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0Table of Contents

1.	Introduction.....	4
	References.....	4
2.	Antenna Requirements.....	4
3.	Antenna Design.....	4
	Lower Ear.....	4
	Behind Upper Ear w/ Clip Use Case (TBD)	6
4.	Antenna Simulation Results	6
	4mm Battery.....	7
	Earring Stud (TBD).....	8
	Inverted-F Antenna	8
	Upper Part of Ear Use Case (TBD)	9
5.	Summary	13

Table of Figures

Figure 1	Lumia 2 behind the lower ear with Ansys simple head model	4
Figure 2	Ansys model showing edge plated antenna on the main PCB	5
Figure 3	Close up of PCB edge plated antenna	5
Figure 4	Ansys model of ILA	5
Figure 5	Ansys model of upper ear location of ILA showing the radiation pattern	6
Figure 6	Ansys simulation outputs (radiation pattern, peak/average gain, S11 and Smith Chart)	7
Figure 7	ILA S11 plot (right) and transmission losses (left)	7
Figure 8	Ansys model of IFA antenna	8
Figure 9	IFA S11 plot (right) and transmission losses (left)	9
Figure 10	Ansys model of ILA antenna	9
Figure 11	Radiation pattern of upper ear location	10
Figure 12	Smith Chart of ILA on upper ear (unmatched) with conductive clip	10
Figure 13	Smith Chart of ILA on upper ear with no conductive clip	11
Figure 14	Radiation pattern of ILA on upper ear	11
Figure 15	S11 plots of single matching network for lower ear and upper ear	12
Figure 16	S11 of upper ear location and conductive clip with 2mm battery (left) and no clip and 4mm battery (right)	13

1. Introduction

The StatHealth Lumia 2 blood monitoring device uses BLE technology to connect to a smartphone. Due to the extremely small size of the device, a custom BLE antenna is required. This report outlines the antenna design effort and gives Ansys simulation results for the performance of the BLE antenna in two use cases: (1) behind lower part of ear and (2) behind upper part of ear, as well as determining the affects of battery size and the conductivity of clip used to hold the device on the upper part of the ear.

References

- 1) Lumia 1 Antenna Report
- 2) 250731 Lumia 2 for F3 Simulation.step

2. Antenna Requirements

The Lumia 1 antenna design showed a peak gain of approx. -18dBi and average gain of -22dBi. These results did not include matching losses. The performance of the Lumia 1 BLE antenna was more than adequate to meet the wireless performance requirements. Thus, our target average gain for the Lumia 2 BLE antenna is to be within 3dB of the Lumia 1 antenna (-25dBi min target) to ensure solid wireless performance.

3. Antenna Design

Lower Ear

The Ansys model of the lower ear use case is shown below.

