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ERA TECHNOLOGY

RF Measurements to Quantify 3G and WiMAX Mobile Interference to DVB-T Receivers

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Summary

Digital broadcasting is roughly six times more efficient than analogue, allowing more channels to be carried across fewer airwaves. Ofcom estimates that the digital switchover programme will release up to approximately 112 MHz of spectrum in the UHF (Ultra High Frequency) band for new uses. The potential future uses of this spectrum are wide ranging and include: broadband wireless access, cellular mobile (for example, 3G and systems beyond IMT-2000), private mobile radio, further terrestrial digital television services (including standard definition television, high definition television and local digital TV), mobile digital multimedia (including mobile television), and Programme Making and Special Events (PMSE).

As part of the Digital Dividend Review (DDR) ERA was asked by Ofcom to investigate the potential interference to DVB-T receivers from 3G and WiMAX mobile transmitters for adjacent and N+9 channel separation. Measurements were undertaken on a range of DVB-T receivers commonly available in the UK. Both conducted and radiated measurements were performed to characterise the receiver performance in terms of the required Carrier-to-Interference (C/I) protection ratio.

Conducted Measurements

Conducted tests were performed to measure the C/I protection ratios for 3G and WiMAX adjacent channel interference for six DVB-T receivers (labelled 1, 2, 3, 4, 5 and 6). The table below shows the average adjacent channel interference for all six receivers, at three guard bands of 0.4 MHz, 1 MHz and 2 MHz.

Table 1:
Average C/I protection ratios for 3G and WiMAX adjacent channel interference to six DVB-T receivers

Interferer	Modulation	C/I (dB) with 0.4 MHz Guard Separation	C/I (dB) with 1 MHz Guard Separation	C/I (dB) with 2 MHz Guard Separation
3G	64QAM	-28	-35	-38
	16QAM	-32	-39	-42
WiMAX	64QAM	-27	-31	-32
	16QAM	-31	-35	-36

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From the above table it can be seen that the 64QAM DVB-T signal requires a slightly higher protection of 3 to 4 dB more than compared with the 16QAM DVB-T signal against 3G and WiMAX adjacent channel interference. As the guard separation increases from 0.4 MHz (smallest allowable guard band) to 2 MHz, the C/I protection ratio decreases by 10 dB for 3G interference and 5 dB for WiMAX interference for both DVB-T modulations.

For 3G interference into the N+9 channel of the wanted DVB-T signal, test receiver 1 produced the worst C/I protection ratio of -27 dB which was on average 20 dB higher compared with the rest of the receivers, using 64QAM modulation. For the 16QAM modulated signal interfered by the 3G signal, the worst N+9 channel C/I protection ratio was -30 dB for test receiver 1, 23 dB higher compared with receivers 2 to 6.

For WiMAX interference into the N+9 channel of the wanted DVB-T signal, the worst C/I protection ratio was -24 dB for test receiver 1, on average 16 dB higher compared with the rest of the tested receivers using 64QAM modulation. For the 16QAM modulated signal interfered by the WiMAX signal, the worst N+9 channel C/I protection ratio was -28 dB, also for test receiver 1 and on average 18 dB higher compared with receivers 2 to 6.

The results indicate that there was a large variation between receiver 1 and receivers 2 to 6 for the N+9 issue, possibly due to the RF filter characteristics.

Radiated Measurements

Outdoor measurements were also performed to simulate the real interference environment from a mobile station. The on-air testing was performed on test receiver 1, which produced the worst N+9 protection ratio.

The 3G and WiMAX interference to DVB-T test receiver 1 was measured as EIRP in dBm for both co-polar and cross-polar antenna orientations. The wanted DVB-T signal measured at the receiver end was set to 54 dBµV/m for the majority of measurements, representing a typical received value for on the fringe area reception.

The local digital signal was transmitted on UHF channel 56 (754 MHz) using a Schwarzbeck UHALP 9107 antenna at a height of 10 m above the ground. The adjacent and N+9 channel interference was transmitted at 762 MHz and 826 MHz respectively.

Mobile interference measurements were made for a 64QAM DVB-T received signal with an electric field strength of 54 dBµV/m received by a medium gain digital antenna at 2 m, 10 m, 27 m, 55 m, 82 m and 120 m separation distances along the bore-sight of the TV antenna. The TV antenna was raised to a height of 8.5 m and the interfering antenna was positioned at a height of 1.5 m. The guard band between the wanted DVB-T channel and the interferer was set to 0.4 MHz, based on 3 dB channel bandwidths measured on the spectrum analyser. Other measurements involved using a higher wanted received electric field strength of 64 dBµV/m and an analogue antenna at a separation distance of 82 m.

From the figure below it can be seen that the DVB-T receiver is most susceptible to 3G and WiMAX interference at a separation distance of 10 m, where an EIRP 10 dBm and 8 dBm is respectively required to cause the onset of noticeable co-polar adjacent channel interference.

The EIRP values peak for a separation distance of 55 m, where the adjacent 3G and WiMAX co-polar interference signals require an EIRP of 19 dBm and 20 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These higher values are due to the interference not being in the main lobe of the TV antenna and not in the side lobes at closer distances of 10 m or so.

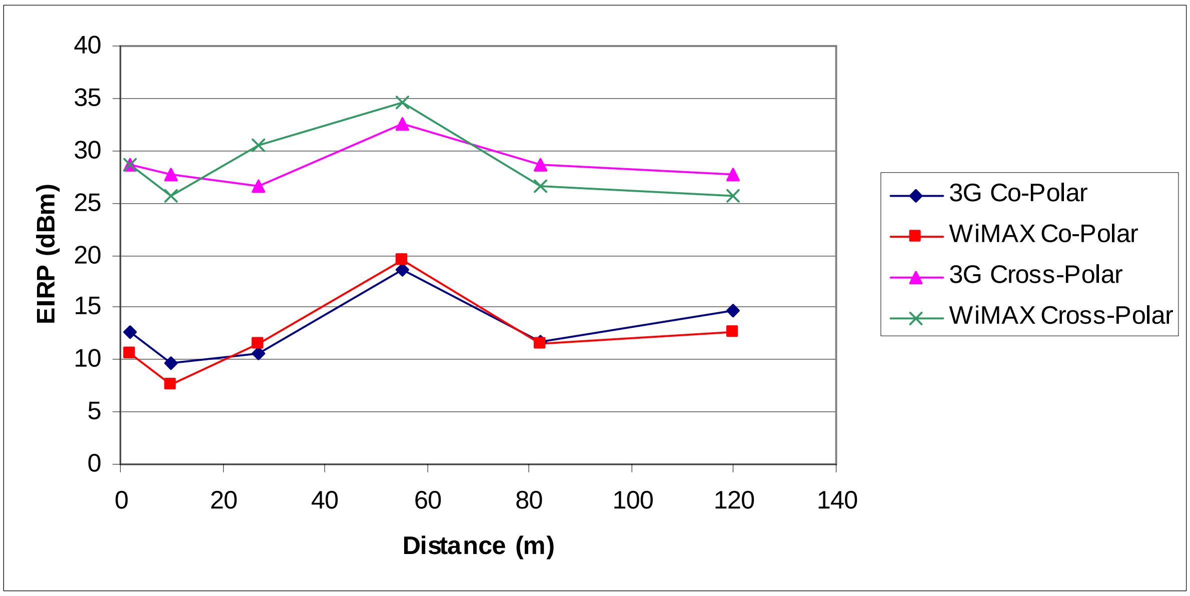

Figure 1: Measured EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 54 dBµV/m using a digital antenna

At separation distances of 82 and 120 m, the adjacent channel interference from the 3G and WiMAX mobile requires less EIRP than at 55 m, because the mobile interferers have moved into the main beam the receiving TV antenna. At a separation of 82 m, both the 3G and WiMAX signals require an EIRP of 12 dBm to cause the onset of adjacent co-polar channel interference to the DVB-T receiver.

For cross-polar interference, the 3G and WiMAX mobile stations require an EIRP 15 to 18 dBm greater than the co-polar results for distances between 2 to 120 m.

Based on the conducted results above, the EIRP would effectively increase by 7 dB and 10 dB for 3G interference and 4 dB and 5 dB for WiMAX interference, for greater guard bands of 1 MHz and 2 MHz compared with the co-polar and cross-polar adjacent channel interference using a 0.4 MHz guard band.

For N+9 channel interference from 3G and WiMAX signals, the DVB-T receiver was most susceptible at a separation distance of 27 m. From the figure below, it can be seen that for 3G and WiMAX co-polar signals require an EIRP of 18 and 17 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These EIRP levels are 4 to 5 dB lower than those observed at a separation of 82 m and 120 m.

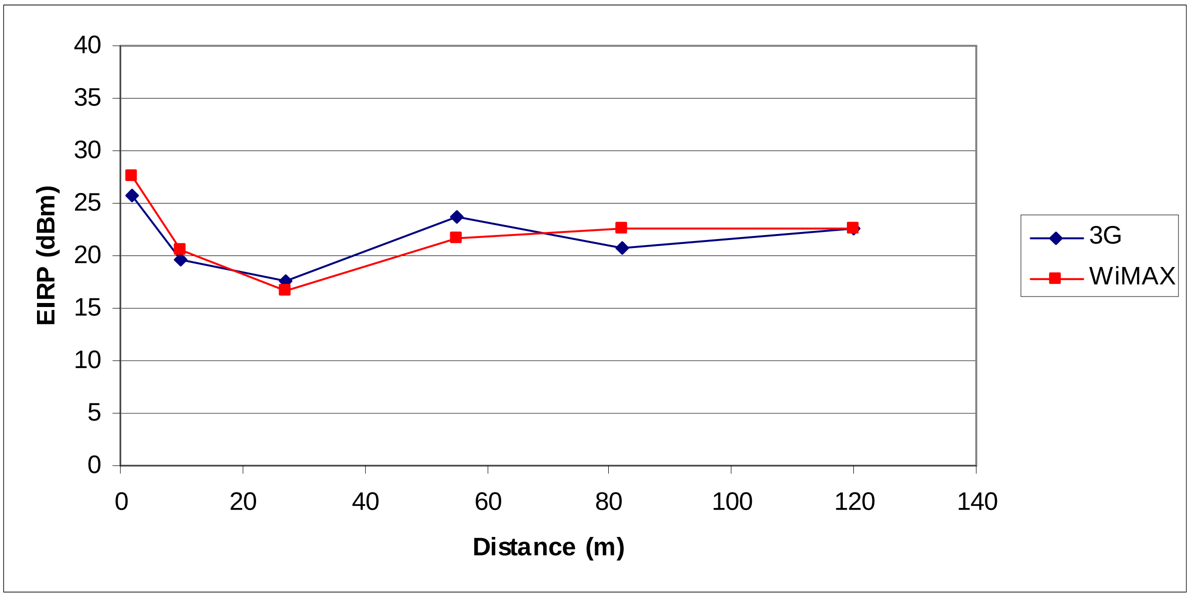

Figure 2: Measured EIRP as a function of distance for 3G and WiMAX N+9 channel co-polar interference to a DVB-T signal with a received electric field strength of 54 dBµV/m using a digital antenna

At a separation distance of 120 m, an EIRP of 22 dBm was required to cause interference for both 3G and WiMAX co-polar N+9 signals. No effect to the DVB-T picture quality was observed for cross-polar interference transmitting on the N+9 channel with an EIRP of 30 dBm (the maximum power that ERA was allowed to transmit). Similar results were also obtained at 82 m and 55 m, with 1 to 3 dB difference when compared to the N+9 results measured at 120 m.

At closer separation distances of 10 m or less the 3G and WiMAX signals require EIRPs in excess of 20 dBm to cause an effect to the DVB-T receiver.

No effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both cross-polarised 3G and WiMAX signals transmitting at the maximum allowed EIRP of 30 dBm for all separation distances.

When the wanted DVB-T signal level increased from 54 dBµV/m to 64 dBµV/m for a separation distance of 82 m, the co-polar interference for 3G and WiMAX signals increased by exactly 10 dB, inline with the 10 dBµV/m increase of the wanted receiver field strength value. For cross-polar interference, no effect to the impairment of the wanted DVB-T picture was observed for adjacent channel interference for both 3G and WiMAX signals. Also, no effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both 3G and WiMAX signals, in both polarisations.

Finally, when digital TV antenna was replaced by an analogue TV antenna the results were very similar, indicating a very similar antenna pattern and gain profile when measured at a separation distance of 82 m.

3G and WiMAX Interference to Portable TV Antennas

3G and WiMAX interference to a portable TV antenna was also analysed based on the outdoor radiated measurement results.

For a portable antenna to receive a DVB-T signal, the field strength would have to be in the order of 20 dBμV/m greater (height reduction plus building loss) than the minimum 47 dBμV/m. For the DVB-T receiver to receive the same wanted input power as via the outdoor TV antenna, the received field strength must be further increased typically by 10 dBμV/m because of the lower gain of the portable antenna compared to the outdoor TV antenna. Therefore, the field received at the portable TV antenna would have to be 57 dBμV/m.

The interfering 3G and/or WiMAX signal would be reduced by 10 dBμV/m, due to the attenuation loss from the building. The received interferer power into the DVB-T receiver would be a further 10 dB lower, because of the lower gain compared to the typical outdoor antenna. The overall net effect is that the interferer power entering the DVB-T receiver via the portable antenna would be 10 dB greater compared to the wanted DVB-T signal.

Assuming a minimum guard band of 0.4 MHz, the overall 3G and WiMAX EIRP measured for a wanted DVB-T field strength of 57 dBμV/m would be reduced by 7 dB, compared to the results shown in Figure 11 (See Figure 15). The N+9 results would also be reduced by 7 dB compared to the results shown in Figure 14 (See also Figure 16), to cause the onset of interference to the DVB-T receiver.

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Abbreviations List

BER	Bit Error Ratio
CDMA	Code Division Multiple Access
C/I	Carrier-to-Interference
DDR	Digital Dividend Review
DVB	Digital Video Broadcast
DTT	Digital Television Transmitter
EIRP	Effective Isotropic Radiated Power
FEC	Forward Error Correction
IF	Intermediate Frequency
PMSE	Programme Making & Special Events
RF	Radio Frequency
TV	Television
UHF	Ultra High Frequency

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1 Introduction

Ofcom announced on 17 November 2005 the beginning of its Digital Dividend Review (DDR) – the project, which will examine the options arising from the release of spectrum afforded by the digital switchover programme. The available spectrum includes the spectrum released by analogue switch off – the UHF spectrum in bands IV and V (470 – 862 MHz) with the exception of the spectrum reserved for the 6 Digital Television Transmitter (DTT) multiplexes [1].

