Igor Institute

v [0.1] — [05/20/2023]

TECHNICAL REPORT:

Finalmouse Mouse Antenna Report

Prepared for: [Finalmouse]
Prepared by: [Timothy Milam]

Revision History

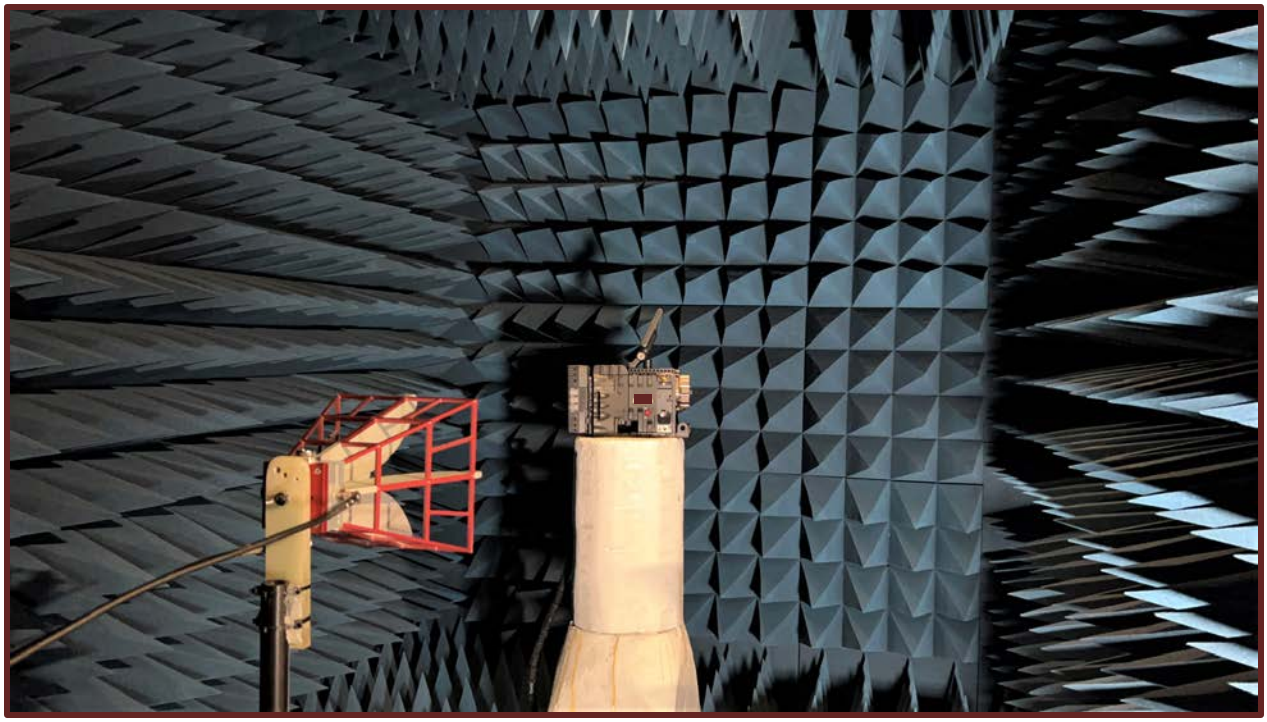
REV	Date	Author	Notes
[0.1]	[2023-05-20]	[Timothy Milam]	Antenna Report including tuning details and measurement data.
[0.2]	[2023-05-20]	[Timothy Milam]	Added data for changing the 3.0 nH shunt inductor on the Mouse to a 3.9 and retesting

Finalmouse USB Dongle and Wireless Mouse Antenna Evaluation Report

Finalmouse requested SMT tuning of the antennas in two products, 1) a USB dongle and 2) a wireless mouse. Due to FCC testing that will occur in a few days, there was no option offered for changing the antenna or any other layout. Later it was agreed to trim the Dongle antenna to see if it would tune better by the method. It did and radiated performance was better also. This trimmed version can be used during the FCC testing, since no copper tape was used, but the antenna radiator length will have to be the same for the final production board.

1 Test Equipment Used During this Antenna Feasibility Study

- Vector Network Analyzer “VNA” used was a CMT (Copper Mountain Technologies) Model #: S5085; a 50 Ohm, 2-Port, 2-Path, 9 kHz to 8.5 GHz, VNA S/N: 20107496.
- A CIA custom designed and built, 13 ft. x 9 ft. x 9 ft. anechoic antenna measurement chamber fully lined with Cumming Microwave “C-RAM SFC-18”, 18 in. deep pyramidal absorber and associated Cumming Microwave corner treatments and walkway absorber, see image below.
- Chamber source antenna is a RF Spin Model “QRH11”, Quad Ridged Horn Antenna, S/N: 200721Q11.
- Various Mini-Circuits “Flex Test” test cables and Precision Pasternack connectors and adapters were used in the closed system setup, as well as Teledyne “CCR33S80T” SPDT coaxial switches.
- CMT “TW-SMA” Torque Wrench (no S/N).
- CMT “S911T” Calibration Kit, SN: A266049.
- Omano 7x to 45 x trinocular microscope with Hayear Model: HY-5099 (no S/N) Industrial Inspection Camera and SW.



CIA's Anechoic Chamber

2 DUTs as Used for the VSWR and Radiated Pattern Measurements

The Dongle and Mouse DUTs were supplied by Finalmouse and contained the latest hardware as it intended for FCC testing and ultimately production. Images of both units are shown below.

Fully assembled Dongle as tested

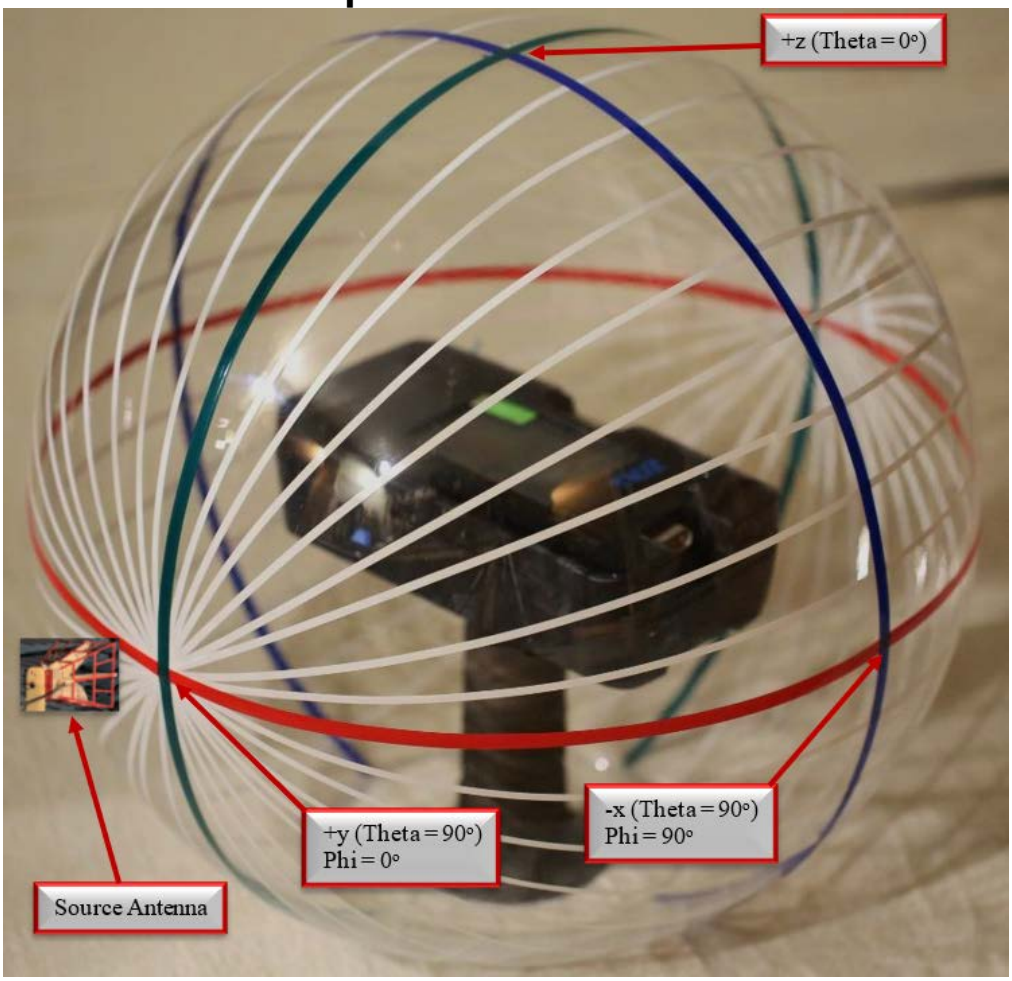
Fully assembled Mouse as tested

3 Measurement Data

The antenna parameters measured were the VSWR and 6 principal radiation patterns (vertical and horizontal polarized data for each of the 3 principal planes of radiation).

VSWR for the Dongle was measured on a wooden surface, the Mouse was also measured on a wooden surface, but had a mouse pad under it. Comparison VSWR was also supplied for the mouse with a hand on it as if it were being used normally (memory trace) and just sitting on the mouse pad with no human interaction; no discernable difference was seen.

