Field Trial Report

Indoor 5G Network using 600 MHz Band – Coverage, Performance, and Interference Analysis on Adjacent Channel TV Signals

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2.0	20 Feb., 2024	Minor Revision
2.1	11 Jun., 2024	Minor Revision

List of Acronyms and Abbreviations

5G	Fifth Generation Mobile Network / Mobile Services
ACLR	Adjacent Channel Leakage Ratio
BW	Bandwidth
CA	Communications Authority of Hong Kong
CABD	Communal Aerial Broadcast Distribution
CATV	Community Antenna television
CDF	Cumulative Distribution Function
DTMB	Digital Terrestrial Multimedia Broadcast
DTT	Digital Terrestrial Television
E.I.R.P	Effective Isotropic Radiated Power
EMF	Electromagnetic Field
ERP	Effective Radiated Power
FDD	Frequency Division Duplexing
FHOB	Freight Head Office Building
FPSL	Free Space Path Loss
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
MIMO	Multiple-Input-Multiple-Output Antenna
MNO	Mobile Network Operator
NIR	Non-ionizing Radiation
OFCA	Office of the Communications Authority
RBS	Radio Base Station
RSRP	Reference Signal Received Power
R&S	Rohde & Schwarz
SA	Standalone
SINR	Signal to Interference & Noise Ratio
SMATV	Satellite Master Antenna Television
UHF	Ultra-High Frequency

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Executive Summary

In Hong Kong, the 600 MHz band (specifically, the 617 - 698 MHz range) has not yet been assigned for mobile services at the time of this report's writing. At the same time, MTR Corporation envisions to utilize dedicated 5G network technology for indoor factory applications, which will enhance connectivity and improve operational efficiency. Using the 600 MHz band for indoor applications only becomes an attractive option. But the premise is to conduct a comprehensive field test study to ensure that 5G signals outside the building will not cause any interference to adjacent channels TV signals. To this end, ASTRI collaborated with the MTR Corporation and selected the Freight Headquarters Building (FHOB) as the trial site to conduct 5G indoor network testing and simulation using the 600 MHz frequency band to evaluate coverage, performance, and interference analysis of adjacent channel TV signals.

The objective of this field trial report is to explore and provide all technical issues related to the indoor deployment of 5G private networks using the 600 MHz frequency band, while being able to coexist with TV broadcasting services and ensuring that the signal quality of adjacent channel TV signals does not deteriorate. This field trial report covers 5G indoor network testing scenario using network simulator and antennas, field measurements to evaluate 5G indoor cell coverage and throughput, field measurements to investigate the impact of 5G signals on adjacent channels TV signals outside FHOB, and NIR levels in FHOB publicly accessible areas. It is confirmed that the 600 MHz frequency band can provide high-quality coverage and throughput performance on indoor area, while the impact of 5G signals on adjacent channels TV signals on outside area is negligible. The main text of this report summarizes the findings as follows:

- Based on research and field investigation, FHOB was selected for field trials and detailed studies. The building is in a rural area and is unlikely to interfere with public users; the surrounding areas have different terrain heights, making it convenient to test different transmitter and receiver scenarios; and the surrounding space is open enough to facilitate on-site measurements.

- Network simulation and antenna are adopted to mimic a 5G indoor system in the trial site, and frequency band uses 600 MHz and 20 MHz bandwidth paired spectrum. The antenna transmit power is set to less than or equal to 2 Watts (i.e., 33 dBm) EIRP.

- Field measurements were conducted to investigate the coverage (e.g., RSRP and SINR) and throughput at 11 test points in the FHOB. The results show that the peak downstream throughput is 93 Mbps.

- Field measurements were conducted at 6 test points outside the FHOB at different distances and heights from the FHOB to investigate interference on adjacent channels TV signals. The results showed that the impact on the TV signal was negligible and that all adjacent channels TV signals had a quality level of 5 (the highest level).

- Field measurements were conducted for investigation of NIR levels generated from the RBSs at 11 testing points in FHOB. The results showed that the associated NIR levels were less than 0.87% of the ICNIRP compliance level.

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1 Introduction

1.1 OFCA's Assignment of the Spectrum 600 MHz

Office of the Communications Authority (OFCA) made a statement of "Arrangements for Assignment of the Spectrum in the 600 MHz and 700 MHz Bands for the Provision of Public Mobile Services and the Related Spectrum Utilisation Fee" on 30 March 2021. This Statement promulgates the decision of the Communications Authority (CA) on the allocation of the 614 – 806 MHz band to mobile service on a primary basis and the associated arrangements for assignment of a total of 140 MHz of spectrum comprising 2 x 35 MHz of spectrum in each of the ranges 617 – 652 MHz paired with 663 – 698 MHz ("600 MHz band") and 703 – 738 MHz paired with 758 – 793 MHz ("700 MHz band") (collectively referred to as the "600/700 MHz bands") for the provision of public mobile services including the fifth generation (5G) services.

Indoor 2 * 35 MHz N71[1] FDD pairs 617-652 and 663-698 MHz was proposed for 2021 auction. The entire proposed N71, however, remains unoccupied after the auction and vacant until present. At the time of this report's writing, the 600 MHz band has not been allocated for mobile services.

1.2 5G Deployment for Indoor Warehouse/Factory Applications

Despite the surge in 5G users in recent years and the rapid expansion of new generation networks, public network coverage in warehouses and factories located in remote areas is still weak. Due to the relatively limited number of users and low profit margins, Mobile Network Operators (MNOs) are unlikely to deploy new base stations over coverage issues in warehouses or factories.

At the same time, many factory applications require real-time data transmission between machines or control systems, especially when developing smart factories with many sensors, robots, and Internet

[1] The term "N71" refers to the 600 MHz frequency band (range 617 - 698 MHz) used for 5G wireless communications in FDD mode. In this report "N71" and "600 MHz band" are used equivalently.

of Thing (IoT) devices. In addition, factory applications with sensitive information or trade secrets often require a higher level of security. 5G private networks provide powerful, tailored security measures in terms of physical layer, transmission, and protocol stacks.

1.3 Advantages of 5G on 600 MHz Band

The 600MHz band is considered useful for 5G indoor factory usage due to several factors:

- **Coverage**: The lower the frequency, the better the signal propagation characteristics. The 600MHz spectrum has better coverage and penetration characteristics, allowing signals to penetrate walls and other obstacles more easily.
- **Cost-Efficiency**: Deploying 5G infrastructure in lower frequency bands is more cost-effective than deploying in higher frequency bands because lower frequency bands require fewer base stations and provide wider coverage. In addition, compared to Wi-Fi systems using active antennas, the 600 MHz band can use traditional antenna systems with lower construction and maintenance costs.
- **Availability:** The availability of spectrum can also impact the decision. If the 600 MHz spectrum is more readily available and less expensive to acquire compared to higher frequency bands in Hong Kong, this can make it an attractive option. Section 1.1 has discussed this aspect.

1.4 Potential Interference on TV Signals

TV signals in Hong Kong primarily operate on the UHF (Ultra High Frequency) band, which include frequencies ranging from 470MHz to 862MHz. This means that some TV signals in Hong Kong may fall within or nearby the 600MHz spectrum (see Table 1).

The deployment of 5G in the 600MHz spectrum is susceptible to cause interference on adjacent channels TV signals, especially if proper mitigation measures are not implemented. Interference can manifest as degraded TV reception, pixelation, or complete signal loss.

Therefore, a field trial study is necessary to explore and provide all technical issues related to the indoor deployment of 5G private networks using the 600 MHz frequency band, while being able to coexist with TV broadcasting services and ensuring that the signal quality of adjacent channel TV signals does not deteriorate.

Table 1: TV signals in Hong Kong fall within or nearby the 600 MHz spectrum.

Centre Frequency (MHz)	Operation Bandwidth (MHz)	TV Channels	Gap Band vs. 642MHz (MHz)
602	**7.56**	81: Jade 96: ViuTVsix 99: ViuTV	40
586	**7.56**	82. J2 83. TVB News 84. Pearl 85. TVB Finance, Sports, and Information Channel	56
522	**7.56**	31. RTHK TV 31 32. RTHK TV 32 33. RTHK TV 33 34. RTHK TV 34	120
482	**7.56**	76. Hong Kong International Business Channel 77. HOY TV 78. HOY Infotainment	160

Lastly, Communal Aerial Broadcast Distribution (CABD) and Satellite Master Antenna Television (SMATV) are two common systems used in Hong Kong for distributing broadcast signals and television services to multiple users within a building or a community. These systems often include Closed-Circuit Television (CCTV) as well. This report will not cover studies of the impacts of these systems, which are not mainstream TV broadcast channels.

1.5 Objectives and Organization of this Study Report

In this report, the combination of a network emulator and antenna is adopted to mimic a 5G indoor network with using the 600 MHz band. The indoor performance evaluation includes coverage and throughput. The impact of such a 5G indoor network using the 600 MHz band on adjacent channels TV signals will be studied, including but not limited to its interference on Digital Terrestrial Television (DTT) service, Adjacent Channel Leakage Ratio (ACLR), maximum tolerable Effective Isotropic

Radiated Power (EIRP), Signal to Interference & Noise Ratio (SINR) and throughput capability. Finally, NIR safety of 5G Radio Base Stations (RBSs) will be evaluated based on ICNIRP EMF guidelines.

This report is divided into the following sections:

- Section 2 provides the trial design and background, and introduces 5G testing scenario with network emulator and antenna;
- Section 3 introduces network emulator and measurement equipment, presents testing points, provides performance evaluation including coverage and throughput for 5G indoor cell, and presents the field measurement results;
- Section 4 introduces measurement equipment for interference test, shows measurement procedure and scenarios, studies the impact of 5G signal on TV channels, presents field measurement and provides field measurement results;
- Section 5 presents study on NIR safety problem of 5G Radio Base Stations (RBSs) based on ICNIRP EMF guidelines; and
- Section 6 sums up the findings of this study.

2 Trial Design, Background and Network Emulator and Antenna

In this section, site selection and trial information will be introduced first, then the 5G testing scenario using network emulator and antenna is discussed.

2.1 Site Selection

In Hong Kong, a total of 70 MHz of spectrum comprising 2 x 35 MHz of spectrum in each of the ranges 617 – 652 MHz paired with 663 – 698 MHz ("600 MHz band") is planned for provision of mobile services in indoor environments and is currently not licensed. This frequency band has low penetration loss and is suitable for the provision of 5G SA private network in warehouse and factory environments. At the same time, MTR's vision is to utilize dedicated 5G network technology in indoor factories, which will feature enhanced connectivity, improved operational efficiency, and the deployment of advanced technologies that rely on low latency and high bandwidth.

Therefore, ASTRI collaborated with the MTR Corporation to choose the Freight Headquarters Building (FHOB) as the trial site. The building is in a rural area and is unlikely to interfere with public users; the surrounding areas have different terrain heights, making it convenient to test different transmitter and receiver scenarios; and the surrounding space is open enough to facilitate on-site measurements.

2.2 Trial Site Information

More details of the trial site FHOB are shown in Table 2. Figure 1 shows the site location in the map.

Table 2: Site name, address and coordinate information.