Digital broadcasting is roughly six times more efficient than analogue, allowing more channels to be carried across fewer airwaves. The plans for digital switchover will therefore allow for an increase in the efficiency with which the spectrum is used - including the potential for a large amount of spectrum to be released for wholly new services.

Ofcom estimates that the digital switchover programme will release up to approximately 112 MHz of spectrum in the UHF (Ultra High Frequency) band for new uses. The UHF band is prime spectrum, because it offers a technically valuable combination of capacity (bandwidth) and range. This part of the spectrum is much sought after for a whole range of services likely to be used by millions of people every day.

The potential future uses of this spectrum are wide ranging and include: broadband wireless access, cellular mobile (for example, 3G and systems beyond IMT-2000), private mobile radio, further terrestrial digital television services (including standard definition television, high definition television and local digital TV), mobile digital multimedia (including mobile television), and Programme Making and Special Events (PMSE). As part of the DDR, ERA was asked by Ofcom to investigate the potential interference to adjacent and N+9 channels from 3G and WiMAX mobile transmitters.

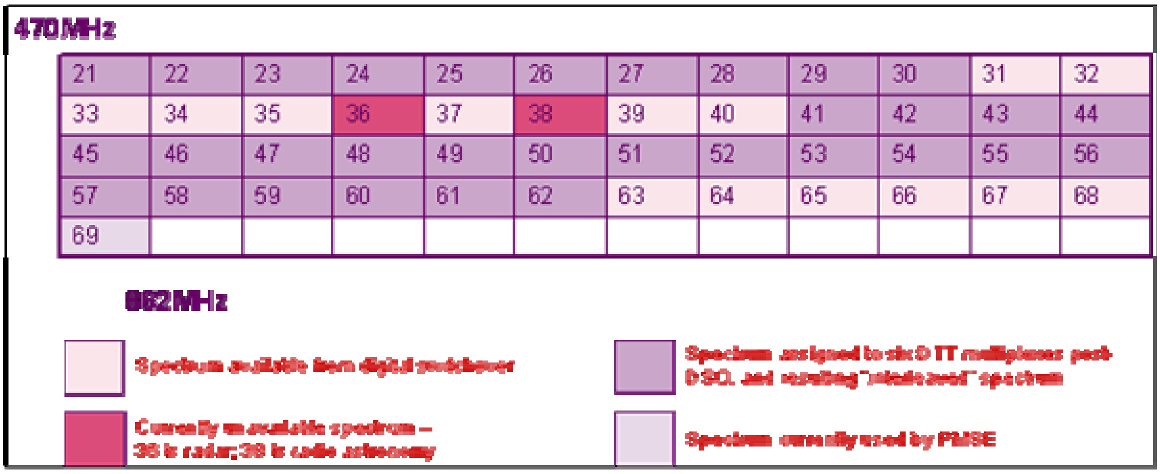

Figure 3: Outline of band plan for 470-862 MHz

The diagram above details the spectrum that will be assigned to 6 DTT multiplexes post switchover and the spectrum available after switch over.

After switch-over 14 channels are expected to become completely clear in the UK and available for new uses. New use of channels 31, 40, and 63 have the potential to cause adjacent channel interference to some of the spectrum assigned to the 6 DTT multiplexes. The use of all but channel 40 of the available spectrum has the potential to cause interference due to the potential N+9 problem. For example, DTT channel 22 has the potential to be interfered with by the use of channel 31 as it is 9 channels away [2].

2 Objectives

The objectives of the programme of work outlined in the proposal were:

- To simulate a mobile 3G and WiMAX system transmitting on the channels to be released post digital switchover and to see if it causes interference to DVB-T receiver/s nine channels below.
- To investigate interference from the adjacent and N+9 channel separation.
- Determine the protection levels required to protect the DVB-T receiver/s to adjacent and nine channels below by testing in a typical laboratory environment.
- Simulate a real life environment with a fixed television-receiving antenna being interfered with a simulated 3G/WiMax mobile transmitter on the DVB-T frequencies.
- To determine the minimum distance a mobile (3G or WiMAX) has to be before it causes interference to a DVB-T receiver.

Both conducted and radiated measurements were made on 6 DVB-T receivers commonly available in the UK market. The receiver performance was characterised in terms of the C/I protection ratio.

3 Measurements

3.1 Conducted Test Set-Up

The programme of work considered conducted measurements to quantify the interference effects of 3G and WiMAX signals on typical DVB-T receivers. The 3G and WiMAX interference measurements to DVB-T receivers were performed using the set-up of equipment shown in Figure 4.

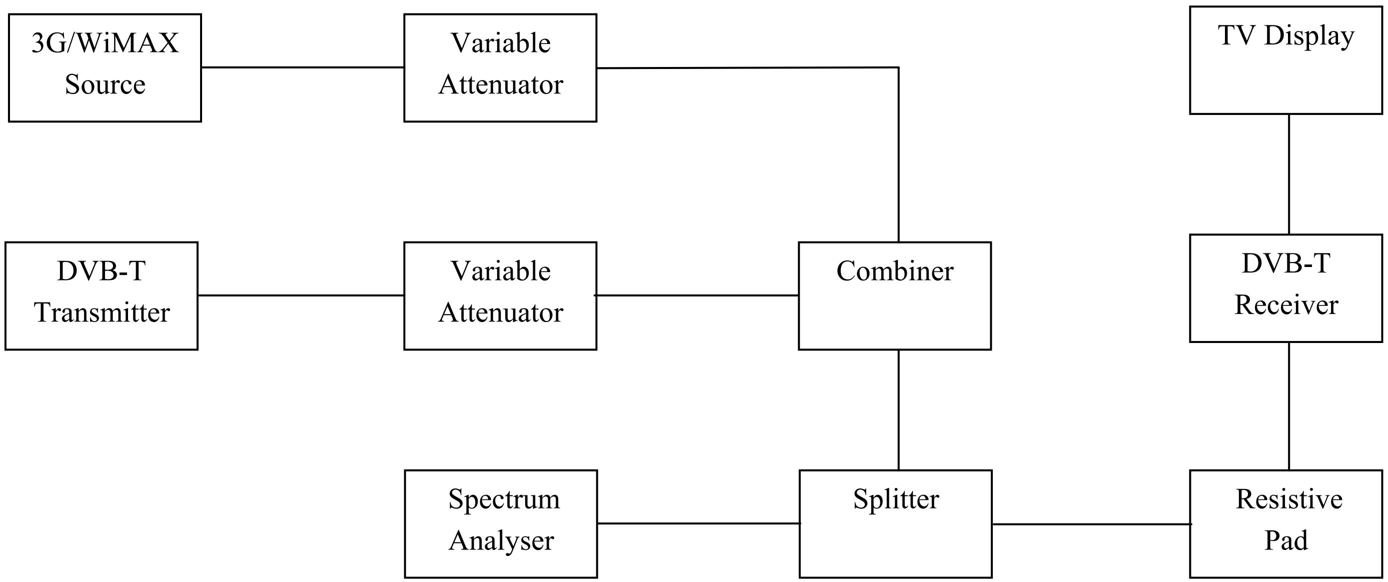

Figure 4: Diagram showing measurement equipment set-up

The DVB-T wanted signal was created using a Rhode & Schwarz (R&S) MPEG2 measurement generator DVG – 2068.8600.03 and R&S TV test transmitter SFQ – 2072.5501.10 connected via a TS parallel port. The MPEG encoder was used convert a moving video display into the correct format required by the DVB-T TV transmitter. The DVB-T TV transmitter, comprising of an input data stream, Forward Error Correction (FEC) encoder, modulation source and a carrier corresponding to the correct transmit frequency. The DVB-T system parameters currently mandated for use in the UK were used as shown in the table below:

Table 2:
DVB-T system parameters currently used in the UK

DVB-T Parameter	I	II
Modulation	64 QAM	16 QAM
Error Coding Rate	2/3	3/4
Guard Interval (µs)	7 ($^1/_{32}$)	7 ($^1/_{32}$)
Data rate (Mbit/s)	24.12	18.09
System C/N (dB)	17.1	13.0
Receiver Implementation Margin (dB)	2.7	2.7
Allowance for ‘real’ conditions (dB)	3	3
C/N (dB)	22.8	18.7

The 3G and WiMAX were simulated using an Agilent MXG signal generator and used to interfere with the wanted signal into the DTT receivers. The 3G interfering signal parameters shown in Table 3, based on Interface Requirement (IR) 2019 were used.

Table 3:
3G signal parameters

3G Parameter	Value
Channel Raster	5 MHz
Channel Modulation	QPSK, 8PSK, 16QAM
Channel Occupation	CDMA/TDMA
Duplex	Time Division Duplex
Maximum EIRP	24 dBm

The WiMAX interfering signal parameters shown in Table 4, based on IEEE 802.16-2004 were used.

Table 4:
WiMAX signal parameters

WiMAX parameter	Value
Bandwidth	10 MHz
Channel modulation	QPSK
FFT Points	256
Occupied Channels	200
Guard Interval	1/32
Channel Occupation	OFDM
Duplex	TDD
Maximum EIRP	30 dBm

The carrier level was set to 3 dB above the minimum sensitivity. The minimum sensitivity was evaluated by decreasing the wanted signal power level until received movie picture just started to show signs of degradation. The degradation observed for all of the DVB-T receivers tested was a blocking effect as shown in the figure below.

Figure 5: Picture showing typical interference observed on the LCD display from 3G and WiMAX signals

For a minimum wanted carrier signal level of 3dB above the DTT receiver sensitivity, the level of interference was monitored until the wanted signal started showing the first signs of degradation on the LCD display, using typical modulation schemes shown in Table 2. The LCD display used in the experiment was connected to each of the DVB-T receivers via a standard scart lead provided. The six DVB-T receivers used in the conducted measurements are shown in Table 5.

Table 5:
DVB-T receivers

Alba STB7
Humax MGT1
Matsui DTR3
Philips DTR 2105
Sagem IT64
Sony VTX-D800

The receiver bandwidth associated with the DVB-T receivers is typically 7.6 MHz and a spectrum analyser used to measure the channel power in the receiver band was also used to measure the power of the interfering 3G and WiMAX signals.

The measurement results were tabled as a function of the Carrier-to-Interference (C/I) versus frequency or channel separation, for both 64QAM and 16QAM modulation schemes and 3G and WiMAX interference. Instead of just sample testing several DTT receivers on adjacent channel and N+9 channels highlighted in Figure 3, a full sweep of frequencies were performed as shown in the table below:

Table 6:
Channel numbers and frequencies used to for adjacent channel and N+9 interference testing

Channel to be simulate by 3G and WiMAX system as potential interferer	Frequency MHz
Co-channel	546 to 551
Co-channel/Adjacent	552
Co-channel/Adjacent	553
Adjacent (N+1)	554
Adjacent	555
N+2	562

Channel to be simulate by 3G and WiMAX system as potential interferer	Frequency MHz
N+3	570
N+4	578
N+5	586
N+6	594
N+7	602
N+8	610
N+9	618
N+10	626
N+11	634
N+12	642
N+13	650

3.2 Conducted Interference Measurement Procedure

The 3G and WiMAX interference measurements to a selection of DVB-T receivers shown in Table 5 were performed using the set-up of equipment shown in Figure 4.

The measurement procedure for assessing the potential for interference to DVB-T receivers from 3G and WiMAX signals is presented below.

1. For each of the digital receiver specified in Table 5, the wanted signal level was adjusted to levels to 3 dB above the minimum sensitivity of the receiver necessary.

2. The wanted channel power level was recorded using the spectrum analyser.

3. The external 3G generator was initially set to same channel frequency as the DVB-T receiver and a signal level to –20 dB from the noise floor of the spectrum analyser, measured in the channel bandwidth of 7.6 MHz of the digital receiver.

4. The signal level of the 3G interference was adjusted as to achieve the required degradation of the received quality of the DVB-T signal by using the programmable attenuator.

5. The wanted signal was switched off and the power level of the interference source was measured in the IF bandwidth of the receiver using RMS detection.

6. Steps 2 to 5 were repeated to for each of the channel frequencies shown in Table 6.

7. Steps 2 to 5 were then repeated for WiMAX interference.

Note: a standard scart lead was used to connect the DVB-T receiver to the LCD display. Also, the measured average minimum sensitivity observed for all six DVB-T receiver using 64QAM modulation was -82 dBm and -86 dBm for 16 QAM modulation.

3.3 Radiated Measurement Test Set-Up

Outdoor measurements were performed to simulate the real interference environment from a mobile station. The on-air testing was performed on test receiver 1, which produced the worst N+9 protection ratio. The radiated tests were carried out onsite at ERA.

The outdoor test environment was recreated by having an 8.5 m high TV antenna receiving the local digital transmitted signal and feeding into the DVB-T receiver. The receiving antenna was mounted on a cherry pick and raised to a height of 8.5 m (See Figure 6).

Figure 6: Picture of TV antenna mounted on a cherry pick

The receiver connected to the TV antenna via the 75 Ω cable was placed inside a trailer. The LCD display used to observe the quality of the received TV signal was connected using a standard scart lead.

The local DVB-T transmitter was on the second floor outside the west wing emergency exit of ERAs main building. The height of the transmitter was 10 m above the ground. The local digital signal was transmitted on UHF channel 56 (754 MHz) using a Schwarzbeck UHALP 9107 antenna at a height of 10 m above the ground (See Figure 7).

Figure 7: Picture of DVB-T Transmitter

The separation distance between the wanted transmitter and receiver antennas was measured as 90 m. The DVB-T signal was transmitted using horizontal polarisation. The wanted DVB-T receiver signal was set to the required electric field strengths of 54 dBμV/m (typical fringe area values) and 64 dBμV/m respectively at a height of 8.5 m. The electric field strength value was set by substituting the TV antenna with a calibrated Schwarzbeck UHALP 9107 log periodic antenna (with a known antenna correction factor of 23 dB/m at 754 MHz) and varying RF input of the DVB-T transmitter. The loss of the cable used to connect the R&S ESPG spectrum analyser and log periodic antenna was measured as 2 dB. The TV antenna was then repositioned back to its original receiver height of 8.5 m.