3.1 Radiated Pattern Description



Radiated Pattern Illustration Sphere

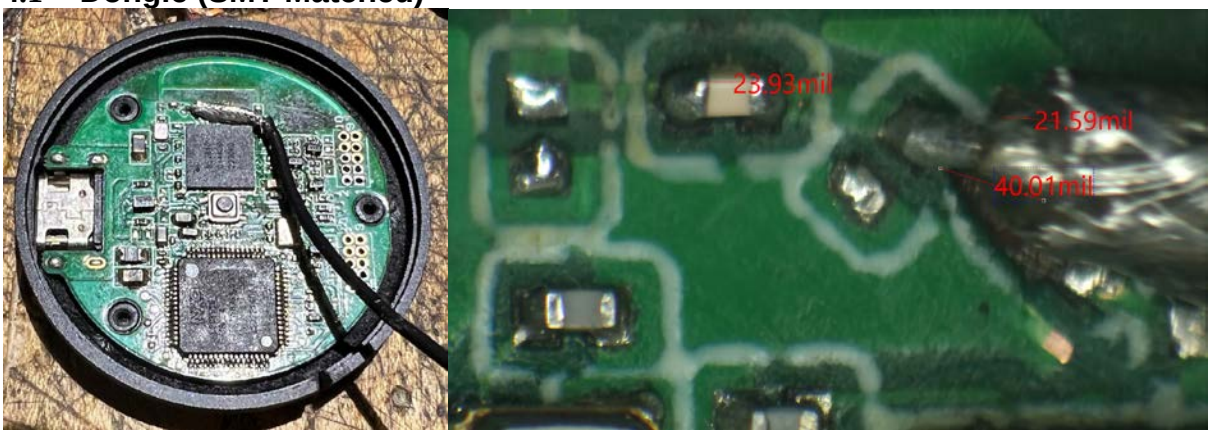
NOTE: To minimize the number of illustrations a generic DUT is shown inside the pattern illustration sphere.
NOTE: The source antenna is represented as pointing toward the DUT from the 0-degree data point as shown in the plots below.
NOTE: Some labs have different interpretations of the spherical as well as the Cartesian coordinate systems than given below. They may point x, y, and z in different directions or define + or – signs differently on both coordinate systems. The descriptions below use the conventions that are used in the CIA lab.

3.1.1 Three Principal Planes of Radiation

- The red horizontal line, circumnavigating the sphere, represents the azimuth plane of radiation (cut), as labeled in the plots below.
  - Azimuth is also known as just the Phi plane or Phi at Theta = 90° in a spherical coordinate system or the xy plane in the Cartesian coordinate system.
- The dark green vertical line represents the Elevation Front to Back (F/B) cut.
  - AKA the Theta plane at (that passes through) Phi = 0° and 180° in a spherical coordinate system or the yz plane in the Cartesian coordinate system.
- The dark blue vertical line represents the Elevation Left to Right (L/R) cut.
  - AKA the Theta cut at Phi = 90° and 270° or the xz plane in the Cartesian coordinate system. *FYI: Some labs use Phi = +90° and -90° in a spherical coordinate system.*
- When radiation pattern data is measured in both polarizations (V and H), the 6 resulting patterns are known as the 6 principal planes or "cuts".
- The planes represented by the white lines are only measured when a full 3D data set is required.
- All principal and secondary planes or cuts are measured by positioning the DUT appropriately, for the plane to be measured and rotating the pedestal by 360 degrees, capturing VNA S21 (received signal amplitude) measurement data every 10°.

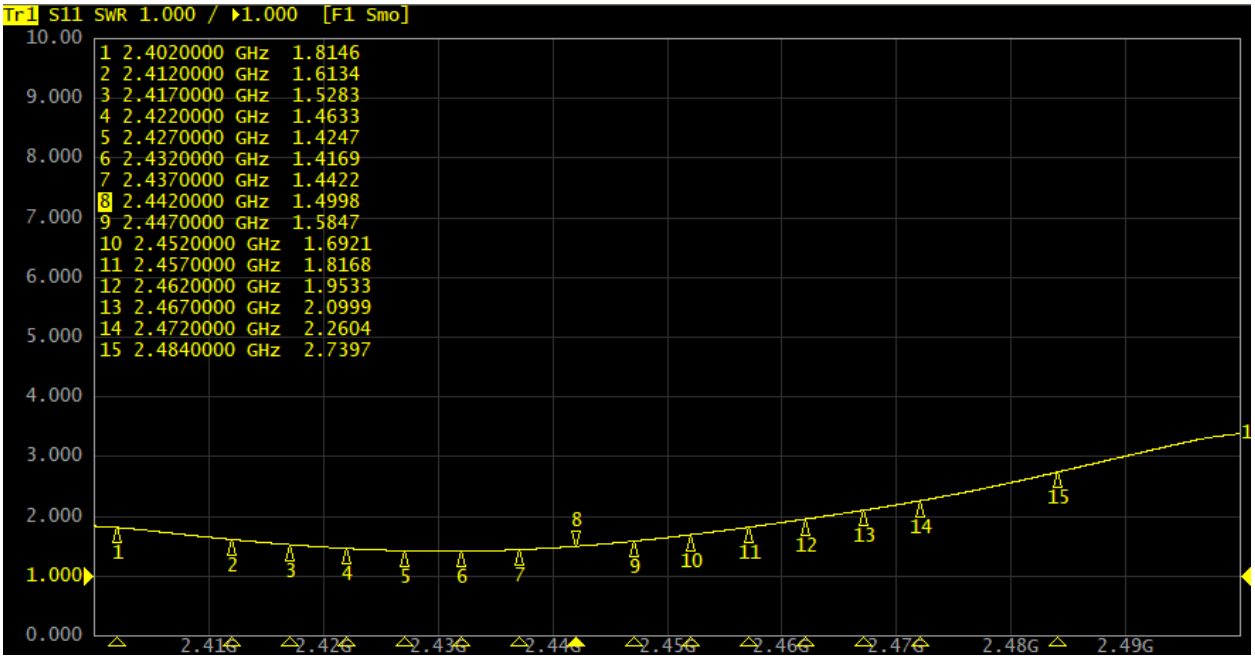
4 Finalmouse Antenna Data

4.1 Dongle (SMT Matched)



Inside view with the 1.37 mm U.FL test cable attachment to the Dongle's PCB CPW transmission line

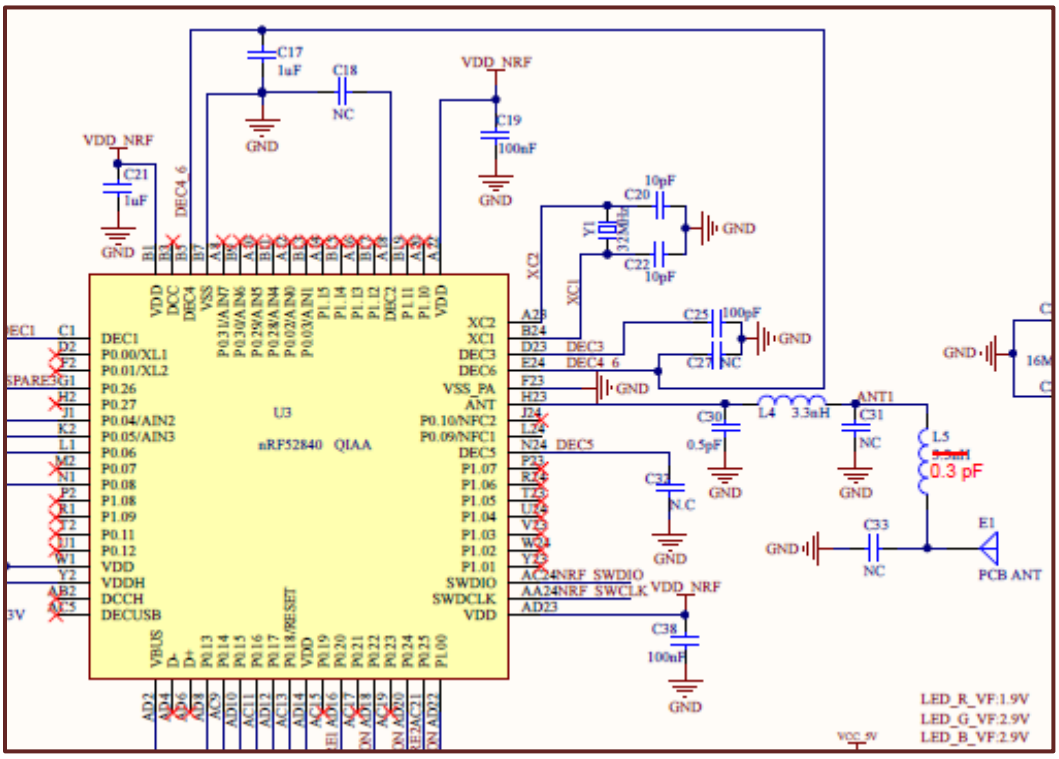
4.1.1 VSWR



VSWR for the Dongle, with a 0.3 pF capacitor (Johanson P/N: 250R05L0R3BV4S) in the L5 series position of the antenna matching circuit. As seen here, the Dongle antenna still isn't optimally tuned, but this was as close as it could be tuned with the available components. The series capacitor value was already getting very low and it needed to go a little lower to center the resonance, see recommendations below.