Site	Information
Name	Freight Head Office Building (FHOB)
Address	MTR Hung Hom Stabling Sidings Cheong Tung Road South, Hung Hom
Coordinate Information	Northing (m), Eating (m): 817866, 836808 Latitude (N), Longitude (E): 22.29973, 114.18211

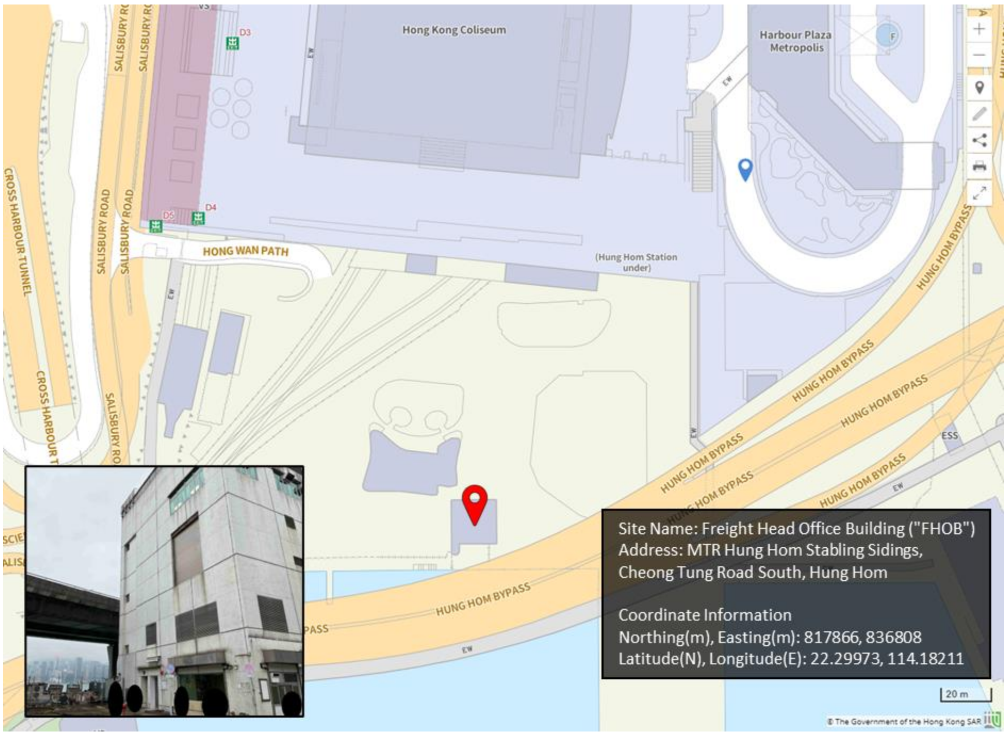


Figure 1: Site location at the map.

2.3 Deployment Design of Network Emulator and Antenna

To build up a 5G indoor network, there are two approaches:

- **Real 5G deployment**: Real deployment of 5G refers to the implementation of 5G networks using actual hardware, infrastructure, and frequencies in a live environment. It involves the installation of 5G base stations, antennas, and related equipment to provide wireless coverage and connectivity to users.

- **Network emulator and antenna**: The combination of a network emulator and antenna can mimic a real 5G network. A network emulator is a device that simulates the behaviors and characteristics of a 5G network, and it can simulate various network conditions, such as latency, bandwidth, packet loss, and interference. An antenna is a physical device and is used to transmit and receive 5G signals.

ASTRI has 5G end-to-end solution and is able to deploy a 5G private network for enterprises. But at this stage of trial, a combination of a network emulator and appropriate antennas is adopted to mimic a 5G deployment for testing or development purposes. A network emulator simulates the behavior and characteristics of a 5G network. Antennas are essential components for 5G, which can transmit and receive 5G signals.

The benefits of using network emulator and antenna include but not limited to –

- **Testing and Validation**: A network emulator can simulate various aspects of a real 5G network, including radio conditions, network traffic, and protocol behavior. This helps in identifying and addressing potential issues and optimizing the performance of the real 5G deployment.
- **Cost and Time Efficiency**: Emulating a 5G deployment using a network emulator and antennas can significantly reduce costs and time compared to deploying a physical 5G network for testing purposes. Emulators provide a flexible and scalable environment that can simulate different network scenarios, eliminating the need for complex and expensive infrastructure setups. This allows for efficient testing and faster time-to-market for 5G solutions.

At the trial site, network emulator and one omnidirectional antenna are used to emulate a 5G network. Only one antenna is used in this phase of trial, and the target is to evaluate the coverage characteristics that one antenna can provide. By emulating the 5G deployment in this field trial, the optimal antenna layout, coverage areas and overall network architecture can be identified to further improve the performance and efficiency of the next phase of real 5G deployment. The antenna information is shown in Table 3. Network emulator is installed on the first floor, connecting to one omnidirectional antenna which is mounted on the ceiling, see Figure 2 and Figure 3.

Table 3: Antenna's parameters

Parameters	Information	Antenna View
Frequency Range	617-960 / 1710-2700 / 3300-3800 MHz	
Gain	4 / 6 / 7 dBi	
Radiation	Omni-Direction	
Polarization	Vertical	

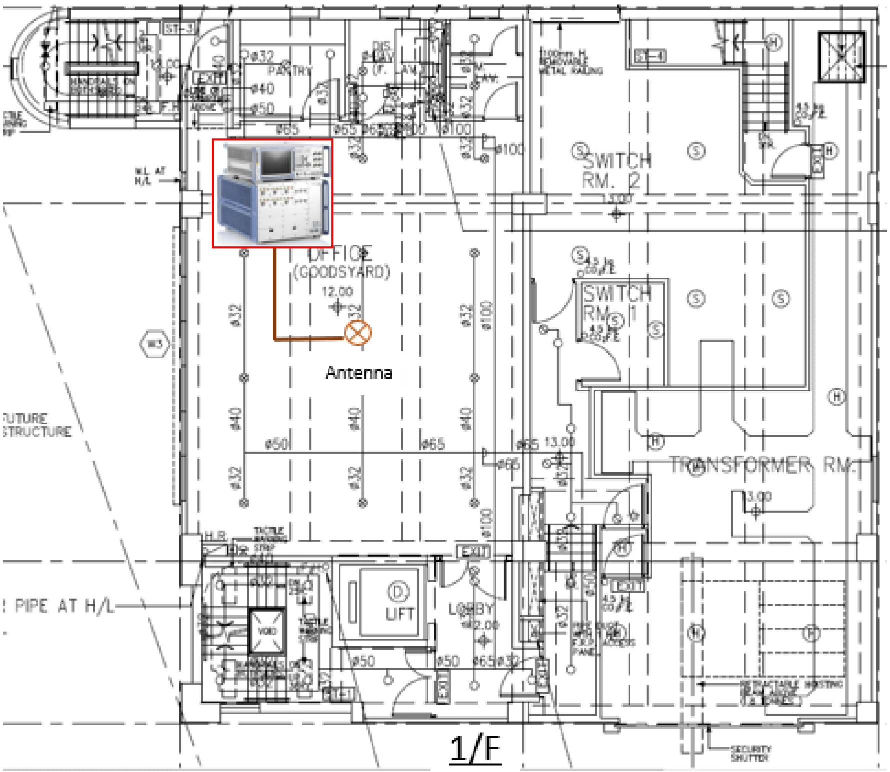


Figure 2: Location of emulator and antennas.

Figure 3: Setup of X-Pol omni antenna

5G mobile signal is transmitted in the trial site, and frequency band uses 600 MHz (i.e., band N71) and 20 MHz bandwidth paired spectrum. The transmit power of the antenna is set to less than or equal to 2 Watts (i.e., 33 dBm) Effective Isotropic Radiated Power (EIRP). The network parameters are shown in Table 4.

Table 4: Network parameters of 5G indoor system.

Parameters	Information
Technology	5GNR
Effective Radiated Power (ERP)	1.22 Watts (30.85 dBm) per indoor antenna
Effective Isotropic Radiated Power (EIRP)	2 Watts (33 dBm) per indoor antenna
5G Frequency Band	Downlink: 632 to 652MHz Uplink: 678 to 698MHz
Bandwidth	20 MHz

3 Measurement Results on Coverage and Throughput

This section focuses on field measurements on a 5G indoor cell using the 600 MHz band. The measurement of 5G signal includes both coverage (i.e., RSRP and SINR) and throughput.

3.1 Network Emulator and Measurement Equipment

R&S CMX500 and R&S CMW500 are adopted to emulate a 5G Radio Base Station (RBS), and R&S BBA150 broadband amplifier is used to enhance the 5G signal. The whole emulation system is equivalent to a live 5G network deployed in an indoor scenario. Figure 4 shows how R&S CMX500, R&S CMW500, R&S BBA150 and antenna are connected at antenna side, and what measurement equipment are used at measurement side. Table 5 summarizes the 5G network emulation system and measurement equipment with details on 1) the type of measurement that each equipment is used for, as well as 2) the technical specifications of each equipment.

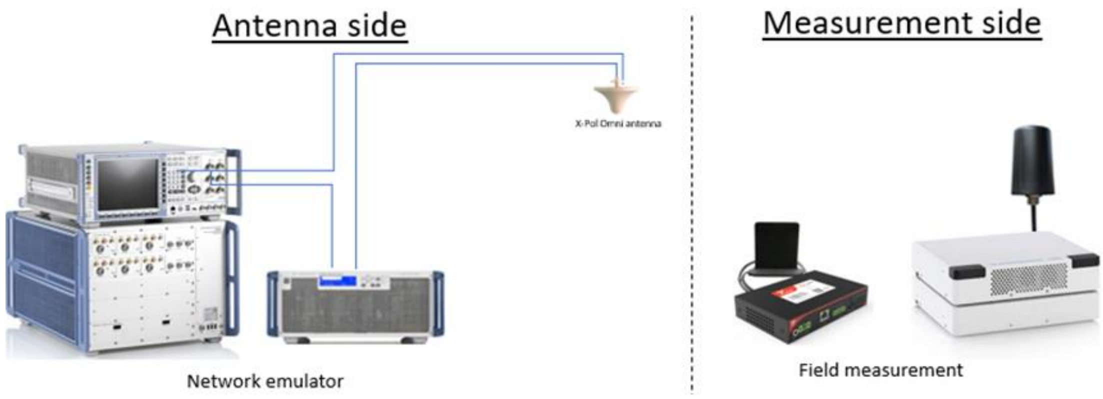


Figure 4: Connection diagram

Table 5: Summary of network emulator and measurement equipment for coverage and throughput.

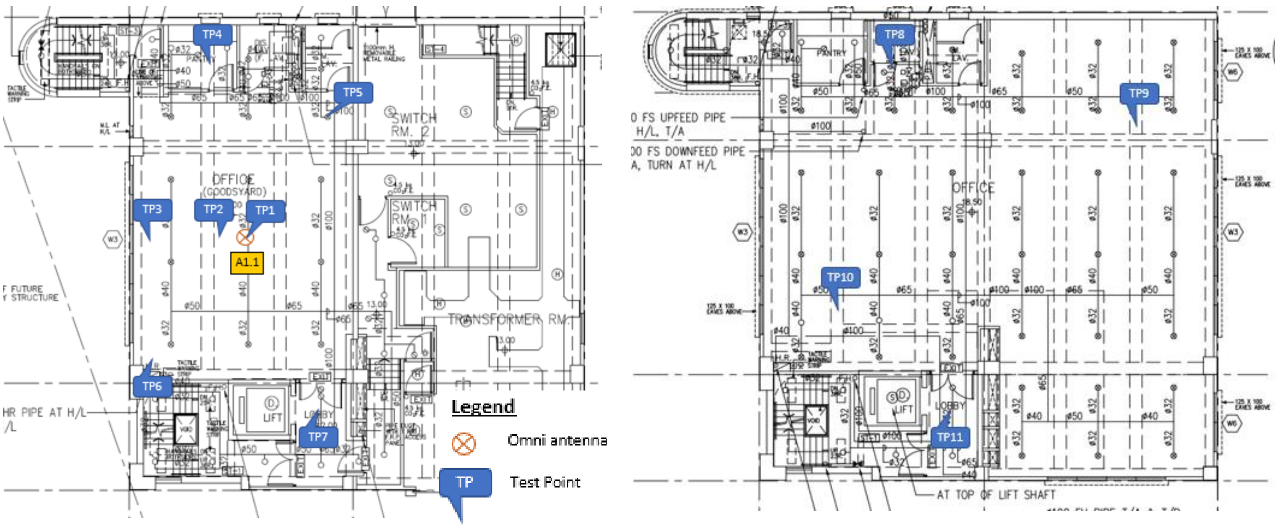
Equipment Descriptions	Equipment Type	Key Facts
Network emulator	• R&S CMX500 one-box signaling tester 	• LTE, 5G FR1 frequency range up to 8 GHz and FR2 millimeter wave frequency range up to 50 GHz in one instrument • Support of 5G stand-alone mode non-stand-alone mode • Can combine several present and future LTE and 5G 3GPP bands • One scalable hardware platform with tailored and use-case specific configurations • Web-based CMsquares user interface for RF, functional, application and protocol tests
	• R&S CMW500 wideband radio communication tester 	• Multi-RAT signaling: LTE, WCDMA, GSM, WLAN, Bluetooth • LTE-Advanced: 8DL CC up to 4x4/8x2 MIMO fading, 2 UL CA • WLAN 11 a / b / g / n / ac / ax SISO and MIMO signaling test • Internal server for application testing
	• R&S BBA150 Broadband Amplifier 	• Frequency range between 4KHz and 6 GHz • Output power between 15W and 3000W at 1dB compression point • 100% mismatch tolerance • Suitable for amplitude, frequency, phase, pulse and OFDM modulation • Extensive switching options for flexible system configurations
Network scanner	• R&S TSMA6 AUTONOMOUS MOBILE NETWORK SCANNER 	• No limitations in 3GPP (e.g. 5G NR, LTE, WCDMA, GSM, NB-IoT) frequency bands up to 6 GHz, including a multi-GNSS receiver for uninterrupted location tracking • Maximum connectivity, with support for additional scanner hardware, Windows based PCs, Android based UEs and tablets using wireless and wired connections
CPE	• TOZED IR 100 CPE 	• Industrial router is a high-performance 5G indoor communication industrial routing terminal, supports NR (SA&NSA), LTE, converts cellular network data into Gigabit wired network port data, and effectively meets various 5G communication industry and enterprise application

3.2 Test Points

Table 6 lists the configuration parameters of a 5G indoor N71 cell. Test points locate in both general-accessible area and lift area, as in typical indoor environments. In general-accessible area, 11 test points are selected, which locate at 1st floor and 2nd floor (see Figure 5). Another 4 test points are selected in lift area (see Table 6).

