

**Evaluation Report**

**on**

**Interference Impacts**

**of**

**Ultra Wideband Devices**

**on**

**Satellite Receiving Station**

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# Table of Content

<b>1. Abstract .....</b>	<b>1</b>
<b>2. Introduction.....</b>	<b>1</b>
<b>3. Methodology .....</b>	<b>2</b>
3.1. Equipment Setup.....	2
3.2. Theoretical Model.....	7
3.2.1. Calculation of C/N without Interference.....	7
3.2.2. Calculation of CINR with Interference.....	9
3.2.3. Horizontal Plane Approximation .....	11
3.3. Relationship among BER, C/N and Video Quality.....	12
<b>4. Theoretical and Experimental Results.....</b>	<b>14</b>
4.1. CINR Against Off-Axis Angle.....	14
4.2. CINR Against Distance.....	16
4.3. Aggregate Interference.....	17
<b>5. Conclusion .....</b>	<b>19</b>

References

## **1. Abstract**

The purpose of this report is to assess the interference potential of a commercially available Ultra Wideband (UWB) device being deployed outdoor near a typical C-band satellite receiving antenna. The results of field measurements were compared with those derived by theoretical calculations. It was found that they were in pretty good agreement with each other. When the UWB device was transmitting inside the main lobe of the dish antenna at a distance of less than 5m, the television signal was seriously distorted and the picture and sound qualities were unacceptable. When the UWB device was moved away from the main lobe to side-by-side, the interference became almost negligible and the picture resumed normal. The aggregate interference of using up to three UWB devices operating at the same time and same location was also evaluated by field test and the aggregate effect was noticeable. A “No UWB Device” zone of 10m radius is proposed in this report to protect a C-band satellite television receiver free from interference possibly caused by a UWB device operating in the WiMedia Band Group 1 and with -41.3dBm/MHz output power spectral density. All these results will be useful for spectrum regulatory bodies that are currently responsible for defining UWB emission limits and the corresponding compliance measurement procedures.

## **2. Introduction**

UWB is a fast emerging technology with many unique advantages inviting applications for communications, radar, imaging and positioning systems. Because of its “ultra wideband” and “underlay technology” in nature, a thorough study on its coexistence with other wireless systems is necessary before it is widely deployed.

One of the first commercially available products is the wireless USB hub. It employs Multi-band Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB technology with the standard first proposed by the WiMedia Alliance [1] and subsequently adopted by the ISO/IEC, and more recently the USB Implementers Forum, Bluetooth

Special Interest Group and Wireless USB Promoter Group. The standard defines the specifications for the transceivers disseminating data at up to 480Mbps within the UWB spectrum of 3.1 to 10.6GHz.

However, the 3.4 to 4.2GHz band is mainly used by fixed satellite receiving stations. They are mostly the Satellite Master Antenna Television (SMATV) and Television Receive Only (TVRO) systems which are widely distributed over the Hong Kong territory. The main objective of this project is to investigate the coexistence of the wireless USB hub (as an example of UWB device) and a domestic satellite television system (as an example of fixed satellite receiving station) when they are deployed outdoor, by both theoretical evaluations and field measurements.

The field measurements were performed in December 2008 under the conditions stipulated in the Permit No. T00335 issued by the Office of the Telecommunications Authority (OFTA) of Hong Kong on 11 December 2008.

### **3. Methodology**

#### **3.1. Equipment Setup**

The evaluation of impacts of UWB devices on a satellite receiver is mainly the over-the-air interference when the UWB devices are operating around the dish antenna. A low-cost free-to-air satellite TV receiver was used as an example of the victim being jammed by a number of wireless USB hubs. Interference analysis on its link budgets, carrier-to-interference-plus-noise-ratio (CINR) and bit-error-rate before forward error correction (FEC) and after Viterbi decoding were evaluated. An assessment of the interference model was also evaluated by field measurements.

Table 1 lists the major equipment deployed. Figures 1 and 2 illustrate their interconnections and photo respectively. The dish antenna was setup on the rooftop of a high-rise building near an antenna tower for easy access of its main radiation lobe pointing to the Sinosat 3 [2] which is a satellite TV transponder with good reception in Hong Kong. The down-converted IF signal was splitted into 2 paths. One path was connected to the Sat

Level Meter for measuring its carrier-to-noise ratio (C/N) and bit error rate (BER). The other one was fed to the Satellite Receiver for subjective evaluation of its picture and sound quality, and then it was looped through to the Spectrum Analyzer for visual appreciation of its IF spectrum characteristics and verification of the C/N measured by the Sat Level Meter. The Notebook Computer installed with necessary software was used to capture the measurement results and spectrum displays for further analysis.

Table 1: List of Major Test Equipment

Make and Model	Key Specifications
JONSA P1806 1.8m Solid Dish Antenna	Gain at 4GHz: 35.9dB; Efficiency: 65%; Elevation Angle: 61.2°; Azimuth Angle: 153.2°.
PRO BROADBAND Turbo-1800 Low Noise Block (LNB) Downconverter	Gain: 65dB; Noise Figure: 0.3dB; Skew Angle: -24°.
COSHIP CDVB2000G Digital Satellite Receiver	Full Compliant with DVB-S, ETSI/EN300 421 and MPEG-2.
PROMAX Prolink-4C Premium Digital TV and Sat Level Meter	Measurements: C/N, BER before FEC, BER after Viterbi, MER, CSI, Signal Levels, DVB/MPEG-2 Decoding.
HEWLETT PACKARD 8593E Spectrum Analyzer	Frequency Range: 9kHz-26.5GHz.
Others: Video Monitor, Notebook Computer, Laser Distance Meter, Angle Measure, Compass, Radio Transceivers, Splitter and Cables, etc..	

