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Further Assessment of DVB-T Interference into WiMAX

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Summary

In 2007, ERA undertook a measurement programme on behalf of Ofcom to assess the potential for interference into a range of technologies including Universal Mobile Telecommunication System (UMTS), Worldwide Interoperability for Microwave Access (WiMAX), Digital Video Broadcast – Terrestrial (DVB-T) and Digital Video Broadcast - Handheld (DVB-H). The work was undertaken as part of the Digital Dividend Review (DDR) – the project examining the options arising from the release of spectrum post digital switchover.

At the time of testing, mobile WiMAX equipment was not readily available and so measurements were performed to assess DVB-T interference into a fixed WiMAX terminal conforming to IEEE standard 802.16-2004. The equipment was configured to use parameters that could be considered representative of mobile WiMAX, for example by limiting the modulation scheme to QPSK ½. However, there were a number of limitations to the testing including:

- The channel bandwidth of the system was fixed at 20 MHz. The results therefore had to be scaled for mobile WiMAX as $10\log_{10}$(bandwidth ratio), assuming that an Orthogonal Frequency Division Multiplex (OFDM) signal scales by the same proportion as Additive White Gaussian Noise (AWGN).
- It was not possible to undertake separate measurements on the uplink and downlink, since there was limited control over the settings for the Base Station (BS) and Subscriber Station (SS) transmit powers.
- The available bit rate and bandwidth combination was not considered representative of a mobile WiMAX system.

Since the testing, ERA has obtained new WiMAX equipment which, although still not fully conforming to the mobile WiMAX standard (IEEE 802.16e), allows much greater control and configuration of operating parameters.

<u>Measurement Results</u>

Conducted measurements were undertaken to assess the Carrier to Interference (C/I) protection ratios for an interfering DVB-T signal at varying frequency offsets. The effect of interference into both BS and SS devices was measured.

Operation of the WiMAX BS and SS in the presence of DVB-T interference for a fixed path loss was measured for four scenarios.

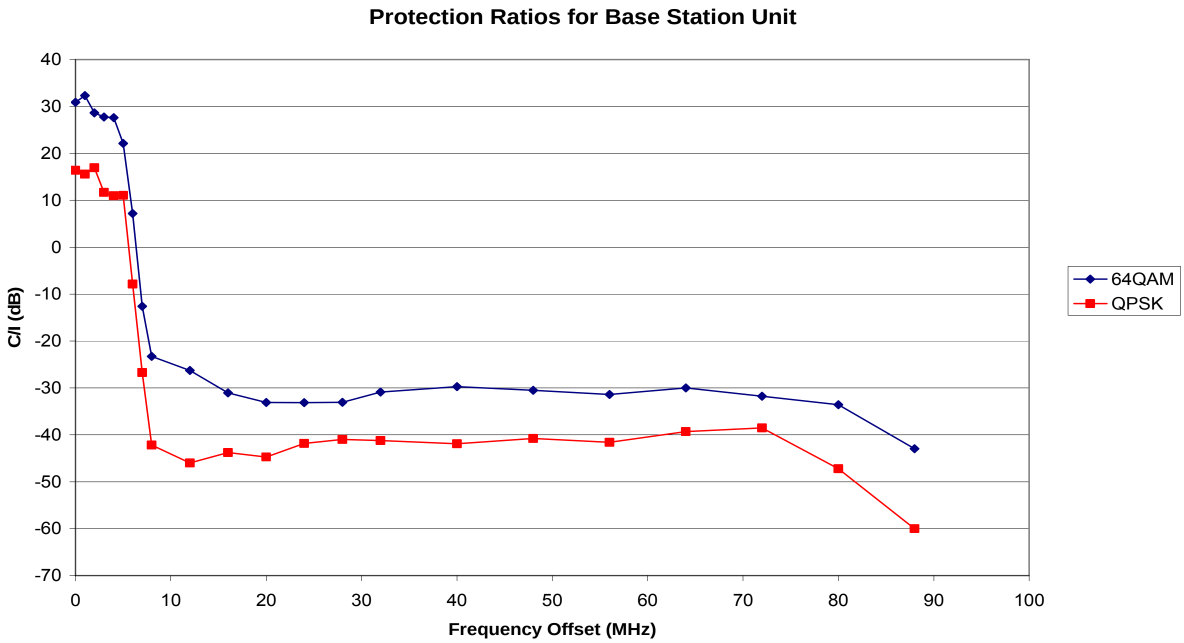
- Edge of coverage operation using a 64-QAM ¾ downlink MCS.
- Edge of coverage operation using a QPSK ¾ downlink MCS.

- Edge of coverage operation using a 64-QAM ¾ uplink MCS.
- Edge of coverage operation using a QPSK ¾ uplink MCS.