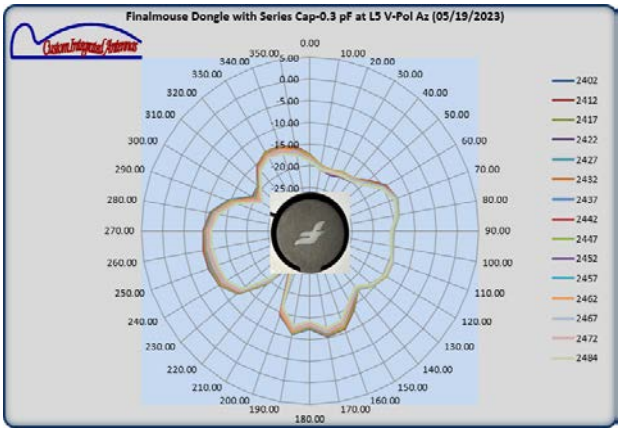
- The best option is likely to trim the radiator length of the Dongle antenna to a suitable length and if further tuning is necessary, continue with that to achieve best resonance and impedance match.
- Without trimming the PIFA radiator, I'd recommend a 0.2 pF or possibly a 0.1 pF in the series position at L5.

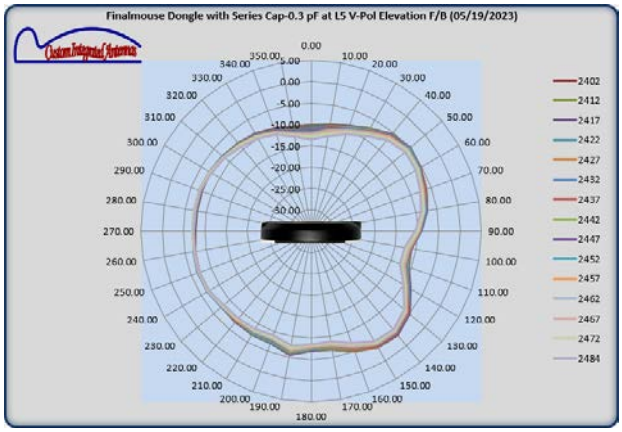
4.1.2 Schematic with Matching Capacitor Location

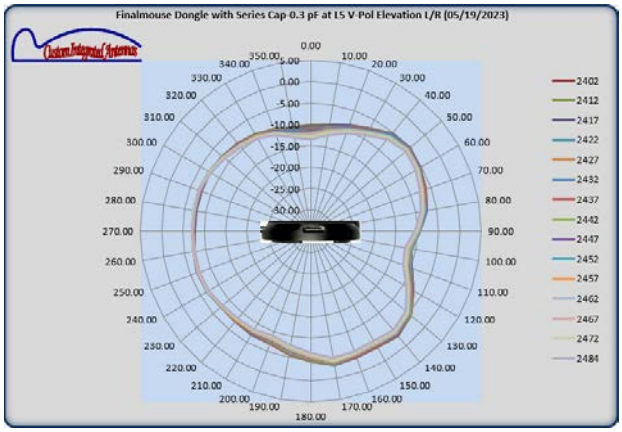


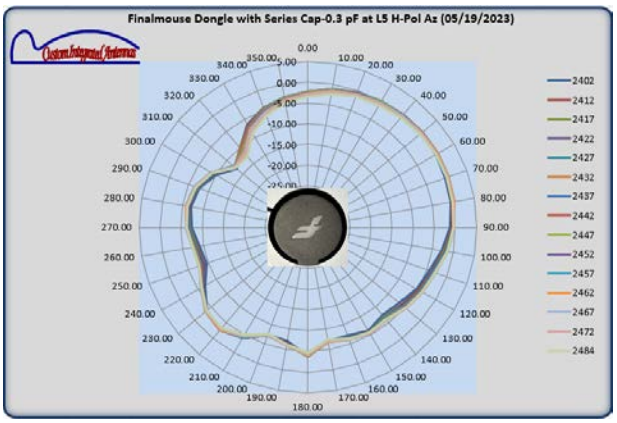
Schematic markup for the Dongle antenna matching components. The red markup value (0.3 pF) was used to tune the antenna as shown in the VSWR plot above.

