5220	42.9778	2.65749	-3.667558195
5240	38.7585	2.64007	-4.11633039
5260	42.8974	2.40783	-3.675690295
5280	42.9166	2.74708	-3.673746916
5300	46.3395	2.79165	-3.340486565
5320	45.1299	3.12785	-3.455356288
5340	40.8771	3.11373	-3.885199225
5360	39.9357	2.85483	-3.986386988
5380	37.5907	2.79679	-4.249195869
5400	37.5421	2.46658	-4.254814378
5420	35.311	2.5401	-4.520899831
5440	35.171	1.96765	-4.538152834
5460	32.8472	1.87138	-4.835016452
5480	32.9131	1.83684	-4.826312107
5500	32.2432	1.72203	-4.915618629

Frequency	*Efficiency [%]*	*Peak Gain [dBi]*	*Efficiency [dB]*
5520	35.6435	2.06189	-4.480196572
5540	36.6793	2.54909	-4.355789611
5560	36.799	2.58147	-4.34163983
5580	34.465	2.37219	-4.626217172
5600	39.8009	2.33702	-4.001071073
5620	39.4107	2.55674	-4.043858513
5640	44.478	2.21478	-3.518547495
5660	37.6123	2.21449	-4.246701086
5680	36.1674	1.38851	-4.416827107
5700	38.7232	1.16338	-4.120287607
5720	40.7951	1.12045	-3.89391998

5740	41.4829	1.51934	-3.821308904
5760	38.6359	1.43073	-4.130089667
5780	37.7821	1.07573	-4.227139068
5800	39.2644	0.987563	-4.060010346
5820	41.9328	1.37659	-3.774461373
5840	39.5542	1.31506	-4.028073948
5860	36.8916	1.17386	-4.330725089
5880	33.2982	0.859185	-4.775792425
5900	37.4132	0.878981	-4.269751444
5920	32.5703	0.833726	-4.871782412
5940	35.106	0.943249	-4.546186515
5960	26.5326	0.822329	-5.762201903
5980	28.4592	0.523727	-5.457773123
6000	25.3768	-0.0301562	-5.955631431

Table 3, shows the antenna characteristics at 2.4GHz Port2.

Frequency	*Efficiency [%]*	*Peak Gain [dBi]*	*Efficiency [dB]*
2400	21.1028	-1.89108	-6.75659917
2402	21.3087	-1.80817	-6.714430449
2405	21.7024	-1.69444	-6.634922362
2410	22.4627	-1.45679	-6.485380431
2415	23.5272	-1.19069	-6.284297557
2420	24.8961	-0.888635	-6.038686803
2425	25.9135	-0.666713	-5.864739252
2430	27.6513	-0.402833	-5.582844459
2435	28.4421	-0.248257	-5.46038341
2440	28.5963	-0.23351	-5.436901555

2441	28.5986	-0.227997	-5.436552266
2445	28.7881	-0.204437	-5.407869974
2450	29.3659	-0.121561	-5.321566845
2455	29.2183	-0.157746	-5.343450561
2460	27.5568	-0.414925	-5.597712158
2462	27.0979	-0.492359	-5.670643642
2465	26.7341	-0.551822	-5.729344318
2470	26.3391	-0.630419	-5.793990688
2475	25.698	-0.753767	-5.901006752
2480	24.835	-0.946181	-6.049358357
2485	23.9479	-1.1618	-6.20732564
2490	23.2426	-1.4048	-6.337152918
2495	22.1956	-1.64151	-6.537331105
2500	21.0521	-1.89443	-6.767045757

Table 4, shows the antenna characteristics at 5.0 GHz Port2.

Frequency	*Efficiency [%]*	*Peak Gain [dBi]*	*Efficiency [dB]*
5000	23.5836	-0.17684	-6.273898998
5020	23.6796	-0.31456	-6.256256381
5040	23.7653	-0.36889	-6.24056699
5060	21.0665	-0.996538	-6.764076123
5080	22.1685	-0.75534	-6.542636918
5100	20.9405	-1.01789	-6.790129528
5120	18.7256	-1.55726	-7.275642579
5140	19.0831	-1.54082	-7.193510739
5160	15.7731	-2.47744	-8.020829433
5180	15.1675	-2.51046	-8.190859964
5200	15.1593	-2.40838	-8.193208523

5220	15.8465	-2.18235	-8.00066645
5240	14.8351	-2.47791	-8.287095219
5260	10.4908	-3.90085	-9.791913924
5280	10.5213	-3.87852	-9.779305959
5300	9.32124	-4.39817	-10.3052631
5320	9.25034	-4.39608	-10.33842304
5340	10.1951	-3.96432	-9.9160851
5360	9.46703	-4.35576	-10.23786247
5380	8.34686	-4.93074	-10.78476871
5400	8.25203	-4.94226	-10.83439202
5420	8.40578	-4.87074	-10.75421981
5440	7.38538	-5.4468	-11.31627154
5460	6.88547	-5.72962	-11.6206641
5480	7.70186	-5.2357	-11.1340438
5500	7.58494	-5.33187	-11.2004785

Frequency	*Efficiency [%]*	*Peak Gain [dBi]*	*Efficiency [dB]*
5520	5.28297	-6.87373	-12.77121856
5540	4.99305	-7.14983	-13.01634085
5560	4.37391	-7.74184	-13.59130157
5580	4.4359	-7.6136	-13.53018253
5600	4.56636	-7.43681	-13.40429853
5620	3.88976	-8.07857	-14.10077194
5640	3.4333	-8.46753	-14.64288246
5660	3.80995	-7.95556	-14.19080724
5680	4.15599	-7.53256	-13.81325506
5700	3.72578	-8.02531	-14.28782793
5720	3.66984	-8.19226	-14.3535287
5740	4.16887	-7.77312	-13.79981647

5760	4.37975	-7.67156	-13.58550679
5780	3.7793	-8.38766	-14.22588633
5800	3.5785	-8.57833	-14.46298978
5820	3.72268	-8.33668	-14.29144294
5840	3.48566	-8.47604	-14.57714977
5860	3.29555	-8.539	-14.82072095
5880	3.80267	-7.78316	-14.19911362
5900	4.19115	-7.28536	-13.77666796
5920	3.84667	-7.58857	-14.1491507
5940	3.69051	-7.70342	-14.32913614
5960	4.1757	-7.00503	-13.7927071
5980	4.15007	-6.92997	-13.81944578
6000	3.48811	-7.58551	-14.57409828

