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TECHNIQUE TO MEASURE 5G OUT-OF-BAND RF INTERFERENCE WITH DRONES

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1 ABSTRACT

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The target of this bachelor’s thesis was to describe Nokia Otava drone 5G field testing, tools and used equipment and investigate unwanted emissions of 5G radios and perform measurement flights. Nokia’s 5G drone team perform field testing to ensure that 5G radios are performing as specified in field conditions. Field measurements were performed using a Nokia drone and a Rohde & Schwarz TSME6 datalogger payload.

A measurement report was created from the measurement results and a user guide created for the 5G MABS device. These are Nokia’s internal documents and not included in this thesis.

Keywords: drone, out-of-band, spurious, radio frequency emissions, GPS

CONTENTS

2 VOCABULARY

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G MABS	5G Measuring Antenna Balancing System
AMSL	Above Mean Sea Level
BTS	Base Transceiver Station
CDMA	Code-Division Multiple Access
dB	Decibel
dBm	Decibel-milliwatts
EIRP	Effective Isotropic Radiated Power
EUT	Equipment Under Test
GHz	Gigahertz
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

GSM	Global System for Mobile Communications
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
LNA	Low Noise Amplifier
LTE	Long Term Evolution
MHz	Megahertz
MiMo	Multiple-input, Multiple-Output
NR	New Radio
OoB	Out-of-Band
OTAVA	Over the Air Validation Area
PIM	Passive Intermodulation
PSD	Power Spectral Density
QoS	Quality of Service
RF	Radio Frequency
RSRP	Reference Signal Received Power
SMS	Short Message Service
SSB	Synchronisation Signal Block

TDD	Time Division Duplex
TRP	Total Radiated Power
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

3 INTRODUCTION

Nokia's history in telecommunications began in the 1980s and, using Nokia equipment, the first GSM call was made in 1992. In 2013, Nokia bought Siemens and that event laid the foundation for Nokia's transformation into a network hardware and software provider, Nokia Networks. The acquisition of the telecommunications equipment provider Alcatel-Lucent broadened the scope of Nokia's portfolio and customer base. Several company acquisitions have made Nokia a global technology leader in the telecommunications industry. [1].

In 2020, Nokia employed approximately 92,000 people across the world and did business in more than 130 countries. Nokia reported annual revenues of around 21.9 billion euros. [2].

Otava (Over the Air Validation Area) is Nokia's test laboratory of 8,500m^2 located in Oulu, Finland. Currently, over 100 Nokia employees and people from telecommunication operators and component manufacturers work in the Otava premises. There are dozens of 5G test lines, multiple large antenna walls and RF chambers in the Otava test laboratory and it is possible to use these test lines to test 5G UEs and other RF-related equipment [3]. Nokia 5G field testing, which includes cars and drones, also works out of Otava.

The aim of this thesis was to describe how Nokia 5G RF drone field testing is done and how the equipment is used. The focus was to investigate and measure Nokia's 5G radio RF out-of-band interference with a Rohde & Schwarz TSME6 datalogger, which was inside the drone payload, and use the results to produce an internal measurement report for the measured radios and a user guide for the 5G MABS payload for Nokia.

4 CELLULAR NETWORKS

A cellular network or mobile network consists of multiple signal areas called cells. Cells join or overlap each other to form a large coverage area. Network users can cross into different cells without losing connection. In each cell, you can find a base station or mobile phone tower, which sends and receives mobile transmissions. Different UEs will connect to the nearest or least-congested base station. In areas where the population density is higher, cell sizes are smaller, and the number of base stations is higher. [4].

4.1 Base Station

The base station sends and receives RF signals and is responsible for forming the cell area. A typical cell tower contains antennas to send and receive RF signals, the tower or supporting structure itself, a base transceiver station in a cabinet or shelter and a cable or wireless connection back to the digital exchange, where the communication is sent to other telephone or data networks. [5]. Figure 1 presents base station locations in different areas.

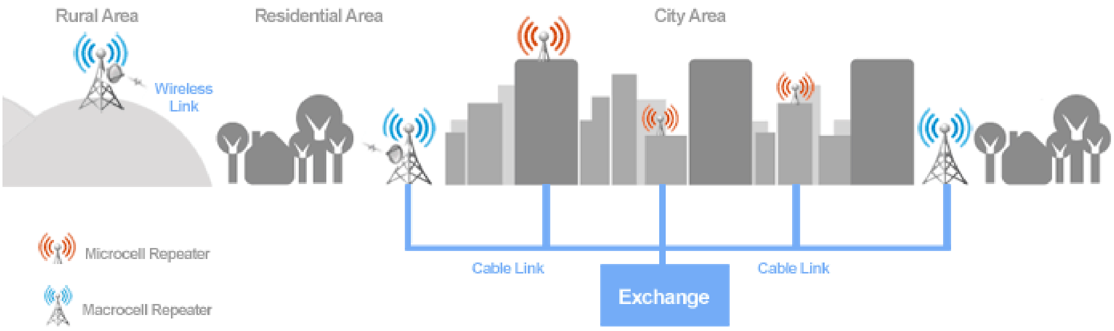

FIGURE 1. Base Stations – Cell Coverage [6]

Figure 1 shows that in city areas, there is a large number of users and obstructions, so there is a need for many more base stations to cover the demand, and cell sizes need to have radius of 2-5km. Rural areas are large open spaces so the base stations will be further apart with a cell radius of around 10-32km. [5]. Figure 2 presents different cell sizes and an approximate coverage radius.

Base Station Type	Typical Coverage Radius	Typical Use
Femtocell	10m	Home or office use
Picocell	200m	High rise building, hotel or car park use
Microcell	1-2km	Shopping centers, transport hubs, mine sites, city block, temporart ecents or natural disasters
Macrocell	5-32km	Suburban, city and rural use

FIGURE 2. Base Station Types [5]

4.2 1G

The first-generation cellular network was introduced in the late 1970s and by the 1980s fully implemented standards had been established. Radio signals are analogue, so the voice of a call is modulated to a higher frequency than being encoded to digital signals. [6].

4.3 2G

The GSM (Global System for Mobile Communication) was introduced in the early 1990s and was the second generation of cellular networks. For the first time, 2G allowed users to roam and it allowed digital voice and data to be sent across the network. Many 1G and 2G services are still in use, such as SMS, internal roaming, conference calls, call hold and billing based on services. [6].

4.4 3G

The Third generation was introduced in 2001, and the aims were to facilitate greater voice and data capacity, support a wider range of applications and increase data transmission at a lower cost. The Third generation supported high speed wide band Internet access and fixed wireless Internet access and allowed for video calls, chatting and conference calls, mobile TV, video on demand services, navigational maps, email, mobile gaming, music and digital services well as movies for the first time in the cellular network history. [6].

4.5 4G

The Fourth generation is an all-IP-based network system which was initiated in 2010. 4G provides high speed, quality and capacity to users while improving security and lowering the cost of voice and data services. The major benefits of an IP-based network are the seamless handover of voice and data to GSM, UMTS and CDMA2000 technologies from the previous infrastructure of different generations. [6].

4.6 5G

The Fifth generation is a new global wireless standard after all the previous cellular network generations, it will enable a new kind of network that is designed to connect everyone and everything together, including machines, objects and devices. 5G technologies are meant to deliver higher multi-Gbps peak speeds, ultra-low latency, reliability and massive network capacity and to increase availability. They are also meant to seamlessly connect a massive number of sensors on virtually everything to unleash a massive IoT ecosystem. [7].

5 5G RF MEASUREMENTS WITH THE DRONE

5G RF measurements are performed using a Nokia drone. Currently, in the Oulu area there are two Nokia 5G test sites, Rusko area and OuluZone. Basic measurements contain different flight routes e.g. a vertical and horizontal cut and 360-degree around the test tower. During these flights, SSB RSRP levels, radiation pattern and RF power levels are measured from the 5G radio using an R&S TSME6 datalogger. All automated flight missions are performed using ArduPilot Mission Planner flight planning software [Figure 3]. The software communicates with a Pixhawk flight controller, which is located inside the drone.

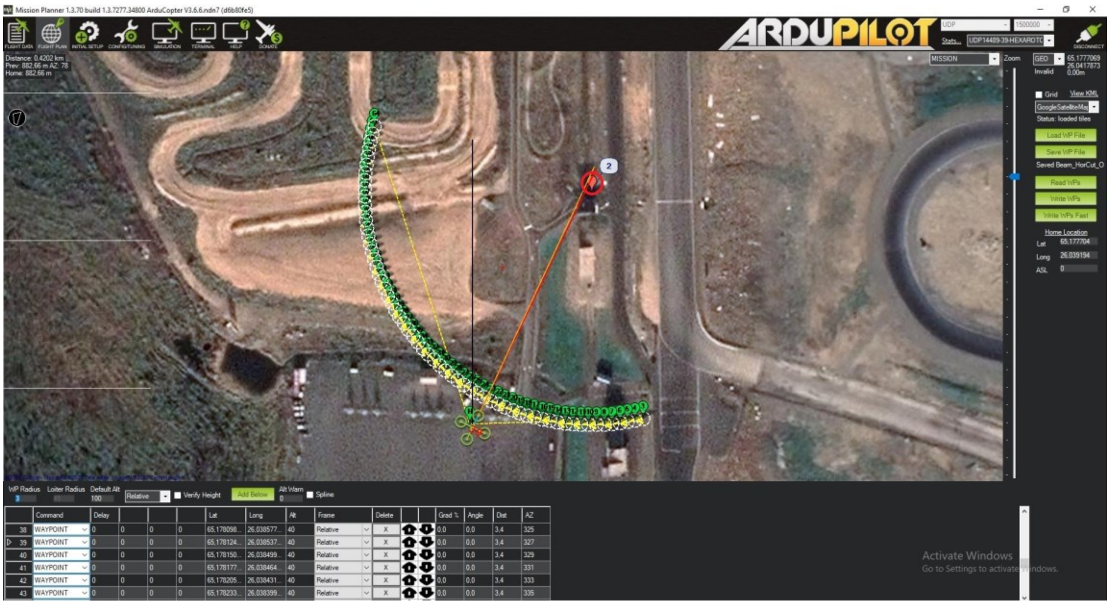

FIGURE 3. ArduPilot Mission Planner software

5.1 Flight Planning

5G RF measurements with drone preparations start with the flight route planning. Figure 4 shows Nokia's internal application, the Waypoint Service Tool. With the tool, the user can input all needed parameters, e.g. antenna height, tilt angle, azimuth. When these parameters are given, the tool outputs a file which contains GPS waypoints to the flight mission file [Figure 5]. The file is transferred to the ArduPilot Mission Planner software. The Mission Planner software visualises the flight route GPS waypoints on a map and the drone will follow the waypoints automatically. It is possible to do some fine-tuning to the flight route via Mission Planner software, such as, for example, drone heading and ground speed, and check that all the waypoints and drone flying heights are correct, so the drone does not collide with any obstacles, such as trees or buildings.