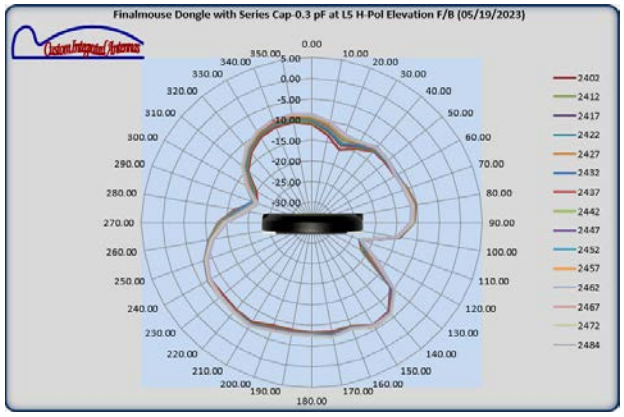
4.1.3 Radiated Patterns

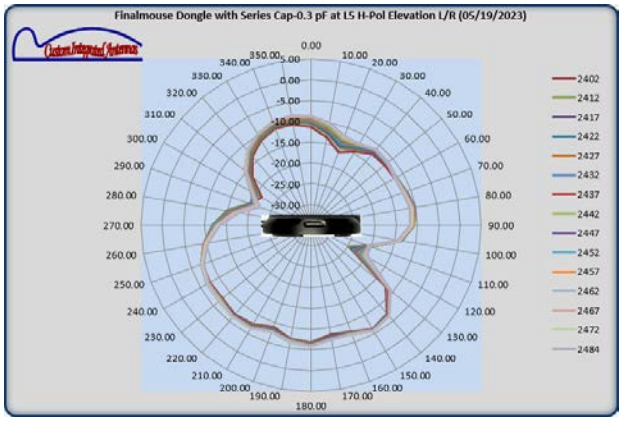




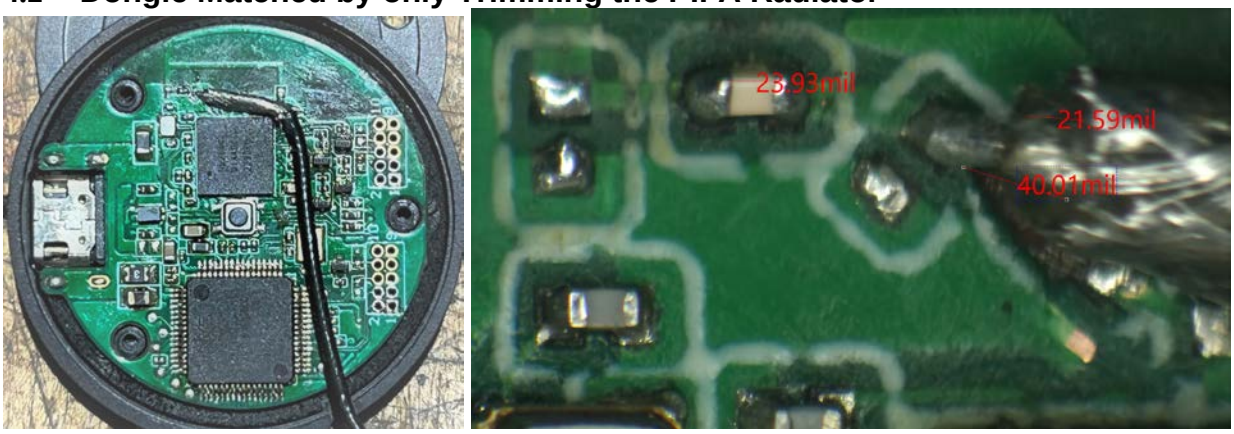






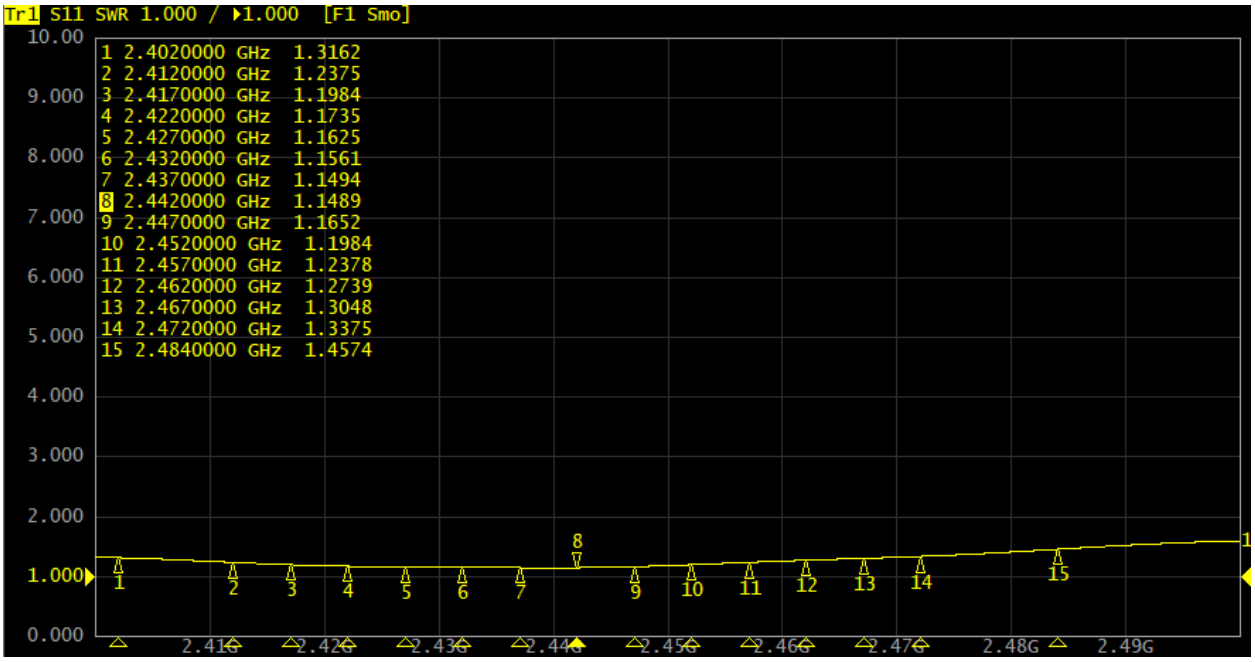


4.2 Dongle Matched by only Trimming the PIFA Radiator



Inside view with the 1.37 mm U.FL test cable attachment to the Dongle's PCB CPW transmission line and trimmed PIFA

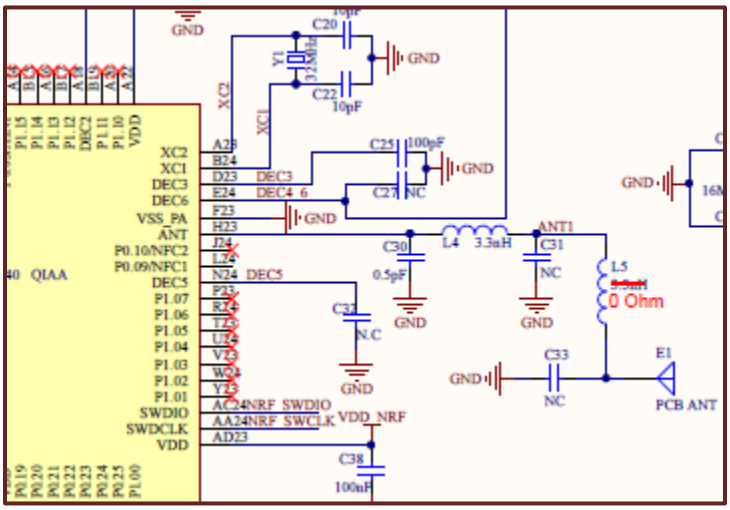
4.2.1 VSWR



VSWR for the Dongle, with a 0 Ohm jumper in the L5 series position of the antenna matching circuit and the PIFA radiator trimmed by 3.85 mm.

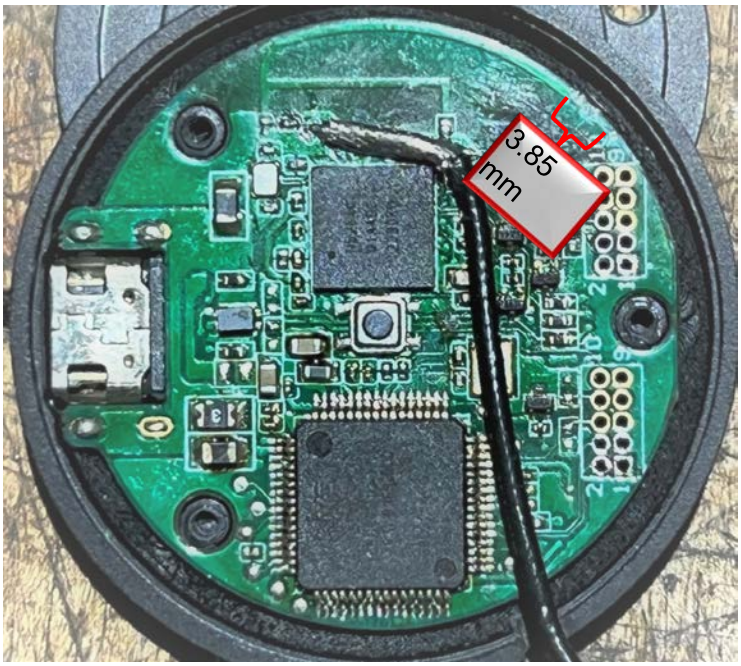
The Dongle tuned much better by the trimming method.

4.2.2 Schematic with 0 Ohm Jumper Location



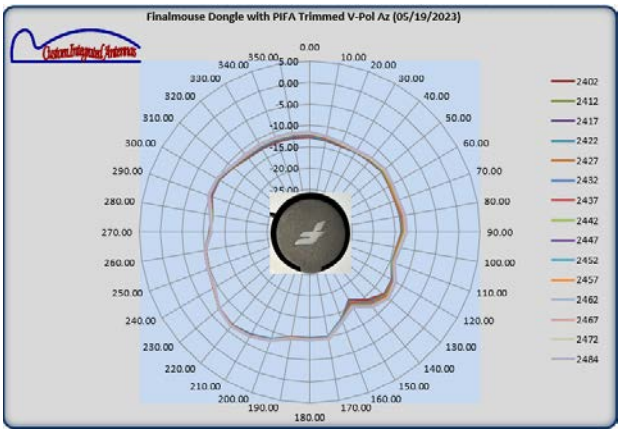
Schematic markup for the Dongle antenna matching components. The red markup value (0 Ohm jumper) and a 3.85 mm shorter PIA radiator tuned the antenna as shown in the VSWR plot above.

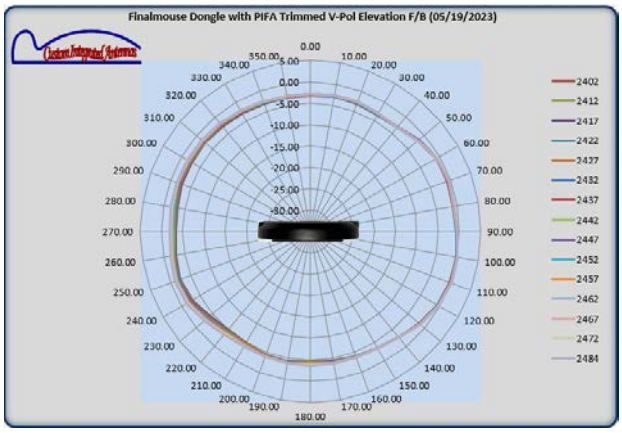
4.2.3 PCBA After Trimming the Antenna

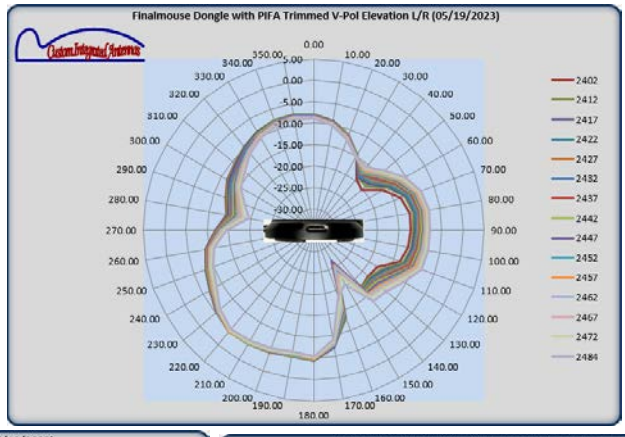


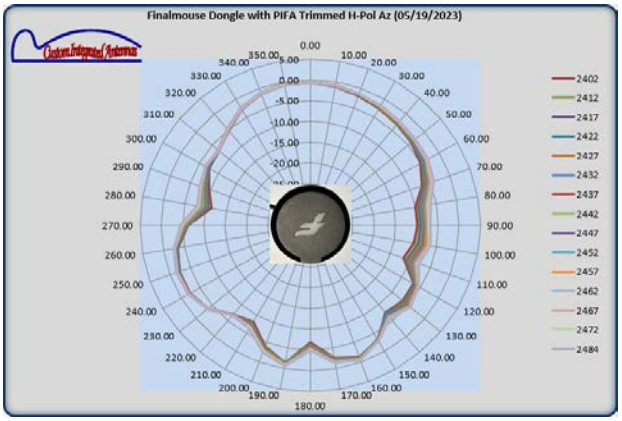
Dongle PIFA radiator trimmed 3.85 mm. No SMT tuning was required.