5.7 Radiattion Patterns

5.7.1 Reference coordinate system

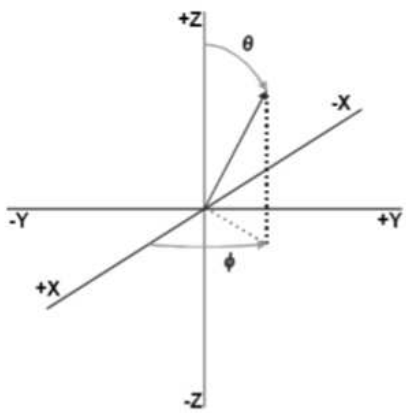


Figure 23. Reference coordinate system

X-axis: Theta =+90° / Phi=0°
Y axis: Theta=+90 and Phi =+90
Z axis: Theta=0

5.7.2 EUT Orientation

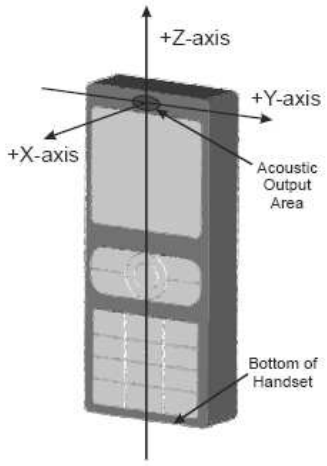


Figure 24. OUT orientation

5.7.3 3D Radiation Patterns

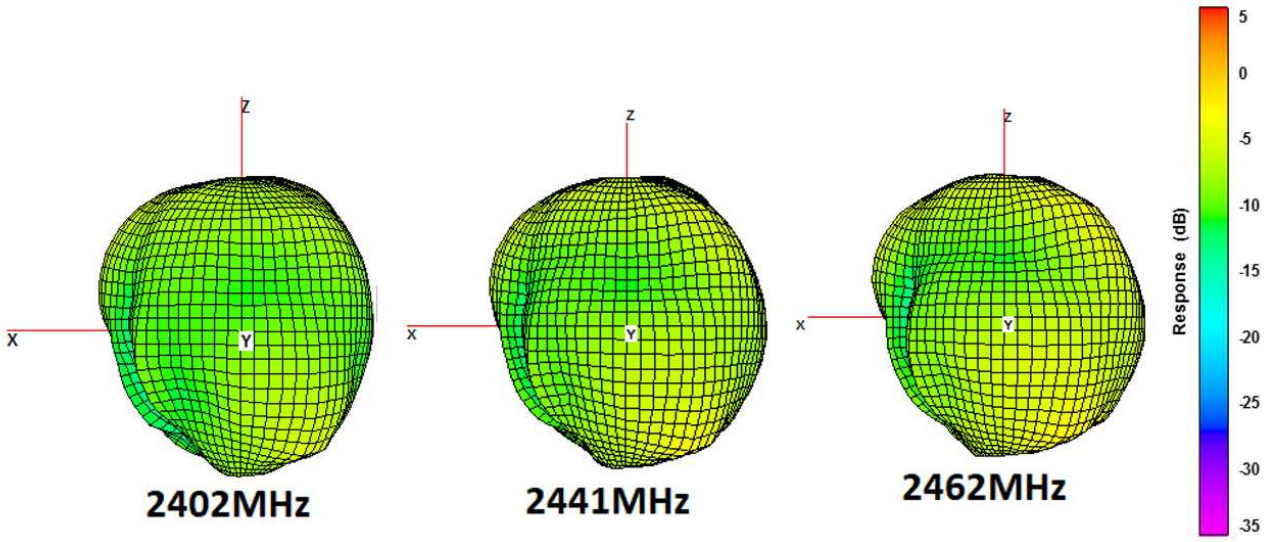


