OFCOM

Conductive Measurements of DTT Receiver Selectivity in Response to Interference from Adjacent Channel White Space Devices and LTE Mobiles

by

DTG Testing Limited

Final Report

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1. Executive Summary

Increasingly DTT services have to operate in spectrum bands in close proximity to a range of technologies. One such example of this will be potential future deployments of white space device (WSD) technologies operating in the DTT frequency range. As these signals could operate over a range of frequencies and signal power levels, understanding the impact on existing DTT services is crucial to a smooth introduction of new services.

A further example has been LTE 800 MHz where one method of mitigation against potential DTT interference has been to implement a reverse duplex arrangement resulting in an increased frequency separation between LTE user equipment (UE) and DTT services. However, future implementations within 700 MHz may not employ this arrangement, meaning that LTE UE signals, which are more likely to be time discontinuous in comparison to base station signals, will be operating in closer proximity to DTT services.

As part of its responsibilities for mitigation of potential interference to Digital Terrestrial Television ("**DTT**") caused by the introduction of WSD and LTE services in the UK, Ofcom have commissioned a measurement programme to investigate the potential effects of these services on DTT. This report presents the results of the measurement programme which was carried out for a range of wanted DTT, WSD and LTE UE signal levels and frequency offsets as well as studying the impact of pre-amplification on DTT susceptibility to interference. The results of the study are intended to inform Ofcom on safe levels of operation of WSD and LTE UE signals, which should avoid potential interference issues with DTT and to provide guidance as to contributing factors such as pre-amplification and the susceptibility to interference of the top selling DTT receivers. In addition the performance of the receivers can be used as a comparator to existing measurements currently used in modelling locations where interference could potentially occur.

A selection of 50 DTT receiver chassis was made based on sales data to provide a cross sectional representation of the types of receivers available, such as those with silicon tuners and super-heterodyne "can" tuners, set top boxes and integrated TV tuners. This selection represents over 50% of receivers sold in the UK since 2007.

The LTE UE signals used in testing were recorded from an LTE equipment vendor's test network. The recordings were made during three different traffic loading scenarios: maximum traffic load with 100% loading, half traffic load with 50% loading and idle mode, which has no traffic and causes time discontinuous pulses.

Two of the WSD signals were WiMAX and WiFi recordings made by the BBC taken from commercially available equipment. These were then band pass filtered using software to reduce adjacent channel emissions. The third WSD signal used the Weightless standard and was taken directly from a base station provided by a machine to machine WSD vendor.

The requirement of the project was to test 50 DTT receivers in parallel against the LTE and WSD test signals up to a maximum interferer level of 0dBm. This was also the maximum level that could be reached whilst testing 50 receivers in parallel. During protection ratio tests using stronger DTT levels or greater frequency separations between the DTT signal and the unwanted signal, some of the receivers did not fail when the maximum in band power level was reached and so the protection ratio could not be measured. Appendix A shows the protection ratio results and a bold line is shown on the graphs to indicate the maximum power level of the unwanted signal that could be achieved during the testing. Where the protection ratio curves meet the limit line it means that the receiver did not fail at this level of unwanted signal. This was the case for all of the LTE signals as well as the WiMAX and WiFi signals. To obtain data for all DTT signal levels and frequency separations, during testing of the Weightless signal, the number of receivers tested in parallel was reduced to 8 meaning higher power levels were achievable. As a result, all of the receivers were tested until failure to allow the protection ratios to be measured.

The results are presented as measured carrier to interference protection ratios and derived adjacent channel selectivity values for a selection of the 50 test receivers whilst using pre-amplification. These indicate the impact of pre-amplification on the maximum tolerable level of interfering signal that can be present at a receiver before degradation to picture quality is caused.

The impact of fading on the DTT and unwanted signal is also presented as the changes in maximum tolerable WiMAX and LTE full load signals with and without fading applied.

The impact of filtering was also measured for LTE signals using channel 59 and 60 LTE 800 filters and carrying out measurements of protection ratios before and after the filter was applied.

Finally the measured carrier to interference protection ratios and derived adjacent channel selectivity results are presented for the 50 test receivers using the LTE and WSD signals along with analysis highlighting any trends or common behaviour.

2. Background

This test programme has been carried out in response to the OFCOM ITQ: Conductive Measurements of DTT Receiver Selectivity in Response to Interference from Adjacent Channel White Space devices and LTE Mobiles.

The aim of the work was to measure the maximum carrier to interference ratios permissible in a range of DTT receivers whilst still maintaining an acceptable level of picture quality in the presence of a range of interfering signals. The measurement results will be used to understand the scale of DTT receiver selectivity in the market.

As there is a wide range of factors which contribute to the final results, the programme has incorporated a number of different methods for testing, which are listed in section 3: Scope and Objectives. In addition, the receiver chassis samples selected for testing represent over 50% of receivers sold in the market since 2007. The final results therefore provide a comprehensive baseline of signal levels that can be used when planning safe operating limits.

This report is an overview of the test methodology and results.

3. Scope and objectives

The overall aims of the measurement study were to derive the carrier to interference ratios in order to calculate the adjacent channel selectivity (ACS) values of a sample of test receivers.

The objective of the test programme was to investigate the following:

a) Market penetration of DTT receivers
b) The effect of DTT receiver pre-amplifiers on protection ratios and ACS values
c) The impact of fading
d) The impact of filtering on LTE co-existence
e) Protection ratio testing on a 50% market sample of DTT receivers against WSD and LTE signal sources.

The interfering signals used for the testing were from LTE UEs and WSD CPEs from three candidate WSD technologies which were WiFi, WiMAX and Weightless.

4. Market penetration of DTT receivers

The DTT receivers used for the testing were chosen initially based upon DTG sales data as the top selling 50 receivers between 2007 and 2013. This was so that the results would provide a good representation of the effects of LTE on the most commonly found receivers.

In addition to purely sales data, receivers were also chosen to represent different receiver types, tuner types i.e. silicon or can and those that support either DVB-T or both DVB-T and DVB-T2 transmission modes.

Table 1 lists the types of receivers under test.

Test ID	Receiver type	Product type	Total chassis sales units
1	DVB-S, DVB-T	iDTV	144813
2	DVB-S, DVB-T2	3D-iDTV	581205
3	DVB-S, DVB-T2	3D-iDTV	254999
4	DVB-T2	STB	159294
5	DVB-T2	DTR	159294
6	DVB-T2	DTR	86549
7	DVB-T2	iDTV	428375
8	DVB-T2	DTR	192715
9	DVB-T2	iDTV	159164
10	DVB-T2	DTR	159294
11	DVB-T2	iDTV	444020
12	DVB-T2	iDTV	697392
13	DVB-T2	iDTV	159164
14	DVB-T2	iDTV	254999
15	DVB-T2	STB	1121372
16	DVB-T2	STB	159294
17	DVB-T2	iDTV	192715
18	DVB-T2	iDTV	159164
19	DVB-T2	iDTV	178317
20	DVB-T	iDTV	374381
21	DVB-T	DTR	685527
22	DVB-T	iDTV	238895
23	DVB-T	DTR	350855
24	DVB-T	STB	994048
25	DVB-T	STB	138662
26	DVB-T	iDTV	428375
Test ID	Receiver type	Product type	Total chassis sales units

28	DVB-T	iDTV	776829
29	DVB-T	iDTV	428375
30	DVB-T	STB	215857
31	DVB-T	iDTV	238895
32	DVB-T	STB	18874
33	DVB-T	DVD-R	380008
34	DVB-T	iDTV	729580
35	DVB-T	iDTV	195181
36	DVB-T	DTR	151509
37	DVB-T	iDTV	287103
38	DVB-T	iDTV	250346
39	DVB-T	iDTV	171010
40	DVB-T	iDTV	195894
41	DVB-T	DTR	326406
42	DVB-T	iDTV	159355
43	DVB-T	iDTV	171010
44	DVB-T	iDTV	420270
45	DVB-T	iDTV	234734
46	DVB-T	iDTV	505502
47	DVB-T	iDTV	118
48	DVB-T	STB	343881
49	DVB-T	iDTV	556304
50	DVB-T	iDTV	638567

Table 1 Receivers under test

The sales information is based upon market data for receivers (set top boxes and TVs) since 2007 representing sales made by retailers in the UK an includes online sales. The data is grouped by the receiver chassis, the details of which are obtained from the receiver manufacturers. This means that an individual model of television may have relatively low sales but if it shares the same chassis as other receivers then the overall sales attributable to that chassis can be much greater. Testing one particular model of receiver as a representative of all receivers with the same chassis therefore allows DTG Testing to test a significant proportion of receivers in the market.

Different models of receiver are classed as having the same chassis if they have;

- The same tuner and demodulator
- The same SI/PSI middleware software (including active format descriptor (AFD) and subtitle selection)
- The same multimedia and hypermedia experts group (MHEG-5) engine
- At least the same amount of memory for the MHEG-5 engine and other applications.

4.2 Wanted signal

The DTT wanted signal was generated using Alitronika modulators and PC Stream Xpress software, which is a DTT modulator system allowing multiple test steams to be set up. The signal parameters were set up as in Table 2.

Parameter	DVB-T	DVB-T2
Multiple access	COFDM	COFDM
Modulation	64-QAM	256-QAM
Forward error correction	2/3	2/3
FFT points	8 k	32 k
Guard Interval (μs)	7 ($^1/_{32}$)	28 ($^1/_{128}$)
Data rate (Mbit/s)	24.1	40.2
Channel bandwidth	8 MHz	8 MHz

Table 2 DVB-T1/T2 signal parameters

4.3 Failure criteria for testing

The method for ascertaining the maximum level of interfering signal that can be tolerated by the test receivers whilst still maintaining a clear picture was based upon the D-Book description for picture failure shown in Table 3.

This requires observing the picture during each transition of the interfering signal level and ensuring that there is no break in the picture. A break in the picture would consist of blocking or pixelation and an example is shown in Figure 1.

The D-Book recommends that if a receiver suffers from picture degradation in 2 out of 3 consecutive ten second periods then the receiver has reached failure point i.e. 2 out of 3 periods must be good in order for the receiver to pass this test.

In reality, it was observed that the receivers generally failed fairly suddenly when the interferer was increased in 1dB steps.

Figure 1 Picture failures as used during failure criteria observations

Criterion	Description	Comments
BER_{REF}	DVB-T Post inner decoder BER=2x10^{-4} DVB-T2 Post inner decoder BER=1x10^{-7}	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 TS 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 'Errored Seconds' (Used for 'mobile' applications)
PF	"Picture Failure". No 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.[a]
SFP	"Subjective failure point"	Essentially the same as PF

Table 3 Comparison of degradation criteria[1]

[1] DTG D-Book 7 Part A v3, Table 10-3

4.4 Signal Sources – Interfering signal, WSD

The WSD signals used for the testing were played back using either a Rohde & Schwarz SFU arbitrary signal generator, Agilent MXG or an actual WSD radio. The signals were chosen to represent three candidate WSD technologies.

The WSD technologies used were WiMAX, WiFi and a machine to machine (M2M) base station signal based upon the Weightless standard. The WiMAX and WiFi signals were recordings made by the BBC as part of a DTT protection testing programme, the results of which are documented in *SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices*[2]. These test signals were recorded using an end to end BS to CPE link comprising of commercially available WiMAX and WiFi equipment with an IP traffic loading tool in order to generate varying traffic profiles. The WiMAX signal was a 5 MHz variant of the 802.16e standard of the technology which is mobile WiMAX while the WiFi signal was a quarter bandwidth (5 MHz) variant of 802.11g standard. The WiMAX and WiFi recordings were band pass filtered into 8 MHz channels using software prior to playback in order to ensure an ACLR as large as possible. As the Weightless signal was played directly from the M2M base station, no software band pass filtering was carried out on this signal. During playback test waveforms were band pass filtered using a tuneable band pass filter.

The WiMAX and WiFi signals used for the testing comprised of a data rate of 50kbps being sent via the CPE to capture the worst case scenario of time discontinuous transmissions caused by the low data rate. In addition, the TDD structure of the technology means that the peak to mean ratio of the uplink waveforms is greater as a result and also adds to the discontinuous nature of the waveform. More detail on the difference between the peak and average powers is described in section 4.6

The M2M Weightless signal was an 8 MHz signal made up of pulses with 10ms spacing and was transmitted from a M2M base station connected directly to the test setup. The base station was provided by a UK based wireless communication company that specialises in machine to machine (M2M) communication. Table 4 details the waveform characteristics for each of the WSD test signals.

Waveform	**Channel bandwidth**	**Modulation**	**Data rate**	**Duty cycle**
WiMAX	8MHz	Not known as it was automatically set up by the WSD CPE	50kbps	Variable between 2% and 20%
WiFi	8MHz	Not known as it was automatically set up by the WSD CPE	50kbps	36%
Weightless	8MHz	QPSK	1.2Mbps	35%

Table 4 WSD waveform characteristics

At the time of testing there were no minimum specifications for WSD signal characteristics upon which the signals could be based. The decision was made to aim for as high an ACLR value as possible when carrying out the testing. By using a high level of ACLR this ensures that interference experienced at the DTT receiver is a function of the receiver selectivity rather than co-channel

[2] SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices, Tim Harrold, Mark Waddell, BBC R&D

interference caused by out-of-band emissions of the test signal. A higher level of ACLR also allows for derivations of ACS values based upon lower levels of ACLR to interpret worst case scenarios.

The resultant waveforms are shown in Figures 2, 3 and 4. These show the waveform emission masks with the tuneable band pass filter blocking the out-of-block emissions on the lower frequency side. Depending on the DTT to interferer frequency offset at the time of testing, the band pass filter may alternatively have been tuned to filter out-of-block emissions on the upper frequency side of the waveform.

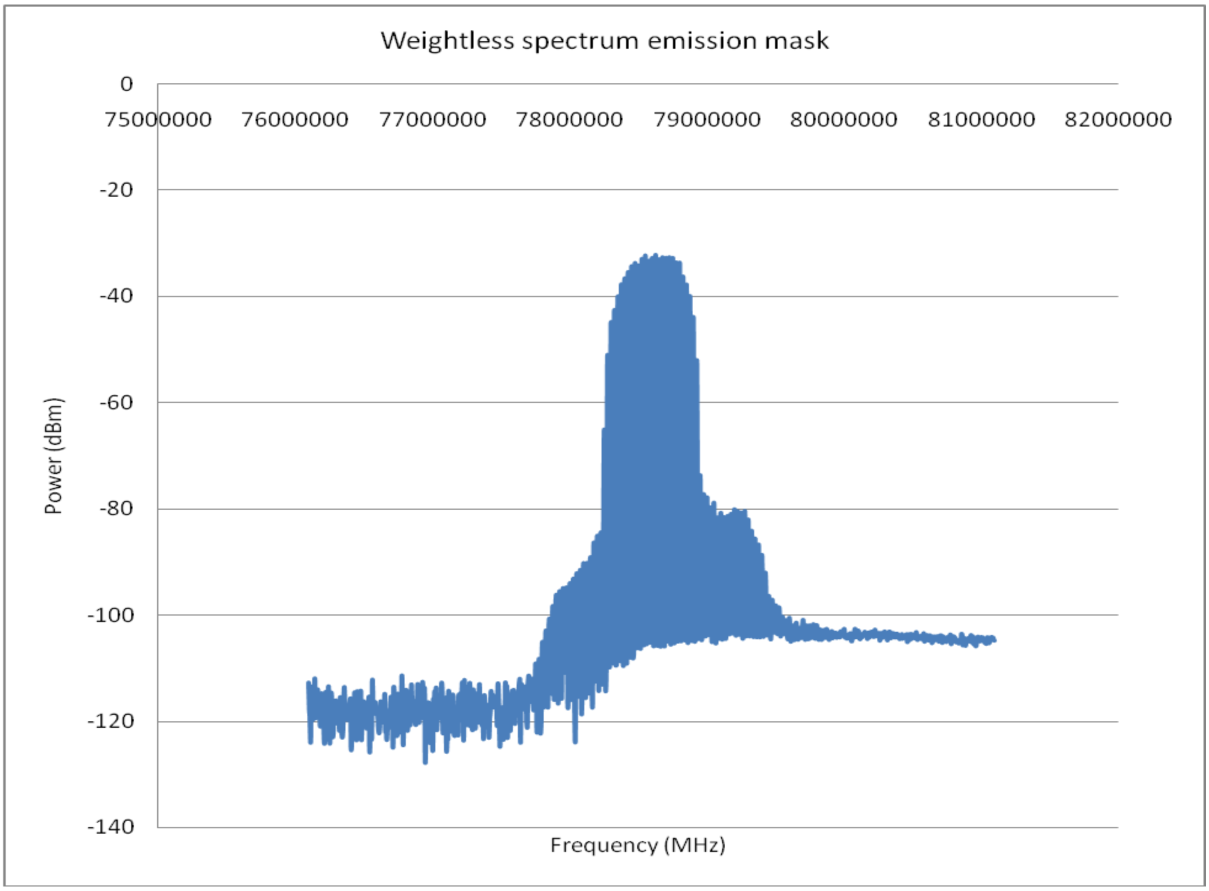

Figure 2 Spectral emissions for Weightless waveform

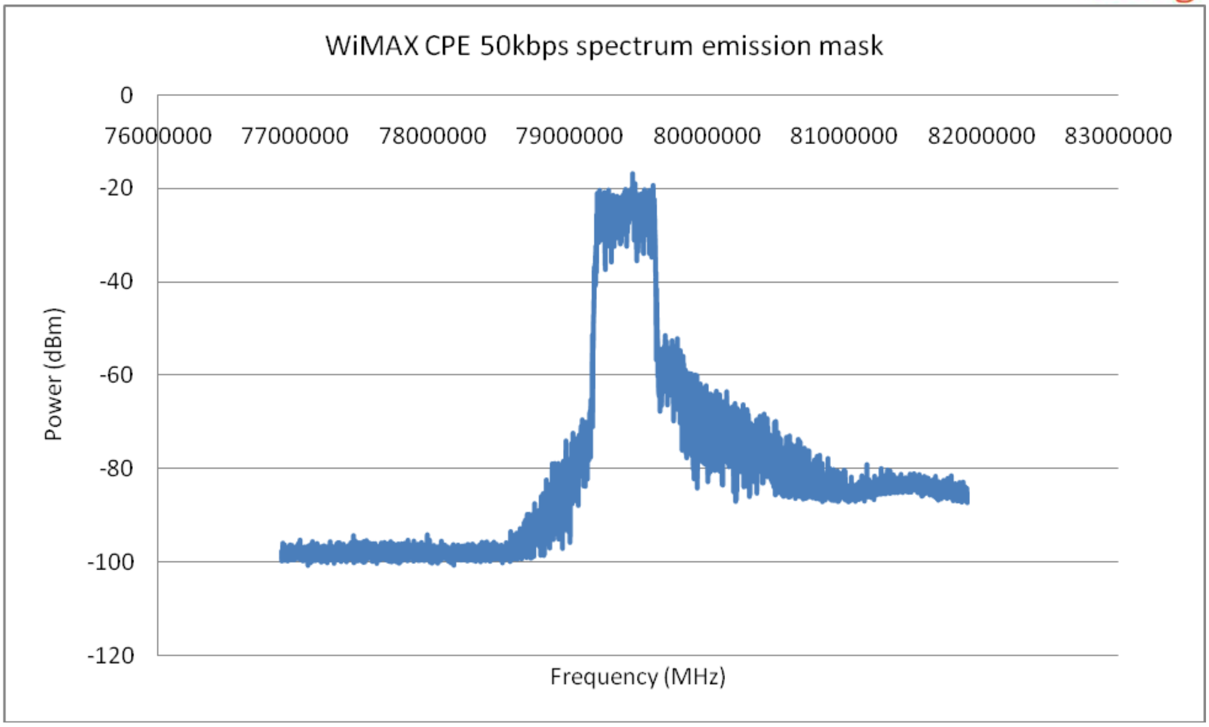

Figure 3 Spectral emissions for WiMAX CPE 50kbps waveform

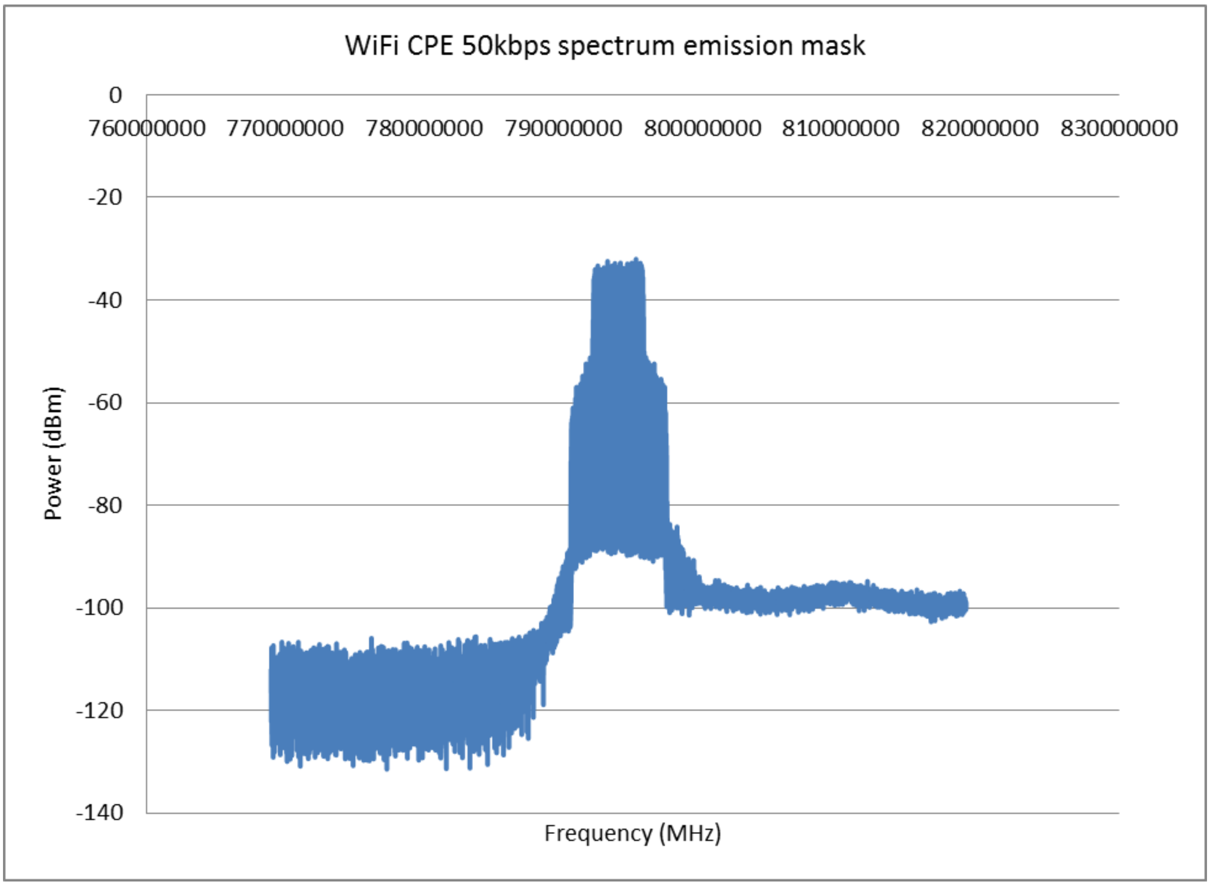

Figure 4 Spectral emissions for WiFi CPE 50kbps waveform

4.4.1 WSD CPE adjacent channel leakage ratios (ACLR)

Measuring the ACLR can be difficult when the ratio is large since the measurements become limited by the noise floor of the spectrum analyser.

To counter this problem, the ACLR measurements were made in two stages. Firstly the signal was measured at full capacity and the level recorded. This is shown in Figure 5.

Following this, a filter was placed in line with the analyser to block out the large test signal. This had the result of being able to reduce the input attenuation of the analyser to 0dB from 20dB which reduced the noise floor. In addition, noise floor extension could be applied to the analyser which mathematically modelled the noise of the instrument itself and removed this from the resultant displayed values.

Overall this had the effect of being able to increase the ACLR measurements by up to 15dB from the initial value measured with the large test signal.

Figure 6 shows the same test signal measured with a filter to block out the in band power. As can be seen, the absolute level of the lower adjacent signal has reduced from -69dB to -84dB meaning an increase in measurement of 15dB.

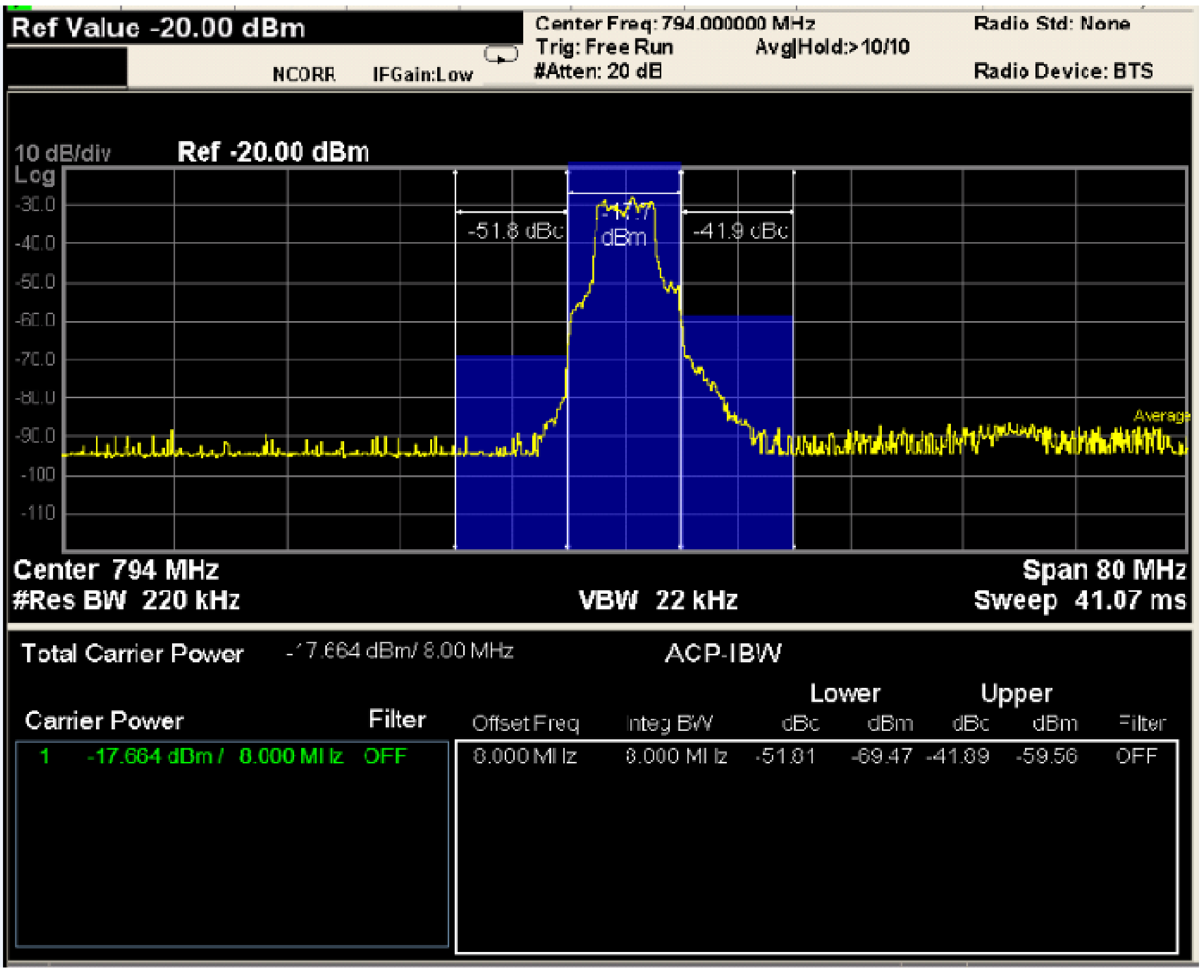

Figure 5 - WiFi CPE 50kbps test signal for ACLR measurements prior to filtering

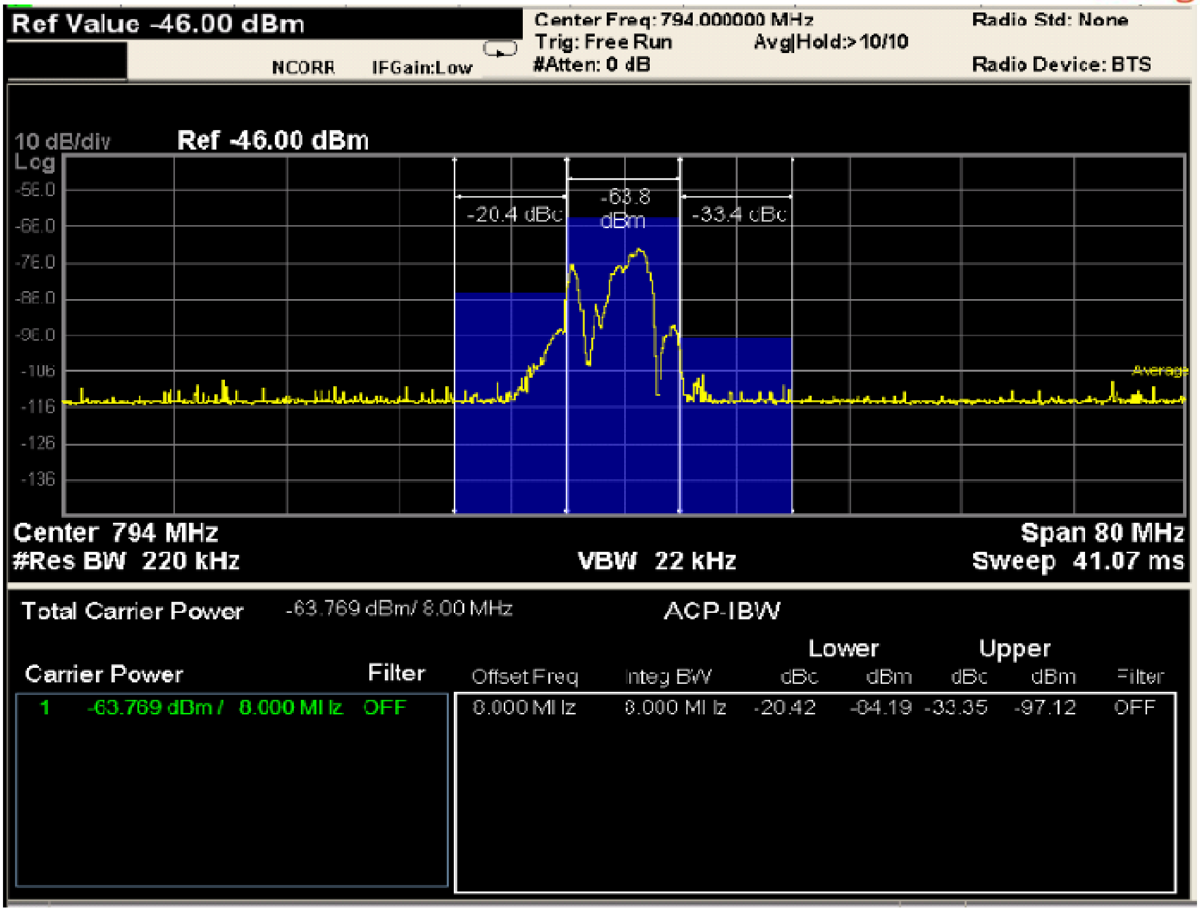

Figure 6 WiFi CPE 50kbps filtered test signal for ACLR measurements

Table 5 shows the ACLRs for the WSD test signals which were all measured using the same methodology as the WiFi example above. It was assumed that the ACLR was 90dB from the 3rd adjacent channel onwards

Waveform	DTT to Interferer Offset	1st Adjacent ACLR (dB)	2nd Adjacent ACLR (dB)
WiMAX	8MHz	60	72
WiFi	8MHz	67	70
Weightless	8MHz	60	82

Table 5 ACLR for 1st and 2nd adjacent channels for WSD signals

4.5 Signal Sources – Interfering signal, LTE UE

The LTE UE signals used for the testing were played back using an Agilent MXG arbitrary signal generator, with recorded LTE UE waveforms. This approach allows the captured waveform to be played back at any output frequency and at a range of required power levels.

The LTE signals represented three different traffic loading scenarios of the UE which are low, half load and full load. The recordings were played back at a range of frequencies to create offsets from the wanted DTT signal.

The LTE UE signals were provided by the BBC and recorded by them using a BS and UE link comprising of commercially available LTE equipment to form an end to end link. An IP traffic tool was then used to load the link to achieve the varying traffic loading. The test signal recordings were made by the BBC as part of a DTT protection testing programme, the results of which are documented in *SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices*[3]. Table 6 details the characteristics of the LTE UE waveforms.

In order to ensure that measurements were not contaminated by out-of-band signals captured during the recording process, the signals were band pass filtered in software prior to playback. In addition, during playback the test waveforms were filtered using a tuneable band pass filter to ensure an adjacent channel leakage ratio (ACLR) as large as possible. The details of the ACLR requirements are described in section 4.5.1.

The resultant waveforms are shown in Figure 7, Figure 8 and Figure 9. These show the waveform emission masks with the tuneable band pass filter blocking the out-of-block emissions on the lower frequency side. Depending on the DTT to interferer frequency offset at the time of testing, the band pass filter may alternatively have been tuned to filter out-of-block emissions on the upper frequency side of the waveform.

Waveform	Channel bandwidth	Modulation	Data rate	Duty cycle
LTE UE Idle mode	10MHz	Not known as it was automatically set up by the UE	1Mbps	30%
LTE UE half load	10MHz	Not known as it was automatically set up by the UE	10Mbps	75%
LTE UE full load	10MHz	Not known as it was automatically set up by the UE	20Mbps	100%

Table 6 LTE UE waveform characteristics

[3] SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices, Tim Harrold, Mark Waddell, BBC R&D

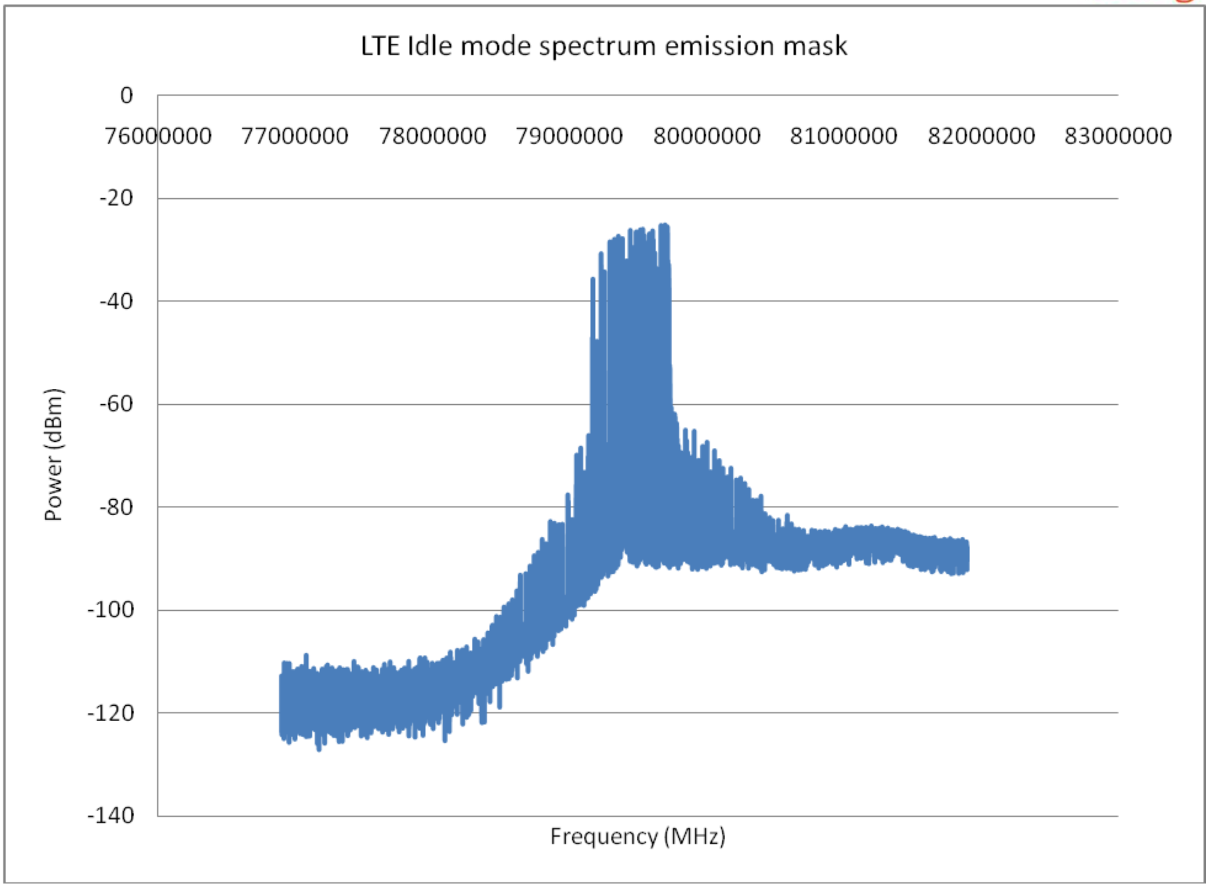

Figure 7 Spectral emissions for LTE user equipment recording operating at low traffic mode

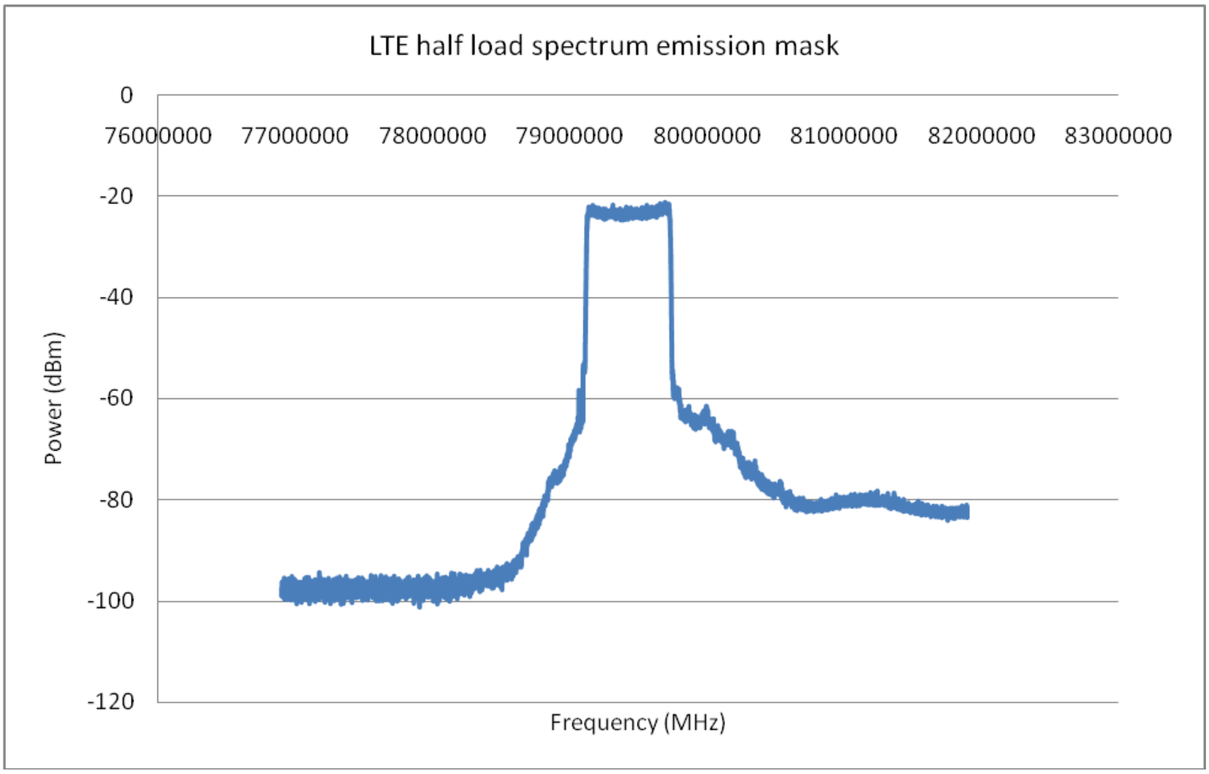

Figure 8 Spectral emissions for LTE user equipment operating at 50% traffic load

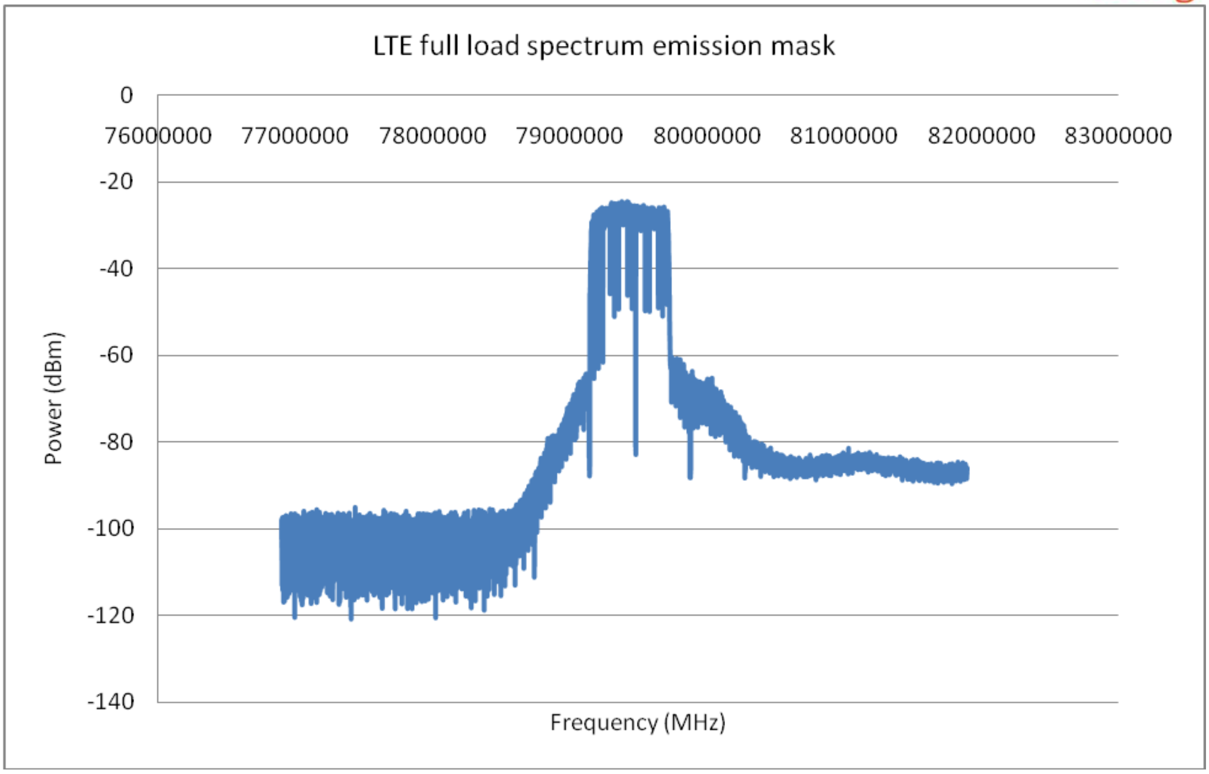

Figure 9 Spectral emissions for LTE user equipment operating at 100% traffic load

4.5.1 LTE UE adjacent channel leakage ratios (ACLR)

The minimum RF characteristics and performance for LTE UEs are detailed in the ETSI technical specification TS 136 101[4]. This includes ACLR requirements. Table 7 below is based upon this specification. To determine ACS values, it was decided that as high a level of ACLR as possible would be used for the testing. By using a high level of ACLR this allows for derivations of ACS values based upon lower levels of ACLR to interpret worst case scenarios.

	Channel bandwidth / $E\text{-}UTRA_{ACLR1}$ / measurement bandwidth					
	1.4 MHz	**3.0 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
$E\text{-}UTRA_{ACLR1}$	30 dB	30 dB	30 dB	30 dB	30 dB	30 dB
E-UTRA channel Measurement bandwidth	1.08 MHz	2.7 MHz	4.5 MHz	9.0 MHz	13.5 MHz	18 MHz
Adjacent channel centre frequency offset (in MHz)	+1.4 / -1.4	+3.0 / -3.0	+5 / -5	+10 / -10	+15 / -15	+20 / -20

Table 7 – ETSI TS 136 101 E-UTRA ACLR minimum requirements[4]

The ACLR of the LTE UE signals were measured using the same process as for the WSD CPE signals as described in Section 4.4.1. These were measured using a 10 MHz channel with adjacent channels at centre frequency offsets of ±10 MHz as specified in Table 7.

Table 8 shows the measured ACLR values for the LTE UE signals.

[4] **Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 11.4.0 Release 11)**

Waveform	DTT to Interferer Offset	1st Adjacent ACLR (dB)	2nd Adjacent ACLR (dB)
LTE UE Full Load	10MHz	69	81
LTE UE Half Load	10MHz	72	84
LTE UE Idle	10MHz	69	82

Table 8 Measured ACLR values for LTE UE signals

4.6 Waveform power correction

For signals that are time discontinuous in nature such as those with a low data traffic rate or TDD based signals, the difference between the RMS power measured and the peak power can be markedly different.

The harmful interference to the DVB-T waveforms is caused by the peak power levels so as a result these need to be recorded and factored in to the measured C/I values.

The peak measurements are made by setting the spectrum analyser to zero span mode to look at the signal in the time domain. A measurement is then made between the start and end of a period where the waveform is operating at peak power. This is referred to as the licensed power for the unwanted signal and is equivalent to the RMS power of the signal during the on period. The difference between the licensed power measurement and the RMS measurement is the correction factor which is included in the final C/I results.

Figure 10 and Figure 11 show how the correction factor for the WiMAX test signal was calculated and compared to a list of measurements taken by the BBC for the same signals. The results show that the correction values measured by the BBC and measured at the DTG Testing facilities were consistent.

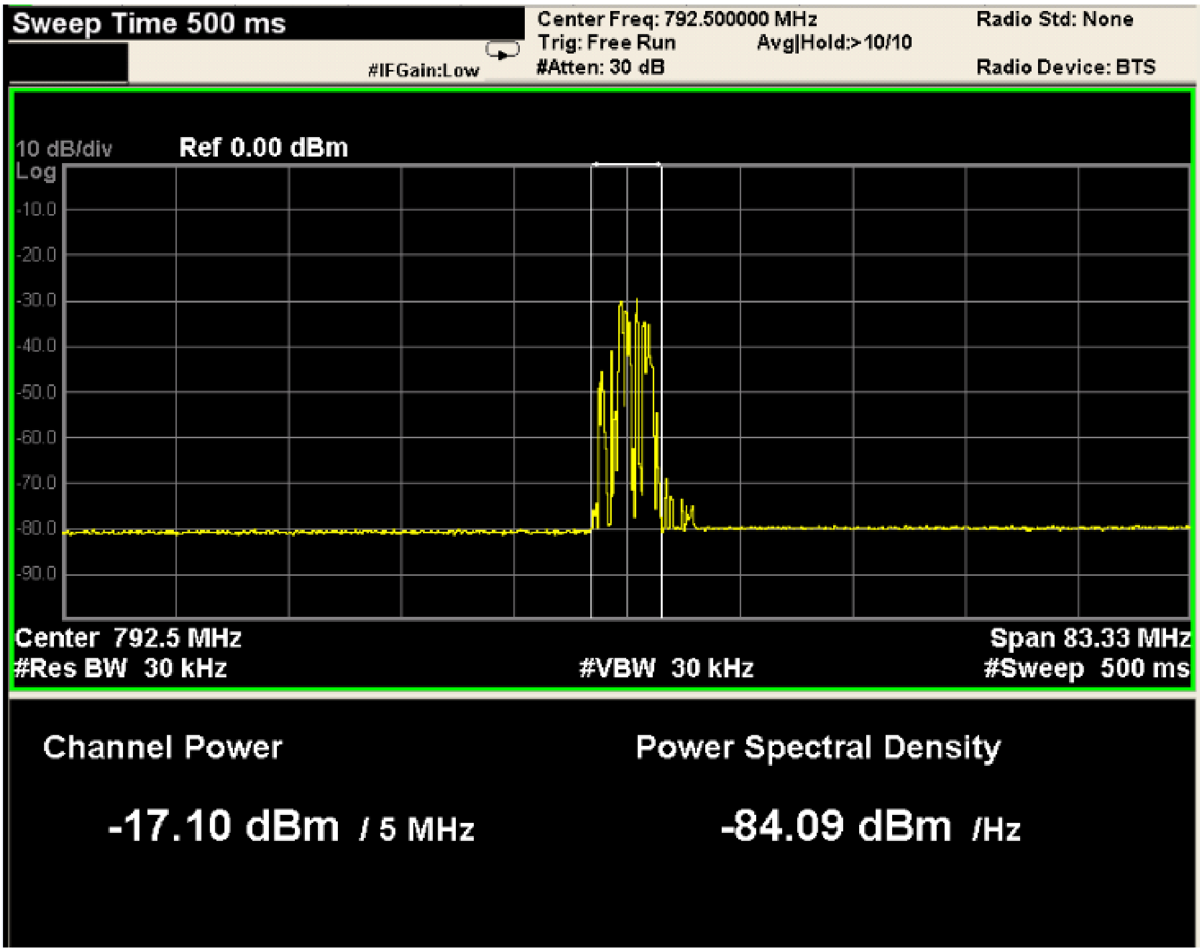

Figure 10 WiMAX CPE 50Kbps signal measured using channel power mode on the spectrum analyser

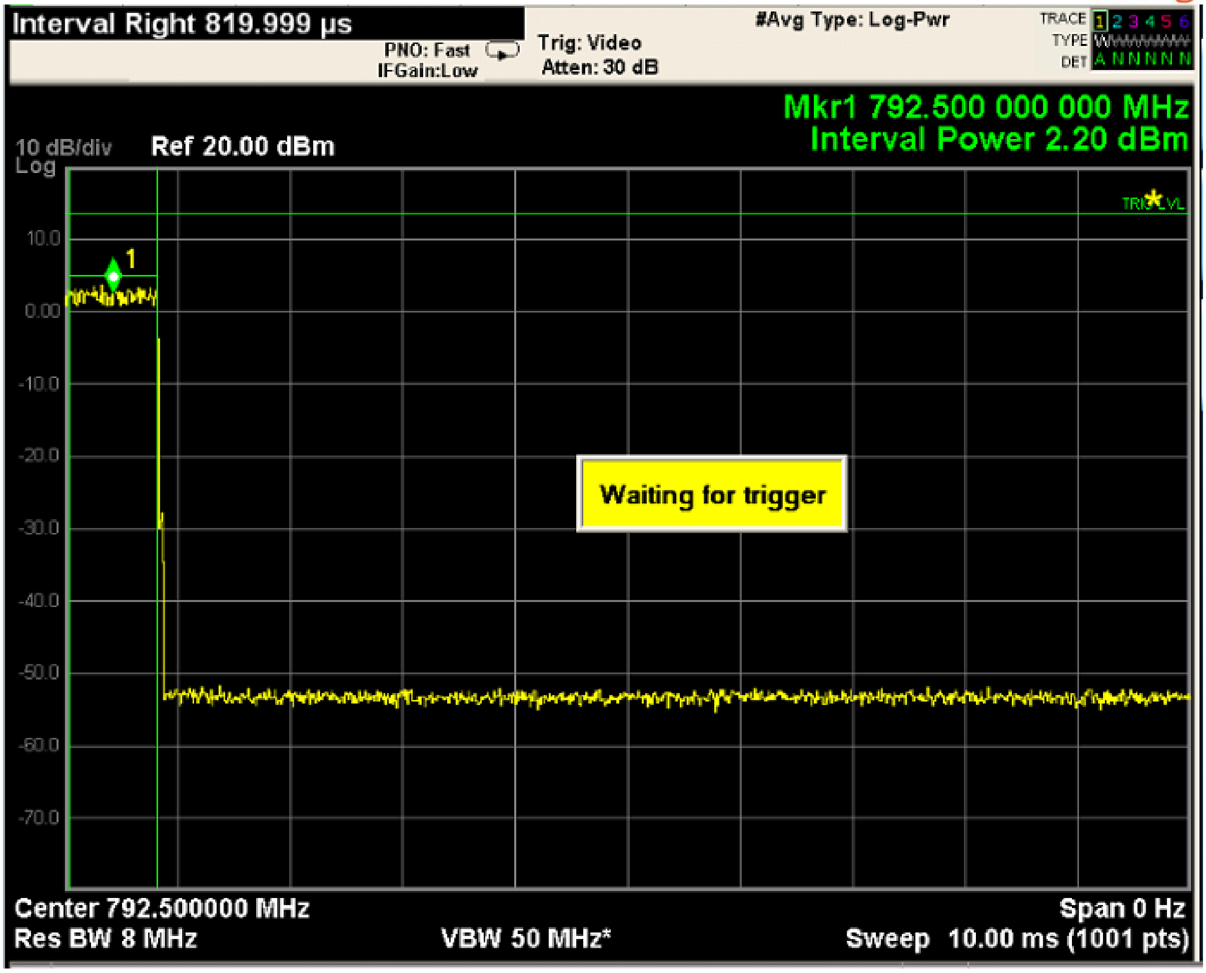

Figure 11 WiMAX CPE 50Kbps signal measured using zero span mode on the spectrum analyser

As can be seen from Figures 10 and 11, the difference between the RMS measurement of the signal and the peak on period was (17.1dBm + 2.2dBm) 19.3dBm. The measurement made by the BBC for the same signal was 20.4dB[5]. For LTE UE Idle, the measurement made at the DTG Testing facility was 9.53dB and the measurement made by the BBC was 8.9dB. As the separate measurements produced similar values, the decision was made to use the correction factors measured by the BBC to maintain consistency between the testing.

Table 9 shows the peak to average and the licensed to average measurements for the range of test signals used for this testing programme. The licensed to average results were used as the correction factors for the C/I measurements made and that are presented in this report. For example, if an interference measurement was made for a WiMAX CPE 50Kbps signal, the final result would have 20.4dB added to the interference level when the C/I protection ratio was calculated.

[5] SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices, Tim Harrold, Mark Waddell, BBC R&D

Waveform	PAPR (dB) P_{pk}- P_{RMS}	LAPR (dB) P_{Lic}- P_{RMS}
WIMAX CPE IDLE	31.7	20.4
WIFI CPE IDLE	8.8	4.0
WEIGHTLESS*	3.5	3.2
LTE UE 100%	6.3	-0.8
LTE UE 50%	8.4	1.1
LTE UE IDLE	16.3	8.9

Table 9 Correction factors for test signals as measured by BBC R&D[6] (*measured by DTG Testing)

[6] SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices, Tim Harrold, Mark Waddell, BBC R&D.

5. ACS calculations

The ACS is a measure of the receiver capability to receive the wanted DTT signal in the presence of an interfering signal in an adjacent frequency channel. The ACS is calculated from the measured co-channel protection ratio (PR_0), the measured protection ratio at a given frequency offset (PR(Δf)) and the ACLR of the interfering signal.

The ACS is calculated using the following formula:

$$ACS(\Delta f) = -10\log\left(10^{\frac{PR_0 - PR(\Delta f)}{10}} - 10^{-\frac{ACLR}{10}}\right)$$

Equation 1 Formula for calculating adjacent channel selectivity

6. The effect of DTT receiver pre-amplification on protection ratios and ACS values

6.1 Overview

As many households use pre-amplifiers to boost low level signal strengths or to supply multiple receivers, a range of measurements was carried out to investigate the impact such amplifiers have on the measured ACS value.

Past measurements have indicated that pre-amplification can degrade the overall ACS due to the overloading of the receiver or the pre-amplifier itself.

The tests included a typical home use masthead consumer amplifier and a launch amplifier used for multi dwelling scenarios.

The amplifiers had fixed gains of 10dB and 20dB for the consumer and communal versions respectively.

6.2 Measurement setup

The test set up used to perform the pre-amplifier C/I measurements is shown in Figure 12. The DVB-T/T2 signal was played into a DTT pre-amplifier via a variable attenuator, which was used to control the level of the signal.

The unwanted test signal was played back using the signal generator which was then amplified and then filtered.

The DTT and unwanted signal were combined using a 10dB directional coupler.

A splitter was used to allow the DTT and LTE signal at the input to the pre-amplifier to be measured using a spectrum analyser. The matching losses of 5.7dB at the input to the analyser were accounted for during calculations of the C/I results.

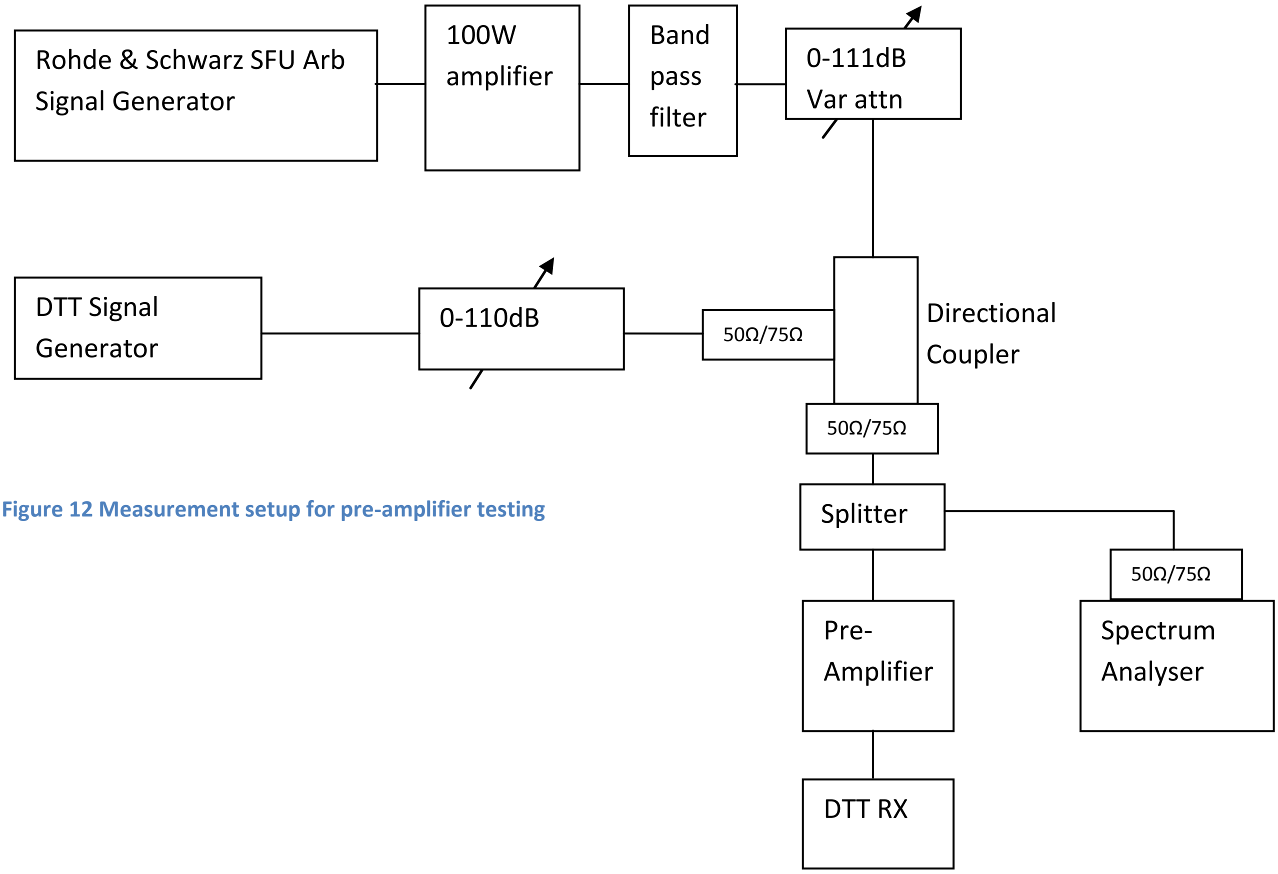

Figure 12 Measurement setup for pre-amplifier testing

6.2.1 Amplifier setup

Frequency sweeps over the range 470 to 790MHz taken for the amplifiers used for the testing are shown below. The markers on the screen shots show the amplitude of the amplifier response at DTT channels 21, 30, 40, 50, 60 to show spot values across the DTT frequency range. Figure 13 shows the communal launch amplifier frequency response which highlights gain that varies by around 1.5dB between the maximum and minimum levels but in general varies by ±0.5dB around a centre value of 22.5dB.

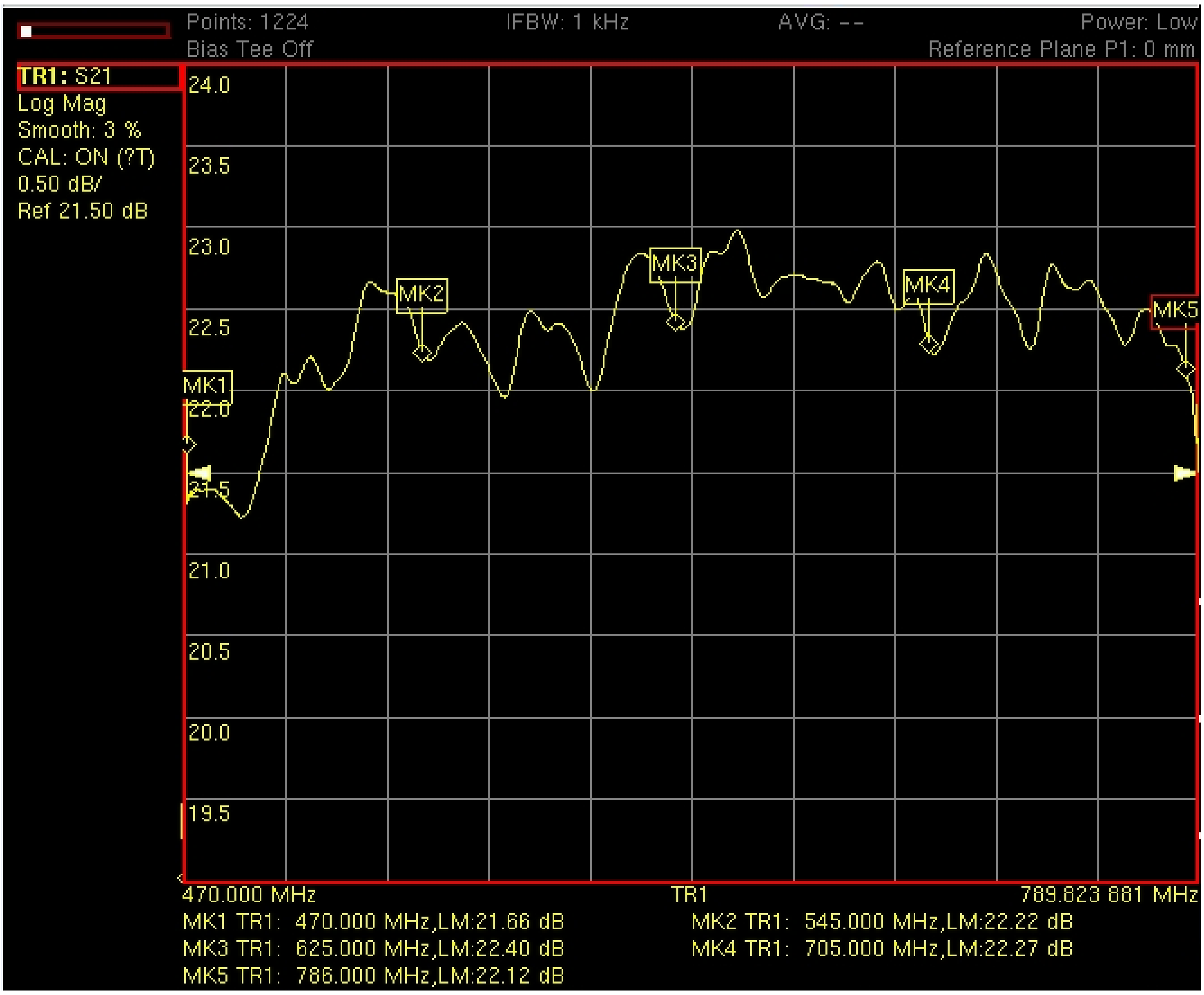

Figure 13 Communal launch amplifier frequency response

For the masthead amplifier the range between the smallest and largest gain was around 2dB and in general the gain varied by around ±1dB from a centre of 11.6dB over the frequency range 470 to 790MHz. This is shown in Figure 14.

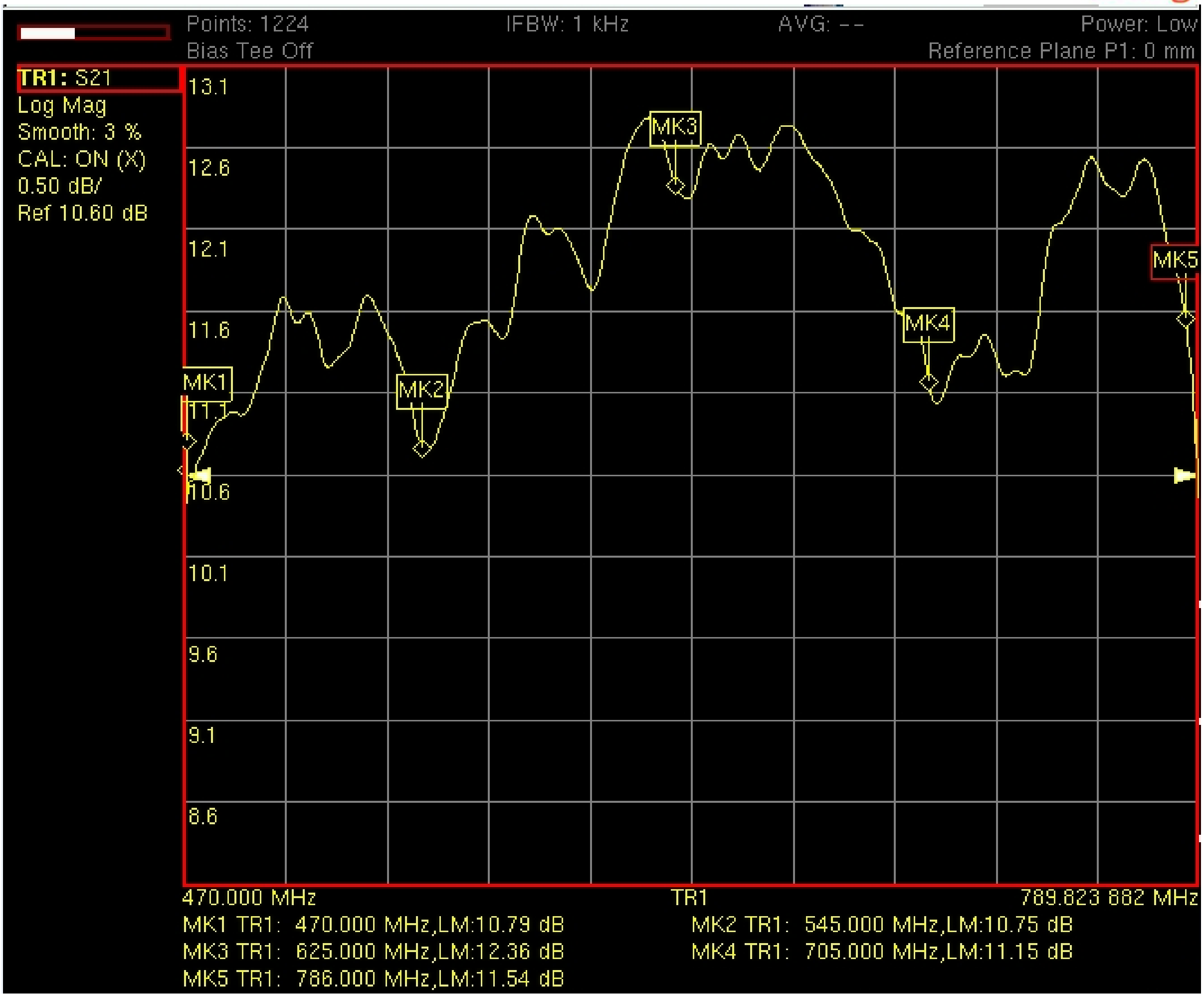

Figure 14 Consumer masthead amplifier frequency response

The 1dB compression point for the launch amplifier and masthead amplifier is shown in Figure 15 and Figure 16 respectively. This is defined as the point where the difference the linear transfer characteristic of the amp and the actual transfer characteristic varies by 1dB. The masthead amp reaches a maximum input level of -28dBm before the compression point is reached and following this it was observed that the gain reduced before levelling off. This is much lower in comparison with the launch amp which starts to compress at a level of-20.5dBm at the input to the amplifier.

The measurements were taken at 666MHz corresponding to a centre frequency for UHF channel 45.

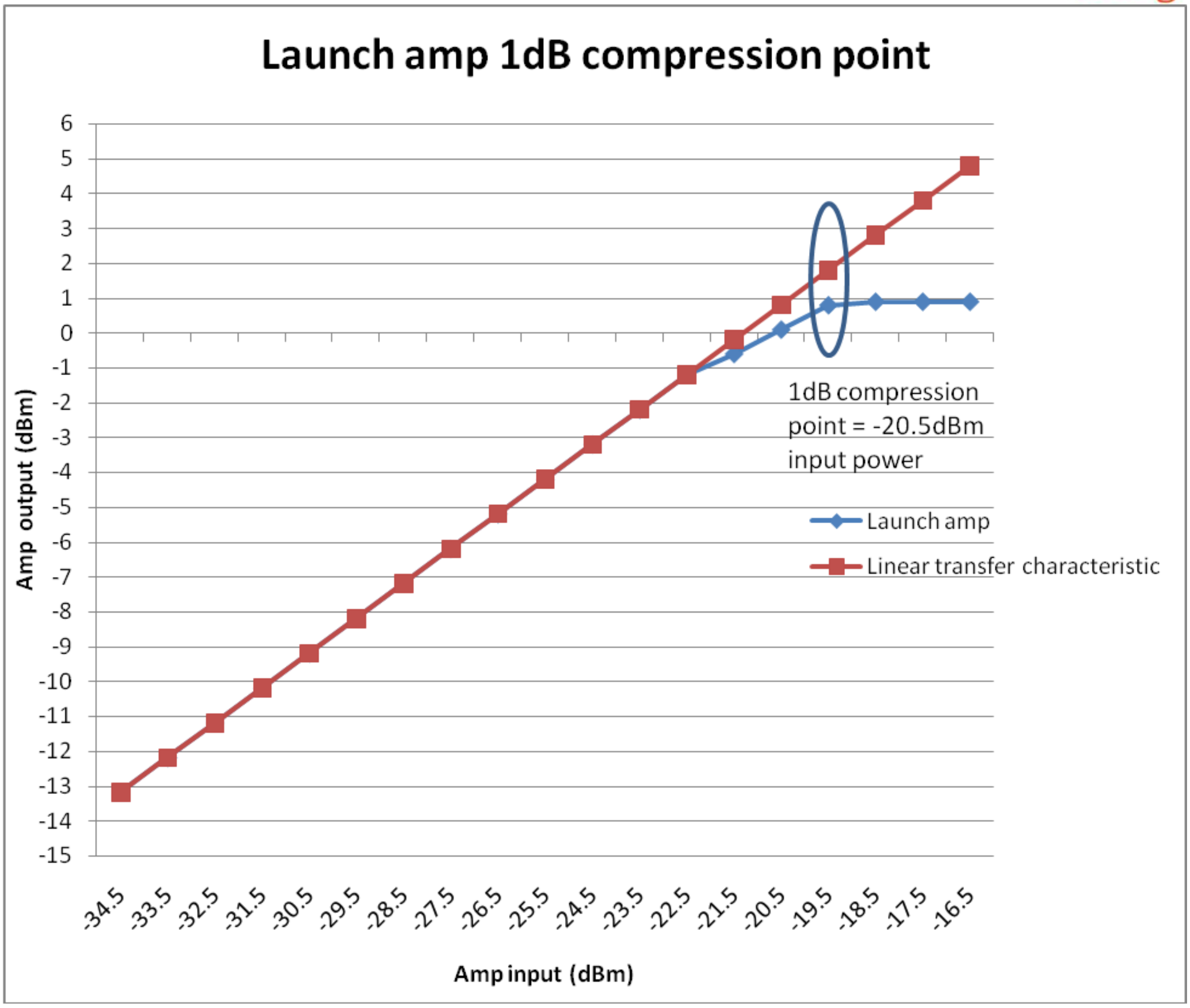

Figure 15 Communal launch amplifier input/output transfer characteristic

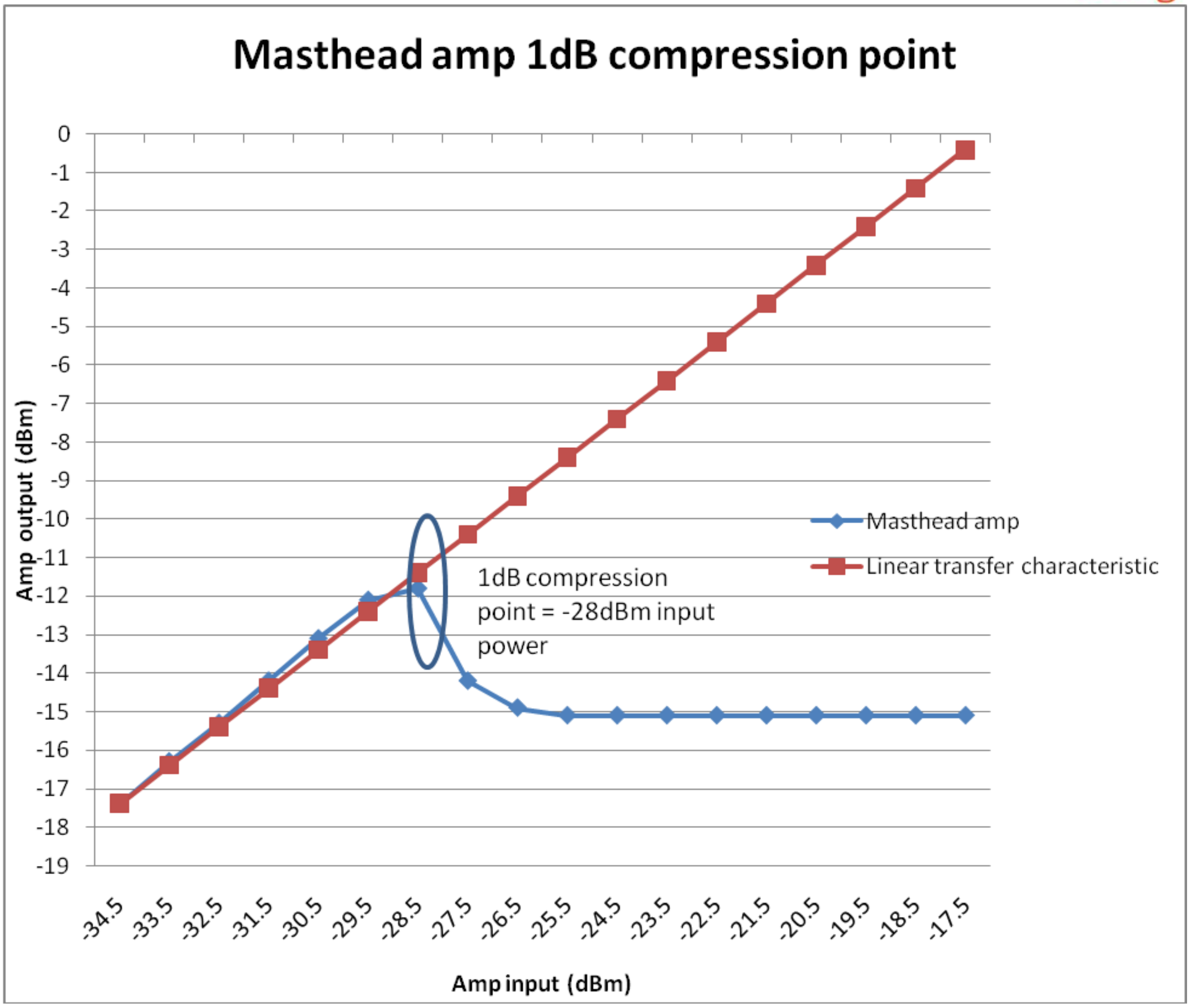

Figure 16 Consumer masthead amplifier input/output transfer characteristic

6.3 Test method

The following test procedure was used to calculate the C/I ratio of the DTT receivers under test when using a pre-amplifier:

1. The test receivers were initially tuned and verification of smooth video and audio was carried out.
2. The total carrier power of the DTT signal was adjusted using the variable attenuator to a pre-defined level at the input to the pre-amplifier.
3. The DTT signal was then switched off and then the interfering signal switched on.
4. The interfering signal ACLR was then adjusted to achieve the maximum level using a tuneable band pass filter.
5. The DTT signal was reapplied to the receiver under test and the level of the interferer was set to maximum.
6. The interfering signal was then gradually reduced until the DTT picture returned and no blocking or pixilation was present.
7. The level of the interfering signal at the input to the pre-amplifier was recorded at the point at which the picture returned without any errors.

The testing was repeated for DTT power levels of -40dBm, -50dBm, -60dBm and -70dBm, using DVB-T1 and DVB-T2 transmission modes. In addition a range of WSD/LTE to DTT frequency offsets were used which for the WiMAX and WiFi signals were ±k where k = 0, 1, 2, ... 11, 20, 30 and k refers to a channel separation of 8 MHz. For Weightless the offsets tested were ±k where k = 0, 1, 2, ... 11 and k refers to a channel separation of 8 MHz. For LTE the offsets were +10MHz, +18MHz then 18+8k MHz where k = 1, 2, ... 11, 15, 20 and 25.

The tests were carried out for two receivers which were chosen on the basis that during previous testing they had performed in the top and bottom 10% of receivers in terms of protection ratio levels.

6.4 Results

The results have shown that for a receiver that generally performs well, the amplifier may mask the performance by overloading before the receiver fails due to selectivity problems.

Figure 17 highlights this in a graph taken from the test results using the WiFi CPE 50kbps signal and the two different pre-amplifiers.

As can be seen, the receiver suffered from increased interference at the image frequency at N+9. However the effect is mainly noticeable for the launch amplifier and not the masthead amplifier. The 1dB compression point for the masthead amplifier is only -28dBm, which can be seen in Figure 15 above, and after this the amplifier response becomes non-linear. The level of WiFi at the input to the amplifier at N+9 is greater than -29.5dBm at the point receiver 16 fails. This highlights that the amplifier is masking the performance of the receiver and the failure is due to the masthead amplifier.

The ACS improves as the frequency separation between the DTT and the interferer increases.

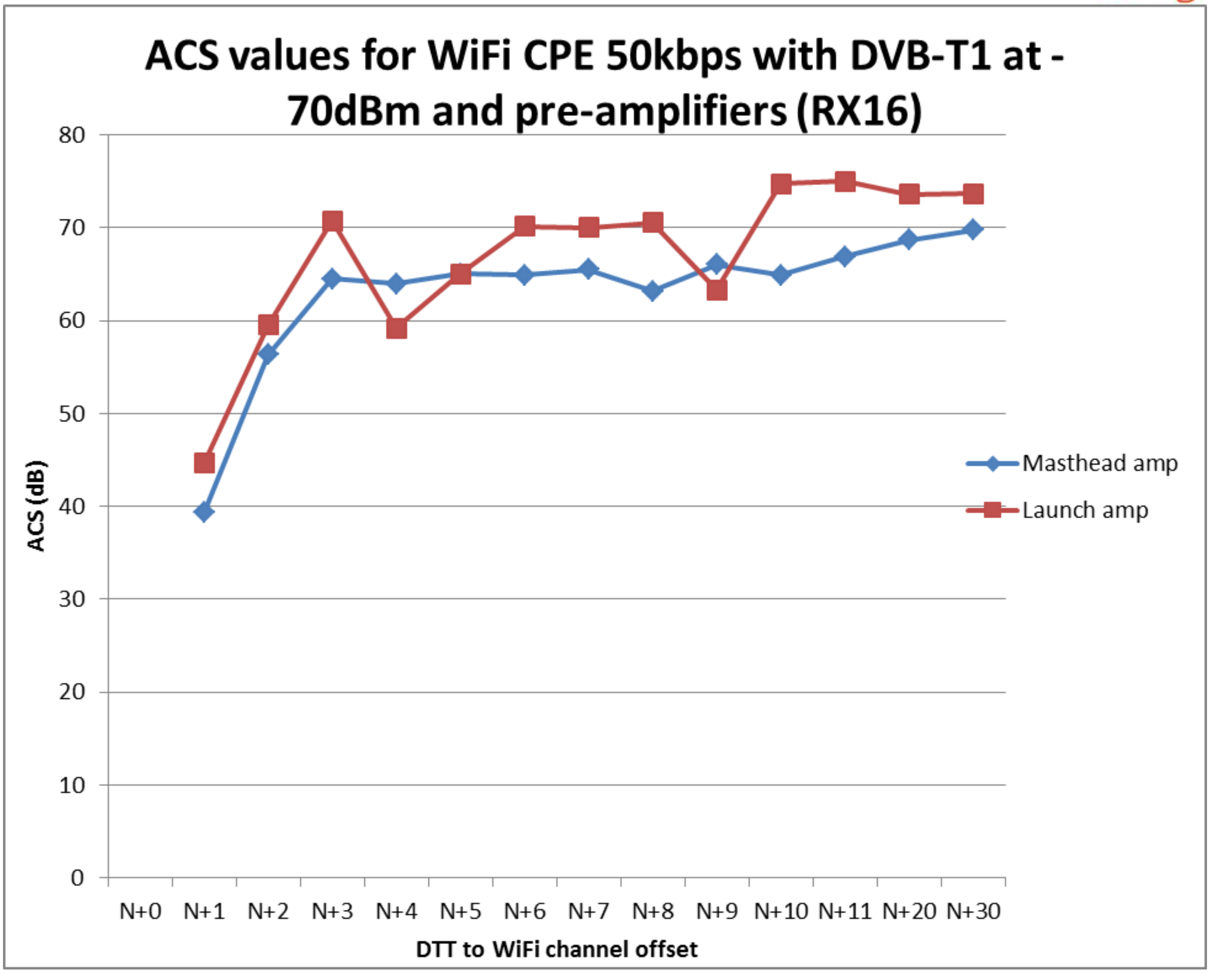

Figure 17 ACS values for WiFi CPE 50kbps, DVB-T1, -70dBm and pre-amplifiers, RX16

For the high DTT signal levels, it can be seen that for both receivers tested, the resultant difference in ACS corresponded to the gain difference of the amplifiers.