The 3G signal was generated using an Agilent E4438C signal generator and R&S AMIQ external modulation box controlled via a Laptop and GBIP card. The WiMAX interference signal was created using the Agilent E4438C signal generator and Agilent Signal Studio Software again controlled via a Laptop and GBIP card. The interference signals were then amplified using an Amplifier Research 5W100 amplifier. The 3G and WiMAX signals representing a mobile station were then transmitted using a Schwarzbeck UHALP 9107 antenna located on tripod 1.5 m above the ground, on channels 57

(762 MHz) and 65 (826 MHz) for both co-polar and cross-polar interference scenarios. The equipment used to generate the 3G and WiMAX signals was placed and controlled inside a Land Rover.

For a fixed distance of 2 m, 10 m, 27 m, 55 m, 82 m and 120 m, the 3G and WiMAX signals were initially transmitted at a power 20 dB below the minimum wanted receive power and increased in 3 dB steps until a degradation of the quality of picture was observed.

The RF input level required to cause interference was recorded. For a given input of -50 dBm, the interference signal level entering the antenna was measured in a channel bandwidth of 7.6 MHz equal to the wanted DTT channel using a spectrum analyser, for both 3G and WiMAX. The Effective Isotropic Radiated Power (EIRP) of interfering transmitter was calculated as the power entering the interfering mobile antenna (with reference to the -50 dBm input level) plus the gain of the amplifier and the UHALP 9107 log periodic. The maximum interference EIRP allowed to transmit under the license was 30 dBm for an antenna height of 1.5 m.

This measurement procedure was carried out for both 3G and WiMAX mobile interfering signals for the following scenarios:

Table 7:
Radiated test scenarios

Test Scenario	
1	64QAM DVB-T with an electric field strength of 54 dBµV/m received by a medium gain digital antenna at 2 m, 10 m, 27 m, 55 m and 82 m separation distances along the bore-sight of the TV antenna
2	64QAM DVB-T with an electric field strength of 64 dBµV/m received by a medium gain digital antenna at a 82 m separation distance the bore-sight of the TV antenna
3	64QAM DVB-T with an electric field strength of 54 dBµV/m received by a standard analogue antenna at a 82 m separation distance the bore-sight of the TV antenna
4	64QAM DVB-T with an electric field strength of 54 dBµV/m received by a medium gain digital antenna at 120 m separation distance along the bore-sight of the TV antenna in order to validate interferer in the man beam of the TV antenna

The TV antenna receivers (medium gain digital antenna on the LHS and standard analogue antenna on the RHS) used in the radiated set-up are shown in the figure below.

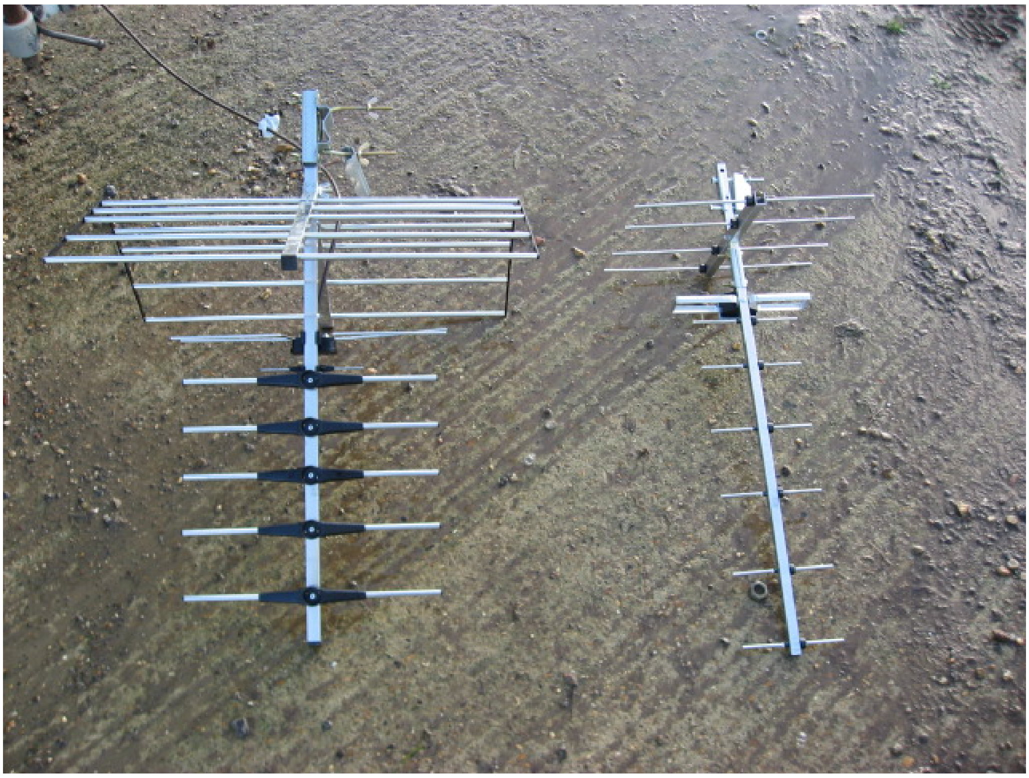

Figure 8: Picture of medium gain digital antenna and standard analogue antenna respectively

Using the free-space line of sight model, the separation distances were extrapolated to distances that match the maximum radiated powers allowed for WiMAX and 3G mobile stations.

4 Results

4.1 Conducted Measurements

4.1.1 Adjacent channel

The C/I protection ratios for the six DVB-T receivers shown in Table 5 were measured as a function of frequency as shown in Appendix A, using the test procedure described in Section 3.2. From the results, the adjacent channel C/I protection ratios for 64QAM and 16QAM DVB-T modulation have been extracted and tabulated in Tables 8 and 9 for 3G and WiMAX interference respectively. The centre frequencies for the adjacent 3G and WiMAX interferers were 552.25 MHz and 554.8 MHz respectively. This scenario represented the worst-case with a minimum available guard band of 0.4 MHz between the DVB-T signal and adjacent interferer. Measurements were also extrapolated for guard bands of 1 MHz and 2 MHz, to show the effect of increasing frequency separation with respect to the C/I protection ratio.

The centre frequency for the N+9 channel 3G and WiMAX interferers was 618 MHz. The measured average minimum sensitivity observed for all six DVB-T receiver using 64QAM modulation was -82 dBm and -86 dBm for 16 QAM modulation.

Table 8:
DVB-T adjacent channel protection ratios for 3G interference

DVB-T Receiver	64QAM r=2/3 FFT= 2k	16QAM r=3/4 FFT= 2k
1	-26	-30
2	-28	-32
3	-27	-31
4	-27	-31
5	-30	-33
6	-31	-34

Table 9:
DVB-T adjacent channel protection ratios for WiMAX interference

DVB-T Receiver	64QAM r=2/3 FFT= 2k	16QAM r=3/4 FFT= 2k
1	-32	-36
2	-26	-26
3	-24	-30
4	-24	-32
5	-29	-33
6	-25	-28

From Table 8, it can be seen that the adjacent channel C/I protection ratios vary from -26 dB to -31 dB for test receivers 1 and 6 respectively, when a 64QAM modulated DVB-T signal is interfered with a 3G signal. For the 16QAM modulated signal interfered by the 3G signal the adjacent channel protection ratios vary from -30 dB to -34 dB for test receivers 1 and 6 respectively.

For WiMAX interference into the adjacent band of the DVB-T channel a C/I protection ratio of -24 dB to -32 dB is required for test receivers 3, 4 and 1 respectively for a wanted signal using 64QAM modulation. For the 16QAM modulated signal interfered by the WiMAX signal the adjacent channel protection ratios vary from -28 dB to -36 dB for test receivers 6 and 1 respectively (See Table 9).

The table below summarises the average adjacent channel interference for all six receivers, at three guard bandwidth intervals of 0.4 MHz, 1 MHz and 2 MHz.

Table 10:
Average C/I protection ratios for 3G and WiMAX adjacent channel interference to six DVB-T receivers

Interferer	Modulation	C/I (dB) with 0.4 MHz Guard Separation	C/I (dB) with 1 MHz Guard Separation	C/I (dB) with 2 MHz Guard Separation
3G	64QAM	-28	-35	-38
	16QAM	-32	-39	-42
WiMAX	64QAM	-27	-31	-32
	16QAM	-31	-35	-36

.

From the above table it can be seen that the 64QAM DVB-T signal requires a slightly higher protection of 3 to 4 dB more than compared with the 16QAM DVB-T signal against 3G and WiMAX adjacent channel interference. As the guard separation increases from 0.4 MHz (smallest allowable guard band as measured at the 3 dB points on a spectrum analyser) to 2 MHz, the C/I protection ratio decreases by 10 dB for 3G interference and 5 dB for WiMAX interference for both DVB-T modulations.

4.2 N+9 Channel

Table 11:
DVB-T N+9 channel protection ratios for 3G interference

DVB-T Receiver	64QAM r=2/3 FFT= 2k	16QAM r=3/4 FFT= 2k
1	-27	-30
2	-49	-53
3	-46	-49
4	-49	-53
5	-47	-51
6	-49	-53

Table 12:
DVB-T N+9 channel protection ratios for WiMAX interference

DVB-T Receiver	64QAM r=2/3 FFT= 2k	16QAM r=3/4 FFT= 2k
1	-24	-28
2	-41	-46
3	-40	-44
4	-41	-45
5	-40	-44
6	-41	-46

From Table 11 it can be seen that the worst N+9 channel protection is -27 dB for test receiver 1, on average 20 dB higher compared with the rest of the receivers, for a 64QAM modulated DVB-T signal being interfered with a 3G signal. For the 16QAM modulated signal interfered by the 3G signal, the highest N+9 channel C/I protection ratio was -30 dB for test receiver 1, 23 dB higher compared with receivers 2 to 6. The next most susceptible receiver to the N+9 channel interference was test receiver 3. The rest of the test receiver did not show any significant susceptibility to N+9 channel interference for both 3G and WiMAX signals.

For WiMAX interference into the N+9 channel of the wanted DVB-T signal, the worst protection ratio was -24 dB for test receiver 1, on average 16 dB higher compared with the rest of the tested receivers using 64QAM modulation. For the 16QAM modulated signal interfered by the WiMAX signal, the worst N+9 channel C/I protection ratio was -28 dB, also for test receiver 1 and 18 dB higher compared with receivers 2 to 6 (See Table 12).

The low N+9 interference may have been due to the interferer power being so low, because the conducted tests were carried out at 3 dB above the minimum sensitivity of the receiver. To validate this phenomenon, four DVB-T receivers (1, 3, 5 and 6) were subjected to 3G interference at N+9 channels away from its centre frequency of 546 MHz. The interfering power entering in the front end of DVB-T receivers was increased on average by 40 dBm to -8 dBm.

Table 13:
N+9 channel C/I protection ratio comparison between measurements made at 3dB and 43 dB above the minimum sensitivity respectively

DVB-T Receiver	Interferer	Modulation	C/I(dB) 3dB above minimum sensitivity	C/I (dB) 43dB above minimum sensitivity
1	3G	64QAM	-27	-30
		16QAM	-30	-33
3	3G	64QAM	-46	-39
		16QAM	-49	-44
5	3G	64QAM	-47	-40
		16QAM	-51	-44
6	3G	64QAM	-49	-42
		16QAM	-53	-46

From the above table it can be seen that the C/I protection ratio for test receivers 3, 5 and 6 increases by 5 to 7 dB for the higher interferer power level compared with the results when measured at 3 dB above the minimum sensitivity of the receiver. These protection ratio increases may be due to non-linear effects, because of the higher interference powers entering the front end of the IF section of the DVB-T receiver. The only exception to the increase in the N+9 channel protection ratio was test receiver 1, where the C/I ratio dropped by 3 dB for the higher 3G interference signal levels.

4.3 Radiated Measurements

The radiated measurement results were performed at the ERA site for test receiver 1, using the test procedure described in Section 3.3. The mobile 3G and WiMAX interference to DVB-T test receiver 1 was measured as EIRP in dBm for both co-polar and cross-polar antenna orientations. The wanted DVB-T signal measured at the receiver end was set to 54 dBuV/m for the majority of measurements, with the exception of test scenario 2, where the received power was increased to 64 dBuV/m.

As with the conducted measurements, the frequency separation between the wanted DVB-T signal and adjacent interferer was set 0.4 MHz at the 3 dB points for 3G and WiMAX respectively. This separation value was chosen because the measured bandwidth of the DVB-T signal in an 8 MHz channel was 7.6 MHz. Therefore, resulting in a guard bandwidth of 0.2 MHz either side of the envelope of the DVB-T signal, as shown in Figure 9 and Figure 10.

