Consultancy Report

Assessments on and Recommendations to Enable the Electromagnetic Compatibility between Public Mobile Services and Fixed Satellite Service Operating in the C-Band

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Executive Summary

For decades, the 3.4 – 4.2 GHz band, commonly known as the C-Band, has been allocated to downlinks of fixed satellite service in Hong Kong. This band is also predominantly used by Satellite Master Antenna Television ("SMATV") systems for receiving satellite TV programmes from sky and distributing the signals to some 886,569 user outlets (as of January 2018). In addressing the growing demand for public mobile communications services, on 27 July 2017, the Communications Authority ("CA") launched a public consultation on the proposed change in the allocation of the 3.4 – 3.7 GHz band from fixed satellite service to mobile service. As set out in the CA's proposal, 200 MHz of spectrum in the 3.4 – 3.6 GHz band will be used for the provision of public mobile services while the remaining 100 MHz of spectrum in the 3.6 – 3.7 GHz band will be partitioned as a guard band. To tie in with the public consultation, in August 2017, the CA initiated a consultancy study for assessments and recommendations on mitigating measures to enable the co-existence between SMATV systems operating in the 3.7 – 4.2 GHz band and systems of future public mobile services operating in the 3.4 – 3.6 GHz band ("the Consultancy Study"). Rohde & Schwarz Hong Kong Ltd was commissioned by the CA as the consultant and it partnered with Hong Kong Applied Science and Technology Research Institute Company Limited as a sub-consultant to undertake part of the Consultancy Study.

The objectives of the Consultancy Study were to draw up specific requirements with a view to enhancing the technical performance of existing SMATV systems, assess on interference impacts and devise mitigating measures to protect the existing SMATV systems from being interfered by the future mobile systems as far as practicable. The Consultancy Study was completed in January 2018. It affirmed that with the implementation of appropriate mitigating measures, SMATV systems operating in the 3.7 – 4.2 GHz band can co-exist with systems of future mobile services operating in the 3.4 – 3.6 GHz band. The findings along with the proposed mitigating measures are summarised below in succinct and the detailed assessments can be found in the body of this report:

- Existing SMATV systems could be upgraded by retrofitting a band-pass filter ("Upgraded System") in order to ensure their co-existence with the future mobile base stations of the public mobile services.

- The size of 100 MHz guard band is optimal in order to warrant sufficient signal suppression of the relatively strong mobile signals by the band-pass filter to ensure normal operation of the Upgraded System. In particular, leveraging on the 100 MHz guard band, the recommended band-pass filter that operates in the 3.7 – 4.2 GHz range shall suppress unwanted mobile signals at frequencies below 3.6 GHz by at least 55 dB.

- While SMATV systems shall operate in the reduced frequency range of 3.7 – 4.2 GHz, under the recommended configuration of the Upgraded System, the low-noise block downconverter of existing SMATV systems that receive in the 3.4 – 4.2 GHz range might continue to be used until end of equipment life. New or replacement LNB should operate in the 3.7 – 4.2 GHz band.

- Indoor and outdoor small cells of the public mobile service as well as macro mobile base stations installed at a height lower than an antenna dish of an Upgraded System in the vicinity can co-exist with that Upgraded System without any need for mitigating measures.

- When the antennas of a macro base station of the public mobile service and that of an Upgraded System are installed at the same building rooftop, there should not be interference to the latter in practice owing to the wide angular separations and different pointing direction of the respective antennas.

- When the antennas of a macro base station of the public mobile service are higher than that of an Upgraded System in close proximity with their antennas directly facing each other, interference to the latter may occur. Under such a circumstance, the antenna of the macro base station concerned should be relocated by a horizontal distance of some 65 m in the east or west directions. In practice, moving the macro base station to an adjacent building in the respective directions will generally satisfy the requirement.

The Consultancy Study also assessed the effect of spurious emissions of mobile base stations potentially affecting an Upgraded System. It is because the band-pass filter has no effect on in-band signals, i.e. spurious emissions of the mobile base station, and high level spurious emissions from mobile base stations might reduce signal to noise ratio of an Upgraded System thus affecting the overall effectiveness of the mitigating measures. In the interference analysis of spurious emissions, reference was made to the threshold value of – 52 dBm/MHz specified in 5G New Radio base station specification TS 38.104 V1.0.0 (2017-12) published by the Third Generation Partnership Project ("3GPP"). Essentially, base station equipment will need to conform with 3GPP standards and the use of -52 dBm/MHz truly reflected the future deployment scenario. Notwithstanding that, it is advisable for the Office of the Communications Authority ("OFCA") to prescribe the spurious emission limit of – 52 dBm/MHz in the future local standard for 5G base stations operating in the 3.4 – 3.6 GHz band.

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List of Acronyms and Abbreviations

3GPP	Third Generation Partnership Project
4G	The fourth generation mobile services
4G LTE	4G Long-Term Evolution
5G	The fifth generation mobile services
5G NR	5G New Radio
8PSK	Eight Phase-shift Keying
ACLR	Adjacent Channel Leakage Ratio
AAS	Active Antenna System
BPF	Band-pass Filter
BS	Base Station
C/I	Carrier-to-interference ratio
C/N	Carrier-to-noise ratio
CA	Communications Authority
C-Band	Frequency band from 3.4 GHz to 4.2 GHz
CW	Continuous Wave
dB	Decibel
dBi	Antenna gain expressed in decibels relative to that of an isotropic radiator
dBm	Power level expressed in decibels relative to 1 milliWatt (mW)
DVB-S	Digital Video Broadcasting – Satellite
EIRP	Equivalent Isotopically Radiated Power
EMC	Electromagnetic Compatibility
ETSI	European Telecommunications Standards Institute
F1	The first Fresnel zone
F/D	Focal length-to-diameter ratio
FSS	Fixed Satellite Service
GHz	Gigahertz
IF	Intermediate Frequency
IM	Intermodulation
IMD	Intermodulation Distortion
IMD3	Third Order Intermodulation Distortion
IRD	Integrated Receiver/Decoder
ITU	International Telecommunication Union
ITU-R	Radiocommunication Sector of the International Telecommunication Union
LNB	Low-noise Block Downconverter
LOS	Line-of-sight
LTE	Long-Term Evolution
macro cell	Cell with a large cell radius, typically up to several tens of kilometres
MHz	Megahertz
microcell	Cells with low antenna sites, with a typical cell radius of up to 1 kilometre
MIMO	Multiple Input Multiple Output
M-MIMO	Massive MIMO

NR	New Radio – a globally standardised access technology for 5G networks
OFCA	Office of the Communications Authority
P1dB input	The LNB input signal power greater than which the LNB conversion gain drops by 1 dB compared to the conversion gain for small-value input signals
OutputP1dB	The LNB output signal power greater than which the LNB conversion gain drops by 1 dB compared to the conversion gain for small-value input signals
QPSK	Quadrature Phase-shift Keying
RF	Radio Frequency
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
small cell	Low-powered cells with a small cell radius, typically up to several tens of metres
SMATV	Satellite Master Antenna Television
TRXUA	Transceiver Unit Array
VSWR	Voltage Standing Wave Ratio
WG	Waveguide

1 Introduction

1.1 Background

The 3.4 – 3.6 GHz frequency band (hereinafter referred to as "the 3.5 GHz band") is one of the core bands for the deployment of the fifth generation mobile services ("5G") being considered by telecommunications regulators and mobile network operators in major economies including the European Union, mainland China, Australia, USA, UK and Japan. In Hong Kong, the 3.4 – 4.2 GHz frequency band (commonly known as the C-Band) is currently allocated to fixed satellite service ("FSS") in the space-to-Earth direction on a primary basis. To cope with the demand for new spectrum in the 5G era, the CA is considering to re-allocate the 3.4 – 3.7 GHz frequency band from FSS to the mobile service, while the 3.7 – 4.2 GHz frequency band shall continue to be allocated to FSS. 200 MHz spectrum in 3.4 – 3.6 GHz will be used for the provision of public mobile service, and the 100 MHz spectrum in 3.6 – 3.7 GHz will be partitioned as a guard band to minimize interference to FSS (hereafter collectively referred as "the Proposed Re-Allocation"). Figure 1-1 compares the existing allocation in the C-Band with the Proposed Re-Allocation.

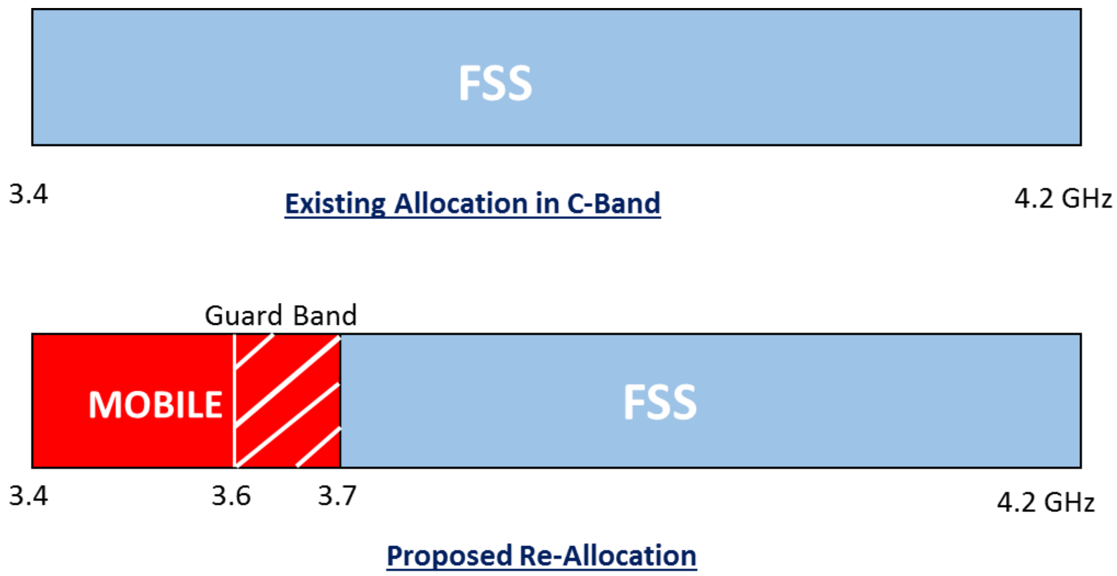


Figure 1-1: C-Band Allocation in Hong Kong.

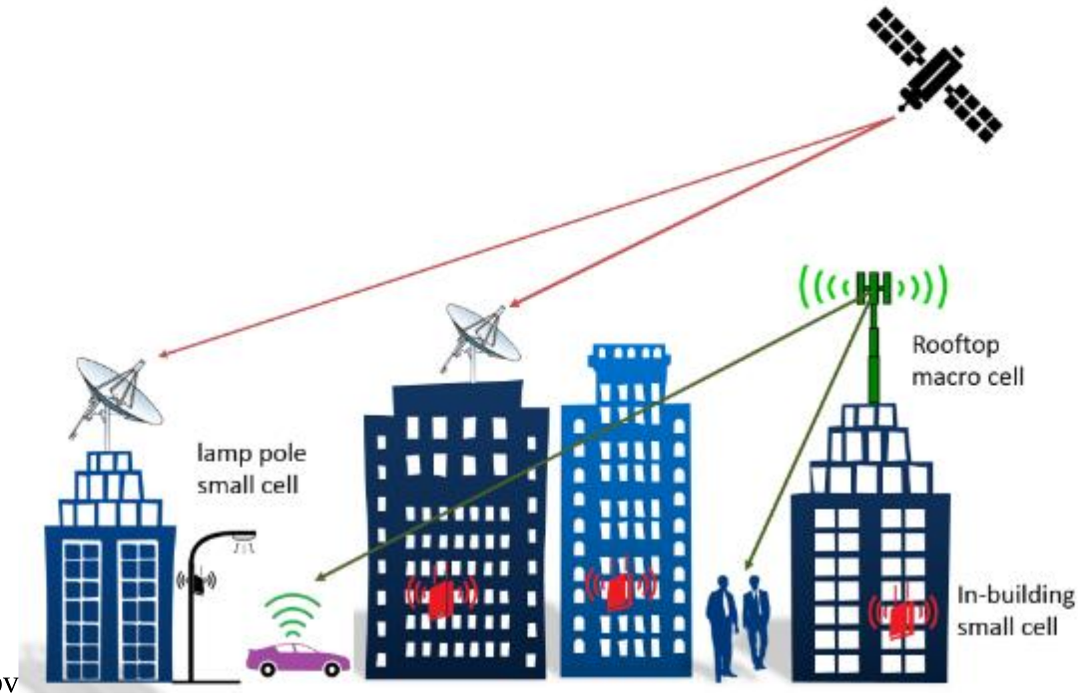
In Hong Kong, as of January 2018, there are 1,574 SMATV systems managed by 69 licensed SMATV operators distributing satellite TV programme signals to 886,569 user outlets[1] (as of

[1] Source: https://www.ofca.gov.hk/filemanager/ofca/en/content_295/eng_smatv.pdf

January 2018). These systems are generally configured to operate in the entire 3.4 – 4.2 GHz band for receiving as many satellite TV channels as possible. It is conceivable that these systems will be affected by the Proposed Re-Allocation unless some tailor-designed interference mitigating measures are implemented. Against this background, this Consultancy Study has been undertaken, with due regard to the Proposed Re-Allocation, to provide assessments on and recommendations to enable the co-existence between systems of the future public mobile services and SMATV systems operating in the C-Band.

1.2 Potential Interference Scenarios Experienced by SMATV Systems

As far as the usage of the 3.5 GHz band is concerned, mobile network operators of Hong Kong have expressed that they are interested in and will use this band solely for their 5G network deployment employing macro, micro and small cells to provide ubiquitous outdoor and indoor coverage (see section 2.1). In particular, relatively large number of small cells would be set up at street level as capacity fillers which necessitate mounting remote radio units on lamp poles or at podium level. Figure 1-2 provides a visualization of the co-existence of 5G systems and SMATV systems in the future, when effective mitigating measures are properly implemented.



fbv

Figure 1-2: Visualization of 5G systems and SMATV systems working in harmony.

Driven by the need of a clear and unblocked view to the sky, SMATV antennas are typically installed on rooftops with only a minority installed at lower levels. According to OFCA's records, among the 1,574 SMATV systems in Hong Kong, 1,465 (i.e., 93 %) of them have the dish antennas installed at heights higher than 5 floors, or 15 metres above ground. When 5G networks operating in the 3.5 GHz band are rolled out, SMATV antennas and mobile base station antennas would be erected in close proximity. In a worst-case scenario, the main beam of base station antennas installed at higher levels might fall into the main lobe of up-tilted SMATV antennas. These operating conditions will introduce a variety of interference scenarios jeopardizing the normal operations of SMATV systems.

In spite of the band segmentation and the 100 MHz frequency separation outlined in the Proposed Re-Allocation, three interference scenarios affecting SMATV systems are identified in this study as outlined below.

Scenario 1*: Saturation of the SMATV system, caused by high-level base station signals in the 3.5 GHz band, as shown in Figure 1-3*

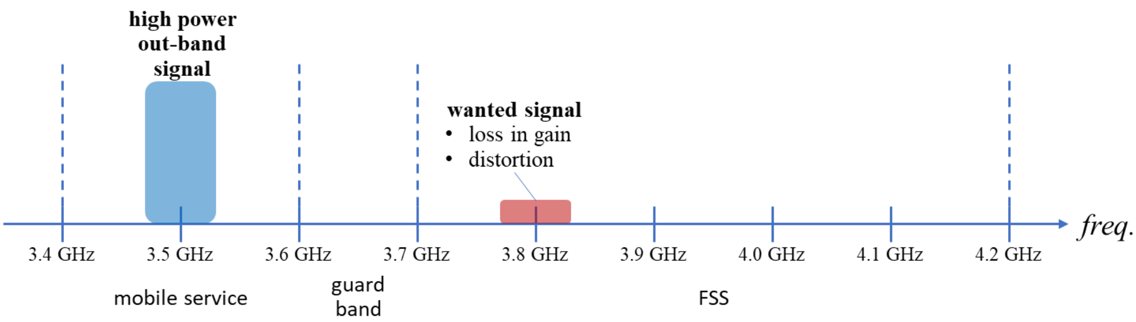


Figure 1-3: Illustration of Scenario 1 – SMATV system saturation caused by high-power base station signals.

A base station in the 3.5 GHz band which is located near or in direct line-of-sight ("LOS") with an antenna dish of a SMATV system may saturate the latter. The saturation occurs at the Low-noise Block Downconverter ("LNB") of the SMATV system (see Figure 3-1). When the LNB is driven into saturation, it ceases to amplify the wanted weak satellite signals in a linear fashion thus decreasing the conversion gain significantly.

Scenario 2*: Strong signals of mobile base station resulting in intermodulation products (“IMD”) interfering with the wanted SMATV signals, as shown in Figure 1-4*

Inherently, IMD is caused by nonlinearities of the active radio frequency (“RF”) components (which are located after the feedhorn, including waveguide bandpass filter, LNB, etc.) of the SMATV system (see Figure 3-1). For example, two base station signals of frequencies around 3.4 GHz and 3.6 GHz at the SMATV receiver input would generate the product of third-order IMD (“IMD3”) at 3.8 GHz as in-band interference to the desired SMATV signal. Details of how IMD affects the SMATV system can be found in Annex 1.

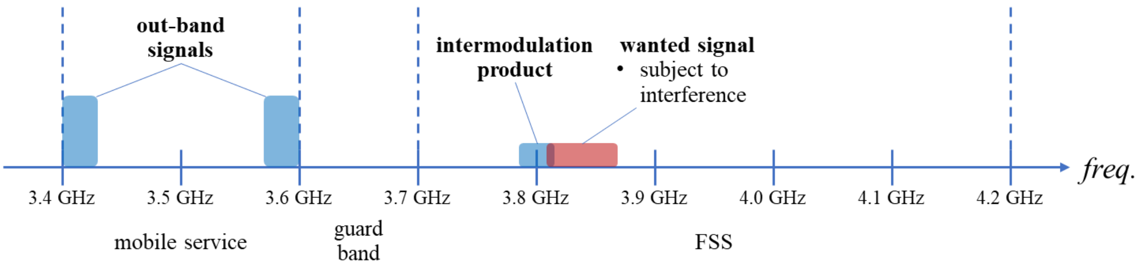


Figure 1-4: Illustration of Scenario 2 – IMD generated within the SMATV system from base station signals.

Scenario 3*: Unwanted spurious emissions of mobile base stations traversing the 3.7 – 4.2 GHz frequency range*

Spurious emissions requirements of public mobile services are defined in the fourth generation mobile (“4G”) and 5G technical standards. In 4G Long-Term Evolution (“4G LTE”) terminology, the frequency ranges below and above 10 MHz of an LTE signal operating band (equivalent to channel bandwidth) are defined as the LTE spurious emissions (see Figure 1-5). On the other hand, in 5G New Radio (“NR”) terminology, the frequency ranges below and above up to 40 MHz of an NR signal operating band (equivalent to channel bandwidth) are defined as the NR spurious emissions. Spurious emissions stemming from an LTE signal or an NR signal in the 3.5 GHz band can straddle across the 3.4 – 3.6 GHz, 3.6 – 3.7 GHz and 3.7 – 4.2 GHz bands. In the context of the Proposed Re-Allocation, only spurious emissions traversing the 3.7 – 4.2 GHz band, which will become interference to SMATV signals, will be considered and analysed for mitigation. Such unwanted spurious emissions will manifest as background noise in the 3.7 – 4.2 GHz frequency band and reduce the signal to noise ratio of the SMATV systems as well. For reference, Annex 2 gives information on 5G NR spurious emission profiles based on TS 38.104 V1.0.0 (2017-12) developed by 3GPP prevailing at the time of this study.

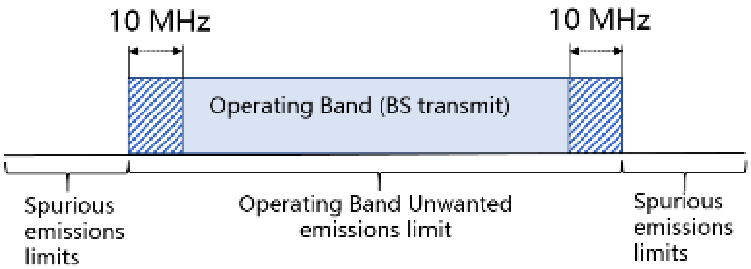


Figure 1-5: Defined frequency range for LTE spurious emissions.

Potential Solution*: Retrofitting a waveguide bandpass filter ("WG BPF")*

Scenario 1 and ***Scenario 2*** are caused by base stations' main signals transmitting in the 3.5 GHz band. Given this circumstance, it follows that retrofitting a suitable WG BPF for suppressing such frequency specific signals at the SMATV system could be a feasible mitigating measure. First and foremost, the use of a WG BPF should be considered ahead of all other mitigating measures or technical solutions.

However, for ***Scenario 3***, the in-band interference cannot be suppressed by simply retrofitting a WG BPF. Other mitigating measures, including, among others, spurious emission limits for compliance by 3.5 GHz base stations and restrictions on base station deployment, will be further considered in the sections 6 – 7 of this study report.

1.3 Objectives and Organization of this Study Report

This report aims at assessing and providing recommendations to enable the co-existence between mobile systems and SMATV systems operating in the C-Band with regards to the CA's Proposed Re-Allocation. The main objectives of this report include:

- To define a SMATV model system ("Model System") which is suitable and capable of operating under the Proposed Re-Allocation;

- To develop an analytical model for interference assessment and to propose interference mitigating measures; and

- To verify the interference assessment results by field trials.

This report is divided into the following sections:

- section 2 summarises the interviews with mobile network operators and SMATV operators;

- section 3 describes the specifications and testing results of commercially available RF components suitable for SMATV systems to operate under the Proposed Re-Allocation;

- section 4 introduces the Model System and recommends its baseline requirements for operating under the Proposed Re-Allocation;

- section 5 gives a ball-park estimate of upgrading an existing SMATV system to comply with the baseline requirements;

- section 6 develops an Analytical Model to predict and evaluate how the Model System can function optimally under different base station deployment scenarios and the corresponding mitigating measures;

- section 7 presents the field trial results;

- section 8 verifies the field trial results against theoretical analysis; and

- section 9 sums up the findings and the proposed mitigating measures of the Consultancy Study.

Aside from these sections, Annexes 1 – 6 provide quantitative information addressing other aspects of interference analysis as part of this study report.

2 Summary of Interview Results with Mobile Network Operators and SMATV Operators

2.1 Interviews with Mobile Network Operators

Interviews with representatives of all four mobile network operators (i.e., Hong Kong Telecommunications (HKT) Limited, Hutchison Telephone Company Limited, SmarTone Mobile Communications Limited and China Mobile Hong Kong Company Limited) were held on 6 – 7 September 2017 to enquire about their intended use of the 3.5 GHz band and their views on mitigating measures for enabling the Proposed Re-Allocation. All the four mobile operators expressed that, if they would be assigned with the spectrum, they would make use of the 3.5 GHz band exclusively for 5G services. However, they questioned on the need of a 100 MHz guard band and requested OFCA to assess with a view to reducing the guard band whereby more spectrum could be allocated to the public mobile service. In terms of network planning, they expressed that they would deploy macro base stations, indoor small cells, as well as outdoor small cells on lamp poles, etc. They particularly emphasized that the provision of gigabits speeds in 5G could only be realized by the use of massive Multiple Input Multiple Output ("M-MIMO") antenna array in 5G base stations. To this end, they pinpointed the technical difficulties of inserting output filters between radio transmitters and the associated M-MIMO antenna architecture. Moreover, they urged that the effects of M-MIMO antenna array should be addressed in the electromagnetic compatibility ("EMC") analysis.

2.2 Interviews with SMATV Operators

Interviews with representatives from Hong Kong's three leading SMATV operators were held on 7 September 2017, namely, Pacific Satellite International Limited, SUNeVision Super e-Technology Services Limited, and Rediffusion Satellite Services Limited. Taken together, these three SMATV operators accounted for some 40% of the market share of the existing SMATV systems in Hong Kong. They said that their installed/maintained C-Band SMATV systems were mostly set up to receive satellite TV signals from satellites AsiaSat 5, AsiaSat 7 and ChinaSat 6B which generally required an antenna elevation angle of around 60 degrees. Moreover, they pointed out that the LNBs in use in their systems were operating in the full range of 3.4 – 4.2 GHz without the use of BPFs. In the interviews, the SMTAV operators provided some technical specifications of their SMATV systems and advised on the estimated costs of LNBs, BPFs, administrative and engineering man-hours should there be a need to modify their existing systems.