Figure 18 highlights this in a graph showing measurements made using a -40dBm wanted DTT signal and WiFi CPE 50kbps unwanted signal.

As can be seen in Figure 18, the image frequency failure at N+9 that was previously seen with receiver 16 is no longer present and the ACS values when using the masthead or launch amplifier are 10dB different. This highlights how the ACS could potentially be degraded when using pre-amplifiers in the DTT setup.

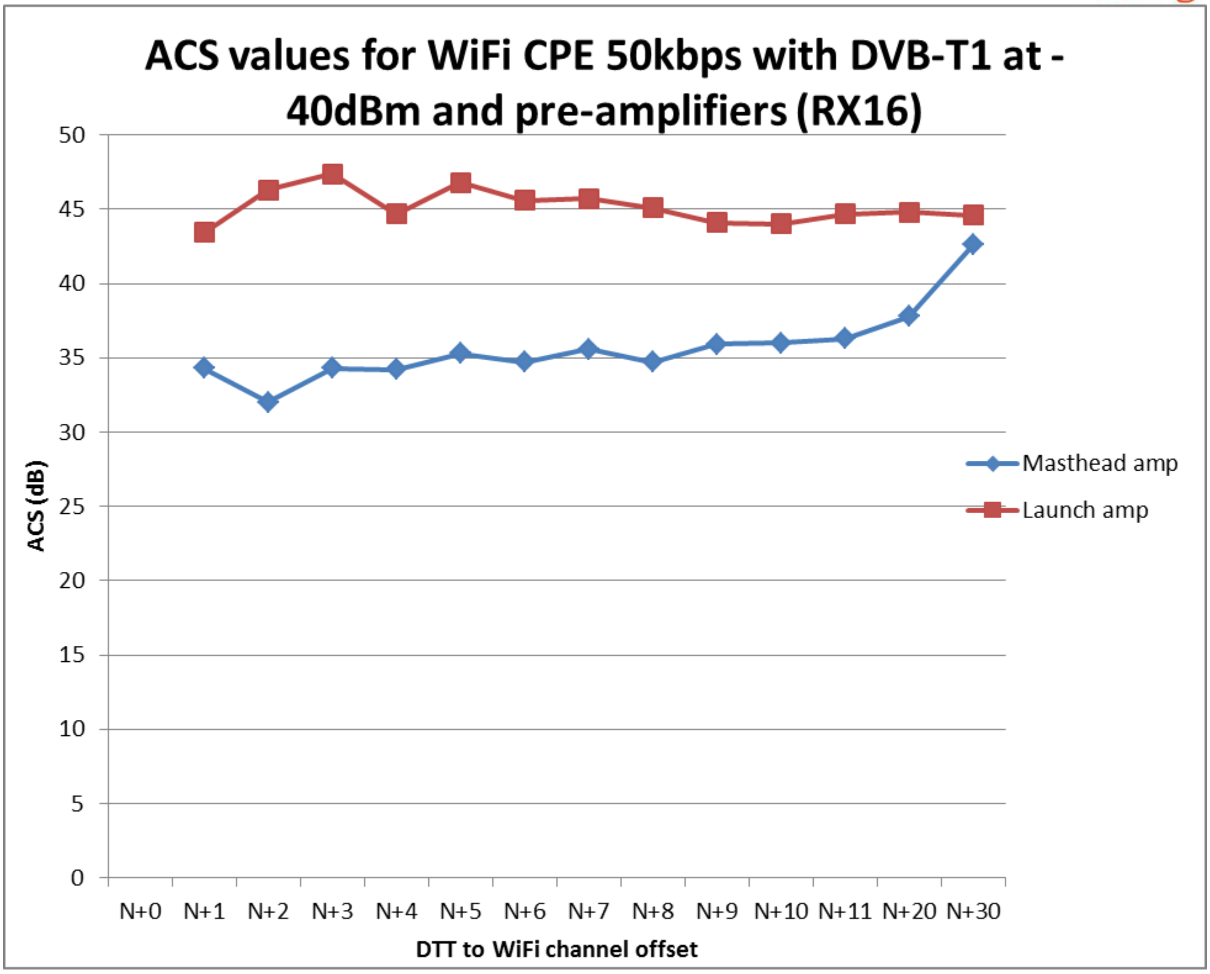

Figure 18 ACS values for WiFi CPE 50kbps, DVB-T1, -40dBm and pre-amplifiers, RX16

6.5 Comparison of receiver performance with and without a pre-amplifier

Figures 19 to 22 show the measured protection ratio and resultant ACS values of receiver 3 with and without a pre-amplifier. As can be seen, the protection ratios and ACS values begin to worsen as the power level of the DTT signal increases. In addition, the effects are more noticeable as the frequency separation between the DTT and interferer increases. This could be due to the fact that at lower levels of DTT when using pre-amplification the interferer has been increased by the gain of the amplifier but the DTT has increased also meaning that the resulting protection ratios with and without the amplifier are comparable. However at increased frequency separation or at increased DTT levels, the levels at the input to the amplifiers increase and the result is amplifier overload meaning a worsened protection ratio compared to the case with no amplifier.

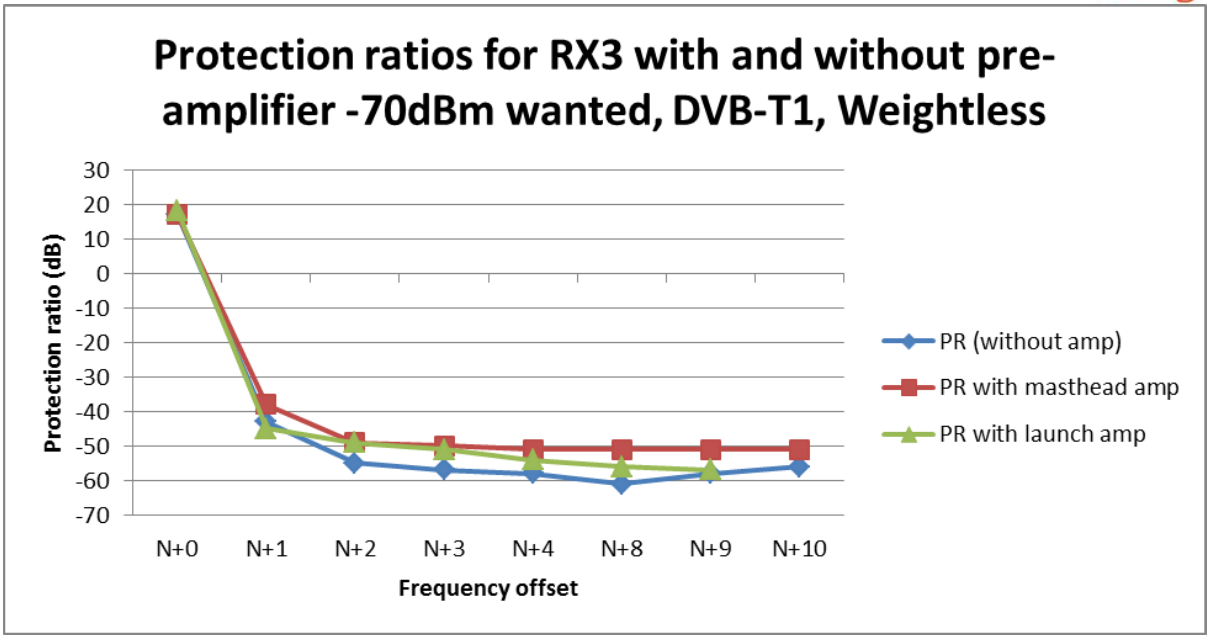

Figure 19 Protection ratio for Weightless, DVB-T1, -70dBm with and without pre-amplifiers, RX3

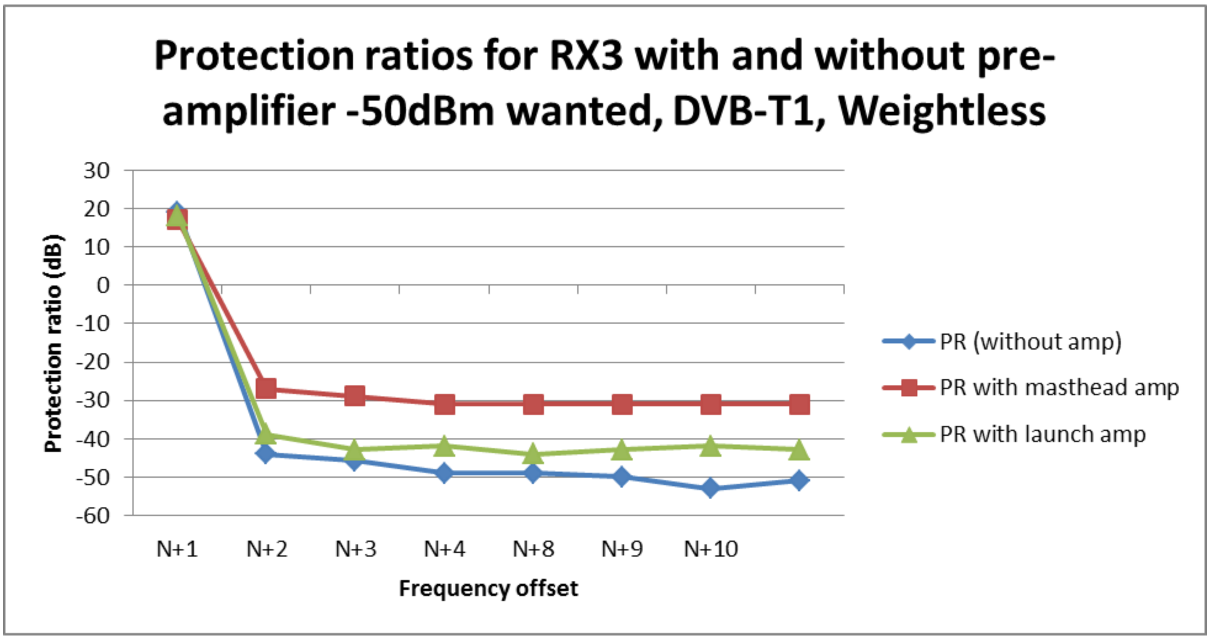

Figure 20 Protection ratio for Weightless, DVB-T1, -40dBm with and without pre-amplifiers, RX3

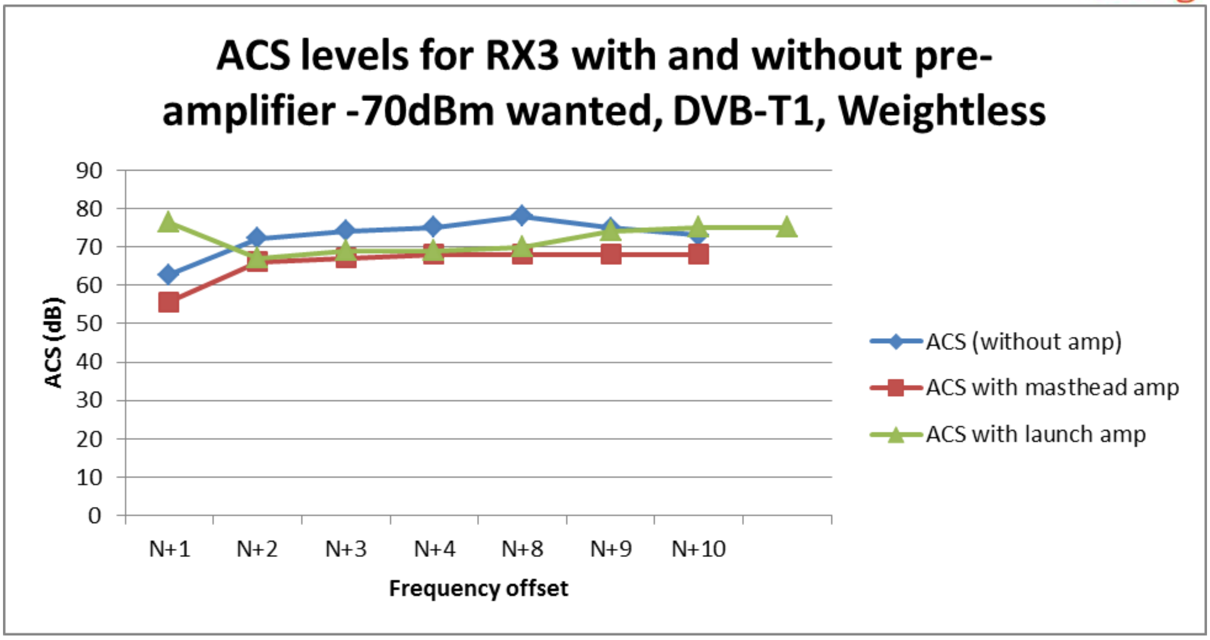

Figure 21 ACS value for Weightless, DVB-T1, -70dBm with and without pre-amplifiers, RX3

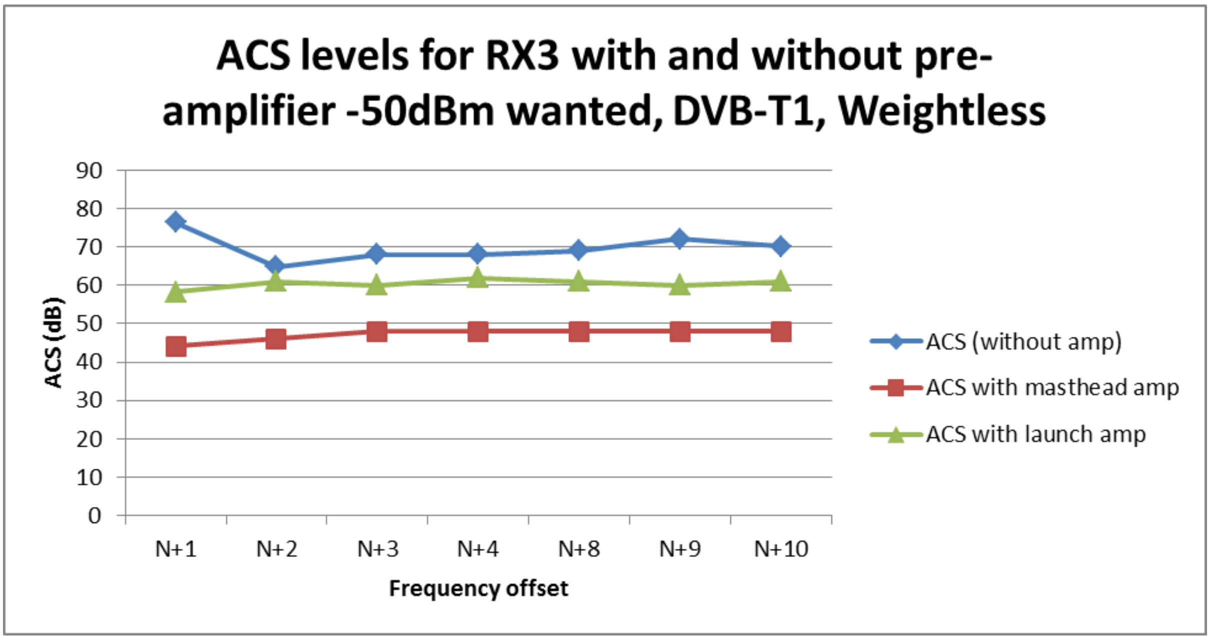

Figure 22 ACS value for Weightless, DVB-T1, -40dBm with and without pre-amplifiers, RX3

The impact of the pre-amplifiers on the ACS of the receiver were less noticeable when the WiMAX signal was used as oppose to LTE UE full load. This could be due to the fact that the amplifiers are less likely to overload as a result of the WiMAX signal as the overall RMS power level is lower due to the low duty cycle and time discontinuous signal. In addition, the receivers are more vulnerable to these kinds of signals and fail at a lower level of interferer prior to the amplifier overloading. Figures 23 to 26 are examples of this and show the measured protection ratios and derived ACS values when testing with the WiMAX signal with and without pre-amplification.

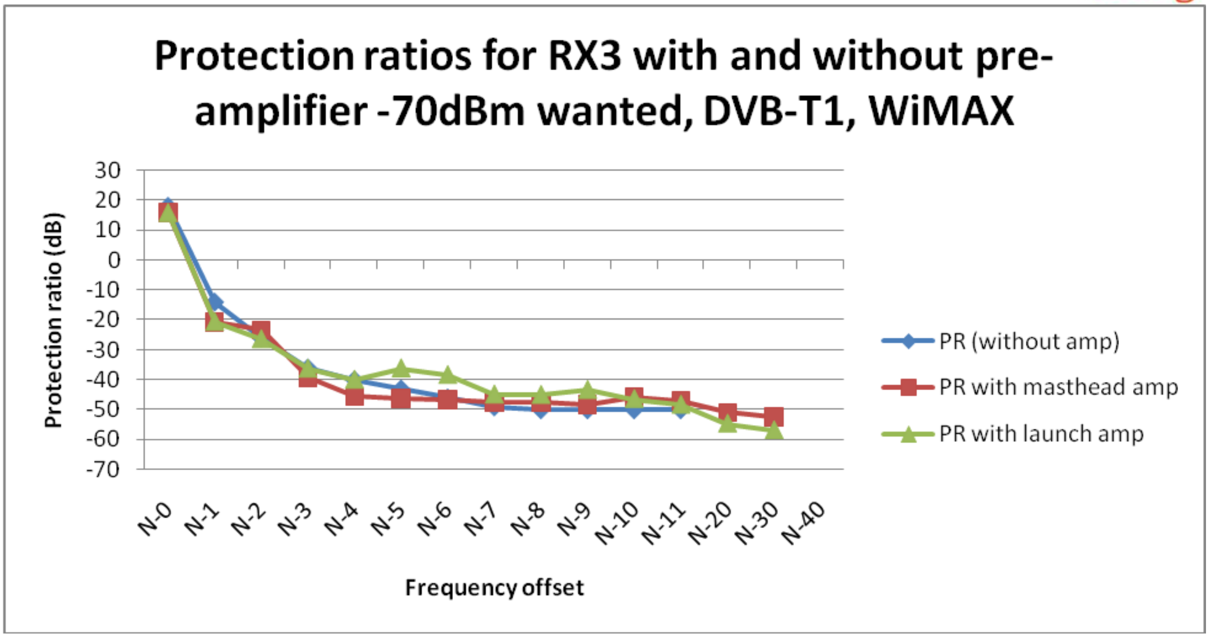

Figure 23 Protection ratio for WiMAX CPE 50kbps signal, DVB-T1, -70dBm with and without pre-amplifiers, RX3

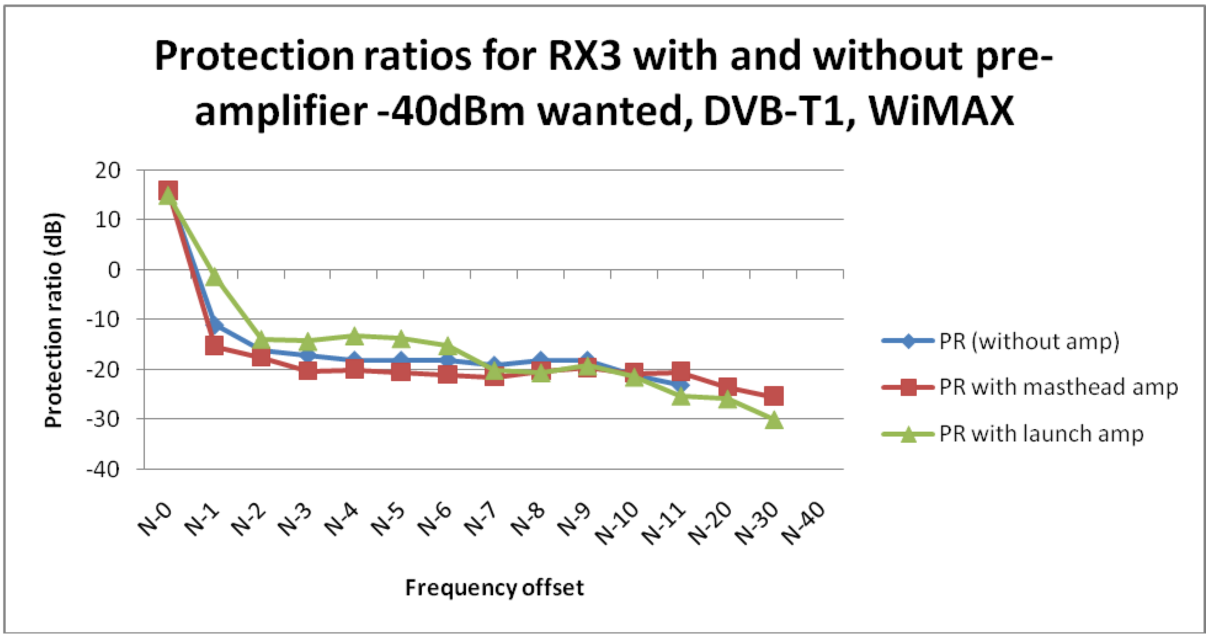

Figure 24 Protection ratio for WiMAX CPE 50kbps signal, DVB-T1, -40dBm with and without pre-amplifiers, RX3

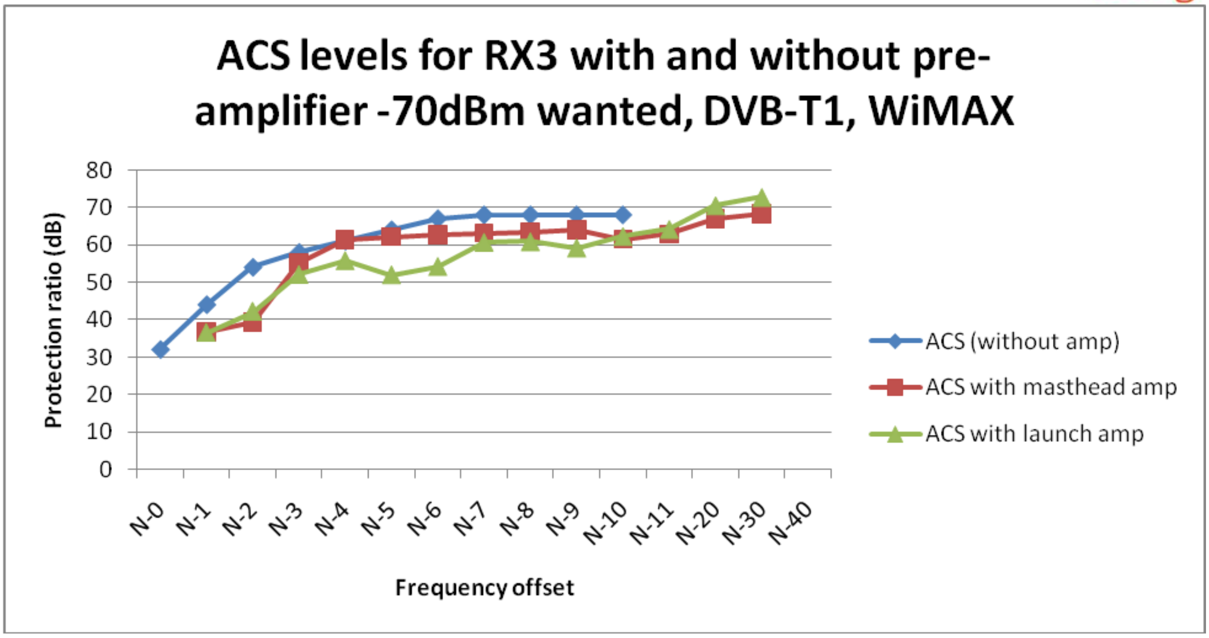

Figure 25 ACS value for WiMAX CPE 50kbps signal, DVB-T1, -70dBm with and without pre-amplifiers, RX3

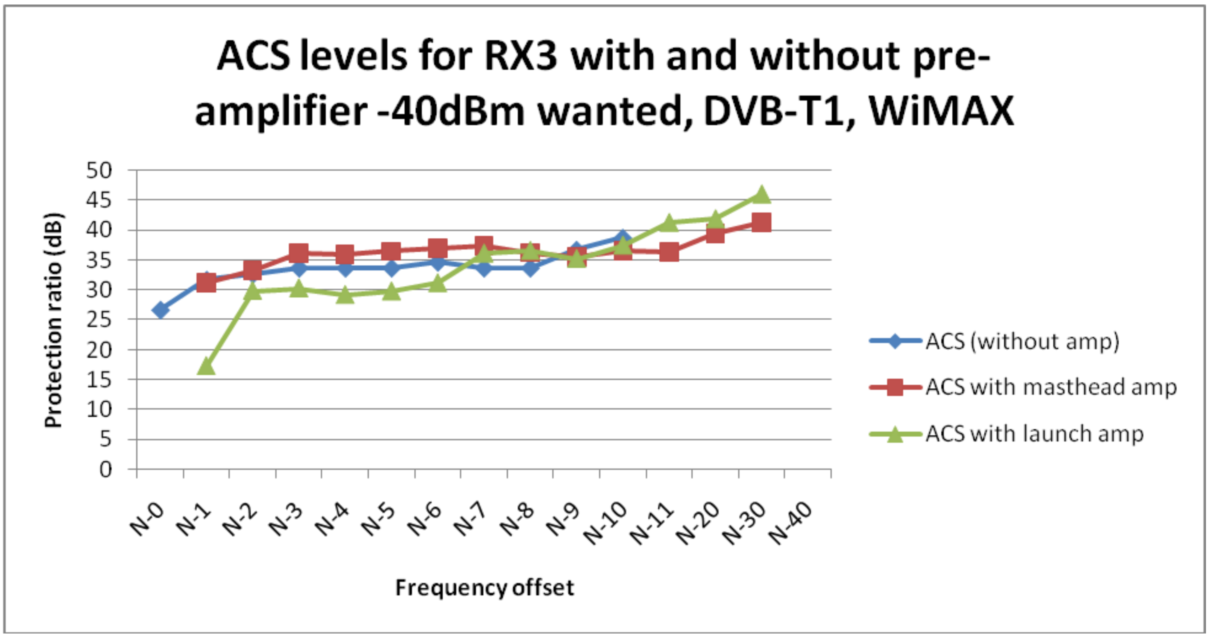

Figure 26 ACS value for WiMAX CPE 50kbps signal, DVB-T1, -40dBm with and without pre-amplifiers, RX3

The comparison graphs for the testing carried out with and without pre-amplification for all the interfering signals and DTT power levels can be seen in Appendix C.

7. Impact of fading

7.1 Overview

The impact of fading was tested on a spot check of one receiver that had been used during the pre-amplifier testing. The test incorporated fading on both the wanted DTT signal and the unwanted WSD signal alternatively as both would be subject similar conditions. The aim of the testing was to perform the measurements using AWGN channels and then repeat with fading channels added to analyse the difference in results.

7.2 Measurement setup

The test setup was as per the amplifier testing as shown in Figure 12 section 6.2.

The fading profiles chosen for the tests were taken from D-Book 7 and are the profiles used for multipath testing. Table 10 and Table 11 below show the parameters for each of the fading profiles.

Delay (μs)	Relative Attenuation (dB)	Phase (degree)
0	2.8	0
0.05	0	0
0.4	3.8	0
1.45	0.1	0
2.3	2.6	0
2.8	1.3	0

Table 10 Short delay echo profile[7]

Delay (μs)	Relative Attenuation (dB)	Phase (degree)
0	0	0
5	9	0
14	22	0
35	25	0
54	27	0
75	28	0

Table 11 Long delay echo profile[8]

[7] D Book 7 Part A v3 short delay echo profile Table 10-14
[8] D Book 7 Part A v3 long delay echo profile Table 10-15b

7.3 Test method

The following test procedure was used to calculate the C/I ratio of the DTT receiver under test when using a pre-amplifier as well as fading and AWGN channel profiles.

1. The test receivers were initially tuned and verification of smooth video and audio was carried out.
2. The total carrier power of the DTT was adjusted using the variable attenuator to -50dBm at the input to the pre-amplifier.
3. The DTT was then switched off and then the interfering signal switched on.
4. The interfering signal ACLR was then adjusted to the correct level using a tuneable band pass filter.
5. The DTT signal was reapplied to the receiver under test and the level of the interferer was set to maximum.
6. The interfering signal was then gradually reduced until the DTT picture returned and no errors were present.
7. The level of the interfering signal at the input to the pre-amplifier was recorded at the point the picture returned without any errors.
8. The interferer was then switched off
9. The AWGN noise source was then switched on and set to maximum.
10. The AWGN was then reduced using a step attenuator until the picture returned and the level recorded. This level is the minimum C/N required in order for the receiver to decode the test stream.
11. The interfering signal was then reapplied to the DTT receiver and was set to maximum.
12. The interfering signal was then gradually reduced until the DTT picture returned and no errors were present. The recorded level of interferer at this point is the maximum tolerable level for a channel with an AWGN channel and no echoes.
13. The echo profile being tested (either short delay or long delay) was then applied to the DTT signal.
14. Step 11 and 12 were then repeated and the maximum level of interferer tolerable recorded for the case with echoes on the DTT channel.
15. The echo profile being tested (either short delay or long delay) was then removed from the DTT channel and applied to the interfering signal.
16. Step 11 and 12 were then repeated and the maximum level of interferer tolerable recorded for the case with echoes on the interferer channel.

The level of the interfering signal at the input to the pre-amplifier was recorded at the point the picture returned without any errors.

7.4 Results

Figure 27 shows the results for the maximum level of WiMAX CPE 50kbps signal for the test receiver before picture failure. This is presented without any fading on either the DTT or WiMAX signal and with fading on either the DTT or the WiMAX signal.

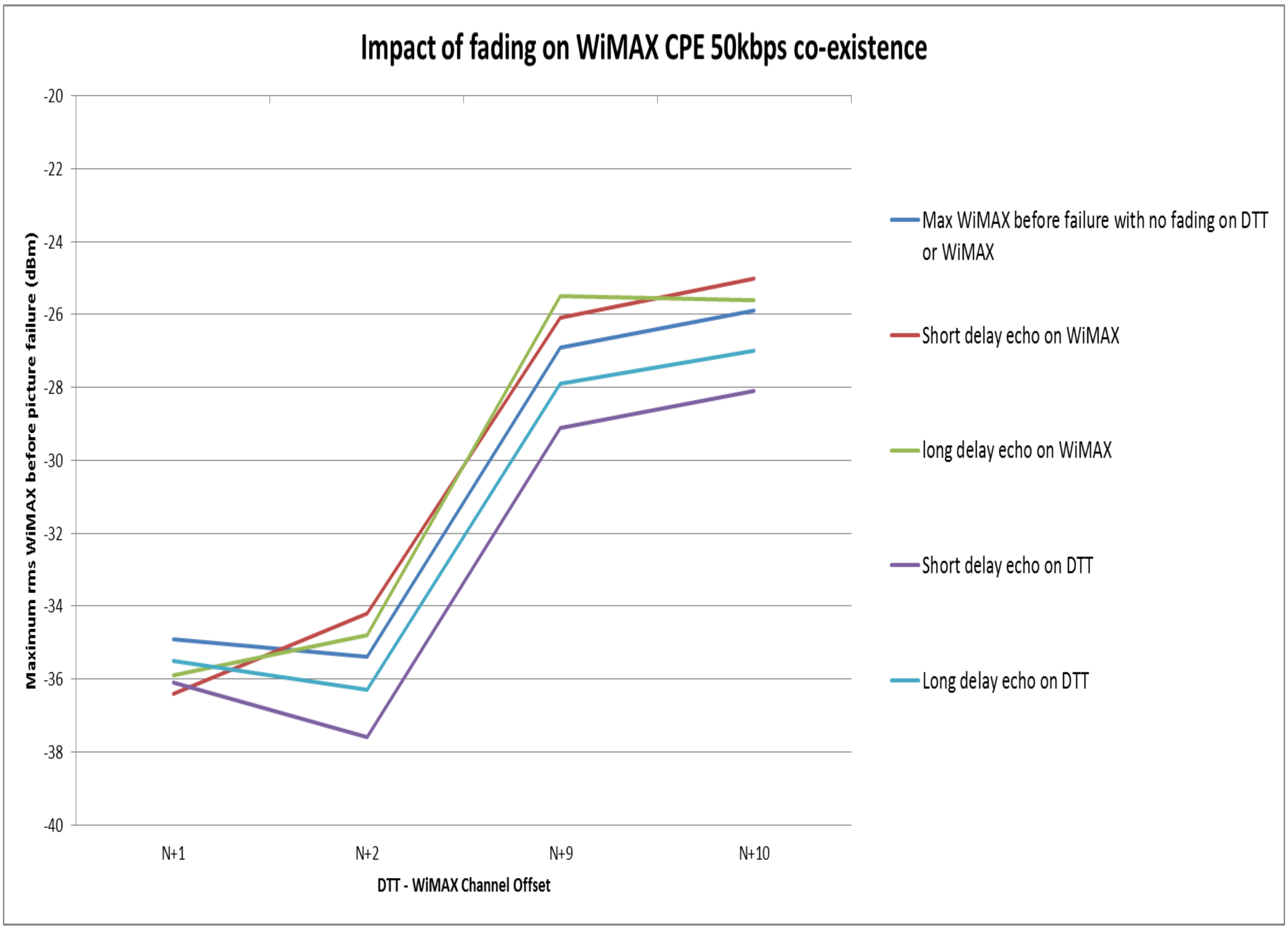

Figure 27 Impact of fading on WiMAX CPE 50kbps coexistence

Figure 27 shows that when the short delay echo is applied to the interfering signal then the maximum tolerable level of WiMAX at the DTT receiver improves by around 1dB from N+2 onwards in comparison to the case of no fading. When the short delay echo is applied to the DTT signal then the maximum tolerable level of WiMAX reduces by around 2dB compared to the case of no fading.

Adding long delay echoes to the WiMAX signal also resulted in an improved tolerance at the DTT receiver from N+2 onwards. When the long delay echo was applied to the DTT, the tolerance to WiMAX reduced but by only half the amount as when short delay echoes was applied to the DTT.

Figure 28 shows the same set of tests carried out using an LTE UE full load signal. As can be seen, applying the fading profiles to the LTE signal resulted in a slight improvement in tolerance to the LTE signal at the DTT receiver.

When the short delay echo profile was applied to the DTT signal there was a reduction in tolerance to the LTE signal by around 1.5dB at the closest frequency offsets compared to the best case scenario. This increased to around 4 dB at offsets N+9 and N+10.

When the long delay echo profile was applied to the DTT signal, there was no reduction in the receiver tolerance to LTE until the further offsets of N+9 and N+10 were tested when the reduction was 2dB and 3dB respectively.

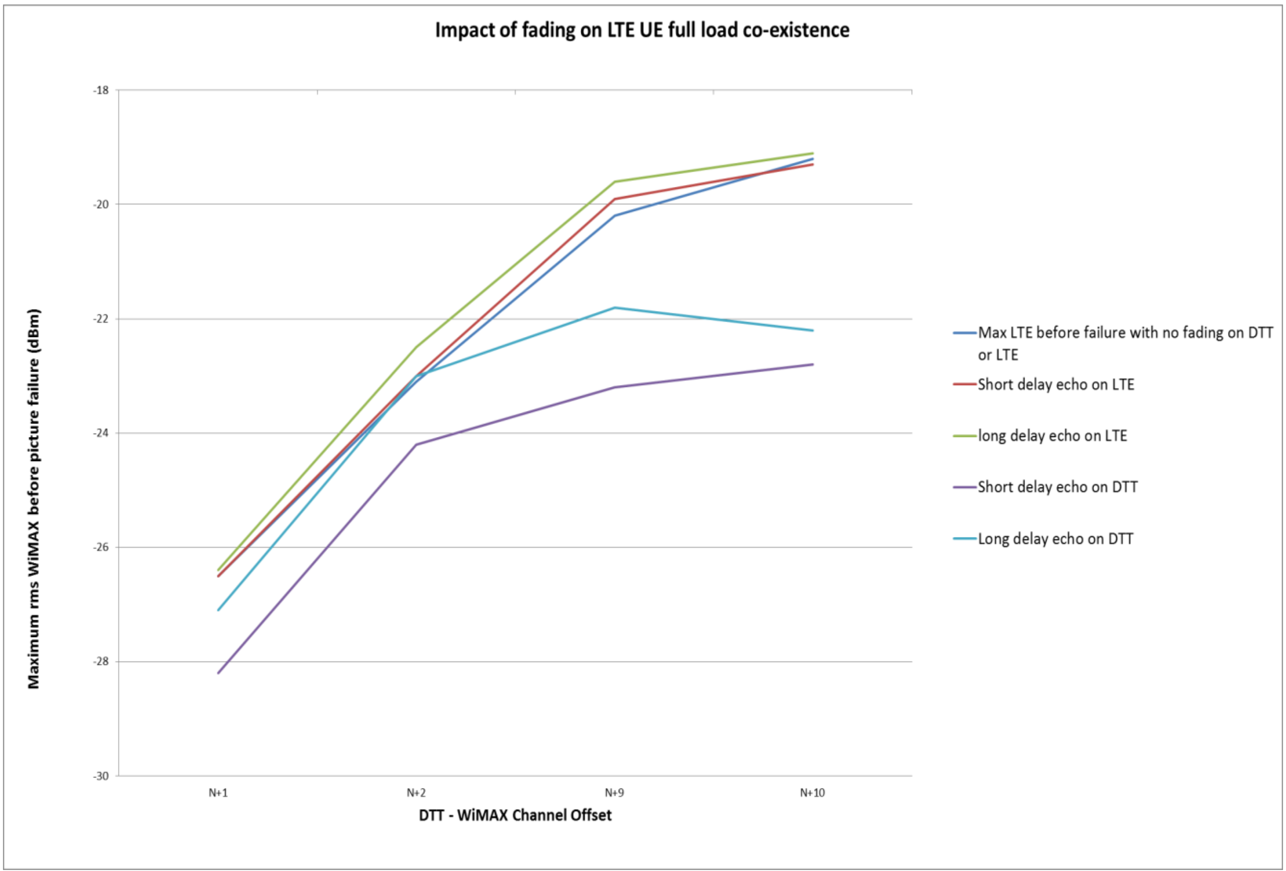

Figure 28 Impact of fading on LTE UE full load coexistence

Overall the results show that the DTT receiver is more susceptible to echoes and fading affecting the DTT signal compared to the improvement gained when the interfering signal is subject to the same echoes and fading. In the case of the LTE UE full load signal, the effect of applying echoes and fading to the DTT signal had a more profound effect at further offsets. This could have been due to the pre-amplifier compounding the effect of the fading whilst amplifying the interferer.

One potential effect of the echoes and fading being applied to the LTE UE full load signal was that it could have appeared more like a time variant signal to the DTT receiver such as the WiMAX CPE 50kbps signal. This could have caused a reduction in the receiver tolerance to the signal compared to the case where no fading was applied to the LTE signal. However the results showed that this was not the case and the DTT receiver tolerance to the LTE UE full load signal improved when echoes and fading were applied to the unwanted signal.

8. Impact of filtering on LTE signals

8.1 Overview

In the context of potential interference from LTE UEs, filtering may be employed as mitigation against the impact as is the case currently for LTE 800. The test programme included spot checks on two receivers used for pre-amplifier testing to investigate the impact of using a filter in line with a DTT receiver.

8.2 Measurement setup

The test setup was as per the amplifier testing as shown in Figure 11 section 6.2 with the addition of an LTE filter before the pre-amplifier.

The LTE was set to 796 MHz and the DTT was varied between channel 59 (778 MHz) and channel 60 (786MHz). The testing was repeated using three different LTE UE traffic loading scenarios representing full load, half load and idle mode.

The LTE filter used was a channel 60 communal filter as would be used in a multi dwelling environment such as a block of flats.

8.3 Test method

The following test procedure was used to calculate the C/I ratio of the DTT receivers under test when using a pre-amplifier and LTE filter.

1. The test receivers were initially tuned and verification of smooth video and audio was carried out.
2. The total carrier power of the DTT signal was adjusted using the variable attenuator to a pre-defined level at the input to the pre-amplifier.
3. The DTT signal was then switched off and then the interfering signal switched on.
4. The interfering signal ACLR was then adjusted to achieve the maximum level using a tuneable band pass filter.
5. The DTT signal was reapplied to the receiver under test and the level of the interferer was set to maximum.
6. The interfering signal was then gradually reduced until the DTT picture returned and no blocking or pixilation was present.
7. The coaxial input to the DTV receiver was then disconnected and an LTE filter connected in line.
8. The output of the filter was connected to the DTV receiver.
9. The LTE test signal was then re-applied to the DTV receiver under test at maximum level and gradually reduced until the receiver presented smooth audio and video.
10. The level of the interfering signal at the input to the pre-amplifier was recorded at the point at which the picture returned without any errors

8.4 Results

The results were as expected with the filter providing a much improved protection ratio compared to the case when the filter was not used.

Figures 29 to 32 show results from the testing and present the maximum tolerable LTE signal levels before and after the filter was applied. The levels are all referenced to the input of the pre-amplifier being used for the testing.

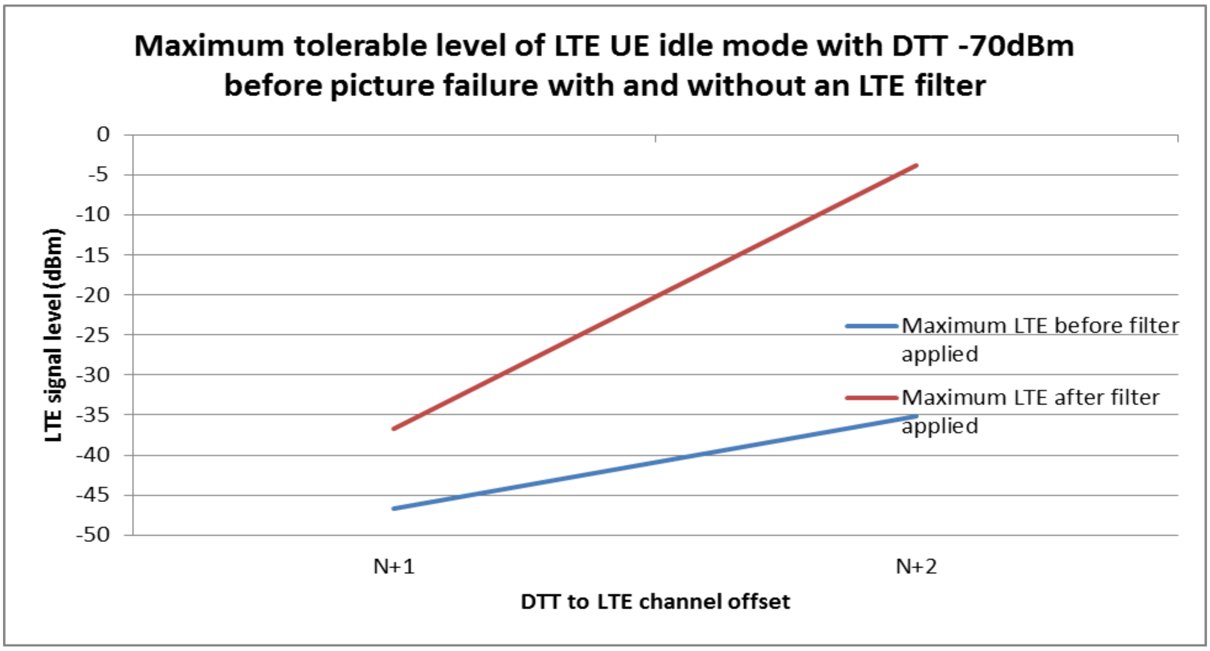

Figure 29 Maximum tolerable level of LTE UE idle mode with DTT -70dBm before picture failure, with and without an LTE filter

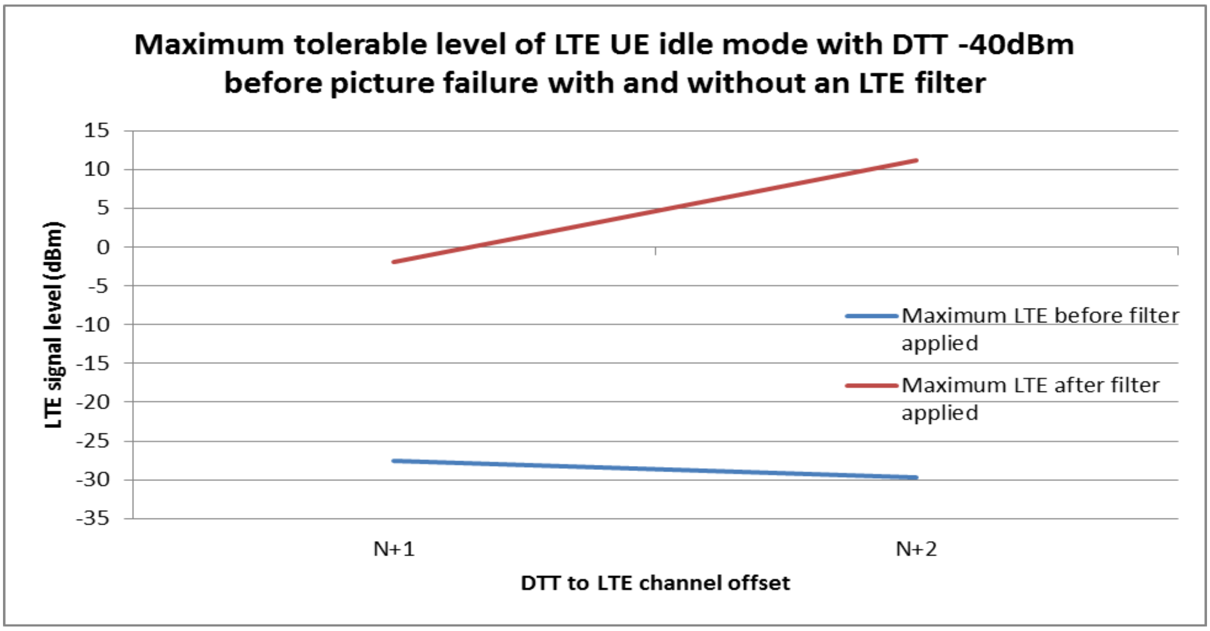

Figure 30 Maximum tolerable level of LTE UE idle mode with DTT -40dBm before picture failure, with and without an LTE filter

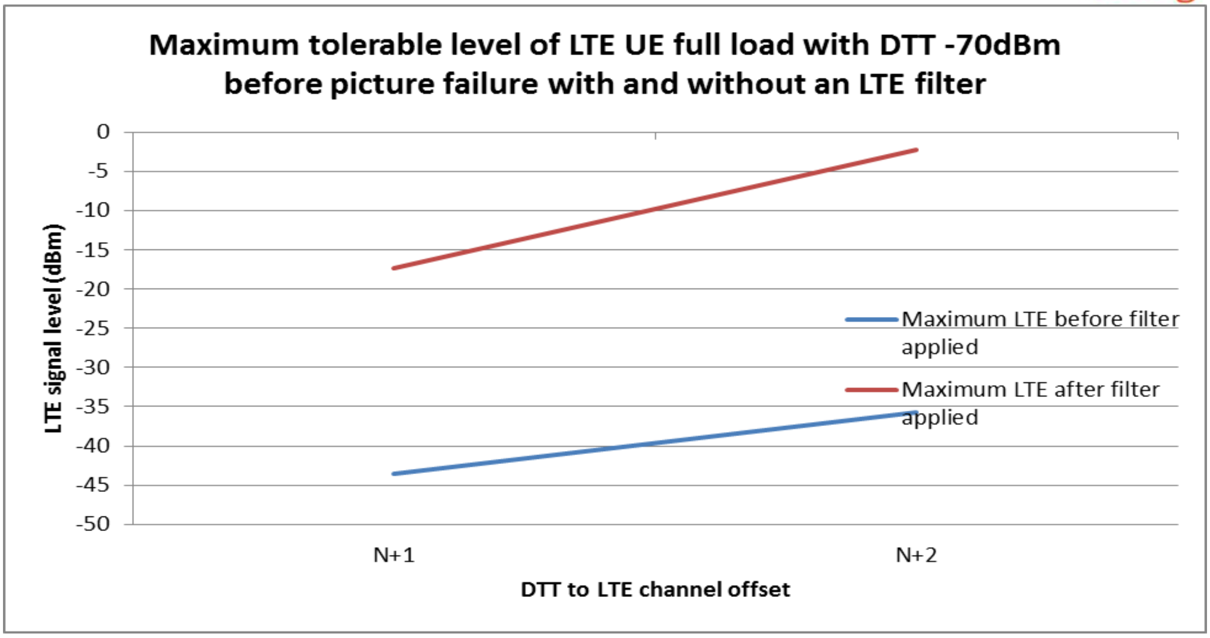

Figure 31 Maximum tolerable level of LTE UE full load with DTT -70dBm before picture failure, with and without an LTE filter

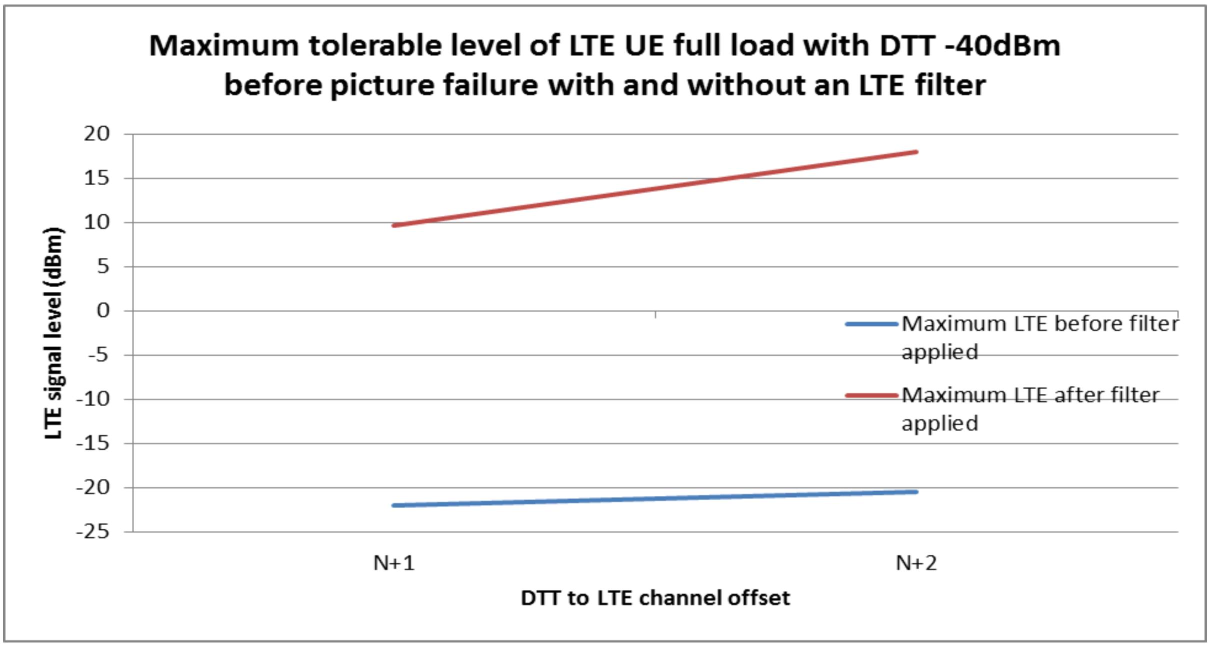

Figure 32 Maximum tolerable level of LTE UE full load with DTT -40dBm before picture failure, with and without an LTE filter

The smallest improvement was with the DTT signal level at -70dBm where at N+1 the difference in tolerable LTE signal with and without the filter was around 10dB. This was not specific to the type of LTE signal, as for the second receiver tested the smallest improvement was also 10dB but for the LTE UE idle mode signals as opposed to the full load.

The largest improvement was seen with the DTT signal level at -40dBm where the difference in the tolerable LTE signal level with and without the filter was between 30dB and 40dB for both receivers and all LTE signal types.

9. Protection ratio testing

9.1 Overview

To follow on from testing receivers using pre-amplification, a programme of conductive bench tests was carried out to ascertain the ACS of a range of 50 digital television receivers in response to interference from WSD CPEs and LTE UEs.

50 receivers were chosen based primarily upon market sales data since 2007, the start of digital switch-over. In addition to sales data, other factors were considered when selecting the models to test in order to ensure a combination of age of receiver, capability of the receiver i.e. whether it was only DVB-T1 capable or both DVB-T1 and DVB-T2 and the type of unit such as STB, PVR, and iDTV.

The relationship between a single receiver chassis and its representative models is defined by the manufacturer so that, for instance, a single TV may represent a series of models with different sized screens and possibly cover a small group of similar model series. In this way the size of the receiver collection can be controlled whilst representing the UK market as a whole. The 50 receivers chosen for the protection ratio testing actually represent over 50% of sold models since 2007 as a result of this factor.

The results indicate how receivers in the market will perform in the presence of a range of coexisting radio technologies.

9.2 Measurement setup

The majority of testing was carried out in the DTG Receiver Zoo using all 50 receivers at the same time but a section of the testing was carried out using 8 receivers at a time, in order to increase the signal strength at the input to the receivers. The test set up used to perform the protection ratio measurements on 50 receivers is shown in Figure 33 and the test setup to perform protection ratio testing on 8 receivers at a time is shown in Figure 34. The DVB-T1/T2 signal was played into a 100W amplifier then into a second smaller DTT pre-amplifier via a variable attenuator, which was used to control the level of the signal.

The unwanted test signal was played back using an Arbitrary Waveform Generator (AWG) which was then amplified and filtered.

The DTT and unwanted signal were combined using a 10dB directional coupler.

A 4-way splitter was used to allow the DTT and LTE signal at the input to be distributed across 6 shelving racks containing around 8 receivers on each.

The outputs of the splitter were connected to a distribution system made up of 8dB and 11dB taps connected via quad shielded coaxial cable. The 8dB taps have 4 outputs and the 11dB taps have 8 outputs. The design of the system is set up so that the input to each receiver will be at the same signal level. In reality there can be a variation which was measured at ±0.5dB.

The setup when using 50 DTT receivers provided maximum signal strength at the input to the test receivers of 0dBm for the interferer and -40dBm for the DTT.

During testing using the WiMAX and WiFi signals it was observed that some of the receivers did not fail at these levels once the frequency separation between the DTT and interferer increased or the DTT signal strength was at the higher levels. This can be seen in Appendix A where a bold black line is shown on the protection ratio graphs. The point at which the protection ratio curve meets the black line means that the receiver did not fail at the maximum interferer power level. In particular this was the case for the Weightless base station signal where for -70dBm DTT some receivers would not fail with a Weightless signal strength input of 0dBm from N±3 onwards. For the higher level DTT of -40dBm this was seen from the first adjacent offsets.

In order to provide a signal strength that would cause a picture failure at the receiver for all frequency offsets and DTT signal levels, a section of the testing was carried out on smaller batches of 8 receivers at a time using the Weightless signal. This allowed for reduction in the losses through the distribution network by removing some of the splitters and taps. The signal strength possible at the input to the DTT receiver was -30dBm for DTT and +10dBm for the interferer (Weightless signal).

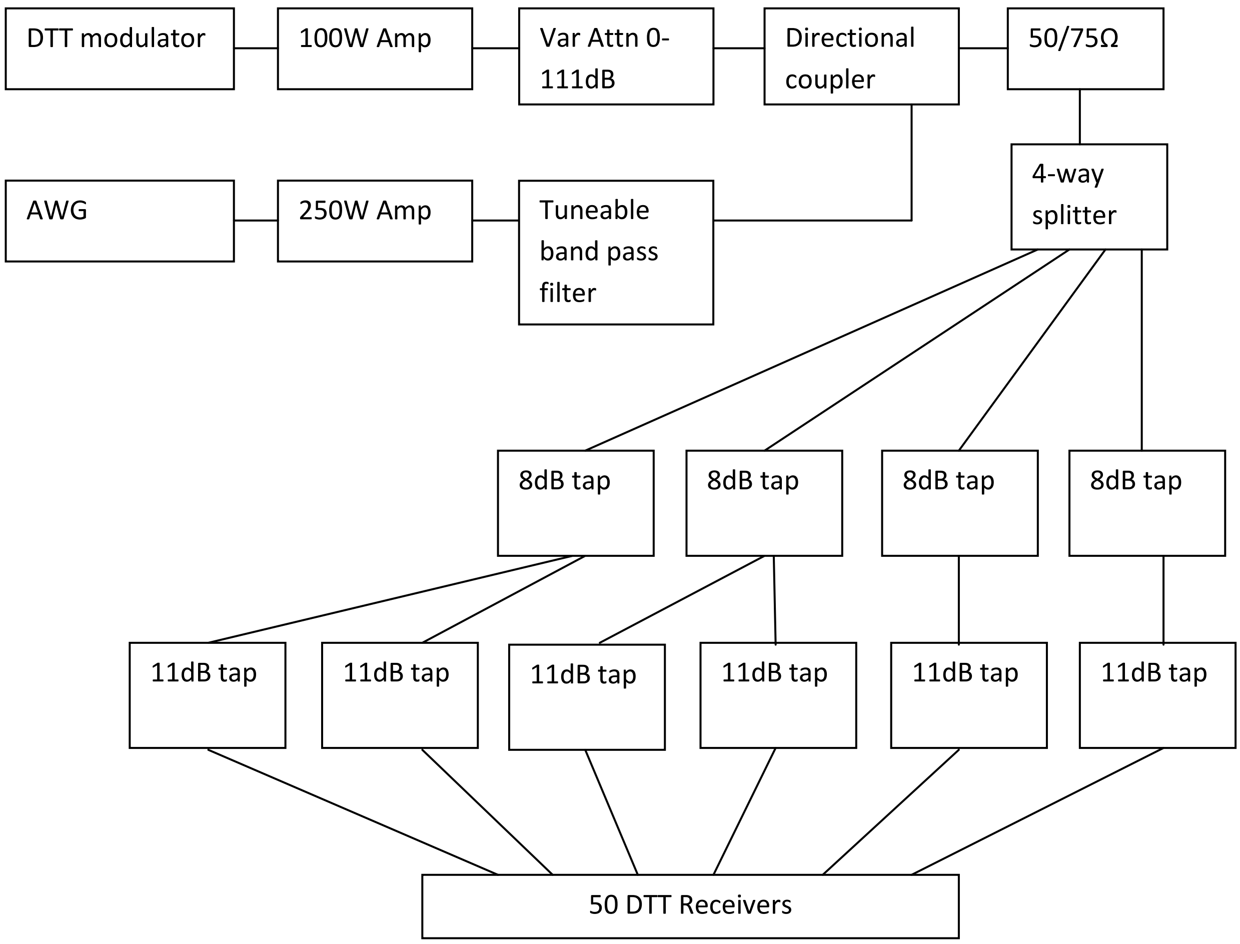

Figure 33 Measurement set up for protection ratio testing in the DTG Receiver Zoo

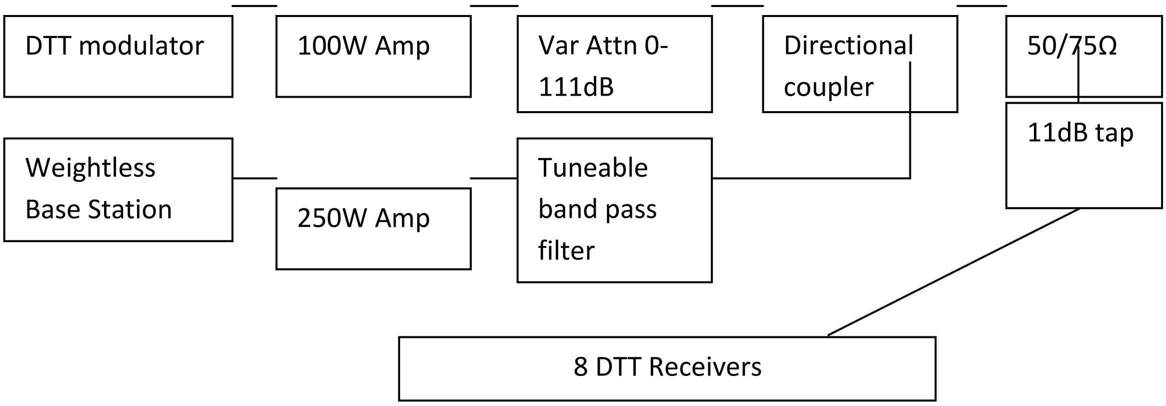

Figure 34 Measurement set up for Weightless base station protection ratio testing in the DTG Receiver Zoo

Test method

The following test procedure was used to calculate the C/I ratio of the DTT receivers under test:

1. The test receivers were initially tuned and verification of smooth video and audio was carried out.
2. The total carrier power of the DTT signal was adjusted using the variable attenuator to a pre-defined level at the input to the pre-amplifier.
3. The DTT signal was then switched off and then the interfering signal switched on.
4. The interfering signal ACLR was then adjusted to achieve the maximum level using a tuneable band pass filter.
5. The DTT signal was reapplied to the receiver under test and the level of the interferer was set to maximum.
6. The interfering signal was then gradually reduced until the DTT picture returned and no blocking or pixelation was present.

The level of the interfering signal at the input to the DTT receiver was recorded at the point at which the picture returned without any errors.

9.3 Results

Frequency offsets in steps of 8 MHz were measured for the WSD CPE signals and of 10 MHz then subsequent steps of 8 MHz for LTE UE signals. The protection ratios using WiMAX, WiFi and LTE UE signals were measured up to N±11 in consecutive steps and then three further offsets were measured ranging up to N±40. The protection ratio using the Weightless signal was measured at selected positive frequency offsets detailed in Table 13.

The full list of frequency offsets for WiMAX , WiFi and LTE UE signals is shown in Table 12. The Weightless signal was tested over fewer frequency offsets due to a change of equipment during the project resulting in time restrictions to complete the work. The list of frequency offsets for Weightless is shown in Table 13. In addition to these offsets, a sample of four receivers was tested at frequency offsets of N+20 and N+40 in order to investigate the impact of increased frequency separation between the DTT and interfering signal. The selected channel offsets were measured at DTT signal levels -70dBm, -60dBm, -50dBm and -30dBm. The change from -40dBm to -30dBm for the Weightless signal only was to explore protection ratios and DTT receiver selectivity at higher wanted signal levels.

Frequency offsets for all LTE		Positive Frequency offsets for WiMAX and WiFi		Negative Frequency offsets for WiMAX	
Offset	Frequency separation from DTT (MHz)	Offset	Frequency separation from DTT (MHz)	Offset	Frequency separation from DTT (MHz)
N+0	0	N+0	0	N-0	0
N+1	10	N+1	8	N-1	-8
N+2	18	N+2	16	N-2	-16
N+3	26	N+3	24	N-3	-24
N+4	34	N+4	32	N-4	-32
N+5	42	N+5	40	N-5	-40
N+6	50	N+6	48	N-6	-48
N+7	58	N+7	56	N-7	-56
N+8	66	N+8	64	N-8	-64
N+9	74	N+9	72	N-9	-72
N+10	82	N+10	80	N-10	-80
N+11	90	N+11	88	N-11	-88
N+15	122	N+20	160		
N+20	162	N+30	240		
N+25	202	N+40	320		

Table 12 Frequency offsets for WiMAX CPE, WiFi CPE and LTE UE testing

Frequency offsets for all Weightless	
Offset	Frequency separation from DTT (MHz)
N+0	0
N+1	10
N+2	18
N+3	26
N+4	34
N+8	66
N+9	74
N+10	82

Table 13 Frequency offsets for Weightless testing

The results for the Weightless signals at the larger frequency offsets are presented below as graphs of protection ratios in Figures 35 to 38. As can be seen, some of the receivers required a larger protection ratio at N+40 compared with closer in offsets of N+20 and N+10. This is highlighted by receiver 30 which could withstand almost 10dB less of interfering signal at a DTT to interferer offset of N+40 when compared with an offset N+20 when using a DTT signal level of -70dBm.

In contrast the protection ratios for receiver 29 improved as the separation between the DTT signal and the interfering signal increased.

Overall the results highlight that there can be variations in the protection ratio performance with increased frequency offsets between the DTT signal and the interfering signal and that it is not a constant level once a certain frequency separation has been reached.

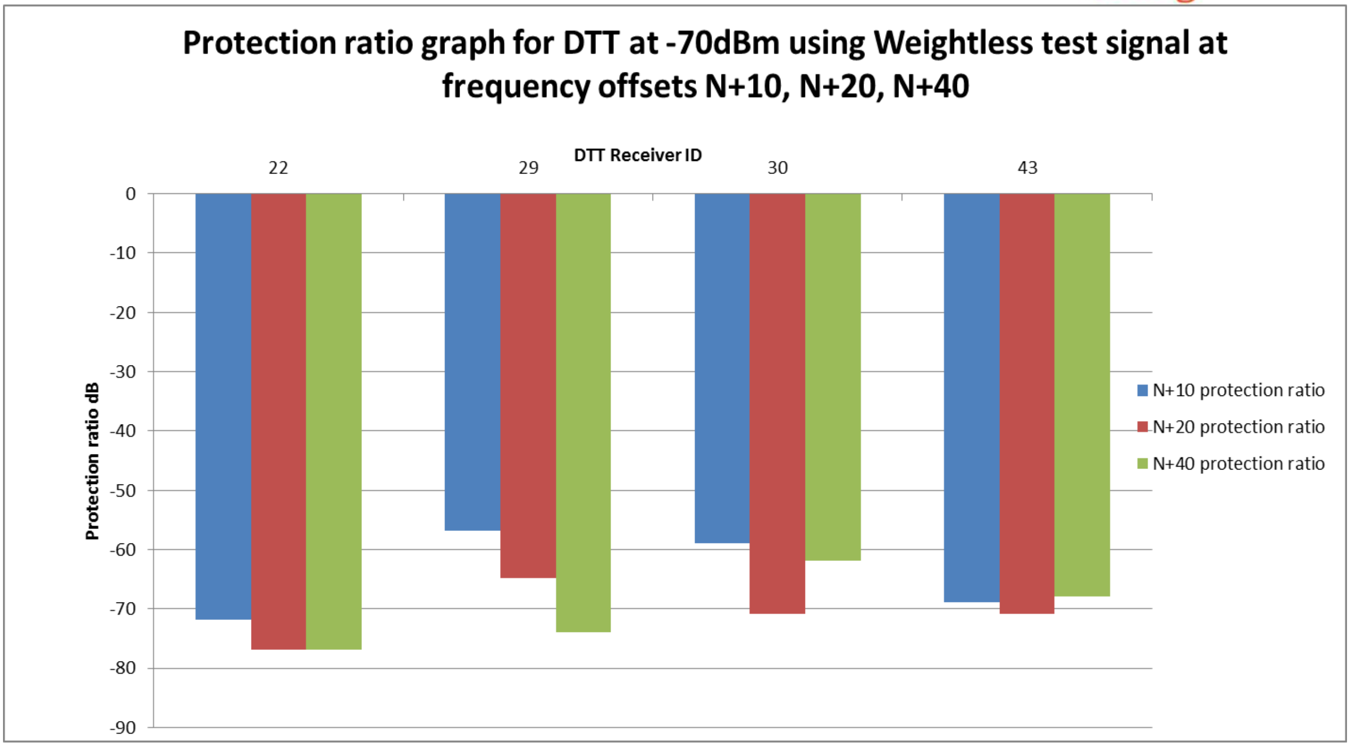

Figure 35 Protection ratio graph for DTT at -70dBm using Weightless test signal frequency offsets N+10, N+20, N+40

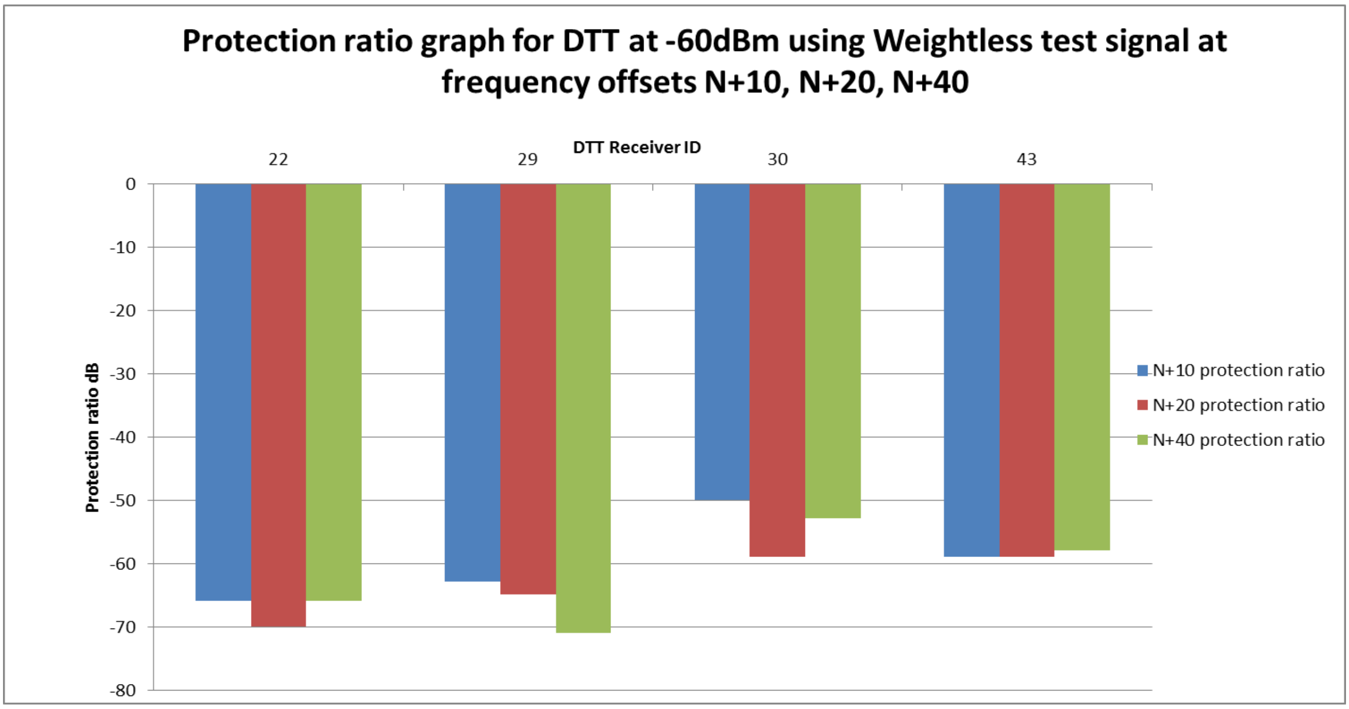

Figure 36 Protection ratio graph for DTT at -60dBm using Weightless test signal frequency offsets N+10, N+20, N+40

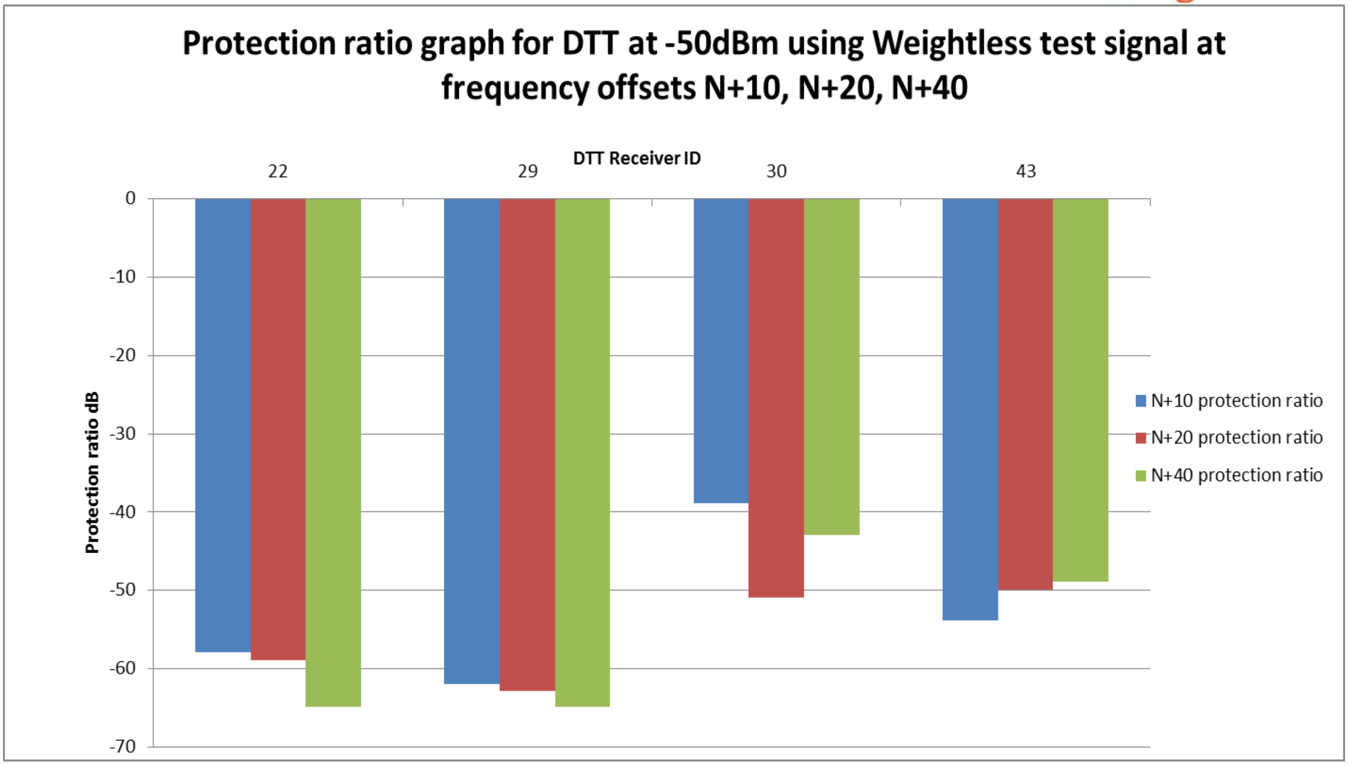

Figure 37 Protection ratio graph for DTT at -50dBm using Weightless test signal frequency offsets N+10, N+20, N+40

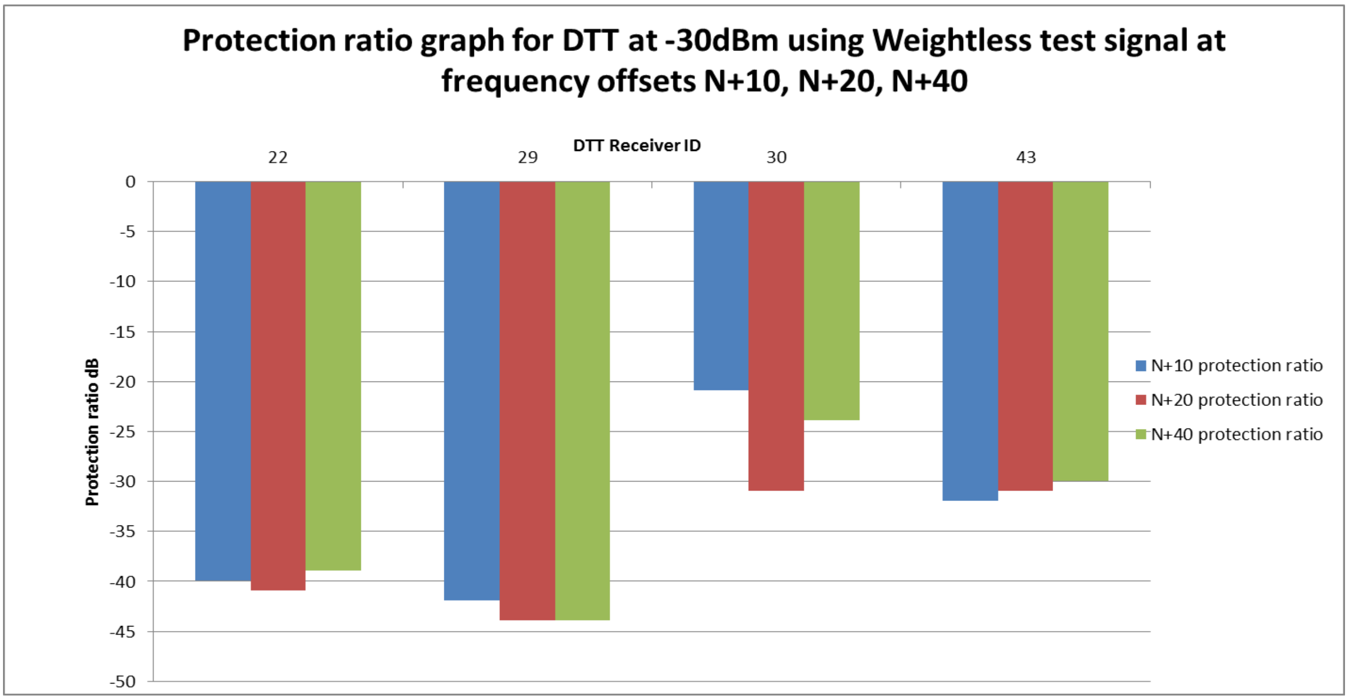

Figure 38 Protection ratio graph for DTT at -30dBm using Weightless test signal frequency offsets N+10, N+20, N+40

The results for all signals and offsets are presented below as the cumulative distribution function (CDF) of the derived ACS values. The ACS values were calculated from measured protection ratios which are shown in Appendix A. The full set of ACS values for all DTT levels and frequency offsets can be seen in Appendix B.

The CDF shows, for a given ACS value, what percentage of receivers achieved better results than that level. The percentage was weighted according to the sales volume of the receiver which is detailed in Section 4. For example, 100% of receivers mean the total sales of all the receivers summed together. As each receiver achieved a certain ACS level, the sales of that receiver as a percentage of the overall sales makes up the percentage that achieved the given ACS level. By weighting the receivers on sales volumes, it makes the ACS values representative of the impact that each test signal has on receivers in use in UK households. Where a receiver may have performed poorly but had limited market sales, the percentage contribution the receiver adds to the ACS graphs will be small to reflect the scale of any potential problem.

The CDF figures can be used to determine which signals are most disruptive and what particular ACS target would be required to ensure a certain percentage of receivers would be protected from interference. An example would be Figure 39 where it can be seen that for LTE UE full load, 50% of receivers had an ACS better than 67dB for -70dBm DTT level at N+1.