Figure 25. *3D radiation patterns at 2.4GHz Port1.*

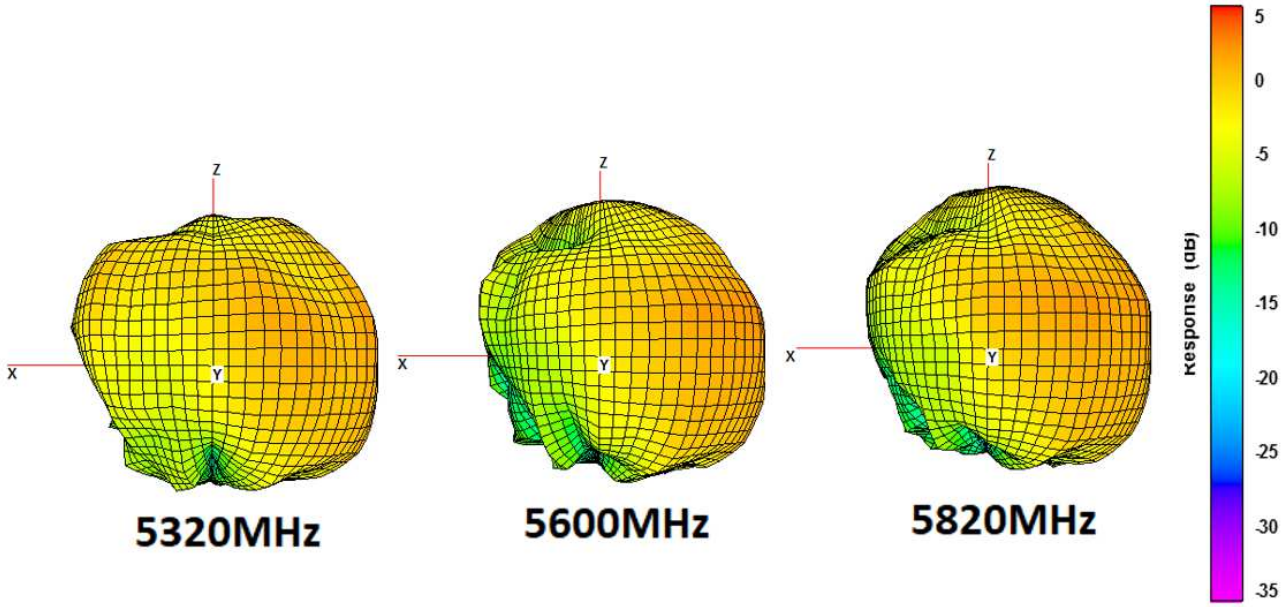


Figure 26. *3D radiation patterns at 5.0GHz Port1.*

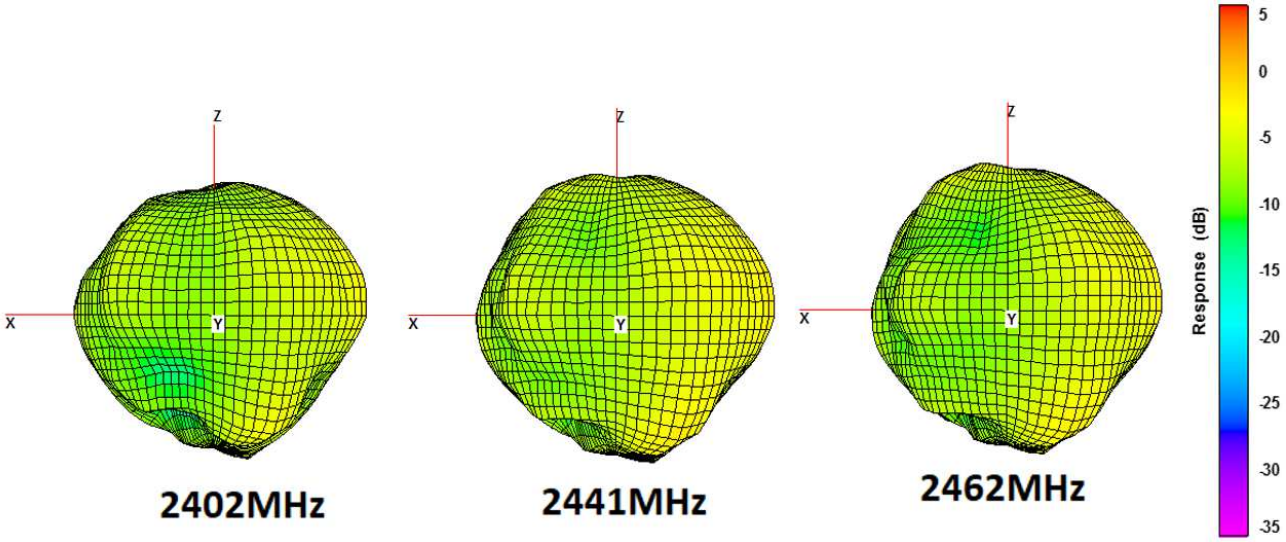


Figure 27. *3D radiation patterns at 2.4GHz Port2.*

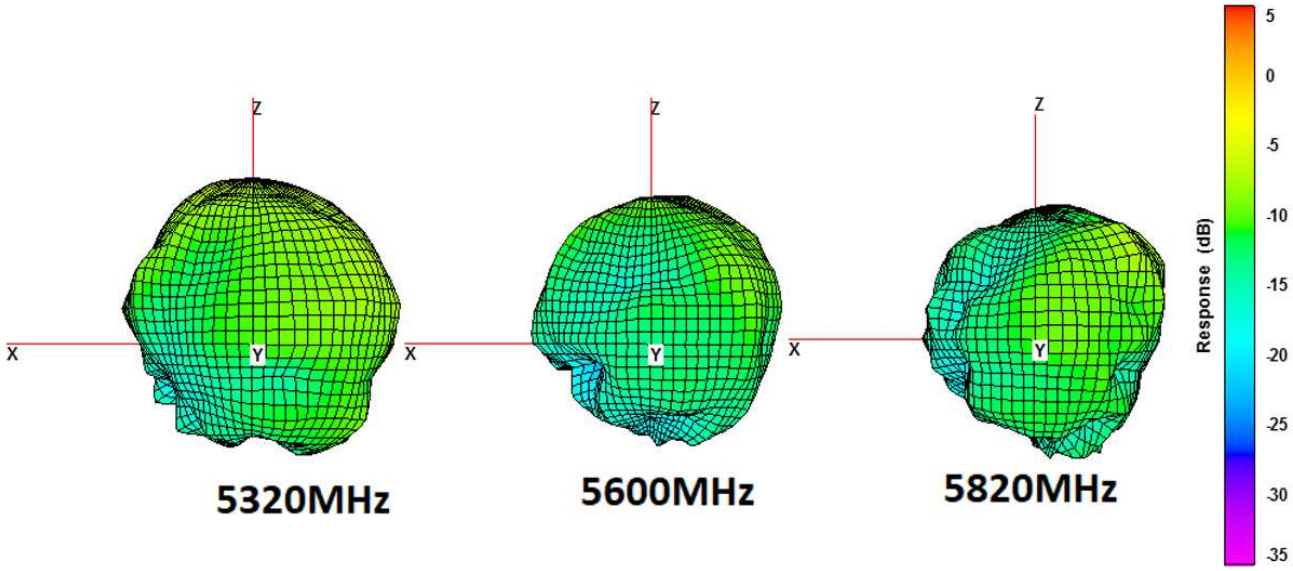


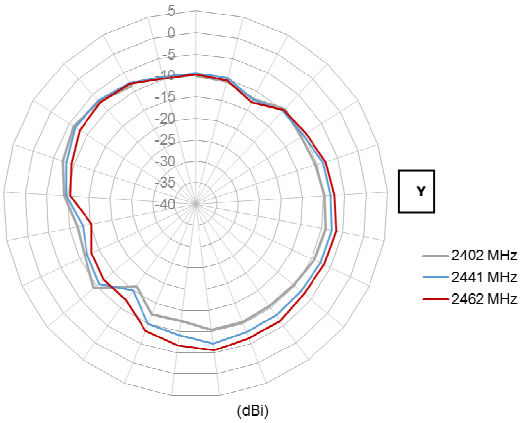
Figure 28. *3D radiation patterns at 5.0GHz Port2.*