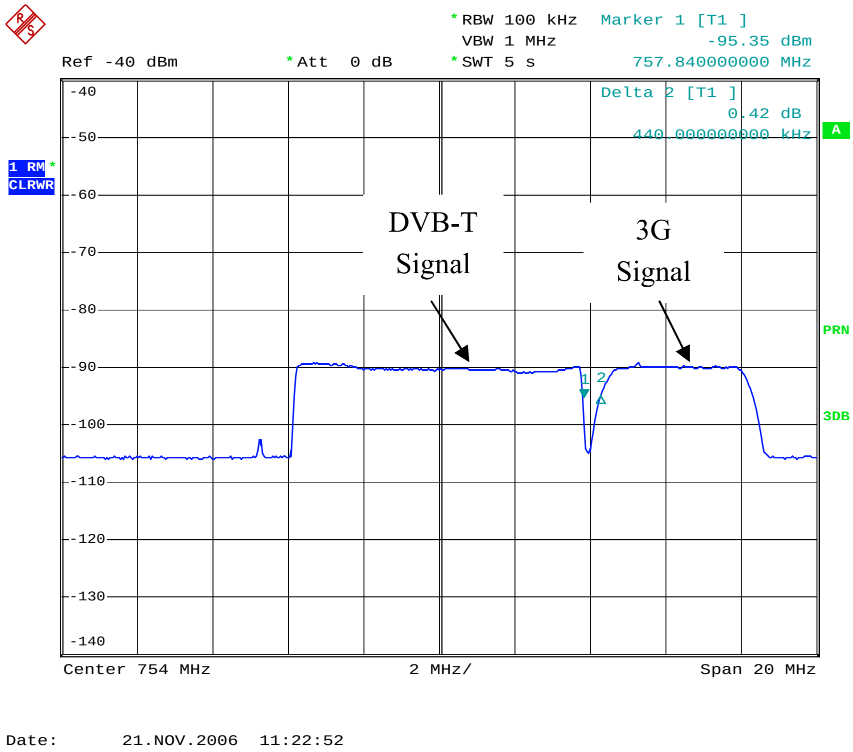

Figure 9: Plot wanted DVB-signal and adjacent 3G signal

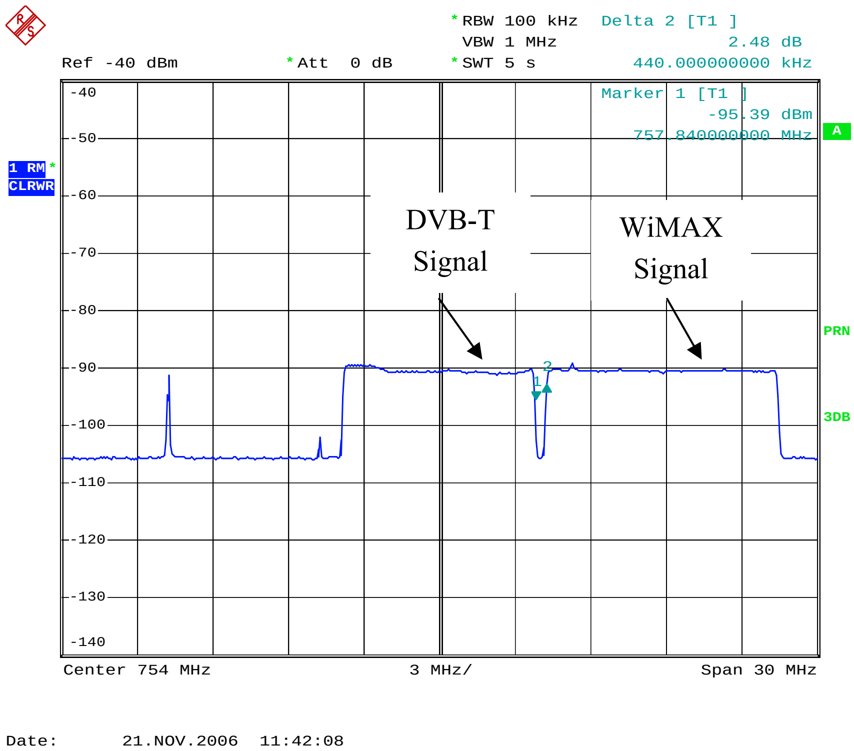

Figure 10: Plot wanted DVB-signal and adjacent WiMAX signal

The centre frequencies for the adjacent 3G and WiMAX interferers were 760.25 MHz and 762.8 MHz respectively. The centre frequency for N+9 channel 3G and WiMAX interferers was 826 MHz.

It should be noted that the cross-polar results for the mobile 3G and WiMAX interferers were particularly sensitive to small movements of 2 to 3 m, resulting in a 7 dB change in received interference power. This was not the case for the co-polar results, as the transmit and receive DVB-T antennas were both horizontally polarised. The 64QAM modulation scheme was chosen for the wanted DVB-T signal because it required 2 to 5 dB more protection compared with 16QAM conducted results for adjacent channel interference. Hence, providing a worst-case scenario for the radiated measurement test set-up described in Section 3.3.

4.3.1 Adjacent channel interference using a digital antenna

From Figure 11, it can be seen that the DVB-T receiver is most susceptible to 3G and WiMAX interference at separation of 10 m, where an EIRP 10 dBm and 8 dBm is respectively required to cause the onset on noticeable co-polar adjacent channel interference, with a minimum guard band of 0.4 MHz. This is most probably due to the interfering signal entering the side-lobe of TV antenna.

For cross-polar adjacent channel interference at a separation distance of 10 m, the EIRP values increase to 28 dBm and 26 dBm for 3G and WiMAX interference respectively (See Appendix B for tabulated results). This is expected because of the cross-polar coupling would require at least an additional 12 dB to achieve the required received interference levels when compared with horizontal results for a TV antenna.

The EIRP values peak for a separation distance of 55 m, where the adjacent 3G and WiMAX co-polar interference signals require an EIRP of 19 dBm and 20 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These higher values are due to the interference not being in the main lobe of the TV antenna and not in the side lobes at closer distances of 10 m or so.

For cross-polar adjacent channel interference at 55 m, no effect to the impairment of the wanted DVB-T picture was observed for adjacent channel interference for both 3G and WiMAX signals transmitting at an EIRP of 30 dBm. EIRPs of 33 dBm and 35 dBm were required to cause the onset of interference to the DVB-T receiver for co-polar 3G and WiMAX adjacent channel interference.

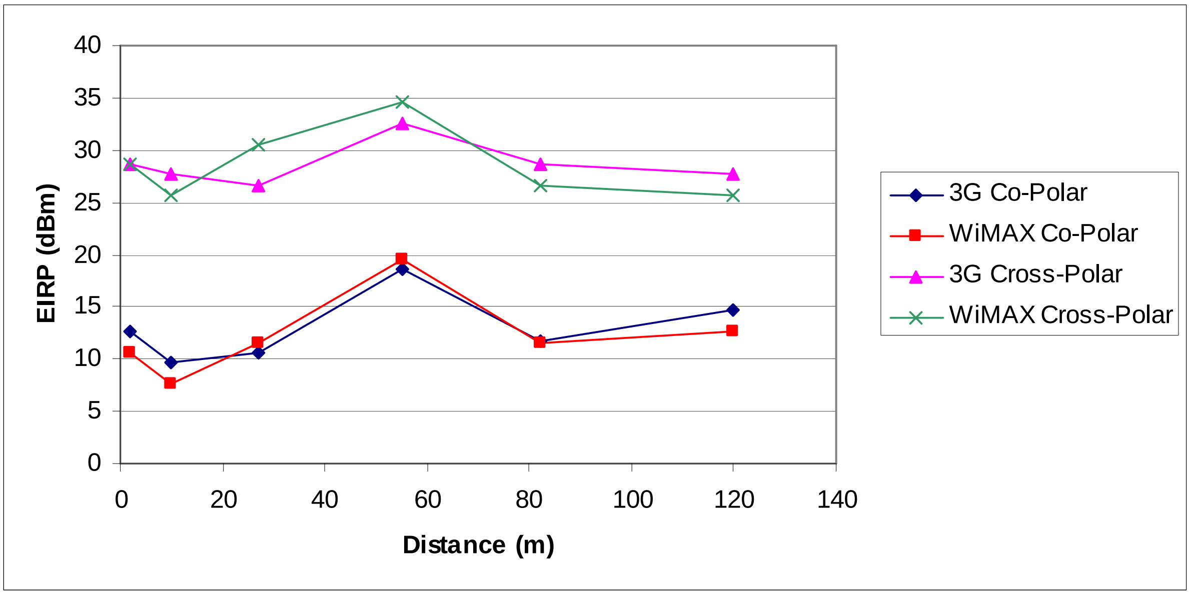

Figure 11: Measured EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna

At separation distances of 82 and 120 m, the adjacent channel interference from the 3G and WiMAX mobiles require less EIRP than at 55 m, because the mobile interferes have moved into the main beam the receiving TV antenna. At a separation of 82 m, both the 3G and WiMAX signals require an EIRP of 12 dBm to cause the onset of adjacent co-polar channel interference to the DVB-T receiver. For cross-polar interference, the 3G and WiMAX mobile stations require an EIRP of 29 and 27 dBm respectively.

Based on the conducted results of Table 10, the EIRP would effectively increase by 7 dB and 10 dB for 3G interference and 4 dB and 5 dB for WiMAX interference, for greater guard bands of 1 MHz and 2 MHz compared with the co-polar and cross-polar adjacent channel interference using a 0.4 MHz guard band.

The following two plots show EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T receiver for 1 MHz and 2 MHz guard bands, based on the onset of the degradation of the received picture quality.

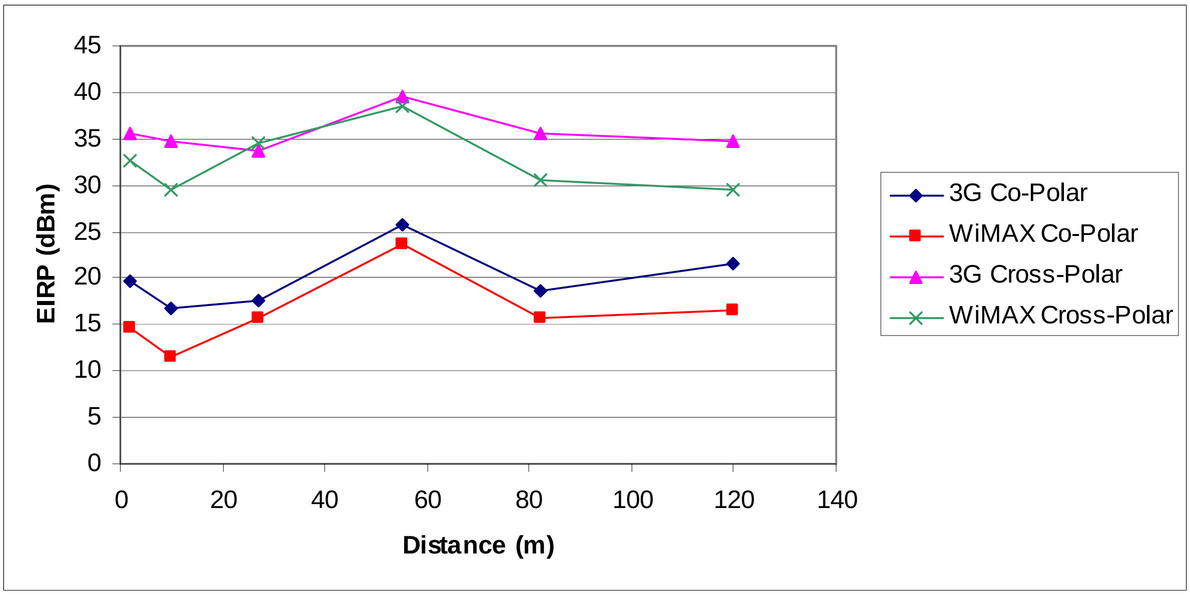

Figure 12: Estimated EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a 1 MHz guard band

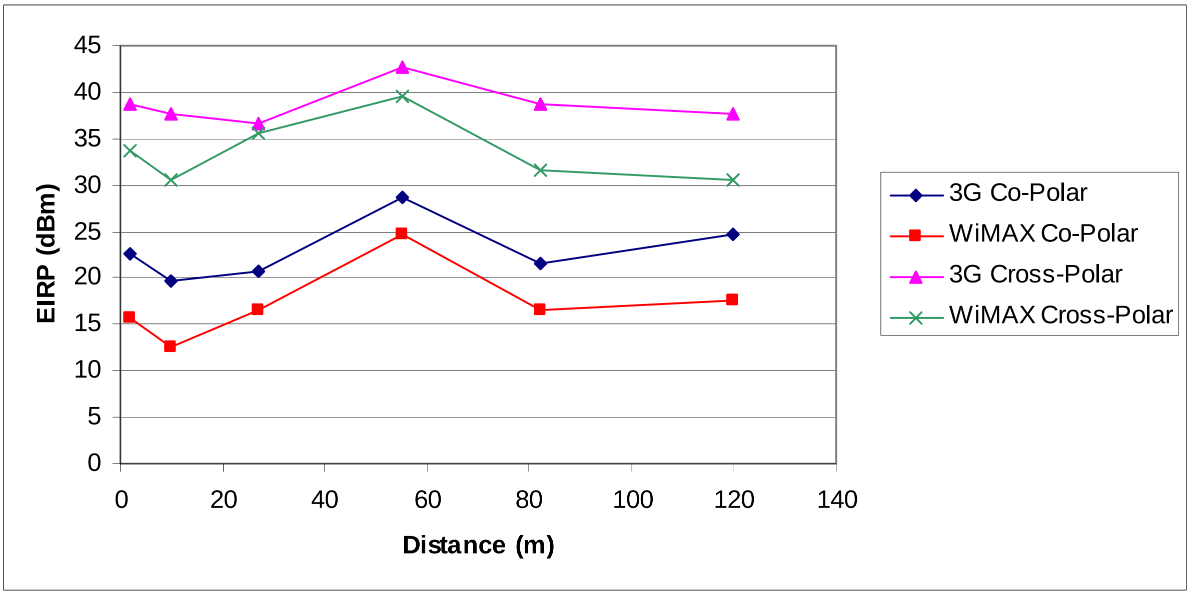

Figure 13: Estimated EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a 2 MHz guard band

4.3.2 N+9 channel interference using a digital antenna

For N+9 channel interference from 3G and WiMAX signals, the DVB-T receiver was most susceptible at a separation distance of 27 m. From the figure below, it can be seen that for 3G and WiMAX co-polar signals require an EIRP of 18 and 17 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These EIRP levels are 4 to 5 dB lower than those observed at a separation of 82 m and 120 m.

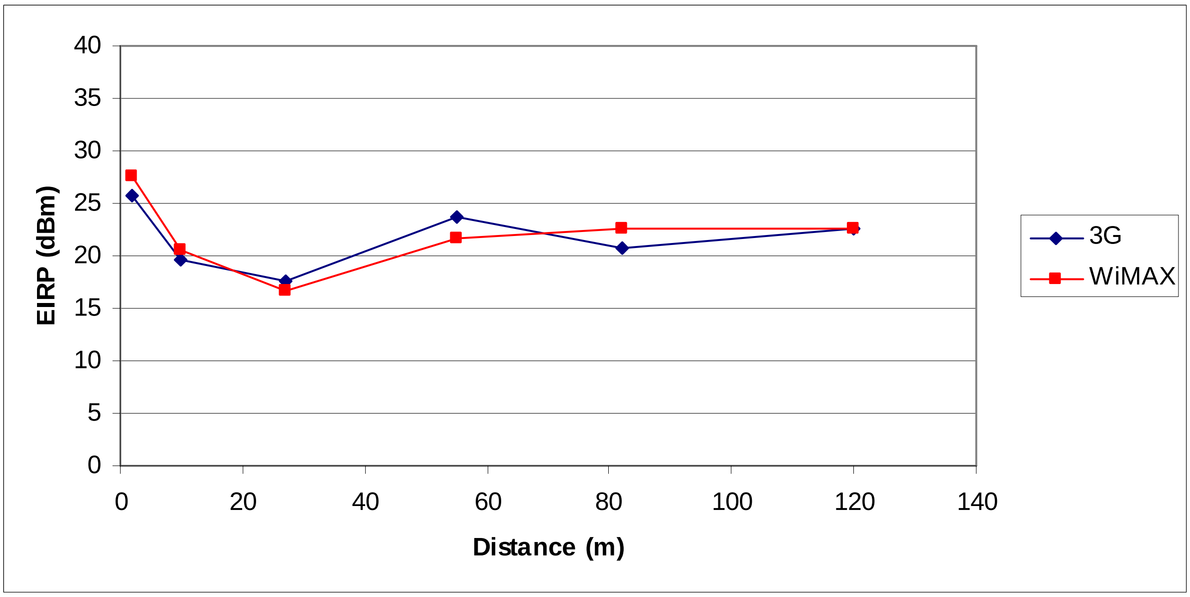

Figure 14: Measured EIRP as a function of distance for 3G and WiMAX N+9 channel co-polar interference to a DVB-T signal with a received electric field strength of 54 dBµV/m using a digital antenna

At a separation distance of 120 m, an EIRP of 22 dBm was required to cause interference for both 3G and WiMAX co-polar N+9 signals. No effect to the DVB-T picture quality was observed for cross-polar interference transmitting on the N+9 channel with an EIRP of 30 dBm. The maximum power that ERA was allowed to transmit was 30 dBm. Similar results were also obtained at 82 m and 55 m, with 1 to 3 dB difference when compared to the N+9 results measured at 120 m.

