -176.311  -15.573  -61.228  -15.575  -80.354  30.9102  30.7481
2021/04/17_18:26:25.760796070  9864.3  0.00  0.00  -15.576  0.095 -175.644  -61.225  0.095 -175.644  -15.576  -61.225  -15.578  -80.036  30.6511  31.1895
2021/04/17_18:26:26.774555922  9864.3  0.00  0.00  -15.577  0.095 -175.798  -61.208  0.095 -175.798  -15.577  -61.208  -15.579  -80.297  30.7022  31.1221
2021/04/17_18:26:27.788316011  9864.3  0.00  0.00  -15.577  0.095 -176.453  -61.215  0.095 -176.453  -15.577  -61.215  -15.579  -80.432  30.7502  30.8694
2021/04/17_18:26:28.802076101  9864.3  0.00  0.00  -15.572  0.095 -176.878  -61.221  0.095 -176.878  -15.572  -61.221  -15.574  -80.339  30.7328  30.4279
#          time          prf     el     az       Hc     Hcorr      Harg      Vc     Vcorr      Varg     IFD0     IFD1   Lag1Hc   Lag1Vc  HLnaTemp  VLnaTemp
2021/04/17_18:26:29.815835953  9864.3  0.00  0.00  -15.568  0.093 -176.350  -61.197  0.093 -176.350  -15.568  -61.197  -15.570  -80.497  30.6571  30.1371
2021/04/17_18:26:30.829596043  9864.3  0.00  0.00  -15.561  0.096 -176.123  -61.190  0.096 -176.123  -15.561  -61.190  -15.564  -80.357  30.5336  29.9295
2021/04/17_18:26:31.843355894  9864.3  0.00  0.00  -15.554  0.094 -176.110  -61.183  0.094 -176.110  -15.554  -61.183  -15.556  -80.509  30.5012  29.9746
2021/04/17_18:26:32.857115984  9864.3  0.00  0.00  -15.545  0.094 -176.273  -61.193  0.094 -176.273  -15.545  -61.193  -15.547  -80.172   30.398  30.1246
2021/04/17_18:26:33.870876074  9864.3  0.00  0.00  -15.536  0.095 -176.730  -61.176  0.095 -176.730  -15.536  -61.176  -15.538  -80.533  30.3172  30.3485
2021/04/17_18:26:34.884635925  9864.3  0.00  0.00  -15.527  0.094 -176.329  -61.166  0.094 -176.329  -15.527  -61.166  -15.530  -80.509    30.63  30.8671
2021/04/17_18:26:35.898396015  9864.3  0.00  0.00  -15.517  0.095 -176.180  -61.158  0.095 -176.180  -15.517  -61.158  -15.519  -80.207  31.1193  31.2573
2021/04/17_18:26:36.912156105  9864.3  0.00  0.00  -15.504  0.095 -176.356  -61.141  0.095 -176.356  -15.504  -61.141  -15.506  -80.331  31.5476  31.6129
2021/04/17_18:26:37.925915956  9864.3  0.00  0.00  -15.493  0.093 -175.983  -61.144  0.093 -175.983  -15.493  -61.144  -15.496  -80.154  31.6297    31.74
