1. OTA PASSIVE ANTENNA TEST REPORT

Date of Report	14/06/2024	**Client's Contact person:**	Jouni Lifländer
Number of pages:	30	**Responsible Test engineer:**	Veli-Matti Niemitalo
Testing laboratory:	**Verkotan Oy** Elektroniikkatie 17 90590 Oulu Finland	**Client:**	Haltian Oy Yrttipellontie 1 D3 90230 Oulu Finland
Tested devices	ADY1		
Testing has been carried out in accordance with:	Passive measurements per customer request		
Documentation:	The test report must always be reproduced in full; reproduction of an excerpt only is subject to written approval of the testing laboratory.		
Test Results:	The test results relate only to devices specified in this document		

Date and signatures:

Jani Kallankari
Chief scientific **14.6.2024**

Document ID: Passive_OTA_test_report_ID5993_ADY1_14062024

2. SUMMARY

2.1 Test Details

Devices under Test (DUT):

Product:	ADY1
Description:	Machine mounted device that enables remote monitoring of the machine. During machine operation, device collects and transmits operating and location information
Note:	Device tested in free space and on metal surface. In cellular antenna measurement setup, device azimuth was rotated 180 degrees.
Manufacturer info:	Sandvik Mining and Construction Oy Taivalkatu 8 P.O.Box 165 15101 Finland
HW Info:	ADY_04, APP_02
SW Info:	2023.11.02.1_ardy_v2
DUT number:	21231
Tested Frequencies [MHz]	Cellular: 640-1000 MHz, 1680-2200 MHz, 2300-2700 MHz GNSS: 1560-1606 MHz BLE: 2400-2485 MHz

Testing information:

Testing performed:	08.01.2024 - 10.01.2024
Notes:	-
Document name:	Passive_OTA_test_report_ID5993_ADY1_14062024
Temperature °C / Humidity RH%	22±2 / 25%±10%
Measurement performed by:	Veli-Matti Niemitalo
Document history:	-

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3. TEST EQUIPMENT

Main used test equipment is listed below. For full equipment list and calibration intervals, please contact the testing laboratory.

Type of Equipment	Type	Manufacturer	Calibration date	Calibration period	Calibration due	Purpose
Diagonal Dual Polarized Horn Measurement Antenna	114960	ETS	Included in range calibration	Included in range calibration	Included in range calibration	Probe antenna
Positioning Controller	2090	EMCO	n/a	n/a	n/a	DUT alignment
3D Positioner	Custom made	ETS-Lindgren	n/a	n/a	n/a	DUT alignment
Anechoic Chamber	4	ETS-Lindgren	23.09.2023	1 year	23.09.2024	Test range
Switching System	MSN-6TD-06-DEC-SP	American Microwave	Included in range calibration	Included in range calibration	Included in range calibration	Probe selection
Switching System	SW6AD-A61	Pulsar	Included in range calibration	Included in range calibration	Included in range calibration	Probe selection
Network Analyzer	E5071C	Agilent	23.05.2023	1 year	23.05.2024	Measurement transmitter / receiver
Dual-Ridge Horn Antenna	SH600	MVG	20.08.2020	n/a	n/a	Calibration antenna 1-9 GHz

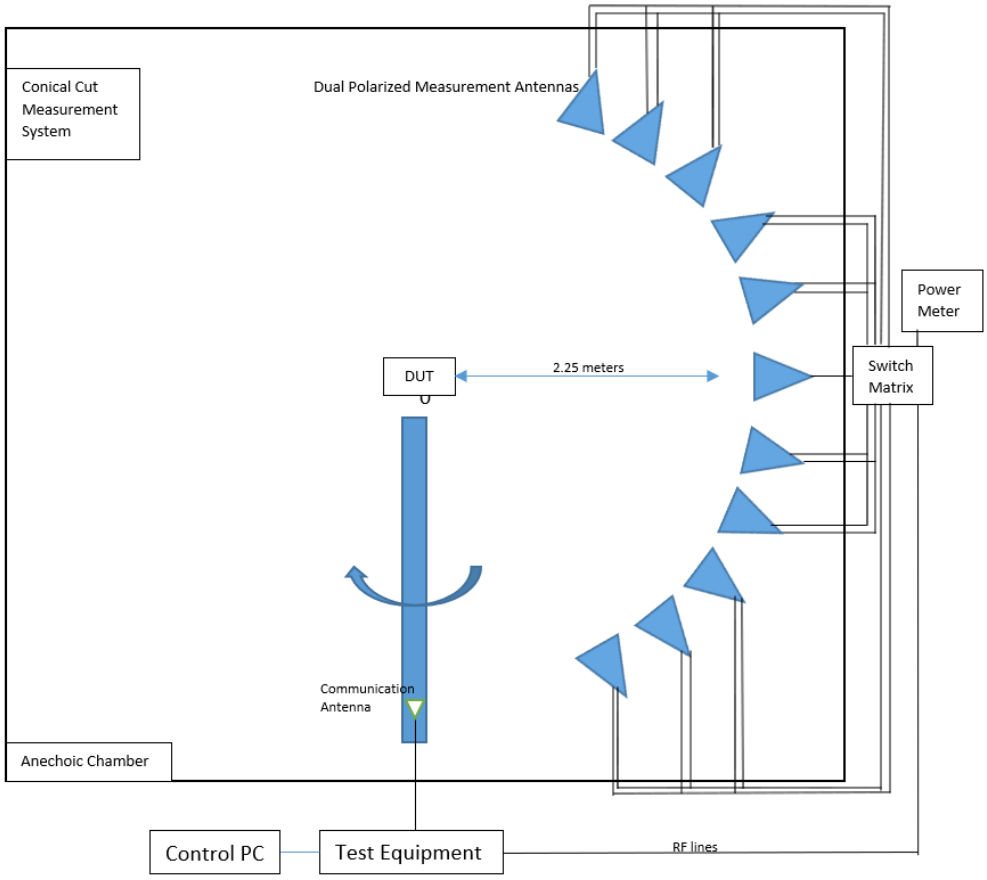

Figure 1. Laboratory 4 chamber schematic.

4. TEST SETUP

4.1 Free Space

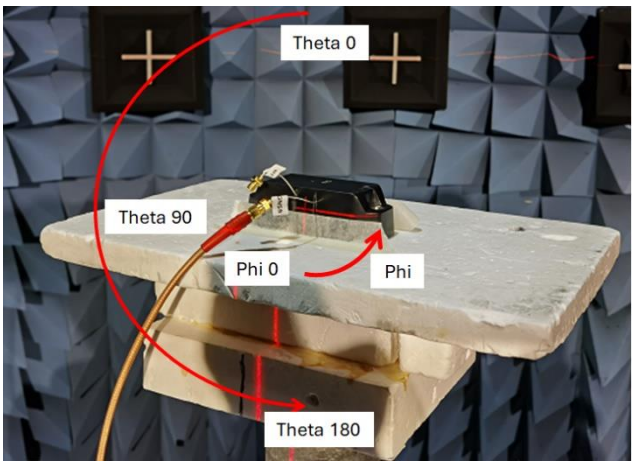

Figure 2 DUT in free space passive measurement and coordinate system; GNSS measurement

Vertical laser in DUT setup position denotes phi=0, horizontal laser denotes theta=90. Theta 0 is directly up from DUT, and theta 180 is down from DUT.

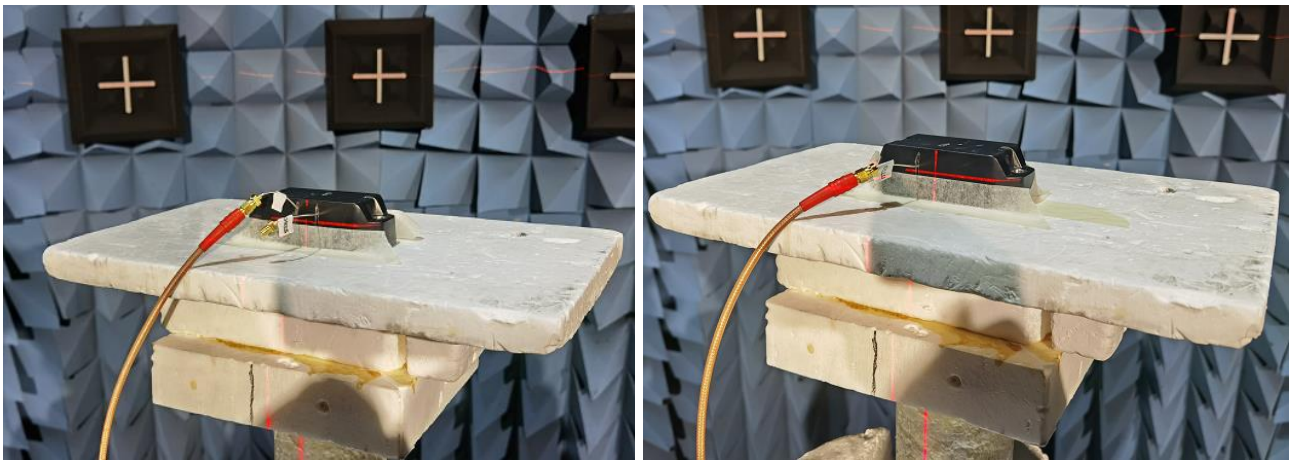

Figure 3 DUT in free space passive measurement, BLE and Cellular measurements, device rotated 180 degrees for cellular antenna measurement