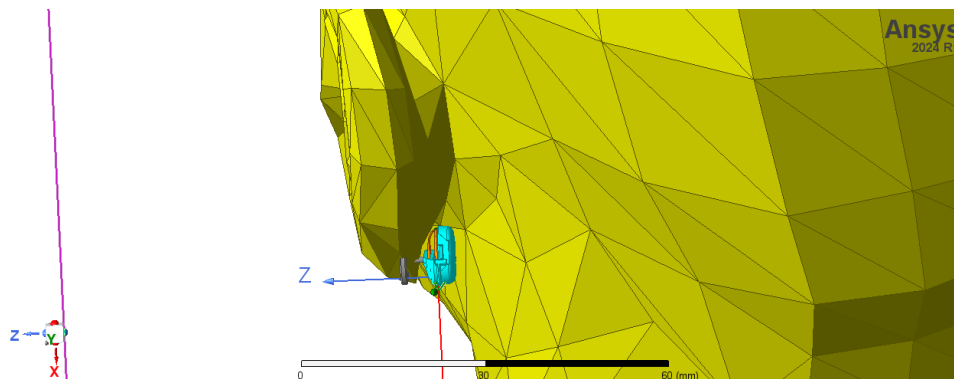


Figure 1 Lumia 2 behind the lower ear with Ansys simple head model

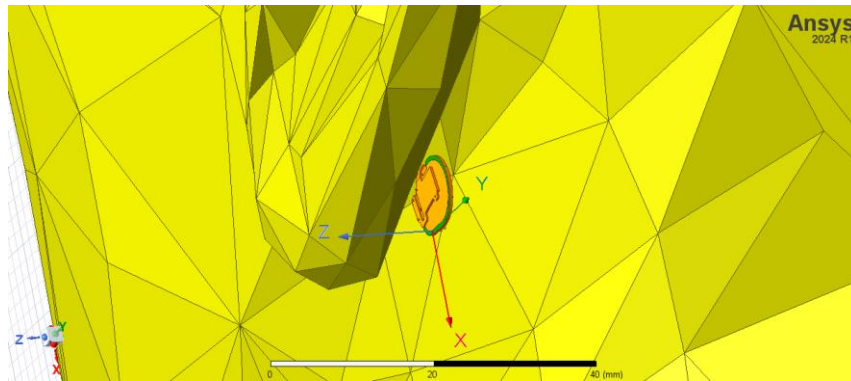


Figure 2 Ansys model showing edge plated antenna on the main PCB

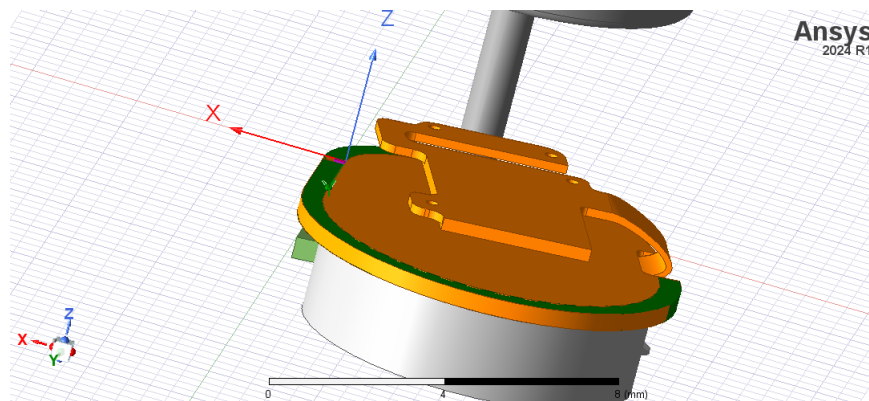


Figure 3 Close up of PCB edge plated antenna

An ILA (inverted-L antenna) was designed as a PCB trace with edge plating on the PCB. The edge plated antenna provides the most separation from the ground plane and the best antenna performance. The antenna is fed from the upper left side of the PCB (pink rectangle in Figure 4) and the ground plane is pulled back from the PCB edge to where the battery sits.

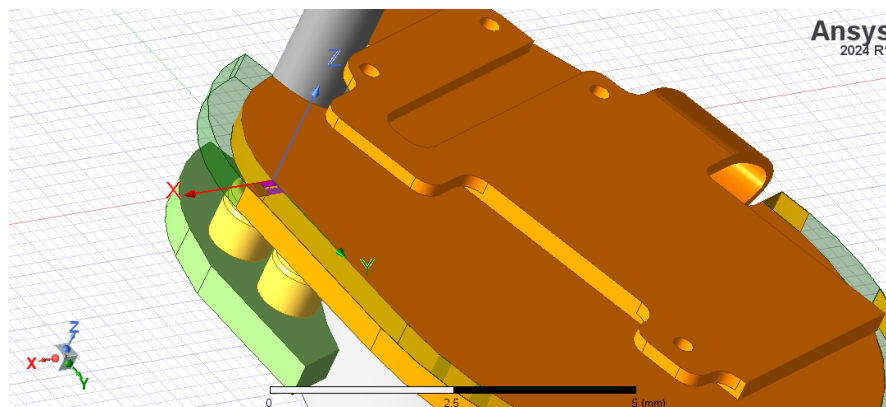


Figure 4 Ansys model of ILA

Behind Upper Ear w/ Clip Use Case

The same edge plated ILA antenna was simulated in the upper ear location. Model is below.

