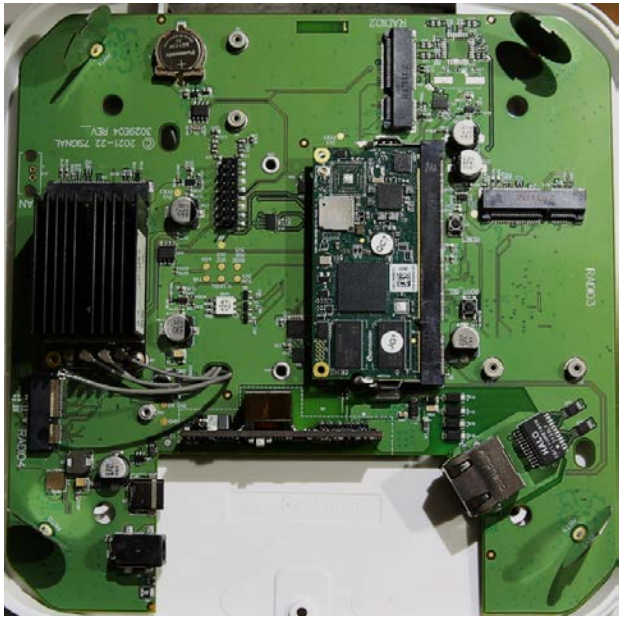
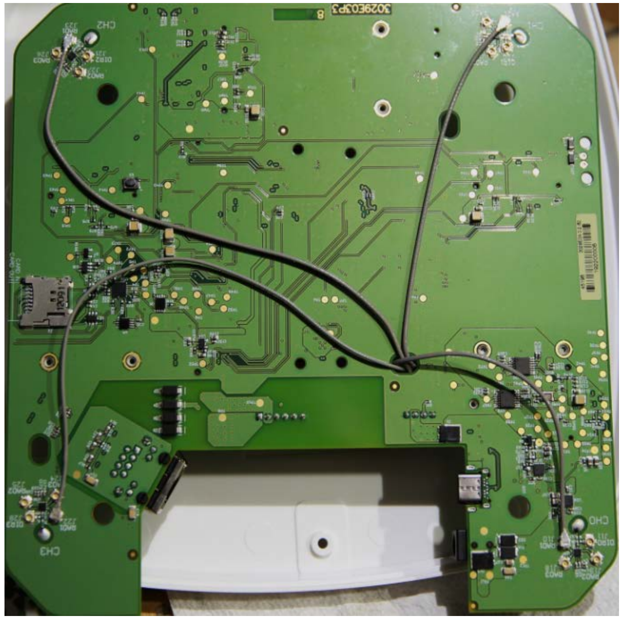
7 SIGNAL's Report:

Sapphire Eye 6200 Antenna Evaluation and Conducted Transmission Path Analysis

March 26, 2022

Device Under Test





- The DUT was the latest version of the Sapphire Eye 6200 supplied to CIA. This device utilized 22 mm circular disk monopole antennas and one radio, hence one coaxial connection from the radio to each switch as shown in the images above.
- CIA was asked to evaluate the highest gain antenna and measure its patterns, correctly assuming there would be slight differences in the antenna patterns and average and peak gain values.
- CIA was also asked to evaluate the insertion loss of the transmission line from the radio to the antenna.

Signal Transmission Path Loss Evaluation

Measurement Calibration and Setup

- Calibration of the measurement system was performed by connecting the low loss coaxial cables to one another using a SMA female to female (bullet) adapter as shown in the image above.
- A Copper Mountain Technologies Model S5085 Vector Network Analyzer (VNA) was used for the measurements.
- The VNA test cables were Mini-Circuits Flex Test GM1006-10 and 27 ft. of LMR-240 low loss cable with Pasternack PE44637 SMA male connectors on each end.

- **The additional insertion loss of the 4 additional components for measurement was accounted for in the "Total Insertion Loss" values given in the tables below.**

- The total insertion loss measurement was accomplished by connecting a 0.086 conformable with SMA male connector to the already calibrated SMA bullet as seen as the right side connection to the PCBA in the image above. The left side connection above was to add a U.FL adapter to a new SMA bullet and attach that adapter to the DUT's coaxial cables, i.e., CH 0, CH 1, CH 2, CH 3 as shown in the table below.
- The insertion loss of the new components are given in the table below.

Additional Component Losses for the Insertion Loss Measurement (dB). Uncertainty for the total of these three comonents is believed to be ± 0.05 dB.*															
Frequency	**2402**	**2412**	**2437**	**2441.75**	**2462**	**2483.5**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
95 mm Formable Cable (from spec)	0.1062	0.1068	0.1073	0.1075	0.1081	0.1088	0.1736	0.1752	0.1792	0.1818	0.1830	0.1854	0.1875	0.1957	0.2064
SMA Bullet (from spec)	0.0324	0.0325	0.0327	0.0328	0.0330	0.0332	0.0530	0.0535	0.0547	0.0555	0.0560	0.0567	0.0572	0.0597	0.0630
U.FL Adapter (from spec)	0.0166	0.0166	0.0167	0.0168	0.0168	0.0169	0.0270	0.0273	0.0278	0.0283	0.0286	0.0288	0.0292	0.0305	0.0321
SMA Cable Connector	0.0166	0.0166	0.0167	0.0168	0.0168	0.0169	0.0270	0.0273	0.0278	0.0283	0.0286	0.0288	0.0292	0.0305	0.0321
Additional Loss	0.1552	0.1559	0.1567	0.1571	0.1579	0.1589	0.2536	0.2560	0.2617	0.2656	0.2676	0.2709	0.2739	0.2859	0.3015

* The asigned uncertainty for the total of the specified insertion loss values above is due to normal wear and tear of the components used, i.e., cables get small deformities and connectors/adaters undergo friction wear.

- The table above identifies additional losses incurred by adding cable, connectors, and adapter components to the measurement system after the system calibration was completed. These components could not be included in the calibration procedure due to the nature of the task.
- The additional component insertion loss values were generated from manufacturer's specification and the uncertainty value is assigned to them based on experience of previous measurements.

Insertion Loss Tables

Table #1: 7SIGNAL Total Measured Transmission Path Insertion Loss *Through the U.FL Cable, Traces,and Switch, i.e., Radio to the Antenna Pad (dB)*															
Frequency (MHz) -->	**2402**	**2412**	**2437**	**2441.75**	**2462**	**2483.5**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
CH 0 Insertion Loss	-1.32	-1.32	-1.33	-1.34	-1.35	-1.36	-2.15	-2.22	-2.36	-2.29	-2.27	-2.30	-2.33	-2.57	-2.77
CH 1 Insertion Loss	-1.30	-1.31	-1.32	-1.32	-1.33	-1.35	-2.07	-2.12	-2.19	-2.15	-2.15	-2.18	-2.21	-2.36	-2.43
CH 2 Insertion Loss	-1.47	-1.48	-1.50	-1.50	-1.52	-1.54	-2.40	-2.49	-2.43	-2.50	-2.55	-2.51	-2.49	-2.79	-2.87
CH 3 Insertion Loss	-1.51	-1.51	-1.54	-1.54	-1.56	-1.58	-2.50	-2.50	-2.50	-2.61	-2.61	-2.62	-2.69	-2.96	-2.96

Table #2: 7SIGNAL Measured Coaxial Cable Insertion Loss *(dB)*															
Frequency (MHz) -->	**2402**	**2412**	**2437**	**2441.75**	**2462**	**2483.5**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
CH 0 Insertion Loss	-0.61	-0.61	-0.61	-0.61	-0.61	-0.62	-0.95	-0.94	-0.99	-1.06	-1.08	-1.06	-1.05	-1.13	-1.12
CH 1 Insertion Loss	-0.61	-0.61	-0.61	-0.61	-0.61	-0.62	0.96	-0.94	-0.99	1.08	-1.09	-1.08	-1.07	-1.13	-1.08
CH 2 Insertion Loss	-0.78	-0.79	-0.79	-0.79	-0.80	-0.80	-1.25	-1.31	-1.32	-1.36	-1.42	-1.47	-1.43	-1.48	-1.43
CH 3 Insertion Loss	-0.79	-0.79	-0.80	-0.80	-0.81	-0.81	-1.25	-1.28	-1.28	-1.35	-1.38	-1.40	-1.39	-1.51	-1.46
Delta between CH0 and CH2	0.17	0.17	0.18	0.18	0.18	0.19	0.30	0.38	0.33	0.30	0.33	0.41	0.38	0.35	0.31
Delta between CH1 and CH3	0.18	0.18	0.19	0.19	0.19	0.20	2.20	0.34	0.29	2.43	0.29	0.32	0.32	0.38	0.38

