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ERA Business Unit:	ERA Technology Ltd
Report Title:	**Conducted Measurements to Quantify Different Types of Interference in the DDR Frequency Spectrum**
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Client:	Ofcom
ERA Report Number:	2007-0632
ERA Project Number:	7G0403801
Report Version:	Final Report

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October 2007

Ref. BR/vs/62/04038/Rep-6190

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Summary

This document describes conducted measurements performed by ERA Technology, to quantify the interference interaction to and from the following services - digital video broadcast – terrestrial (DVB-T), digital video broadcast – handheld (DVB-H), universal telecommunications systems (UMTS) and WiMAX interference in the Digital Dividend Review (DDR) spectrum.

The measurement scenarios considered were:

1. UMTS user equipment interference into a DVB-T receiver.
2. DVB-T interference into UMTS user equipment.
3. UMTS node B interference into a DVB-T receiver.
4. DVB-T interference into UMTS Node B.
5. Mobile WiMAX mobile station interference into a DVB-T receiver.
6. Mobile WiMAX base station interference into a DVB-T receiver.
7. DVB-T interference into a fixed WiMAX system.
8. DVB-T interference into a DVB-H handset.

The test method and parameters for each of the conducted measurement scenarios are documented in this report and a summary of the results is given below.

<u>Interference into a DVB-T receiver</u>

The table below shows the measured carrier-to-interference (C/I) protection ratio comparison (for N-2 to N+2 channels and channel N+9) of DVB-T, UMTS and WiMAX interference and into a typically performing DVB-T receiver.

Table 1: Comparison of C/I protection ratios for DVB-T, UMTS and WiMAX interference into a typically performing DVB-T receiver (64-QAM FEC 2/3)

Interferer	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
DVB-T (static)	-52	-37	15	-33	-47	-49
UMTS UE (static)	-51	-47	20	-44	-44	-50
UMTS UE TPC (3 km/h)	-33	-24	29	-19	-30	-38
UMTS UE TPC (50 km/h)	-37	-26	24	-26	-36	-43
UMTS UE TPC (120 km/h)	-33	-23	28	-22	-32	-38
Node B (static)	-51	-43	18	-41	-45	-50
UMTS Node B (aggregate)	-37	-24	27	-22	-33	-40
Mobile WiMAX uplink	-42	-34	20	-32	-39	-44
Mobile WiMAX downlink	-48	-39	20	-38	-43	-43

From the table above, it can be concluded that a typically performing DVB-T receiver is most susceptible to UMTS UE uplink and Node B downlink interference with transmit power control (TPC) used to compensate for a Rayleigh fading channel at speeds of 3 km/h, 50 km/h and 120 km/h. A mobile WiMAX uplink signal requires 5 to 10 dB more power to cause the onset of interference into the DVB-T receiver compared with the UMTS results. A mobile WiMAX down link signal requires the most power to impair the picture quality of the received DVB-T signal.

The 4 to 5 dB difference between the mobile WiMAX uplink out of band interference results compared with the mobile WiMAX downlink out of band results may be due to the more impulsive nature of the subscriber signal compared to the base station signal.

Overall, the profile of the C/I protection results for UMTS and mobile WIMAX interference into a typically performing DVB-T receiver is similar to that compared for DVB-T interference [11].

DVB-T as the interferer

The conducted measurement results show that:

- For DVB-T co-channel interference a C/I protection of -5 dB and -6.5 dB is required for the UMTS UE operating at a received power of -60 dBm and -75 dBm respectively. At frequency separations of 8 MHz and beyond, the C/I protection ratio decreases to approximately -45 dB for the receiver operating at -60 dBm and -75 dBm.

- For DVB-T co-channel interference, a C/I protection of -10 dB is required for the UMTS Node B operating at 50-60 % load capacity. At frequency separations of ±8 MHz, the C/I protection ratio decreases to approximately -42 to -45 dB for the device under test. At frequency separations of ±16 MHz, the C/I protection ratio further decreases to -52 dB.

- A C/I protection ratio of -5 dB is required for co-channel DVB-T interference into a fixed WiMAX system. For adjacent channel interference (20 MHz separation between centre frequencies) a C/I protection ratio of -21 dB is required. This ratio decreases to -44 dB for two WiMAX channel frequency separations and flattens off for frequency offsets greater than 56 MHz.

- A C/I protection ratio of 8 dB is required for co-channel interference from a DVB-T signal into a DVB-H handset. This ratio decreases to -43 dB and -45 dB for N-1 and N+1 adjacent channel interference respectively. This protection ratio further decreases approximately by 8 to 12 dB to -51 dB and -57 dB for channels N-2 and N+2 respectively.

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Abbreviations List

AWGN	Additive White Gaussian Noise
BER	Bit Error Ratio
BLER	Block Error Ratio
BS	Base Station
CDMA	Code Division Multiple Access
DCH	Dedicated Channel
DPCH	Dedicated Physical Channel
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
DDR	Digital Dividend Review
DL	Downlink
DCD	Downlink Channel Descriptor
DTT	Digital Terrestrial Television
DVB-H	Digital Video Broadcast-Handheld
DVB-T	Digital Video Broadcast-Terrestrial
FCH	Frame Control Header
FEC	Forward Error Correction
IE	Information Element
IF	Intermediate Frequency
MAP	Medium Access Protocol
MIMO	Multiple In Multiple Out
MS	Mobile Station

MUS	Minimum Usable Sensitivity
PMSE	Programming Making and Special Events
PUSC	Partial Usage of Sub-channels
RF	Radio Frequency
RBW	Resolution Bandwidth
RMC	Reference Measurement Channel
RRM	Radio Resource Management
SS	Signal Simulator
STC	Space Time Coding
TPC	Transmit Power Control
TPS	Transport Parameters Signalling
TS	Transport Stream
UL	Uplink
UCD	Uplink Channel Descriptor
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
VBW	Video Bandwidth
WCDMA	Wideband CDMA

1. Introduction

Ofcom announced on 17 November 2005 the beginning of its Digital Dividend Review (DDR) – the project, will examine the options arising from the release of spectrum afforded by the digital switchover program. The available spectrum includes the spectrum released by analogue switch off – the ultra high frequency (UHF) spectrum in bands IV and V (470 – 862 MHz) with the exception of the spectrum reserved for the six digital terrestrial television (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 program will release up to approximately 112 MHz of spectrum in the UHF 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, 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).

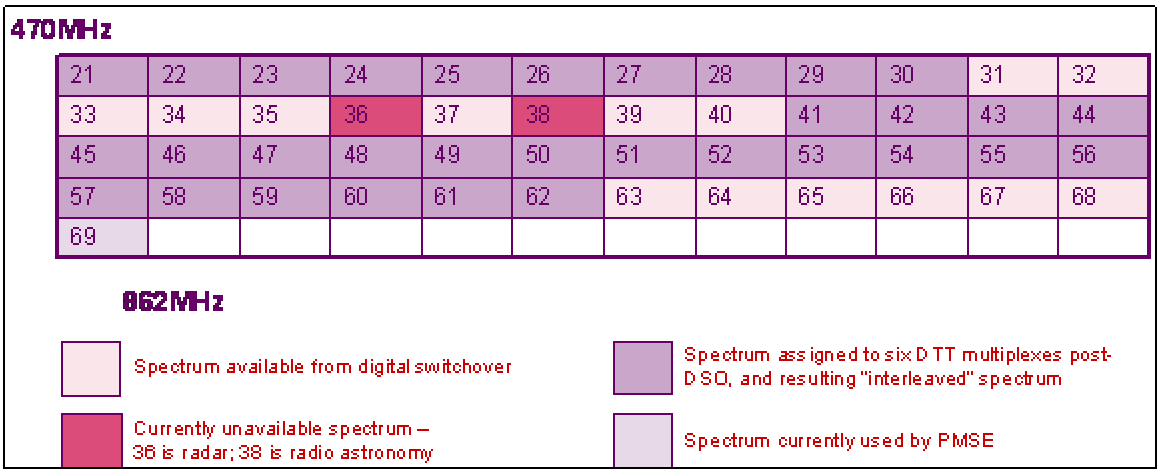

Figure 1: Outline of band plan for 470-862 MHz

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

After switch-over, fourteen 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 six DTT multiplexes. The use of all but channel 40 of the available spectrum has the potential to cause interference due the N+9 image channel.

As part of the DDR, ERA was asked by Ofcom to investigate the potential interference to digital video broadcast-terrestrial (DVB-T) receivers from universal mobile telecommunications system (UMTS) and WiMAX mobile transmitters for adjacent and N+9 channel separation. The results of this initial work were presented in a report to Ofcom in December 2006 [2].

Following on from this work, Ofcom commissioned further measurements to characterize the potential interference for a wider selection of technologies that could potentially occupy the DDR award spectrum. This report presents the results of conducted measurements to determine the required carrier-to-interference (C/I) protection ratios against frequency separation for the following technologies:

Table 2:
Technologies used for conducted measurement testing

Digital video broadcast – terrestrial (DVB-T)
3G UTRA (FDD) (user equipment and Node B)
Mobile WIMAX (mobile and base station)
Digital video broadcast – handheld (DVB-H)

2. Objectives and Scope of Work

The objective of the work was to enable Ofcom to get a fuller picture of the performance of a range of technologies, which could potentially occupy the DDR award spectrum. This information will help to assist Ofcom in the auction design of the DDR spectrum band.

The programme of work was to develop a protection matrix for relevant potential interference scenarios, for the new technologies being considered in the DDR band, such as UMTS, DVB-H and WiMAX as well as existing technologies, such as DVB-T.

3. Test Methodology

3.1 Common Parameters

Measurement results in the report are generally presented as C/I protection ratio versus frequency offset for channel separations between N-11 and N+11 channels. For offsets up to

N±2 channels measurements were made in 1 MHz steps. For offsets between N±2 and N±11 channels measurements were made in 8 MHz steps.

For conducted measurements where DVB-T was the wanted or interfering signal the following parameters based on ETSI EN 300 744 [3] were used.

Table 3:
DVB-T system parameters

DVB-T Parameter	Value
Multiple access	COFDM
Modulation	64-QAM
Forward error correction	2/3
FFT points	8 k
Guard Interval (μs)	7 ($^{1}/_{32}$)
Data rate (Mbit/s)	24.1
Channel raster	8 MHz

In situations where a DVB-T transmitter was used all measurements were based on the non-critical DVB-T mask described in ETSI EN 302 296 [4] as shown in Table 4.

Table 4:
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

The DVB-T transmitter spectrum generated by the signal generator is shown in the figure below.

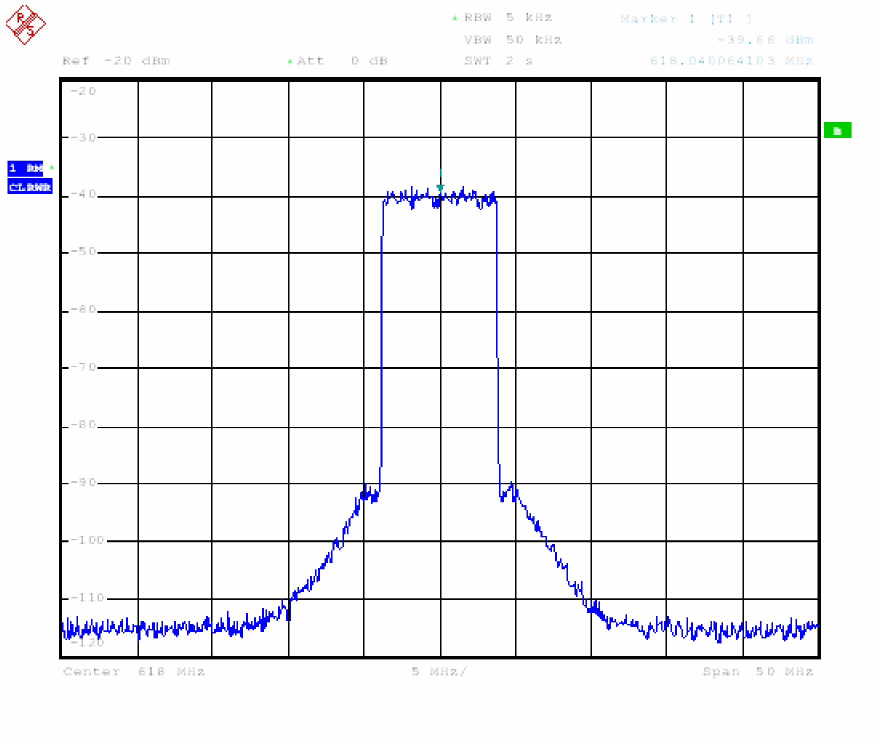

Figure 2: Wanted DVB-T transmitter mask

The above plot was measured using a spectrum analyser set to a resolution bandwidth (RBW) of 5 kHz.

3.2 Requirement for Filtering

The out of band emission levels of the unwanted signal was filtered by a 4-pole UHF filter to conform more closely to the transmission mask set by EN 302 296. The effect of using a filter on the transmit spectrum is shown in the figure below.

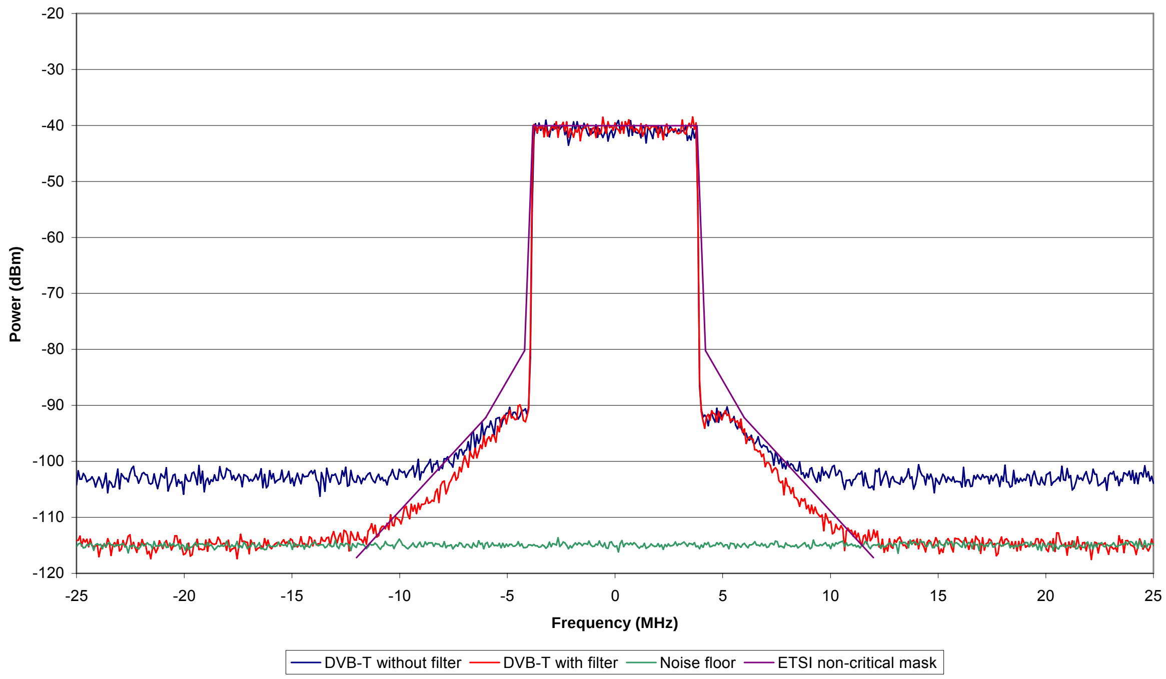

Figure 3: DVB-T interfering signal with and without filter measured in a 5 kHz resolution bandwidth

Without the band pass filter the noise from the signal generator masks the true protection ratios which can otherwise lead to erroneous results for large frequency separations (greater than N+2 channels) between the wanted and unwanted signals. This finding was also observed in an input to CEPT ECC TG 4 by TDF.

The characteristics of the filter used in the conducted measurement tests, when producing the interfering signal is shown in Figure 4.