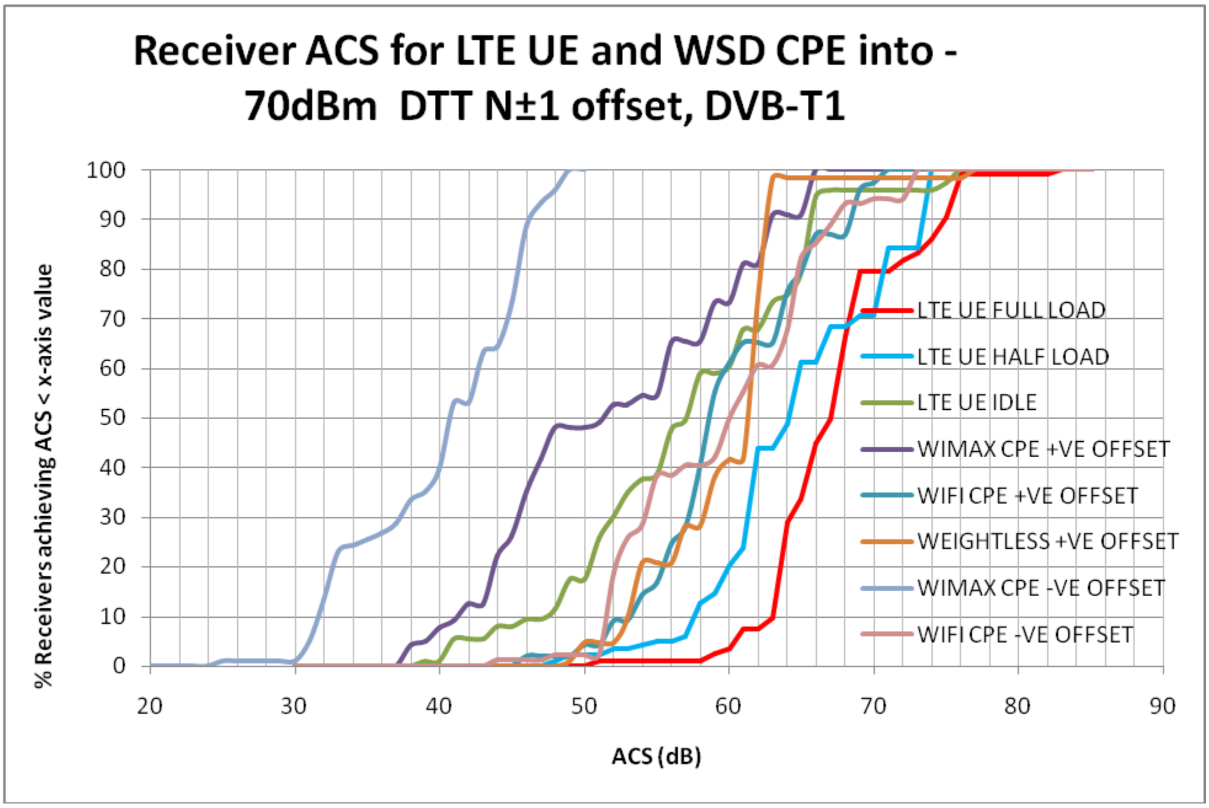

Figure 39 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±1

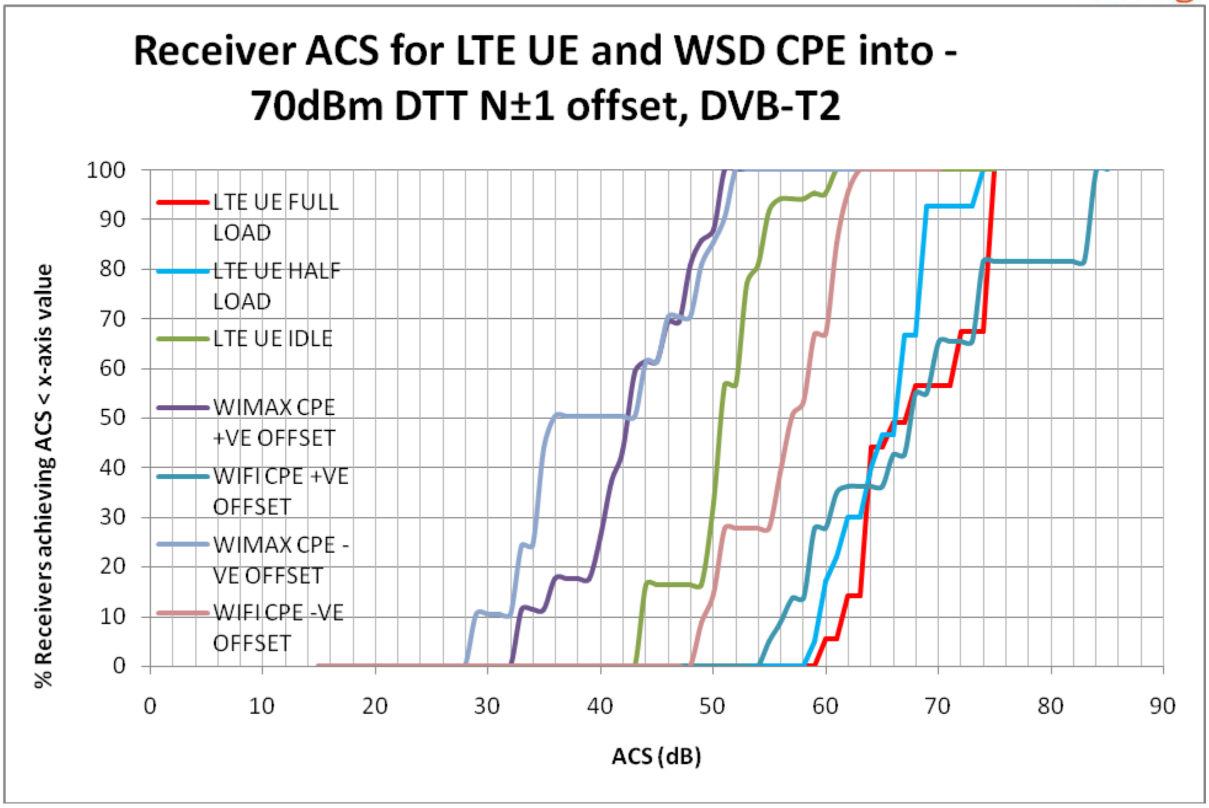

Figure 40 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±1

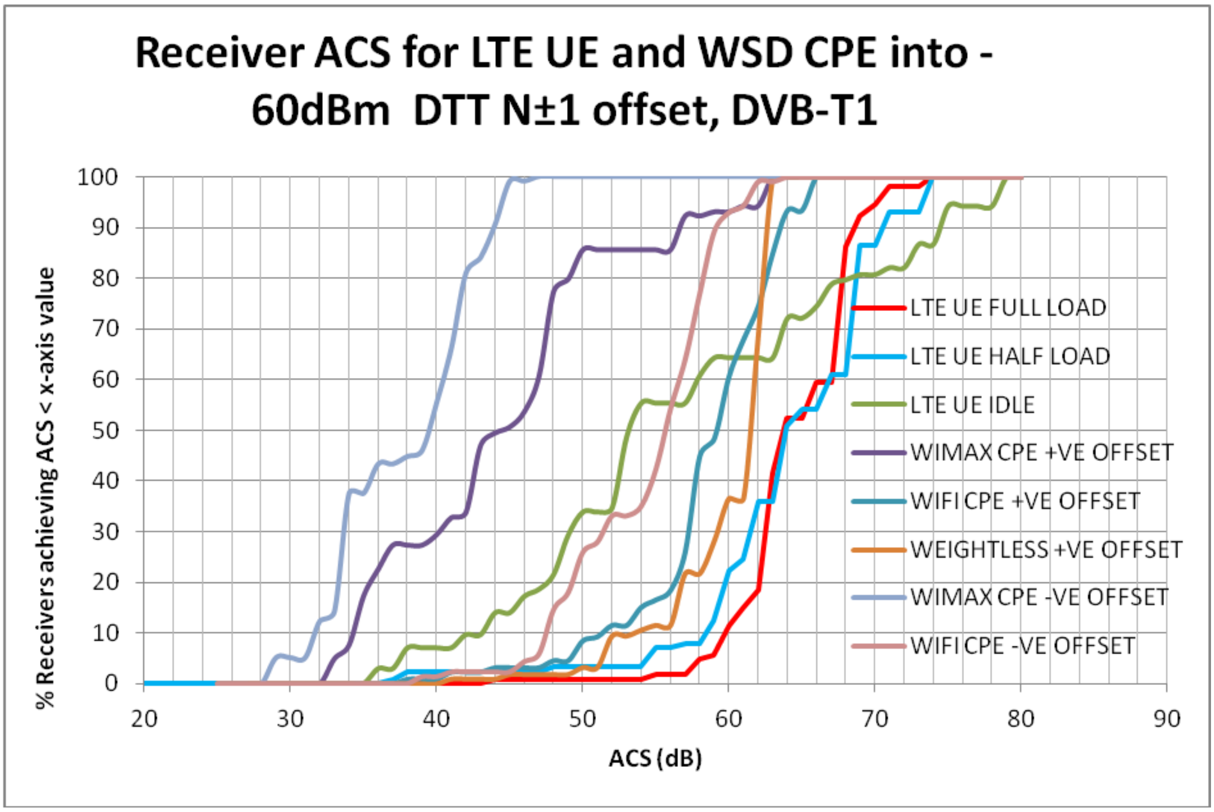

Figure 41 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±1

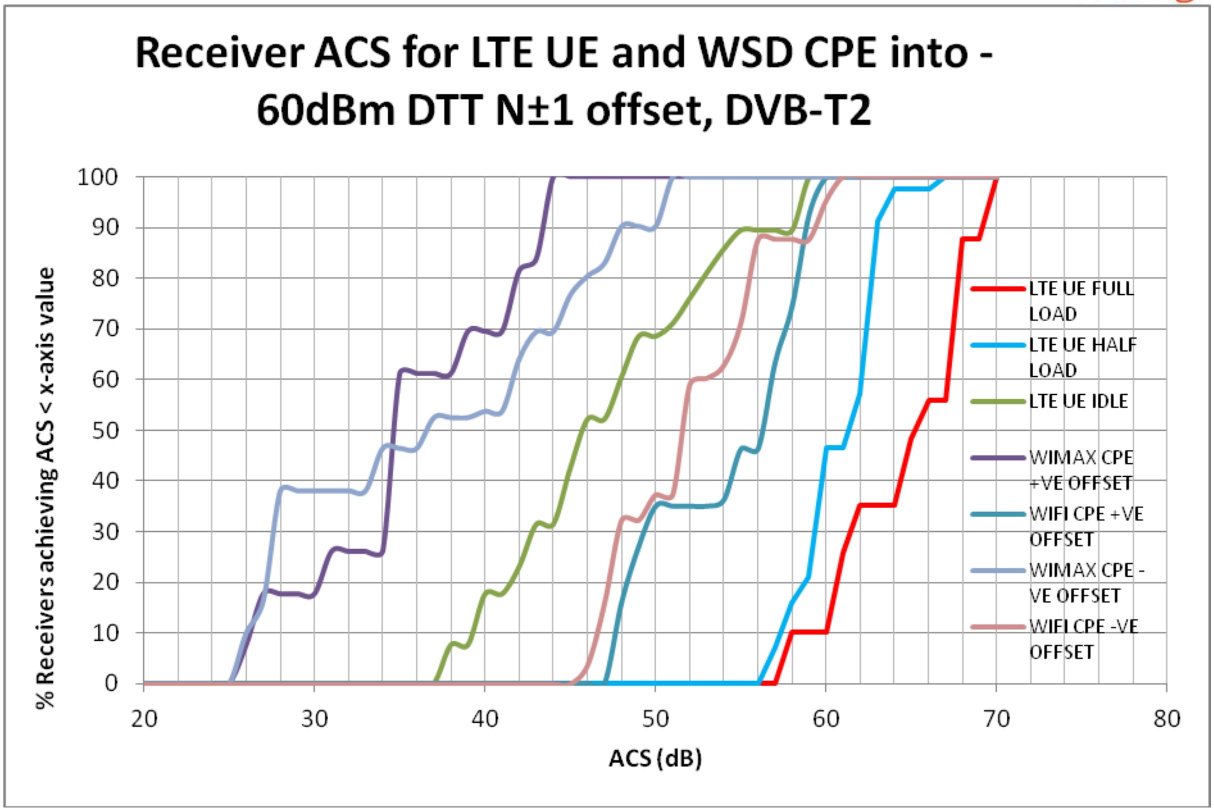

Figure 42 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±1

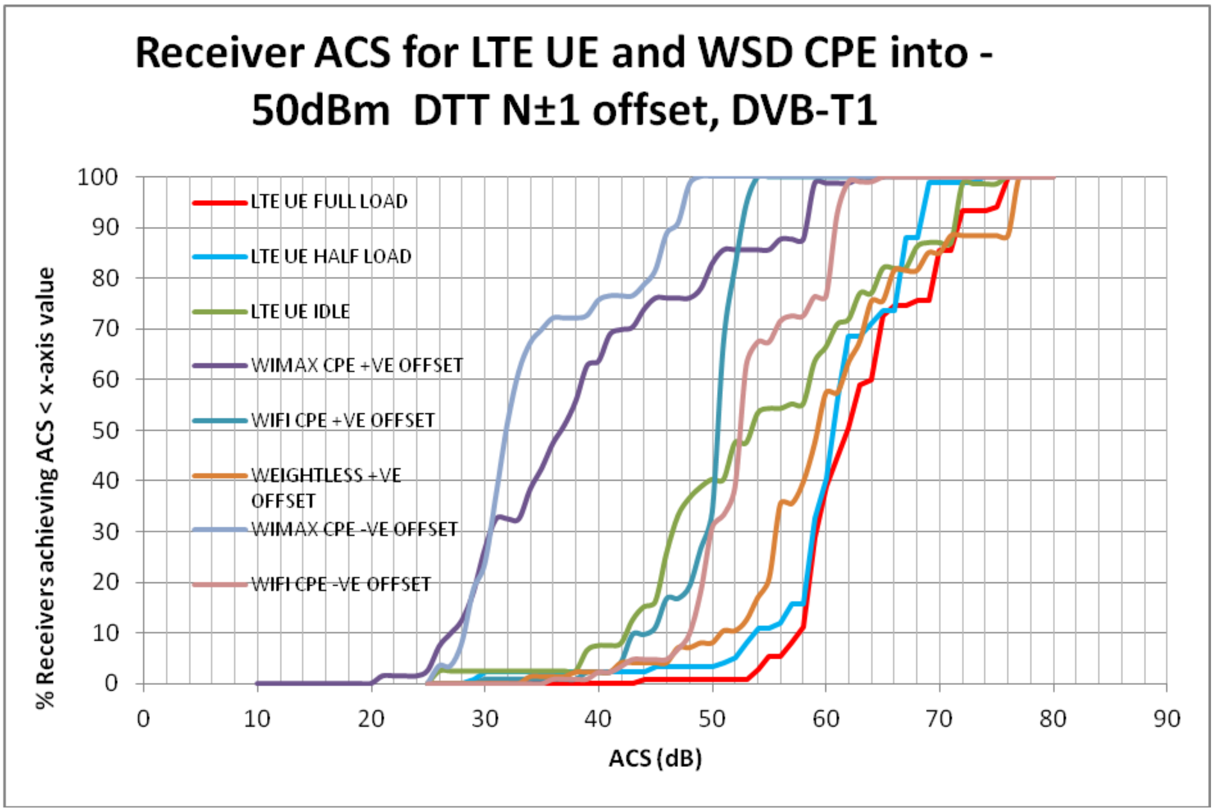

Figure 43 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±1

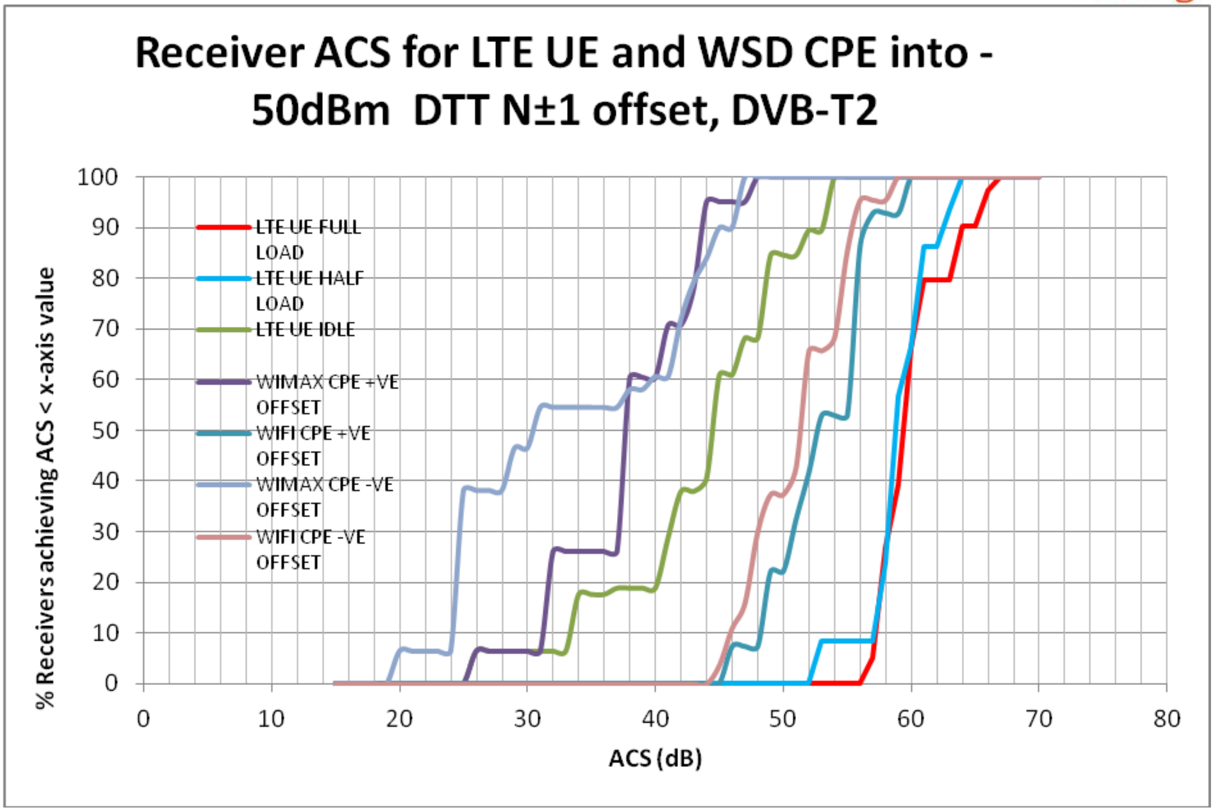

Figure 44 CDF of ACS values at-50dBm DVB-T2 DTT at offsets N±1

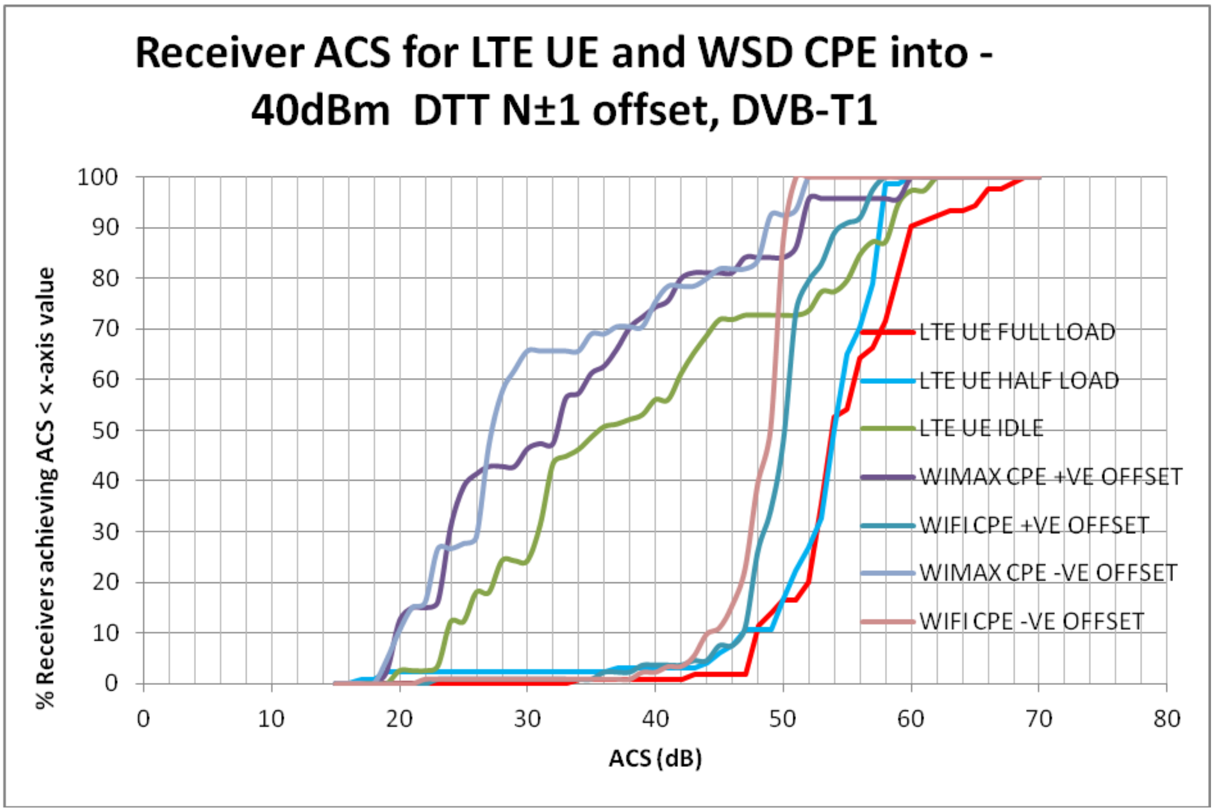

Figure 45 CDF of ACS values at-40dBm DVB-T1 DTT at offsets N±1

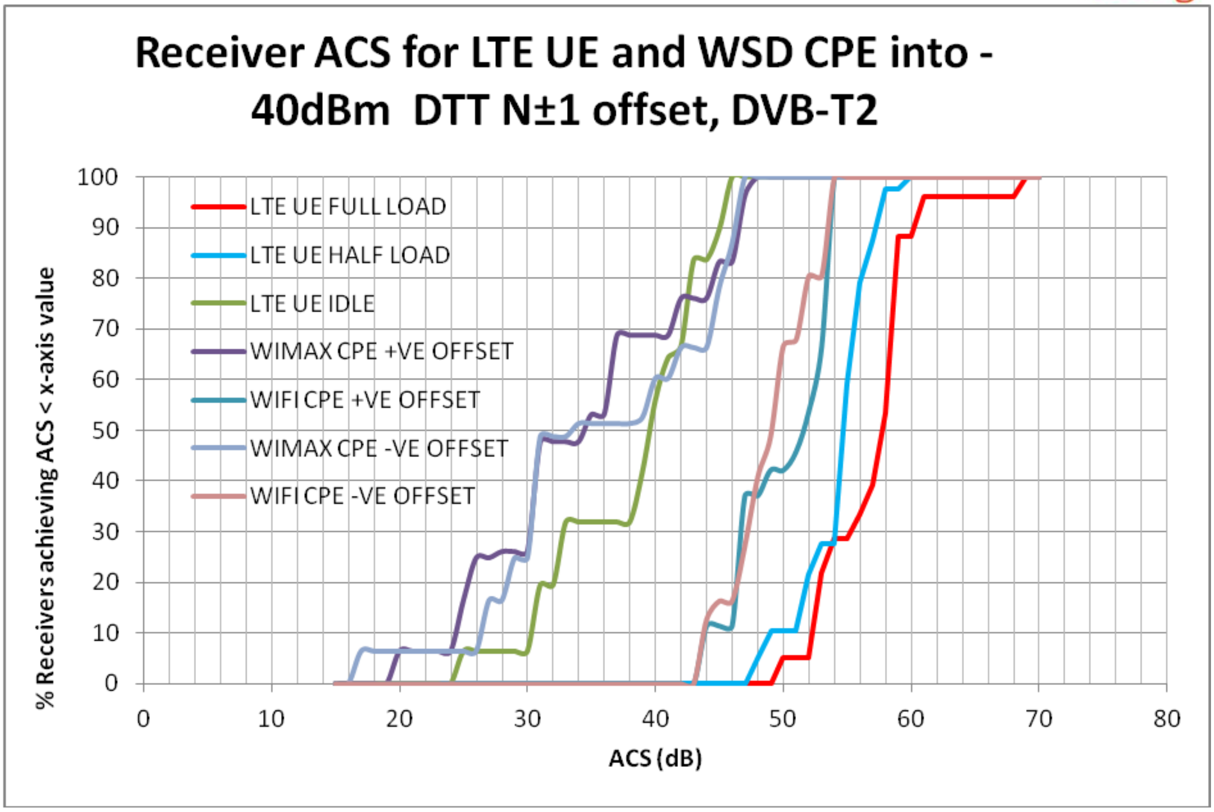

Figure 46 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±1

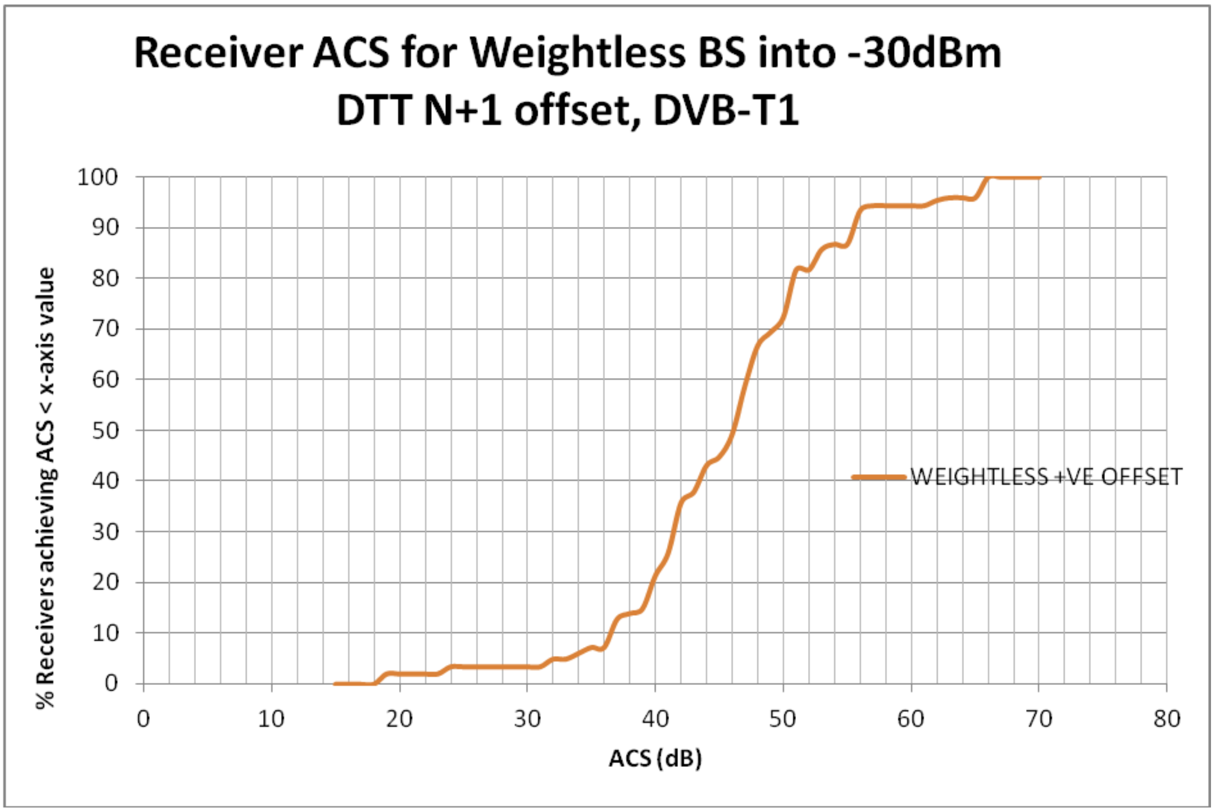

Figure 47 CDF of ACS values for Weightless signal at-30dBm DVB-T2 DTT at offset N+1

The results show that the WiMAX low traffic level signal is the most disruptive to the collection of DTT receivers. The WiMAX signal has a low duty cycle meaning the period of the on power compared to the overall period of the waveform is low. When the BBC carried out testing using same recorded WiMAX signals, they observed the duty cycle to be as low as 2%[2]. The result of this is a high peak to average power, which has a difference of 20.4dB between the peak licensed power and the average power measured across the bandwidth as explained in Section 4.6. In addition, the duty cycle of the WiMAX signal was variable, meaning that the repetition of when the WiMAX CPE was transmitting to when there was no activity fluctuated. This is in contrast to the WiFi and Weightless signals which had a uniform duty cycle throughout. Figures 48 to 50 highlight this and show a time domain measurement of each of the WSD signals. As can be seen, the repetition of when the WiMAX signal is transmitting varies across the timeframe. The result of this is a signal which is disruptive to the receivers owing to the automatic gain control function which cannot cope with large variations in the interfering signal as well as the fluctuating repetition times.

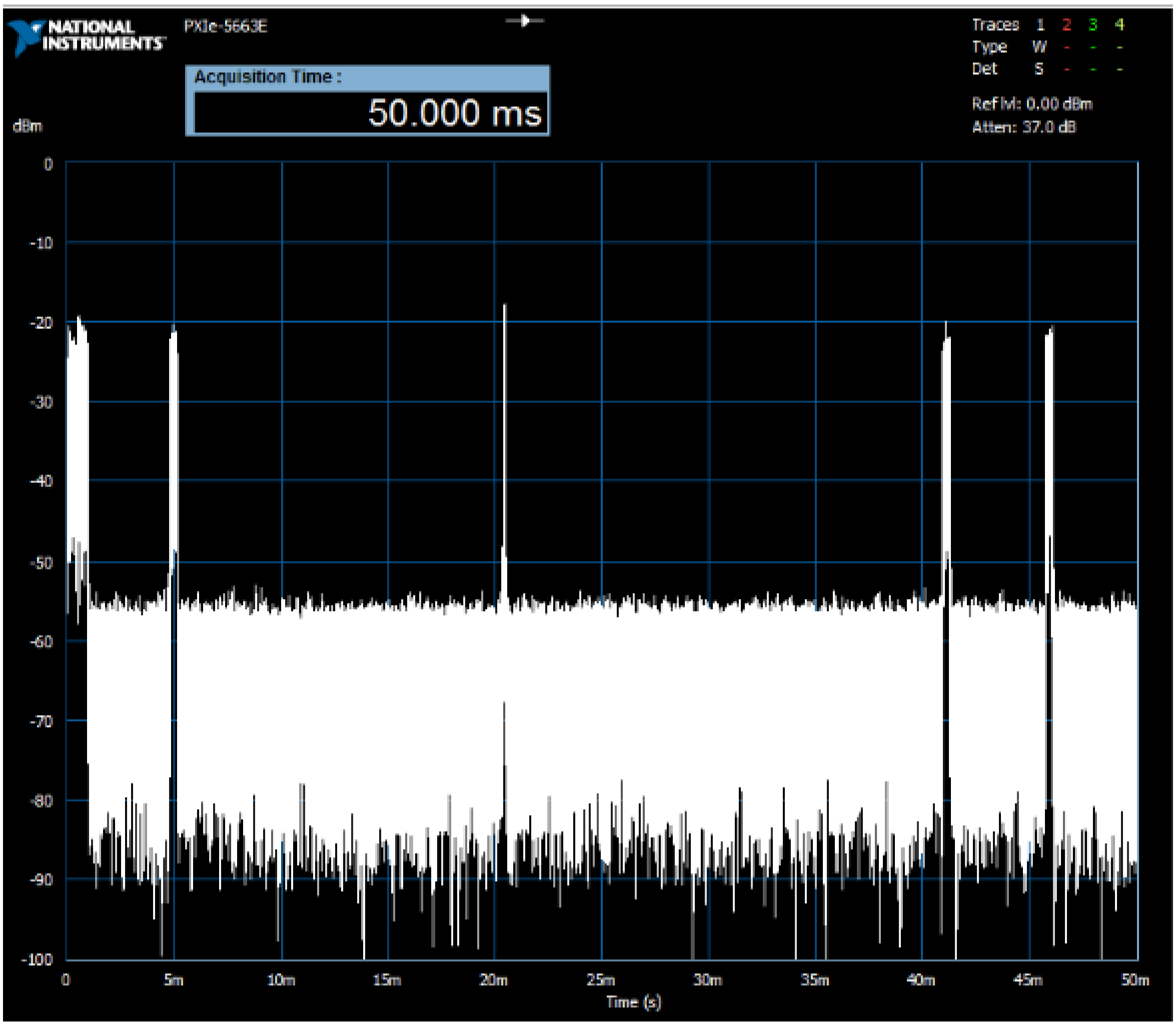

Figure 48 Time domain measurement of WiMAX CPE 50kbps test signal

[2] SE43(12)38_Measured DVB-T Protection Ratios in the presence of Whitespace Devices, Tim Harrold, Mark Waddell, BBC R&D

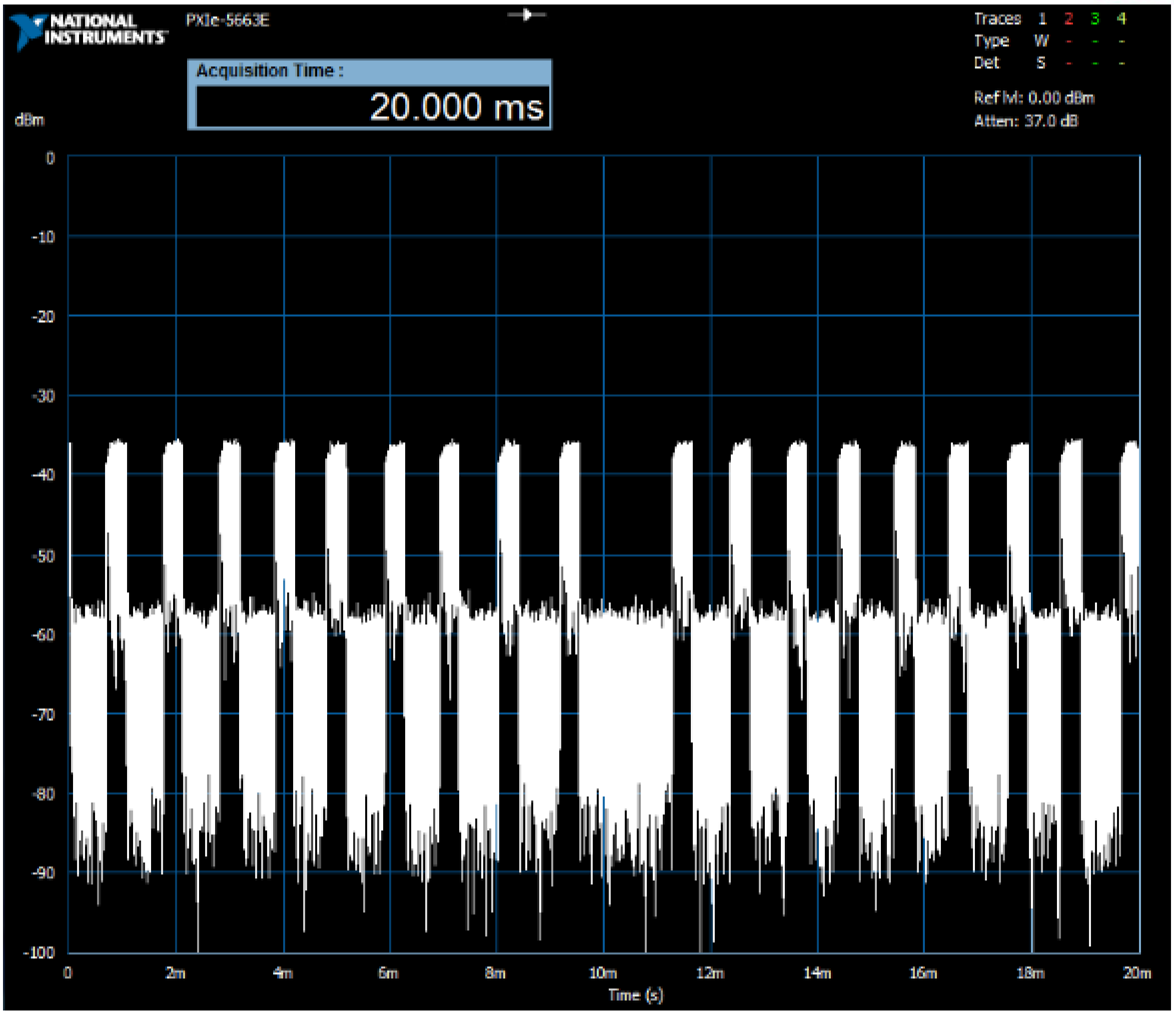

Figure 49 Time domain measurement of WiFi CPE 50kbps test signal

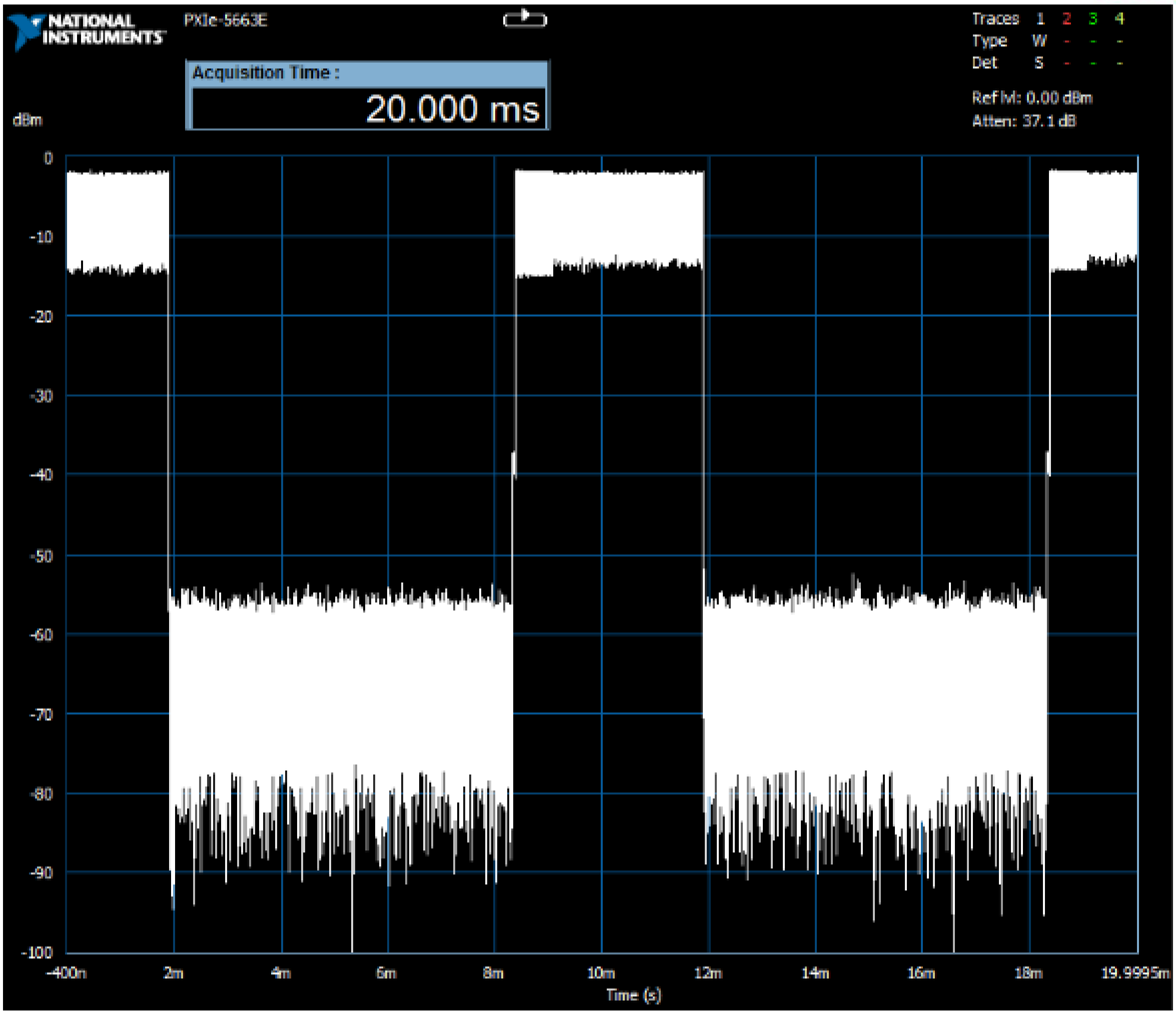

Figure 50 Time domain measurement of Weightless test signal

The least disruptive signals were the LTE UE half load and full load signals which gave an improvement in ACS compared to the WiMAX signal of between 18dB and 29dB at the ACS level that 50% of receivers met.

The results also showed a wide variation between some of the receiver models with the difference being as large as 30dB between models. The variation was greater when using the more time discontinuous test signals such as WiMAX and the LTE UE idle mode.

The WiMAX and WiFi signals were tested over both positive and negative offsets and generally speaking the negative offsets resulted in lower levels of ACS across the receiver range at the nearest frequency offsets. One possible explanation for this has been given as silicon tuners with intermediate frequencies at a low frequency of around 5 MHz. This may result in a skewed performance for the same frequency offset depending on whether the interferer was at a frequency lower or higher than the DTT signal.

Comparisons between T2 and T1 modes of DVB-T show that the resultant ACS values can vary between the two modes and that for close in offsets it was not seen that one mode was predominantly better than the other. For the further away offsets at low level DTT, it was observed that the DVB-T1 ACS levels were better than the DVB-T2 ones. Figures 51 and 52 below show that for a DTT level of -70dBm at an offset of N±11, 50% of receivers achieved an ACS of between 76dB and 90dB whereas for DVB-T2 that range was between 68dB and 81dB. This highlights that for DVB-T2 the receiver is more likely to require an increased C/N ratio in order to demodulate the signal.

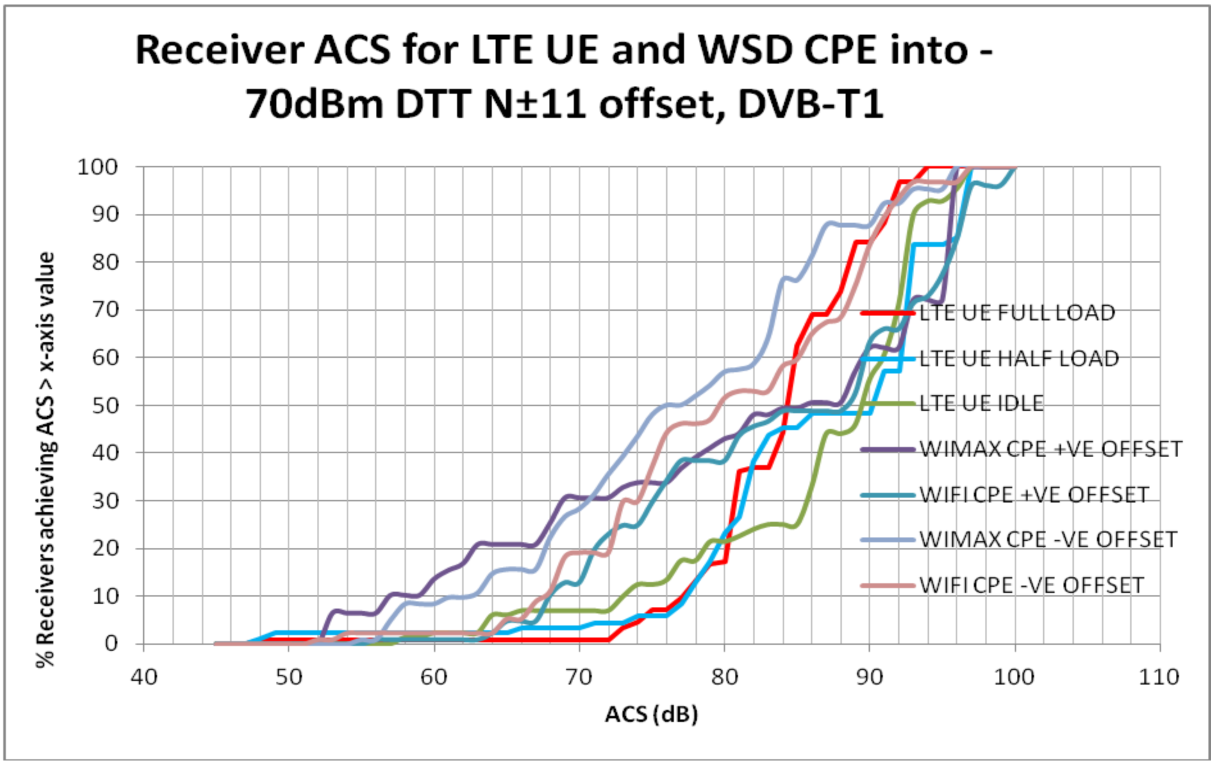

Figure 51 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±11

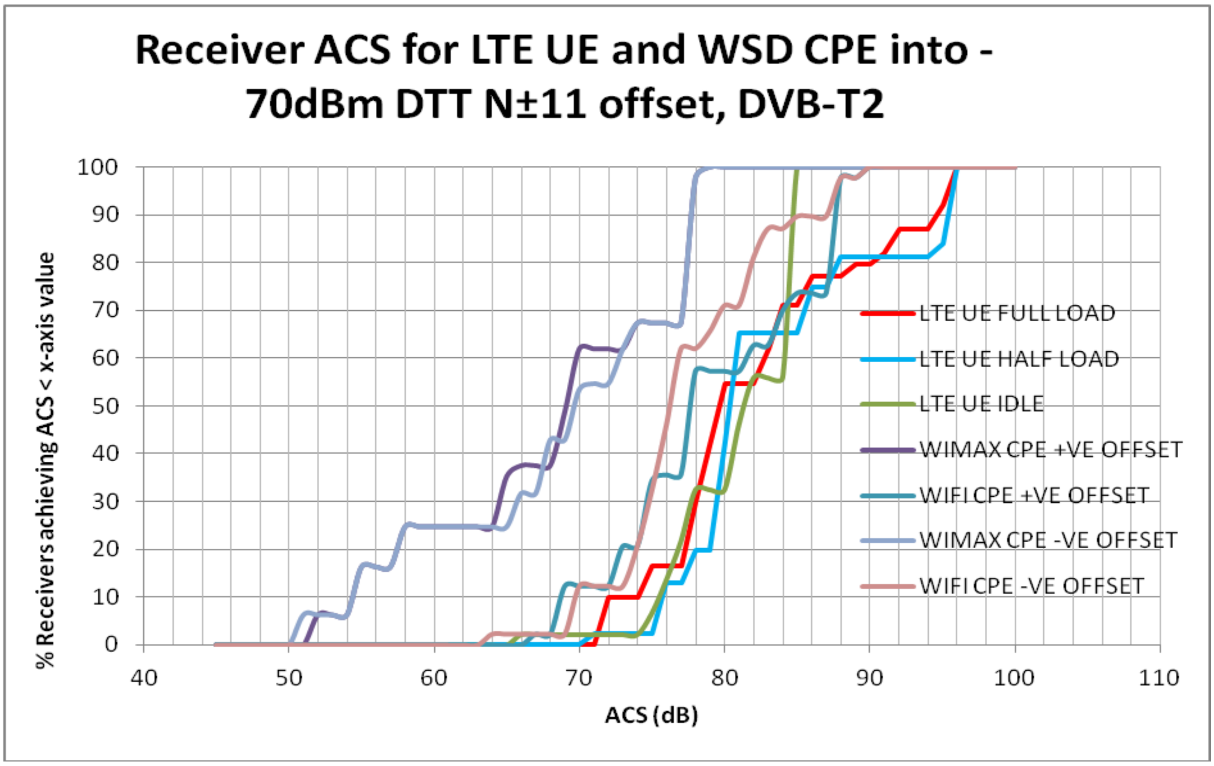

Figure 52 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±11

ACS graphs for DTT to interferer signal offsets of N±1, 2, 3, 4, 9, 11 at DTT levels of -70dBm, -60dBm, -50dBm, -40dBm and -30dBm (-30dBm only applies to the Weightless signal) can be seen in Appendix B.

10. Conclusions

The testing overall produced a wide range of results with the ACS graphs highlighting that for some of the more time discontinuous signals the resilience from one receiver to the next can be quite varied. Below are the key points found during the measurement programme:

- The protection ratios with and without a pre-amplifier in use were comparable when the DTT to interferer offset was low and the DTT level was also low.
- For signals approaching constant power levels such as LTE UE full load, as the DTT level increases or the frequency separation between the DTT and interferer increases pre-amplification reduces the ACS and worsens the protection ratio by approximately the gain value of the amplifier.
- For interfering signals with more time discontinuous characteristics such as the WiMAX signal, the impact on ACS and protection ratios is less pronounced due to pre-amplification.
- Some receivers require a higher protection ratio for negative offsets as oppose to a positive offset between the interferer and DTT signal.
- The difference in protection ratios between DVB-T1 and DVB-T2 modes varied between receivers. Overall the DVB-T2 mode required a better C/N ratio at the furthest offsets in order to demodulate the signal.
- The average protection ratio using the WiMAX CPE 50kbps signal for all 50 receivers in the first adjacent channel was -34dB at -70dBm DTT level. For Weightless this was -40dB and for WiFi it was -44dB.
- The range of results for WiMAX was greater than for Weightless and WiFi with a spread of 22dB between the best and worst performing receivers. For Weightless the range was 16dB and for WiFi it was 19dB.
- The worst protection ratio measured for the WSD interferers was -19dB for the first adjacent channel at -70dBm DTT using the WiMAX CPE 50kbps signal. The best using the same signal was -41dB. This highlights the variation in performance observed across the test receiver range.
- The average protection ratio using the LTE UE idle signal for all 50 receivers in the first adjacent channel is -38dB at -70dBm DTT level. For LTE UE half load this was -44dB and for LTE UE full load this was -46dB.
- The range of results was greatest for LTE UE idle mode with a difference between the best and worst performing receivers of 30dB. For LTE UE half load the range was 22dB and for LTE UE full load the range was 18dB.
- The worst protection ratio measured for the LTE UE interferers was -20dB for the first adjacent channel at -70dBm DTT using the LTE UE idle mode signal. The best protection ratio using the same signal was -50dB.

11. Glossary of terms

- **ACS:** Adjacent channel selectivity is a measure of the receiver ability to detect a wanted signal while rejecting a strong unwanted signal in an adjacent channel.
- **CPE:** Customer premise equipment which is commonly used to describe end user equipment for white space devices.
- **DTT:** Digital terrestrial television which is made up of Freeview and Freeview HD.
- **DVB operating mode:** DVB-T is European-based consortium standard for the broadcast transmission of digital terrestrial television. It uses MPEG-2 video compression and coded orthogonal frequency division multiplexing to send multiple digital streams on multiple carrier frequencies. DVB-T2 is the extension of DVB-T and uses improved error correction and video compression (MPEG-4) to provide enhanced data rates suitable for the broadcast of high definition TV.
- **Full load LTE traffic mode:** The level of LTE base station usage represented by each of the test recordings is the traffic mode. Full load is where the maximum amount of resource blocks for user traffic has been allocated and simulates 100% base station usage.
- **Half load LTE traffic mode:** The level of LTE base station usage represented by each of the test recordings is the traffic mode. Half load is where the 50% of the available resource blocks for user traffic has been allocated.
- **Idle mode LTE traffic mode:** The level of LTE base station usage represented by each of the test recordings is the traffic mode. Idle mode is where there is no user traffic on the base station and the test recording is made up of signalling and reference pulses only.
- **iDTV:** Integrated digital TV which is a television set with an in built DTT receiver.
- **Protection ratio or C/I:** The minimum ratio of wanted carrier signal (C) to the maximum interfering signal (I) that a DTT receiver can tolerate whilst still maintaining an acceptable level of picture quality.
- **PVR:** Personal video recorders which contain DTT receivers as well as capabilities for recording digital television on to in built hard drives. They often include additional features such as the capability to pause live TV, integrated programme guides and series recording.
- **Receiver chassis:** Chassis models are considered the same if they use:
    1. The same tuner and demodulator
    2. The same SI/PSI middleware software (including active format descriptor (AFD) subtitle selection)
    3. The same MHEG-5 engine
- **STB:** Set top box DTT receiver
- **UE:** User equipment which is the term used in the mobile industry to describe mobile technology end user equipment such as mobile handsets.

Appendix A – Carrier to interference protection ratio graphs

A.1 WSD WiMAX CPE 50kbps

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

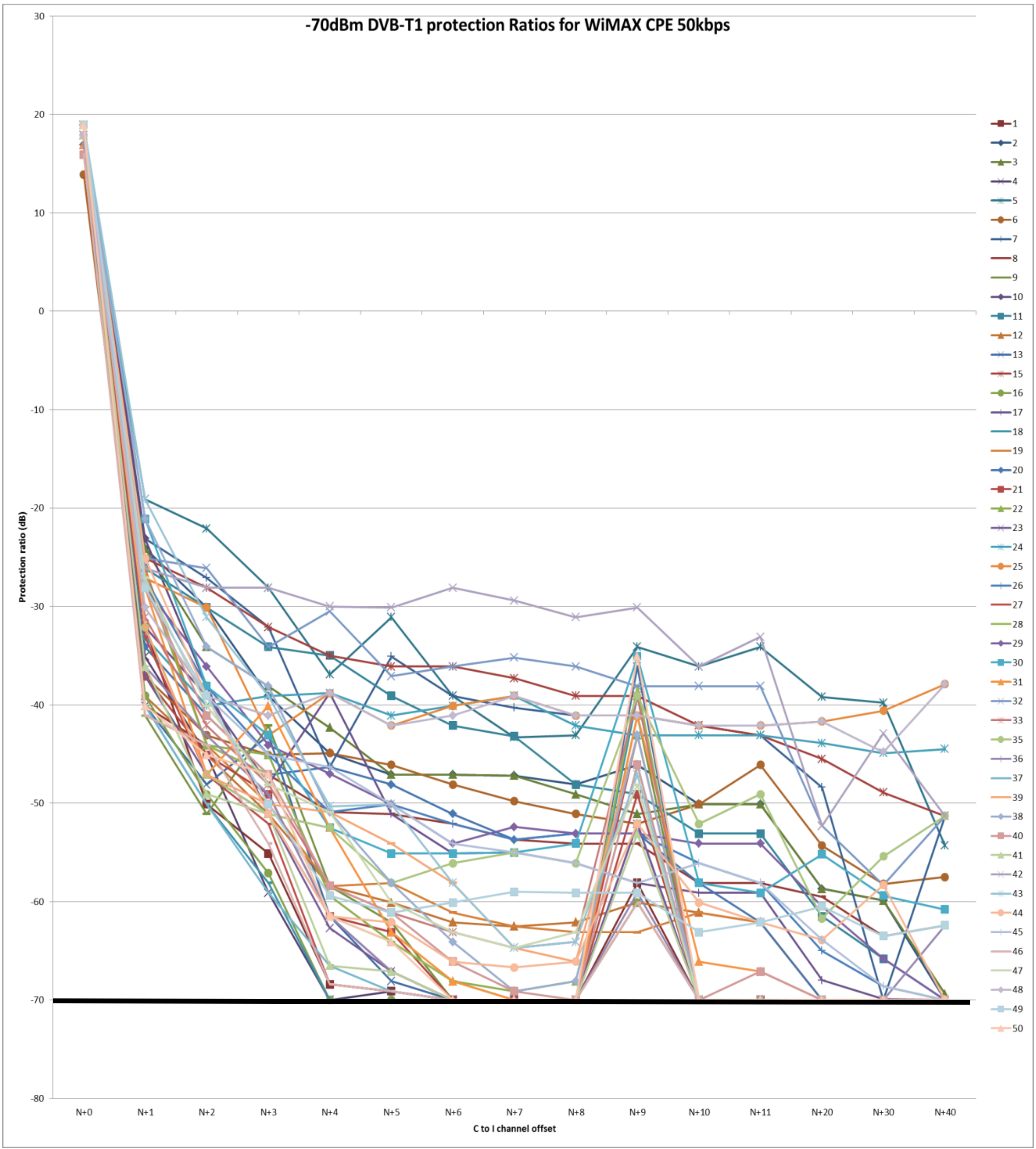

Figure 53 Protection ratio curve for WiMAX CPE 50kbps at-70dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

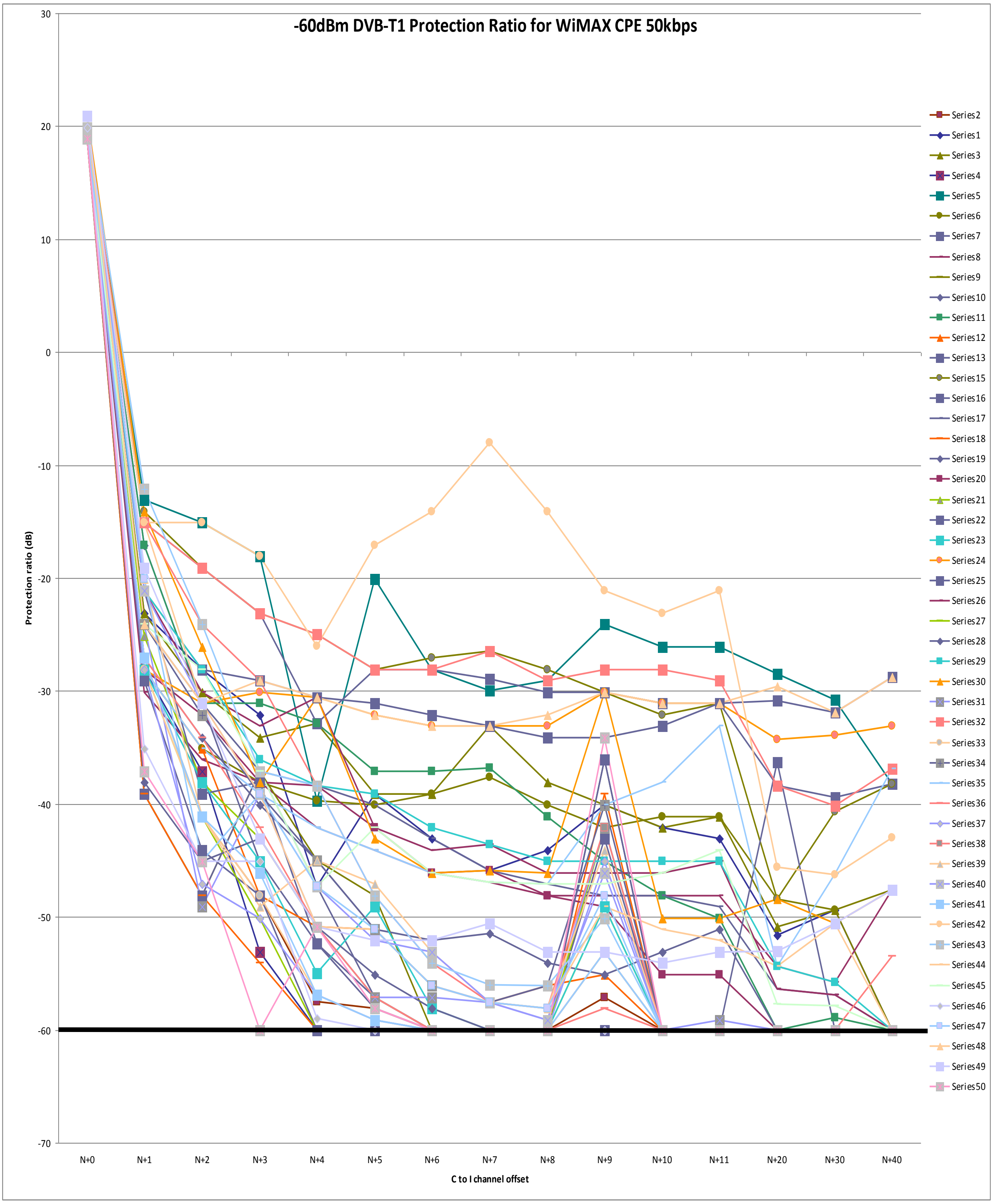

Figure 54 Protection ratio curve for WiMAX CPE 50kbps at-60dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

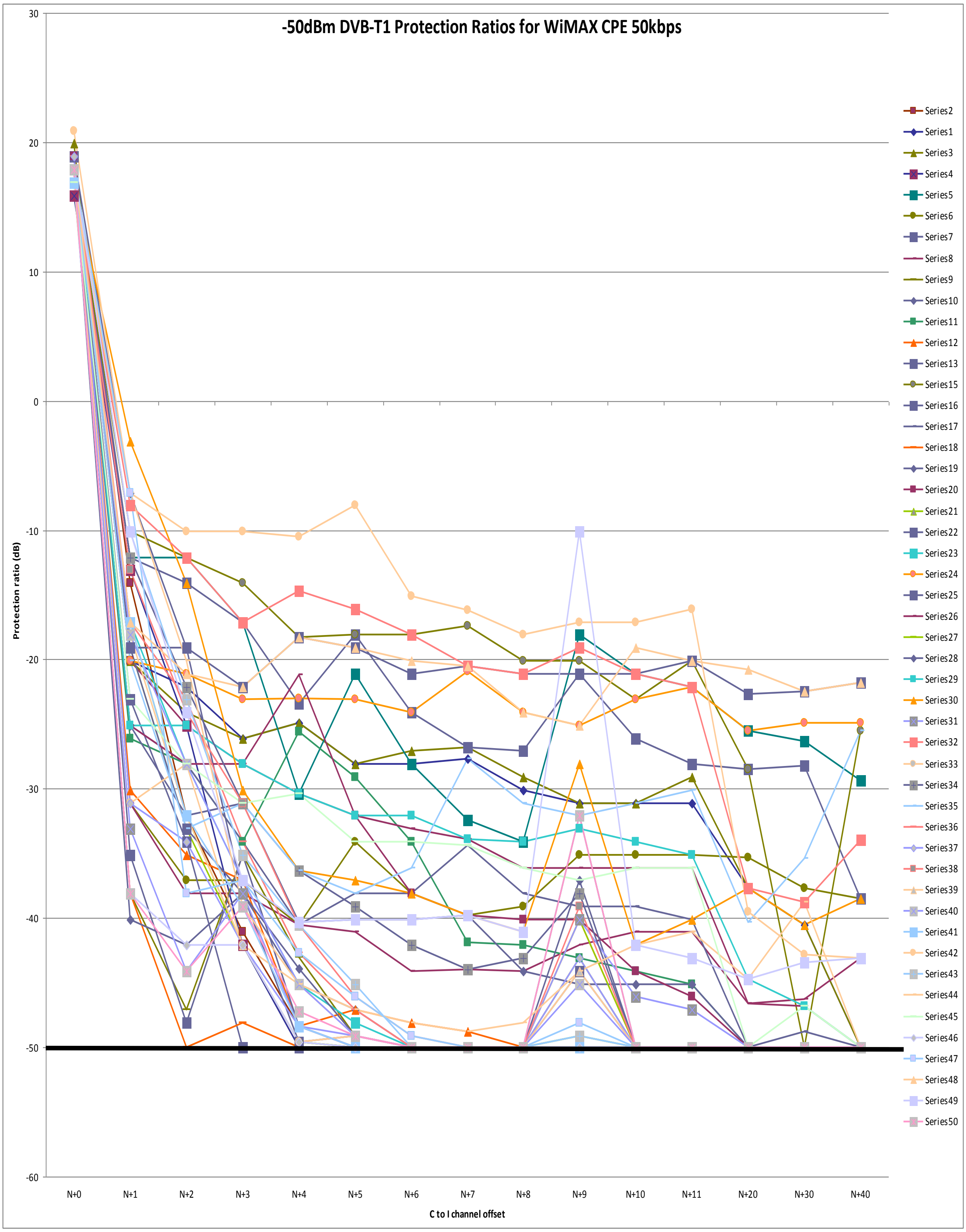

Figure 55 Protection ratio curve for WiMAX CPE 50kbps at-50dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

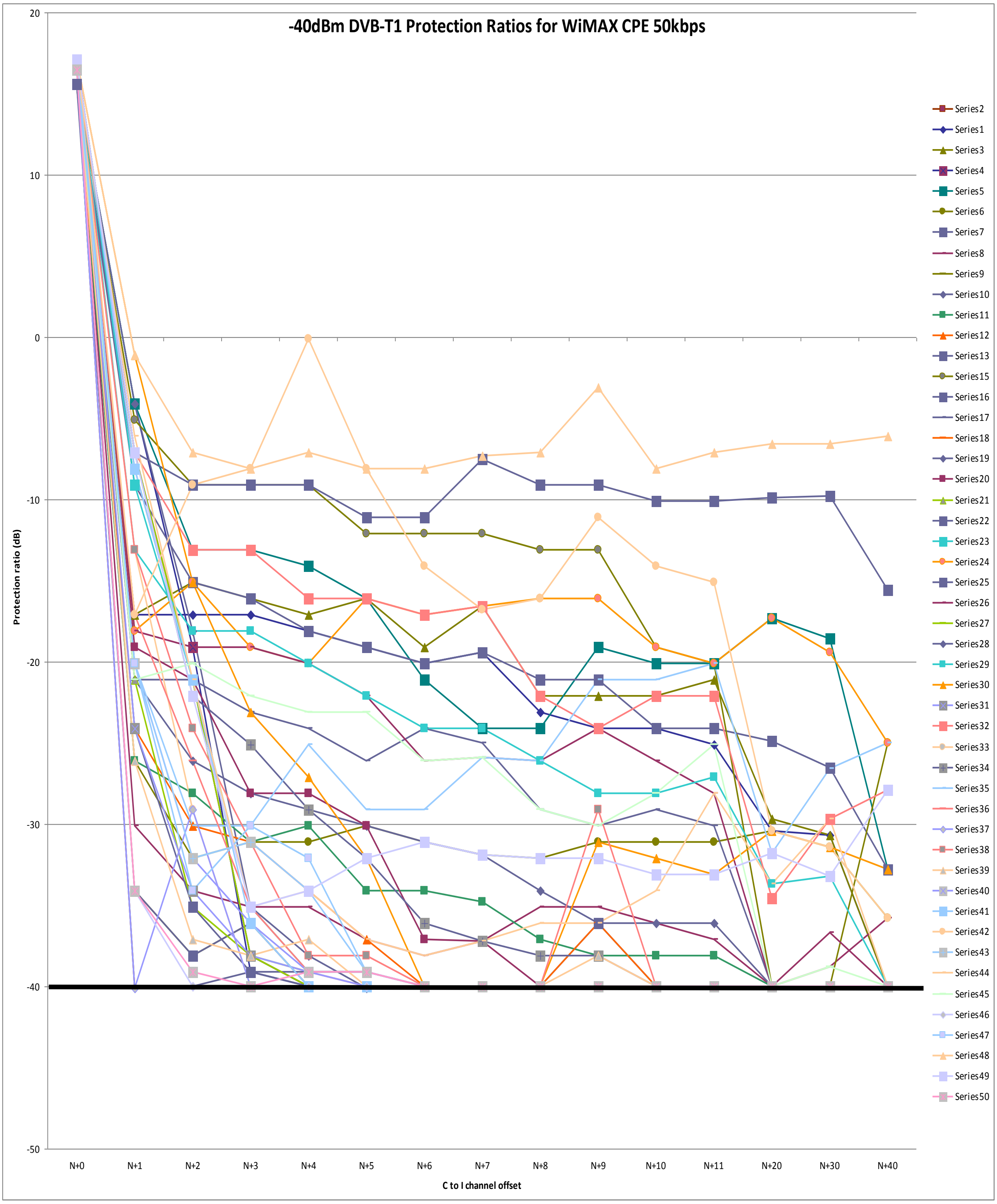

Figure 56 Protection ratio curve for WiMAX CPE 50kbps at-40dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

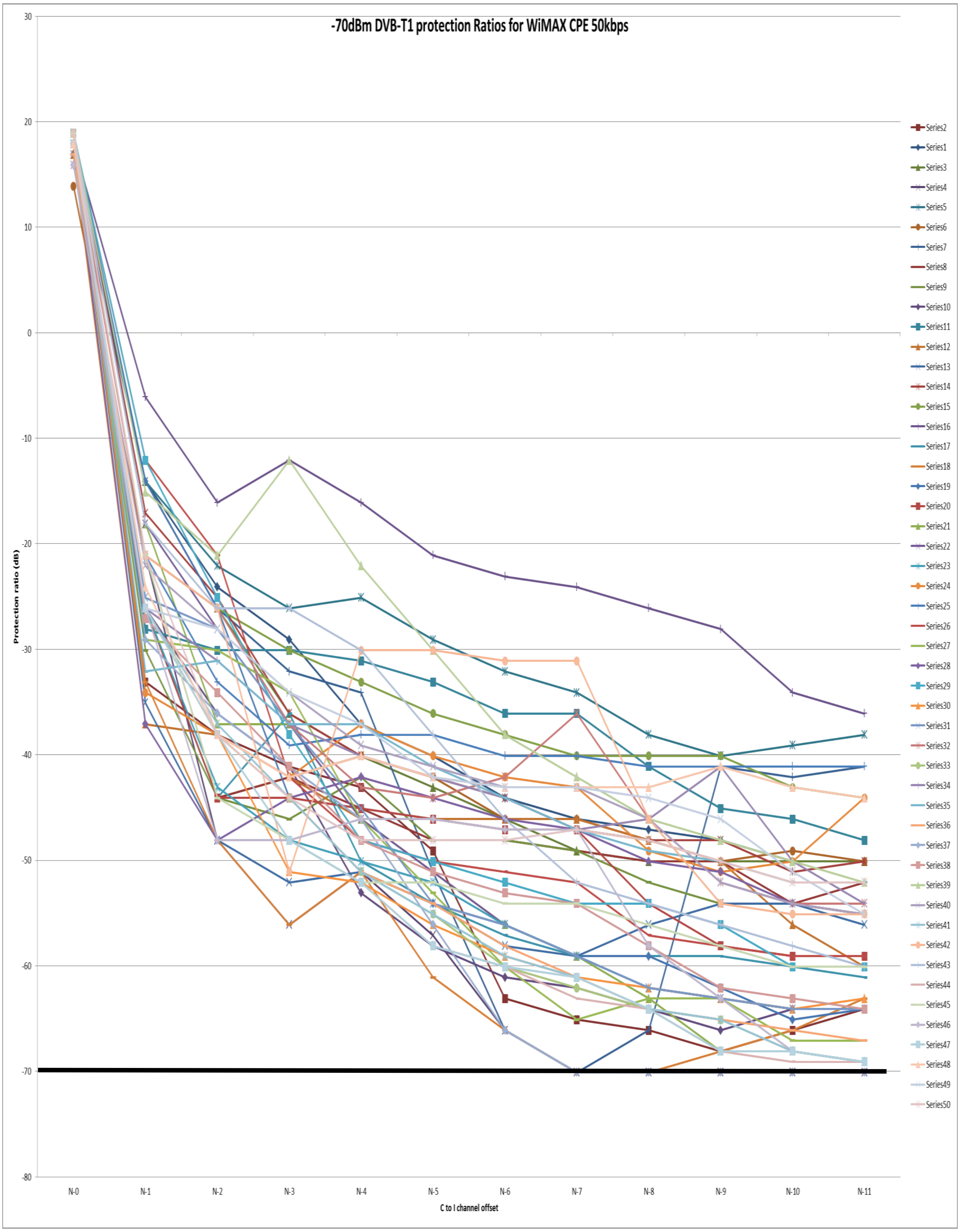

Figure 57 Protection ratio curve for WiMAX CPE 50kbps at-70dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

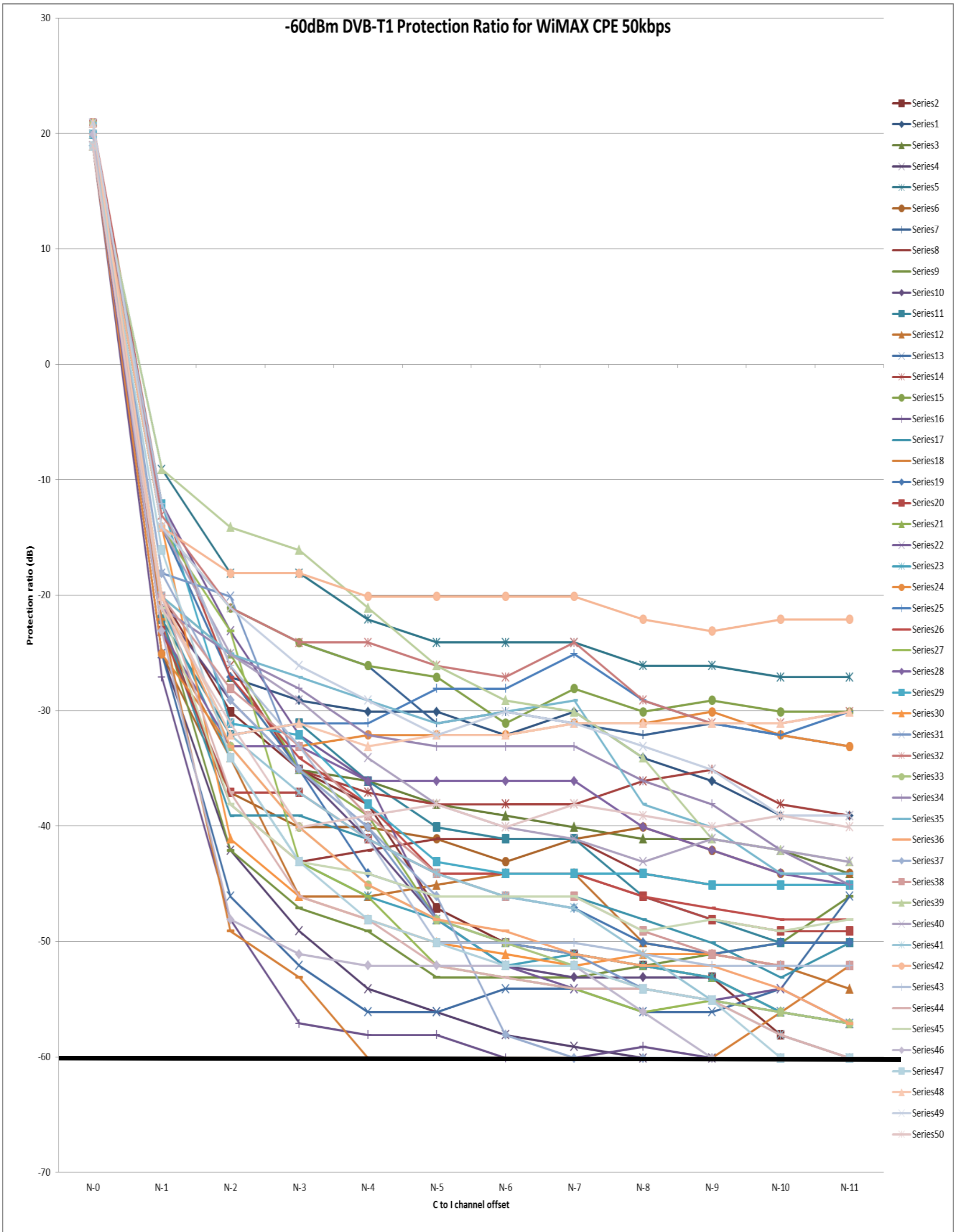

Figure 58 Protection ratio curve for WiMAX CPE 50kbps at-60dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

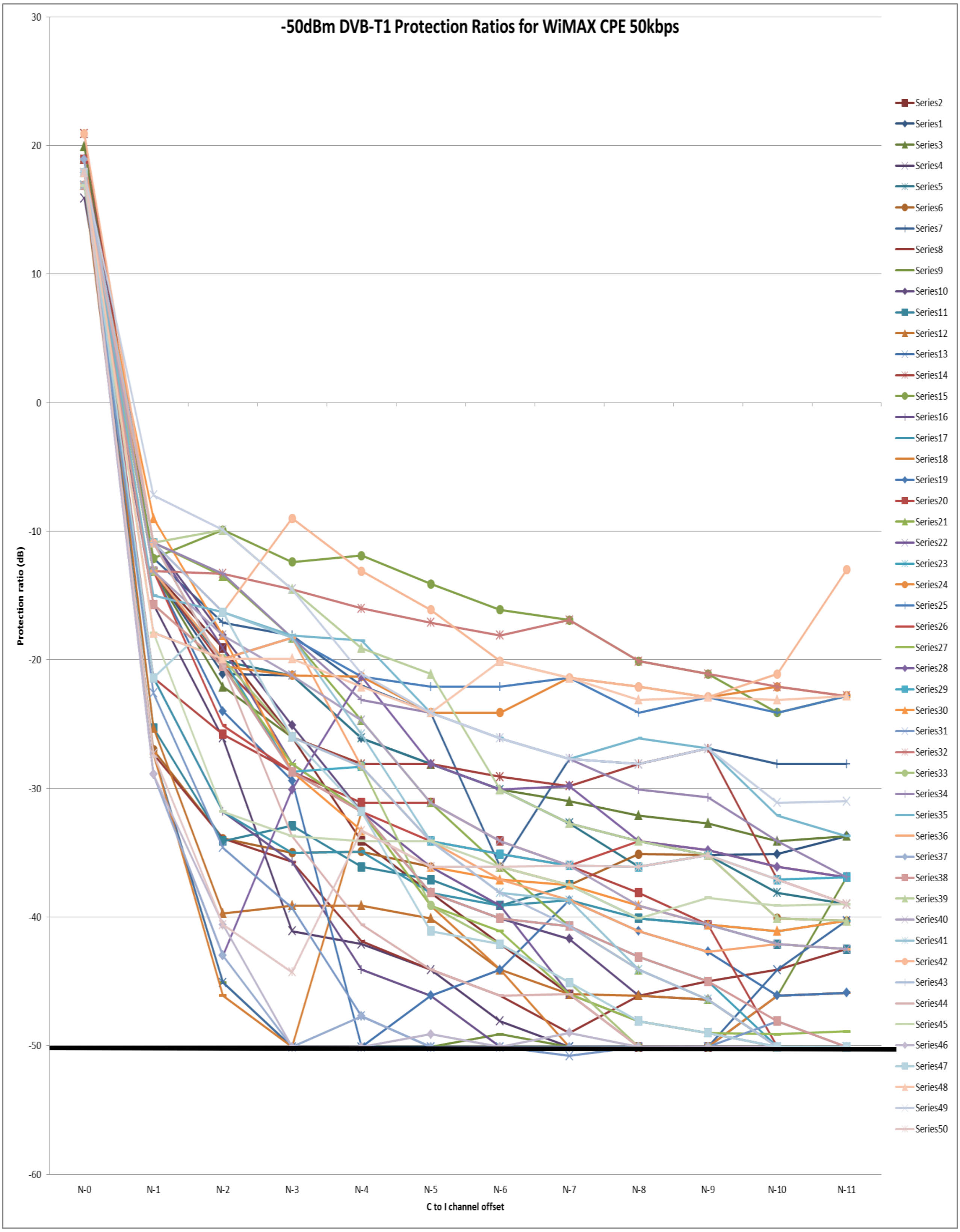

Figure 59 Protection ratio curve for WiMAX CPE 50kbps at-50dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

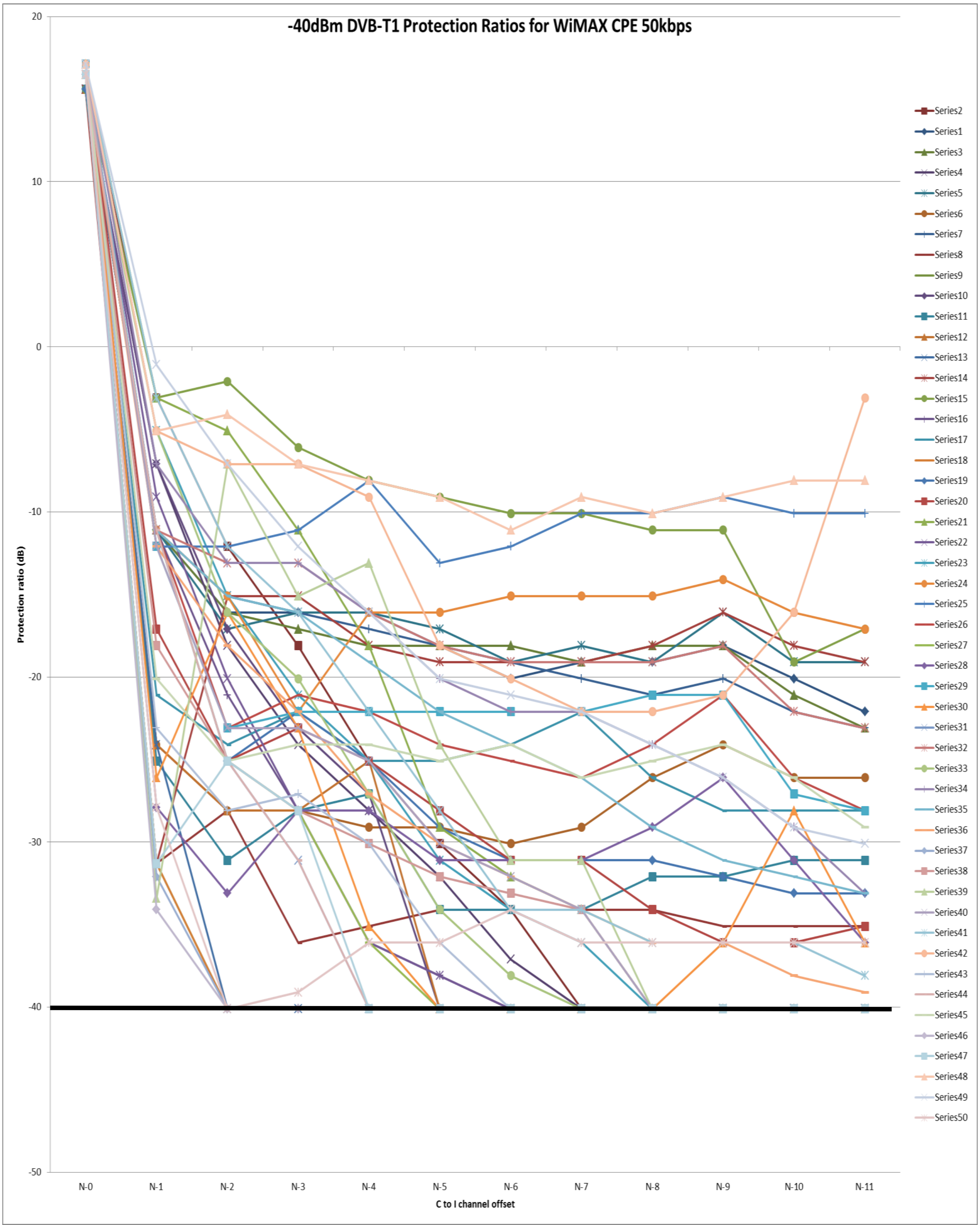

Figure 60 Protection ratio curve for WiMAX CPE 50kbps at-40dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

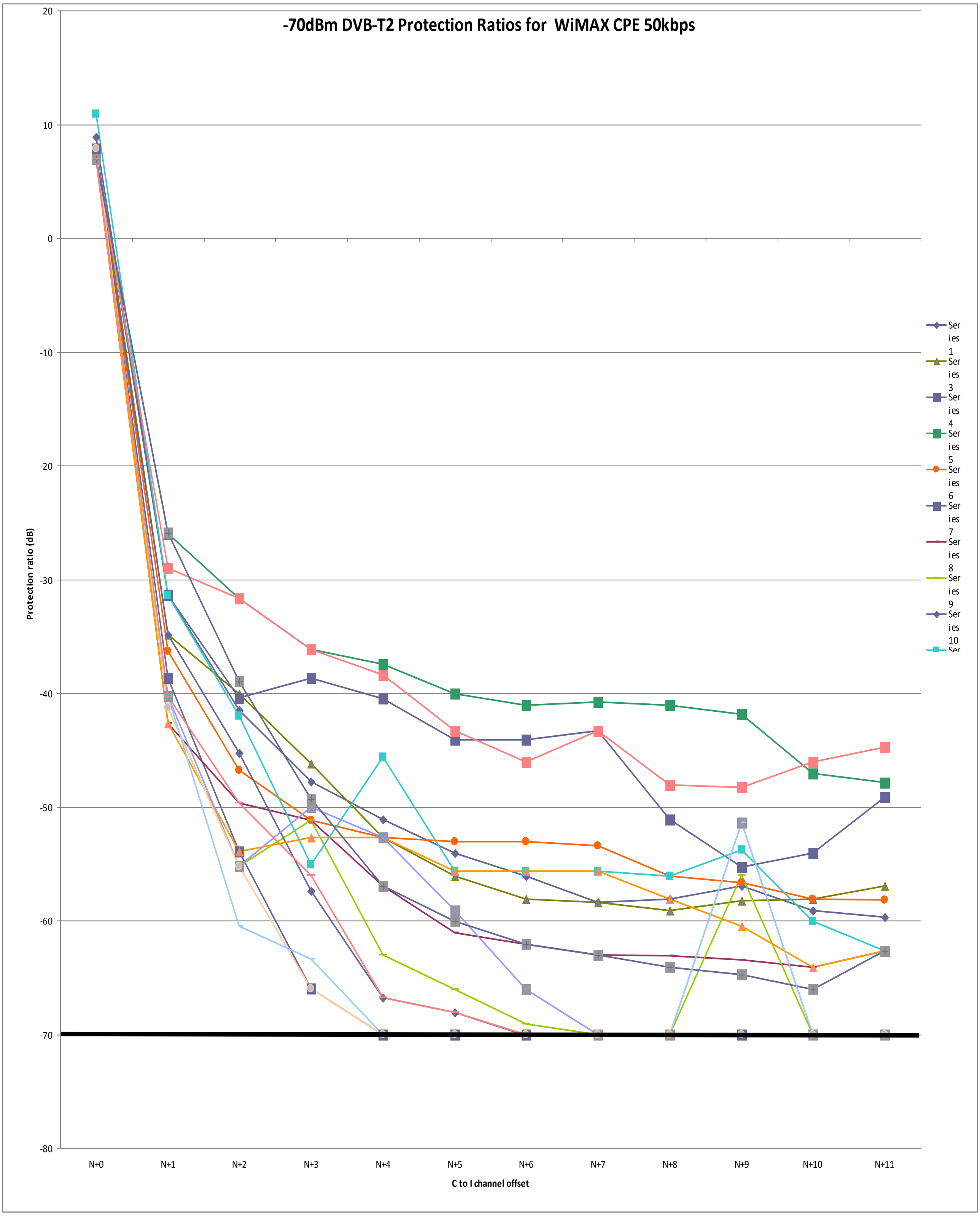

Figure 61 Protection ratio curve for WiMAX CPE 50kbps at-70dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