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4.2 Metal surface

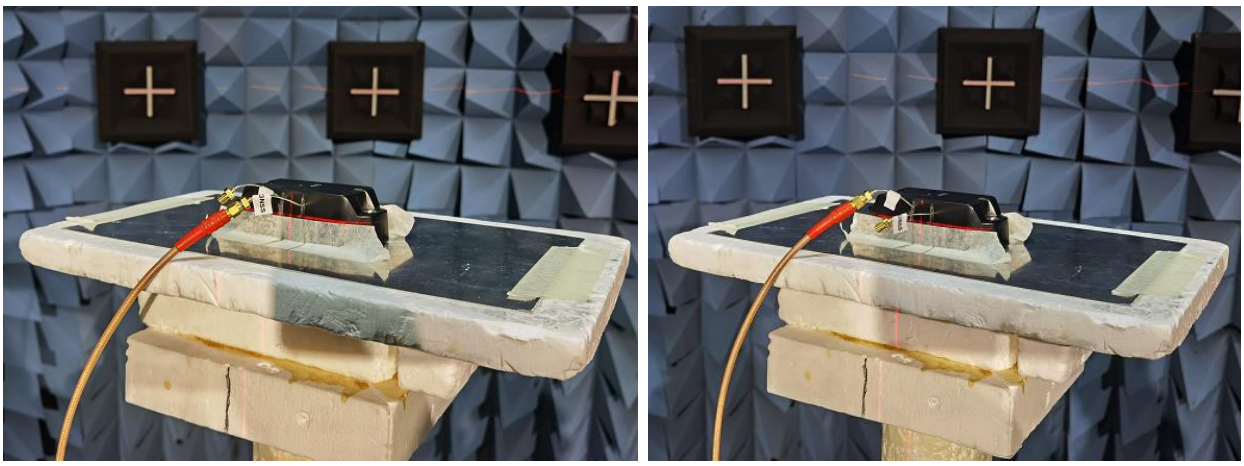


Figure 4 DUT on metal surface passive measurement, GNSS and BLE measurements

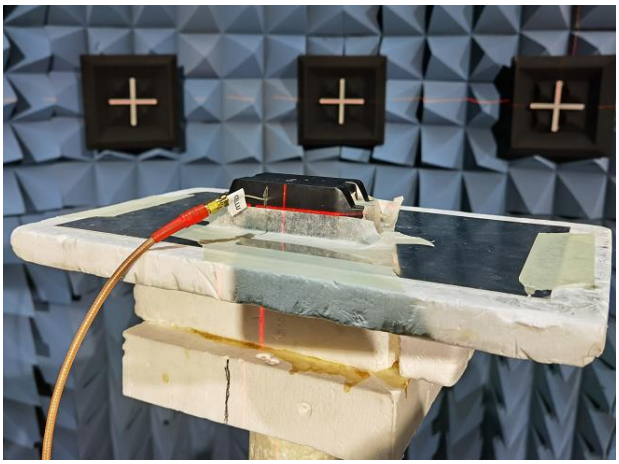


Figure 5 DUT on metal surface passive measurement, device rotated 180 degrees for cellular antenna measurement

5. RESULTS

5.1 Passive OTA measurements

5.1.1 Maximum gain and efficiency, free space

Cellular 640-1000 MHz		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
640	-9.3	-16.4
660	-7.1	-14.8
680	-5.8	-13.6
700	-5.2	-12.2
720	-5.7	-12.7
740	-6.0	-12.8
760	-7.4	-13.6
780	-7.6	-14.0
800	-8.4	-14.6
820	-8.9	-14.7
840	-9.5	-15.1
860	-10.3	-15.8
880	-12.3	-16.7
900	-13.7	-17.9
920	-17.5	-20.9
940	-14.6	-21.4
960	-13.1	-19.7
980	-11.9	-17.0
1000	-10.9	-15.5

Cellular 1680-2200 MHz		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
1680	2.4	-3.0
1700	2.2	-3.9
1720	1.4	-4.3
1740	0.5	-5.3
1760	-0.7	-5.9
1780	-2.0	-5.2
1800	-1.0	-4.4
1820	0.1	-4.2
1840	0.3	-4.3
1860	-0.6	-4.8
1880	-1.2	-5.0
1900	-1.3	-5.1
1920	-1.7	-5.6
1940	-1.7	-5.5
1960	-2.3	-6.0
1980	-2.3	-5.9
2000	-2.3	-6.0
2020	-1.7	-6.0
2040	-1.3	-6.2
2060	-1.7	-6.1
2080	-1.4	-6.1
2100	-1.5	-6.3
2120	-1.6	-6.1
2140	-1.3	-5.8
2160	-1.1	-5.8
2180	-0.7	-5.2
2200	-0.9	-5.4

Table 1 Cellular 640-1000 MHz & 1680-2200 MHz max gain and efficiency, FS

Cellular 2300-2700 MHz								
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]	Frequency [MHz]	Max gain [dBi]	Efficiency [dB]	Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
2300	0.1	-5.2	2435	-0.5	-6.2	2570	-2.8	-7.3
2305	-0.1	-5.2	2440	-0.9	-6.5	2575	-3.0	-7.5
2310	0.1	-4.9	2445	-1.0	-6.5	2580	-3.1	-7.5
2315	0.3	-4.6	2450	-0.7	-6.1	2585	-3.0	-7.4
2320	0.2	-4.7	2455	-0.5	-6.0	2590	-3.1	-7.4
2325	0.1	-4.9	2460	-0.5	-6.0	2595	-3.0	-7.4
2330	-0.2	-5.2	2465	-0.4	-6.0	2600	-3.3	-7.6
2335	-0.1	-5.4	2470	-0.6	-6.2	2605	-3.6	-8.1
2340	0.1	-5.3	2475	-0.6	-6.1	2610	-3.7	-8.3
2345	0.1	-5.4	2480	-0.7	-6.2	2615	-3.7	-8.4
2350	-0.3	-5.8	2485	-1.2	-6.5	2620	-4.2	-8.8
2355	-0.3	-5.4	2490	-1.1	-6.5	2625	-4.6	-9.0
2360	-0.3	-5.4	2495	-0.8	-6.1	2630	-4.9	-9.1
2365	-0.5	-5.6	2500	-0.8	-6.0	2635	-4.8	-8.8
2370	-0.4	-5.7	2505	-0.8	-6.0	2640	-4.6	-8.6
2375	-0.2	-5.6	2510	-0.9	-6.1	2645	-4.8	-8.8
2380	-0.3	-5.8	2515	-1.4	-6.5	2650	-5.4	-9.5
2385	-0.2	-5.8	2520	-1.5	-6.5	2655	-5.7	-9.8
2390	0.1	-5.7	2525	-1.7	-6.6	2660	-5.7	-9.7
2395	-0.2	-6.0	2530	-2.1	-7.0	2665	-5.5	-9.5
2400	-0.2	-5.8	2535	-2.1	-7.0	2670	-5.9	-9.9
2405	-0.1	-5.6	2540	-1.8	-6.7	2675	-6.2	-10.1
2410	-0.2	-5.7	2545	-1.7	-6.7	2680	-6.2	-10.0
2415	-0.3	-5.9	2550	-1.9	-6.8	2685	-5.9	-9.9
2420	-0.2	-5.8	2555	-2.0	-6.9	2690	-5.9	-9.9
2425	-0.4	-6.0	2560	-2.3	-7.1	2695	-6.0	-10.1
2430	-0.5	-6.2	2565	-2.4	-7.2	2700	-6.5	-10.5

Table 2 Cellular 2300-2700 MHz max gain and efficiency, FS

GNSS		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
1560	-5.9	-9.1
1562	-5.7	-8.9
1564	-5.8	-9.0
1566	-5.8	-9.0
1568	-5.5	-8.8
1570	-5.5	-8.8
1572	-5.4	-8.7
1574	-5.2	-8.4
1576	-5.0	-8.3
1578	-5.1	-8.4
1580	-5.1	-8.3
1582	-5.2	-8.3
1584	-5.2	-8.2
1586	-5.2	-8.1
1588	-5.2	-8.1
1590	-5.1	-8.0
1592	-5.0	-7.9
1594	-5.1	-8.0
1596	-5.1	-8.0
1598	-5.0	-8.0
1600	-5.1	-8.1
1602	-5.1	-8.1
1604	-5.0	-8.1
1606	-5.1	-8.1

BLE		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
2400	-1.8	-5.8
2405	-1.8	-5.7
2410	-2.1	-5.8
2415	-2.7	-6.0
2420	-2.9	-6.0
2425	-2.6	-6.0
2430	-2.4	-5.9
2435	-2.6	-6.0
2440	-2.9	-6.1
2445	-3.1	-6.1
2450	-2.7	-5.9
2455	-2.6	-5.7
2460	-2.8	-5.7
2465	-2.8	-5.5
2470	-2.7	-5.7
2475	-2.4	-5.6
2480	-2.0	-5.5
2485	-2.4	-5.9

Table 3 GNSS 1560-1606 MHz and BLE 2400-2485 MHz max gain and efficiency, FS

5.1.2 Maximum gain and efficiency, metal surface

Cellular 640-1000 MHz		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
640	-12.6	-21.5
660	-10.9	-19.9
680	-9.4	-18.3
700	-9.0	-16.6
720	-9.1	-16.4
740	-8.6	-16.1
760	-9.9	-17.0
780	-11.5	-18.4
800	-13.3	-20.1
820	-15.0	-21.2
840	-15.4	-22.2
860	-15.8	-23.0
880	-16.5	-23.8
900	-16.6	-24.2
920	-18.4	-25.4
940	-19.5	-25.0
960	-17.7	-23.6
980	-15.6	-21.3
1000	-14.2	-19.8