Table 6: Configuration parameters of a 5G indoor N71 cell

Parameters	Value	Remark
Number of Carriers	1	
Center Carrier Frequency (MHz)	642	
Carrier Bandwidth (MHz)	20	
Transmit Power/Carrier (dBm)	29	Transmitter output
Aggregated Power from Power Amplifier (dBm)	29	Total Output power
Maximum Antenna Gain (dBi)	4	
Maximum EIRP (dBm)	33	2 Watts
TDD or FDD	FDD	
SISO or MIMO	SISO	



1/F 2/F

Figure 5: Location of 11 test points at general accessible area.

3.3 Field Measurement Results

To address typical indoor environment, the measurements in general-accessible area and lift area are conducted by using R&S TSMA6, which is an autonomous mobile network scanner (see Table 5 for the specification details). This section investigates coverage and throughput evaluation in general-assessable area and lift area.

3.3.1 Coverage in General-Accessible Area

Coverage measurement results are shown in Table 7. In general-accessible area the Reference Singal Received Power (RSRP) is at least -106.8 dBm, and Signal to Interference & Noise Ratio (SINR) is at least 8.95. According to some previous experiments, the area with SS-RSRP ≥ -120 dBm can have 5G connectivity, demonstrating that SS-RSRP ≥ -120 dBm can be used as a supplementary criterion to evaluate the availability of 5G coverage in a certain area. Both RSRP and SINR results show that the coverage performance in general-accessible area is satisfactory.

Table 7: Coverage measurement results in general-accessible area

Test Point	Reference Signal Received Power (RSRP, in dBm)	Signal-to-interference-plus-noise ratio (SINR)
1	-32.17	37.61
2	-54.58	36.85
3	-54.44	37.44
4	-67.25	36.59
5	-75.76	36.26
6	-61.72	37.63
7	-72.43	29.92
8	-97.07	20.06
9	-81.32	35.08
10	-106.8	8.95
11	-92.39	20.71

3.3.2 Coverage in Lift Area

The area near lift is measured as well. The test points are shown in Figure 6, and the results are shown in Table 8. In lift area, the RSRP is at least -117.26 dBm and SINR is at least -5.89. It is noticed that the RSRP is larger than -120 dBm, indicating that the lift area can have 5G connectivity.

To summarize, it is concluded that the coverage in both general-accessible area and lift area is satisfied.

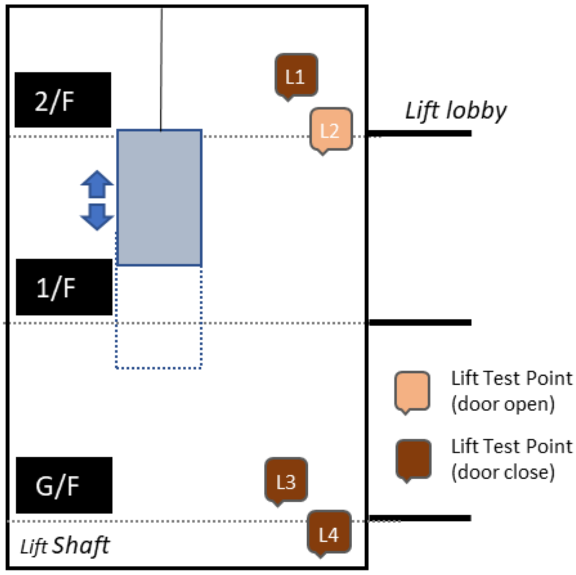


Figure 6: Locations of testing points in lift area

Table 8: Coverage measurement results in lift area

Test Point	Reference Signal Received Power (RSRP, in dBm)	Signal-to-interference-plus-noise ratio (SINR)
L1	-106.51	0.67
L2	-95.91	11.24
L3	-117.26	-5.89
L4	-116.5	-5.33

3.3.3 Throughput

Throughput measurements are conducted at test point 1 -11 and L1 – L4 by using TOZED IR 100 CPE. Table 9 shows the measurement results of RSRP, download and upload throughput. It is noticed that, in general-accessible area, the weakest coverage point is testing point 10, which is located at 2nd floor. Note that the antenna is installed at 1st floor. RSRP at testing point 10 is -111 dBm, which can have 5G connectivity, while the download throughput is 23 Mbps, and the upload throughput is 18 Mbps. Generally, coverage and throughput in lift areas (e.g., L1 – L4) are worse than in general-accessible area because the penetration losses near lift area are much greater.

For the whole area including both general-accessible area and lift area, the weakest coverage point is testing point L3 (which locates in lift area), where the RSRP is -120 dBm, and the download throughput using is 6 Mbps, and the upload throughput is 5 Mbps. The strongest coverage point is testing point 1, where the RSRP is -35 dBm, and the download throughput is 93 Mbps, and the upload throughput is 72 Mbps.

It is concluded that the throughput in both general-accessible area and lift area is satisfied.

Table 9: Throughput measurement results in both general-accessible area and lift area.

Test Point	Reference Signal Received Power (dBm)	Download Throughput (Mbps)	Upload Throughput (Mbps)
1	-35	93	72
2	-56	86	69
3	-60	90	70
4	-73	81	63
5	-77	77	62
6	-64	93	69
7	-77	79	61
8	-101	29	22
9	-85	64	52
10	-111	23	18
11	-96	46	36
L1	-110	20	15
L2	-99	28	20
L3	-120	6	5
L4	-118	8	7

4 Interference Test and Measurement Results

As discussed in Section 1.4, 5G signal is susceptible of causing interference on adjacent channels TV signals. This section focuses on investigating the interference impact of 5G signal on mainstream TV broadcast channels (refer to Table 1), with a certain transmission power (i.e., EIRP is 2 Watts, refer to Table 5) of 5G RBS. The interference effects are discussed below, including interference test setup, field measurement procedures and scenarios, as well as field measurement results.

4.1 Adjacent Channel Leakage Ratio (ACLR)

Adjacent Channel Leakage Ratio (ACLR) is a measurement used to quantify the amount of interference or leakage from a transmitter into adjacent frequency channels, see Figure 7. ACLR is a measure of the power level of the signal in the adjacent channels relative to the power level of the desired signal in the main channel. It is usually expressed in decibels (dB). A lower ACLR value indicates less interference and better spectral efficiency.

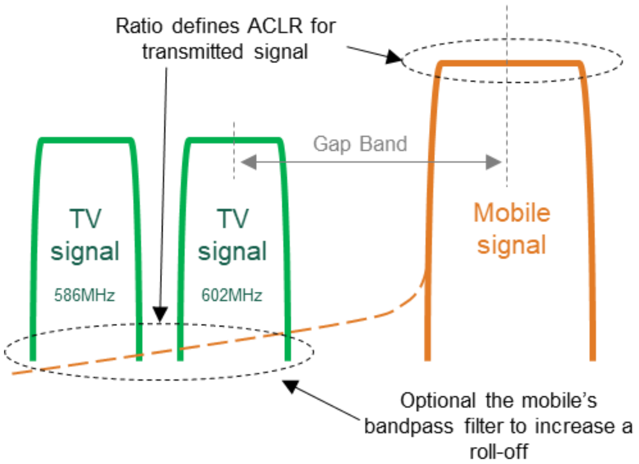


Figure 7: Adjacent Channel Leakage Ratio (ACLR)

4.2 Impact of 5G Signals on TV Channels

In the trial site, when 5G signal is transmitting in indoors environment in FHOB, there is perhaps the potential for energy to spill into adjacent TV channels. Section 4 targets to evaluate the strength of leakage of 5G signal (if any) at some testing points locating at 20 meters (ground level), 100 meters (medium terrain, which is almost same height as FHOB) and 160 meters (high terrain, which is almost same height as FHOB) far away from the FHOB, respectively. The purpose is to ensure that, with a certain transmission power (i.e., EIRP is 2 Watts, refer to Table 5) of 5G RBS, any leakage will not cause interference or degrade the performance of adjacent channels TV signals.

For TV broadcast signals, 600 MHz mobile signals are interference signals, so interference tests will be conducted at some testing points, which are choose carefully with distances of 20 meters, 100 meters and 160 meters around the FHOB building (see Section 4.5 for detailed discussion). The interference test is to decode TV broadcast signals and measure TV signal quality while transmitting 600 MHz mobile signal. On TV quality, there are 5 grades (refer to Table 10).

Table 10: Grades of TV quality

TV Grade	By Observation
5	Excellent. Good quality
4	Best. A little spot and sound freeze
3	Fair. Occasion pixelation or distortion and sound freeze
2	Poor. Usual pixelation, distortion or blackout.
1	No signal.

4.3 Interference Test Setup

To emulate N71 RBS, three equipment including R&S CMX500, R&S CMW500, and R&S BBA150 are used (Table 5 shows the specifications). For interference test, two more equipment including spectrum analyzer and TV analyzer are used in field measurements. Table 11 shows more details on the technical specifications of each equipment. Figure 8 shows the layout of N71 RBS emulator and measurement equipment. It is noticed that, both N71 RBS emulator and measurement equipment are located on 1st floor. The configuration parameters of N71 RBS emulator are shown in Table 12.

Table 11: Measurement equipment used in interference test.