3 Commercially Available RF Components Suitable for SMATV Systems to Operate under the Proposed Re-Allocation

3.1 Specifications of SMATV Systems Commonly Deployed in Hong Kong

The setup of commonly used SMATV systems in Hong Kong is shown in Figure 3-1 and the associated specifications are summarized in Table 3-1. In general, antenna reflectors have a diameter of approximately 3 metres with antenna gains of around 40 dBi. The feedhorn and the LNB receive signals in the entire 3.4 – 4.2 GHz band. The dynamic receiving range of the integrated receiver/decoder ("IRD") is from - 65 dBm to -25 dBm.

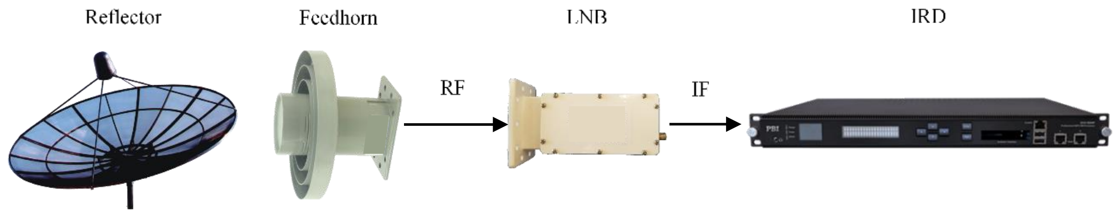


Figure 3-1: Receiver architecture of typical SMATV system commonly deployed in Hong Kong.

Table 3-1: Specifications of a typical SMATV system used in Hong Kong.

Component	Typical Specifications
Reflector	Diameter: Approximately 3 m Gain: Approximately 40 dBi
Feedhorn	Input Frequency Range: 3.4 – 4.2 GHz F/D Ratio[2]: 0.33 – 0.45
BPF	N/A
LNB	Input Frequency Range: 3.4 – 4.2 GHz Conversion Gain: 64 dB OutputP1dB[3]: 8 dBm Output Frequency Range: 950 – 1750 MHz
IRD	Typical Input Range: -65 dBm to -25 dBm

[2] F/D ratio stands for the ratio of the focal length to the diameter of the reflector.
[3] OutputP1dB stands for 1 dB compression point at the output which indicate the output power level that causes the gain to drop by 1 dB from its small-signal value.

3.2 Specifications of Commercially Available LNBs for the Model System

Based on market research, exchange with equipment suppliers, and recommendations from SMATV operators, it was identified that commercial off-the-shelf LNBs listed in Table 3-4 and Table 3-5 might be suitable for SMATV systems to operate under the Proposed Re-Allocation. These LNBs were tested individually for measuring their conversion gain and 1 dB compression point at the input ("P1dB input").

3.2.1 Test Setup

The test setup is shown in Figure 3-2. For completeness sake and the avoidance of doubt, the models of the measuring equipment are given in Table 3-2.

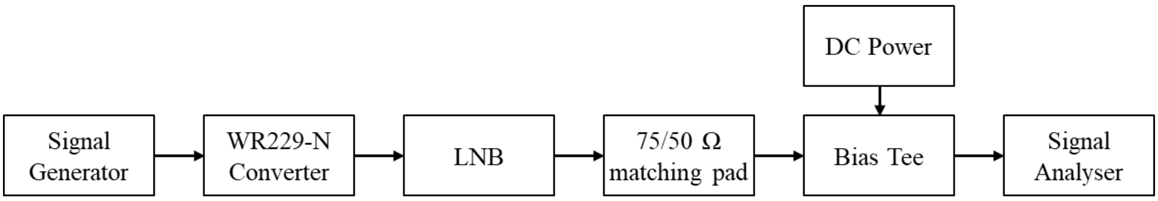


Figure 3-2: Test setup for LNB conversion gain and P1dB measurements.

Table 3-2: Measuring equipment used for LNB conversion gain and P1dB measurements.

Measuring Equipment	Model	Function
Signal Generator	R&S SMBV100A	To generate input signal
Signal Analyser	R&S FSQ	To analyse output signal

3.2.2 Experiment Settings

In the course of LNB testing, continuous wave ("CW") was used as input signal. The merits of using CW for LNB measurements are as follows -

- CW could be generated by most signal generators;
- CW can minimize the level of noise injected into the test setup; and
- CW was a baseline waveform for analysing all other types of signals, i.e., any signal could be represented by linear combinations of continuous waves.

The testing parameters are summarized in Table 3-3.

Table 3-3: Testing parameters for LNB conversion gain and P1dB measurements.

	LNB P1dB Input Measurements	LNB Conversion Gain Measurements[4]
Input Signal Type	CW	CW
Input Signal Frequency	3.8 GHz	3.2 – 4.4 GHz
Input Signal Power Level	-60 dBm to -40 dBm	-70 dBm

3.2.3 Test Results

The specifications and test results for LNBs potentially suitable for SMATV systems to operate under the Proposed Re-Allocation are depicted in Table 3-4 and Table 3-5. The LNBs were categorized as Typical LNBs and Advanced LNBs, and their performances are summarized below.

Performances of three Typical LNBs with input frequency range of 3.4 – 4.2 GHz

- The conversion gains of the three typical LNBs were between 52 dB to 70 dB.
- The P1dB input values of the three typical LNBs were between -52 dBm to -50 dBm.
- Typical LNB 3 was the LNB currently deployed in the majority of SMATV systems in Hong Kong. Therefore, the performances of Typical LNB 3 would be regarded as the benchmarks for testing and analysis.

Performances of two Advanced LNBs with input frequency range of 3.7 – 4.2 GHz

- The conversion gain of both advanced LNBs was around 60 dB.
- The P1dB input values of Advanced LNB 1 and Advanced LNB 2 were -53 dBm and -46 dBm, respectively.

[4] In RF testing practice, the input signal power strength was chosen based on the characteristics of the components according to the following criteria: P_{in} = OutputP1dB − Conversion gain − 10 dB.

Table 3-4: Specifications and test results of commercially available LNBs with input frequency range of 3.4 – 4.2 GHz for the Model System.

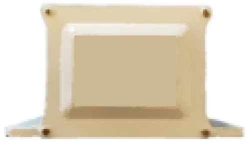
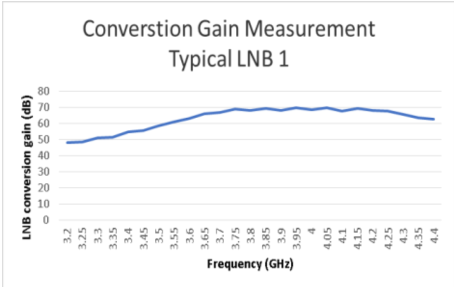
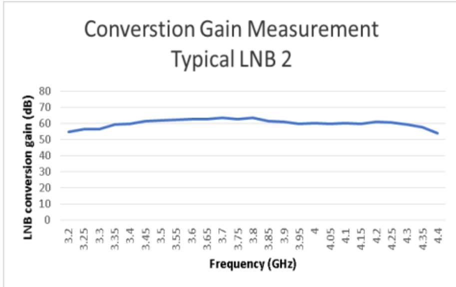
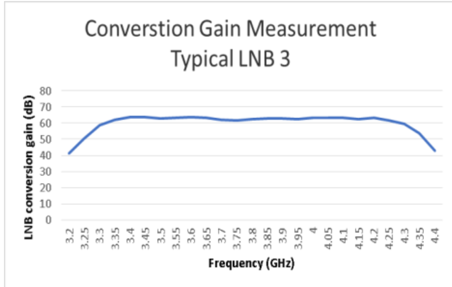
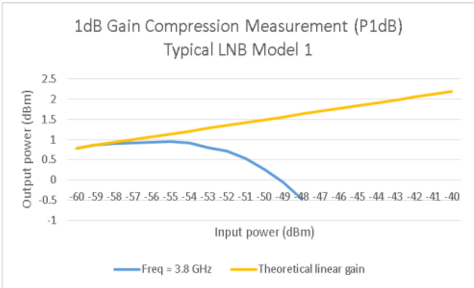
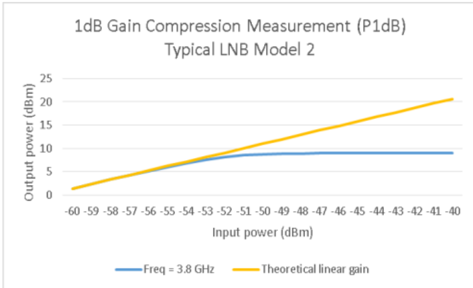
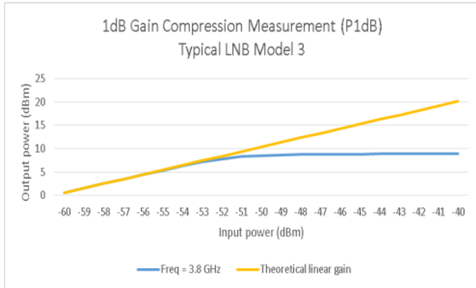
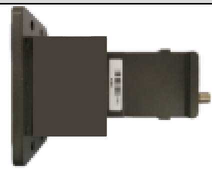
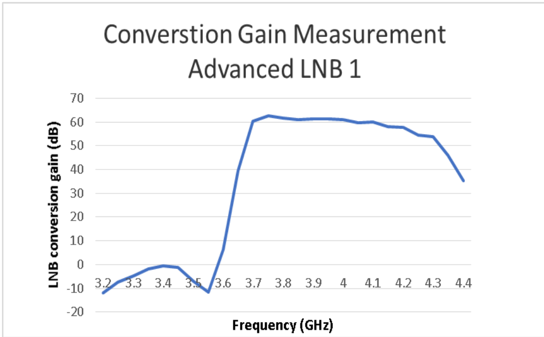
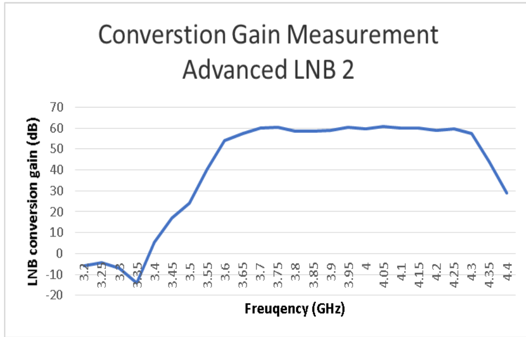
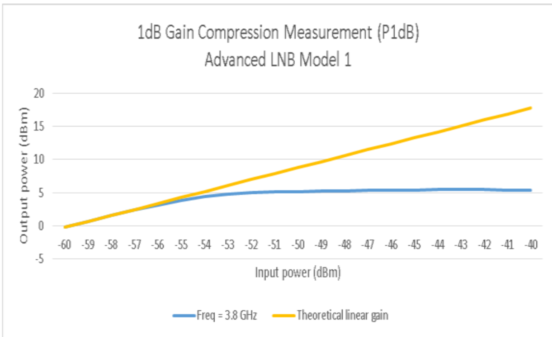
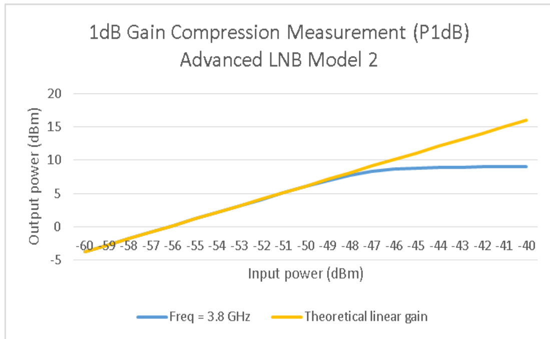
LNB Type	Typical LNB 1	Typical LNB 2	Typical LNB 3
Sample picture			
Test results of LNB conversion gain at 3.4 – 4.2 GHz, with -70 dBm continuous wave input signal	 LNB conversion gain > 52 dB	 LNB conversion gain > 58 dB	 LNB conversion gain > 60 dB
Test results of P1dB input measurement with input signal at 3.8 GHz	 P1dB input was -50 dBm	 P1dB input was -51 dBm	 P1dB input was -52 dBm

Table 3-5: Specifications and test results of commercially available LNBs with input frequency range of 3.7 – 4.2 GHz for the Model System.

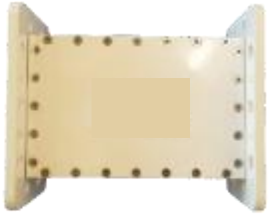
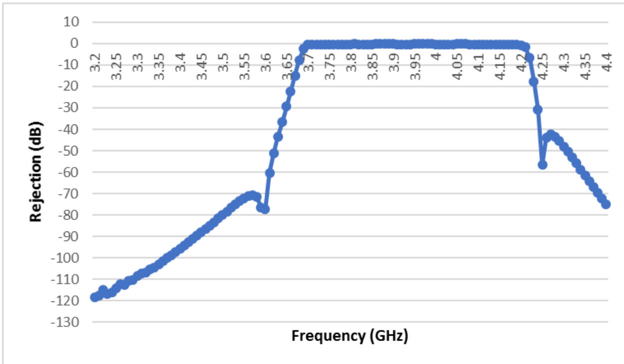
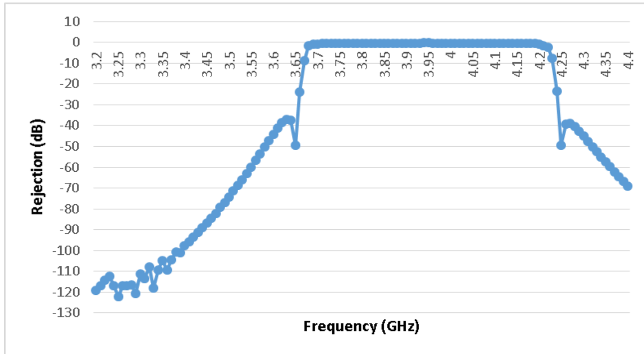
LNB Type	Advanced LNB 1	Advanced LNB 2
Sample picture		
Test results of LNB conversion gain performance at 3.7 – 4.2 GHz, with -70 dBm continuous wave input signal	 LNB conversion gain was around 60 dB	 LNB conversion gain was around 60 dB
Test results of P1dB input measurement with input signal at 3.8 GHz	 P1dB input was -53 dBm	 P1dB input was -46 dBm

3.3 Specifications of Commercially Available Waveguide BPF for the Model System

At the outset, retrofitting a WG BPF is a practical and straightforward method to control unwanted high-level signals from driving SMATV systems into saturation (de-sensitization). In an effort to demonstrate the effects of this configuration, two commercially available WG BPFs were selected for testing and observation. The specifications of these WG BPFs are summarized in Table 3-6. In brief, utilising the roll-off characteristic of the 100 MHz guard band, these BPFs could effectively offer 45 dB to 55 dB signal suppression for frequencies below 3.6 GHz and 50 dB suppression for frequencies above 4.3 GHz. In the case of 50 MHz guard band, the frequency range is from 3.65 GHz to 3.7 GHz and so literally the lower cut-off frequency of the BPF is 3.65 GHz. These BPFs could offer only 20 dB to 35 dB signal suppression for frequencies below 3.65 GHz. Since WG BPF 1 had satisfactory signal suppression for frequencies below 3.6 GHz, the performances of WG BPF 1 would be regarded as the benchmarks for testing and analysis.

In section 4 of this study report, the performances exhibited by a SMATV system with the LNB in cascade with the WG BPF will be explored and compared with those of a typical system without a WG BPF.

Table 3-6: Specifications of commercially available WG BPFs.

BPF Type	WG BPF 1	WG BPF 2
WG BPF sample picture		
Interference rejection	*Specifications* • At least 55 dB at or below 3.6 GHz • At least 50 dB at or above 4.3 GHz • At least 20 dB at or below 3.65 GHz *Measurements* • At least 70 dB at or below 3.6 GHz • At least 50 dB at or above 4.3 GHz • At least 30 dB at or below 3.65 GHz	*Specifications* • At least 45 dB at or below 3.6 GHz • At least 50 dB at or above 4.3 GHz • At least 35 dB at or below 3.65 GHz *Measurements* • At least 44 dB at or below 3.6 GHz • At least 45 dB at or above 4.3 GHz • At least 36 dB at or below 3.65 GHz
Lab test result on BPF interference rejection performance		

4 The Model System Design

Figure 4-1 illustrates the setup of a proposed Model System where a WG BPF is cascaded with a LNB. With the aim of exploring the performance aspects in a holistic manner, the following tests and analysis were undertaken:

- Evaluation of the performance of a typical SMATV system (see Figure 3-1);
- Evaluation of the performance of the Model System with WG BPF in cascade with LNB (see Figure 4-1);
- Comparison of the results of the above two systems with a view to deriving the unwanted signal suppression achievable after retrofitting the WG BPF; and
- Recommendation on which type of LNB could work best with the Proposed Re-Allocation.

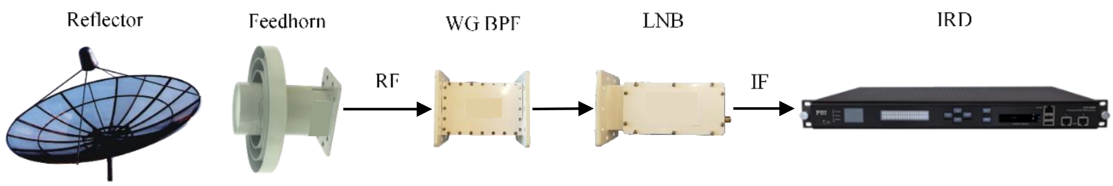


Figure 4-1: Proposed Model System.

4.1 Test Setup

Figure 4-2 and Figure 4-3 show the setup for testing a typical SMATV system and the Model System respectively. With the use of a LTE BPF in the setup, the background noise from Signal Generator A and B could be suppressed effectively.

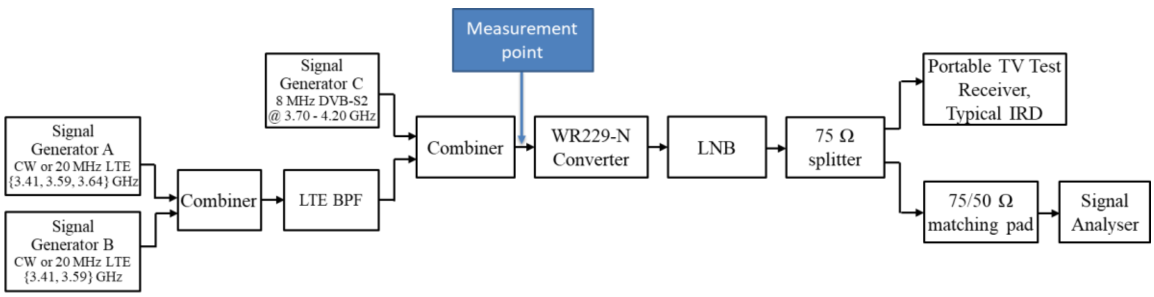


Figure 4-2: Test setup for a typical SMATV system.

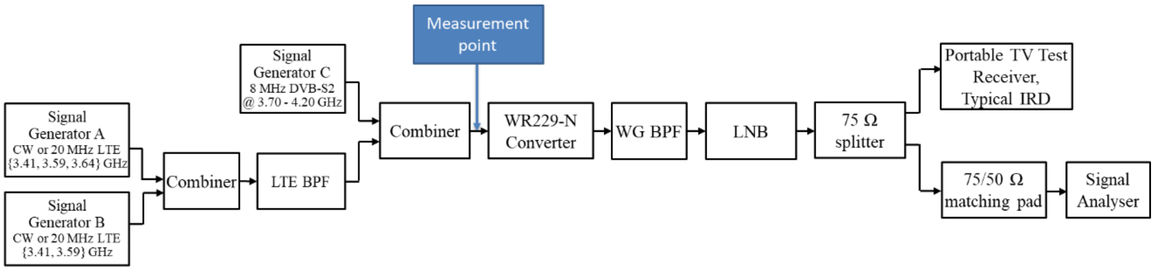


Figure 4-3: Test setup for the proposed Model System.

For completeness sake and avoidance of doubt, the measurement equipment used and the models are listed in Table 4-1:

Table 4-1: Measuring equipment used for testing a typical SMATV system and the proposed Model System.

Measuring Equipment	Model	Function
Signal Generator A	R&S SMBV100A	To generate input signal
Signal Generator B	R&S SMU 200A	To generate input signal
Signal Generator C	R&S BTC	To generate DVB-S2 signal (i.e. SMATV signal)
Signal Analyzer	R&S FSQ	To analyse output signal
Portable TV Test Receiver	R&S EFL340	To display decoded TV signals
Typical IRD	N/A	To decode SMATV signals
LTE BPF	N/A	To keep spurious emissions in 3.7 – 4.2 GHz of the test set up under control
LNB	Typical LNB 3 Advanced LNB 1	Through lab testing to decide which LNB is more suitable for use of the Model System.

4.2 Experiment Settings

Four experiments were conducted to assess the performances of a typical SMATV system and the Model System. The parameters for each experiment are summarized in Table 4-2 to Table 4-5. In the test setup of a typical SMATV system (without WG BPF), the maximum input signal power, i.e. mobile signals, was set at -30 dBm for one signal, and -40 dBm for two signals, in order to protect the LNB from permanent damage due to excessive high level of input signals. Due to test equipment limitation, the maximum power for CW signal was +25 dBm and the maximum power for LTE signal was +13 dBm.

Table 4-2: Parameters of Experiment 1 – Single LTE signal input to SMATV system.

Input signal type	LTE	
Input signal bandwidth	20 MHz	
Input signal frequency	Case 1	3.41 GHz
	Case 2	3.59 GHz
	Case 3	3.64 GHz
Input signal power level	Increasing from -90 dBm until the TV test receiver could not successfully display the decoded TV signal	

Table 4-3: Parameters of Experiment 2 – Two LTE signals input to SMATV system.

	Signal A	**Signal B**
Input signal type	LTE	
Input signal bandwidth	20 MHz	
Input signal frequency	3.41 GHz	3.59 GHz
Input signal power level	Increasing from -90 dBm until the TV test receiver could not successfully display the decoded TV signal	

Table 4-4: Parameters of Experiment 3 – Single CW signal input to SMATV system.

	Signal A	**Signal B**
Input signal type	CW	
Input signal frequency	3.41 GHz	3.59 GHz
Input signal power level	Increasing from -90 dBm until the TV test receiver could not successfully display the decode TV signal	

Table 4-5: Parameters of Experiment 4 – Two different CW signals input to SMATV system.

	Signal A	**Signal B**
Input signal type	CW	
Input signal frequency	3.41 GHz	3.59 GHz
Input signal power level	Increasing from -90 dBm until the TV test receiver could not successfully display the decoded TV signal	

4.3 Test Procedures and Results

In gauging the performances of the typical SMATV system and the Model System, the performance metric used was the maximum mobile signal power (i.e. interference power).

The power level of the interfering signal was increased progressively until a point where the receiver system would not be able to successfully decode the received TV signals (i.e., DVB-S2 format, 8PSK modulation, and forward error correction code rate of 9/10) which set forth the most stringent decoding requirements. This power level was referred as the "maximum tolerable mobile signal power". The power of the interfering signal was probed at the measurement point marked in Figure 4-2 and Figure 4-3 whereby the reading corresponded to power input to the SMATV receiver system. In this respect, a higher tolerable mobile signal power signified a better performance of the receiver system. The test results of individual experiments are summarized in Table 4-6.

Table 4-6: Test results of maximum tolerable signal power above which the receiver system failed to decode the TV signal at 3.77 GHz.