Cellular 1680-2200 MHz		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
1680	2.0	-4.9
1700	1.7	-5.1
1720	1.6	-4.7
1740	2.0	-4.8
1760	2.1	-4.6
1780	1.9	-4.7
1800	2.2	-4.6
1820	2.3	-4.4
1840	2.3	-4.2
1860	2.3	-4.5
1880	2.4	-4.8
1900	2.0	-5.0
1920	1.4	-5.6
1940	1.2	-5.6
1960	0.5	-6.2
1980	0.3	-6.3
2000	-0.2	-6.7
2020	-0.7	-7.1
2040	-1.3	-7.6
2060	-1.4	-7.9
2080	-1.5	-7.9
2100	-2.3	-8.8
2120	-2.0	-8.8
2140	-2.1	-9.1
2160	-2.6	-9.4
2180	-2.2	-8.9
2200	-2.3	-9.3

Table 4 Cellular 640-1000 MHz & 1680-2200 MHz max gain and efficiency, metal

Cellular 2300-2700 MHz								
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]	Frequency [MHz]	Max gain [dBi]	Efficiency [dB]	Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
2300	-0.7	-8.1	2435	0.3	-7.2	2570	-1.0	-7.7
2305	-0.5	-8.0	2440	0.1	-7.5	2575	-1.3	-7.9
2310	-0.2	-7.6	2445	0.2	-7.4	2580	-1.2	-7.8
2315	0.0	-7.3	2450	0.6	-7.1	2585	-1.1	-7.6
2320	0.0	-7.4	2455	0.8	-6.9	2590	-1.1	-7.6
2325	-0.1	-7.5	2460	0.8	-6.9	2595	-1.1	-7.6
2330	-0.4	-7.8	2465	1.0	-6.9	2600	-1.5	-7.8
2335	-0.3	-7.8	2470	0.8	-7.1	2605	-1.9	-8.2
2340	-0.1	-7.6	2475	0.8	-7.0	2610	-2.2	-8.4
2345	-0.1	-7.6	2480	0.8	-7.1	2615	-2.4	-8.5
2350	-0.3	-7.8	2485	0.4	-7.4	2620	-3.0	-8.9
2355	0.2	-7.2	2490	0.5	-7.3	2625	-3.5	-9.3
2360	0.1	-7.3	2495	0.9	-6.9	2630	-3.6	-9.3
2365	-0.3	-7.6	2500	0.8	-6.9	2635	-3.3	-9.1
2370	-0.2	-7.4	2505	0.8	-6.8	2640	-2.9	-8.9
2375	-0.2	-7.4	2510	0.8	-6.9	2645	-2.9	-9.2
2380	-0.4	-7.5	2515	0.3	-7.3	2650	-3.5	-9.9
2385	-0.3	-7.3	2520	0.2	-7.2	2655	-3.8	-10.2
2390	0.0	-7.2	2525	0.0	-7.4	2660	-3.4	-10.2
2395	-0.2	-7.4	2530	-0.4	-7.6	2665	-3.4	-10.1
2400	0.3	-7.0	2535	-0.3	-7.4	2670	-3.6	-10.5
2405	0.6	-6.8	2540	-0.1	-7.1	2675	-3.7	-10.8
2410	0.5	-6.9	2545	-0.3	-7.1	2680	-3.6	-10.7
2415	0.4	-7.1	2550	-0.4	-7.1	2685	-3.4	-10.6
2420	0.4	-7.1	2555	-0.6	-7.3	2690	-3.2	-10.7
2425	0.4	-7.1	2560	-0.8	-7.5	2695	-3.5	-11.0
2430	0.4	-7.1	2565	-0.8	-7.5	2700	-3.8	-11.5

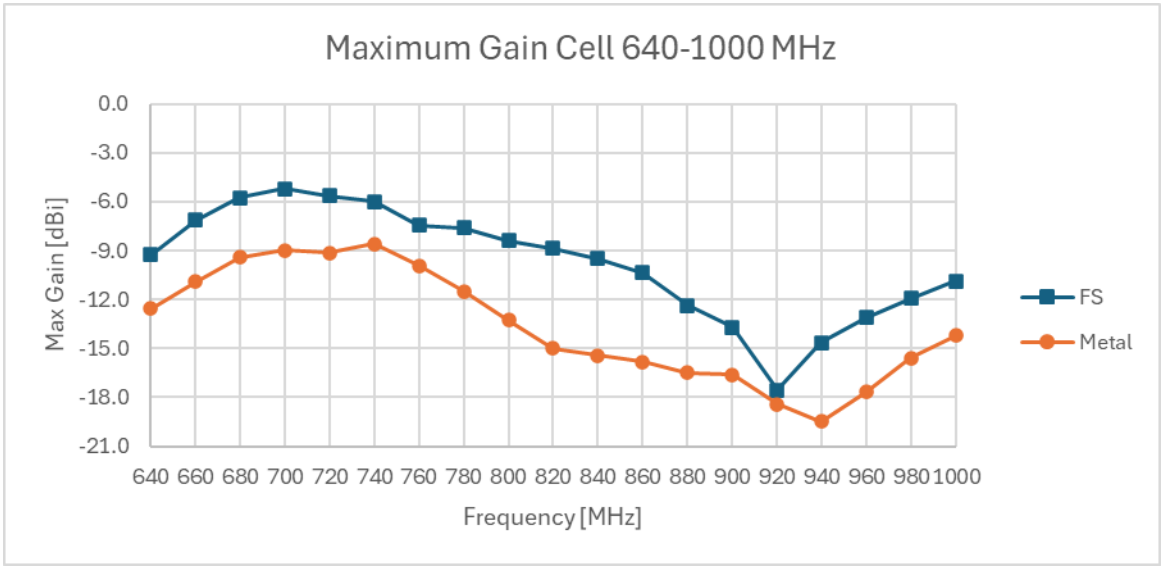
Table 5 Cellular 2300-2700 MHz max gain and efficiency, metal

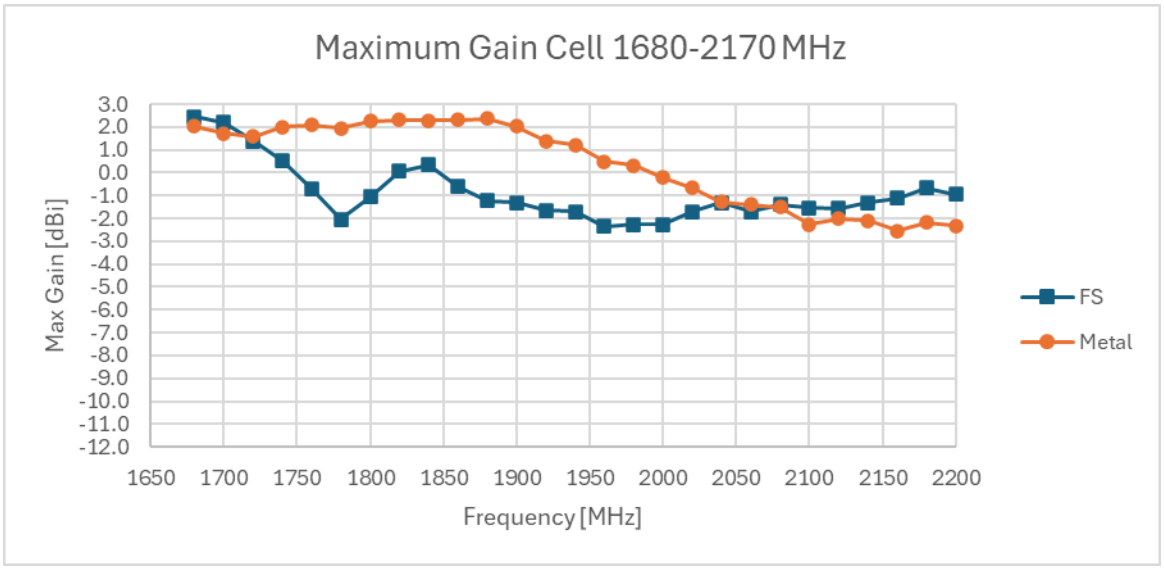
GNSS		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
1560	-4.3	-10.4
1562	-4.1	-10.2
1564	-4.1	-10.3
1566	-4.0	-10.3
1568	-3.6	-10.0
1570	-3.4	-9.9
1572	-3.3	-9.8
1574	-2.9	-9.5
1576	-2.7	-9.3
1578	-2.6	-9.3
1580	-2.5	-9.2
1582	-2.4	-9.2
1584	-2.4	-9.2
1586	-2.3	-9.1
1588	-2.3	-9.1
1590	-2.2	-9.0
1592	-2.1	-8.8
1594	-2.1	-8.8
1596	-2.2	-8.8
1598	-2.1	-8.7
1600	-2.2	-8.8
1602	-2.3	-8.8
1604	-2.2	-8.7
1606	-2.2	-8.7