Equipment Descriptions	Equipment Type	Key Facts
Spectrum analyzer	• R&S FSW signal and spectrum analyzer 	• Unparalleled low phase noise and best sensitivity on the market • 8.3 GHz internal analysis bandwidth • 800 MHz real-time analysis bandwidth • SCPI recorder simplifies code generation • High dynamic range enables outstanding EVM performance
TV analyzer	• R&S ETL TV analyzer with DTMB mode 	• Realtime demodulation • Advanced frontend and FPGA-based demodulation • Preselection with additional 75 Ω RF input • Integrated spectrum analyzer • Video decoder for MPEG-2, H.264 (MPEG-4), HEVC and AVS/AVS+

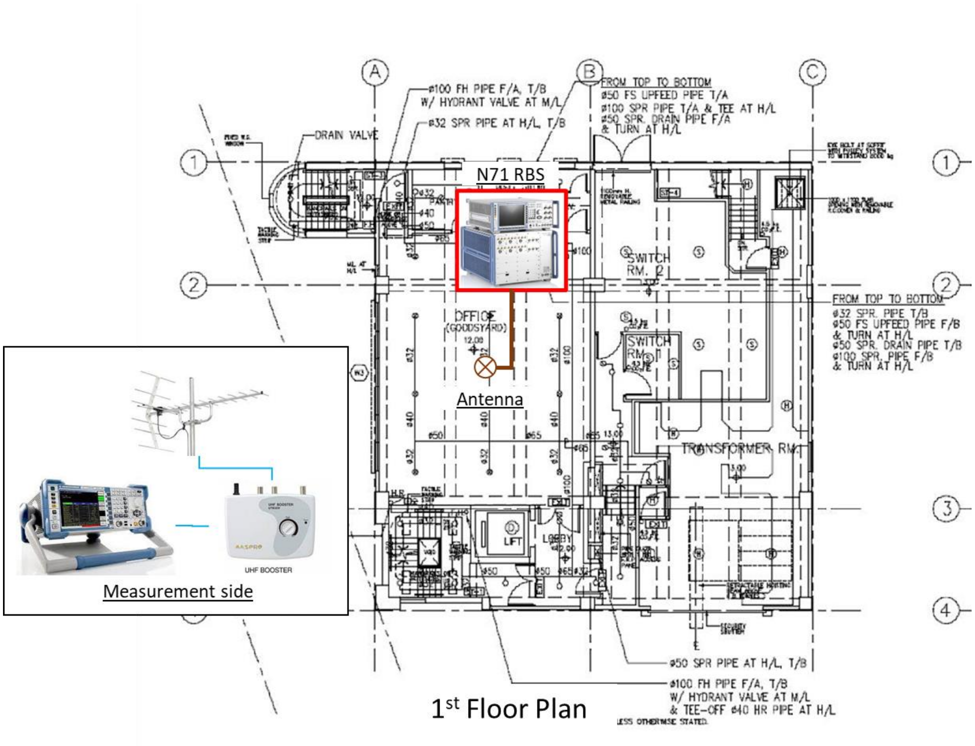


Figure 8: Layout of N71 RBS emulator and measurement equipment

Table 12: Configuration parameters of N71 RBS emulator

Network Emulator	R&S CMX500 one-box signaling tester R&S CMW500 wideband radio communication tester BBA150 Broadband Amplifier
Network Mode	5G SA
Band	N71
Number of Carriers:	1
Carrier Frequency (MHz):	Downlink: 642; Uplink: 688
Carrier Bandwidth (MHz):	20
Tx Rx Mode	Dual Cable, 1Tx 1Rx (SISO)
EIRP (dBm)	33
Tx Antenna	Indoor Omni X-Pol 2Port, 617MHz-6000MHz
Tx Antenna Gain (dBi)	4

4.4 Field Measurement Procedure and Scenarios

In this section, TV signal is measured under two scenarios: 1) normal TV signals without UHF Booster; and 2) TV signals with UHF Booster.

4.4.1 Measurement Procedure

The measurement procedure is descripted as follows:

- Step 1: Choose one 600MHz band adjacent TV channel (from Table 1).
- Step 2: Monitor the audiovisual performance of this TV channel for 5 minutes.
- Step 3: Repeat Steps 1 and 2 until all TV channels are monitored.

The configuration parameters for TV signal measurement are shown in Table 13.

Table 13: Configuration parameters for TV signal measurement

Format	DTMB
Carrier Frequency (MHz)	482, 522, 586, 602
Carrier Bandwidth (MHz)	8MHz per channel
Equipment	1.R&S ETL - For spectrum overview, TV signal measurement (Rx level, BER, MER etc.) 2. DTMB receiver - For signal decode and TV functional test
Rx Antenna	UHF Yagi Antenna
Rx Antenna Gain (dBi)	8-12.5

4.4.2 1st scenario: Measure TV Signal without UHF Booster

Figure 9 shows how the TV signal measurement (without UHF booster) is set up. At antenna side, R&S CMX500, R&S CMW500, R&S BBA150 and antenna are connected; at measurement side, measurement equipment including spectrum analyzer, TV analyzer and DTMB receiver are connected to UHF Yagi antenna.

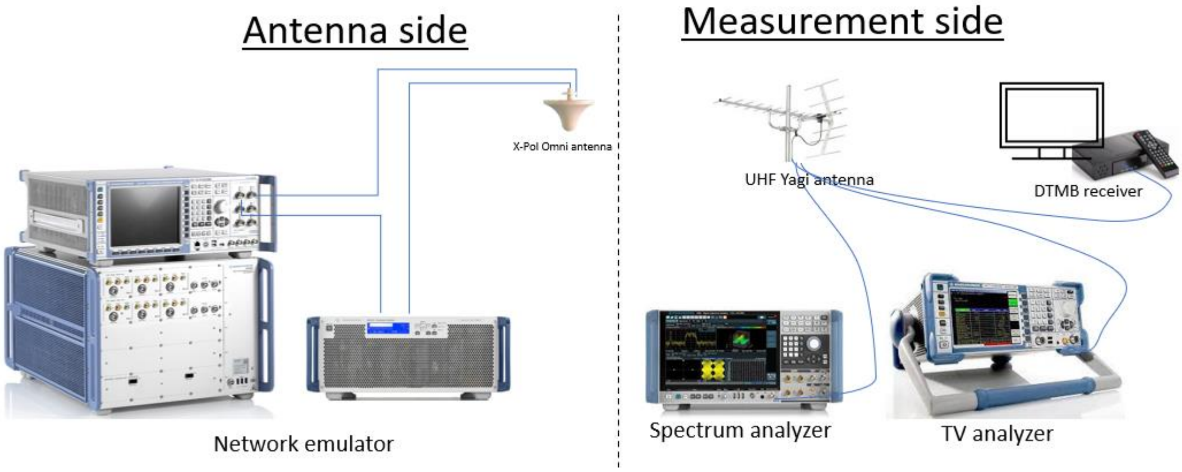


Figure 9: Measure TV signal

4.4.3 2nd Scenario: Measure TV Signal with UHF Booster

In prevailing Community Antenna television ("CATV") system, to provide good signal strength to each user, a UHF power amplifier/booster can be added after receiving antenna. To mimic the genuine deployment scenario of CATV system, a UHF Booster is added as an additional testcase for reference. Figure 10 shows how the TV signal measurement with UHF booster is set up.

For both scenarios, Figure 11 shows the spectrum view of N71 5G signal.

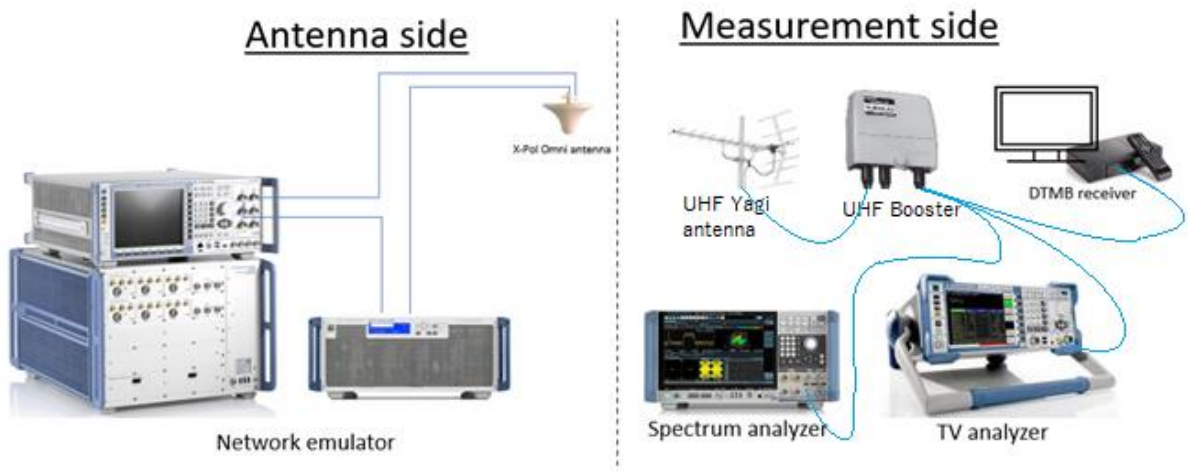
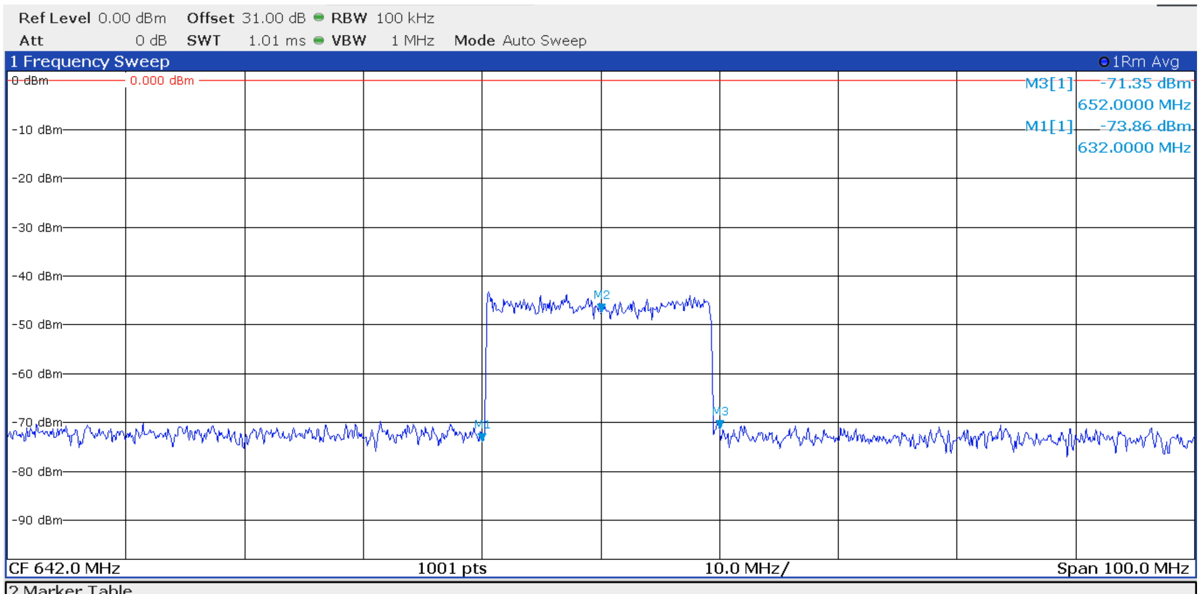


Figure 10: Measure TV signal with UHF booster



Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	632.0 MHz	-73.86 dBm		
M2		1	642.0 MHz	-47.36 dBm		
M3		1	652.0 MHz	-71.35 dBm		

Figure 11: Spectrum view of N71 Cell

4.5 Measurement Results

A total of six test points is selected for the field measurement. Figure 12 shows the location of these test points. It is worth to mention that test point 1 is a critical point, which is 20 meters away from FHOB at ground level with UHF Yagi antenna pointing directly to N71 RBS.