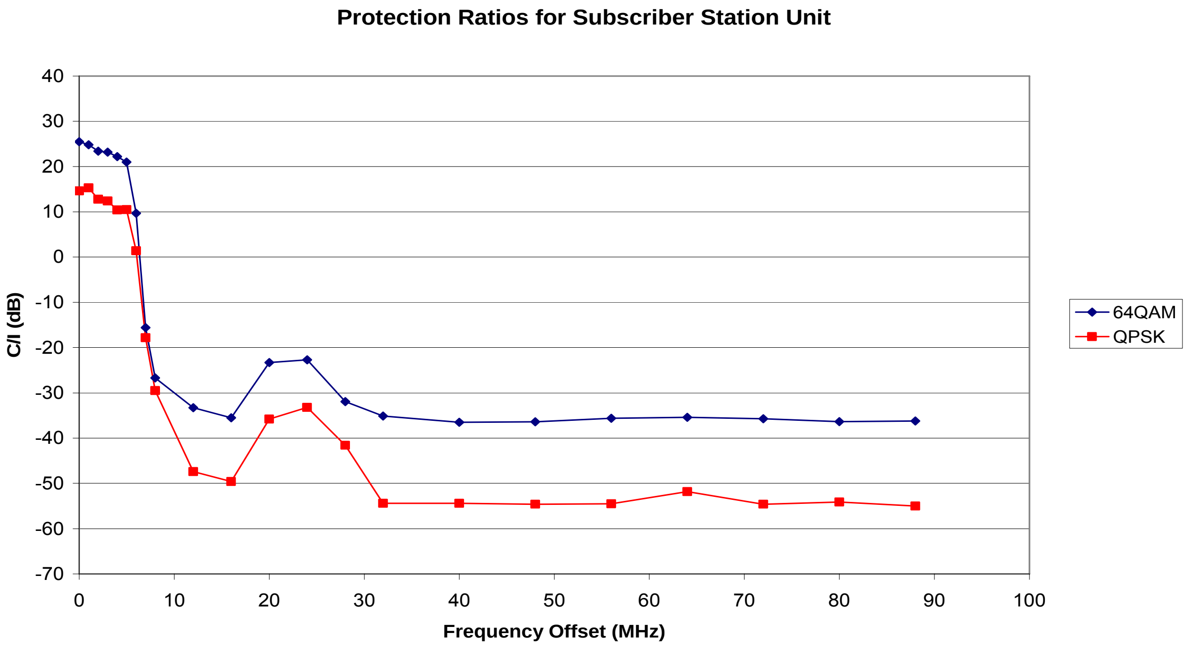
The failure criteria used to judge the performance of the BS and SS was based on a drop in the selected Modulation Coding Scheme (MCS) used by the WiMAX equipment. This drop in MCS was reflected in a drop in the data throughput on the communications link. The failure criteria for the BS and SS for both the 64-QAM ¾ downlink MCS and the QPSK ½ downlink MCS scenarios are summarised in the table below:

	Desired Operating State		Failure Criteria	
	Modulation Scheme	**Throughput (Mbps)**	**Modulation Scheme**	**Throughput (Mbps)**
BS	64 QAM ¾	6.37	64 QAM ⅔	5.66
	QPSK ¾	2.12	QPSK ½	1.4
SS	64 QAM ¾	8.07	64 QAM ⅔	7.16
	QPSK ¾	2.68	QPSK ½	1.78

Measurements were performed to characterise the interference, in terms of C/I protection ratio, for both the BS and SS. These measurements were performed in 1 MHz steps from 0 to 16 MHz, and then in 8 MHz steps out to an 88 MHz offset from the centre frequency of the wanted carrier.



For the BS measurements the co-channel protection ratios for QPSK ¾ and 64 QAM ¾ modulation schemes were seen to be 16 dB and 30 dB respectively. For the adjacent N+1 channel separation of 8 MHz, the protection ratio dropped to -42 dB for QPSK ¾. The protection ratio at N+10, at a channel separation of 80 MHz, fell by a further 5 dB down to -47 dB. The trend was for 64 QAM ¾ modulation scheme was similar to that of QPSK ¾. At the adjacent N+1 channel a protection ratio of -23 dB was required and at channel N+10 this dropped to -33 dB. Overall, it can be concluded that a WiMAX BS operating under a 64-QAM modulation requires 10 to 12 dB more protection compared with a WiMAX BS using QPSK.



For the SS measurements the co-channel protection ratios for the QPSK ¾ and 64 QAM ¾ measurements were 15 dB and 25 dB respectively. For an adjacent N+1 frequency channel separation of 8 MHz, the QPSK ¾ protection ratio dropped to -30 dB and fell by a further 24 dB to -54 dB at channel N+10 (80 MHz). In a similar fashion the 64 QAM ¾ at N+1 dropped to -27 dB and at channel N+10 had dropped to -36 dB. Overall, it can be concluded that a WiMAX SS operating under a 64-QAM modulation requires 10 to 15 dB more protection compared with a WiMAX SS using QPSK.

For either a WiMAX base station or a subscriber station, for a given modulation type and error protection coding rate, the results indicate that the C/I protection ratio remains reasonably constant at frequency offsets between approximately 10 and 80 MHz. The only exception to this was the WiMAX SS, which was more susceptible to DVB-T interference 3 DTT channels away (24 MHz). This may be due to the architecture of the SS being of a super-heterodyne nature, which can result in an image problem if the bandwidth of the Intermediate Frequency (IF) is 12 MHz.