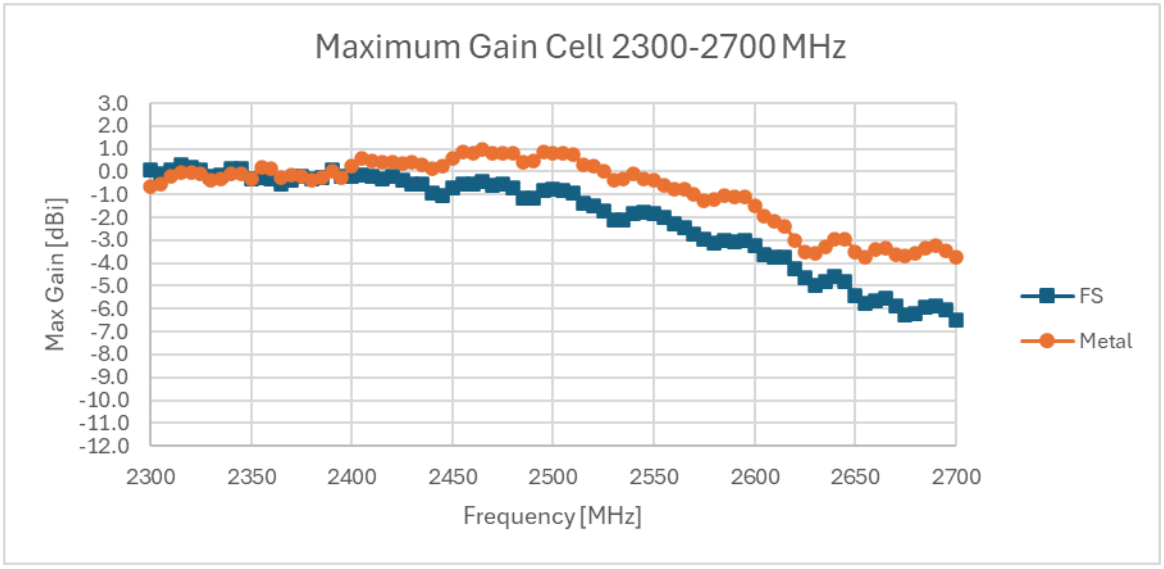
BLE		
Frequency [MHz]	Max gain [dBi]	Efficiency [dB]
2400	1.8	-6.1
2405	1.8	-6.0
2410	1.7	-6.0
2415	1.6	-6.0
2420	1.5	-6.0
2425	1.5	-5.9
2430	1.4	-5.9
2435	1.2	-5.9
2440	0.8	-6.1
2445	0.8	-6.1
2450	1.0	-6.0
2455	1.3	-5.8
2460	1.3	-5.9
2465	1.5	-5.8
2470	1.4	-6.0
2475	1.2	-6.1
2480	1.1	-6.1
2485	0.6	-6.6

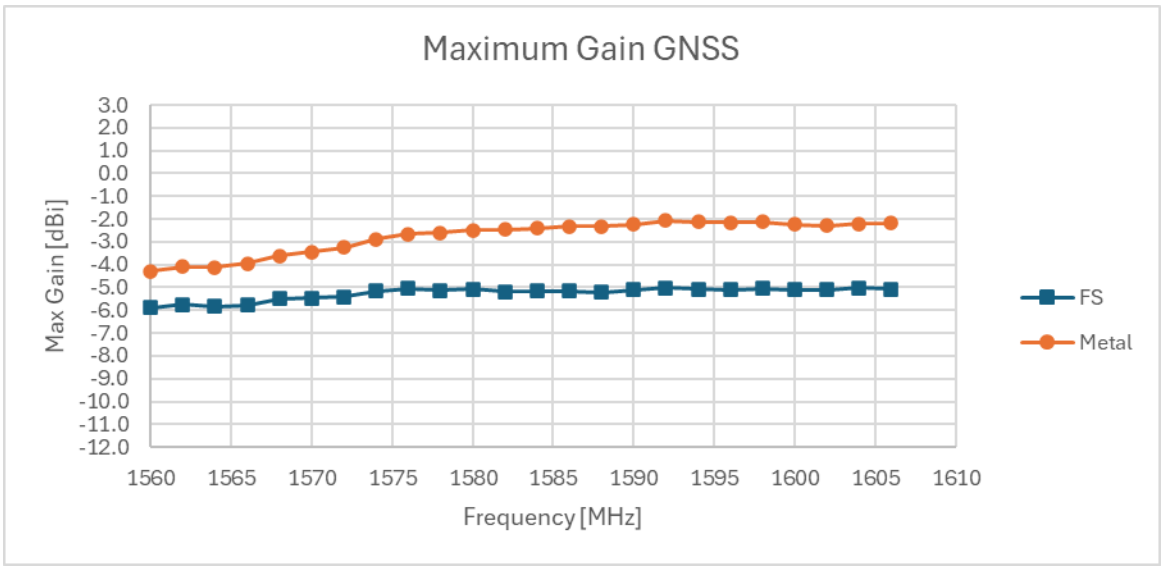
Table 6 GNSS 1560-1606 MHz and BLE 2400-2485 MHz max gain and efficiency, metal

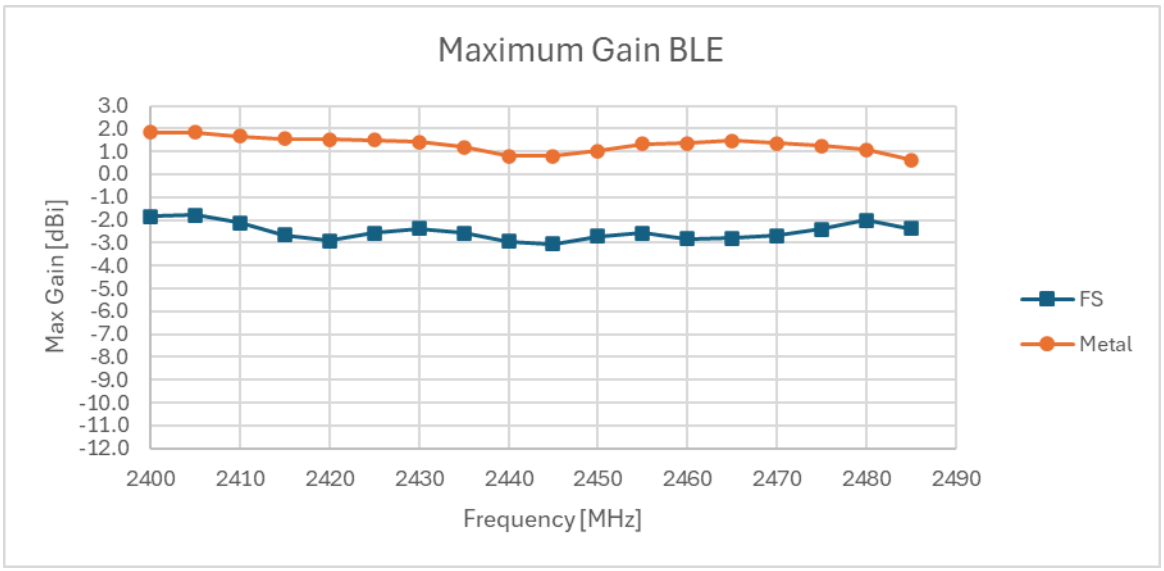
5.1.3 Maximum gain (graphs)