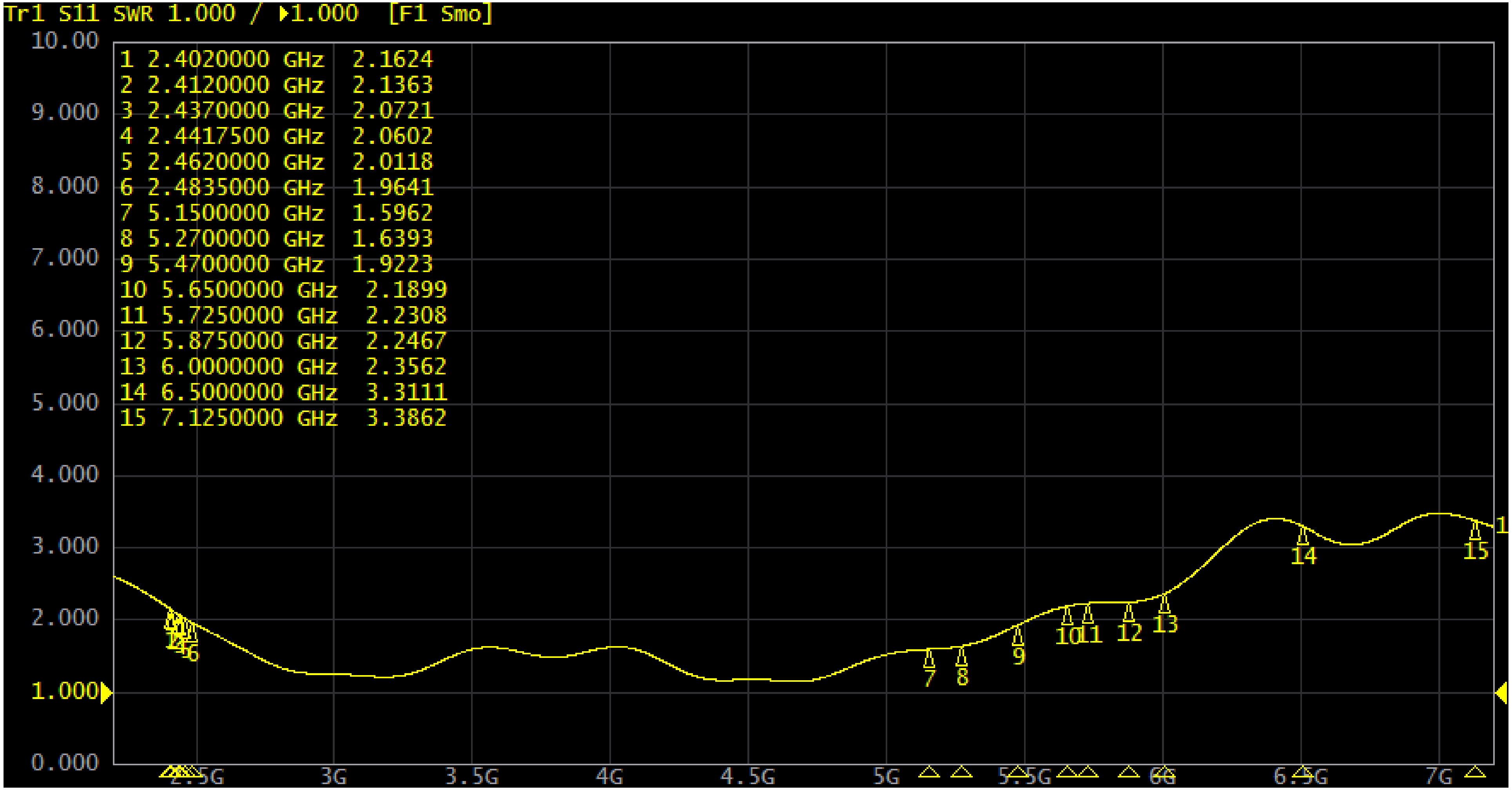
Table #3: 7SIGNAL Calculated PCB Transmission Line and Switch Insertion Loss (dB), i.e., Total Loss (Table #1) Minus Cable Loss (Table #2)															
Frequency (MHz) -->	**2402**	**2412**	**2437**	**2441.75**	**2462**	**2483.5**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
CH 0 Insertion Loss	-0.71	-0.71	-0.72	-0.73	-0.74	-0.75	-1.19	-1.29	-1.37	-1.23	-1.19	-1.24	-1.28	-1.44	-1.65
CH 1 Insertion Loss	-0.69	-0.70	-0.71	-0.71	-0.72	-0.73	-3.02	-1.19	-1.20	-3.23	-1.06	-1.10	-1.14	-1.24	-1.34
CH 2 Insertion Loss	-0.69	-0.70	-0.71	-0.71	-0.73	-0.74	-1.14	-1.18	-1.11	-1.14	-1.14	-1.04	-1.06	-1.31	-1.44
CH 3 Insertion Loss	-0.72	-0.72	-0.74	-0.74	-0.76	-0.77	-1.25	-1.23	-1.22	-1.27	-1.23	-1.22	-1.30	-1.46	-1.50

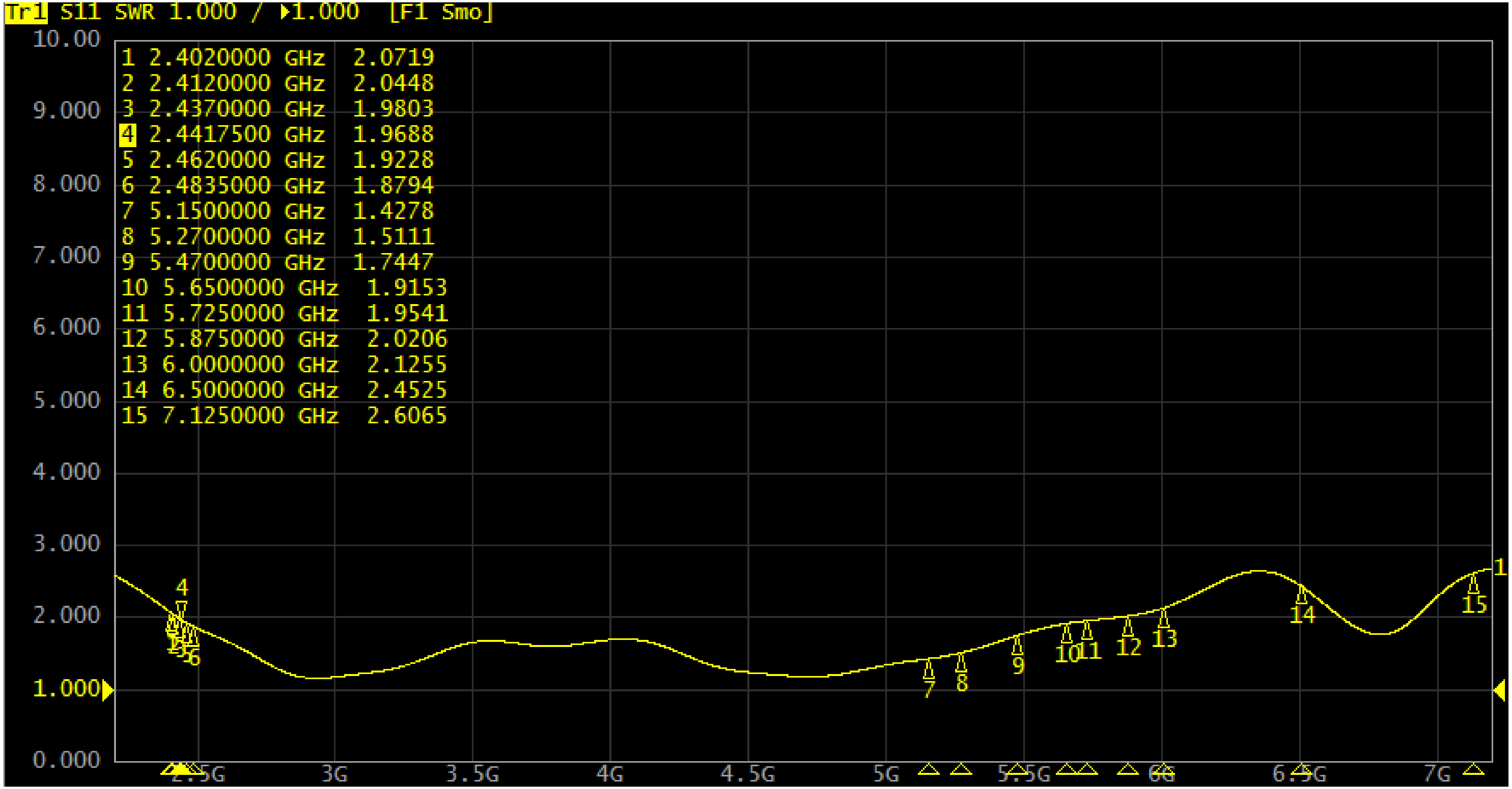
Table #4: 7SIGNAL Calculated PCB Transmission Line Loss, i.e., Table 3 Minus the Switch Manufacturer's Specified Insertion Loss *(dB)*															
Frequency (MHz) -->	**2402**	**2412**	**2437**	**2441.75**	**2462**	**2483.5**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
CH 0 Insertion Loss	-0.28	-0.28	-0.28	-0.29	-0.29	-0.30	-0.72	-0.79	-0.86	-0.69	-0.63	-0.65	-0.67	-0.81	-1.00
CH 1 Insertion Loss	-0.26	-0.27	-0.27	-0.27	-0.27	-0.28	-2.55	-0.69	-0.68	-2.69	-0.50	-0.52	-0.53	-0.61	-0.69
CH 2 Insertion Loss	-0.26	-0.27	-0.27	-0.27	-0.28	-0.29	-0.67	-0.69	-0.60	-0.60	-0.58	-0.46	-0.45	-0.69	-0.79
CH 3 Insertion Loss	-0.29	-0.29	-0.30	-0.30	-0.31	-0.32	-0.78	-0.73	-0.70	-0.73	-0.67	-0.64	-0.69	-0.83	-0.85

- CIA measured the total transmission path insertion loss (Table #1) as well as the coaxial cable loss for each of the 4 cables (Table #2).
- Then the "total PCB loss", i.e., all loss associated with the PCB transmission lines and switch was calculated by subtracting the coaxial cable loss from the total transmission path loss from Table #1.
- Then the PCB transmission line loss was calculated by subtracting the switch manufacturer's specified insertion loss from the total calculated PCB loss in Table #3.
  - Due to various measurement unknowns involved, an uncertainty value of ± 0.15 dB is assigned to these measurements. A primary contributor to uncertainty is the soldered coaxial test cable to the antenna pad vs. PCB trace transmission line. Other lesser contributors are the unknown precise insertion loss of the connectors and adapters, and very small fluctuations inherent to all measurements.