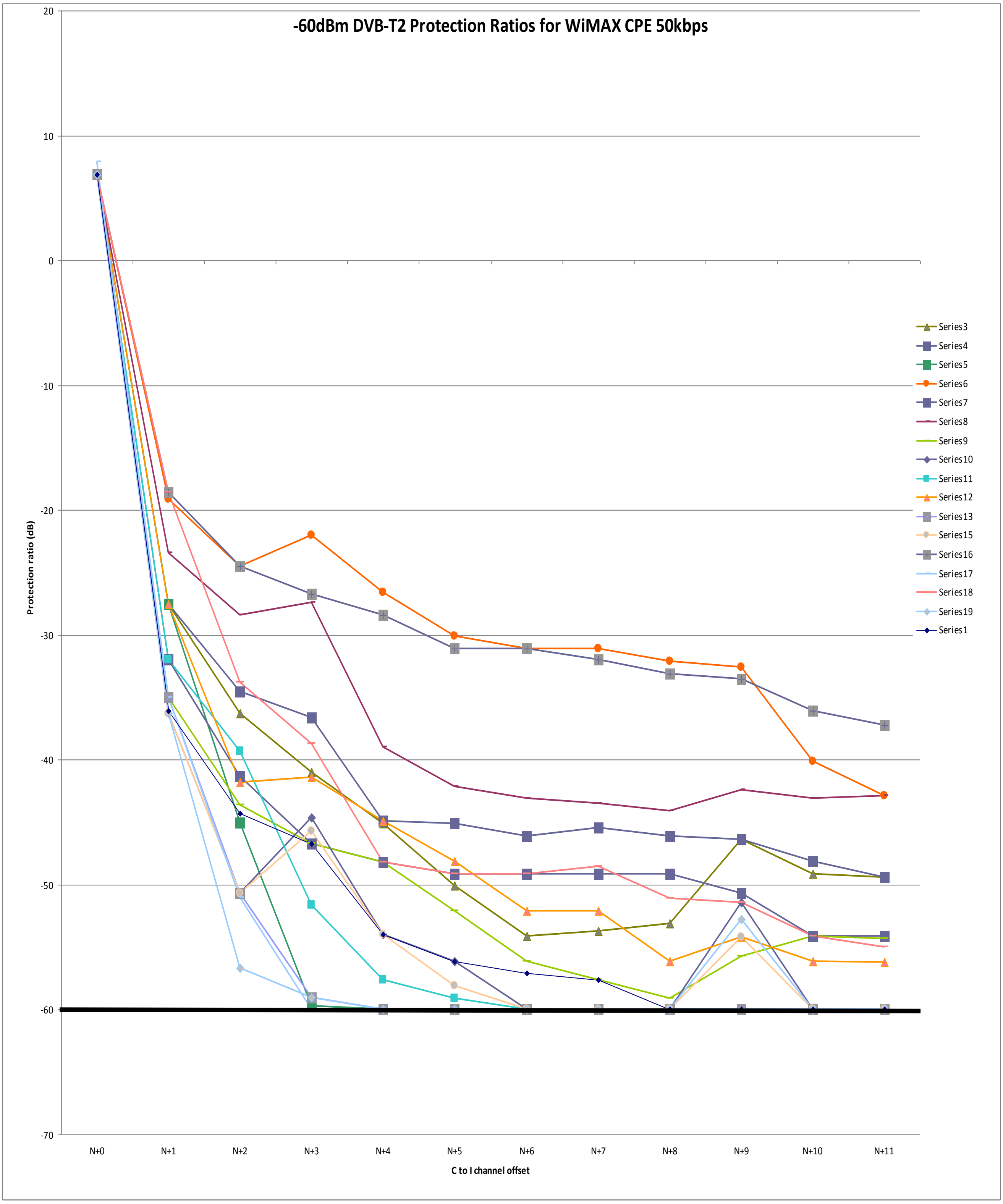

Figure 62 Protection ratio curve for WiMAX CPE 50kbps at-60dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

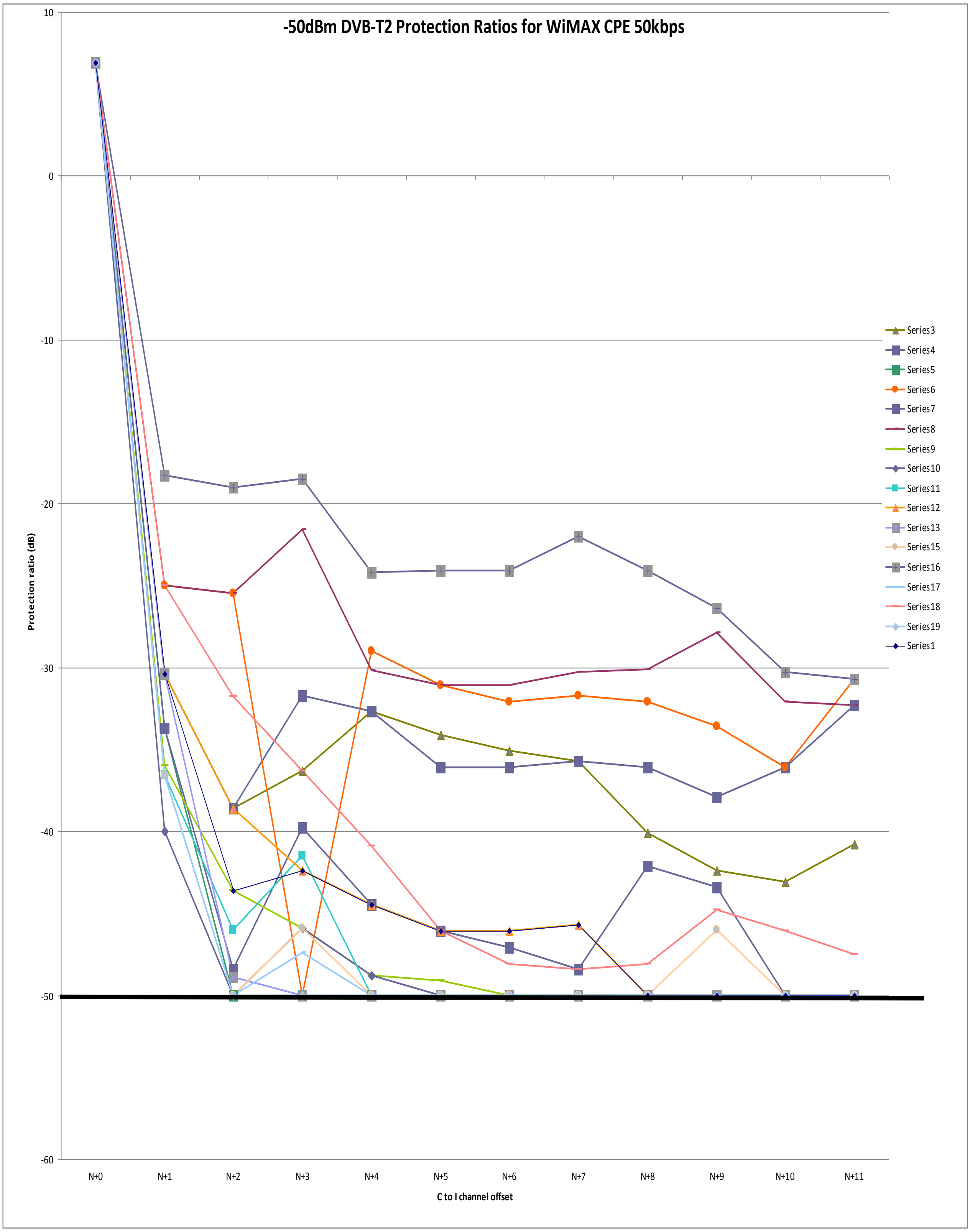

Figure 63 Protection ratio curve for WiMAX CPE 50kbps at-50dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

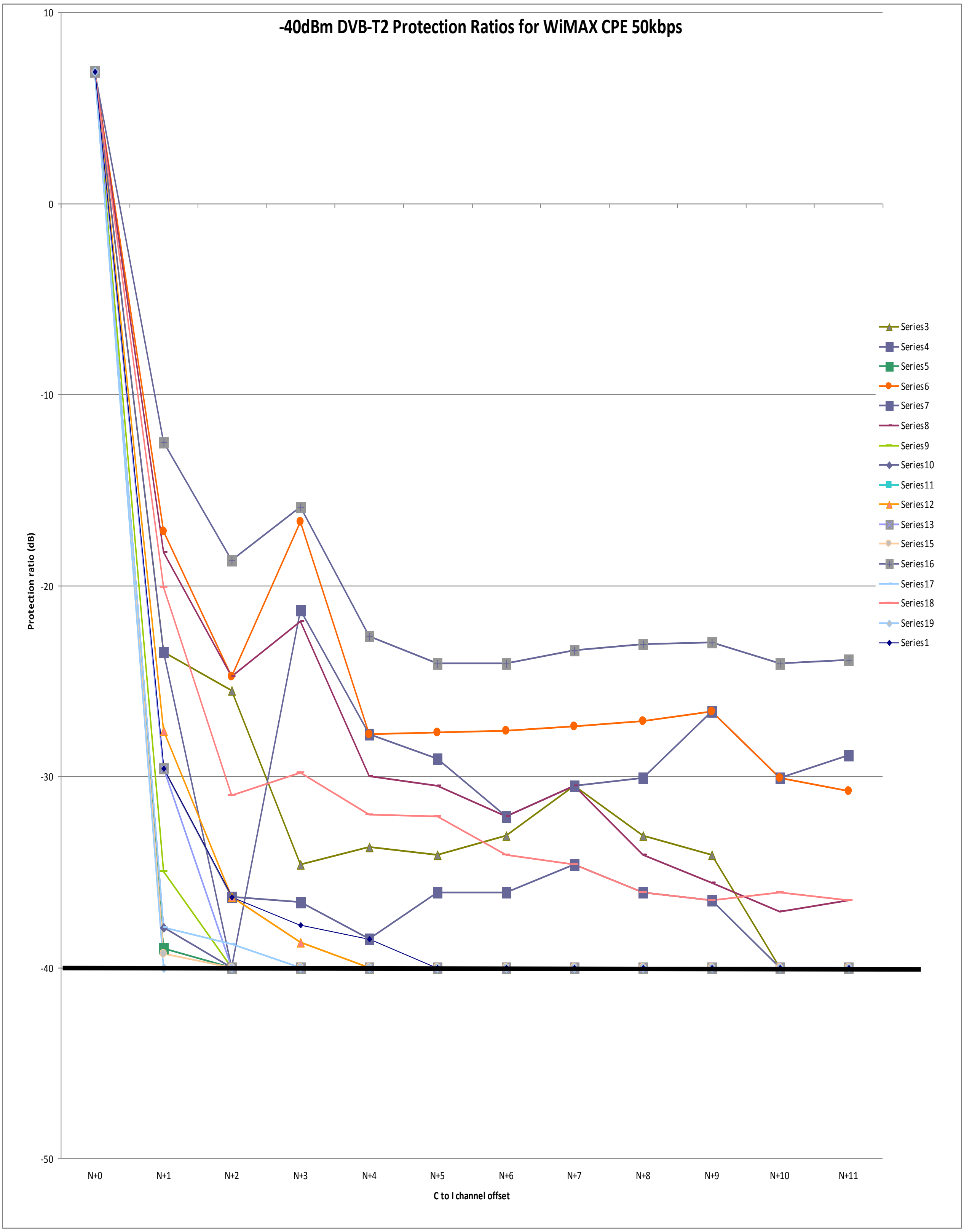

Figure 64 Protection ratio curve for WiMAX CPE 50kbps at-40dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

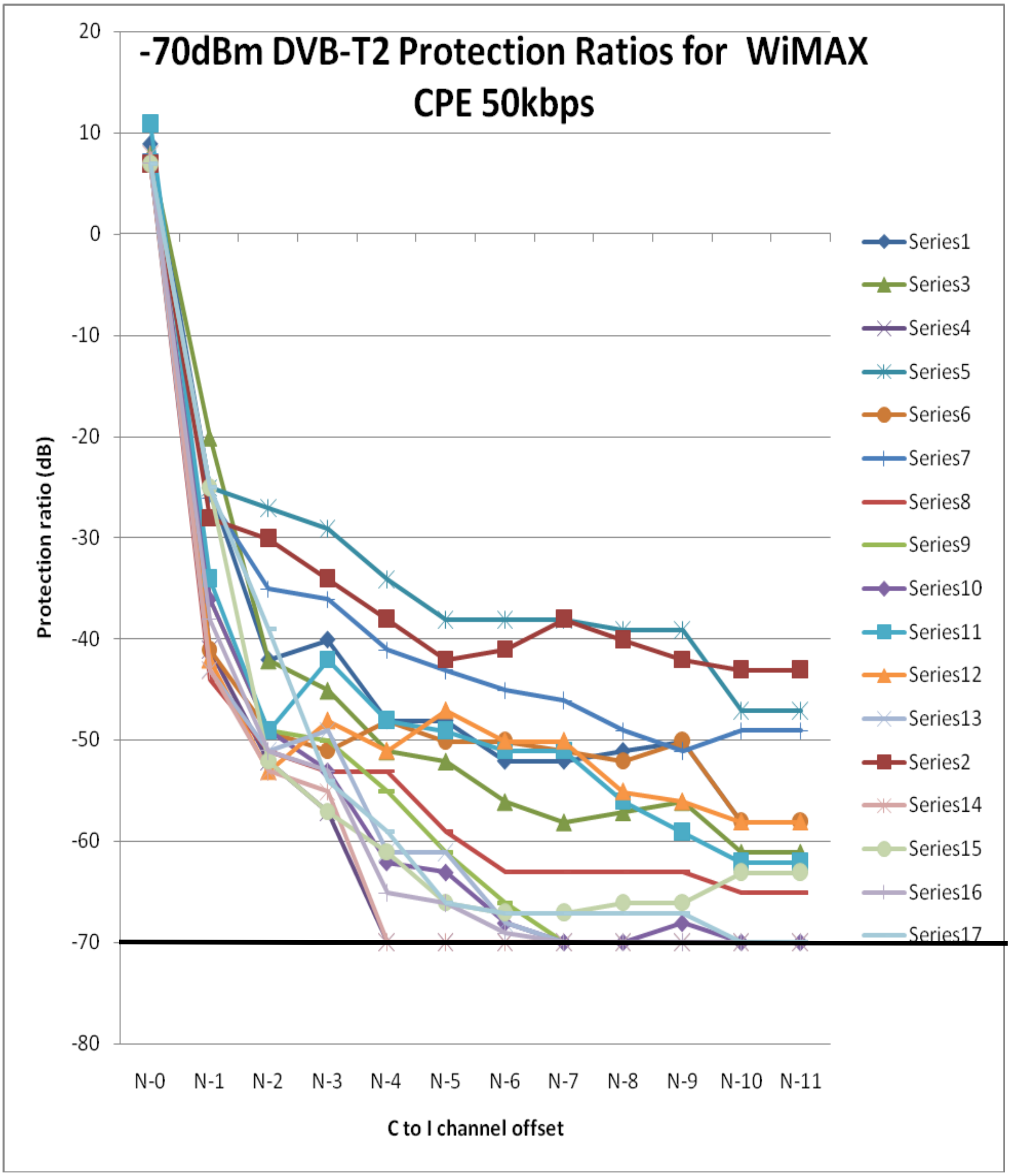

Figure 65 Protection ratio curve for WiMAX CPE 50kbps at-70dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

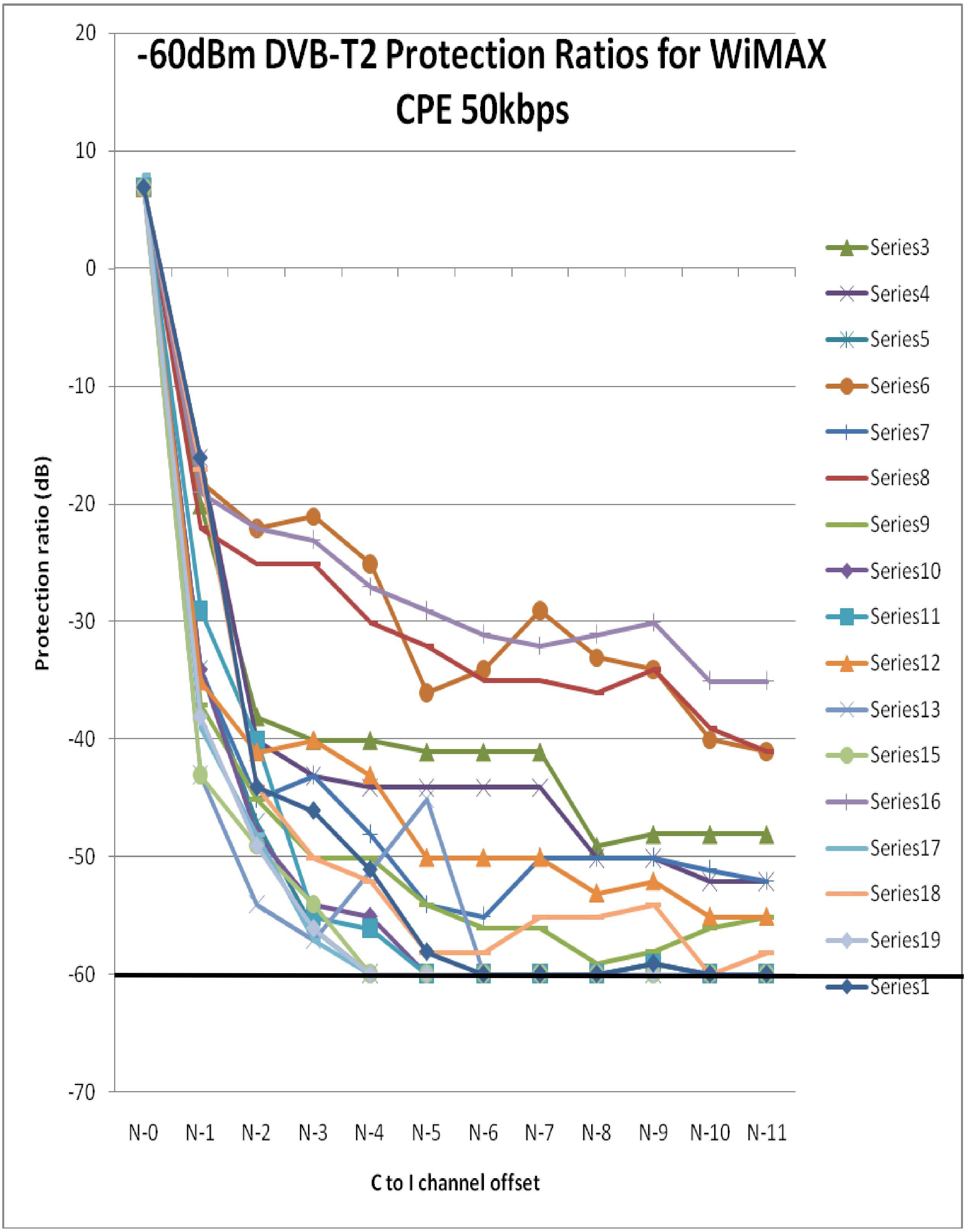

Figure 66 Protection ratio curve for WiMAX CPE 50kbps at-60dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

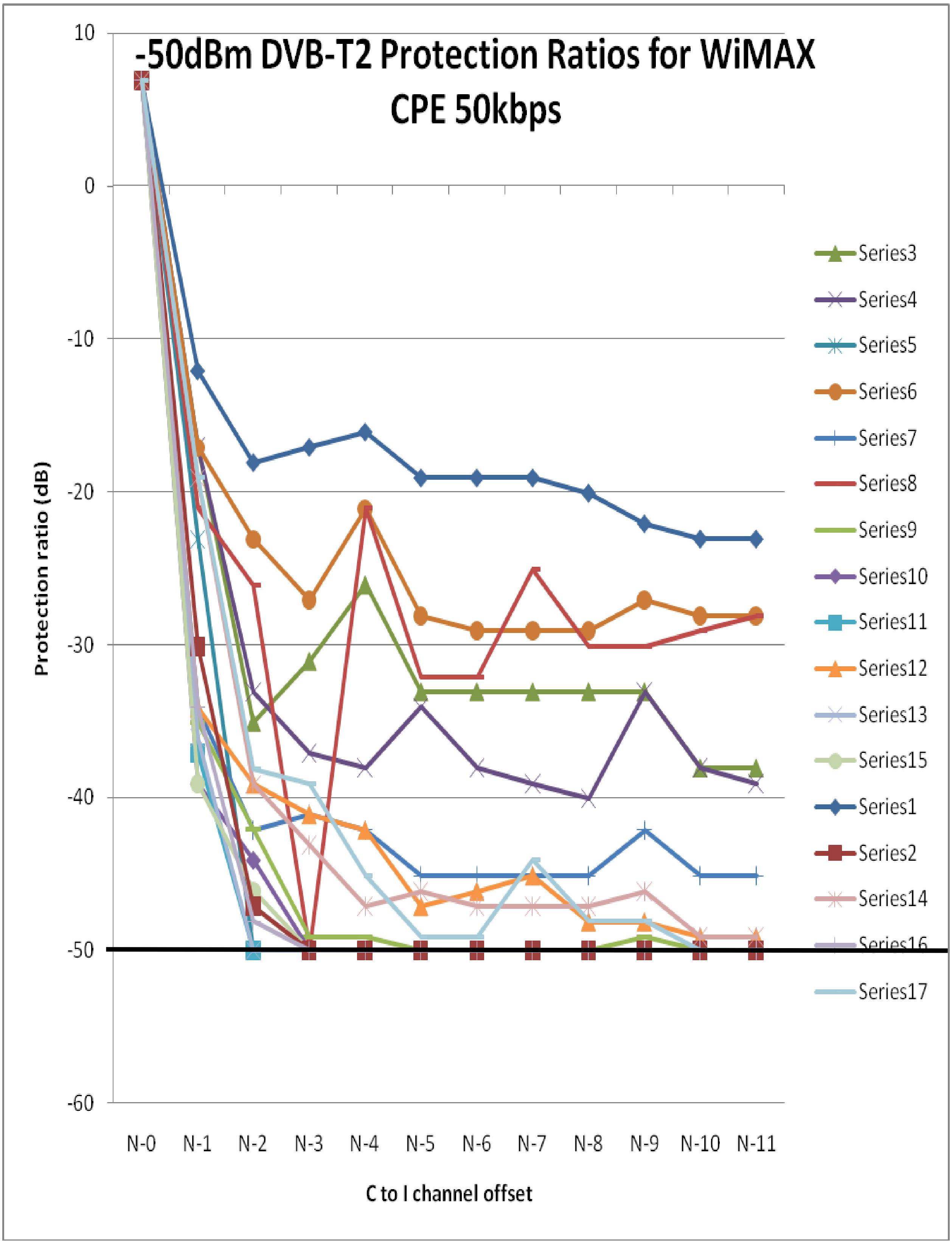

Figure 67 Protection ratio curve for WiMAX CPE 50kbps at-50dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

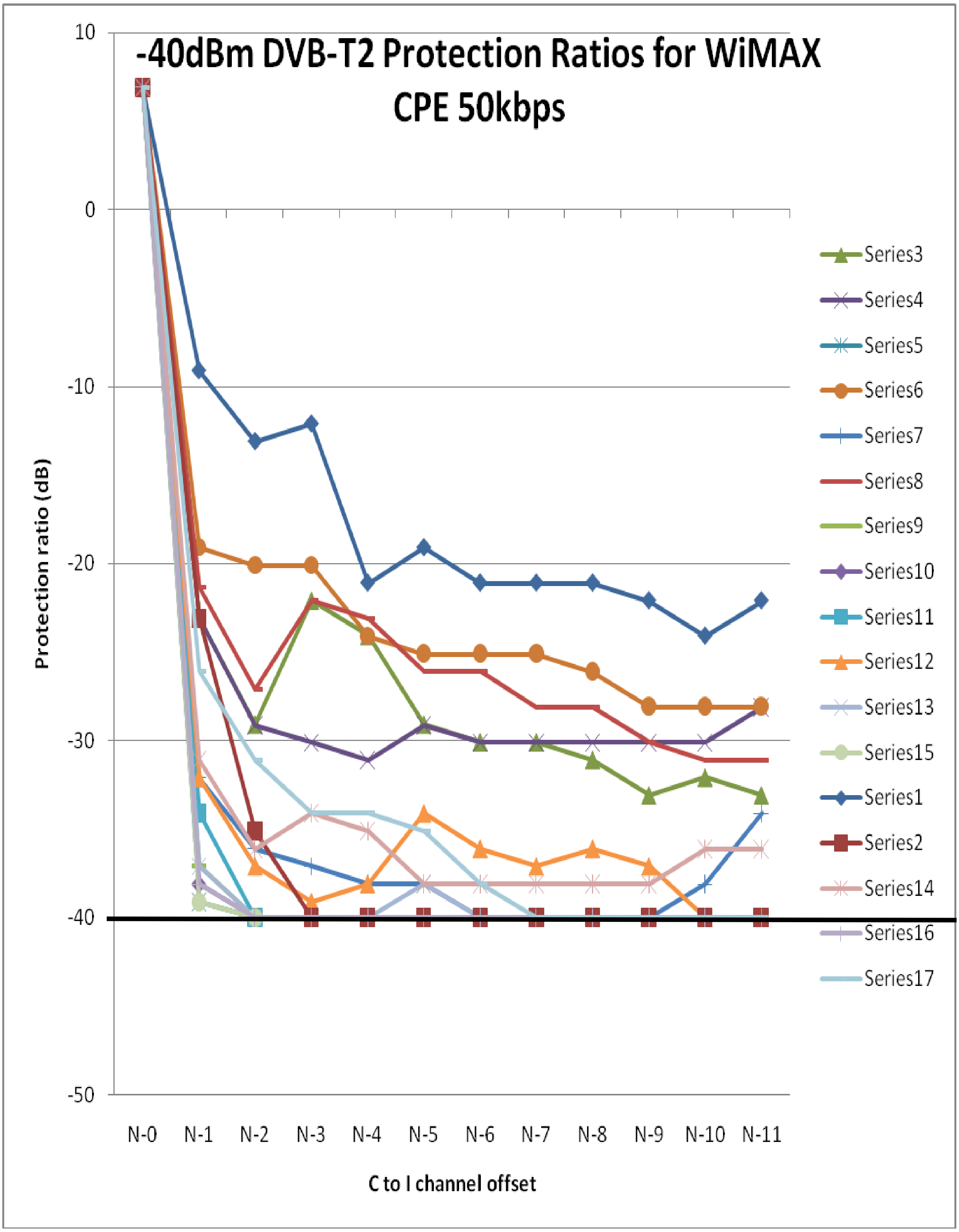

Figure 68 Protection ratio curve for WiMAX CPE 50kbps at-40dBm DVB-T2 DTT at offsets N-1 to N-11

A.2 WSD WiFi CPE 50kbps

The horizontal line at -73dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

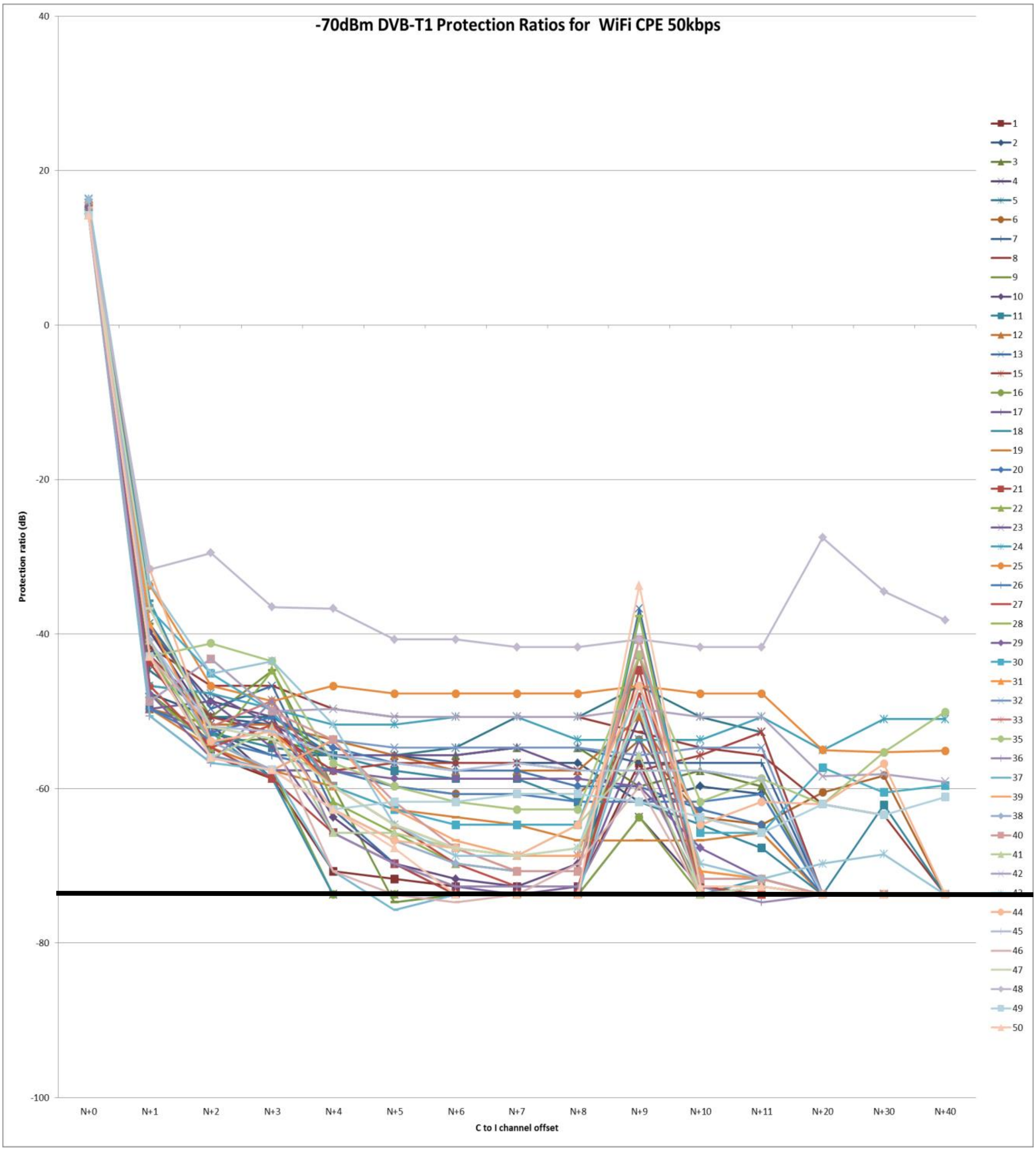

Figure 69 Protection ratio curve for WiFi CPE 50kbps at-70dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -69dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

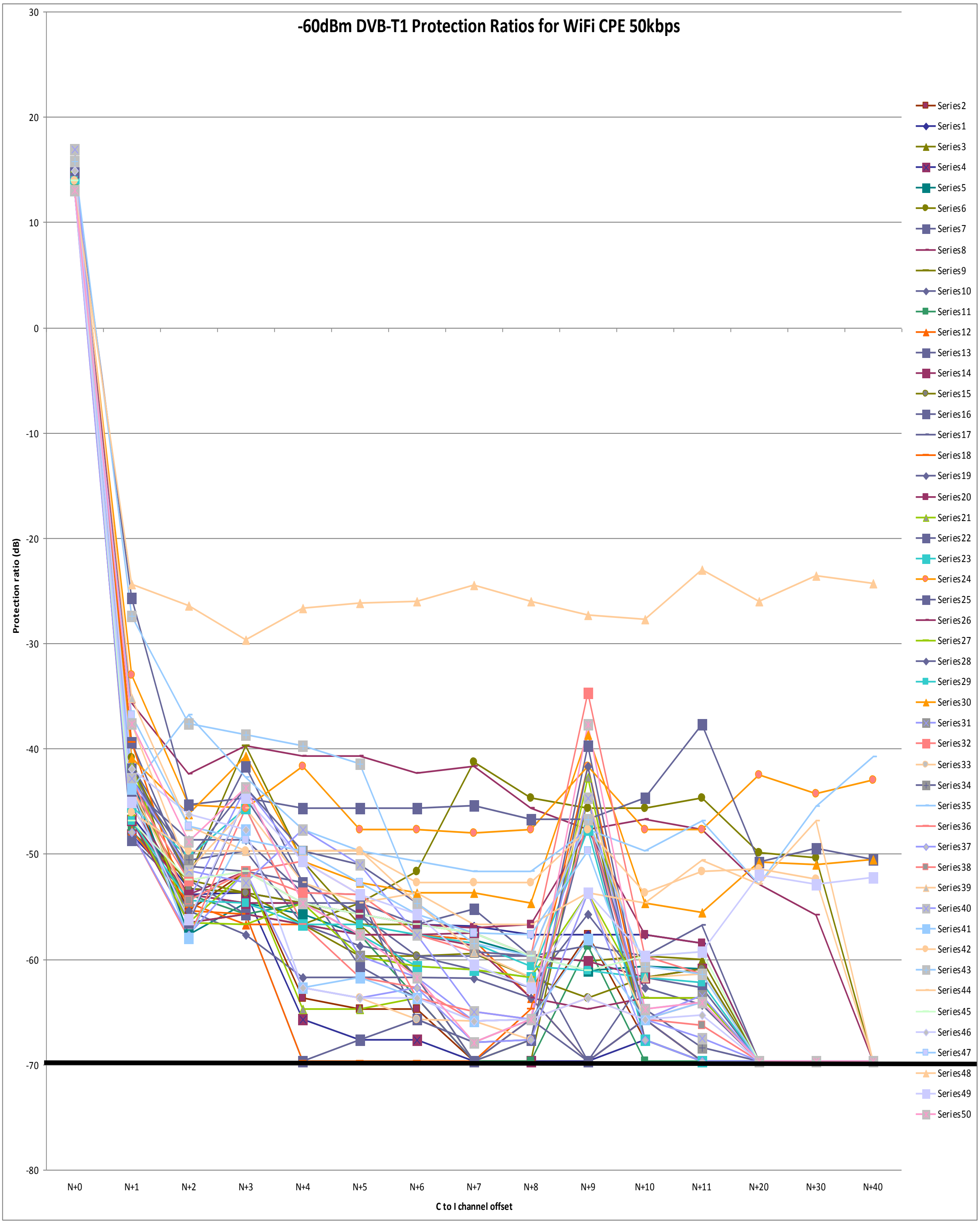

Figure 70 Protection ratio curve for WiFi CPE 50kbps at-60dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

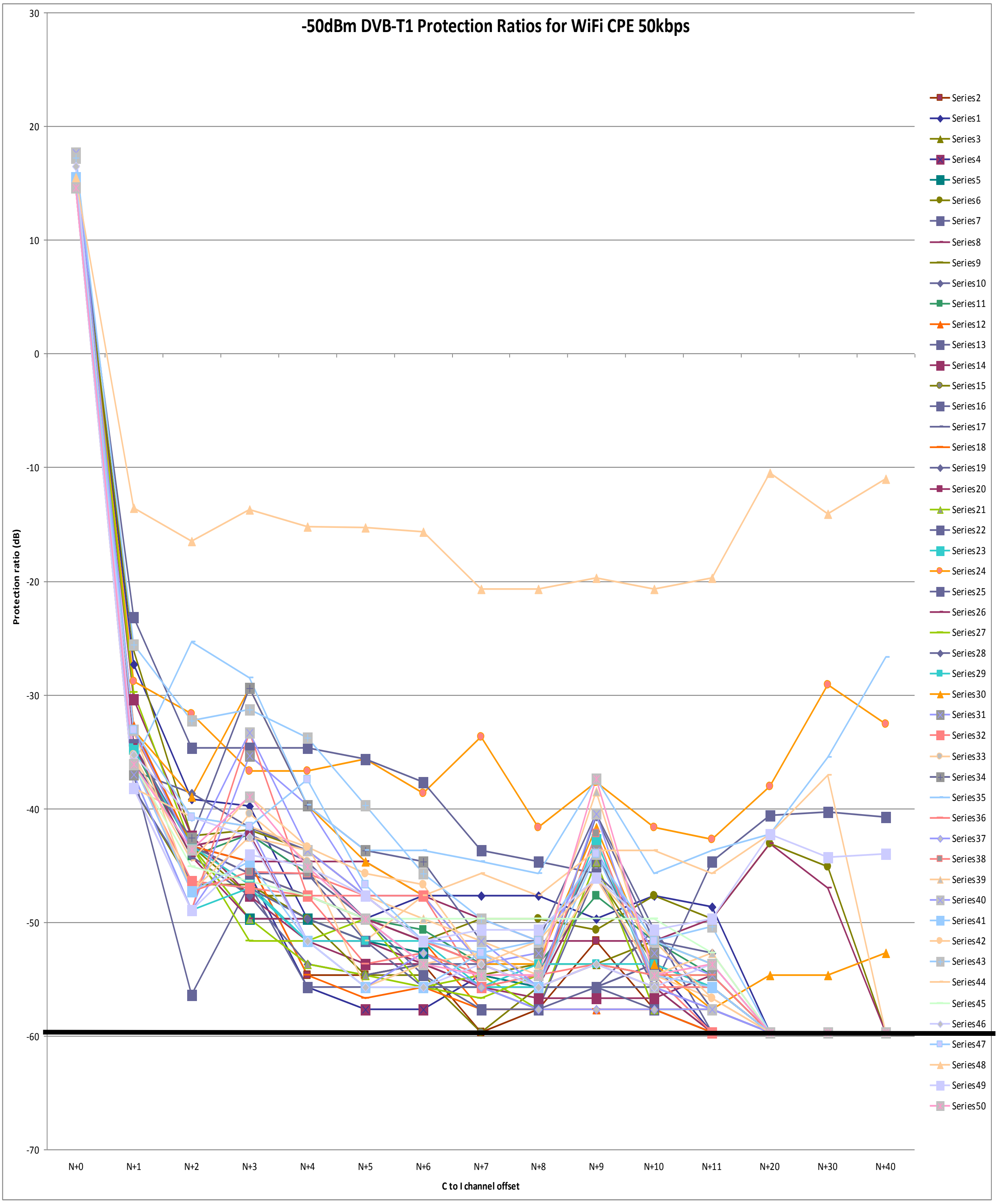

Figure 71 Protection ratio curve for WiFi CPE 50kbps at-50dBm DVB-T1 DTT at offsets N+1 to N+40

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

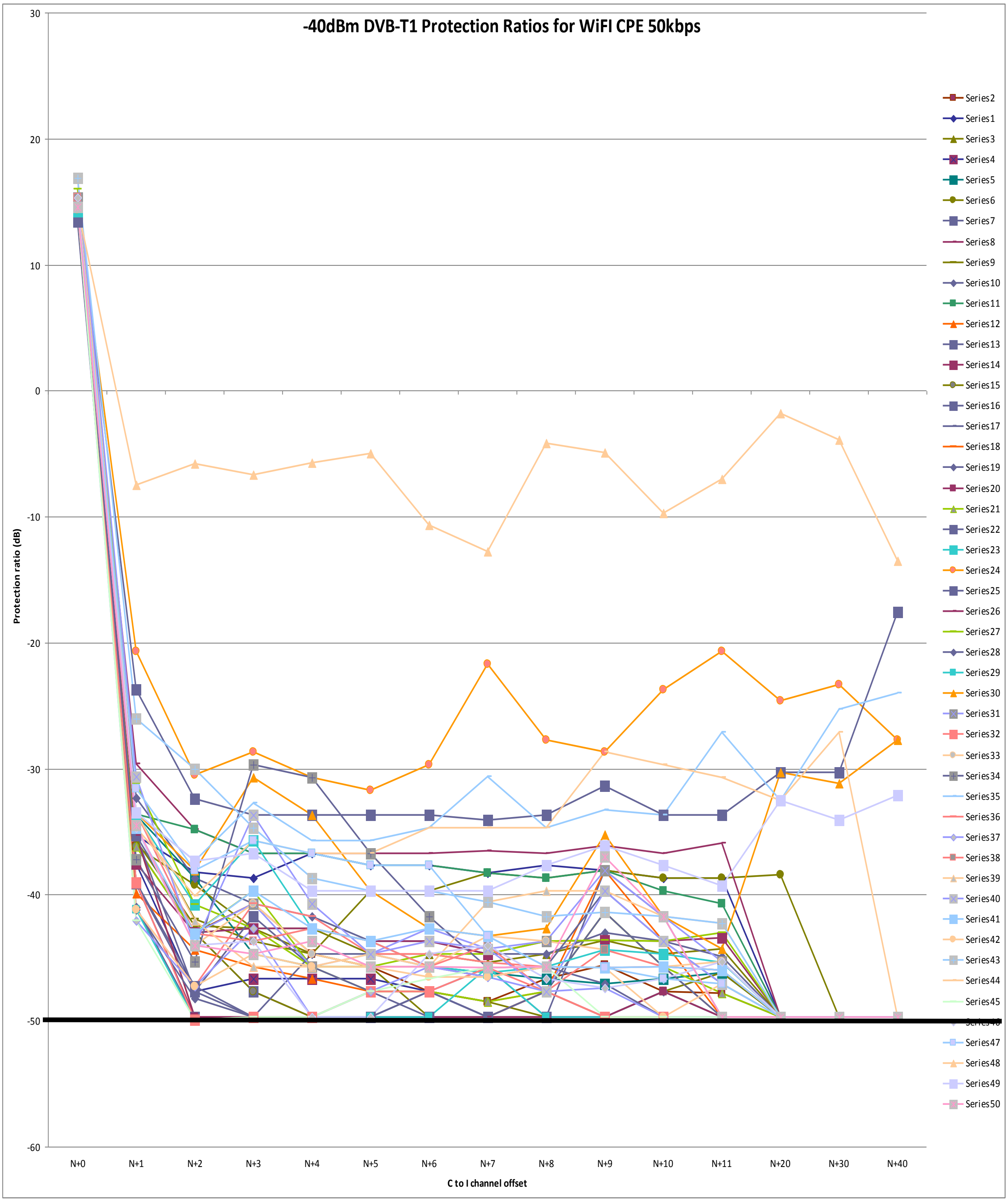

Figure 72 Protection ratio curve for WiFi CPE 50kbps at-40dBm DVB-T1 DTT at offsets N+1 to N+40

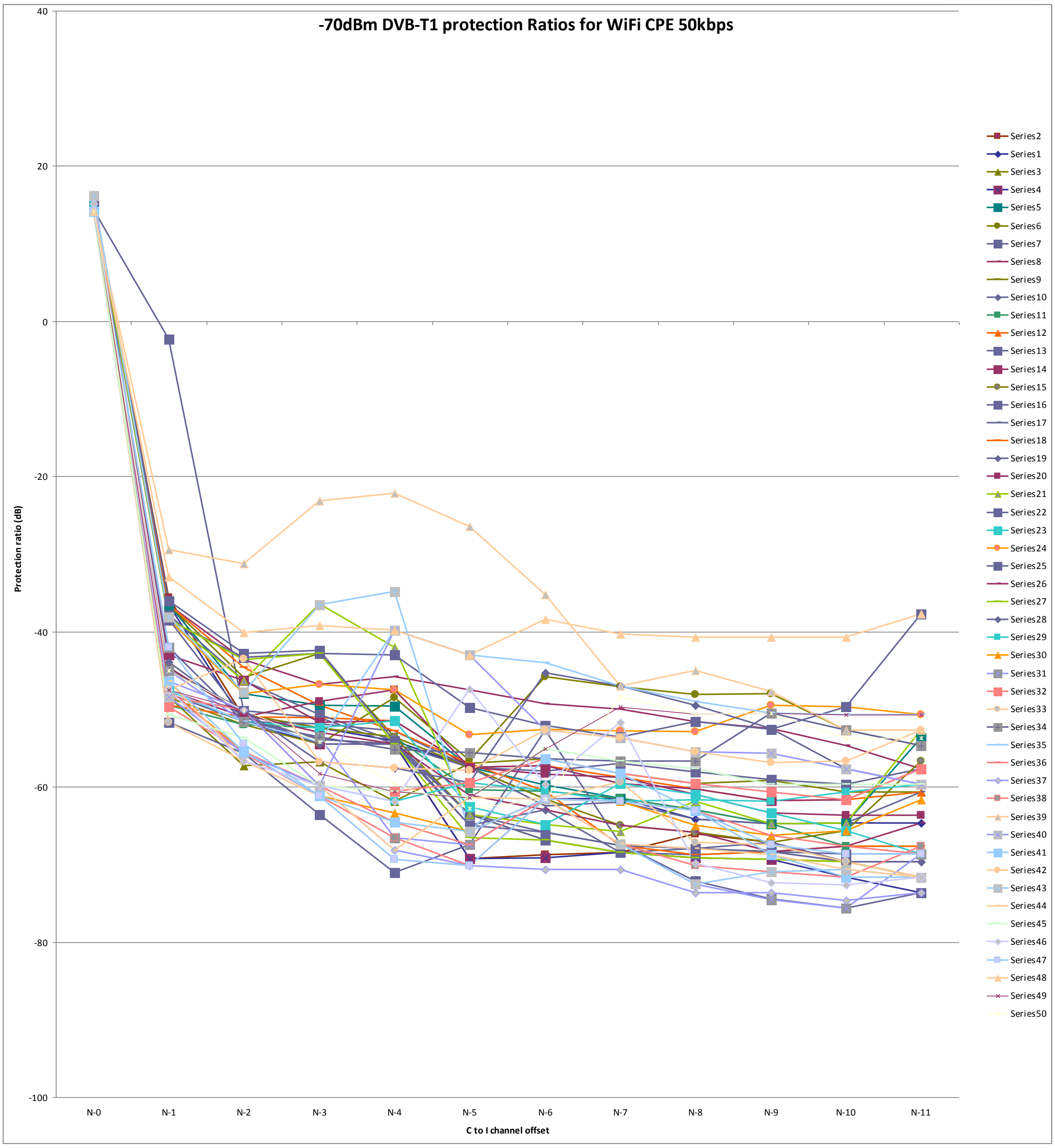

Figure 73 Protection ratio curve for WiFi CPE 50kbps at-70dBm DVB-T1 DTT at offsets N-1 to N-11

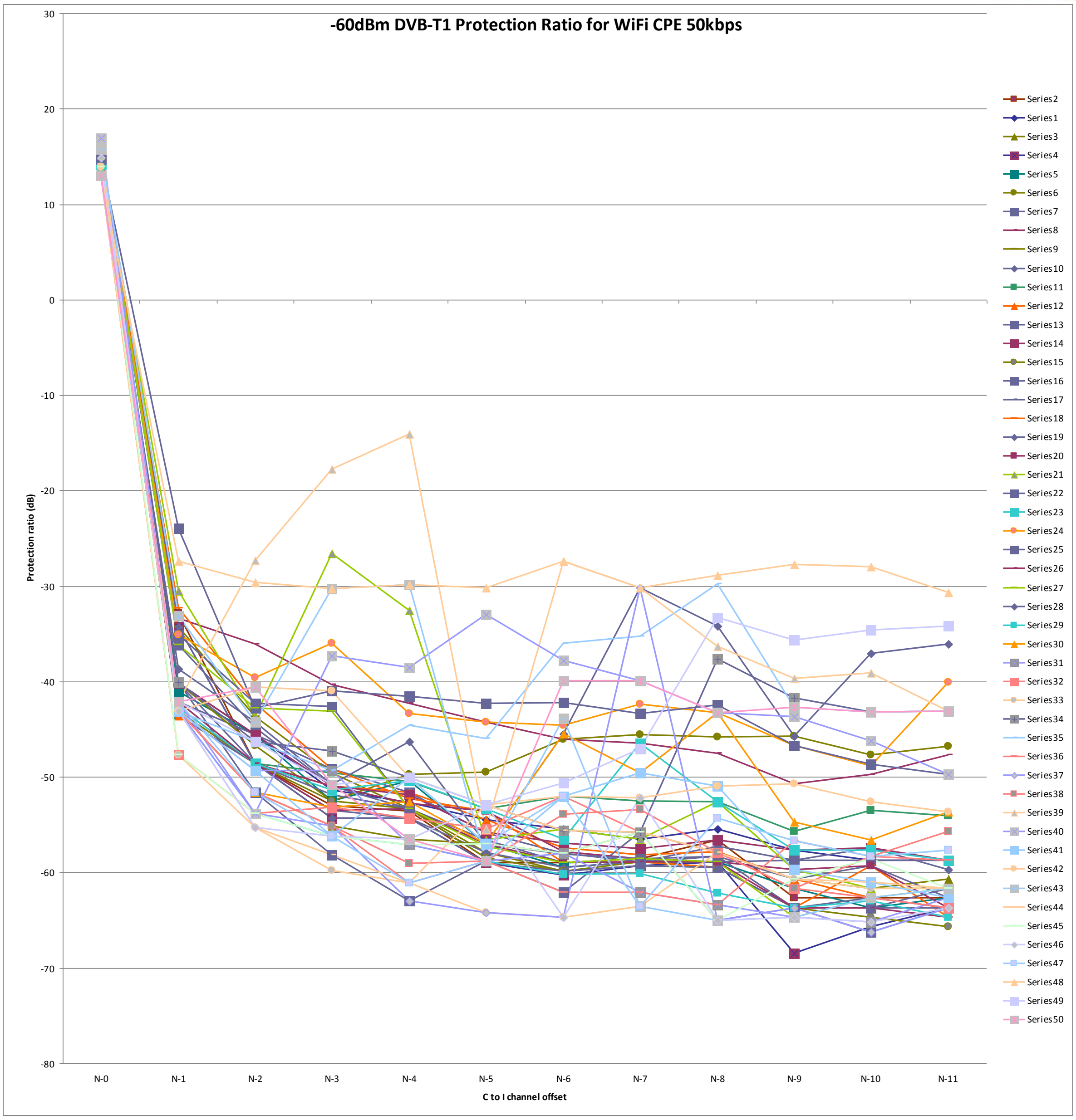

Figure 74 Protection ratio curve for WiFi CPE 50kbps at-60dBm DVB-T1 DTT at offsets N-1 to N-11

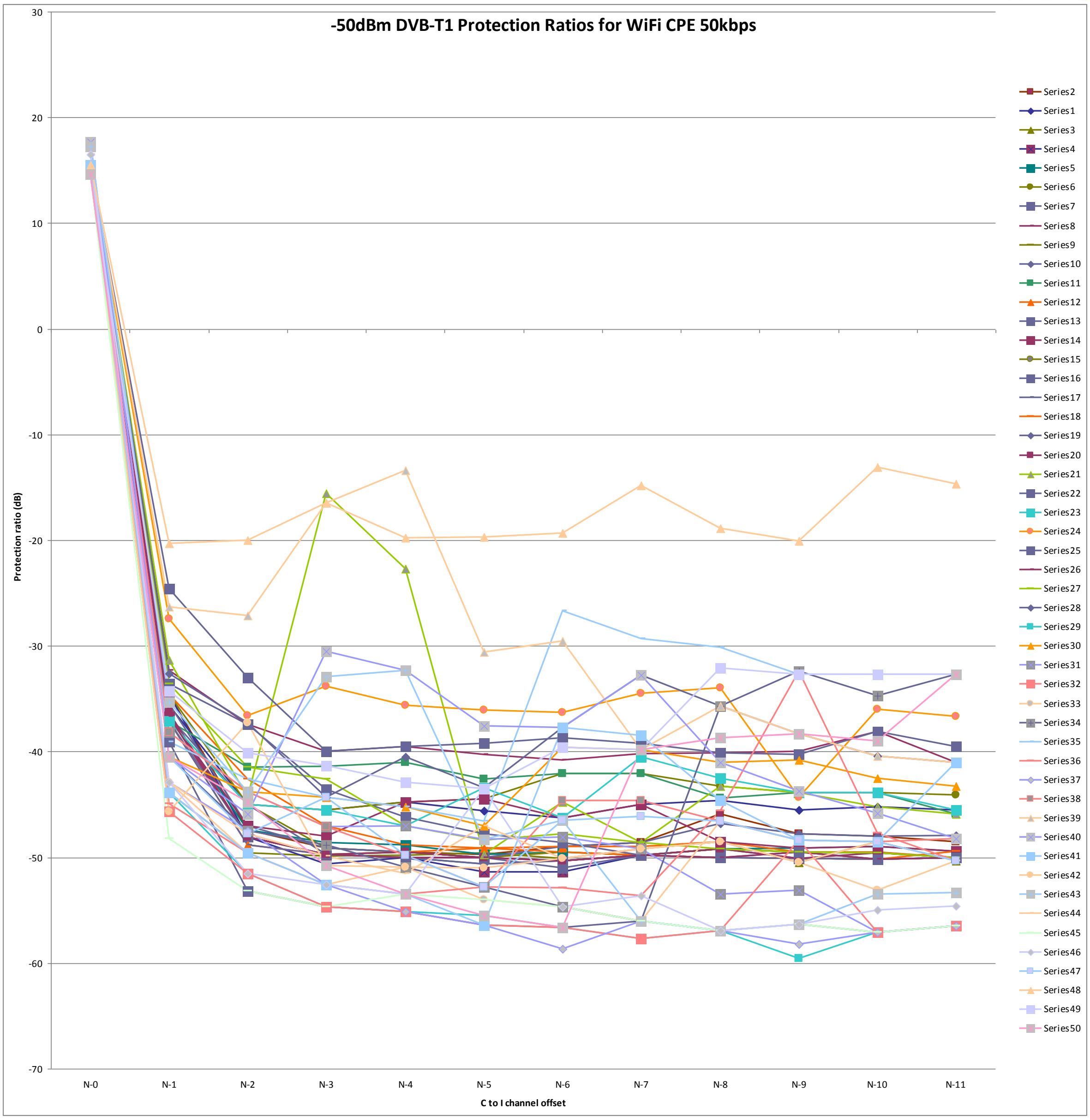

Figure 75 Protection ratio curve for WiFi CPE 50kbps at-50dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

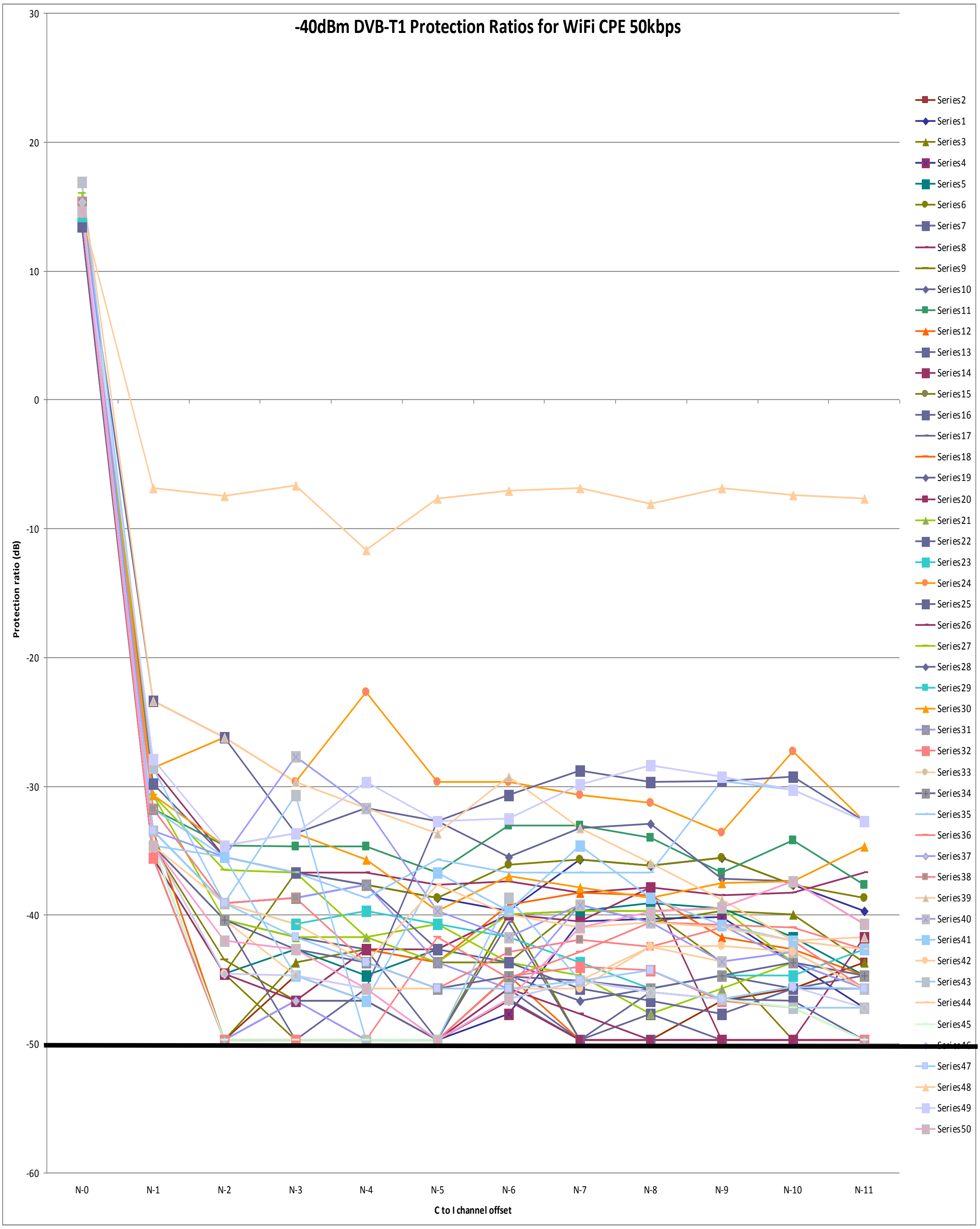

Figure 76 Protection ratio curve for WiFi CPE 50kbps at-40dBm DVB-T1 DTT at offsets N-1 to N-11

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

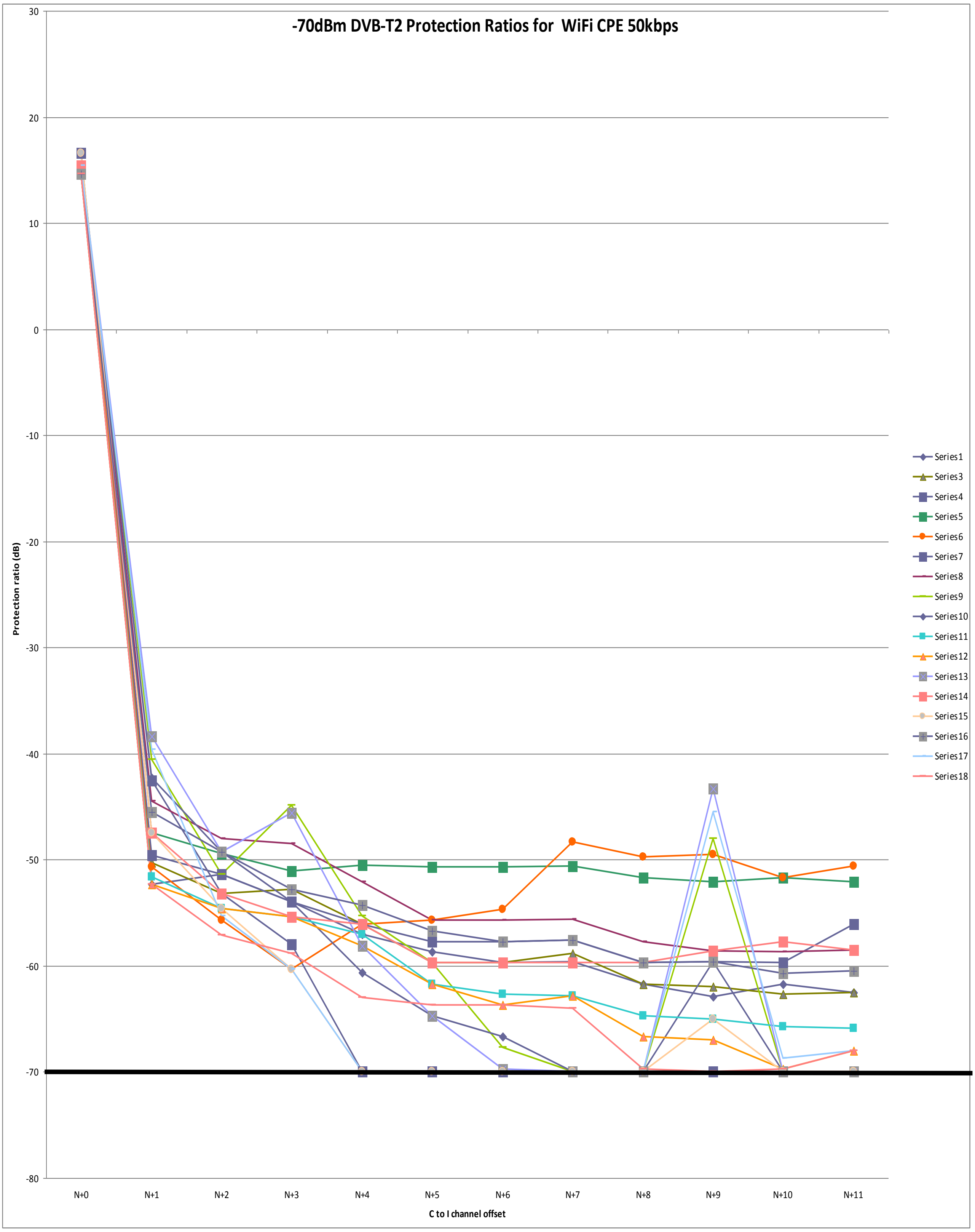

Figure 77 Protection ratio curve for WiFi CPE 50kbps at-70dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

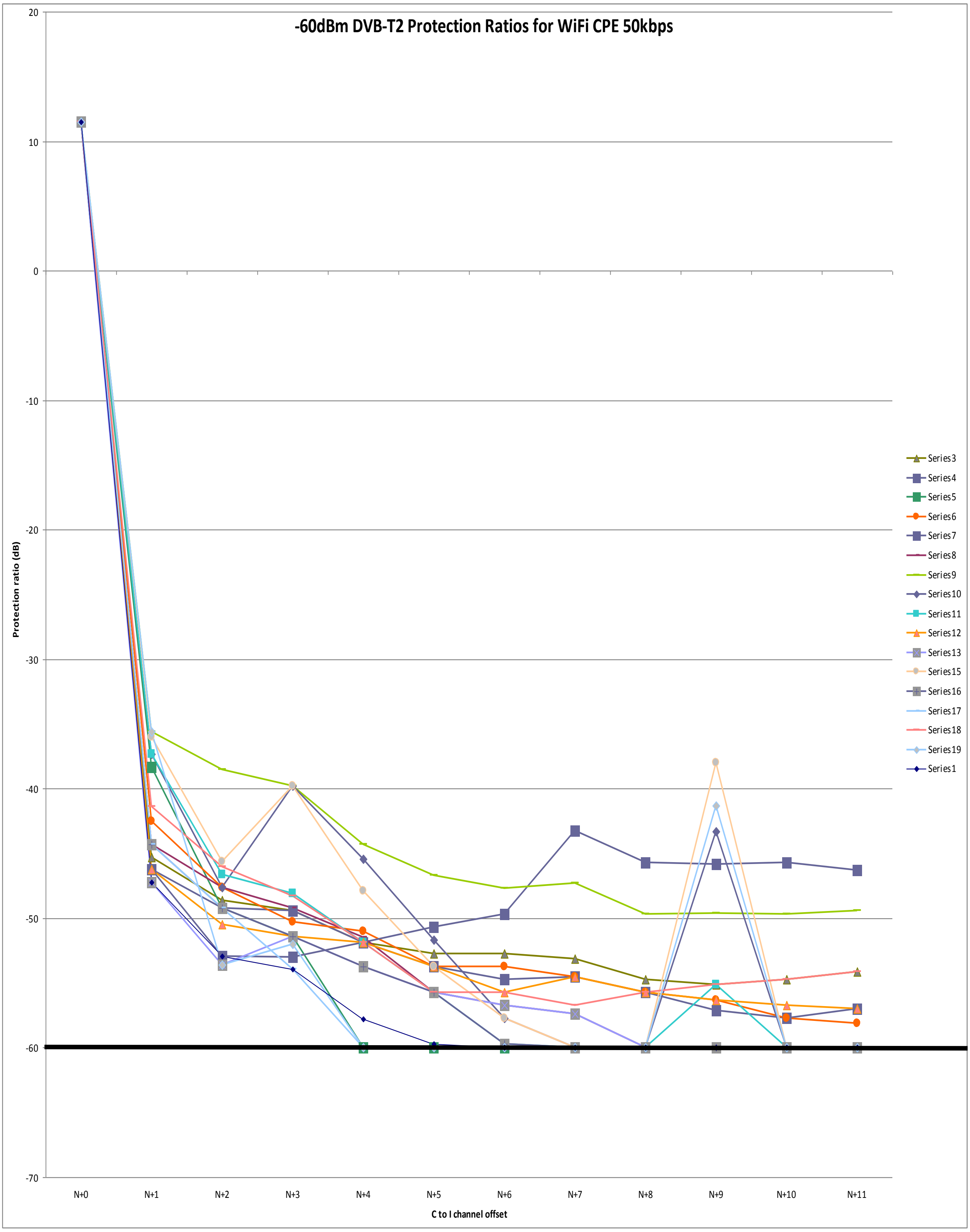

Figure 78 Protection ratio curve for WiFi CPE 50kbps at-60dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

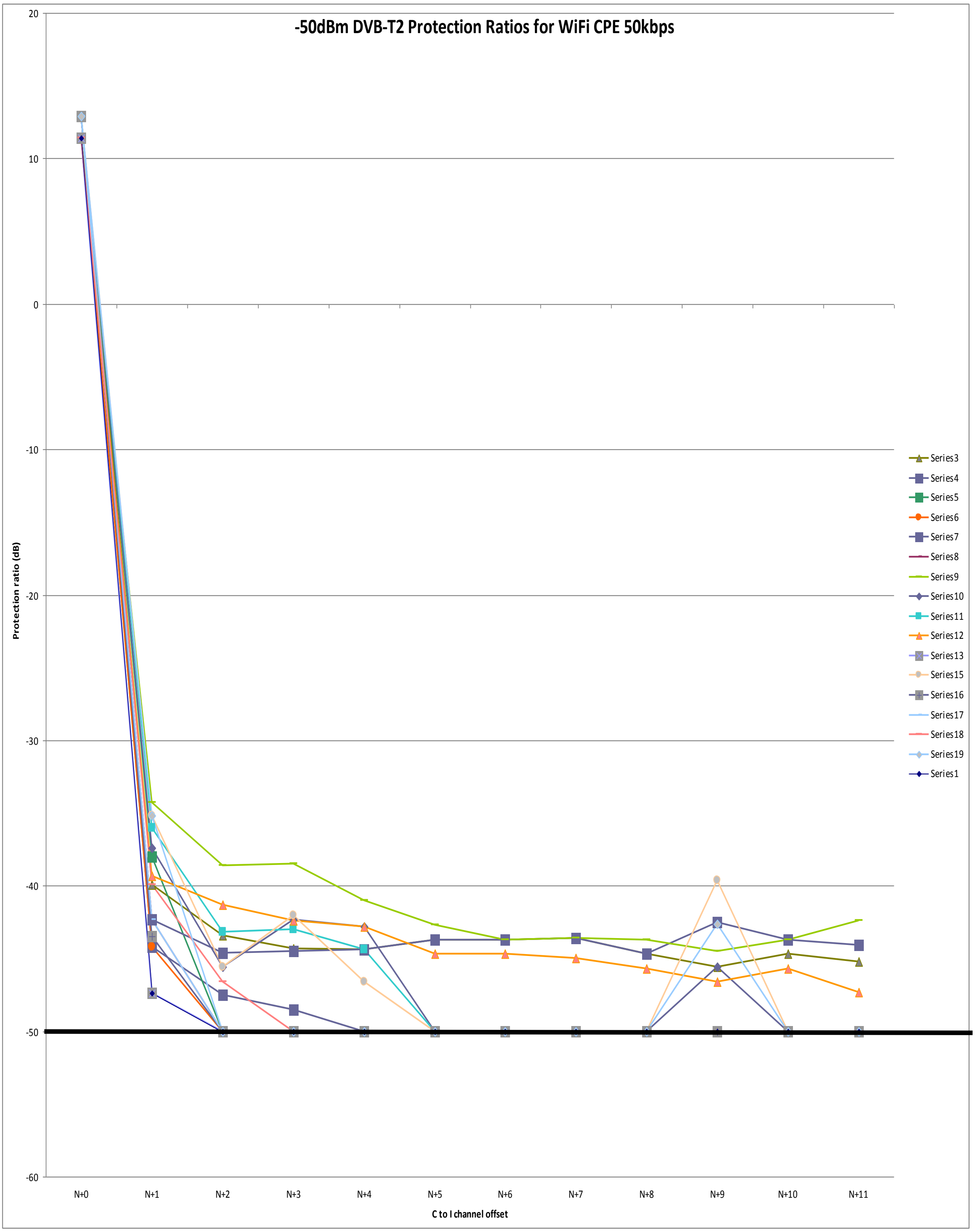

Figure 79 Protection ratio curve for WiFi CPE 50kbps at-50dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

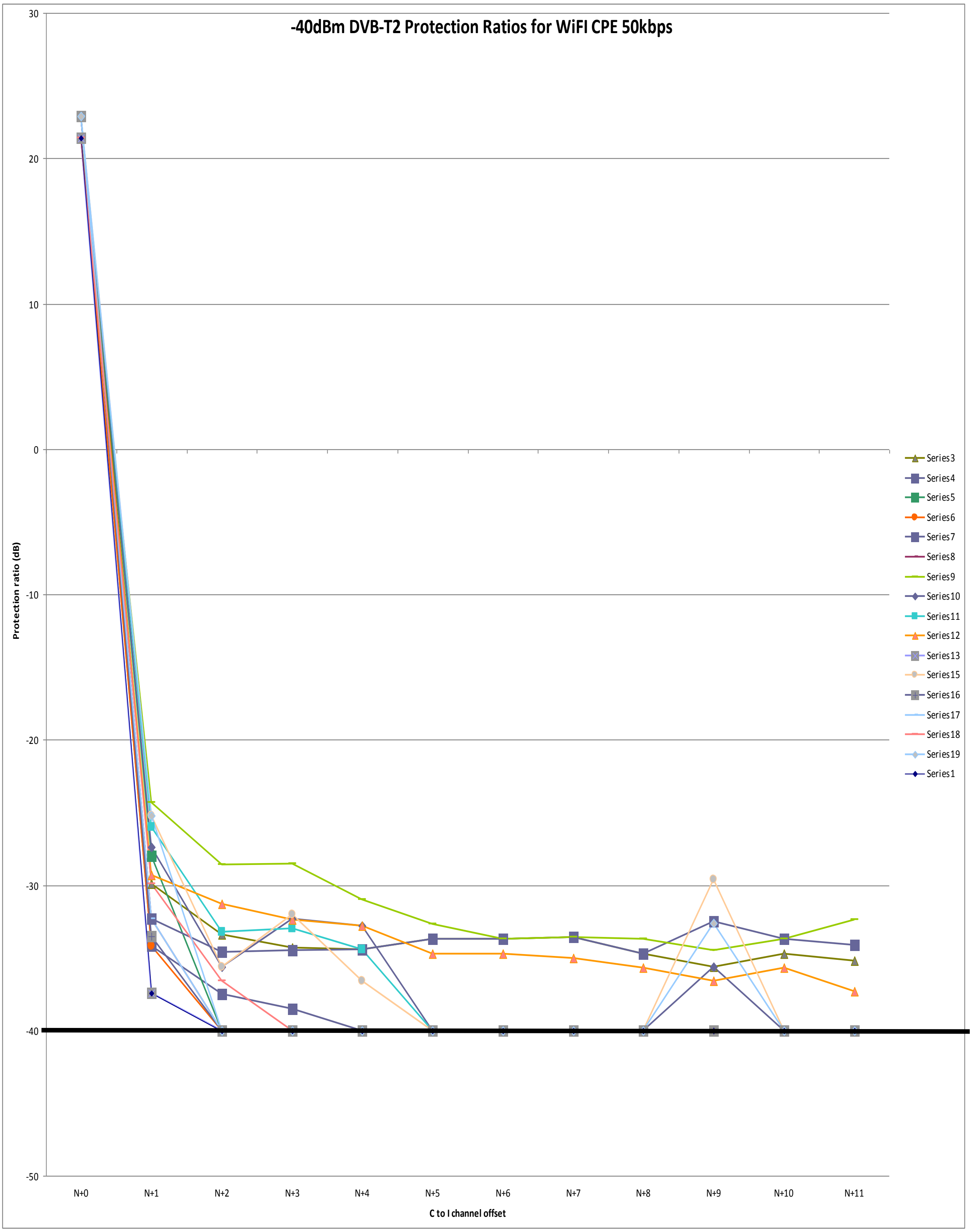

Figure 80 Protection ratio curve for WiFi CPE 50kbps at-40dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

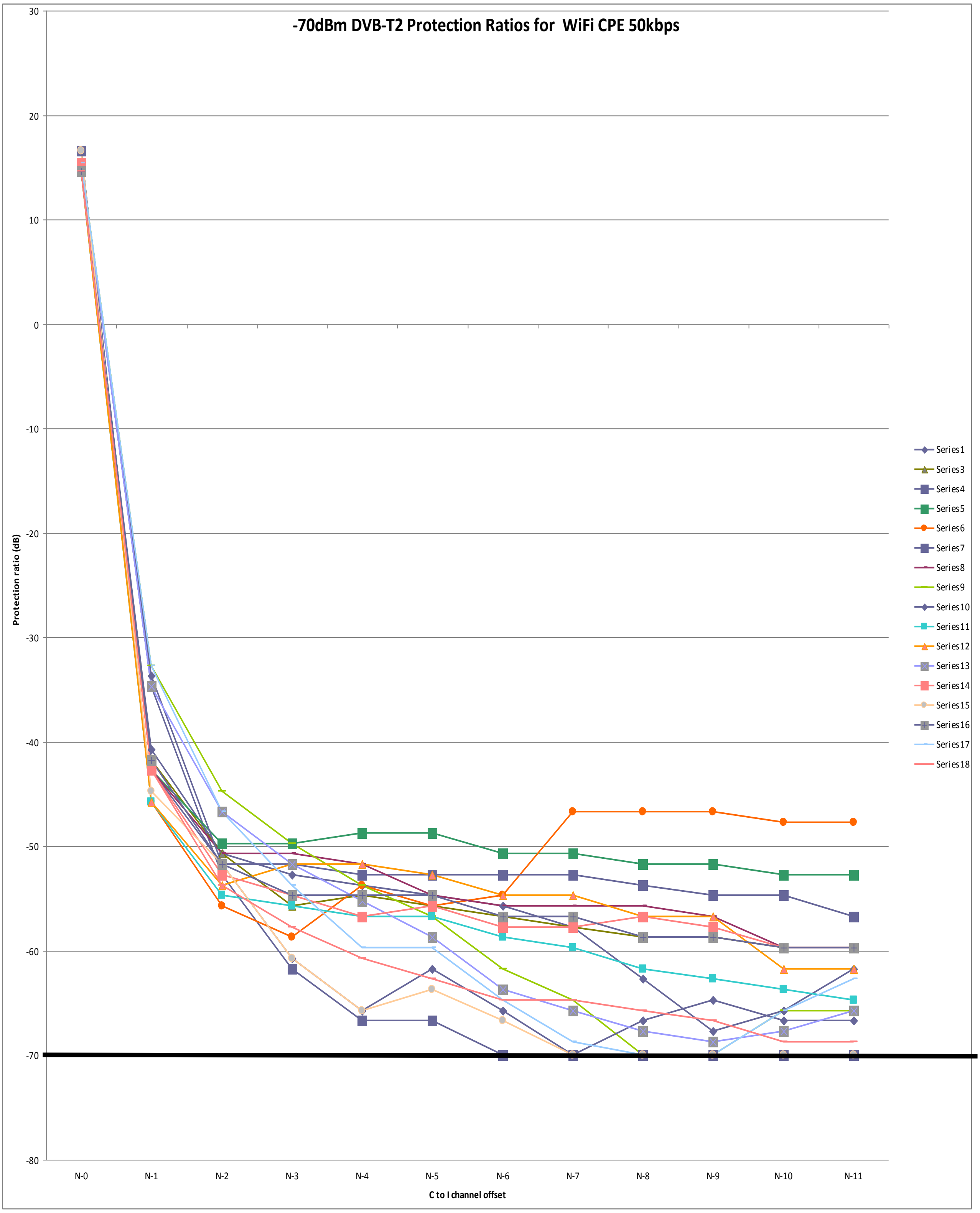

Figure 81 Protection ratio curve for WiFi CPE 50kbps at-70dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

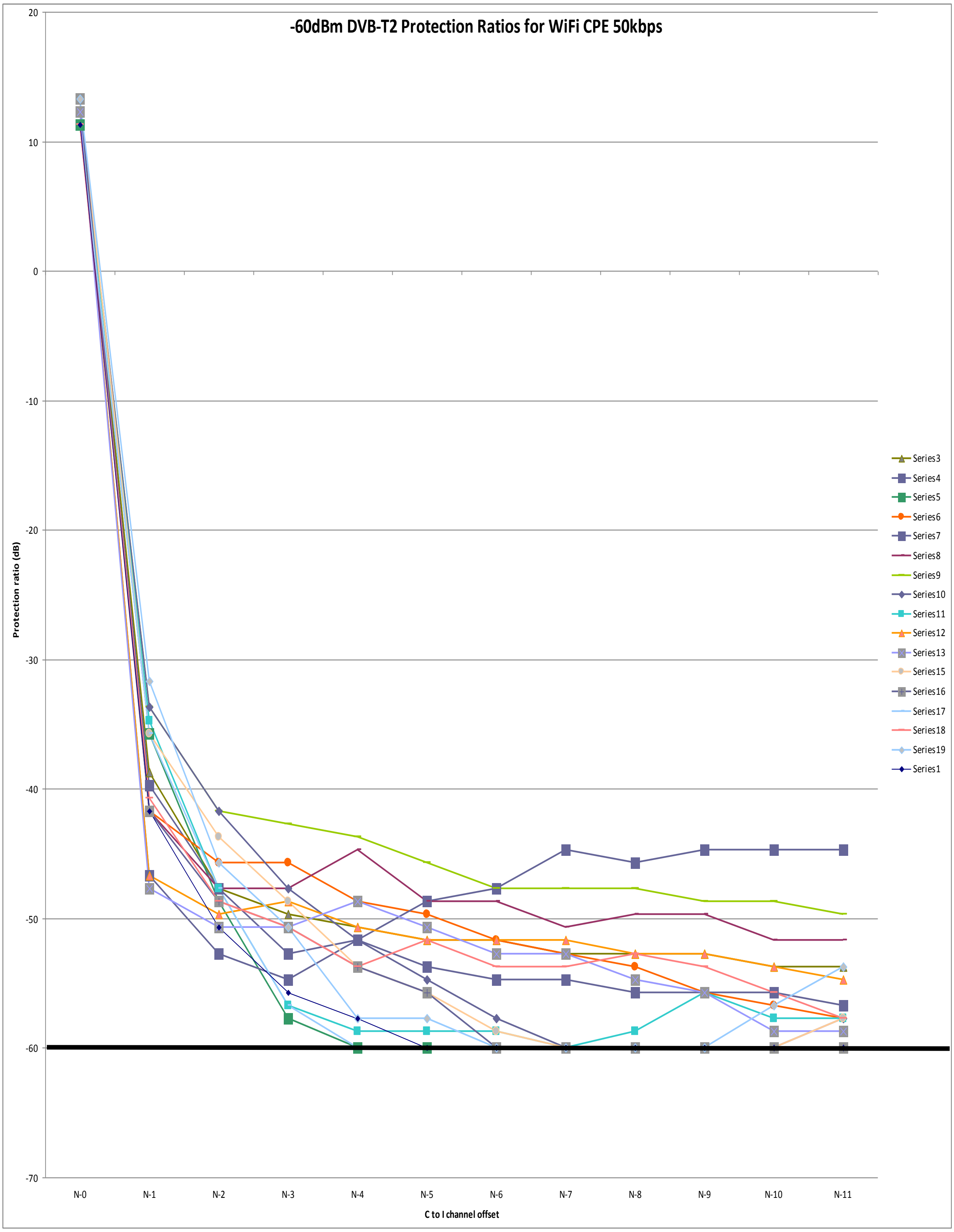

Figure 82 Protection ratio curve for WiFi CPE 50kbps at-60dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

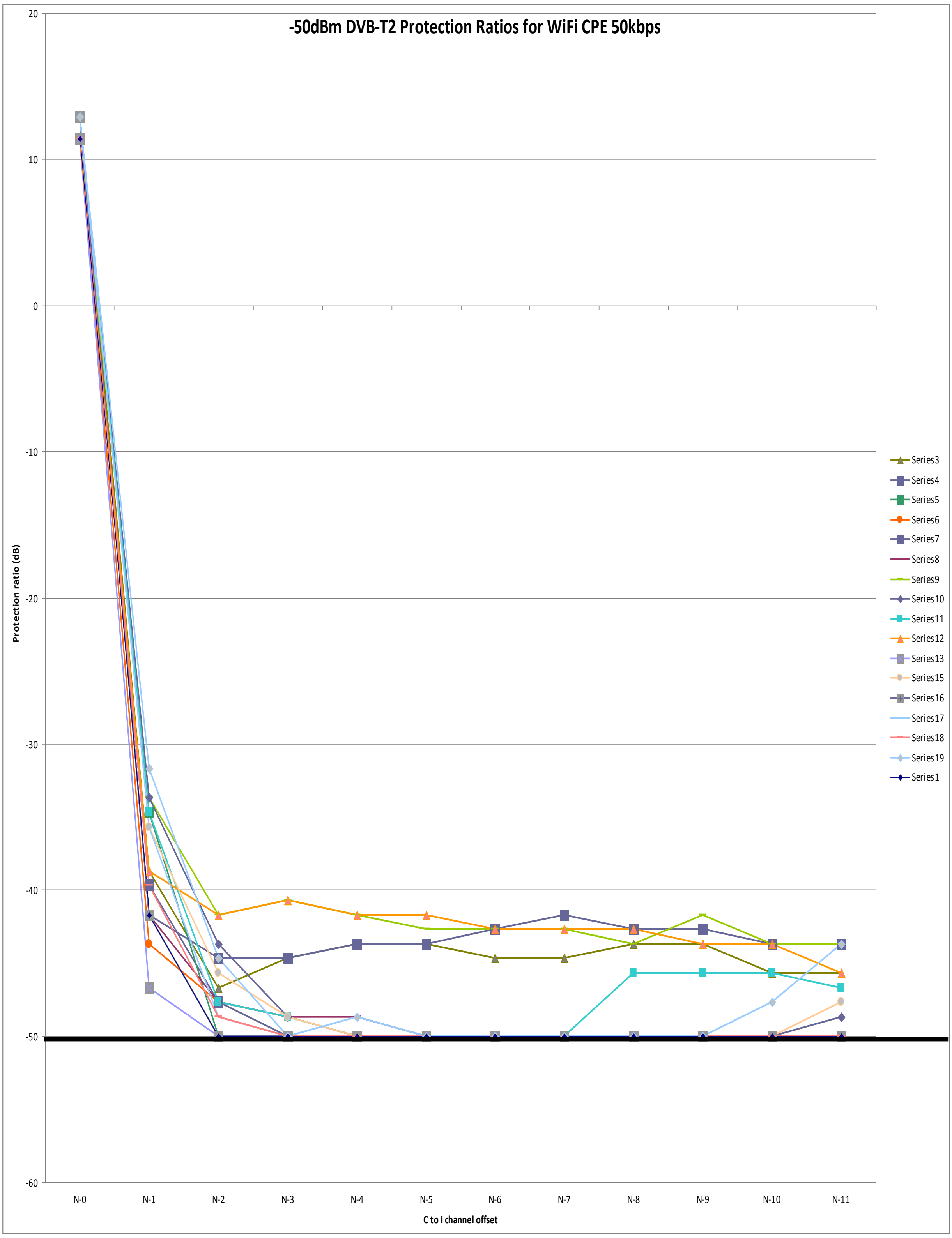

Figure 83 Protection ratio curve for WiFi CPE 50kbps at-50dBm DVB-T2 DTT at offsets N-1 to N-11