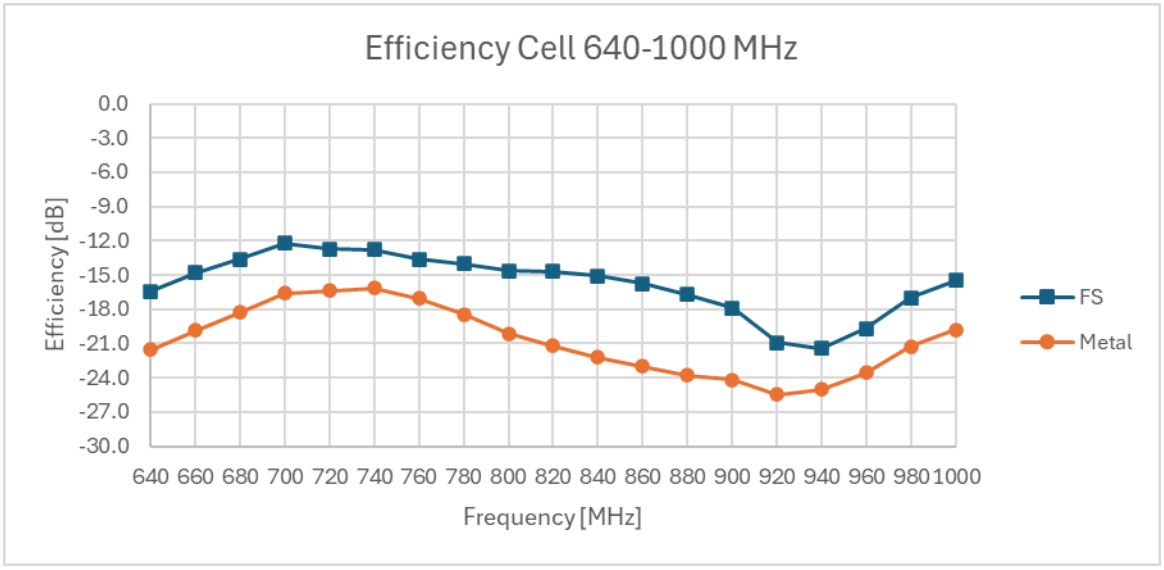


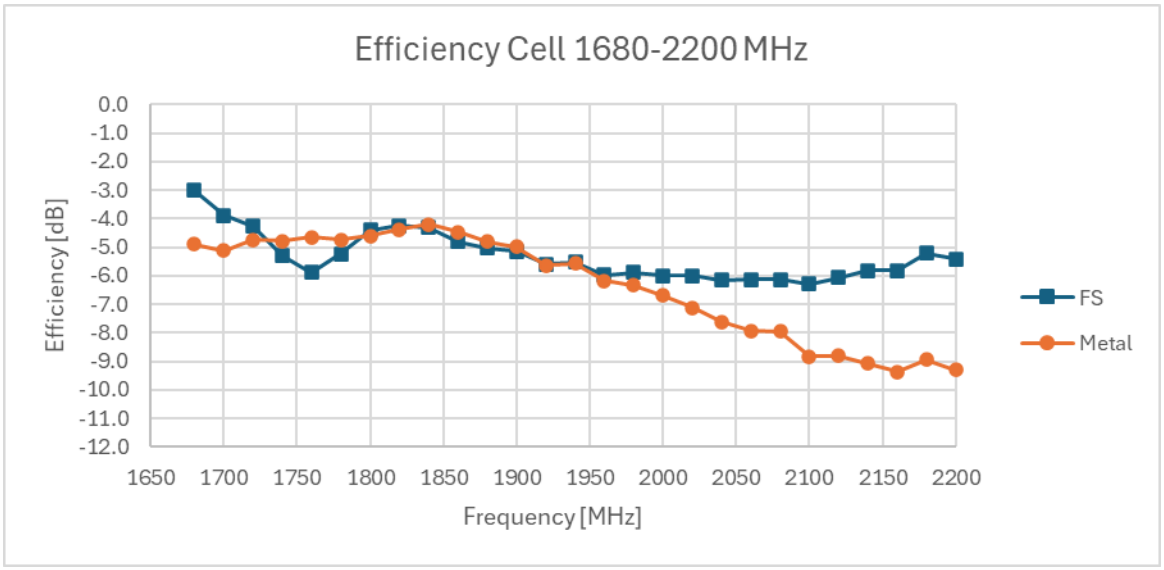


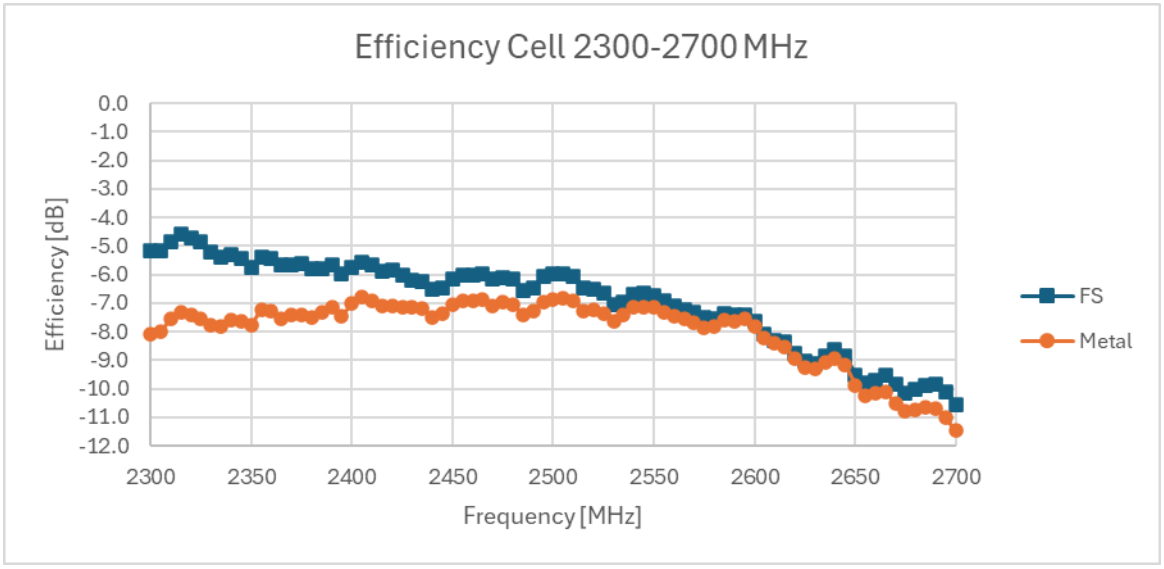


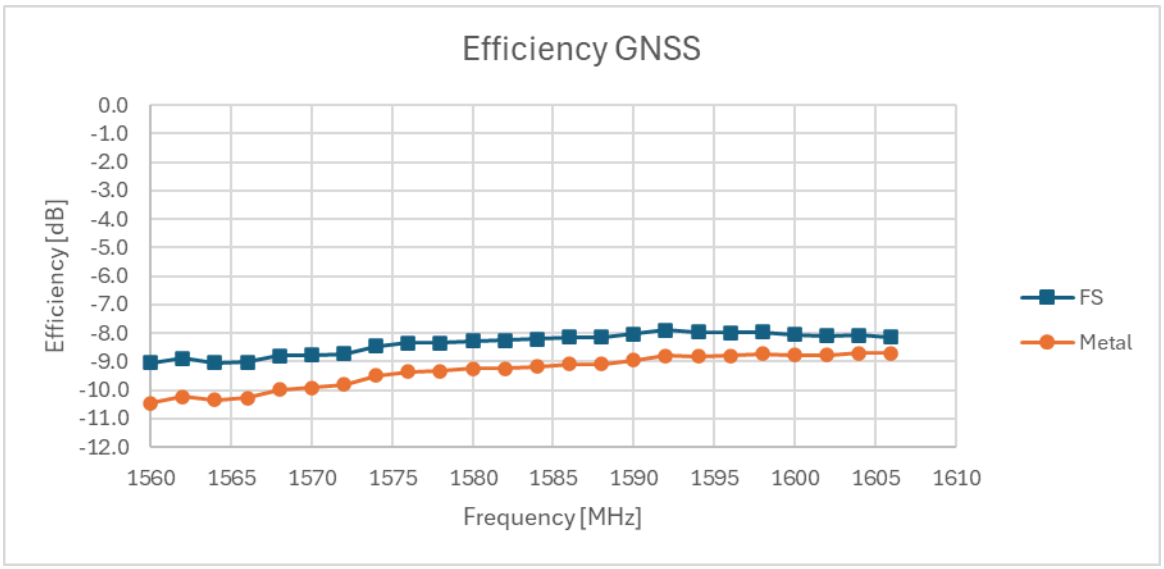


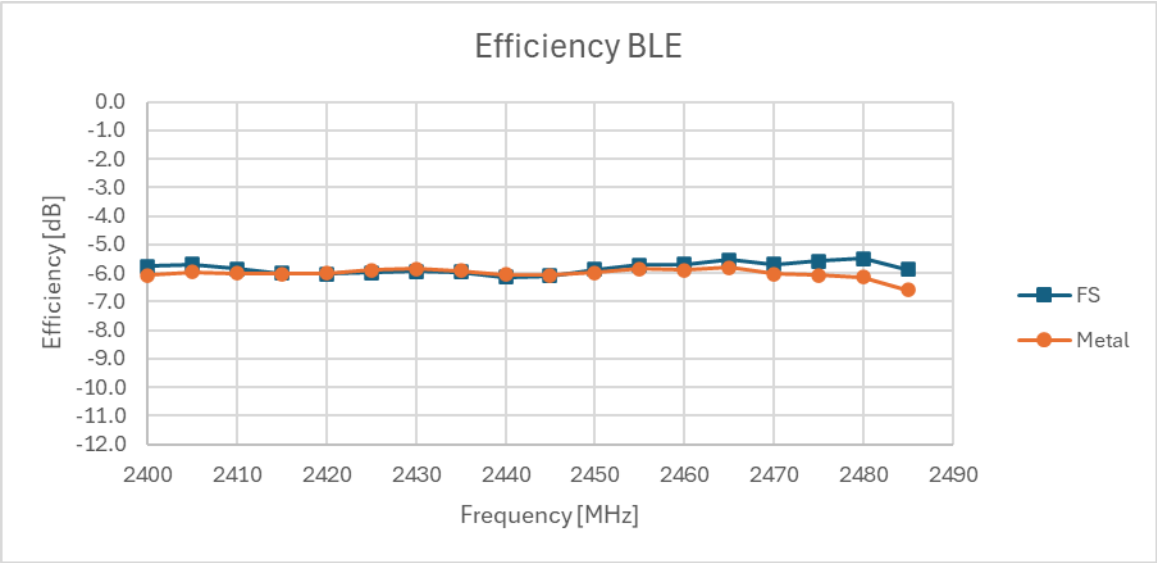
5.1.4 Efficiency (graphs)







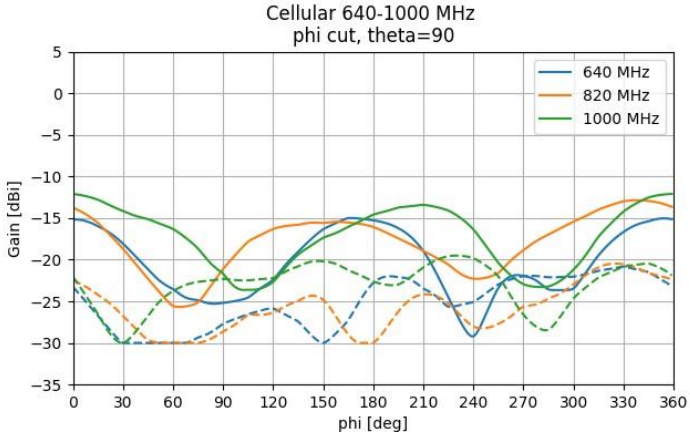


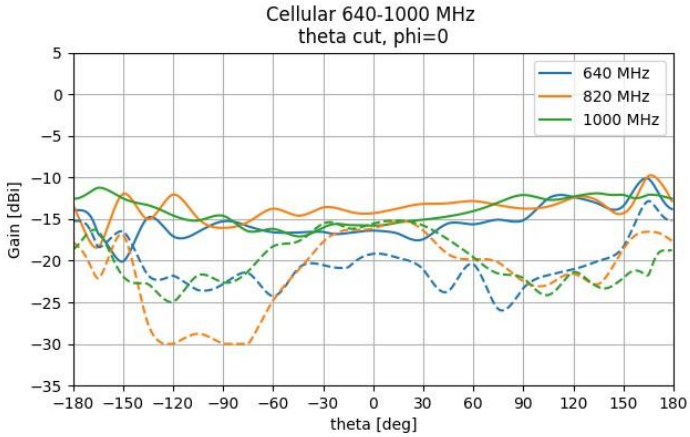


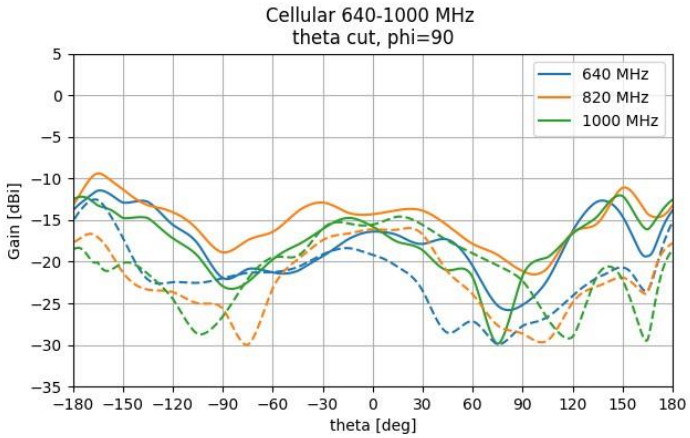
6. ANTENNA PATTERN CUTS

In cut images free space measurement is represented by solid lines and metal surface with dashed lines