VSWR Evaluation

VSWR ANT 0 (CH 0) before tuning; as Seen by the Radio

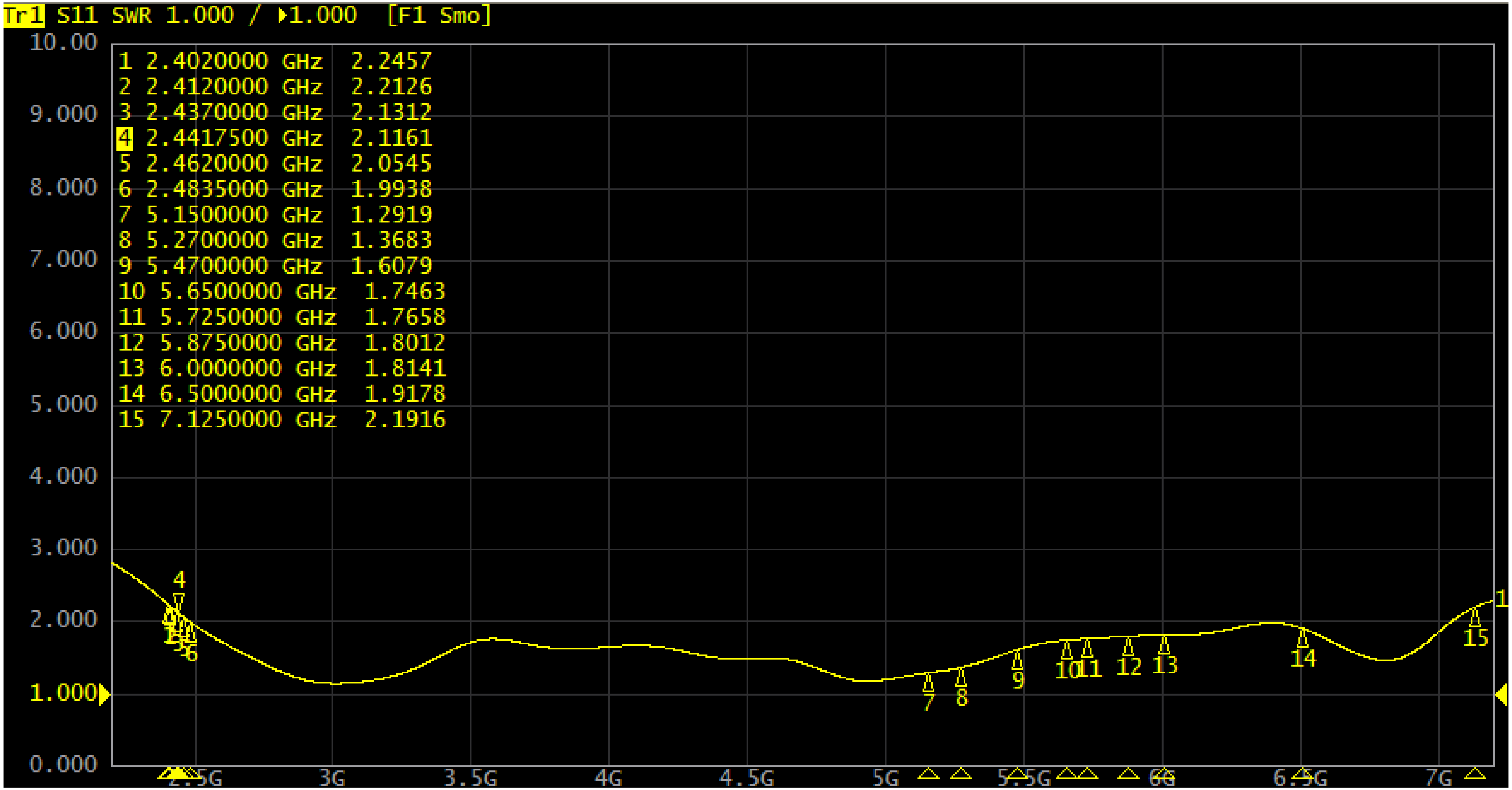




VSWR ANT 0 (CH 0) after tuning with a 39 nH shunt inductor at L17 as shown on the schematic image at the end of this section.

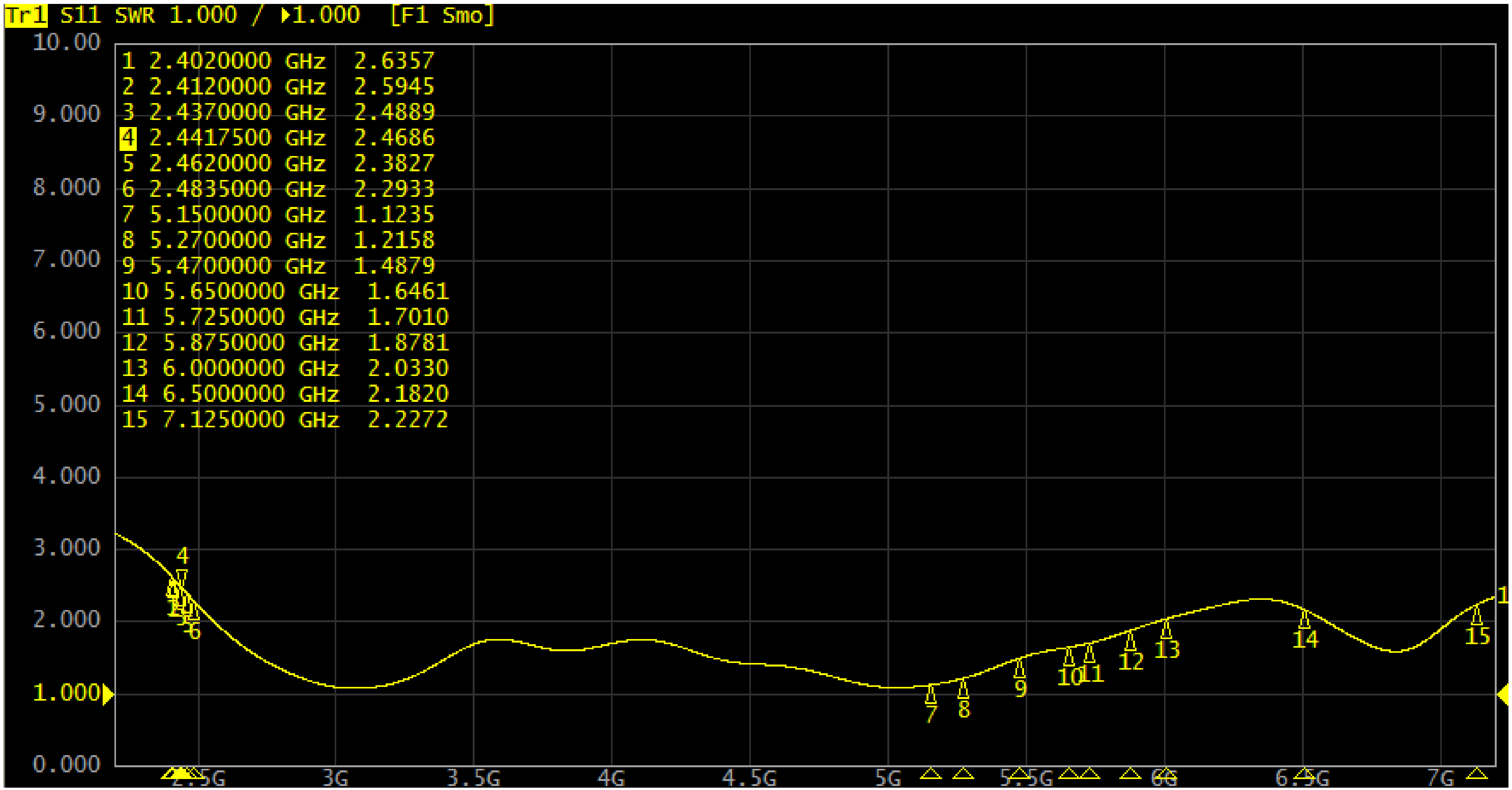
NOTE: The other three antennas followed the same trend of before and after tuning results.