At closer separation distances of 10 m or less the 3G and WiMAX signals require EIRPs in excess of 20 dBm to cause an effect to the DVB-T receiver.

No effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both cross-polarised 3G and WiMAX signals transmitting at the maximum allowed EIRP of 30 dBm for all separation distances.

4.3.3 Adjacent channel interference at 64 dBµV/m

The next scenario involved increasing the wanted signal level by 10 dBµV/m to see if the wanted interference levels increased by the same amount. From Table 14, it can be seen that for co-polar interference, the 3G and WiMAX signals require an EIRP of 22 dBm each, to cause the onset of slightly noticeable degradation in the quality of the received picture, for a separation distance of 82 m. These EIRP levels have increased by exactly 10 dB, inline with the 10 dBµV/m increase of the wanted receiver field strength value from 54 dBµV/m to 64 dBµV/m for a separation distance of 82 m (See Table 21 in Appendix A).

Table 14:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 64 dBµV/m using a digital antenna at a separation distance of 82 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBµV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	82	H	Digital	64	22
3G	64QAM	82	V	Digital	64	No effect @ 30 dBm
WiMAX	64QAM	82	H	Digital	64	22
WiMAX	64QAM	82	V	Digital	64	No effect @ 30 dBm
N+9 Channel						
3G	64QAM	82	H	Digital	64	No effect @ 30 dBm
3G	64QAM	82	V	Digital	64	No effect @ 30 dBm
WiMAX	64QAM	82	H	Digital	64	No effect @ 30 dBm
WiMAX	64QAM	82	V	Digital	64	No effect @ 30 dBm

For cross-polar interference, no effect to the impairment of the wanted DVB-T picture was observed for adjacent channel interference for both 3G and WiMAX signals. Also, no effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both 3G and WiMAX signals, in both polarisations.

4.3.4 Adjacent channel interference using an analogue antenna

Next, the digital TV antenna was replaced by an analogue TV antenna and from the above table it can be seen that the results are very similar to Table 21, indicating a very similar antenna pattern and gain profile when measured at a separation distance of 82 m.

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Table 15:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using an analogue antenna at a separation distance of 82 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	82	H	Analogue	54	12
3G	64QAM	82	V	Analogue	54	30
WiMAX	64QAM	82	H	Analogue	54	12
WiMAX	64QAM	82	V	Analogue	54	29
N+9 Channel						
3G	64QAM	82	H	Analogue	54	21
3G	64QAM	82	V	Analogue	54	No effect @ 30 dBm
WiMAX	64QAM	82	H	Analogue	54	22
WiMAX	64QAM	82	V	Analogue	54	No effect @ 30 dBm

5 Interference to DVB-T Receivers using Portable Antennas

This section describes the calculated EIRPs required to cause 3G and WiMAX interference operating on the adjacent and N+9 DVB-T channel, based on the onset of the slightest degradation of the picture received picture quality. The EIRP calculations involved using the following portable antenna parameters:

- The received wanted DVB-T field strength decreases by 10 dB from a received height of 10 m to 1.5 m.
- The attenuation due to walls is 10 dB.
- The effective gain of the portable antenna, taking local clutter into account, is comparable to a dipole ~ 2 dBi, i.e. 10 dB less than a typical outdoor antenna.
- The cable loss of the portable antenna is negligible.

For a portable antenna to receive a DVB-T signal, the field strength would have to be in the order of 20 dBμV/m greater (height reduction plus building loss) than the minimum 47 dBμV/m. For the DVB-T receiver to receive the same wanted input power as via the outdoor TV antenna, the received field strength must be further increased typically by 10 dBμV/m because of the lower gain of the portable antenna compared to the outdoor TV antenna. Therefore, the field received at the portable TV antenna would have to be 57 dBμV/m.

The interfering 3G and/or WiMAX signal would be reduced by 10 dBμV/m, due to the attenuation loss from the building. The received interferer power into the DVB-T receiver would be a further 10 dB lower, because of the lower gain compared to the typical outdoor antenna. The overall net effect is that the interferer power entering the DVB-T receiver via the portable antenna would be 10 dB greater compared to the wanted DVB-T signal.

Assuming a minimum guard band of 0.4 MHz, the overall 3G and WiMAX EIRP measured for a wanted DVB-T field strength of 57 dBμV/m would be reduced by 7 dB, compared to the results shown in Figure 11 (See Figure 15).

From the Figure 15 below, it can be seen that the DVB-T receiver is most susceptible to 3G and WiMAX adjacent channel interference at 10 m for both co-polar and cross-polar signals. This is most probably due to the interfering signal entering the side-lobe of TV antenna. At 55 m the EIRP required to cause the onset of interference to the DVB-T receiver peaks and then drops off at 82m and 120 m as the interferer enters then main beam of the TV antenna.

The N+9 results would also be reduced by 7 dB compared to the results shown in Figure 11 (See Figure 16), to cause the onset of interference to the DVB-T receiver.

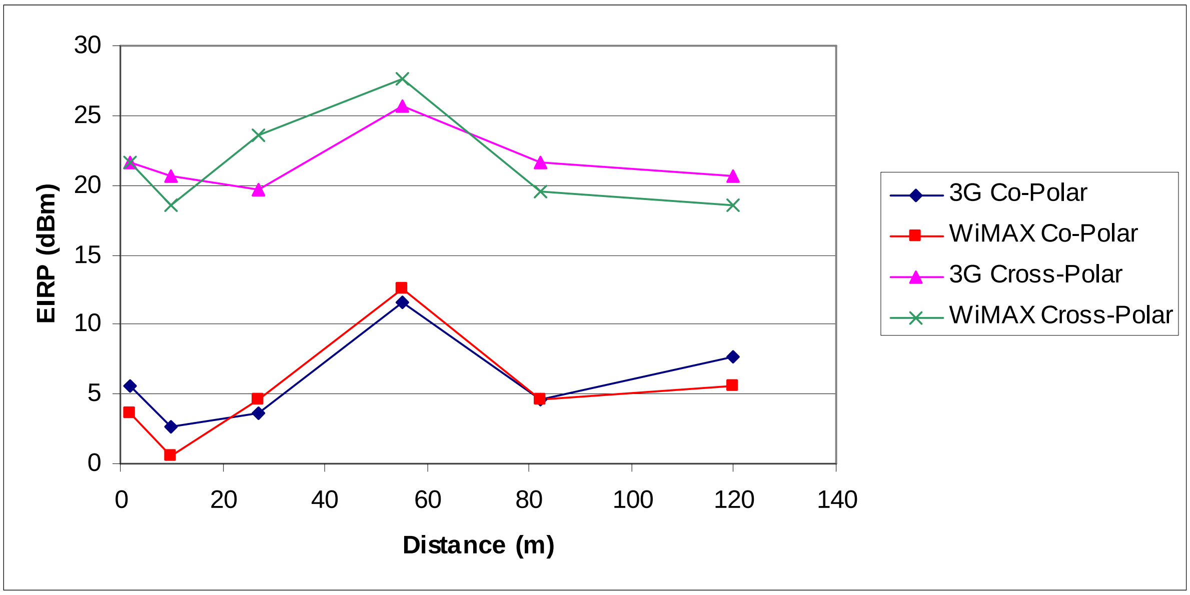

Figure 15: Calculated EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 57 dBμV/m using a portable antenna

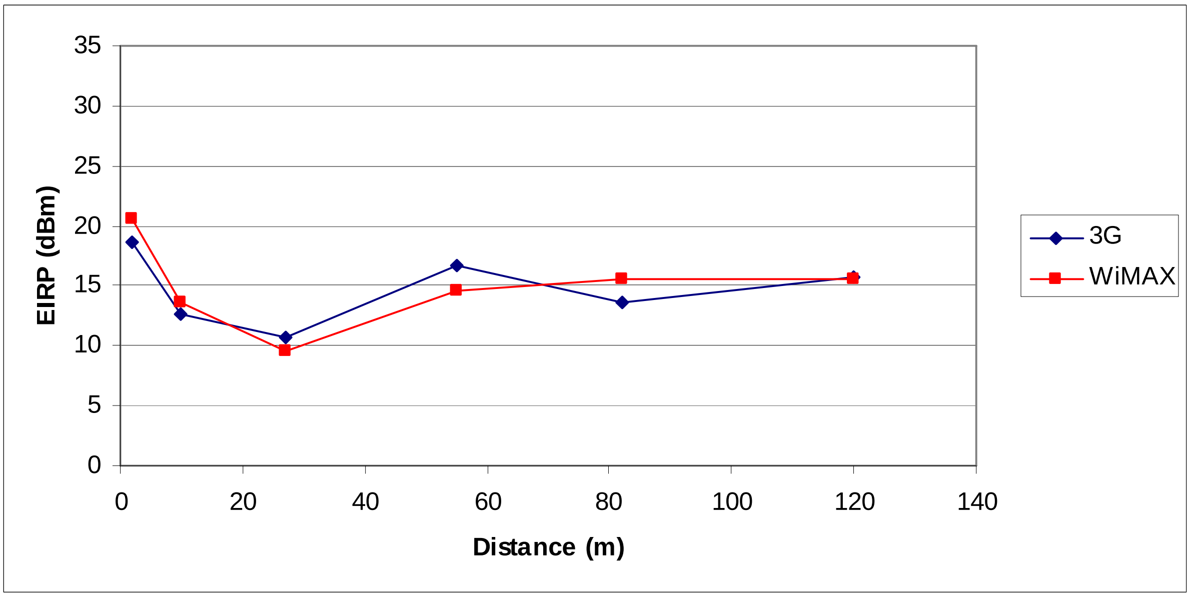

Figure 16: Calculated EIRP as a function of distance for 3G and WiMAX N+9 channel co-polar interference to a DVB-T signal with a received electric field strength of 57 dBμV/m using a portable antenna

6 Conclusions

Digital broadcasting is roughly six times more efficient than analogue, allowing more channels to be carried across fewer airwaves. Ofcom estimates that the digital switchover programme will release up to approximately 112 MHz of spectrum in the UHF (Ultra High Frequency) band for new uses. The potential future uses of this spectrum are wide ranging and include: broadband wireless access, cellular mobile (for example, 3G and systems beyond IMT-2000), private mobile radio, further terrestrial digital television services (including standard definition television, high definition television and local digital TV), mobile digital multimedia (including mobile television), and PMSE.

As part of the Digital Dividend Review, ERA was asked by Ofcom to investigate the potential interference to DVB-T receivers from 3G and WiMAX mobile transmitters for adjacent and N+9 channel separation. Measurements were undertaken on a range of DVB-T receivers commonly available in the UK. Both conducted and radiated measurements were performed to characterize the receiver performance in terms of the required Carrier-to-Interference (C/I) protection ratio.

6.1 Conducted Measurements

Conducted tests were performed to measure the C/I protection ratios for 3G and WiMAX adjacent channel interference for six DVB-T receivers (labelled 1, 2, 3, 4, 5 and 6). The table below shows the average adjacent channel interference for all six receivers, at three guard bands of 0.4 MHz, 1 MHz and 2 MHz.

Table 16:
Average C/I protection ratios for 3G and WiMAX adjacent channel interference to six DVB-T receivers

Interferer	Modulation	C/I (dB) with 0.4 MHz Guard Separation	C/I (dB) with 1 MHz Guard Separation	C/I (dB) with 2 MHz Guard Separation
3G	64QAM	-28	-35	-38
	16QAM	-32	-39	-42
WiMAX	64QAM	-27	-31	-32
	16QAM	-31	-35	-36

.

From the above table it can be seen that the 64QAM DVB-T signal requires a slightly higher protection of 3 to 4 dB more than compared with the 16QAM DVB-T signal against 3G and WiMAX adjacent channel interference. As the guard separation increases from 0.4 MHz (smallest allowable guard band) to 2 MHz, the C/I protection ratio decreases by 10 dB for 3G interference and 5 dB for WiMAX interference for both DVB-T modulations.

For 3G interference into the N+9 channel of the wanted DVB-T signal, test receiver 1 produced the worst C/I protection ratio of -27 dB which was on average 20 dB higher compared with the rest of the receivers, using 64QAM modulation. For the 16QAM modulated signal interfered by the 3G signal, the worst N+9 channel C/I protection ratio was -30 dB for test receiver 1, 23 dB higher compared with receivers 2 to 6.

For WiMAX interference into the N+9 channel of the wanted DVB-T signal, the worst C/I protection ratio was -24 dB for test receiver 1, on average 16 dB higher compared with the rest of the tested receivers using 64QAM modulation. For the 16QAM modulated signal interfered by the WiMAX signal, the worst N+9 channel C/I protection ratio was -28 dB, also for test receiver 1 and on average 18 dB higher compared with receivers 2 to 6.

The results indicate that there was a large variation between receiver 1 and receivers 2 to 6 for the N+9 issue, possibly due to the RF filter characteristics.

6.2 Radiated Measurements

Outdoor measurements were also performed to simulate the real interference environment from a mobile station. The on-air testing was performed on test receiver 1, which produced the worst N+9 protection ratio.

The 3G and WiMAX interference to DVB-T test receiver 1 was measured as EIRP in dBm for both co-polar and cross-polar antenna orientations. The wanted DVB-T signal measured at the receiver end was set to 54 dBµV/m for the majority of measurements, representing a typical received value for on the fringe area reception.