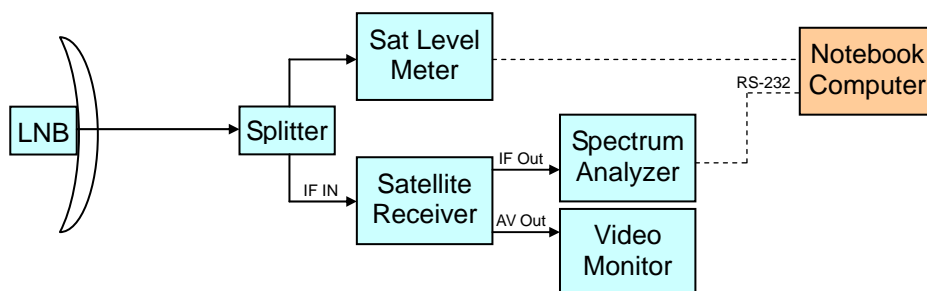


Figure 1: Block Diagram of Test Equipment Setup

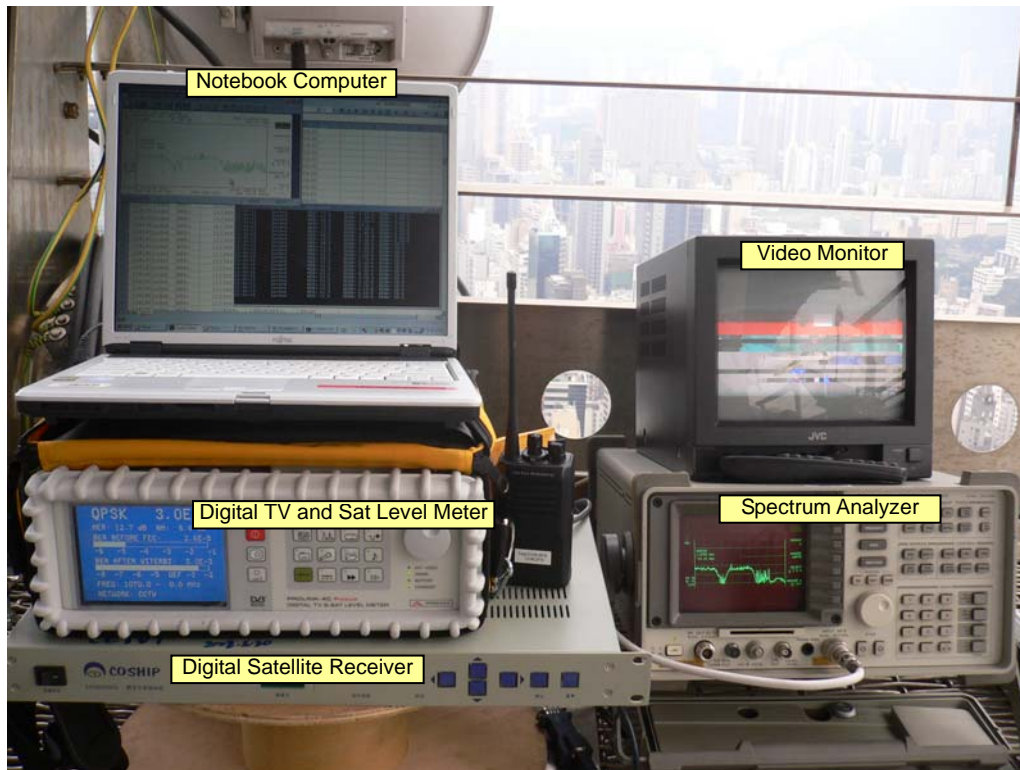


Figure 2: Photo of Some of the Test Equipment

The UWB interference signal source was generated by the setup as shown in Figure 3. It was comprised of a UWB USB host adaptor connected to a notebook computer via a USB extension cable and three UWB USB hubs each connected to a USB flash drive. The interference scenario was emulated by activating an individual disk drive test programme running on the notebook computer for each of the flash drives. When the programme was doing a drive reading test, the USB hub transmitted at its full speed and hence caused most interference radiated from the antenna. The aggregate interference scenario could be emulated by running multiple drive test programmes for the other flash drives. Under the drive reading operation, the interference signal was dominated by that transmitted from the USB hub instead of from the USB adaptor. To measure the output power and spectral characteristics of the signal transmitted from USB hub, the external antenna could be removed from the USB hub and then reconnected it to the input of a spectrum analyzer.

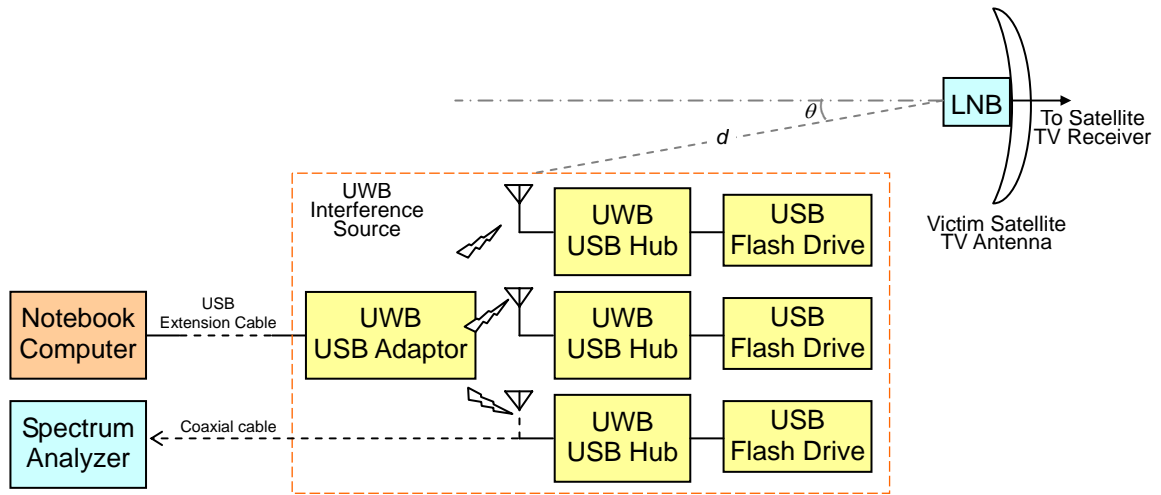


Figure 3: Block Diagram of UWB Interference Signal Generation

Figure 4 and 5 are the photos taken during the field test. As seen in Figure 4, one nylon string was used as a reference line to represent the on-axis beam pointing to the Sinosat 3, whilst another string with some distance markers on it to indicate the distance  $d$  between the UWB devices and the LNB. A laser distance meter was used when taking the measurement if  $d > 6$  m. The three UWB devices were tied together and with their boresight antenna radiation patterns always facing to the satellite dish antenna. Non-conductive materials were used as far as possible for all the mountings and stands put in front of the dish antenna.

Figure 6 shows the spectral display of the peak power output captured at the antenna port of the UWB device for 10s. It can be seen that the output power spectral density of the UWB device is approximately  $-41.3\text{dBm/MHz}$  which is the emission limit in compliance with the regulations of many countries.

Figures 7 and 8 are the spectral displays captured at the IF output from the LNB of the satellite receiving station. Figure 7 is at a state without interference whilst Figure 8 is with the UWB device operating 2m away and at  $90^\circ$  off-axis.