VSWR ANT 1 (CH 1) before tuning; as Seen by the Radio



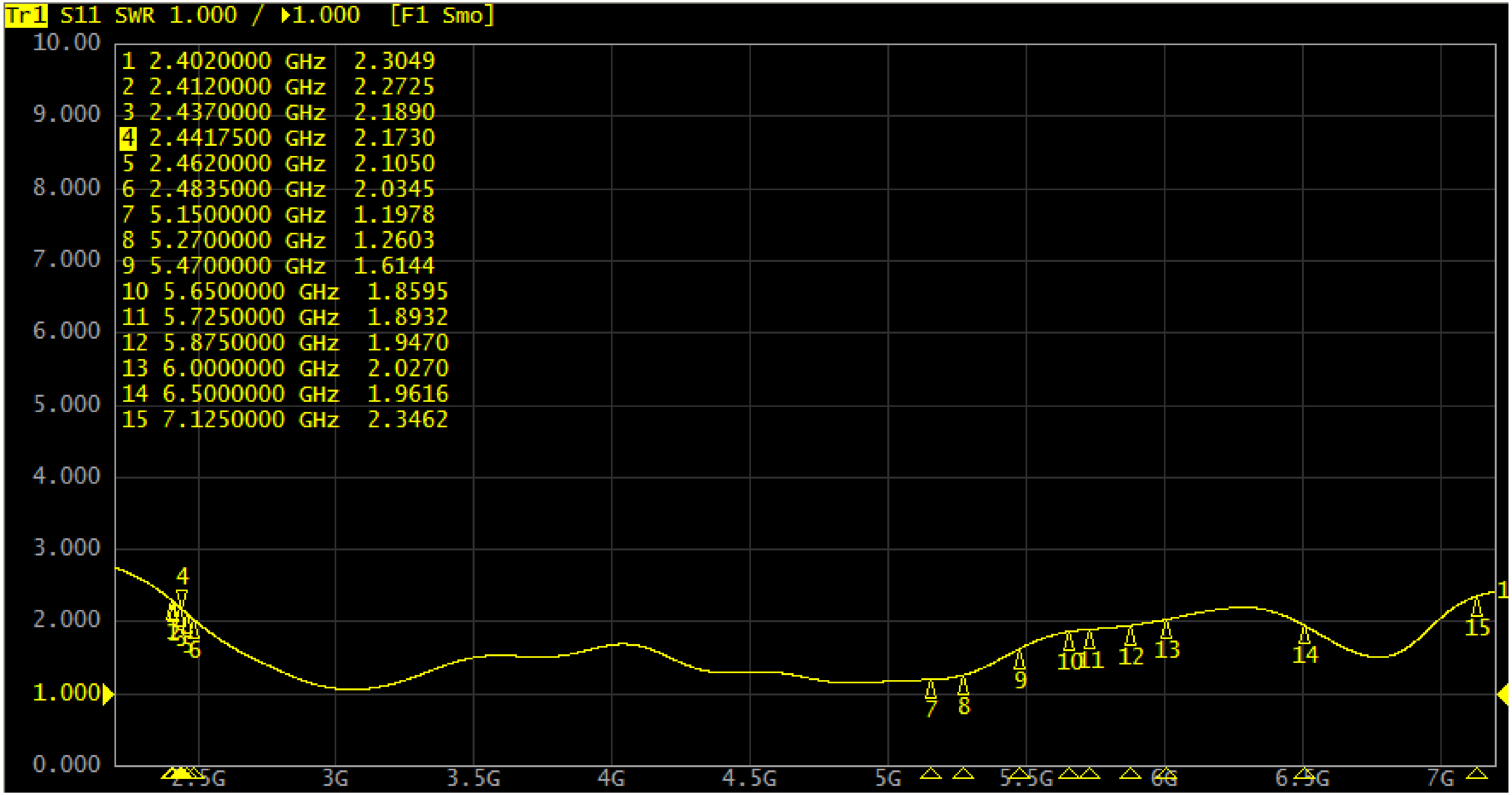
VSWR ANT 1 (CH 1) after tuning with a 39 nH shunt inductor at L19 as shown on the schematic image at the end of this section.

VSWR ANT 2 (CH 2) before tuning; as Seen by the Radio



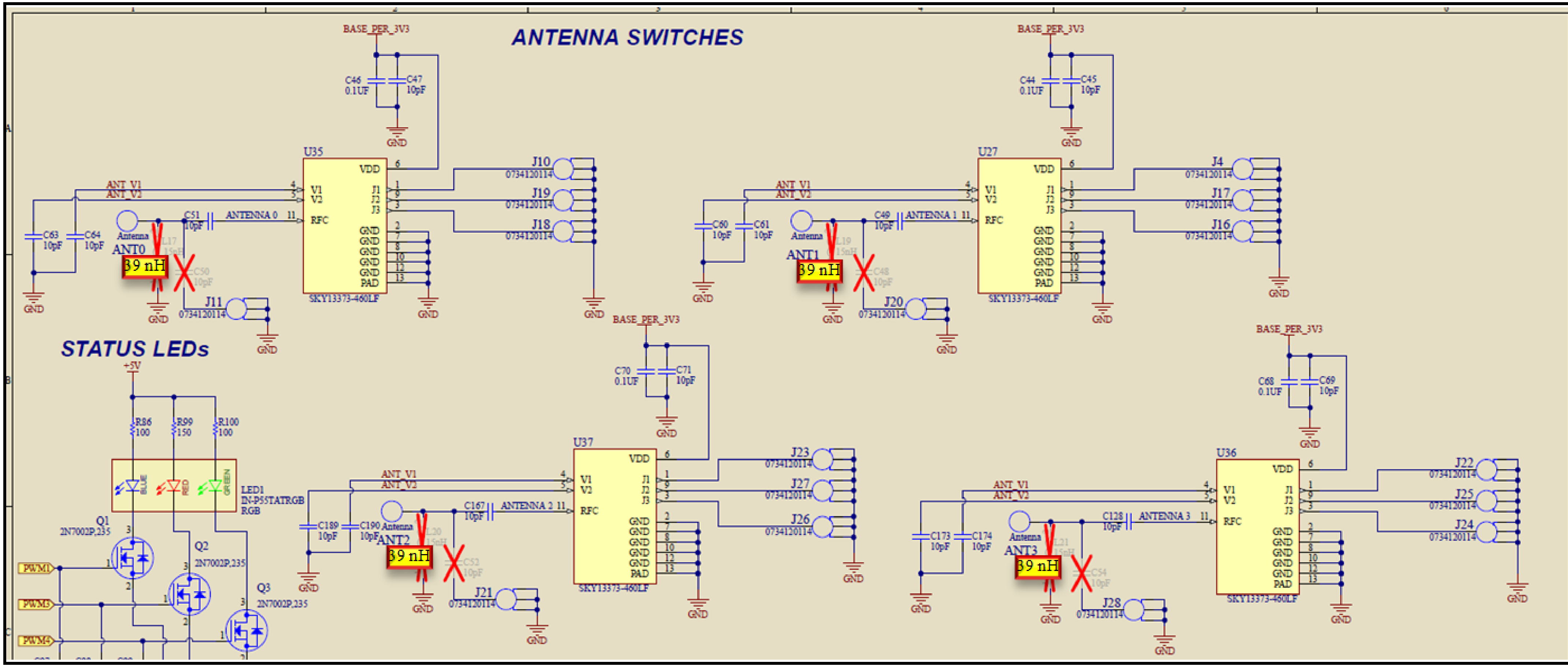
VSWR ANT 2 (CH 2) after tuning with a 39 nH shunt inductor at L20 as shown on the schematic image at the end of this section.

VSWR ANT 3 (CH 3) before tuning; as Seen by the Radio



VSWR ANT 3 (CH 3) after tuning with a 39 nH shunt inductor at L21 as shown on the schematic image at the end of this section.

Switch Schematic with Inductor Value Markups (yellow boxes)

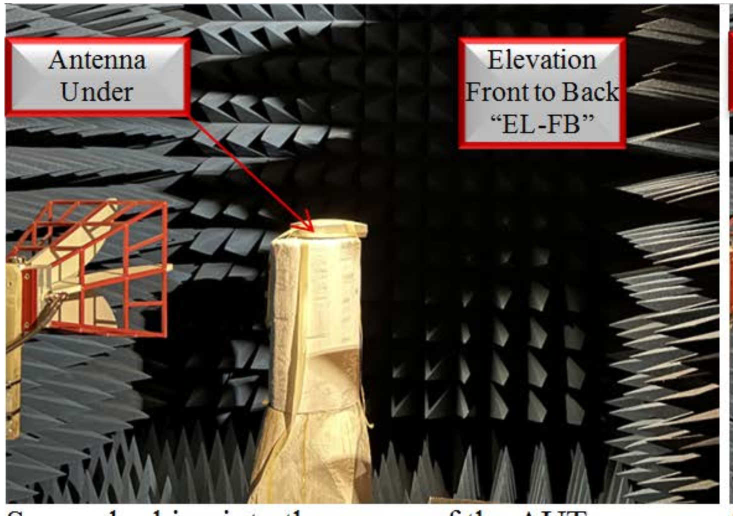


- 39 nH inductor in each shunt position (L17, L19, L20, and L21).
  - **The 39 nH inductor used is TDK Part Number = MLG1005S39NJT000 (DigiKey Part Number = 445-3066-1-ND).**
- Once the tuning was finished, the original “primary” transmission path was restored, except for the 39 nH inductors that remained. The DUT was then ready for antenna pattern testing.