Test Setups	Input Signal Type	Input Signal Frequency	Maximum tolerable interfering signal power above which the receiving system failed to decode the TV signal at 3.77 GHz (dBm)	
			Typical LNB 3 (3.4 – 4.2 GHz)	Advanced LNB 1 (3.7 – 4.2 GHz)
LNB + LTE BPF	Single LTE input	3.41 GHz	-60.0	> -42.3
		3.59 GHz	-60.0	-44.3
		3.64 GHz	-60.0	> -42.3
	Two different LTE inputs	3.41 GHz	-68.6	-58.0
		3.59 GHz	-68.6	-58.0
	Single CW input	3.41 GHz	-60.5	> -40.5
		3.59 GHz	-58.5	> -40.5
	Two different CW inputs	3.41 GHz	-69.7	> -50.5
		3.59 GHz	-69.7	> -50.5
LNB + LTE BPF + WG BPF	Single LTE input	3.41 GHz	> -3.8	> -3.8
		3.59 GHz	> -3.8	> -3.8
		3.64 GHz	-37.0	-34.6
	Two different LTE inputs	3.41 GHz	> -3.8	> -3.8
		3.59 GHz	> -3.8	> -3.8
	Single CW input	3.41 GHz	9.5	> 9.5
		3.59 GHz	9.5	> 9.5
	Two different CW inputs	3.41 GHz	1.0	> 9.5
		3.59 GHz	1.0	> 9.5

4.3.1 Test Results Analysis on RF Components for the Proposed Model System

Typical LNB 3 was the LNB deployed in the majority of SMATV systems in Hong Kong. With this in mind, the performances of a typical SMATV system (see Figure 4-1) with Typical LNB 3 were regarded as benchmarks for analysing the testing results.

To further determine the performances of integrating individual RF components in different combinations, the following three methods were applied in conjunction with the test results in Table 4-6.

***Method 1**: Retrofitting a WG BPF to typical SMATV system*

In this method, the levels of unwanted signal suppression by retrofitting a WG BPF to a typical SMATV system were measured as follows and detailed in Table 4-7.

- larger than 56 dB for the case of a single input LTE signal in the 3.5 GHz band;
- 23 dB for the case of a single input LTE signal in the 3.60 – 3.65 GHz band (i.e., only 50 MHz guard band between mobile service and FSS);
- larger than 64 dB for the case of two different input LTE signals in the 3.5 GHz band;
- Larger than 68 dB for the case of a single input CW signal in the 3.5 GHz band; and
- 70 dB for the case of two different input CW signals in the 3.5 GHz band.

Table 4-7: Test results of maximum tolerable signal power after retrofitting a WG BPF to a typical SMATV system

Test Setups	Input Signal Type	Input Signal Frequency	Maximum tolerable interfering signal power above which the receiving system failed to decode the TV signal at 3.77 GHz (dBm) Typical LNB 3 (3.4-4.2 GHz)	Unwanted signal suppression obtained by retrofitting a WG BPF (dB)
LNB + LTE BPF	Single LTE Signal	3.41 GHz	-60.0	
LNB + LTE BPF + WG BPF			> -3.8	> 56.2
LNB + LTE BPF		3.59 GHz	-60.0	
LNB + LTE + WG BPF			> -3.8	> 56.2
LNB + LTE BPF		3.64 GHz	- 60.0	
LNB + LTE + WG BPF			-37.0	23.0
LNB + LTE BPF	Single CW Signal	3.41 GHz	-60.5	
LNB + LTE BPF + WG BPF			9.5	70.0
LNB + LTE BPF		3.59 GHz	-58.5	
LNB + LTE BPF + WG BPF			9.5	68.0
LNB + LTE BPF	Two Different LTE Signals	3.41 GHz	-68.6	
LNB + LTE BPF + WG BPF			> -3.8	> 64.8
LNB + LTE BPF		3.59 GHz	-68.6	
LNB + LTE BPF + WG BPF			> -3.8	> 64.8
LNB + LTE BPF	Two Different CW Signals	3.41 GHz	-69.7	
LNB + LTE BPF + WG BPF			1.0	70.7
LNB + LTE BPF		3.59 GHz	-69.7	
LNB + LTE BPF + WG BPF			1.0	70.7

Method 2*: Replacing the LNB currently used in typical SMATV system*

In this method, a Typical LNB 3 (3.4 – 4.2 GHz) was tested first and then replaced with the Advanced LNB 1 (3.7 – 4.2 GHz). The levels of unwanted signal suppression after replacement were measured as follows and detailed in Table 4-8.

- larger than 15 dB for the case of a single input LTE signal;
- larger than 10 dB for the case of two different input LTE signals in the 3.5 GHz band;
- larger than 18 dB for the case of a single input CW signal in the 3.5 GHz band; and
- larger than 19 dB for the case of two different input CW signals in the 3.5 GHz band.

Table 4-8: Test results of maximum tolerable signal power after replacing the LNB of a typical SMATV system.

Test Setups	Input Signal Type	Input Signal Frequency	Maximum tolerable interfering signal power above which the receiving system failed to decode the TV signal at 3.77 GHz (dBm)		Unwanted signal suppression obtained by replacing LNB (dB)
			Typical LNB 3 (3.4 - 4.2 GHz)	Advanced LNB 1 (3.7 - 4.2 GHz)	
LNB + LTE BPF	Single LTE Signal	3.41 GHz	-60.0	> -42.3	> 17.7
		3.59 GHz	-60.0	-44.3	15.7
		3.64 GHz	-60.0	> -42.3	> 17.7
	Single CW Signal	3.41 GHz	-60.5	> -40.5	> 20.0
		3.59 GHz	-58.5	> -40.5	> 18.0
	Two Different LTE Signals	3.41 GHz	-68.6	-58.0	10.6
		3.59 GHz	-68.6	-58.0	10.6
	Two Different CW Signals	3.41 GHz	-69.7	> -50.5	> 19.2
		3.59 GHz	-69.7	> -50.5	> 19.2

***Method 3**: Retrofitting a WG BPF and replacing LNB simultaneously*

By way of retrofitting a WG BPF and replacing the 3.4 – 4.2 GHz LNB together, the levels of unwanted signal suppression were measured as follows and summarized in Table 4-9:

- larger than 56 dB for the case of a single input LTE signal in the 3.5 GHz band;
- larger than 25 dB for the case of a single input LTE signal in the 3.60 – 3.65 GHz band (i.e., only 50 MHz guard band between mobile service and FSS);
- larger than 64 dB for the case of two different input LTE signals in the 3.5 GHz band;
- larger than 68 dB for the case of a single input CW signal in the 3.5 GHz band; and
- larger than 79 dB for the case of two different input CW signals in the 3.5 GHz band.

Table 4-9: Test results of maximum tolerable interfering signal power after retrofitting WG BPF and replacing LNB.

Test Setups	Input Signal Type	Input Signal Frequency	Maximum tolerable interfering signal power above which the receiving system failed to decode the TV signal at 3.77 GHz (dBm)		Unwanted signal suppression obtained by retrofitting WG BPF and replacing LNB (dB)
			Typical LNB 3 (3.4 - 4.2 GHz)	Advanced LNB 1 (3.7 - 4.2 GHz) + WF BPF	
a) LNB + LTE BPF for Typical LNB 3; b) LNB + LTE BPF + WG BPF for Advanced LNB 1	Single LTE Signal	3.41 GHz	-60.0	> -3.8	> 56.2
		3.59 GHz	-60.0	> -3.8	> 56.2
		3.64 GHz	-60.0	-34.6	25.4
	Single CW Signal	3.41 GHz	-60.5	> 9.5	> 70.0
		3.59 GHz	-58.5	> 9.5	> 68.0
	Two Different LTE Signals	3.41 GHz	-68.6	> -3.8	> 64.8
		3.59 GHz	-68.6	> -3.8	> 64.8
	Two Different CW Signals	3.41 GHz	-69.7	> 9.5	> 79.2
		3.59 GHz	-69.7	> 9.5	> 79.2

4.3.2 Conclusions

After consolidating the measurement results, the following key findings are discovered:

- Method 1 (retrofitting WG BPF alone) and Method 3 (retrofitting WG BPF and replacing LNB simultaneously) could achieve similar suppression of the unwanted interfering signals over a wide range of power levels.
- The unwanted signal suppression obtained by Method 2 (replacing LNB alone) was the lowest.
- Method 1 (retrofitting WG BPF alone) was the simplest and cost-effective method to improve the performance of the typical SMATV receiver system which provided a sound technical basis to enhance existing SMATV systems.

Therefore, the following conclusions can be drawn.

- For the Model System, a WG BPF before LNB is unavoidable and, as such, the LNBs currently deployed in Hong Kong that operate in the 3.4 – 4.2 GHz band might continue to be used.
- The unwanted signal suppression obtained by retrofitting a WG BPF is larger than 56 dB for a single input LTE signal in the 3.5 GHz band.
- The unwanted signal suppression obtained by retrofitting a WG BPF is only 23 dB given a single input LTE signal in the 3.60 – 3.65 GHz band (i.e., only 50 MHz guard band between mobile service and FSS).
- The unwanted signal suppression obtained by retrofitting a WG BPF is larger than 64 dB for the case of two different LTE input signals.
- The tested WG BPF 1 was measured to be able to suppress interference signal below 3.6 GHz by 15 dB more than the specifications (see Table 3-6). It follows that, in practice, the Model System consisting of a WG BPF 1 cascaded with a Typical LNB 3 can successfully decode SMATV signals in the 3.7 – 4.2 GHz band when there is one unwanted signal in the 3.5 GHz band with power level up to -5.5 dBm/20MHz which gives rise to saturation, or two unwanted signals in the same 3.5 GHz band with power levels up to -14.0 dBm / 20 MHz, causing the worst case interference mechanisms attributed to multiple interferers.
- The tested WG BPF 1 was measured to be able to suppress interference signal below 3.65 GHz by 10 dB more than the specifications (see Table 3-6). It follows that, in practice, the Model System consisting of a WG BPF 1 cascaded with a Typical LNB 3 can successfully decode SMATV signals in the 3.7 – 4.2 GHz band when there is one unwanted signal in the 3.60 – 3.65 GHz band with power level up to -47.0 dBm/20MHz which gives rise to saturation.

4.4 Baseline Requirements

Based on the test results presented in sections 4.3, the baseline requirements of the Model System shall firstly entail a WG BPF with 55 dB suppression for signals below 3.6 GHz retrofitted between the feedhorn and the LNB in the SMATV system. More broadly, insofar as strong out-of-band mobile signals are sufficiently suppressed, this first-line mitigation of fitting a WG BPF is also applicable to other satellite systems operating in the same frequency band, including, inter alia, the satellite receivers of self-provided external telecommunications systems and that employed in satellite-based external fixed telecommunications network services.

The technical requirements of key components of the Model System are set out below.

Satellite Antenna

Technical Parameters	
Antenna diameter	3 metres
Antenna gain	40 dBi
Polarization	Linear

Feedhorn

Technical Parameters	
Operating frequency	3.7 – 4.2 GHz
F/D range	0.33 to 0.45
Polarization	Linear

Band Pass Filter

Technical Parameters	
Pass Band	3.7 – 4.2 GHz
Suppression at 3.6 GHz	Higher than 55 dB
Suppression at 4.2 GHz	Higher than 50 dB
Insertion loss in band	0.5 dB
VSWR	1.4 : 1
Waveguide flange	CPR-229 (input), CPR-229 (output)
Dimensions	120 (L) × 100 (W) × 70 (H) mm
Weight	650 g

Low Noise Block Downconverter

Technical Parameters	
Operating frequency	3.4 – 4.2 GHz (existing systems) 3.7 – 4.2 GHz (new systems)
Noise temperature	20 K
Conversion gain	60 dB
Output 1 dB compression point	8 dBm
Local oscillatory stability	+/- 500 kHz
L.O. frequency	5.15 GHz
Output Intermediate Frequency	950 MHz to 1750 MHz (for 3.4 – 4.2 GHz band) 950 MHz to 1450 MHz (for 3.7 – 4.2 GHz band)
Waveguide flange	CPR 229G
Dimensions	180 (L) × 100 (W) × 70 (H) mm
Weight	425 g
Input VSWR	2.0 : 1
Output VSWR	2.2 : 1

Integrated Receiver/Decoder

Technical Parameters	
Input power range	-65 dBm to -25 dBm
Input frequency range	950 – 1450 MHz

5 Cost Estimate for Upgrading Existing SMATV System to Comply with Baseline Requirements

As mentioned in section 3.1, existing SMATV systems do not have a BPF and the LNBs are operating in full frequency range of 3.4 – 4.2 GHz. It is apparent that an existing SMATV system should be upgraded by retrofitting WG BPF 1 under the Proposed Re-Allocation. The upgrade cost is estimated at around HK$19,100 per standalone typical system, as shown in Table 5-1, which does not take into account any effect of economies of scale by bulk purchase and subcontracting of the engineering work.

Table 5-1: Estimated cost of upgrading a typical SMATV system.

Item	Justifications	Cost (HK$)
WG BPF 1 × 2	- According to OFCA's database records, 87 % of SMATV systems operating in the C-Band use one dish antenna to receive two satellites or one satellite in dual-polarisation, i.e. two LNBs installed.	6,000
Engineering and administrative man-hours	- Retrofitting WG BPFs and complete system overhaul after retrofitting - Purchasing equipment and handling shipment	13,100
Total		19,100

6 Analytical Model and Interference Analysis

In this section, an interference analytical model is developed based on the Proposed Re-Allocation in conjunction with the interference susceptibility of the Model System ("the Analytical Model"). Put it simply, the Analytical Model aims to predict and evaluate how the Model System can function optimally under different base station deployment scenarios. The outcomes of the Analytical Model will be the minimum separation distances and the orientation requirements between the Model Systems and mobile base stations operating in the 3.5 GHz band. Annex 3 provides supplementary information on a network-based solution prohibiting 3.5 GHz mobile terminal transmissions which might interfere with SMATV systems in close vicinity.

6.1 Interference Protection Criteria for Safeguarding the Operations of the Model System

Making reference to the findings in section 4.3.2, the interference protection criteria for safeguarding the operations of the Model System can be established as follows:

- The maximum level of mobile signal in the 3.5 GHz band received by the Model System (after the feedhorn) ("Received Mobile Signal Power") without causing unacceptable interference (i.e. failure to decode the TV signal) is -5.5 dBm/20MHz for a single mobile signal and -14.0 dBm/20MHz each for two mobile signals.

- The maximum level of the Received Mobile Signal Power in the 3.60 – 3.65 GHz band without causing unacceptable interference to the Model System is -47.0 dBm/20MHz for a single mobile signal.

- Spurious emissions account for the in-band interference signal injected by mobile base stations into SMATV systems, which are sporadic spikes across the 3.7 – 4.2 GHz band. Due to their sporadic characteristic, spurious emissions from mobile base stations impacting on SMATV systems from individual mobile base stations do not aggregate constructively. The maximum level of in-band interference received by the Model System (after the feedhorn) ("Received In-band Interference") is -112 dBm/36MHz, as shown in Annex 4. In developing the Analytical Model, the in-band interference is modelled as a white noise with constant power level. It should be noted that such use of white noise to emulate mobile base station spurious emissions represents an interference environment much more profound than any worst case scenario in practical deployment.

6.2 Overview of the Analytical Model

As envisaged in section 2.1, 5G networks will consist of macro cells, indoor small cells, and outdoor small cells at street level such as those mounted on lamp poles. Each type of mobile base stations will have their own technical specifications on maximum transmission power, antenna pattern, and antenna gain. Furthermore, the signal to be received by a SMATV system would be influenced by the local environments along the radio paths such as heights of the installations, antenna pointing directions, building diffraction and wall penetration losses etc.

In enabling the co-existence between mobile base stations and SMATV systems, both the Received Mobile Signal Power and the Received In-band Interference shall meet the interference protection criteria set out in section 6.1 under different deployment scenarios. Empirically, the Analytical Model shall correlate the interference received by SMATV systems from mobile base stations expressed as:

$$I_{mobile} = P_{signal} + G_{t,eff} - PL(d) + G_{r,eff},$$
$$I_{in-band} = P_{spurious} + G_{t,eff} - PL(d) + G_{r,eff},$$

where

I_{mobile}	: Received Mobile Signal Power (dBm/20MHz)
P_{signal}	: base station signal transmission power (dBm)
$I_{in-band}$	: Received In-band Interference (dBm/36MHz)
$P_{spurious}$	: base station spurious emissions power (dBm)
$G_{t,eff}$	: effective transmit antenna gain of the mobile base station (dBi)
$PL(d)$	: pathloss attenuation (dB)

d : propagation distance (m)

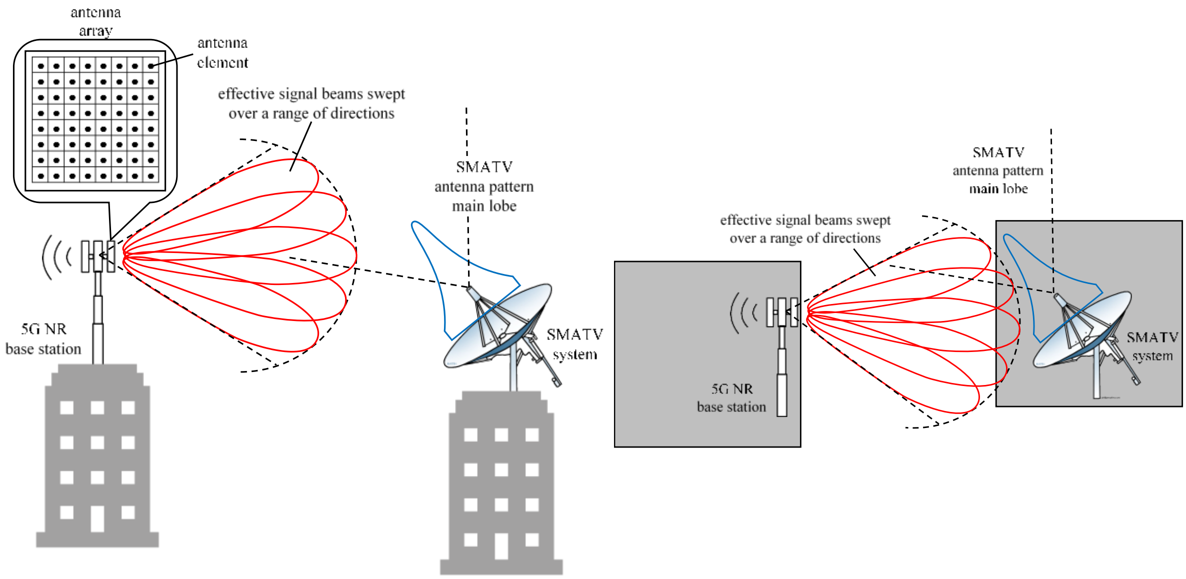
$G_{r,eff}$: effective receive antenna gain of the SMATV receiver (dBi).

Apart from radio propagation characteristics, beam-sweeping of 5G NR base stations shall be factored into relevant antenna gains in the above formulas when running the Analytical Model.

6.2.1 Technical Specifications

6.2.1.1 Effects of Beam-sweeping in 5G NR Base Stations

M-MIMO and beamforming technologies will be amongst the defining features of 5G NR base stations. By virtue of beamforming and beam-sweeping, a 5G NR base station can dynamically focus its radiated energy in specific directions to improve the signal strength as illustrated in Figure 6-1. Leveraging on these technical merits, 5G mobile signals will have the same peak Equivalent Isotopically Radiated Power ("EIRP") across a range of angles in three-dimensional space. Thus, in this study, peak transmit antenna gain of mobile base station is assumed in any direction from the front of the antenna array of mobile base stations.



(a) (b)

Figure 6-1: Illustration of 5G NR base station beam-sweeping and how the mobile signal can incident on the SMATV antenna; (a) Front view; (b) Top view.

6.2.1.2 Spurious Emissions of Mobile Base Stations

As far as spurious emissions are considered, it is assumed that 5G NR base stations shall conform to the limit of -52 dBm/MHz, as prescribed in 3GPP TS 38.104 V1.0.0 (2017-12), to facilitate co-existence with other legacy mobile systems operating in different frequency bands.

6.2.1.3 Technical Specifications Adopted in the Analytical Model

The technical parameters in Table 6-1 to Table 6-4 are adopted in the Analytical Model where Table 6-1 to Table 6-3 are for base stations whereas Table 6-4 are the characteristics of the SMATV antenna.

Table 6-1: Specifications of macro base stations.

Parameter	Values
Antenna pattern	Omni-directional with beam-sweeping
Max. antenna gain	18 dBi (see section 6.2.1.1)
Transmission power	33 dBm
Spurious emission limit	-52 dBm/MHz (see section 6.2.1.2)

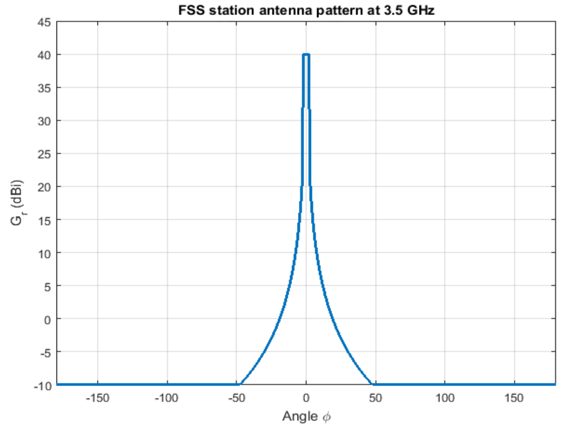
Table 6-2: Specifications of outdoor small cells.

Parameter	Values
Antenna pattern	Omni-directional
Max. antenna gain	5 dBi
Transmission power	24 dBm
Spurious emission limit	-52 dBm/MHz (see section 6.2.1.2)

Table 6-3: Specifications of indoor small cells.

Parameter	Values
Antenna pattern	Omni-directional
Max. antenna gain	0 dBi
Transmission power	24 dBm
Spurious emission limit	-52 dBm/MHz (see section 6.2.1.2)

Table 6-4: Antenna characteristics of the Model System.

Parameter	Values
Operating frequencies	3.7 – 4.2 GHz
Antenna pattern	 (see [Ref 9])
Max. antenna gain	40 dBi
Antenna size	3.5 m in diameter

6.2.2 Pathloss Models

As mentioned in the beginning of section 6.2, signals transmitted from a mobile base station as received by a SMATV system would be influenced by the local environments along the radio paths such as height of the installations, antenna directions, building diffractions and wall penetration losses. Taking these physical factors into consideration, the pathloss models for various base station deployments can be summarized in Table 6-5.

Table 6-5: Pathloss models for various base station deployments.

Physical Factor	Outdoor Base Station Higher than or at Same Height as SMATV System	Outdoor Base Station Lower than SMATV System	Indoor Base Station Higher than or at Same Height as SMATV System	Indoor Base Station Lower than SMATV System
Free Space Path Loss	✓	✓	✓	✓
Diffraction Effect		✓		✓
Penetration Loss			✓	✓

Going further, the pathloss models for the deployment scenarios in Table 6-1 are given as:

Outdoor Mobile Base Station Higher than or Same Height as SMATV System:

$$PL(d) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d)$$

Outdoor Mobile Base Station Lower than SMATV System:

$$PL(d_1, d_2) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d_1 + d_2) + J(v)$$

Indoor Mobile Base Station Higher than or Same Height as SMATV System:

$$PL(d) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d) + L_{wall}$$

Indoor Mobile Base Station Lower than SMATV System:

$$PL(d_1, d_2) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d_1 + d_2) + J(v) + L_{wall}$$

where

$PL(d)$	:	pathloss attenuation without diffraction effect (dB)
$PL(d_1, d_2)$	:	pathloss attenuation with diffraction effect (dB)
f	:	carrier frequency (GHz)
d	:	LOS distance from mobile base station to the SMATV system(m)
d_1	:	distance from the mobile base station to the diffraction point (m)
d_2	:	distance from the diffraction point to the SMATV system (m)
L_{wall}	:	wall penetration loss (dB)
$J(v)$	:	Fresnel-Kirchoff diffraction loss (dB).

Figure 6-2 illustrates a diffraction model for interference analysis applied in the Analytical Model. According to the single knife-edge obstacle diffraction model in Recommendation ITU-R P.526-7 [Ref 6], $J(v)$ is calculated as below:

$$J(v) = 6.9 + 20\log_{10}\left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1\right),$$

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)},$$

where

$J(v)$: Fresnel-Kirchoff diffraction loss (dB)

h : distance from the building edge to the link connecting the mobile BS and the SMATV system (m)

λ : wavelength of the interfering signal (m).