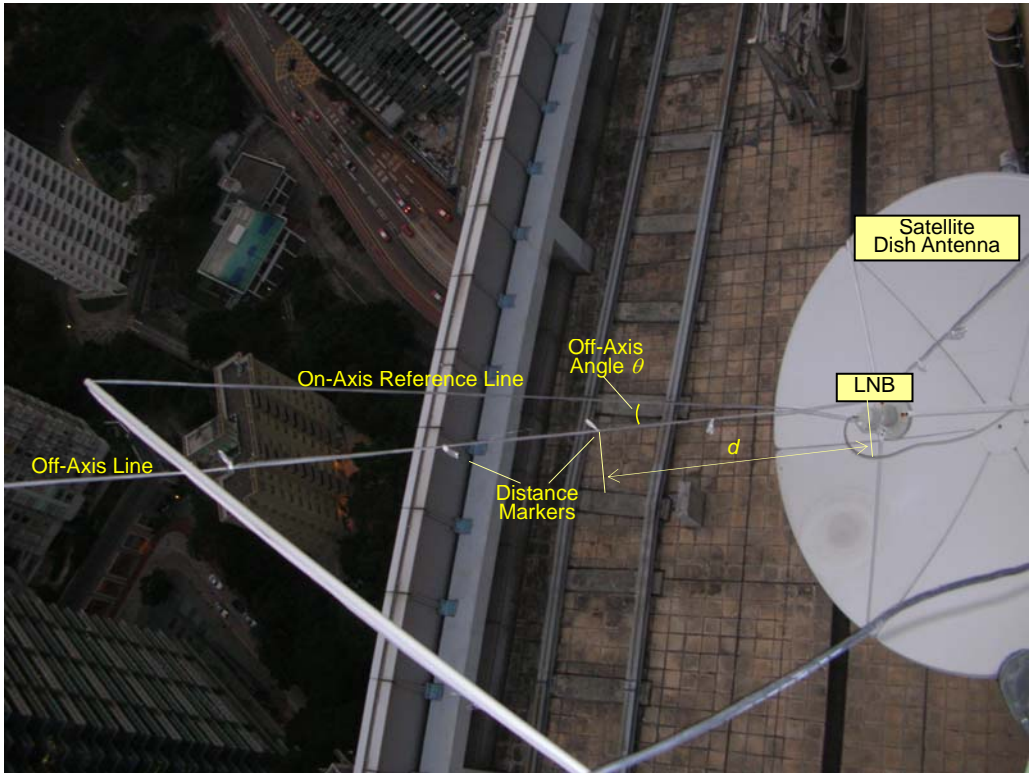


Figure 4: Photo of Satellite Receiving Antenna

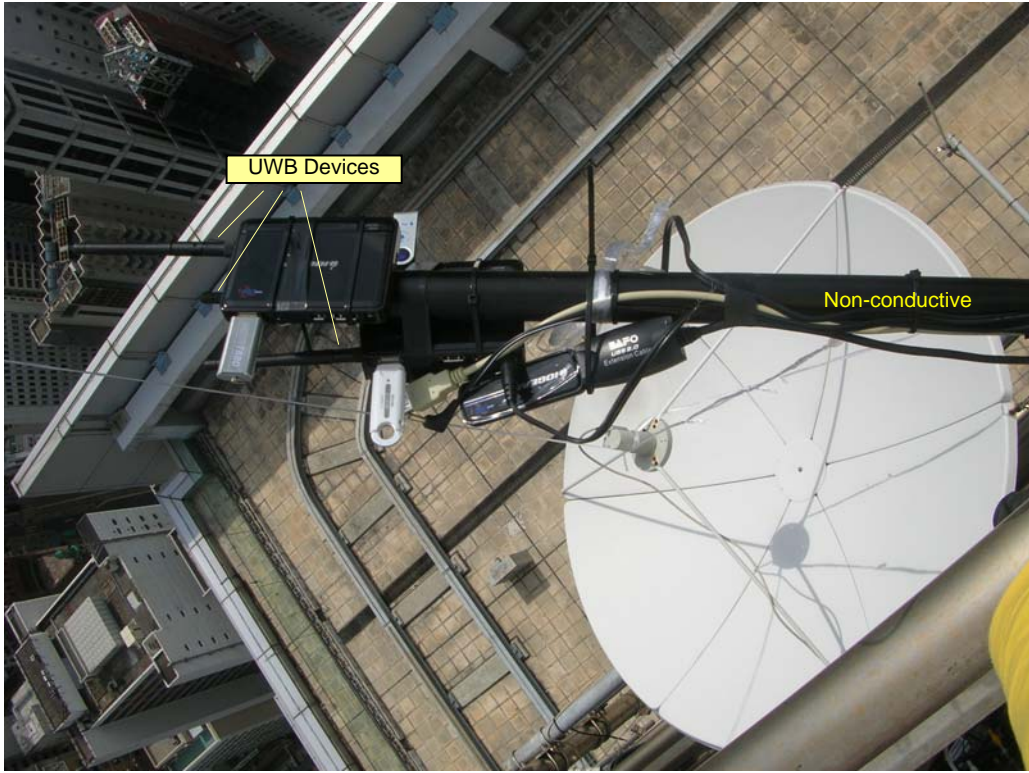


Figure 5: Photo of UWB Devices Mounted on a Non-conductive Pole

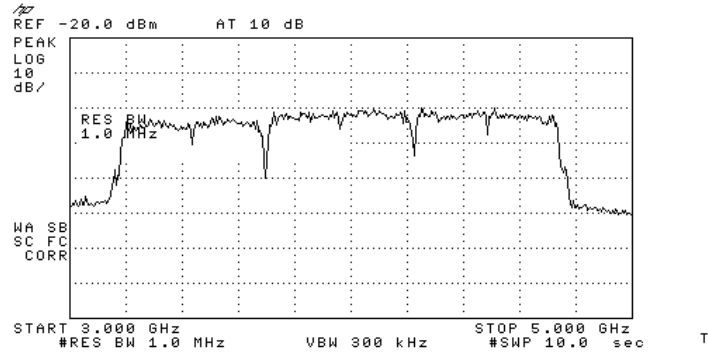


Figure 6: Spectral Capture of Antenna Output Port of UWB Device

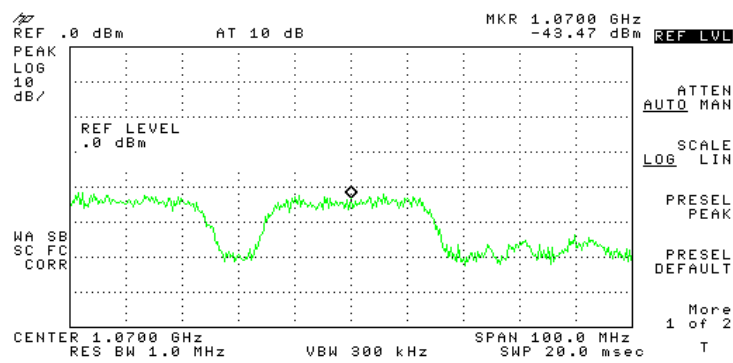


Figure 7: Spectral Capture of IF without Interference

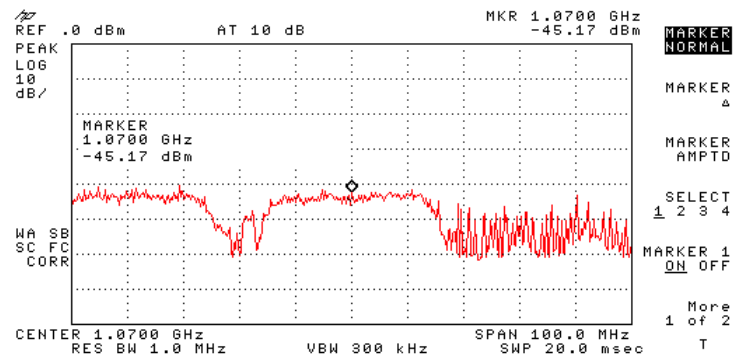


Figure 8: Spectral Capture of IF with UWB Interference at 2m Off-Axis

### 3.2. Theoretical Model

#### 3.2.1. Calculation of C/N without Interference

The interference analysis is started by theoretical modelling of a typical satellite TV receiving system with the presence of a UWB device working in the overlapping

frequency band between 3.4 and 4.2 GHz. Table 2 shows the key parameters of the satellite TV receiving system with parameters being configured to receive the CCTV (中央電視台) Channel 1 transmitted from Sinosat 3.