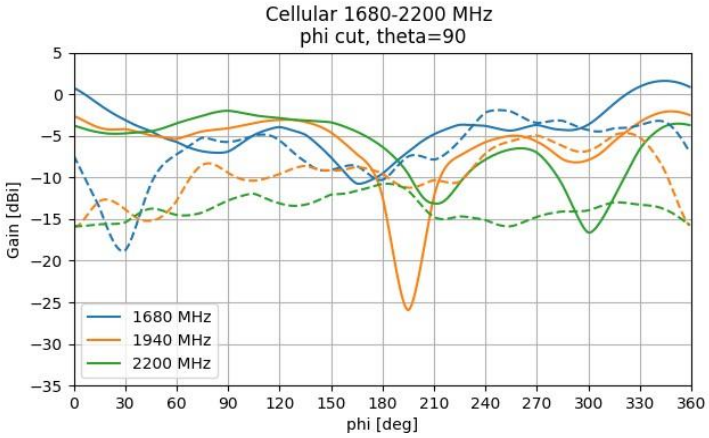
6.1 Cellular 640-1000 MHz

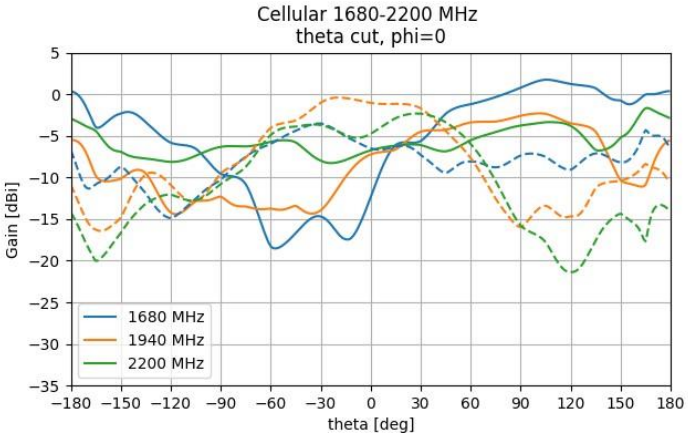


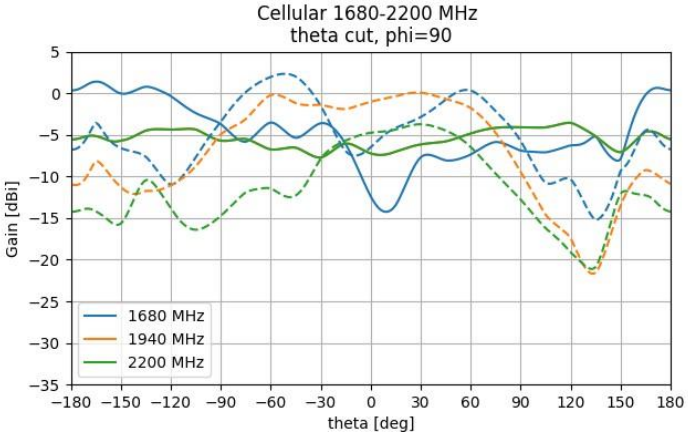




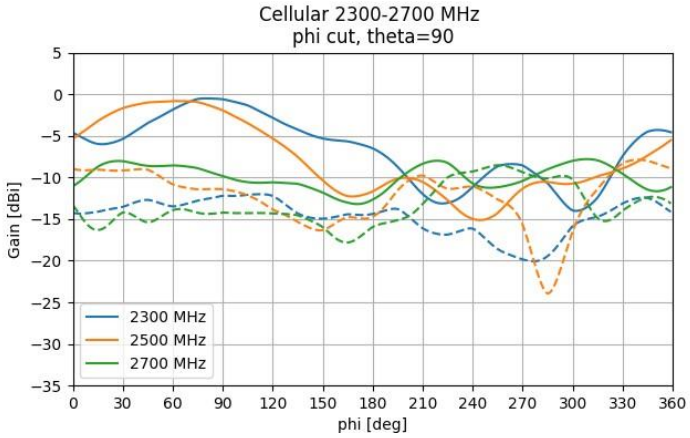
6.2 Cellular 1680-2170 MHz

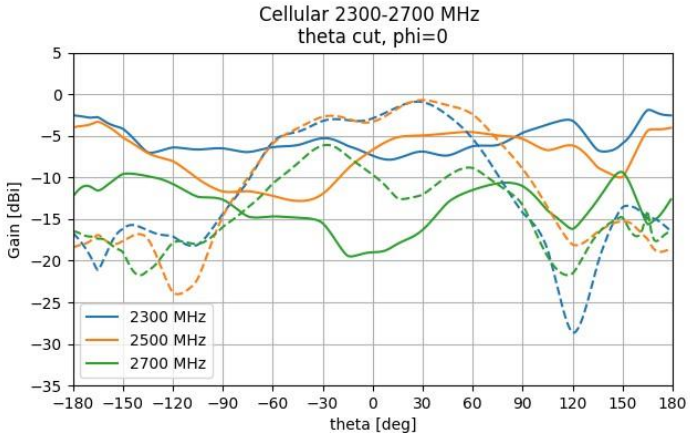


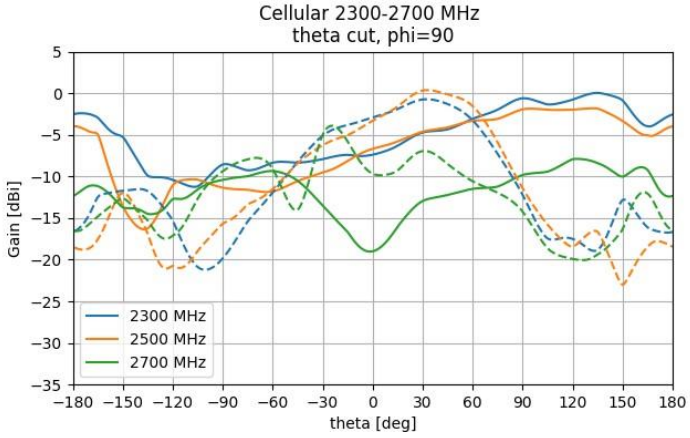