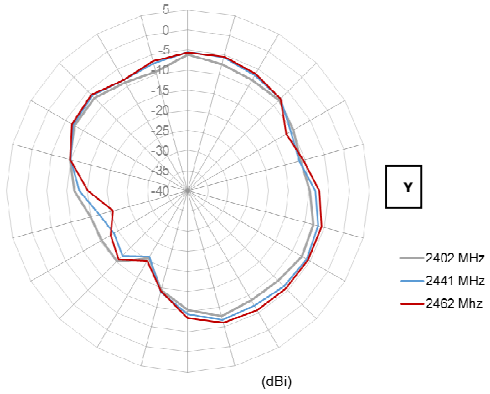
5.7.4 2D Radiation Patterns

Figure 29, 30, 31 and 32 shows the 2D radiation patterns of the antenna at three different frequencies.

x

z





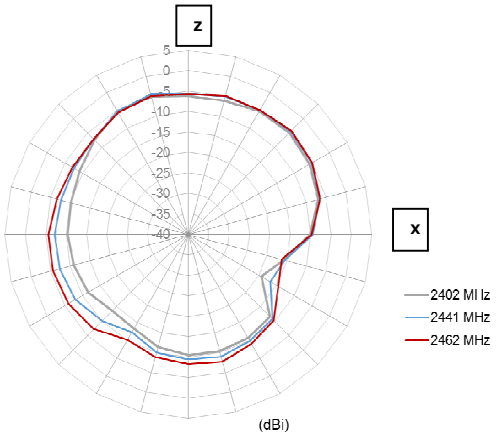


Figure 29. *2D radiation patterns WLAN at 2.4GHz Port 1.*

x

z

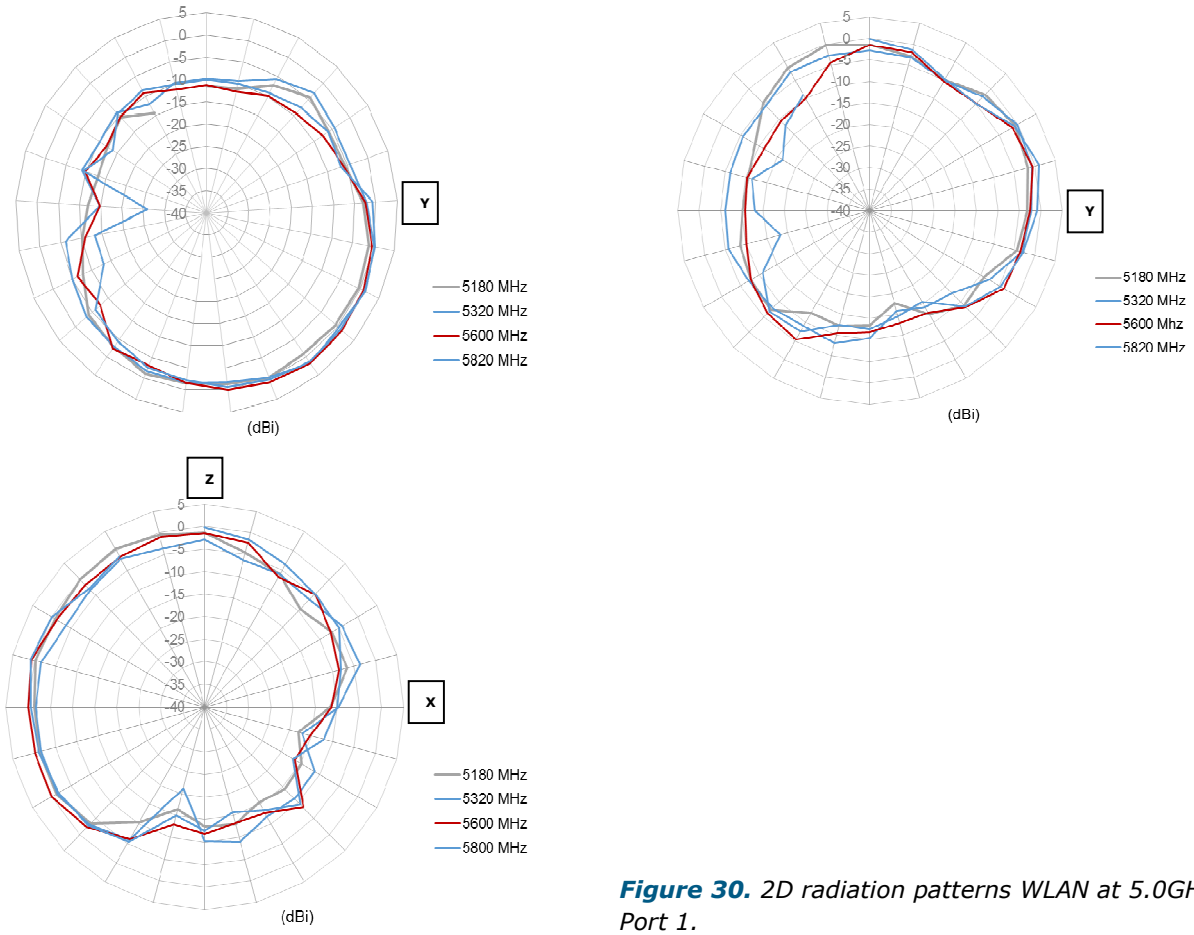
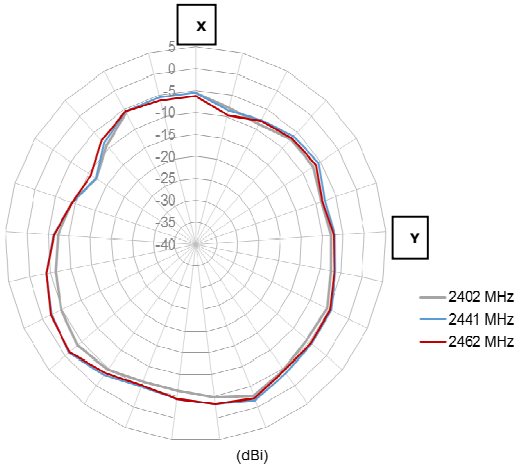
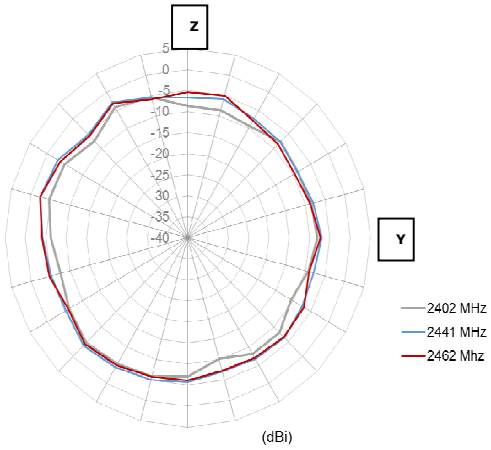