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

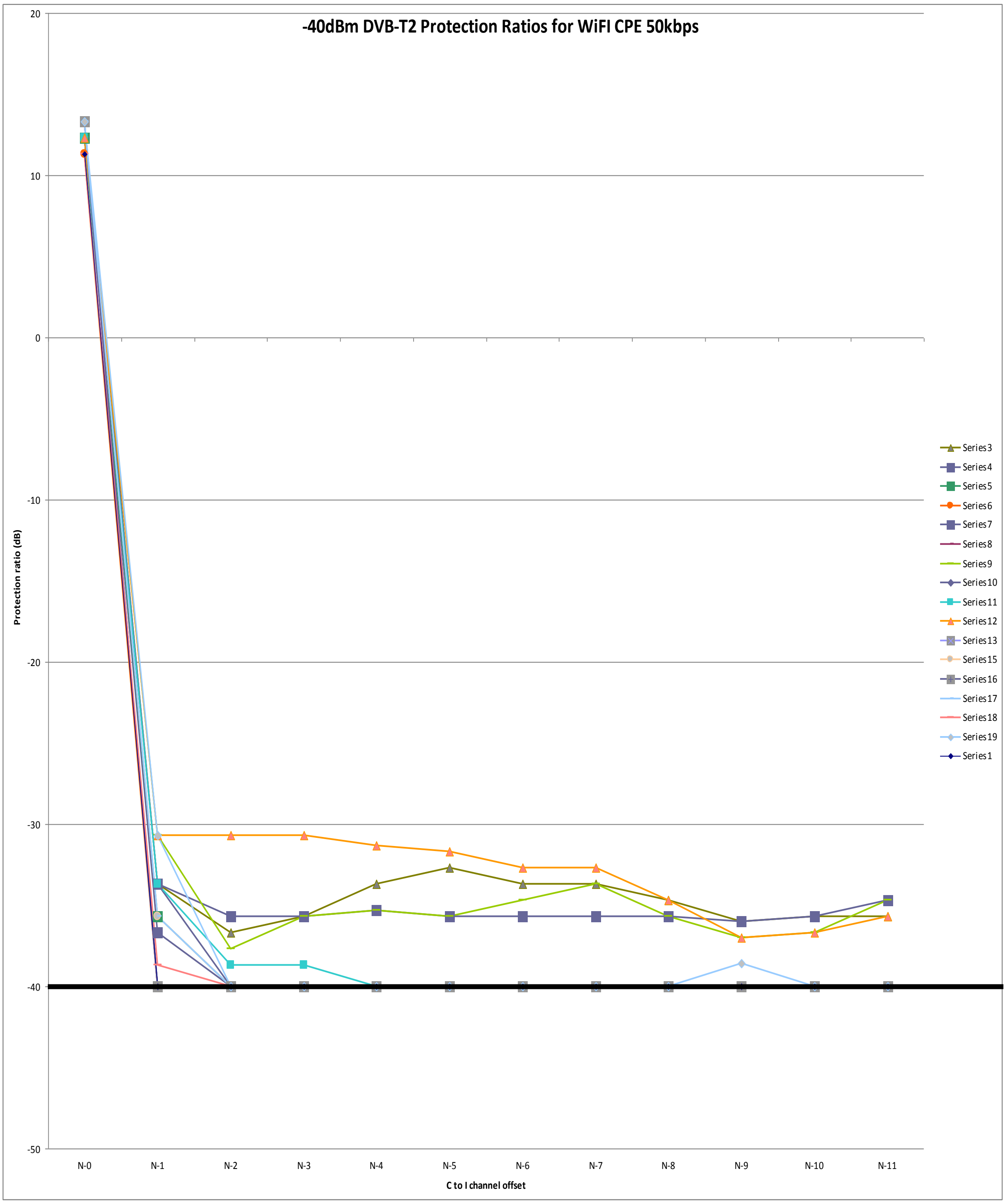

Figure 84 Protection ratio curve for WiFi CPE 50kbps at-40dBm DVB-T2 DTT at offsets N-1 to N-11

A.3 WSD Weightless base station

Figure 85 Protection ratio curve for Weightless-40dBm DVB-T1 DTT at offsets N+1 to N+10

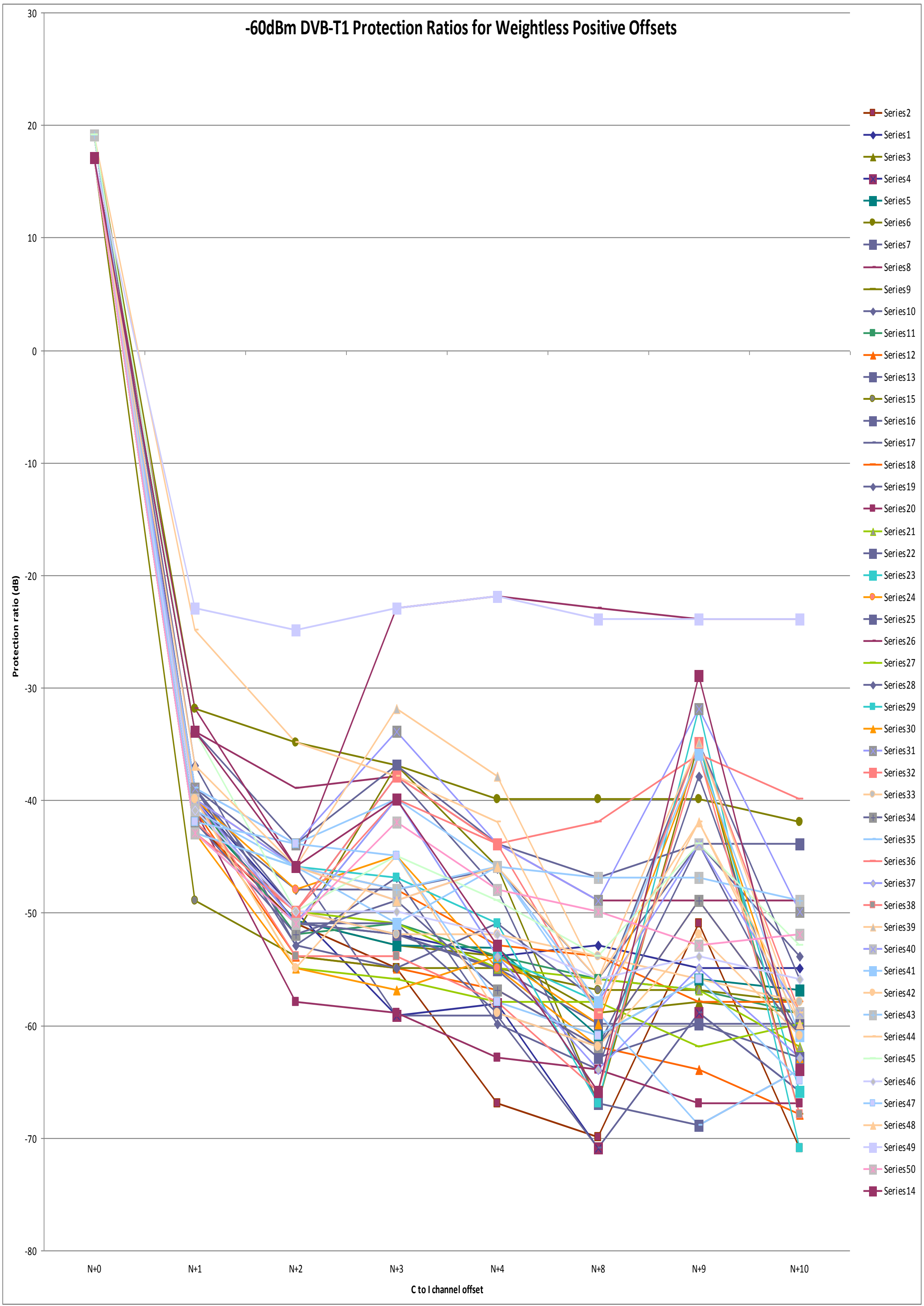

Figure 86 Protection ratio curve for Weightless at-60dBm DVB-T1 DTT at offsets N+1 to N+10

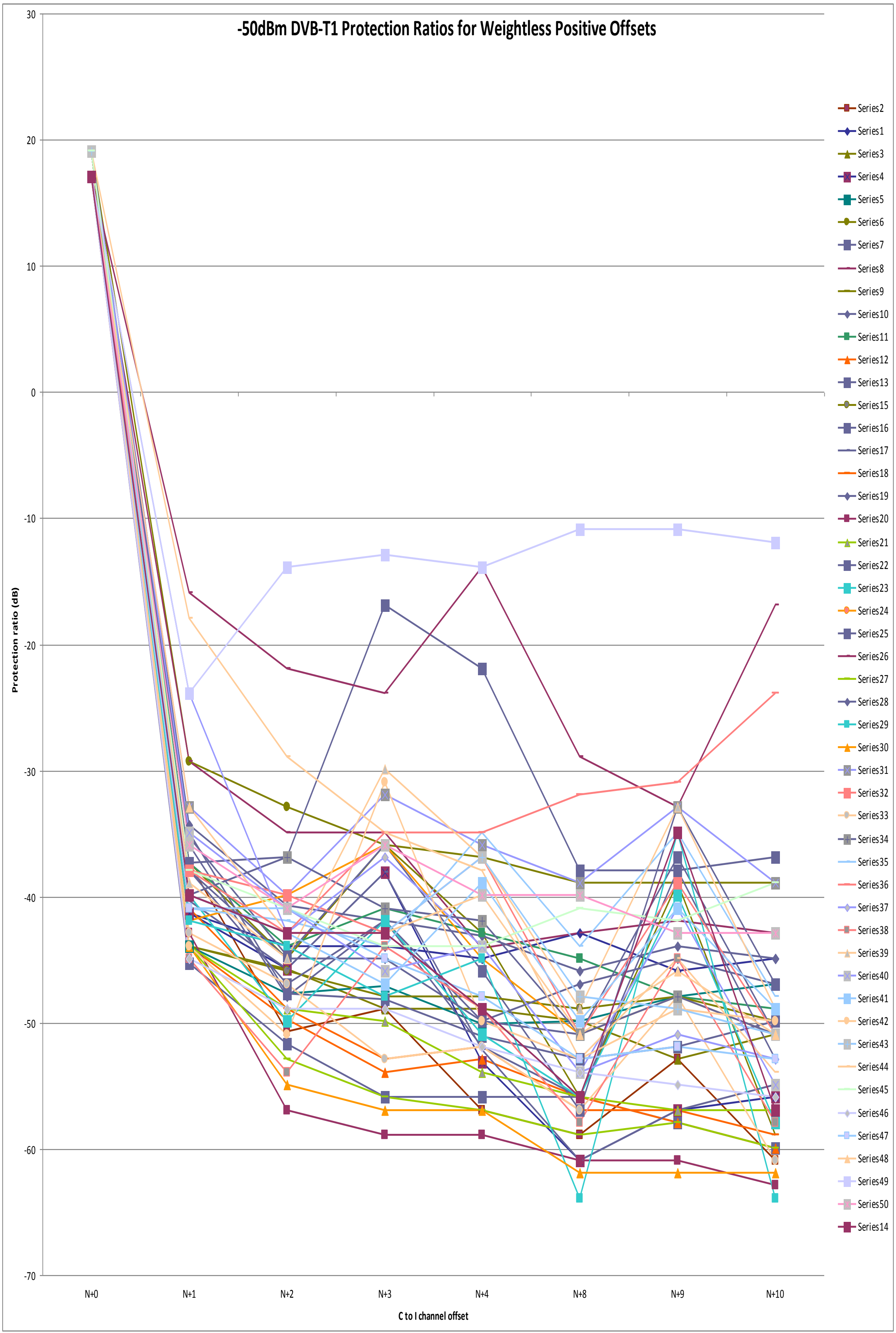

Figure 87 Protection ratio curve for Weightless at-50dBm DVB-T1 DTT at offsets N+1 to N+11

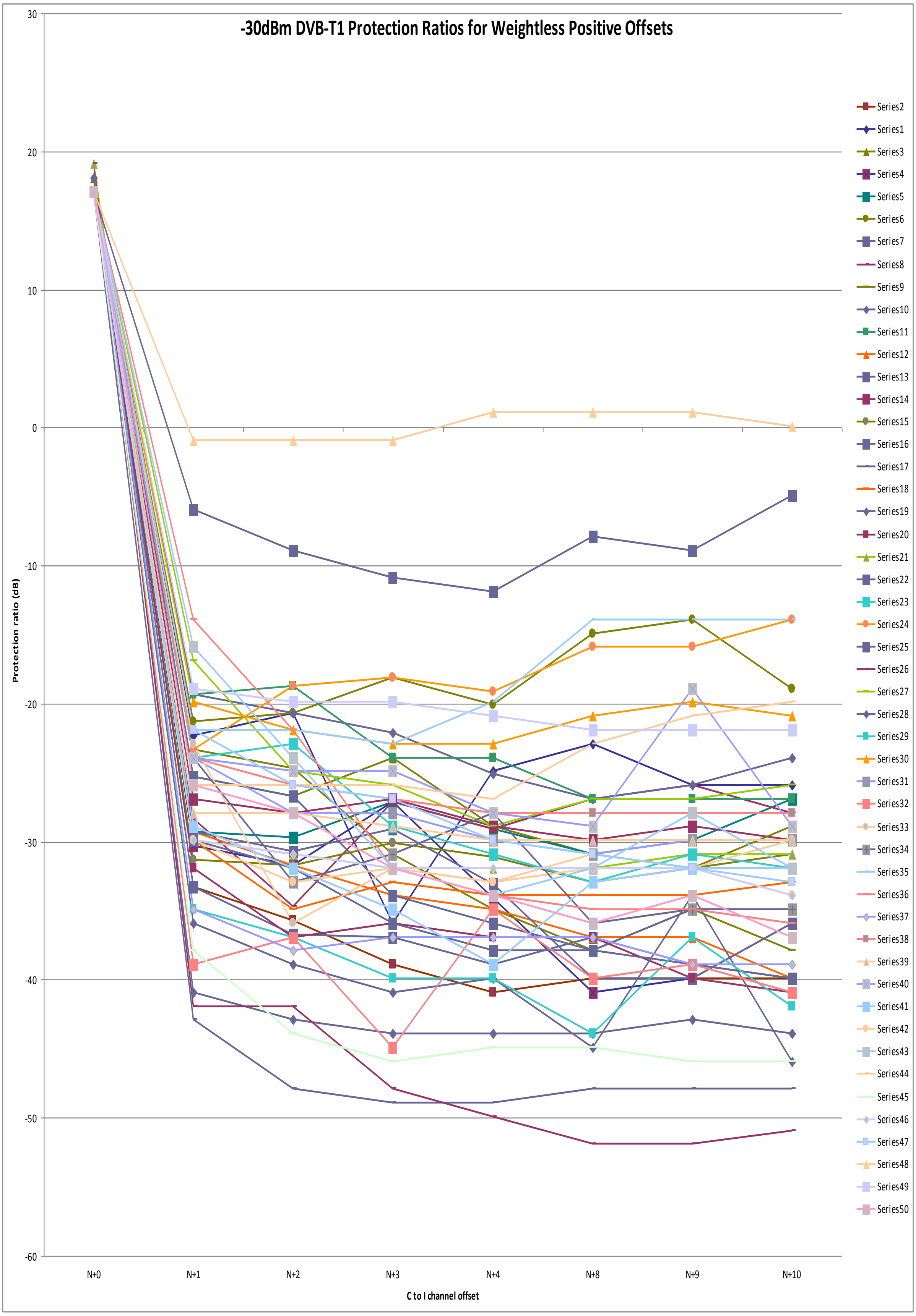

Figure 88 Protection ratio curve for Weightless at-30dBm DVB-T1 DTT at offsets N+1 to N+11

A.4 LTE UE full load

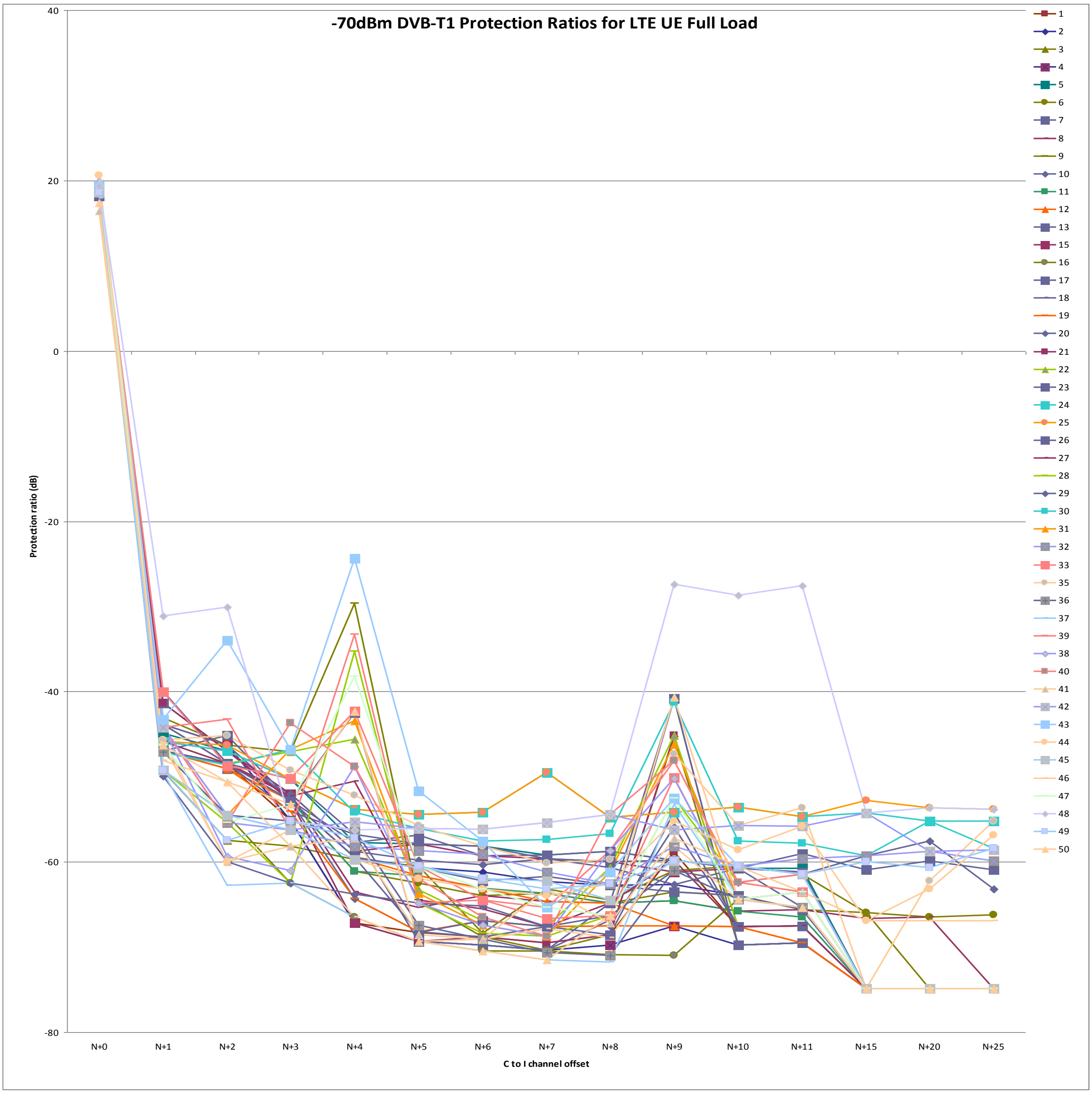

Figure 89 Protection ratio curve for LTE UE full load at -70dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -66dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

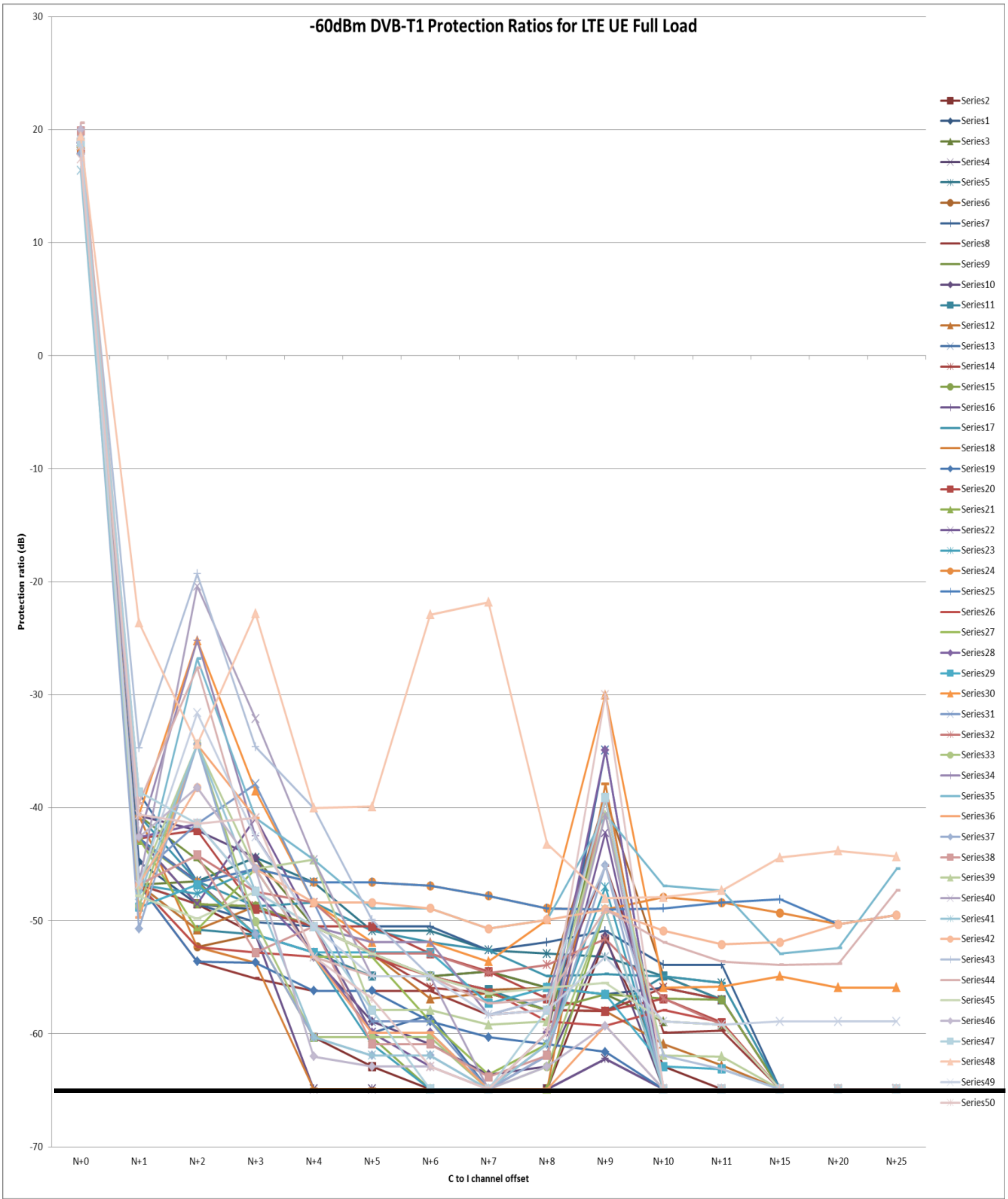

Figure 90 Protection ratio curve for LTE UE full load at -60dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -56dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

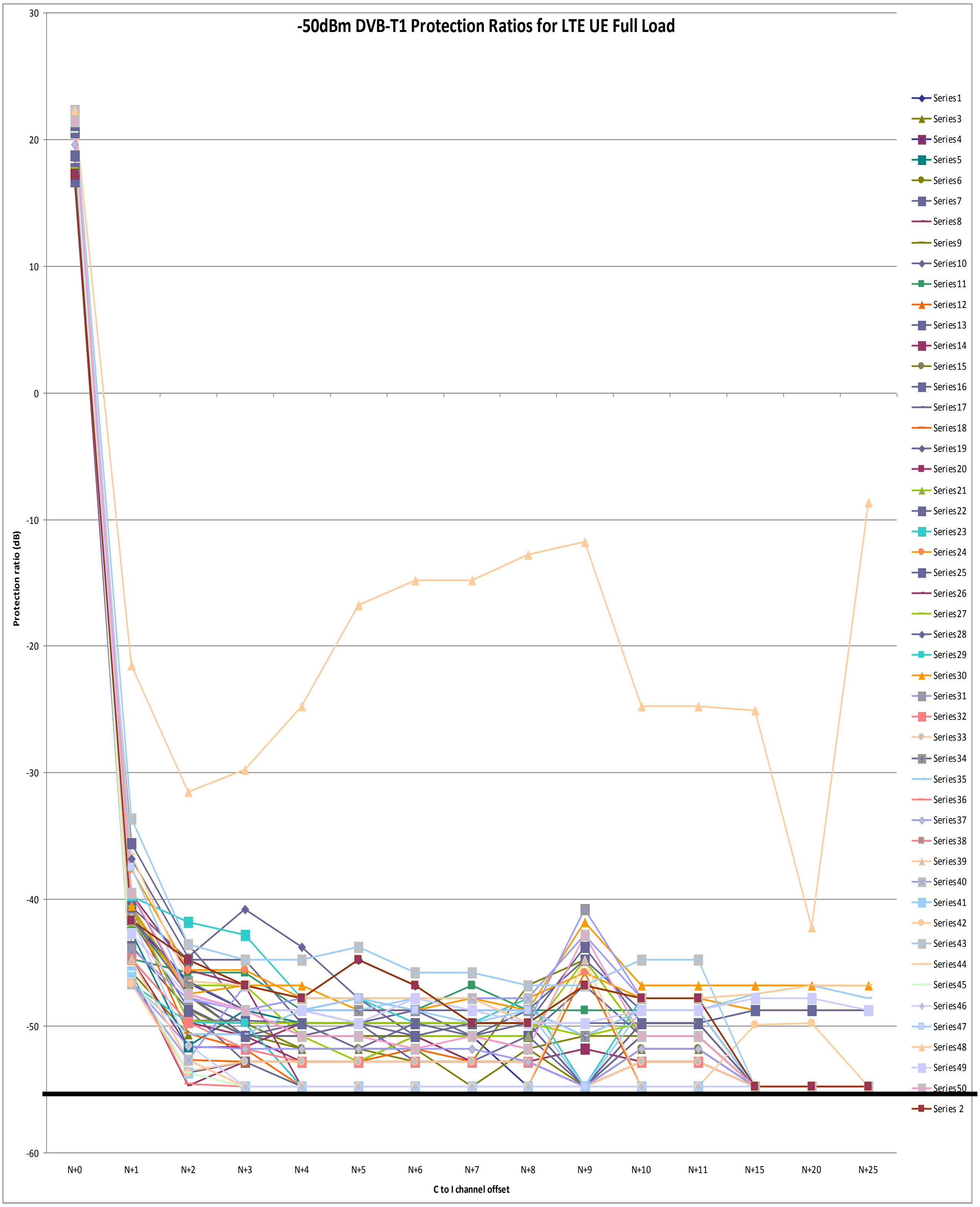

Figure 91 Protection ratio curve for LTE UE full load at-50dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -46dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

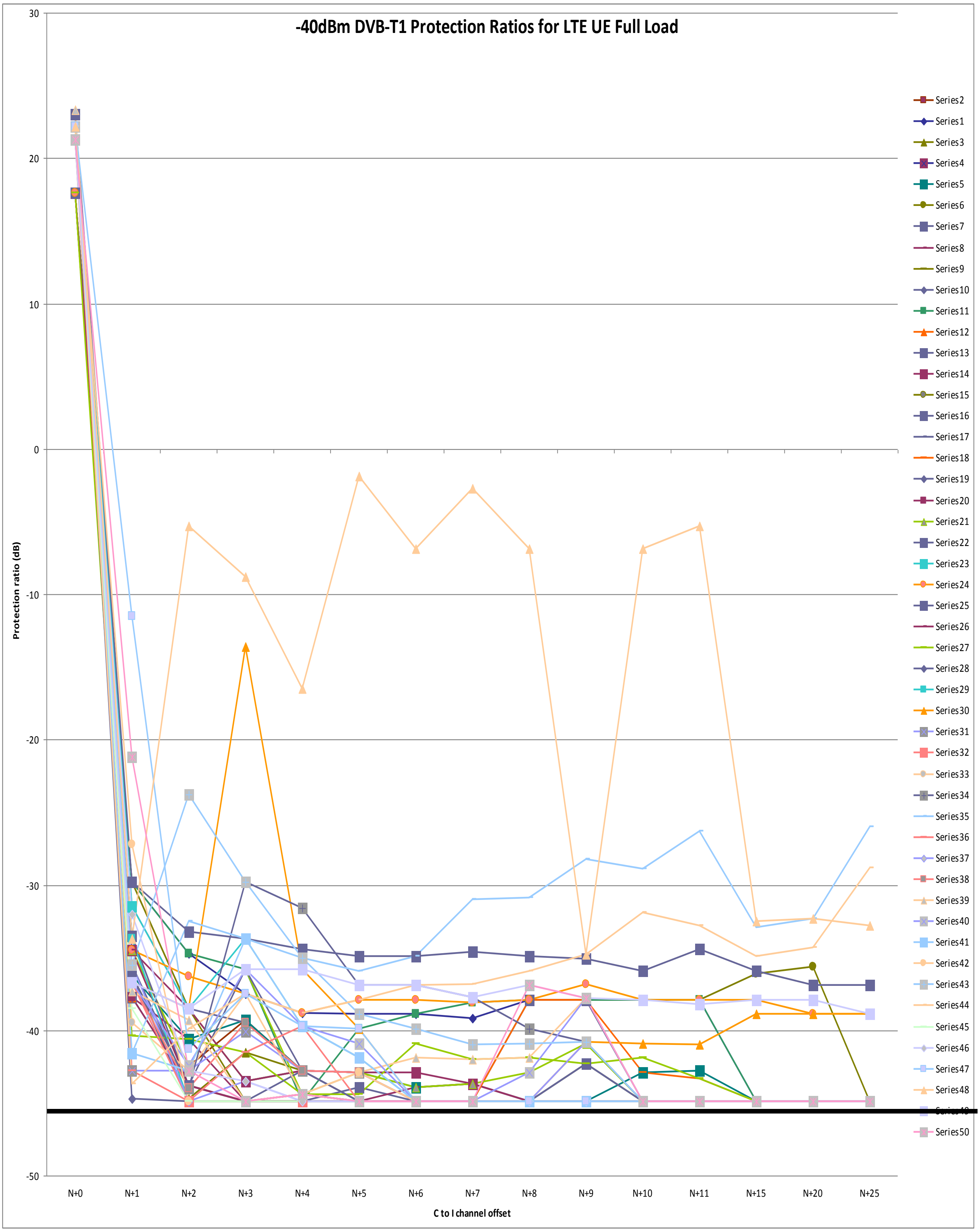

Figure 92 Protection ratio curve for LTE UE full load at-40dBm DVB-T1 DTT at offsets N+1 to N+25

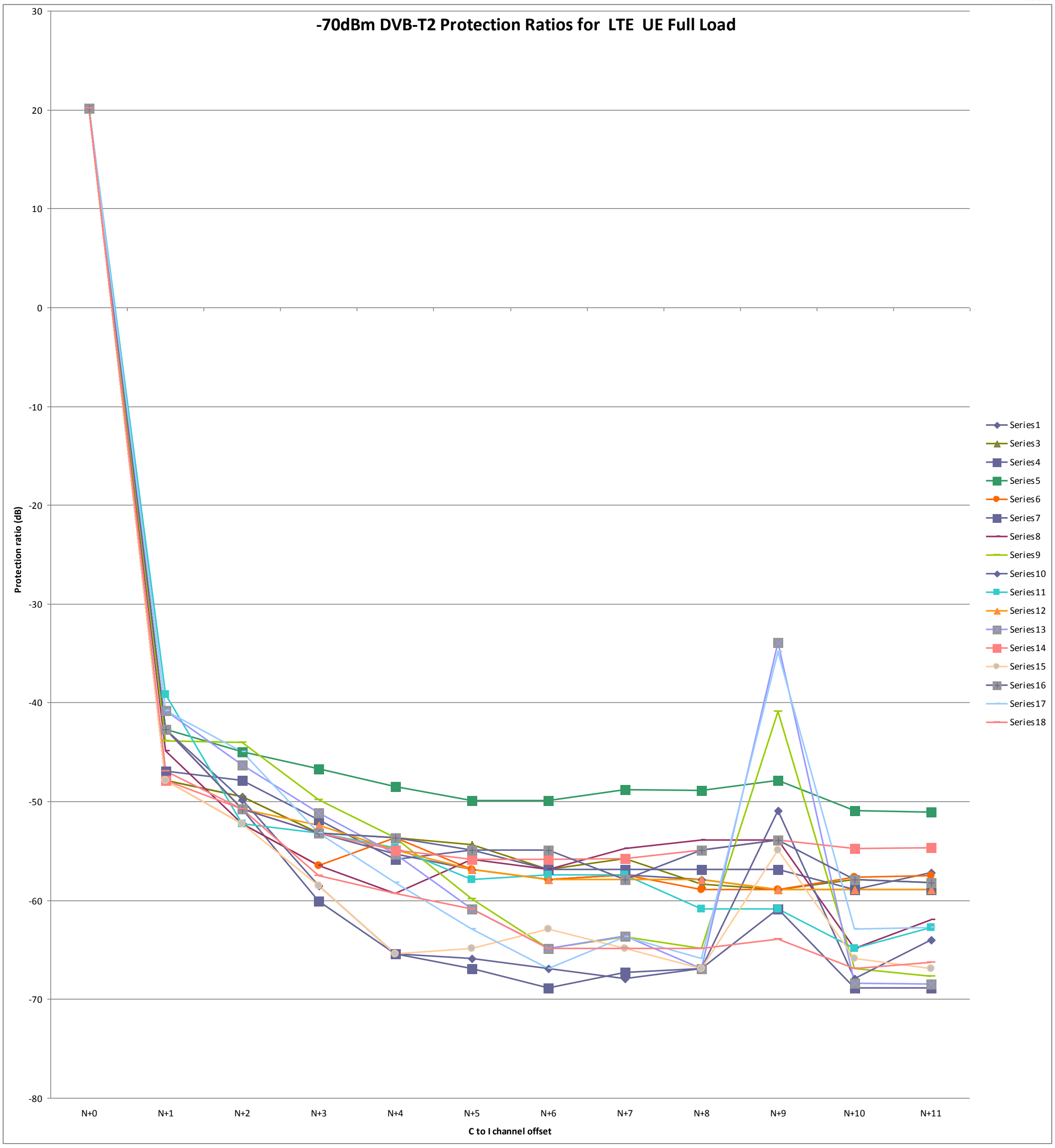

Figure 93 Protection ratio curve for LTE UE full load at-70dBm DVB-T2 DTT at offsets N+1 to N+11

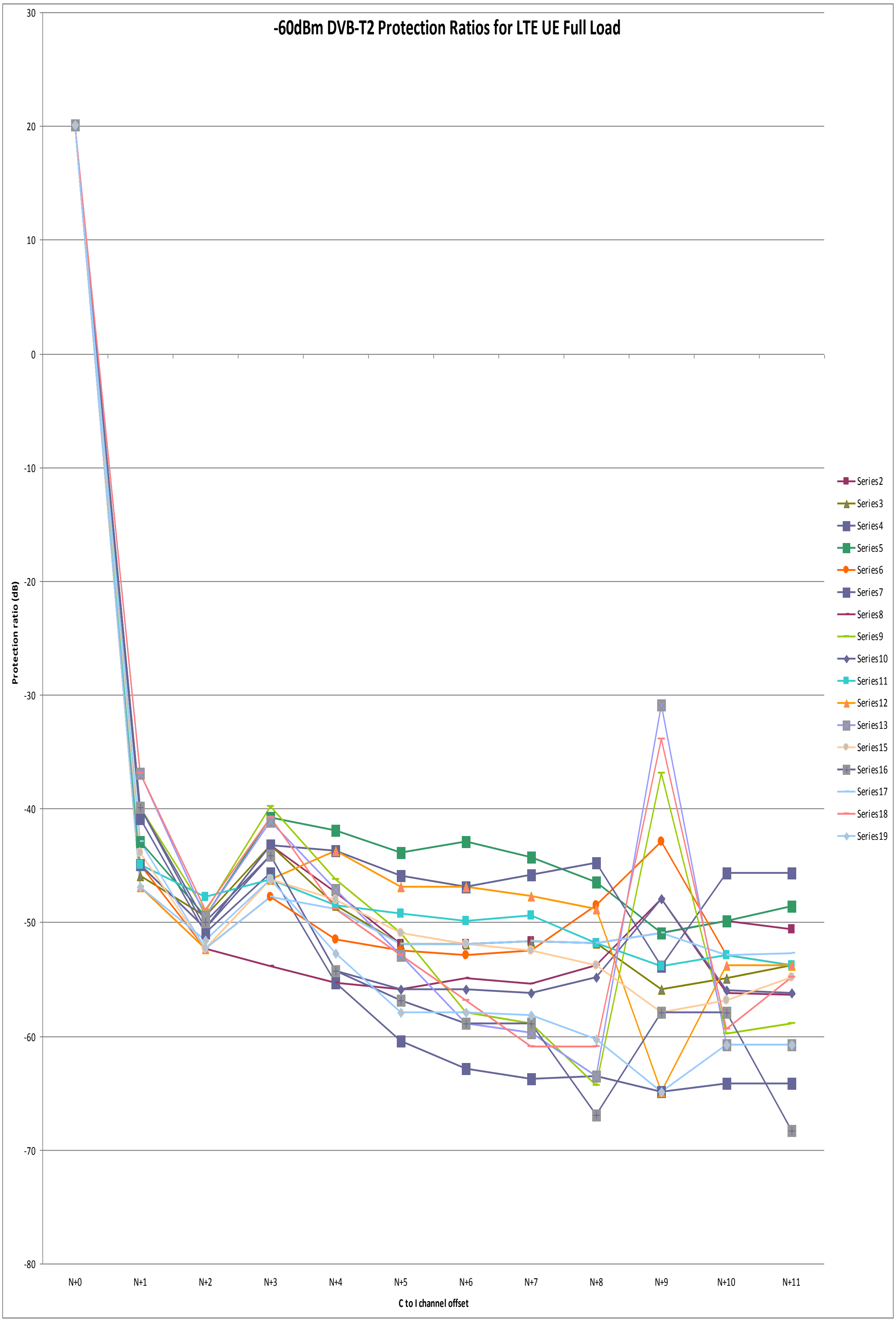

Figure 94 Protection ratio curve for LTE UE full load at-60dBm DVB-T2 DTT at offsets N+1 to N+11

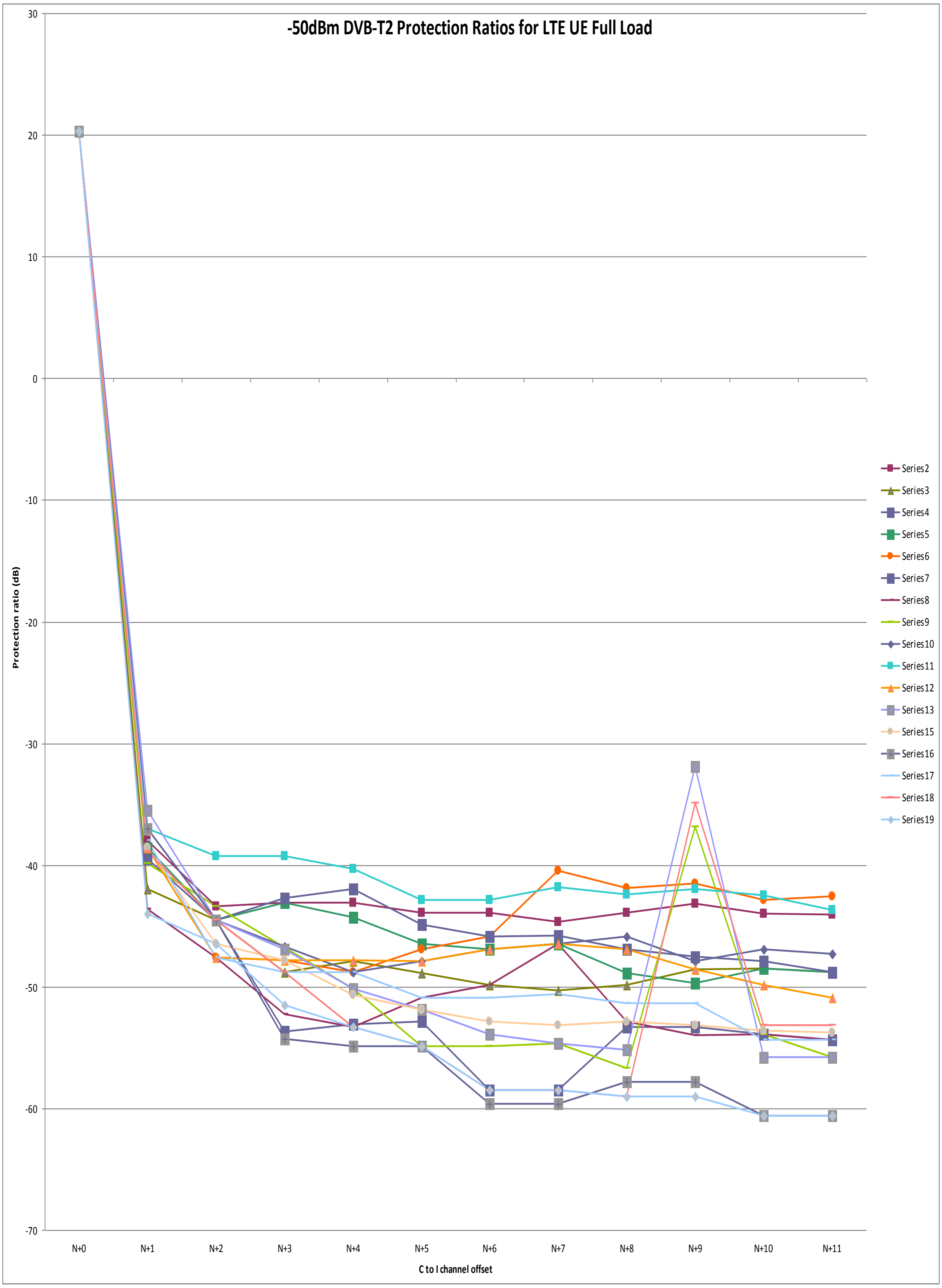

Figure 95 Protection ratio curve for LTE UE full load at-50dBm DVB-T1 DTT at offsets N+1 to N+11

The horizontal line at -46dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

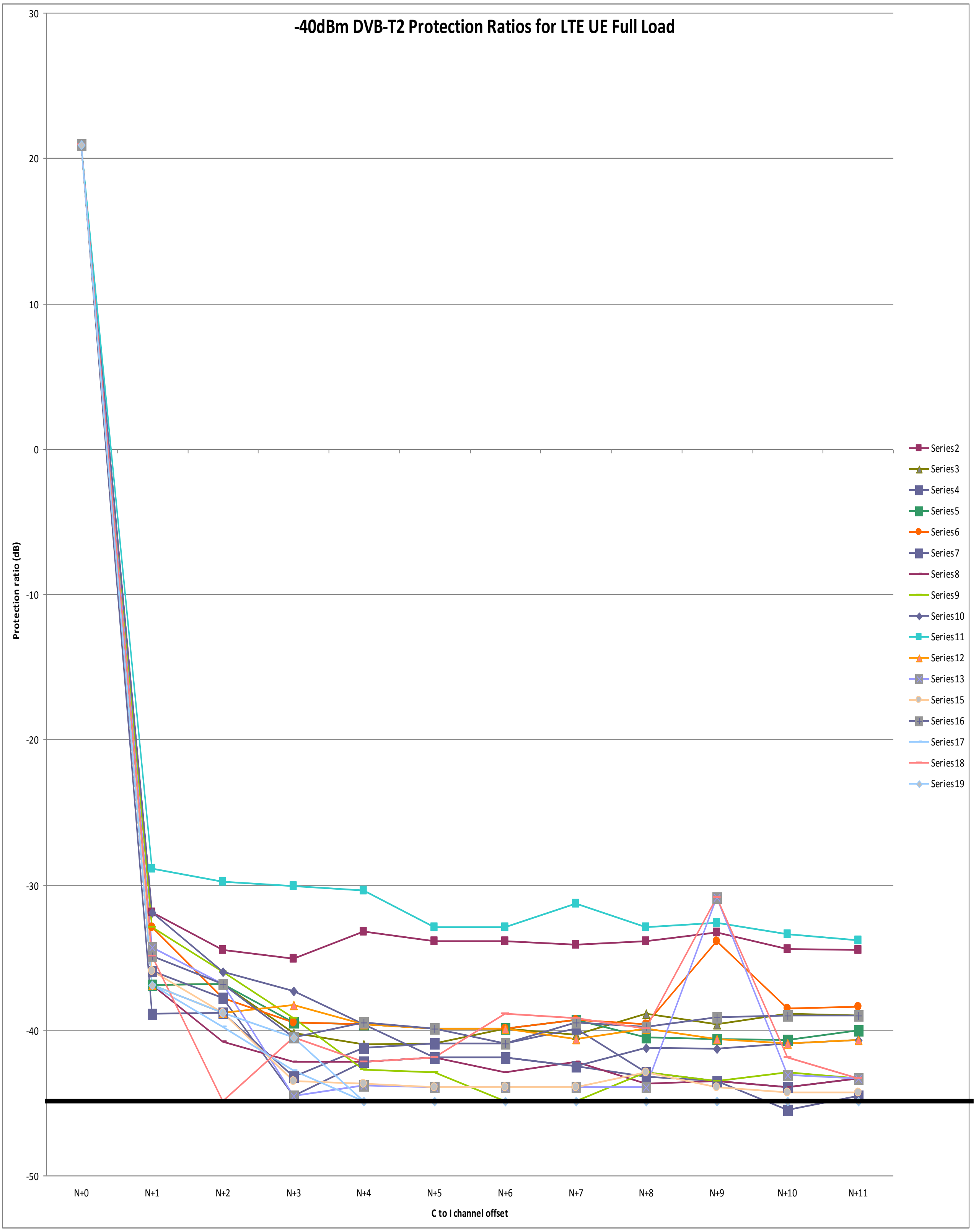

Figure 96 Protection ratio curve for LTE UE full load at-40dBm DVB-T2 DTT at offsets N+1 to N+11

A.5 LTE UE half load

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

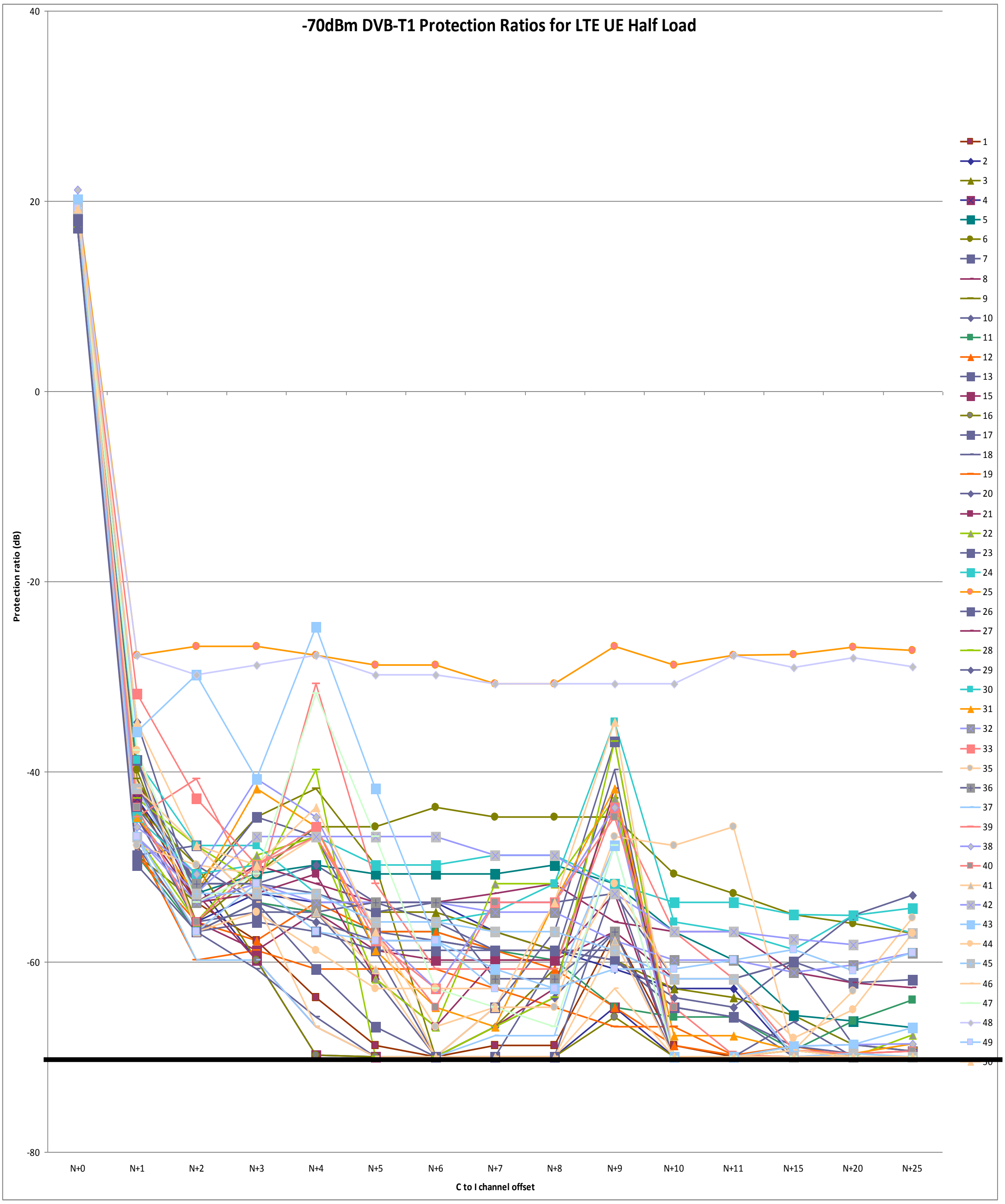

Figure 97 Protection ratio curve for LTE UE half load at-70dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

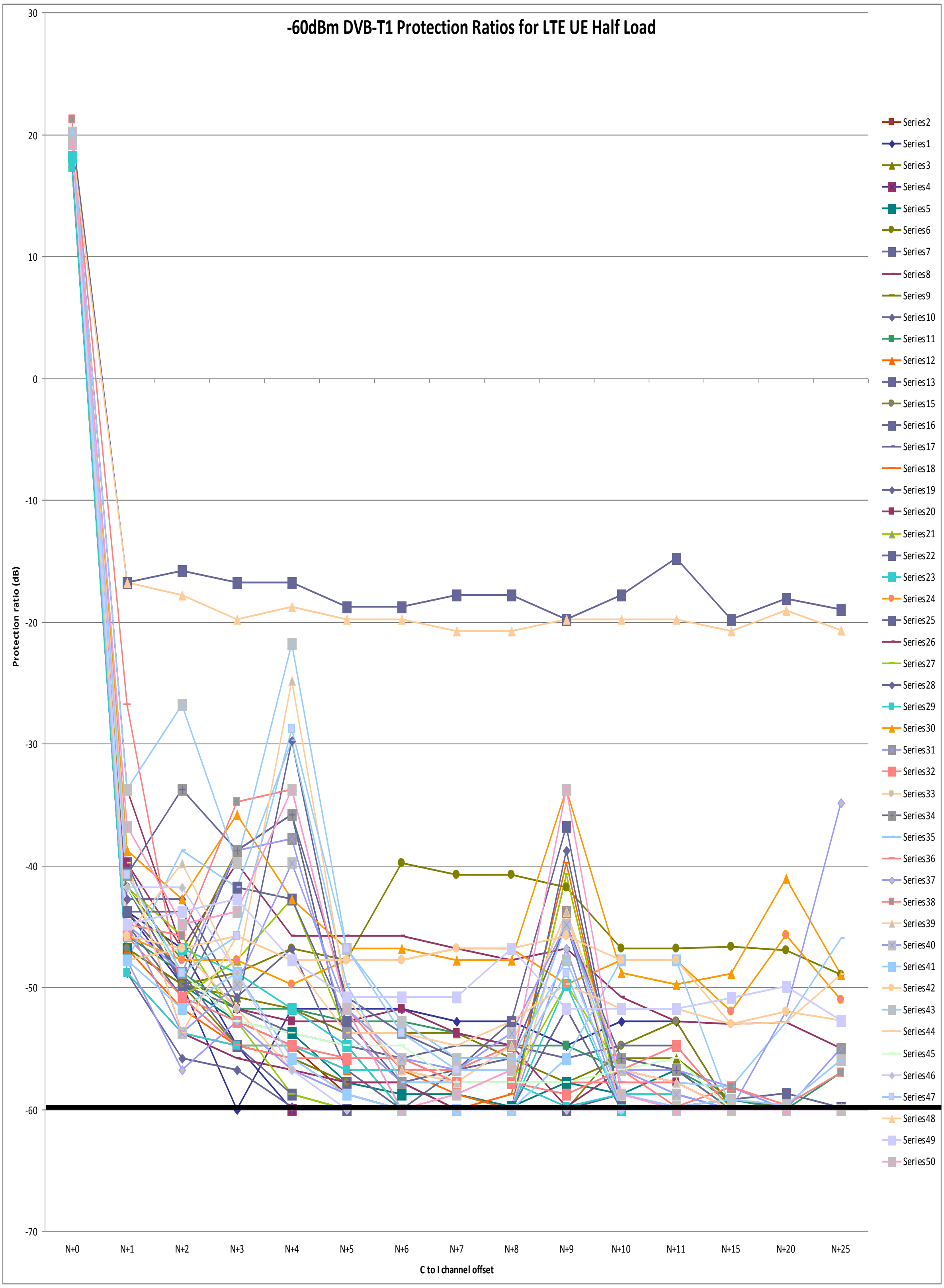

Figure 98 Protection ratio curve for LTE UE half load at-60dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -50dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

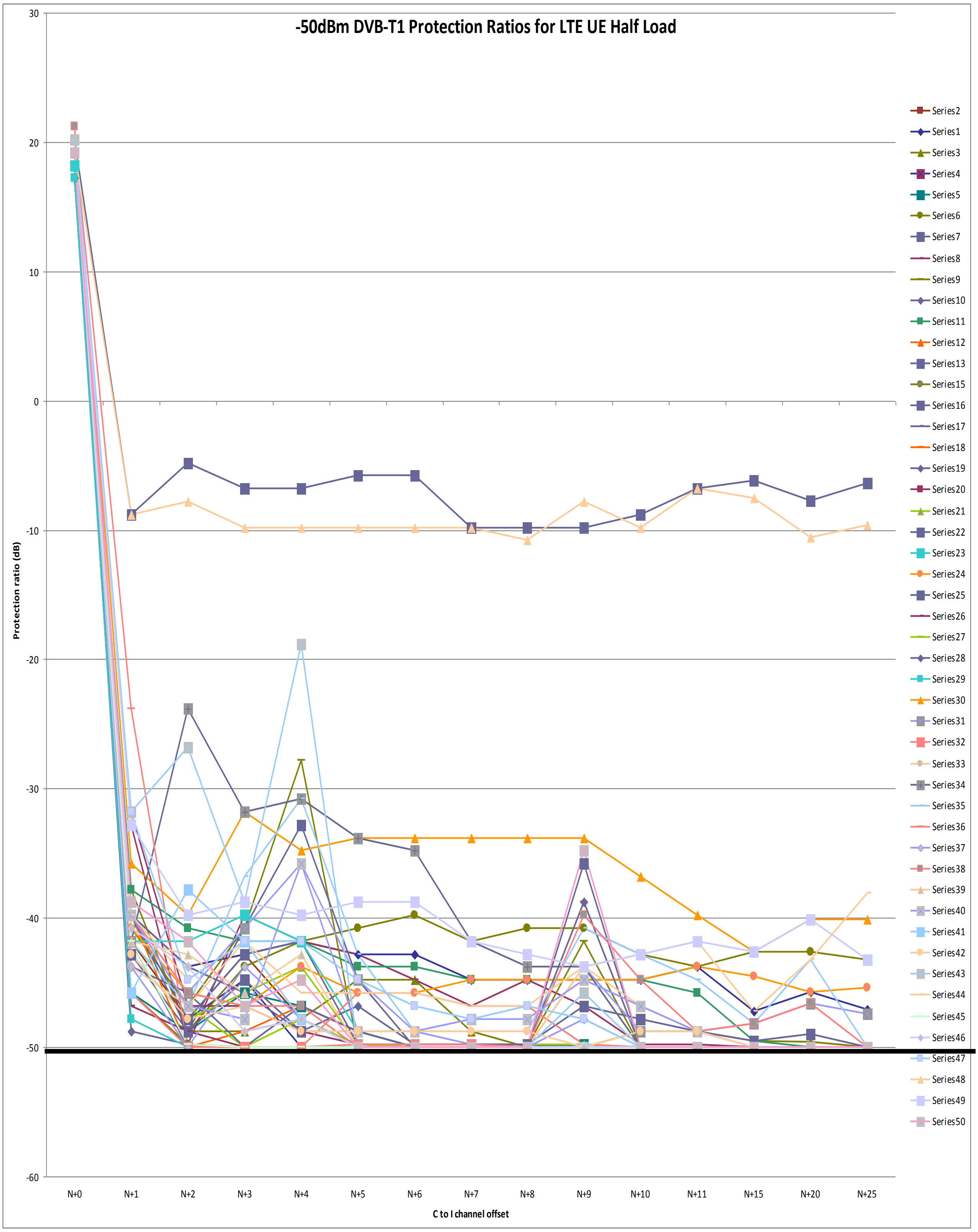

Figure 99 Protection ratio curve for LTE UE half load at-50dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -40dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

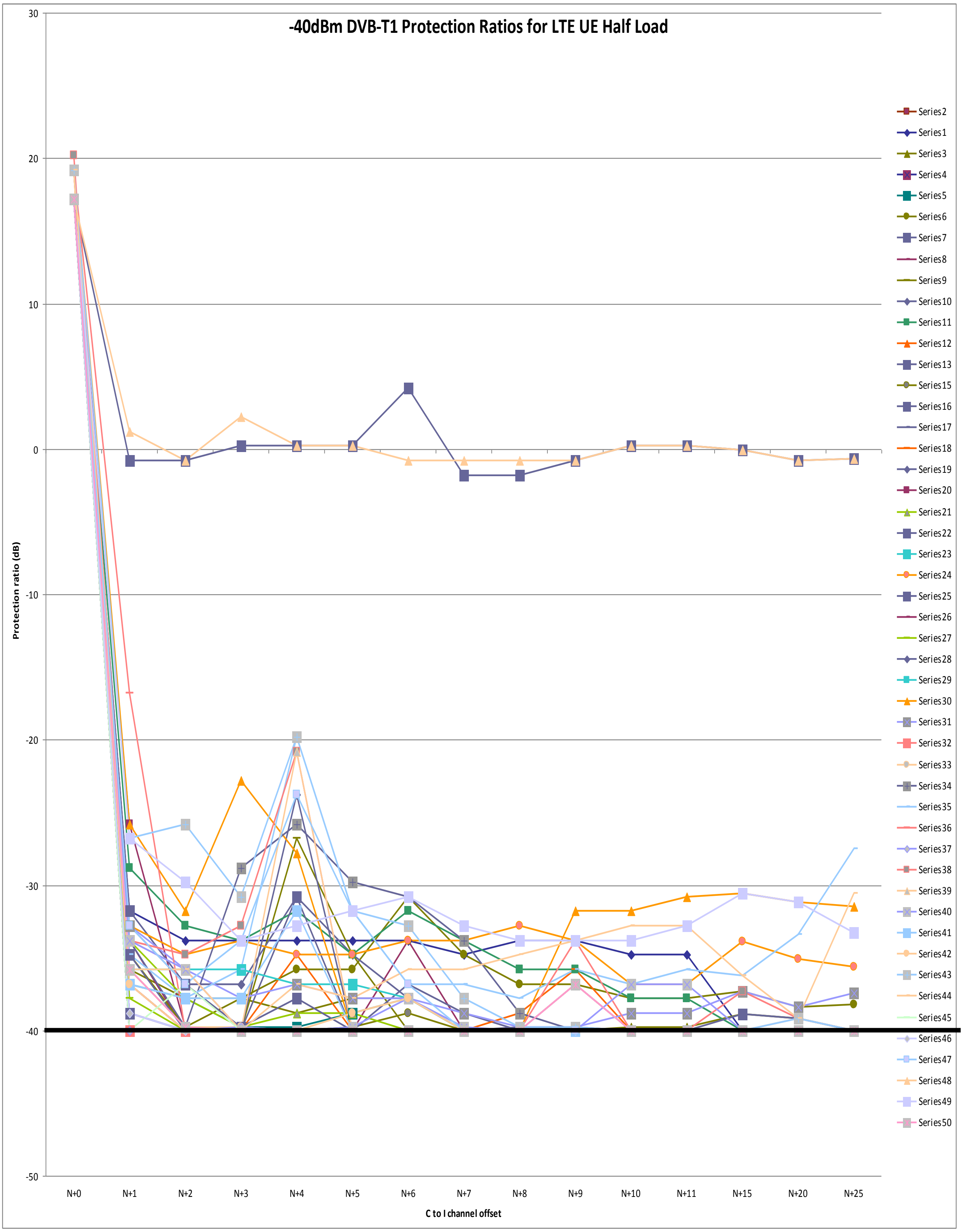

Figure 100 Protection ratio curve for LTE UE half load at-40dBm DVB-T1 DTT at offsets N+1 to N+25

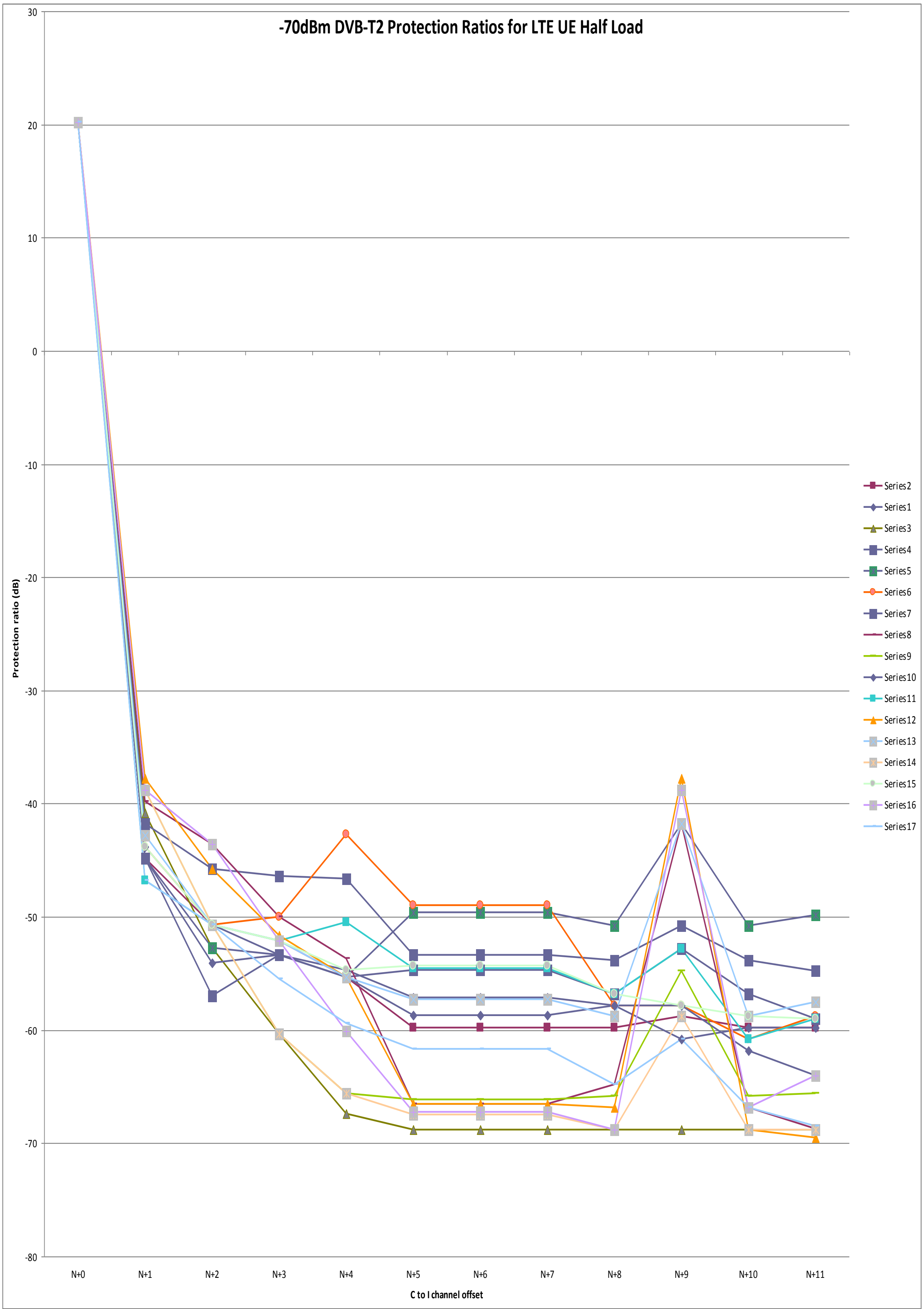

Figure 101 Protection ratio curve for LTE UE half load at-70dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -67dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

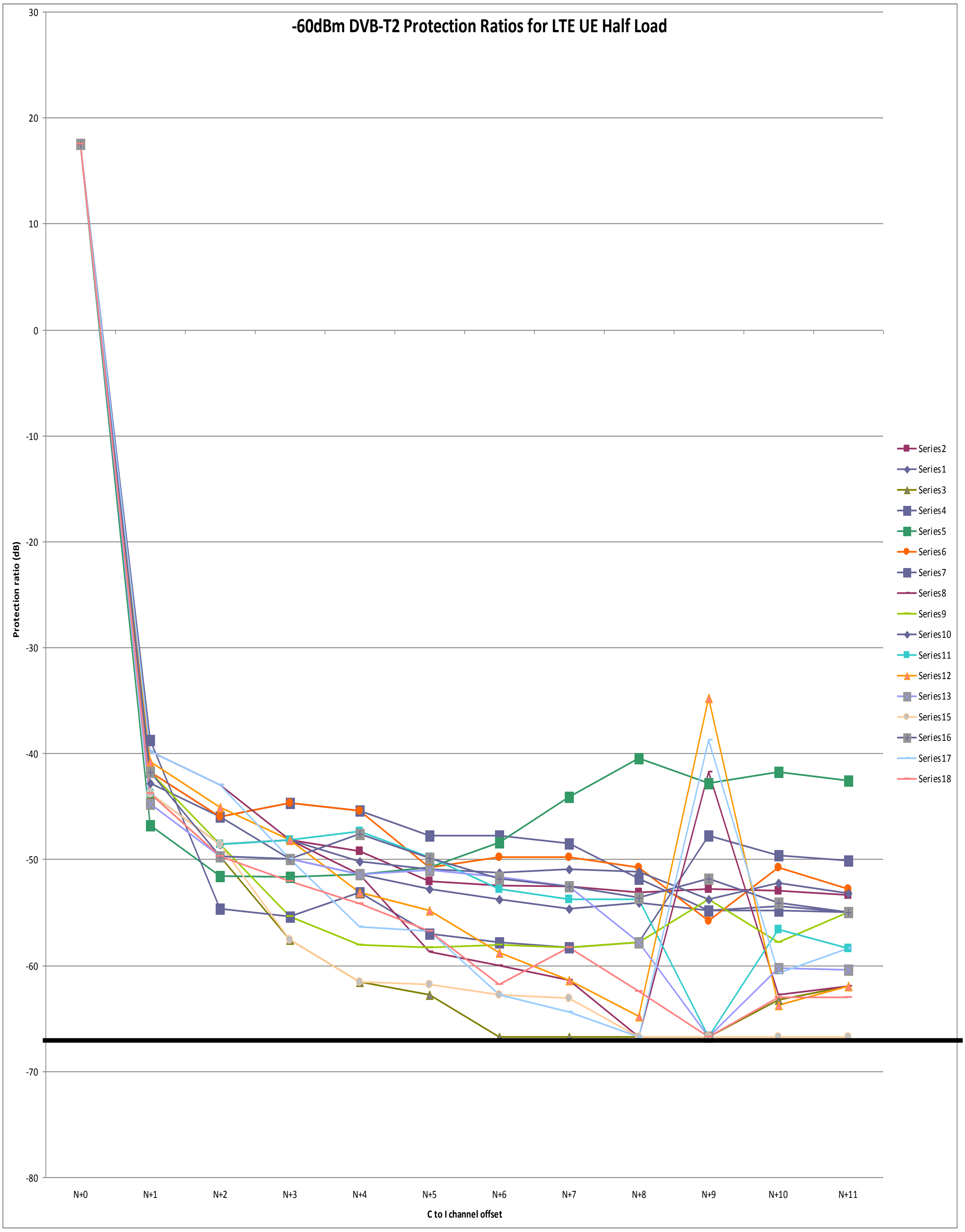

Figure 102 Protection ratio curve for LTE UE half load at-60dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -57dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

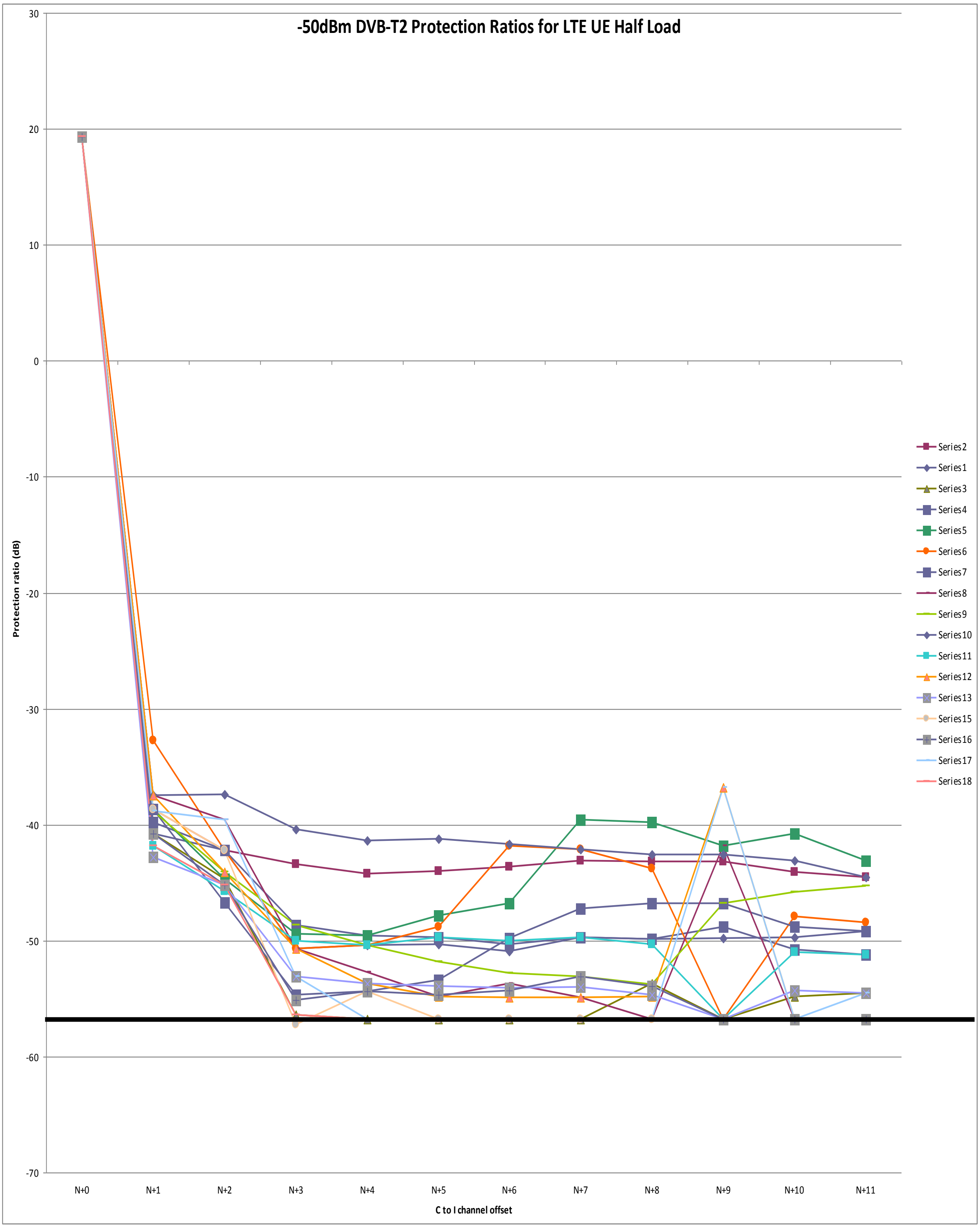

Figure 103 Protection ratio curve for LTE UE half load at-50dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -47dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

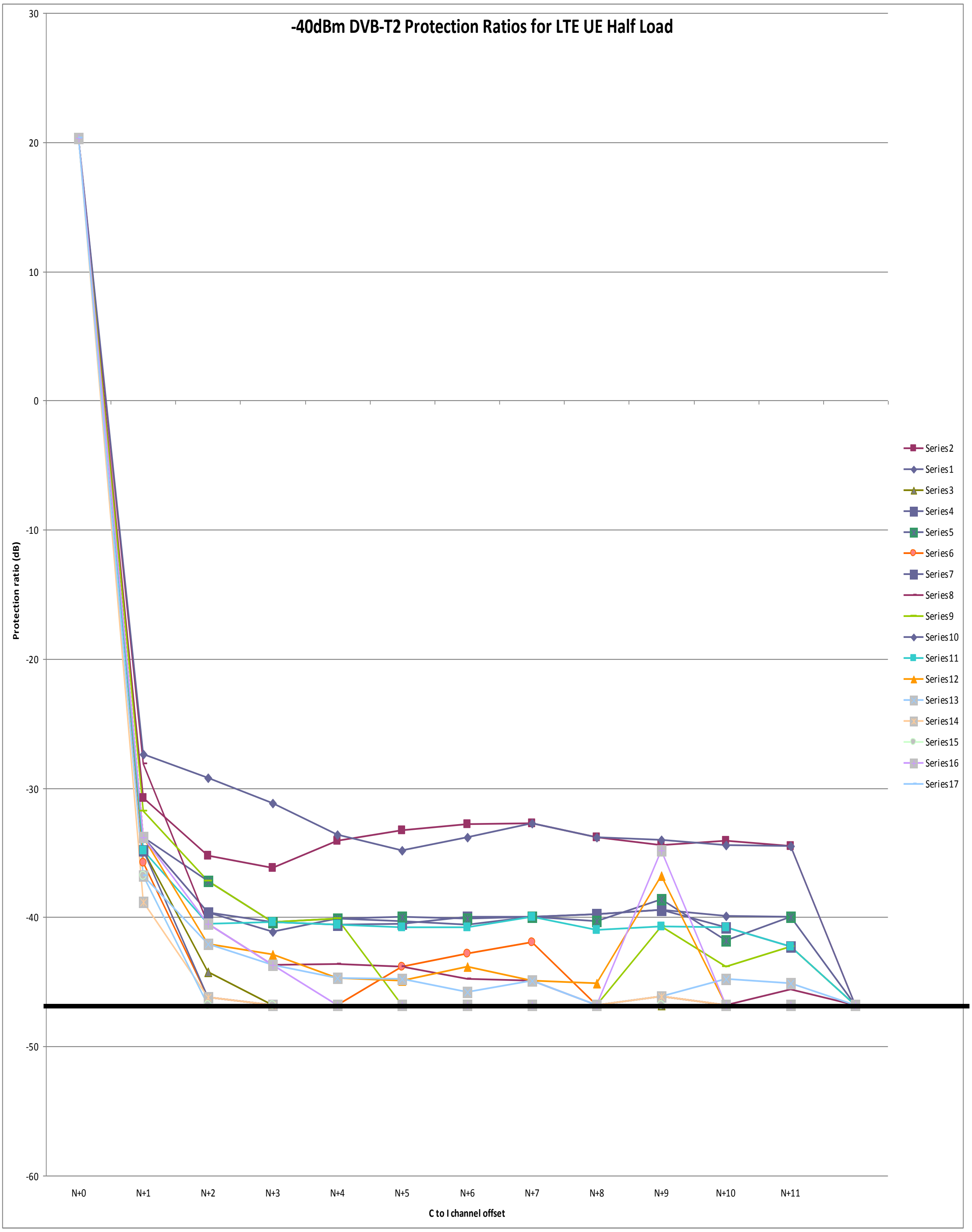

Figure 104 Protection ratio curve for LTE UE half load at-40dBm DVB-T2 DTT at offsets N+1 to N+11

A.6 LTE UE idle mode

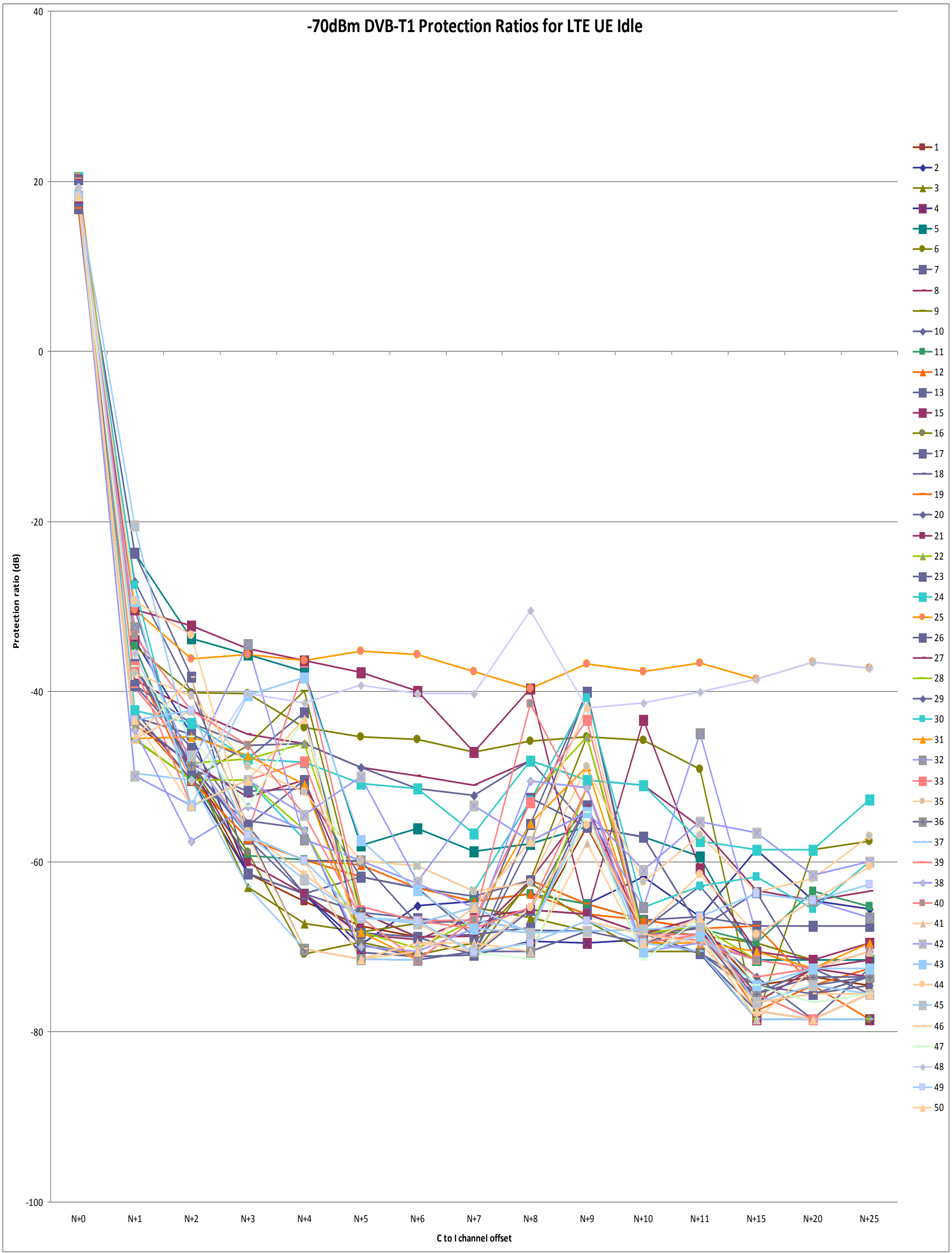

Figure 105 Protection ratio curve for LTE UE idle mode at-70dBm DVB-T1 DTT at offsets N+1 to N+25