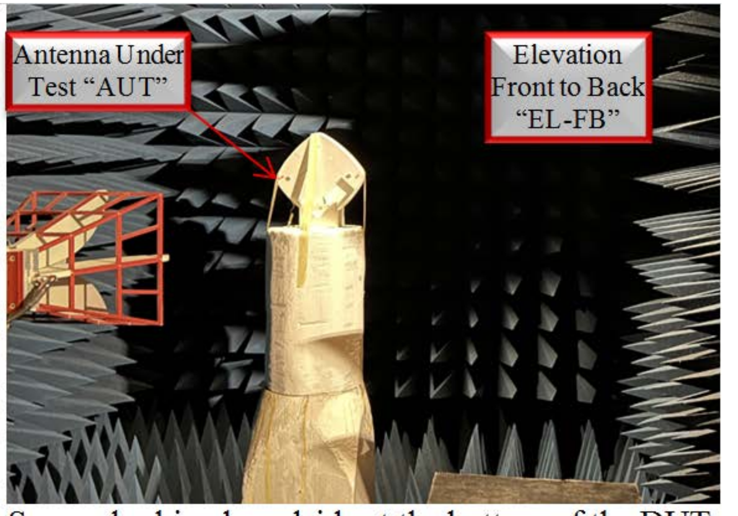
5/26/2022

Six Principal Antenna Radiation Patterns

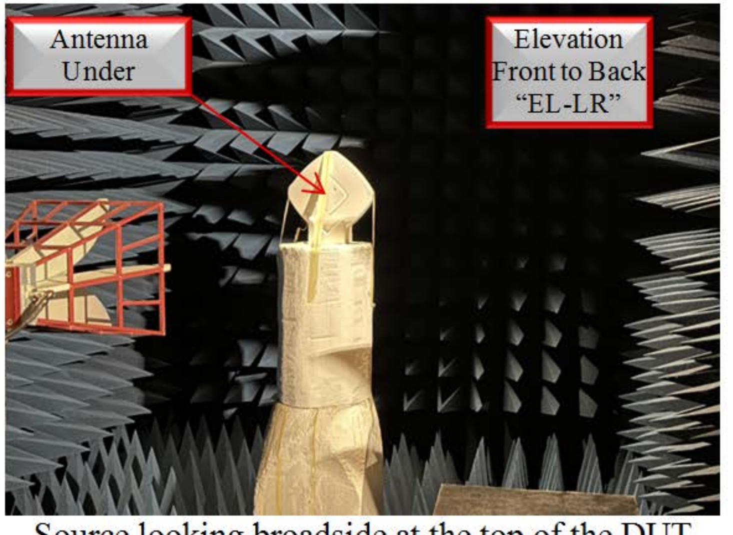
Pattern Measurement Setup



Source looking into the corner of the AUT

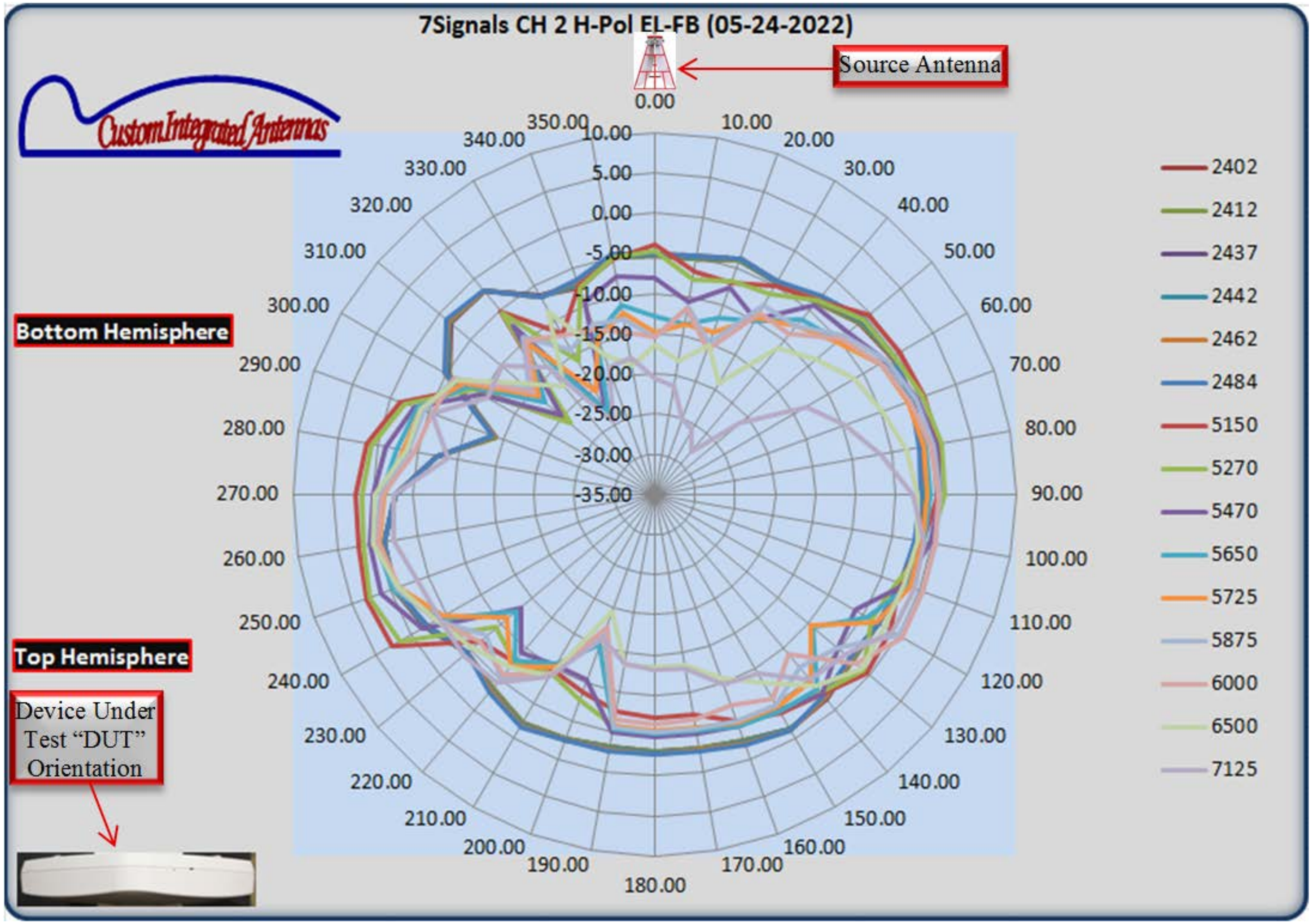


Source looking broadside at the bottom of the DUT



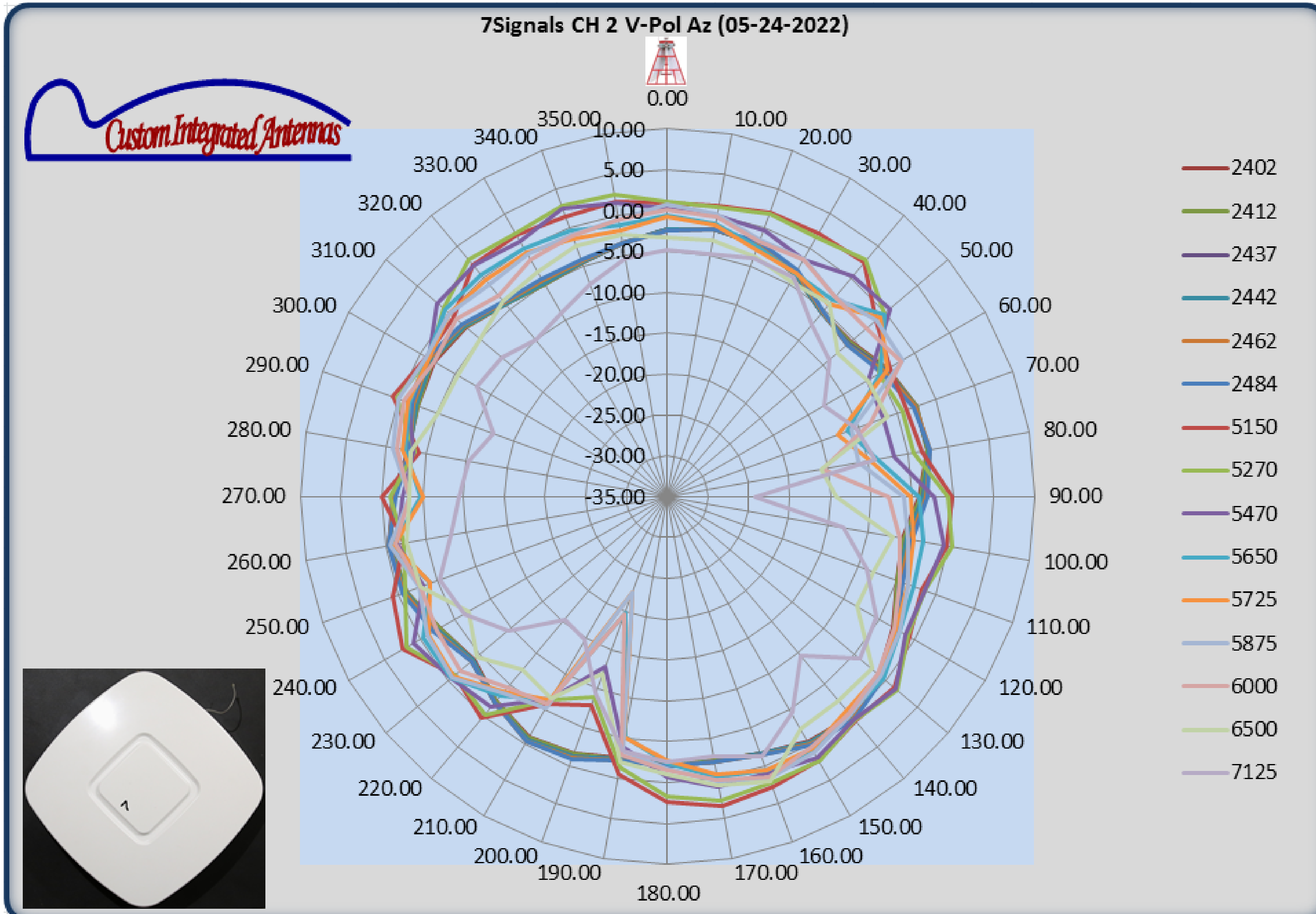
Source looking broadside at the top of the DUT