Table 2: Parameters of Satellite TV Receiving System

Specifications	Data
Satellite	Sinosat 3
<i>EIRP</i> at Hong Kong Region	45dB W [2]
Distance between Sinosat 3 and Hong Kong $d_s$	36,464 km
Transmitting Frequency $f$	4.08 GHz
Channel Bandwidth $B$	36 MHz
Modulation	QPSK
FEC Coding	3/4 RS and Convolutional
Receive Antenna Diameter $D$	1.8 m
Receive Antenna Radiation Pattern	ITU-R BO.1213 [3]
Receive Antenna Efficiency $\eta$	0.65
System Noise Temperature $T_n$	100 K [4]
Noise Figure of LNB $N_f$	0.3 dB
Atmospheric Loss $L_s$	2 dB [5]

The values of C/N are essential to determine the quality of the reception by a satellite TV receiver. Using the free-space loss model [5], the received carrier power  $C$  is calculated by:

$$C = EIRP - L_{fs} - L_a + G_{max} \quad (1)$$

where  $EIRP$  is the effective isotropic radiated power of the satellite,  $L_{fs}$  and  $L_a$  are the free space loss and atmospheric loss respectively, and  $G_{max}$  is the maximum receive antenna gain. Free space loss is given by:

$$\begin{aligned} L_{fs} &= 10 \log \left( \frac{4\pi d_s f}{c} \right)^2 \\ &= 195.89 \text{ dB} \end{aligned} \quad (2)$$

where  $d_s$  is the distance between Sinosat 3 and Hong Kong, and  $f$  is the downlink frequency of CCTV Channel 1.  $G_{max}$  is given by [3]:

$$G_{max} = 10 \log \left( \eta \left( \frac{\pi D f}{c} \right)^2 \right) \quad (3)$$

$$= 35.85 \text{ dBi}$$

where  $\eta$  is the antenna efficiency, and  $D$  is the antenna diameter. Hence,

$$C = 45 - 195.89 - 2 + 35.85$$

$$= -117.04 \text{ dBW}$$

The noise generated in the receiver system is given by [5]:

$$N = 10 \log(kTB) + N_f \quad (4)$$

$$= -132.74 \text{ dBW}$$

where  $k$  is the Boltzmann's constant ( $1.38 \times 10^{-23}$  W/K-Hz),  $T$  is the receive antenna temperature,  $B$  is the bandwidth of the satellite channel, and  $N_f$  is the noise figure of the LNB. Then the nominal C/N without interference is:

$$C/N = C - N \text{ (in dB)} \quad (5)$$

$$= 15.7 \text{ dB}$$

### 3.2.2. Calculation of CINR with Interference

Interference imposed on the satellite receiving system is caused by the UWB signal emitted from the UWB device comprising a wireless USB hub and a USB adaptor. This product has been launched recently in the commercial market. It allows computer to wirelessly communicate at high speed with USB thumb drives, printers, scanners, etc. Table 3 shows the key parameters of this UWB device:

Table 3: Parameters of UWB Device

Specifications	Data
Made and Model	IOGEAR GUWH104KIT
Frequency Band, WiMedia Band Group 1	3.168 – 4.752 GHz
Output Power Spectral Density $D_{uwb}$	-41.3 dBm/MHz
Antenna Gain $G_T$	0 dBi
Duty-Cycle	0.05 at full transfer rate

With the presence of UWB device, the interference signal is now added to the thermal noise and the C/N is modified to form the CINR. In this experiment, interference was mainly caused by the transmission from the USB hub. Due to the nearly flat spectral characteristics of UWB signals as seen from a narrowband satellite system, UWB

interference can be approximated by additive white Gaussian noise (AWGN) [6]. So, both  $I$  and  $N$  are additive and the CINR can be expressed as follows:

$$\text{CINR} = \frac{C}{I + N} \quad (6)$$

The path-loss model of a UWB signal is represented by [7]:

$$R_{uwb} = P_{uwb} - L_o - 10n \log\left(\frac{d}{d_o}\right) \quad (7)$$

where  $R_{uwb}$  is the received power of the UWB signal at a distance  $d$  with effective output power  $P_{uwb}$  of the UWB signal source, and  $L_o$  is path-loss at reference distance  $d_o = 1\text{m}$ . As recommended by IEEE 802.15.4a UWB channel modelling subgroup,  $n = 1.58$  and  $L_o = 49\text{dB}$  for an outdoor open environment with line-of-sight. In the special case of the UWB signal as seen by the satellite TV receiver, the effective output power  $P_{uwb}$  is given by:

$$P_{uwb} = D_{uwb} + 10\log(C_d) + 10\log(B) + G_T \quad (8)$$

where  $D_{uwb}$  is the power spectral density of the UWB signal source,  $C_d$  is its duty cycle,  $B$  is the channel bandwidth of the satellite receiver, and  $G_T$  is the antenna gain.

The satellite dish antenna exhibits different amplifications or attenuations when the UWB device is placed with different off-axis angle  $\theta$ . The antenna radiation pattern as recommended by ITU-R BO.1213 [3] is adopted here. Although the model was originally developed for Ku-band broadcasting-satellite service antenna, practical experience and measurements have shown that it is equally applicable for C-band antenna. Figure 9 plots the antenna gain  $G_R$  for the 1.8m dish antenna against the off-axis angle based on the ITU-R BO.1213 recommendation.