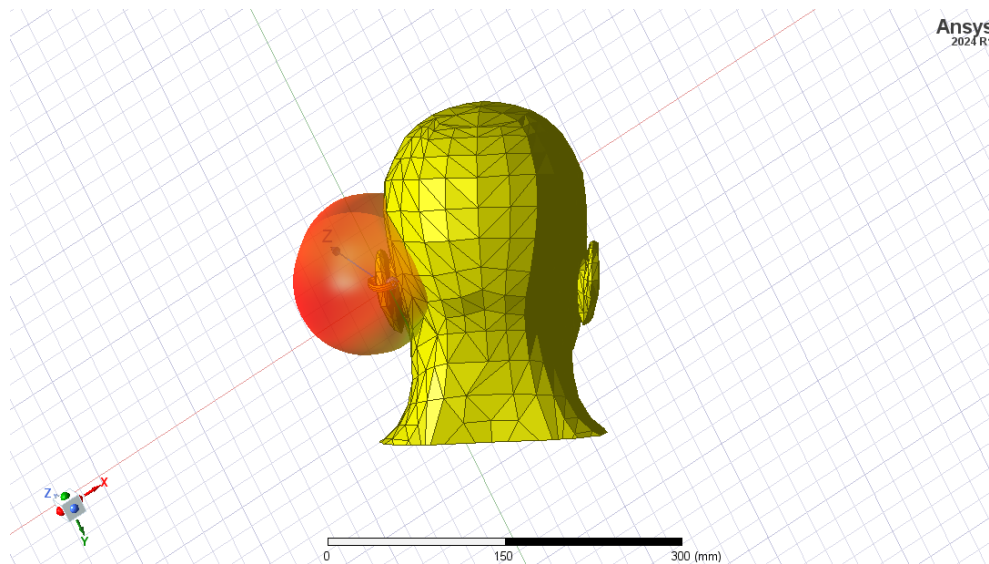


Figure 5 Ansys model of upper ear location of ILA showing the radiation pattern

4. Antenna Simulation Results

The results of the Ansys simulations are given below. S11 plots, radiation patterns, and average gain are shown for each form factor. All data includes the Ansys head model in the simulation. The head model is simplistic and uses average muscle tissue for the ear and everything within the head. This is a conservative representation, as skin, cartilage and fat are much less lossy than muscle tissue.

The S11 plot shows differing antenna lengths with the red plot being the best tuning and that length is shown in Figure 3. Radiation efficiency is -23.4dB and peak gain is -18.4dBi with the best tuning (red trace). These numbers do not include all the matching losses, which will be an additional ~1dB. From the Smith Chart below, we can see that further impedance matching is required (i.e., larger shunt inductor than the 1.5nH used in the model, as well as a series capacitor).