2021/04/17_18:26:38.939676046  9864.3  0.00  0.00  -15.480  0.093 -175.161  -61.147  0.093 -175.161  -15.480  -61.147  -15.483  -80.349  31.7481  31.6448
2021/04/17_18:26:39.953435898  9864.3  0.00  0.00  -15.468  0.095 -176.548  -61.134  0.095 -176.548  -15.468  -61.134  -15.471  -80.458   31.636  31.6932
2021/04/17_18:26:40.967195988  9864.3  0.00  0.00  -15.457  0.094 -175.574  -61.128  0.094 -175.574  -15.457  -61.128  -15.460  -80.043  31.5369  31.6293
2021/04/17_18:26:41.980956078  9864.3  0.00  0.00  -15.450  0.092 -175.205  -61.120  0.092 -175.205  -15.450  -61.120  -15.452  -80.390  31.7714  31.5195
2021/04/17_18:26:42.994715929  9864.3  0.00  0.00  -15.442  0.093 -175.665  -61.107  0.093 -175.665  -15.442  -61.107  -15.445  -80.462  32.1087  31.5099
2021/04/17_18:26:44.008476019  9864.3  0.00  0.00  -15.436  0.092 -175.032  -61.097  0.092 -175.032  -15.436  -61.097  -15.439  -80.327  32.2556  31.5387
2021/04/17_18:26:45.022236109  9864.3  0.00  0.00  -15.433  0.092 -175.572  -61.072  0.092 -175.572  -15.433  -61.072  -15.435  -80.354   31.951  31.6135
2021/04/17_18:26:46.035995960  9864.3  0.00  0.00  -15.434  0.093 -175.209  -61.048  0.093 -175.209  -15.434  -61.048  -15.436  -80.219  31.6332  31.8614
2021/04/17_18:26:47.049756050  9864.3  0.00  0.00  -15.434  0.093 -174.766  -61.053  0.093 -174.766  -15.434  -61.053  -15.436  -80.386   31.668  31.9439
2021/04/17_18:26:48.063515902  9864.3  0.00  0.00  -15.431  0.093 -174.231  -61.044  0.093 -174.231  -15.431  -61.044  -15.434  -80.279  31.7458  32.0753
2021/04/17_18:26:49.077275991  9864.3  0.00  0.00  -15.429  0.093 -175.389  -61.037  0.093 -175.389  -15.429  -61.037  -15.431  -80.329  31.6931  31.9726
2021/04/17_18:26:50.091036081  9864.3  0.00  0.00  -15.430  0.094 -175.679  -61.047  0.094 -175.679  -15.430  -61.047  -15.433  -80.227   31.577    32.09
```

Figure 3b: TsPrint output showing -15 dBm power in the H channel, and noise (-61 dBm) power in the V channel

3.3 Running the calibration for the H channel

In this example we will run the cal for the 256 ns pulse width.

Bring up a terminal window. Then run the following:

```
cd projDir/calibration/params
TsCalAuto -params TsCalAuto.wband.h_only.256ns
```

You will see the text as in Figure 3c below.

You will be prompted to hit 'Return' after certain actions have been completed on the hardware setup.

The first prompt is to set the frequency on the siggen to 94.4062 GHz. Then hit Return.

Then set the variable attenuator, as indicated by the 'delta' prompt value. The first delta is 0. So set the attenuator to 0 dB. In the TsPrint window check to ensure that the Hc power shows up around +5 dBm. Then hit Return.

TsCalAuto will take 2 seconds of time series data, compute the powers and print a line of data below the prompt. The power in Hc should show up around +5 - it should be the same as in the TsPrint window.

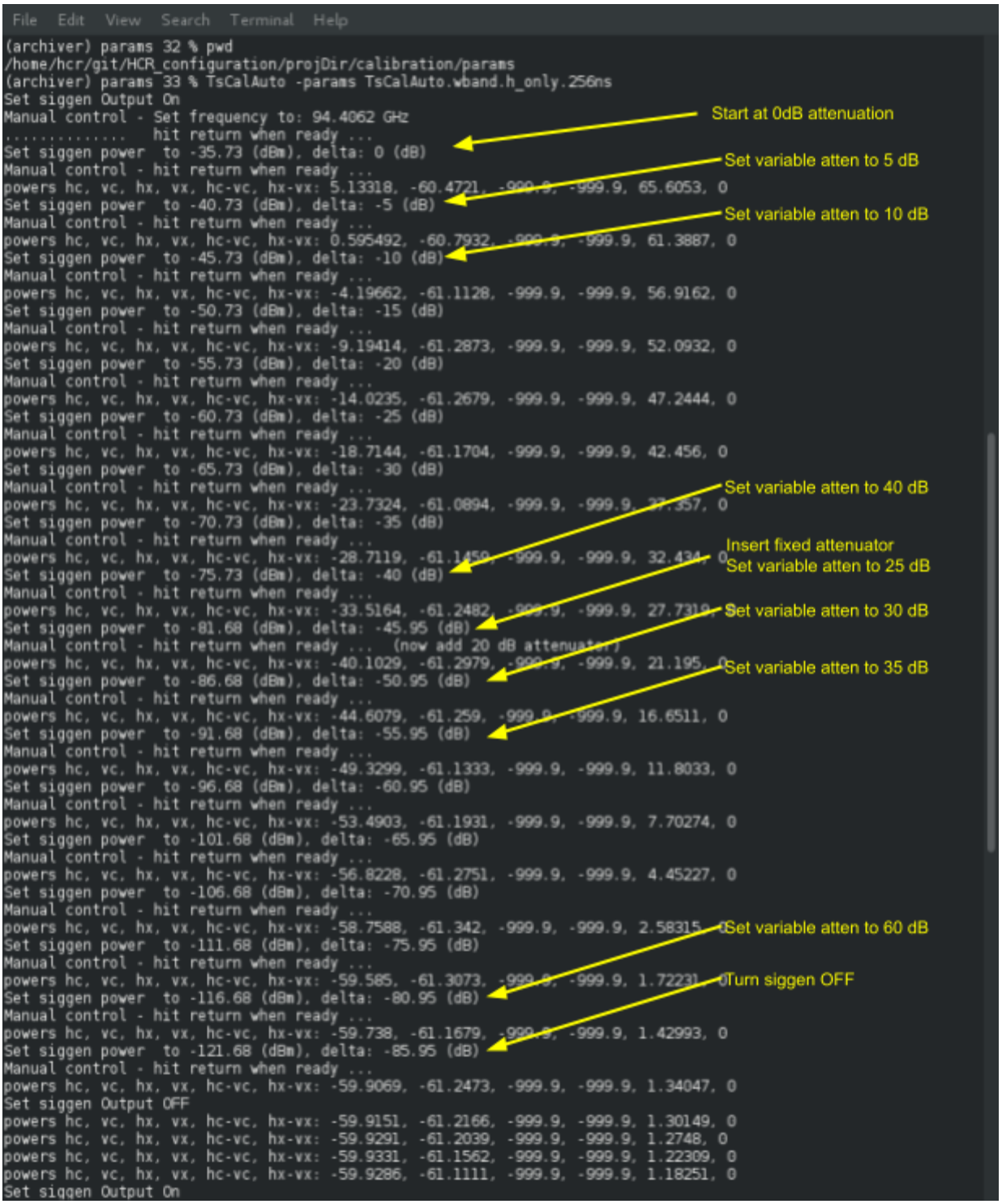


Figure 3c: TsCalAuto -params TsCalAuto.wband.h_only.256ns

If all is good, then proceed by increasing the attenuation in 5 dB steps up to a maximum of 40 dB. Each time you will be prompted with the attenuation to dial in on the variable attenuator.

After you have taken the data for an attenuation of 40 dB, you will be prompted for an attenuation (delta) of 45.95 dB.

Turn the siggen RF off, and insert the fixed (20.95 dB) attenuator.

Then turn the siggen RF on and set the variable attenuator to 25 dB. This will total the 45.95 dB for which you are being prompted. Once that is all set up, hit Return to take the data for that power setting.

You will then be prompted for an attenuation (delta) of 50.95. Dial in 30 dB on the variable attenuator, and hit Return. This continues in 5 dB steps up to a requested delta of 80.95 dB, which will be 60 dB on the variable attenuator. Hit return for that final attenuator setting.

Then turn the siggen RF off, and hit Return. TsCalAuto will then take 4 readings in the noise - i.e. with no siggen power.

At that point, the script:

```
~/projDir/calibration/scripts/do_calplot.dyn_range
```

will run, and produce a plot similar to that in Figure 3d.

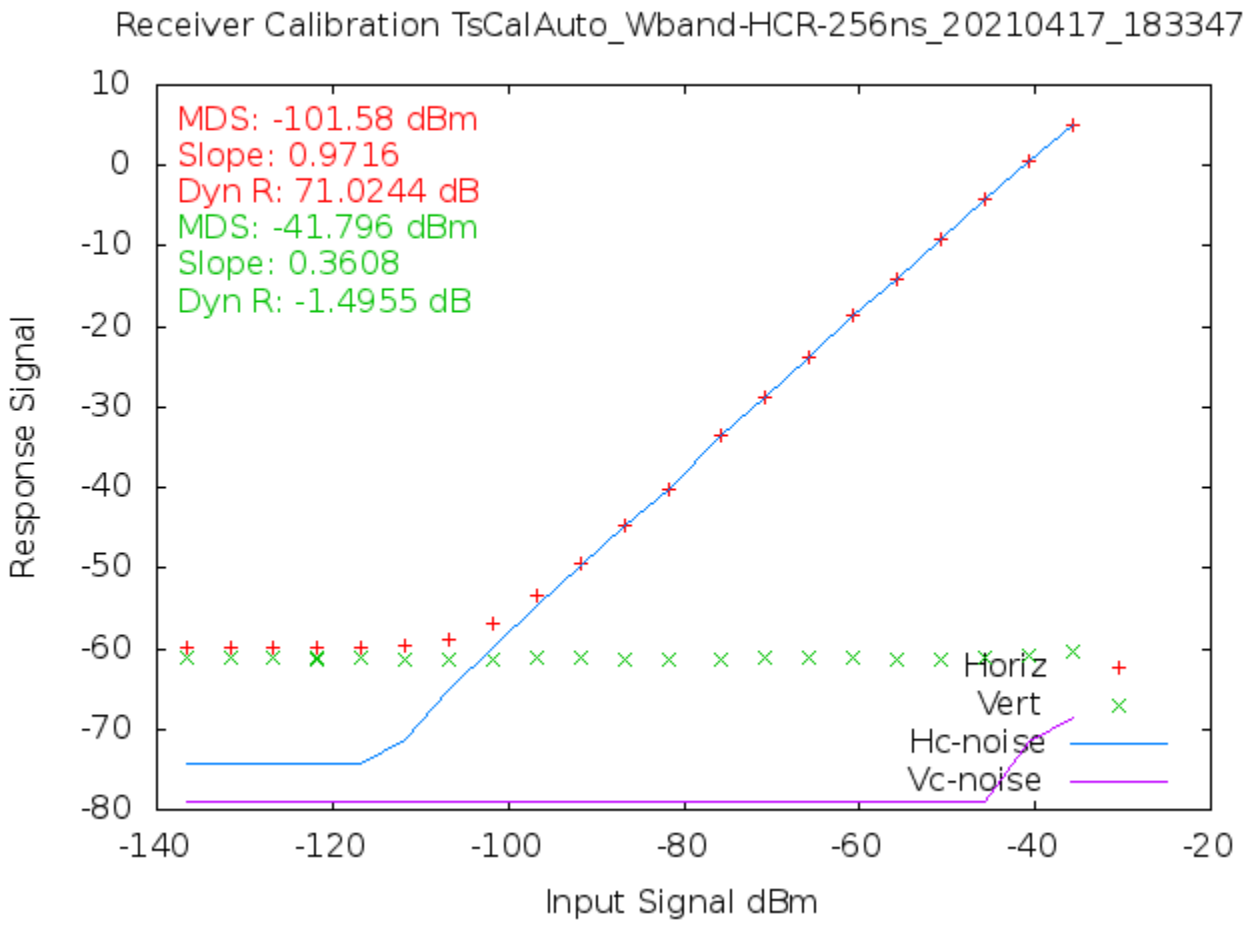


Figure 3d: example plot for H channel calibration.

Inspect the plot to make sure that it looks reasonable. There will generally be a small discontinuity in the linearity at an output power of about 38 dBm, because this is where we insert the 20 dB fixed attenuation. It is difficult to get everything to match perfectly.

Once you are happy with the plot, close it. TsCalAuto will then exit, saving the data.

3.4 Running the calibration for the V channel

Repeat the procedure for the V channel. The signal generator connection will need to be moved to the port at the center of the instrument.

The command to run is:

```
cd projDir/calibration/params
TsCalAuto -params TsCalAuto.wband.v_only.256ns
```

The rest of the procedure is the same as for the H channel. Just check TsPrint to make sure that the power is showing up in the Vc column instead of Hc.

4. Combining the H and V results into a single calibration

Because we run the H and V cals separately, the data for each is stored in a separate location.

You will find the output from the cals in:

```
~/projDir/calibration/data/wband_256ns/h_only
~/projDir/calibration/data/wband_256ns/v_only
```

For each calibration, 3 files are produced.

For example, for 20210421 at 222329, for the H channel, the files in:

```
~/projDir/calibration/data/wband_256ns/h_only
```

are:

```
TsCalAuto_Wband-HCR-256ns_20210414_222329.xml
TsCalAuto_Wband-HCR-256ns_20210414_222329.txt
TsCalAuto_Wband-HCR-256ns_20210414_222329.png
```

The .txt file stores the raw data values.
The .png file contains the image produced by do_calplot.dyn_range.
The .xml file contains the calibration results that are used by app (Iq2Dsr) that computes the moments.

In order to combine the H and V results, we need to combine the data in the .txt files for each calibration.

To combine the data, we first copy the H .txt file:

```
TsCalAuto_Wband-HCR-256ns_20210414_222329.txt
```

up by 1 directory, i.e. to:

```
~/projDir/calibration/data/wband_256ns
```

This file has the contents shown in Figure 4a:

Input power (dBm)	H dBm (data)	V dBm (noise)				
-35.730	5.047	-60.713	-999.900	-999.900	65.760	0.000
-40.730	0.467	-61.136	-999.900	-999.900	61.603	0.000
-45.730	-4.405	-61.319	-999.900	-999.900	56.914	0.000
-50.730	-9.202	-61.444	-999.900	-999.900	52.242	0.000
-55.730	-14.049	-61.509	-999.900	-999.900	47.460	0.000
-60.730	-18.895	-61.533	-999.900	-999.900	42.638	0.000
-65.730	-23.854	-61.504	-999.900	-999.900	37.650	0.000
-70.730	-28.859	-61.424	-999.900	-999.900	32.564	0.000
-75.730	-33.919	-61.333	-999.900	-999.900	27.414	0.000
-81.680	-39.910	-61.513	-999.900	-999.900	21.603	0.000
-86.680	-44.512	-61.530	-999.900	-999.900	17.018	0.000
-91.680	-49.033	-61.531	-999.900	-999.900	12.498	0.000
-96.680	-52.984	-61.474	-999.900	-999.900	8.489	0.000
-101.680	-56.514	-61.358	-999.900	-999.900	4.844	0.000
-106.680	-58.427	-61.313	-999.900	-999.900	2.886	0.000
-111.680	-59.398	-61.323	-999.900	-999.900	1.925	0.000
-116.680	-59.761	-61.339	-999.900	-999.900	1.578	0.000
-121.680	-59.901	-61.378	-999.900	-999.900	1.477	0.000
-121.680	-59.910	-61.394	-999.900	-999.900	1.484	0.000
-126.680	-59.919	-61.405	-999.900	-999.900	1.486	0.000
-131.680	-59.930	-61.425	-999.900	-999.900	1.495	0.000
-136.680	-59.938	-61.440	-999.900	-999.900	1.501	0.000

Figure 4a: cal results for H-channel only

There are actually more data columns in this file, but here we are only showing the first 7 columns.

The important columns for this discussion are:

1. the input power
2. the received power for H
3. the received power for V

As you can see from Figure 4a, the received power in H varies with the input power, but the received power for V is just in the noise, around -61 dBm. This is as expected, since the V LNA is not connected.

You need to identify the files for the V channel that match the H channel results closely in time. For the H example above, the appropriate files for the V channel are in:

```
~/projDir/calibration/data/wband_256ns/v_only
```

They are:

```
TsCalAuto_Wband-HCR-256ns_20210414_221647.xml
TsCalAuto_Wband-HCR-256ns_20210414_221647.txt
```