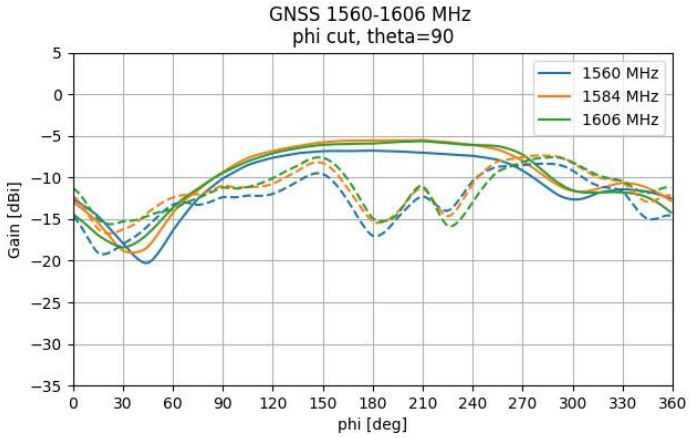
6.3 Cellular 2300-2700 MHz

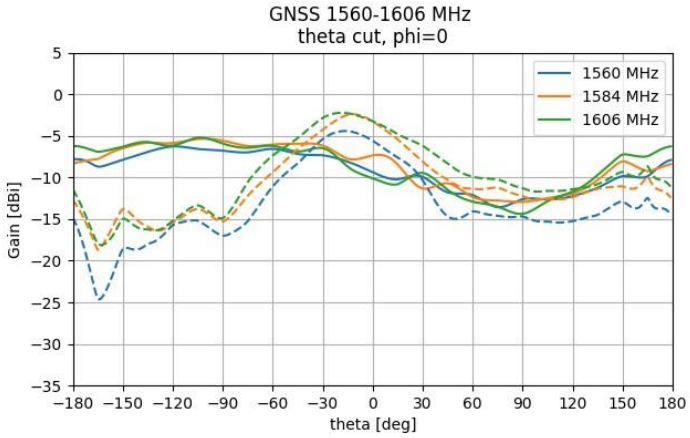


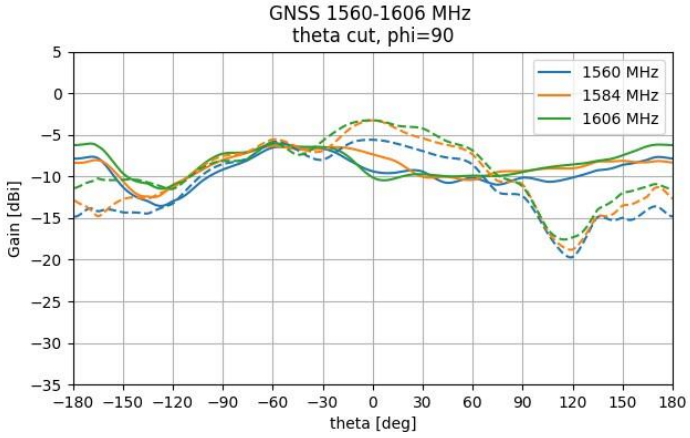




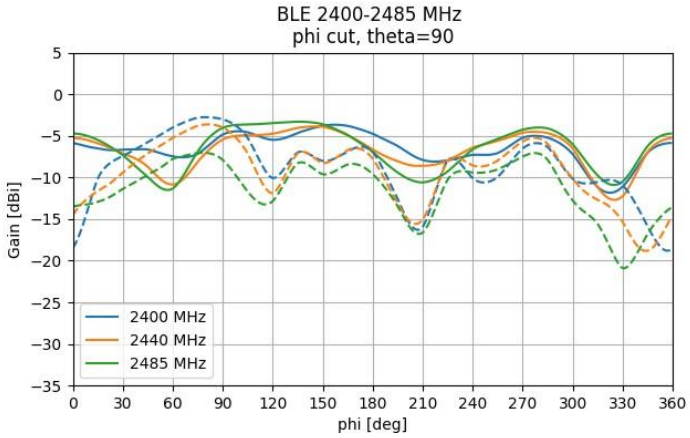
6.4 GNSS

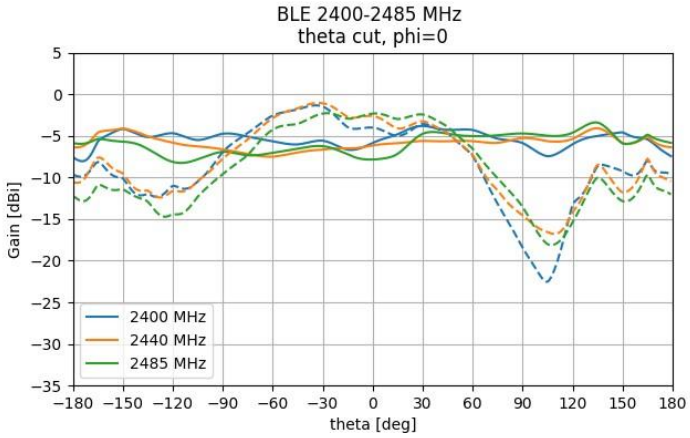


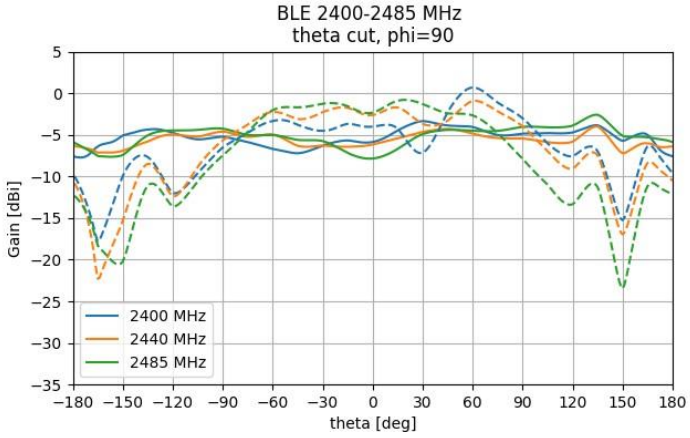