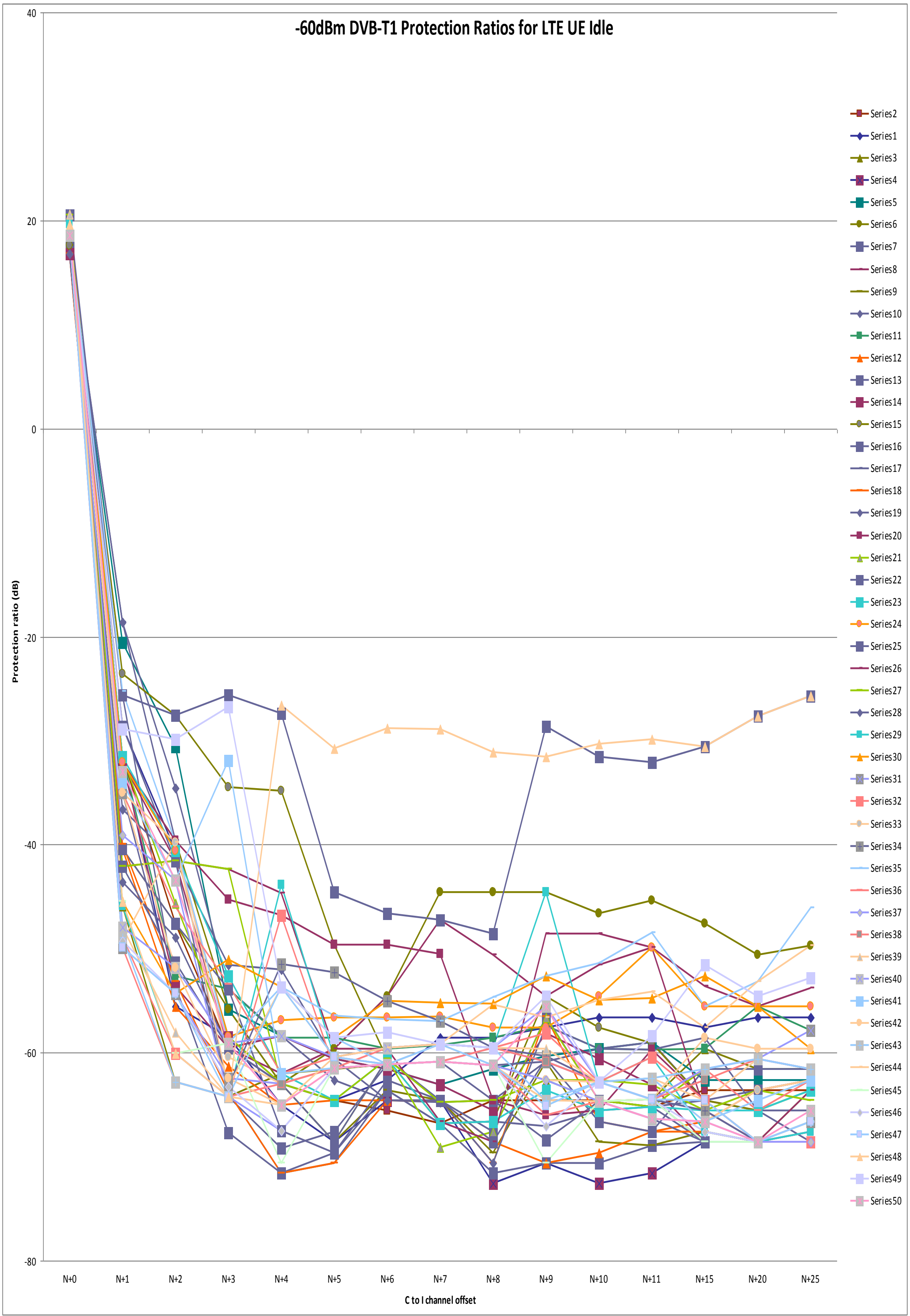

Figure 106 Protection ratio curve for LTE UE idle mode at-60dBm DVB-T1 DTT at offsets N+1 to N+25

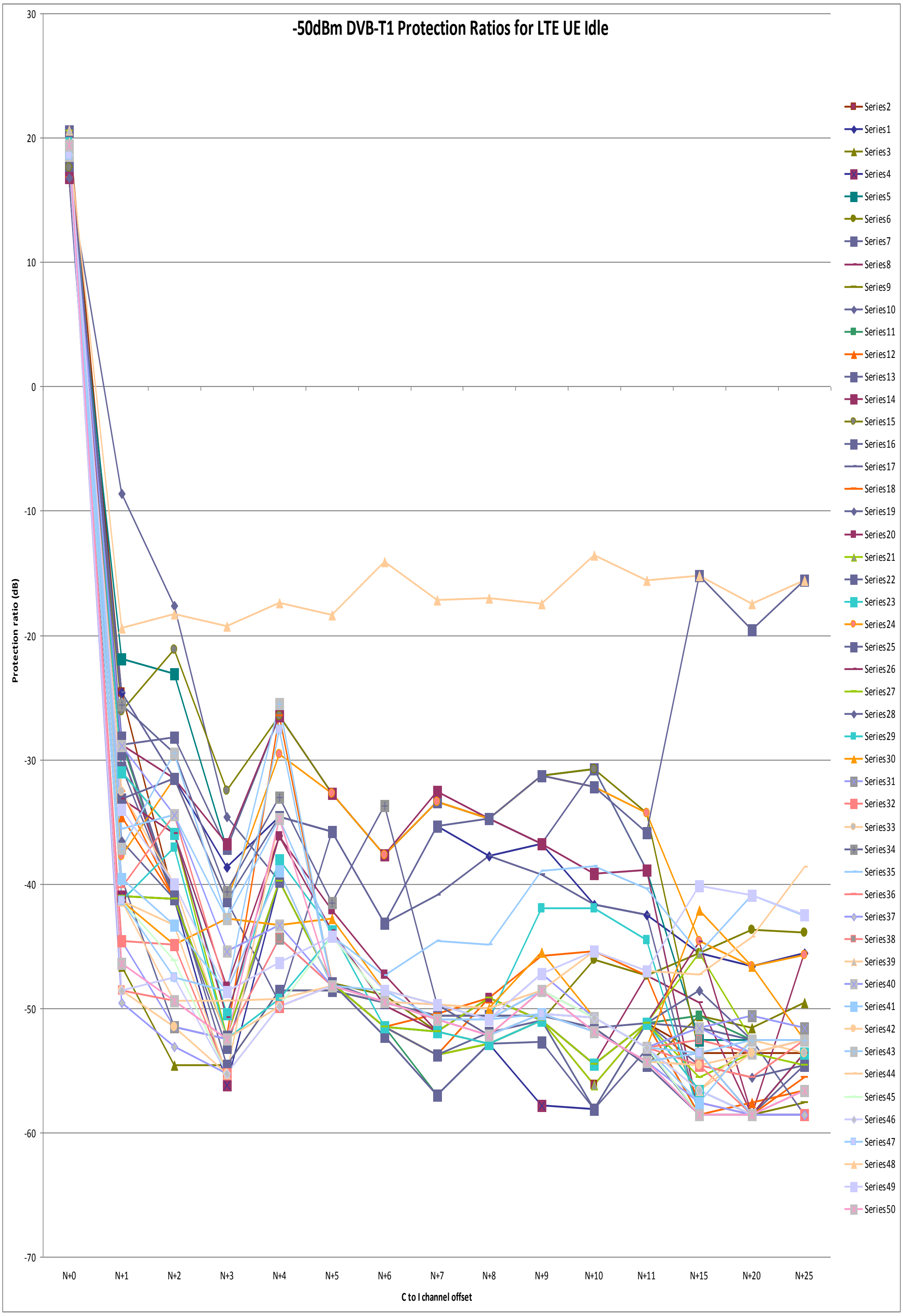

Figure 107 Protection ratio curve for LTE UE idle mode at-50dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -48dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

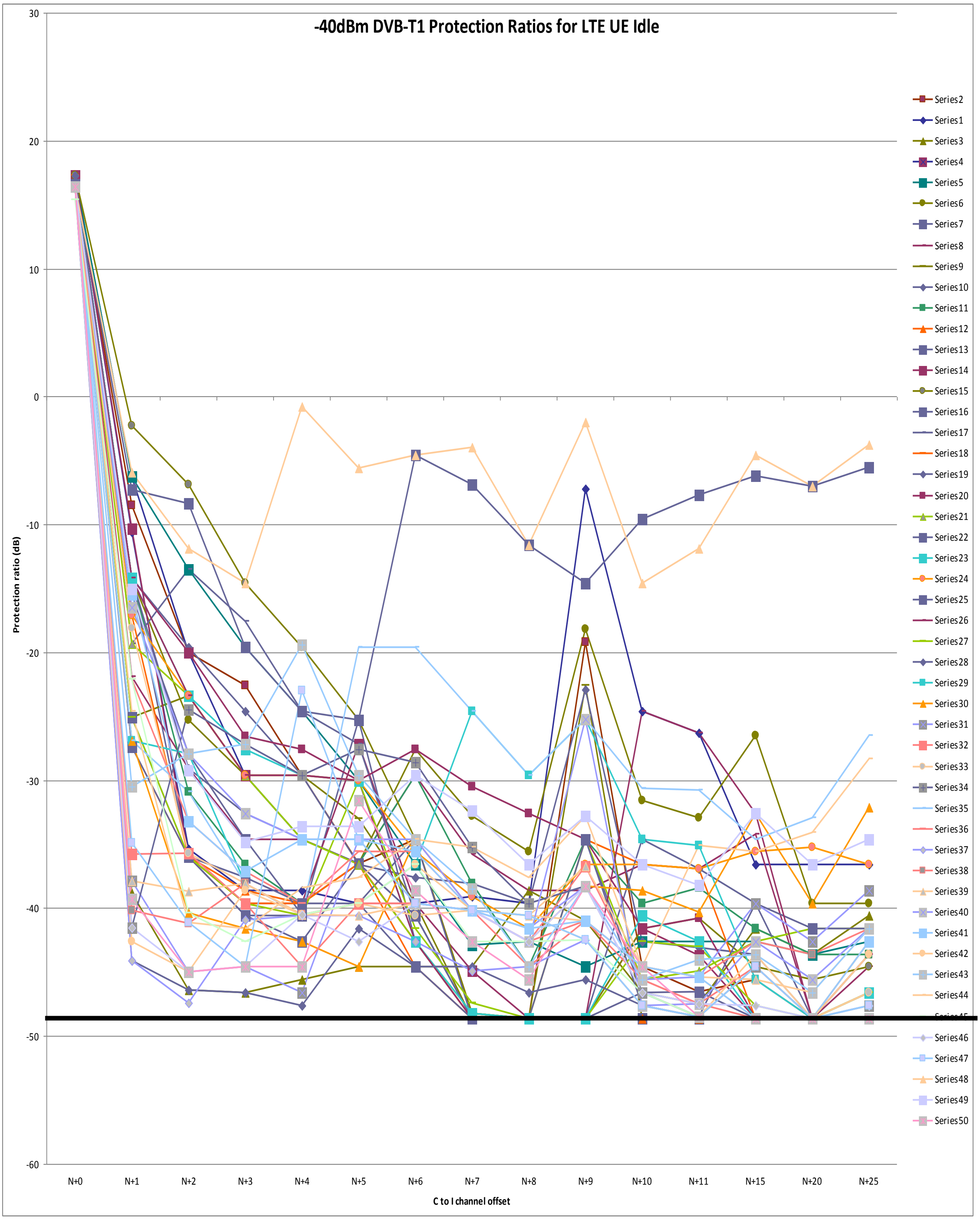

Figure 108 Protection ratio curve for LTE UE idle mode at-40dBm DVB-T1 DTT at offsets N+1 to N+25

The horizontal line at -70dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

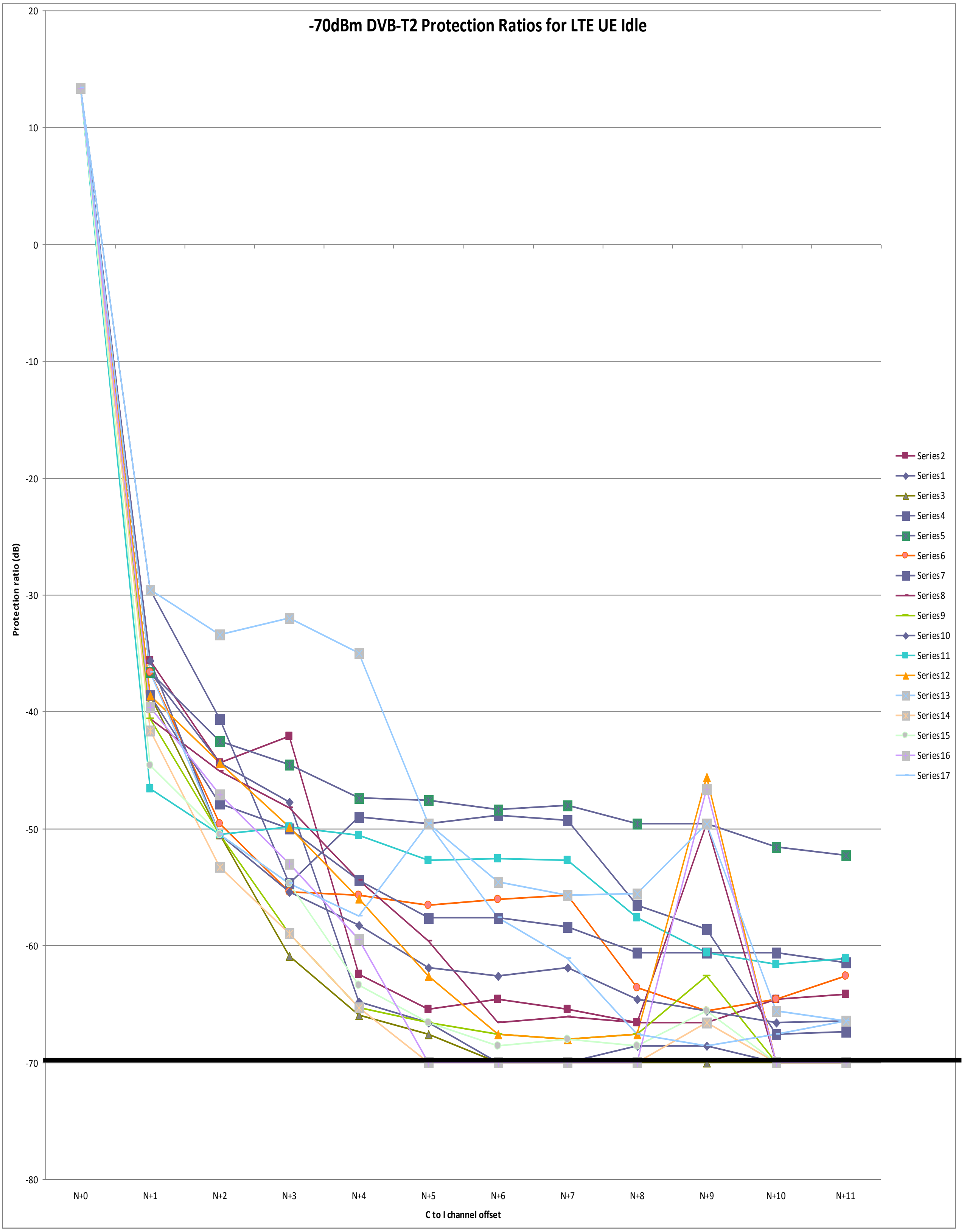

Figure 109 Protection ratio curve for LTE UE idle mode at-70dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at 60dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

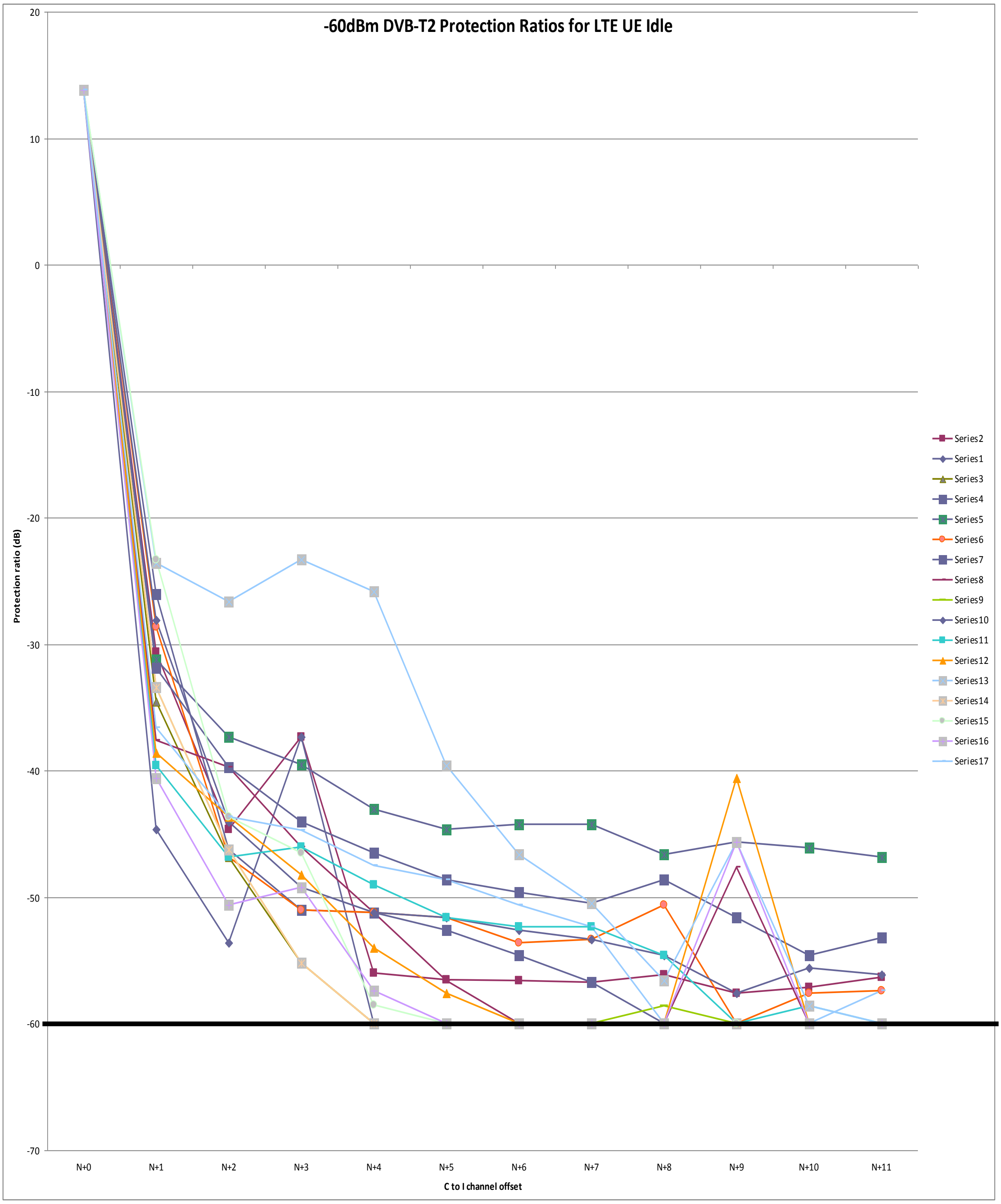

Figure 110 Protection ratio curve for LTE UE idle mode at-60dBm DVB-T2 DTT at offsets N+1 to N+11

The horizontal line at -46dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

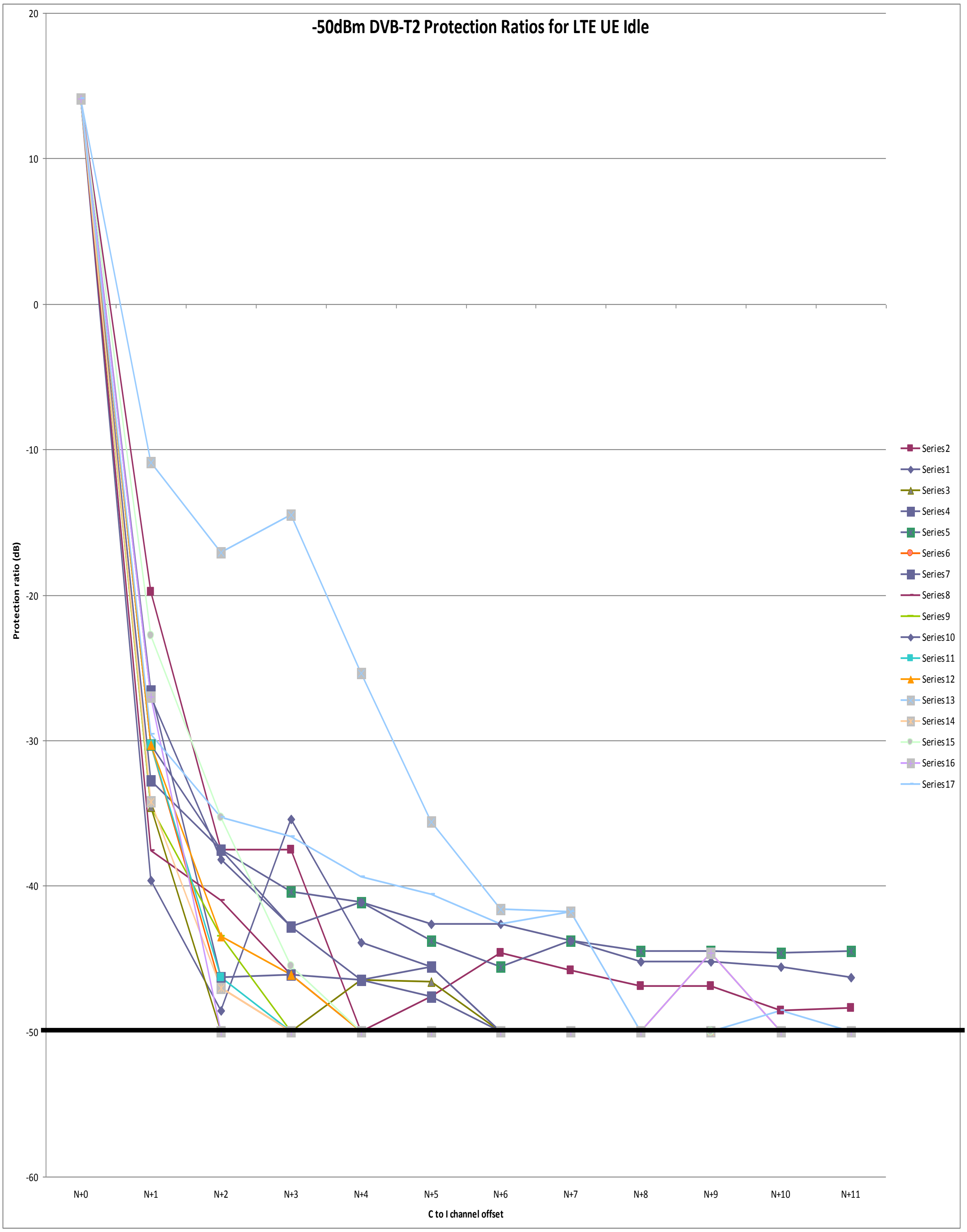

Figure 111 Protection ratio curve for LTE UE idle mode at-50dBm DVB-T1 DTT at offsets N+1 to N+11

The horizontal line at -46dBm protection ratio represents the maximum limit for the interferer. Where the protection ratio curves level off at this point it means that the receiver did not fail when the maximum level had been reached.

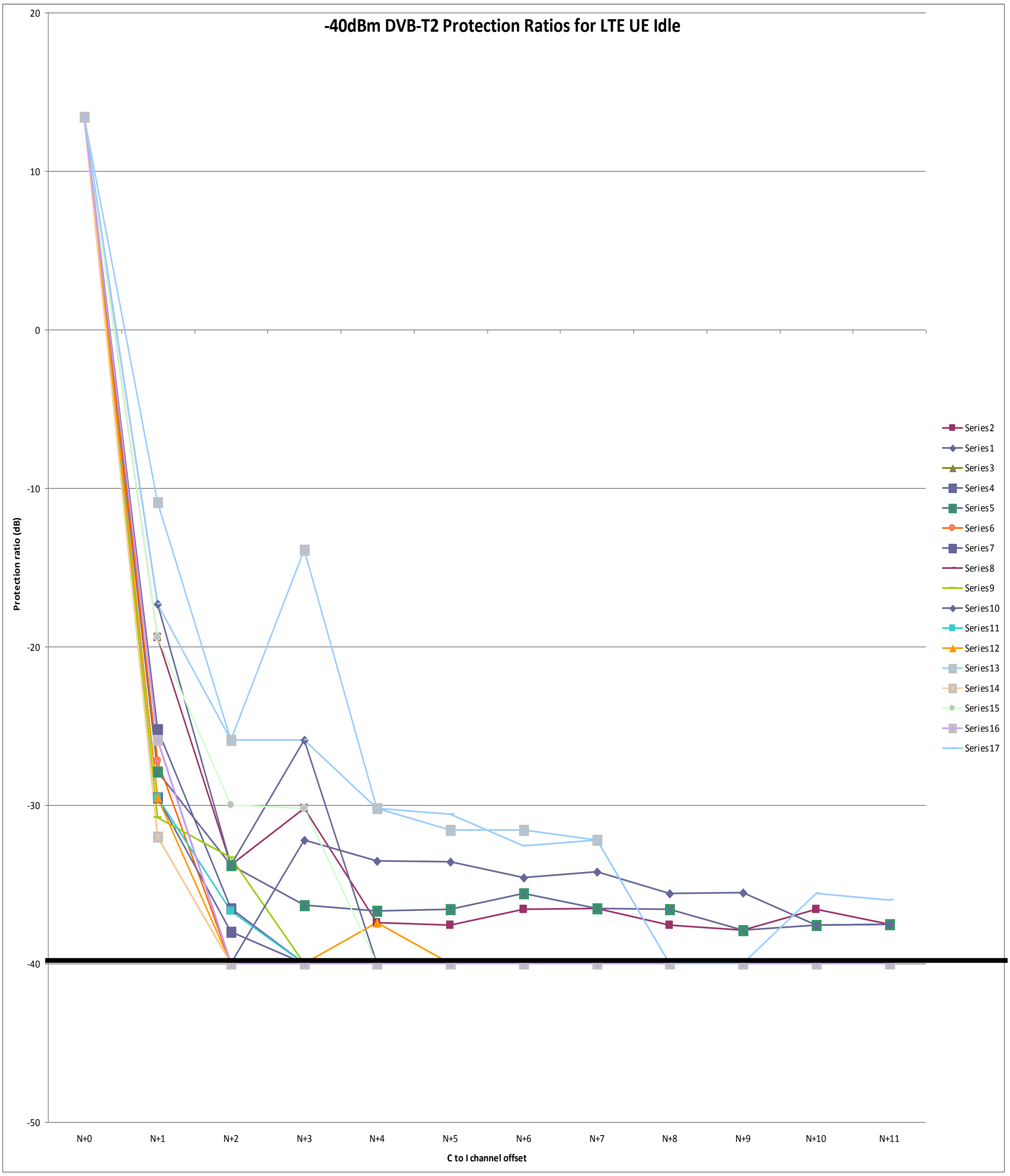

Figure 112 Protection ratio curve for LTE UE idle mode at-40dBm DVB-T2 DTT at offsets N+1 to N+11