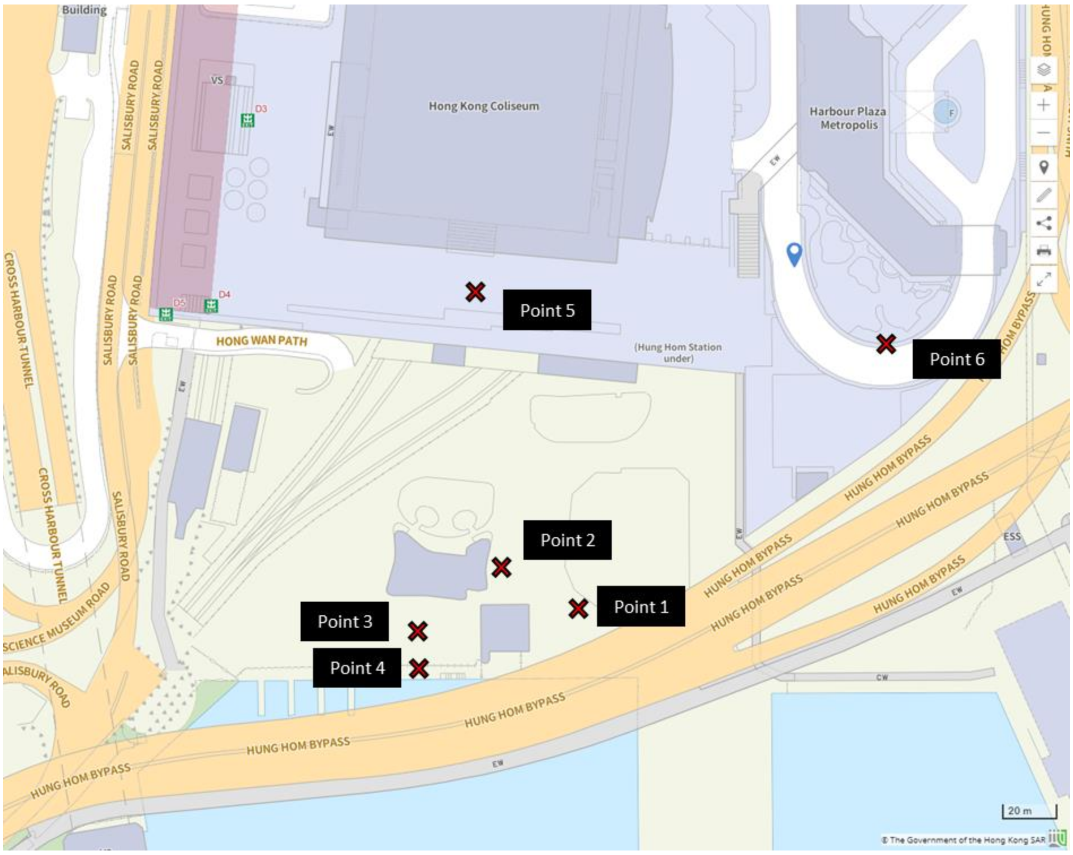


Figure 12: All test points on the map

The six test points are divided into three test cases, located at different altitudes for on-site measurements. Test points 1 to 4 locates at 20 meters away and at ground level; test point 5 locates at 100 meters away at medium altitude, which is below antennae height; and test point 6 locates at 160 meters away at high altitude, which is almost as same as antennae height. Table 14 summarizes the features of three test cases and Figure 13 demonstrates six testing points at different altitudes.

Table 14: Features of three test cases

Test Cases	Test Points	Features
1	1 – 4	20 meters away, ground level
2	5	100 meters away, medium altitude which is below antenna height
3	6	160 meters away, high altitude which is almost as same as antenna height

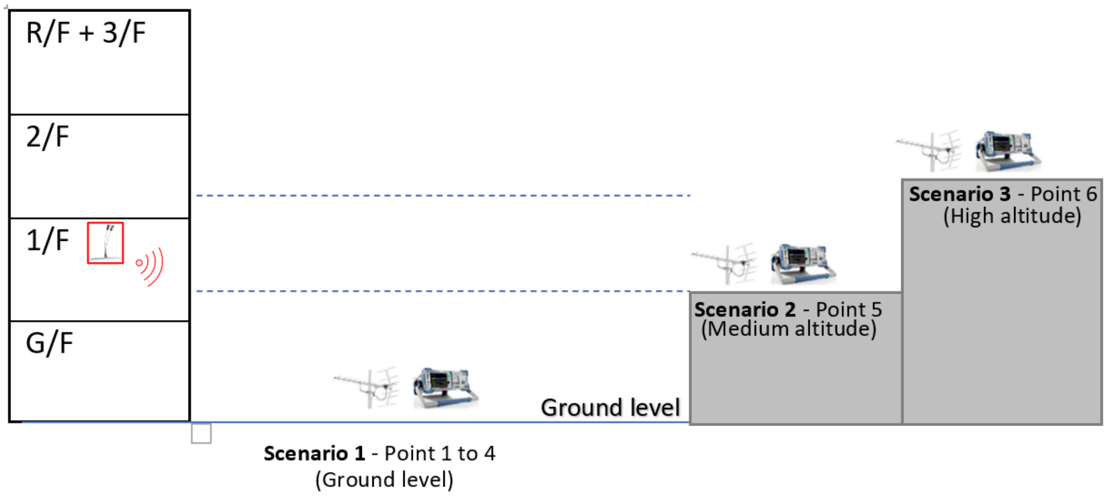
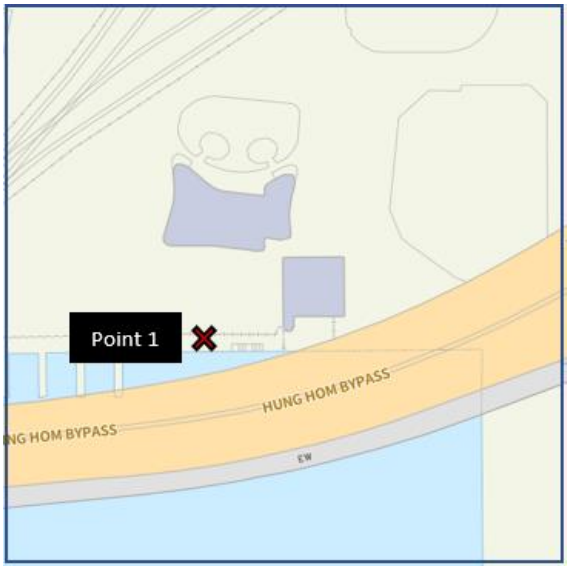


Figure 13: Six test points at different altitudes

4.5.1 Point 1 – TV antenna pointing directly to N71 RBS (Critical case)



(a)

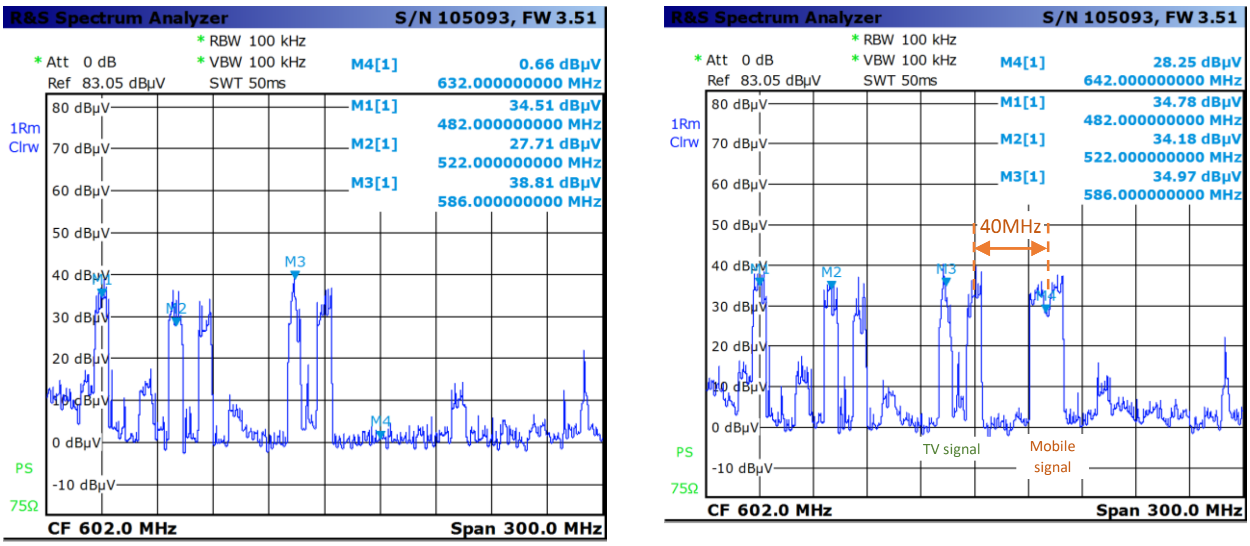
(b)

Figure 14: Location of test point 1

Table 15: Measurement result of TV signal at point 1

Point 1	Level (dBμV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	Off	On	Off	On	Off	On	Off	On
602	54	55	26	27	<0.01	<0.01	5	5
586	53	53	24	25	<0.01	<0.01	5	5
522	52	52	24	25	<0.01	<0.01	5	5
482	54	54	26	25	<0.01	<0.01	5	5
Added UHF Booster								
602	75	74	25	25	<0.01	<0.01	5	5
586	75	75	26	25	<0.01	<0.01	5	5
522	73	73	25	25	<0.01	<0.01	5	5
482	78	80	26	26	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P



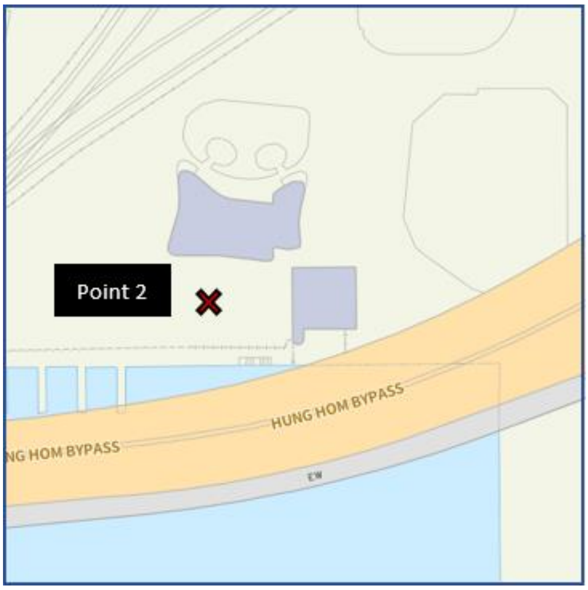
(a) N71 off-air

(b) N71 on-air

Figure 15: Spectrum view of 1st scenario at test point 1

The measurement results of 1st scenario and 2nd scenario at test point 1 are shown in Table 15. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 15 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is almost the same as the reception level of TV channels.

4.5.2 Point 2 – West side of FHOB



(a)

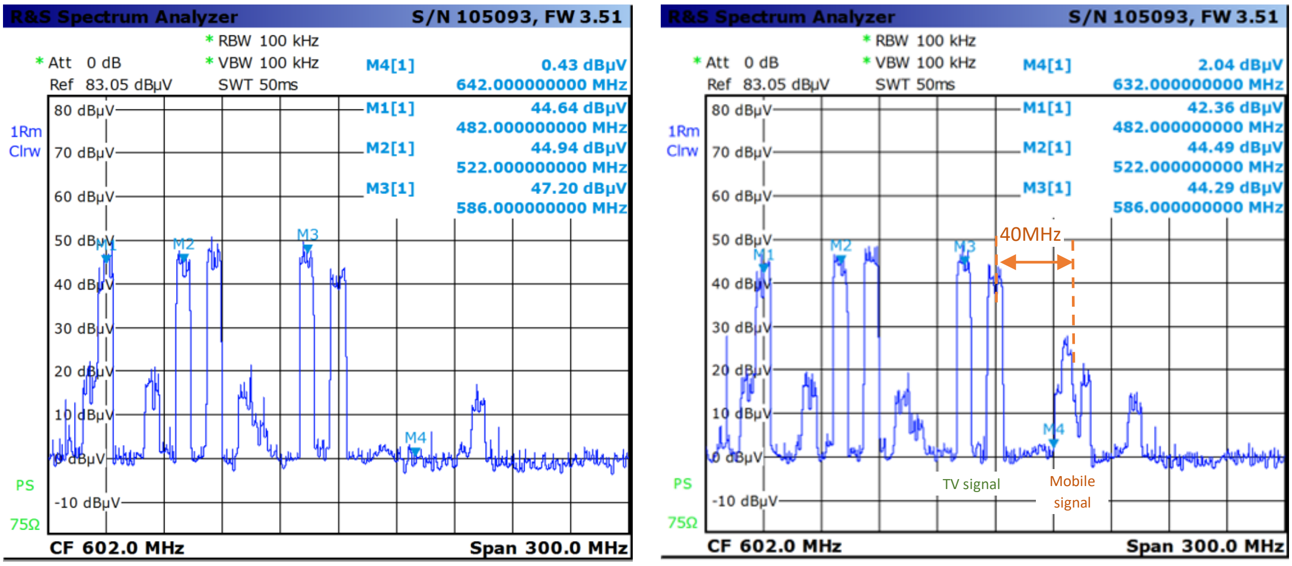
(b)