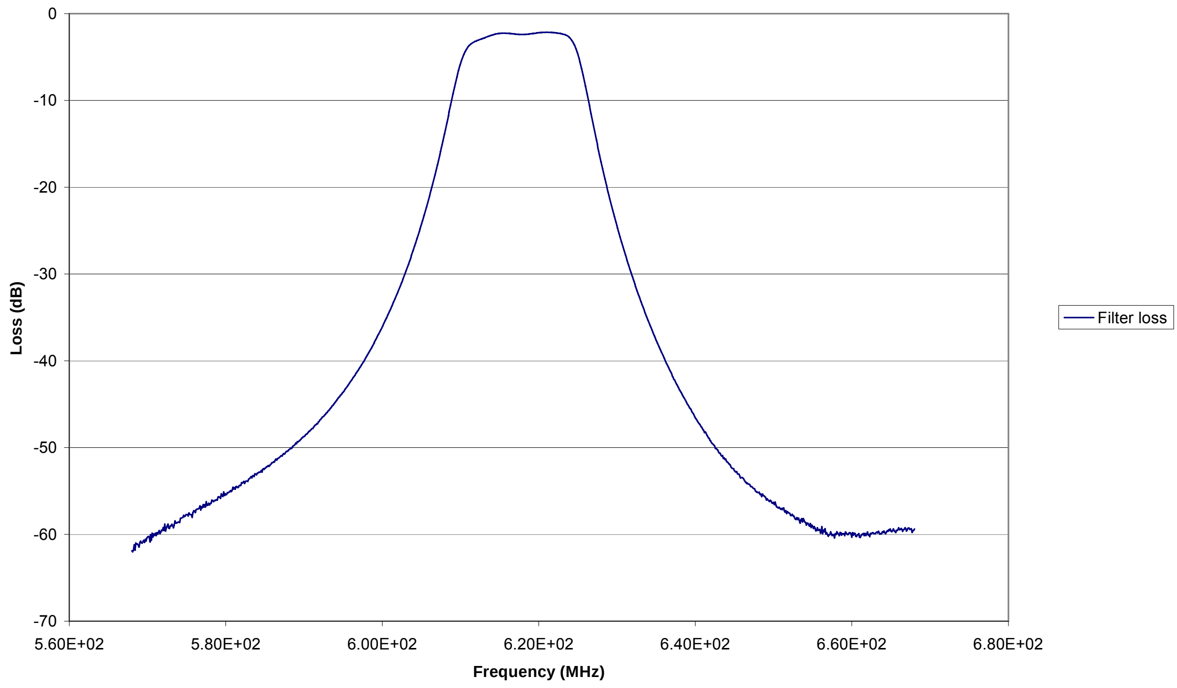

Figure 4: Characteristics of 4 pole UHF band pass filter used on the interfering signal

From the figure above, it can be seen that the bandwidth of the pass-band filter is approximately 18 MHz wide at -3 dB from the carrier.

3.3 UMTS User Equipment into DVB-T

3.3.1 Wanted system parameters

The DVB-T parameters shown in Table 3 were used as the wanted signal source. This wanted signal was generated using a Rhode & Schwarz (R&S) MPEG-2 measurement generator and an R&S TV test transmitter. The MPEG encoder was used to convert a moving video display into the correct format required by the DVB-T TV transmitter. The transmitter, comprising of an input data stream, forward error correction (FEC) encoder, modulation source and a RF carrier, was used to generate the wanted signal at the required frequency.

The wanted signal level was set to 50 dBµV/m, this being equivalent to a received power level of -73 dBm for a 75 Ω system via an antenna with a gain of 10 dBd and a cable loss of 3 dB.

3.3.2 Interfering system parameters

The UMTS UE uplink (UL) signal parameters based on ETSI TS 125 101 (3GPP TS 25.101) [5] were used as the interference source, as shown in the table below.

Table 5:
UMTS signal parameters

Parameter	Value
Multiple access method	WCDMA
Channel modulation	QPSK
Number of carriers	1
Chip rate	3.84 Mcps
Modulation filter	Root raised cosine α = 0.22
Channel raster	5 MHz
Duplex	FDD

A signal generator was used to produce the UE uplink signal using its internal 3GPP WCDMA settings (conforming to 3GPP release 5 specifications), based on the parameters shown in Table 5 above, as well as the additional parameters shown below.

Table 6:
Additional UE parameters

Parameter	Value
Filter function	Root cosine
Window function	Rectangular
Reference measurement channel	12.2 kbps
Data pattern	9 PRBS

The following physical and transport parameters were taken from ETSI TS 125.101 (3GPP TS 25.101) [5], for a UL reference measurement channel (RMC) based on 12.2 kbps, as shown in Table 7 and Table 8 below.

Table 7:
UL reference measurement channel physical parameters (12.2 kbps)

Parameter	Unit	Level
Information bit rate	kbps	12.2
DPDCH	kbps	60
DPCCH	kbps	15
DPCCH Slot Format #i	-	0
DPCCH/DPDCH power ratio	dB	-5.46
TFCI	-	On
Repetition	%	23

Table 8:
UL reference measurement channel, transport channel parameters (12.2 kbps)

Parameters	DTCH	DCCH
Transport Channel Number	1	2
Transport Block Size	244	100
Transport Block Set Size	244	100
Transmission Time Interval	20 ms	40 ms
Type of Error Protection	Convolution Coding	Convolution Coding
Coding Rate	1/3	1/3
Rate Matching attribute	256	256
Size of CRC	16	12

Figure 5 below shows a comparison of the simulated UMTS UE uplink signal, based on the physical and transport parameters described in the tables above, compared to a real UE.

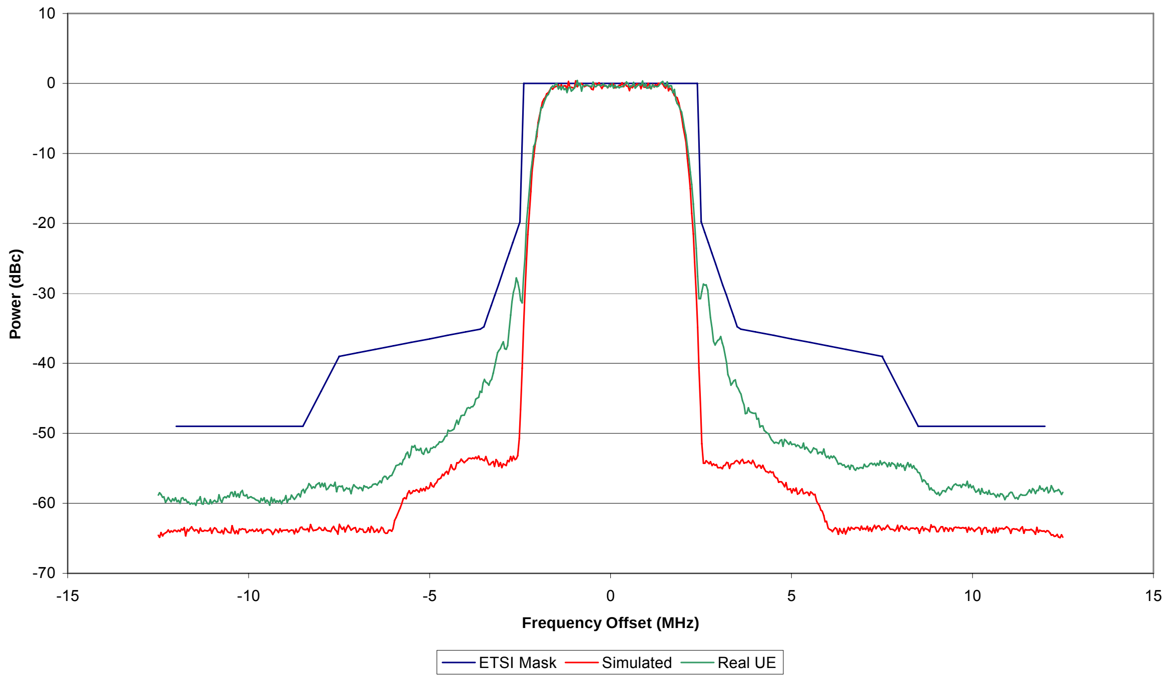

Figure 5: Comparison of a simulated transmitter mask to a real UE with respect to the ETSI mask

The inner loop power control of the UE compensating for signal fluctuations due to fading was derived by measuring the fading profile on a spectrum analyser for test cases shown in the table below (taken from TS 25.104 Annex B).

Table 9:
Multi-path fading conditions

Case 1		**Case 2**		**Case 3**		**Case 4**	
Speed for Band I, II, III, IV, IX, X 3 km/h		Speed for Band I, II, III, IV, IX, X 3 km/h		Speed for Band I, II, III, IV, IX, X 120 km/h		Speed for Band I, II, III, IV, IX, X 250 km/h	
Speed for Band V, VI, VIII 7 km/h		Speed for Band V, VI, VIII 7 km/h		Speed for Band V, VI, VIII 280 km/h		Speed for Band V, VI, VIII 583 km/h (Note 1)	
Speed for Band VII 2.3 km/h		Speed for Band VII 2.3 km/h		Speed for Band VII 92 km/h		Speed for Band VII 192 km/h	
Relative Delay [ns]	**Average Power [dB]**	**Relative Delay [ns]**	**Average Power [dB]**	**Relative Delay [ns]**	**Average Power [dB]**	**Relative Delay [ns]**	**Average Power [dB]**
0	0	0	0	0	0	0	0
976	-10	976	0	260	-3	260	-3
		20000	0	521	-6	521	-6
				781	-9	781	-9

NOTE: For the 50 km/h fading condition, Case 5 was taken from TS 25.101 Annex B.

The average power of the measured fading profile was then calculated for a 10 second period of time, i.e. the same time period as the transmit power control (TPC) profile used before being repeated. Using this average power, the difference in the actual power for each time slot was inverted to give the TPC profile of the UE uplink to compensate for the fading seen at the Node B.

This TPC profile was programmed into the signal generator in order to simulate the UE uplink in a moving environment. The TPC profiles for the fast-fading channel speeds of 3, 50 and 120 km/h are shown in the figures below.

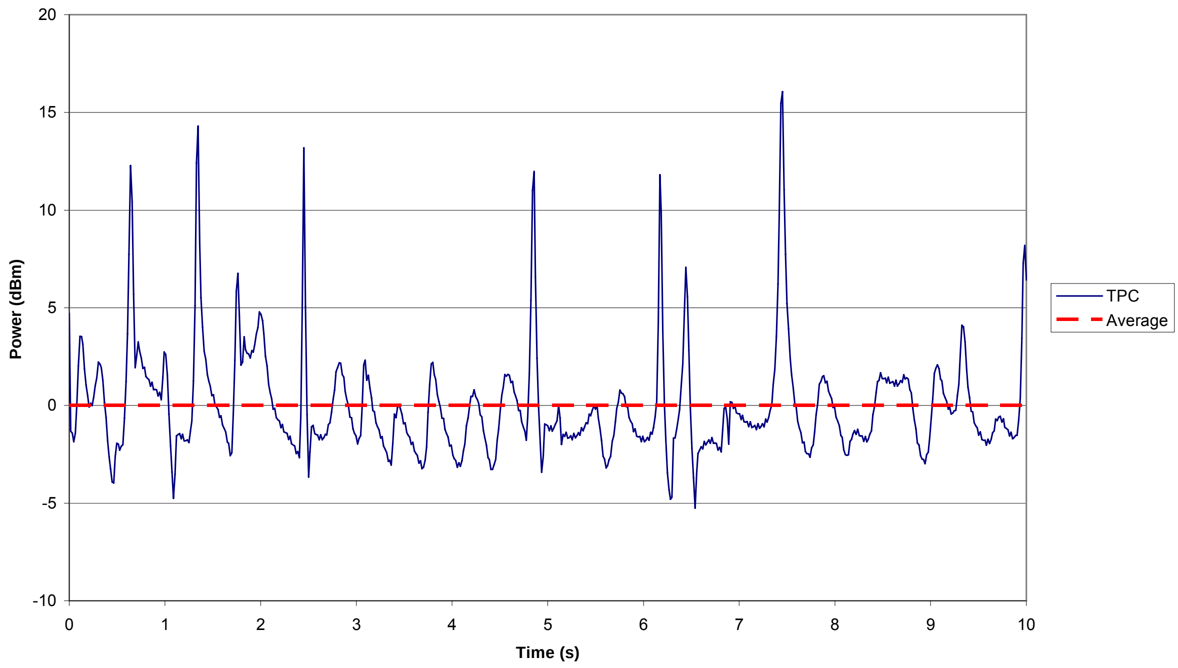

Figure 6: Profile of transmit power control for a user travelling at 3 km/h

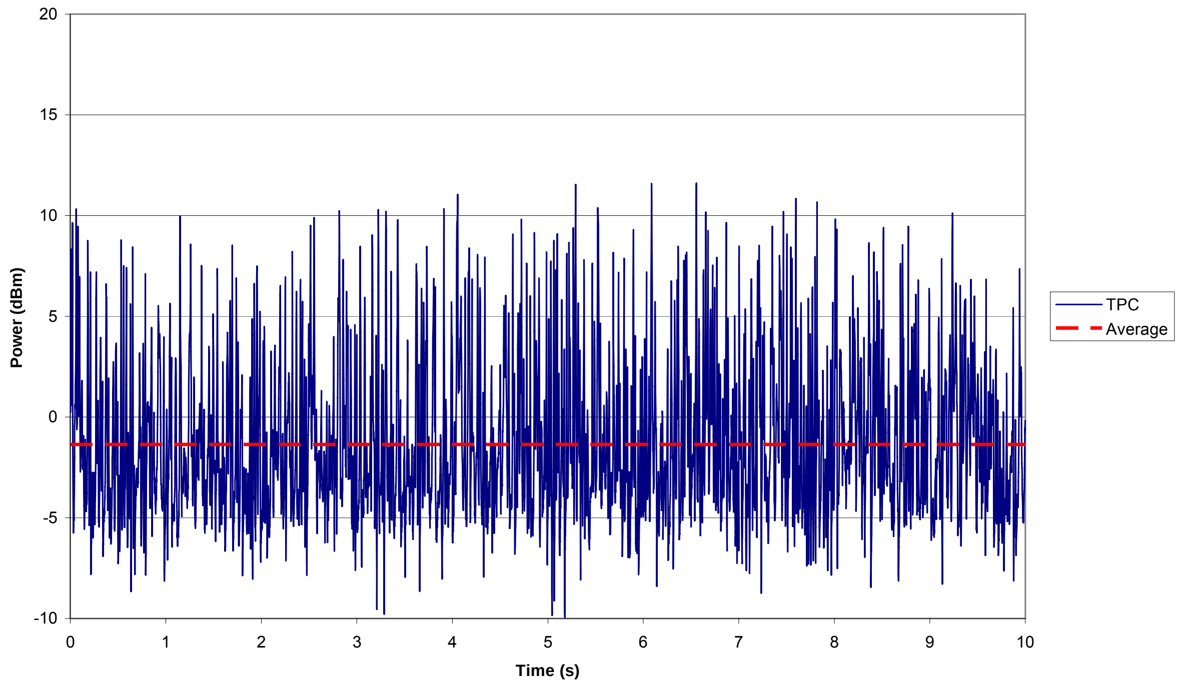

Figure 7: Profile of transmit power control for a user travelling at 50 km/h

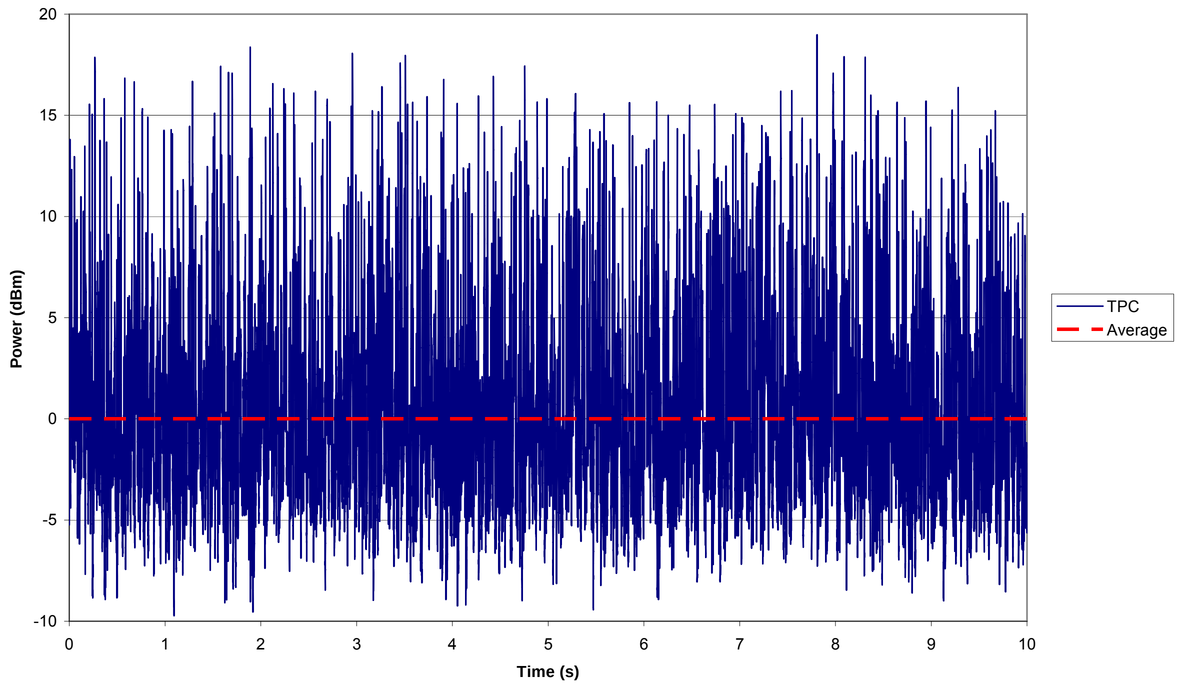

Figure 8: Profile of transmit power control for a user travelling at 120 km/h

Based on the simulated UE signal with fast power control using TPC commands in the inner loop, the following scenarios were investigated:

- UE uplink with no transmit power control and no fading (static conditions) interference into a DVB-T receiver.
- UE uplink with transmit power control only, for speeds of 3 km/h, 50 km/h and 120 km/h interference into a DVB-T receiver.
- UE uplink with transmit power control and additional uncorrelated fading as seen by the DVB-T receiver, for the 3 km/h case.