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Abbreviations List

BS	Base Station
C	Carrier
DDR	Digital Dividend Review
DVB-H	Digital Video Broadcast - Handheld (DVB-H)
DVB-T	Digital Video Broadcast – Terrestrial
ETSI	European Telecommunications Standards Institute
I	Interference
MCS	Modulation Coding Scheme
N	Noise
OFDM	Orthogonal Frequency Division Multiplex
SNR	Signal to Noise Ratio
SS	Subscriber Station
TDD	Time Division-Duplex
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
UMTS	Universal Mobile Telecommunication System
WiMAX	Worldwide Interoperability for Microwave Access

1. Introduction

In 2007 ERA undertook a measurement programme on behalf of Ofcom to assess the potential for interference into a range of technologies including UMTS, WiMAX, DTT and DVB-H [1] [2] [3]. The work was undertaken as part of the Digital Dividend Review (DDR) – the project examining the options arising from the release of spectrum post digital switchover.

At the time of testing, mobile WiMAX equipment was not readily available and so measurements were performed to assess Digital Video Broadcasting – Terrestrial (DVB-T) interference into a fixed WiMAX terminal conforming to IEEE standard 802.16-2004. The equipment was configured to use parameters that could be considered representative of mobile WiMAX, for example by limiting the modulation scheme to QPSK ½. However, there were a number of limitations to the testing including:

- The channel raster of the system was fixed at 20 MHz. The results therefore had to be scaled for mobile WiMAX as $10\log_{10}$(bandwidth ratio), assuming that the Orthogonal Frequency Division Multiplex (OFDM) signal scales by the same proportion as Additive White Gaussian Noise (AWGN).
- It was not possible to undertake separate measurements on the uplink and downlink, since there was only limited control over setting the Base Station (BS) and Subscriber Station (SS) transmit powers.
- The available bit rate and bandwidth combination was not considered representative of a mobile WiMAX system.

Since the testing, ERA has obtained new WiMAX equipment which, although still not fully conforming to the mobile WiMAX IEEE 802.16e standard, allows much greater control and configuration of operating parameters.

2. Objectives

The objective of this study was to undertake conducted measurements of DVB-T interference into WiMAX equipment.

The equipment was configured, as far as possible, to perform like a mobile WiMAX system with appropriate channel bandwidth and data rates.

Measurements were performed to characterise the interference, in terms of Carrier-to-Interference (C/I) protection ratio, for both the BS and SS. Measurements were performed in 1 MHz steps from 0 to 16 MHz, and then in 8 MHz steps out to 88 MHz offset from the centre frequency of the wanted carrier.

The results are presented as curves of C/I protection ratio against relative carrier offset.

3. Conducted Measurement Test Set-Up

3.1 Wanted WiMAX Signal

ERA has an almost fully operational WiMAX IEEE 802.16e system [4], which was used for conducted interference measurements. This WiMAX system is manufactured by AirSpan. The AirSpan system comprises of a base station designed to meet the IEEE 802.16-2005 MAC and physical layer (PHY) specifications. However, the firmware controlling the system is fully compliant for IEEE 802.16d [5], but not completely for IEEE 802.16e.

The base station contains a baseband processor on a single card which is directly connected to the RF stage via a low noise amplifier (LNA), which in turn would be connected to an appropriately installed mast antenna. The AirSpan subscriber station is designed as a "Plug and Play" device for connection to a PC. The modulation schemes and transmit power levels can be controlled through a software interface.

It should be noted that the AirSpan system is designed to work at 3.6 GHz and the spectrum of the WiMAX subscriber uplink signal is shown in Figure 1.

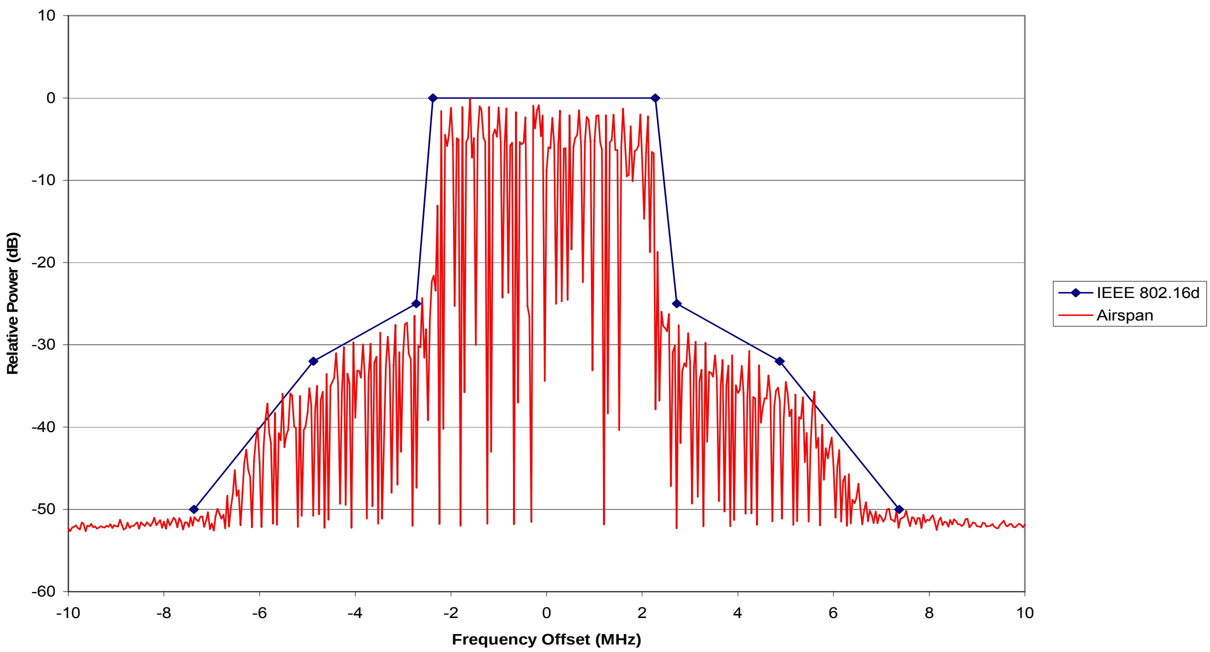

Figure 1: Measured Air Span spectrum emission mask compared with the IEEE 802.16d WiMAX standard

This equipment was set-up using the internet browser interface to the WiMAX kit through a connected laptop computer. The WiMAX equipment was set-up with the following signal parameters.