Figure 30. *2D radiation patterns WLAN at 5.0GHz Port 1.*





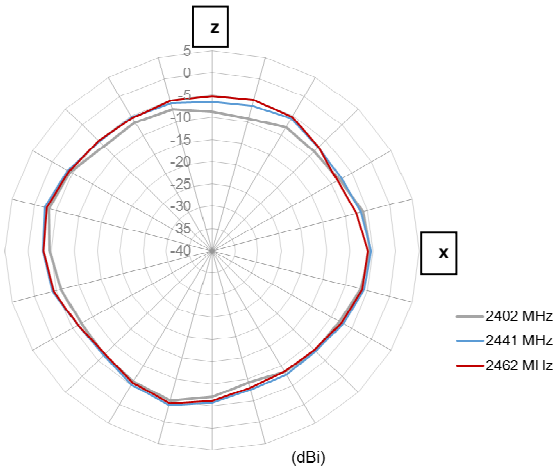
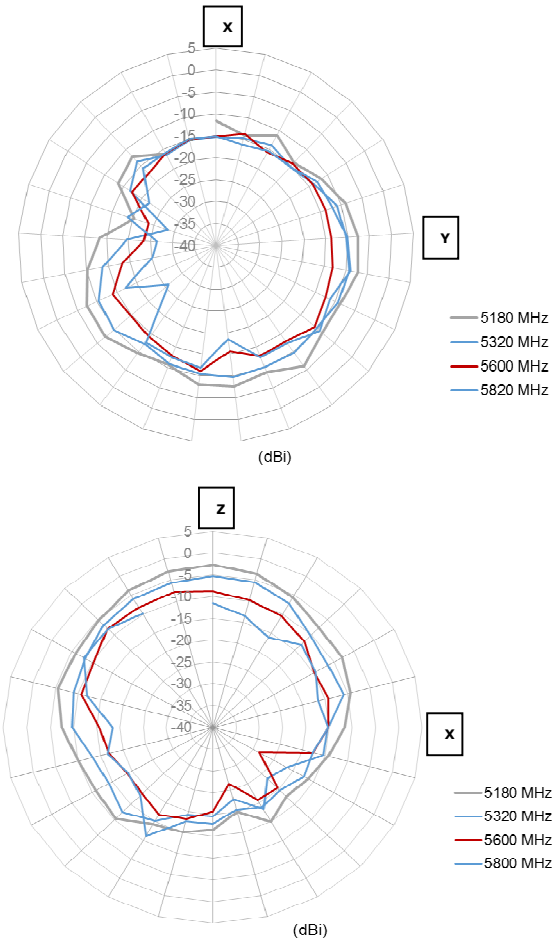


Figure 31. *2D radiation patterns WLAN at 2.4GHz Port 2.*



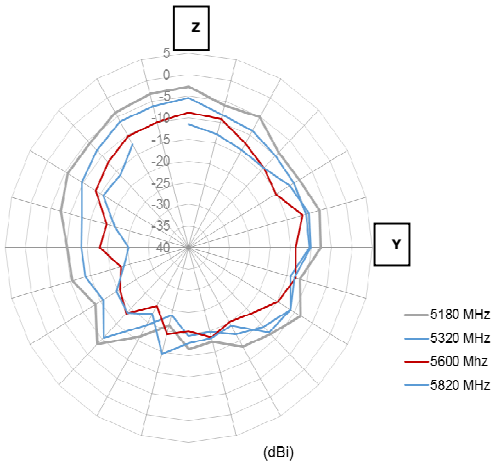


Figure 32. *2D radiation patterns WLAN at 5.0GHz Port 2.*

6 Conclusions

This report presents the antenna characterization of the Harman internal antenna.

Anex A

Basic Definitions of the antenna parameters

A.1 Antenna Impedance and Bandwidth

The antenna is essentially a transducer between the characteristic impedance of the radio system (nominally 50 ohms) and the impedance of free space. As such, the antenna impedance and the radio frequencies over which that impedance is maintained are critical. It is essential that the antenna present an acceptable impedance match over the frequency band(s) of operation.

Antenna impedance and the quality of the impedance match are most commonly characterized by either Return Loss (represented by the scattering parameter S_{11}) or Voltage Standing Wave Ratio (VSWR); these two parameters are simply different formats of exactly the same impedance data. The Return Loss, is typically measured on a logarithmic (dB) scale, while the VSWR is a unit-less ratio.

These impedance parameters measure how much of the power supplied to the antenna reflects back from the antenna terminals. Ideally, but impossible to achieve if the antenna is perfectly matched to the system, all of the power supplied to the antenna will be radiated with no reflection.

It is important to note that the return loss measured at the antenna terminals is relevant for both receive and transmit operation. In transmit mode, compromised S_{11} will reflect power back into the final output amplifier, while in receive mode the power is reflected back into the antenna.

Table A.1. *Return Loss (S11) and VSWR Relationship*

S11 (dB)	VSWR	Reflection Loss (dB)	Comment
-6.0	3:1	1.2	Marginal
-9.5	2:1	0.5	Acceptable (and typical Antenna Specification)
-15.0	1.4:1	0.15	Good

Some shifting of the frequency response will also occur during normal use when the device is near other objects, a secondary or temporary enclosure, the user's hand or head and so forth. Therefore, excess bandwidth should be designed in from the beginning of the product design.

The bandwidth of an antenna over which the return loss is acceptable is directly proportional to the volume the antenna occupies, so very small antennas can produce inadequate bandwidth, especially in the 700 MHz band where the effective volume is smallest relative to the frequency of operation.

A.2 Efficiency

The antenna efficiency is arguably the most important performance parameter, assuming the antenna produces an acceptable return loss and Peak Gain over the band of interest.

Efficiency is simply a measure of what portion of the power supplied to the antenna, including any reflection loss, is actually radiated by the antenna.

The efficiency of small antennas that are tightly integrated into a small product can be affected substantially. Nearby grounded conductors and dielectric materials (like a typical plastic housing) will constrain and absorb the near-fields of the antenna and cause significant losses. below illustrates the efficiency concept.