The results are presented as C/I protections ratios where the interference was measured as the mean average power as measured in an additive white Gaussian noise (AWGN) channel.

3.3.3 Interference criteria

DVB-T systems use coded orthogonal frequency division multiplexing (COFDM) which spreads the information over a large number of orthogonal carriers. Forward error correction is then applied to improve the bit error ratio (BER). In many digital systems the data to be transmitted undergoes two types of FEC coding; Reed Solomon and convolutional coding (Viterbi). At the receiver end, the pseudo-random sequence added at the transmitter by the convolutional encoder is decoded by the Viterbi decoder, followed by Reed Solomon decoding for parity checking.

The error protection employed by such digital systems usually results in an abrupt "cliff-edge" effect in the presence of interference when compared to analogue systems. The Digital TV Group[1] publishes the D-Book, which includes degradation criteria to be used when assessing interference to digital systems. The different DVB-T receiver degradation criteria taken from the D-Book are compared in Table 10 below.

[1] The Digital TV Group is the industry association for digital television in the UK. See http://www.dtg.org.uk/

Table 10:
D-Book comparison of degradation criteria

Criterion	Description	Comments
REF_{BER}	Post Viterbi BER=2x10^{-4}	BER can be very erratic with some types of impairment (e.g. impulsive inference), so an accurate measure can be hard to achieve. A measure of BER is often not available (e.g. in a commercial receiver).
UCE	No un-correctable Transport Stream errors in a defined period.	Probably the most useful measure, but unfortunately this is often not available (e.g. in a commercial receiver).
UCE Rate	A measure of the number of UCE in a defined period.	Sometimes normalised to 'Error Seconds' (Used for 'mobile' applications).
PF	"Picture Failure". No. of observed, (or detected) picture artefacts in a defined period.	This is what the consumer sees and cares about. There is always access to a 'picture' in a commercial receiver. However, when testing demodulators alone, MPEG decoding and picture display is not always available.
SFP	"Subjective failure point"	Essentially the same as PF

The reference BER, defined as BER = 2 x 10^{-4} after Viterbi decoding, corresponds to the quasi error free (QEF) criterion in the DVB-T standard, which states "less than one uncorrelated error event per hour".

However, as noted in the D-Book, there is often no direct way of identifying BER or transport stream errors for commercial receivers. In this case picture failure (PF) is the only means of assessing the interference effects.

The PF point was identified by manual observation. Figure 9 below shows the onset of un-correctable errors (UCE) used to determine the failure point. The onset of a complete picture failure, i.e. no reception, could be observed with a 1 to 2 dB increase in the interfering signal from the PF point.

Figure 9: Received picture showing onset of interference

3.3.4 Equipment set-up and test procedure

UMTS UE interference measurements into a DVB-T receiver were performed using the conducted measurement set-up shown in the diagram below.

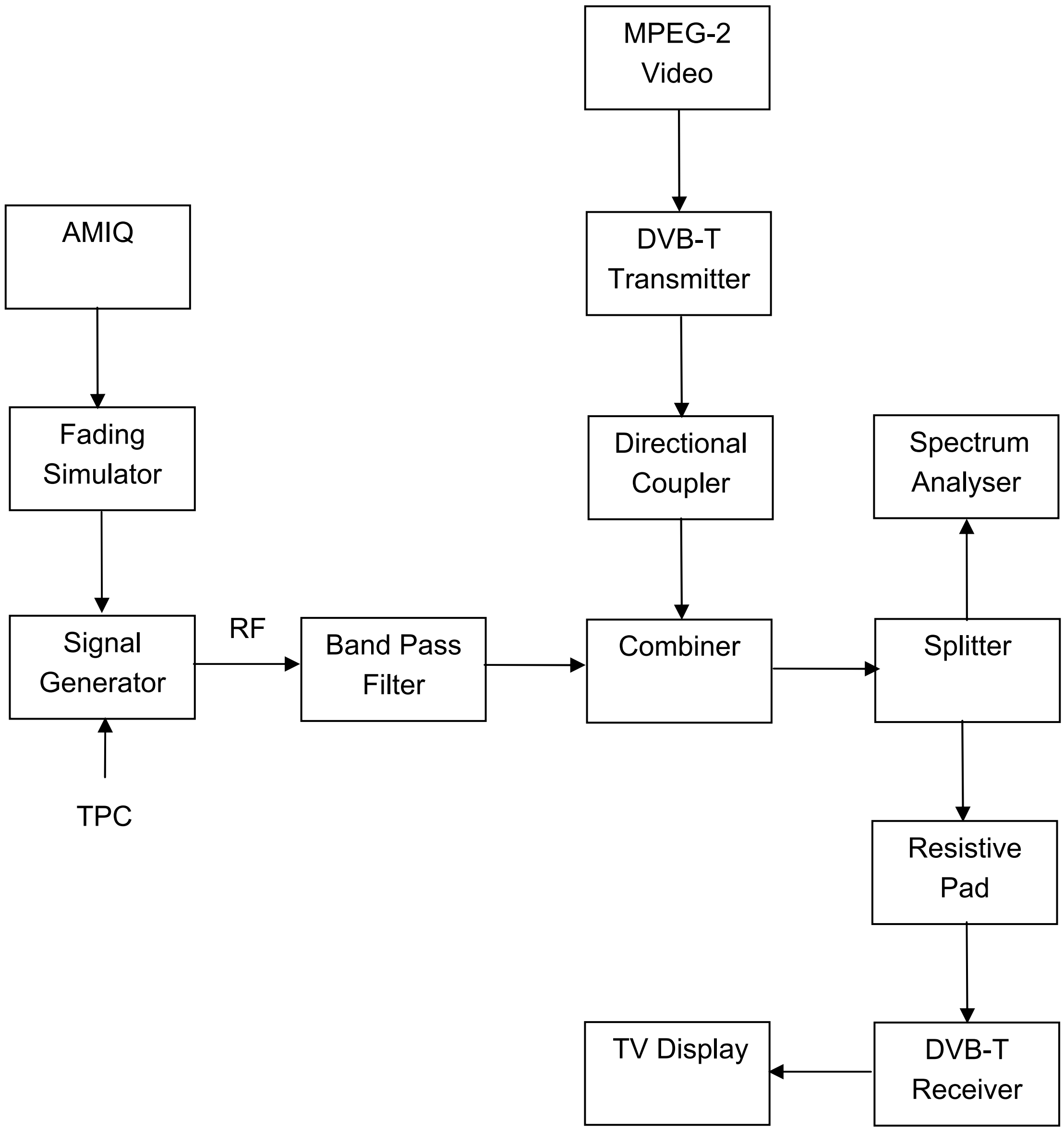

Figure 10: UE uplink interference into a DVB-T receiver using TPC and fading

Based on the above measurement parameters and test set-up, the following test procedure was used:

1. The wanted signal level was set to a power level ‘C’ of -73 dBm, equivalent to a wanted field strength of 50 dBμV/m.

2. The wanted channel power level ‘C’ was measured in the bandwidth of the receiver with a spectrum analyser using RMS detection, a RBW of 100 kHz and video bandwidth (VBW) of 1 MHz.

3. The level of unwanted interference was increased to achieve the required degradation of the received quality of the decoded MPEG signal.

4. The interference channel power 'I' was measured in a bandwidth equal to one channel spacing, using RMS detection, a RBW of 100 kHz and VBW of 1 MHz.

5. The C/I protection ratio was calculated from Steps 2 and 4.

The above procedure was carried out in 8 MHz steps for channel spacing between N-11 to N+11, where N = channel 39 (618 MHz).

Also, a directional coupler was used to improve the isolation by 20 dB, between the output stages of the unwanted signal generator and the wanted TV generator signals at the combiner stage. The combiner itself provided 40 dB of isolation, between the wanted and unwanted signal ports.

The receiver bandwidth of the DVB-T receiver is 7.6 MHz and a spectrum analyzer was used to measure the channel power in the receiver band as well as to measure the power of the interferer.

Note: a standard scart lead was used to connect the DVB-T receiver to the LCD display.

3.4 DVB-T into UMTS User Equipment

3.4.1 Wanted system parameters

The test set-up (see Section 3.4.4) for DVB-T interference into a UMTS UE is similar to that defined in Figure A.10 of ETSI TS 134.121-1 (3GPP TS 34.121-1) [6] for single test cells with multi-path fading conditions. Table 11 shows the propagation conditions that can be used for performance measurements in a multi-path fading environment.

Table 11:
Propagation conditions for multi-path fading environments

Case 1, speed 3km/h		Case 2, speed 3 km/h		Case 3, speed 120 km/h		Case 4, speed 3 km/h		Case 5, speed 50 km/h *		Case 6, speed 250 km/h	
Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]
0	0	0	0	0	0	0	0	0	0	0	0
976	-10	976	0	260	-3	976	0	976	-10	260	-3
		20000	0	521	-6					521	-6
				781	-9					781	-9

NOTE 1: Case 5 is only used in requirements for support of radio resource management (RRM)

NOTE 2: Speed above 250 km/h is applicable to demodulation performance requirements only

Measurements were based on Case 1 (for a speed of 3 km/h) for the following scenarios:

- A symmetrical reference measurement channel (RMC) of 12.2 kbps, representing a voice call, for both the uplink and downlink (DL).
- A symmetrical RMC of 384 kbps representing a data call.

Similar test parameters for the dedicated channel (DCH) based on Case 1 multi-path fading conditions described in TS 25.101, are shown in the table below.

Table 12:
DCH test parameters for Case 1 multi-path fading propagation conditions

Parameter	Unit	Test	
Phase reference		P-CPICH	
$\hat{I}_{or}$	dBm/3.84 MHz	-60 and -75	
Information Data Rate	Kbps	12.2	384

Where, $\hat{I}_{or}$ is the received power spectral density (integrated in a bandwidth of (1+α) times the chip rate and normalized to the chip rate) of the downlink signal as measured at the UE antenna connector.

The parameters for a 12.2 kbps DL RMC are specified in Table 13 and the parameters for the 384 kbps DL RMC are specified in Table 14 below.

Table 13:
DL reference measurement channel, physical parameters (12.2 kbps)

Parameter	Unit	Level
Information bit rate	kbps	12
DPCH	ksps	30
Slot Format # i	-	11
TFCI		On
Power offsets PO1, PO2 and PO3	dB	0
Puncturing	%	14.7

Table 14:
DL reference measurement channel, physical parameters (384 kbps)

Parameter	Unit	Level
Information bit rate	kbps	384
DPCH	ksps	480
Slot Format # i	-	15
TFCI		On
Power offsets PO1, PO2 and PO3	dB	0
Puncturing	%	22

The data pattern of the DTCH (user data) sent on the dedicated physical channel (DPCH) was a 15-bit pseudo-random bit sequence (CCITT PRBS15).

3.4.2 Interfering system parameters

The DVB-T parameters shown in Table 3 were used as the interference source.

3.4.3 Interference criteria

ETSI TS 134.121-1 defines the single link performance for a receiver in multi-path fading propagation conditions as:

"The receive characteristics of the dedicated channel (DCH) in different multi-path fading environments are determined by the block error ratio (BLER) values. BLER is measured for each of the individual data rate specified for the DPCH. DCH is mapped into the DPCH."

Using the loopback 2 test mode and a "Used for Data" settings on the Agilent E5515C signal simulator, the BLER was measured on:

- A symmetrical RMC of 12.2 kbps, representing a voice channel, for both the uplink and downlink.
- A symmetrical RMC of 384 kbps representing a data call, for both the uplink and downlink.

The measurement requirement for testing was based on the average downlink $\frac{DPCH\_E_c}{I_{or}}$ power ratio to be set at the specified values given in Table 15. Where, I_{or} is the total transmit power spectral density (integrated in a bandwidth of (1+α) times the chip rate and normalized to the chip rate) of the downlink signal at the Node B antenna connector.

Table 15:
Test requirements for DCH in multi-path fading propagation conditions (Case 1, 3km/h)

Test Number	$\frac{DPCH\_E_c}{I_{or}}$	BLER
1	-15.0 dB	10^{-2}
2	-13.9 dB	10^{-1}
	-10.0 dB	10^{-2}
3	-10.6 dB	10^{-1}
	-6.8 dB	10^{-2}
4	-6.3 dB	10^{-1}
	-2.2 dB	10^{-2}

The BLER value in test number one in the table above was used as the interference measurement criterion for a DVB-T signal intefering with a UE receiving data in a fast fading channel form a UMTS Node B downlink 12.2 kbps voice channel.

The BLER value in test number four in the table above was used as the interference measurement criterion for a DVB-T signal intefering with a UE receiving data in a fast fading channel from a UMTS Node B downlink 384 kbps data channel.

3.4.4 Equipment set-up and test procedure

DVB-T interference measurements into a UMTS UE were performed using the conducted measurement set-up shown in the diagram below.

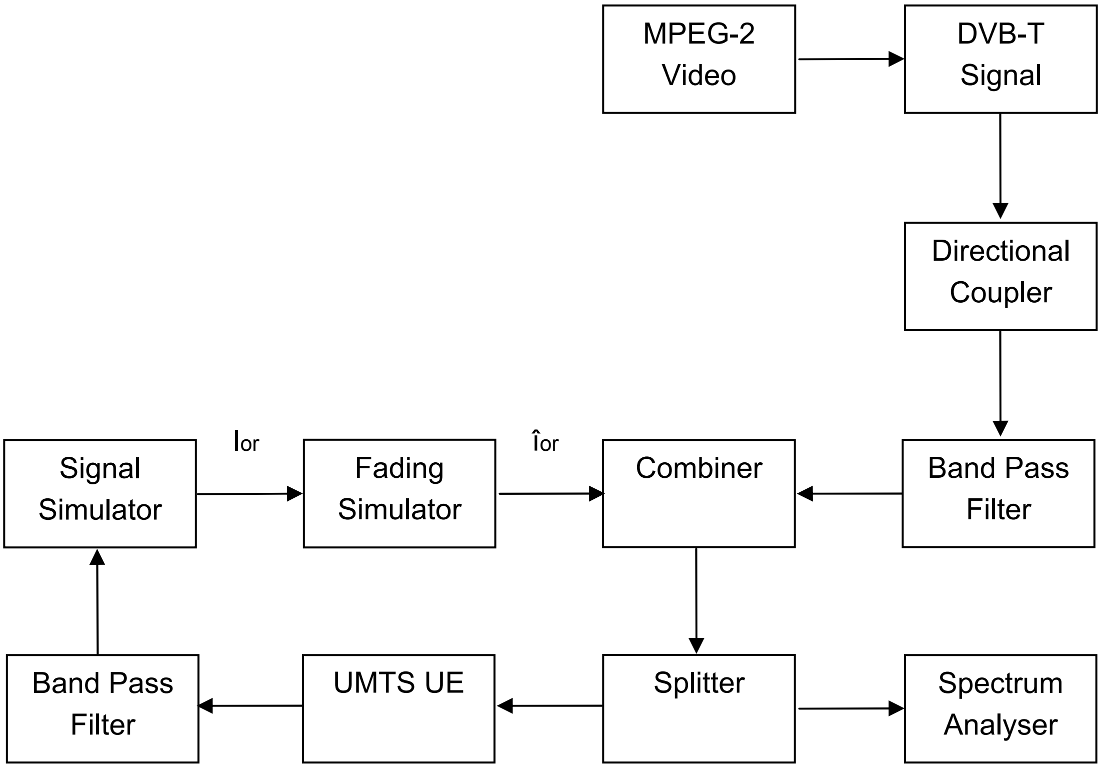

Figure 11: Measurement set-up of DVB-T interference into a UMTS UE

Based on the above measurement parameters and test set-up, the following test procedure was used:

1. The signal simulator, multi-path fading simulator and the DVB-T source were connected to the UE antenna connector as shown in Figure 11.