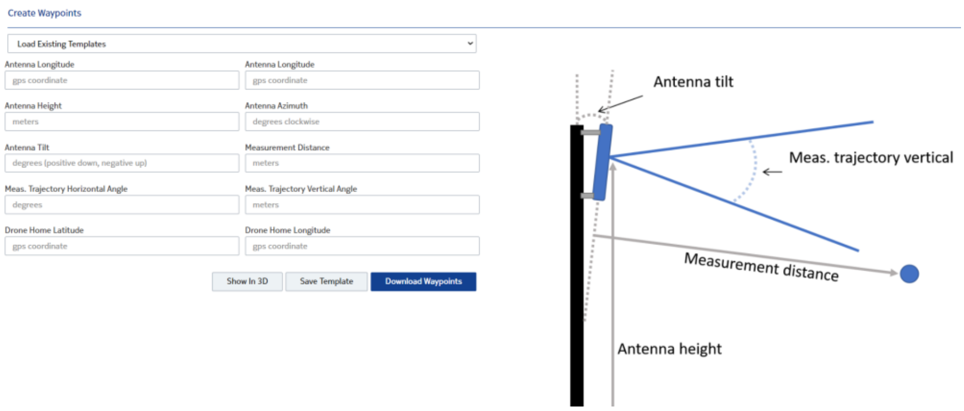

FIGURE 4. Waypoint Service Tool

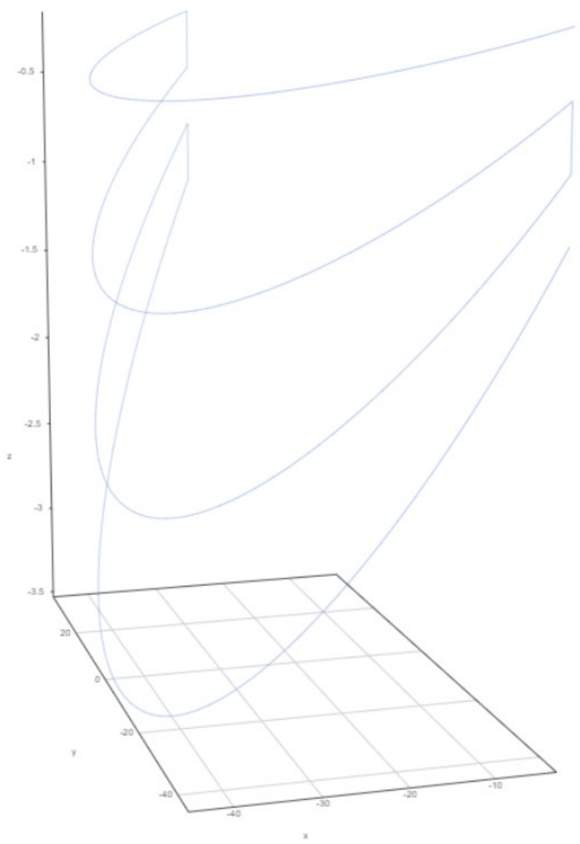

FIGURE 5. Example of Waypoint Service Tool output

5.2 5G Measuring Antenna Balancing System

The 5G drone payload consists of a horizontally balanced measuring antenna. The system is called 5G MABS (5G Measuring Antenna Balancing System). The balancing system eliminates off-set roll axis angle errors from the measurement results. Pitch axis angle errors have only minimal effects because flight missions are performed near or equal to the altitude of the measured radio transmitter and the measuring antenna vertical pattern is wide-angled. The correction of yaw axis is done automatically by the drone. The user can check through the inspection window that the antenna stabilisation hardware is working before each flight [Figure 6].

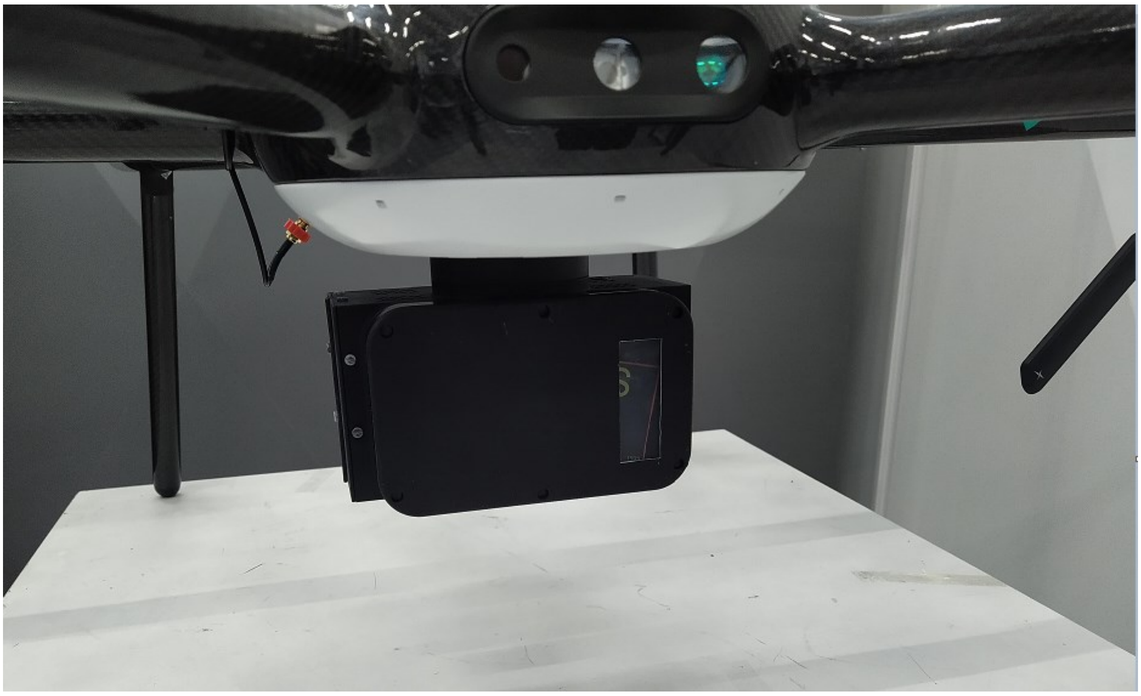

FIGURE 6. 5G MABS attached to Nokia drone

5.2.1 Hardware

Figure 7 presents an exploded view of the 5G MABS payload. The payload consists of an Intel® Compute stick, Rohde & Schwarz TSME6 datalogger, USB hub for more USB and Ethernet ports, voltage regulators and gimbal hardware with Maximus FXUB66 antenna with a bandwidth of 700 MHz to 6 GHz. The payload is attached to the Nokia drone with a “Plug and Play” quick-release adapter and a connection to the payload PC can be made via TightVNC remote desk connection software [Appendix 1]. With the remote desktop connection, it is possible to control the R&S TSME6 datalogger from the ground control PC.

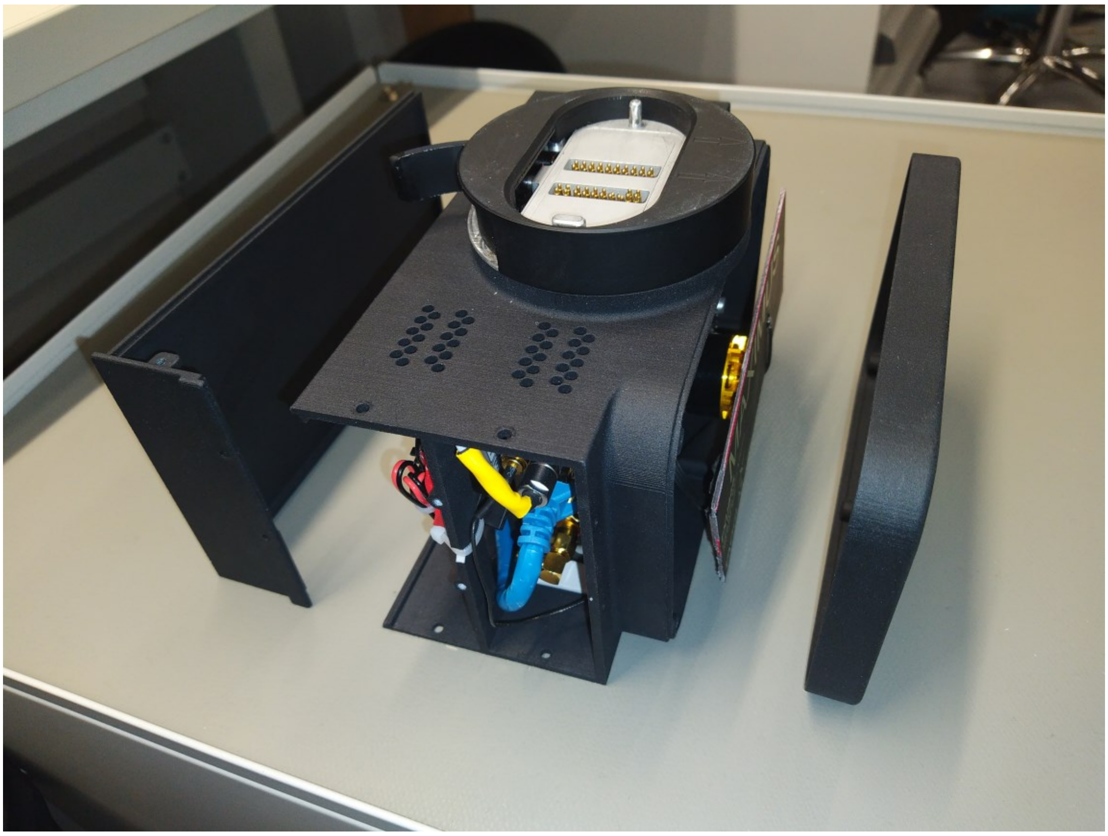

FIGURE 7. Exploded view of the 5G MABS

5.2.2 RF Chamber Verification

The drone with its 5G Measuring Antenna Balancing System payload was measured in an RF chamber in Nokia's OTAVA premises. The gain and radiation pattern of the measuring antenna was measured. The frequency bands used were 2.4 – 2.6 GHz [Figures 8 & 9] and 3.3 – 3.9 GHz [Figures 10 & 11]. Figures 8, 9, 10 and 11 present the radiation patterns of the 5G MABS measurement antenna so it is possible to determine antenna gain in different frequencies. These values are used when calculating TRP and EIRP from the radio measurement results.