The effective power of UWB signal as received by the satellite TV receiver depends on the location of the UWB device and as a factor of its distance  $d$  away from the LNB and the off-axis angle  $\theta$ . The power of the interference  $I$  can be represented mathematically as:

$$I = R_{uwb} + G_R(\theta) \quad (9)$$

or

$$I = P_{uwb} - L_o - 10n \log\left(\frac{d}{d_o}\right) + G_R(\theta) \quad (10)$$

where  $G_R(\theta) = G_{max} - 2.5 \times 10^{-3} \left( \frac{D}{\lambda} \theta \right)^2$  for  $0 \leq \theta < \theta_m$  (11)

$$\theta_m = \frac{\lambda}{D} \sqrt{\frac{G_{max} - G_1}{0.0025}} \quad (12)$$

$$G_1 = 29 - 25 \log \theta_r, \text{ and } \theta_r = 95 \frac{\lambda}{D} \quad (13)$$

$$\begin{aligned} G_R(\theta) &= G_1 && \text{for } \theta_m \leq \theta < \theta_r \\ G_R(\theta) &= 29 - 25 \log \theta && \text{for } \theta_r \leq \theta < \theta_b \text{ where } \theta_b = 10^{(34/25)} \\ G_R(\theta) &= -5 && \text{for } \theta_b \leq \theta < 70^\circ \\ G_R(\theta) &= 0 && \text{for } 70^\circ \leq \theta < 180^\circ \end{aligned}$$

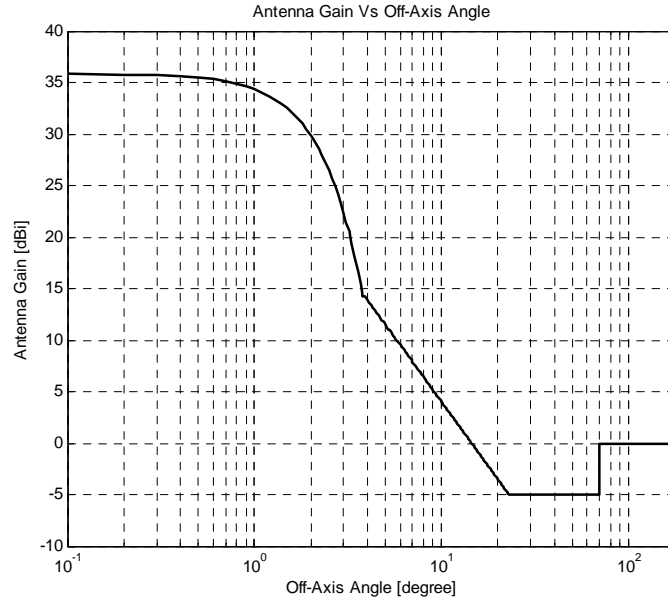


Figure 9: 1.8m Dish Antenna Radiation Pattern at 4.08 GHz

### 3.2.3. Horizontal Plane Approximation

As shown in Table 1, the elevation and azimuth angles of the dish antenna were set to  $61.2^\circ$  and  $153.2^\circ$  respectively to receive the satellite signal. When making measurements with  $d < 5\text{m}$ , the antenna radiation plane was used. Figure 10 illustrates 1) the on-axis line along which the maximum antenna gain  $G_{max}=35.85\text{dBi}$  was achieved, and 2)  $90^\circ$  off-axis with respect to the antenna plane giving the antenna gain  $G_R=0\text{dBi}$ . However, it became very difficult to access to the locations when  $d > 5\text{m}$ . In the following Section 4.2 when making off-axis measurements with  $d$  varying from 1m to 19m, the UWB devices

moved along the horizontal plane and in effect the antenna gain was approximated by the 90° off-axis antenna gain. The antenna plane was used throughout this report unless otherwise specified.

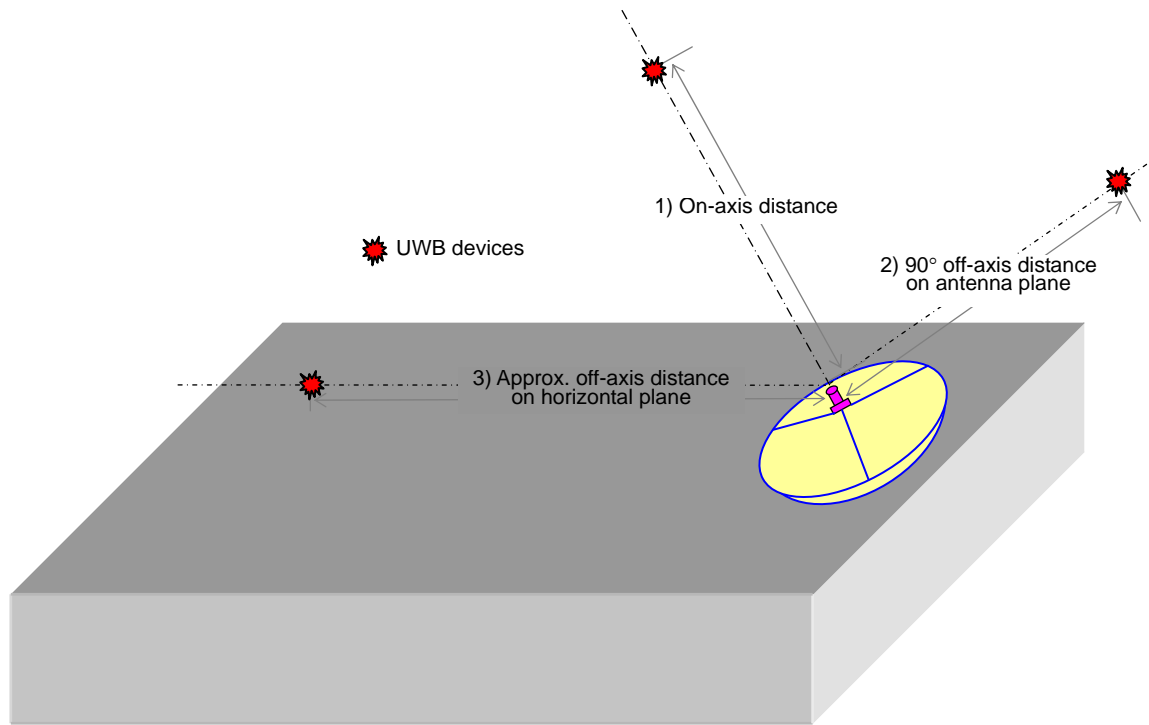


Figure 10: Three-dimensional View of Dish Antenna

### 3.3. Relationship among BER, C/N and Video Quality

The satellite receiving station under study adopts the DVB-S standard tuned to CCTV Channel 1 with QPSK modulation, Reed-Solomon (RS) 3/4 code rate and Viterbi decoder for forward error correction (FEC), and MPEG-2 transport stream decoder for video decompression. The BER performance before FEC exhibits close relationship with C/N as shown in Figure 11 [8]. The figure also shows the values of both calculated and measured C/N under interference-free environment. The theoretical C/N is 15.7dB as calculated in Section 3.2.1 which gives a theoretical BER of  $3 \times 10^{-8}$  before FEC, whilst the average measured values of C/N and BER are 14.5dB and  $1.8 \times 10^{-6}$  respectively as shown in Figure 11.