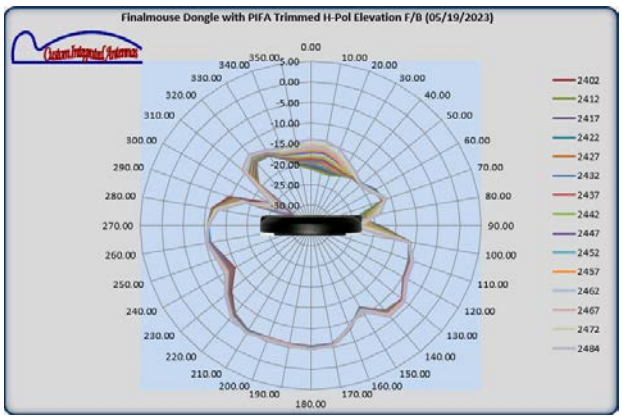
4.2.4 Radiated Patterns

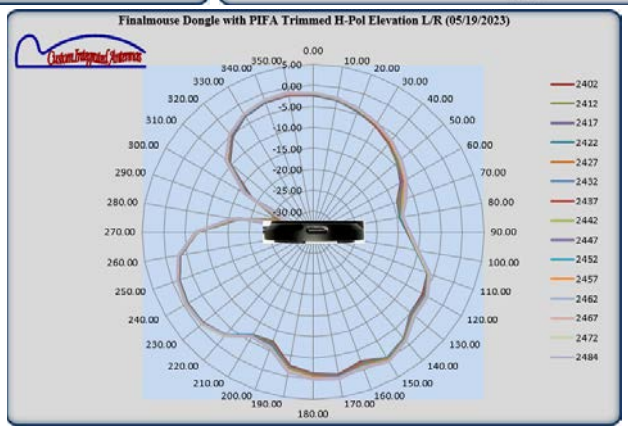




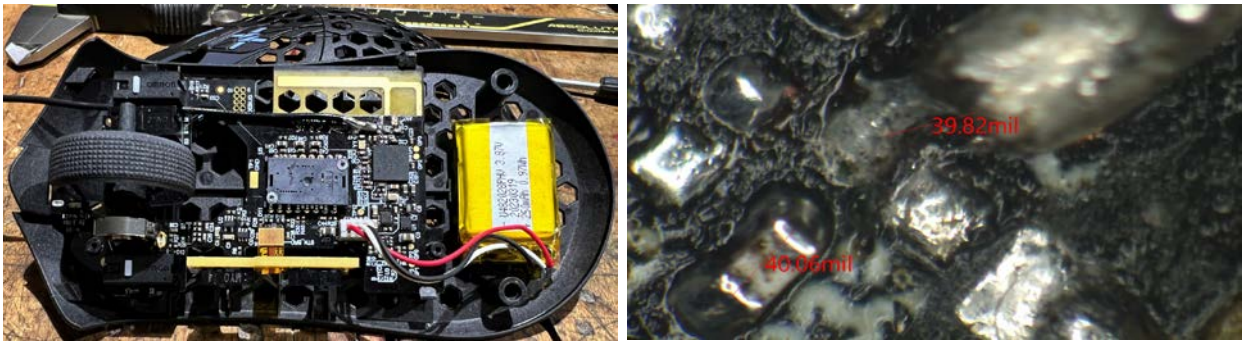






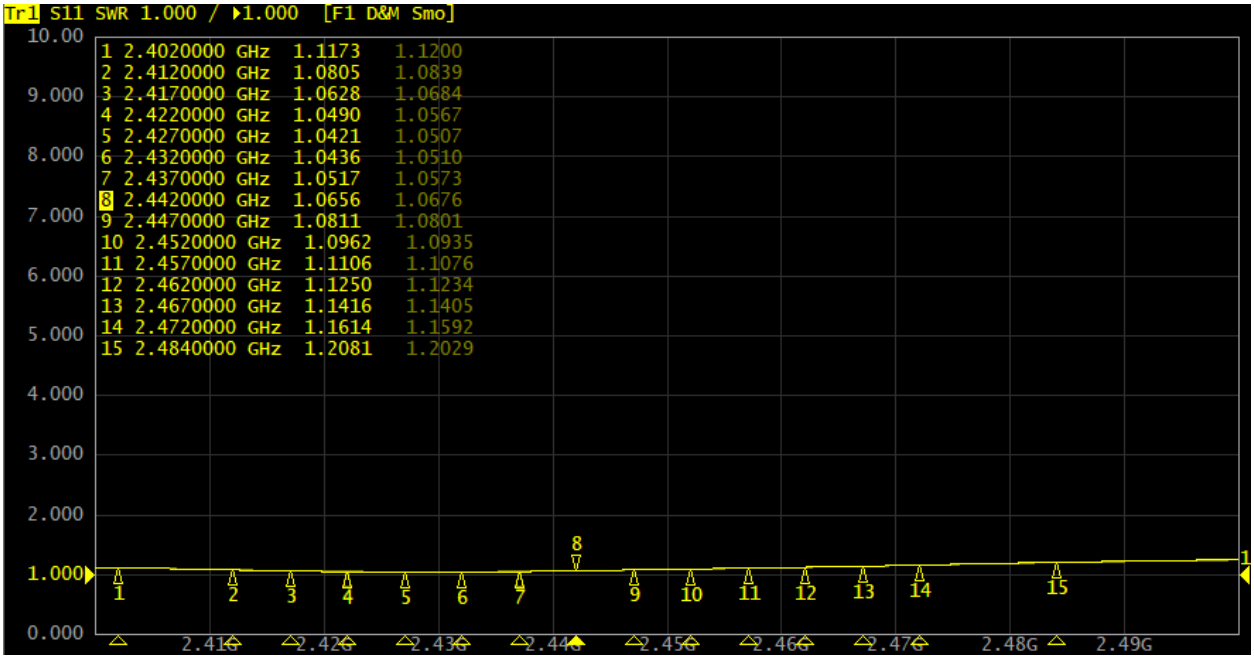


4.3 Mouse with 3.0 nH Shunt Inductor



Inside view with the 1.37 mm U.FL test cable attachment to the Mouse's PCB CPW transmission line

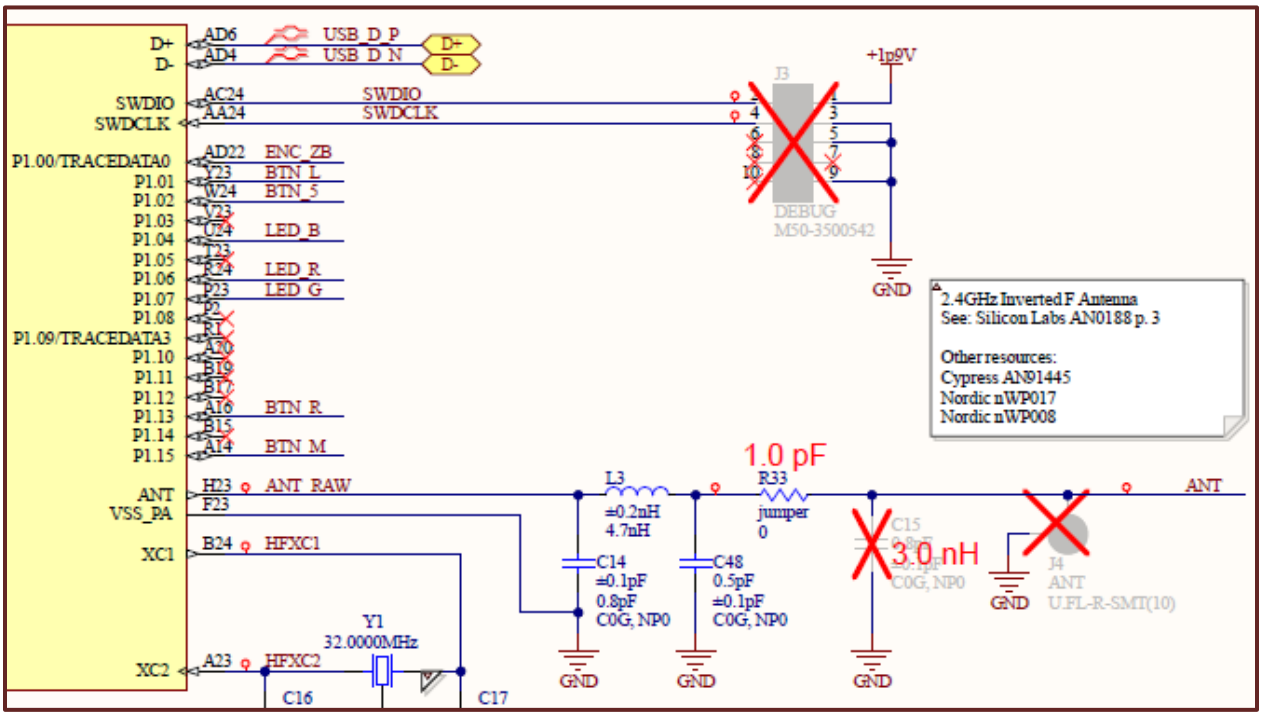
4.3.1 Mouse VSWR



VSWR of the mouse PIFA with a series 1.0 pF cap (muRata P/N: GJM1555C1H1R0BB01) in position R33 and a shunt 3.0 nH (TDK P/N: MLG1005S3N0CT000) inductor in position C15

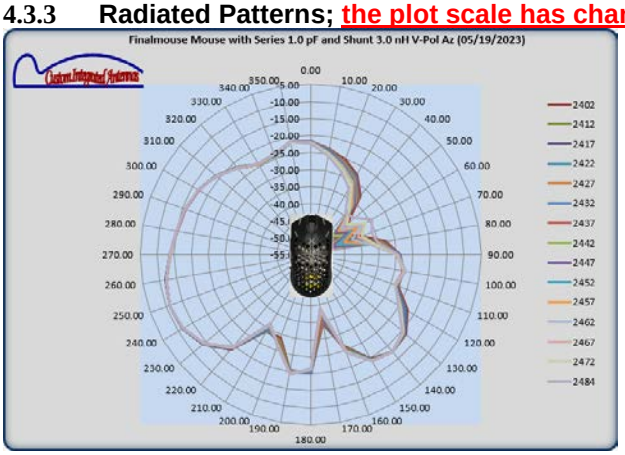
NOTE: The VSWR trace above is actually a live trace (no hand on the mouse) overlaid on a memory trace (with hand on the mouse). No discernable difference was seen, as is evident in the plot. The mouse was on a mouse pad on a wooden bench.