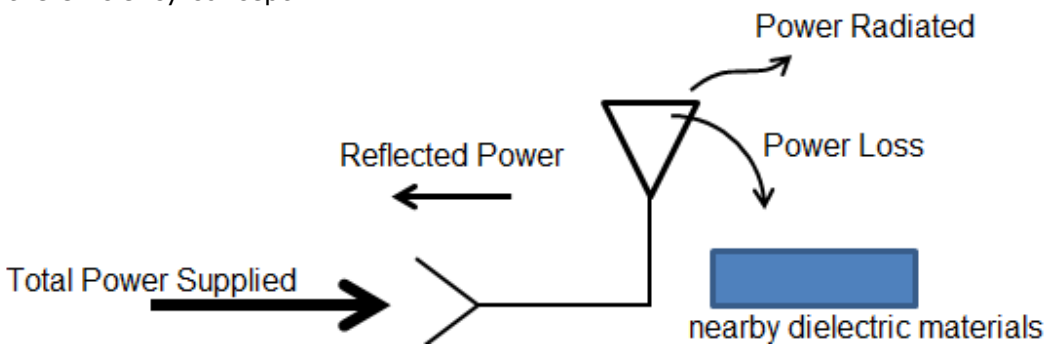


Figure A.1. *Efficiency Concept*

Common plastic materials, like polycarbonate or ABS (Acrylonitrile Butadiene Styrene), can become significant absorbers of RF energy when very close to an antenna. Energy loss will occur during both receive and transmit operation.

The efficiency of a typical embedded antenna can range from about 40 to 75%. Greater than 75% efficiency is challenging to obtain from a fully embedded antenna and lower than 40% efficiency will typically cause certification failures but this depends on the TRP(Total Radiated Power) and TIS(Total Isotropic Sensitivity) limits from the network provider. In most cases, the efficiency goal should be 60%, with 40% as an absolute minimum.

It is important to understand that good return-loss performance can be inadvertently achieved at the expense of efficiency. An extreme example of this concept is a 50 ohm resistor: the resistor has an excellent return loss but has virtually 0% efficiency, and is obviously not an antenna. Therefore, an understanding of the return loss and efficiency concepts is critical to good antenna design.

A.3 Average Gain

Efficiency is typically expressed as a percentage, but it is helpful to translate efficiency into the same logarithmic scale used in other antenna performance parameters, when the antenna efficiency is represented in logarithmic scale is named Average Gain. Next table shows the relationship between the Antenna Efficiency in % and the Average Gain in dB

Table A.2. *Efficiency (%) and Average Gain (dB) Relationship*

Efficiency (%)	Average Gain (dB)
90	-0.5
75	-1.2
50	-3.0
25	-6.0

As shown in the table above, antenna efficiency in percentage can be converted to a dB scale (Average Gain) by a 10 log (%) function.

A.4 Peak Gain

Peak Gain is the maximum energy radiated by the antenna in one direction. The peak Gain is usually referred to an isotropic antenna and with the designation dBi.

A.5 Radiation Patterns

An antenna is a physical device that radiates energy, almost always with some directional dependence. An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius

An isotropic radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions".

A directional antenna is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others".
The omnidirectional antenna has a no directional pattern in a given plane and a directional pattern in any orthogonal plane." An omnidirectional patterns then special type of a directional pattern".

Anex B

Anechoic ("No echo") chambers

A radio frequency "anechoic chamber" is a shielded room whose walls have been covered with a material that scatters or absorbs so much of the incident energy that it can simulate free space. Electromagnetic wave measurements involving very low signal levels are commonly performed in laboratory facilities that provide high isolation from external electromagnetic environment. Shielded enclosures with isolation performance in excess of 100 dB prevent extraneous energy from masking measurements of the intended signals. However, electromagnetic wave generally propagates in all directions and waves reflected by the walls, ceiling, and floor of the shielded enclosure will give rise to a complex wave front at the test region where the test antenna is to be placed. As it is desirable to provide an environment for electromagnetic energy to propagate between the test antenna and the device-under-test (DUT) in a simple and well defined manner, waves propagating towards the walls, ceiling, and floor of the enclosure must be absorbed using a suitable absorbing material. A shielded enclosure with the entire inner surfaces covered with wave absorber to create a non-reflecting environment equivalent to free space is known as Anechoic Chamber.

B.1 Kinds of anechoic chambers

B.1.1 Tapered Anechoic Chamber

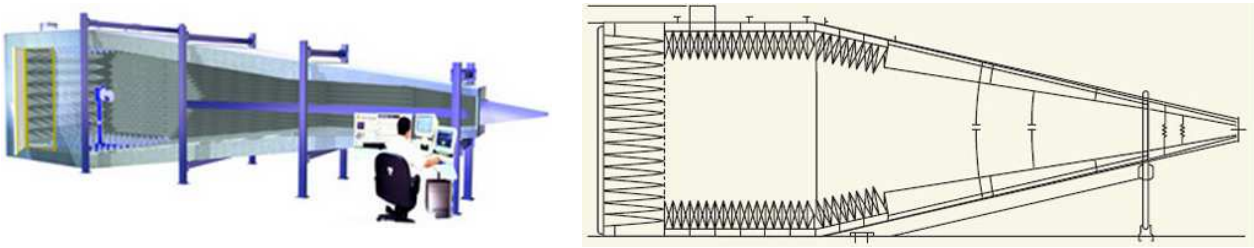


Figure B.1. *Tapered Anechoic Chamber*

- The tapered chamber actually uses the reflections off the walls to its advantage. It was found that suppression of reflections for low frequency broad-beamed antennas was almost impossible.

- Tapering one end of the chamber would cause the chamber to act like an indoor ground reflection range. The reflections off of the chamber walls actually add together to form an

almost uniform plane wave at the test region. The shape of this chamber and the wave front emanating from it is reminiscent of horn antenna.

- The cost of a tapered chamber is usually less than a rectangular chamber.

- The tapered chambers are used mostly for low frequencies in the VHF(30-300 MHz) / UHF(300 MHz a 3 GHz) range.