2. $\frac{DPCH\_E_c}{I_{or}}$ was set for Test 1 for voice and Test 4 for data as specified in Table 15.

3. The fading simulator was configured for the Case 1 fading condition given in Table 11.

4. A call was initiated according to the generic call set-up procedure.

5. The wanted channel power level 'C' was measured with a spectrum analyser using RMS detection, a RBW of 30 kHz and a VBW of 300 kHz.

6. The UE was placed into loopback test mode and the loopback test was started.

7. The level of unwanted DVB-T interference was increased until the Test 1/Test 4 conditions shown in Table 15 were met.

8. The interference level ‘I’ was measured in a channel bandwidth equal to one channel spacing, using RMS detection, a RBW of 30 kHz and a VBW of 300 kHz.

9. The C/I protection ratio was calculated from Steps 5 and 8.

The above procedure was carried out for co-channel interference out to 16 MHz in 1 MHz steps and out to 40 MHz frequency separations using 8 MHz steps.

3.5 UMTS Node B into DVB-T

3.5.1 Wanted system parameters

The DVB-T parameters shown in Table 3 were used as the wanted signal source.

The DVB-T wanted signal was generated using an R&S MPEG-2 measurement generator and an R&S TV test transmitter. The MPEG encoder was used to convert a moving video display into the correct format required by the DVB-T TV transmitter. The transmitter, comprising of an input data stream, FEC encoder, modulation source and a RF carrier, was used to generate the wanted signal at the required frequency.

The wanted signal level was set to 50 dBµV/m, this being equivalent to a received power level of -73 dBm for a 75 Ω system, via an antenna with a gain of 10 dBd and a cable loss of 3 dB.

3.5.2 Interfering system parameters

The UMTS Node B signal parameters based on ETSI TS 125.104 (3GPP TS 25.104) [7] were used as the interference source, as shown in the table below.

Table 16:
UMTS signal parameters

Parameter	Value
Multiple access method	WCDMA
Channel modulation	QPSK
Number of carriers	1
Chip rate	3.84 Mcps
Modulation filter	Root raised cosine α = 0.22
Channel raster	5 MHz
Duplex	FDD

The uplink and downlink RMCs were set to the symmetrical values defined for the measurement scenario of DVB-T interference into a UMTS UE as described in Section 3.4. The DL parameters for a reference measurement channel for 384 kbps are specified in Table 14.

The data pattern of the DTCH data (user data) sent on the DPCH was set to CCITT PRBS15 - a 15-bit pseudo-random bit sequence.

Conducted measurements were performed for the following scenarios:

- Static case, assuming no transmit power control.
- Aggregate transmit power control on the DL based on a multi-path fading condition for a fast fading channel of 3 km/h, 50 km/h and 120 km/h case as specified for Cases 1, 5 and 3 of Annex B of TS 25.101, respectively.

The aggregate transmit power control power profile was made up of the three channel conditions described above, assuming a constant common pilot channel power level. This resulted in a typical traffic profile for a wide mix of paths to mobiles for various channel conditions.

3.5.3 Interference criteria

The interference criterion was based on picture failure as described in Section 3.3.3.

3.5.4 Equipment set-up and test procedure

UMTS Node B interference measurements into a DVB-T receiver were performed using the conducted measurement set-up shown in the diagram below.

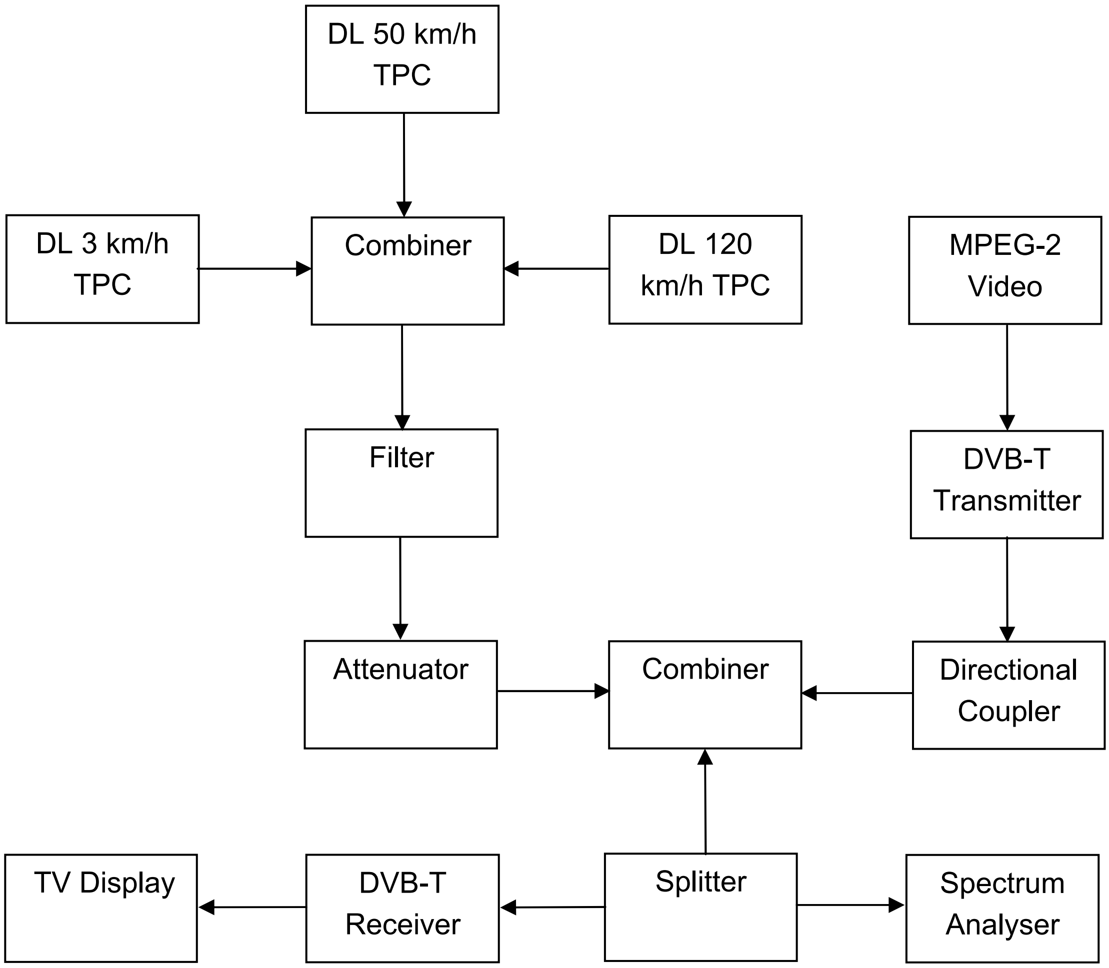

Figure 12: Measurement set-up of Node B interference into a DVB-T receiver

Based on the conducted measurement set-up shown above and the multi-path environments for cases 1, 3 and 5 as defined in 3GPP TS 25.101, the three Node B DL signals were combined and filtered to produce an aggregate DL signal. This signal was adjusted via a variable attenuator until the onset of interference was observed at the DVB-T receiver using the same procedure as described in Section 3.3.4.

3.6 DVB-T into UMTS Node B

3.6.1 Wanted system parameters

High speed packet data access (HSPDA) signal parameters based on a 16-QAM modulation scheme (3GPP TS 25.101) [5] were used as the wanted source.

The test set-up (Section 3.6.4) used for DVB-T interference into a Node B is similar to that defined in Figure B.14A of ETSI TS 125 141 (3GPP TS 25.141 version 7.8.0 release 7) [8] for demodulation of the dedicated channel, in static conditions for a Node B transceiver.

Conducted measurements were performed using static propagation conditions for a symmetrical uplink and downlink RMC of 384 kbps representing a data call. The parameters for the 384 kbps UL reference measurement channel are specified in the table below.

Table 17: Parameters for a 384 kbps UL reference measurement channel

Parameter		DCH for DTCH / DCH for DCCH	Unit
DPDCH	Information bit rate	384/2.4	kbps
	Physical channel	960/15	kbps
	Spreading factor	4	
	Repetition rate	-18/-17	%
	Interleaving	40	ms
	Number of DPDCHs	1	
DPCCH	Dedicated pilot	6	bit/slot
	Power control	2	bit/slot
	TFCI	2	bit/slot
	Spreading factor	256	
Power ratio of DPCCH/DPDCH		-9.54	dB
Amplitude ratio of DPCCH/DPDCH		0.3333	

Pseudo-random bit sequence data was transmitted on the uplink from three UE's to achieve a cell loading between 50 to 60 %. A trade-off was observed between the uplink power and the maximum cell loading that could be achieved.

Therefore, in order to carry out the conducted measurements, the uplink power was fixed to -25 dBm to allow reasonable cell loading, whilst ensuring enough DVB-T power was available to perform measurements from -16 MHz to +16 MHz offsets in 1 MHz steps.

A throughput of 1.3 Mbps was observed for one UE communicating with the Node B. For three UE's this throughput dropped to 420 kbps for a cell loading between 50 to 60 %.

3.6.2 Interfering system parameters

The DVB-T parameters shown in Table 3 were used as the interference source injected into the Node B transceiver.

3.6.3 Interference criteria

The interference measurement criterion of the DCH for the static case was determined by a 75 to 100 % fall in data throughput using a RMC of 384 kbps. This level of drop in throughput was chosen, because initial tests showed that the throughput did not drop-off gradually with increased interference power, but changed dramatically with an increase of 1 dB difference.

Note: Tests using the mean opinion score (MOS) for a reference measurement channel of 12.2 kbps (voice) was not performed, because the MOS could not be satisfactorily measured in the absence of interference.

3.6.4 Equipment set-up and test procedure

DVB-T interference measurements into a UMTS Node B transceiver were performed using the conducted measurement set-up shown in the diagram below.

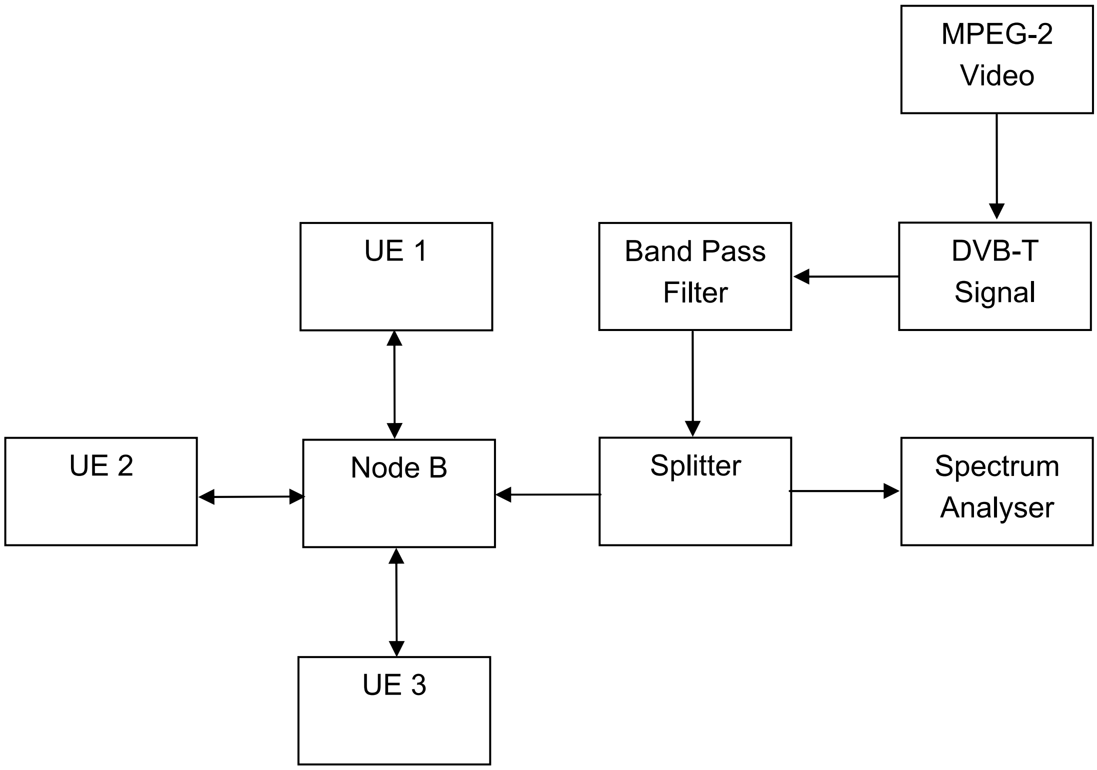

Figure 13: Measurement set-up of DVB-T interference into a Node B

Based on the parameters described in Section 3.6.1 to 3.6.3 and test set-up shown in Figure 13, the following procedure was used:

1. For a Node B without Rx diversity, three HSPDA UE's using 16-QAM modulation were used to achieve a cell loading 50 to 60 %.
2. The wanted signal uplink 'C' was fixed at -25 dBm using software controlling the Node B parameter settings.
3. The uplink signal entering the Node B receiver was verified on a UE connected to a port accessing the Node B.
4. The static DVB-T signal was transmitted into the Node B antenna connector via a combining network as shown in Figure 13.
5. The wanted signal 'I' was adjusted, so that the desired drop in level of throughput for UE 1 was achieved.

6. The interference level 'I' was measured in a channel bandwidth equal to one channel spacing, using a RMS detector set to a RBW of 30 kHz and a VBW of 300 kHz.

7. The C/I protection ratio was calculated from Steps 2 and 6.

The above procedure was carried for frequency separation from -16 MHz to 16 MHz in 1 MHz steps.

3.7 Mobile WiMAX Mobile Station Interference into a DVB-T Receiver

3.7.1 Wanted system parameters

The DVB-T parameters shown in Table 3 were used as the wanted signal source received by the digital receiver under test.

The DVB-T wanted signal was generated using an R&S MPEG-2 measurement generator and a R&S TV test transmitter. The MPEG encoder was used to convert a moving video display into the correct format required by the DVB-T TV transmitter. The transmitter, comprising of an input data stream, FEC encoder, modulation source and a RF carrier, was used to generate the wanted signal at the required frequency.

The wanted signal level was set to 50 dBμV/m, this being equivalent to a received power level of -73 dBm for a 75 Ω system, via an antenna with a gain of 10 dBd and a cable loss of 3 dB.

3.7.2 Interfering system parameters

The mobile WiMAX signal (for both mobile station and base station) was generated using an Agilent E4438C signal generator controlled by a laptop running Signal Studio option N7615B WiMAX 802.16 OFDMA. A simulation file supplied by Agilent and approved by the WiMAX forum was used to simulate a typical base station and subscriber scenario.

The file used to create the mobile WIMAX signal simulated a 2x1 matrix 'A' space time coding (STC) set-up, with fading applied to the signals from both transmit antennas. The separate signals were then combined to form a single waveform to be applied to the receiver under test. The waveform contained two DL-PUSC (downlink - partial usage of sub-channels) zones.

The first zone contained a frame control header (FCH), downlink – medium access protocol (DL-MAP), uplink – medium access protocol (UL-MAP), downlink channel descriptor (DCD), and an uplink channel descriptor (UCD). The second DL-PUSC zone had matrix 'A' coding and contained 5 data bursts. The Pedestrian 'A' channel model was applied with a speed of 3 km/h and medium correlation. A speed of 3 km/h was applied as a typical user speed expected in a mobile WiMAX environment.

The uplink signal comprised of a single burst of data using QPSK modulation with a FEC of ½. The transmitted data was a PRBS sequence consisting of a PN 9 code. The total length of the data stream was 42 bytes and was repeated every time frame. The DL and UL power envelope is shown in the figure below.