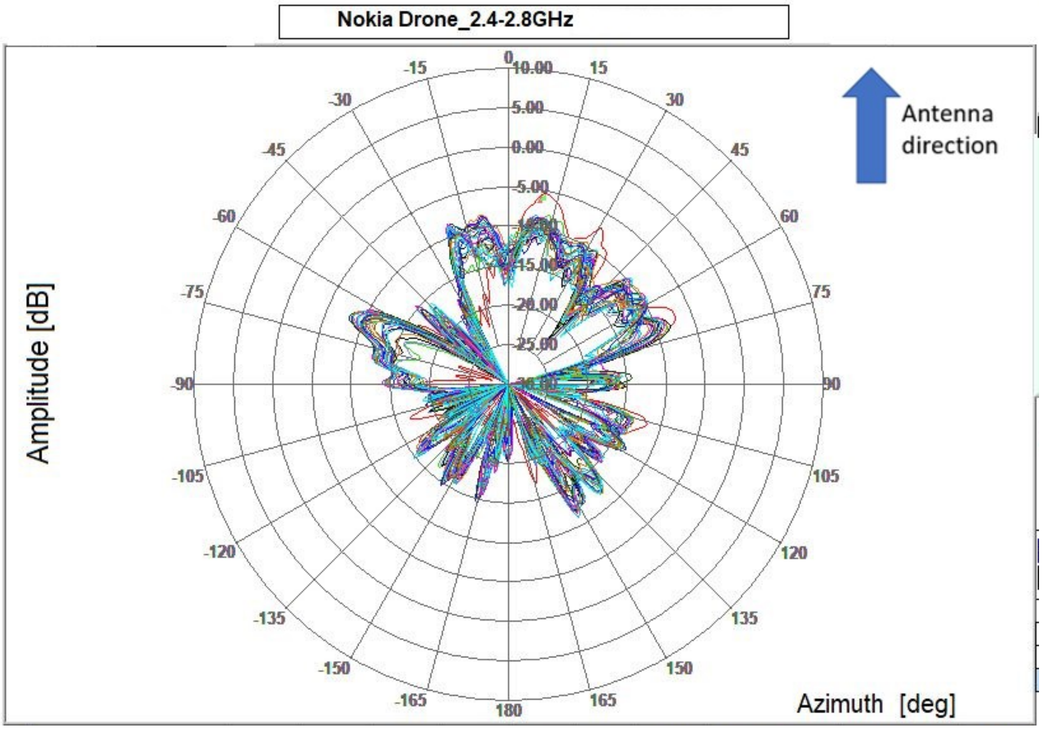

FIGURE 8. Measuring antenna horizontal radiation pattern at 2.4-2.8 GHz

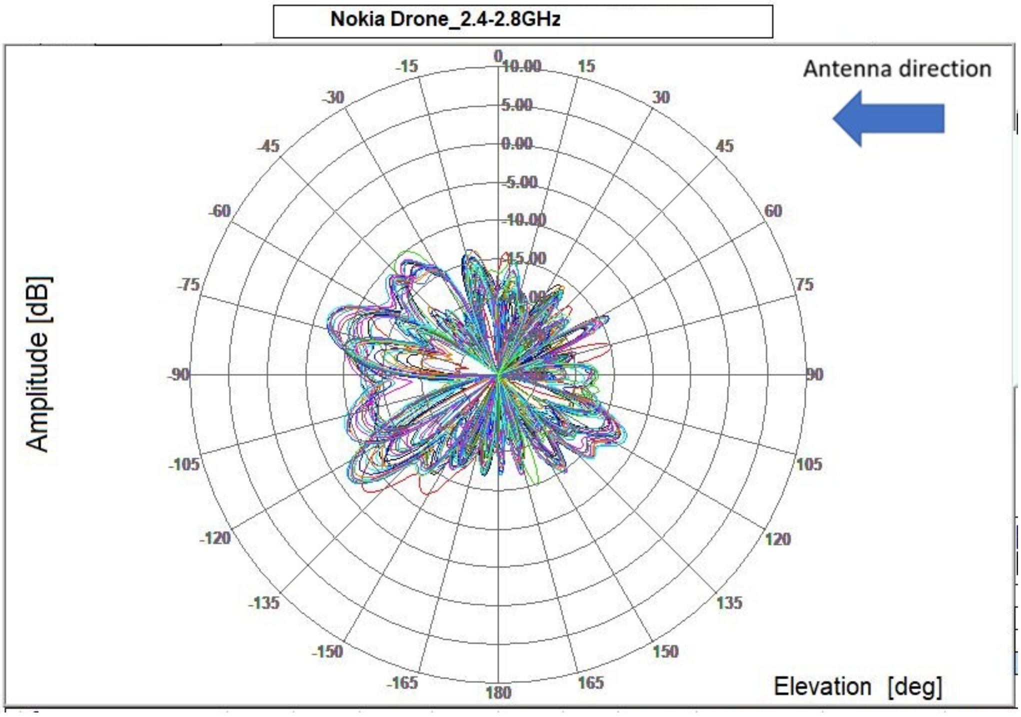

FIGURE 9. Measuring antenna vertical radiation pattern 2.4-2.8 GHz

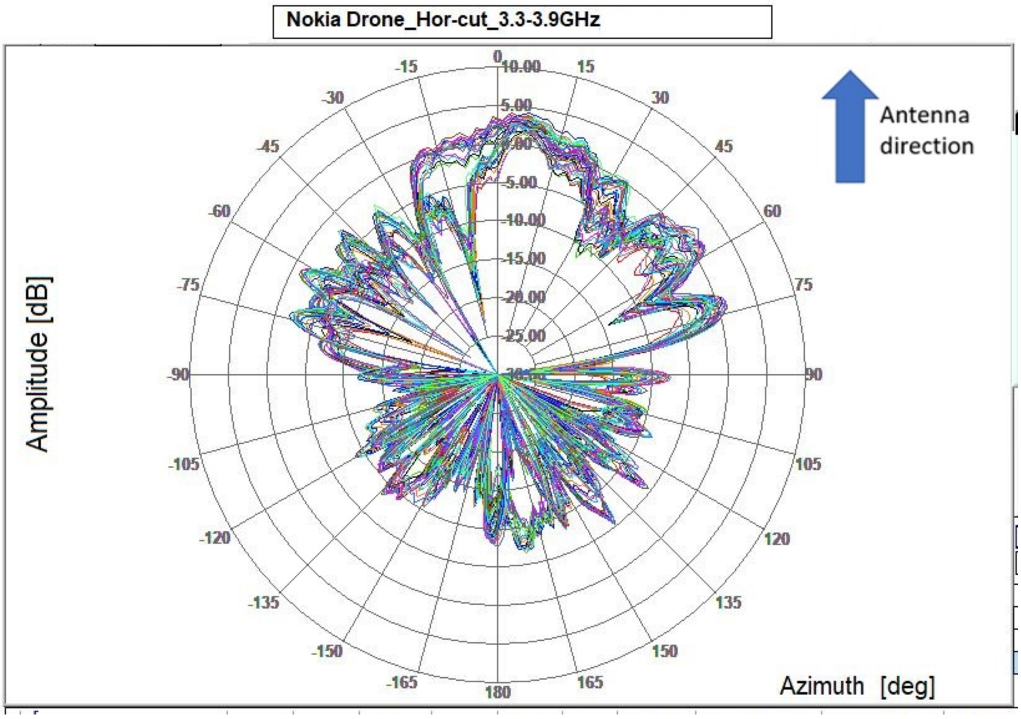

FIGURE 10. Measuring antenna horizontal radiation pattern 3.3-3.9 GHz

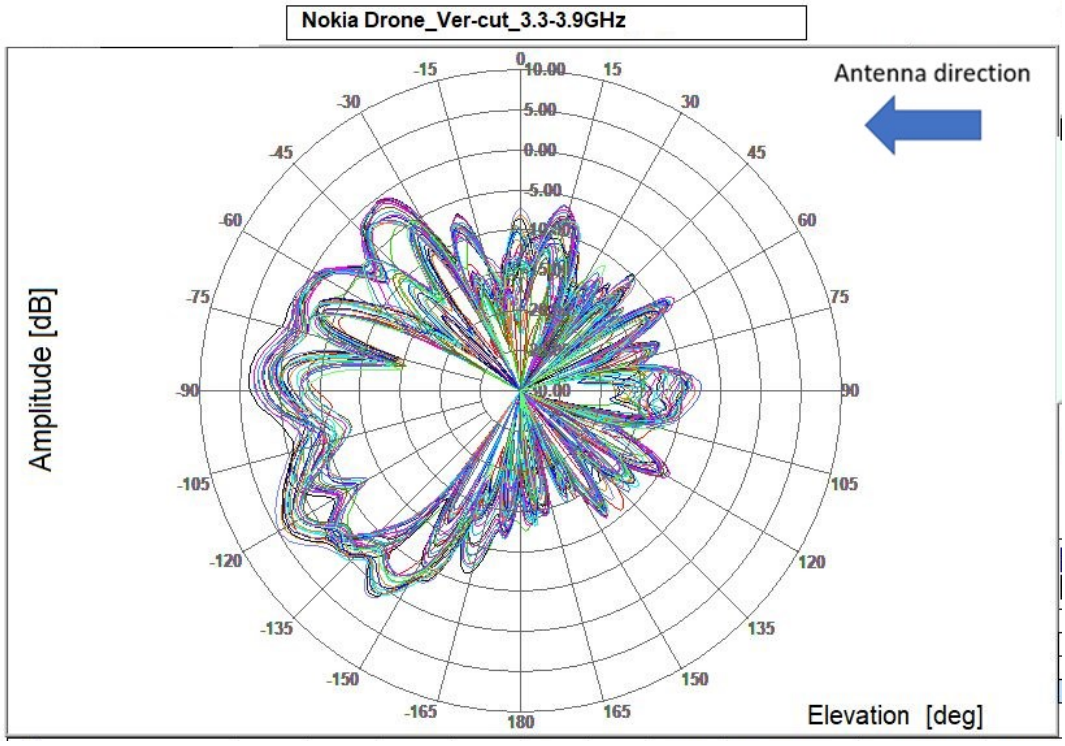

FIGURE 11. Measuring antenna vertical radiation pattern 3.3-3.9 GHz

5.3 Nokia Drone Networks

FIGURE 12. Nokia drone with camera gimbal payload [8]

Nokia Drone Networks is an end-to-end solution comprising Nokia drones [Figure 12], private and secure cellular broadband, cloud connectivity and a control centre, collecting data and information to meet business needs, for example related to security and transport, and to facilitate operations in mission-critical situations, such as in public safety [9].

5.3.1 Nokia Drone

The Nokia drone is a hexa-copter which weights around 8 kilograms and has a flight time up to one hour [Figure 12]. The temperature range is -20°C to +50°C so it is a good tool for field measurements. The drone is customised to fulfil R&D requirements for aerial 5G RF field testing measurements. The Nokia drone uses a private LTE network to send telemetry data to the ground service computer. Using the same network, the drone operator can make a remote connection to the drone payload and control both the drone and measurement.