Figure 16: Location of test point 2

Table 16: Measurement result of TV signal at point 2

Point 2	Level (dBµV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	Off	On	Off	On	Off	On	Off	On
602	61	60	34	34	<0.01	<0.01	5	5
586	65	64	37	36	<0.01	<0.01	5	5
522	63	63	35	35	<0.01	<0.01	5	5
482	63	62	32	32	<0.01	<0.01	5	5
Added UHF Booster								
602	81	81	35	35	<0.01	<0.01	5	5
586	85	83	37	38	<0.01	<0.01	5	5
522	85	84	36	36	<0.01	<0.01	5	5
482	89	88	33	33	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P

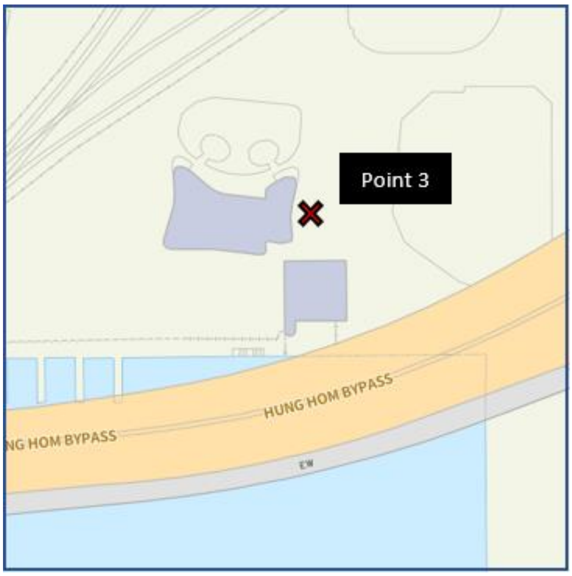


(a) N71 off-air (b) N71 on-air

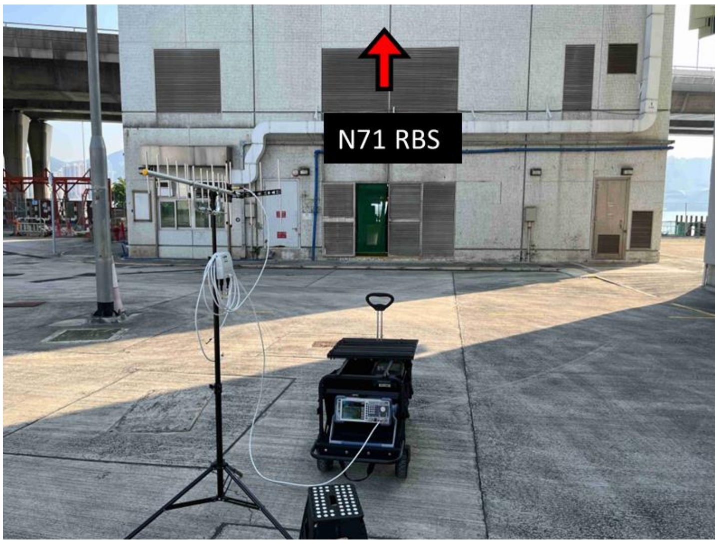
Figure 17: Spectrum view of 1st scenario at test point 2

The measurement results of 1st scenario and 2nd scenario at test point 2 are shown in Table 16. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 17 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is around 20 dB lower than the reception level of TV channels.

4.5.3 Point 3 – North side of FHOB



(a)



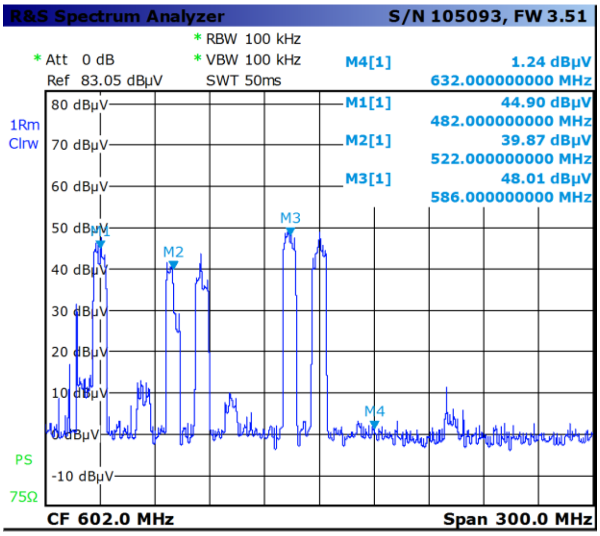
(b)

Figure 18: Location of test point 3

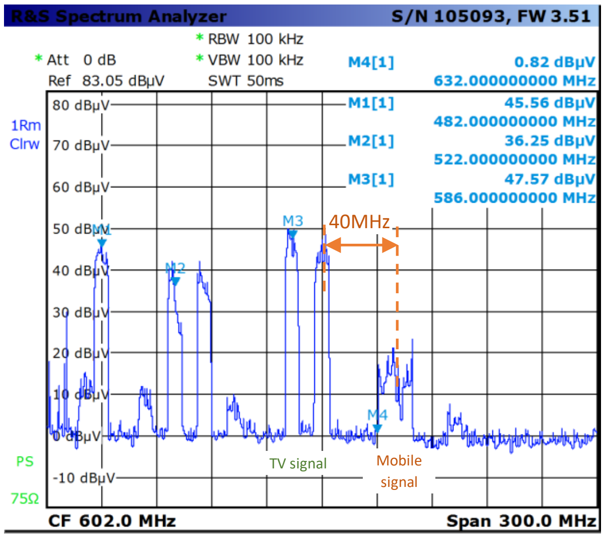
Table 17: Measurement result of TV signal at point 3

Point 3	Level (dBµV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	Off	On	Off	On	Off	On	Off	On
602	66	63	39	37	<0.01	<0.01	5	5
586	65	66	38	38	<0.01	<0.01	5	5
522	56	56	26	26	<0.01	<0.01	5	5
482	62	63	35	35	<0.01	<0.01	5	5
Added UHF Booster								
602	82	83	39	39	<0.01	<0.01	5	5
586	85	85	39	40	<0.01	<0.01	5	5
522	79	78	28	28	<0.01	<0.01	5	5
482	86	86	35	36	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P



(a) N71 off-air

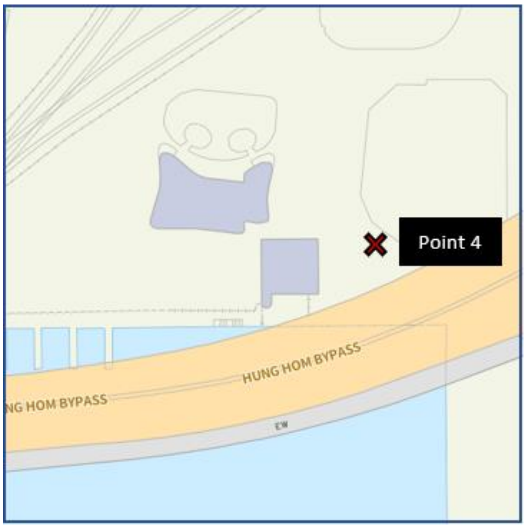


(b) N71 on-air

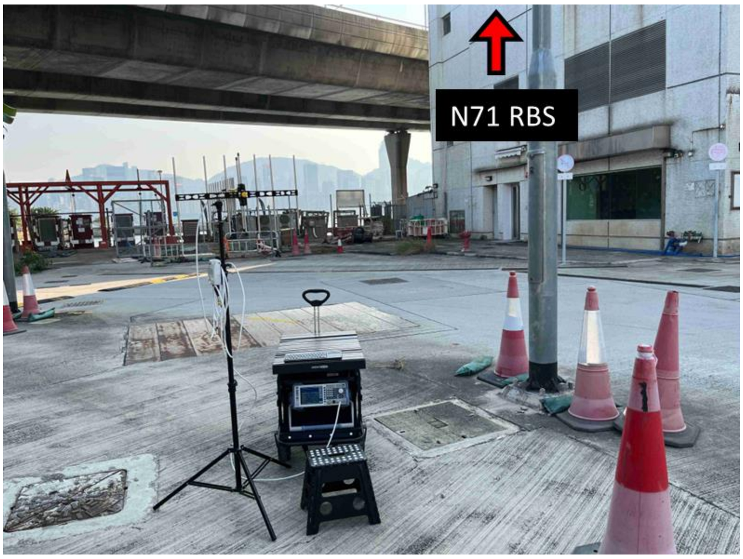
Figure 19: Spectrum view of 1st scenario at test point 3

The measurement results of 1st scenario and 2nd scenario at test point 3 are shown in Table 17. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 19 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is at least 30 dB lower than the reception level of TV channels.

4.5.4 Point 4 – East side of FHOB



(a)



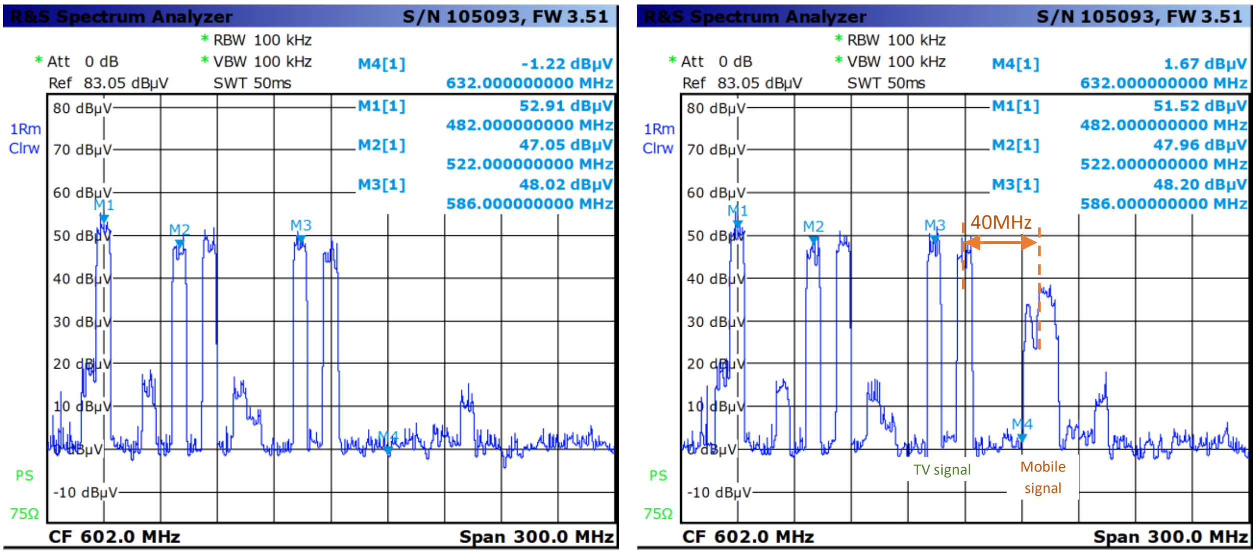
(b)

Figure 20: Location of test point 4

Table 18: Measurement result of TV signal at point 4

Point 4	Level (dBµV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	Off	On	Off	On	Off	On	Off	On
602	64	65	37	37	<0.01	<0.01	5	5
586	67	67	39	38	<0.01	<0.01	5	5
522	65	65	35	35	<0.01	<0.01	5	5
482	71	70	36	36	<0.01	<0.01	5	5
Added UHF Booster								
602	84	85	38	38	<0.01	<0.01	5	5
586	85	85	39	39	<0.01	<0.01	5	5
522	85	85	35	36	<0.01	<0.01	5	5
482	94	94	35	36	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P

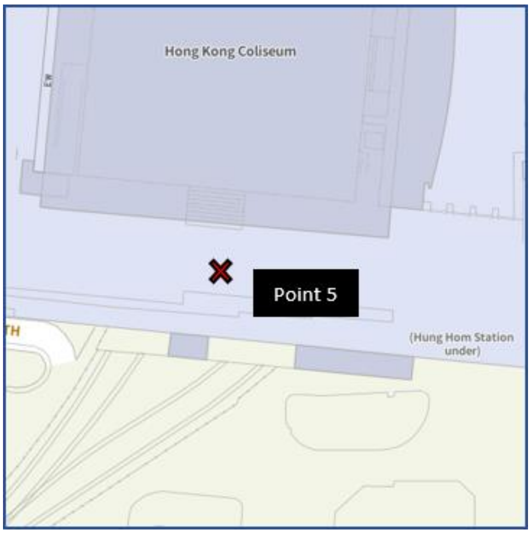


(a) N71 off-air (b) N71 on-air

Figure 21: Spectrum view of 1st scenario at test point 4

The measurement results of 1st scenario and 2nd scenario at test point 4 are shown in Table 18. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 21 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is approximately 10 dB lower than the reception level of TV channels.