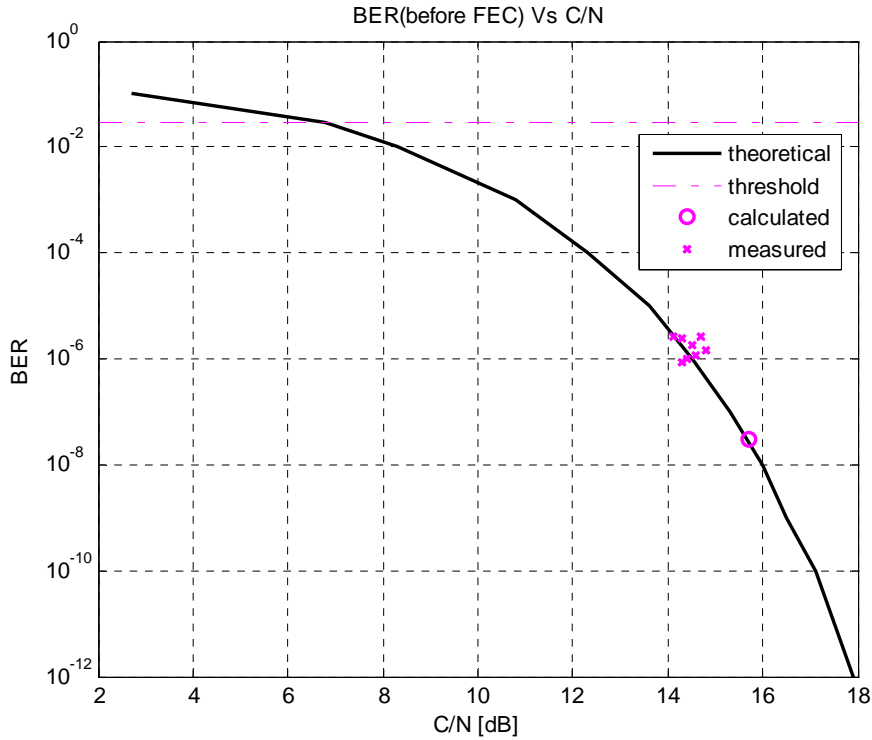


Figure 11: Plot of BER Before FEC Against C/N for DVB-S Receiver [8]

The received picture quality of the system depends very much on the BER after FEC, i.e. a combination of Viterbi and RS decoders. A threshold value of  $1 \times 10^{-11}$  for the BER after FEC is commonly adopted by the digital video broadcasting industry [9]. This approximately corresponds to one error per hour and is defined as quasi error free (QEF) value. This threshold also corresponds to the “fall off the cliff” or “brickwall” effect, beyond which slightly more noise will break down the transmission abruptly.

However, in real-life measurements, recording the BER after FEC at around QEF value is very time consuming. So, the measurement of BER before FEC is commonly adopted by the industry and Figure 11 shows its values against C/N by theoretical calculations. Figure 12 further illustrates the relationship of the threshold BER values when taking measurements in different stages of a DVB-S receiver with specific QPSK modulation and 3/4 code rate in this case [8].

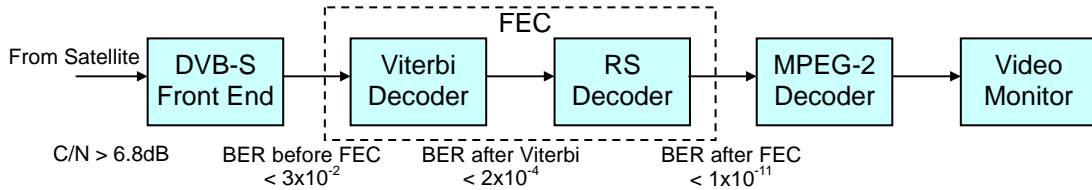


Figure 12: Required BER at Different stages for QEF Reception

For a better appreciation of the impact of the UWB interference on the TV reception, Table 4 shows our subjective assessment of the video and audio quality against different C/N values. The varying C/N was done by off-tuning the dish antenna under interference free environment.

Table 4: Subjective Assessment of Video and Audio Qualities with Varying C/N

C/N [dB]	Video Quality	Audio Quality
< 2	No picture	No sound
3	Only some colour strips	Totally unreadable
4	Constant interruptions	Occasional interruptions
5	Occasional interruptions	Sometimes distorted
6	Very occasional artefact	Almost perfect
> 7	Perfect	Perfect

## 4. Theoretical and Experimental Results

### 4.1. CINR Against Off-Axis Angle

As seen in Section 3.2.2 above, the dish antenna exhibits a highly directional characteristic with approximately 3° beamwidth. In other words, the location of the interference source with respect to the on-axis beam of the dish antenna is also very critical to the CINR performance and hence the BER and picture quality. This section investigates the interference impacts in terms of CINR when the UWB device was placed at a fixed distance 5m away from the LNB and with a variable off-axis angles  $\theta$  deviated from 0 degree (i.e. exactly in front of the dish antenna) to 180 degree (exactly behind the dish antenna). Using the methodology as described in Section 3, the results could be obtained by both theoretical models and field measurements, and they are plotted on the same Figure 13

for the ease of comparison.