Appendix B – ACS CDF graphs

B.1 ACS values at frequency offsets N±1, 2, 3, 4, 9, 11 for DTT at -70dBm

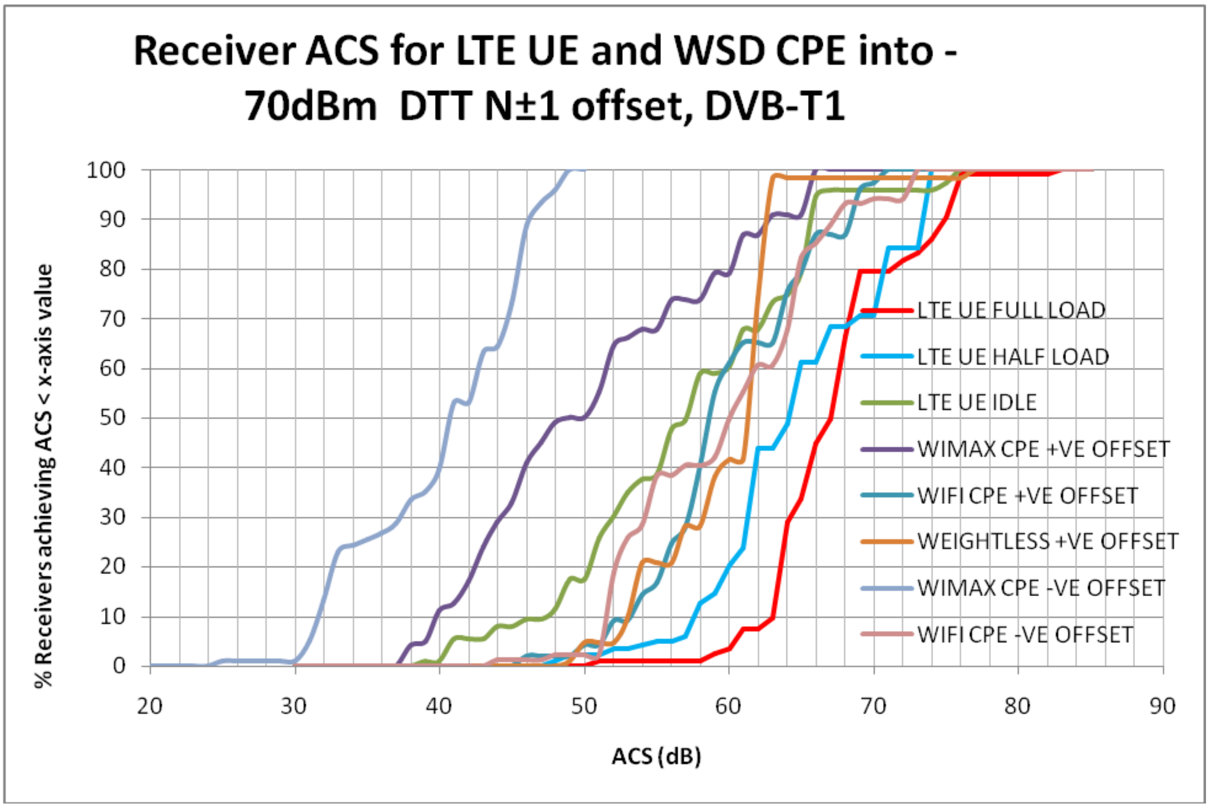

Figure 113 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±1

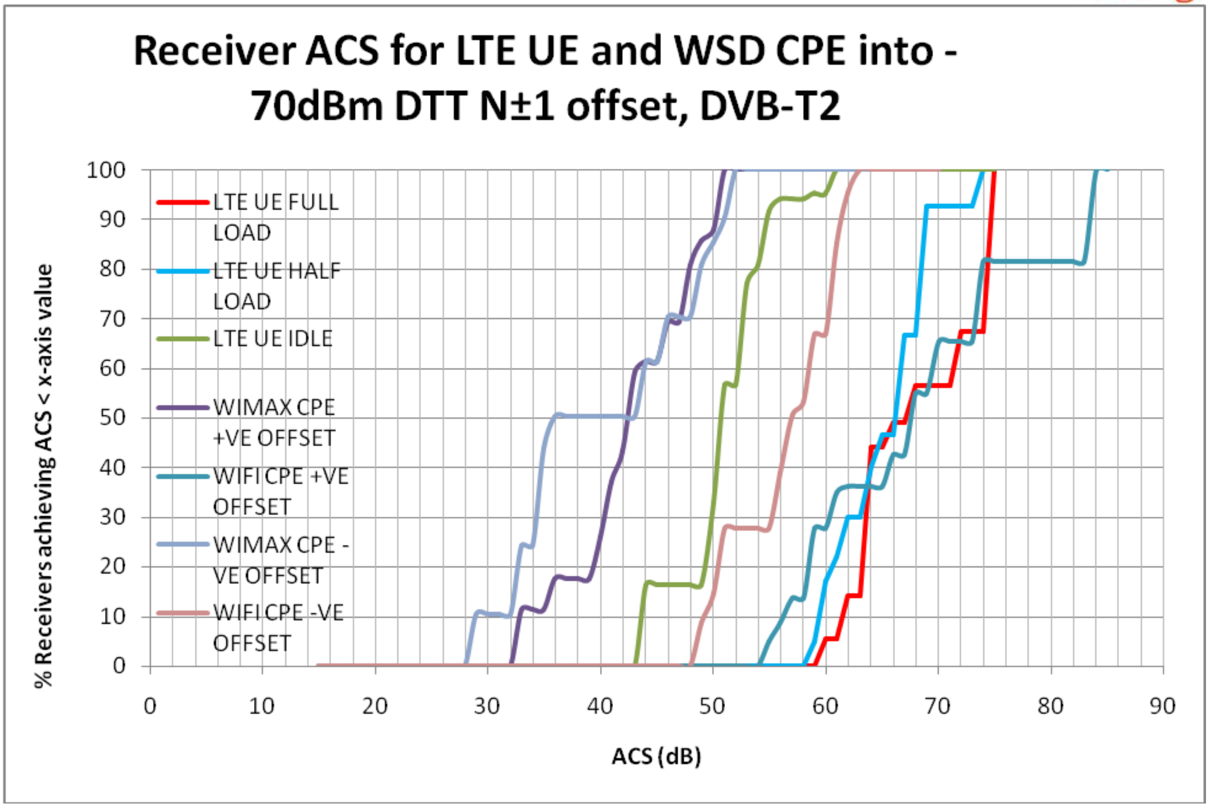

Figure 114 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±1

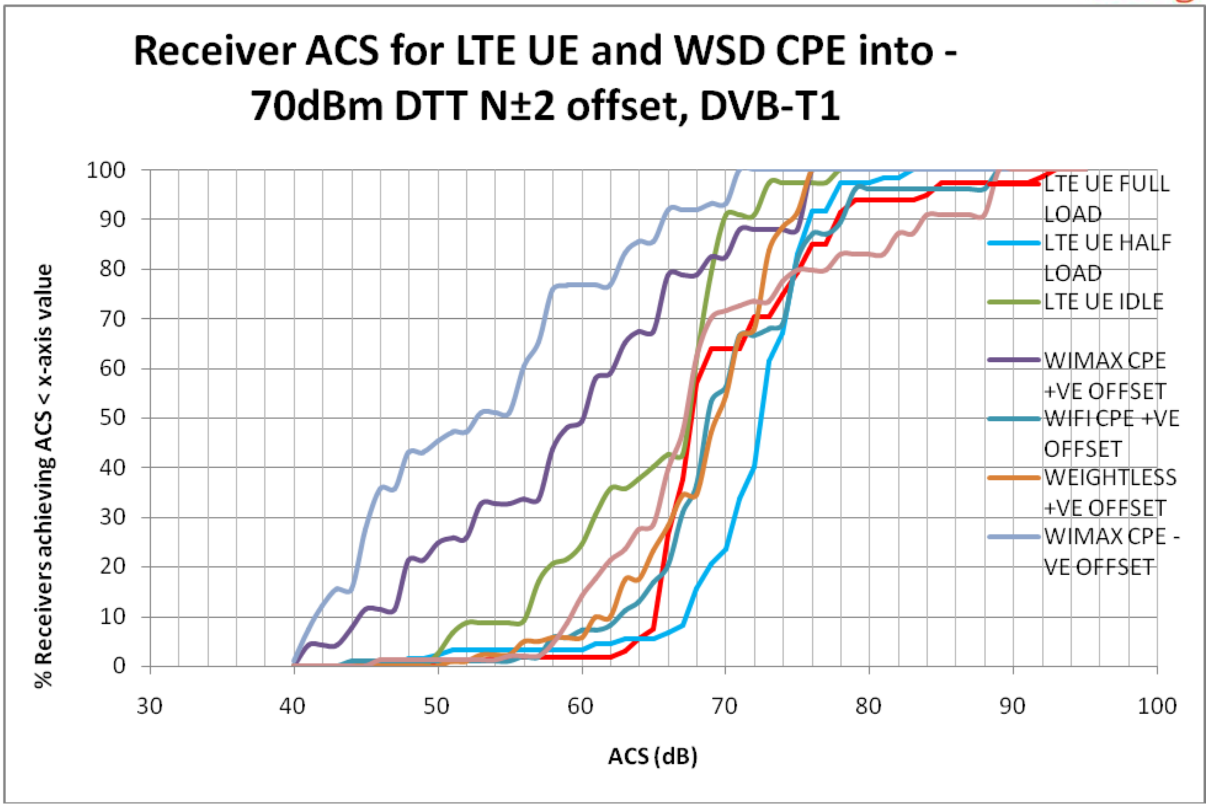

Figure 115 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±2

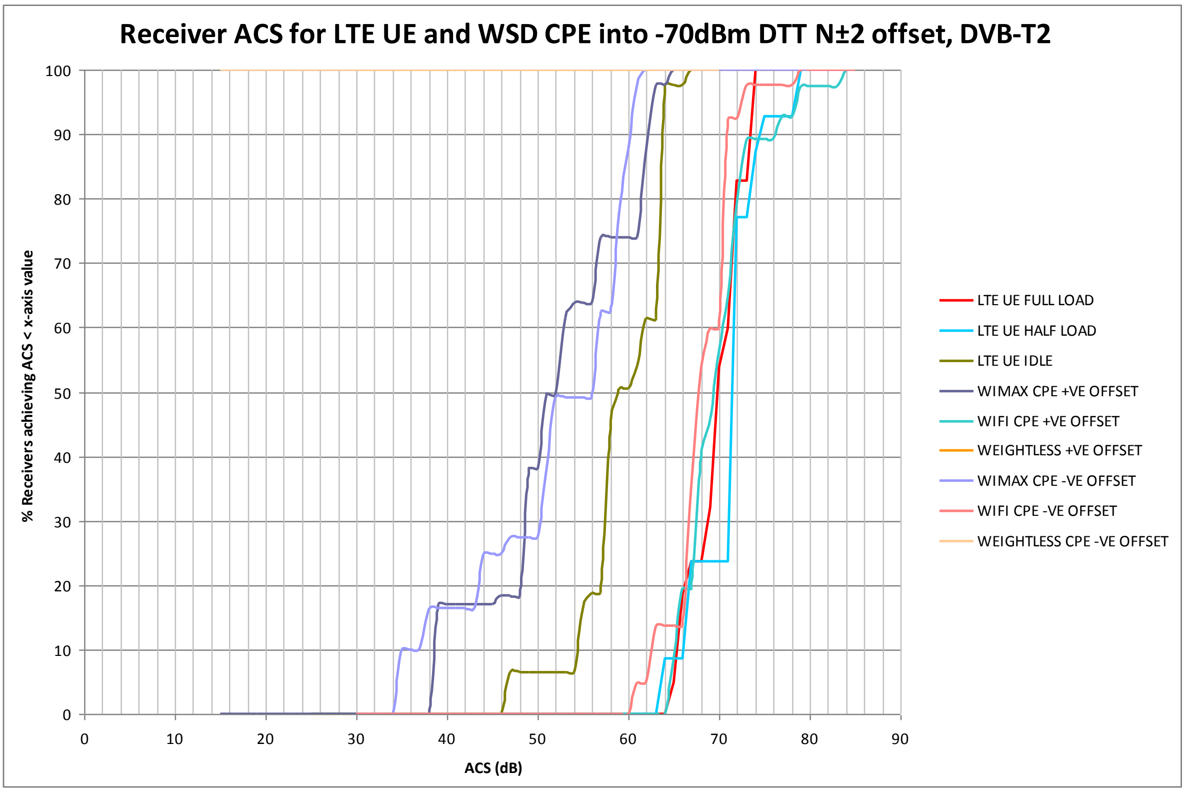

Figure 116 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±2

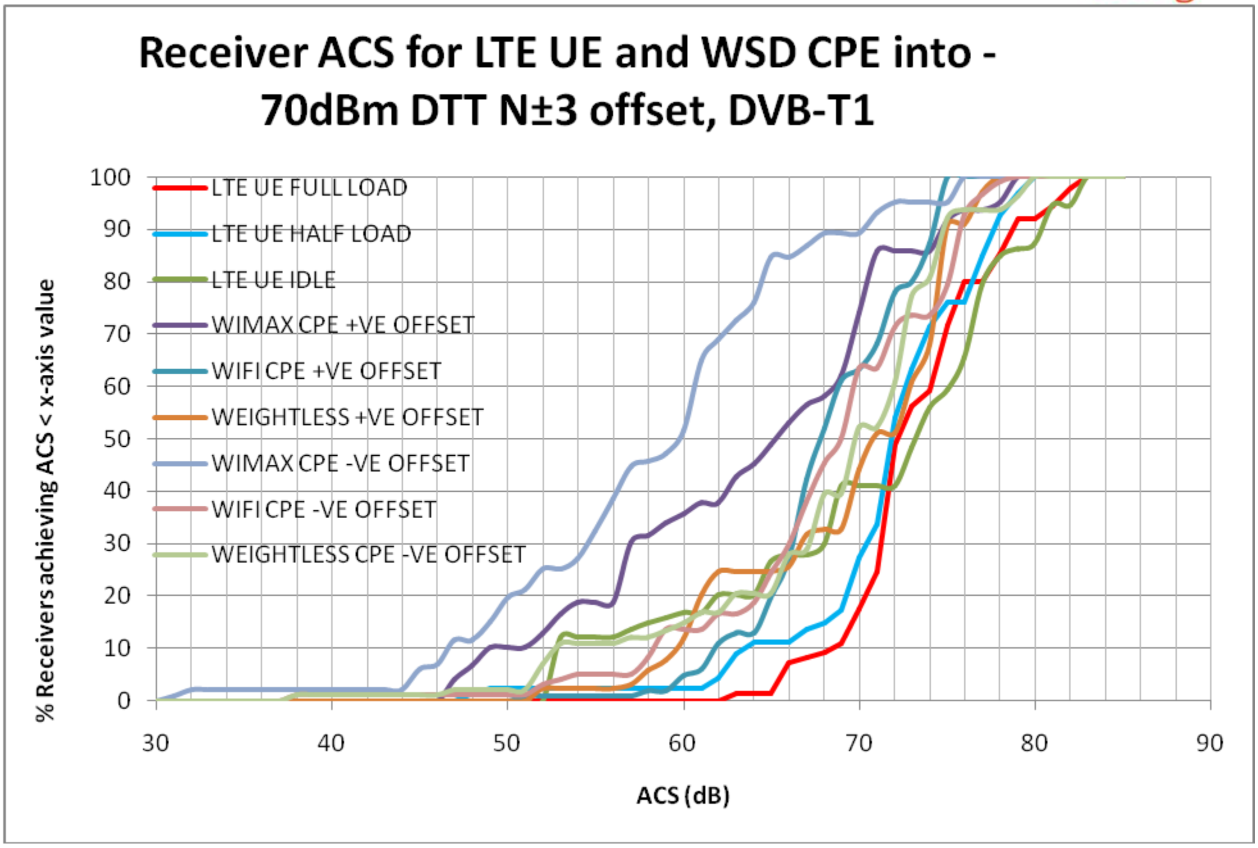

Figure 117 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±3

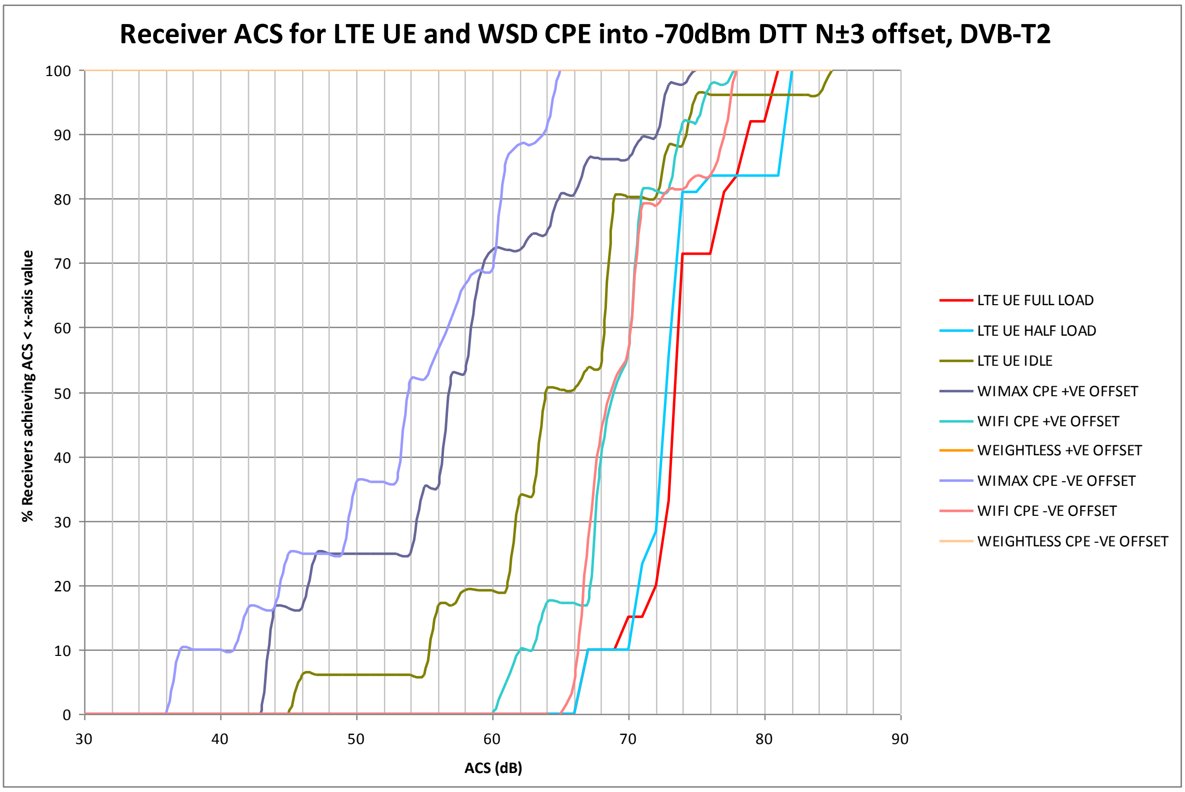

Figure 118 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±3

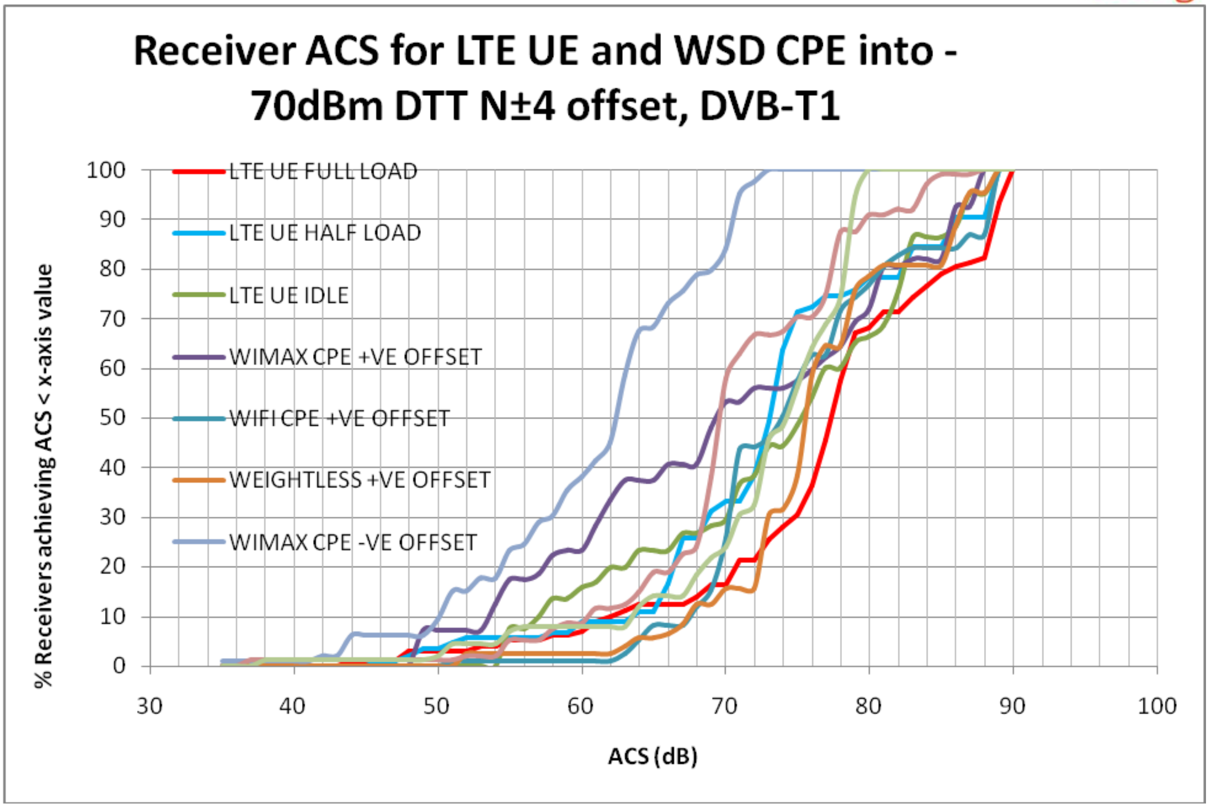

Figure 119 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±4

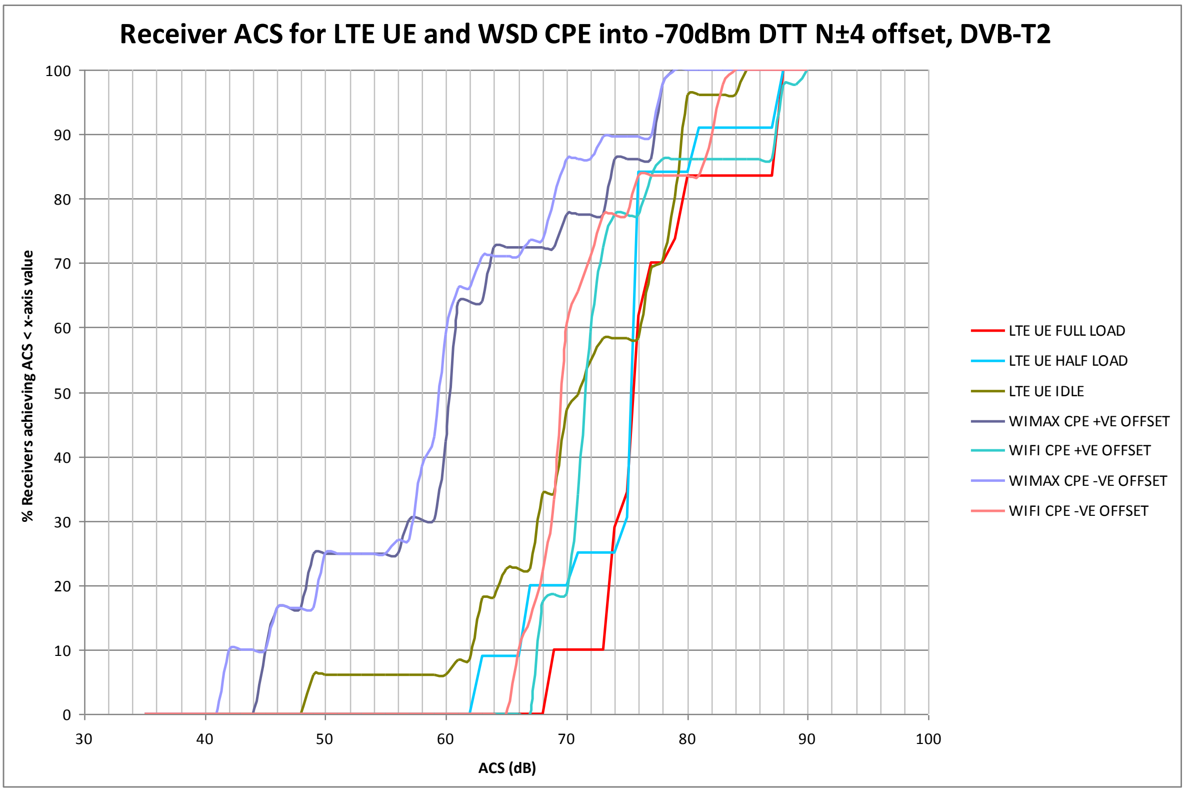

Figure 120 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±4

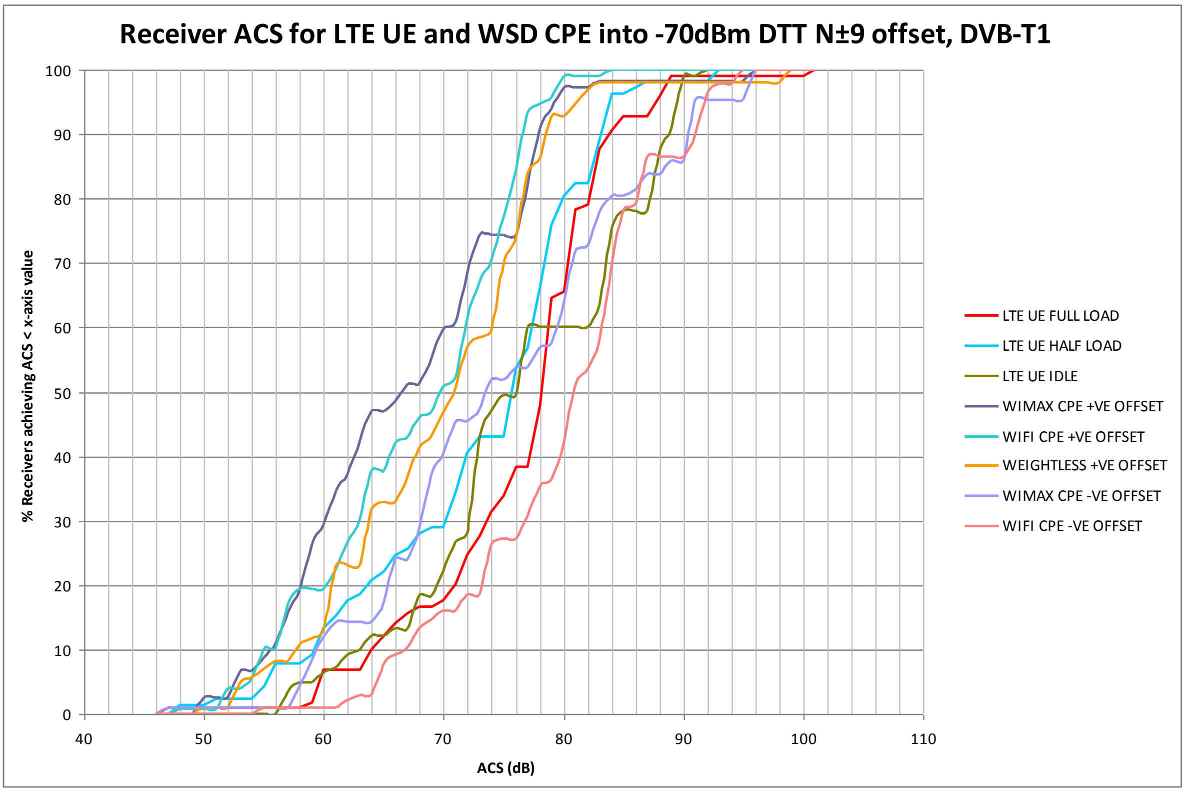

Figure 121 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±9

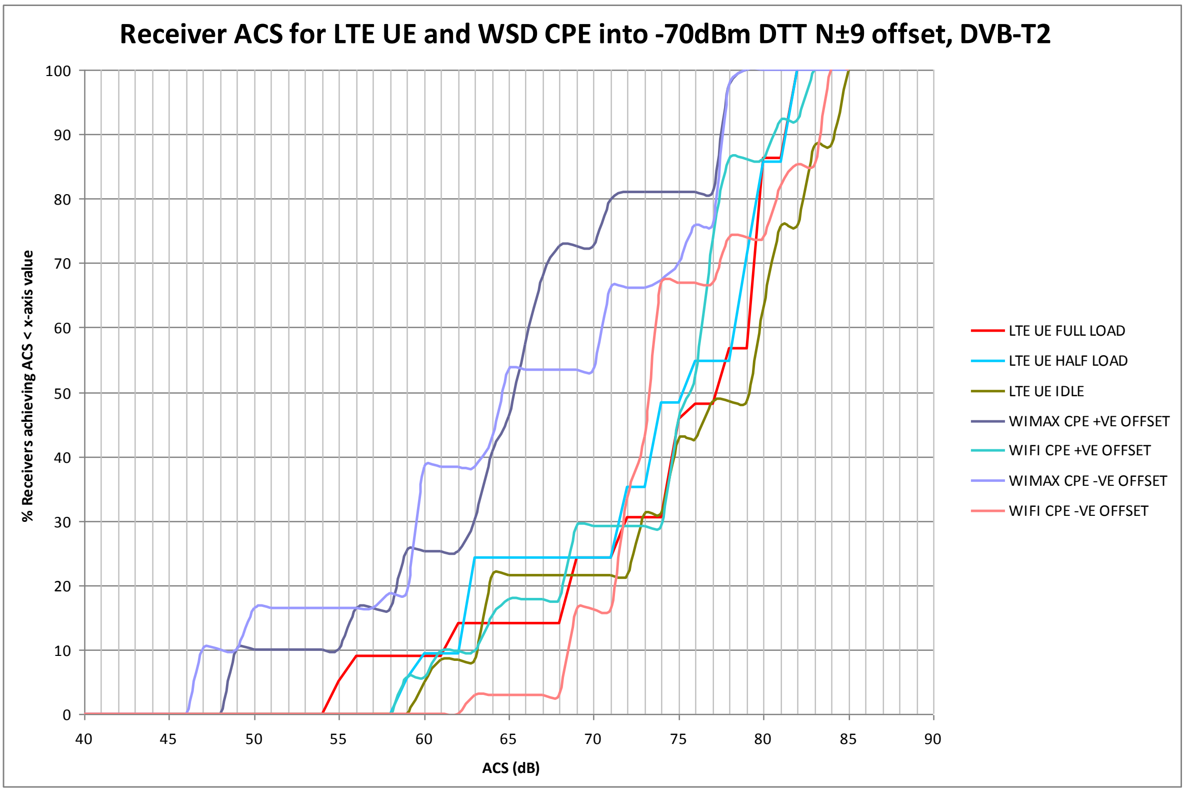

Figure 122 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±9

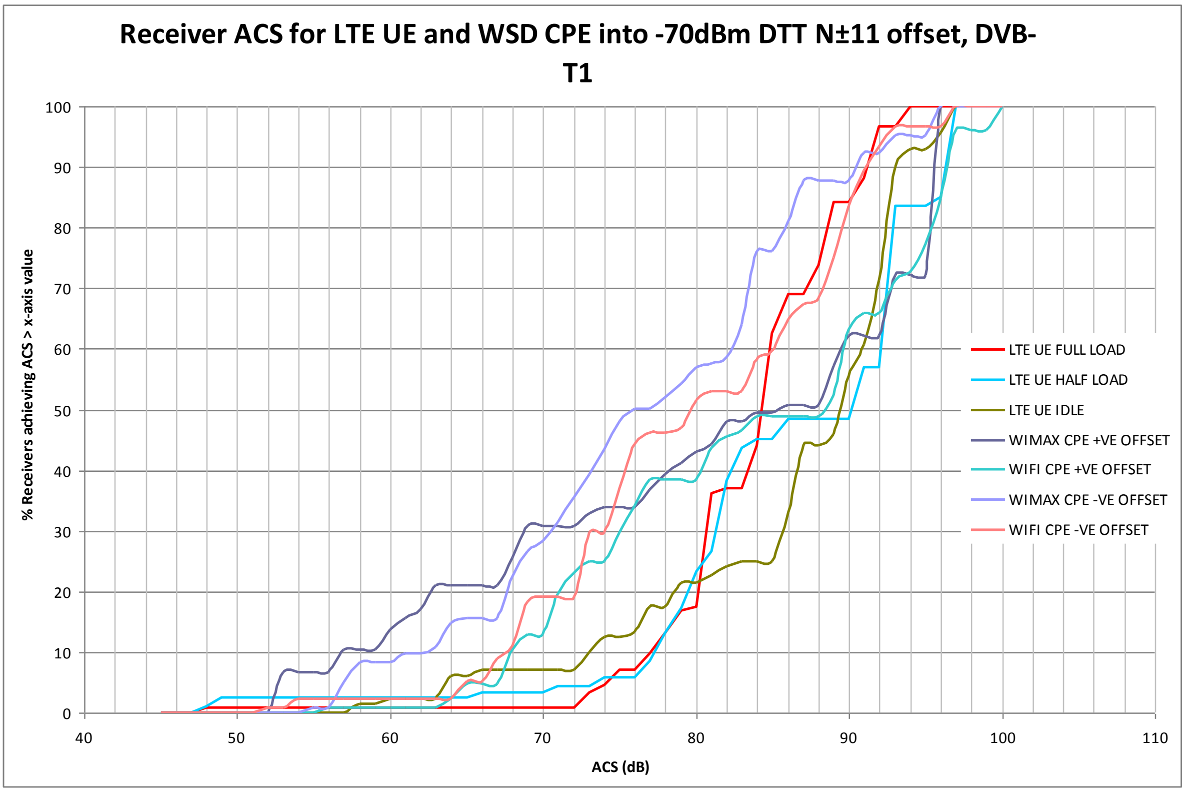

Figure 123 CDF of ACS values at-70dBm DVB-T1 DTT at offsets N±11

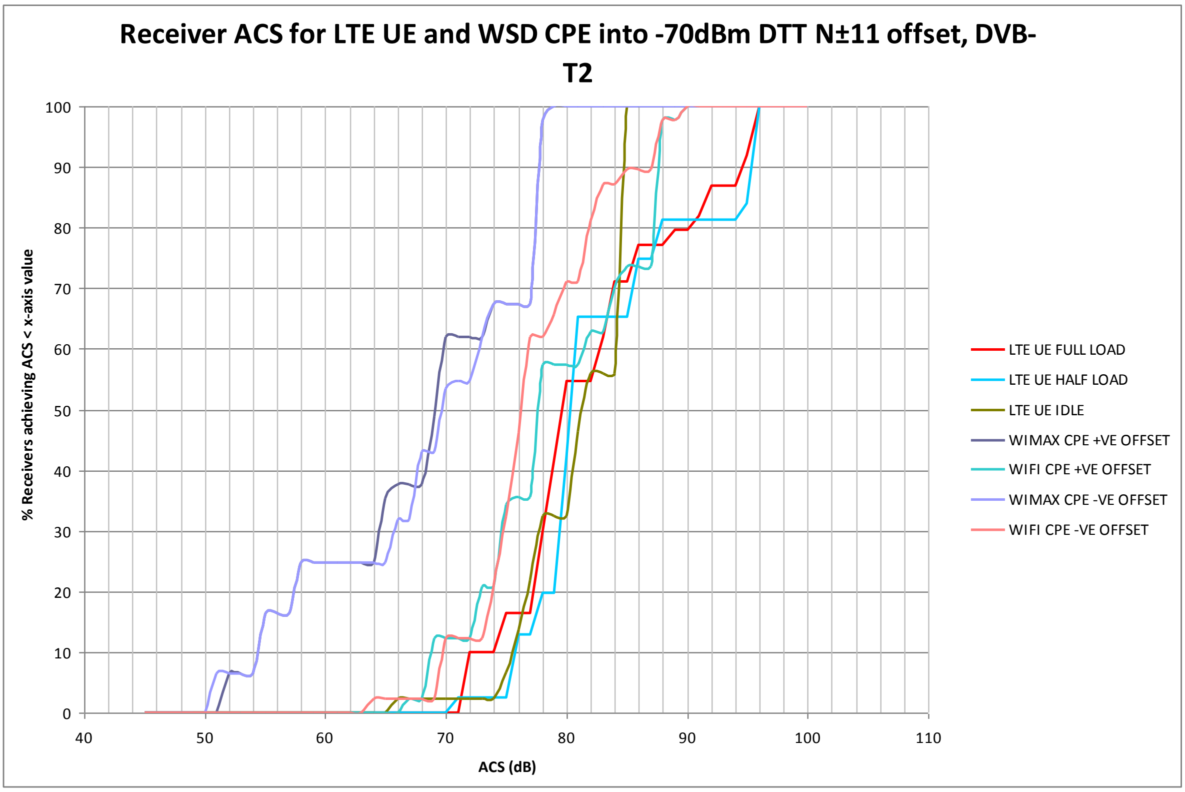

Figure 124 CDF of ACS values at-70dBm DVB-T2 DTT at offsets N±11

B.2 ACS values at frequency offsets N±1, 2, 3, 4, 9, 11 for DTT at -60dBm

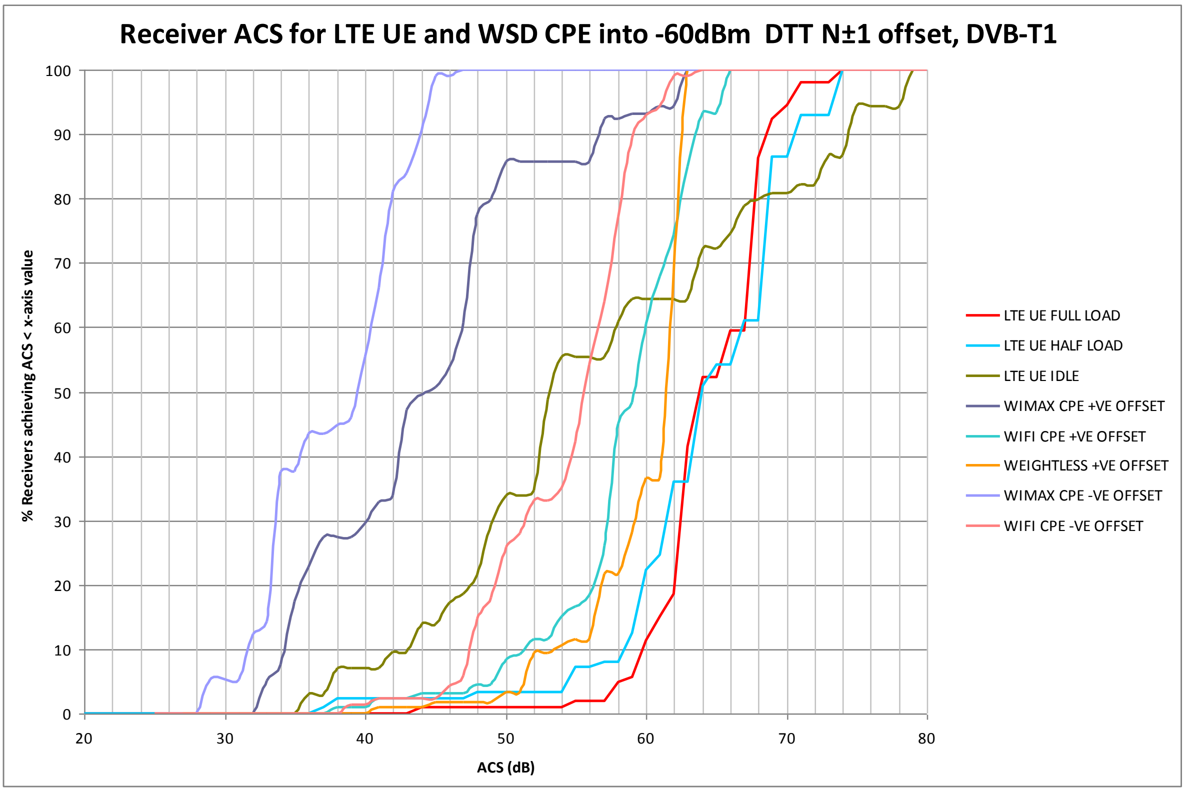

Figure 125 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±1

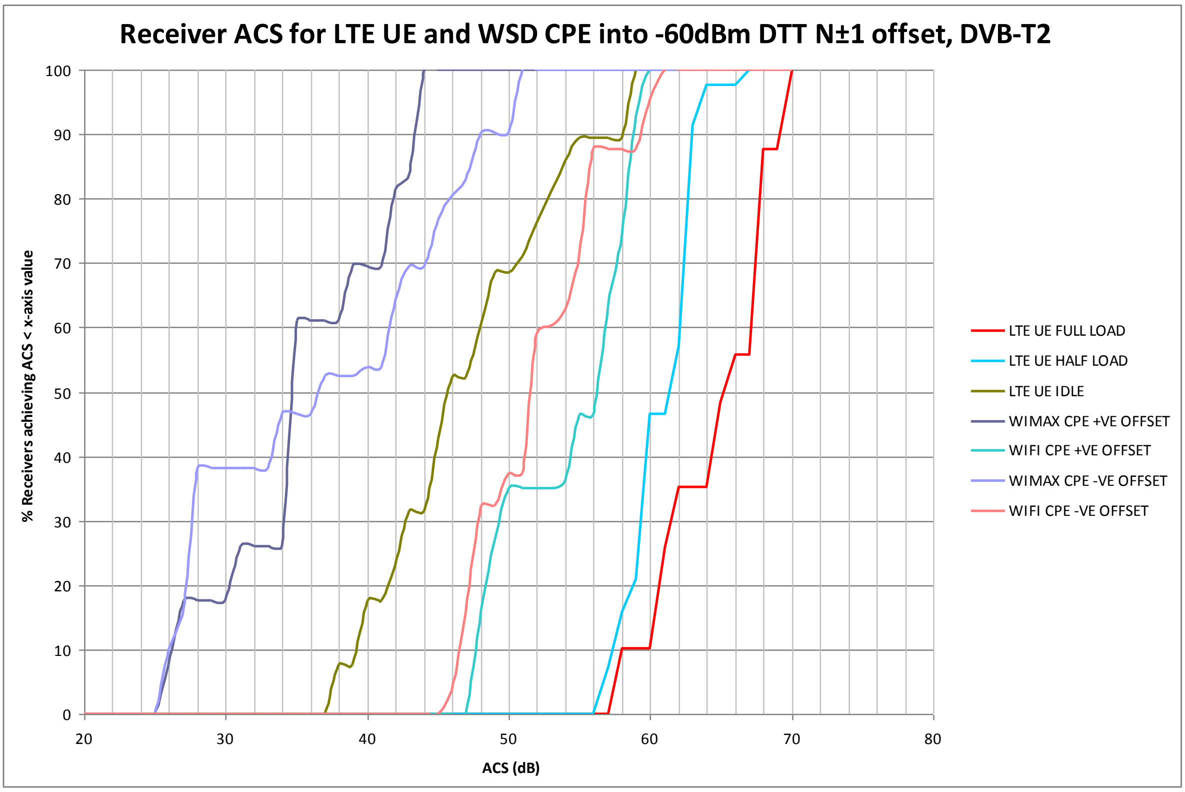

Figure 126 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±1

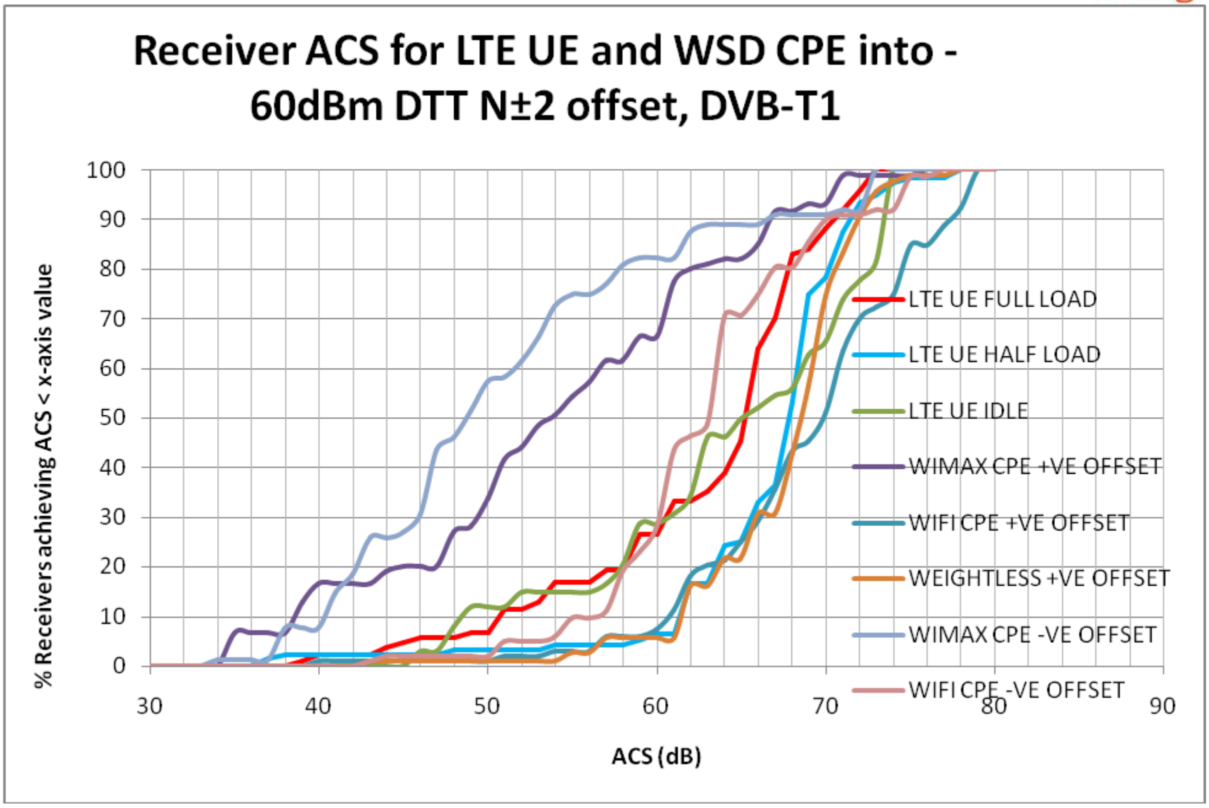

Figure 127 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±2

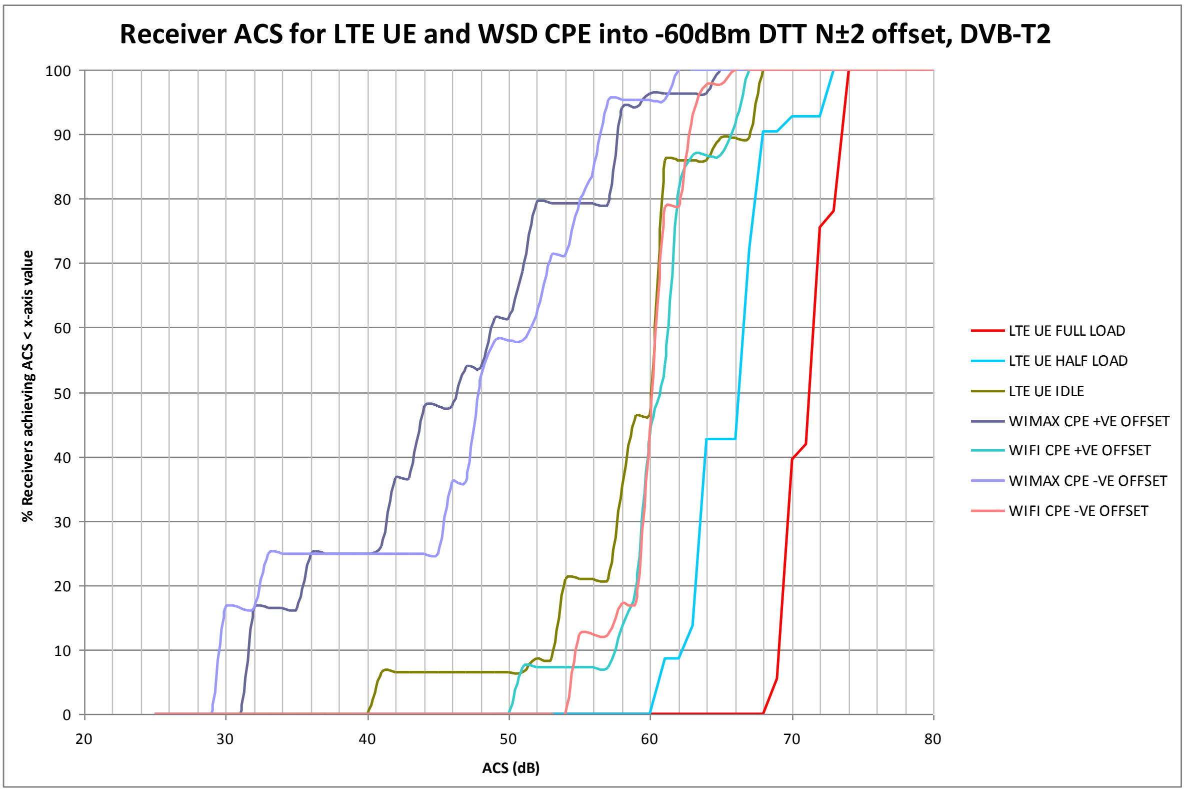

Figure 128 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±2

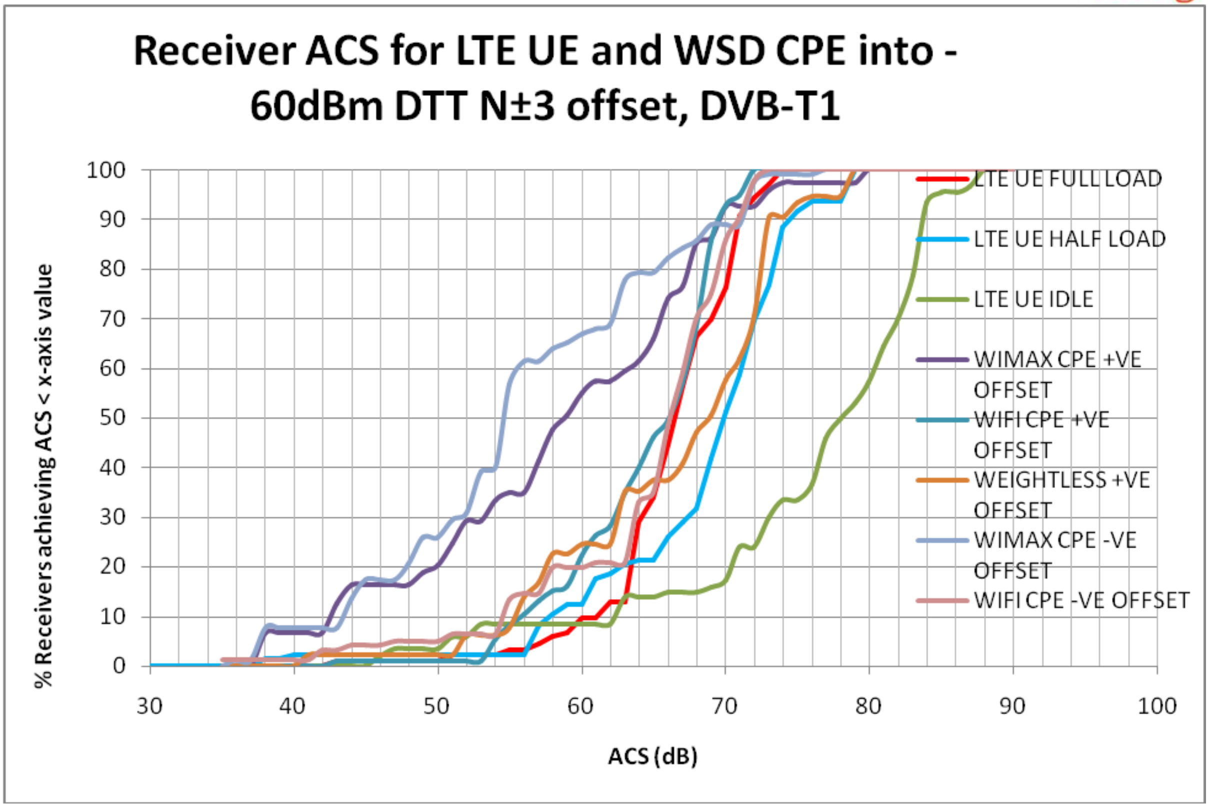

Figure 129 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±3

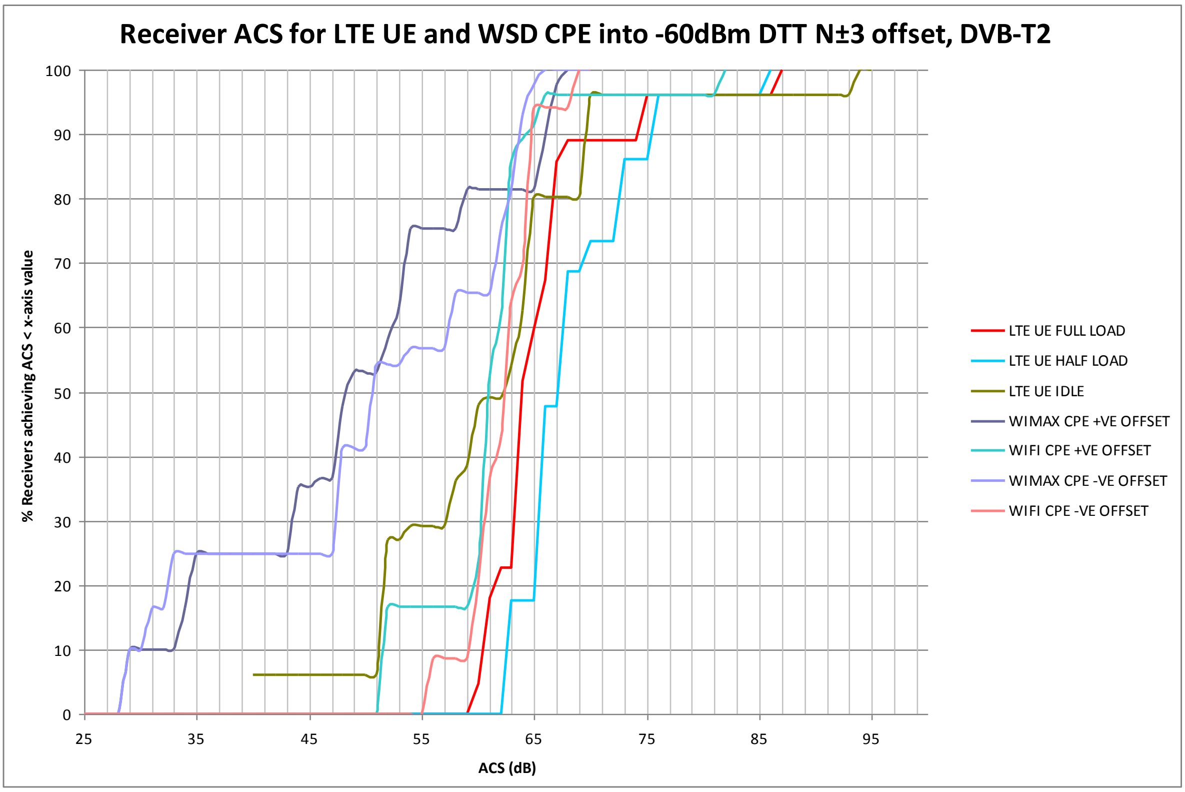

Figure 130 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±3

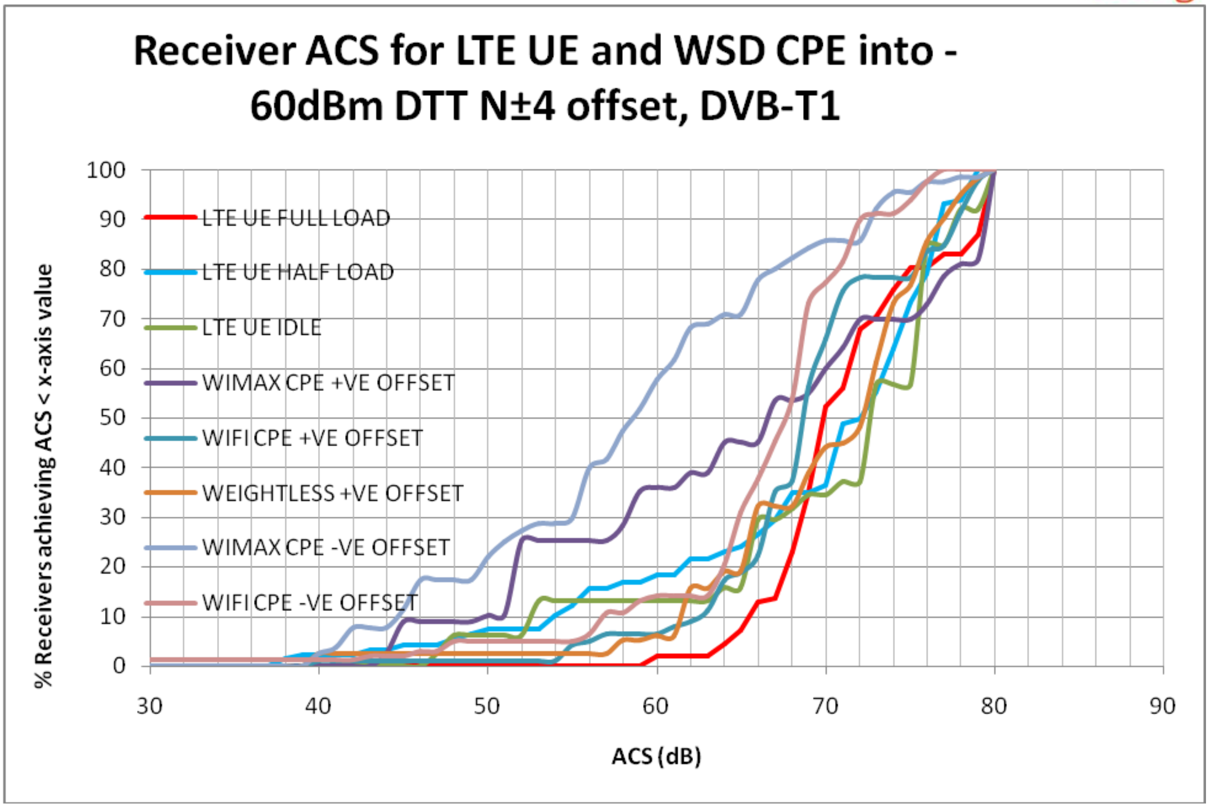

Figure 131 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±4

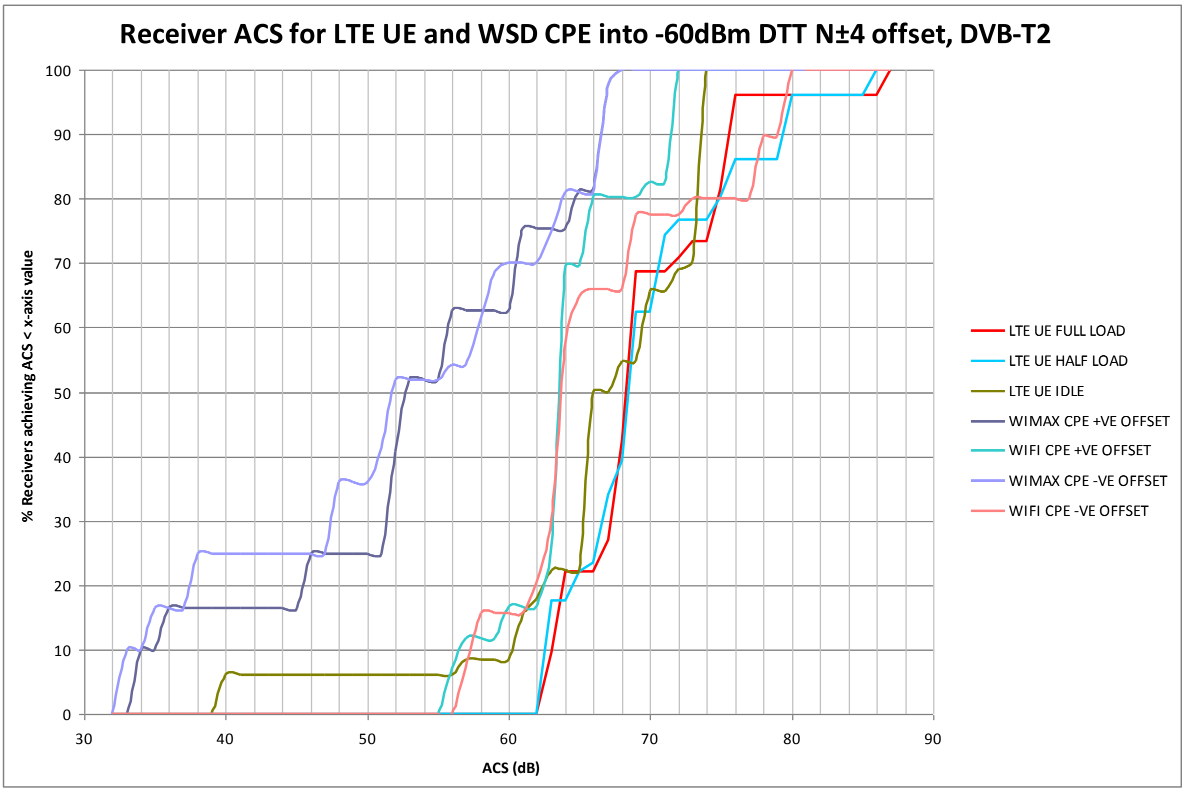

Figure 132 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±4

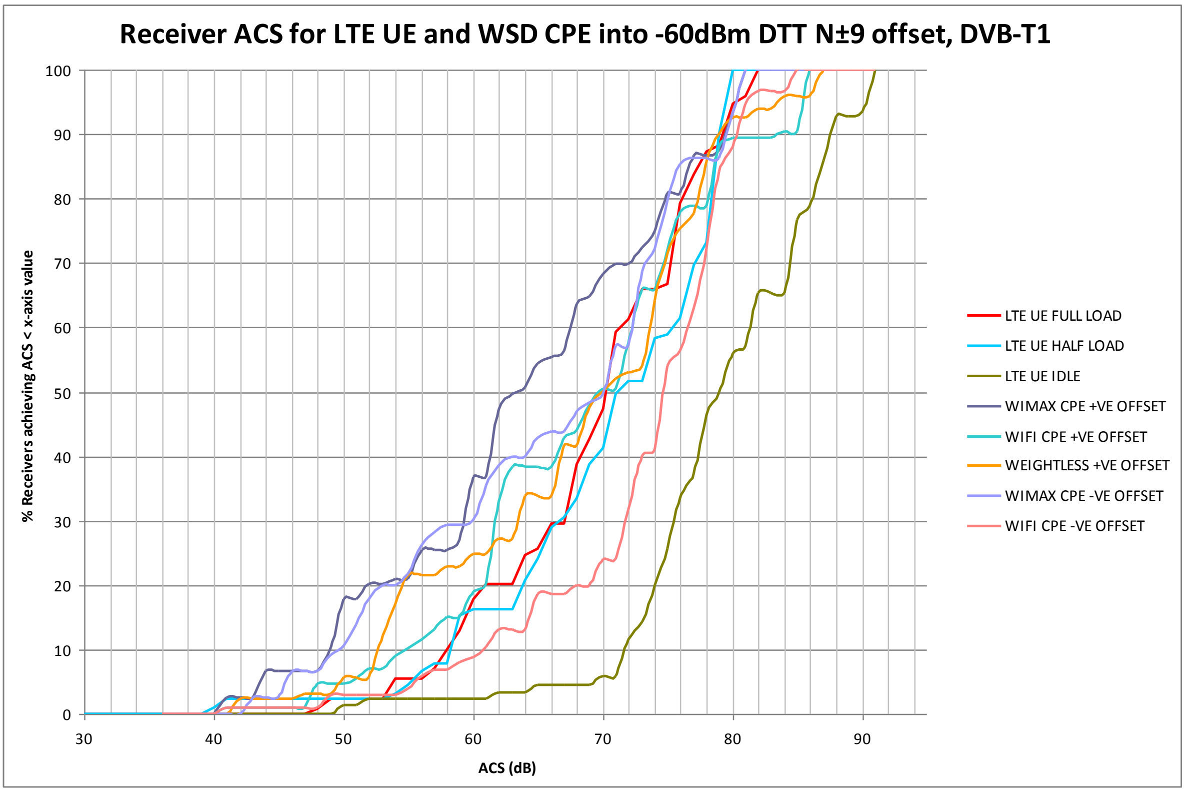

Figure 133 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±9

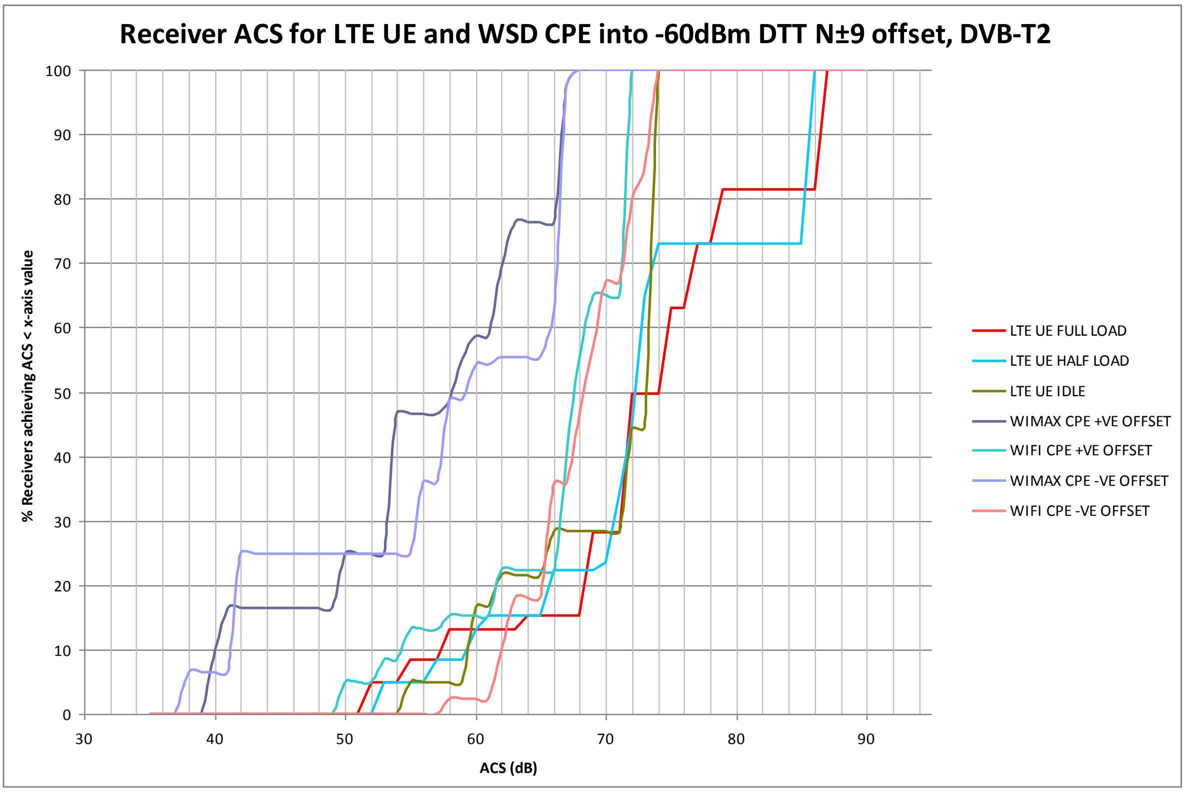

Figure 134 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±9

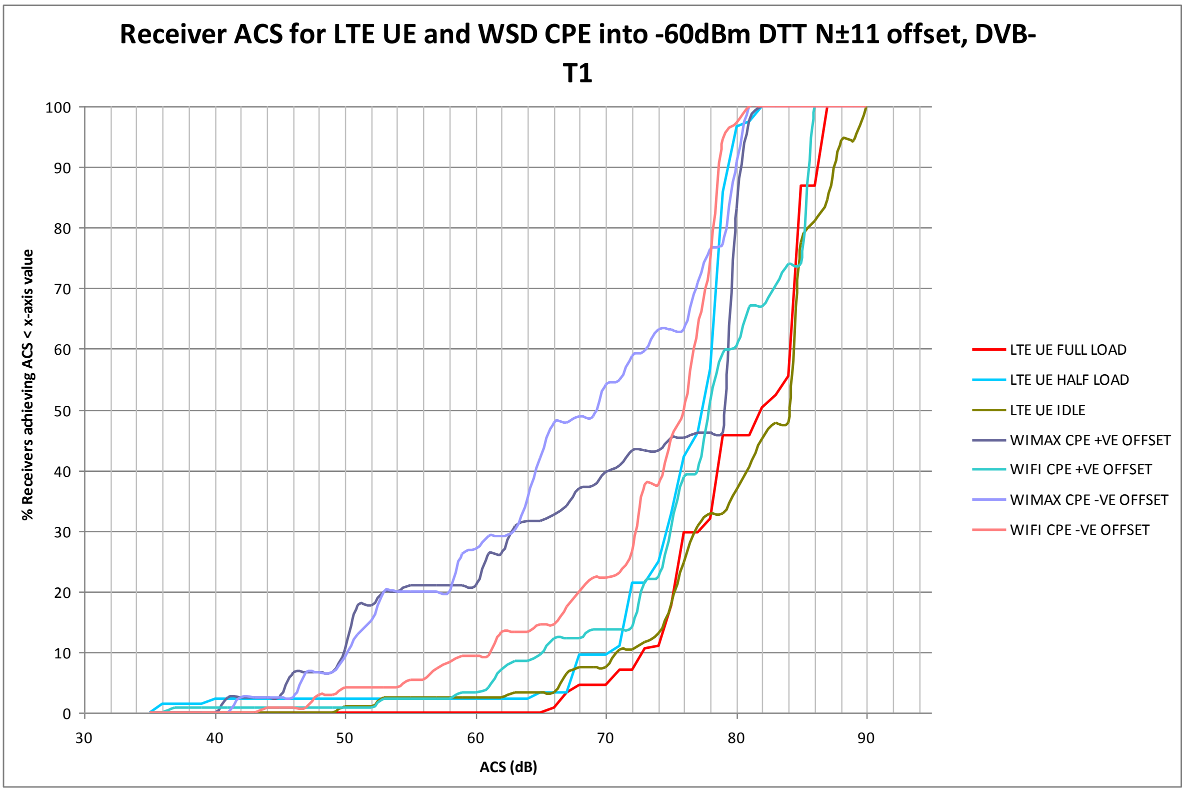

Figure 135 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±11

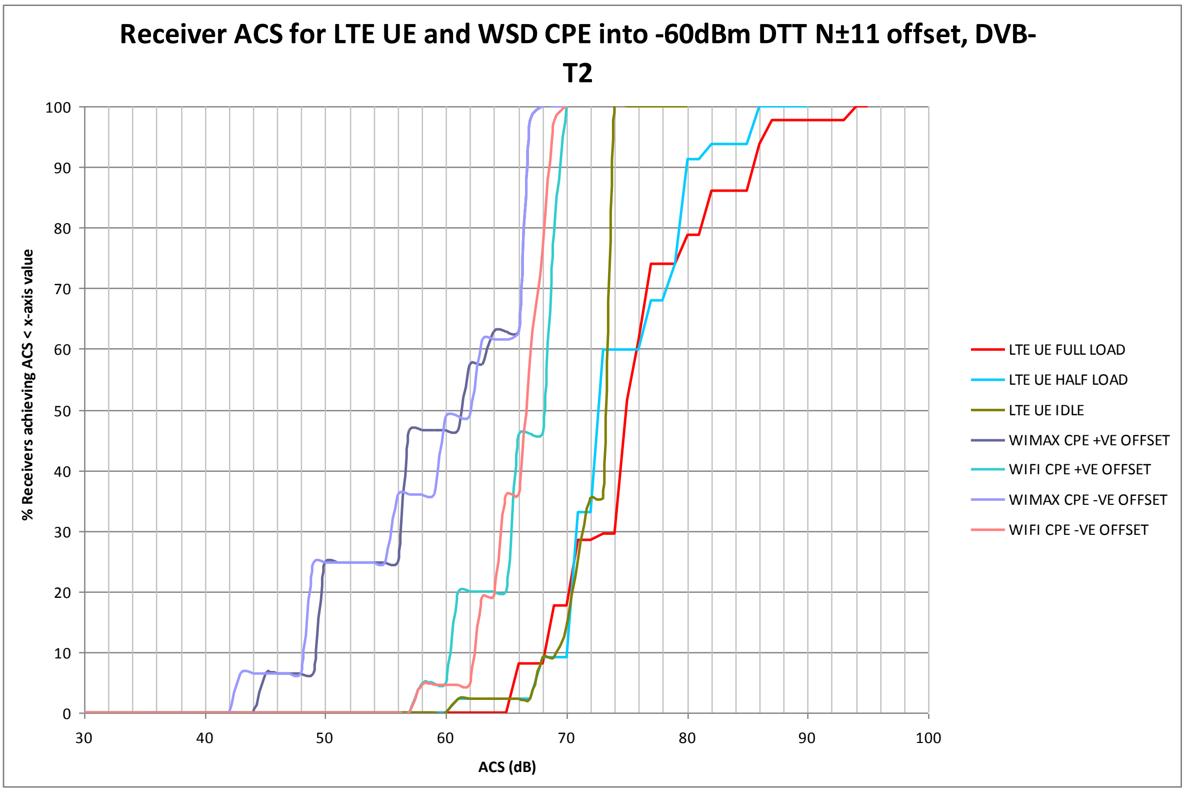

Figure 136 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±11

B.3 ACS values at frequency offsets N±1, 2, 3, 4, 9, 11 for DTT at -50dBm

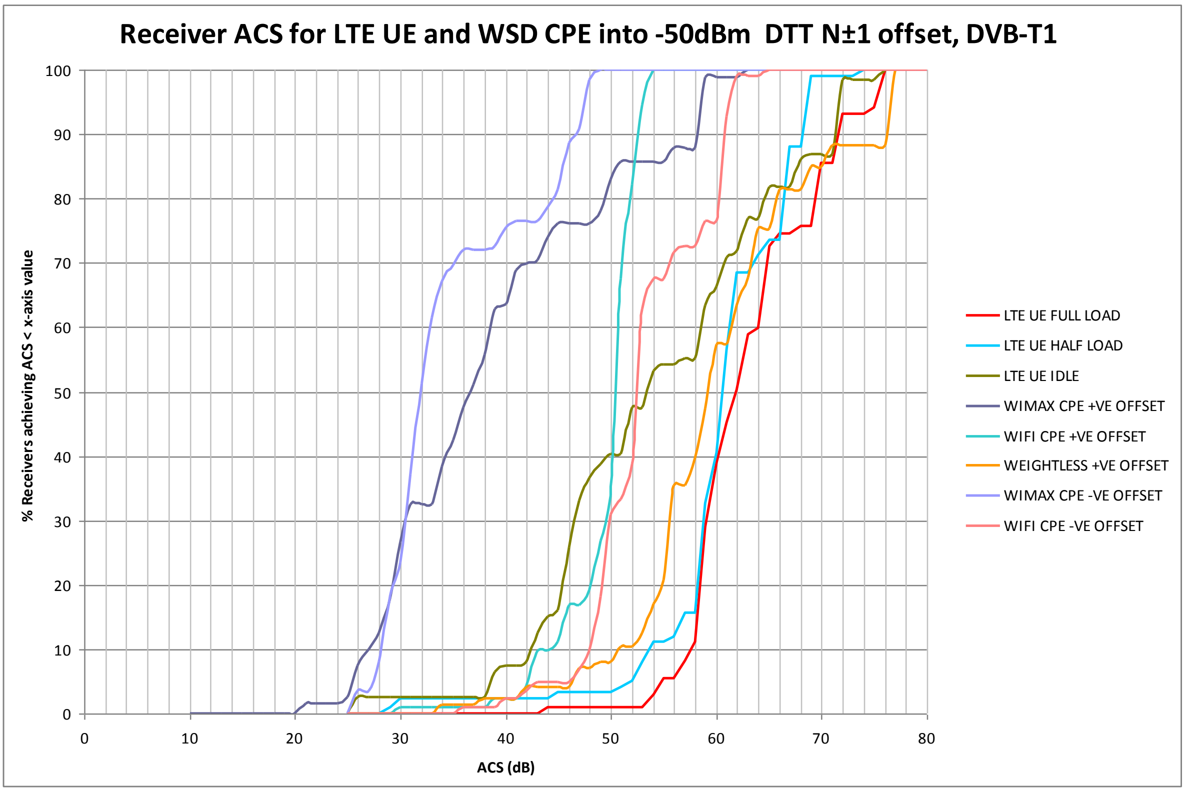

Figure 137 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±1

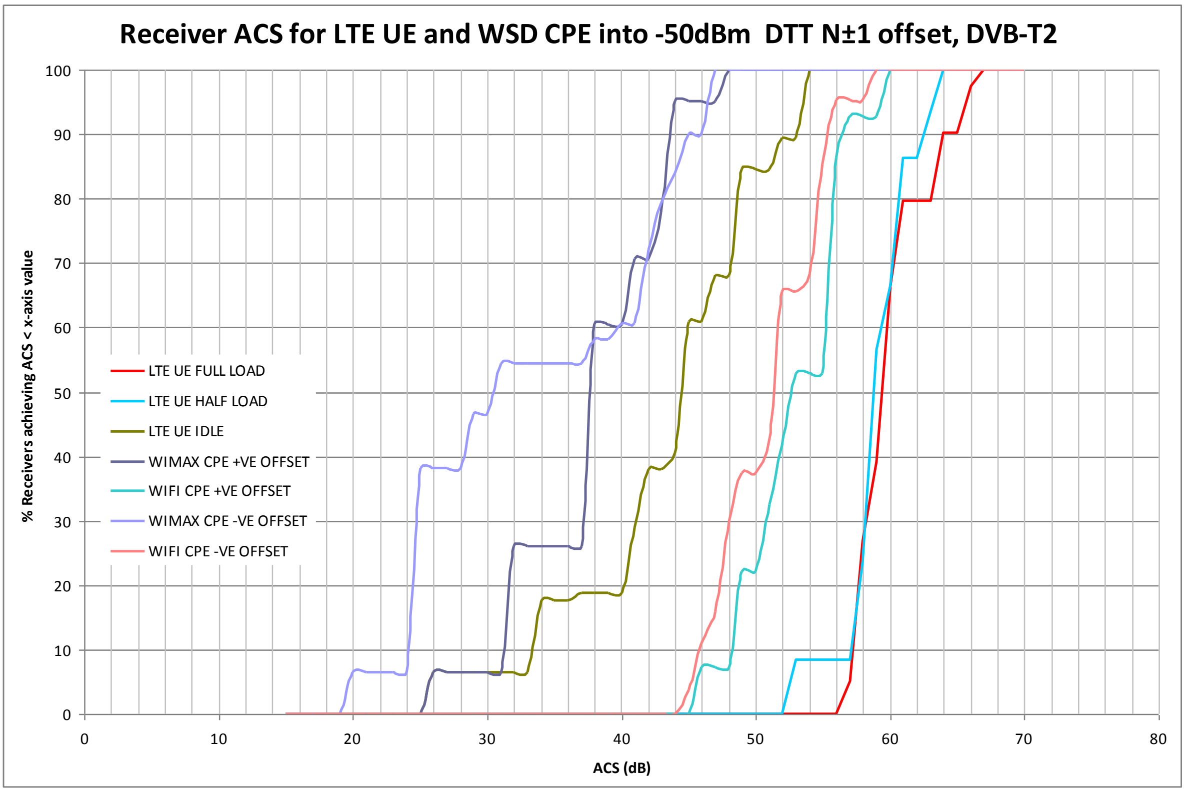

Figure 138 CDF of ACS values at-50dBm DVB-T2 DTT at offsets N±1

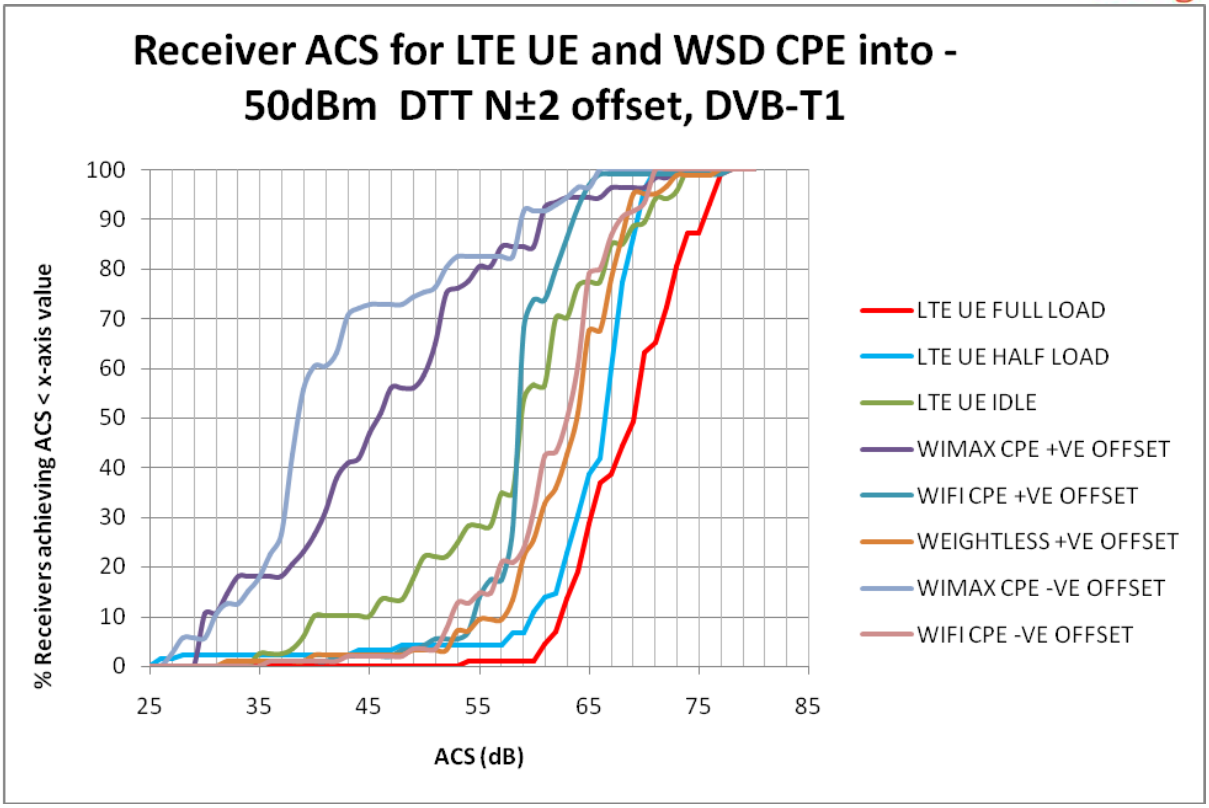

Figure 139 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±2

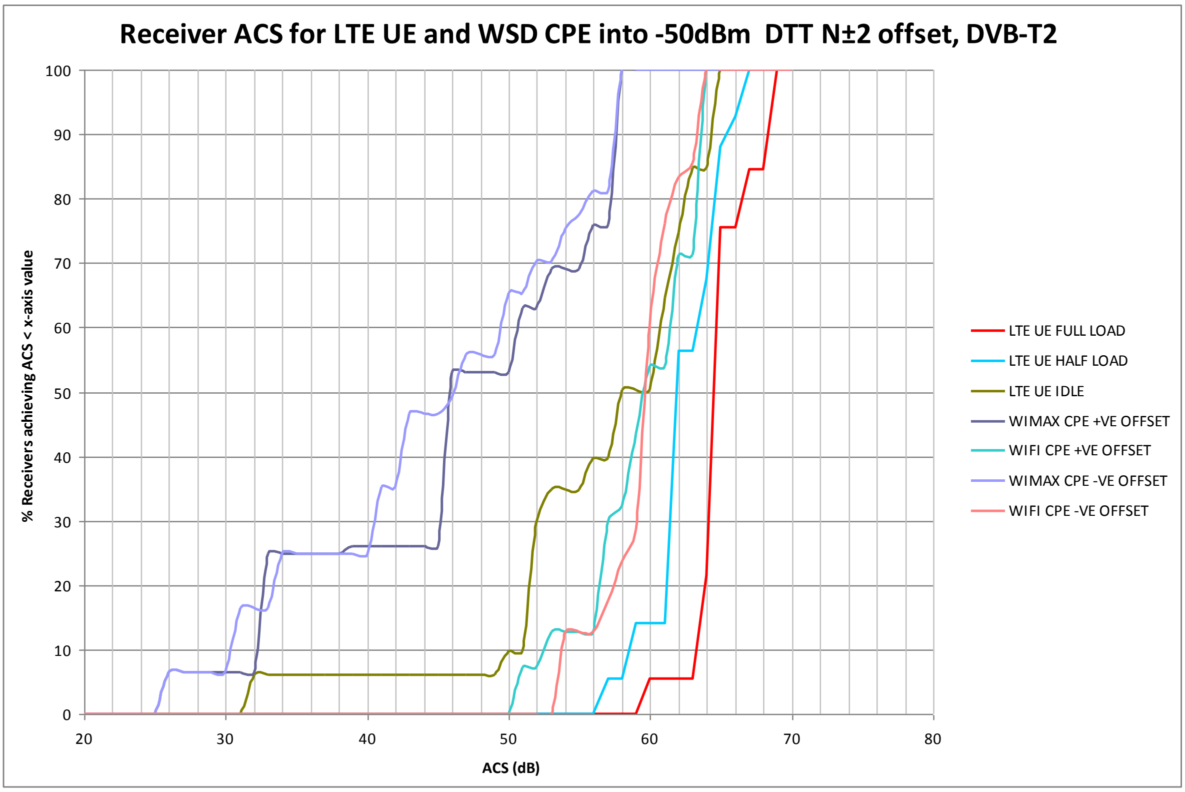

Figure 140 CDF of ACS values at-50dBm DVB-T2 DTT at offsets N±2

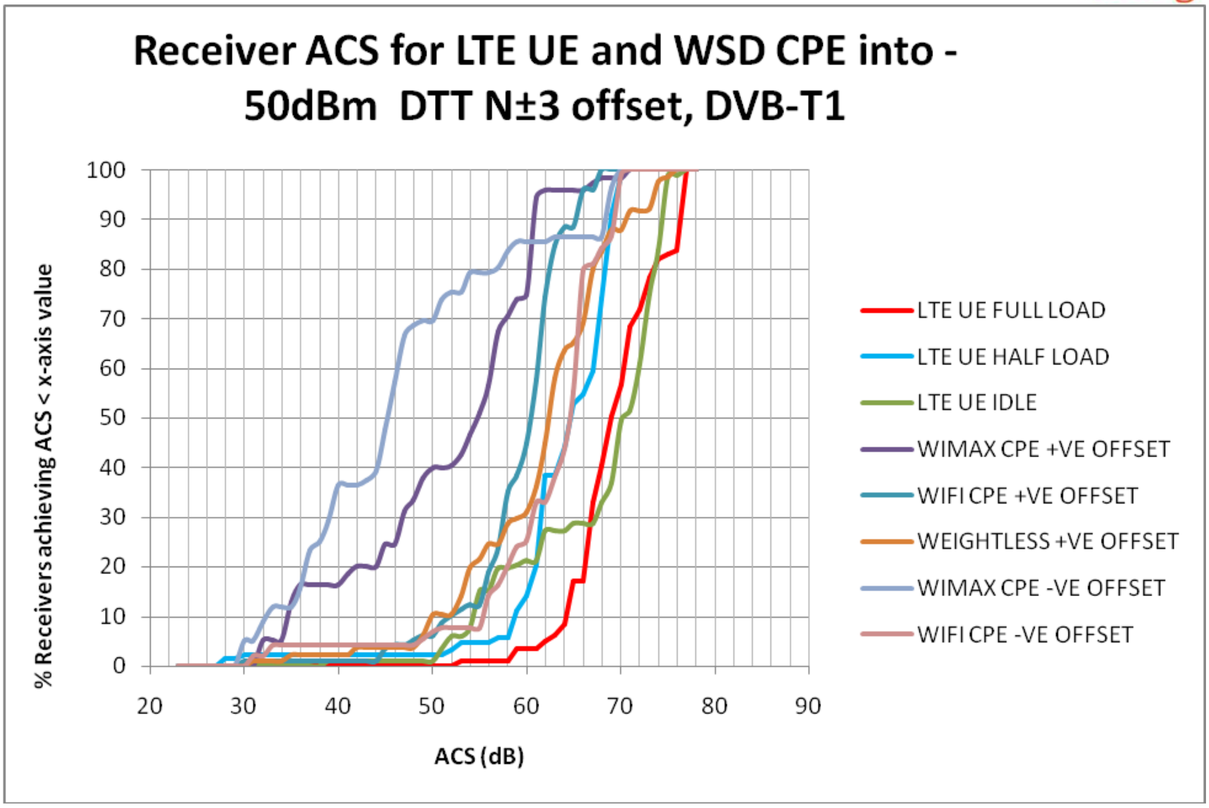

Figure 141 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±3

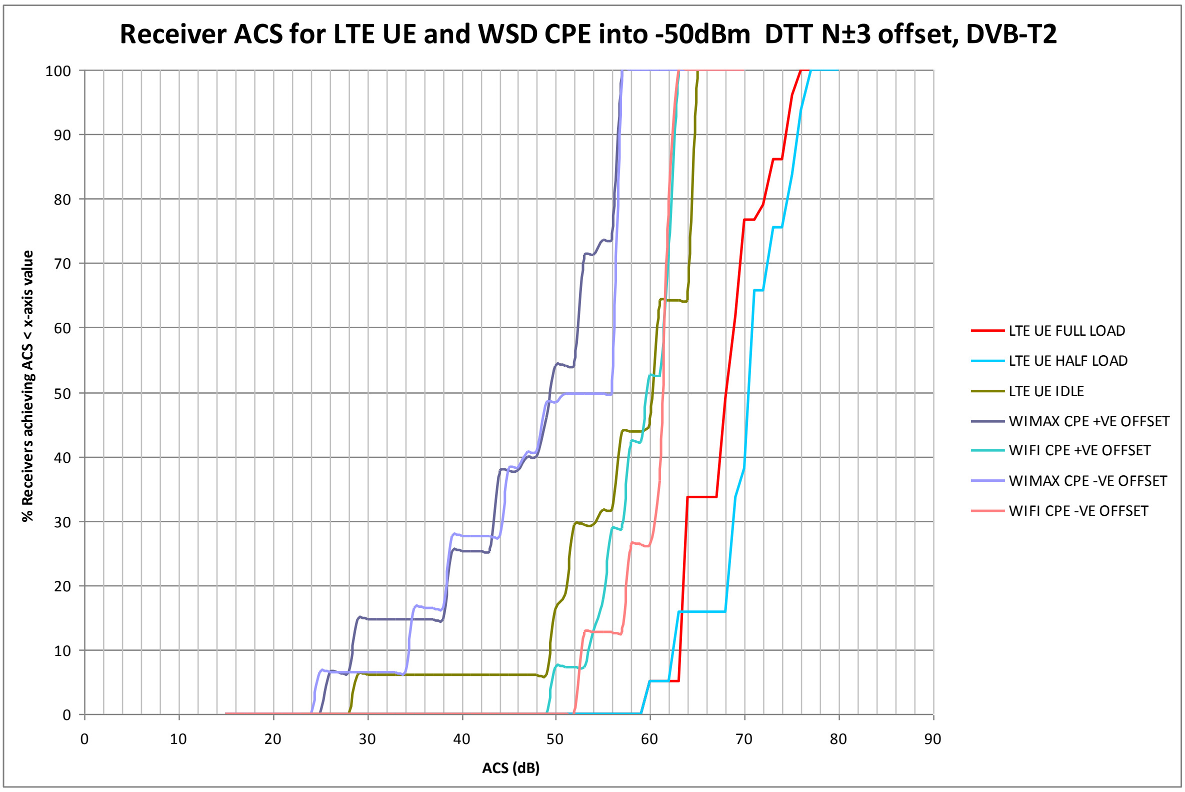

Figure 142 CDF of ACS values at-60dBm DVB-T2 DTT at offsets N±3

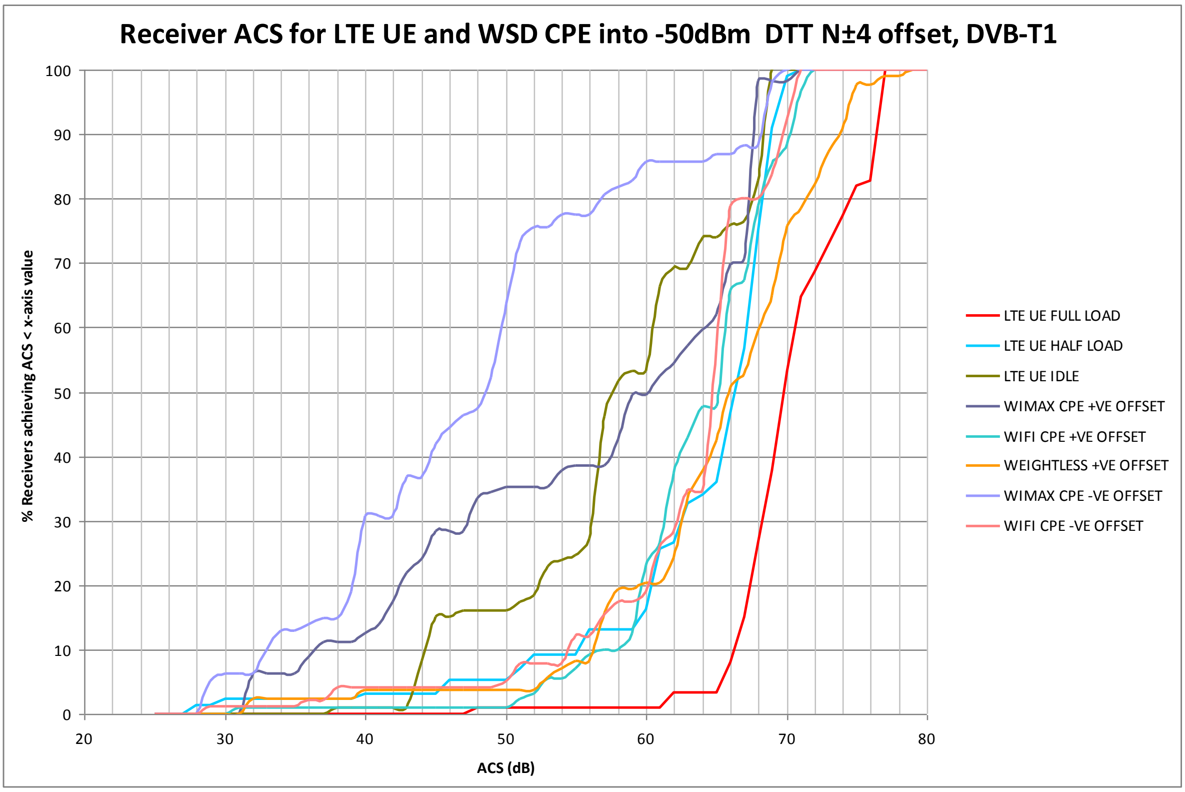

Figure 143 CDF of ACS values at-50m DVB-T1 DTT at offsets N±4

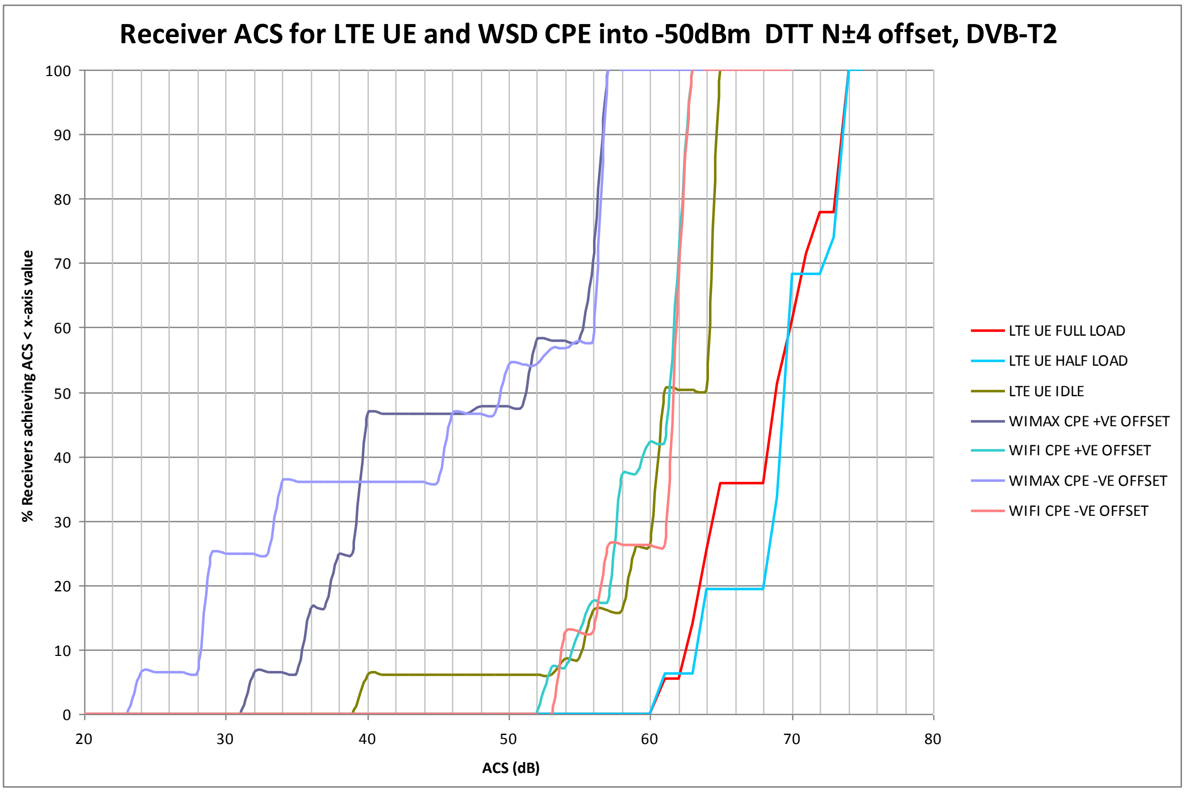

Figure 144 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±4

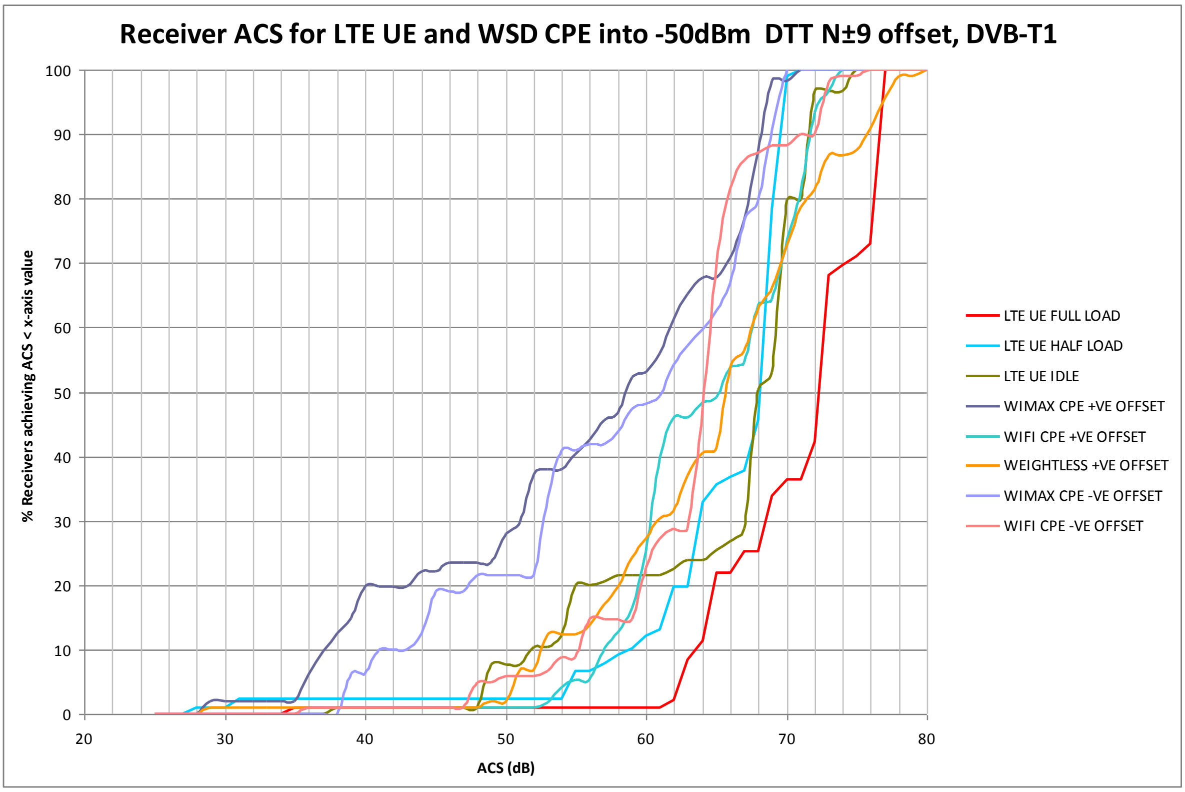

Figure 145 CDF of ACS values at-60dBm DVB-T1 DTT at offsets N±9

Note that many of the receivers did not fail at the maximum level of interferer signal during -50dBm DTT testing at N±11. This is why the ACS lines are almost vertical at the higher levels.

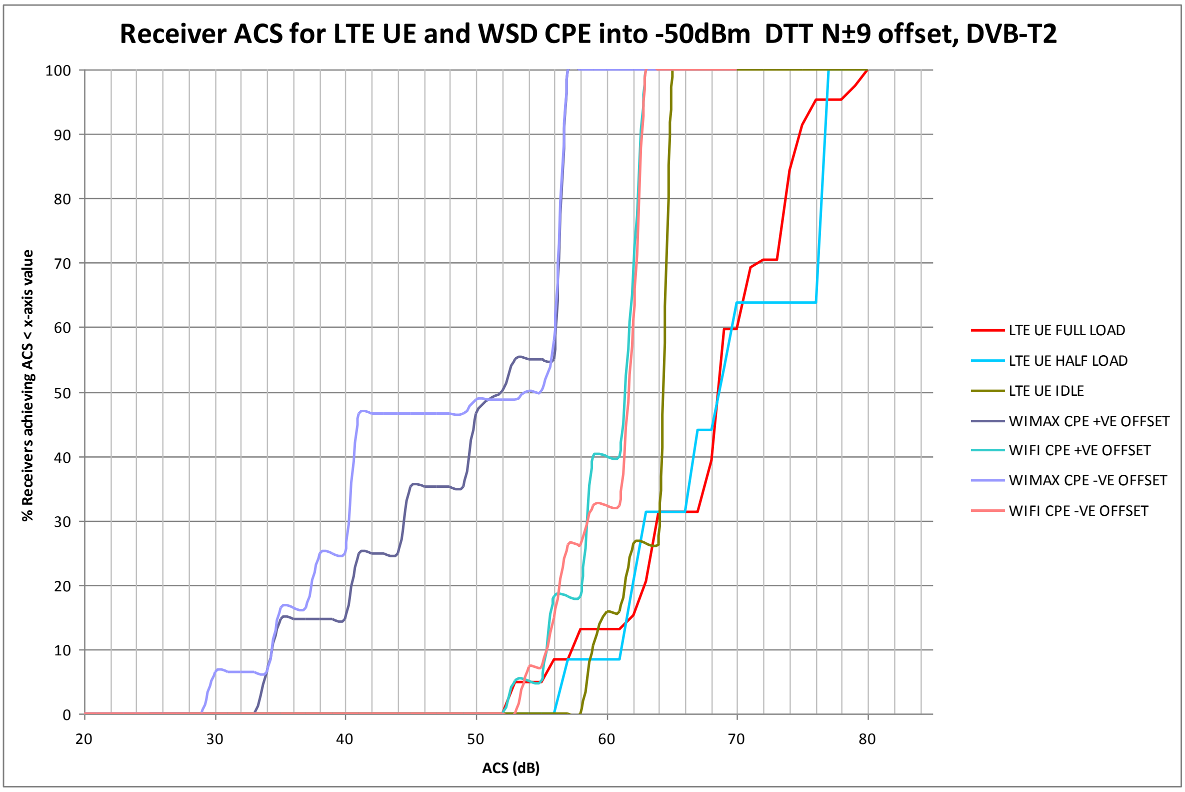

Figure 146 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±9

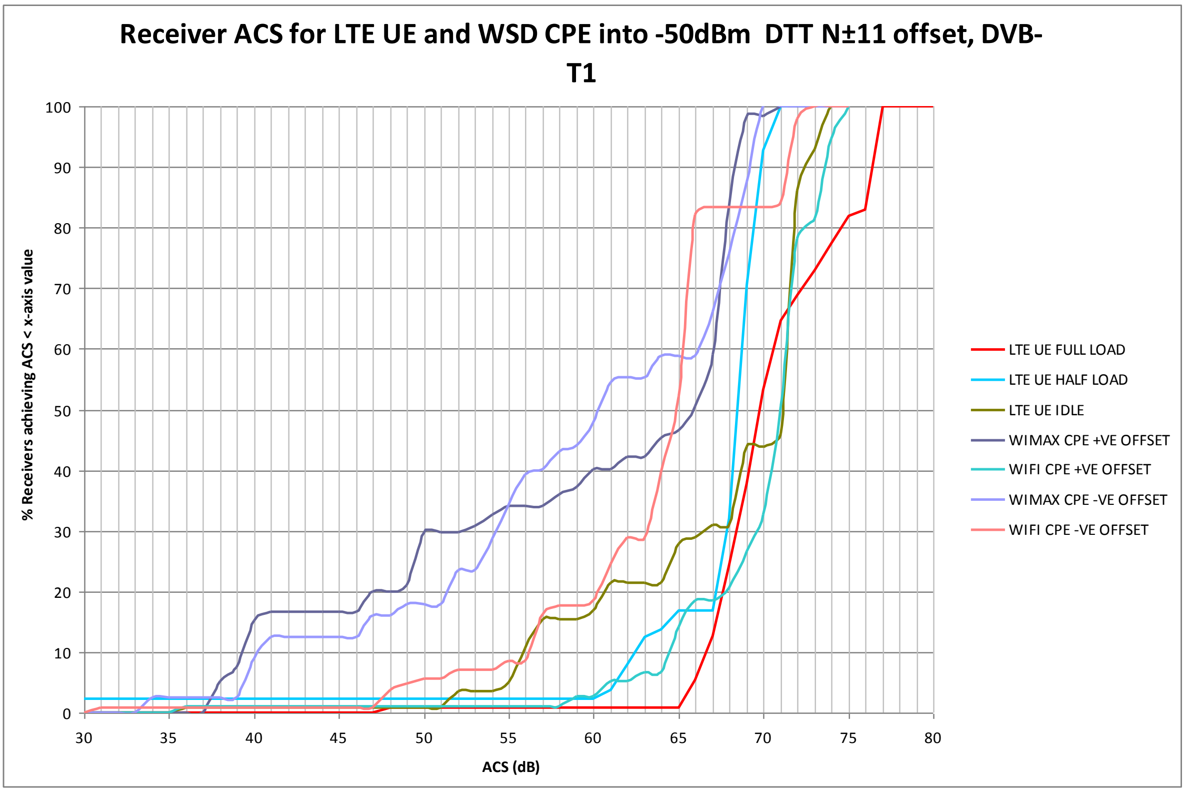

Figure 147 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±11

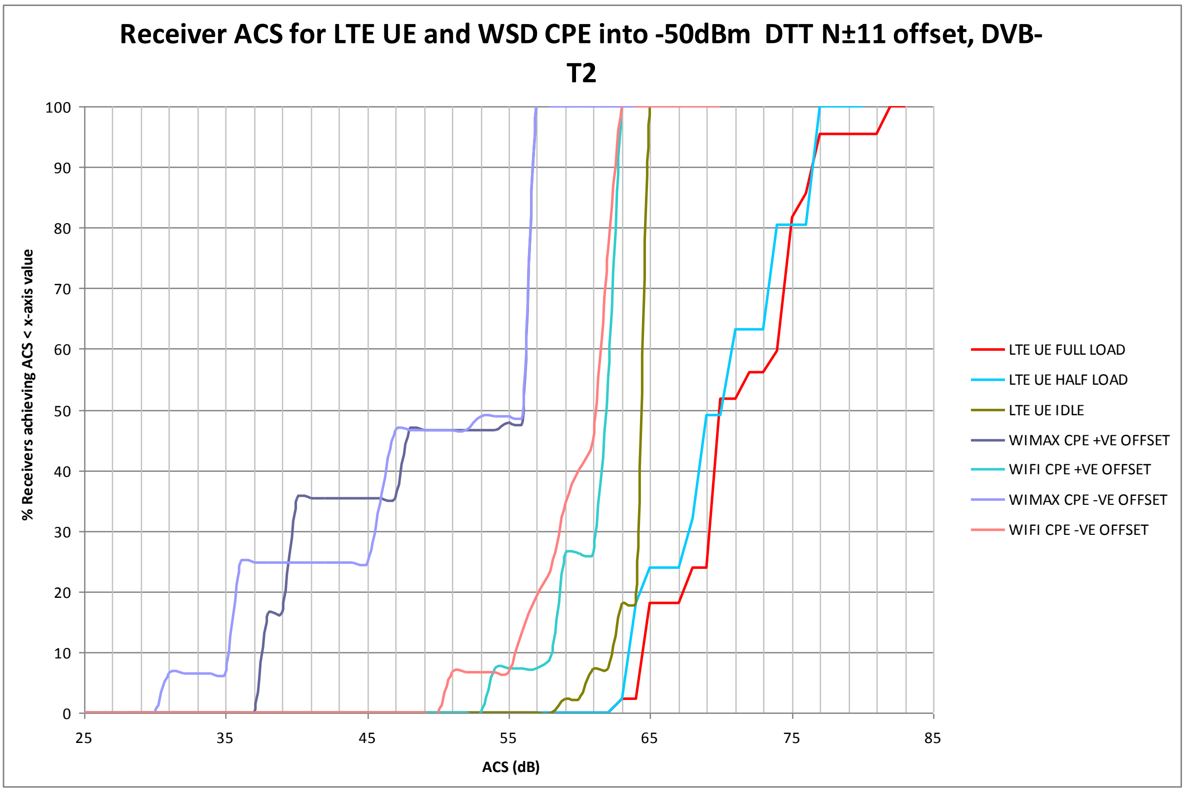

Figure 148 CDF of ACS values at-50dBm DVB-T2 DTT at offsets N±11

B.4 ACS values at frequency offsets N±1, 2, 3, 4, 9, 11 for DTT at -40dBm

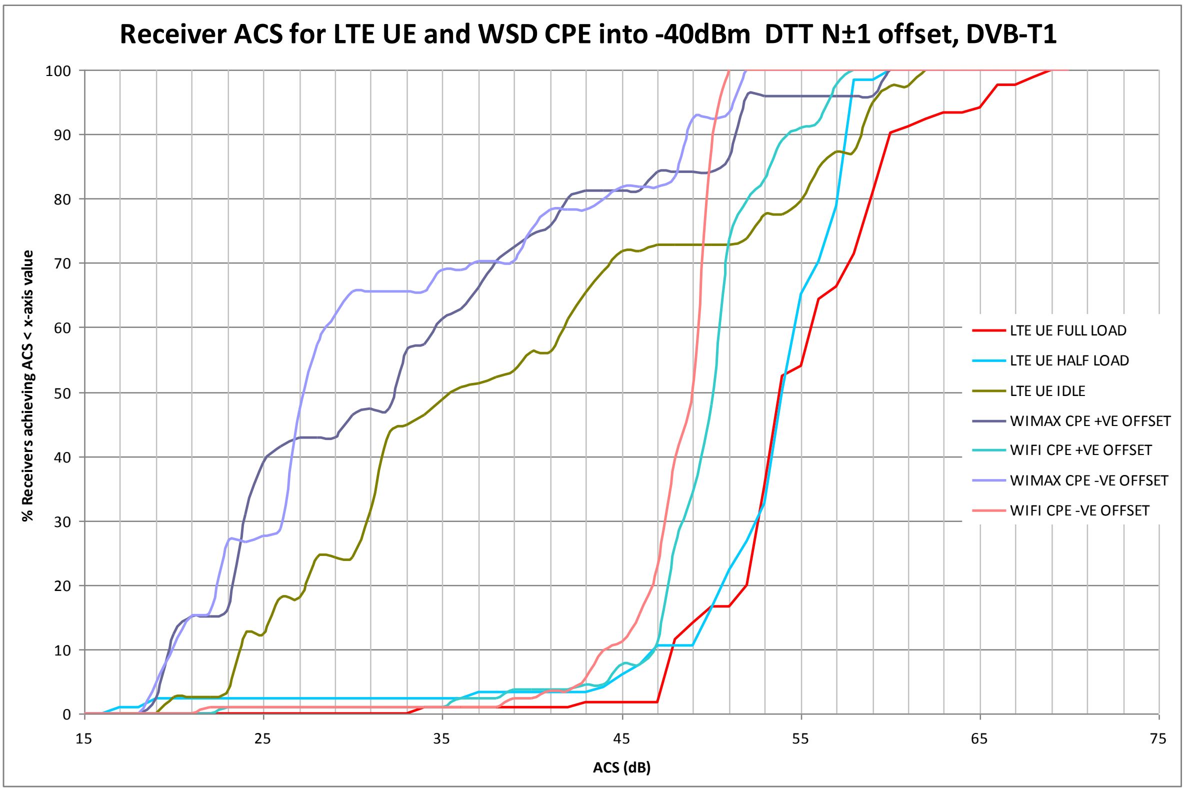

Figure 149 CDF of ACS values at-40dBm DVB-T1 DTT at offsets N±1

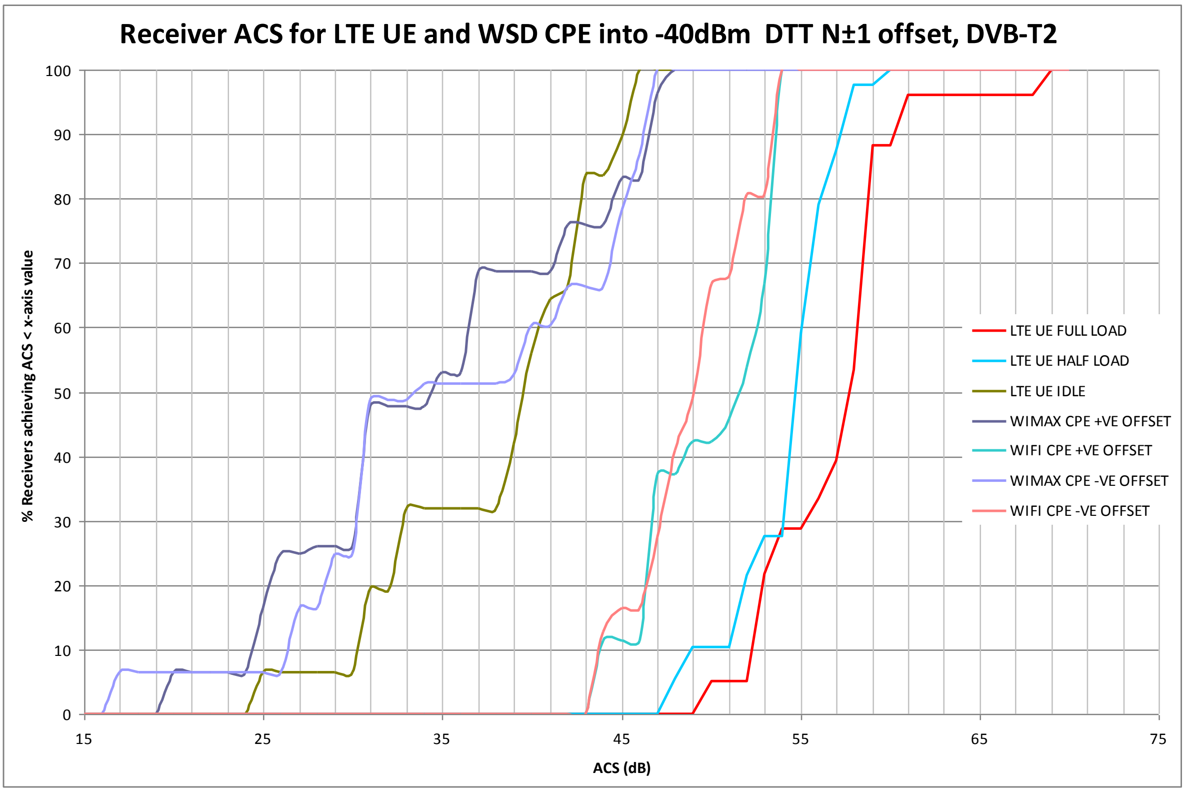

Figure 150 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±1

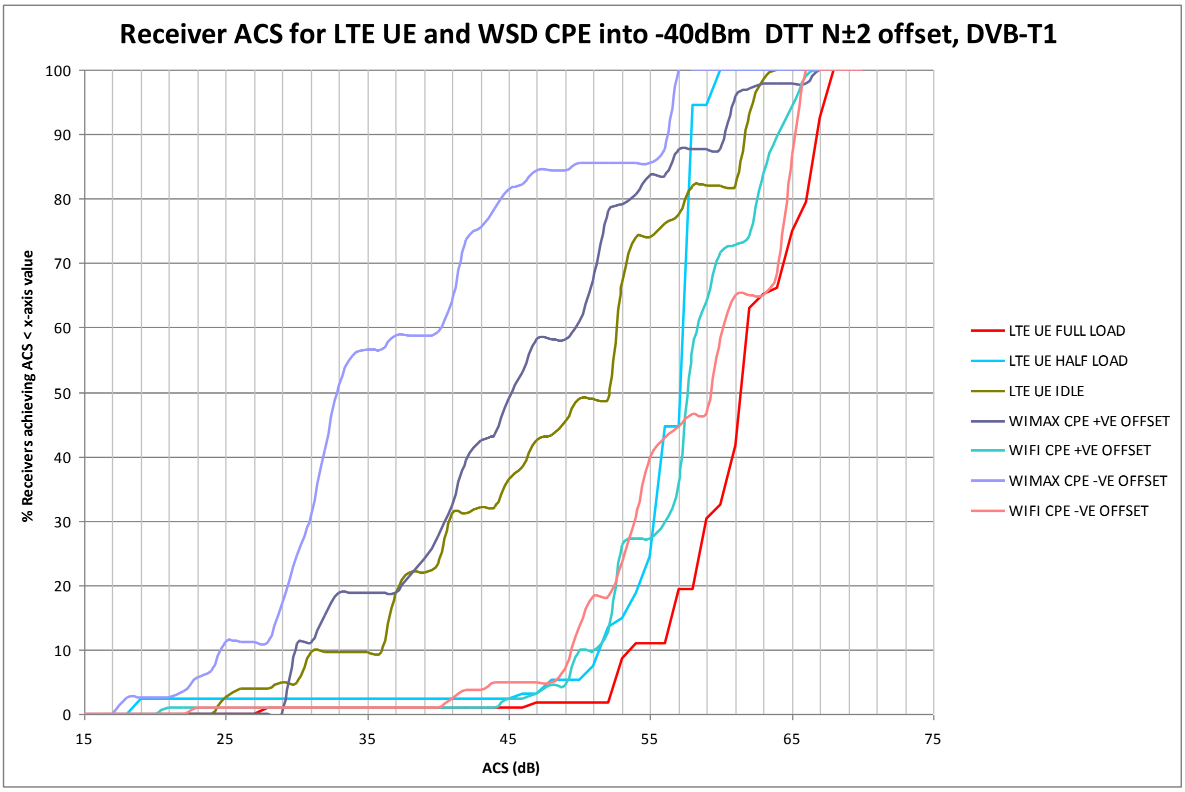

Figure 151 CDF of ACS values at-40dBm DVB-T1 DTT at offsets N±2

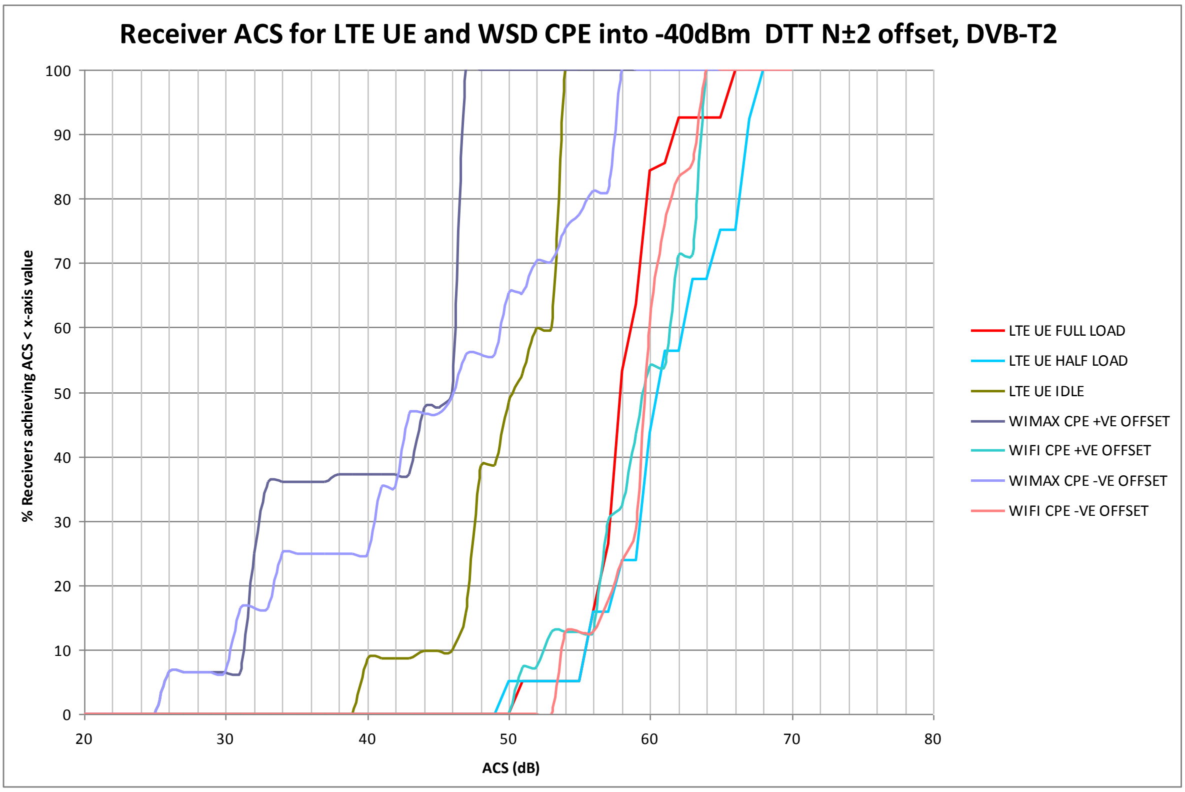

Figure 152 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±2

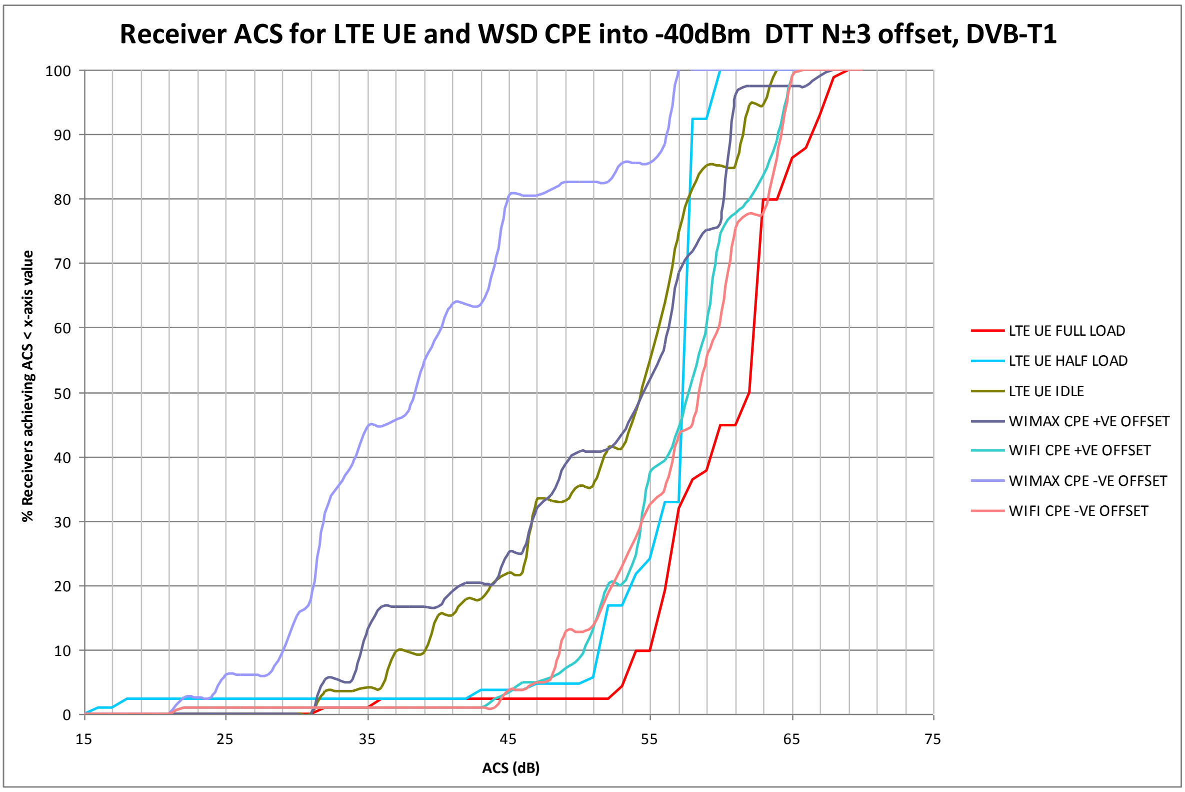

Figure 153 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±3

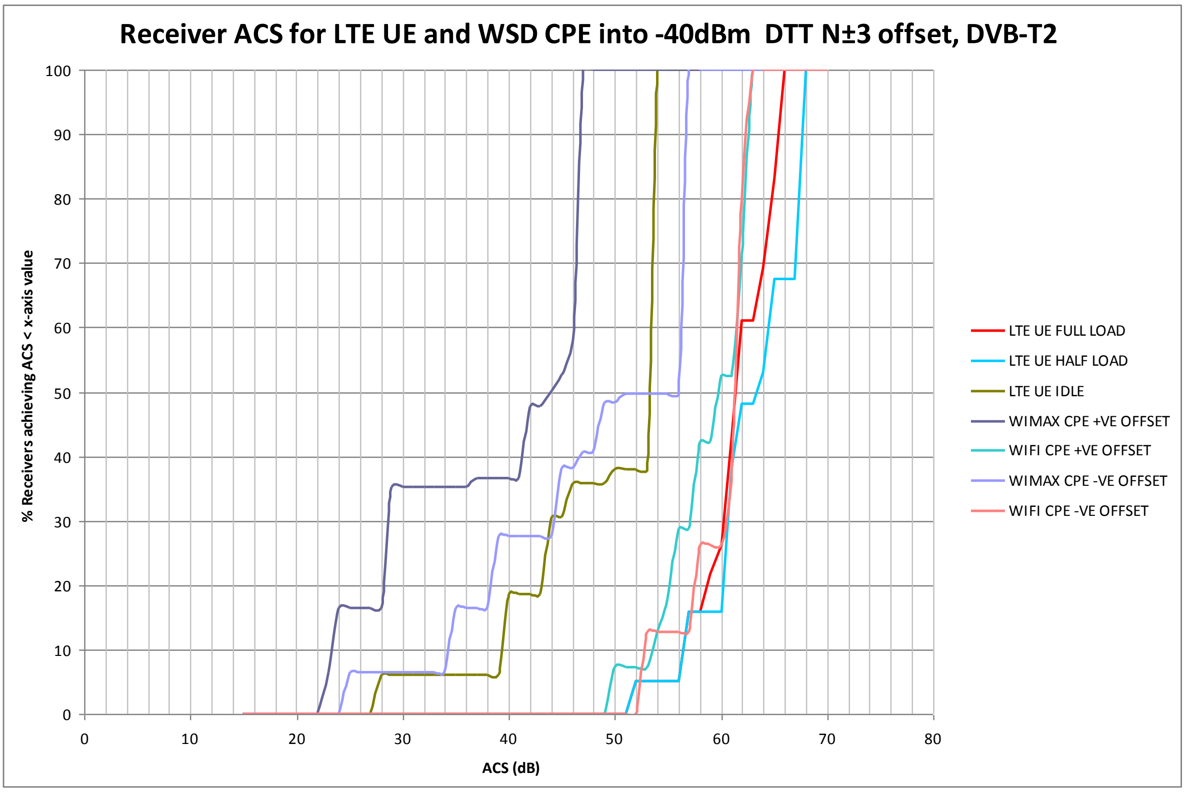

Figure 154 CDF of ACS values at-50dBm DVB-T2 DTT at offsets N±3

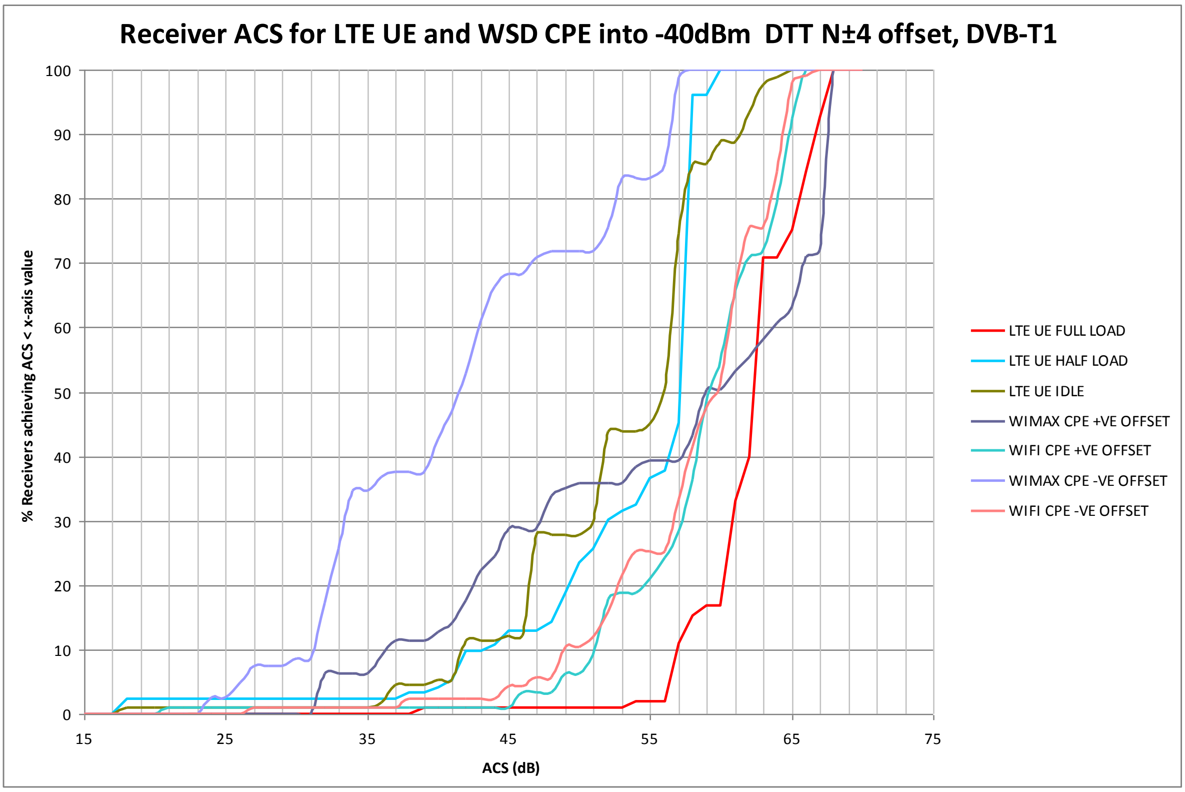

Figure 155 CDF of ACS values at-40dBm DVB-T1 DTT at offsets N±4

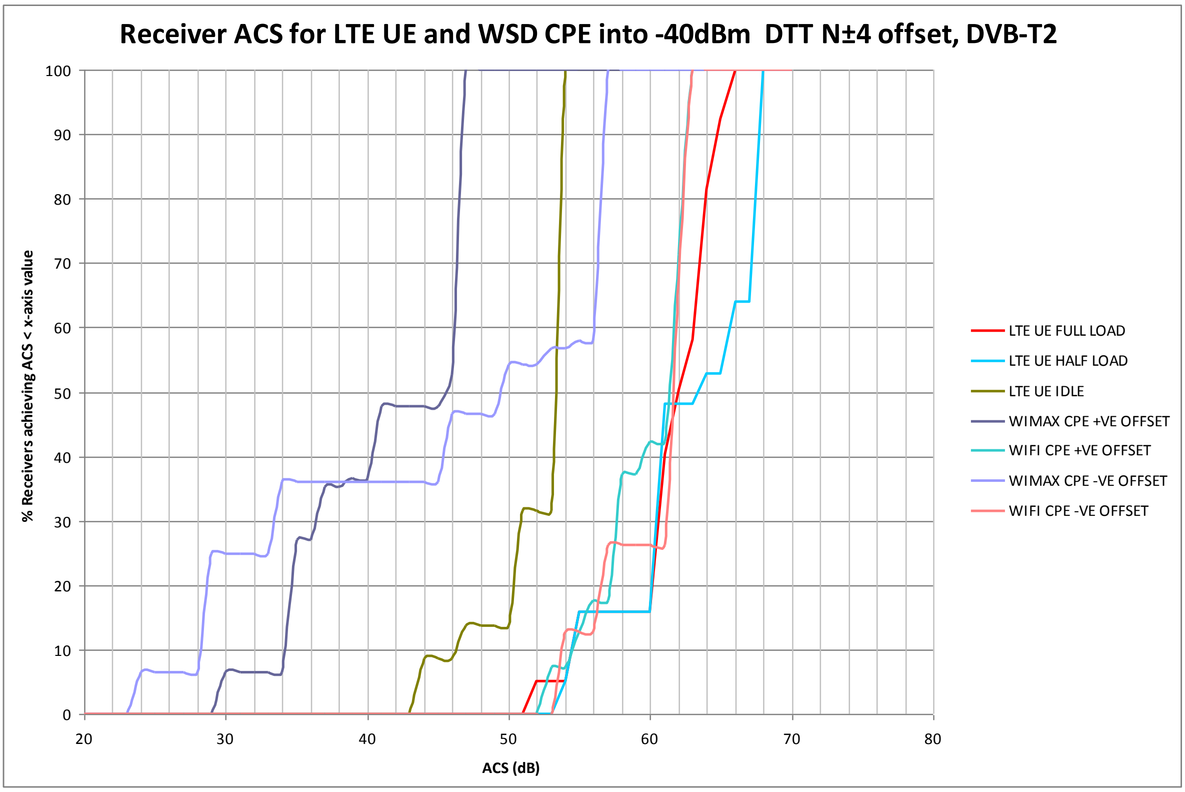

Figure 156 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±4

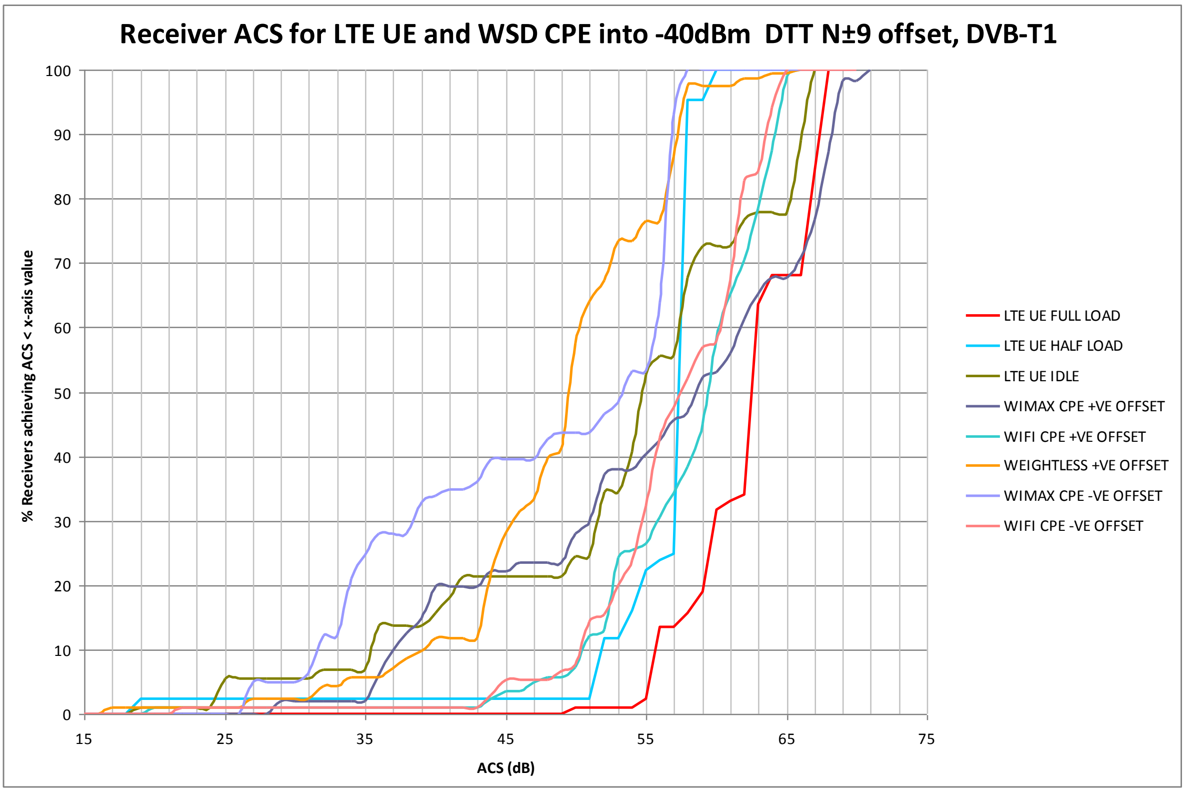

Figure 157 CDF of ACS values at-50dBm DVB-T1 DTT at offsets N±9

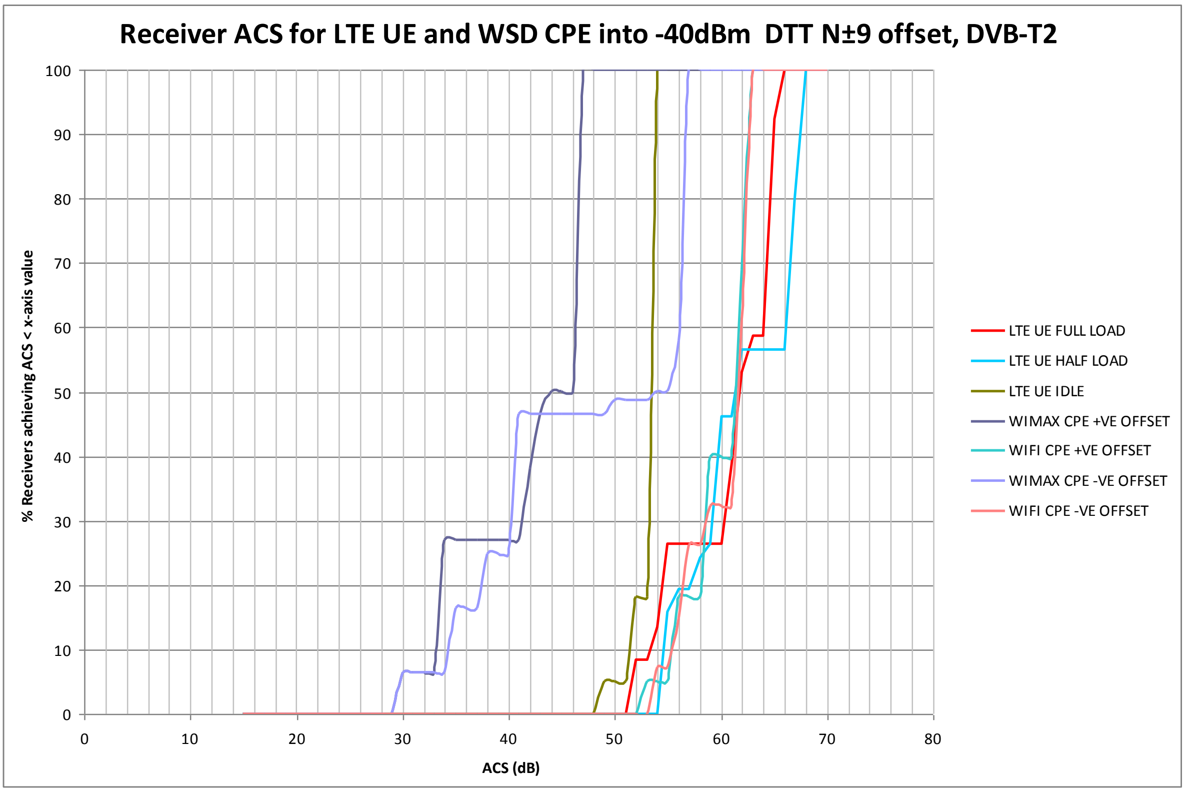

Figure 158 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±9

Note that many of the receivers did not fail at the maximum level of interferer signal during -40dBm DTT testing at N±11. This is why the ACS lines are almost vertical at the higher levels.