5.4 Payload Adapter

The communication adapter for the 5G Measuring Antenna Balancing System was designed and made such that it is possible to use other than a Nokia drone to do 5G measurements. The adapter allows the 5G Measuring Antenna Balancing System payload to be connected to almost every other drone. The upper part of the payload in Figure 13 imitates the Nokia drone communication link, so it is possible to undertake a remote desk control of the payload via Nokia's private LTE test network.

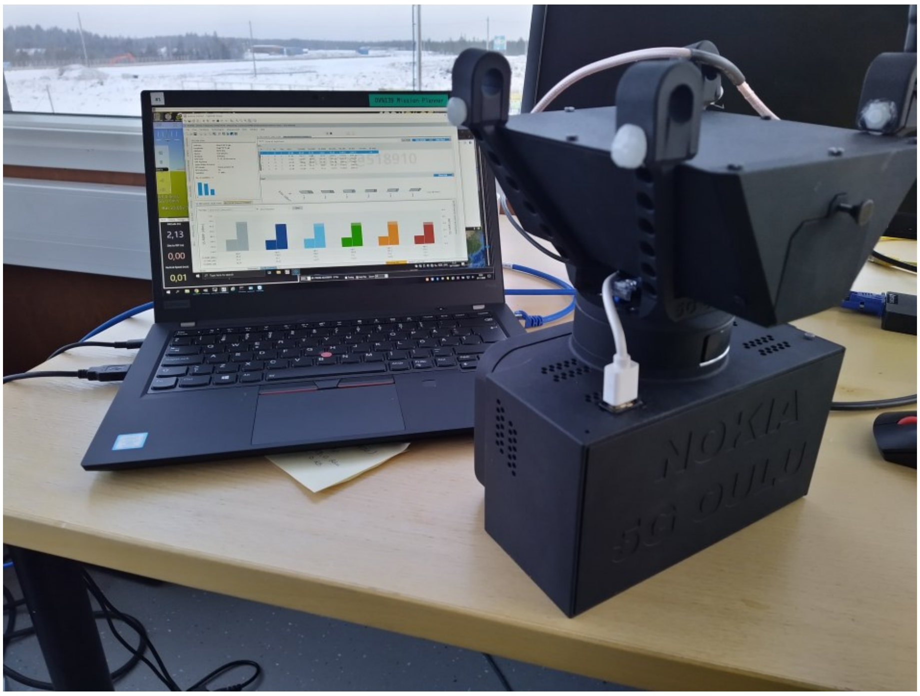

FIGURE 13. R&S ROMES4 software, payload adapter and 5G MABS

5.5 Rohde & Schwarz ROMES4

Rohde & Schwarz ROMES4 is a software platform for network engineering, optimisation and troubleshooting purposes. In combination with UEs and R&S scanners, it provides solutions for coverage measurements, interference identification and QoS [Figure 14]. While measuring and displaying parameters, data and statistics are processed and calculated in real time. [10].

FIGURE 14. ROMES4 software and TSME6 datalogger [10]

5.5.1 Rohde & Schwarz TSME6 5G NR Network Scanner

The 5G NR scanner views show the information obtained in the 5G network scans performed by the R&S 5G NR radio network analyser. The 5G NR network scanner measures SSB power and quality levels [Figure 15]. In the drone usage, this is the main software to measure 5G radio beam patterns and SSB power levels.

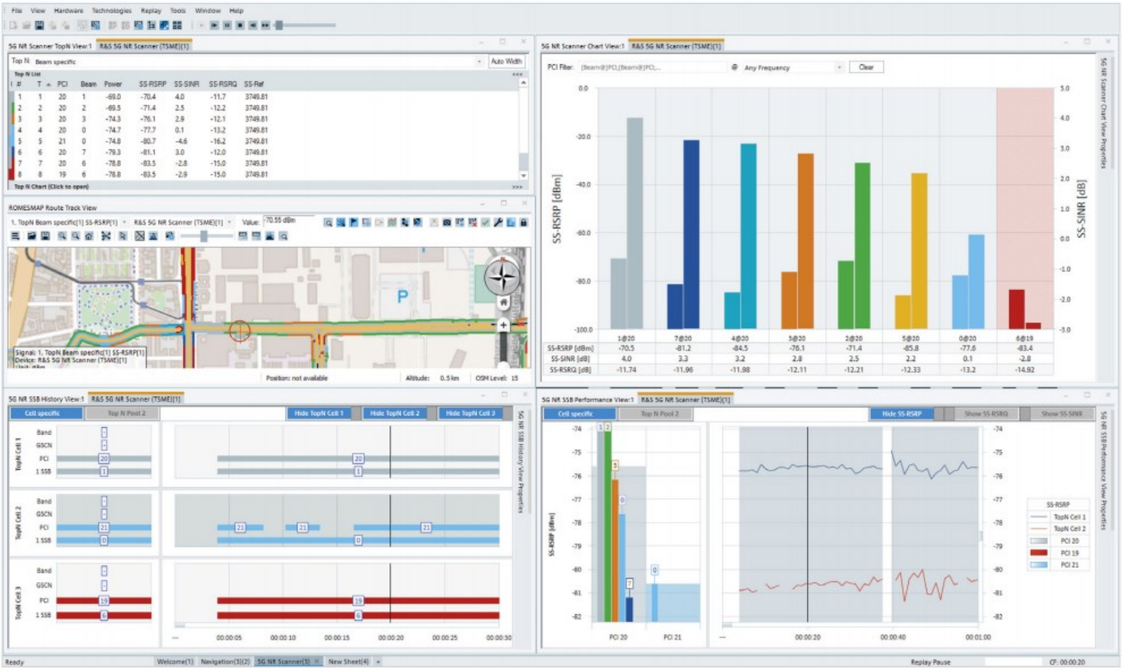

FIGURE 15. 5G NR Network Scanner view [11]

5.5.2 Rohde & Schwarz TSME6 Power Scan

The RF Power Scanner views show the RF power information obtained in the RF power scan performed by the Rohde & Schwarz TSME6 datalogger. The R&S Power Scanner option allows signals to be created for each selected sweep and it also allows a elementary spectrum measurement and analysis. The analysis results are displayed in three different ways in Figure 16.

When measuring RF frequencies, it is useful to know the antenna gain and cable loss. In ROMES4, these parameters can be given to the RF Power Scanner parameters before actual measurements, but these values have no impact on the raw measurement. Values are stored in the measurement file header for later documentation and analysis purposes.

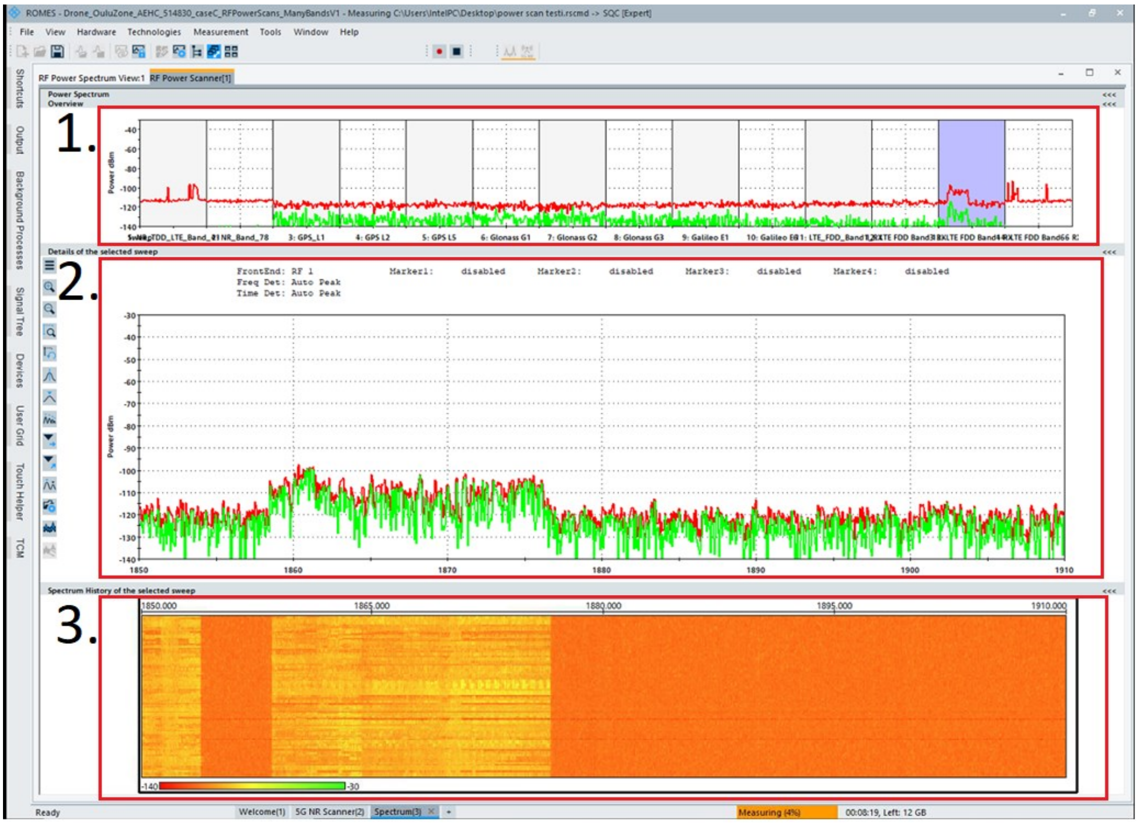

FIGURE 16. Screen capture of ROMES4 Power Scan view

1. Power Spectrum Overview.

   The top section of the view displays an overview of the sweeps which were configured in the driver.

2. Spectrum View.

   The middle section of the view displays the spectrum of the selected sweep in detail.

3. Spectrum History View.

   The bottom section of the view displays the spectrum with a time dimension ("Spectrum History"). The power values are indicated through a colour scale.

The sweeps displayed in the middle and bottom section can be chosen from the list of channels in the top section by clicking on them.

6 PRACTICAL MEASUREMENTS WITH 5G MABS

The main reason to use the 5G MABS on daily measurement flights is that the drone is off-set on the roll axis level because it can compensate for the wind effect by leaning against the wind force. That compensation gives visual [Figure 18] and numerical errors in measurement results as the measurement antenna also follows the drone’s leaning angles [Figure 17]. Pitch axis angle errors have only minimal effect as the drone is flying near or equal to the altitude of the measured radio transmitter. The yaw axis correction is done automatically by the drone. In these practical 5G RF measurements, it is possible to determine that all measured beam sets, radiation patterns, SSB RSRP values, TRP and EIRP are the same as in the radio model datasheet and there are no errors in the different software builds that can affect radio transmitter or other current BTS equipment.