The local digital signal was transmitted on UHF channel 56 (754 MHz) using a Schwarzbeck UHALP 9107 antenna at a height of 10 m above the ground. The adjacent and N+9 channel interference was transmitted at 762 MHz and 826 MHz respectively.

Mobile interference measurements were made for a 64QAM DVB-T received signal with an electric field strength of 54 dBµV/m received by a medium gain digital antenna at 2 m, 10 m, 27 m, 55 m, 82 m and 120 m separation distances along the bore-sight of the TV antenna. The TV antenna was raised to a height of 8.5 m and the interfering antenna was positioned at a height of 1.5 m. The guard band between the wanted DVB-T channel and the interferer was set to 0.4 MHz, based on 3 dB channel bandwidths measured on the spectrum analyser. Other measurements involved using a higher wanted received electric field strength of 64 dBµV/m and an analogue antenna at a separation distance of 82 m.

From the figure below, it can be seen that the DVB-T receiver is most susceptible to 3G and WiMAX interference at a separation distance of 10 m, where an EIRP 10 dBm and 8 dBm is respectively required to cause the onset of noticeable co-polar adjacent channel interference.

The EIRP values peak for a separation distance of 55 m, where the adjacent 3G and WiMAX co-polar interference signals require an EIRP of 19 dBm and 20 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These higher values are due to the interference not being in the main lobe of the TV antenna and not in the side lobes at closer distances of 10 m or so.

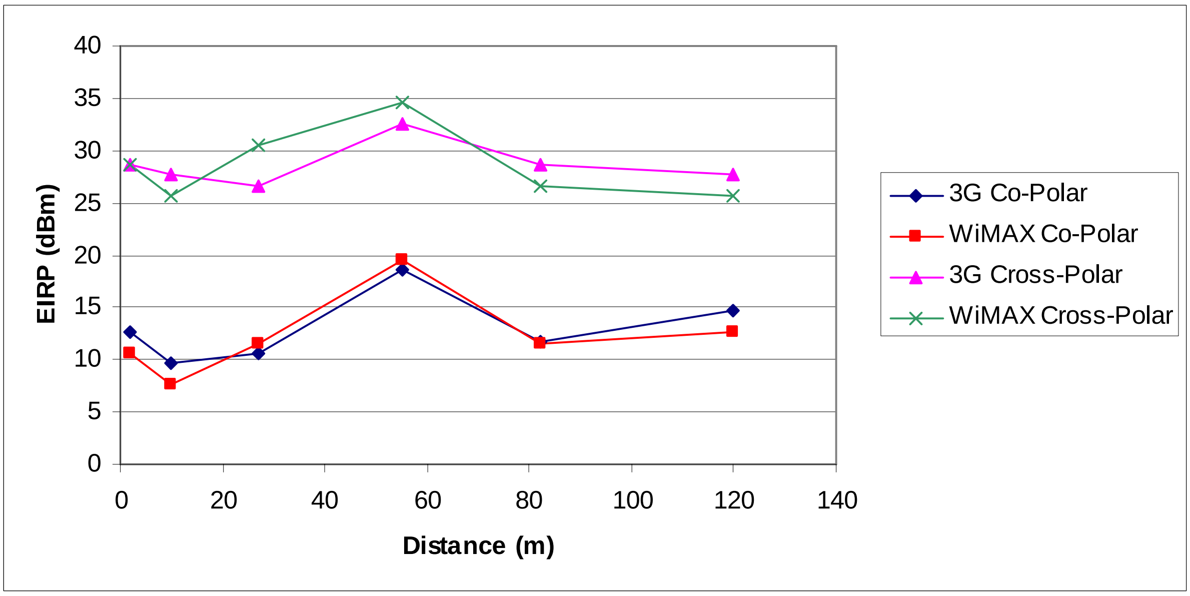

Figure 17: Measured EIRP as a function of distance for 3G and WiMAX adjacent channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna

At separation distances of 82 and 120 m, the adjacent channel interference from the 3G and WiMAX mobile requires less EIRP than at 55 m, because the mobile interferers have moved into the main beam the receiving TV antenna. At a separation of 82 m, both the 3G and WiMAX signals require an EIRP of 12 dBm to cause the onset of adjacent co-polar channel interference to the DVB-T receiver.

For cross-polar interference, the 3G and WiMAX mobile stations require an EIRP 15 to 18 dBm greater than the co-polar results for distances between 2 to 120 m.

Based on the conducted results above, the EIRP would effectively increase by 7 dB and 10 dB for 3G interference and 4 dB and 5 dB for WiMAX interference, for greater guard bands of 1 MHz and 2 MHz compared with the co-polar and cross-polar adjacent channel interference using a 0.4 MHz guard band.

For N+9 channel interference from 3G and WiMAX signals, the DVB-T receiver was most susceptible at a separation distance of 27 m. From the figure below, it can be seen that for 3G and WiMAX co-polar signals require an EIRP of 18 and 17 dBm respectively, to cause the onset of slightly noticeable degradation in the quality of the received picture. These EIRP levels are 4 to 5 dB lower than those observed at a separation of 82 m and 120 m.

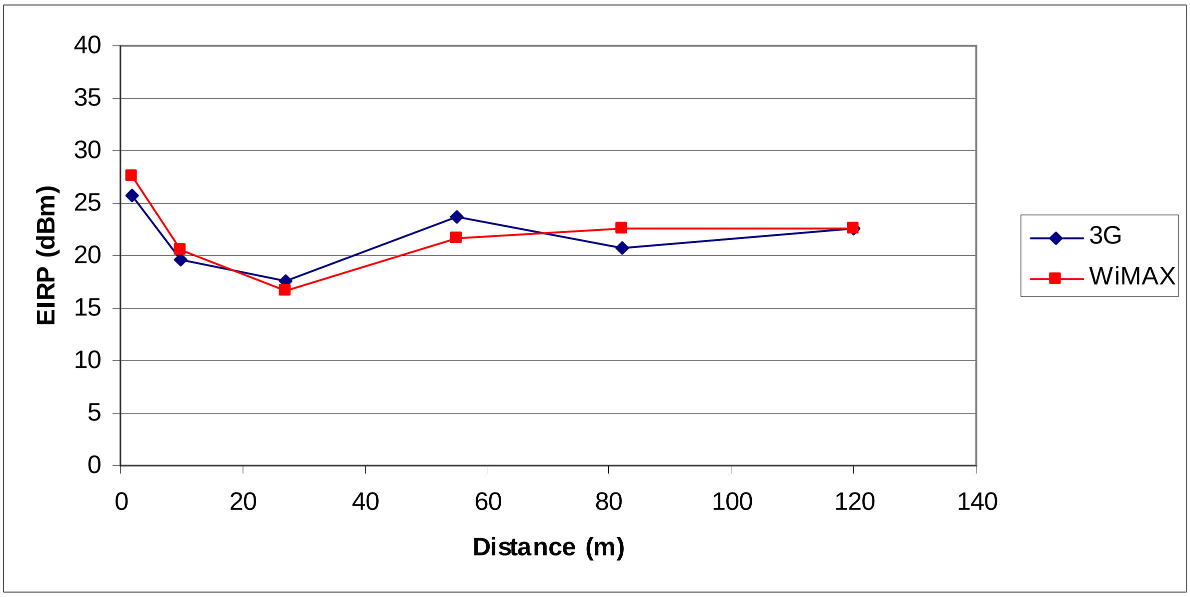

Figure 18: Measured EIRP as a function of distance for 3G and WiMAX N+9 channel co-polar interference to a DVB-T signal with a received electric field strength of 54 dBµV/m using a digital antenna

At a separation distance of 120 m, an EIRP of 22 dBm was required to cause interference for both 3G and WiMAX co-polar N+9 signals. No effect to the DVB-T picture quality was observed for cross-polar interference transmitting on the N+9 channel with an EIRP of 30 dBm. The maximum power that ERA was allowed to transmit was 30 dBm. Similar results were also obtained at 82 m and 55 m, with 1 to 3 dB difference when compared to the N+9 results measured at 120 m.

At closer separation distances of 10 m or less the 3G and WiMAX signals require EIRPs in excess of 20 dBm to cause an effect to the DVB-T receiver.

No effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both cross-polarised 3G and WiMAX signals transmitting at the maximum allowed EIRP of 30 dBm for all separation distances.

When the wanted DVB-T signal level increased from 54 dBµV/m to 64 dBµV/m for a separation distance of 82 m, the co-polar interference for 3G and WiMAX signals increased by exactly 10 dB, inline with the 10 dBµV/m increase of the wanted receiver field strength value. For cross-polar interference, no effect to the impairment of the wanted DVB-T picture was observed for adjacent channel interference for both 3G and WiMAX signals. Also, no effect to the impairment of the wanted DVB-T picture was observed for N+9 channel interference for both 3G and WiMAX signals, in both polarisations.

Finally, when digital TV antenna was replaced by an analogue TV antenna the results were very similar, indicating a very similar antenna pattern and gain profile when measured at a separation distance of 82 m.

6.3 3G and WiMAX Interference to Portable TV Antennas

3G and WiMAX interference to a portable TV antenna was also analysed, based on the outdoor radiated measurement results.

For a portable antenna to receive a DVB-T signal, the field strength would have to be in the order of 20 dBμV/m greater (height reduction plus building loss) than the minimum 47 dBμV/m. For the DVB-T receiver to receive the same wanted input power as via the outdoor TV antenna, the received field strength must be further increased typically by 10 dBμV/m because of the lower gain of the portable antenna compared to the outdoor TV antenna. Therefore, the field received at the portable TV antenna would have to be 57 dBμV/m.

The interfering 3G and/or WiMAX signal would be reduced by 10 dBμV/m, due to the attenuation loss from the building. The received interferer power into the DVB-T receiver would be a further 10 dB lower, because of the lower gain compared to the typical outdoor antenna. The overall net effect is that the interferer power entering the DVB-T receiver via the portable antenna would be 10 dB greater compared to the wanted DVB-T signal.

Assuming a minimum guard band of 0.4 MHz, the overall 3G and WiMAX EIRP measured for a wanted DVB-T field strength of 57 dBμV/m would be reduced by 7 dB, compared to the results shown in Figure 11 (See Figure 15). The N+9 EIRP results would also be reduced by 7 dB compared to the results shown in Figure 14 (See Figure 16), to cause the onset of interference to the DVB-T receiver.