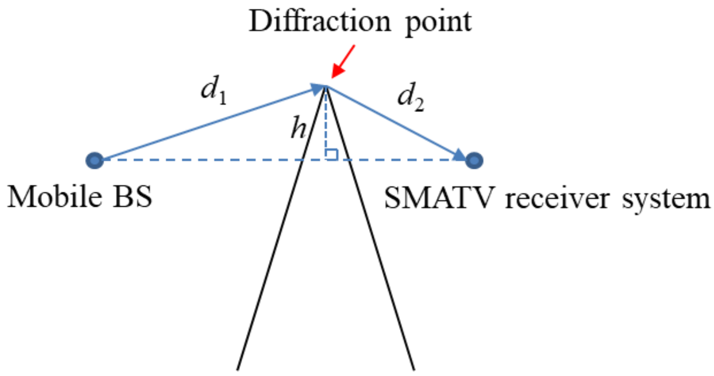


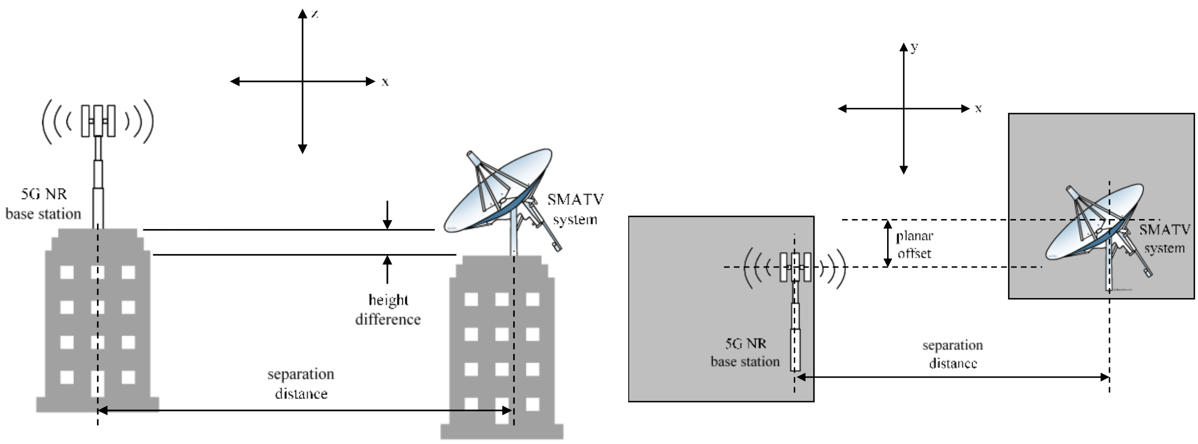
Figure 6-2: Geometrical elements for the single knife-edge obstacle diffraction model.

6.3 Theoretical Analysis

<u>Coordinate System Adopted in the Deployment Scenarios</u>

To facilitate the modelling of the radio propagation between the mobile base station and the SMATV system, a coordinate system has been defined. Figure 6-3 shows a coordinate system for base station and SMATV system positioning as follows:

- z-axis indicates heights of a mobile base station and a SMATV system, i.e. height difference indicated in Figure 6-3 (a);
- x-axis indicates separation distance of a mobile base station from the front of a SMATV system, i.e. separation distance indicated in Figure 6-3; and
- y-axis indicates horizontal distance of a mobile base station from either side of a SMATV system, i.e. planar offset indicated in Figure 6-3 (b).



(a) (b)

Figure 6-3: Coordinate system adopted in the Analytical Model; (a) Front view; (b) Top view.

Deployment Scenarios

Macro cell deployment is the main focus in the co-existence study due to the following reasons:

- A macro cell has a substantially larger EIRP compared to indoor and outdoor small cells, making it the dominant interfering source for SMATV systems.

- Outdoor small cells in Hong Kong will be deployed at lamp poles or podiums with heights much lower than most of the SMATV systems. In effect, this will lead to a negative antenna gain and large pathloss, which diminishes their impact on SMATV receiver systems.

- Mobile signals emitted from indoor small cells will be attenuated by approximately 20 dB due to wall penetration, which also greatly diminishes their negative impact on SMATV receiver systems.

Intuitively, while the majority of interference to SMATV systems will stem from macro cells, in some rare cases, indoor small cells placed at higher positions directly facing a SMATV system might also pose interference risk. Additional interference analysis on such deployment is conducted so as to obtain a fuller picture.

6.3.1 Macro Base Stations

6.3.1.1 Deployment Scenarios

First and foremost, it should be noted that the dish antenna of a SMATV system is normally erected at the centre of a rooftop given that the SMATV licence prohibits any part of the antenna over or upon any portion of any street whether or not on land held under lease from the Government. As for base station antennas, they are mounted along the corners or edges of a rooftop in order to have the best street views and unblocked uptilt and downtilt angles. On the basis of these physical settings, three macro base station deployment scenarios are studied which reflect the typical environments in Hong Kong.

- ***Scenario 1***: The base station antenna and the SMATV antenna are installed on the same rooftop with each side in "a" metre length, as demonstrated in Figure 6-4. The base station antenna is installed at the edge whereas the SMATV antenna is installed at the centre.

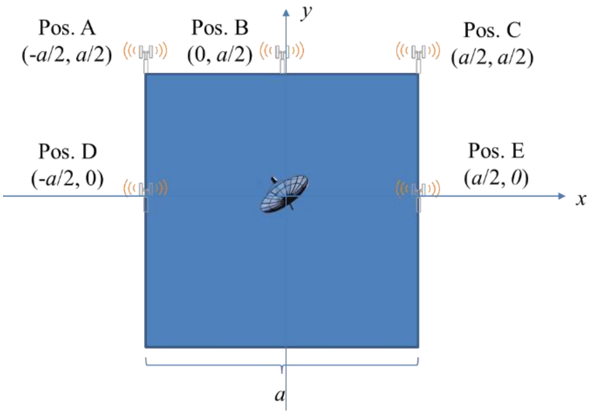


Figure 6-4: Macro base station and SMATV System on the same rooftop.

- ***Scenario 2***: The base station antenna is installed on a rooftop lower than an adjacent rooftop on which a SMATV antenna is installed, as demonstrated in Figure 6-5. The base station antenna is located at $(-d, 0, h - \Delta h)$ and the SMATV antenna is located at $(0, 0, h)$, and d is the separation distance between them.

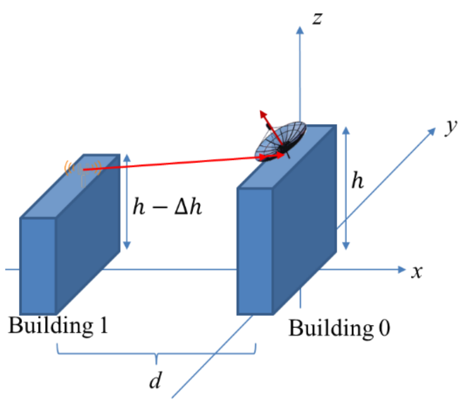


Figure 6-5: Macro base station on an adjacent rooftop lower than that of the SMATV system.

- ***Scenario 3***: The base station antenna is installed on a rooftop higher than an adjacent rooftop on which a SMATV antenna is installed, as demonstrated in Figure 6-6. The base station antenna is located at $(-d, 0, h + \Delta h)$ and the SMATV antenna is located at $(0, 0, h)$, and d is the separation distance between them. Driven by the need of a clear and unblocked view of the sky, the azimuth angle of the SMATV antenna should be adjusted accordingly.

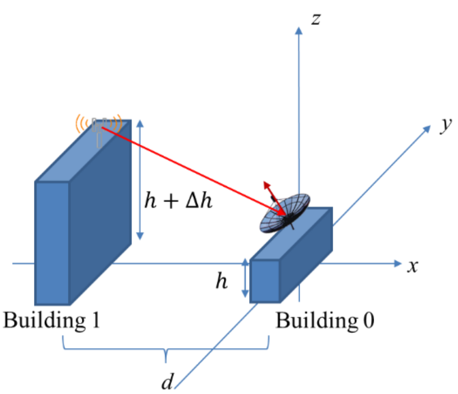


Figure 6-6: Macro base station on an adjacent rooftop higher than that of the SMATV system.

6.3.1.2 Simulation Results

<u>Scenario 1 – Same rooftop</u>

In this analysis, two assumptions have been made:

- The serving area of the base station is targeted at street level. The base station antenna is at the back of the SMATV antenna on the same rooftop. According to Recommendation ITU-R F.1336-4 [Ref 8] and making reference to 180° azimuth angle and 0° elevation angle, the effective antenna gain is estimated to be -19 dBi; and

- Length of all the four sides of the rooftop is a metres long where the five positions A to E shown in Figure 6-4 are located at $(-a/2\,, a/2)$, $(0, a/2)$, $(a/2\,, a/2)$, $(-a/2\,, 0)$, and $(a/2\,, 0)$ respectively in a two-dimensional coordinate system with the SMATV system at the origin.

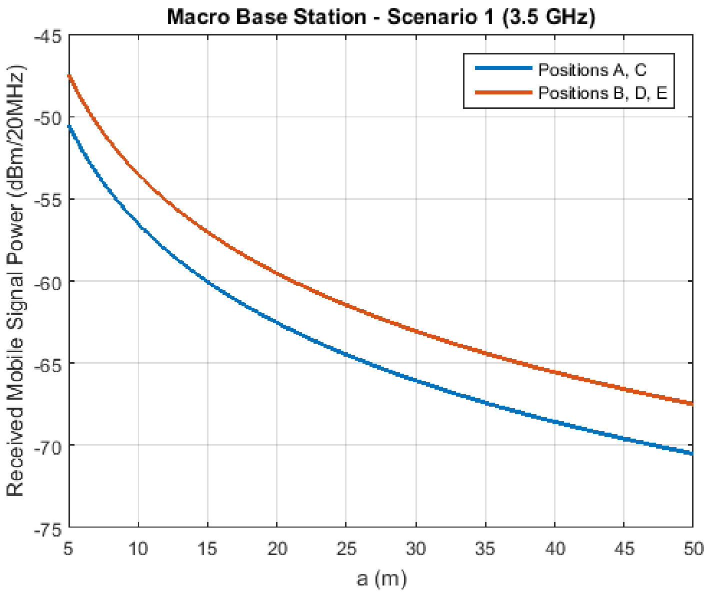
i) Single-entry interference analysis

Figure 6-7 shows the variations of Received Mobile Signal Power versus a, the length of rooftop in one side. The following observations can be made:

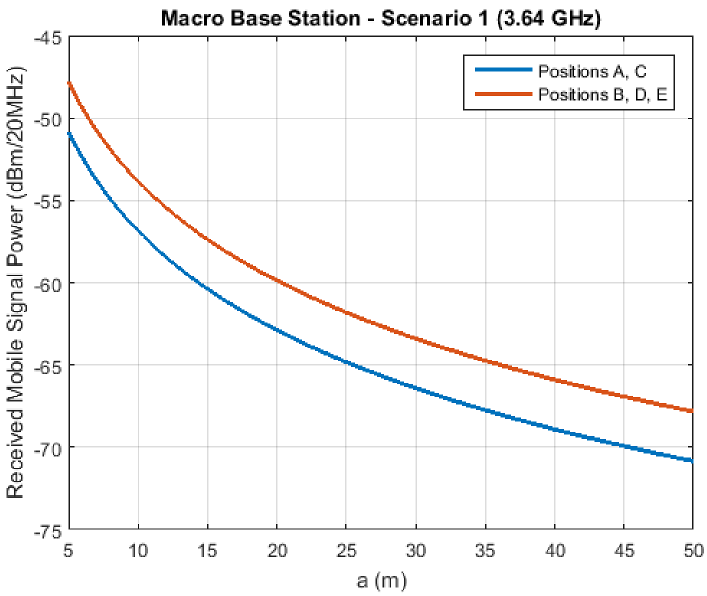
- When a is 5 m, a base station antenna placed at Positions B, D, E and transmits at 3.5 GHz will induce a maximum Received Mobile Signal Power of -47.5 dBm/20MHz. This is significantly lower than the applicable threshold in Section 6.1 (i.e. -5.5 dBm/20MHz).

- As for a base station antenna placed at Positions B, D, E and operates at 3.64 GHz when a is 5 m, it will induce a maximum Received Mobile Signal Power of -47.8 dBm/20MHz, just sufficient to meet the applicable threshold in section 6.1 (i.e. -47.0 dBm/20MHz).

The results above indicate that in the same rooftop case, a macro base station will not cause unacceptable interference to the Model System. However, while there is around 42 dB margin when the macro base station operates in the 3.5 GHz band, there is only around 1 dB margin if the base station operates in the 3.60 – 3.65 GHz band. It follows that multiple macro base stations transmitting in the 3.60 – 3.65 GHz band simultaneously could cause unacceptable interference to the Model System.



(a) A single interfering mobile signal centred at 3.50 GHz.



(b) A single mobile signal centred at 3.64 GHz.

Figure 6-7: Received Mobile Signal Power versus the side length “*a*” of the rooftop.

In Figure 6-8, when *a* is 5 m, a base station antenna at Positions B, D, E generating background noise with power level of -52 dBm/MHz will induce a maximum Received In-band Interference of -121 dBm/36MHz. By cross-checking with the applicable threshold in section 6.1 (i.e. -112 dBm/36MHz), there is around 9 dB margin in the same rooftop case. It implies that a macro base station installed on the same rooftop with the Model System will not cause in-band interference to the latter.

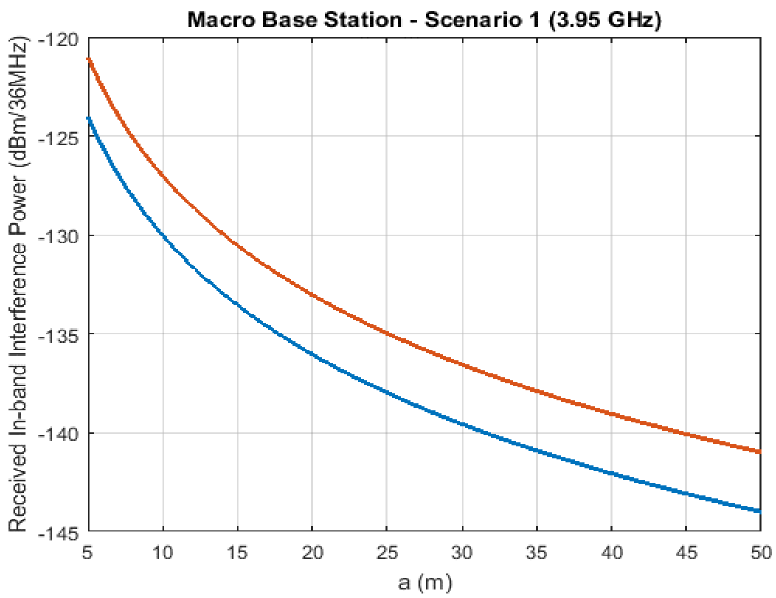


Figure 6-8: Received In-band Interference at 3.95 GHz versus the side length "*a*" of the rooftop.

ii) Multi-entry interference analysis

Figure 6-9 shows the changes of the Received Mobile Signal Power due to the aggregated effects of mobile signals centred at 3.41 GHz and 3.59 GHz with respect to a. When a is 5 m, two co-site macro base stations (or a multi-sector base station) at Positions B, D, E will generate a maximum Received Mobile Signal Power of -47.3 dBm/20MHz and -47.7 dBm/20MHz for mobile signal centred at 3.41 GHz and 3.59 GHz respectively. By cross-checking with the applicable threshold in section 6.1 (i.e. -14 dBm/20MHz for two mobile signals in the 3.5 GHz band), there is now more than 33 dB margin in the same rooftop case. Hence, it implies that up to two co-site macro base stations installed on the same rooftop with the Model System will not cause unacceptable interference to the Model System.

Relevant to spurious emissions, on the premise that multiple spurious emissions from base stations do not add up constructively, the Received In-band Interference is expected to be identical to that coming from a single base station. With a negligible effect in the single entry analysis as discussed previously, it can be further asserted that multiple macro base stations installed on the same rooftop will not cause in-band interference to the Model System.

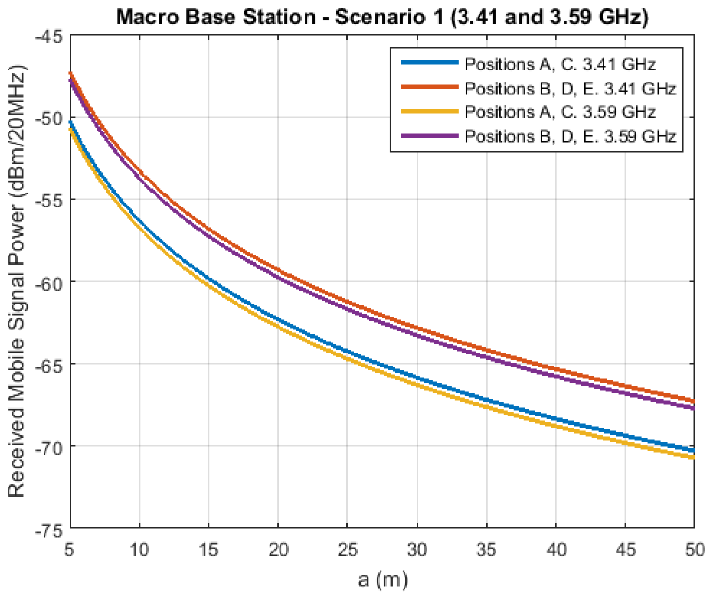


Figure 6-9: Received Mobile Signal Power versus rooftop side length "*a*" when interfered by 3.41 GHz and 3.59 GHz mobile signals.

<u>Scenario 2 – Base Station(s) at a height lower than a Model System</u>

In this scenario, the mobile signal from the macro base station will be diffracted by the building edge since the SMATV antenna is erected at the centre of a building rooftop as illustrated in Figure 6-10.

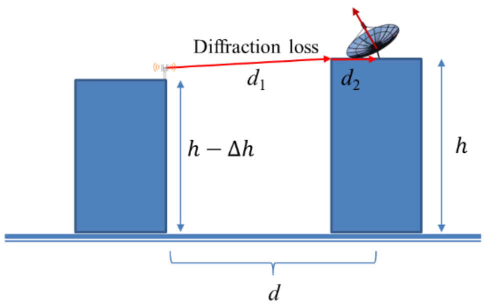


Figure 6-10: Illustration of mobile signal being diffracted by the building edge.

i) Single-entry interference analysis

Figure 6-11 shows the Received Mobile Signal Power versus the building height difference Δh. Sample separation distances d between the macro base station and the SMATV system ranging from 10 to 250 m are considered. The following observations can be drawn:

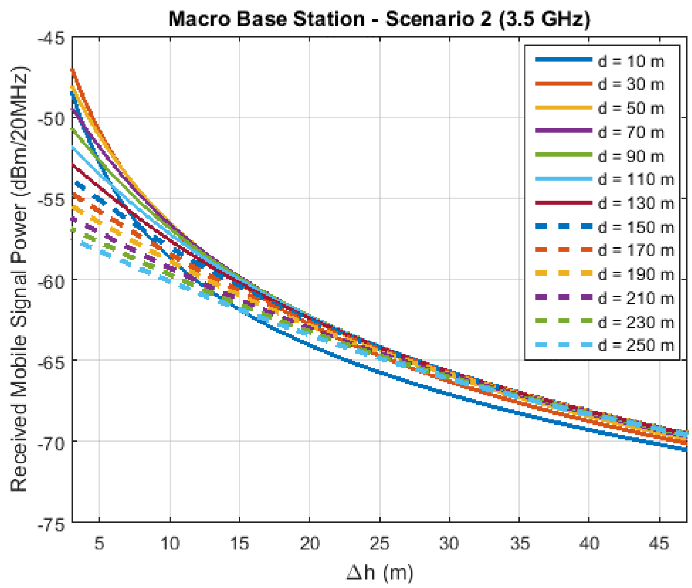
- For a fixed separation distance d, the Received Mobile Signal Power decreases monotonically with Δh.

- For a fixed Δh, a larger separation distance d does not necessarily reduce the Received Mobile Signal Power. This is because the diffraction loss decreases with the separation distance whereas the path loss has the opposite effect.

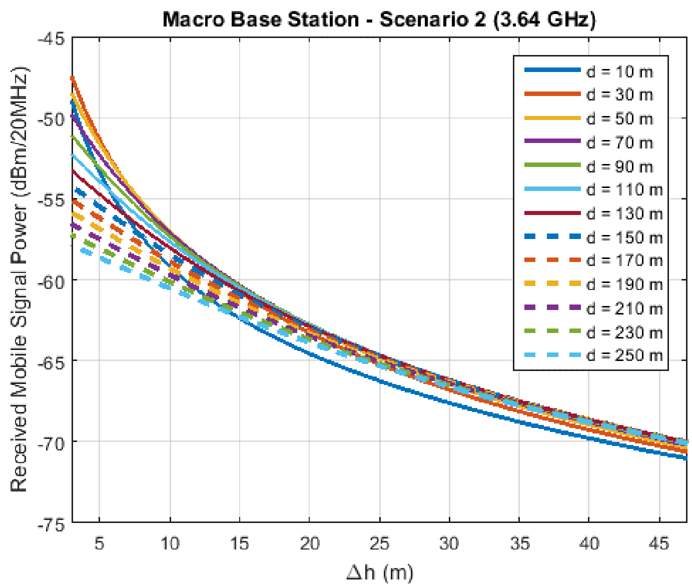
- When a macro base station operates at 3.5 GHz, the maximum Received Mobile Signal Power is -48 dBm/20MHz. It is much lower than the applicable threshold in section 6.1 (i.e. -5.5 dBm/20MHz).

- When a macro base station operates at 3.64 GHz, the maximum Received Mobile Signal Power is -47.5 dBm/20MHz. It is still able to meet the applicable threshold in section 6.1 (i.e. -47 dBm/20MHz).

The above results indicate that a macro base station operating in the 3.5 GHz band installed on a rooftop lower than that of the Model System will not cause unacceptable interference to the Model System. However, a macro base station operating in the 3.60 – 3.65 GHz band will cause unacceptable interference to the Model System nearby when the height difference is small as there is just a small margin with regards to the maximum allowable level.



(a) A single interfering mobile signal centred at 3.50 GHz.



(b) A single interfering mobile signal centred at 3.64 GHz.

Figure 6-11: Received Mobile Signal Power versus building height difference Δ*h* when interfered by a single mobile signal at 3.50 GHz or 3.64 GHz.

Figure 6-12 shows the changes of Received In-band Interference versus Δ*h*. The maximum Received In-band Interference is -121 dBm/36MHz. Making a cross reference to the applicable threshold in section 6.1 (i.e. -112 dBm/36MHz), it is found that a macro base station installed on a rooftop lower in height than that of the Model System will not cause in-band interference to the Model System.