- The Device Under Test (DUT) was placed on a Styrofoam pedestal as shown in the images to the left and rotated 360 degrees for each of the 3 principal planes, i.e., the three dimensional xy, xz, and yz, AKA the 3 orthogonal planes of radiation.
- For each plane measured, the vertical and horizontal patterns were measured by switching the polarization 90 degrees at the source antenna (the red quad ridge horn antenna in the left foreground).
  - Measuring both polarizations for each orthogonal plane, achieved the 6 principal radiation patterns provided in this report.
- The pattern plots provided below can be read as if the reader were looking down onto the DUT from the ceiling directly above the pedestal and imagining the source antenna as being at 0 degrees, i.e., the source antenna is looking directly at the Device Under Test (DUT) as oriented in the images below.

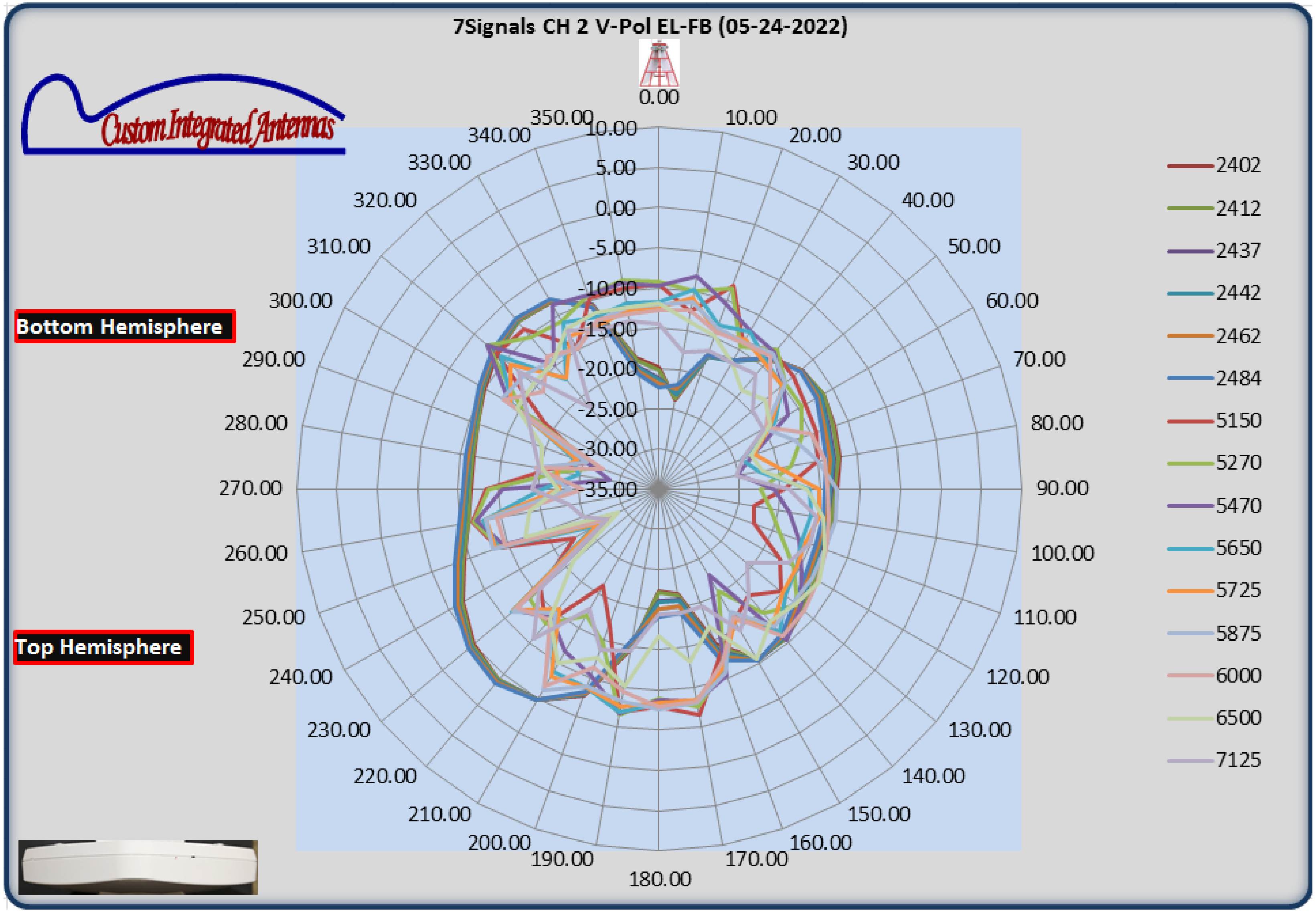


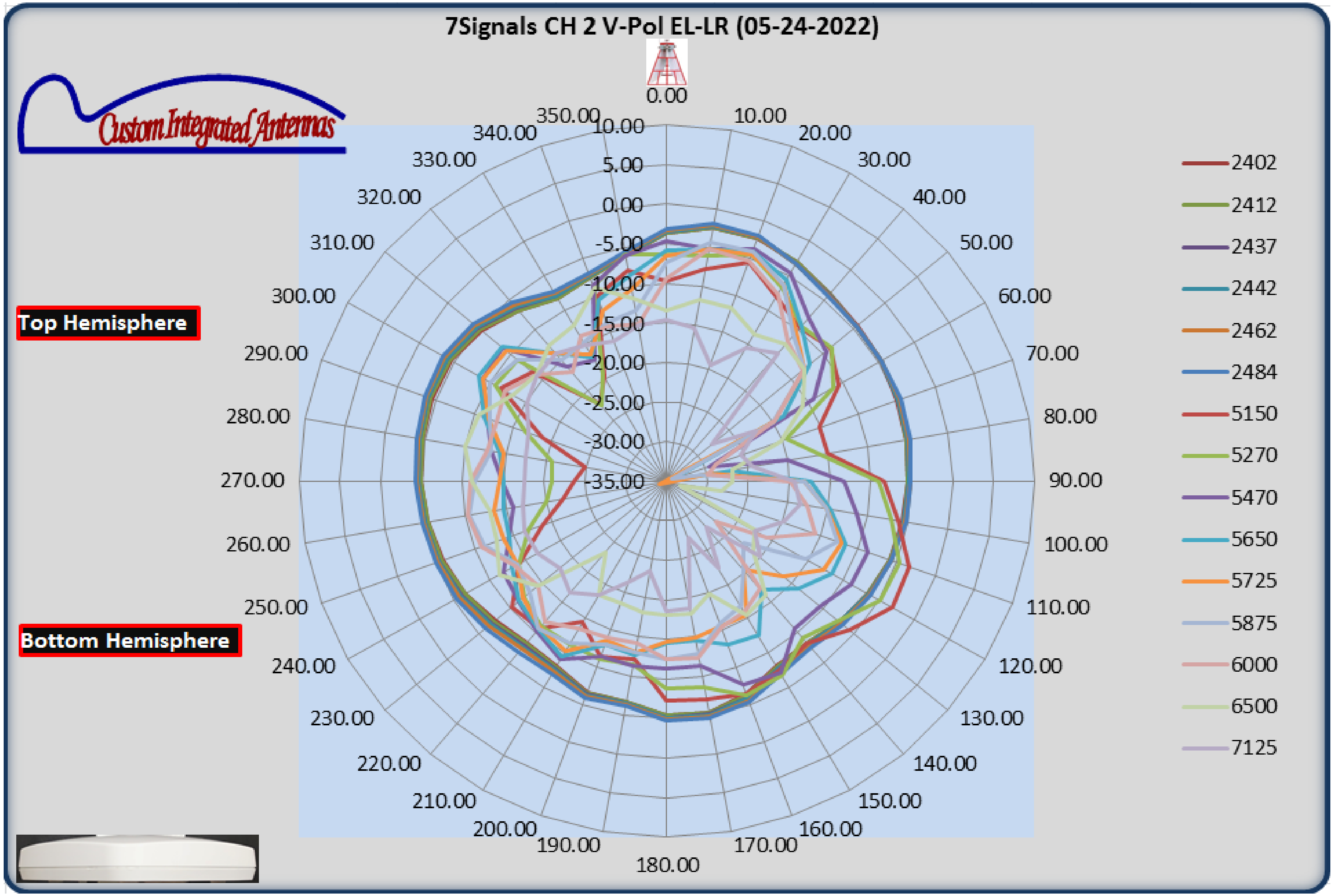
- In this Elevation Front to Back example, the DUT was oriented with the bottom of the device toward the source antenna, which resulted in the – elevation data (across the bottom of the DUT from front to back) at in the top hemisphere of the pattern, i.e. the bottom hemisphere of the DUT is in the top hemisphere of the plot.
- **NOTE 1:** The Elevation Left to Right will be opposite, i.e., the top hemisphere of the DUT will be in the top hemisphere of the pattern.
  - **NOTE 1.a**: The reason why the hemispheres flip is due to the position of the test cable attached to the antenna and access to the measurement system cable. It was not advisable to move either cable, since cable radiation is always a consideration, especially with wide band measurement like these.
- **NOTE 2:** The Azimuth plots are more self-explanatory by the image in the lower left corner of the plots.