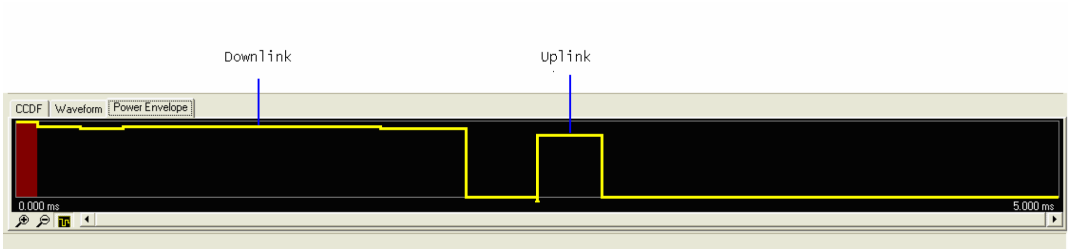

Figure 14: Downlink and uplink power envelope used for a 5 ms mobile WiMAX time frame

The spectrum of the mobile WiMAX uplink signal is shown in the figure below.

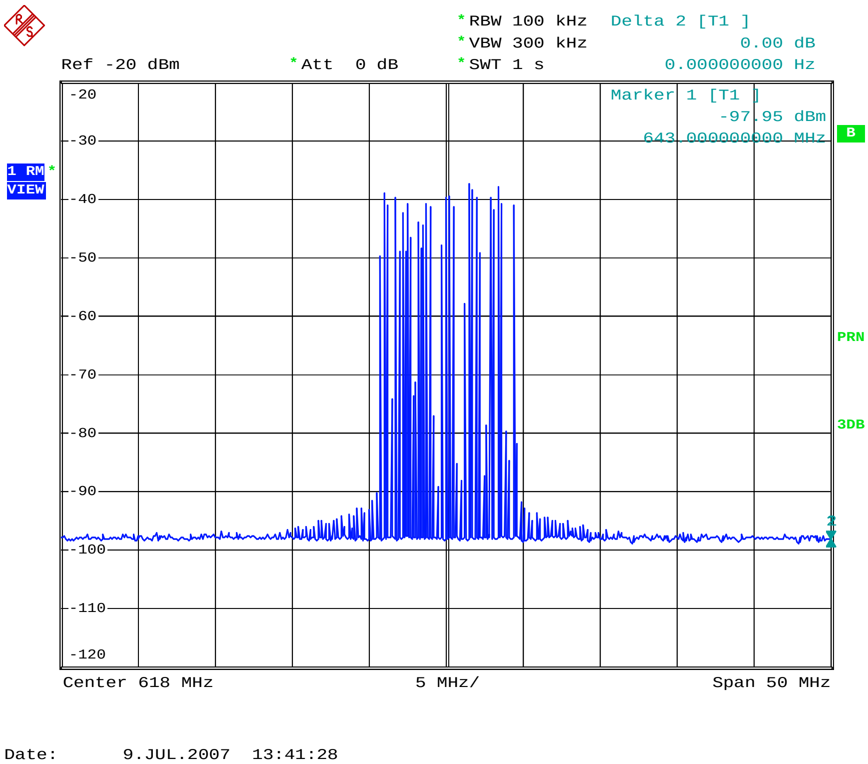

Figure 15: Spectrum plot of a mobile WiMAX uplink signal

The rest of the mobile WiMAX mobile parameters were set up as shown in the table below.

Table 18:
Mobile WiMAX uplink signal parameters

Parameter	Value
Multiple access method	OFDMA
Modulation	QPSK
FEC	½
FFT points	1024
Guard interval	1/8
Frame duration	5 ms
Channel raster	10 MHz
Duplex	TDD

3.7.3 Interference criteria

The interference criterion was based on picture failure as described in Section 3.3.3.

3.7.4 Equipment set-up and test procedure

WiMAX mobile station interference measurements into a DVB-T receiver were performed using the conducted measurement set-up shown in the figure below.

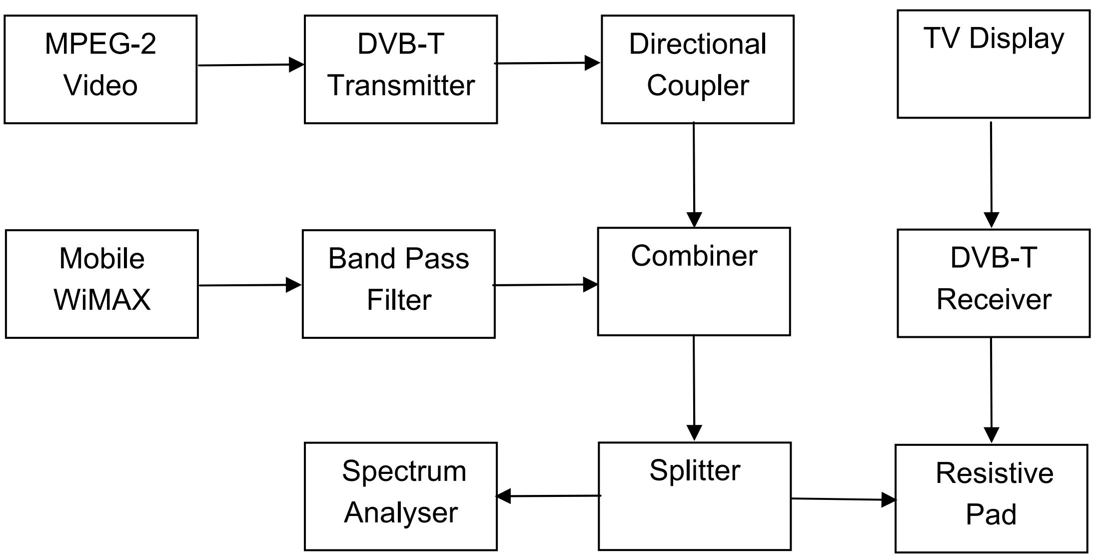

Figure 16: Measurement set-up of WiMAX mobile station interference into DVB-T

The procedure used to measure the C/I protection ratios for the DVB-T receiver was performed in the exact manner to that described in Section 3.3.4 above.

3.8 Mobile WiMAX Base Station into a DVB-T Receiver

3.8.1 Wanted system parameters

The DVB-T parameters shown in Table 3 were used as the wanted signal source received by the digital receiver under test.

The DVB-T wanted signal was generated using a R&S MPEG-2 measurement generator and a R&S TV test transmitter. The MPEG encoder was used to convert a moving video display into the correct format required by the DVB-T TV transmitter. The transmitter, comprising of an input data stream, FEC encoder, modulation source and a RF carrier, was used to generate the wanted signal at the required frequency.

The wanted signal level was set to 50 dBμV/m, this being equivalent to a received power level of -73 dBm for a 75 Ω system, via an antenna with a gain of 10 dBd and a cable loss of 3 dB.

3.8.2 Interfering system parameters

The mobile WiMAX base station signal was generated in the same way as the mobile station described in Section 3.7.2.

The downlink mobile WiMAX base station signal comprised of a five bursts of data, these being:

1. QPSK modulation with a FEC of ½
2. 16QAM modulation with a FEC of ¾
3. 64QAM modulation with a FEC of ½
4. QPSK modulation with a FEC of ¾
5. 16QAM modulation with a FEC of ¾

The transmitted data on each burst was a pseudo random bit stream (PRBS) comprising of a PN 9 code. The total length of the data stream was 2680 bytes and was repeated every time frame. The spectrum of the downlink signal is shown in the figure below.

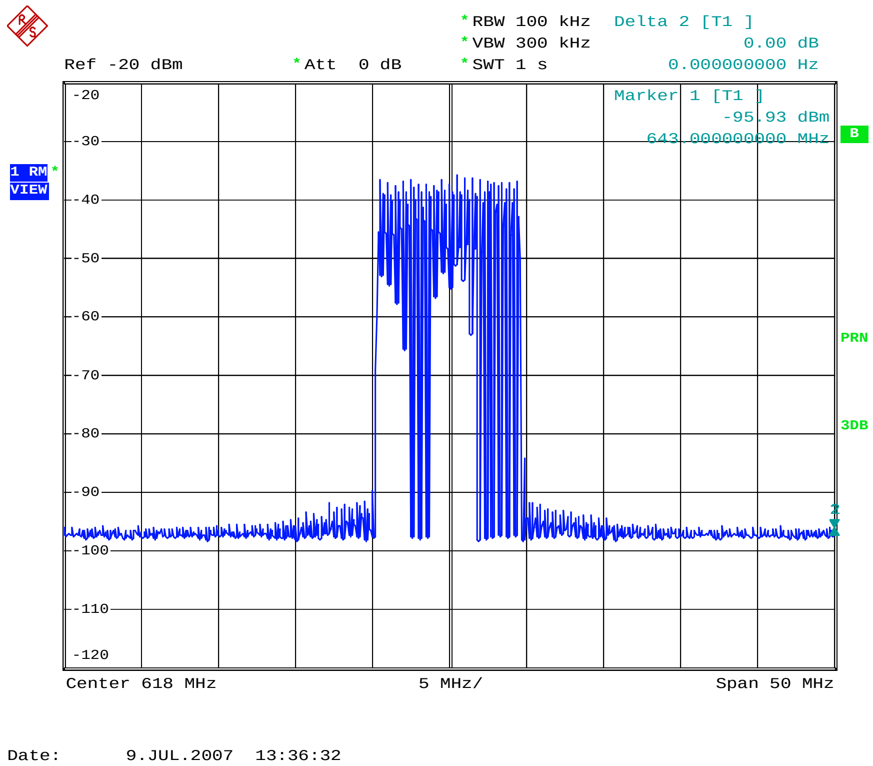

Figure 17: Spectrum plot of a WiMAX 802.16e downlink link signal

The rest of the mobile WiMAX base station parameters were set-up as shown in Table 18.

3.8.3 Interference criteria

The interference criterion was based on picture failure as described in Section 3.3.3.

3.8.4 Equipment set-up and test procedure

WiMAX base station interference measurements into a DVB-T receiver were performed using the conducted measurement set-up shown in the diagram below.

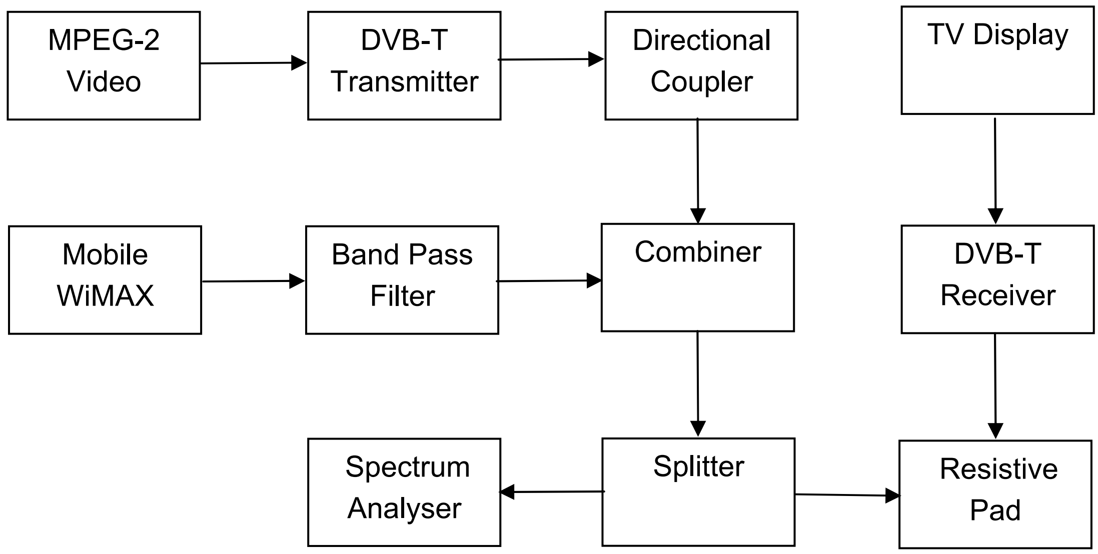

Figure 18: Measurement set-up of WiMAX BS interference into a DVB-T receiver

The procedure used to measure the C/I protection ratios for the DVB-T receiver was performed in the exact manner to that outlined in Section 3.3.4.

3.9 DVB-T Interference into Fixed WiMAX

Mobile WiMAX technology is relatively immature in the UK, with the IEEE standard 802.16e [9] being approved in December 2005. ERA was unable to secure any mobile WiMAX test equipment in the timescales for this project. Therefore, for these tests a fixed WiMAX terminal conforming to the IEEE 802.16-2004 [10] specification was used, which was configured to use parameters that could be considered representative of mobile WiMAX.

3.9.1 Wanted system parameters

ERA has a fully operational fixed WiMAX system conforming to the IEEE 802.16-2004 signal parameters shown in the table below. The system is designed to provide broadband wireless infrastructure and can be deployed for fixed and mobile wireless access and backhaul applications. It provides the following features: Up to 72 Mbps raw and 49 Mbps Ethernet throughput; dynamic time division duplex transmission; bi-directional dynamic adaptive modulation; point-to-point and point-to-multipoint; dynamic frequency selection (DFS) and automatic transmit power control (ATPC) options.

Table 19:
Fixed WiMAX signal parameters

Parameter	Value
Multiple access method	OFDM
Modulation	QPSK
FEC	½
FFT points	256
Guard interval	1/16
Frame duration	5 ms
Channel raster	20 MHz
Duplex	TDD

As no mobile WIMAX transceivers were readily available a fixed WiMAX system was used. The bandwidth of this system is 20 MHz and has a time frame of 5 ms. The modulation of the system was fixed at QPSK ½ and no automatic repeat request (ARQ) option was presented by the system in order to improve the BER.

The level of interference required to cause the BER to drop to by a certain percentage for the fixed WIMAX device under test can be scaled for mobile WIMAX as $10\log_{10}$(bandwidth ratio), since the OFDM signal scales by the same proportion as white noise.

Also, by measuring the sensitivity of the system the noise figure of the fixed WiMAX system can be calculated from the difference of the measured minimum receiver sensitivity and noise level calculated using kBT, where k is Boltzmann's constant, B is the receiver bandwidth and T is the operating temperature. Once again this noise figure can be scaled proportionally to the bandwidth of the mobile WiMAX receiver.

Finally, it may be assumed that the distribution of the signal across the 256 tones for the fixed case instead of across 1024 tones (apart form the interleaving), should be a second order effect compared to the effects of changing the bandwidth and noise figure of a fixed or mobile WiMAX system.

3.9.2 Interfering system parameters

The DVB-T parameters shown in Table 3 were used as the interference source.

3.9.3 Interference criteria

The WiMAX equipment uses TDD multiplexing and therefore it was not possible to undertake separate measurements on the uplink and downlink. Instead, any interference resulted in an overall drop in data throughput on the WiMAX link.

The results are presented as the C/I level that produced a 50% degradation in throughput.

3.9.4 Equipment set-up and test procedure

DVB-T interference measurements into a fixed WiMAX system were performed using the conducted measurement set-up shown in the diagram below.

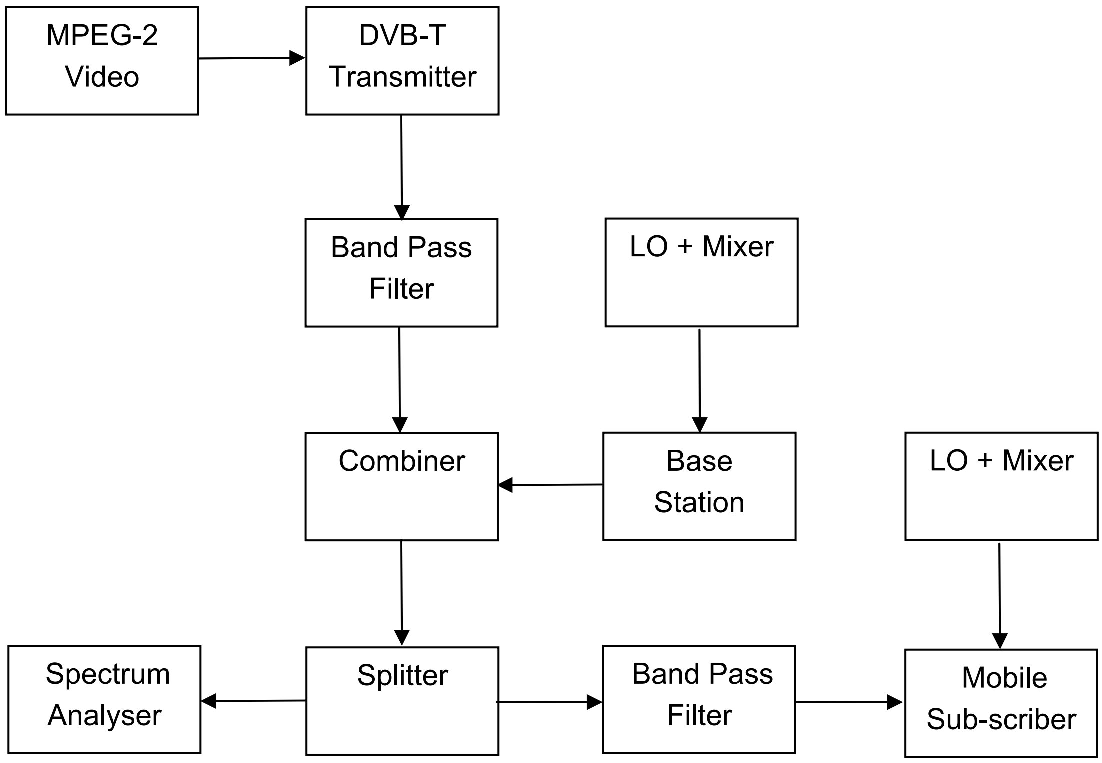

Figure 19: Measurement set-up of DVB-T interference into fixed WiMAX

Based on the above measurement parameters and test set-up, the following test procedure was used:

1. The fixed WiMAX system was set to QPSK modulation, representative of the modulation used by mobile WiMAX equipment.

2. The wanted received signal level was reduced to 3 dB above the MUS.

3. The wanted channel power level ‘C’ was measured with a spectrum analyser using RMS detection, a RBW of 100 kHz and a VBW of 1 MHz.