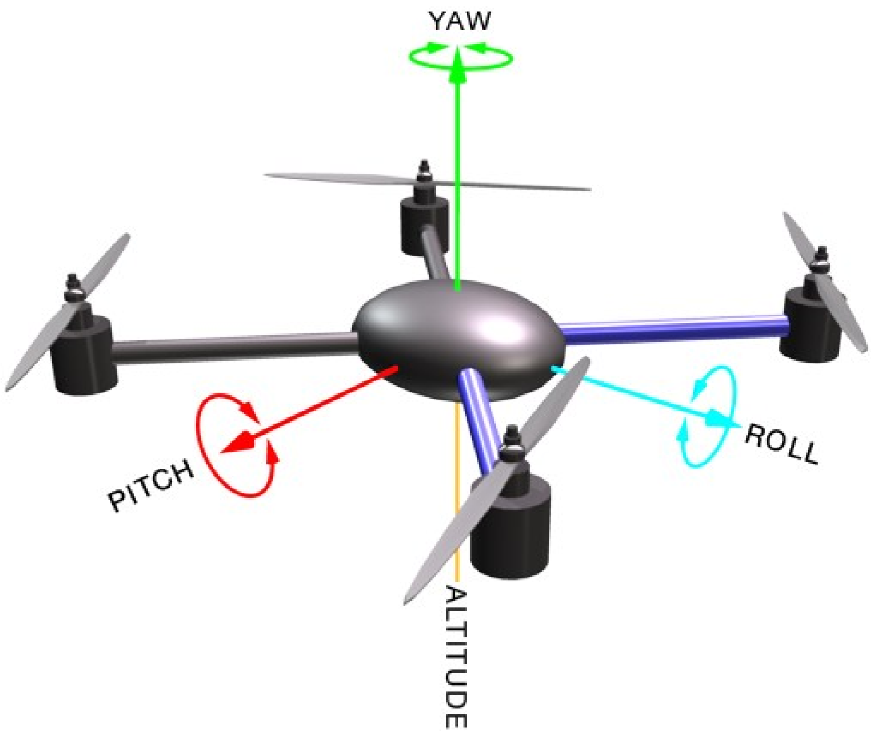

FIGURE 17. Drone leaning angles [12]

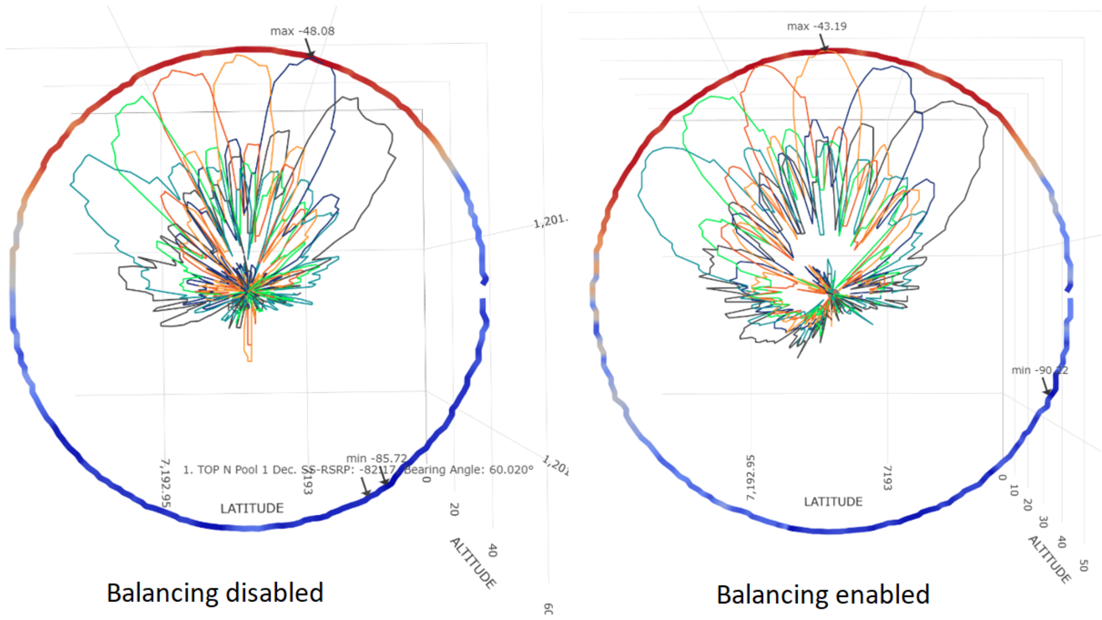

FIGURE 18. 360-degree flights with 5G MABS balancing disabled and enabled

Figure 18 presents an overhead view of two 360-degree measurements where the 5G MABS balancing has been disabled and enabled. Figure 18 clearly shows that when antenna balancing is enabled, the 5G radio beam patterns are smoother.

6.1 5G NR Network Scanner Vertical Cut Measurements

When a new measurement plan is started for a 5G radio, the first procedure is to measure the height of the beams. This is done simply by taking off approximately 50 metres away from the radio and vertically slowly ascending to an altitude of 80 metres. It is important to position the drone in the middle of the radio sector to ensure that the beam height results are precise. At an altitude of 80 metres, the drone slowly descends while measurement is on. Figure 19 presents the vertical cut measurement results. The drone flight route is marked by 1 and the orange SSB RSRP levels by 2. The red circle presents the highest SSB RSRP values, so 5G radio SSB beams are in this case around a height of 58 metres. The zero point of altitude is the GNSS measured Above Mean Sea Level (AMSL).

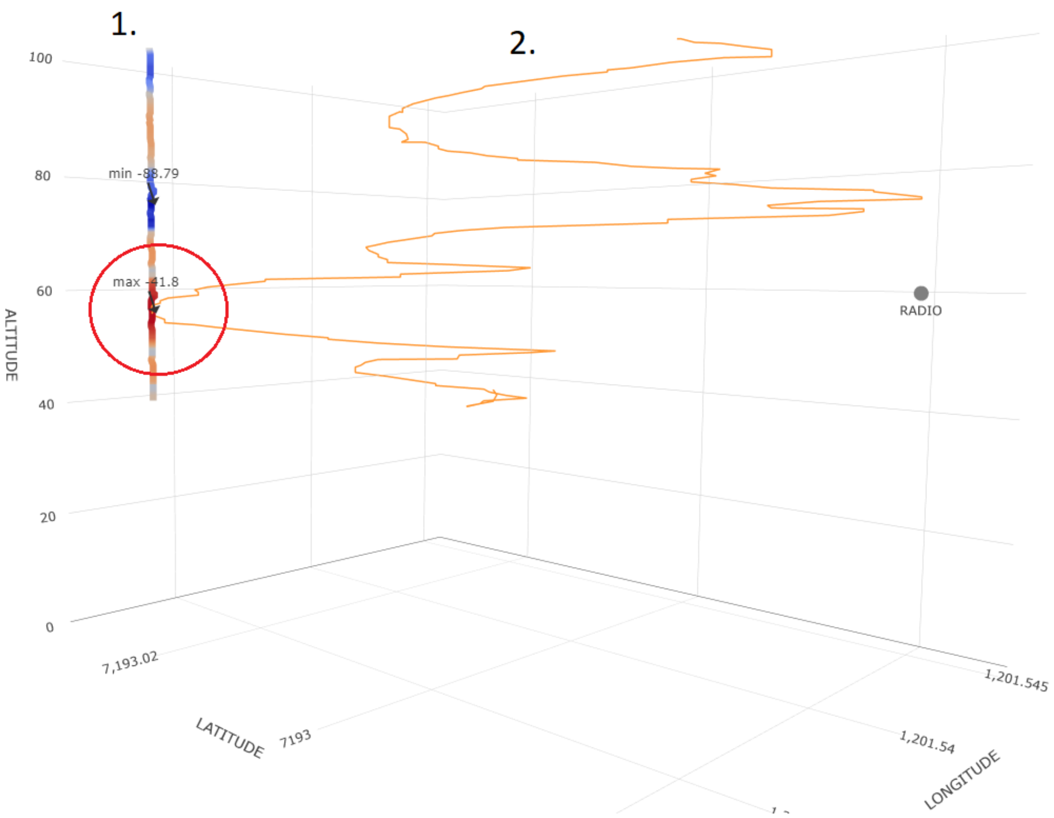

FIGURE 19. Vertical cut

6.2 5G NR Network Scanner Horizontal Cut Measurements

The horizontal cut [Figure 20] is sufficient if the radio side or back lobe is not needed. The horizontal cut automated flight is also faster to perform than a 360-degree flight. The horizontal cut is usually used when it is not possible to perform a 360-degree mission because of obstacles or the possibility of the drone pilot losing the visual line of sight on the drone. Figure 21 presents an overhead view of the horizontal cut measurement results for one of Nokia's 5G radio models.

FIGURE 20. Horizontal cut flight route

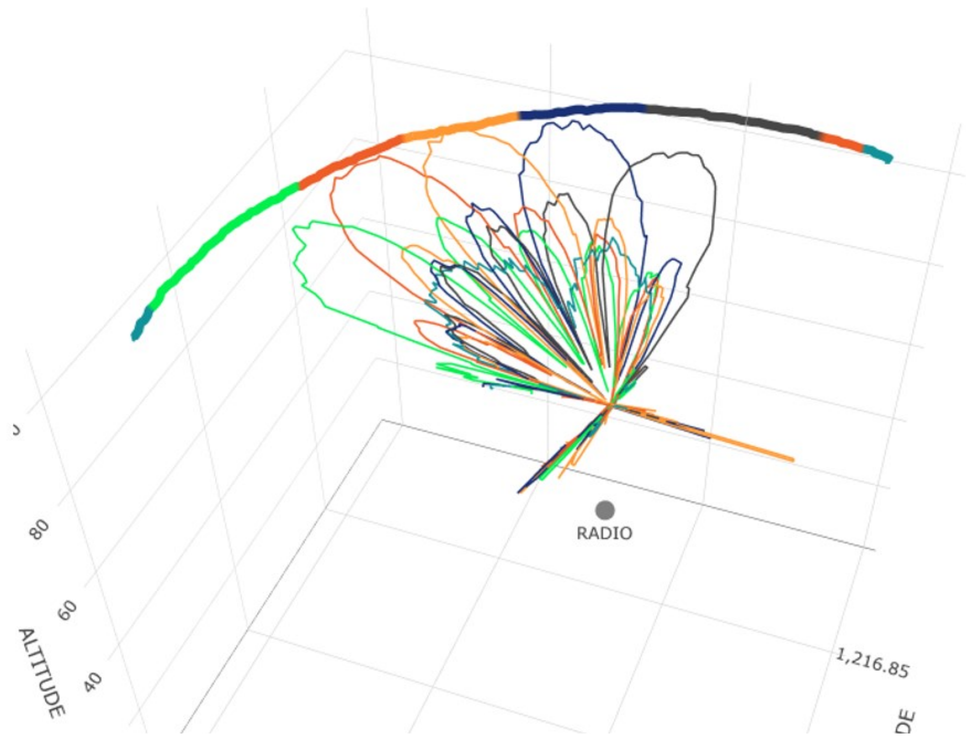

FIGURE 21. Horizontal cut measurement results

6.3 5G NR Network Scanner 360-degree Circle Measurements

The most commonly used flight route for measuring 5G radios is a 360-degree circle around the radio [Figure 22]. On this flight route, it is possible to measure data, such as SSB RSRP and RF power, for the main beams. It is also possible to measure the side and back lobes and beam reflections caused by the environment and different kind of interference. Figure 23 presents an overhead view of the 360-degree flight measurement results for one of Nokia's 5G radio models. The 360-degree measurement result shows 8 beam patterns in different colours and the side and back lobes of that radio model.