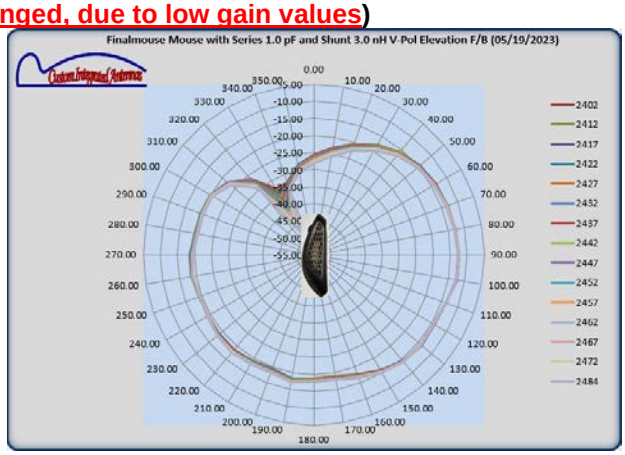
4.3.2 Schematic with 0 Ohm Jumper Location

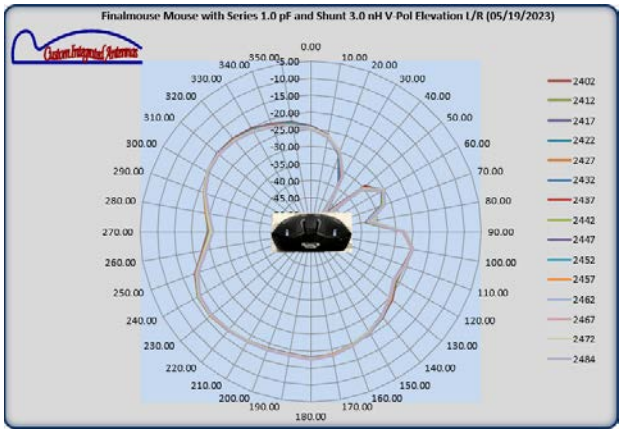


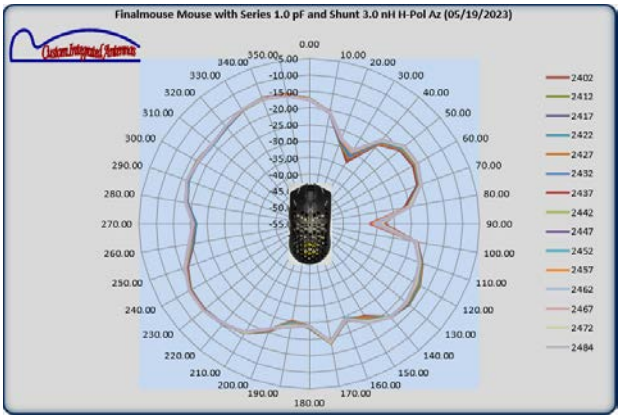
Schematic markup for the Mouse antenna matching components. Red values were used to tune the antenna at the length supplied.

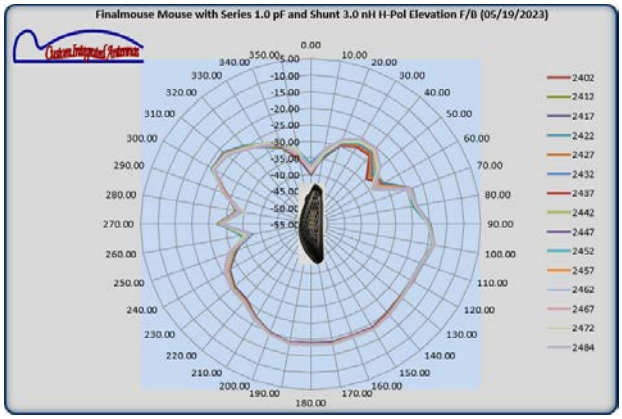
4.3.3 Radiated Patterns; the plot scale has changed, due to low gain values)