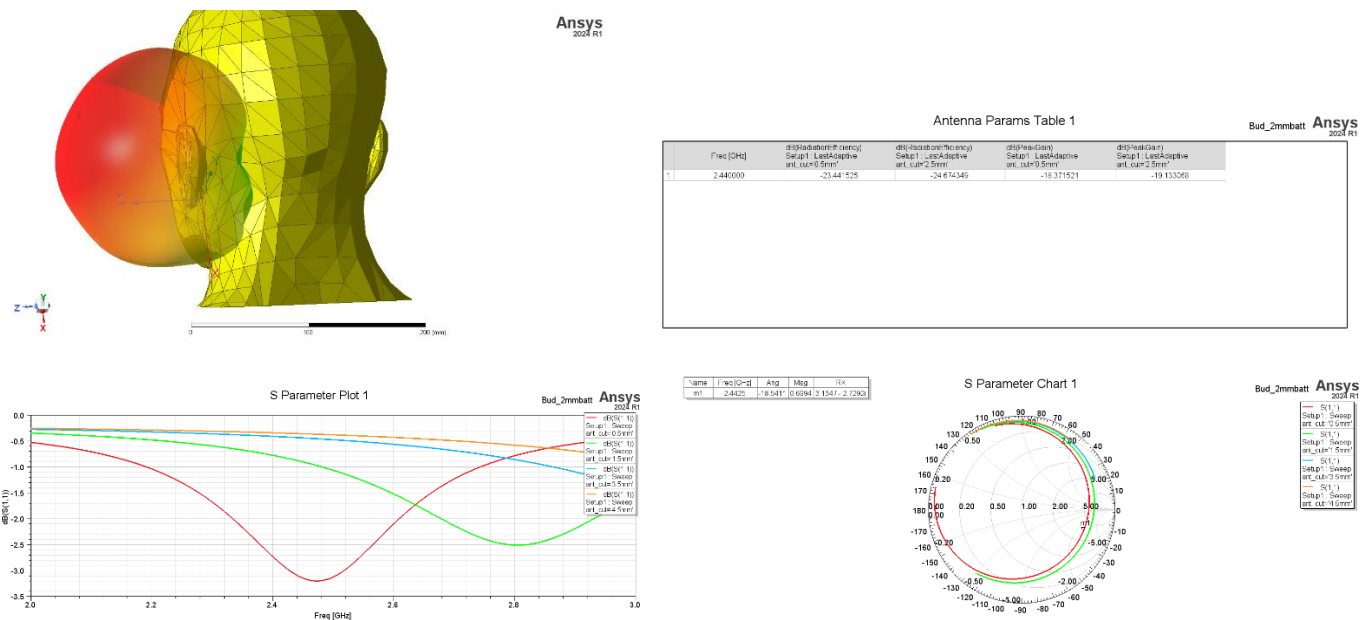


Figure 6 Ansys simulation outputs (radiation pattern, peak/average gain, S11 and Smith Chart)

The ideal impedance match of the ILA antenna is a 1.2nH shunt next to the antenna, and then a 1pF series cap. Due to the low real part of the impedance of the antenna, the matching losses are estimated at ~3dB. The S11 plot and transmission plots are below.

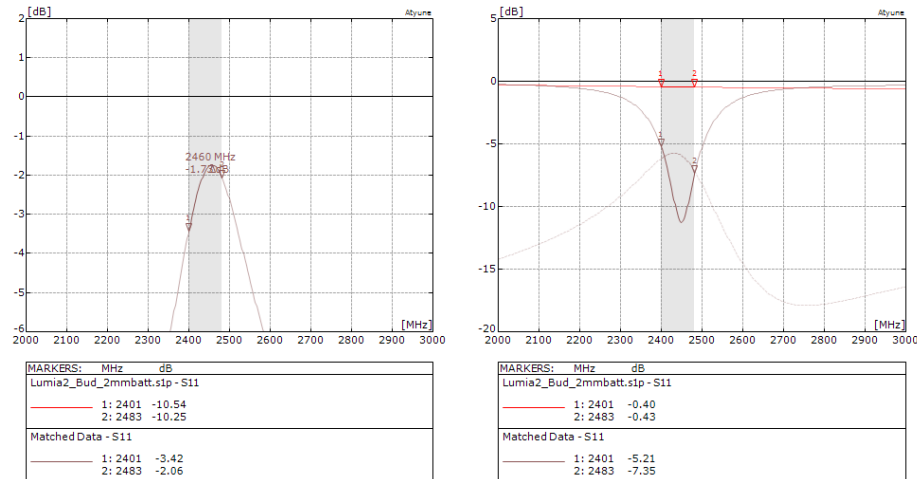


Figure 7 ILA S11 plot (right) and transmission losses (left)

4mm Battery

Note, the 4mm battery did have some negative impacts as radiation efficiency and peak gain each dropped ~3dB. Also, the impedance does change and we may need separate matching networks for the 2mm solution

and 4mm solution. More simulation work is required to know if the same matching network can be used for both batteries.

Earring Stud

How are the impedance and gain affected by the earring stud? It was found that a conductive stud into the ear has little to no impact on the gain, efficiency or impedance of the antenna.

Inverted-F Antenna

Another antenna type is the inverted-F antenna, which has a DC short to gnd. A model of the edge plated IFA is below. This antenna has the shunt inductor built in, and so would likely only require a series capacitor for impedance matching.

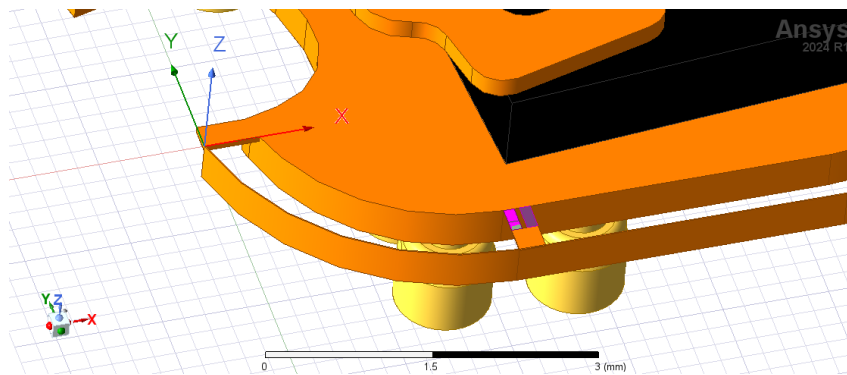


Figure 8 Ansys model of IFA antenna

The IFA has a gain and radiation efficiency ~1dB lower than the ILA, however the matching losses are ~1dB less. S11 and matching transmission plots are below. Red plots are before the match and violet plots are after the match. The IFA requires a series 0.8pF cap for the matching network. After further review of the PCBA, the IFA is not recommended due to the space constraints on the PCB and the desire to keep the RF currents away from other components. Thus, a shunt inductor will be used to match the antenna vs the DC short of the IFA.