7 References

[1] http://www.ofcom.org.uk/radiocomms/ddr/documents/ddr_tor/

[2] 3G WiMAX into DTT Receivers Proposal v2a.doc

APPENDIX A
Conducted Measurement Plots

A.1 Receiver 1

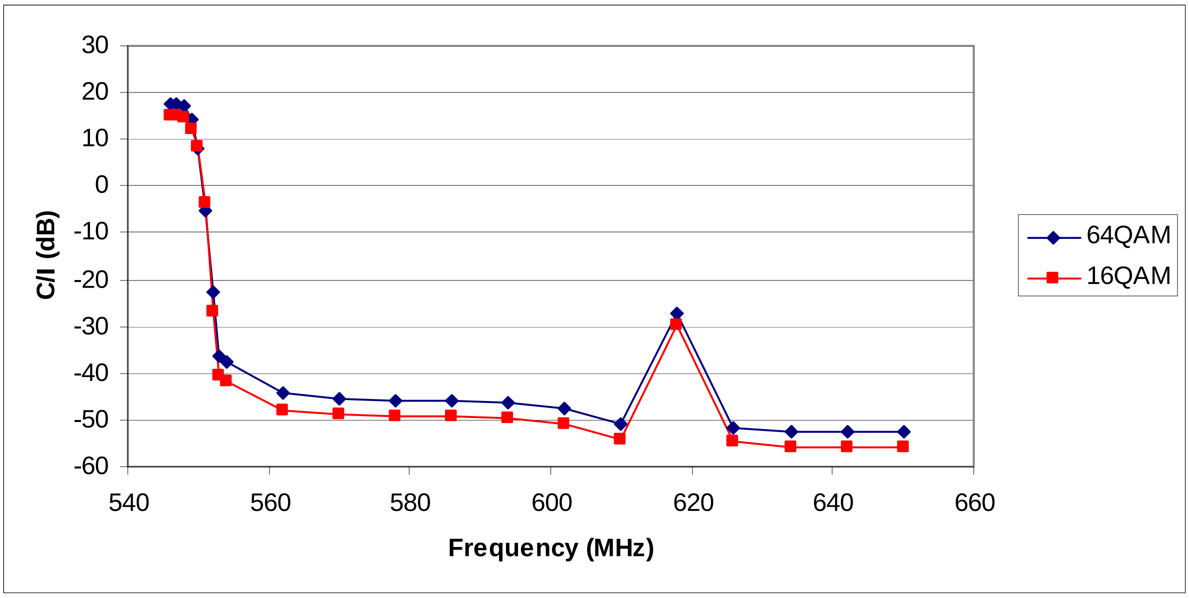

Figure 19: Protection ratio for 3G interference to DVB-T receiver 1

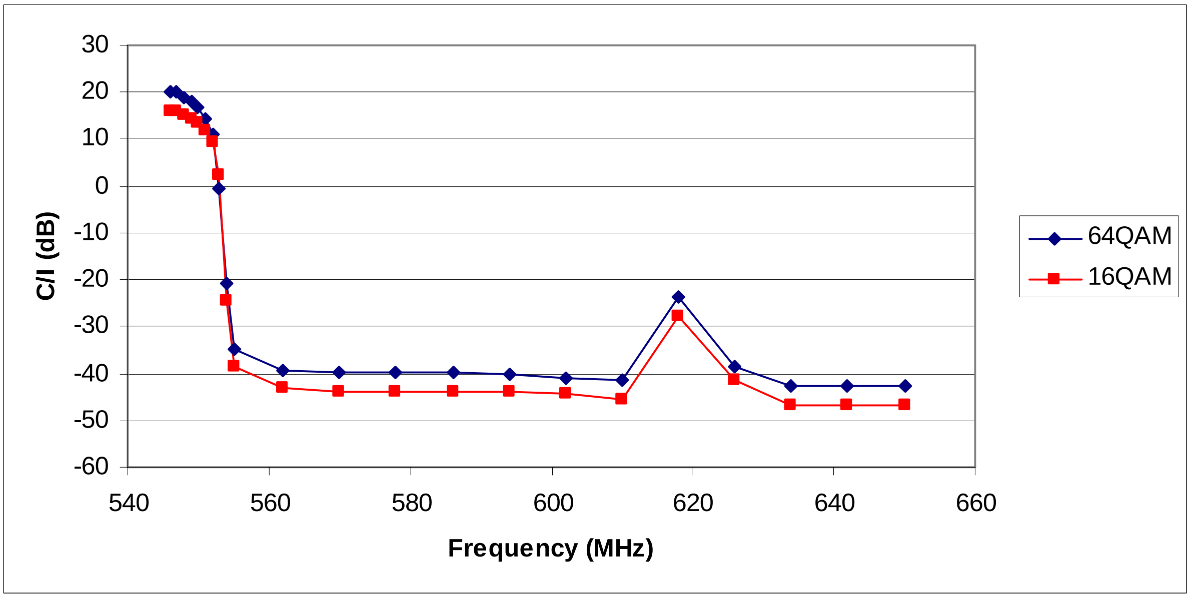

Figure 20: Protection ratio for WiMAX interference to DVB-T receiver 1

A.2 Receiver 2

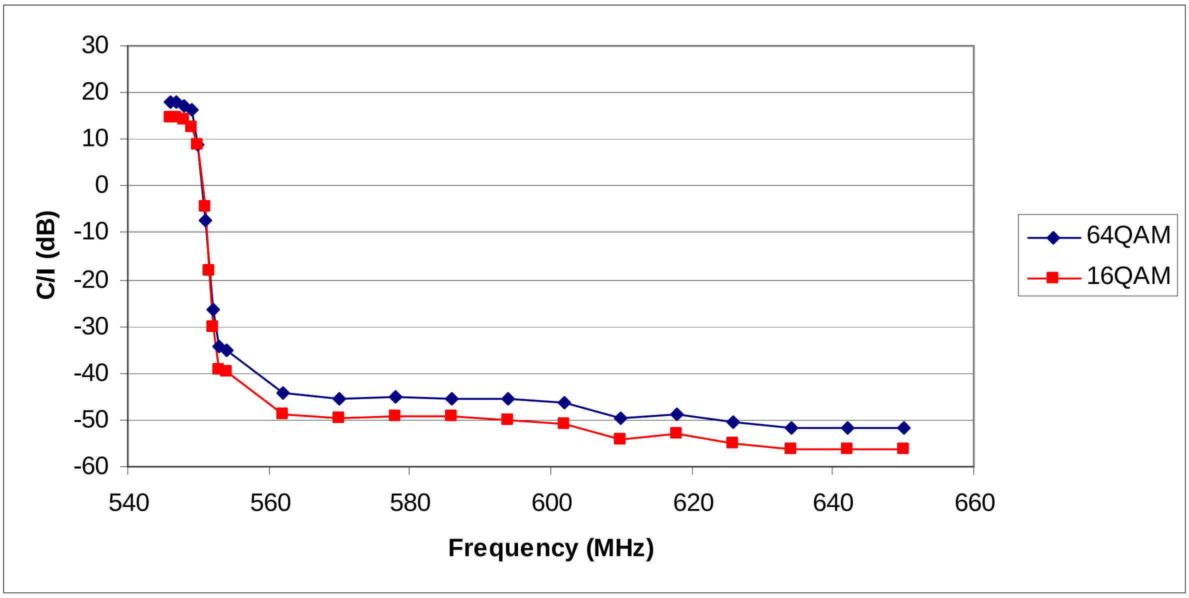

Figure 21: Protection ratio for 3G interference to DVB-T receiver 2

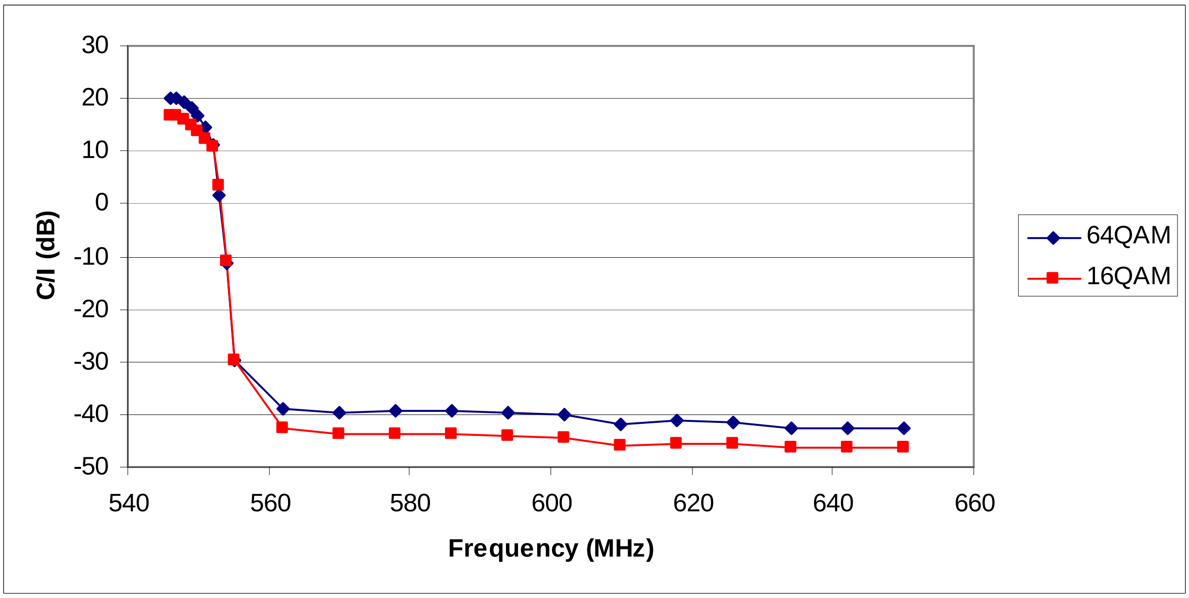

Figure 22: Protection ratio for WiMAX interference to DVB-T receiver 2

A.3 Receiver 3

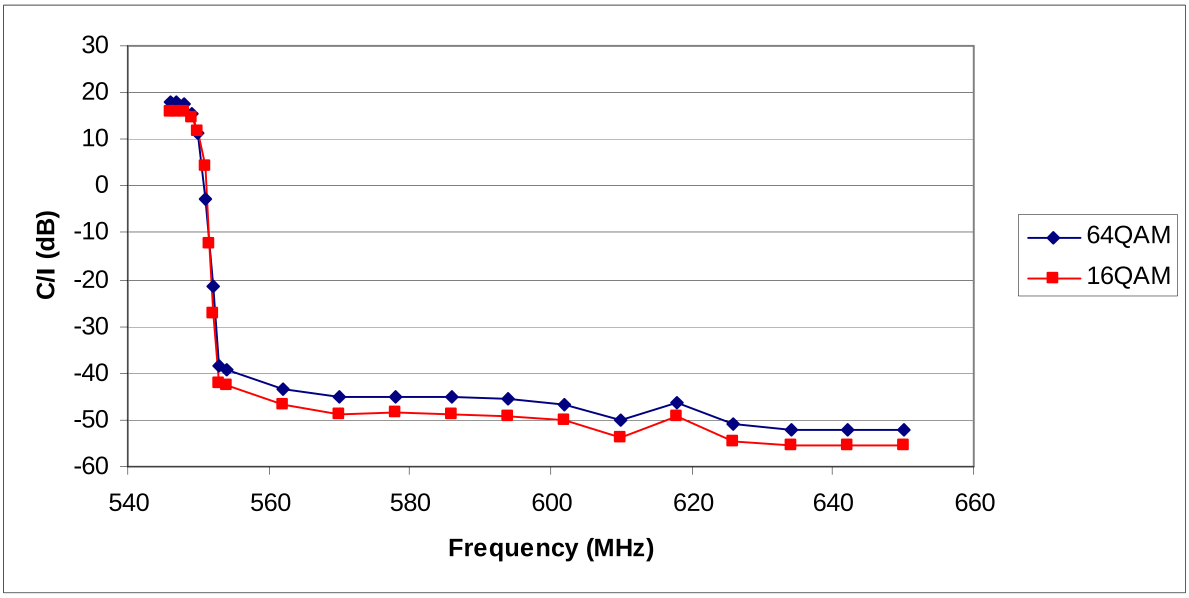

Figure 23: Protection ratio for 3G interference to DVB-T receiver 3

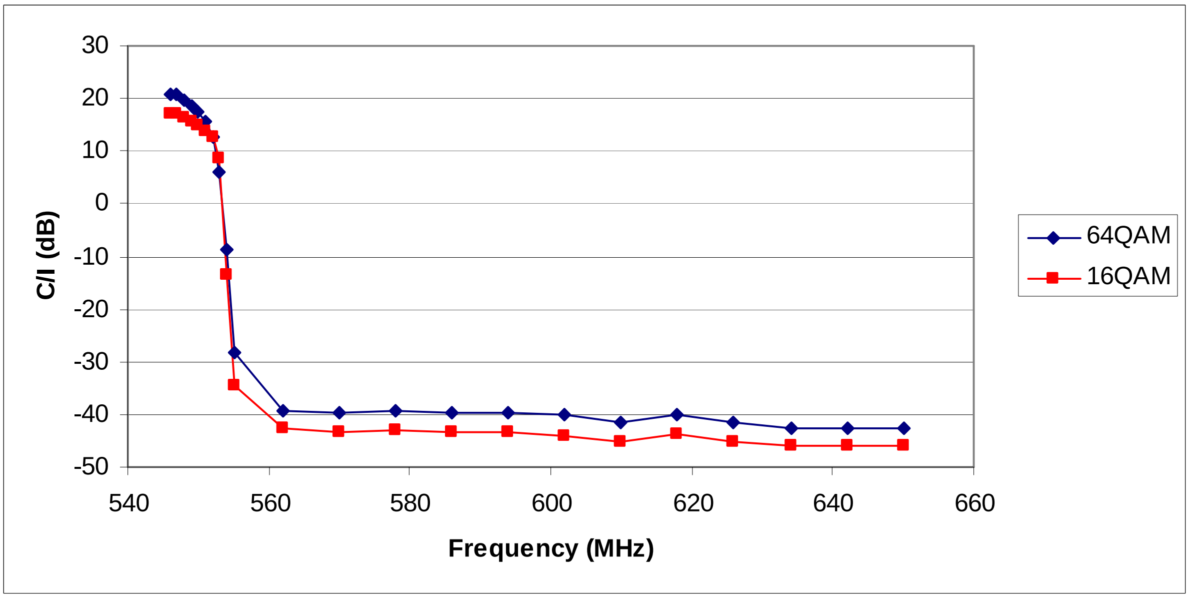

Figure 24: Protection ratio for WiMAX interference to DVB-T receiver 3

A.4 Receiver 4

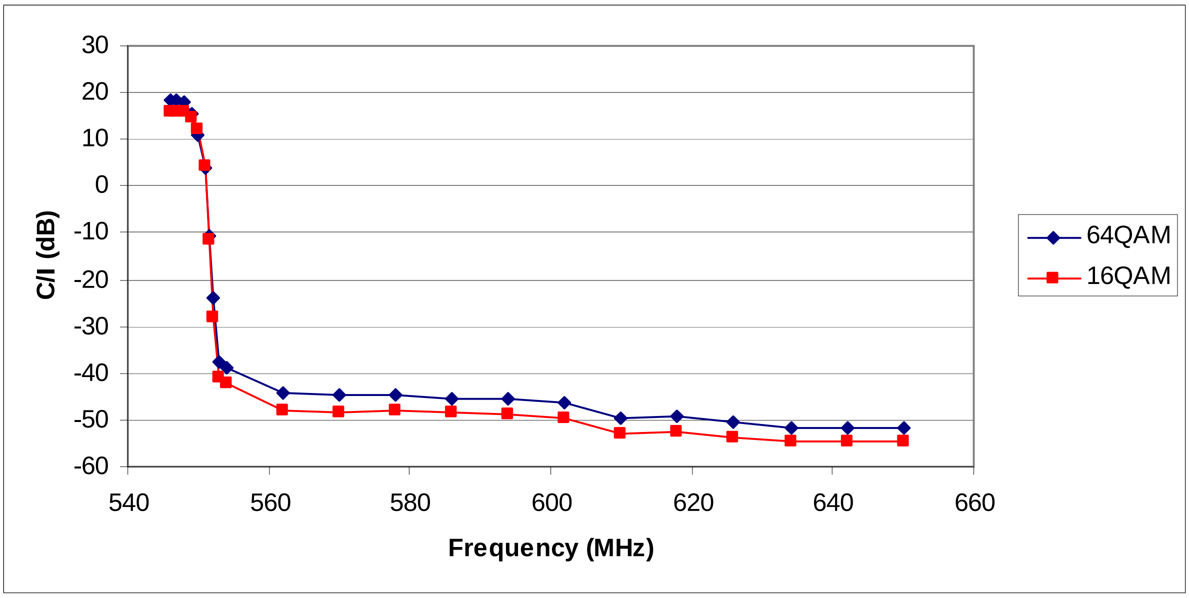

Figure 25: Protection ratio for 3G interference to DVB-T receiver 4

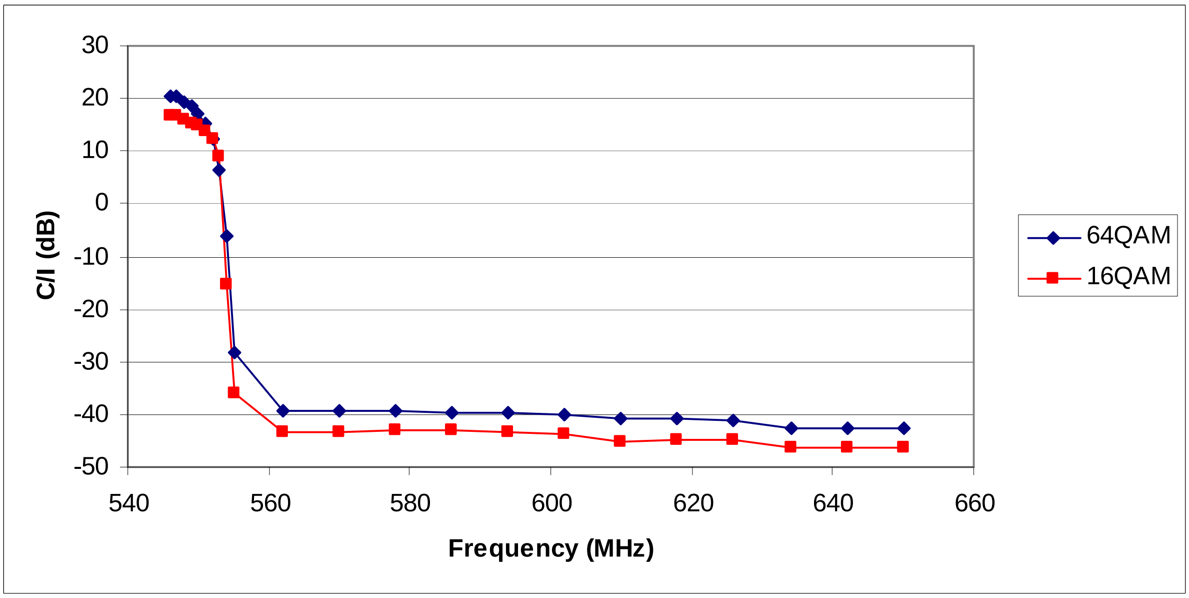

Figure 26: Protection ratio for WiMAX interference to DVB-T receiver 4

A.5 Receiver 5

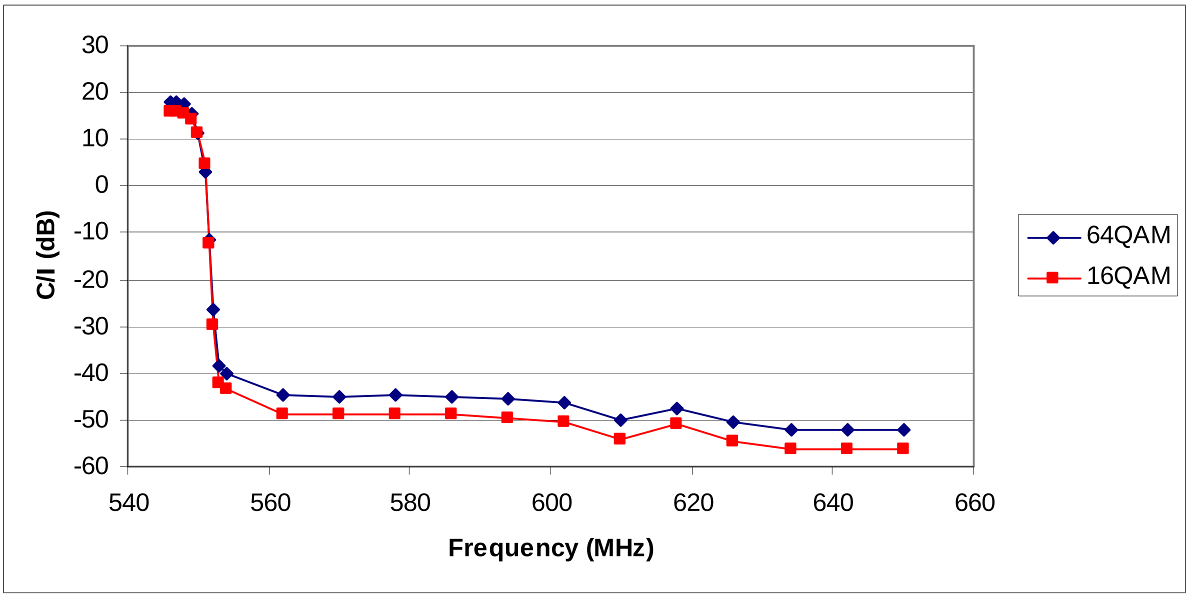

Figure 27: Protection ratio for 3G interference to DVB-T receiver 5

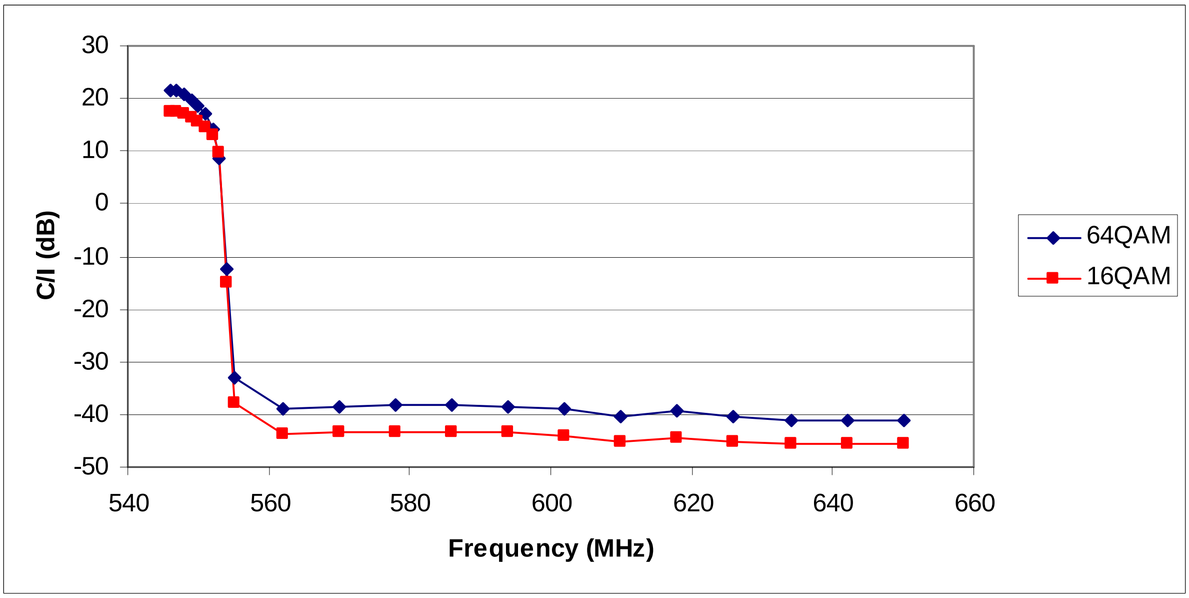

Figure 28: Protection ratio for WiMAX interference to DVB-T receiver 5

A.6 Receiver 6

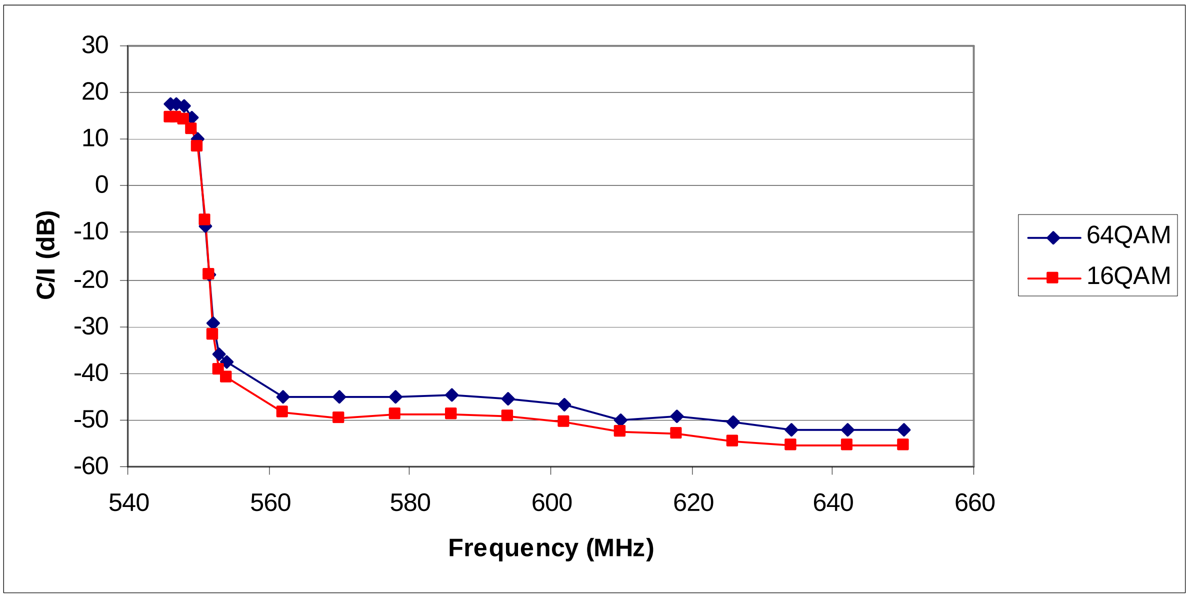

Figure 29: Protection ratio for 3G interference to DVB-T receiver 6

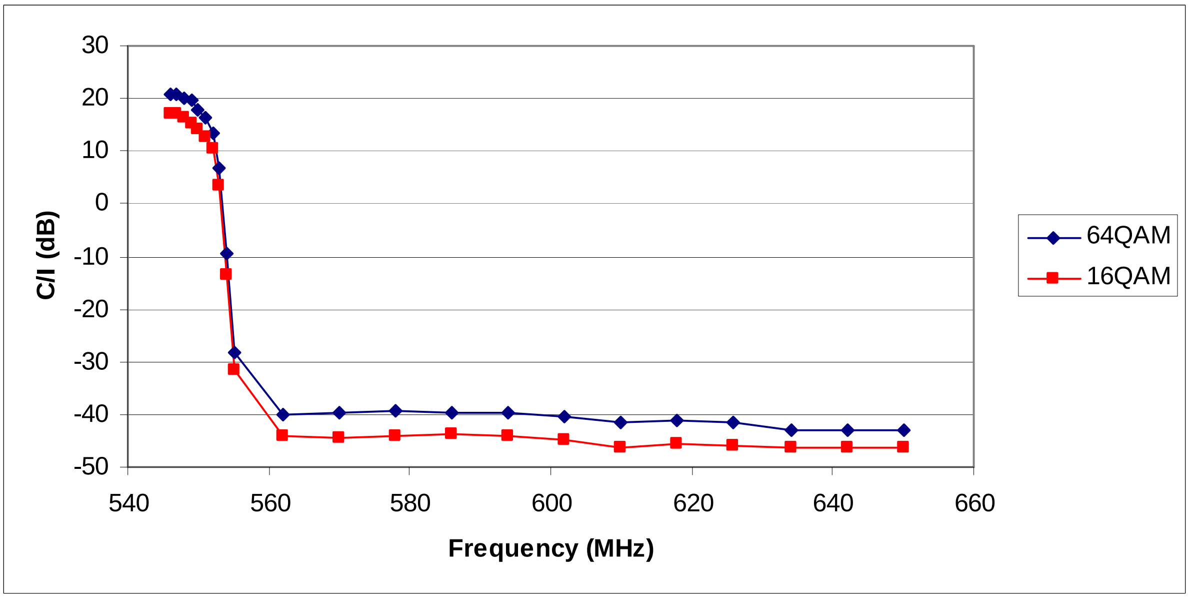

Figure 30: Protection ratio for WiMAX interference to DVB-T receiver 6

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APPENDIX B
Radiated Results

Table 17:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBµV/m using a digital antenna at a separation distance of 2 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	2	H	Digital	54	13
3G	64QAM	2	V	Digital	54	29
WiMAX	64QAM	2	H	Digital	54	11
WiMAX	64QAM	2	V	Digital	54	29
N+9 Channel						
3G	64QAM	2	H	Digital	54	26
3G	64QAM	2	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	2	H	Digital	54	28
WiMAX	64QAM	2	V	Digital	54	No effect @ 30 dBm

Table 18:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna at a separation distance of 10 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	10	H	Digital	54	10
3G	64QAM	10	V	Digital	54	28
WiMAX	64QAM	10	H	Digital	54	8
WiMAX	64QAM	10	V	Digital	54	26
N+9 Channel						
3G	64QAM	10	H	Digital	54	20
3G	64QAM	10	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	10	H	Digital	54	21
WiMAX	64QAM	10	V	Digital	54	No effect @ 30 dBm