4. The level of unwanted interference was increased until 50 % degradation in throughput of the fixed WiMAX system was observed.

5. The power level of the interferer ‘I’ was measured in a channel bandwidth equal to one channel spacing, using RMS detection, a RBW of 100 kHz and a VBW of 1 MHz.

6. The C/I protection ratio was calculated from Steps 3 and 5.

The above procedure was carried out for co-channel interference out to 16 MHz in 1 MHz steps and out to 88 MHz frequency separations using 8 MHz steps.

3.10 DVB-T Interference into a DVB-H Handset

3.10.1 Wanted system parameters

The DVB-H signal received by the handset was generated using a R&S SFU signal generator. A transport stream specific for the DVB-H handset was loaded onto the hard drive of the signal generator and played back to the DVB-H handset based on the following parameters.

Table 20:
DVB-H signal parameters

Parameter	Value
Multiple access method	OFDM
Modulation	QPSK
FEC	½
FFT points	8 k
Guard interval	1/8
Channel raster	8 MHz
Time slicing	Yes

The frequency of the wanted signal was fixed at 562 MHz because of the way the transport parameters signalling (TPS) header was constructed for the particular DVB-H handset.

3.10.2 Interfering system parameters

The DVB-T parameters shown in Table 3 were used as the interference source.

3.10.3 Interference criteria

The same interference criterion was used to test the DVB-H handset as for the DVB-T receiver. The criterion was based on measuring the receiver quality performance as described in the D-Book (see Section 3.3.3).

3.10.4 Equipment set-up and test procedure

DVB-T interference measurements into a DVB-H handset were performed using the conducted measurement set-up shown in the diagram below.

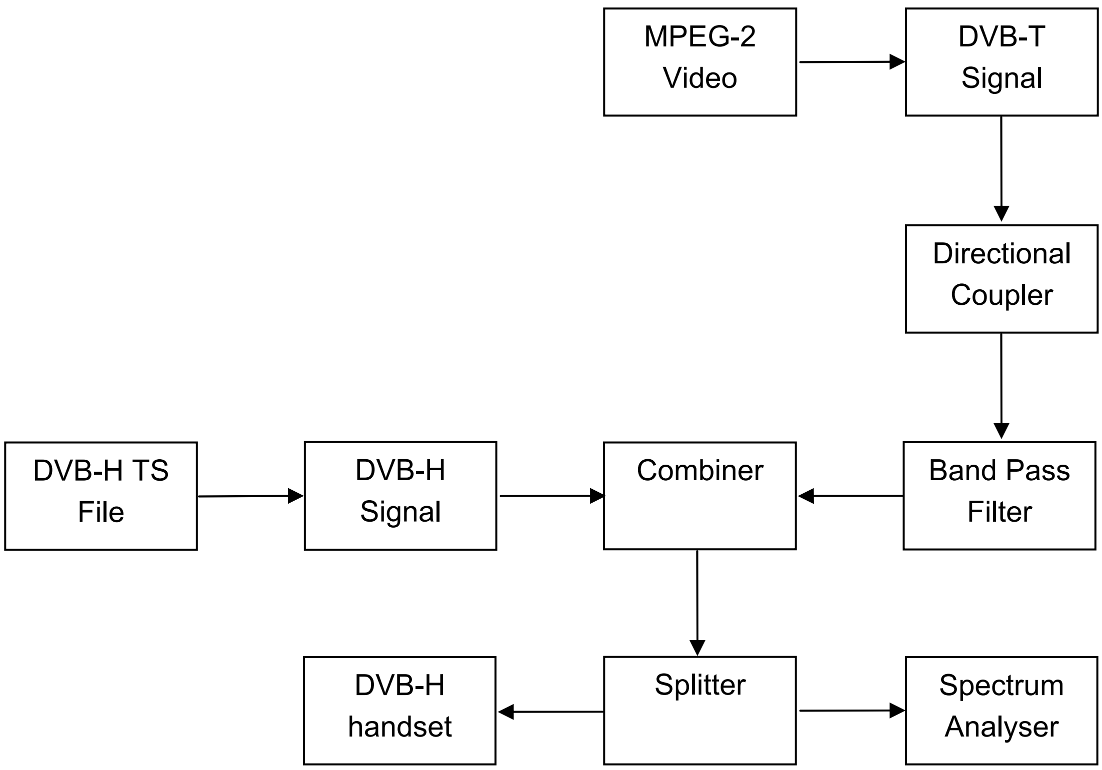

Figure 20: Measurement set-up of DVB-T interference into a DVB-H handset

The DVB-H handset did not have an external antenna port and therefore was placed in a strip-line to perform the immunity tests.

The strip-line was used to create a uniform field between the parallel plates and the handset was placed in the middle of the device. The orientation of the handset was such that the received field was its maximum, i.e. co-polar to the vertical electric field produced in the strip-line (see figure below).

Figure 21: Picture of a DVB-H handset positioned in the middle of a strip-line

The procedure used to measure the C/I protection ratio of the DVB-H handset was based on the picture quality criterion described in Section 3.3.3.

4. Results

4.1 UMTS User Equipment Interference into a DVB-T Receiver

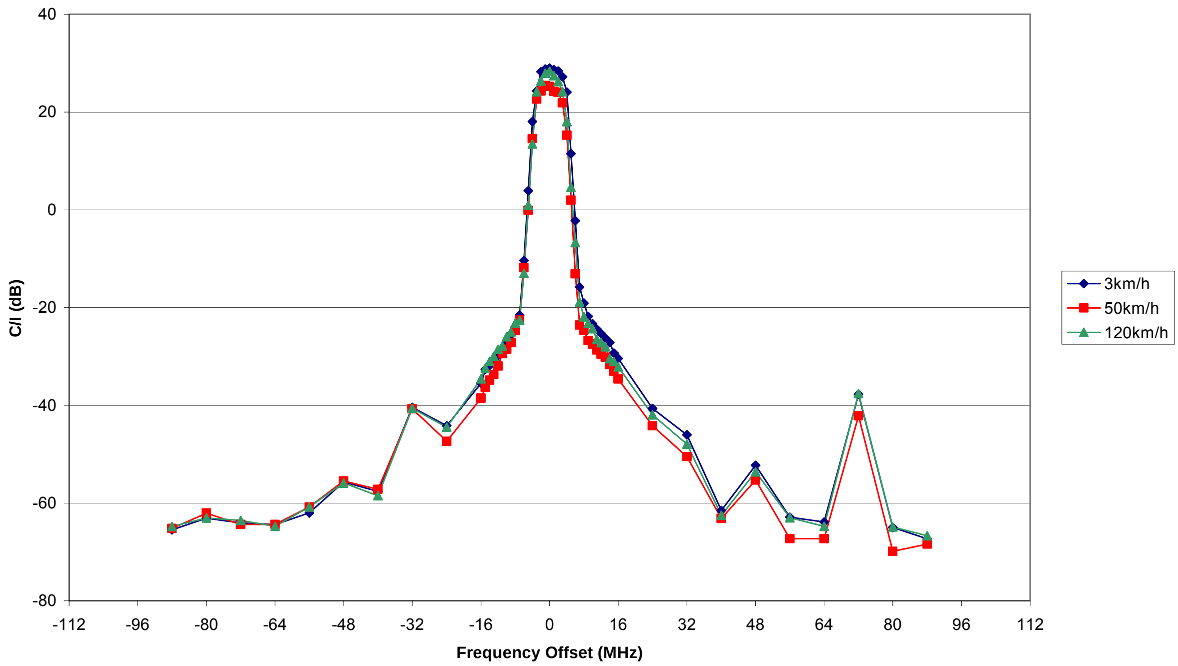

Figure 22: C/I protection ratios for UMTS UE interference into a DVB-T receiver under transmit power control conditions for 3 km/h, 50 km/h and 120 km/h

The figure above shows the measured C/I protection ratios for UMTS UE uplink interference into a DVB-T receiver under three TPC conditions based on 3 km/h, 50 km/h and 120 km/h fast fading channels. These TPC profiles are shown in Figure 6, Figure 7 and Figure 8 for each of the fast fading channel speeds.

The results show that the C/I protection ratios measured for a typically performing DVB-T receiver are very similar regardless of the speed of the UE. The 4 to 5 dB difference between the 50 km/h results and the 3 and 120 km/h results is comparable to the differences in the peak transmitted power in the TPC profiles used as shown in the figures of Section 3.3.2.

Also, the UMTS UE uplink interference into a typically performing DVB-T receiver is similar in profile to that compared for DVB-T interference [11].

The table below shows the comparison (for selected channels) between DVB-T interference and UMTS UE interference into a typically performing DVB-T receiver.

Table 21:
Comparison of C/I protection ratios for DVB-T and UMTS UE interference into a typically performing DVB-T receiver

Interferer	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
DVB-T (static)	-52	-37	15	-33	-47	-49
UMTS UE (static)	-51	-47	20	-44	-44	-50
UMTS UE TPC (3 km/h)	-33	-24	29	-19	-30	-38
UMTS UE TPC (50 km/h)	-37	-26	24	-26	-36	-43
UMTS UE TPC (120 km/h)	-33	-23	28	-22	-32	-38

The 10 to 13 dB drop in the measured C/I protection ratios for UMTS UE interference with TPC for adjacent channels, co-channel and channel N+9, compared with DVB-T interference into a typically performing DVB-T receiver, is due to the impulsive peaks of the TPC profiles puncturing the receiver.

The figure below shows the comparison between the interim results submitted for ECC study group TG4 and the results re-measured using a larger TPC profile and signal generation technique for the 120 km/h fast fading channel.

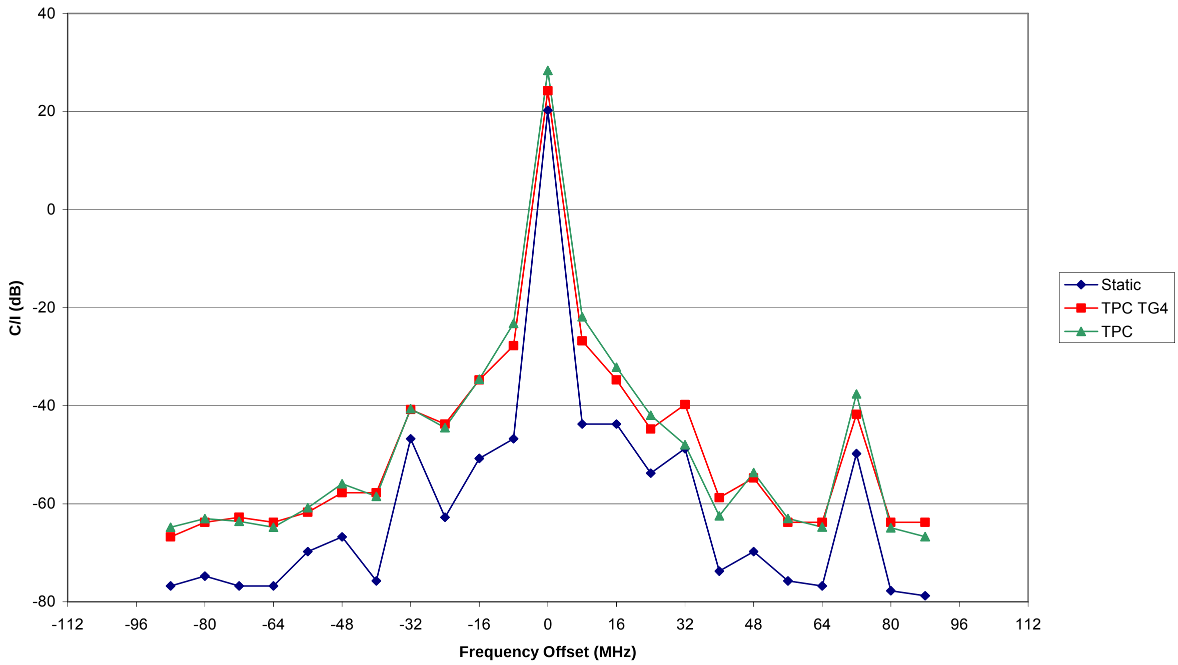

Figure 23: Comparison of 120 km/h case with results submitted to TG4

From the figure above, it can be seen that UMTS UE uplink interference with TPC into a typically performing DVB-T receiver varies by 2 to 4 dB across the measure frequency spectrum. The difference in results between the UMST UE using the two TPC profiles is once again in the difference in amplitude of the impulsive peaks.

The measured results also show a 10 to 13 dB difference between the UMTS UE with TPC conditions compared to a static UMTS UE interfering into a typically performing DVB-T receiver. This difference is once again due to the impulsive nature of the TPC profile of the UE puncturing the DVB-T receiver.

4.2 DVB-T Interference into UMTS User Equipment

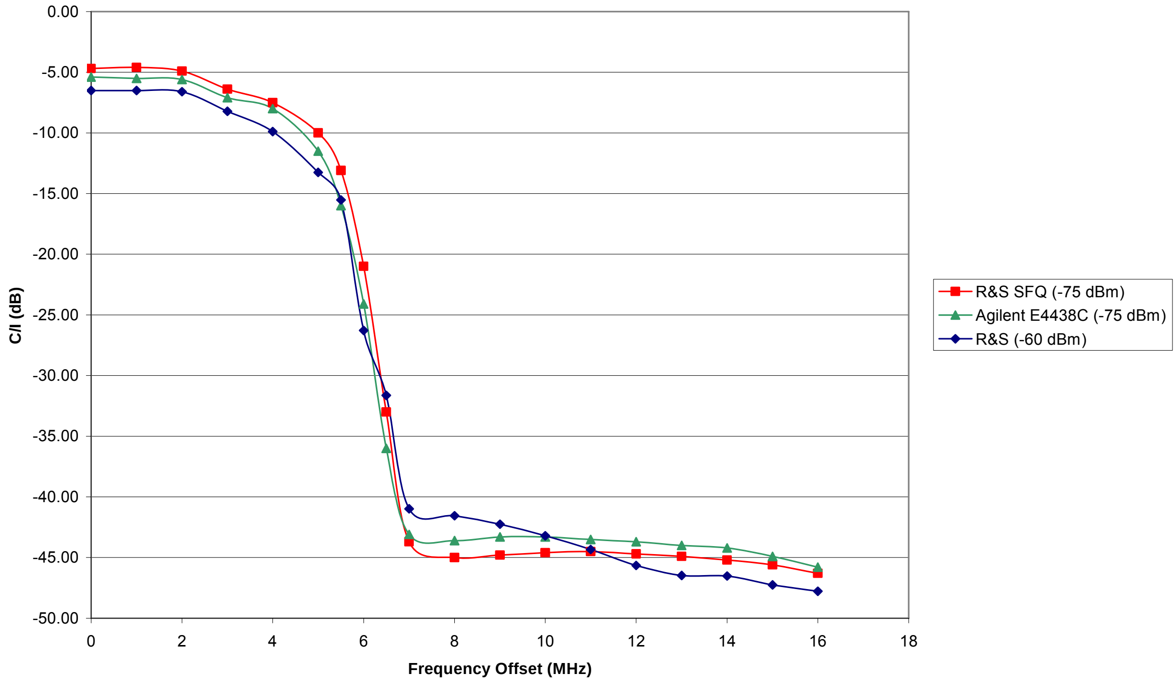

Figure 24: C/I protection ratios for DVB-T interference into a UE for 3km/h fading conditions

Figure 24 above shows the measured C/I protection ratios for DVB-T interference into a UMTS UE for a fast fading channel based on a speed of 3 km/h. The C/I protection ratios were measured for a RMC of 12.2 kbps representing voice using the test set-up described in Section 3.4.4.