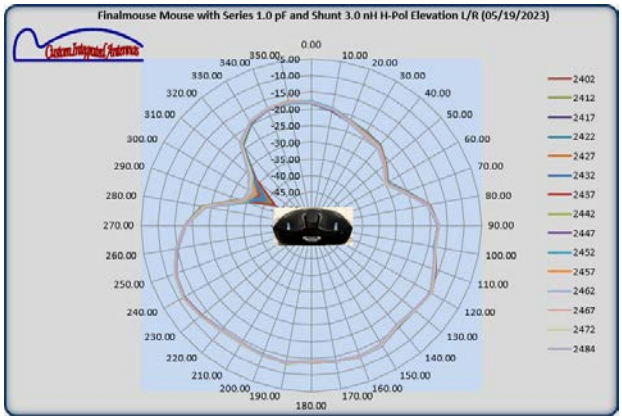








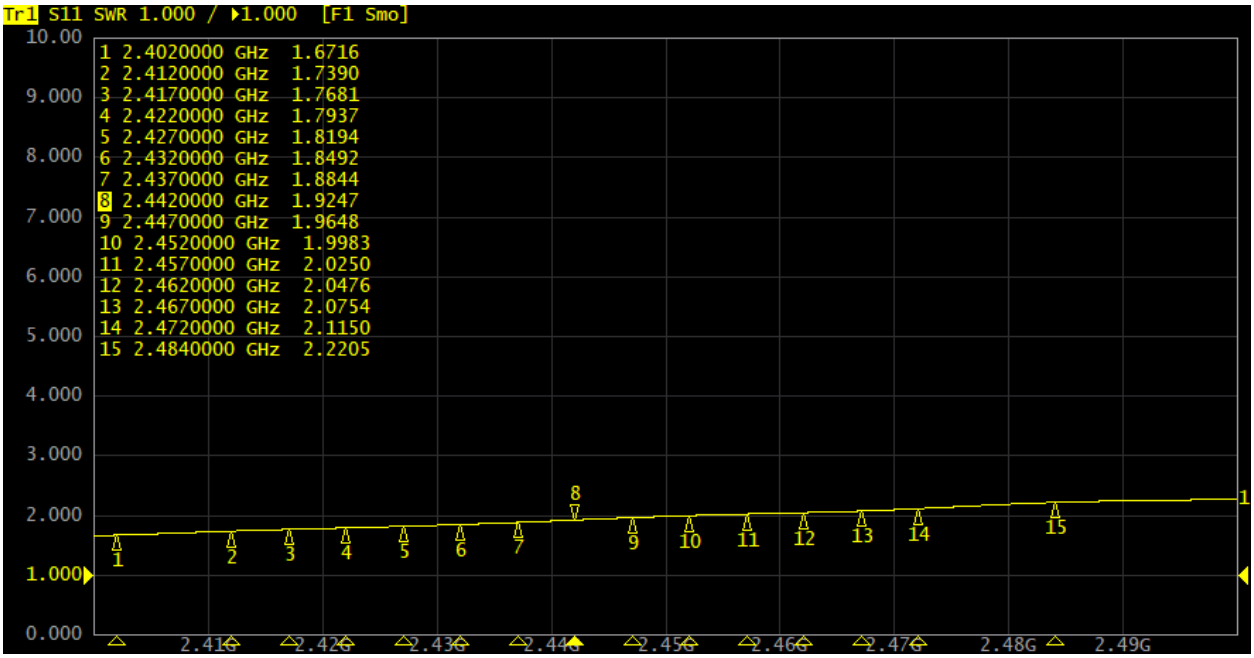




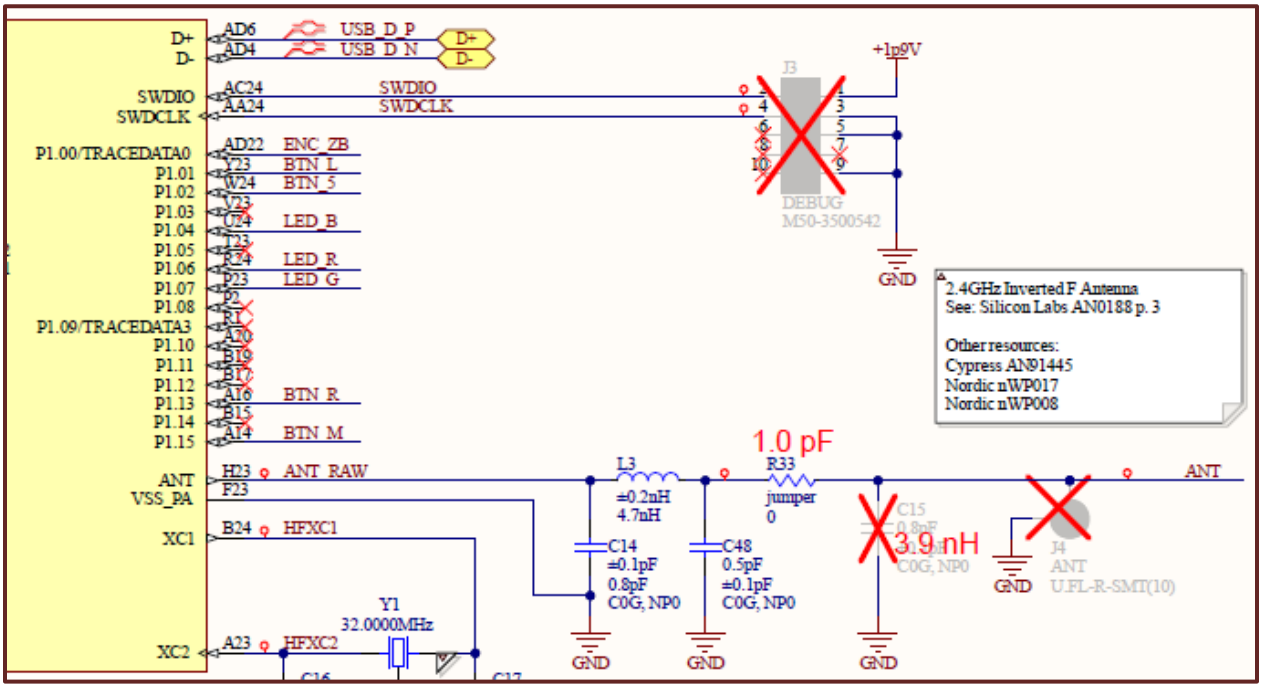
4.4 Mouse with 3.9 nH Shunt Inductor

No change to the DUT images.

4.4.1 VSWR

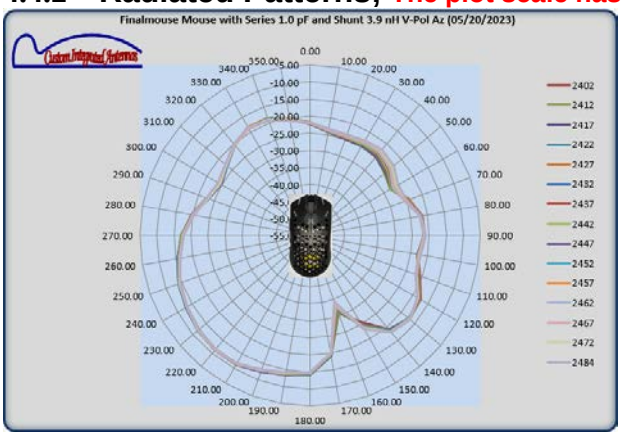


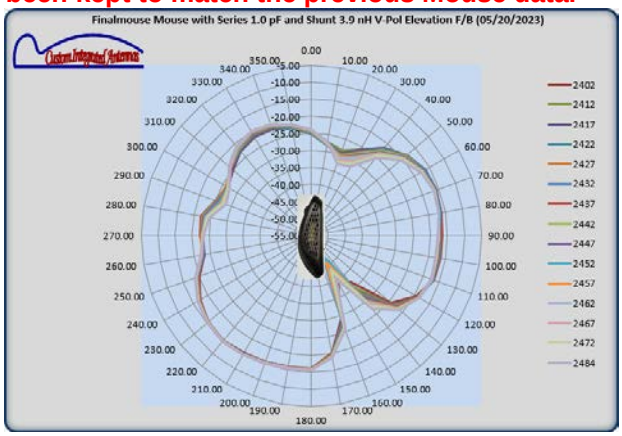
VSWR of the mouse PIFA with a series 1.0 pF cap (muRata P/N: GJM1555C1H1R0BB01) in position R33 and a shunt 3.9 nH (TDK P/N: MLG1005S3N9CT000) inductor in position C15

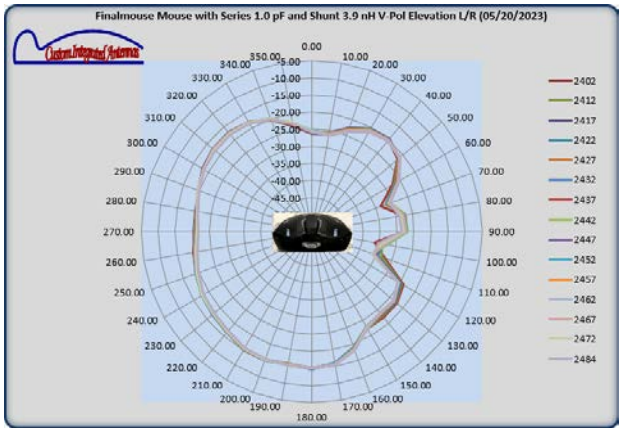


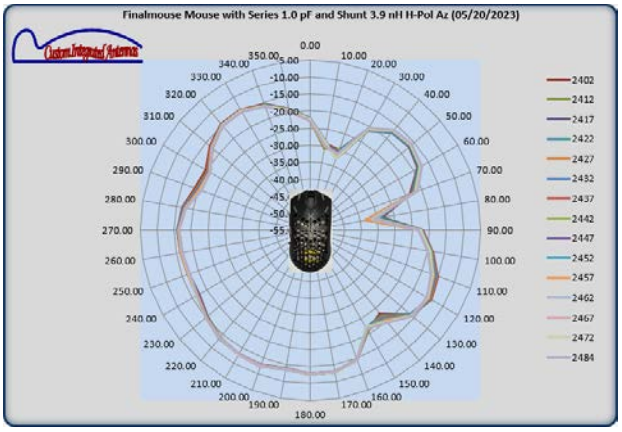
Schematic markup for the Mouse antenna matching components. Red values were used to tune the antenna at the length supplied, per Finalmouse request on 05/20/2023.

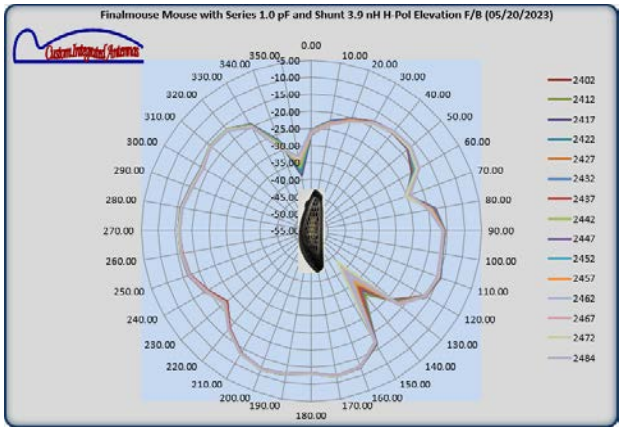
4.4.2 Radiated Patterns; The plot scale has been kept to match the previous Mouse data.