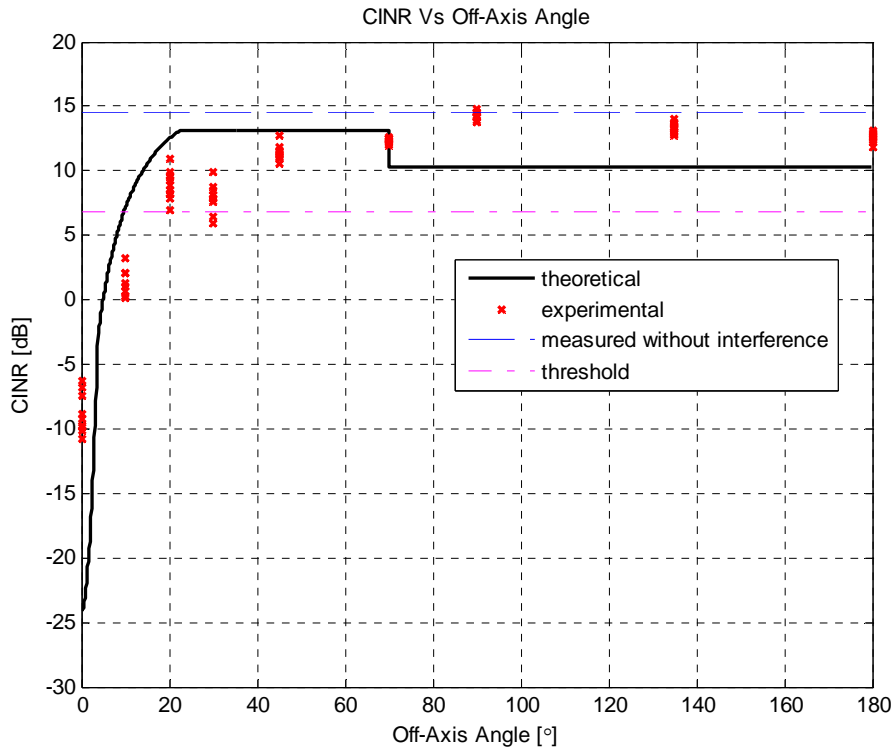


Figure 13: Plot of CINR Against Off-Axis Angle with UWB Device 5m Away

As shown in Figure 13, despite there a bit frustrated values of the field measurements, the tendency of the results by both theoretical and experimental methods pretty much agreed each other. The frustrations, particularly in the on-axis case, were mainly due to the burst mode operation of the UWB device when transmitted symbols represented by OFDM sub-carriers hop across the sub-bands. If the UWB device was placed exactly on-axis, i.e.  $\theta = 0^\circ$ , both the theoretical and experimental CINR gave negative values and the reception was totally lost. The 15dB difference between these two values was due to the saturation in the front end of the Sat Level Meter. When the off-axis angle  $\theta$  was about  $10^\circ$ , both the calculated and measured CINR values were below the threshold and the picture quality was still unacceptable. When the UWB device was placed further away from the antenna main lobe, say from  $90^\circ$  to  $180^\circ$  off-axis, there exhibited approximately 2dB degradation in CINR compared with the “no-interference” scenario, but with no bad effect on both the audio and video quality.

In real-life deployments, a UWB device is very unlikely operated on axis with a few meters away from the dish antenna of a satellite receiving system, even when it is

operated in such a congested urban area in Hong Kong. So, the on-axis interference scenario is extremely rare to happen.

#### 4.2. CINR Against Distance

This section studies the interference impacts when the UWB device was placed exactly on-axis and approximately  $90^\circ$  off-axis at variable distance  $d$  away from the LNB. In view of the physical constraints and as described in Section 3.2.3, it was not possible to keep exactly  $90^\circ$  off-axis when the UWB device was placed more than 5m away from the LNB. Having considered the antenna gain outside the main lobe (i.e. more than  $10^\circ$  off-axis) that maintained relatively a uniform value, the horizontal plane was therefore used instead of the antenna radiation plane. Both the theoretical and experimental results are plotted on the same Figure 14 for comparison.

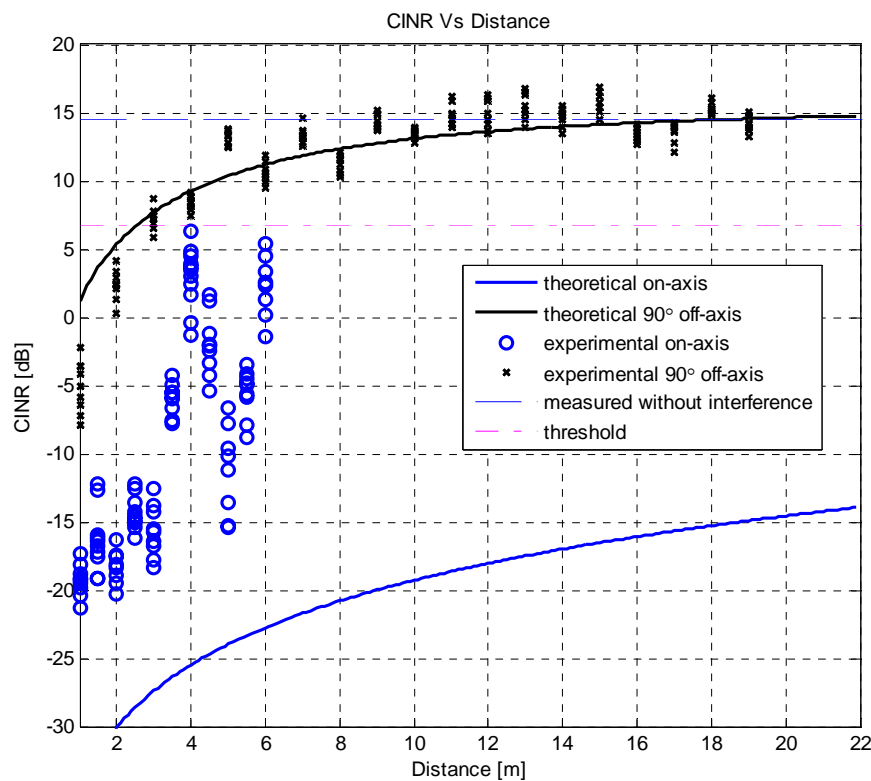


Figure 14: Plot of CINR Against Distance with UWB Device at On- and Off-Axis

As shown in Figure 14 for the off-axis scenario, the theoretical and experimental evaluations agreed each other quite well. When the UWB device was placed more than 3m

away from the LNB, the CINR increased beyond the threshold level. In this case, the interference was not quite noticeable when we viewed on the video monitor. When the UWB device was moved to 10m away, both the picture and sound quality was perfect but with a 2dB degradation in C/N compared with the “no-interference” scenario.

However, for the on-axis scenario, both the theoretical and experimental evaluations exhibited unacceptable results even when the UWB device was placed 6m away, and even as far as 22m away theoretically. Again in real-life deployments, on-axis interference is not common. It is worth to mention that there was a great discrepancy between the theoretical and experimental results for the on-axis case. It was due to the lower dynamic range of the Sat Level Meter or the LNB being saturated by the higher UWB signal when the UWB device was placed unreasonably close to the front of the dish antenna.

### **4.3. Aggregate Interference**

In view of the increasing popularity of numerous UWB devices to be mass deployed for domestic and commercial uses, this section attempts to investigate the aggregate interference by experiment for the specific scenario that all the three UWB devices were tied and working together simultaneously at off-axis locations. The measured results in terms of CINR at three different locations are shown in Figure 15.

It can be seen that there was approximately 1dB degradation in CINR when the number of UWB device was increased from one to two, and further 0.5dB degradation when increased to three. It was because the UWB devices under test were able to coordinate among one another to utilize the frequency spectrum without collision. In other words, the C-band spectrum was jammed by more frequent transmissions and hence causing lower CINR. The aggregate interference was also noticeable in the IF spectrum. Figures 16(a) and (b) show the capture of the IF spectrum when one and two UWB devices respectively placed 2m away and 90° off-axis were active in full speed file transfer.