4.5.5 Point 5 – G/F, near Hong Kong Coliseum (approximate 10 meters from N71 RBS)



(a) Point 5 at a map

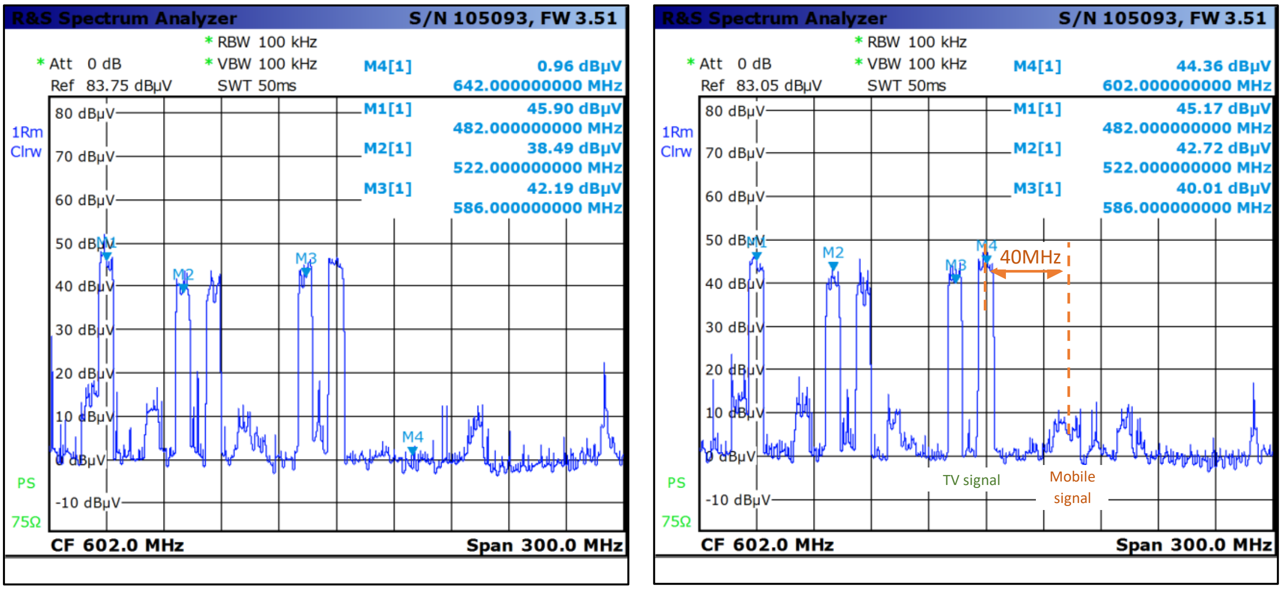
(b) Picture of point 5

Figure 22: Location of test point 5

Table 19: Measurement result of TV signal at point 5

Point 5	Level (dBµV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**	**On**
602	64	64	37	37	<0.01	<0.01	5	5
586	61	62	35	36	<0.01	<0.01	5	5
522	59	60	34	35	<0.01	<0.01	5	5
482	64	64	35	35	<0.01	<0.01	5	5
Added UHF Booster								
602	81	81	38	37	<0.01	<0.01	5	5
586	80	80	36	36	<0.01	<0.01	5	5
522	80	80	35	32	<0.01	<0.01	5	5
482	86	86	34	35	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P



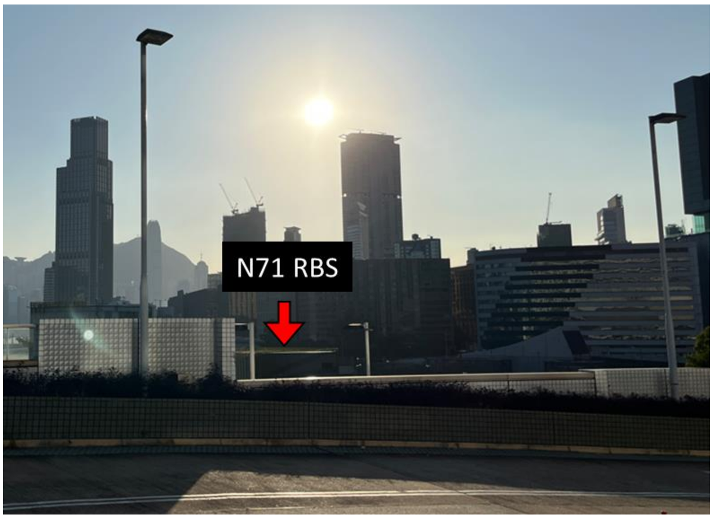
(a) N71 off-air (b) N71 on-air

Figure 23: Spectrum view of 1st scenario at test point 5

The measurement results of 1st scenario and 2nd scenario at test point 5 are shown in Table 19. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 23 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is at least 30 dB lower than the reception level of TV channels.

4.5.6 Point 6 – Harbour Plaza Metropolis (approximate 160m from N71 RBS)

(a)



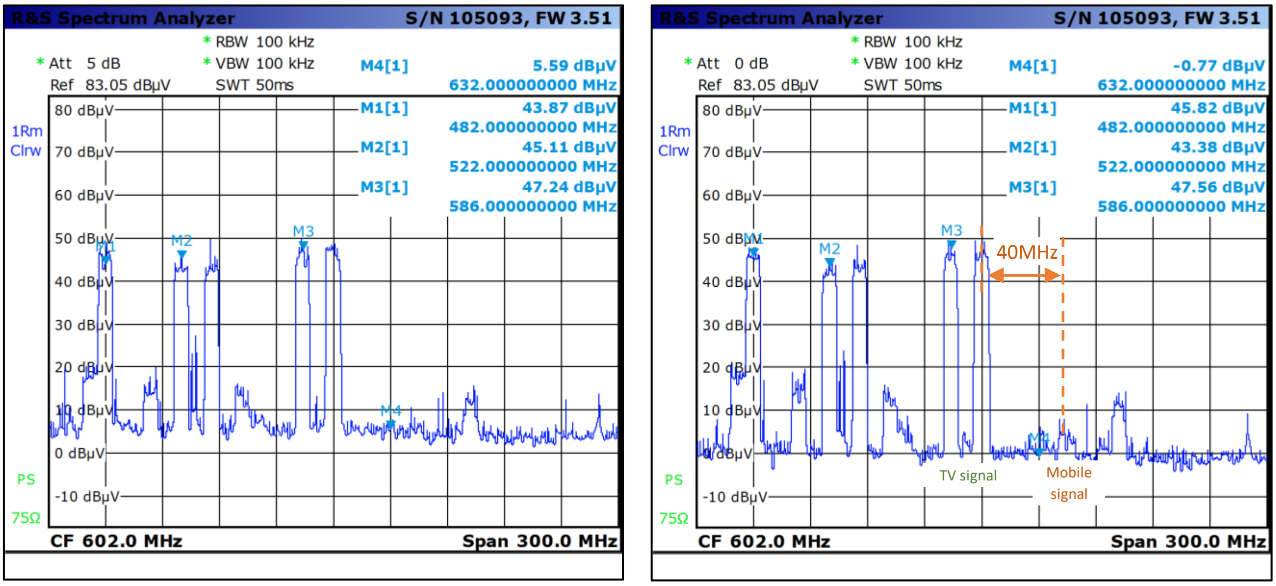
(b)

Figure 24: Location of test point 5

Table 20: Measurement result of TV signal at point 6

Point 6	Level (dBµV)		MER (dB)		BER		TV Quality (Grade)	
TV channel (MHz)	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**	**On**
602	66	65	36	37	<0.01	<0.01	5	5
586	64	65	37	37	<0.01	<0.01	5	5
522	61	62	34	35	<0.01	<0.01	5	5
482	64	63	34	33	<0.01	<0.01	5	5
Added UHF Booster								
602	84	85	37	37	<0.01	<0.01	5	5
586	84	84	37	38	<0.01	<0.01	5	5
522	83	84	35	36	<0.01	<0.01	5	5
482	88	88	34	34	<0.01	<0.01	5	5

Off: N71 off-air
On: N71 on-air 33dBm E.I.R.P



(a) N71 off-air (b) N71 on-air

Figure 25: Spectrum view of 1st scenario at test point 6

The measurement results of 1st scenario and 2nd scenario at test point 6 are shown in Table 20. The TV quality grade at all four different frequency bands is level 5, which is the best quality of TV signals. Figure 25 shows the spectrum view of the TV signal for 1st scenario before and after 5G N71 is powered on. The reception N71 signal strength is at least 30 dB lower than the reception level of TV channels.

4.6 Result Summary

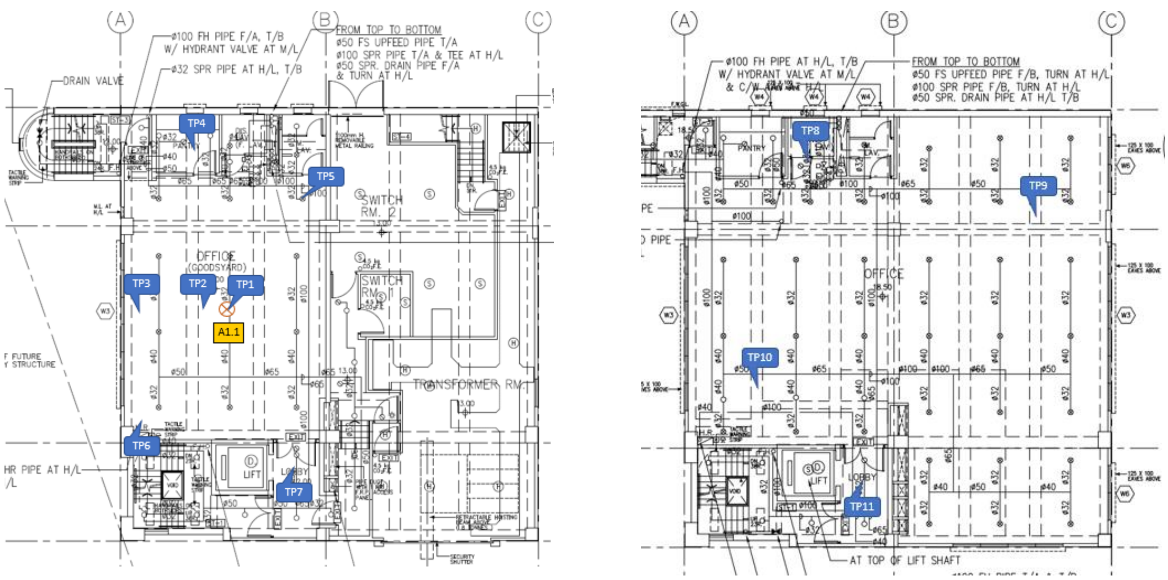
5G indoor private network using the 600 MHz band is simulated in FHOB for indoor usage, and 5G RBS maximum transmitting power EIRP is 2 Watts (33dBm). On-site measurements were conducted at a total of 6 test points at 20 meters, 100 meters and 160 meters away from the FHOB, emulating ground level, medium attitude, and high attitude. At each test point all adjacent TV channels are monitored. Field measurement results show that there is no obvious difference for the adjacent TV channels by observation before and after 5G signal is power on, and the TV signal quality level is level 5 (the highest level). Therefore, it is concluded that 5G signals using the 600 MHz frequency band with a transmission power of 2 watts are interference-free to adjacent channels TV signals and are feasible for indoor factory or warehouse applications.

5 NIR in Public-Accessible Areas in FHOB

Hong Kong adopts the safety limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) as regulatory measures to monitor and control the radiation safety of 5G base stations. The use of the 600MHz band also needs to meet non-ionizing radiation (NIR) safety requirements. Therefore, NIR levels need to be measured. This section focuses on NIR evaluation in FHOB.