FIGURE 22. 360-degree circle flight route

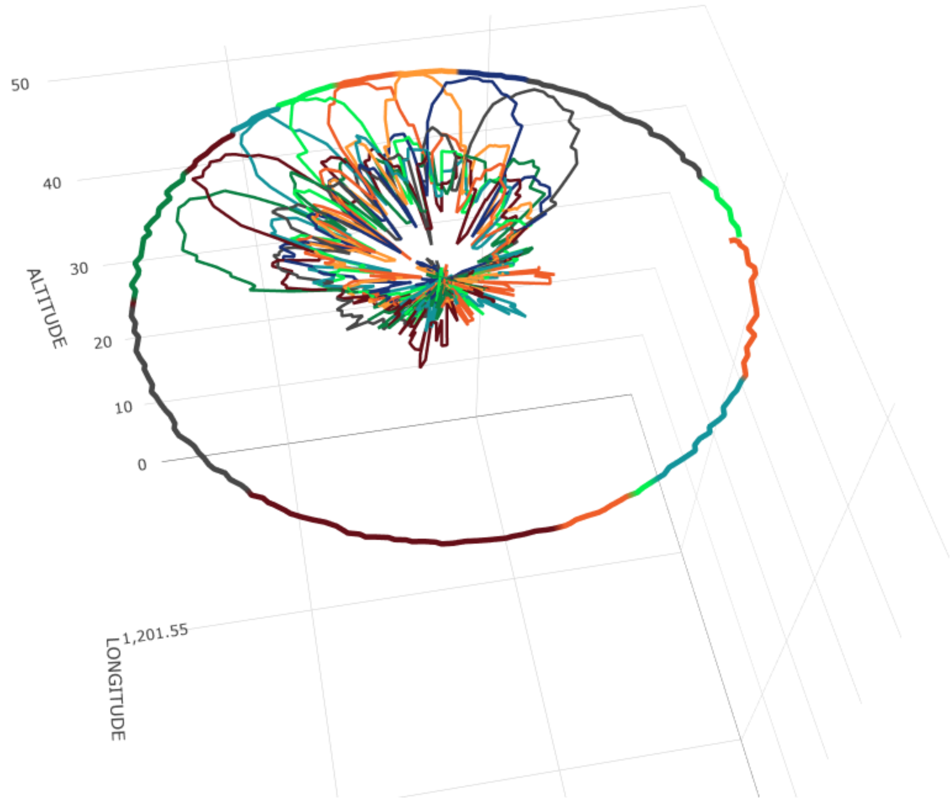

FIGURE 23. 360-degree flight route measurement results

6.4 5G Power Scan Measurements

In this example, the Rohde & Schwarz TSME6 datalogger was measuring 5G NR SSB levels and RF power levels in every SSB beam which was transferring data to a mobile device (UE).

6.4.1 Test Setup

In this setup, the UE was in a static position on the ground under two SSB beam serving directions. When the UE was attached to the 5G service, a data throughput test was activated, and the drone flew a 360-degree automated mission between the radio tower and the UE with 5G NR and Power Scanner active [Figure 24]. The total radiated power and effective isotropic radiated power were calculated from the measurement result to confirm that the 5G radio model datasheet values matched the measured field values.

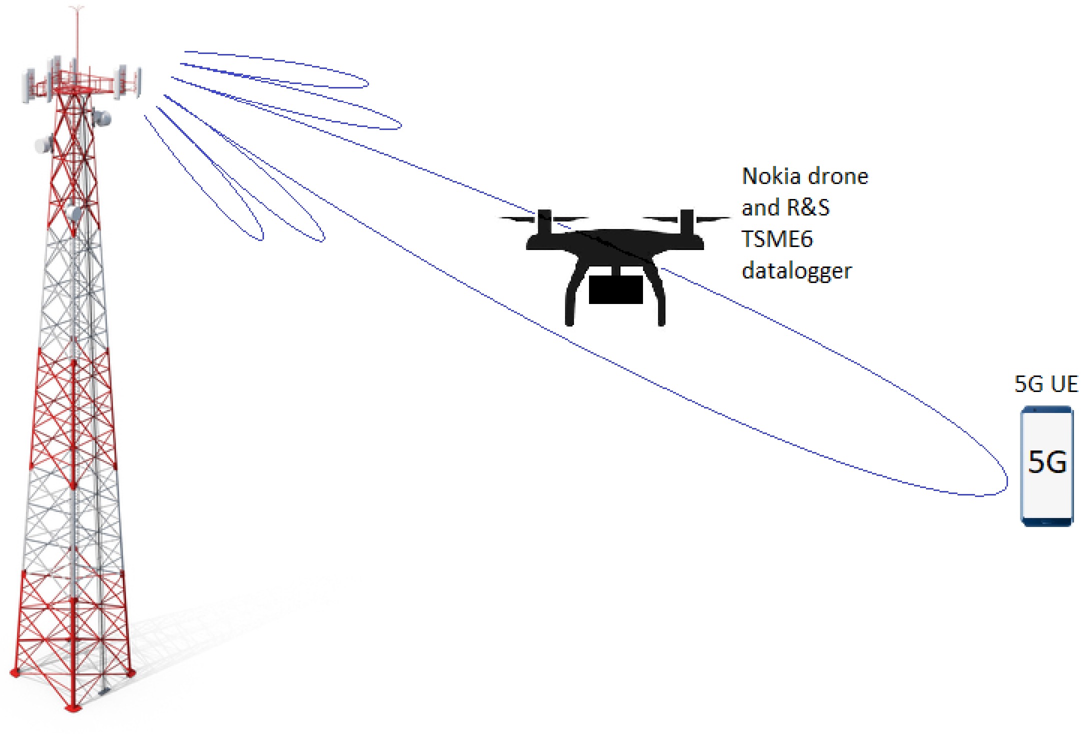

FIGURE 24. Test setup

6.4.2 Results

In Figure 25, the results are visualised in a 180-degree view, when only the main lobes are visible. The blue line shows the NR SSB RSRP levels and the orange line the RF Power Scanner power levels. Figure 25 shows that RF power is transmitted via SSB#0 and SSB#1 at -38 dBm to the UE.

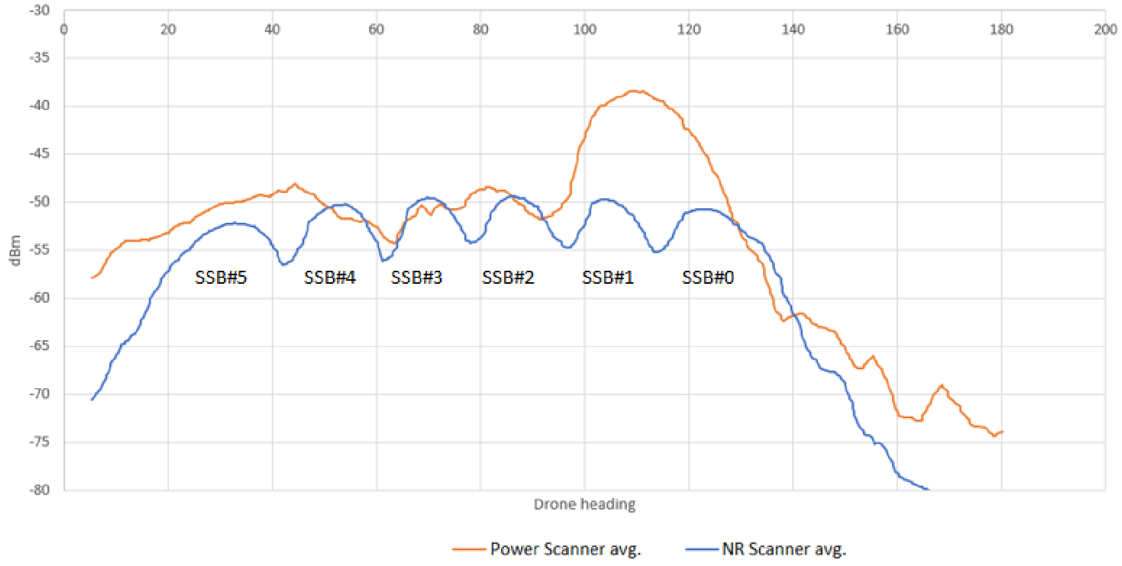

FIGURE 25. Power Scanner and NR RSRP results

7 UNWANTED EMISSIONS

Radio transmitters emit radio frequency signals that may also cause unwanted radio frequency interference to some radio receivers. Because of unwanted emissions and limited radio frequency bands, country, regional and even global official regulators are needed. At the country level, the regulator mainly checks the frequency, bandwidth, output power and unwanted emissions, which consist of spurious emissions and out-of-band emissions. The fundamental concern in regulating RF systems is unwanted emissions because their levels affect the appropriate introduction of any new system. Figure 26 presents the boundaries of these emissions. [13].