Table 19:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna at a separation distance of 27 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	27	H	Digital	54	11
3G	64QAM	27	V	Digital	54	27
WiMAX	64QAM	27	H	Digital	54	12
WiMAX	64QAM	27	V	Digital	54	31
N+9 Channel						
3G	64QAM	27	H	Digital	54	18
3G	64QAM	27	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	27	H	Digital	54	17
WiMAX	64QAM	27	V	Digital	54	No effect @ 30 dBm

Table 20:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna at a separation distance of 55 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	55	H	Digital	54	19
3G	64QAM	55	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	55	H	Digital	54	20
WiMAX	64QAM	55	V	Digital	54	No effect @ 30 dBm
N+9 Channel						
3G	64QAM	55	H	Digital	54	24
3G	64QAM	55	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	55	H	Digital	54	22
WiMAX	64QAM	55	V	Digital	54	No effect @ 30 dBm

Table 21:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna at a separation distance of 82 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	82	H	Digital	54	12
3G	64QAM	82	V	Digital	54	29
WiMAX	64QAM	82	H	Digital	54	12
WiMAX	64QAM	82	V	Digital	54	27
N+9 Channel						
3G	64QAM	82	H	Digital	54	21
3G	64QAM	82	V	Digital	54	No effect @ 30 dBm
WiMAX	64QAM	82	H	Digital	54	23
WiMAX	64QAM	82	V	Digital	54	No effect @ 30 dBm

Table 22:
Measured EIRP of 3G and WiMAX for adjacent and N+9 channel interference to a DVB-T signal with a received electric field strength of 54 dBμV/m using a digital antenna at a separation distance of 120 m

Interference Signal	Wanted Modulation	Distance (m)	Polarisation	Receive Antenna	Received E-field (dBuV/m)	EIRP (dBm)
Adjacent Channel						
3G	64QAM	120	H	Analogue	54	15
3G	64QAM	120	V	Analogue	54	28
WiMAX	64QAM	120	H	Analogue	54	13
WiMAX	64QAM	120	V	Analogue	54	27
N+9 Channel						
3G	64QAM	120	H	Analogue	54	23
3G	64QAM	120	V	Analogue	54	No effect @ 30 dBm
WiMAX	64QAM	120	H	Analogue	54	23
WiMAX	64QAM	120	V	Analogue	54	No effect @ 30 dBm

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APPENDIX C
Test Equipment

B.1 Test Equipment List

- R&S MPEG2 measurement generator DVG – 2068.8600.03
- R&S TV test transmitter SFQ – 2072.5501.10
- Agilent MXG signal generator
- Agilent E4438C signal generator
- R&S AMIQ external modulator
- Wiltron Bridge
- HP splitter
- Amplifier Research 5W100 amplifier
- Marconi Programmable attenuators
- R&S ESPG spectrum analyser
- DVB-T receiver
- TV to display the wanted DVB-T signal
- 50 Ω to 75 Ω pad
- Schwarzbeck UHALP 9107 x2
- Standard TV scart lead