6.5 BLE

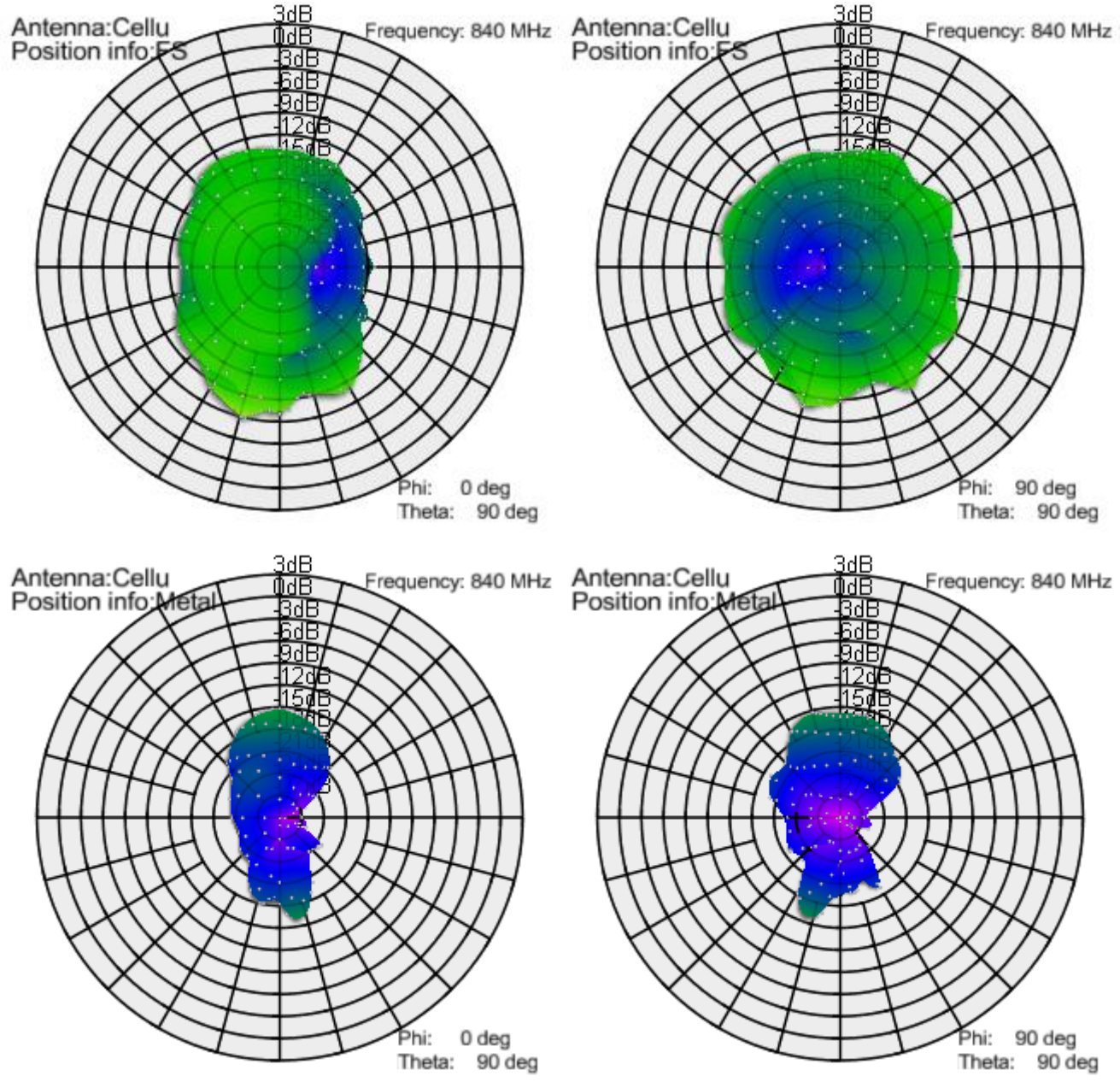




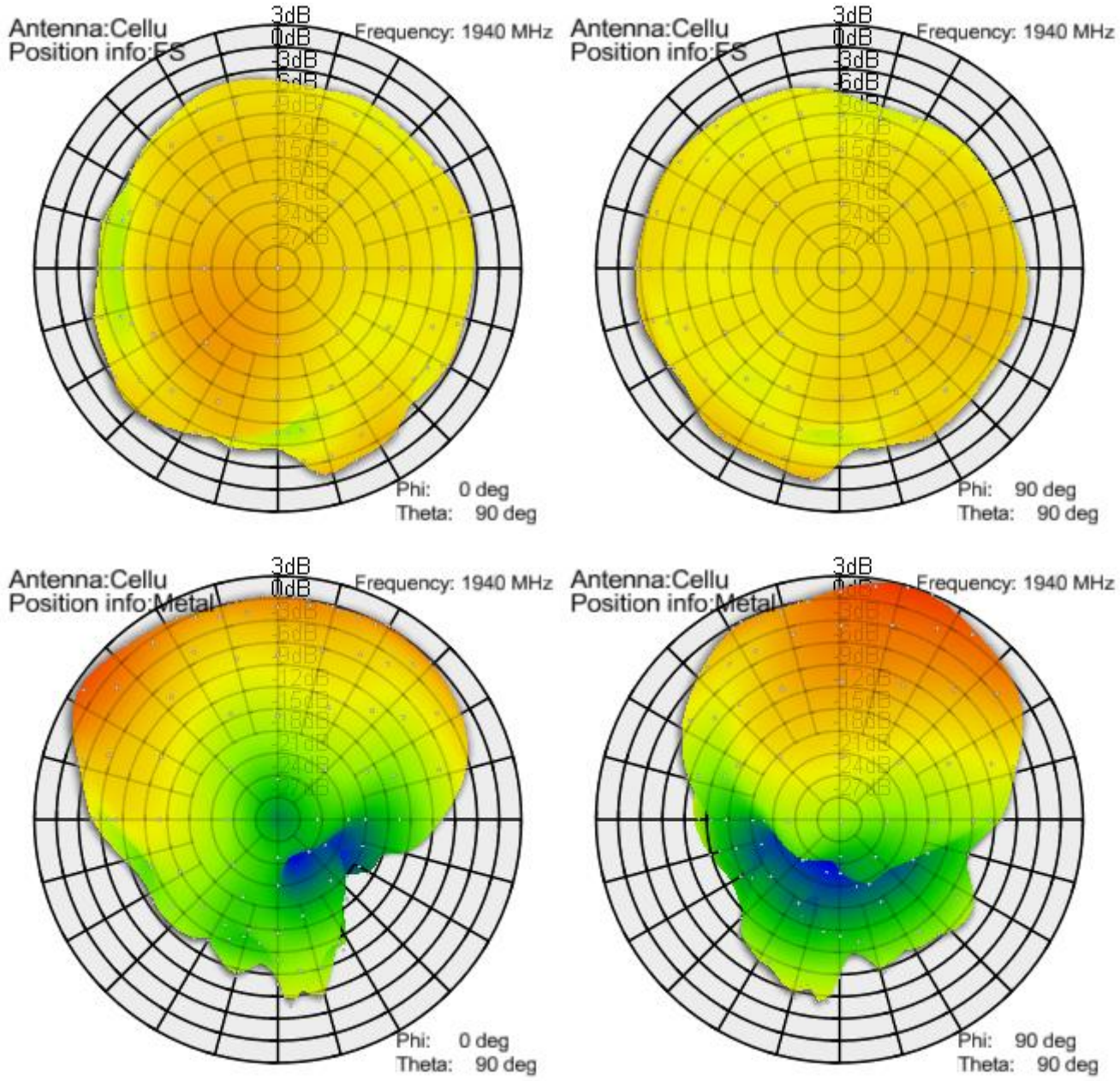


7. ANTENNA PATTERNS

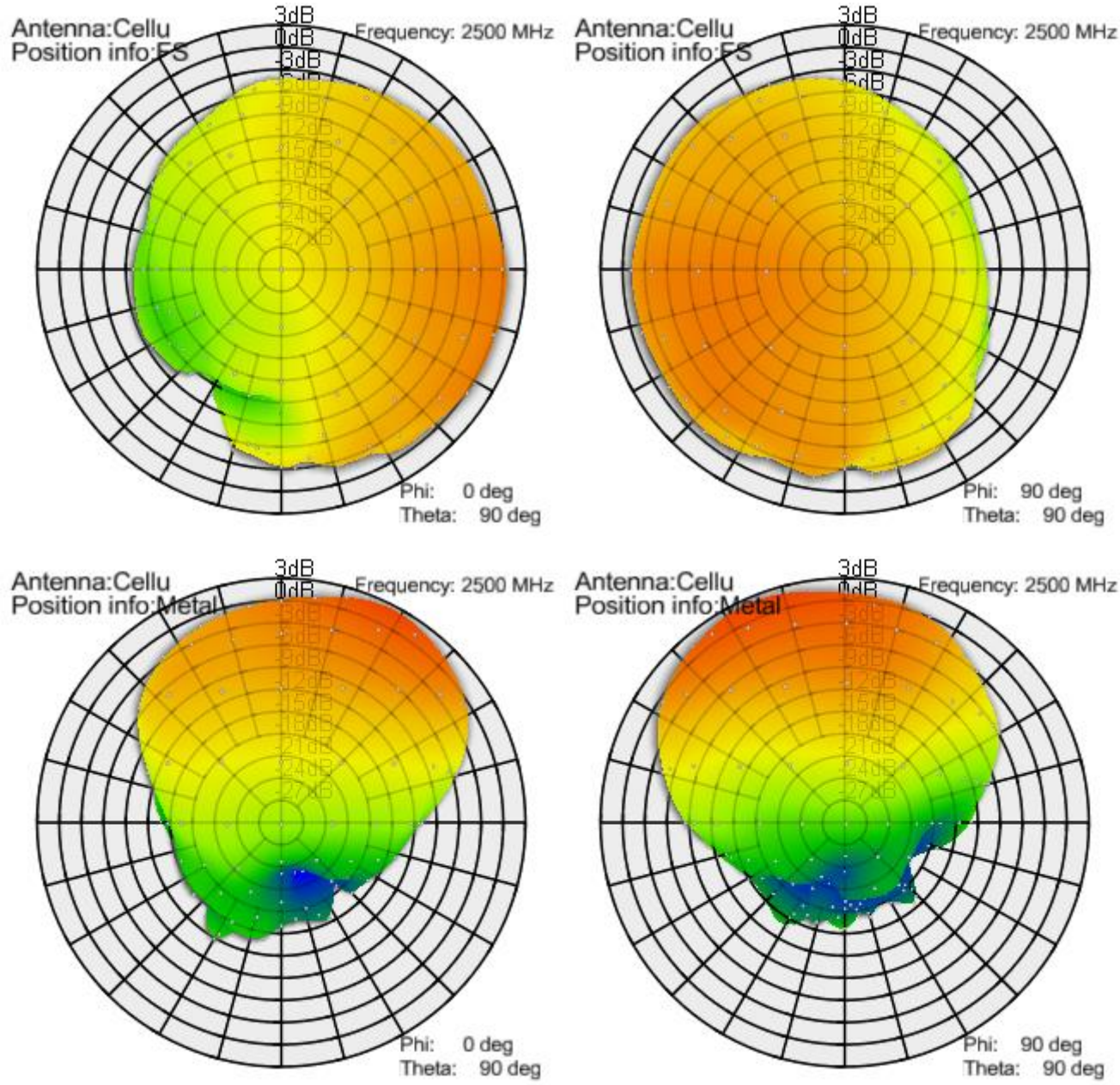
7.1 Cellular 640-1000 MHz



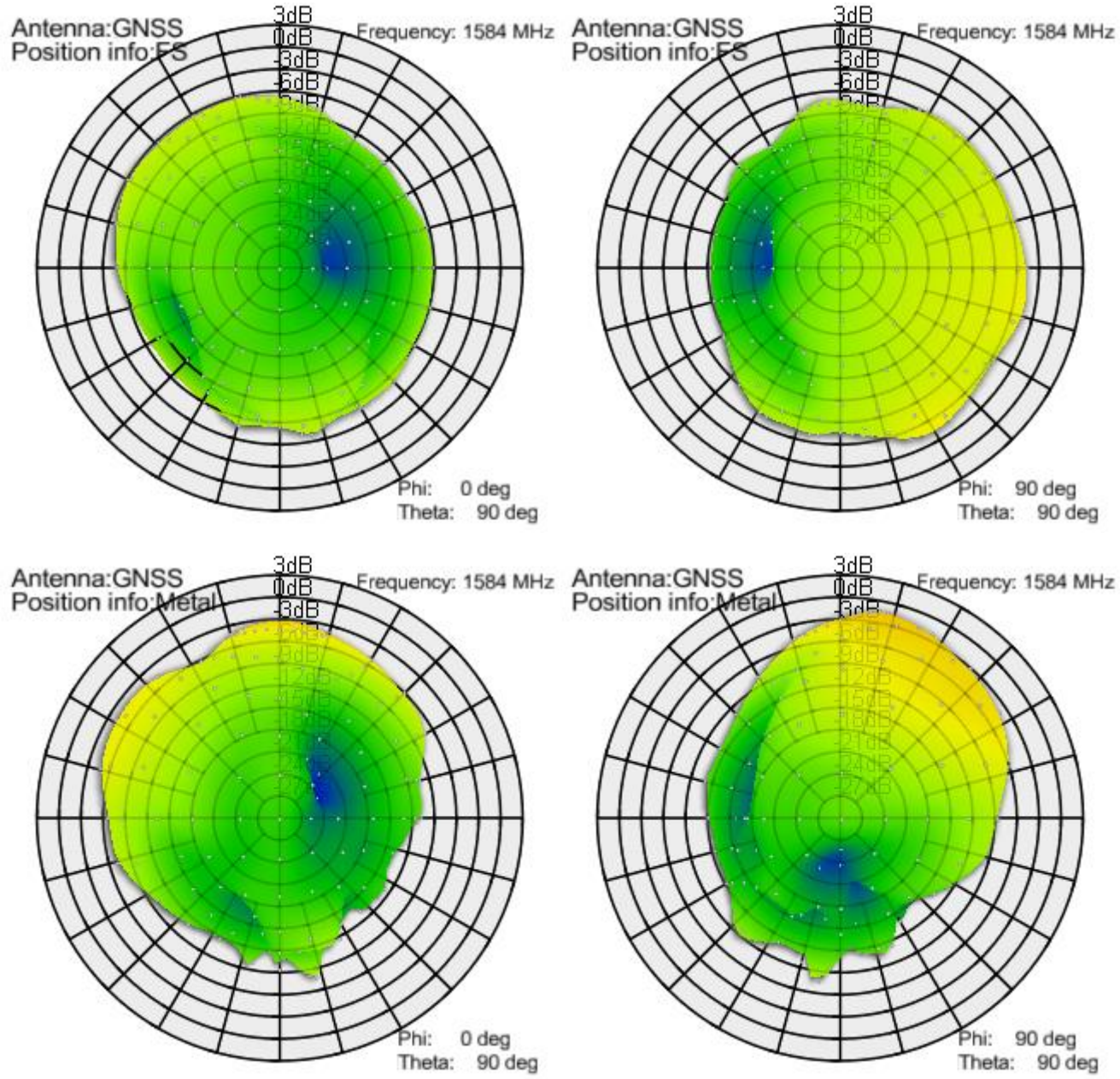
7.2 Cellular 1680-2200 MHz



7.3 Cellular 2300-2700 MHz



7.4 GNSS



7.5 BLE