Table 1:
WiMAX signal parameters

Parameter	Value
Channel bandwidth	5 MHz
TDD frame length	10 ms
BS transmit power	32 dBm
BSS receiver threshold	- 70 dBm
Frequency	3.6125 GHz
Sub-channelization	active

3.2 Interfering DVB-T Signal

The interfering signal was generated by an Agilent E4438C Vector Signal Generator controlled by the Agilent Signal Studios software. The software was set to produce a DVB-T signal with the following parameters based on ETSI EN 300 744 [6], shown in the table below:

Table 2:
DVB-T signal parameters

Parameter	Value
Modulation	64 QAM
Error coding	2/3
Guard interval	7 (1/32)
Data rate	24.1 Mbps
Channel bandwidth	8 MHz
System C/N	17.1 dB
Receiver Margin	2.7
C/N	22.8 dB

The DVB-T signal used in the measurements was based on the non-critical DVB-T mask described in ETSI EN 302 296 [7] as shown Table 3.

**Table 3:
DVB-T transmit masks**

Offset (MHz)	Critical Mask dBc	Non-critical mask dBc	Relaxed non-critical mask dBc	Ref Bandwidth (kHz)
+/-3.8	32.8	32.8	32.8	4
+/-4.2	83	73	67.8	4
+/-6	95	85	85	4
+/-12	120	110	110	4
+/-20	120	110	110	4

A comparison of the generated DVB-T signal measured in a 3 kHz bandwidth with the non-critical mask described in ETSI EN 302 296 can be seen in Figure 2.

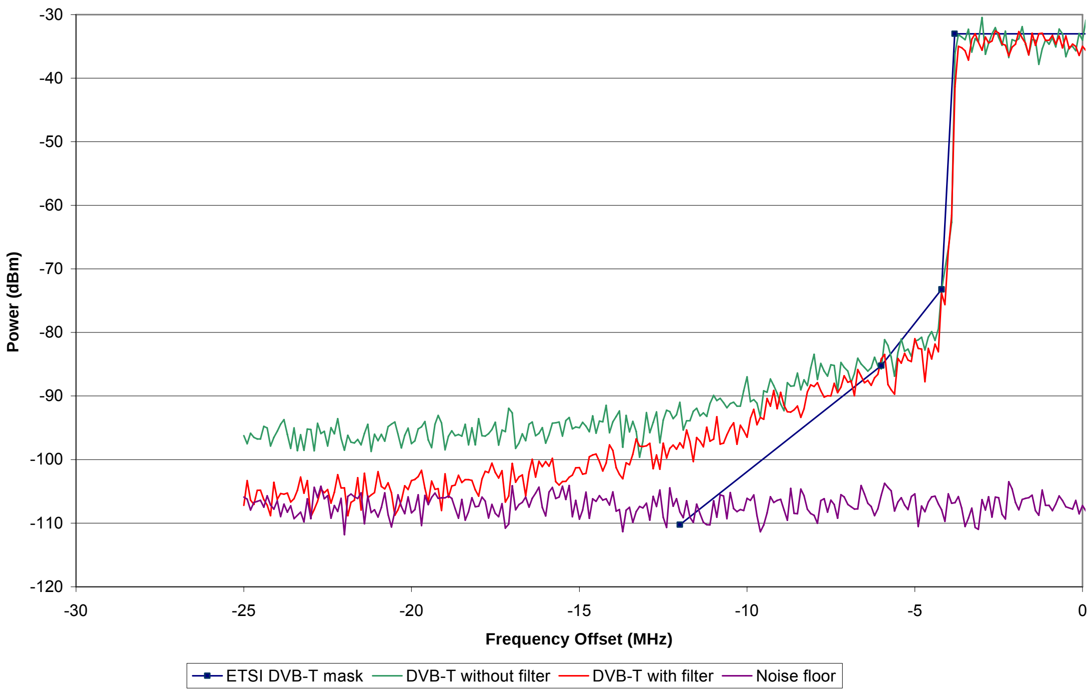

Figure 2: Generated DVB-T signal compared with non-critical ETSI mask

From the above plot it can be seen that the DVB-T signal with the filter does not drop as quickly as the non-critical ETSI DVB-T mask. Ideally a tighter filter would have been used. Attempts to bring the WiMAX link down in frequency to allow the use of a filter with a tighter response were made. This involved the use of frequency mixers. However, there was latency within the mixer circuitry and when combined with the Time Division-Duplex (TDD) incorporated by the WiMAX system, no link could be established between the BS and SS devices.