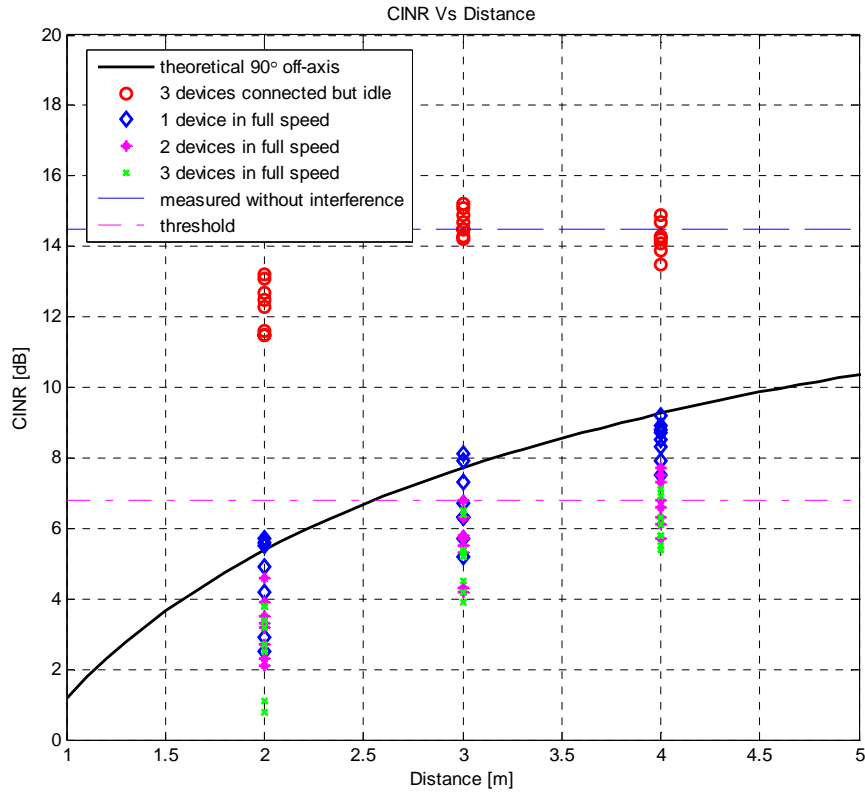


Figure 15: Plot of CINR Against Distance with Multiple UWB Devices

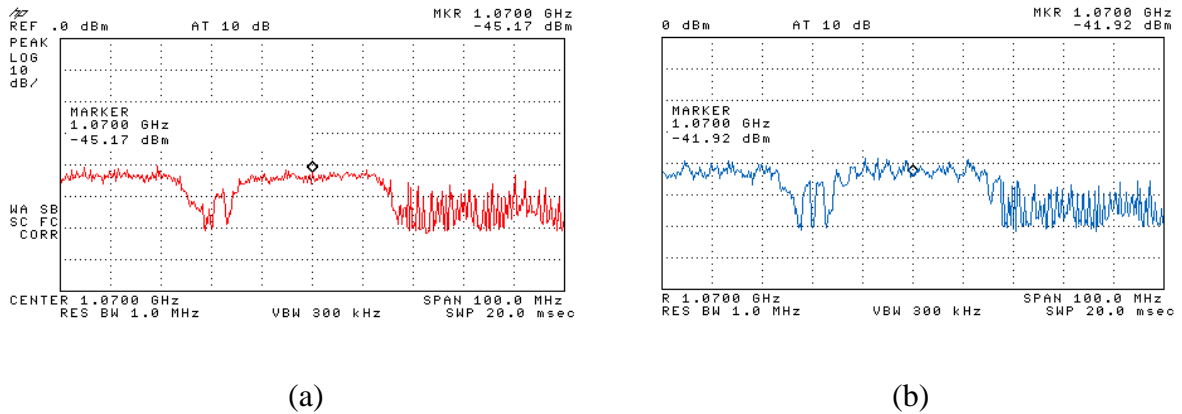


Figure 16: Spectral Capture with UWB devices when (a) one active, and (b) two active

The burst mode operation of the UWB devices depended on the traffic flow of the USB port. They caused much lesser interference when there was no traffic and only minimum transmission was present to maintain the connections between the wireless hubs and USB adaptor. As seen in Figure 15, the interference was almost negligible when the UWB devices were idle and at an off-axis location of more than 3m away from the LNB.

## 5. Conclusion

This report has presented the theoretical and experimental analysis of interference impacts on the C-band fixed satellite receiving station caused by the commercially available UWB devices. It was found that UWB devices did cause interference to the station when they were operated in close proximity and particularly within the main lobe of the antenna of the satellite receiving station. More UWB devices also caused more interference because of their aggregated effect. If UWB devices with output power spectral density of  $-41.3$  dBm/MHz are to operate at the C-band, we should not allow such devices to go near to the C-band TV satellite receiver. If they are as close as 2m side-by-side away from the dish antenna, the TV picture may be frozen. If they are placed 5m away, interference may not be noticeable but the fade margin will be degraded by approximately 2~4 dB. If they are moved to 10m away, the interference effect can be negligible. So, preferable a “No UWB Device” zone with radius at least 10m should be declared surrounding the dish antenna of satellite receiver.

However, in real world deployments, such UWB devices are usually used indoor and are very unlikely operated in front of and closed to the antenna of a satellite receiving station. Also, if appropriate interference mitigation techniques are employed and operated outside a pre-defined “No UWB Device” zone or limiting the spectral density of the emissions in the C-band down to  $-70$  dBm/MHz as suggested by the spectrum regulators of Hong Kong [10] and many other countries, the interference impacts caused by the UWB device on the C-band satellite receiving stations should not be noticeable in normal circumstances.

# References

1. WiMedia Alliance Web Site, <http://www.wimedia.org>.
2. Sinosat Web Site, <http://www.sinosatcom.com>.
3. ITU-R, "Reference Receiving Earth Station Antenna Pattern for the Broadcasting-Satellite Service in the 11.7-12.75 GHz Band", *Recommendation ITU-R BO.1213-1*, 2005.
4. ITU-R, "Apportionment of the Allowable Error Performance Degradation to Fixed Satellite Service (FSS) Hypothetical Reference Digital Paths Arising from Time Invariant Interference for Systems Operating Below 30 GHz", *Recommendation ITU-R S.1432-1*, 2006.
5. Bernard Sklar, "Digital Communications: Fundamentals and Applications", Prentice Hall, 2<sup>nd</sup> Edition, Prentice Hall, 2001.
6. S.M. Wong, F.C.M. Lau, "Passband Simulation of Interference Impacts in the Presence of Ultra Wideband and Narrowband Systems", *Proceedings, The 10<sup>th</sup> International Conference on Advanced Communication Technology (ICACT 2008)*, Phoenix Park, Korea, Feb 2008, pp. 569-574.
7. T.S. Rappaport, "Wireless Communications: Principles and Practice", 1<sup>st</sup> Edition, Prentice Hall, 1996.
8. W. Fischer, "Transmitting Digital Television Signals by Satellite – DVB-S/S2", Book Chapter of *Digital Video and Audio Broadcasting Technology A Practical Engineering Guide*, 2<sup>nd</sup> Edition, Springer Berlin Heidelberg, 2008.
9. ETSI, "Digital Video Broadcasting (DVB) Measurement Guidelines for DVB Systems" *ETSI Technical Report ETSI TR 101 290 V.1.2.1*, European Telecommunications Standards Institute, 2001-2005.
10. OFTA, "Consultation Paper Creation of a Class License for Ultra-Wideband Radiocommunications Devices Under Section 7B(2) of the Telecommunications Ordinance (Cap. 106)", *Office of the Telecommunications Authority*, 20 March 2009.