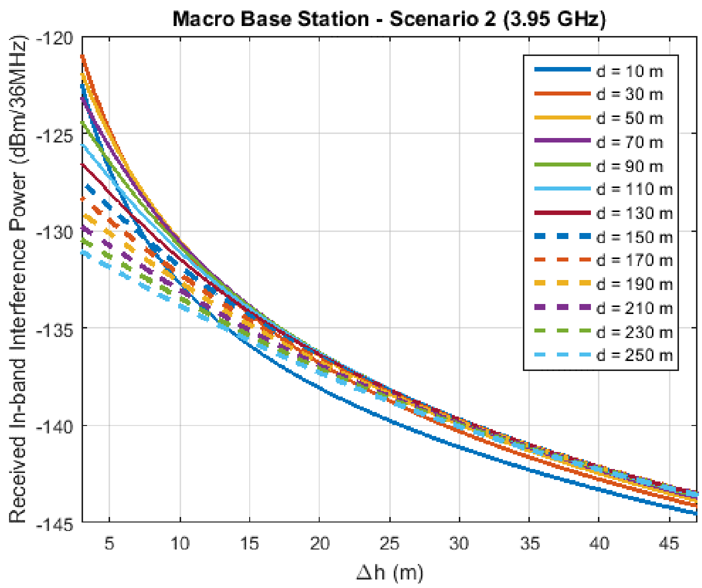
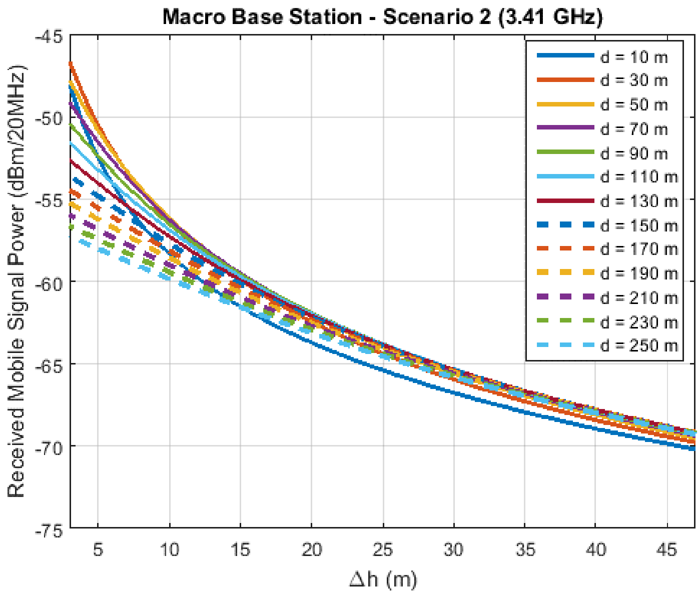


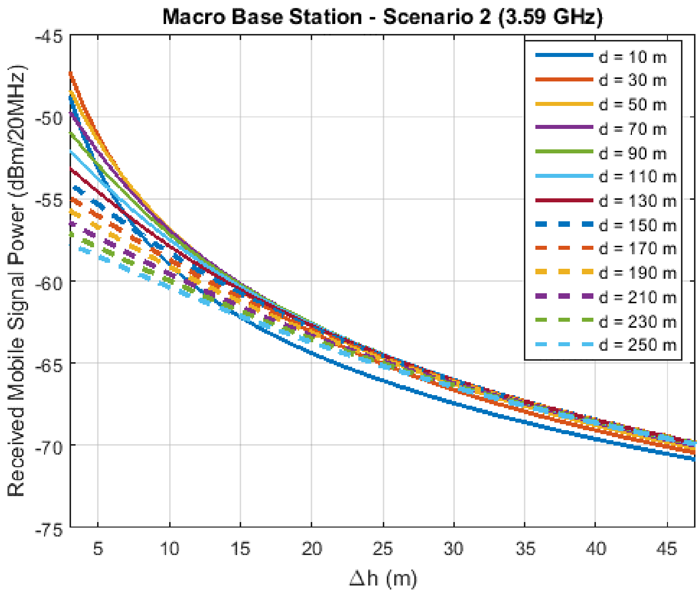
Figure 6-12: Received In-band Interference at 3.95 GHz versus building height difference Δ*h*.

ii) Multi-entry interference analysis

Figure 6-13 shows the changes of the Received Mobile Signal Power with Δh due to the aggregated effects of mobile signals centred at 3.41 GHz and 3.59 GHz. The maximum Received Mobile Signal Power is -46.7 dBm/20MHz and -47.3 dBm/20MHz for mobile signal at 3.41 GHz and 3.59 GHz respectively. By cross checking with the applicable threshold in section 6.1 (i.e. -14 dBm/20MHz for two mobile signals in the 3.5 GHz band), the results indicate that two co-site macro base stations installed on a rooftop lower than that of the Model System will not cause unacceptable interference to the Model System.



(a) Received Mobile Signal Power at 3.41 GHz.



(b) Received Mobile Signal Power at 3.59 GHz.

Figure 6-13: Received Mobile Signal Power versus building height difference Δ*h* when two mobile signals centred at 3.41 GHz and 3.59 GHz are interfering the SMATV system.

Since the spurious emissions from multiple base stations have negligible difference to that coming from a single base station, it also infers that multiple macro base stations installed on a rooftop lower than that of the Model System will not cause in-band interference to the Model System.

<u>Scenario 3 – Base Station(s) in front of and higher than a Model System</u>

In this scenario, since the macro base station antenna is installed on a rooftop higher than and in front of a SMATV antenna, the SMATV signal path might be obstructed. To overcome the physical obstruction, the azimuth angle of the SMATV antenna may be adjusted during installation to prevent any blockage within the first Fresnel zone (see Annex 5). This will change the angular alignments between the base station antenna and the SMATV antenna and the overall effects will be examined.

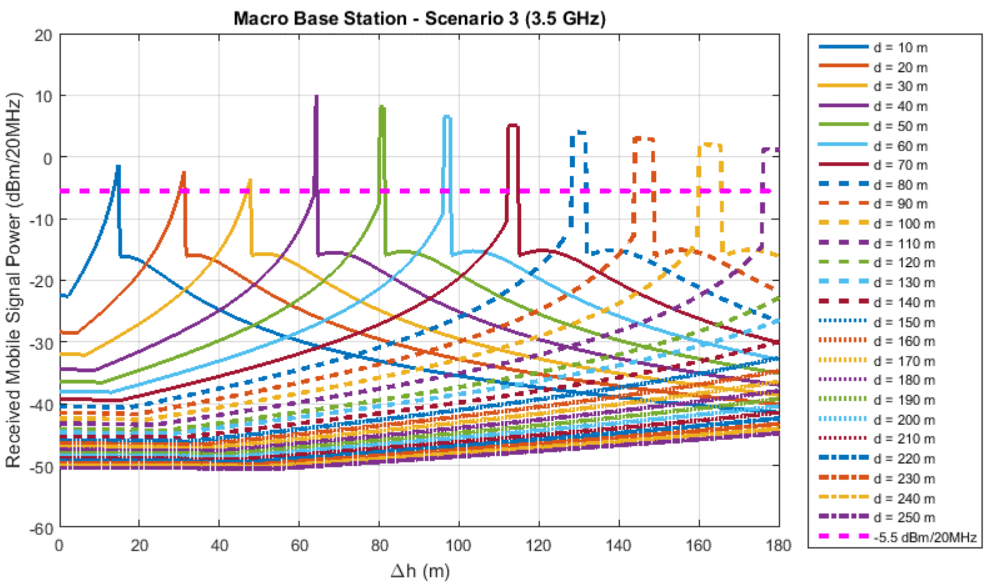
Single-entry interference analysis

Figure 6-14 shows the changes of Received Mobile Signal Power versus the height difference of building, Δh. Sample separation distances d between the macro base station and the SMATV system ranging from 10 to 250 m are taken. The following observations can be drawn:

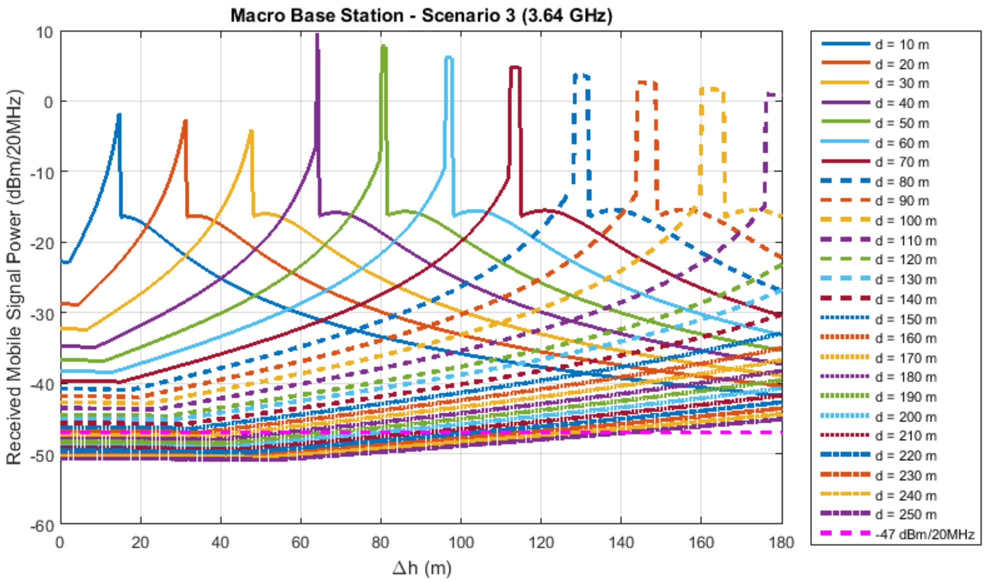
- When a macro base station operates at 3.5 GHz, if the beam-sweeping direction of base station and the pointing direction of the SMATV antenna are spatially aligned, the Received Mobile Signal Power will increase substantially which will eventually exceed the maximum allowable level, as seen by the sharp peak curves in Figure 6-14 (a).

- When a macro base station operates at 3.64 GHz, the Received Mobile Signal Power will exceed the maximum allowable level over a wide range of separation distances d and building height difference Δh, as shown in Figure 6-14 (b).

The above results highlight that a macro base station operating in the 3.5 GHz band installed on a rooftop higher than that of the Model System will cause unacceptable interference to the Model System. For this reason, multi-entry interference without mitigating measures will not be examined further in this section.



(a) A single interfering mobile signal centred at 3.50 GHz.



(b) A single interfering mobile signal centred at 3.64 GHz.

Figure 6-14: Received Mobile Signal Power versus building height difference Δh when a single mobile signal centred at 3.50 GHz or 3.64 GHz is interfering the SMATV system.

Figure 6-15 shows that the Received In-band Interference will exceed the maximum allowable level over a wide range of separation distances d and building height difference Δh. It will increase substantially when the beam-sweeping direction of base station and the pointing direction of the SMATV antenna are spatially aligned as seen by the sharp peak curves. This indicates that a macro base station installed on a rooftop higher than that of the Model System will cause in-band interference to the Model System.

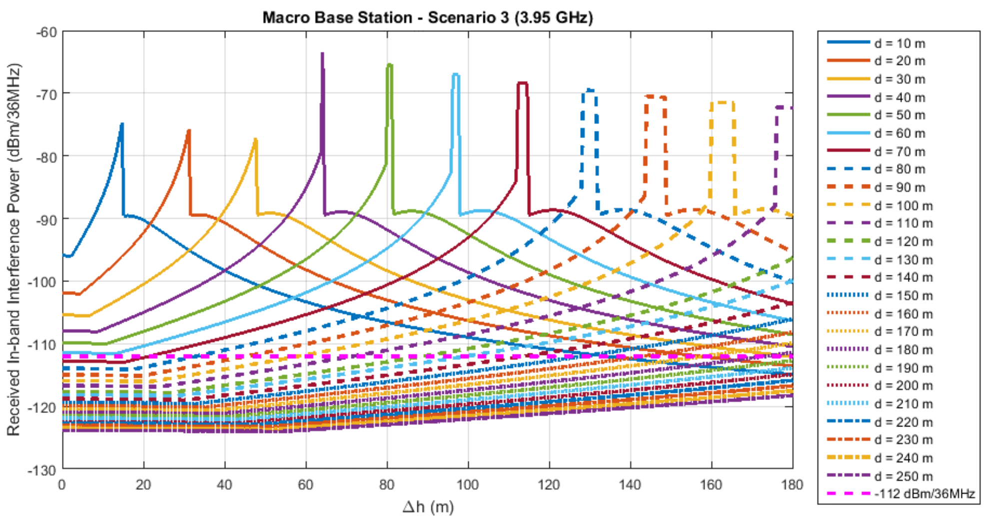


Figure 6-15: Received In-band Interference at 3.95 GHz versus building height difference Δh.

6.3.2 Impacts of Outdoor and Indoor Small Cells to the Model System

Outdoor small cells will always be installed at low heights, such as podiums of buildings, car parks and lamp poles at street level, which are much lower than most of the Model Systems. Since there is a large distance separation coupled with the front-to-back ratio and side lobe effects of the respective antennas, the interference impacts to the Model System installed on rooftops are negligible and need not be considered. However, there is still a legitimate concern about the impacts of indoor cells which are placed at a higher position and directly facing the Model System. This sub-section draws up the relevant scenarios and provides the interference analysis.

6.3.2.1 Deployment Scenarios

- ***Scenario 4*:** An indoor small cell inside a building is higher than an adjacent building rooftop on which a SMATV system is installed.

  a) As illustrated in Figure 6-16, the building with indoor small cell installed is not so high that it is in the right south direction of the SMATV system. In this case, the indoor small cell is installed on a floor higher than the SMATV system.

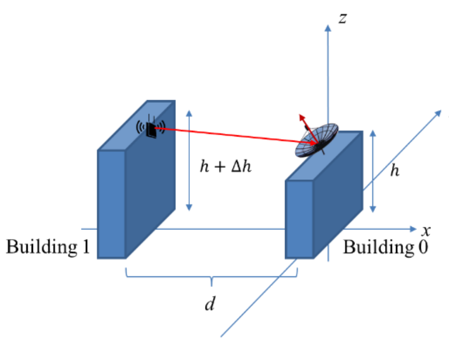


Figure 6-16: Indoor small cell inside an adjacent building slightly higher than the building on which the SMATV system is installed.

  b) As shown in Figure 6-17, the building with indoor small cell installed is so high that it shall be located out of the first Fresnel zone of the SMATV system for an open view of the sky for the SMATV antenna (see Annex 5). The indoor small cell is installed on a floor higher than the SMATV system.

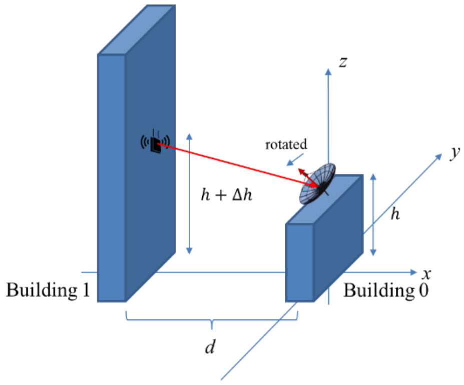


Figure 6-17: Indoor small cell installed inside an adjacent building much higher than the building on which the SMATV system is installed.

6.3.2.2 Simulation Results

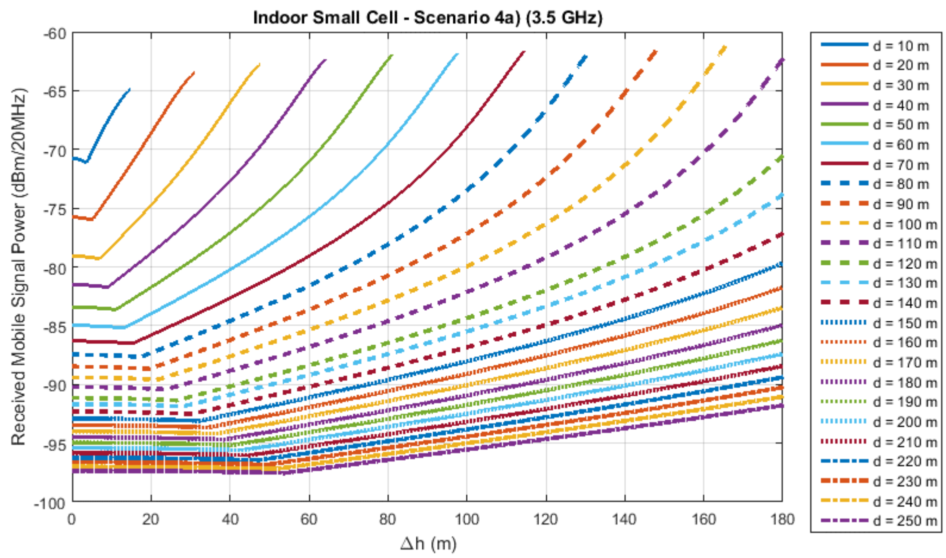
Scenario 4a) – Indoor small cell inside an adjacent building slightly higher than the building on which the Model System is installed

i) Single-entry interference analysis

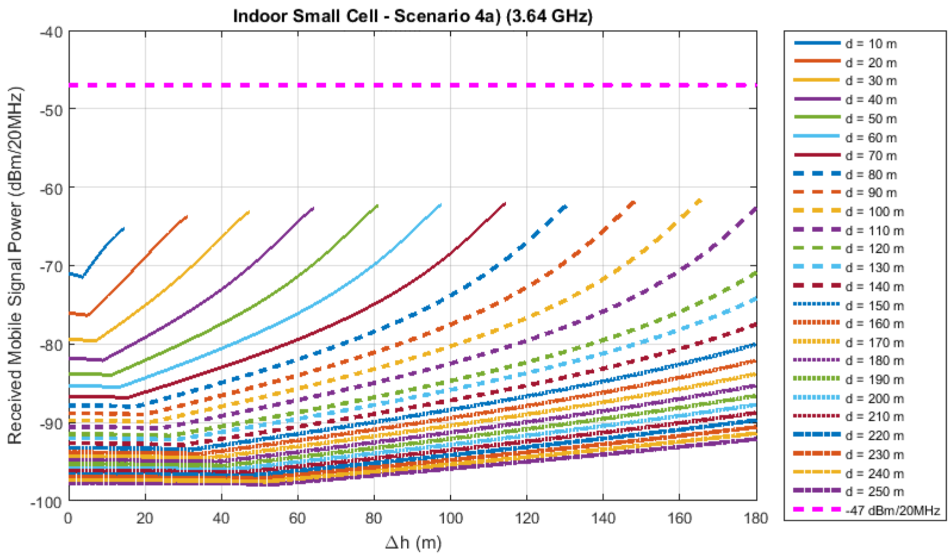
Figure 6-18 shows the changes of Received Mobile Signal Power versus the height difference Δh between a higher indoor small cell and the Model System. Sample separation distances d between the indoor small cell and the SMATV system ranging from 10 to 250 m are taken. It should be noted that the maximum height difference Δh is limited by the building height without the first Fresnel zone of the SMATV antenna being blocked. With practical considerations in mind, the indoor small cell should not directly face the SMATV antenna and is separated from the centre of the SMATV antenna by a horizontal distance of several metres (e.g. at least 5 – 6 m). The following observations can be drawn:

- As seen from Figure 6-18 (a), when an indoor small cell at higher height transmits at 3.5 GHz, the maximum Received Mobile Signal Power at the Model System is around -62.0 dBm/20MHz, which is at least 56 dB below the applicable threshold in section 6.1 (i.e. -5.5 dBm/20MHz). This indicates that a nearby indoor small cell at higher height operating in the 3.5 GHz band will not cause unacceptable interference to the Model System.

- In Figure 6-18 (b), when an indoor small cell at higher height transmits at 3.64 GHz, the maximum Received Mobile Signal Power is around -62.0 dBm/20MHz, which is at least 15 dB below the applicable threshold in section 6.1 (i.e. -47.0 dBm/20MHz). This indicates that a nearby higher indoor small cell operating in the 3.60 – 3.65 GHz band will not cause unacceptable interference the Model System.



(a) A single interfering mobile signal centred at 3.50 GHz.



(b) A single interfering mobile signal centred at 3.64 GHz.

Figure 6-18: Received Mobile Signal Power versus height difference Δh when a single mobile signal centred at 3.50 GHz or 3.64 GHz is interfering the SMATV system.

Figure 6-19 shows the changes of Received In-band Interference Power versus the height difference Δ*h* between a higher indoor small cell and a SMATV system. As the values are below the applicable threshold in section 6.1 (i.e. -112 dBm/36MHz), this implies that a nearby higher indoor small cell will not cause in-band interference to the Model System.

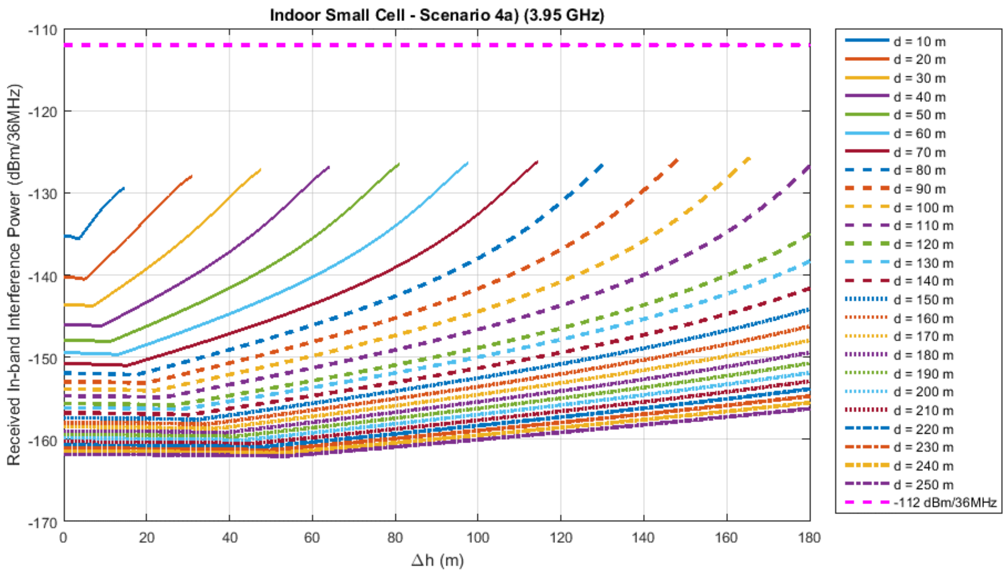
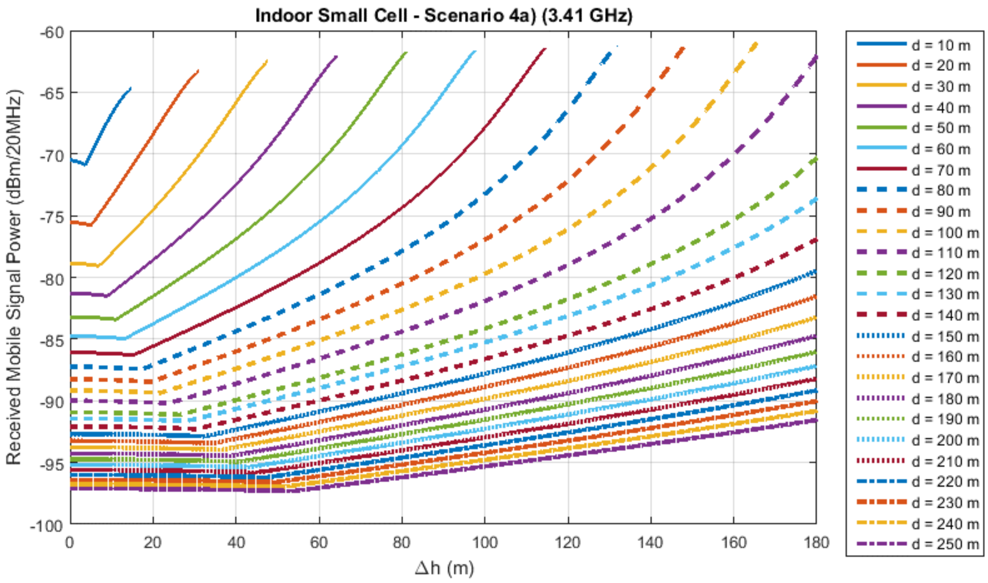


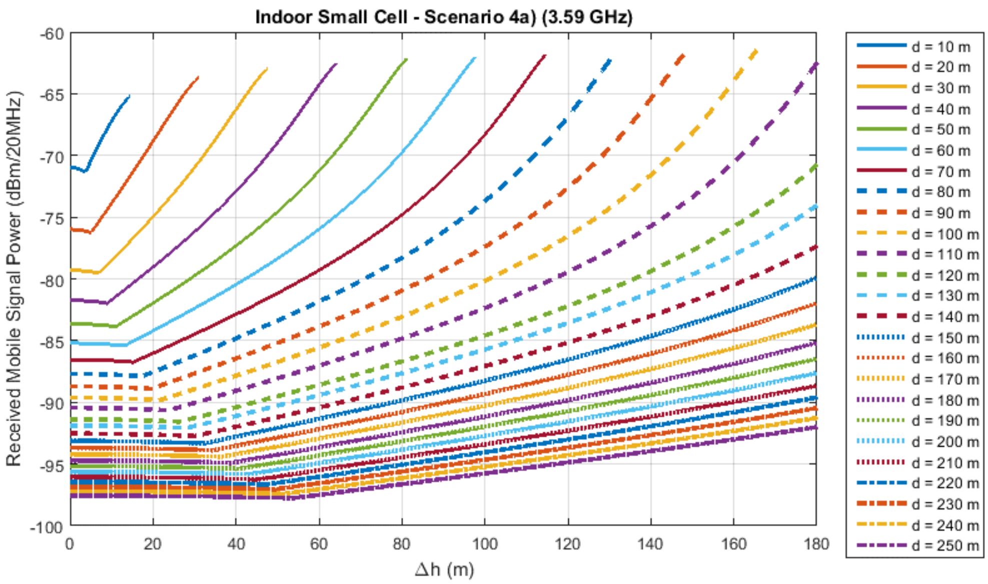
Figure 6-19: Received In-band Interference at 3.95 GHz versus building height difference Δ*h*.

ii) Multi-entry interference analysis

Figure 6-20 shows the changes of the Received Mobile Signal Power due to the aggregated effects of mobile signals centred at 3.41 GHz and 3.59 GHz with respect to the height difference Δ*h* between a higher indoor small cell and the Model System. The maximum Received Mobile Signal Power is -62 dBm/20MHz for mobile signal at 3.41 GHz and 3.59 GHz. These values are lower than the applicable threshold in section 6.1 (i.e. -14 dBm/20MHz for two mobile signals in the 3.5 GHz band). Such results imply that up to two nearby higher indoor small cells operating in the 3.5 GHz band will not cause unacceptable interference to the Model System.