3.3 Base Station Set-Up

To measure the effects of interference into the BS device the following test set-up was used:

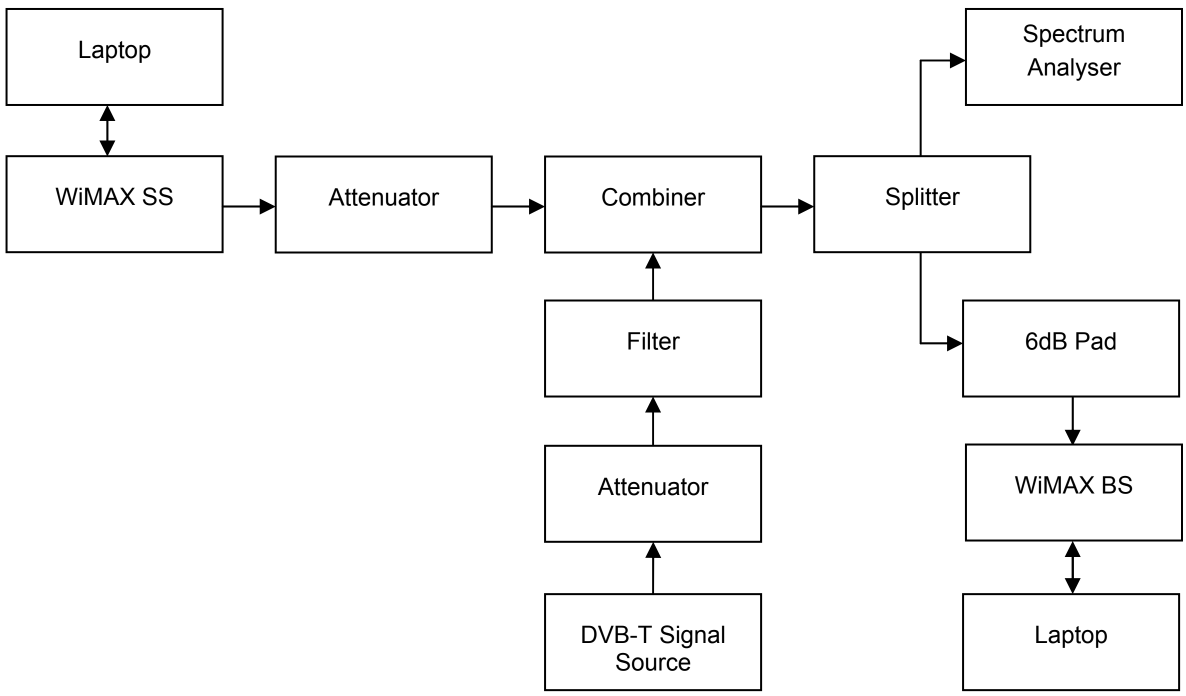

Figure 3: Base station measurement set-up

The WiMAX equipment selects a Modulation Coding Scheme (MCS) that allows the maximum data throughput based on the received wanted signal strength. The attenuator on the output of the SS allowed the link loss to be varied and in turn the strength of the WiMAX signal at the BS to be varied. This allowed the MCS selected by the WiMAX devices to be set to the desired scheme.

The effect of the attenuator on the received wanted signal strength and MCS is summarised in the table below.

Table 4:
Effects of attenuator on received signal strength and MCS in BS

Attenuator Setting (dB)	Received Signal Level (dBm)	MCS
76	-86	QPSK ¾
60	-70	64 QAM ¾

The positioning of this attenuator meant that the interfering signal was reduced on the input of the SS but not the BS, allowing the interference effect to be isolated to the BS device.

3.4 Subscriber Station

To measure the effects of interference into the SS unit the following test set-up was used:

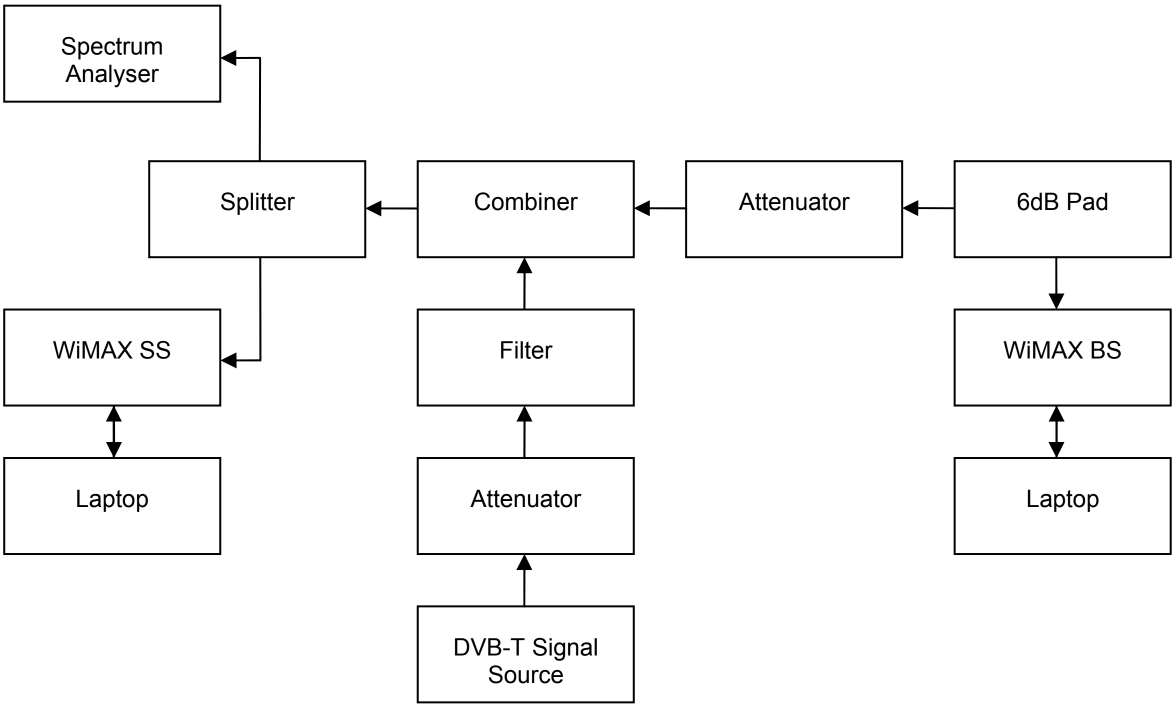

Figure 4: Subscriber station test set-up

The attenuator on the output of the BS allowed the link loss to be varied and in turn the strength of the WiMAX signal at the SS to be varied. This also allowed the MCS selected by the WiMAX devices to be set to the desired scheme.

The effect of the attenuator on the received wanted signal strength and MCS is summarised in the table below.

Table 5:
Effects of Attenuator on Received Signal Strength and MCS in SS

Attenuator Setting (dB)	Received Signal Level (dBm)	MCS
82	-93	QPSK ¾
69	-80	64 QAM ¾

3.5 Establishing and Monitoring the Link

The WiMAX devices were interfaced via Internet Explorer and command prompt windows present on a lap top computer connected to each of the BS and SS. These interfaces allowed a connection to be established and monitored.

Transmit frequency and power could be set via Internet Explorer. This could then be used to monitor several important parameters during the measurement run. These included:

- MCS
- Received WiMAX signal strength
- Signal to Noise Ratio (SNR)

The received WiMAX signal strength displayed on this interface was verified before measurements were commenced. This was achieved by looking at a single time frame using the trigger function on the spectrum analyser set to a zero Hz span and a RBW of 10 MHz. By measuring the insertion loss of the system the measured received WiMAX strength was proved to be within 1 dB of the displayed value on the graphical user interface via Internet Explorer for both uplink and downlink wanted signals.

Data transmission was triggered by use of the IPERF command in a command prompt window. This then monitored the data throughput. Combined with the Internet Explorer user interface this allowed both the MCS and the data throughput to be simultaneously analysed throughout the conducted measurement process.

4. Measurement Procedure

The operation of the WiMAX BS and SS in the presence of DVB-T interference for a fixed path loss was measured for four scenarios:

- Edge of coverage operation using a 64-QAM ¾ downlink MCS.

- Edge of coverage operation using a QPSK ½ downlink MCS.
- Edge of coverage operation using a 64-QAM ¾ uplink MCS.
- Edge of coverage operation using a QPSK ½ uplink MCS.

The failure criteria used to judge the performance of the BS and SS was based on a drop in the selected MCS used by the WiMAX equipment. This drop in MCS is also reflected in a drop in the data throughput. The failure criteria for the BS and SS are summarised in the table below:

Table 6:
Failure criteria for BS and SS units

	Desired Operating State		Failure Criteria	
	Modulation Scheme	**Throughput (Mbps)**	**Modulation Scheme**	**Throughput (Mbps)**
BS	64 QAM ¾	6.37	64 QAM ⅔	5.66
	QPSK ¾	2.12	QPSK ½	1.4
SS	64 QAM ¾	8.07	64 QAM ⅔	7.16
	QPSK ¾	2.68	QPSK ½	1.78

The following measurement procedure was used to perform conducted DVB-T interference into WiMAX measurements:

1. A connection was established between BS and SS units using the Internet Explorer interface.
2. Data was transferred to the Device Under Test (DUT) at the receiving end via the IPERF command line using a command window.
3. The path loss was altered until the desired MCS and throughput was achieved without any interference and monitored via the user interface from Internet Explorer and the command prompt window respectively.
4. The MCS and throughput were recorded.
5. The DVB-T interference was set to the correct frequency offset and switched on via the signal generator.
6. The interference was increased until the failure criteria was met.
7. The MCS, throughput, SNR and received WiMAX signal strength recorded from internet explorer and command prompt windows.
8. The DVB-T signal strength was measured on the spectrum analyser in a 7.6 MHz channel bandwidth using a 100 kHz resolution bandwidth and a RMS detector.

9. The interference was turned off and Steps 4-7 were repeated for different frequency offsets.

5. Results

5.1 Base Station

Using the test procedures shown above (Section 4) the results for the BS protection ratios were measured and are shown in the following figure:

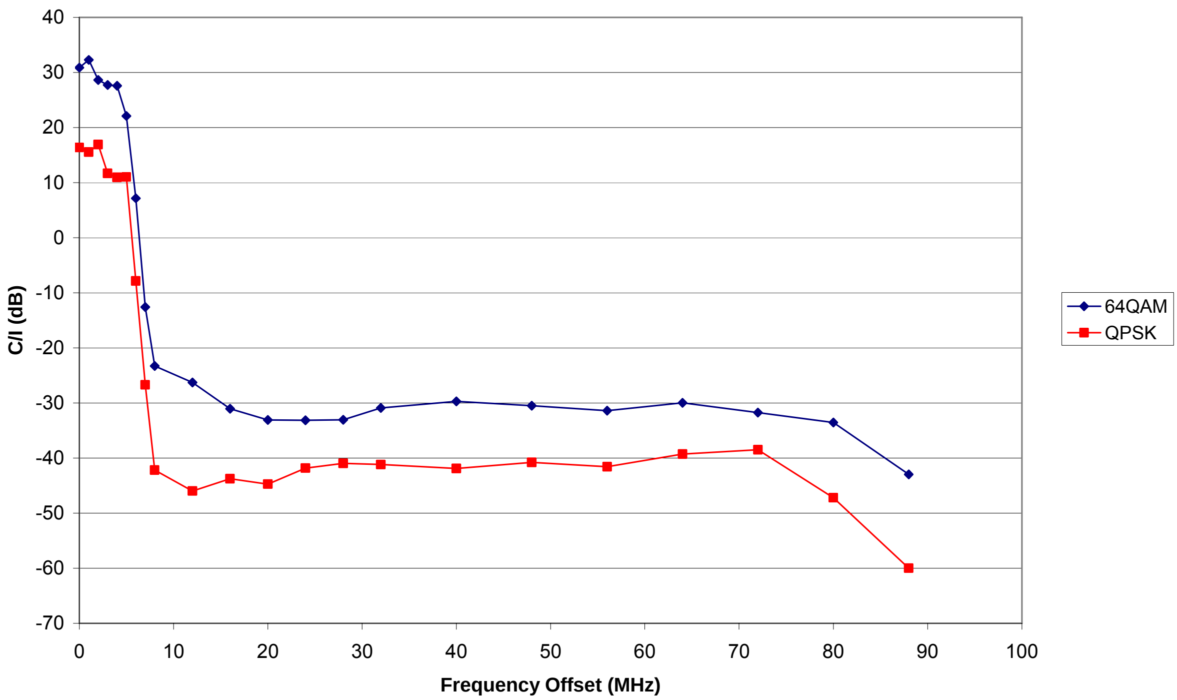

Figure 5: Measured protection ratios for a WiMAX base station

From Figure 5 it can be seen that the co-channel protection ratios for DVB-T interference into a WiMAX BS using QPSK ¾ and 64 QAM ¾ modulation schemes are 16 dB and 30 dB respectively. For an adjacent N+1 frequency channel separation of 8MHz the QPSK ¾ protection ratio drops to -42 dB and further drops to -47 dB at channel N+10 (80 MHz).

The plot reveals that the trend for 64 QAM ¾ modulation scheme is similar to that of QPSK ¾. At the adjacent N+1 channel a protection ratio of -23 dB is required and at channel N+10 this drops to -33 dB. Overall, it can be concluded that a WiMAX BS operating under a 64-QAM modulation requires 10 to 12 dB more protection compared with a WiMAX BS using QPSK.

5.2 Subscribers Station

Using the test procedures shown above (Section 4) the results for the SS protection ratios were measured and are shown in the following figure:

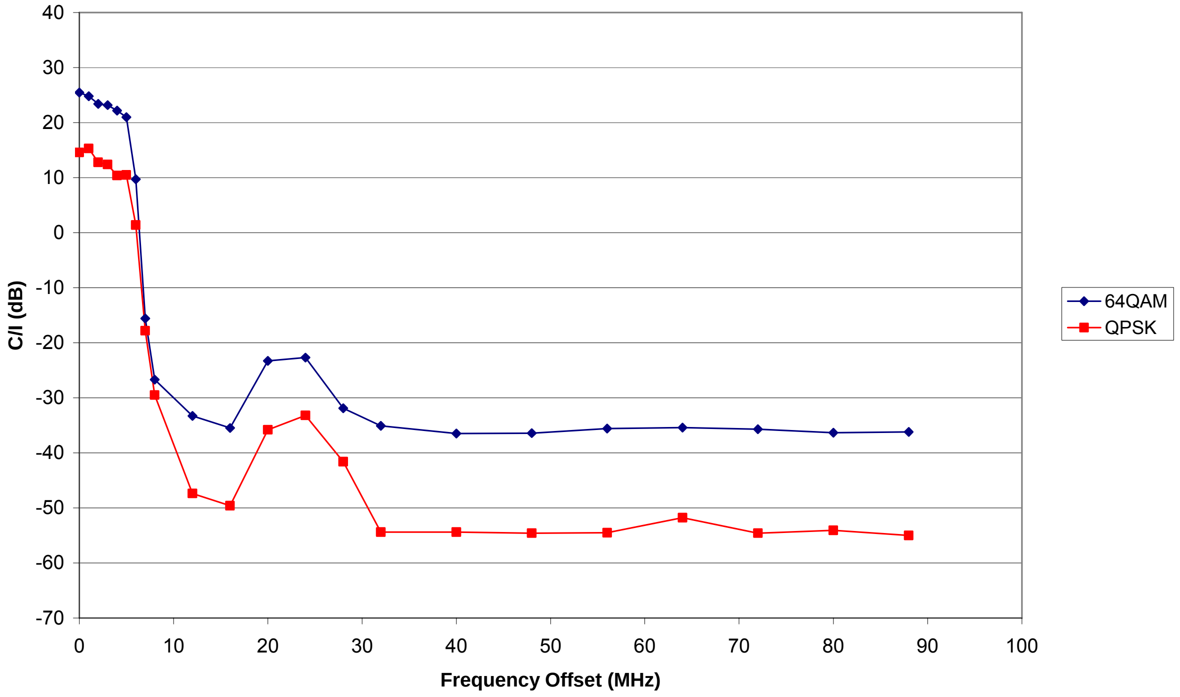

Figure 6: Measured protection ratios for a WiMAX subscriber station

From Figure 6 it can be seen that the co-channel protection ratios DVB-T interference into a WiMAX SS for the QPSK ¾ and 64 QAM ¾ schemes are 15 dB and 25 dB respectively. For an adjacent N+1 frequency channel separation of 8MHz, the QPSK ¾ protection ratio drops to -30 dB and at channel N+10 (80 MHz) this drops further by 24 dB to -54 dB. In a similar fashion the 64 QAM ¾ at N+1 drops to -27 dB and at channel N+10 drops to -36 dB. Overall, it can be concluded that a WiMAX SS operating under a 64-QAM modulation requires 10 to 15 dB more protection compared with a WiMAX SS using QPSK.

Also, from the plot it can be seen that WiMAX is more susceptible to DVB-T interference 3 DTT channels away (24 MHz). This may be due to the architecture of the SS being of a super-heterodyne nature, which can result in an image problem if the bandwidth of the Intermediate Frequency (IF) is 12 MHz.

6. Summary and Conclusions

ERA was asked to perform measurements to characterise the effect of DVB-T interference into a WiMAX communication link. A series of conducted measurements were made looking at interference effects into both the BS and SS devices.

For the BS and SS devices two separate scenarios were considered:

- Edge of coverage operation using a 64-QAM ¾ downlink MCS.
- Edge of coverage operation using a QPSK ½ downlink MCS.

An interfering DVB-T signal was fed into the BS and SS individually. The frequency of the interference was in discrete steps starting at co-channel; increasing in 1MHz steps up to an 8 MHz separation and there after in 8 MHz steps up to 88 MHz. Using the recorded DVB-T and WiMAX signal levels a series of C/I protection ratios were calculated.

For the BS measurements the co-channel protection ratios for QPSK ¾ and 64 QAM ¾ modulation schemes were seen to be 16 dB and 30 dB respectively. For the adjacent N+1 frequency channel separation of 8 MHz, the protection ratio dropped to -42 dB for QPSK ¾. The protection ratio at N+10 80 MHz fell by a further 5 dB down to -47 dB. The trend was for 64 QAM ¾ modulation scheme was similar to that of QPSK ¾. At the adjacent N+1 channel a protection ratio of -23 dB was required and at channel N+10 this dropped to -33 dB. Overall, it can be concluded that a WiMAX BS operating under a 64-QAM modulation requires 10 to 12 dB more protection compared with a WiMAX BS using QPSK.

For the SS measurements the co-channel protection ratios for the QPSK ¾ and 64 QAM ¾ measurements were 15 dB and 25 dB respectively. For an adjacent N+1 frequency channel separation of 8MHz, the QPSK ¾ protection ratio dropped to -30 dB and fell by a further 24 dB to -54 dB at channel N+10 (80MHz). In a similar fashion the 64 QAM ¾ at N+1 dropped to -27 dB and at channel N+10 dropped to -36 dB. Overall, it can be concluded that a WiMAX SS operating under a 64-QAM modulation requires 10 to 15 dB more protection compared with a WiMAX SS using QPSK.

For either a base station or a subscriber station, for a given modulation type and error protection coding rate, the results indicate that the C/I protection ratio remains reasonably constant at frequency offsets between approximately 10 and 80 MHz. The only exception to this was the WiMAX SS, which was more susceptible to DVB-T interference 3 DTT channels away (24 MHz). This may be due to the architecture of the SS being of a super-heterodyne nature, which can result in an image problem if the bandwidth of the Intermediate Frequency (IF) is 12 MHz.

7. References

[1] "RF measurements to quantify 3G and WiMAX mobile interference to DVB-T receivers", ERA Technology, December 2006

[2] "Conducted Measurements to Quantify Different Types of Interference in the DDR Frequency Spectrum", ERA Technology, October 2007

[3] "Conducted Measurements to Quantify DVB-T interference into DTT Receivers", ERA Technology, October 2007

[4] IEEE Standard for local and metropolitan areas network areas part 16: Air interface for fixed and mobile broadband wireless access systems, 802.16e-2005

[5] IEEE Standard for local and metropolitan areas network areas part 16: Air interface for fixed and mobile broadband wireless access systems, 802.16-2004

[6] ETSI EN 300 744 – Digital Video Broadcasting (DVB); Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television

[7] ETSI EN 302 296 - Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the digital television broadcast service, Terrestrial (DVB-T); Harmonized EN under article 3.2 of the R&TTE Directive

APPENDIX 1: Equipment List

Signal Sources	**Identifier**
Airspan WiMAX Base Station	
Airspan WiMAX Subscriber Station	
Agilent E4438C Signal Generator	03306
Laptops x2	
Attenuators	
Marconi Programmable Attenuator	02128
Marconi Programmable Attenuator	02129
HP Step Attenuator	02298
6dB Pad	02298
Miscellaneous	
Rhode and Schwarz ESPI Test Receiver	03245
K & L Filter	02420
HP Splitter	00018
VSWR Bridge	00831