From the plot above it can be seen that for co-channel interference, a C/I protection of -5 dB and -6.5 dB is required for the receiver operating at -60 dBm and -75 dBm respectively. At frequency separations of 8 MHz and greater the C/I protection ratio decreases to approximately -45 dB for the receiver operating at -60 dBm and -75 dBm, even when using a different DVB-T signal source (Agilent E4438C).

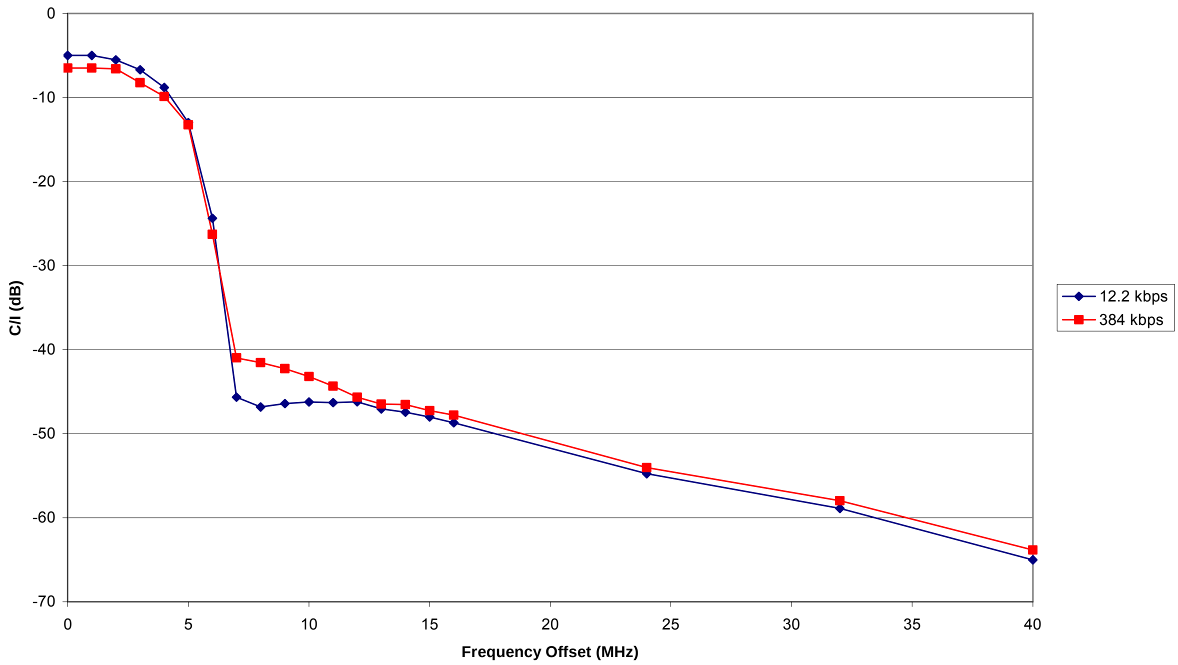

Figure 25: Comparison of C/I protection ratios for DVB-T interference into a UE using a RMC of 12.2 kbps and 384 kbps

Figure 25 above shows the comparison of C/I protection ratios for DVB-T interference into a UMTS UE receiving a DL RMC of 12.2 kbps representing voice and 384 kbps representing data, respectively.

From the plot above it can be seen results are very similar for both RMC channels. The similarity can be explained by the relative increase in the DCH level of 12.8 dB compensating for the increased data rate in signal of 15 dB (see Table 15).

4.3 UMTS Node B Interference into a DVB-T Receiver

The figure below shows measured C/I protection ratios for Node B interference using a 384 kbps RMC channel into a typically performing receiver for both static and TPC conditions compensating for a fast fading Rayleigh channel based on a speed of 3 km/h. The conducted measurements were performed using the test set-up described in Section 3.5.4.

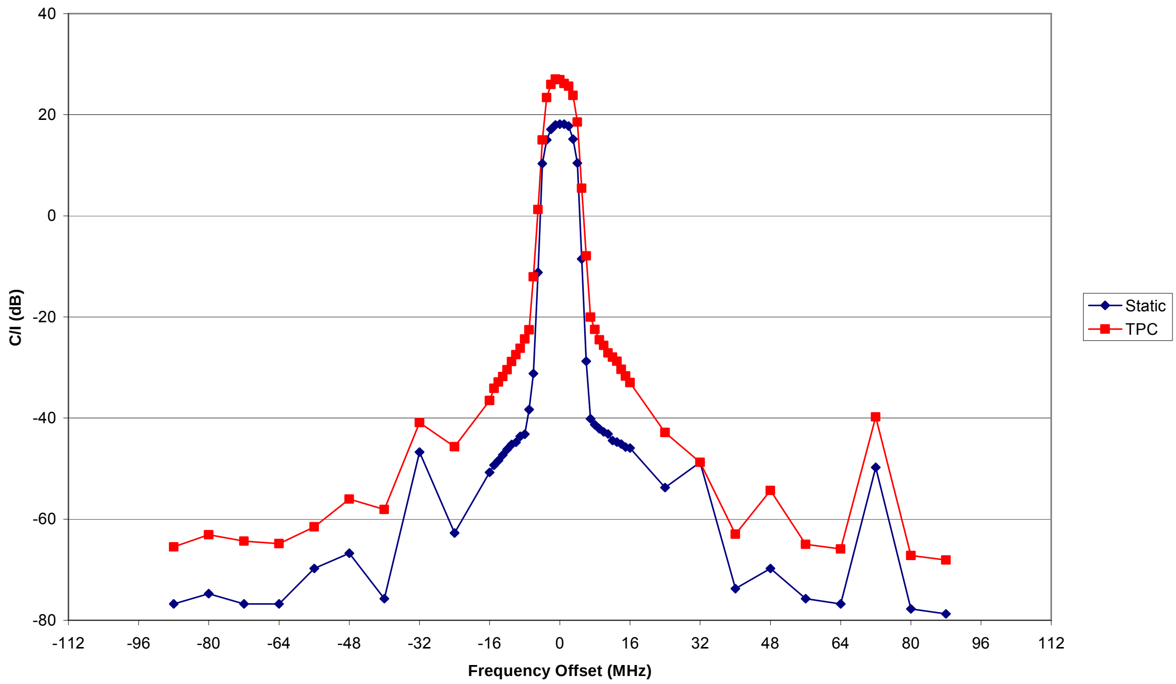

Figure 26: C/I protection ratios for Node B interference into a DTT receiver under static and TPC conditions (for 3 km/h case)

The results above give a similar C/I protection profile when compared to the UMTS UE interference results into a typically performing DVB-T receiver (see Figure 22).

This difference between the static measured results and the Node B DL TPC results is once again due to the impulsive nature of the TPC profile puncturing the DVB-T receiver.

Note: the Node B TPC profile was a summation of three individual TPC profiles presenting a fast fading channel of 3 km/h, 50 km/h and 120 km/h speeds.

The table below gives the comparison (for selected channels) between UMTS Node B interference into a DVB-T receiver in a static channel, UMTS UE and a UMTS Node B interference with a TPC profile based on a aggregate profile described above.

Table 22: Comparison of C/I protection ratios for UMTS Node B and UMTS UE interference into a typically performing DVB-T receiver

Interferer	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
Node B (static)	-51	-43	18	-41	-45	-50
UMTS UE TPC (3 km/h)	-33	-24	29	-19	-30	-38
UMTS Node B (aggregate)	-37	-24	27	-22	-33	-40

The measured results show a 10 to 13 dB difference between both the UMTS UE uplink and Node B downlink with TPC conditions compared to a static UMTS Node B interfering into a typically performing DVB-T receiver. This difference is once again due to the impulsive nature of the TPC profile of the UE puncturing the DVB-T receiver. It should be noted, however, that the fading profile is in some senses a worst case since the common pilot channel and the combination of larger numbers of mobile stations would be expected to reduce the statistical variation of the transmit power in practice.

4.4 DVB-T Interference into a UMTS Node B

The figure below shows measured C/I protection ratios for DVB-T interference using a 384 kbps RMC channel into a Node B for static conditions. The conducted measurements were performed using the test set-up described in Section 3.6.4.

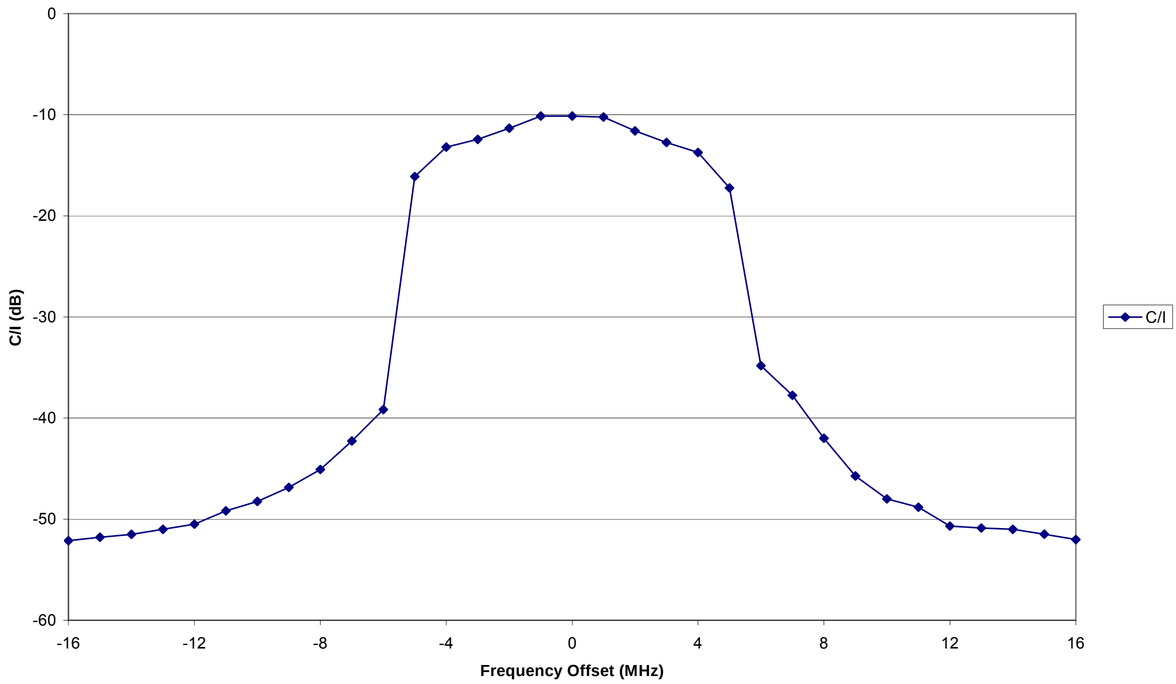

Figure 27: C/I protection ratios for DVB-T interference into a Node B based on static conditions

From the figure above it can be seen that a co-channel C/I protection of -10 dB is required for the UMTS Node B operating at 50-60 % load capacity. At frequency separations of ±8 MHz, the C/I protection ratio decreases to approximately -42 to -45 dB for the device under test. At frequency separations of ±16 MHz, the C/I protection ratio further decreases to -52 dB.

The results in Figure 27 reveal that the Node B tested is approximately 5 dB less susceptible to DVB-T interference compared with the UE results (Figure 24).

4.5 Mobile WiMAX Interference into a DVB-T Receiver

Figure 28, below shows the measured C/I protection ratios for mobile WiMAX uplink and downlink interference into a typically performing DVB-T receiver. The mobile WIMAX signals were based on a fading profile for a pedestrian travelling at speed of 3 km/h. The conducted measurements were performed using the test set-up described in Sections 3.7.4 and 3.8.4.

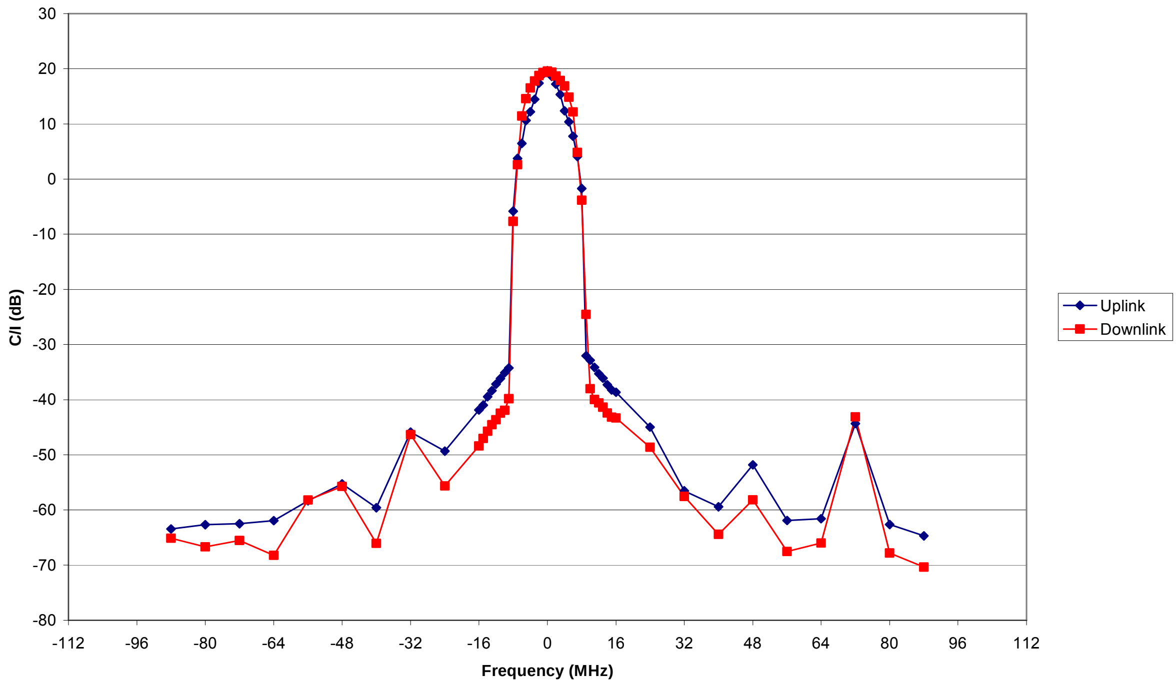

Figure 28: C/I protection ratios for mobile WiMAX interference into a DVB-T receiver (for pedestrian channel at 3 km/h)

Once again, the mobile WiMAX interference into a typically performing DVB-T receiver is similar in profile as that compared for DVB-T interference [11].

The 4-5 dB difference between the mobile WiMAX uplink interference results compared with the mobile WiMAX downlink results is due to the more impulsive nature of the uplink signal from the subscriber compared with the base station downlink signal into the DVB-T receiver.

The table below gives the comparison (for selected channels) between DVB-T interference into a DVB-T receiver in a static channel and mobile WiMAX for a fading channel of 3 km/h.

Table 23:
Comparison of C/I protection ratios for mobile WiMAX uplink and downlink interference into a typically performing DVB-T receiver

Interferer	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
DVB-T (static)	-52	-37	15	-33	-47	-49
Mobile WiMAX uplink	-42	-34	20	-32	-39	-44
Mobile WiMAX downlink	-48	-39	20	-38	-43	-43

The table above shows a 4-5 dB difference between the mobile WiMAX uplink out of band interference results compared with the mobile WiMAX downlink out of band results, with the exception at channel N+9. This difference in results may be due to the more impulsive nature of the subscriber signal compared to the base station signal.

4.6 DVB-T Interference into a Fixed WiMAX System

Figure 29 below shows measured C/I protection ratios for DVB-T interference into a fixed WiMAX system. The fixed WIMAX system has a receiver bandwidth of 20 MHz. The conducted measurements were performed using the test set-up described in Section 3.9.4.