(a) Received Mobile Signal Power at 3.41 GHz.



(b) Received Mobile Signal Power at 3.59 GHz.

Figure 6-20: Received Mobile Signal Power versus height difference Δh when two mobile signals centred at 3.41 GHz and 3.59 GHz are interfering the Model System.

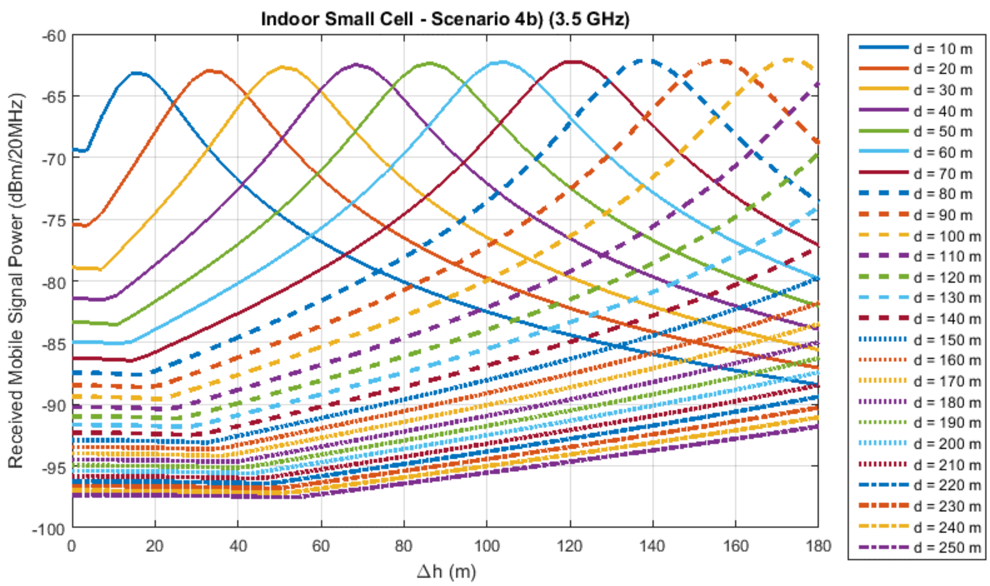
Scenario 4b) – Indoor small cell installed inside an adjacent building much higher than the building on which the SMATV system is installed

i) Single-entry interference analysis

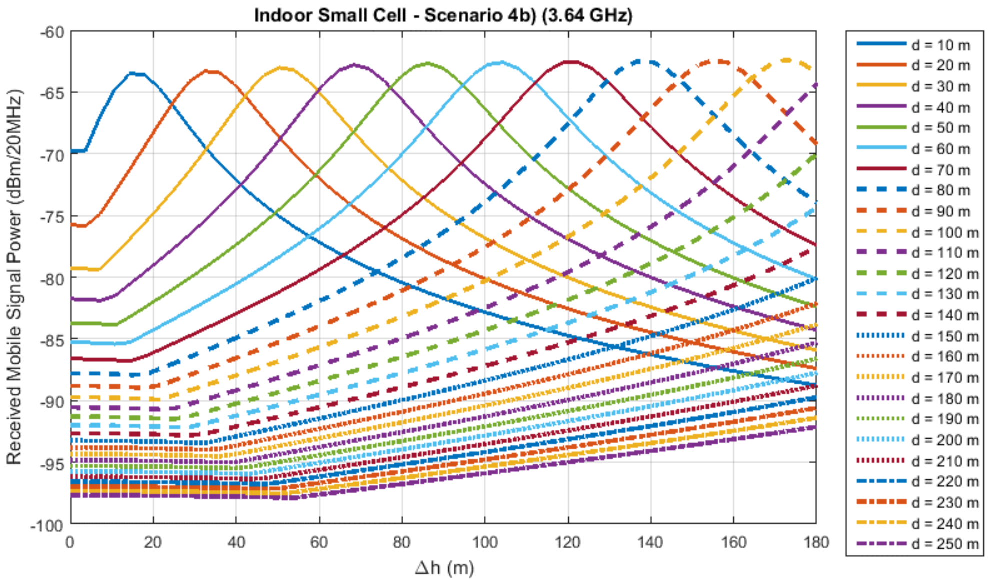
Figure 6-21 shows the changes of Received Mobile Signal Power versus the height difference Δh between a higher indoor small cell and the Model System. Sample separation distances d between the indoor small cell and the SMATV system ranging from 10 to 250 m are taken. The following observations can be drawn:

- As seen from Figure 6-21 (a), when a higher indoor small cell transmits at 3.5 GHz, the maximum Received Mobile Signal Power is around -62.0 dBm/20MHz, which is at least 56 dB better than the applicable threshold in section 6.1 (i.e. -5.5 dBm/20MHz). This indicates that a nearby higher indoor small cell operating in the 3.5 GHz band will not cause unacceptable interference to the Model System.

- Figure 6-21 (b) shows that when a higher indoor small cell transmits at 3.64 GHz, the maximum Received Mobile Signal Power is around -62.0 dBm/20MHz, which is at least 15 dB better than the applicable threshold in section 6.1 (-47.0 dBm/20MHz). This indicates that a nearby higher indoor small cell operating in the 3.60 – 3.65 GHz band will not cause unacceptable interference the Model System.



(a) A single interfering mobile signal centred at 3.50 GHz.



(b) A single interfering mobile signal centred at 3.64 GHz.

Figure 6-21: Received Mobile Signal Power versus height difference Δh when a single mobile signal centred at 3.50 GHz or 3.64 GHz is interfering the Model System.

Figure 6-22 shows the changes of Received In-band Interference Power versus the height difference Δh between a higher indoor small cell and the Model System. As the values are below the applicable threshold in section 6.1 (i.e. -112 dBm/36MHz), this implies that a nearby higher indoor small cell will not cause in-band interference to the Model System.

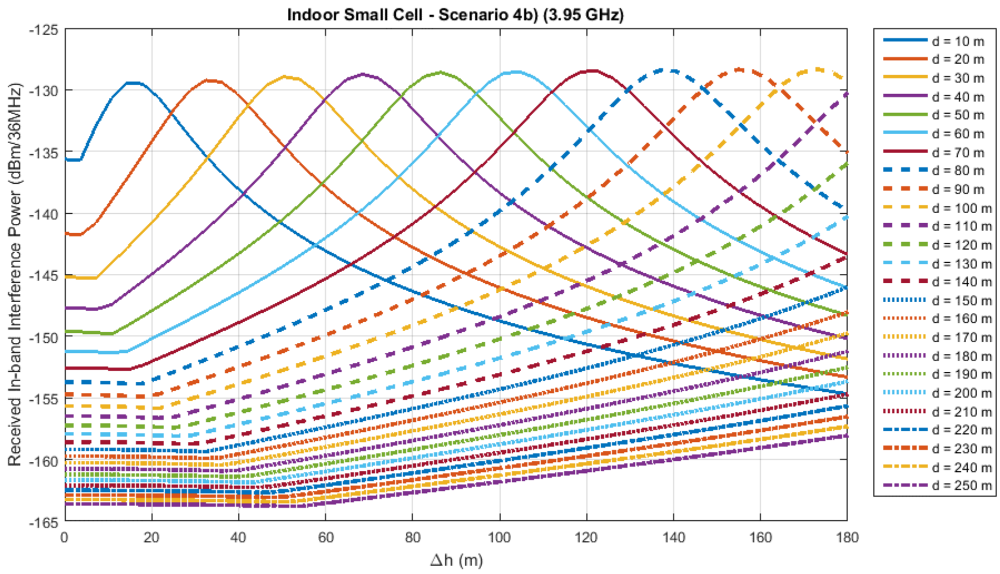
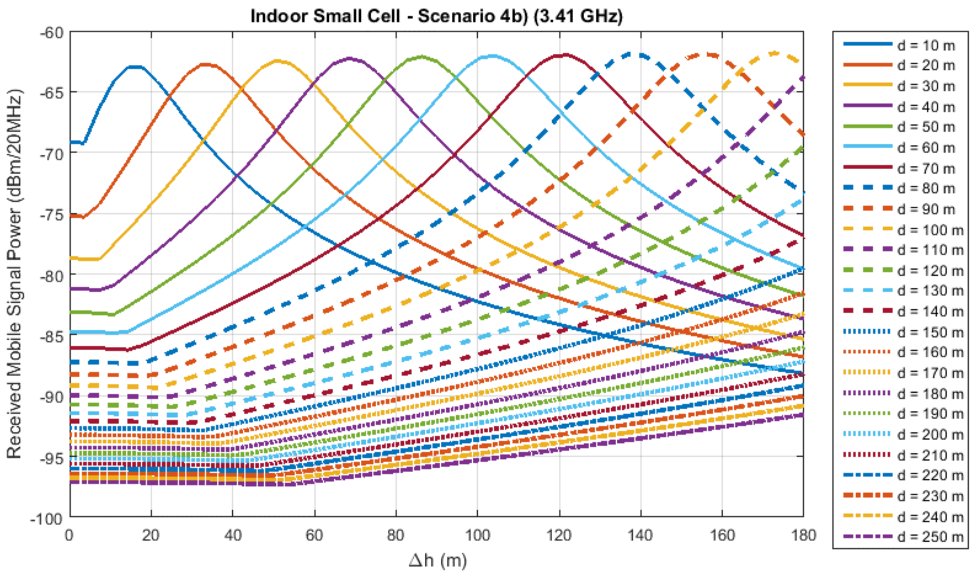


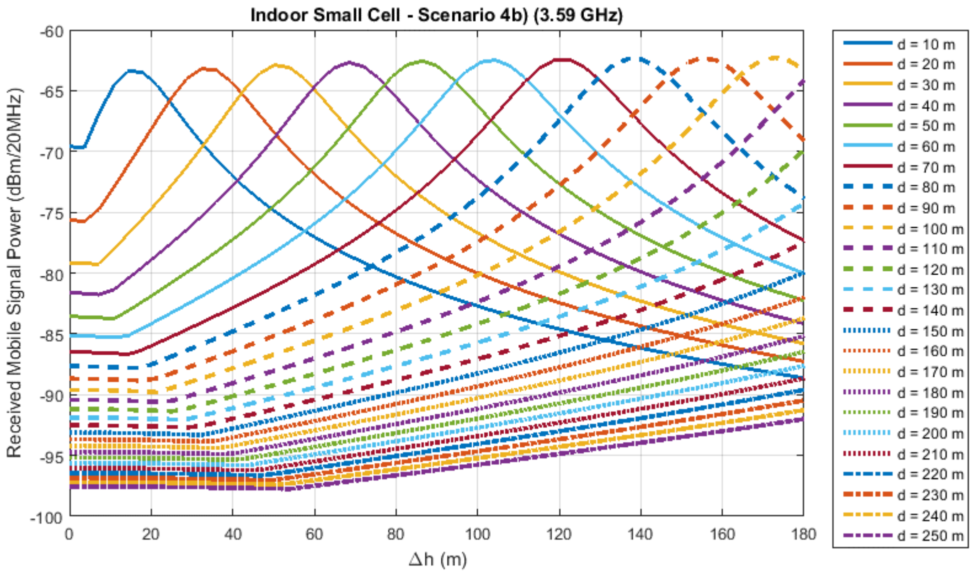
Figure 6-22: Received In-band Interference Power at 3.95 GHz versus height difference Δ*h*.

ii) Multi-entry interference analysis

Figure 6-23 shows the changes of the Received Mobile Signal Power due to the aggregated effects of mobile signals centred at 3.41 GHz and 3.59 GHz with the height difference Δ*h* between higher indoor small cells and a rotated SMATV system. As the maximum Received Mobile Signal Power is -62.0 dBm/20MHz for mobile signal at 3.41 GHz and 3.59 GHz which is lower than the applicable threshold in section 6.1 (i.e. -14 dBm/20MHz for two mobile signals in the 3.5 GHz band), it follows that two nearby higher indoor small cells operating in the 3.5 GHz band will not cause unacceptable interference the Model System.



(a) A single interfering mobile signal centred at 3.41 GHz.



(b) A single interfering mobile signal centred at 3.59 GHz.

Figure 6-23: Received Mobile Signal Power versus height difference Δ*h* when a single mobile signal centred at 3.41 GHz or 3.59 GHz is interfering the SMATV system.

6.4 Proposed Mitigating Measures

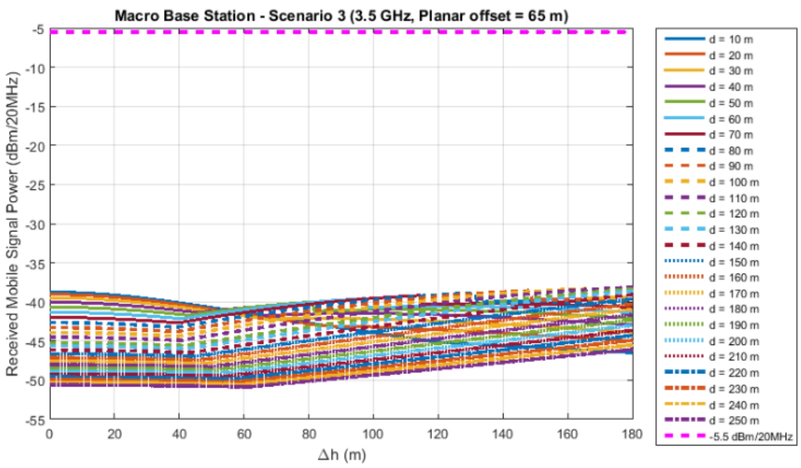
Macro base station antennas installed on rooftops higher than those of SMATV antennas may cause unacceptable interference to the Model Systems.

With a view of looking into the interference issue from a wider angle, inserting spurious suppression filters in 5G NR base stations for combatting spurious emissions has been considered but concluded not to be practical. Annex 6 summarises a study on inserting filters in 5G NR base stations to suppress in-band interference to SMATV systems.

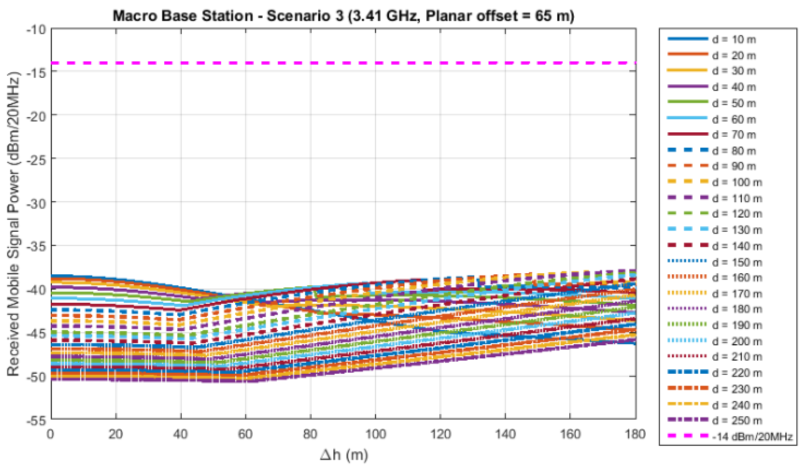
In the following paragraphs, interference mitigating measures for macro base stations operating in the 3.5 GHz band are proposed and verified by some simulation tests.

Comparing Figure 6-13 (a)-(b) and Figure 6-14, it can be noted that in-band interference is the dominant issue since the Received In-band Interference far exceeds the applicable threshold in section 6.1 over a wide range of separation distances *d* and building height difference Δ*h*. ***Given Hong Kong is in the northern hemisphere geographically and that***

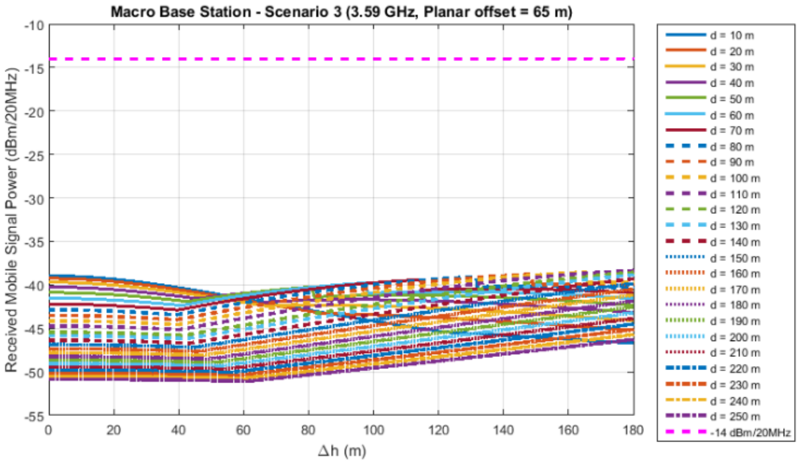
geostationary satellites are orbiting over the equator, satellite antennas in Hong Kong are pointing southward at various elevation angles. With this in mind, the targeted mitigating in counteracting this dominant issue is to move the interfering base station to another building some 65 meters away horizontally in the east or west direction. By doing so, as validated by the simulation results in Figure 6-24, at least up to two macro base stations operating in the 3.5 GHz band installed on a rooftop higher than that of the Model System will not cause unacceptable interference to the Model System.



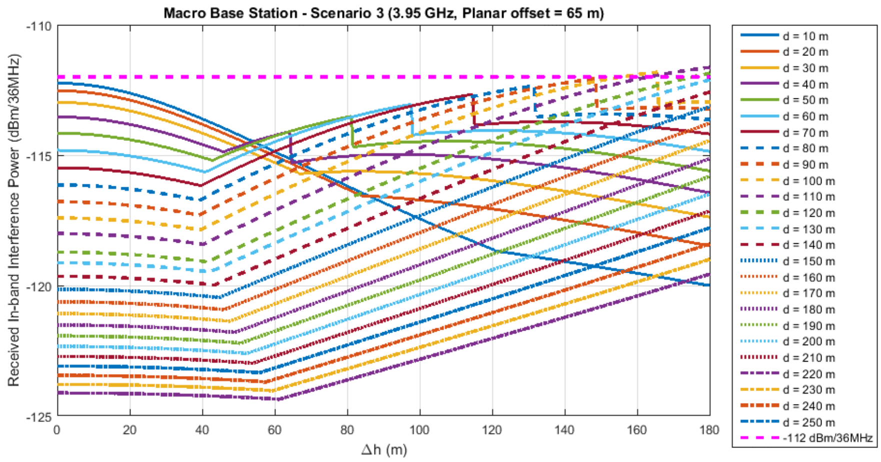
(a) Received Mobile Signal at 3.5 GHz (a single interfering mobile signal)



(b) Received Mobile Signal at 3.41 GHz (two interfering mobile signals)



(c) Received Mobile Signal at 3.59 GHz (two interfering mobile signals)



(d) Received In-band Interference Power at 3.95 GHz

Figure 6-24: Received Mobile Signal Power/In-band Interference versus building height difference Δ*h* with a 65 m shift in base station position.

6.5 Summary of Results, Findings and Mitigating Measures

After consolidating all simulation results, it was found that outdoor and indoor small cell deployment scenarios will not have interference impacts to the Model System and the established key findings for macro base station deployment scenarios are summarized in Table 6-6. Summing up, mobile base stations operating in the 3.5 GHz band (with a 100 MHz guard band) can co-exist with the Model System without special interference mitigating measures under deployment ***Scenario 1*** and ***Scenario 2***, and must be separated from the Model System by a horizontal distance of some 65 m in east or west directions of the Model System under deployment ***Scenario 3 for macro base station***. On the other hand, mobile base stations operating in the 3.60 – 3.65 GHz band (50 MHz guard band) can in general co-exist with the Model System under deployment ***Scenario 1*** and ***Scenario 2*** but cannot co-exist with the Model System under deployment ***Scenario 3, especially for macro base station***.

Table 6-6: Interference analysis for typical mobile base station deployment scenarios in Hong Kong.

	Mobile Base Stations Operating in the 3.5 GHz Band (100 MHz Guard Band)	**Mobile Base Stations Operating in the 3.60 – 3.65 GHz Band (50 MHz Guard Band)**
Scenario 1 – Macro Base Stations and the Model System located on the same rooftop		
Co-existence	No interference to the Model System.	Multiple nearby macro base stations might cause unacceptable interference to the Model System
Mitigating measures	N/A	N/A
Scenario 2 – Base Station located lower than the Model System		
Co-existence	No interference to the Model System.	1. Macro base station should be deployed at heights sufficiently lower than (i.e. at least 3 m) the nearby Model System; and 2. No interference from other types of mobile base station deployments to the Model System.
Mitigating measures	N/A	N/A
Scenario 3 – Base Stations located higher than and on adjacent rooftop to the Model System		
Co-existence	1. Interference from macro base station to the Model System unless interference mitigating measures are in place; and 2. No interference from other types of base station deployments to the Model System.	1. Not feasible for macro base station deployment; and 2. No interference from other types of base station deployments to the Model System.
Mitigating measures	Impose a horizontal distance separation of some 65 m for macro base station in the east and west directions.	N/A

7 Field Trial Results

One of the prime requirements in this Consultancy Study is to verify all laboratory test results and the findings of the Analytical Model by putting up field trials. Through the field trials, the interference susceptibility of the Proposed Model System, the applicability and robustness of the Analytical Model and the associated mitigating approaches in actual working environment could be verified. As elaborated in section 6.3.2, in the field trials, it was not necessary to test out the deployment scenarios of indoor cells and outdoor small cells at street level by virtue of their insignificant interference impact.

After careful site selection, field trials were set up at the rooftops of Yau Tong Industrial City, Ko Fai Road, Yau Tong, Kowloon, Hong Kong. All the tests were conducted on 12 – 14 December 2017 with satisfactory results which further supported that the findings and recommendations in this report were technically sound and workable.

Primarily, the field trials were tailor-designed to examine the following interference:

- Multiple LTE signals interfering a typical SMATV system;
- Multiple LTE signals interfering the Model system; and
- White noise interfering the Model System.

As the conducted spurious emission of the commercial LTE base station was measured as -72 dBm/MHz, it was not practical to use such weak level to test the impact of spurious emission to the SMATV systems (including the typical SMATV system and the Model System). Instead, a white noise generator to emulate spurious emissions of 5G NR base stations was deployed. White noise is a random noise signal that features constant spectral power density over a specific bandwidth and compares with spurious emissions from mobile base stations, the latter are attributed to unintentional emissions mainly from harmonics and oscillator leakages. In the field trials, the use of white noise to emulate 5G NR base station spurious emissions for observing carrier-to-noise (“C/N”) ratio impact resembled an interference environment more profound than any worst case scenarios in actual deployment.

7.1 Test Setup

Figure 7-1 shows the technical configuration of the field trials consisting of interferers and the victim SMATV systems.

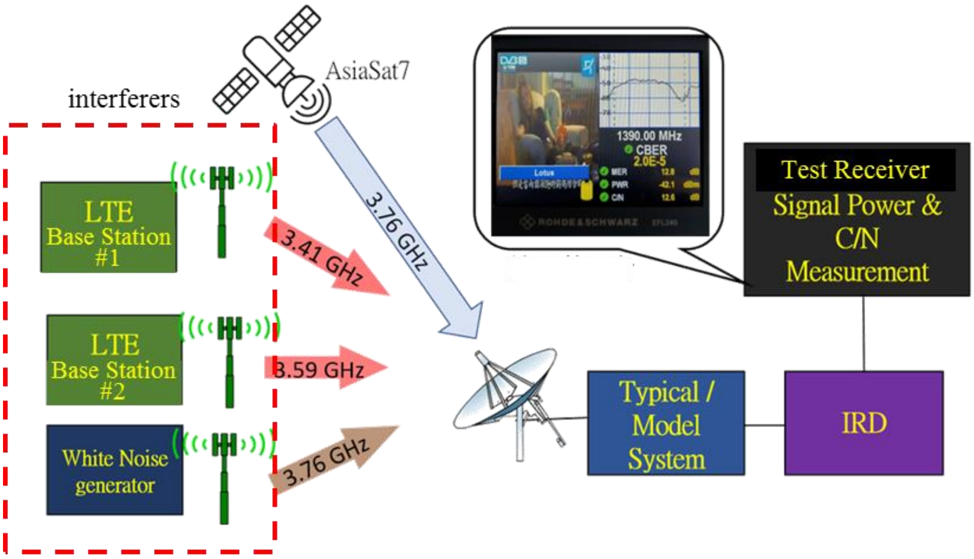


Figure 7-1: Technical configuration of the field trials.