B.1.2 Near Field Anechoic Chamber

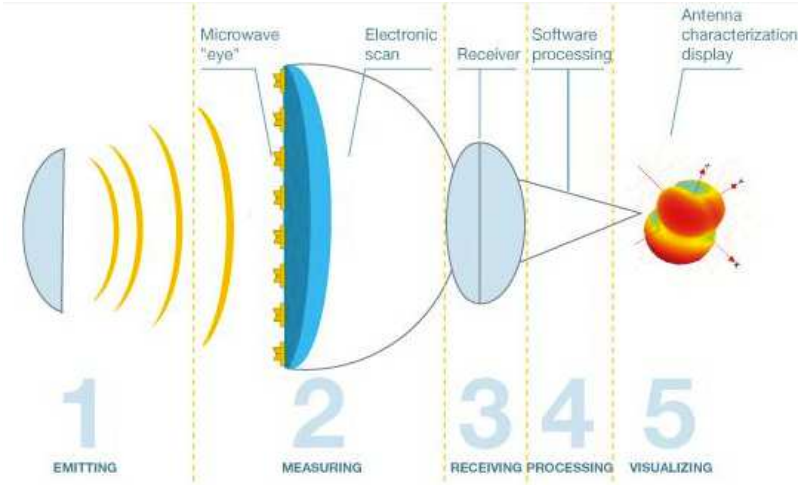


Figure B.2. *Near Field Anechoic Chamber*

- The test antenna is measured in the near-field and a near-field to far-field transform is used to obtain the far-field pattern.

- The disadvantage of this method is that points in different planes are needed to get an accurate far-field calculation.

- Other disadvantage is that this method is very math intensive and requires more equipment to get a complete scan of the antenna.

B.1.3 Rectangular Chamber

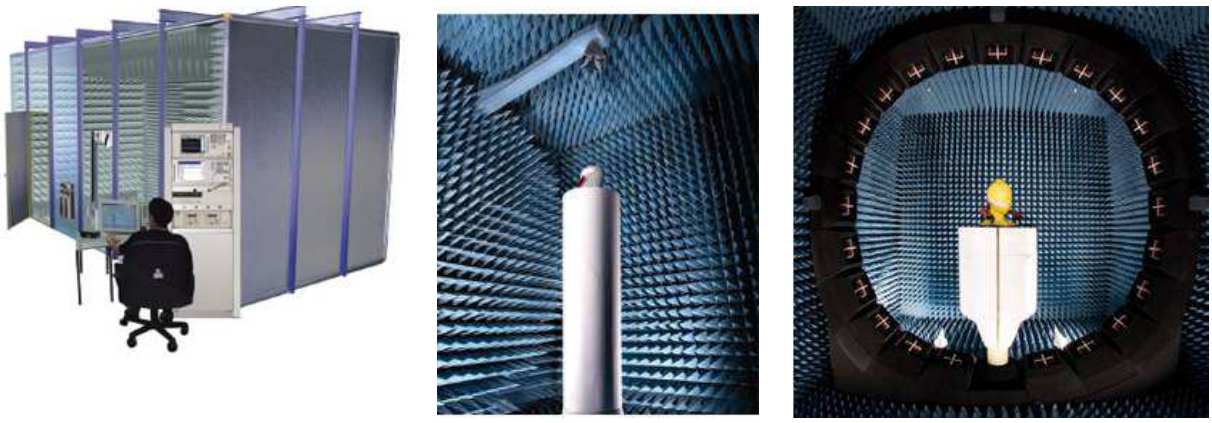


Figure B.3. *Rectangular Anechoic Chamber*

- Most common type of chamber because they are easy to build and easier to design than other types of chambers.
- These chambers range in size depending on what the operating frequency is and also on what is being tested. The major specification is that the chamber must be long enough so that the antennas under test are in the far-field.
- The chamber to be deep enough so that we don't get a skipping effect of the electromagnetic wave off the floor of the chamber.

B.2 Chamber coordinate systems

The chambers utilize the spherical measurement system, and can be distributed or combined. Each of the two referenced chamber setups have different coordinate system orientations This is due to the difference in implementation of the chamber axes. However, the EUT coordinate systems will apply independent of the physical orientations of the EUT inside the chamber. Figure B.4 shows the typical setup using a combined axis system. In addition to the pictured Theta axis rotation, the EUT will have to be rotated about the Z-axis (Phi rotation) in order to perform the full spherical scans. Figure B.5 shows the typical setup using the distributed axis system. In this configuration, the Phi and Theta angles are traversed separately by the distributed positioners in the chamber.

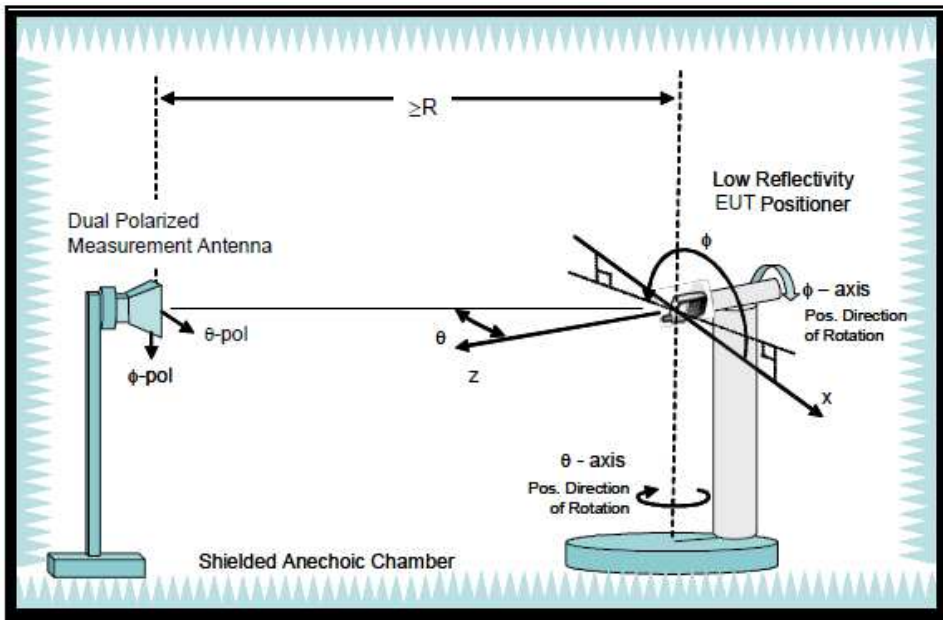


Figure B.4. *Shows the typical setup using a combined axis system. In addition to the pictured Theta axis rotation, the EUT will have to be rotated about the Z-axis (Phi rotation) in order to perform the full spherical scans.*