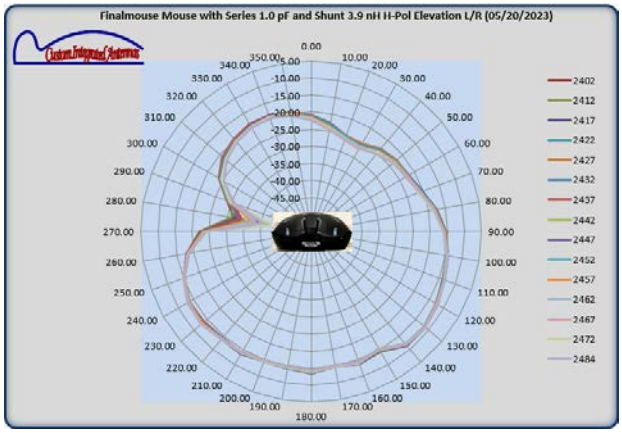












5 Tabular Data

Average Gain Comparison: All data points averaged for each frequency and all angles (dBi)									
Frequency (MHz)	**2402**	**2412**	**2417**	**2422**	**2427**	**2432**	**2437**	**2442**	**2447**
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Az (05/19/2023)	-13.84	-13.73	-13.78	-13.90	-13.81	-13.80	-13.92	-13.91	-13.94
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Az (05/19/2023)	-3.69	-3.45	-3.37	-3.40	-3.28	-3.18	-3.19	-3.16	-3.15
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Elevation F/B (05/19/2023)	-7.04	-7.02	-7.04	-7.11	-7.08	-7.11	-7.24	-7.30	-7.35
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Elevation F/B (05/19/2023)	-10.39	-10.06	-9.96	-9.87	-9.69	-9.62	-9.62	-9.51	-9.46
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Elevation L/R (05/19/2023)	-6.66	-6.63	-6.64	-6.71	-6.69	-6.72	-6.84	-6.89	-6.96
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Elevation L/R (05/19/2023)	-10.26	-9.93	-9.83	-9.75	-9.57	-9.49	-9.49	-9.38	-9.34
Finalmouse Dongle with PIFA Trimmed V-Pol Az (05/19/2023)	-11.17	-11.03	-11.02	-11.04	-10.90	-10.86	-10.87	-10.75	-10.71
Finalmouse Dongle with PIFA Trimmed H-Pol Az (05/19/2023)	-4.13	-3.96	-3.90	-3.91	-3.74	-3.64	-3.62	-3.51	-3.45
Finalmouse Dongle with PIFA Trimmed V-Pol Elevation F/B (05/19/2023)	-2.59	-2.47	-2.44	-2.44	-2.31	-2.26	-2.28	-2.19	-2.14
Finalmouse Dongle with PIFA Trimmed H-Pol Elevation F/B (05/19/2023)	-10.71	-10.63	-10.57	-10.53	-10.45	-10.47	-10.42	-10.28	-10.26
Finalmouse Dongle with PIFA Trimmed V-Pol Elevation L/R (05/19/2023)	-9.10	-9.04	-9.05	-9.10	-9.04	-9.05	-9.10	-9.05	-9.10
Finalmouse Dongle with PIFA Trimmed H-Pol Elevation L/R (05/19/2023)	-4.27	-4.11	-4.08	-4.10	-3.94	-3.85	-3.84	-3.73	-3.67
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Az (05/19/2023)	-18.47	-18.41	-18.44	-18.54	-18.50	-18.47	-18.54	-18.53	-18.55
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Az (05/19/2023)	-18.46	-18.44	-18.51	-18.59	-18.45	-18.40	-18.49	-18.45	-18.40
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Elevation F/B (05/19/2023)	-16.88	-16.85	-16.85	-16.93	-16.86	-16.85	-16.92	-16.89	-16.87
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Elevation F/B (05/19/2023)	-22.80	-22.74	-22.75	-22.75	-22.60	-22.60	-22.68	-22.53	-22.45
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Elevation L/R (05/19/2023)	-21.23	-21.27	-21.27	-21.32	-21.30	-21.32	-21.37	-21.38	-21.39
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Elevation L/R (05/19/2023)	-16.37	-16.38	-16.33	-16.32	-16.27	-16.33	-16.37	-16.24	-16.23
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Az (05/20/2023)	-17.32	-17.25	-17.28	-17.36	-17.33	-17.33	-17.40	-17.38	-17.39
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Az (05/20/2023)	-16.44	-16.46	-16.53	-16.56	-16.43	-16.46	-16.57	-16.52	-16.47
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Elevation F/B (05/20/2023)	-19.14	-19.08	-19.07	-19.11	-19.04	-19.03	-19.10	-19.06	-19.04
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Elevation F/B (05/20/2023)	-16.66	-16.60	-16.59	-16.64	-16.60	-16.63	-16.68	-16.60	-16.59
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Elevation L/R (05/20/2023)	-19.39	-19.41	-19.41	-19.42	-19.37	-19.40	-19.46	-19.42	-19.40
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Elevation L/R (05/20/2023)	-16.31	-16.17	-16.17	-16.29	-16.31	-16.29	-16.27	-16.21	-16.29

Average Gain Comparison: All data points averaged for each frequency and all angles (dBi)							Avg Gain (dBi)	Max Gain (dBi)
Frequency (MHz)	2452	2457	2462	2467	2472	2484	2.4 GHz Band	
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Az (05/19/2023)	-14.16	-14.27	-14.30	-14.53	-14.78	-15.19	**-14.10**	**-9.38**
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Az (05/19/2023)	-3.23	-3.25	-3.26	-3.36	-3.46	-3.71	**-3.34**	**0.61**
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Elevation F/B (05/19/2023)	-7.46	-7.56	-7.67	-7.81	-7.91	-8.27	**-7.38**	**-3.51**
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Elevation F/B (05/19/2023)	-9.52	-9.49	-9.47	-9.52	-9.51	-9.68	**-9.68**	**-5.75**
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol Elevation L/R (05/19/2023)	-7.08	-7.17	-7.28	-7.42	-7.53	-7.89	**-6.99**	**-3.20**
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol Elevation L/R (05/19/2023)	-9.39	-9.35	-9.33	-9.39	-9.39	-9.55	**-9.55**	**-5.60**
Finalmouse Dongle with PIFA Trimmed V-Pol Az (05/19/2023)	-10.75	-10.68	-10.62	-10.64	-10.64	-10.63	**-10.82**	**-6.15**
Finalmouse Dongle with PIFA Trimmed H-Pol Az (05/19/2023)	-3.45	-3.38	-3.32	-3.30	-3.29	-3.25	**-3.58**	**-0.35**
Finalmouse Dongle with PIFA Trimmed V-Pol Elevation F/B (05/19/2023)	-2.13	-2.08	-2.04	-2.04	-2.00	-1.98	**-2.22**	**0.26**
Finalmouse Dongle with PIFA Trimmed H-Pol Elevation F/B (05/19/2023)	-10.26	-10.15	-10.09	-10.04	-9.95	-9.92	**-10.31**	**-4.84**
Finalmouse Dongle with PIFA Trimmed V-Pol Elevation L/R (05/19/2023)	-9.17	-9.16	-9.19	-9.25	-9.28	-9.36	**-9.13**	**-4.06**
Finalmouse Dongle with PIFA Trimmed H-Pol Elevation L/R (05/19/2023)	-3.65	-3.57	-3.51	-3.49	-3.47	-3.44	**-3.77**	**0.70**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Az (05/19/2023)	-18.60	-18.58	-18.56	-18.60	-18.62	-18.64	**-18.54**	**-10.95**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Az (05/19/2023)	-18.41	-18.35	-18.33	-18.35	-18.33	-18.33	**-18.42**	**-14.15**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Elevation F/B (05/19/2023)	-16.92	-16.91	-16.91	-16.94	-16.95	-17.00	**-16.90**	**-12.30**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Elevation F/B (05/19/2023)	-22.52	-22.50	-22.45	-22.44	-22.41	-22.47	**-22.58**	**-18.02**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol Elevation L/R (05/19/2023)	-21.38	-21.35	-21.40	-21.41	-21.37	-21.43	**-21.35**	**-16.63**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol Elevation L/R (05/19/2023)	-16.34	-16.35	-16.32	-16.29	-16.26	-16.43	**-16.32**	**-11.54**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Az (05/20/2023)	-17.46	-17.44	-17.43	-17.45	-17.47	-17.51	**-17.39**	**-11.31**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Az (05/20/2023)	-16.54	-16.53	-16.53	-16.57	-16.55	-16.62	**-16.52**	**-12.51**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Elevation F/B (05/20/2023)	-19.09	-19.08	-19.08	-19.09	-19.08	-19.12	**-19.08**	**-14.51**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Elevation F/B (05/20/2023)	-16.71	-16.70	-16.67	-16.67	-16.67	-16.77	**-16.65**	**-11.60**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol Elevation L/R (05/20/2023)	-19.44	-19.46	-19.49	-19.51	-19.50	-19.69	**-19.45**	**-14.75**
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol Elevation L/R (05/20/2023)	-16.40	-16.34	-16.29	-16.31	-16.34	-16.40	**-16.29**	**-11.33**

Overall Average Gain for Vertical and Horizontal Polarizations (dBi)	
AUT	2.4 GHz Band
Finalmouse Dongle with Series Cap-0.3 pF at L5 V-Pol	-6.34
Finalmouse Dongle with Series Cap-0.3 pF at L5 H-Pol	-8.52
Finalmouse Dongle with PIFA Trimmed V-Pol	-4.51
Finalmouse Dongle with PIFA Trimmed H-Pol	-6.95
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH V-Pol	-17.87
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH H-Pol	-19.20
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH V-Pol	-17.49
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH H-Pol	-17.22

Overall Average Gain with Polarizations Combined (dBi)	
AUT	2.4 GHz Band
Finalmouse Dongle with Series Cap-0.3 pF at L5	-7.30
Finalmouse Dongle with PIFA Trimmed	-5.56
Finalmouse Mouse with Series 1.0 pF and Shunt 3.0 nH	-18.49
Finalmouse Mouse with Series 1.0 pF and Shunt 3.9 nH	-17.35

6 Conclusions

The Dongle tuned significantly better by trimming the antenna rather than using SMT components only. The radiated performance also improved on average by 1.74 dB when it was tuned by trimming the radiator only. Making this modification for the test unit (s) is recommended.

The Mouse exhibited significantly less radiated gain performance than the Dongle and this is highly likely to be caused by the carbon fiber material used for the top housing. As first tuned, The Mouse had an average gain 12.93 lower than the trim tuned Dongle. After the 3.0 nH shunt inductor was replaced with a 3.9 nH a 1.14 dB gain waws realized, even though the match was not as good. This is a good example of cable radiation helping. The standing wave was higher; therefore, it actually helped the system (the integrated antenna and product as a whole). This would be seen in the actual use case as higher current on the ground plane. It could possibly lead to higher spurious emissions, but that has to be determined in an EMC lab, since there are a multitude of possible paths and implications of each. This also sheds light on why actual real world field testing is the most important wireless performance test done.