The locations of interferers at the rooftops are marked in Figure 7-2 and the discrete setups at each location are described in Table 7-1.

Figure 7-2: Locations of the interferers.

Table 7-1: Discrete setups at each location.

<table>
<tr><th>Location</th><th>Height of antennas above floor level (metres)</th><th>Interferer Antenna direction</th><th>Separation from the SMATV system (metres)</th><th>Interferer</th></tr>
<tr><td>A</td><td>1.75 and 3 (note 1)</td><td>Pointed directly at the SMATV system</td><td>35</td><td rowspan="6">LTE signals</td></tr>
<tr><td>B</td><td rowspan="4">1.75</td><td rowspan="4">Pointed to the edges of the rooftop (away from the SMATV system)</td><td>55</td></tr>
<tr><td>D</td><td>35</td></tr>
<tr><td>E</td><td>30</td></tr>
<tr><td>F</td><td>17</td></tr>
<tr><td>C</td><td>1.75</td><td>Pointed directly at the SMATV system</td><td>15</td></tr>
<tr><td>G (note 2)</td><td>3</td><td>Pointed directly at the SMATV system</td><td>7</td><td>White noise</td></tr>
<tr><td colspan="5">Note 1: Antennas at Location A were erected at two different heights to show the reflective effect induced by the floor.

Note 2: Demonstrate the minimum separation distance required under the influence of white noise level at -52 dBm/MHz.</td></tr>
</table>

7.2 Test Methodologies

As shown in Figure 7-1, high-power LTE signals and white noise signals were intentionally jamming the SMATV system receiving from a satellite TV channel of AsiaSat 7 as the reference channel for signal measurements. The reference channel exhibited the following key parameters:

- Format: DVBS
- Symbol rate: 26000 kS/s
- Forward error correction: 7/8
- Center frequency: 3.76 GHz
- Wanted signal power measured by IRD (“Channel Power”) : -46.0 dBm
- Minimum requirement of C/N of an SMATV channel (“Channel C/N Ratio”) measures by IRD: 7.2 dB

As far as the technical trials were concerned, signal measurements were made at the IRD to record the signal receiving conditions when interference occurred. The reference point for such data measurement was different to that of the Analytical Model which referred to LNB input instead of IRD output.

Characteristics of the SMATV system under test is summarised below:

- reflector 3.5 metres in diameter with a maximum antenna gain of 40 dBi
- LNB operating frequency 3.4 – 4.2 GHz with 60 dB conversion gain
- The IF cable link (i.e. connecting the LNB and the IRD) 90 metres in length, type RG-11, 10.8 dB cable loss; and
- IRD with signal power display and C/N logging capabilities.

For completeness sake and avoidance of doubt, the measurement equipment used and the models are listed in the Table 7-2:

Table 7-2: Measuring equipment used for field trial.

Measuring Equipment	Model	Function
Noise Generator	R&S SMBV100A	To generate the white noise
2 LTE Base Stations	Band 42 TD-LTE base station	To generate the interfering out-band mobile signals
Mobile Antenna	Directional panel antenna	To convert output signal of the base stations/signal generator to radio waves
Evolved Packet Core Emulator	TD-LTE core network	To enable interoperation between testing LTE base stations and terminals
IRD	Typical IRD	To display decoded TV signals, signal power and C/N ratio
LNB	Typical LNB 3	To implement the Model System.
BPF	Typical WG BPF 1	To implement the Model System.

7.3 Settings of the Experiments

Three experiments were conducted to assess the performance of both a typical SMATV system and the Model System interfered by multiple LTE signals and white noise signals. The technical parameters for each experiment are summarized in Table 7-3 to Table 7-5.

Table 7-3: Parameters for Experiment 1 – Two different LTE signals interfering the typical SMATV system.

Parameter	Values
Input signal type	LTE
Input signal bandwidth	20 MHz
Input signal frequency	3.41 GHz and 3.59 GHz
Interference source locations	Points A, B, C, D, E, F
Input signal power level	33 dBm/20MHz
Antenna gain	18 dBi
EIRP from LTE base station	51 dBm/20 MHz

Table 7-4: Parameters for Experiment 2 – Two different LTE signals interfering the Model SMATV system.

Parameter	Values
Input signal type	LTE
Input signal bandwidth	20 MHz
Input signal frequency	3.41 GHz and 3.59 GHz
Interference source locations	Points A, B, C
Input signal power level	33 dBm/20MHz
Antenna gain	18 dBi
EIRP from LTE base station	51 dBm/20 MHz

Table 7-5: Parameters for Experiment 3 – White noise interfering the Model SMATV system.

Parameter	Values
Input signal type	White noise
Input signal bandwidth	40 MHz
Input signal frequency	3.76 GHz
Interference source location	Point G
Conducted signal power level	-52 dBm/MHz
Antenna gain	18 dBi

7.4 Test Procedures and Results

7.4.1 Two LTE Signals Interfering the Typical SMATV System

<u>Test Procedures</u>

The typical SMATV system shown in Figure 7-3 below was jammed by two LTE interferers at 3.41 GHz and 3.59 GHz. The Channel Power and the Channel C/N Ratio measured by

IRD for the reference SMATV channel were monitored with a view to determining whether the SMATV system was adversely affected. For each of the locations in Points A, B C, D, E, and F, the two LTE interferers were turned on one by one: the 3.59 GHz LTE interferer was turned on first. If the reference SMATV channel was decodable, i.e. the Channel Power and the Channel C/N Ratio could be measured, then the 3.41 GHz interferer was to be turned on afterwards. This made sure that any sudden irregularities in the SMATV system could be tracked and traced.

Figure 7-3: Typical SMATV receiver system setup in the field trials.

<u>Test Results</u>

- At Points A, C, D, E and F, when the first LTE interferer at 3.59 GHz was transmitting, the SMATV system failed to decode the reference SMATV channel and the Channel Power and the Channel C/N Ratio could not be measured.

- When the LTE interferer at Point B was transmitting, the SMATV system continued to successfully receive the reference channel and the signal quality was not affected. In other words, the Channel Power and the Channel C/N Ratio were measured and the Channel C/N Ratio was maintained.

These observations were in line with the laboratory measurements for the typical SMATV system, i.e., a nearby LTE base station that operated at the 3.5 GHz band was able to cause unacceptable interference to typical SMATV system.

7.4.2 Two LTE Signals Interfering the Proposed Model System

Test Procedures

The typical SMATV system was upgraded by retrofitting a 3.7 – 4.2 GHz waveguide bandpass filter as shown in Figure 7-4, i.e. the Model System. Consistent with the same test procedures in section 7.4.1, the Channel Power and the Channel C/N Ratio were recorded at individual locations.

Figure 7-4: Model System in the trial site.

Test Results

The Channel Power and the Channel C/N Ratio are shown in Table 7-6.

In line with the findings in laboratory measurements, Table 7-6 demonstrates that LTE interferers with sufficient distance separation might not cause unacceptable interference to the Model System, where both the Channel Power and the Channel C/N Ratio were not varied. However, at Point C, the Channel C/N Ratio was found reducing to a large extent (from 13.8 dB to 12.7 dB for LTE signal at 3.59 GHz and from 13.8 dB to 9.9 dB for LTE signal at 3.41 GHz). This suggests that a nearby LTE interferer could reduce the LNB gain and introduce distortions in the Model System.

Table 7-6: Measured Channel Power and Channel C/N Ratio when the Model System was interfered by LTE signals.

Criteria for no interference impact to received satellite signal Channel Power = -46.0 dBm, Channel C/N Ratio = 13.8 dB				
Point	3.59 GHz LTE as interferer		3.41 GHz LTE as interferer	
	Measured Channel Power (dBm)	Measured Channel C/N Ratio (dB)	Measured Channel Signal Power (dBm)	Measured Channel C/N Ratio (dB)
A (1.75 m antenna height, 35 m separation)	-46.0	13.8	-45.0	13.9
A (3.5 m antenna height, 35 m separation)	-46.0	13.8	-46.0	13.8
B (55 m separation)	-46.0	13.8	-46.0	13.8
C (15 m separation)	-46.0	12.7	-46.0	9.9

7.4.3 White Noise Interfering the SMATV System

Test Procedures

A white noise signal at 3.76 GHz with 40 MHz bandwidth to emulate 5G NR spurious emissions was transmitted from Points A through G for monitoring the Channel Power and the Channel C/N ratio.

Test Results

The Channel Power and the Channel C/N Ratio are shown in Table 7-7.

Table 7-7: Measured Channel Power and the Channel C/N Ratio when the Model System was interfered by white noise.

Criteria for no interference impact to received satellite signal Channel Power = -46.0 dBm, Channel C/N Ratio = 13.8 dB		
Point	**Measured Channel Power (dBm)**	**Measured Channel C/N Ratio (dB)**
A (antenna height 1.75 m, 35 m separation)	-46.0	13.5
A (antenna height 3.5 m, 35 m separation)	-46.0	13.7
B (55 m separation)	-46.0	13.7
C (15 m separation)	-46.0	12.1
F (17 m separation)	-46.0	13.7
G (7 m separation)	-46.0	7.2

Table 7-2 reveals the following key findings:

- When the interferer was pointing towards the best reception direction of the SMATV system, the Channel C/N Ratio was significantly impacted by the antenna height of the interferer (relative to the surface of the building rooftop).

- At -52 dBm/MHz noise power level, the Channel C/N Ratio would not be degraded unless the separation distance between the interferer and the SMATV system was sufficiently small, as demonstrated at Point G.

8 Verifications of the Interference Impacts to the Model System in the Field Trials

To build up confidence with the field trial results, it is necessary to verify some sampled results with the theoretical impacts of in-band interference to the Model System. In performing the verifications, the following assumptions are made based on the technical specifications in section 6.2.1:

- The LTE base station transmission power was 33 dBm;
- The spurious emission level was -52 dBm/MHz;
- Contributed by main lobe, the antenna gain of the interferer was $G_{t,eff} = 18\ dBi$ when pointing at the maximum reception direction of the SMATV systems;
- By way of side lobe, the antenna gain of the interferer was $G_{t,eff} = -19.15\ dBi$ when the interferer pointed at edges of the rooftop;
- When interference signal was picked up by side lobe of the SMATV antenna, the receiver antenna gain was by $G_{r,eff} = -10\ dBi$;
- The gain of the LNB was $G_{LNB} = 60\ dB$;.
- The cabling loss was given by $G_{Cable} = -16.8\ dB$; and
- The IRD measured the signal power of an SMATV channel per 8 MHz bandwidth, P_{sat}, and the Channel C/N Ratio.

8.1 Impacts of LTE Signals and In-band Interference to the Model System

The propagation paths from the interferer up to the IRD part are drawn in Figure 8-1.

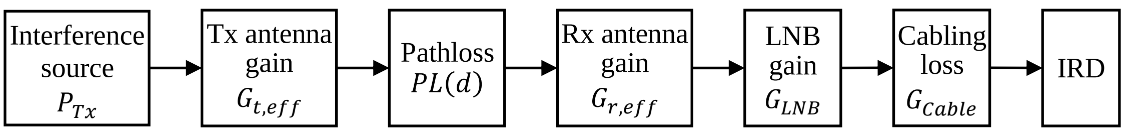


Figure 8-1: Propagation paths from the inteferer up to the IRD.

Mobile Signal Rejection Capability of the Model System

When the interference source is a base station signal, $P_{Tx} = P_{signal}$, and the Received Mobile Signal Power is given by:

$$I_{mobile} = P_{signal} + G_{t,eff} - PL(d) + G_{r,eff}.$$

In the field trial, there is line-of-sight between the interference source and the SMATV system and so the path loss is given by

$$PL(d) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d).$$

As shown in section 7.4.2, the Model System as interfered by LTE interferers at Point C did not cause decoding error although the Channel C/N Ratio was found reducing to a large extent. Since Point C and the Model System were separated by 15 m, the path loss was approximately 67 dB. Moreover, the base station antenna pointed directly at the side of the SMATV antenna, so the antenna gain of the interferer was $G_{t,eff} = 18\ dBi$ and the SMATV antenna gain was $G_{r,eff} = -10\ dBi$. It follows that the Received Mobile Signal Power was -26 dBm/20MHz for mobile signal at 3.41 GHz and 3.59 GHz which is lower than the applicable threshold in section 6.1 (i.e. -14 dBm/20MHz for two mobile signals in the 3.5 GHz band). This result is in line with the findings in the field trial.

Impact of In-band Interference to the Model System

When the interference source is a base station signal, $P_{Tx} = P_{signal}$, and the in-band interference power to the IRD is given by:

$$I_{IRD} = P_{spurious} + G_{t,eff} - PL(d) + G_{r,eff} + G_{LNB} + G_{Cable}$$

Table 8-1 summarizes the theoretical received in-band interference power and the measured Channel C/N Ratio due to interferers at each location. In line with the field trial results, while interferers at all locations did not cause decoding error, as expected, the nearest interferers at Points C and G could cause the Channel C/N Ratio to reduce.

Table 8-1: Impact of the In-band Interference on the Channel C/N Ratio

<table>
<tr><th colspan="5">Criteria for no interference impact to received satellite signal

Channel C/N Ratio = 13.8 dB</th></tr>
<tr><th>Point</th><th>Path Loss
PL(d)
(dB)</th><th>Interferer Antenna Gain
$G_{t,eff}$
(dBi)</th><th>Theoretical In-band Interference
(dBm/36 MHz)
*note</th><th>Measured Channel C/N Ratio
(dB) as given in Table 7-7</th></tr>
<tr><td>A
(antenna height 1.75 m, 35 m separation)</td><td rowspan="2">74.9</td><td rowspan="2">18</td><td rowspan="2">-103.3</td><td>13.5</td></tr>
<tr><td>A
(antenna height 3.5 m, 35 m separation)</td><td>13.7</td></tr>
<tr><td>B
(55 m separation)</td><td>78.8</td><td>-19</td><td>-144.2</td><td>13.7</td></tr>
<tr><td>C
(15 m separation)</td><td>67.5</td><td>18</td><td>-95.9</td><td>12.1</td></tr>
<tr><td>F
(17 m separation)</td><td>68.6</td><td>-19</td><td>-134.0</td><td>13.7</td></tr>
<tr><td>G
(7 m separation)</td><td>60.9</td><td>18</td><td>-89.3</td><td>7.2</td></tr>
</table>

*Note – The theoretical in-band interference is given by:

$$I = P_{spurious} + G_{t,eff} - PL(d) + G_{r,eff}$$

where $P_{spurious} = -52\ dBm/MHz$

9 Conclusions

This report presents in details the assessments on electromagnetic compatibility and mitigating measures to enable the co-existence of SMATV systems and future mobile systems to be operated under the CA's Proposed Re-Allocation. The interference impacts of using 50 MHz guard band versus 100 MHz have also been examined. The findings and the proposed mitigating measures are measurement-based, coupled with system-level simulations in which an analytical model is tailor-designed to emulate 5G NR base stations interfering with a typical SMATV system and the Model System. The simulation results are further backed up by the field trials. The key conclusions as drawn from the findings of sections 4 – 7 of this report are described in the succeeding paragraphs.

The Model System

- The proposed Model System shall consist of a WG BPF cascaded with a LNB. The WG BPF shall have a pass band of 3.7 – 4.2 GHz with at least 55 dB suppression for signals below 3.6 GHz, and at least 50 dB suppression for signals above 4.2 GHz.

- SMATV systems currently deployed in Hong Kong shall be upgraded by retrofitting a WG BPF between the feedhorn and the LNB, but the existing LNBs that operate in the 3.4 – 4.2 GHz band need not be replaced.

Interference Assessment and Mitigating Measures

- Outdoor and indoor small cell deployment scenarios will not cause interference to the Model Systems.
- Three macro base station deployment scenarios were considered:
    - ***Scenario 1*** – Base station antenna(s) and SMATV antenna installed on the same rooftop
    - ***Scenario 2*** – Base station antenna(s) at a height lower than the Model System
    - ***Scenario 3*** – Base station antenna(s) in front of and higher than the Model System

- Mobile base stations operating in the 3.5 GHz band (with 100 MHz guard band) can co-exist with the Model System without special interference mitigating measures under the deployment ***Scenario 1*** and ***Scenario 2***. Under ***Scenario 3***, the mobile base station might induce interference to the Model System. In this case, the base station should be relocated by a horizontal distance of some 65 m in east or west directions.

- Mobile base stations operating in the 3.60 – 3.65 GHz band (with 50 MHz guard band) can in general co-exist with the Model System under deployment ***Scenario 1*** and ***Scenario 2*** but cannot co-exist with the Model System under deployment ***Scenario 3.***

Field Trial Results

- Field trials were carried out to verify the interference susceptibility of the Model System, the applicability and robustness of the Analytical Model and the associated mitigating approaches in actual working environment.

- The results have demonstrated that a nearby LTE base station that operated at the 3.5 GHz band can cause unacceptable interference to a typical SMATV system, whereas LTE interferers with sufficient distance separation (i.e. approximately 15 m) might not cause unacceptable interference to the Model System. Moreover, a white noise inference source has negligible impact on the Model System when they are separated by at least 15 m.

9.1 Limitations of the Study

In hindsight, there were several limitations of this Consultancy Study posed by the equipment characteristics and the testing methodologies.

9.1.1 Limitations of the Testing Equipment

First, at the time of study, there was no commercially available 5G NR base stations with M-MIMO antenna or 5G mobile terminals for testing. During the field trials, LTE base stations and white noise generator were deliberately used to mimic 5G NR mobile signals and spurious emissions from 5G NR base stations respectively. The bandwidth of the emulated mobile signal was just 20 MHz. In this regard, 5G NR base stations could support channel bandwidths from 20 MHz to 100 MHz. Relative to beam-sweeping, in the field trials, this function was emulated by aligning the base station antenna and the SMATV antenna in an effort to maximize the antenna gain of the interfering base station.

Second, the maximum power for CW and LTE signals were set at 25 dBm and 13 dBm respectively. Further increases in power levels had resulted in burning out of various LNBs even the tests were conducted under a highly controlled environment. This was not surprising on the understanding that LNBs were designed to receive very weak signal power. Notwithstanding such drawback, the transmitted power levels were sufficient high to test the performances of various front-end RF components of typical SMATV systems and the Model System.

9.1.2 Limitations of the Testing Methodologies

At the time of the study, the 5G NR base station conformance testing standard, 3GPP TS 38.141[5], was still at the infancy stage of development. This standard would provide comprehensive test plans, testing environments and measurement techniques. In the lack of reference to the abovementioned standard, the testing methodologies adopted in this study were predominantly tallied with 4G LTE technologies.

9.2 Prospect and Further Study

In a separate development, it is expected that 5G NR base stations, M-MIMO antenna and mobile terminals would be available earliest by 2019. In this study, while representative LNBs and BPFs in the market were picked for testing, the performance aspects of such RF components as given in this report are by no means exhaustive. Subject to resource availability, OFCA might consider further testing of 5G NR base stations with a diverse range of LNBs and BPFs after 2019. Such testing could be outsourced to a competent testing laboratory in Hong Kong.

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[5] TS 38.141 - 3rd Generation Partnership Project; Technical Specification Group RAN; NR; Base Station (BS) conformance testing, Part 2, radiated conformance testing (Release 15)

References

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[Ref 2] TR 36.942: 3GPP TSG RAN, E-UTRA, Radio Frequency (RF) system scenarios (Release 14), V14.0.0, Mar. 2017, Available at https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2592.

[Ref 3] 3GPP TS 38.104: TSG RAN, NR, Base Station (BS) radio transmission and reception (Release 15) V1.0.0, Dec. 2017, Available at https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3202.

[Ref 4] Recommendation ITU-R SF.1486, Sharing methodology between fixed wireless access systems in the fixed service and very small aperture terminals in the fixed-satellite services in the 3400 – 3700 MHz band (2010-10).

[Ref 5] Recommendation ITU-R P.452-16 Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above 0.1 GHz (2015-07).

[Ref 6] Recommendation ITU-R P.526-7 Propagation by diffraction (2013-11).

[Ref 7] EN 300 421 V1.1.2, "Digital video broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services," European Telecommunications Standards Institute (ETSI), Aug. 1997.

[Ref 8] Recommendation ITU-R F.1336-4 Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile services for use in sharing studies in the frequency range from 400 MHz to about 70 GHz (2014-02).

[Ref 9] Recommendation ITU-R S.465-6 Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 – 31 GHz (2010-01).

[Ref 10] "Further advancements for E-UTRA physical layer aspects," 3GPP TR 36.814. Available at: http://www.3gpp.org/ftp//Specs/archive/36_series/36.814/

[Ref 11] Recommendation ITU-R S.2368-0 Sharing studies between International mobile telecommunication – Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3400-4200 MHz and 4500-4800 MHz frequency bands in the WRC study cycle leading to WRC-15 (2015-06).

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[Ref 13] "Report of working group on assessment of potential Interference between broadband Wireless Access Systems in the 3.4 – 3.6 GHz band and fixed satellite

Services in the 3.4 – 4.2 GHz band,” Office of the Telecommunications Authority (2006-08). (http://tel_archives.ofca.gov.hk/en/ad-comm/rsac/paper/rsac5-2006.pdf).

[Ref 14] 3GPP TS 38.331: TSG RAN, NR, Radio Resource Control (RRC) Protocol specification (Release 15) V0.4.0, Dec. 2017, Available at https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3197.

Annex 1 Analysis of IMD3 Generated from Two Mobile Signals

A1.1 Definition of Intermodulation Distortion

Intermodulation distortion ("IMD") is the phenomenon when two or more frequencies mix with one another (intermodulate) in a non-linear device resulting in undesired frequencies which are the sum and difference of the original frequencies as well as multiples of the original frequencies. The undesired frequencies are collectively named as IMD products which might cause interference to other radiocommunications systems.

A1.2 Theoretical Calculation of IMD3 Frequencies

The IMD generated from multiple input signals can be calculated theoretically. Among IMD products, the third-order IMD ("IMD3") generally has highest power level. For this reason, IMD3 is the dominant interference affecting the SMATV systems in this study. For the electromagnetic compatibility between mobile services and SMATV services operating in the C-Band under the Proposed Re-Allocation, all the possible frequencies of IMD3 generated from two mobile signals with 20 MHz bandwidth in 3.4 – 3.65 GHz band can be calculated and grouped in Table A1-1.

Table A1-1: Frequencies of all IMD3 generated from two mobile signals with 20 MHz bandwidth in 3.4 – 3.65 GHz band.