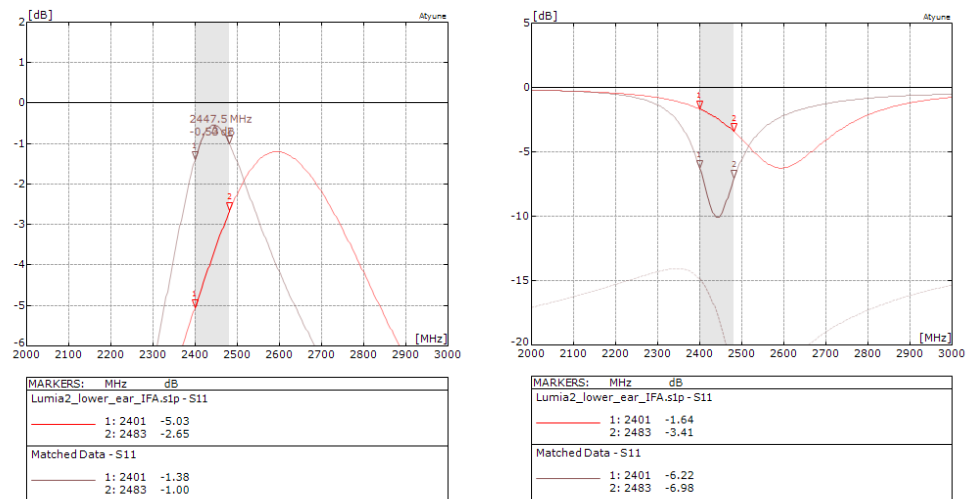


Figure 9 IFA S11 plot (right) and transmission losses (left)

Upper Part of Ear Use Case

The same edge plated Inverted-L Antenna (ILA) with 16.5mm of length, was modeled on the upper part of the ear. The Ansys model is shown below.