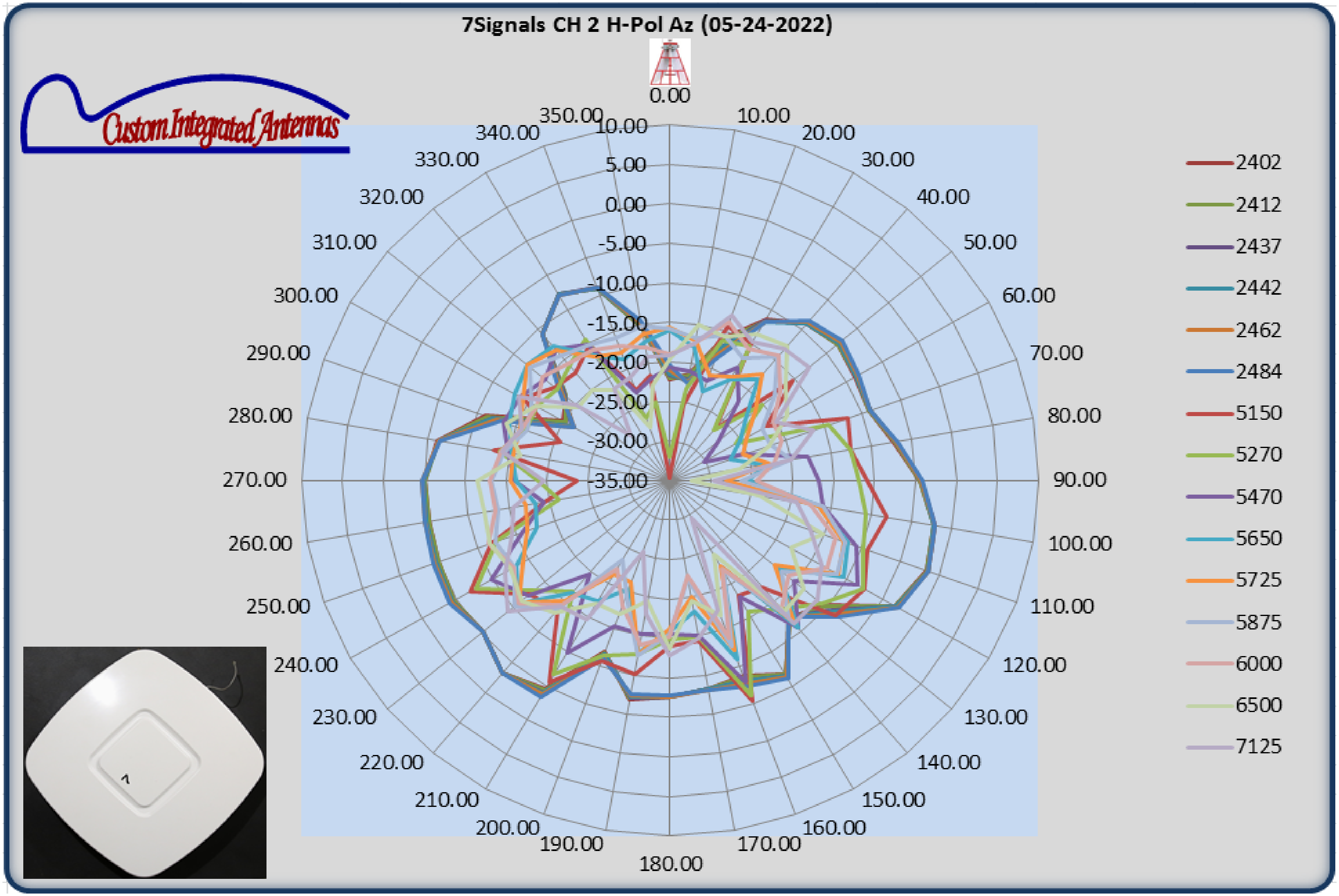
Vertically Polarized Azimuth Pattern



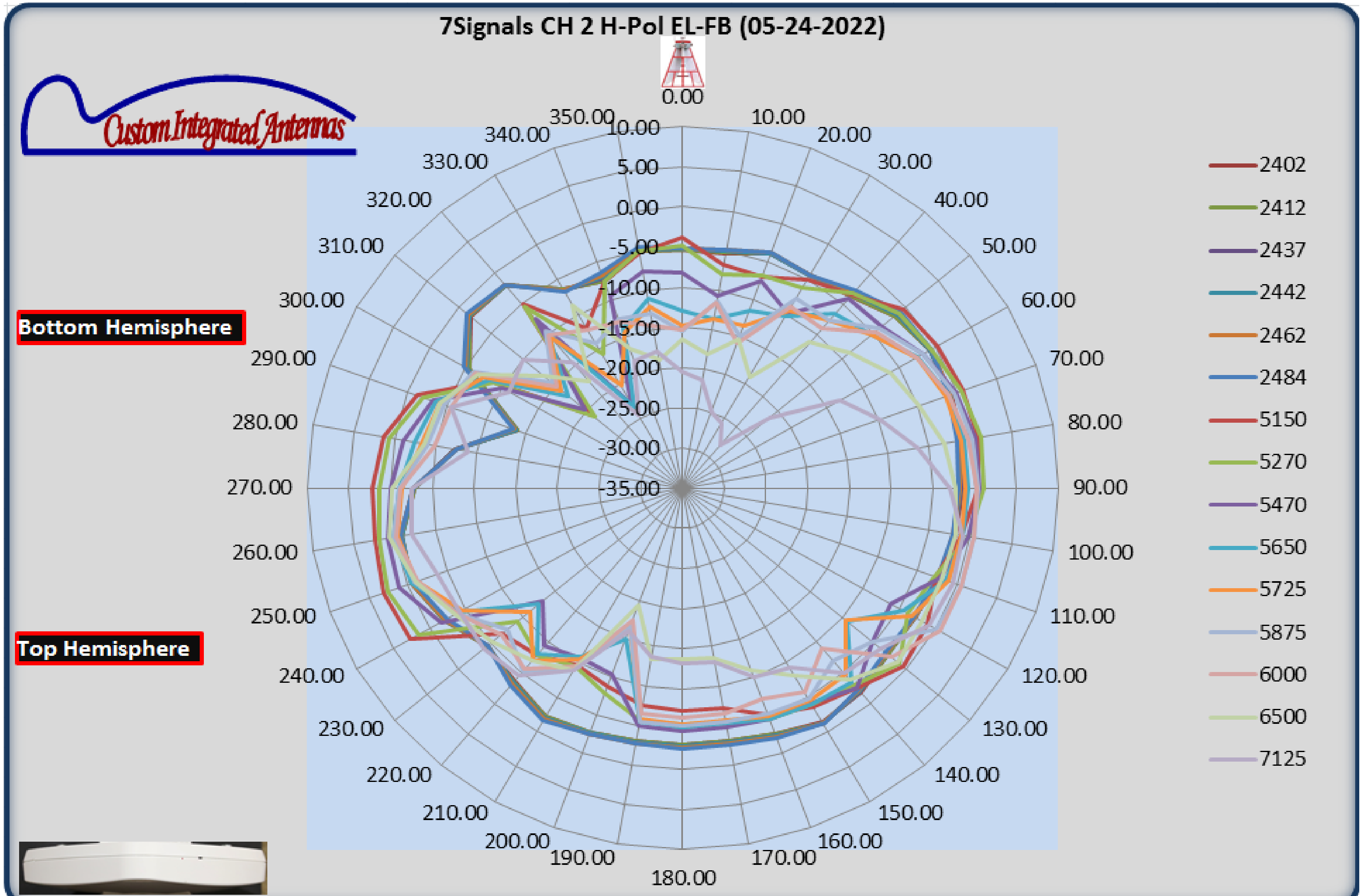
Vertically Polarized Elevation Front to Back Pattern