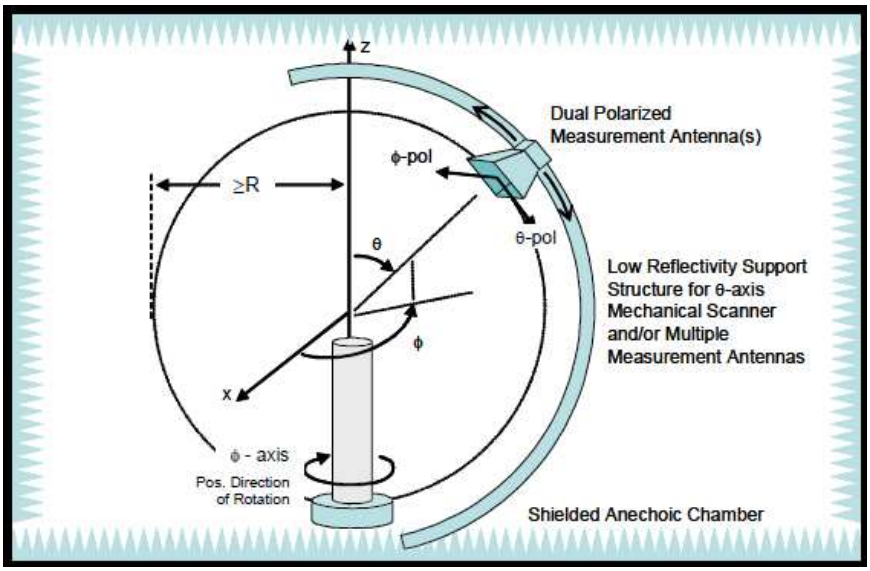


Figure B.5. *Shows the typical setup using the distributed axis system. In this configuration, the Phi and Theta angles are traversed separately by the distributed positioners in the chamber.*

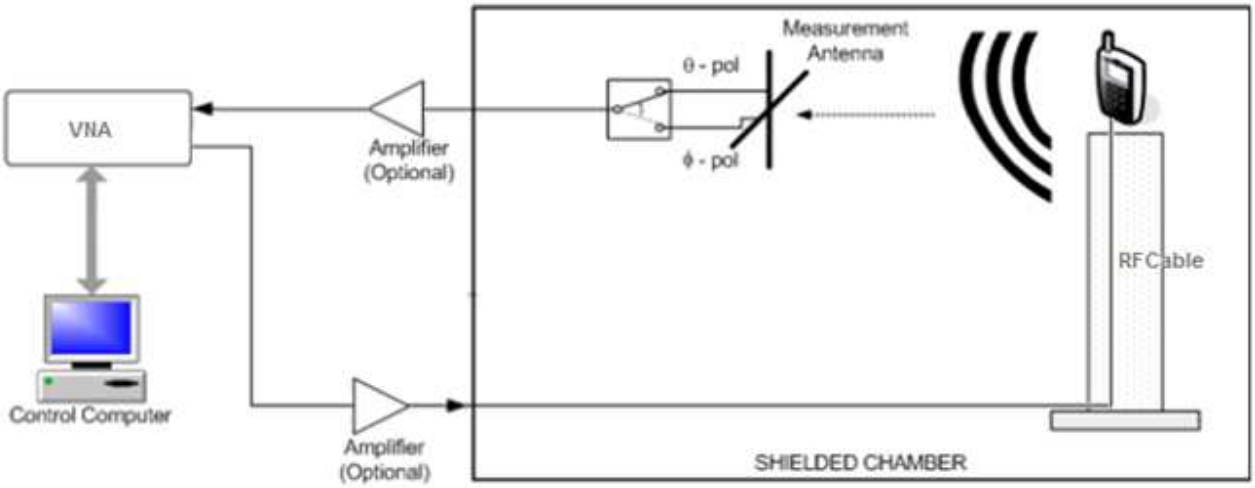


Figure B.6. *Simplified block diagram showing the common configuration for the passive antenna measurement*

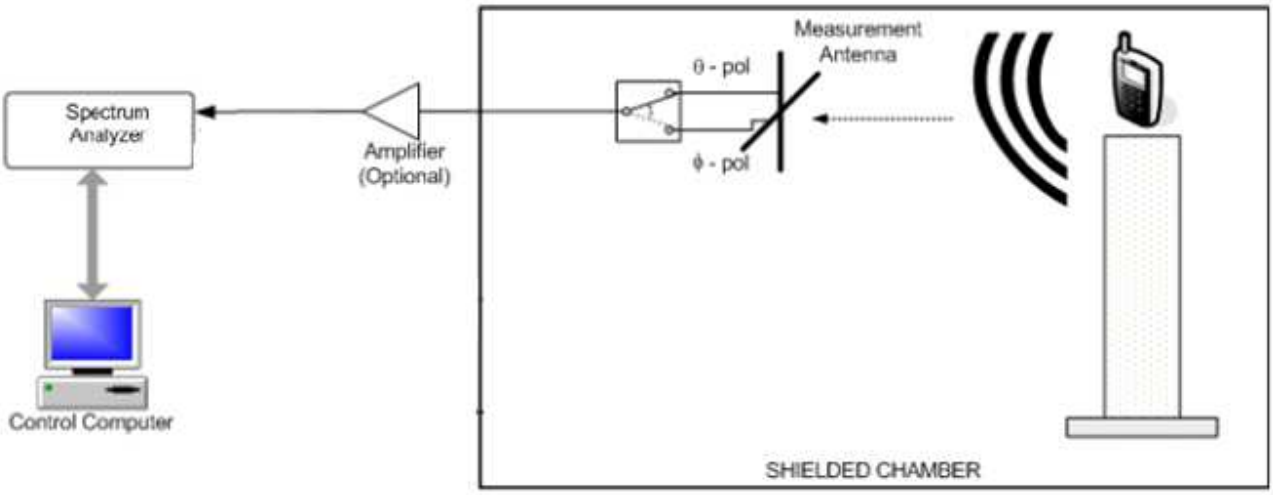


Figure B.7. *Simplified block diagram showing the common configuration for the TRP, in TX power mode antenna measurement*

End of Report