IMD3		Center Frequency of First Signal (GHz)												
		3.41	**3.43**	**3.45**	**3.47**	**3.49**	**3.51**	**3.53**	**3.55**	**3.57**	**3.59**	**3.61**	**3.63**	**3.65**
Center Frequency of Second Signal (GHz)	**3.41**	3.41, 3.41	3.45, 3.39	3.49, 3.37	3.53, 3.35	3.57, 3.33	3.61, 3.31	3.65, 3.29	3.69, 3.27	3.73, 3.25	3.77, 3.23	3.81, 3.21	3.85, 3.19	3.89, 3.17
	3.43	3.39, 3.45	3.43, 3.43	3.47, 3.41	3.51, 3.39	3.55, 3.37	3.59, 3.35	3.63, 3.33	3.67, 3.31	3.71, 3.29	3.75, 3.27	3.79, 3.25	3.83, 3.23	3.87, 3.21
	3.45	3.37, 3.49	3.41, 3.47	3.45, 3.45	3.49, 3.43	3.53, 3.41	3.57, 3.39	3.61, 3.37	3.65, 3.35	3.69, 3.33	3.73, 3.31	3.77, 3.29	3.81, 3.27	3.85, 3.25
	3.47	3.35, 3.53	3.39, 3.51	3.43, 3.49	3.47, 3.47	3.51, 3.45	3.55, 3.43	3.59, 3.41	3.63, 3.39	3.67, 3.37	3.71, 3.35	3.75, 3.33	3.79, 3.31	3.83, 3.29
	3.49	3.33, 3.57	3.37, 3.55	3.41, 3.53	3.45, 3.51	3.49, 3.49	3.53, 3.47	3.57, 3.45	3.61, 3.43	3.65, 3.41	3.69, 3.39	3.73, 3.37	3.77, 3.35	3.81, 3.33
	3.51	3.31, 3.61	3.35, 3.59	3.39, 3.57	3.43, 3.55	3.47, 3.53	3.51, 3.51	3.55, 3.49	3.59, 3.47	3.63, 3.45	3.67, 3.43	3.71, 3.41	3.75, 3.39	3.79, 3.37
	3.53	3.29, 3.65	3.33, 3.63	3.37, 3.61	3.41, 3.59	3.45, 3.57	3.49, 3.55	3.53, 3.53	3.57, 3.51	3.61, 3.49	3.65, 3.47	3.69, 3.45	3.73, 3.43	3.77, 3.41
	3.55	3.27, 3.69	3.31, 3.67	3.35, 3.65	3.39, 3.63	3.43, 3.61	3.47, 3.59	3.51, 3.57	3.55, 3.55	3.59, 3.53	3.63, 3.51	3.67, 3.49	3.71, 3.47	3.75, 3.45
	3.57	3.25, 3.73	3.29, 3.71	3.33, 3.69	3.37, 3.67	3.41, 3.65	3.45, 3.63	3.49, 3.61	3.53, 3.59	3.57, 3.57	3.61, 3.55	3.65, 3.53	3.69, 3.51	3.73, 3.49
	3.59	3.23, 3.77	3.27, 3.75	3.31, 3.73	3.35, 3.71	3.39, 3.69	3.43, 3.67	3.47, 3.65	3.51, 3.63	3.55, 3.61	3.59, 3.59	3.63, 3.57	3.67, 3.55	3.71, 3.53
	3.61	3.21, 3.81	3.25, 3.79	3.29, 3.77	3.33, 3.75	3.37, 3.73	3.41, 3.71	3.45, 3.69	3.49, 3.67	3.53, 3.65	3.57, 3.63	3.61, 3.61	3.65, 3.59	3.69, 3.57
	3.63	3.19, 3.85	3.23, 3.83	3.27, 3.81	3.31, 3.79	3.35, 3.77	3.39, 3.75	3.43, 3.73	3.47, 3.71	3.51, 3.69	3.55, 3.67	3.59, 3.65	3.63, 3.63	3.67, 3.61
	3.65	3.17, 3.89	3.21, 3.87	3.25, 3.85	3.29, 3.83	3.33, 3.81	3.37, 3.79	3.41, 3.77	3.45, 3.75	3.49, 3.73	3.53, 3.71	3.57, 3.69	3.61, 3.67	3.65, 3.65

The frequencies of IMD3 falling inside 3.7 – 4.2 GHz are marked as red in Table A1-1. The red values reflect the dominant interfering frequencies to SMATV systems. Lab measurements were conducted to assess the impacts of these interferers. With an aim of producing an IMD3 near the 3.8 GHz range for observation, the two interfering LTE carriers chosen were 3.41 GHz and 3.59 GHz, thus crafting the IMD3 of 3.77 GHz. IMD3 at 3.77 GHz was evident at the output of a LNB through which this 3.77 GHz frequency was converted to 1.38 GHz as depicted in Figure A1-1 after mixing with the LNB oscillator frequency at 5.15 GHz. In the same figure, the interfering carriers 3.41 GHz and 3.59 GHz were converted to frequencies at 1.56 GHz and 1.74 GHz respectively, again, after mixing with the 5.15 GHz LNB oscillator frequency.

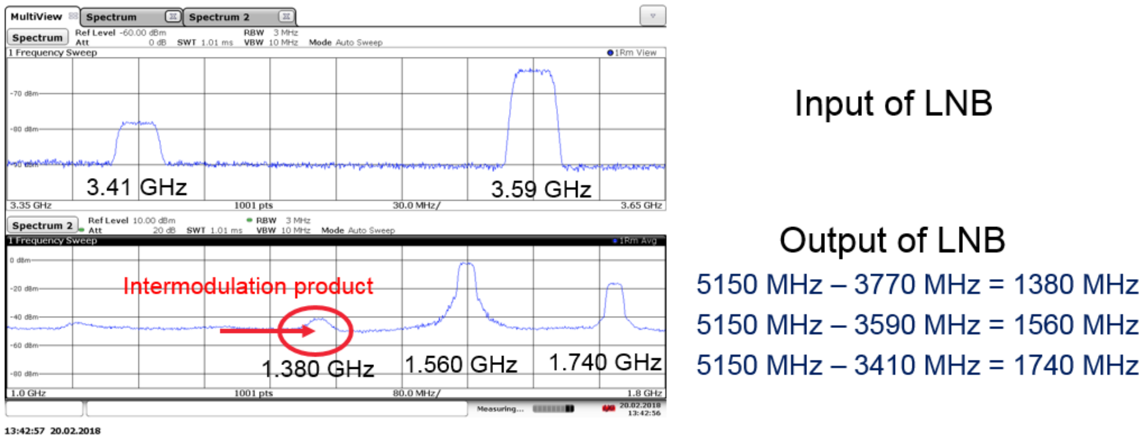


Figure A1-1: Intermodulation product generated by 3.41 GHz and 3.59 GHz LTE carriers at the output of the LNB.

Annex 2 Information on 5G Spurious Emissions

Unwanted emissions are further categorised into (a) out-of-band emissions and (b) spurious emissions. Out-of-band emissions are unwanted emissions immediately outside the channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions. Spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

For 5G NR base station, the out-of-band emission requirement for base station transmitters is specified both in terms of Adjacent Channel Leakage Ratio ("ACLR") and Operating band unwanted emissions. The Operating band unwanted emissions define all unwanted emissions in each supported downlink operating band plus the frequency ranges Δf above and Δf below each band. Unwanted emissions outside of this frequency range are limited by a spurious emission requirement. The maximum offset Δf of the operating band unwanted emissions mask from the operating band edge is:

- 10 MHz for operating band less than 100 MHz, and
- 40 MHz for operating band equal to or larger than 100 MHz.

Diagrammatically, the frequency ranges of spurious emissions for 5G NR base station are shown in Figure A2-1 and Figure A2-2.

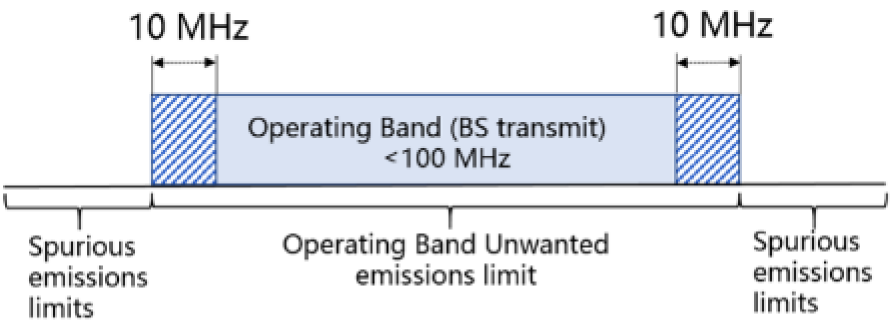


Figure A2-1: Defined frequency ranges for 5G NR spurious emissions for channel bandwidth below 100 MHz.

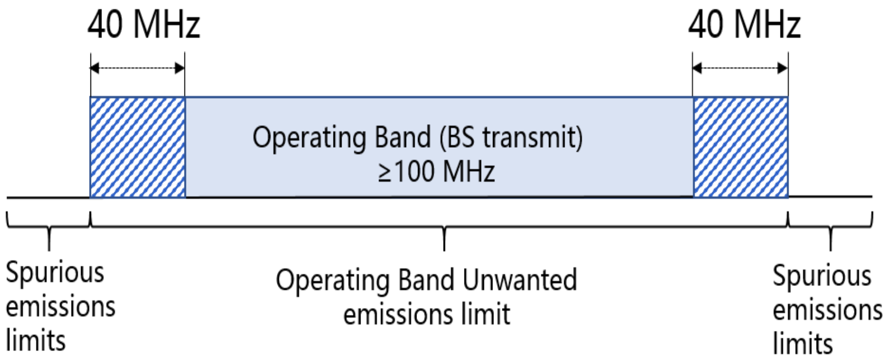


Figure A2-2: Defined frequency ranges for 5G NR spurious emissions for channel bandwidth equal to or larger than 100 MHz.

Regardless of the channel bandwidths, 5G NR base stations operating in the 3.5 GHz band will generate spurious emissions straddling across the 3.4 – 3.6 GHz, 3.6 – 3.7 GHz and 3.7 – 4.2 GHz bands. In the context of the Proposed Re-Allocation, only spurious emissions traversing the 3.7 – 4.2 GHz band, which will become interference to SMATV signals, will be considered and analysed for mitigation.

Annex 3 Supplementary Note on Network-Based Solution to Prohibit Mobile Terminal Transmissions at the 3.5 GHz Band

This annex illustrates the use of a network-based solution to prohibit mobile terminal transmissions at 3.5 GHz from interfering with SMATV systems. Unlike mobile base stations which operate at fixed locations, the mobility of a user terminal might pose interference risk to a SMATV system.

Figure A3-1 shows a potential interference case. Cell 1 is established by a 5G NR base station operating in 3.5 GHz band which does not interfere with a SMATV system. However, when a mobile terminal is moving along Cell 1 and getting close to the SMATV system, the received 3.5 GHz signal power incident on the SMATV system could potentially exceed the interference protection criteria for safeguarding the operations of the Model System as set out in section 6.1. To curb such occurrence, a network-based solution (hereinafter referred to as "Forced Handover") can be employed to intentionally handover the established connection to another base station not operating in the 3.5 GHz band ("Non-3.5 GHz Band").

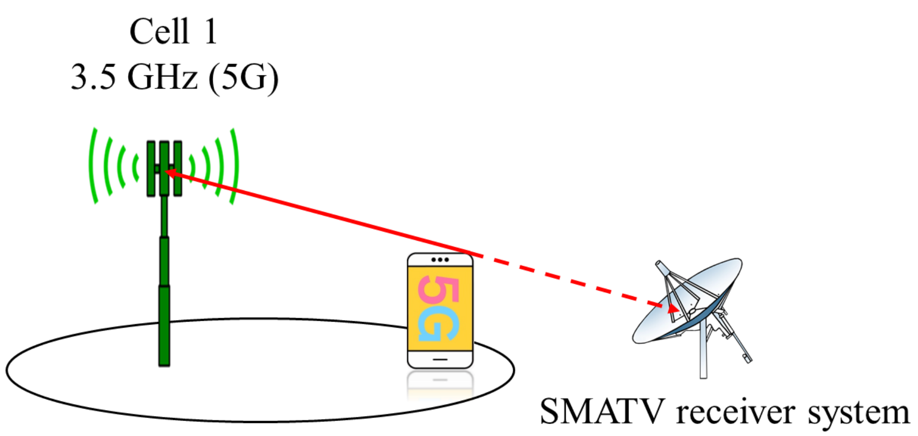


Figure A3-1: A mobile terminal interfering with a nearby SMATV system.

In terms of radio access protocols, a mobile terminal shall continuously report the received signal qualities quantified as a Reference Signal Received Power ("RSRP") from the connected the cell as well as other neighbouring cells. The reporting events with respect to RSRP are depicted in Figure A3-2.

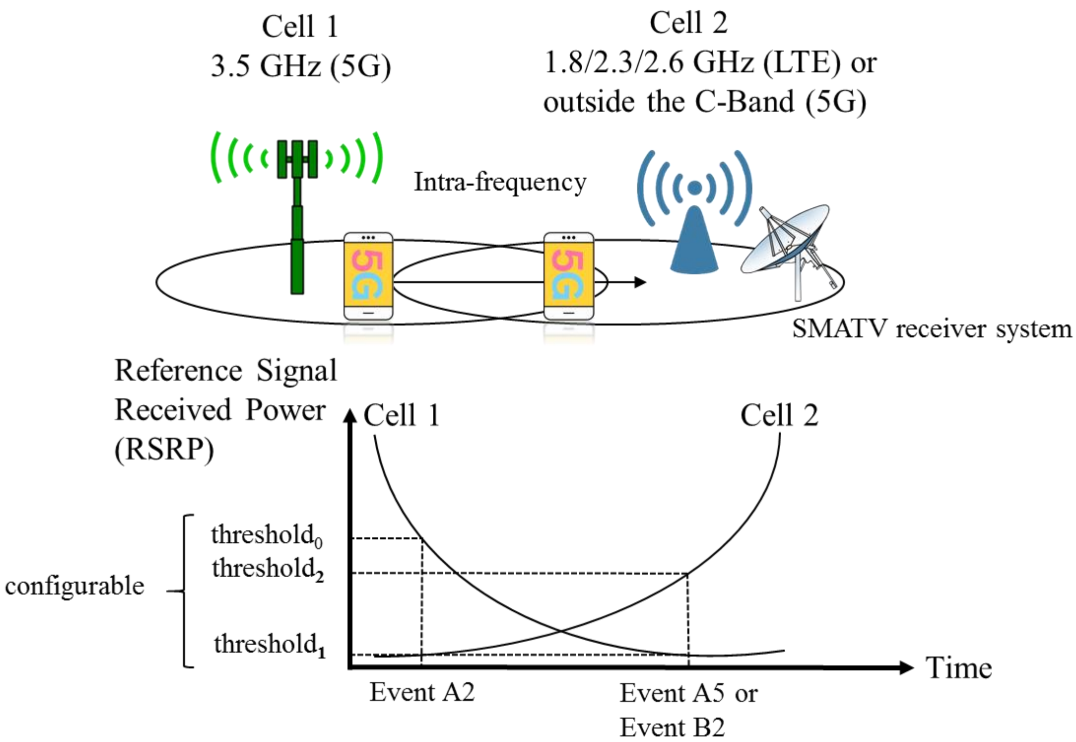


Figure A3-2: Illustration of Forced Handover to limit the area where mobile terminal can transmit at the 3.5 GHz band.

On passage, the signal quality of Cell 1 will drop whereas the signal quality of Cell 2 will rise until a point where Cell 1 will handover the connection with the mobile terminal to Cell 2. The handover procedure is defined by a sequence of two events predicated by three thresholds as outlined below:

- Event A2 is triggered when the signal quality of Cell 1 is measured by the mobile terminal to be below threshold 0. As a result, the mobile terminal will start reporting the signal quality for both Cell 1 and Cell 2.

- Event B2 for 4G LTE cellular network and Event A5 of a 5G NR cellular network are triggered when the quality of Cell 1 falls below threshold 1 and the quality of Cell 2 rises above threshold 2. As a result, Cell 1 will handover the connection with the mobile terminal to Cell 2.

For mobile terminals, the above mechanisms virtually establish an “uncovered area” purported to be in Cell 1 which offers additional protection to a SMATV system in the vicinity, if necessary.

Annex 4 Calculation of the Maximum Allowable In-band Interference Level

According to principles laid down in Recommendation ITU-R SF.1486[6], interference to a SMATV system is significant when the receiver is subject to an interference level 10 dB below the receiver thermal noise floor for more than 20% of any month. Let I_{max} denote the maximum aggregate in-band interference.

Thus,

$$I_{max} = (10\log_{10}(kBT)\text{ -10})\text{ dBW}$$

where $k = 1.38 \times 10^{-23}\mathrm{J}\cdot\mathrm{K}^{-1}$ is the Boltzmann's constant,

B is the satellite transponder bandwidth equals to 36 MHz and

$T = 114.8\ K$ is the noise temperature for satellite antenna.

$$I_{max} = -142\ dBW/36MHz$$

$$or\ -112\ dBm/36MHz$$

[6] Recommendation ITU-R SF. 1486 - Sharing methodology between fixed wireless access systems in the fixed service and very small aperture terminals in the fixed-satellite service in the 3 400-3 700 MHz band

Annex 5 Introduction to First Fresnel Zone of SMATV Systems

A Fresnel zone is one of a series of concentric prolate ellipsoidal regions of space between and around a transmitting antenna and a receiving antenna system. They are used by propagation theory to calculate refraction and diffraction loss between a transmitter and receiver. Fresnel zones are numbered and are called “F1”, “F2”, “F3”, etc.

Specifically, the first Fresnel zone (“F1”) radius is calculated so that the difference in path length between the main signal and a reflected signal from the F1 radius distance is 180° as shown in Figure A5-1. The main signal will add together with the reflected signal, which is shifted by 180° from the actual reflection point. This will not lead to phase cancellation and have no effect on the reception performance.

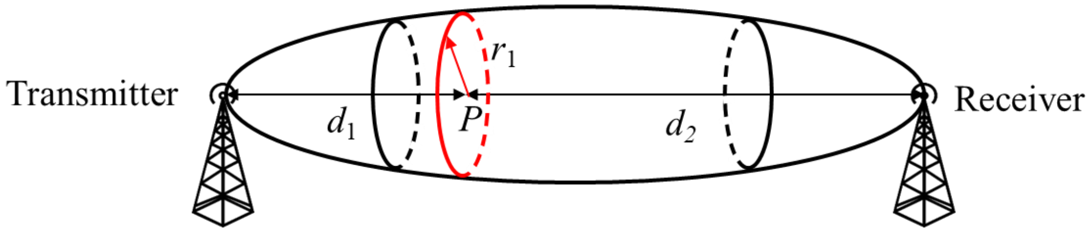


Figure A5-1: The first Fresnel zone.

The equation for calculating the first Fresnel zone radius at any point in between the endpoints of the link is given as:

$$F_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}},$$

where

$F1$: first Fresnel zone radius (m)

λ : wavelength of the transmitted signal (m)

d_1 : distance between point P from the transmitter (m)

d_2 : distance of P from the receiver[7] (m).

SMATV systems require an open view of the sky so that its first Fresnel zone will not be obstructed. When a building is in front of the main lobe of a SMATV antenna, the azimuth

[7] For SMATV systems in Hong Kong receiving satellite signals $d_2 \approx 39220$ km.

angle of the SMATV antenna may need to be adjusted during installation as illustrated in Figure A5-2. Mathematically, the conditions governing the adjustment are given as follows:

$$\Delta h > d_1 \sin\theta - F_1 \cos\theta,$$
$$d = F_1 \sin\theta + d_1 \cos\theta,$$

where

Δh : height difference between SMATV antenna and the building in front (m)

F_1 : first Fresnel zone radius (m)

d : separation distance between SMATV antenna and building in front (m)

θ : uptilt angle of the SMATV antenna (degrees).

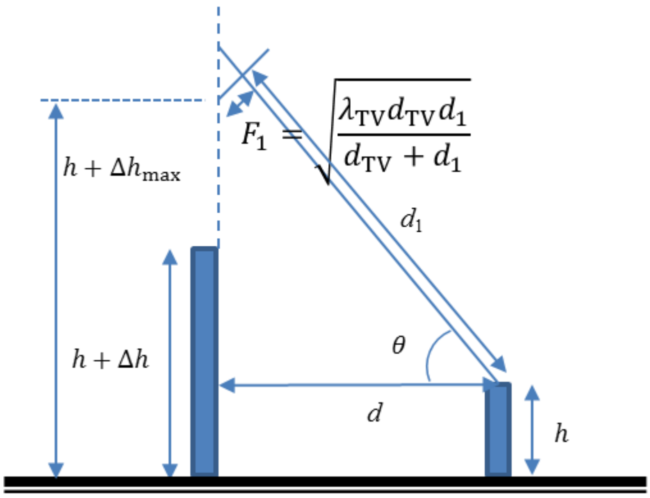


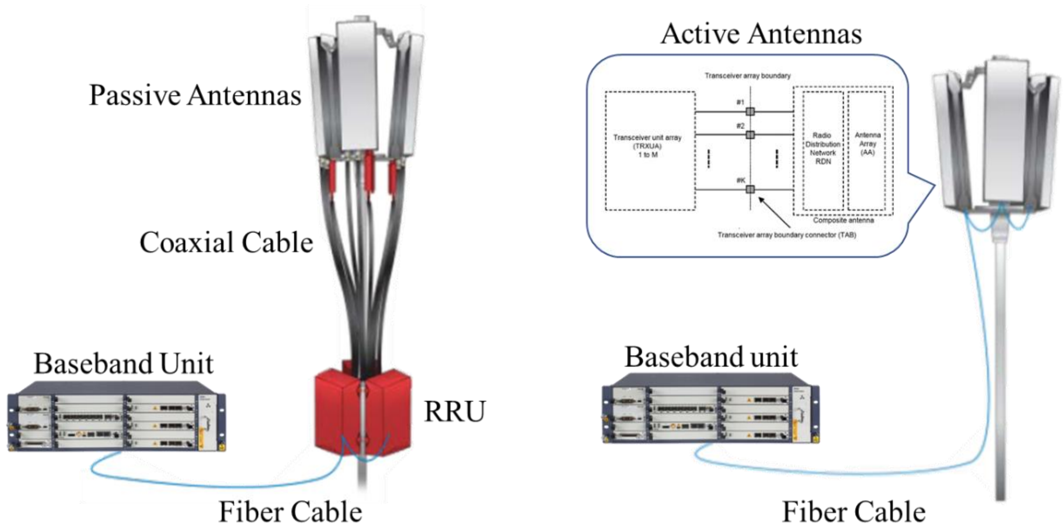
Figure A5-2: Illustration of SMATV antenna azimuth angle adjustment.

In cases adjustment of the SMATV antenna is necessary, the azimuth angle adjustment can be derived according to the formula below:

$$\gamma = \tan^{-1}\left(\frac{0.5 \cdot \text{building width}}{d}\right) + \tan^{-1}\left(\frac{F_1}{\sqrt{d^2 + (0.5 \cdot \text{building width})^2}}\right).$$

Annex 6 Feasibility of Inserting Spurious Suppression Filters in 5G NR Base Stations to Mitigate In-Band Interference

The use of spurious suppression filters and band stop filters has been widely popular in radiocommunications systems in stopping spurious emissions from the sources. In a similar way, it is necessary to study the option of inserting spurious suppression filters into 5G NR base station as a means of circumventing the interference impact to SMATV systems. Practically, to meet the many fold increase in network capacity, 5G NR base station will feature a large number of antenna elements housed in an antenna array for supporting the essential functions of M-MIMO and beamforming. The beamforming operation requires dynamic adjustment of radiation patterns and it drives 5G NR base stations to evolve from the legacy radio architecture to the Active Antenna System ("AAS") based radio architecture. Specifically, while LTE base stations make use of separable Remote Radio Unit ("RRU") and passive antennas, 5G NR base stations will have a compact design by embedding a transceiver unit array ("TRXUA") with a passive antenna array shrouded in a radome as shown in Figure A6-1.



(a) Conventional base station architecture (b) AAS based base station architecture

Figure A6-1: Conventional and AAS based base station architectures.

Figure A6-2 presents a typical active antenna architecture extracted from 3GPP TS 38.104 V1.0.0 (2017012). By design, an active antenna consists of a transceiver unit array that is connected to a composite antenna made up of a radio distribution network and an antenna array. The demarcation point between the transceiver unit array and the composite antenna is the transceiver array boundary at which point conducted power can be measured. As noted in Figure A6-2, the large number of connection ports at the transceiver array boundary will require equal number of filters which renders the filtering option prohibitively costly and impractical to implement.

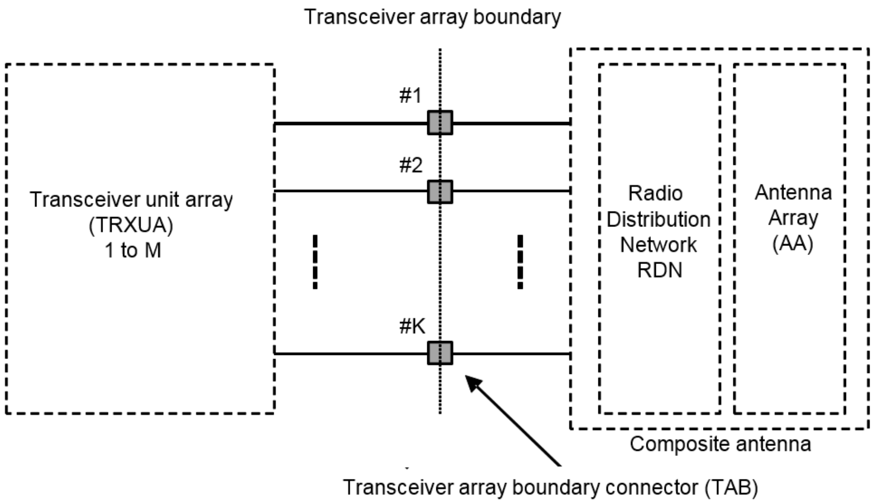


Figure A6-2: Typical active antenna architecture.

Due to the integrated form factor of AAS based 5G base station as well as the engineering and economical challenges to build customized AAS with spurious suppression filters, there is no further need to consider the use of spurious suppression filters in the 5G base station side as an interference mitigating measure.