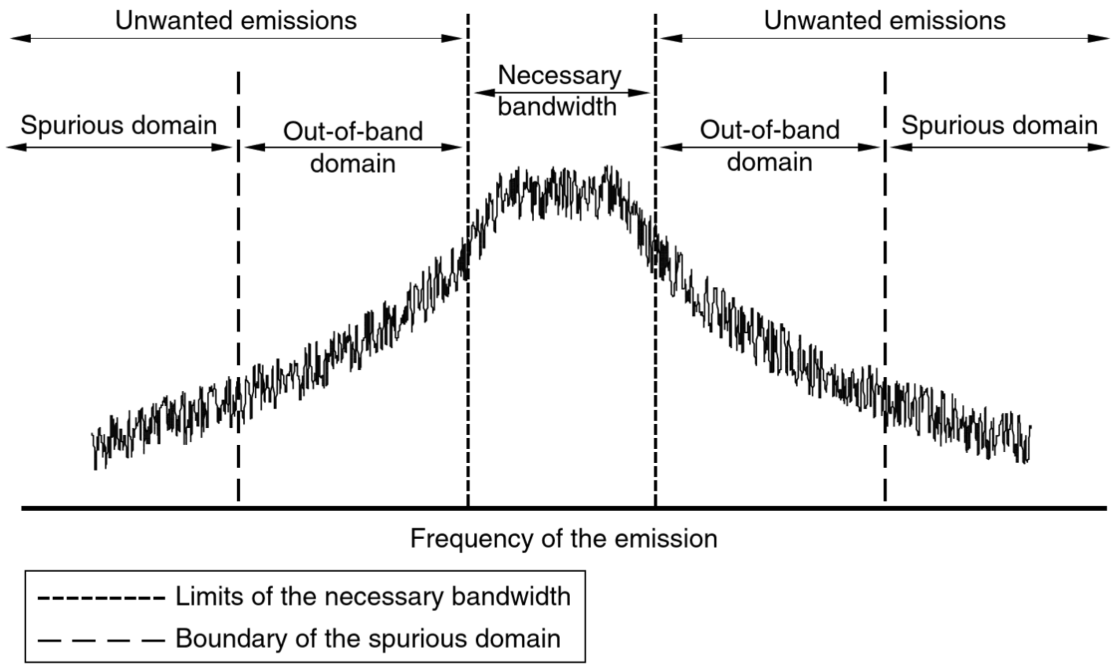

FIGURE 26. Unwanted emission limits [13]

7.1 Out-of-band Emissions

An out-of-band emission is an emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, excluding spurious emissions. In Figure 27, any emission outside the necessary frequency bandwidth which occurs in a range from the assigned frequency of the emission by less than 2.5 times the necessary bandwidth of the emission will be considered an emission in the OoB domain. [14].

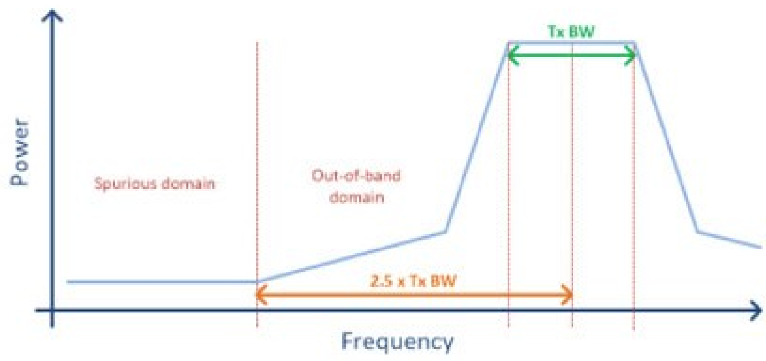

FIGURE 27. Out-of-band domain [15]

7.2 Spurious Emissions

A spurious emission is an emission on a frequency or frequencies which are outside the necessary bandwidth, the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions. All these emissions which fall at frequencies separated from the centre frequency of the emission by 2.5 times or more of the necessary bandwidth of the emission will be considered emissions in the spurious domain. [14]. Figure 28 presents transmission spurious emission limits according to 3GPP standards.

Band	Maximum Level
1000 MHz ↔ 2100 MHz	-30 dBm
2100 MHz ↔ 2102.5 MHz (Fc1 - 50 MHz)	-25 dBm
2102.5 MHz ↔ 2140 MHz	-15 dBm
2140 MHz ↔ 2165 MHz	47 dBm (TX signal)
2165 MHz ↔ 2180 MHz	-15 dBm
2180 MHz ↔ 12.75 GHz	-30 dBm

FIGURE 28. Limits for spurious emissions close to the 3GPP transmit channel [16]

8 OUT-OF-BAND MEASUREMENTS

Out-of-band field measurements were conducted in the Rusko and OuluZone area. During measurement flights, the Rohde & Schwarz datalogger measured the 5G radio bandwidth, unwanted emissions and transmit power levels. The measuring device was a Rohde & Schwarz TSME6 datalogger with a balanced measuring antenna system inside the drone measurement payload. The Nokia 5G radio “Artificial Load” feature was used during these measurements. With that feature, the radio transmits at the maximum RF power without the need for data transfer between the 5G radio and the UE.

8.1 Rusko Area Measurements

The Rusko area measurements were conducted using one of the Nokia 5G radio types, operating in the n78 band. The 5G NR n78 bandwidth is 3,300-3,800 MHz.

8.1.1 Test Equipment Parameters

Drone 360-degree flight parameters:

- Altitude: 28 metres
- Radius: 50 metres
- Groundspeed: 1.5 metres/second
- Datalogger measuring antenna orientation towards the tower

Rohde & Schwarz TSME6 Power scanner settings:

- Max Measurement Rate: 50 Hz
- Max Visualisation Rate: 50 Hz
- Bandwidth: 20,000,000 Hz (20 MHz)
- Sample Rate: 23,000,000 Hz
- FFT size 1024 (22.460 kHz) *

- Start Frequency: 3,300 MHz
- Stop Frequency: 3,800 MHz
- Frequency Detector: Auto Peak
- Measuring antenna attenuation: 20 dB

*Fast-Fourier-Transformation (FFT) size and sample rate, it is possible to adjust the frequency resolution of the spectrum.

8.1.2 Rusko Band n78 Results

The 5G radio was transmitting in a bandwidth of 60MHz between 3,510-3,570 MHz. When the -20dB antenna line attenuator was calculated from the results, the radio was transmitting the RF power at a level of -50 dBm (Figure 29). The purple line presents the whole 360-degree flight envelope results. It shows all RF power spikes in the measured bandwidth. Figure 29 presents exactly what is given in the radio parameters. In the Rusko area, there is a large amount of other network operators' traffic in band n78 and possible interference coming inside the Nokia laboratories (Figure 29, Number 2), so it is hard to investigate any possible unwanted emissions that the radio is transmitting in the Rusko area. What can be confirmed in the Rusko area measurements is that the radio is transmitting at exactly the right bandwidth. The background noise level is -130 dBm when the -20 dB attenuator is calculated off.

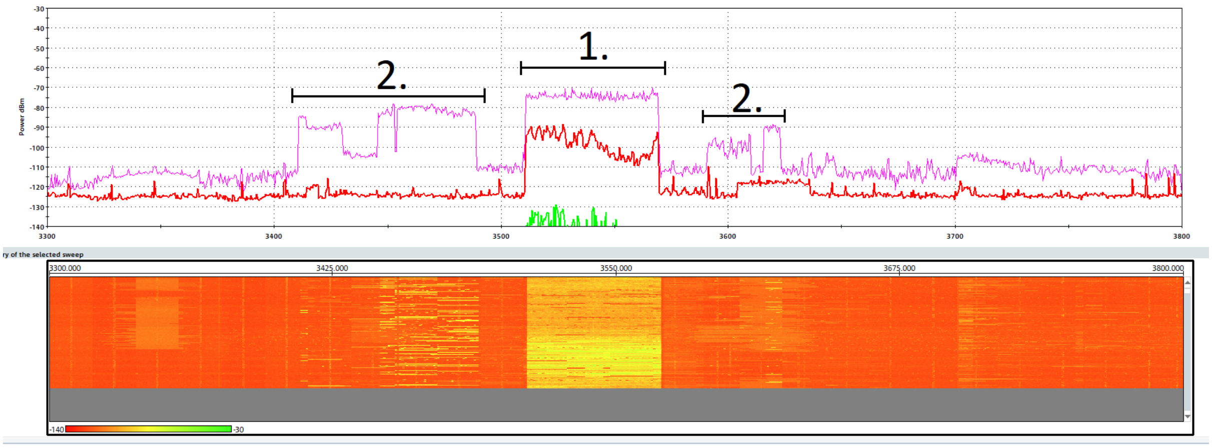

FIGURE 29. Rusko area band n78 results

8.2 OuluZone Area Measurements

The OuluZone area measurements were conducted with one of the Nokia 5G radio types, operating in the n41 band. The 5G NR n41 bandwidth is 2,496-2,690 MHz. The measured 5G radio model has 5G and LTE concurrent modes. LTE operates in the b41 band. The LTE b41 bandwidth is 2,496-2,690 MHz. In this case, the LTE side acts as a drone network so it is possible to get telemetry and payload data to the ground control.

8.2.1 Test equipment parameters

Drone 360-degree flight parameters:

- Altitude: 34 metres
- Radius: 50 metres
- Groundspeed: 1.5 metres/second
- Datalogger measuring antenna orientation towards the tower

Rohde & Schwarz TSME6 Power scanner settings:

- Max Measurement Rate: 50 Hz
- Max Visualisation Rate: 50 Hz
- Bandwidth: 20,000,000 Hz (20 MHz)
- Sample Rate: 23,000,000 Hz
- FFT size 1024 (22.460 kHz) *
- Start Frequency: 2,496 MHz
- Stop Frequency: 2,690 MHz
- Frequency Detector: Auto Peak
- Measuring antenna attenuation: 0 dB

*Fast-Fourier-Transformation (FFT) size and sample rate, it is possible to adjust the frequency resolution of the spectrum.

8.2.2 OuluZone Band n41/b41 Results

The 5G radio was transmitting in a 60 MHz bandwidth between 2,545-2,605 MHz and the radio was transmitting power of -45 dBm (Figure 30). The purple line presents the whole 360-degree flight envelope results. It shows all RF power spikes in the measured bandwidth. In Figure 30, the 5G side bandwidth is marked 1 and the LTE side 2 at 2,620-2,640 MHz. Number 3 presents passive intermodulation. Passive intermodulation occurs when two or more signals are present. The signals will mix or multiply with each other to generate other signals that are related to the first ones [17]. In this case, passive intermodulation is happening between the NR + LTE signals. In the worst case, the PIM can block calls or even create interference that will reduce a cell's receiving sensitivity. The PIM interference can affect both the cell that creates it and other nearby receivers. High transmission powers create PIM, so on-site testing needs to be done to make sure that the test reveals any PIM issues [18]. In figure 30, low power out-of-band RF spikes are marked 4 and these do not affect the operation of the 5G radio. The background noise level is -130 dBm. [Appendix 2].