5.1 Location of Antenna and Test Points

The location of antenna and all test points (i.e., TP1 ~ TP11) are shown in Figure 26. Figure 27 shows the location of points TP1, TP2 and TP3.



(a) Antenna and test points at 1/F

(b) Test points at 2/F

Figure 26: Location of antenna and test points

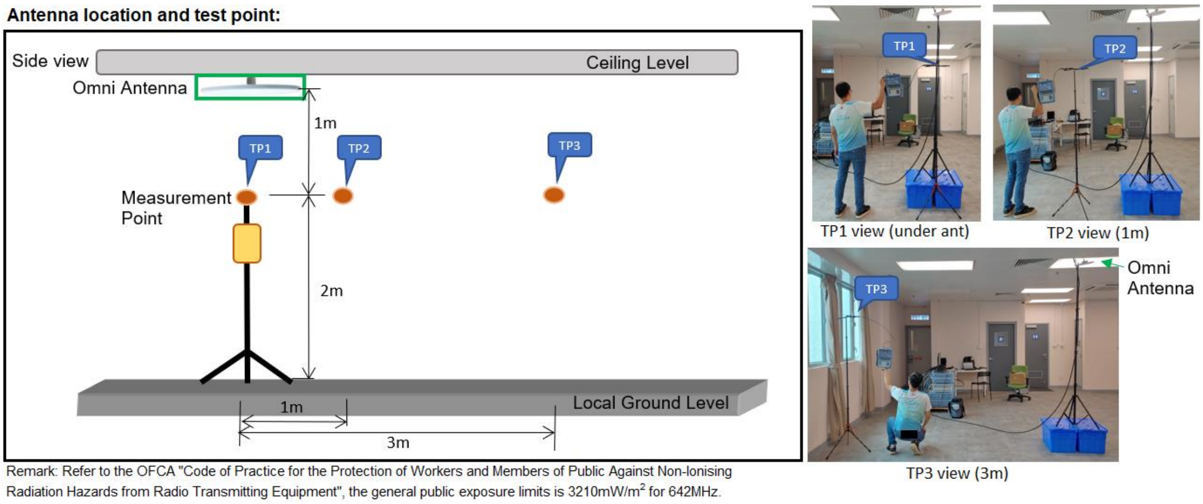


Figure 27: Test points of TP1, TP2 and TP3

5.2 NIR Measurement Results

NIR Broadband measurement results are shown in Table 21. It is noticed that the maximum incident power density is 17.8 mW/m^2, which is below 0.56% of ICNIRP compliance level. NIR frequency-selective measurement results are shown in Table 22. It is observed that that incident power density is 27.9 mW/m^2, which is below 0.87% of ICNIRP compliance level.

Table 21: NIR broadband measurement results

Measurement Equipment		
Manufacturer: R&S Measurement Height: 2 meters above ground	Model: FPH spectrum analyzer	
Test Point (TP)	**Incident Power Density (mW/m^2)**	**ICNIRP Compliance Level† (%)**
1	17.8	0.554515
2	4.7	0.145182
3	2.7	0.083929
4	0.1	0.003483
5	0.2	0.006854
6	0.7	0.022178
7	0.1	0.001671
8	1.6E-05	5.0E-07
9	2.2E-05	6.8E-07
10	8.7E-05	2.7E-06
11	9.0E-06	2.8E-07

† As the 642 MHz band is the lowest frequency band assigned for the provision of mobile services, the incident power density reference level corresponding to 642 MHz is adopted for the calculation of the ICNIRP compliance level, i.e., the ICNIRP compliance level is given by $\left(\frac{\text{Total Incident Power Density}}{3210\ mW/m^2}\right)(100\%)$.

Frequency-Specific Measurement Required: ■ Yes ☐ No

Table 22: NIR frequency-selective measurement results

Measurement Equipment			
Manufacturer: R&S		Model: TSMA6 Network Scanner	
Measurement Height: 2 meters above ground			
Test Point (TP)	**Reference Signal Received Power (dBm)**	**Incident Power Density (mW/m^2)**	**ICNIRP Compliance Level† (%)**
1	-34.2	27.9	0.867761
2	-38.7	9.9	0.307893
3	-46.0	1.9	0.057863
4	-63.3	0.03	0.001068
5	-59.7	0.08	0.002451
6	-58.6	0.10	0.003151
7	-64.1	0.03	0.000888
8	-99.2	8.8E-06	2.8E-07
9	-91.5	5.2E-05	1.6E-06
10	-89.8	7.8E-05	2.4E-06
11	-87.9	1.2E-04	3.7E-06

NIR Levels Are Within the ICNIRP Safety Limits: ■Yes ☐ No

5.3 Results Verification

Figure 28 shows the spectrum view of antenna's output power, which is about 28.42 dBm. Since the antenna gain is about 4 dBi, the EIRP in the air is about 32.4 dBm. Figure 29 shows the signal measurement results at testing points TP1, TP2 and TP3, whose maximum value are all about 29 dBm maximum value and are consistent with the EIRP value in the air. It is concluded that the emission of RBS in the 600MHz frequency band will not lead to noticeable hazard to human beings.

Aggregated Power from Power Amplifier (dBm)
EIRP = Output power (dBm) + Antenna Gain (dBi) = 28.4 + 4 = 32.4 dBm

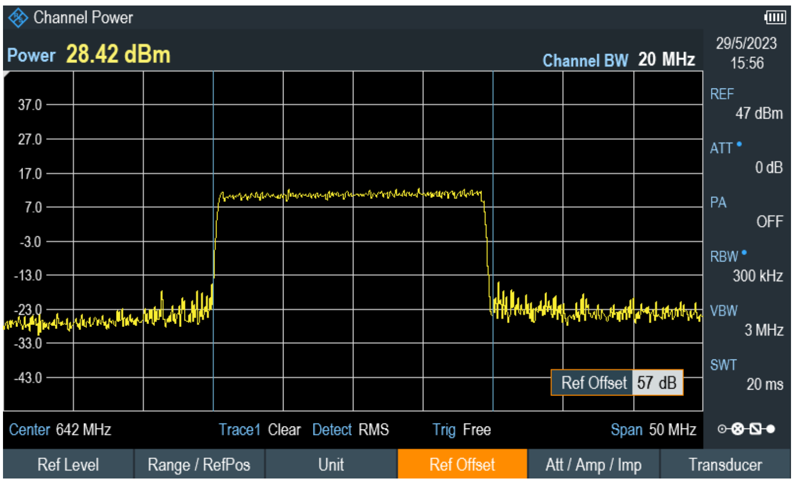
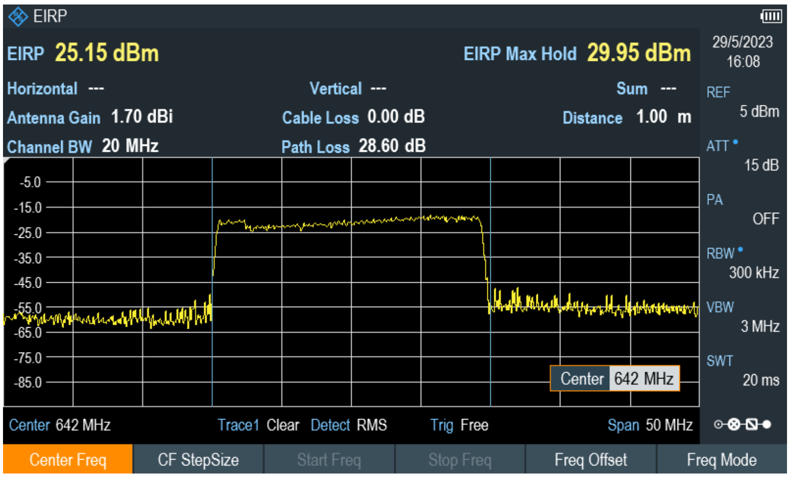
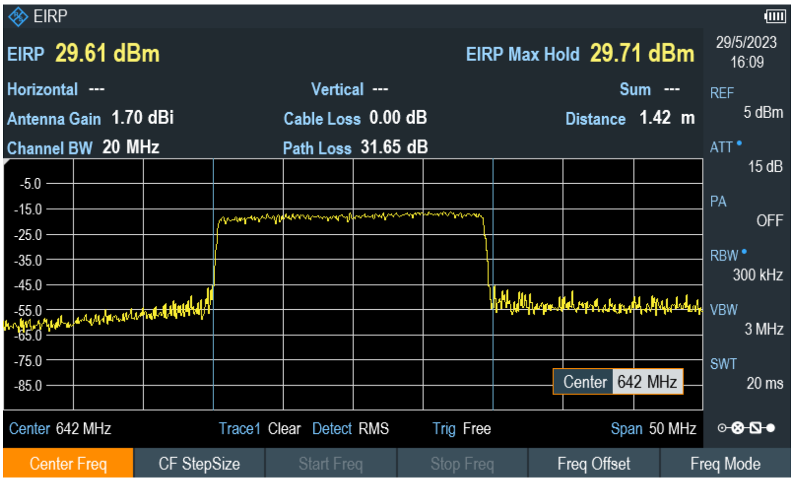


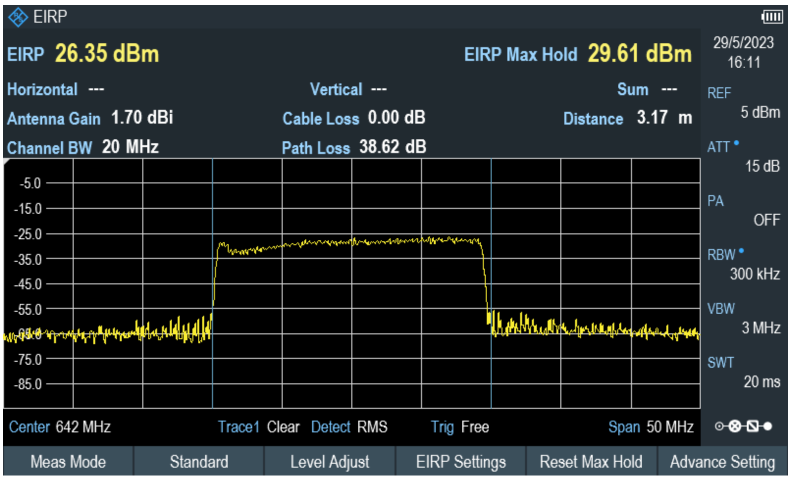
Figure 28: Spectrum view of antenna's output power



(a) TP1 EIRP (29.95 dBm max)



(b) TP2 EIRP (29.71 dBm max)



(c) TP3 EIRP (29.61 dBm max)

Figure 29: Signal measurement results at TP1, TP2 and TP3

6 Conclusion

The report provided a detailed assessment of technical issues related to 5G private network deployments using the 600 MHz frequency band which is intended for indoor use only. The potential interference on adjacent channels of TV signals is investigated. Field measurement results are used to investigate coverage and throughput performance within FHOB, as well as TV signal quality outside FHOB when N71 5G signals are transmitted. The main conclusions are described in the following paragraphs.

- When 5G mobile signal using 600 MHz band and 20 MHz bandwidth paired spectrum is transmitted in FHOB, and the antenna transmitting power is set to less than or equal to 2 Watts (i.e., 33 dBm) EIRP, a high-quality coverage and throughput performance can be achieved. At the same time, no noticeable interference was measured on adjacent TV channels outside of FHOB.

- Both Broadband Measurement and Frequency-Selective Measurement are conducted to evaluate NIR in FHOB public-accessible areas. At each measurement location, both measurement results did not exceed 0.87% of the ICNIRP compliance level, showing that NIR levels are safe.

- At this stage, it is concluded that using the 600 MHz band with an antenna transmit power set to less than or equal to 2 watts (i.e., 33 dBm) EIRP is suitable and feasible for indoor factory and warehouse applications.

- Entering the next phase of trial testing, a real 5G private network will be deployed in FHOB. Based on this trial study, three sets of omnidirectional antennas will be deployed on two floors and set the transmit power of each antenna to less than or equal to 2 Watts EIRP. Furthermore, a lower part of 600 MHz band will be used, i.e., 617 to 637 MHz paired with 663 to 683 MHz. More complex radio environments with multiple emissions will be carefully evaluated and studied.