```
TsCalAuto_Wband-HCR-256ns_20210414_221647.png
```

The contents of the .txt file are shown in Figure 4b:

Input power (dBm)	H dBm (noise)	V dBm (data)				
-35.730	-58.008	4.869	-999.900	-999.900	-62.878	0.000
-40.730	-58.923	0.241	-999.900	-999.900	-59.165	0.000
-45.730	-59.244	-4.634	-999.900	-999.900	-54.610	0.000
-50.730	-59.587	-9.511	-999.900	-999.900	-50.076	0.000
-55.730	-59.763	-14.259	-999.900	-999.900	-45.504	0.000
-60.730	-59.658	-18.960	-999.900	-999.900	-40.698	0.000
-65.730	-59.603	-23.834	-999.900	-999.900	-35.769	0.000
-70.730	-59.597	-28.856	-999.900	-999.900	-30.741	0.000
-75.730	-59.648	-34.046	-999.900	-999.900	-25.602	0.000
-81.680	-59.571	-40.871	-999.900	-999.900	-18.700	0.000
-86.680	-59.745	-45.750	-999.900	-999.900	-13.995	0.000
-91.680	-59.807	-50.193	-999.900	-999.900	-9.614	0.000
-96.680	-59.825	-54.345	-999.900	-999.900	-5.480	0.000
-101.680	-59.859	-57.660	-999.900	-999.900	-2.199	0.000
-106.680	-59.887	-59.756	-999.900	-999.900	-0.130	0.000
-111.680	-59.915	-60.682	-999.900	-999.900	0.767	0.000
-116.680	-59.949	-61.081	-999.900	-999.900	1.132	0.000
-121.680	-59.972	-61.330	-999.900	-999.900	1.359	0.000
-121.680	-59.951	-61.335	-999.900	-999.900	1.384	0.000
-126.680	-59.929	-61.337	-999.900	-999.900	1.408	0.000
-131.680	-59.919	-61.351	-999.900	-999.900	1.432	0.000
-136.680	-59.902	-61.379	-999.900	-999.900	1.478	0.000

Figure 4b: cal results for V-channel only

As expected, in this file, the H column shows noise while the V column shows powers that vary with the input power.

To combine the results, we need to copy the V column from the V results file to the H results file. For some editors this requires some cutting and pasting for each line. Emacs has a 'rectangle' mode which allows you to cut and paste a column instead of a row.

Figure 4c shows the result of copying the V data from the V channel file into the combined file:

```
TsCalAuto_Wband-HCR-256ns_20210414_222329.txt
```

that we have created in the directory:

```
~/projDir/calibration/data/wband_256ns
```

Input power (dBm)	H dBm (data)	V dBm (data)				
-35.730	5.047	4.869	-999.900	-999.900	0.178	0.000
-40.730	0.467	0.241	-999.900	-999.900	0.226	0.000
-45.730	-4.405	-4.634	-999.900	-999.900	0.229	0.000
-50.730	-9.202	-9.511	-999.900	-999.900	0.309	0.000
-55.730	-14.049	-14.259	-999.900	-999.900	0.210	0.000
-60.730	-18.895	-18.960	-999.900	-999.900	0.065	0.000
-65.730	-23.854	-23.834	-999.900	-999.900	-0.020	0.000
-70.730	-28.859	-28.856	-999.900	-999.900	-0.003	0.000
-75.730	-33.919	-34.046	-999.900	-999.900	0.127	0.000
-81.680	-39.910	-40.871	-999.900	-999.900	0.961	0.000
-86.680	-44.512	-45.750	-999.900	-999.900	1.238	0.000
-91.680	-49.033	-50.193	-999.900	-999.900	1.160	0.000
-96.680	-52.984	-54.345	-999.900	-999.900	1.361	0.000
-101.680	-56.514	-57.660	-999.900	-999.900	1.146	0.000
-106.680	-58.427	-59.756	-999.900	-999.900	1.329	0.000
-111.680	-59.398	-60.682	-999.900	-999.900	1.284	0.000
-116.680	-59.761	-61.081	-999.900	-999.900	1.320	0.000
-121.680	-59.901	-61.330	-999.900	-999.900	1.429	0.000
-121.680	-59.910	-61.335	-999.900	-999.900	1.425	0.000
-126.680	-59.919	-61.337	-999.900	-999.900	1.418	0.000
-131.680	-59.930	-61.351	-999.900	-999.900	1.421	0.000
-136.680	-59.938	-61.379	-999.900	-999.900	1.441	0.000

Figure 4c: combined cal results for H and V channels

To analyze the combined calibration we need to run TsCalAuto on this combined data file, in archive mode.

To do this:

```
cd ~/projDir/calibration/params
TsCalAuto -params TsCalAuto.wband.256ns -f
../data/wband_256ns/TsCalAuto_Wband-HCR-256ns_20210414_222329.txt
```

That will rerun the calibration analysis, now using both columns of data. The resulting plot is shown in Figure 4d.

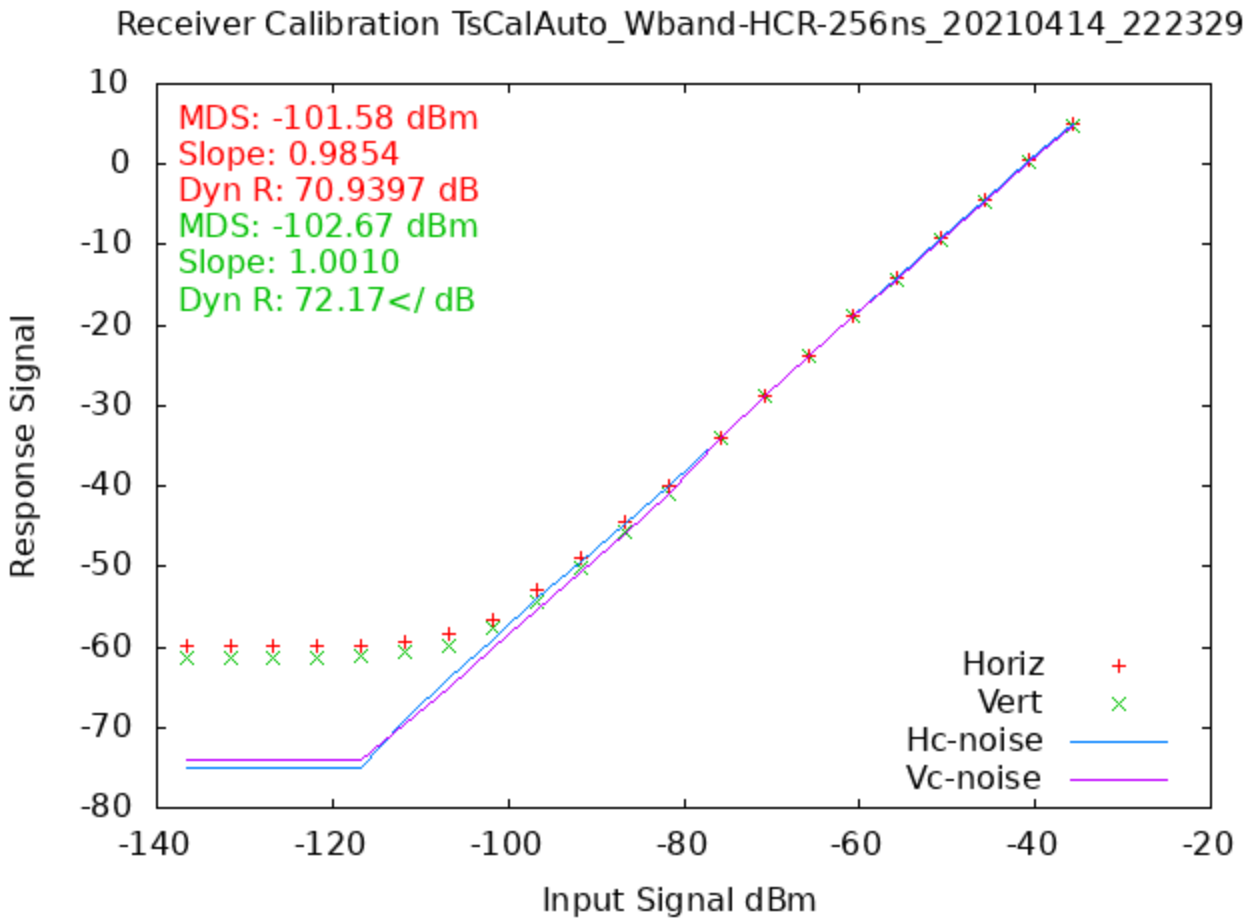


Figure 4d: plot for combined cal results for both H and V channels

The 3 files that result from this operation are in:

```
~/projDir/calibration/data/wband_256ns
```

The file names are:

```
TsCalAuto_Wband-HCR-256ns_20210414_222329.xml
TsCalAuto_Wband-HCR-256ns_20210414_222329.txt
TsCalAuto_Wband-HCR-256ns_20210414_222329.png
```

The .xml file will be automatically found by the moments generation application, Iq2Dsr, when the radar is running with a 256 ns pulse width.

5. Calibrating for 512 ns pulse width

If the 512ns pulse width is to be used by the radar, this procedure will need to be repeated for the 512ns pulse.