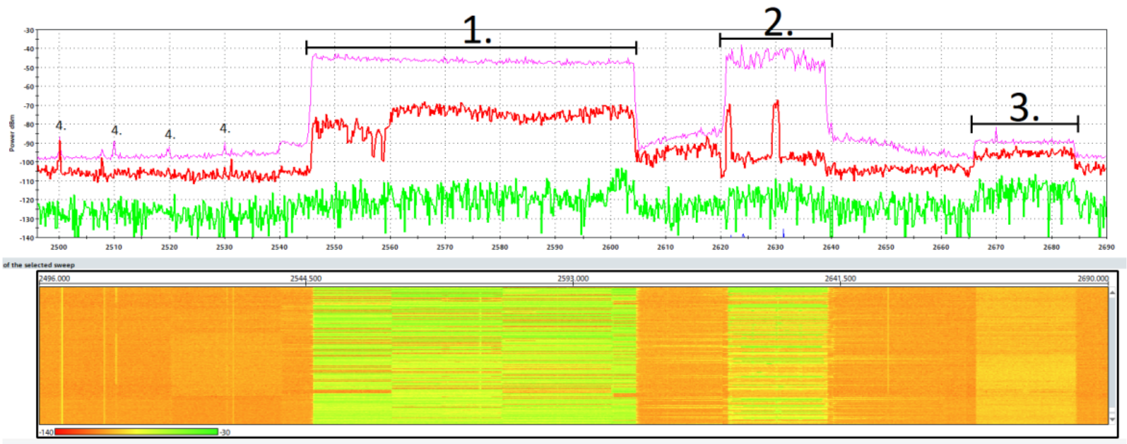

FIGURE 30. OuluZone band n41/b41 results

8.2.3 OuluZone 2,200-3,000 MHz Results

In this measurement, the radio and measurement equipment settings were the same as for the band n41/b41 tests but the measurement bandwidth was 800 MHz at 2,200-3,000 MHz. The purple line presents the whole 360-degree flight envelope results. It shows all RF power spikes in the measured bandwidth. In figure 31, 1 marks the NR side of the radio and 2 the LTE side. Number 3 presents the passive intermodulation and 4 the out-of-band and spurious emissions. With a longer bandwidth it is possible to detect more out-of-band and spurious emissions, although the emissions are so far away on the radio spectrum and low power so that in this case they do not affect the operation of the 5G radio.

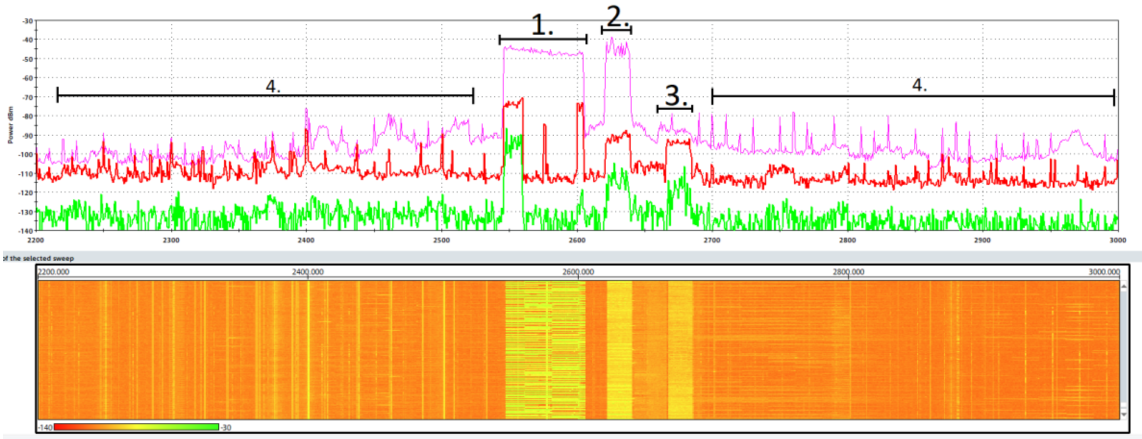

FIGURE 31. OuluZone 2,200-3,000 MHz bandwidth results

8.2.4 OuluZone GPS L1 and L2 Band Results

The L1 and L2 GPS bands were also measured in the OuluZone tests on the same flight. The GPS L1 bandwidth is 1567.7475-1583.0925 MHz and L2 is 1222.1-1233.1 MHz. The purple line presents the whole 360-degree flight envelope results. It shows all RF power spikes in the measured bandwidth. Figure 32 presents the GPS L1 band and Figure 33 the GPS L2 band measurement results. The GPS L1 band spectrum is clean, but two RF spikes are visible in the GPS L2 band spectrum. These can indicate that 5G radio is transmitting interference frequency in the GPS-dedicated bands. In Figure 33 1 marks peak power of approximately -85 dBm and 2 marks -80 dBm. The Nokia drone uses a uBlox ANN-MB series multi-band, high-precision GNSS antenna with an LNA gain of 28±3 dB [19]. When GPS antenna gain is added to 1 and 2 of Figure 33 RF spikes, the real GPS interference level is around -50 dBm. This rarely causes any GPS errors because the drone GPS antenna is multi-band, so it works on both the L1 and L2 bands at the same time. Devices with only one GPS band support, such as some mobile phones, smart/sport watches and car navigators, may be affected by these interference spikes. It is a known problem that some radios operating NR bands which are close or directly next to GPS bands cause interference problems, such as bad accuracy and GPS position wandering [20].

FIGURE 32. GPS L1 band

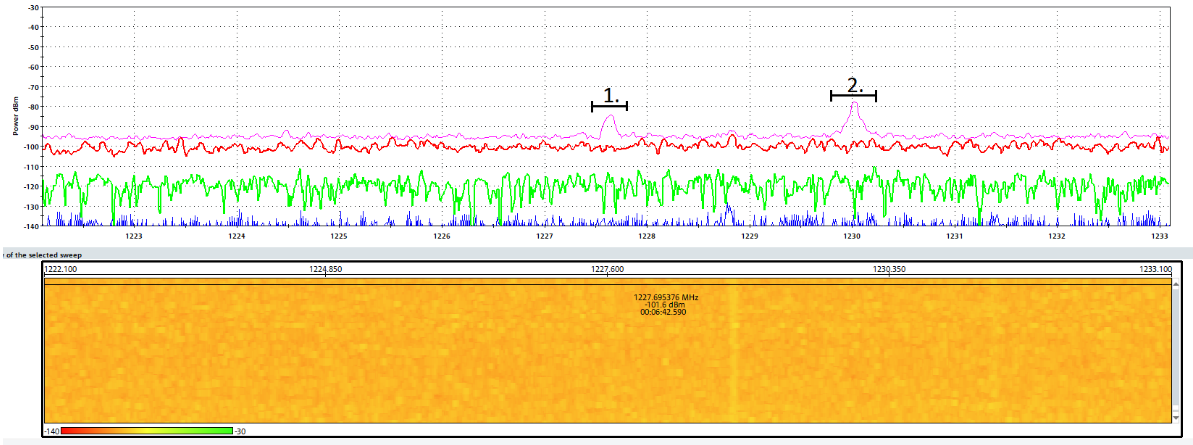

FIGURE 33. GPS L2 band

8.3 Alternative Measurement Technique

More precise and advanced unwanted emission testing can be done in the laboratory environment, where a fixed spectrum analyser and the measured radio are in the same calibrated and RF-noise-free chamber. Fixed spectrum analysers also have multiple times more measurement accuracy than the handheld datalogger used with the drone. Fixed and a few handheld spectrum analysers can measure power spectral density (PSD). PSD is the measure of signals power content versus frequency. A PSD is typically used to characterise broadband random signals [21]. The measurement unit of PSD is dBm/Hz or dBm/MHz. It provides a ratio of the power in one Hertz/Megahertz of bandwidth, where power is expressed in units of dBm. This measurement can bring out more RF noise and interference.

In the measurement example in Figure 34, the equipment under test (EUT) was set up on a non-conductive support, in this case a tilt device at 1.5 metres high in a fully anechoic chamber. The antenna distance is 3 metres. The turntable angle range is -180º to 135º and the step size is 45º. The horizontal and vertical polarisations are also measured. [22].

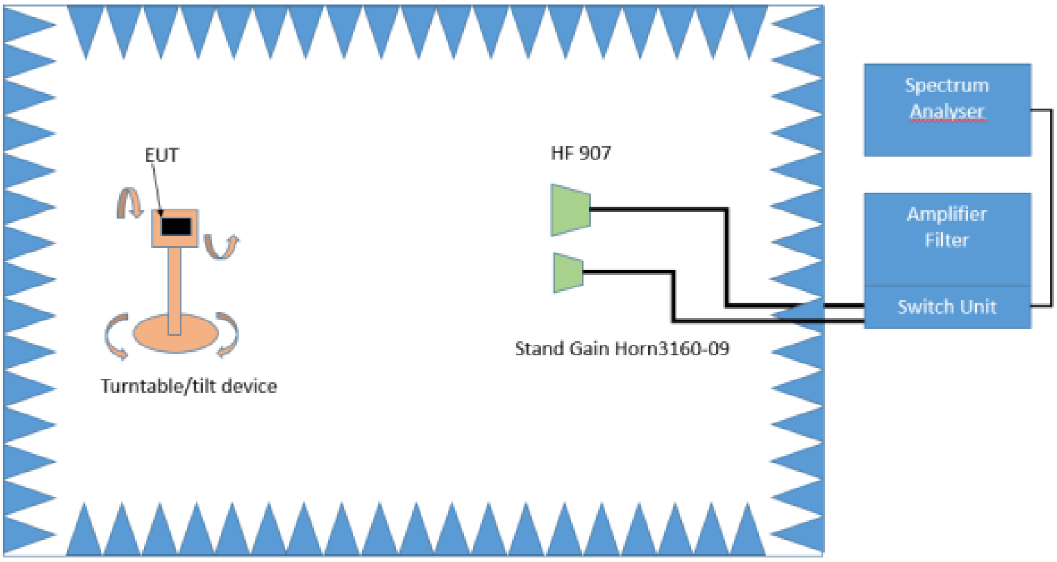

FIGURE 34. Test setup: Measuring spurious emissions at 1 GHz-26.5 GHz [22]

9 CONCLUSION

Out-of-band and spurious emissions on Nokia 5G radios were investigated and measured using a drone and, as internal documents, a user guide to 5G MABS and a measurement report were created.

Drone OoB measurements give a good overall picture of radio emissions. TSME6 measurement spectral accuracy is not as good as with fixed spectral analysers, but it is still a good tool for investigating unwanted emissions in field conditions. The user guide for the 5G MABS payload gives good instructions to the drone field testing team on how to use it and what to do when there are technical problems with the payload. The measurement report for the measured 5G radio was a more detailed document for the results, with radio software build, more precise TSME6 logger settings and other internal parameters visible.

The number of measurement flights remained low because around the Rusko area test tower, there is too much external interference and the OuluZone test area has a high reservation rate for other 5G field testing. External RF interference in city areas is the largest problem when measuring unwanted emissions with the drone. Measuring in rural areas where there are no other RF sources, or it is well-known what frequency other RF sources are operating on and where they are coming from, helps analysing of the measurement results. OuluZone area is a valuable place to measure 5G radios because there are no other RF transmitters at the same time as drone measurements are being done. It would have been useful to measure more 5G radios, but the OuluZone area is highly reserved by Nokia and other users such as motorsports activities.

This thesis gave the author an excellent experience in investigating and measuring RF emissions. OoB measurements on more 5G radio models will continue in the future when there is more time and new radios are installed in the OuluZone area. New unwanted emissions standards are coming and changing as new 5G frequencies are released, so it is important to stay up to date.

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10 APPENDICES

Appendix 1. User guide to 5G MABS. Nokia internal document

Appendix 2. Nokia 5G radio OoB measurement report. Nokia internal document