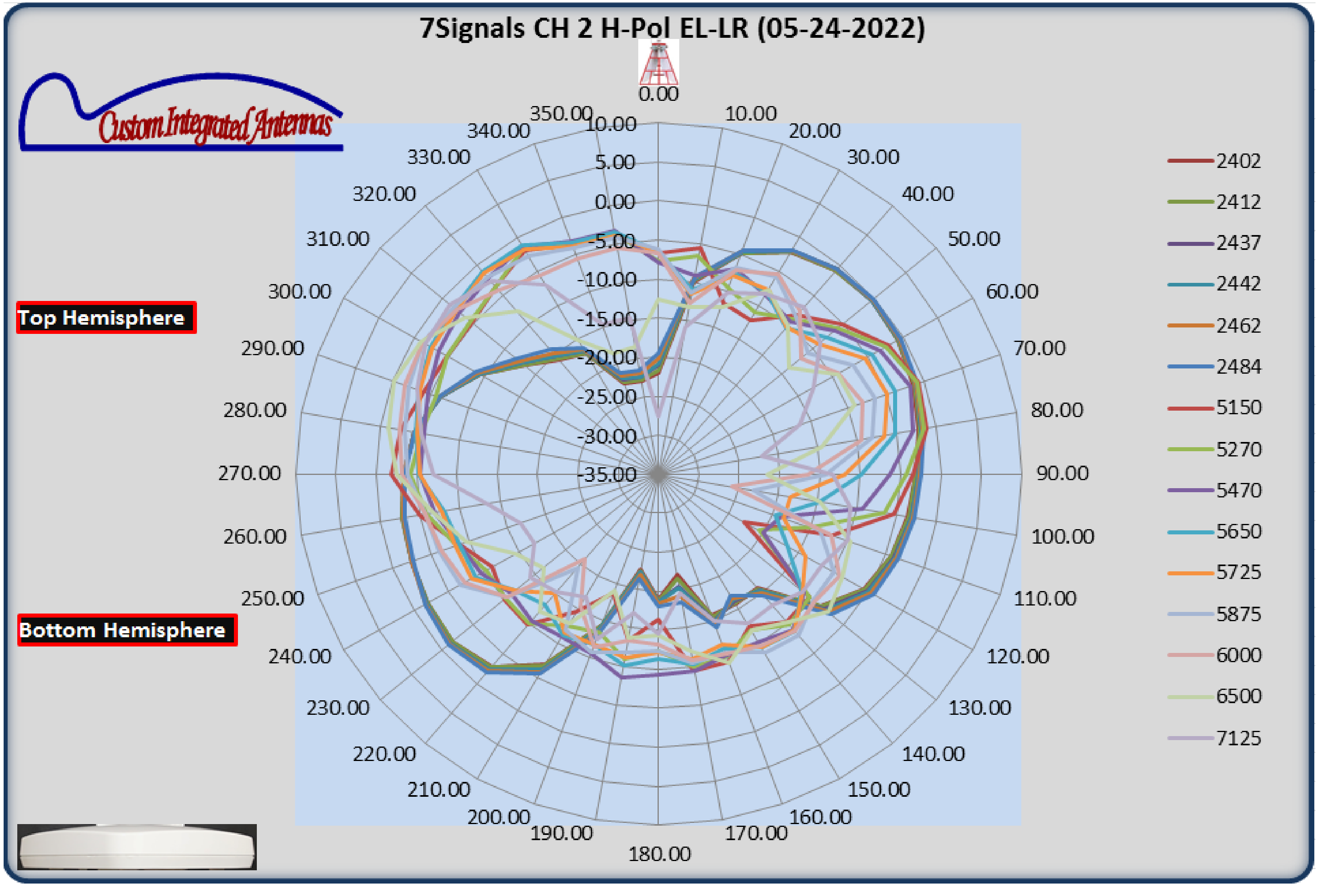

7Signals CH 2 V-Pol EL-LR (05-24-2022)
Custom Integrated Antennas
Top Hemisphere
Bottom Hemisphere
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
120.00
130.00
140.00
150.00
160.00
170.00
180.00
190.00
200.00
210.00
220.00
230.00
240.00
250.00
260.00
270.00
280.00
290.00
300.00
310.00
320.00
330.00
340.00
350.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
2402
2412
2437
2442
2462
2484
5150
5270
5470
5650
5725
5875
6000
6500
7125


7Signals CH 2 H-Pol Az (05-24-2022)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
120.00
130.00
140.00
150.00
160.00
170.00
180.00
190.00
200.00
210.00
220.00
230.00
240.00
250.00
260.00
270.00
280.00
290.00
300.00
310.00
320.00
330.00
340.00
350.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
2402
2412
2437
2442
2462
2484
5150
5270
5470
5650
5725
5875
6000
6500
7125

Horizontally Polarized Elevation Front to Back Pattern



Horizontally Polarized Elevation Left to Right Pattern



Tabular Data and Conclusions

Average Gain Comparison: All data points averaged for each frequency and all angles (dBi)															
Frequency (MHz)	**2402**	**2412**	**2437**	**2442**	**2462**	**2484**	**5150**	**5270**	**5470**	**5650**	**5725**	**5875**	**6000**	**6500**	**7125**
7Signals CH 2 V-Pol Az (05-24-2022)	-2.50	-2.47	-2.34	-2.35	-2.24	-2.15	0.46	0.43	-0.54	-1.80	-2.21	-1.53	-2.08	-3.70	-6.60
7Signals CH 2 H-Pol Az (05-24-2022)	-7.00	-6.96	-6.83	-6.84	-6.73	-6.64	-11.88	-12.79	-14.34	-15.31	-15.59	-14.86	-15.30	-15.62	-15.23
7Signals CH 2 V-Pol EL-FB (05-24-2022)	-10.28	-10.25	-10.15	-10.16	-10.06	-9.99	-12.30	-12.01	-11.76	-12.44	-12.83	-12.25	-12.72	-14.39	-16.41
7Signals CH 2 H-Pol EL-FB (05-24-2022)	-2.87	-2.86	-2.79	-2.81	-2.75	-2.72	-1.94	-2.33	-3.48	-4.50	-4.78	-3.84	-4.11	-5.28	-6.47
7Signals CH 2 V-Pol EL-LR (05-24-2022)	-5.47	-5.41	-5.20	-5.19	-5.01	-4.84	-9.06	-9.07	-9.33	-10.73	-11.36	-11.38	-12.30	-14.10	-17.61
7Signals CH 2 H-Pol EL-LR (05-24-2022)	-5.08	-5.02	-4.84	-4.84	-4.70	-4.60	-5.73	-6.17	-6.16	-6.41	-6.78	-6.35	-6.87	-7.86	-8.82

Average Gain Comparison: All data points averaged for each frequency and all angles (dBi)						
Frequency (MHz)	**Avg Gain 2.4 GHz Band (dBi)**	**Avg Gain 5 GHz Band (dBi)**	**Avg Gain 6-7 GHz Band (dBi)**	**Max Gain * 2.4 GHz Band (dBi)**	**Max Gain * 5 GHz Band (dBi)**	**Max Gain * 6-7 GHz Band (dBi)**
7Signals CH 2 V-Pol Az (05-24-2022)	**-2.34**	**-0.74**	**-3.75**	**0.58**	**3.42**	**2.08**
7Signals CH 2 H-Pol Az (05-24-2022)	**-6.83**	**-13.91**	**-15.38**	**-1.39**	**-5.30**	**-9.18**
7Signals CH 2 V-Pol EL-FB (05-24-2022)	**-10.15**	**-12.25**	**-14.25**	**-3.52**	**-6.14**	**-6.59**
7Signals CH 2 H-Pol EL-FB (05-24-2022)	**-2.80**	**-3.35**	**-5.18**	**-0.49**	**3.10**	**0.64**
7Signals CH 2 V-Pol EL-LR (05-24-2022)	**-5.18**	**-10.04**	**-14.16**	**-1.97**	**-3.11**	**-5.22**
7Signals CH 2 H-Pol EL-LR (05-24-2022)	**-4.84**	**-6.26**	**-7.78**	**-0.22**	**-0.81**	**-0.07**

*****Red highlighted cells in the Max Gain columns are the maximum (Peak) gain values measured for the antenna.

- As expected the elevation patterns do not have average gain values as high as the azimuth plane and the peak gain values were in the horizontal (azimuth) plane. This is a sit should be, even though the desire may be to have a more equal distribution of energy in 3D space (a more isotropic pattern).
- Insertion losses were within reason, given unknown very small imperfections in the cables, connectors, and adapters as well as how small (tight) the PCB transmission line topology was.
  - Tight transmission line geometries like this can lead to near electromagnetic field interferences and fluctuations from trace to trace, component pad to component pad, transmission line to reference ground distance, … that impede some of the available energy from making it to the antenna.
- Given that a tight layout was required, I was pleased to see the ground cutout on layer 7 (Gerbers.G6) under the switch circuitry, which in effect moved the reference ground plane to layer 6 (Gerber.G5). This allowed for a more efficient return path for the underlying fields. Really close underlying ground references can "crowd" the expanding fields and lead to further loss. All in all, the design seemed very good.
  - I credit the EE that did the layout for some very good work and attention to RF detail.

Custom Integrated Antennas
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