The results below show that a C/I protection ratio of -5 dB is required for co-channel interference. For adjacent channel interference (20 MHz separation between centre frequencies) a C/I protection ratio of -21 dB is required from an interfering DVB-T signal. This ratio decreases to -44 dB for two WiMAX channel frequency separations and flattens off for frequency offsets greater than 56 MHz.

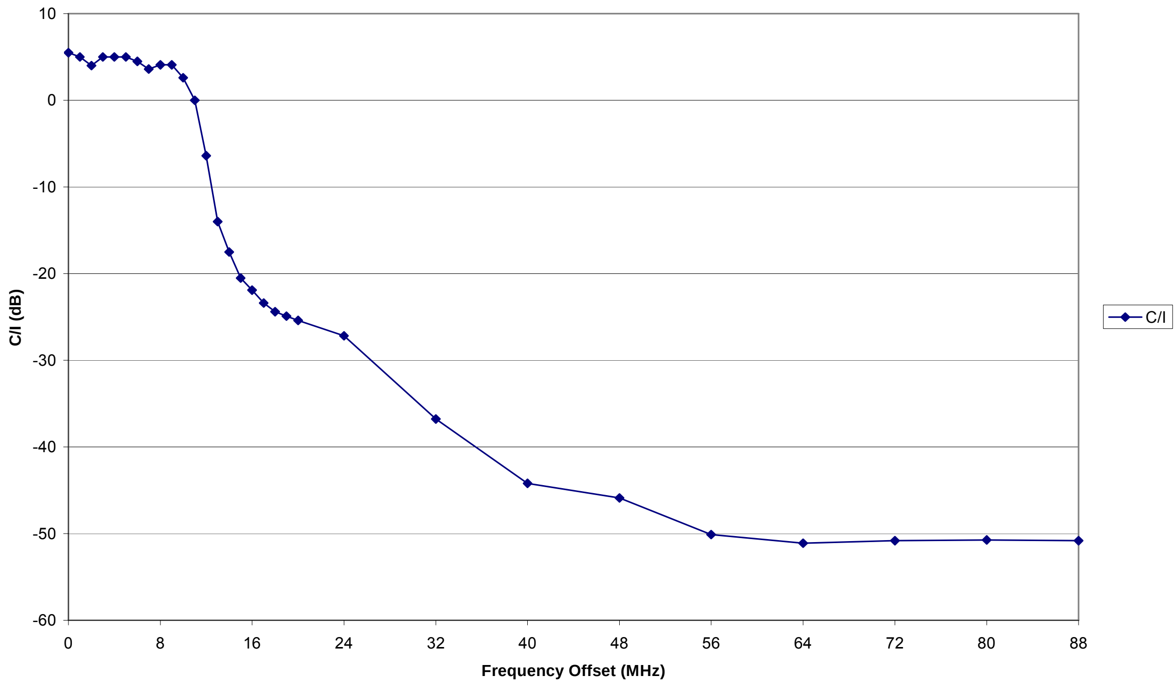

Figure 29: C/I protection ratios for DVB-T interference into a fixed WiMAX system

The C/I protection ratio results were based on a throughput drop as 50 % as the fixed WiMAX receiver did not need too much of an increase in interference (2 dB) for the throughput to drop from 100 % to 0 % (see Figure 30).

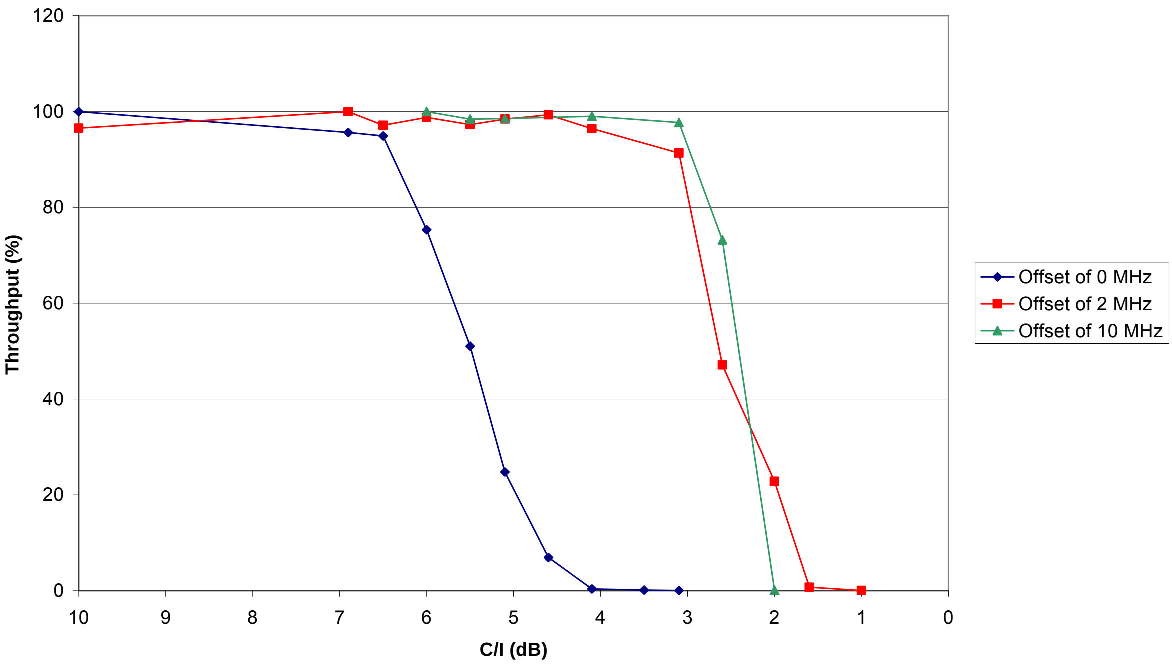

Figure 30: Throughput vs C/I for DTT interference into a fixed WiMAX system

4.7 DVB-T Interference into a DVB-H Handset

Figure 29 below shows the measured C/I protection ratios for DVB-T interference into a DVB-H handset. The conducted measurements were performed using the test set-up described in Section 3.10. The DVB-H handset received a transport stream (TS) using QPSK modulation at a fixed frequency of 586 MHz and had a receiver bandwidth of 8 MHz. The TS file used to observe the impairment of the quality the received moving picture was specific to the handset manufacturer.

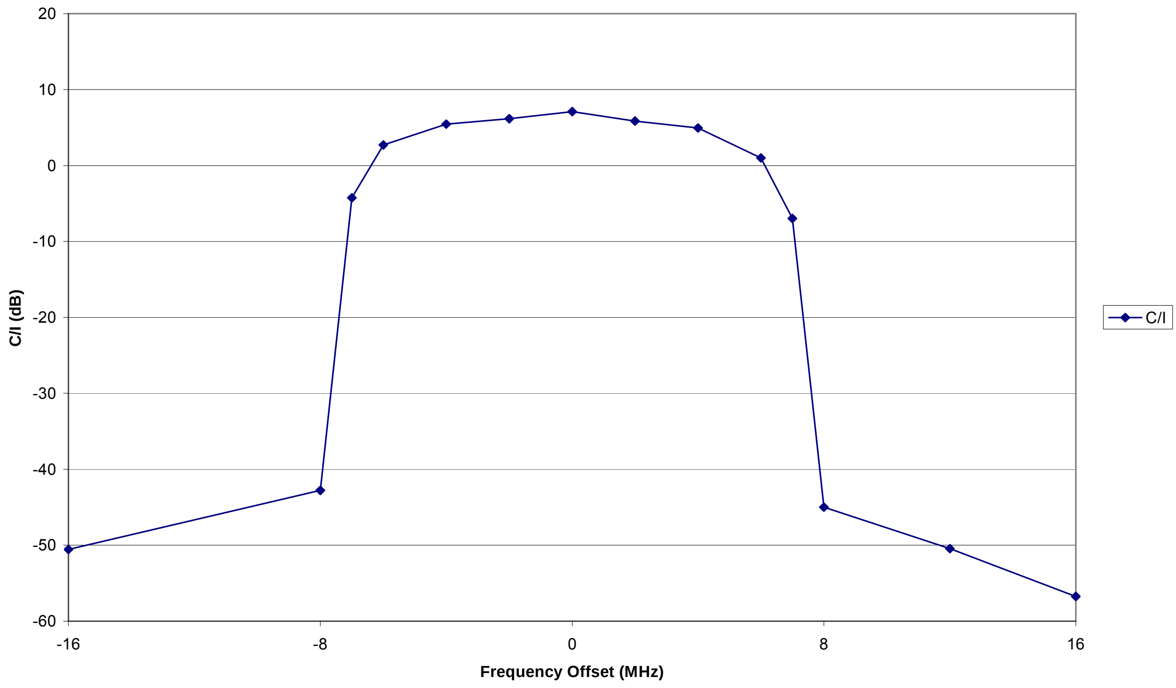

Figure 31: C/I protection ratios for DVB-T interference into a DVB-H handset

The plot above shows that a C/I protection ratio of 8 dB is required for co-channel interference from a DVB-T signal. This ratio decreases to -43 dB and -45 for N-1 and N+1 adjacent channel interference respectively. This protection ratio decreases approximately by 10 dB to -51 dB and -57 dB for channels N-2 and N+2 respectively.

The C/I protection ratios at further frequency channel separations could be not be measured, because of the conducted measurement set-up using the strip-line could not produce enough power to cause the onset of interference to the DVB-H handset, without overloading the amplifier.

The table below gives a comparison between DVB-T interference into a DVB-H handset against a typically performing DVB-T receiver [11].

Table 24:
Comparison of C/I protection ratios for DVB-T interference into a DVB-H handset and a typically performing DVB-T receiver

Receiver	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
DVB-H	-51	-43	8	-45	-57	-
DVB-T	-52	-37	15	-33	-47	-49

From the table above it can be seen that the DVB-H handset has a better C/I protection ratio at N-1, N, N+1 frequency channel separation for DVB-T interference compared the typically performing DVB-T receiver. This difference of approximately 7 to 8 dB is due the DVB-H receiver operating in QPSK mode compared to the DVB-T receiver operating in 64-QAM mode.

At channels N-2 the protection ratios for both receivers tested have a difference of 1 dB. However, at N+2 frequency channel separations the DVB-H handset has a 10 dB better protection margin compared with DVB-T receiver. This may be due to the difference in IF filter characteristics between the devices.

5. Summary and Conclusions

As part of the DDR, ERA was asked by Ofcom to investigate the potential interference to DVB-T receivers from UMTS and WiMAX mobile transmitters for adjacent and N+9 channel separation. The results of this initial work were presented in a report to Ofcom in December 2006 [2].

Following on from this work Ofcom commissioned further measurements to characterize the potential interference for a wider selection of technologies that could potentially occupy the DDR award spectrum, these being:

Table 25:
Technologies used for conducted measurement testing

Digital video broadcast – terrestrial (DVB-T)
3G UTRA (FDD) (user equipment and Node B)
Mobile WIMAX (mobile and base station)
Digital video broadcast – handheld (DVB-H)

ERA was asked to provide measurement results for the following scenarios:

1. UMTS user equipment interference into a DVB-T receiver.
2. DVB-T interference into UMTS user equipment.
3. UMTS node B interference into a DVB-T receiver.
4. DVB-T interference into UMTS Node B.
5. Mobile WiMAX mobile station interference into a DVB-T receiver.
6. Mobile WiMAX base station interference into a DVB-T receiver.
7. DVB-T interference into a fixed WiMAX system.
8. DVB-T interference into a DVB-H handset.

The test method and parameters for each of the conducted measurement scenarios are documented in this report and a summary of the results is given below.

Interference into a DVB-T receiver

The table below shows the measured C/I protection ratio comparison (for N-2 to N+2 channels and channel N+9) of DVB-T, UMTS and WiMAX interference and into a typically performing DVB-T receiver.

Table 26: Comparison of C/I protection ratios for DVB-T, UMTS and WiMAX interference into a typically performing DVB-T receiver (64-QAM FEC 2/3)

Interferer	Measured C/I protection ratio (dB)					
	N-2	N-1	N	N+1	N+2	N+9
DVB-T (static)	-52	-37	15	-33	-47	-49
UMTS UE (static)	-51	-47	20	-44	-44	-50
UMTS UE TPC (3 km/h)	-33	-24	29	-19	-30	-38
UMTS UE TPC (50 km/h)	-37	-26	24	-26	-36	-43
UMTS UE TPC (120 km/h)	-33	-23	28	-22	-32	-38
Node B (static)	-51	-43	18	-41	-45	-50
UMTS Node B (aggregate)	-37	-24	27	-22	-33	-40
Mobile WiMAX uplink	-42	-34	20	-32	-39	-44
Mobile WiMAX downlink	-48	-39	20	-38	-43	-43

From the table above, it can be concluded a typically performing DVB-T receiver is most susceptible to UMTS UE uplink and Node B downlink interference with TPC used to compensate for a Rayleigh fading channel at speeds of 3 km/h, 50 km/h and 120 km/h. A mobile WiMAX uplink signal requires 5 to 10 dB more power to cause the onset of interference into the DVB-T receiver compared with the UMTS results. A mobile WiMAX down link signal requires the most power to impair the picture quality of the received DVB-T signal.

The 4 to 5 dB difference between the mobile WiMAX uplink out of band interference results compared with the mobile WiMAX downlink out of band results may be due to the more impulsive nature of the subscriber signal compared to the base station signal.

Overall, the profile of the C/I protection results for UMTS and mobile WIMAX interference into a typically performing DVB-T receiver is similar to that compared for DVB-T interference [11].

DVB-T as the interferer

The conducted measurement results show that:

- For DVB-T co-channel interference a C/I protection of – 5 dB and -6.5 dB is required for the UMTS UE operating at a received power of -60 dBm and -75 dBm respectively. At frequency separations of 8 MHz and beyond, the C/I protection ratio decreases to approximately -45 dB for the receiver operating at -60 dBm and -75 dBm.

- For DVB-T co-channel interference, a C/I protection of -10 dB is required for the UMTS Node B operating at 50-60 % load capacity. At frequency separations of ±8 MHz, the C/I protection ratio decreases to approximately -42 to -45 dB for the device under test. At frequency separations of ±16 MHz, the C/I protection ratio further decreases to -52 dB for the device under test.

- A C/I protection ratio of -5 dB is required for co-channel DVB-T interference into a fixed WiMAX system. For adjacent channel interference (20 MHz separation between centre frequencies) a C/I protection ratio of -21 dB is required. This ratio decreases to -44 dB for two WiMAX channel frequency separations and flattens off for frequency offsets greater than 56 MHz.

- A C/I protection ratio of 8 dB is required for co-channel interference from a DVB-T signal into a DVB-H handset. This ratio decreases to -43 dB and -45 dB for N-1 and N+1 adjacent channel interference respectively. This protection ratio further decreases approximately by 8 to 12 dB to -51 dB and -57 dB for channels N-2 and N+2 respectively.

6. References

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

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

[3] ETSI EN 300 744: Digital Video Broadcasting; Framing structure, channel coding and modulation for digital terrestrial television, v1.5.1 November 2004

[4] ETSI EN 302 296: Transmitting equipment for the digital television broadcast service, terrestrial (DVB-T), v1.1.1 January 2005

[5] ETSI TS 125.101: Universal Mobile Telecommunications System (UMTS); User Equipment (UE) radio transmission and reception (FDD) (3GPP TS 25.101 version 7.8.0 Release 7)

[6] ETSI TS 134.121-1: Universal Mobile Telecommunications System (UMTS); User Equipment (UE) conformance specification; radio transmission and reception (FDD); Part 1 conformance specification (3GPP TS 34.121-1 version 7.5.0 Release 7)

[7] ETSI TS 125.104: Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104 version 7.7.0 Release 7)

[8] ETSI TS 125 141: Universal Mobile Telecommunications Systems (UMTS); Base Station (BS) conformance testing (FDD) (3GPP TS 25.141 version 7.8.0 Release 7)

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

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

[11] Conducted measurements to quantify DVB-T interference into DTT receivers", ERA Technology, August 2007

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APPENDIX A: Test Equipment

A.1 Test Equipment List

- Agilent 8960 series 10 wireless communications test receiver
- Agilent E4438C signal generator
- R&S MPEG encoder
- R&S SFQ DVB-T TV transmitter
- R&S AMIQ baseband I/Q signal generator
- R&S SFU signal generator
- Wiltron VSWR bridge (0.5 MHz to 2 GHz)
- HP splitter (DC to 18 GHz)
- Marconi programmable 20 GHz attenuators
- R&S SFU spectrum analyser
- DVB-T receivers
- Digix LCD TV display
- 50 Ω to 75 Ω matching pad
- Standard TV scart lead