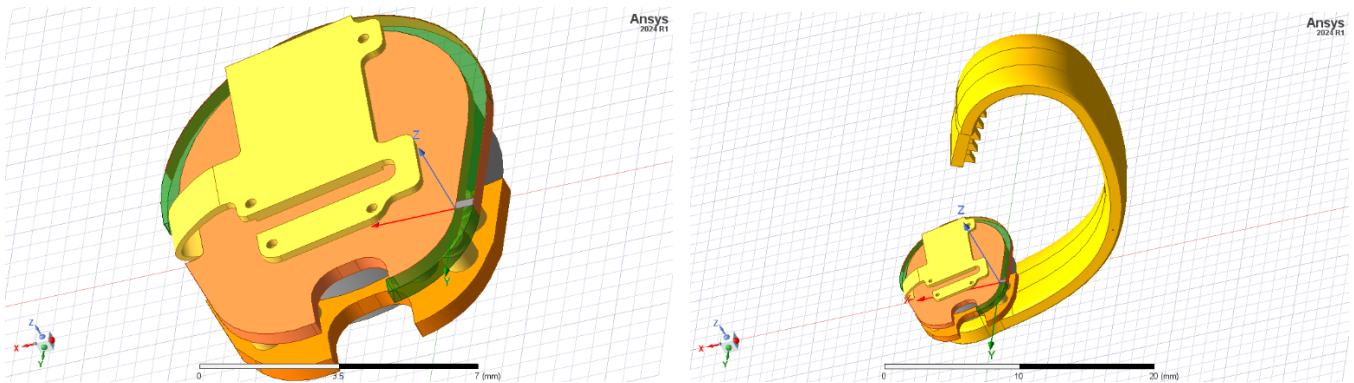


Figure 10 Ansys model of ILA antenna

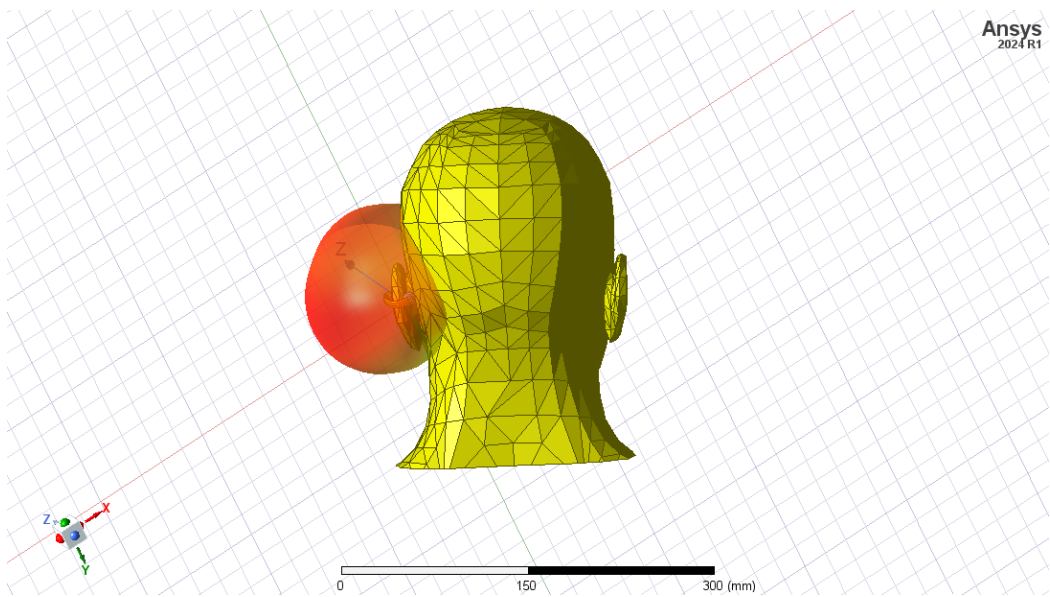


Figure 11 Radiation pattern of upper ear location

The starting impedance of the ILA on the upper ear is given below for a conductive clip (Figure 12) and nonconductive clip (Figure 13). The clip has very little impact on the antenna impedance.

Name	Freq [GHz]	Ang	Mag	RX
m1	2.44	-129.0090	0.9472	0.0333 - 0.4764i

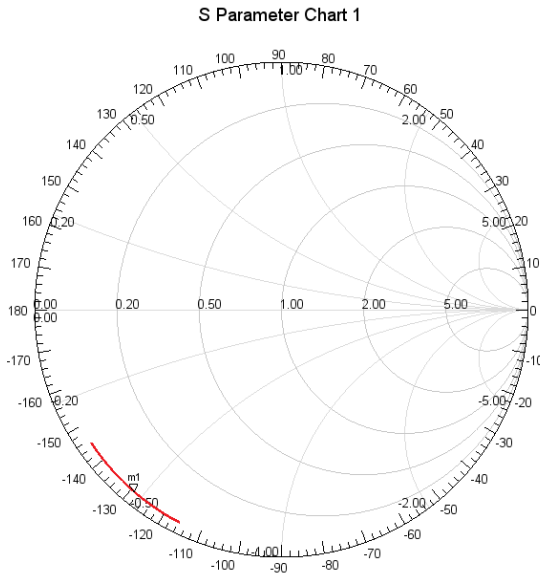


Figure 12 Smith Chart of ILA on upper ear (unmatched) with conductive clip

Name	Freq [GHz]	Ang	Mag	RX
m1	2.44	-129.8796	0.9445	0.0347 - 0.4671i

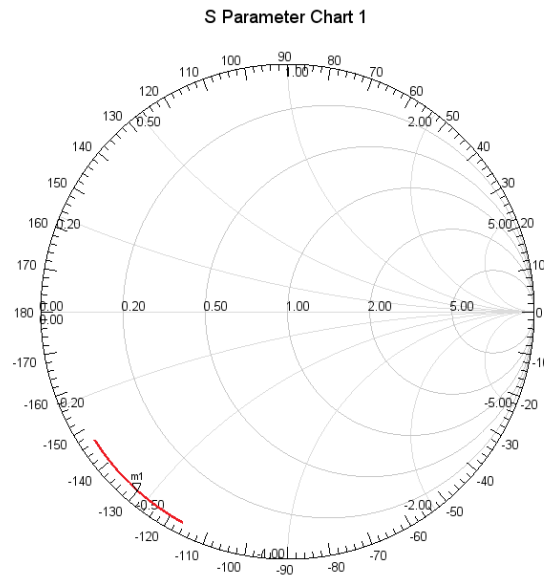
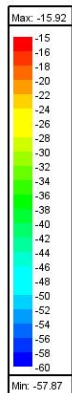


Figure 13 Smith Chart of ILA on upper ear with no conductive clip

Peak gain is -16dBi with non-conductive clip and 15.9dBi with a conductive clip. Radiation efficiency (or average gain expressed in dBi) is -21.2dB (2.2dB better than the lower ear location). Radiation pattern is below. Note, the conductive clip improves the average gain by 0.4dB.

Ansys Inc.



Gain Plot 1

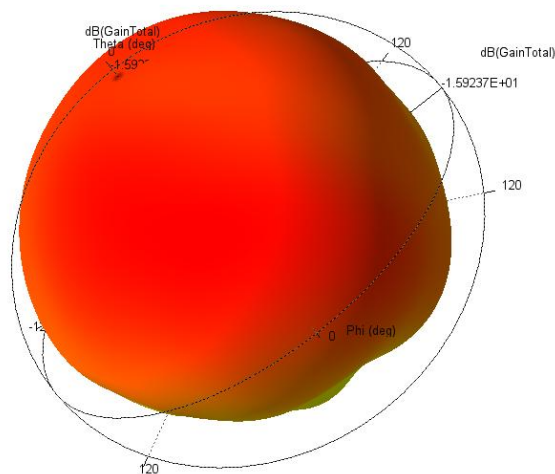
Ansys
2024 R1

Figure 14 Radiation pattern of ILA on upper ear

Impedance Matching

When it comes to multiple battery sizes and various locations on the ear, we need to be sure a single impedance matching network can reasonably match the antenna to 50Ω in all use cases. It was found that the radiation efficiency with the upper ear location is slightly better than the lower ear, thus the impedance matching should be offset to favor the lower ear use case slightly. The battery size had negligible impact on the radiation efficiency, so this is not a key factor. Same goes for the clip around the ear and whether it is conductive or not. It is not a significant factor.

Several impedance matching networks were simulated for each use case and the optimal match was found to be a shunt 1.3nH inductor next to the antenna feed and then a series 1.5pF capacitor between the inductor and the radio. The Ansys simulations give a fairly low starting impedance ($\sim 1.5\Omega$) for the antennas, and I expect this to be slightly higher in the field ($2\text{--}3\Omega$); thus, the impedance matching network should be less severe to start with. For example, the shunt inductor starting value should be 3.3nH and the series capacitor should be $6.8\text{--}22\text{pF}$ (6.8pF gives close to $j0$ reactance at 2.4GHz and 22pF will be slightly inductive). This 3.3nH shunt, 6.8pF impedance match is a better starting point and should lead to much more bandwidth for the antenna vs proximity to 50Ω at the center of the BLE ($2400\text{--}2483\text{MHz}$) frequency band. S11 plots for a common match for each use case are below.

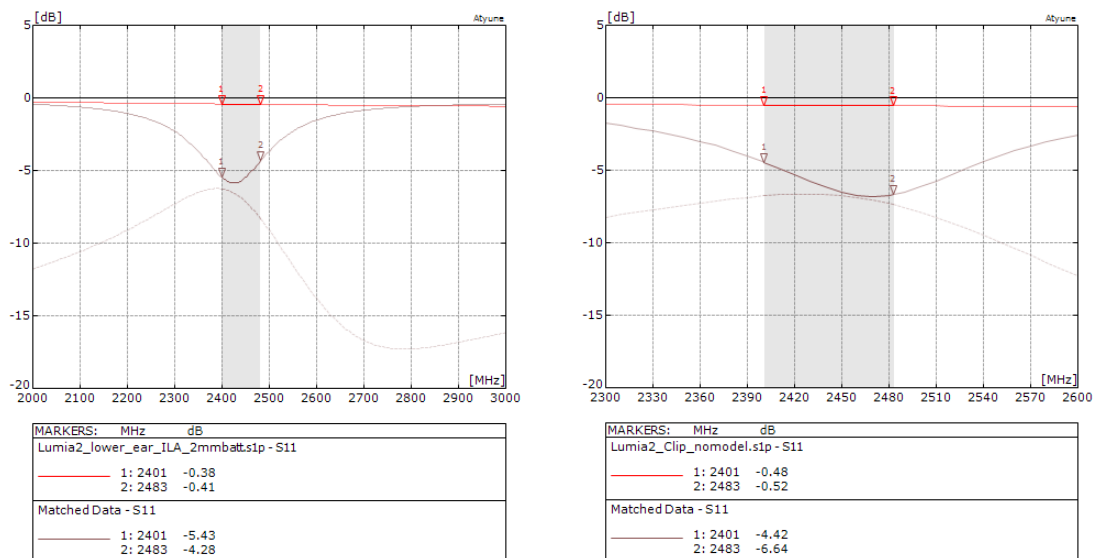


Figure 15 S11 plots of single matching network for lower ear (left) and upper ear (right)

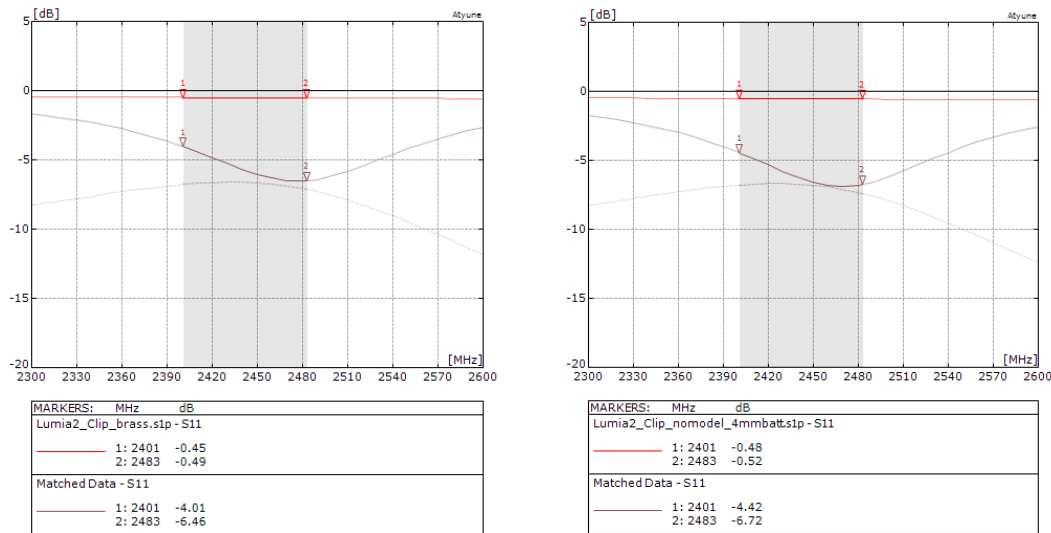


Figure 16 S11 of upper ear location and conductive clip with 2mm battery (left) and no clip and 4mm battery (right)

With all the scenarios, the worst case S11 is -4.01dB, resulting in ~3dB in matching losses including reflections and real losses in the finite Qs of the inductor and capacitor. Considering the proximity of the ear and the different battery sizes and the clip conductivity, this is an acceptable level of performance.

5. Summary

The lower ear use case was modeled in Ansys with a PCB edge plated inverted-L antenna. The simulated average antenna gain (same as radiation efficiency) is -23.4dBi and meets our target of -25dBi or greater.

The upper ear use case was modeled in Ansys with the same inverted-L antenna. The average gain was found to be -20.2 dBi, which meets our target of -25dBi.

The ILA will always require a shunt inductor next to the antenna and a series capacitor to help match it to 50ohm, regardless of battery size, location on the ear and clip conductivity.

A common impedance matching network can be used in both use cases, either a 2mm or 4mm tall battery and with a conductive or non-conductive clip around the ear. A common match is acceptable due to the small variations with antenna impedance across several use cases. The impedance matching network suggested to start with is a shunt 3.3nH inductor next to the antenna feed and a 6.8pF series capacitor between the inductor and the radio. After initial testing with prototypes, we can determine alternate matching networks to use and test. It is important to note that the smaller the shunt inductor is, the higher Q the impedance match will be and hence less bandwidth. Therefore, it is wise to use a value slightly higher than an optimal match in any use case, to ensure all use cases have good field performance.