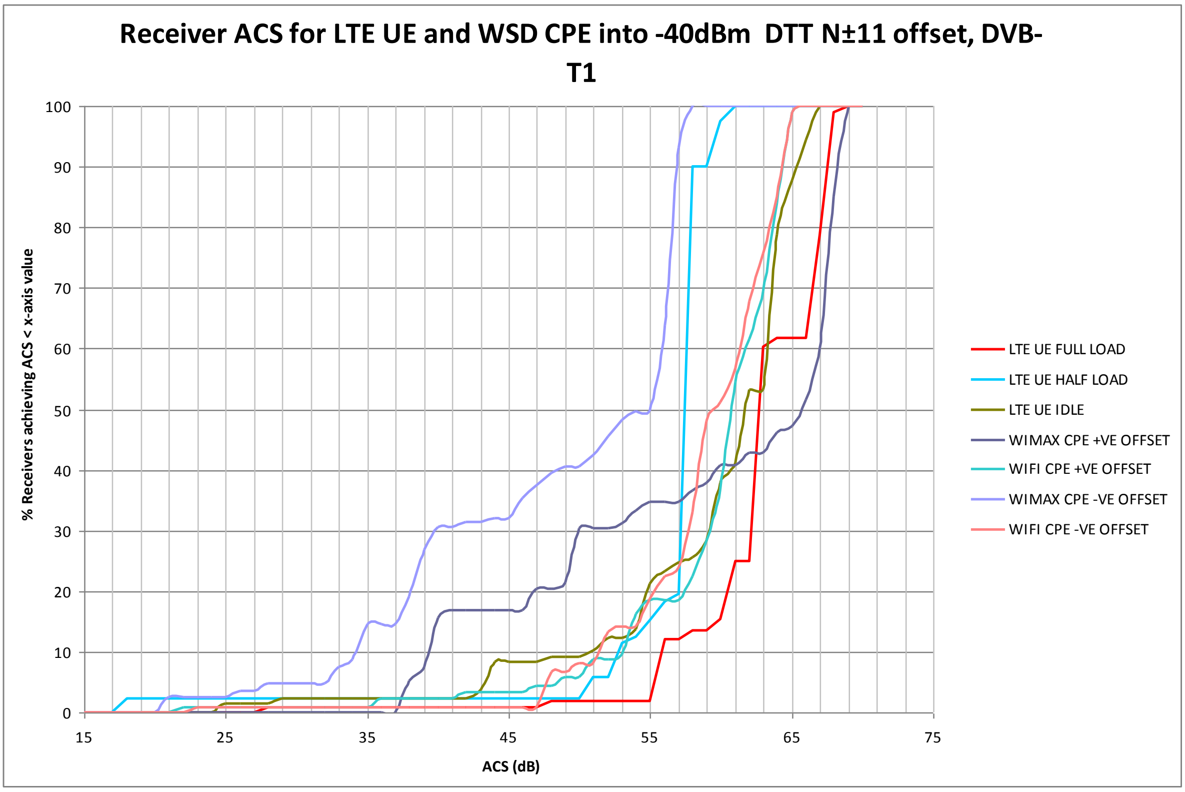

Figure 159 CDF of ACS values at-40dBm DVB-T1 DTT at offsets N±11

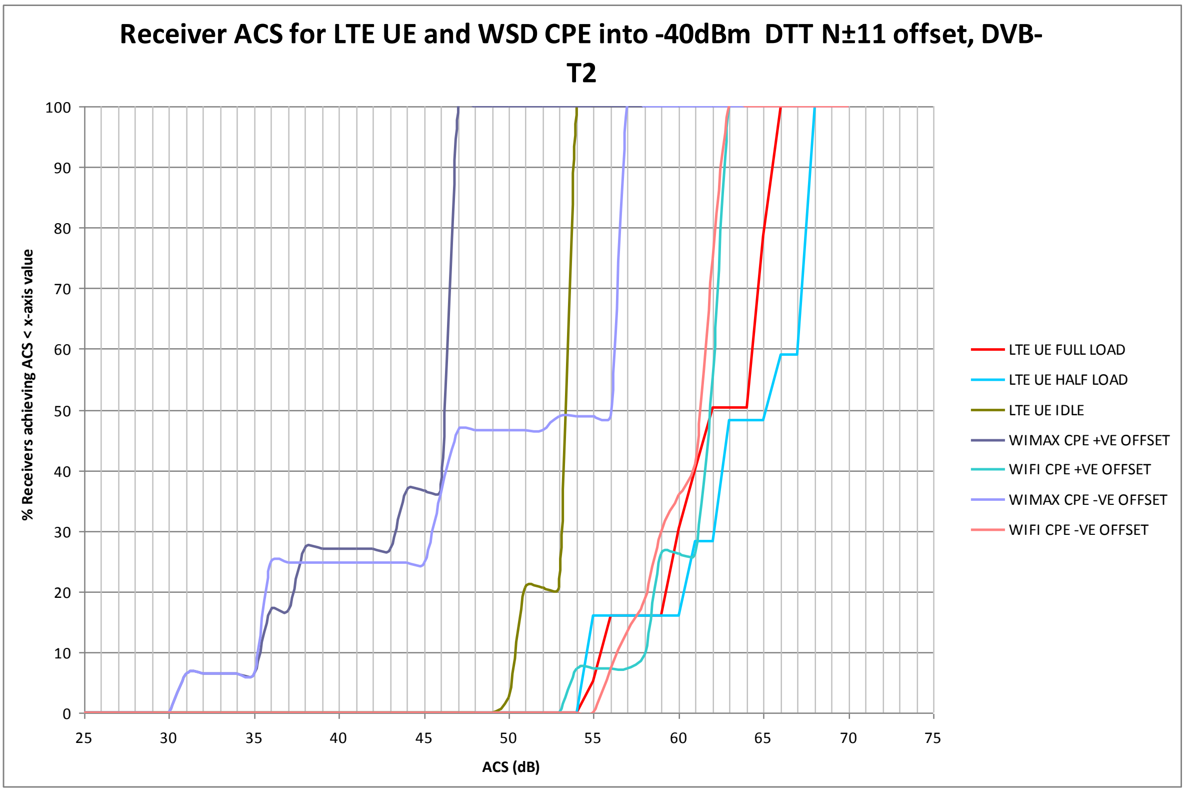

Figure 160 CDF of ACS values at-40dBm DVB-T2 DTT at offsets N±11

B.5 ACS values for Weightless base station at frequency offsets N+1, 2, 3, 4, 8, 9, 10 for DTT at -30dBm

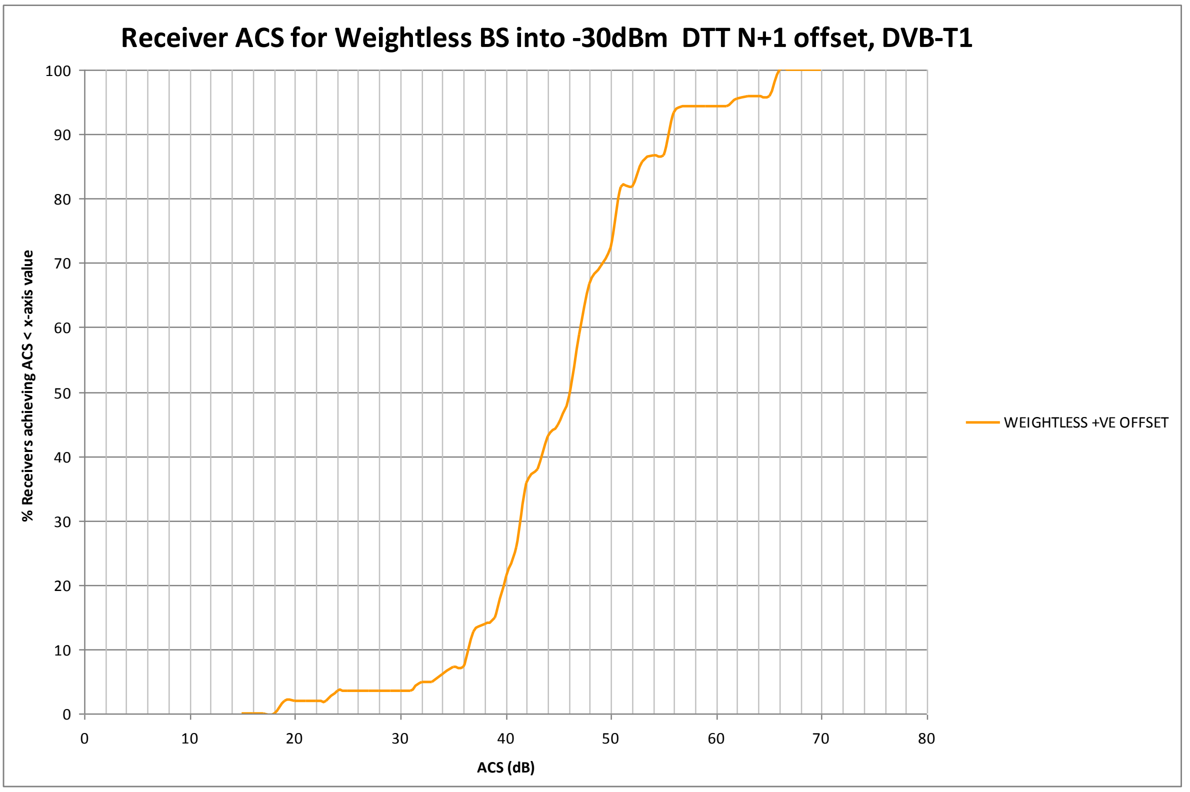

Figure 161 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+1

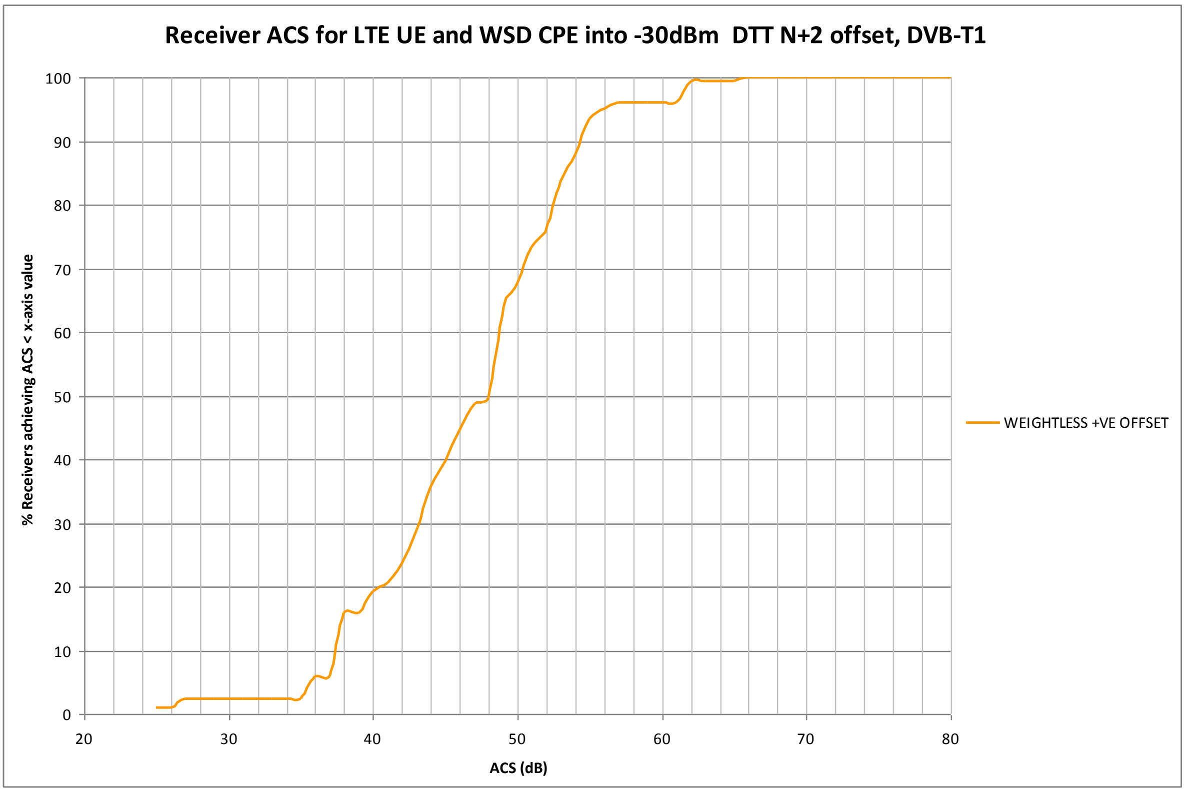

Figure 162 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+2

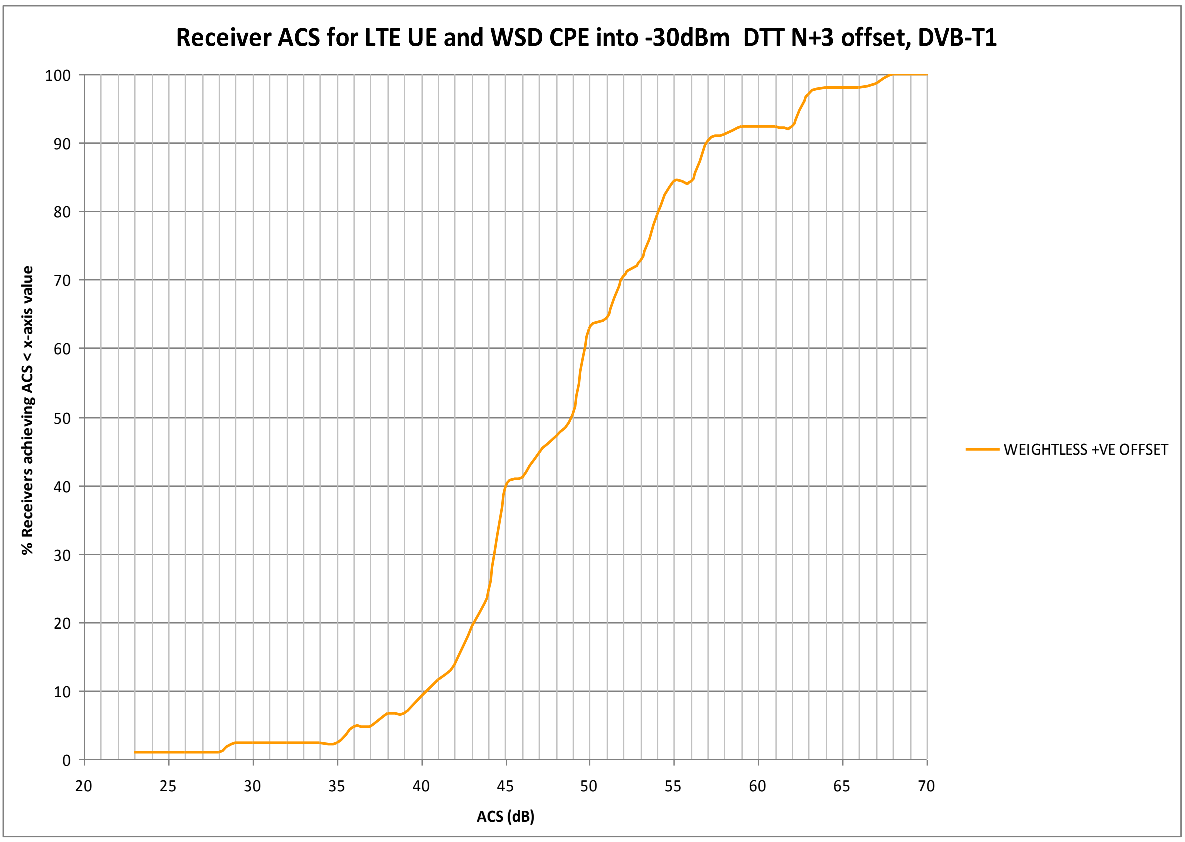

Figure 163 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+3

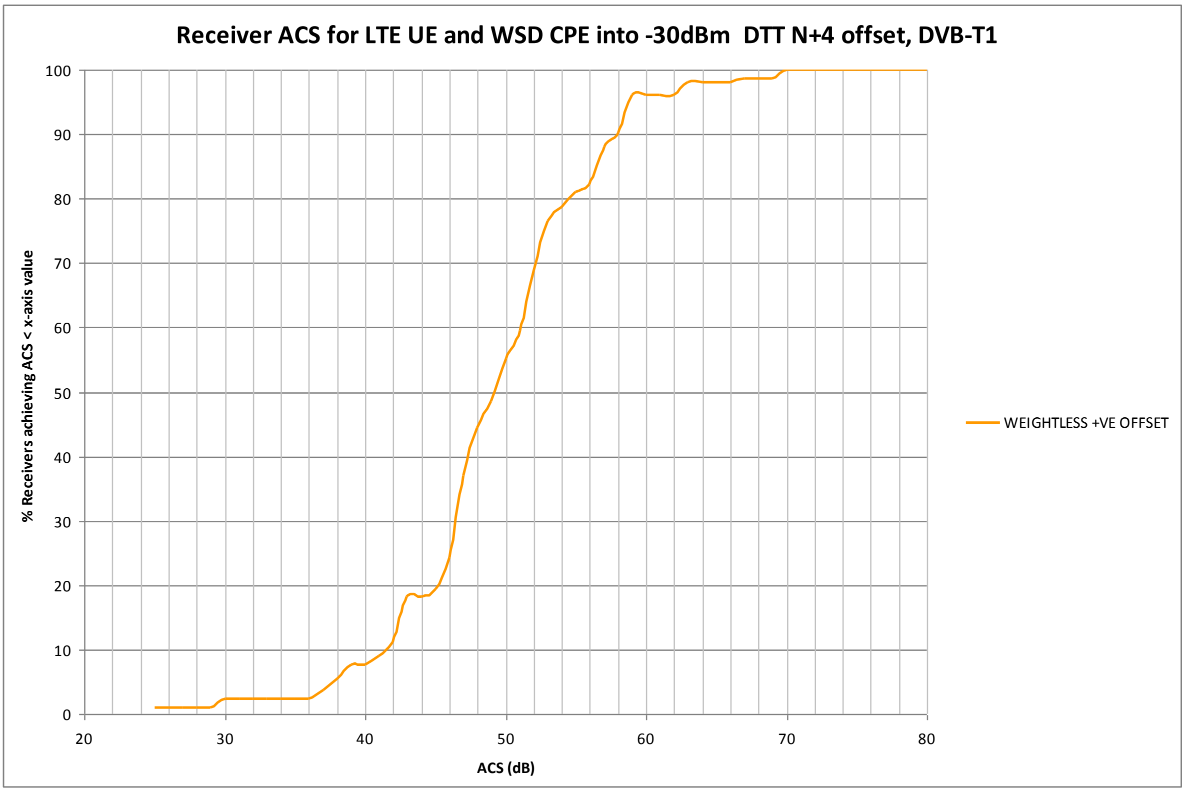

Figure 164 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+4

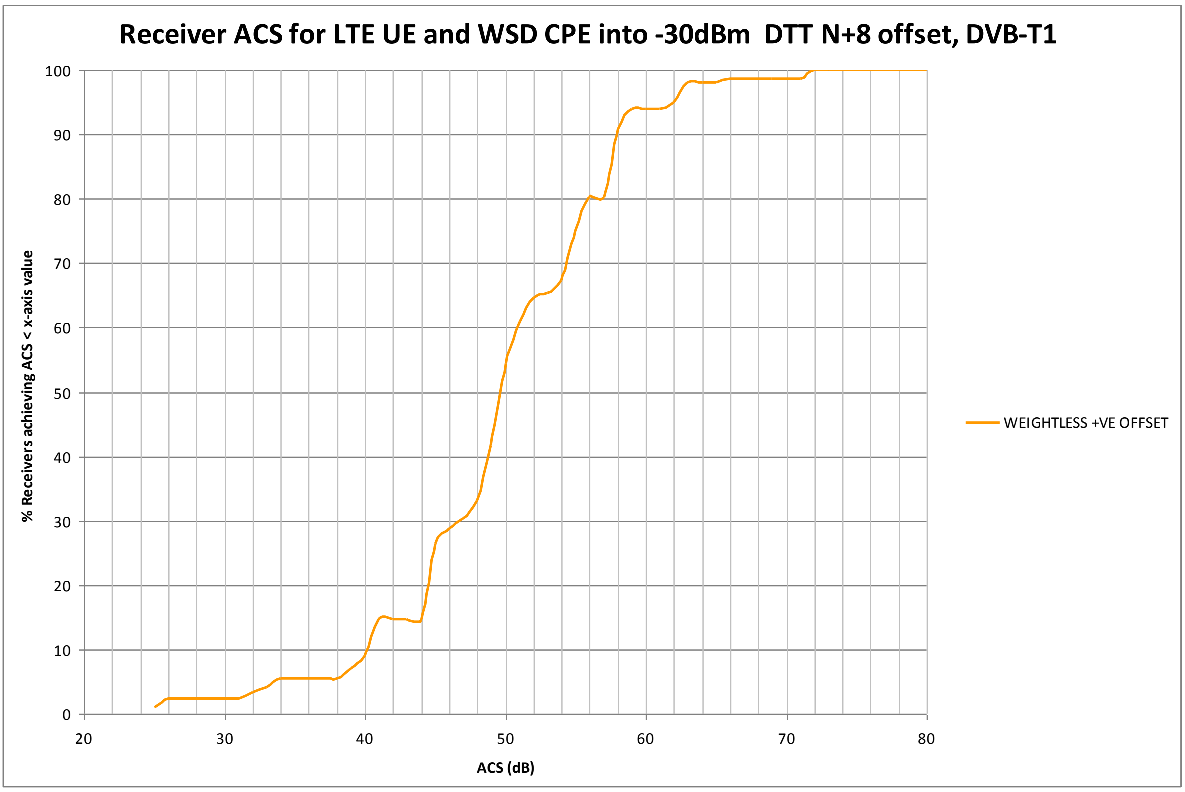

Figure 165 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+8

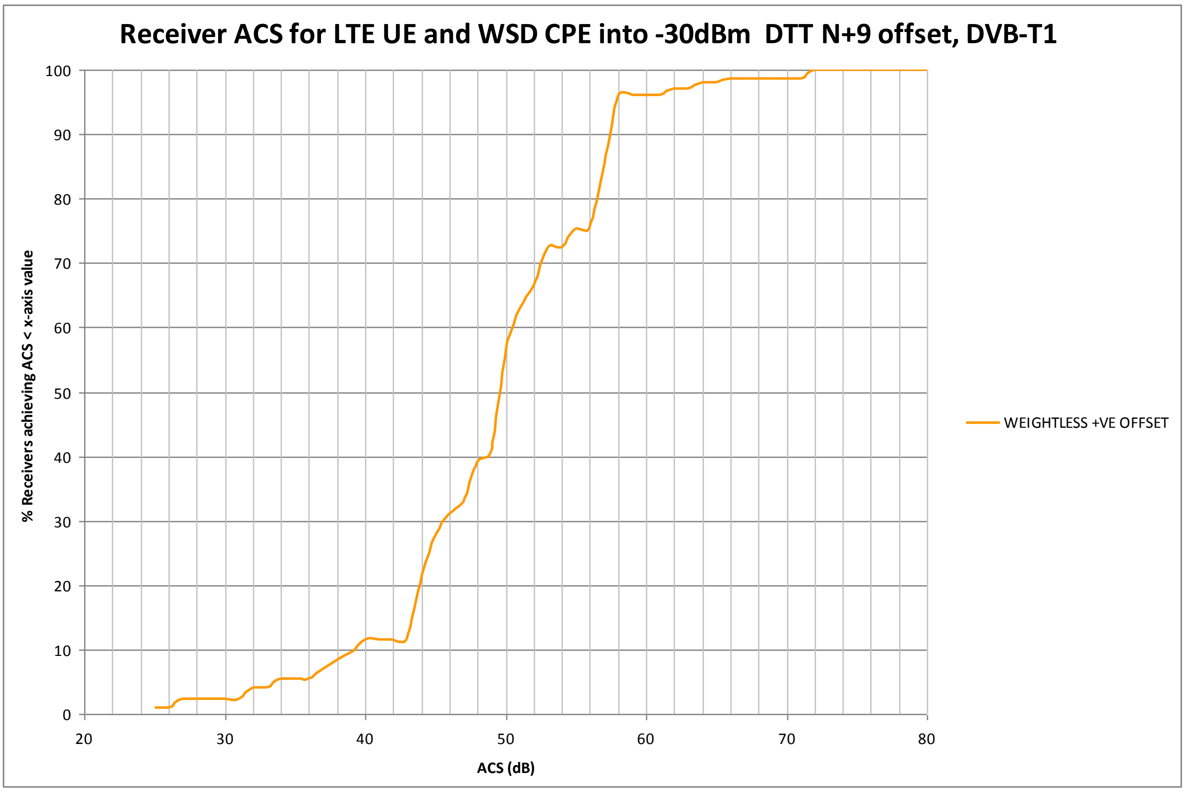

Figure 166 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+9

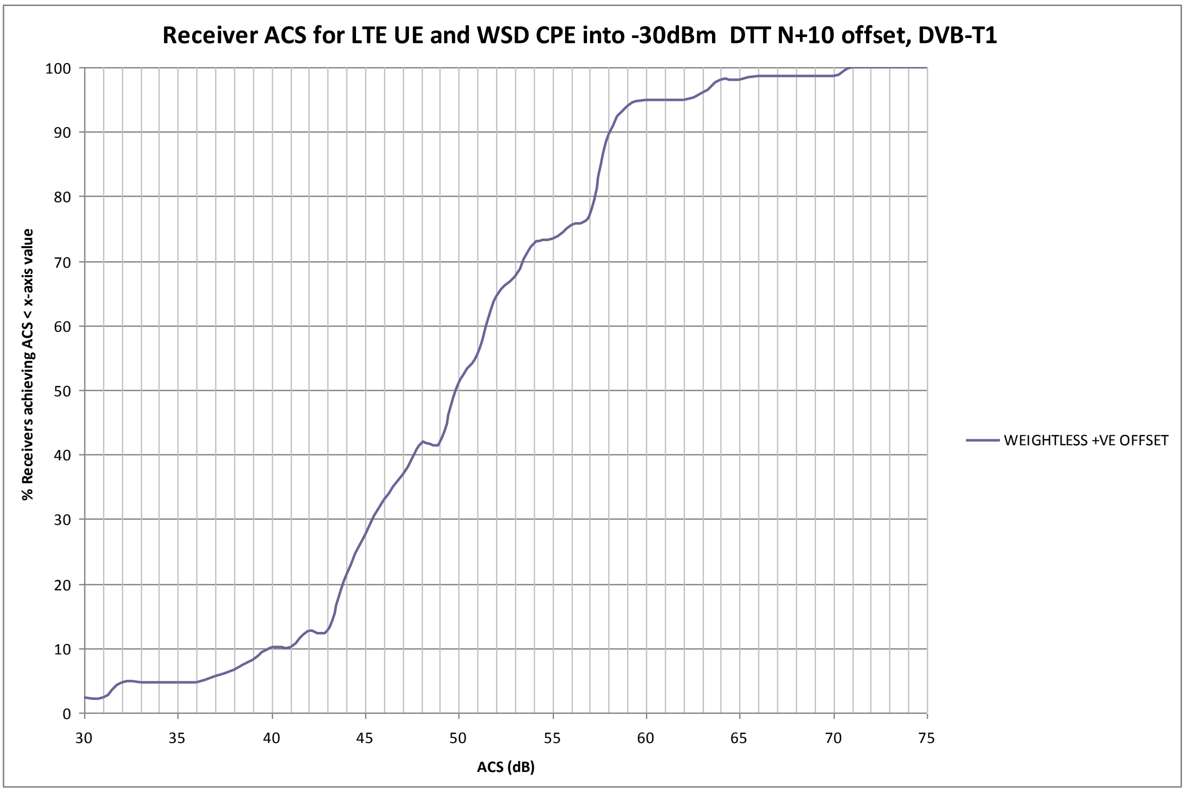

Figure 167 CDF of ACS values for Weightless base station at-30dBm DVB-T1 DTT at offsets N+10

Appendix C – Comparisons of carrier to interference ratios with and without pre-amplification

C.1 WSD WiMAX CPE 50kbps protection ratios with and without pre-amplification, test receiver 3

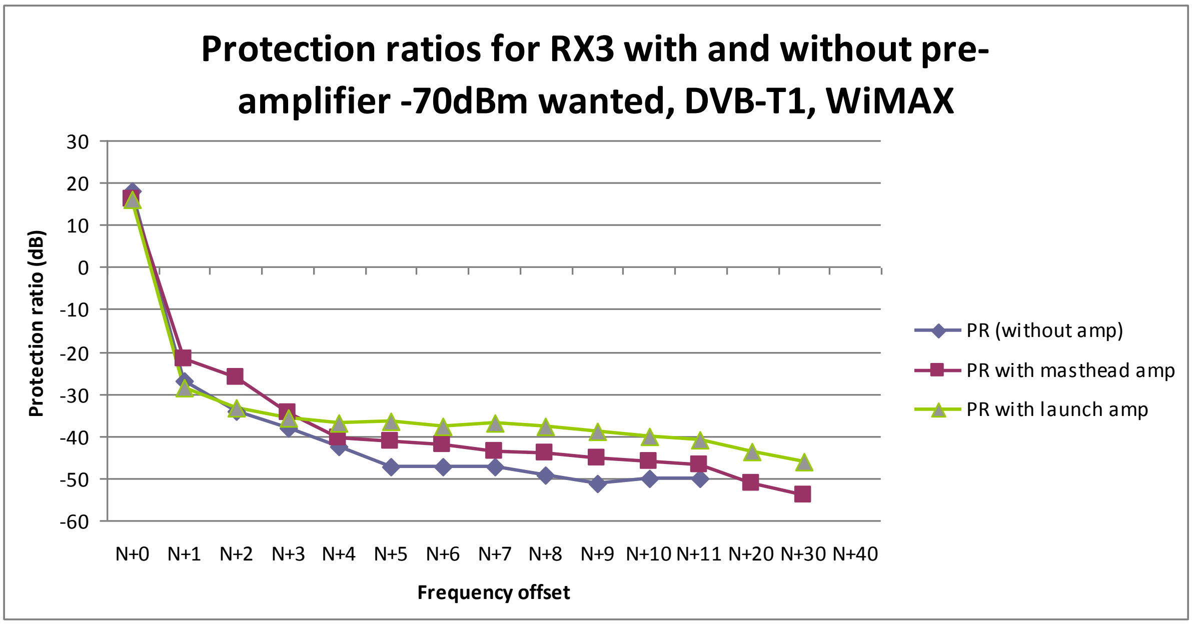

Figure 168 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

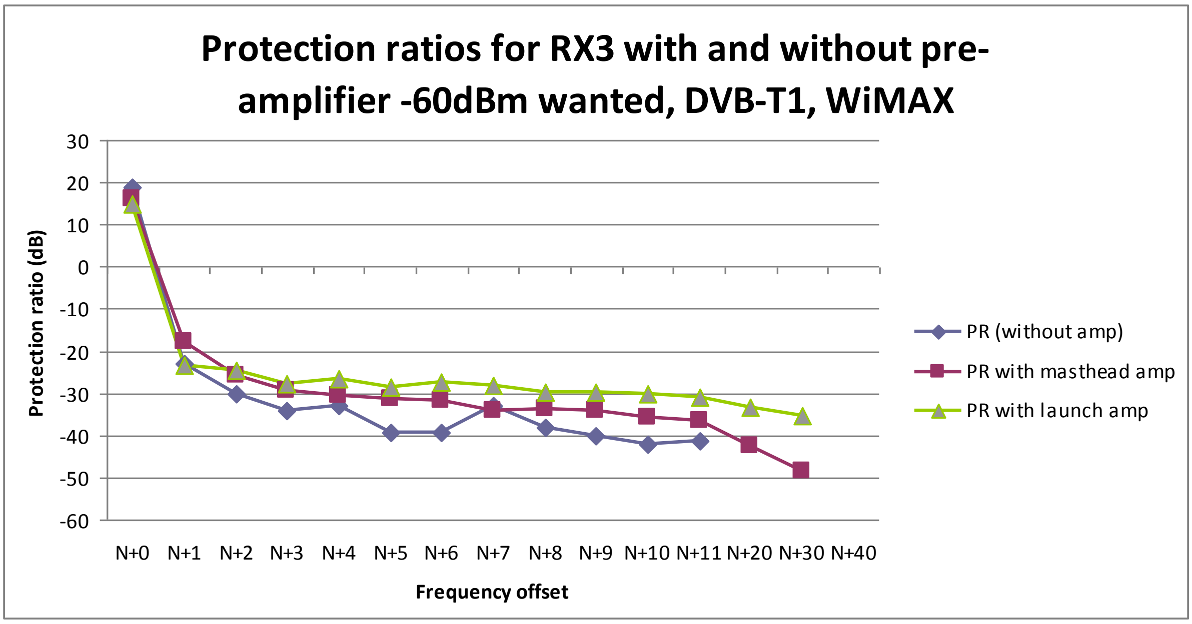

Figure 169 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

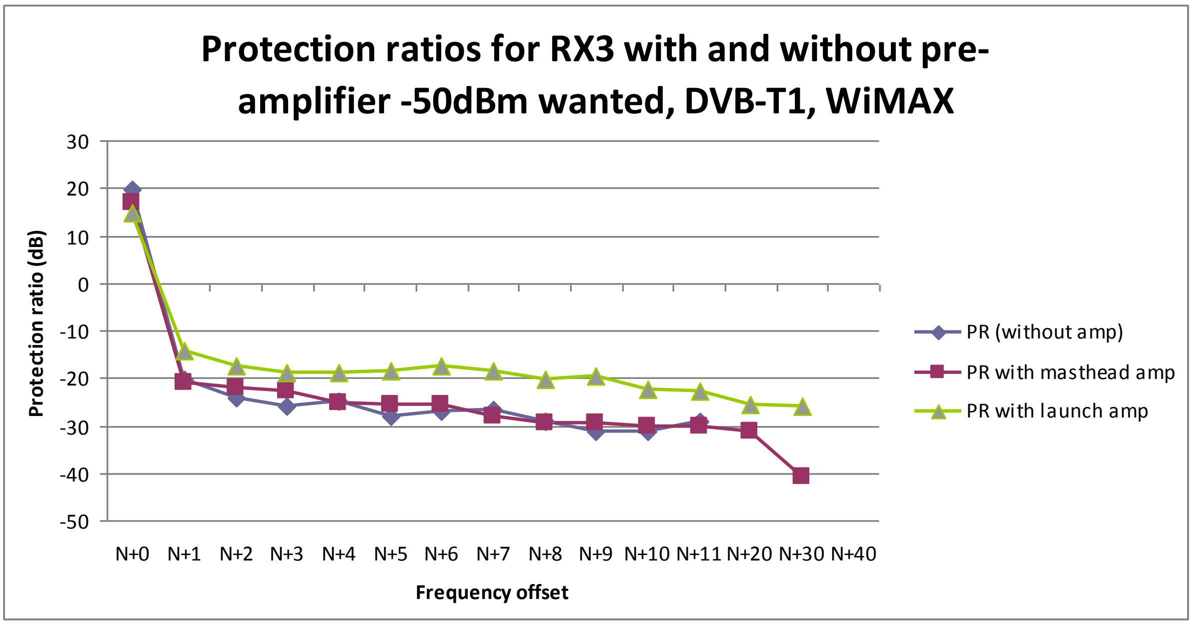

Figure 170 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

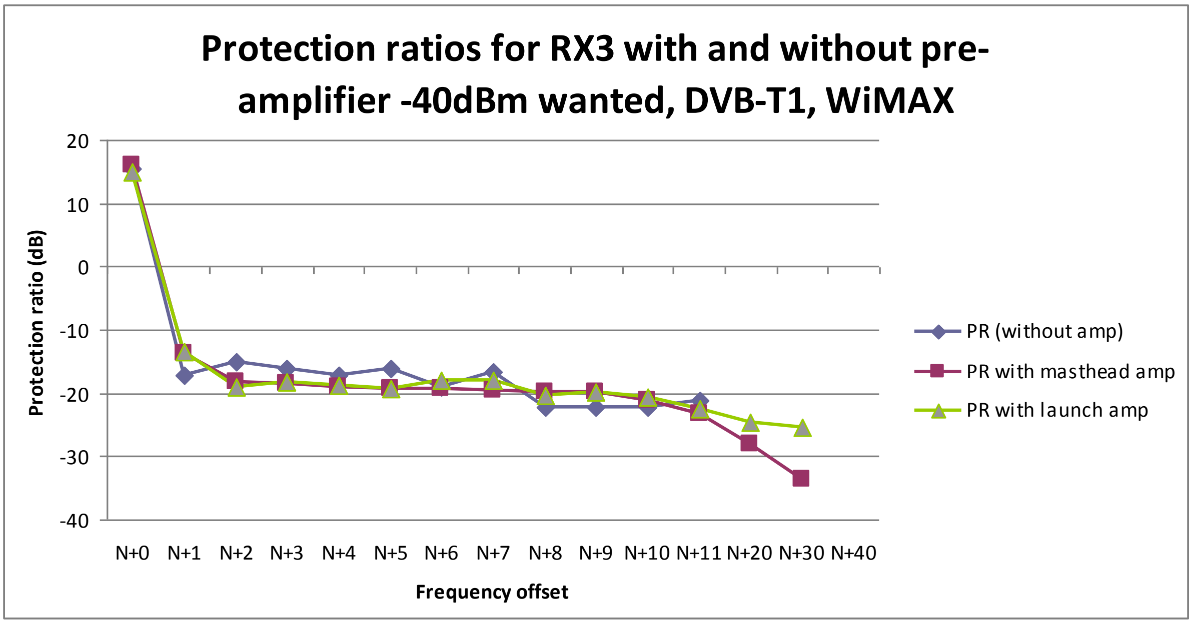

Figure 171 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-40dBm DVB-T1 DTT with and without pre-amplification, RX3

C.2 WSD WiMAX CPE 50kbps protection ratios with and without pre-amplification, test receiver 16

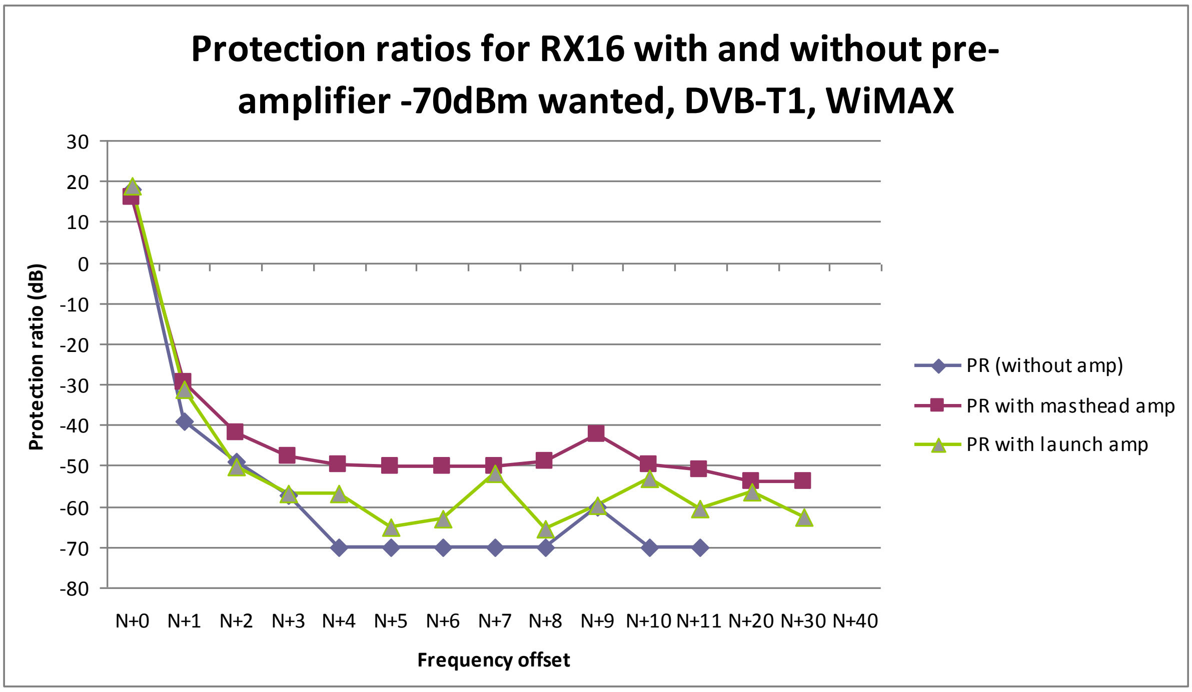

Figure 172 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

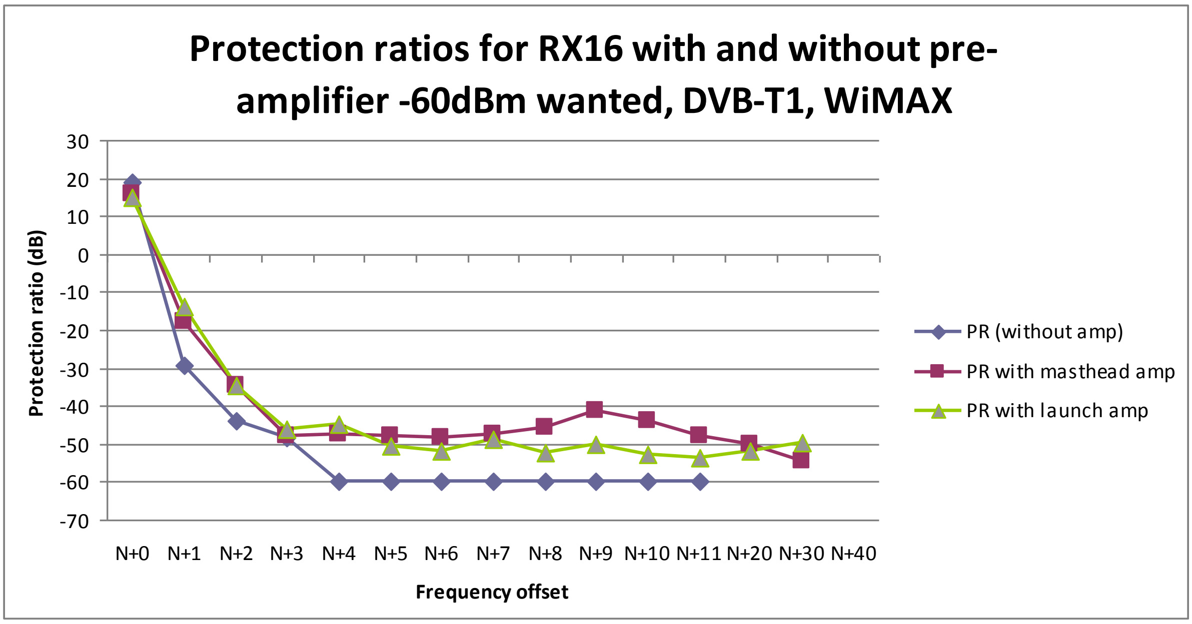

Figure 173 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

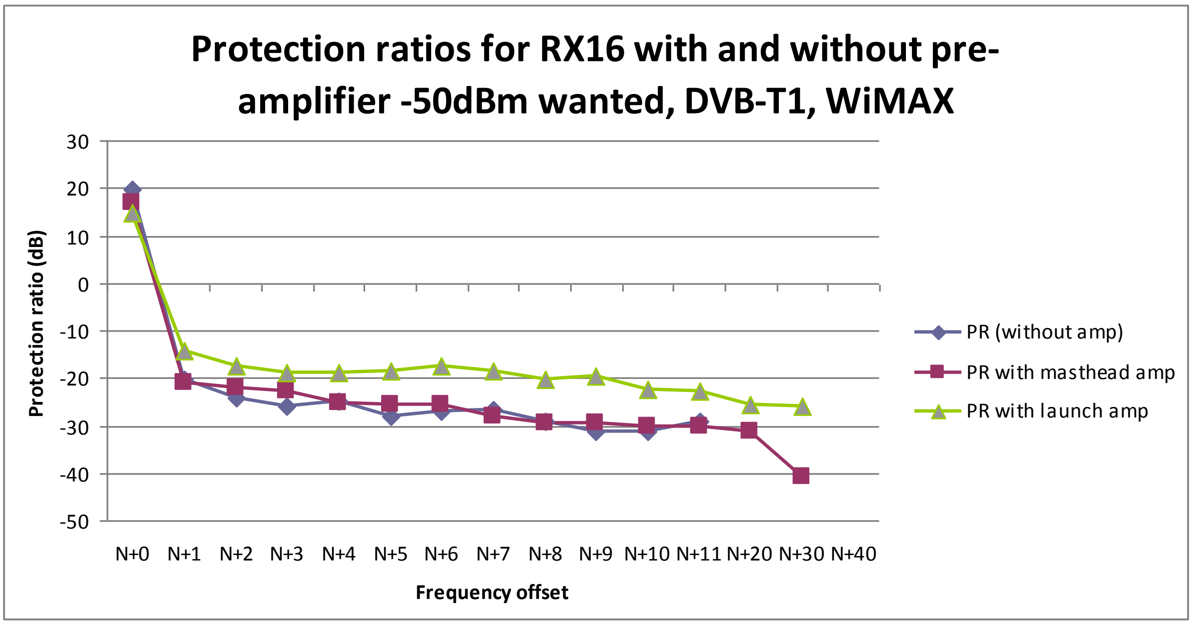

Figure 174 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

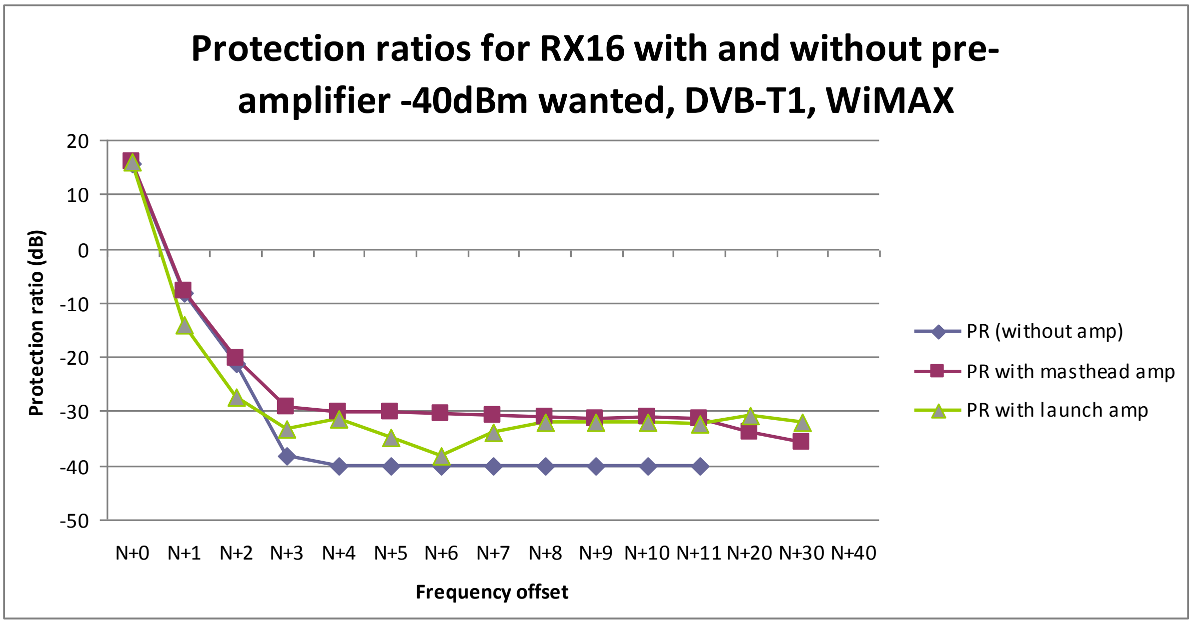

Figure 175 Protection ratio versus frequency offset for WiMAX CPE 50kbps at-40dBm DVB-T1 DTT with and without pre-amplification, RX16

C.3 WSD WiFi CPE 50kbps protection ratios with and without pre-amplification, test receiver 3

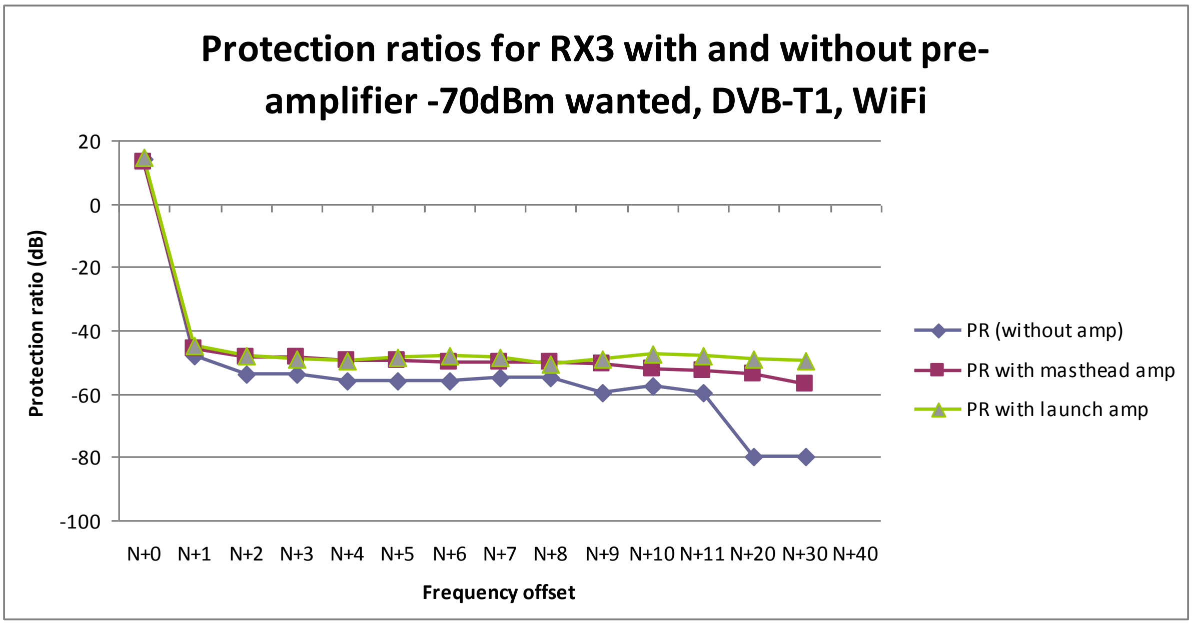

Figure 176 Protection ratio versus frequency offset for WiFi CPE 50kbps at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

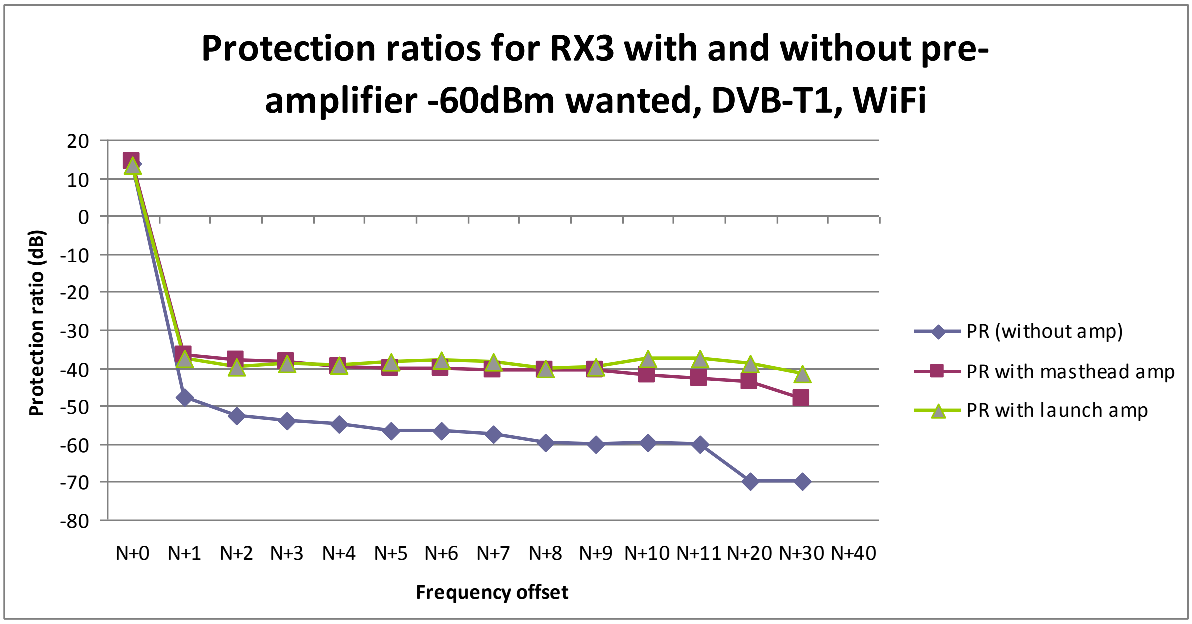

Figure 177 Protection ratio versus frequency offset for WiFi CPE 50kbps at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

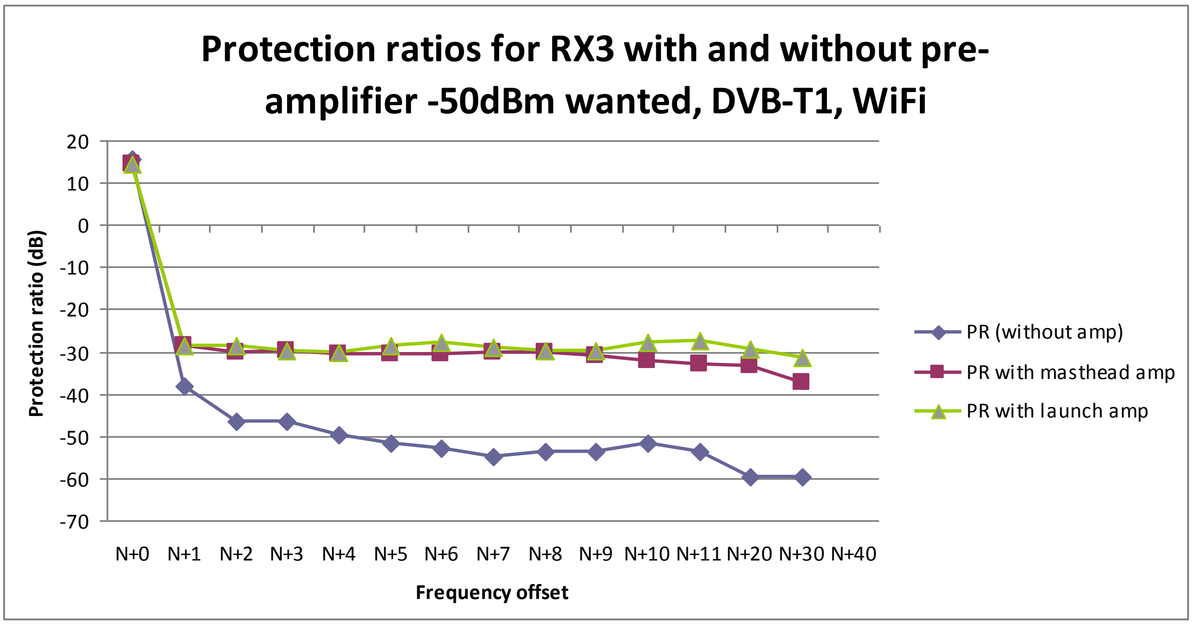

Figure 178 Protection ratio versus frequency offset for WiFi CPE 50kbps at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

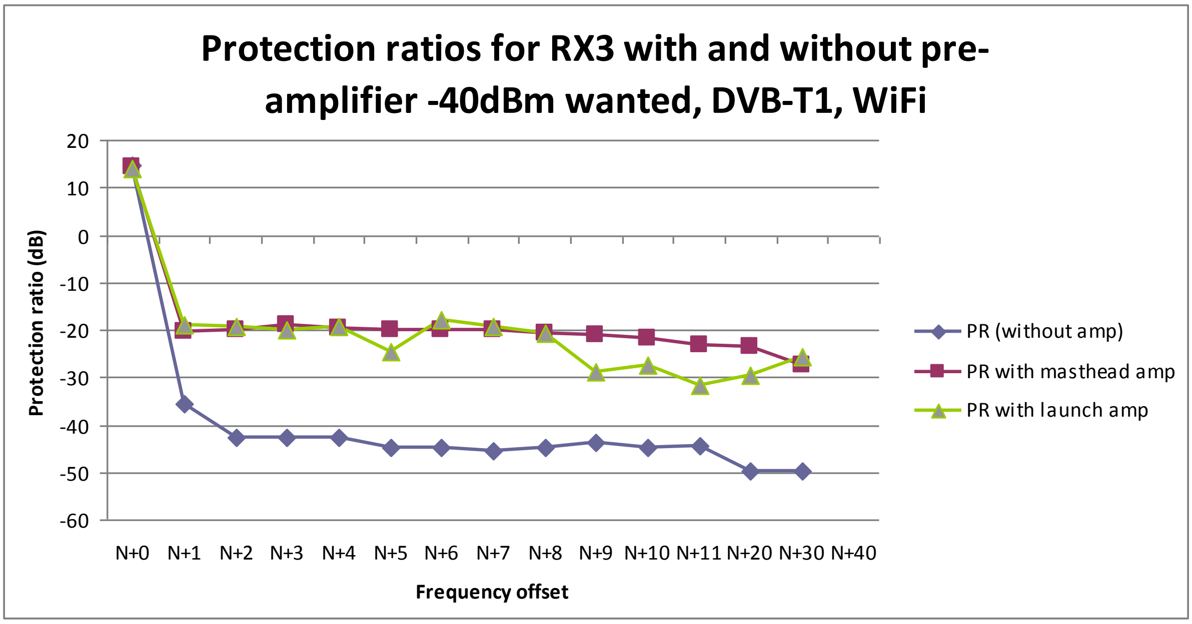

Figure 179 Protection ratio versus frequency offset for WiFi CPE 50kbps at-40dBm DVB-T1 DTT with and without pre-amplification, RX3

C.4 WSD WiFi CPE 50kbps protection ratios with and without pre-amplification, test receiver 16

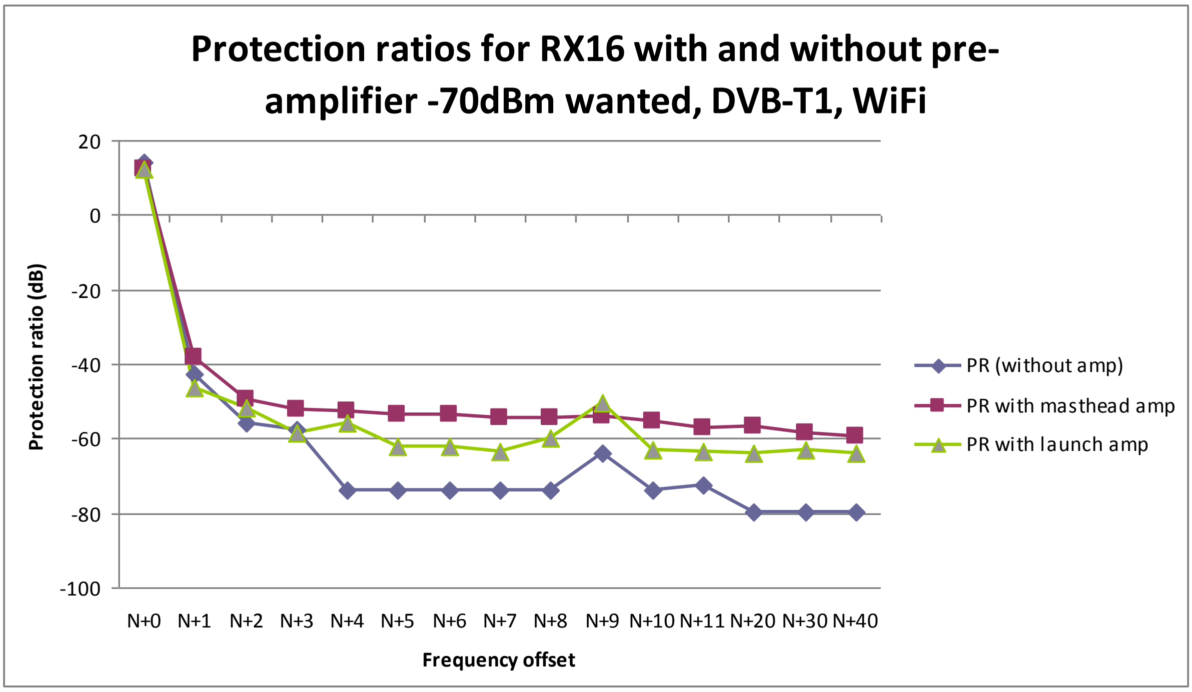

Figure 180 Protection ratio versus frequency offset for WiFi CPE 50kbps at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

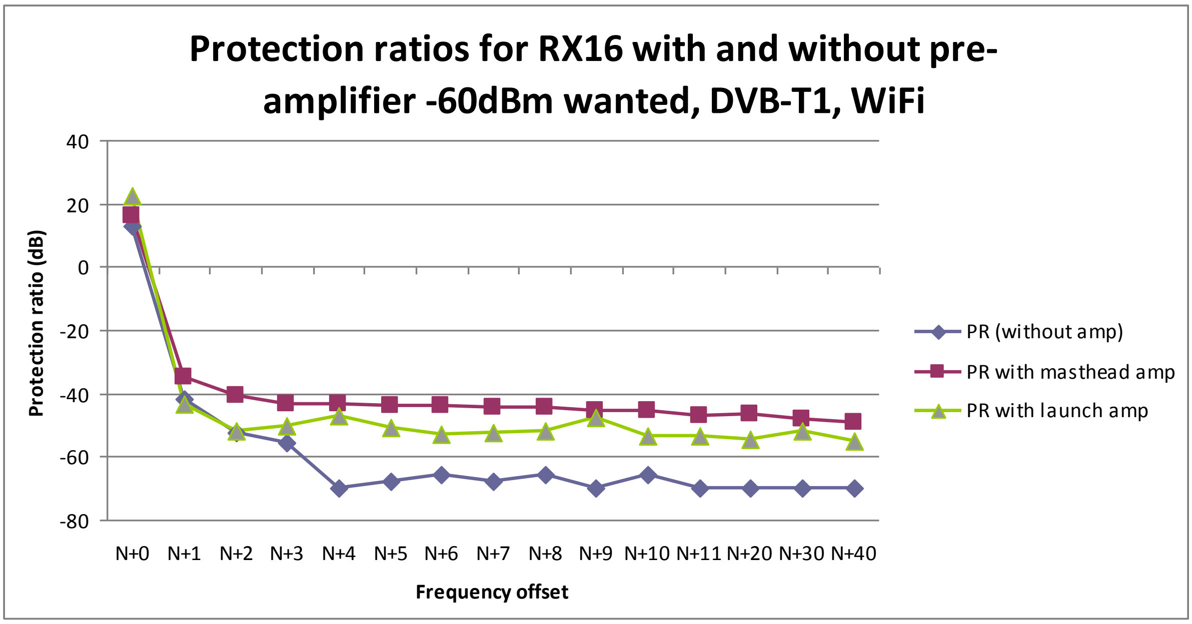

Figure 181 Protection ratio versus frequency offset for WiFi CPE 50kbps at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

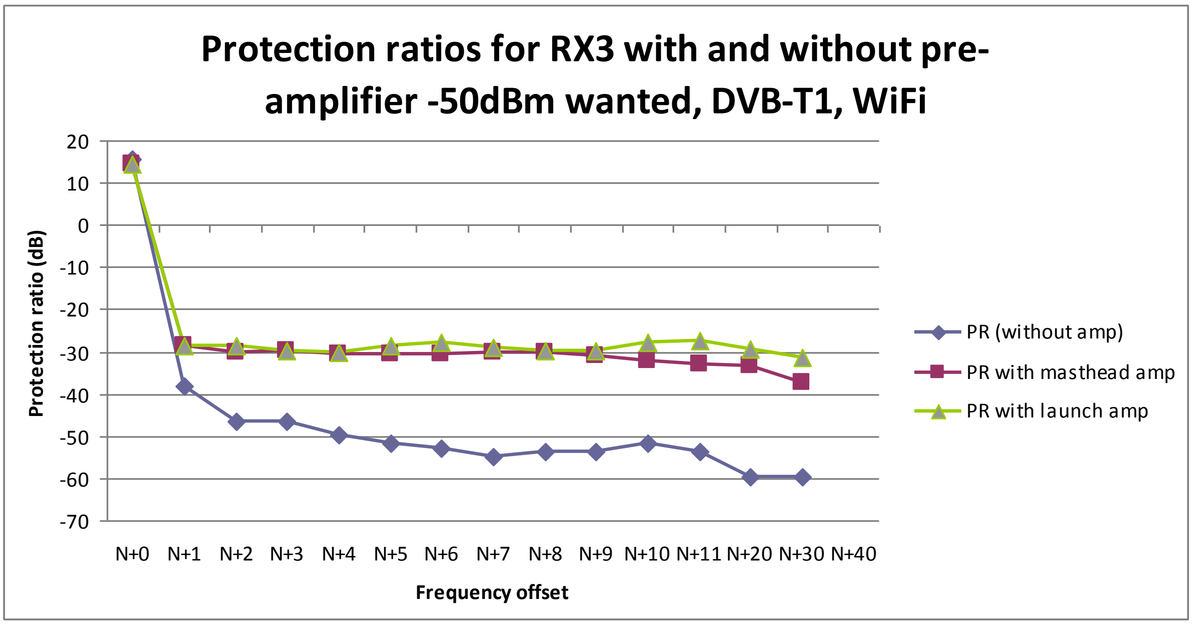

Figure 182 Protection ratio versus frequency offset for WiFi CPE 50kbps at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

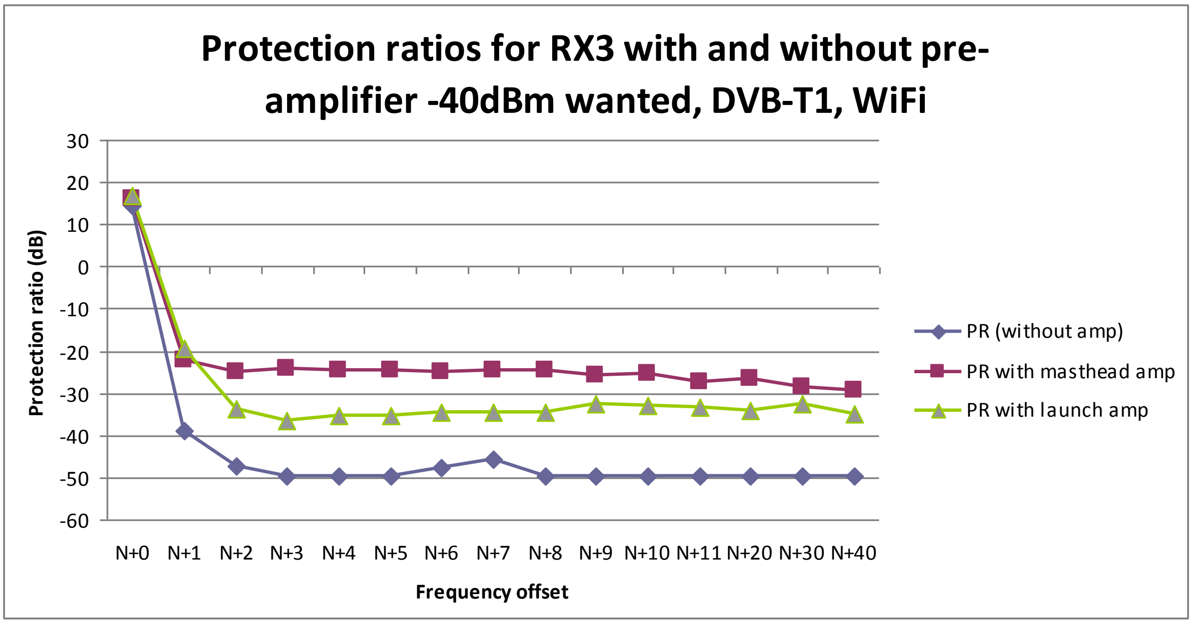

Figure 183 Protection ratio versus frequency offset for WiFi CPE 50kbps at-40dBm DVB-T1 DTT with and without pre-amplification, RX16

C.5 WSD Weightless base station protection ratios with and without pre-amplification, test receiver 3

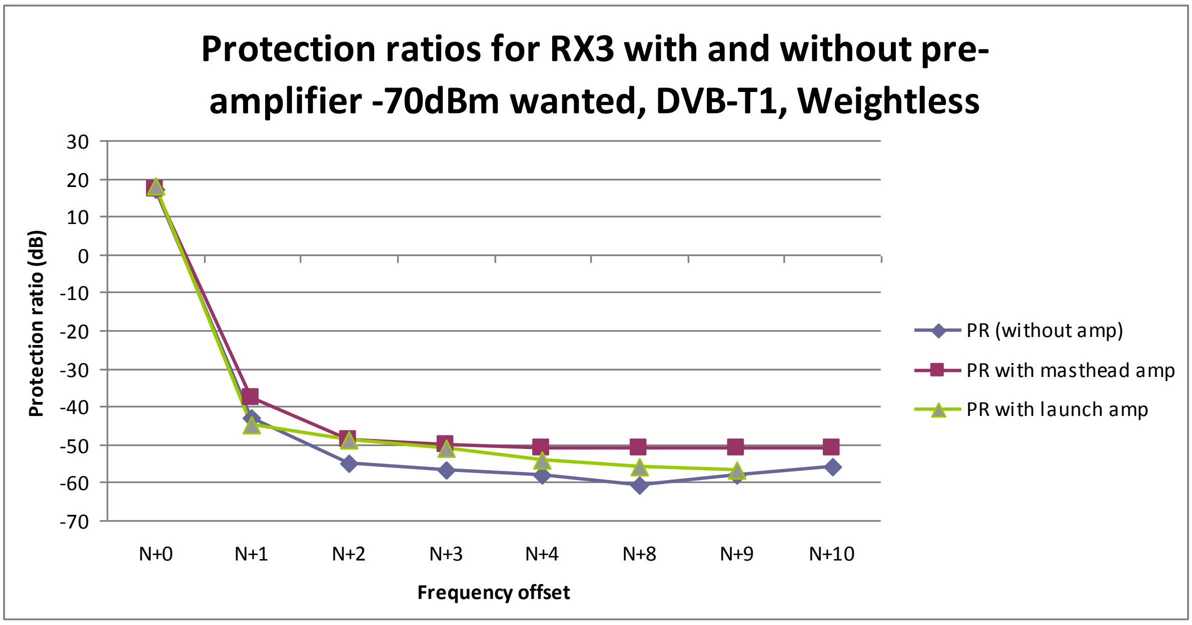

Figure 184 Protection ratio versus frequency offset for Weightless base station at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

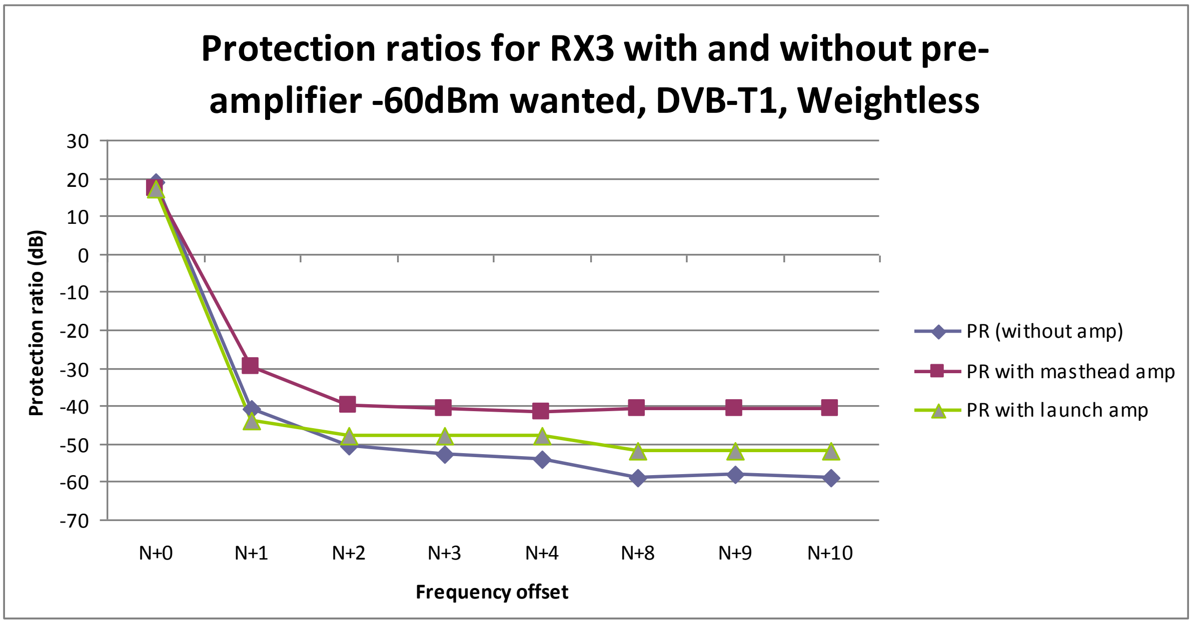

Figure 185 Protection ratio versus frequency offset for Weightless base station at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

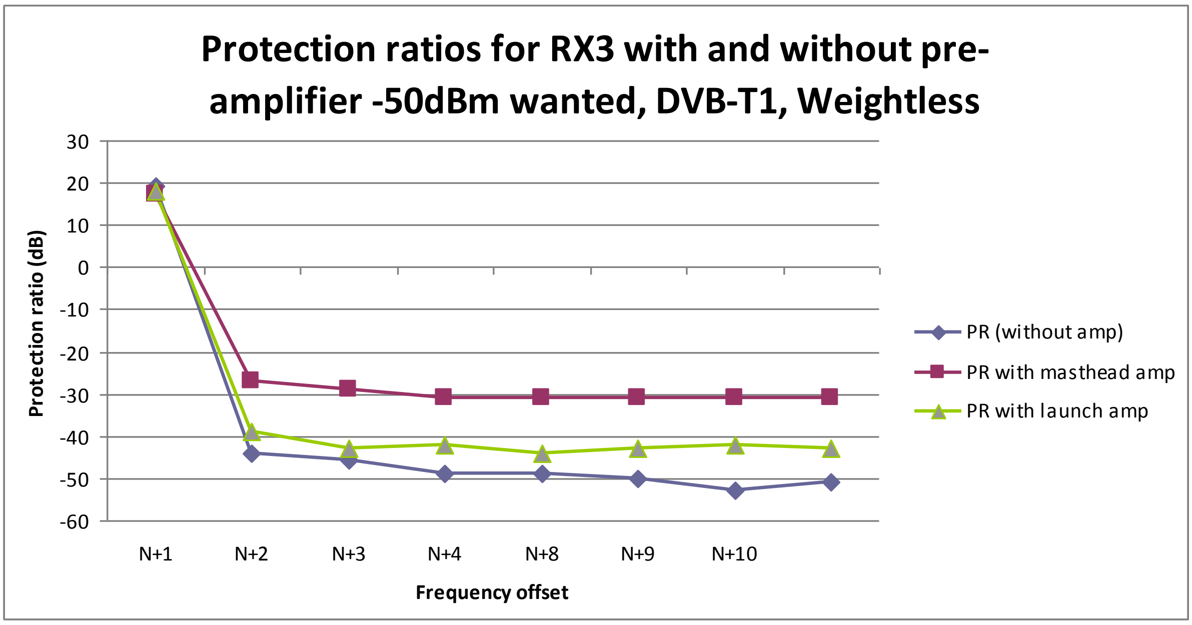

Figure 186 Protection ratio versus frequency offset for Weightless base station at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

C.6 WSD Weightless base station protection ratios with and without pre-amplification, test receiver 16

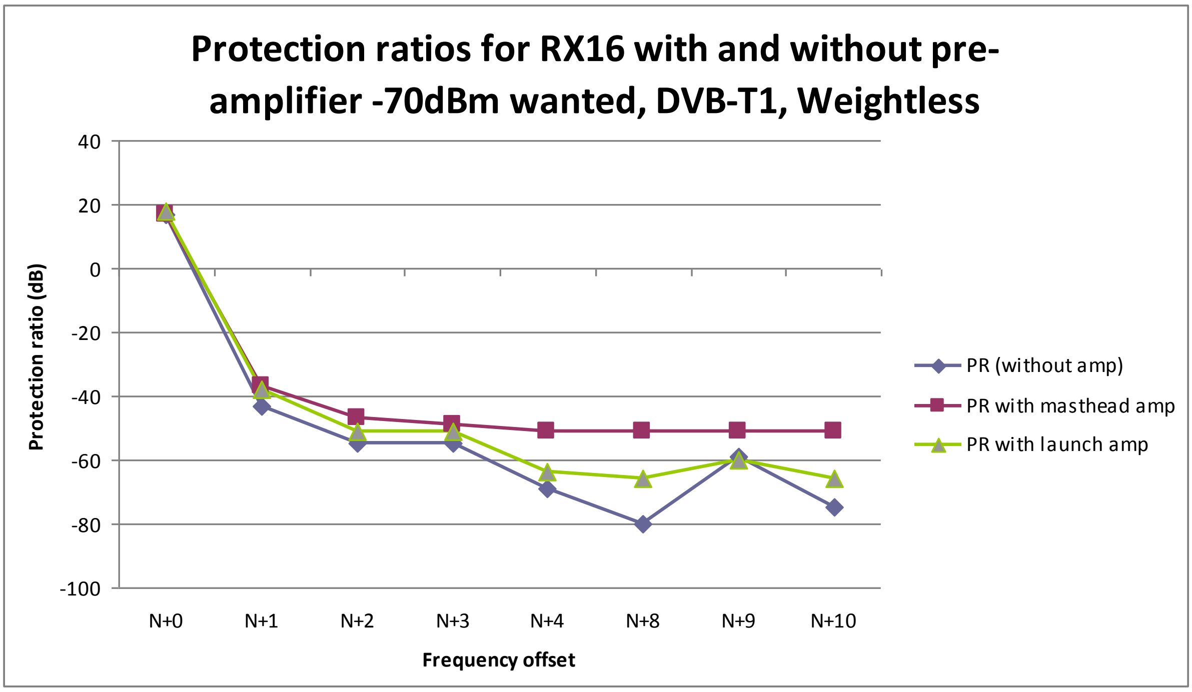

Figure 187 Protection ratio versus frequency offset for Weightless base station at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

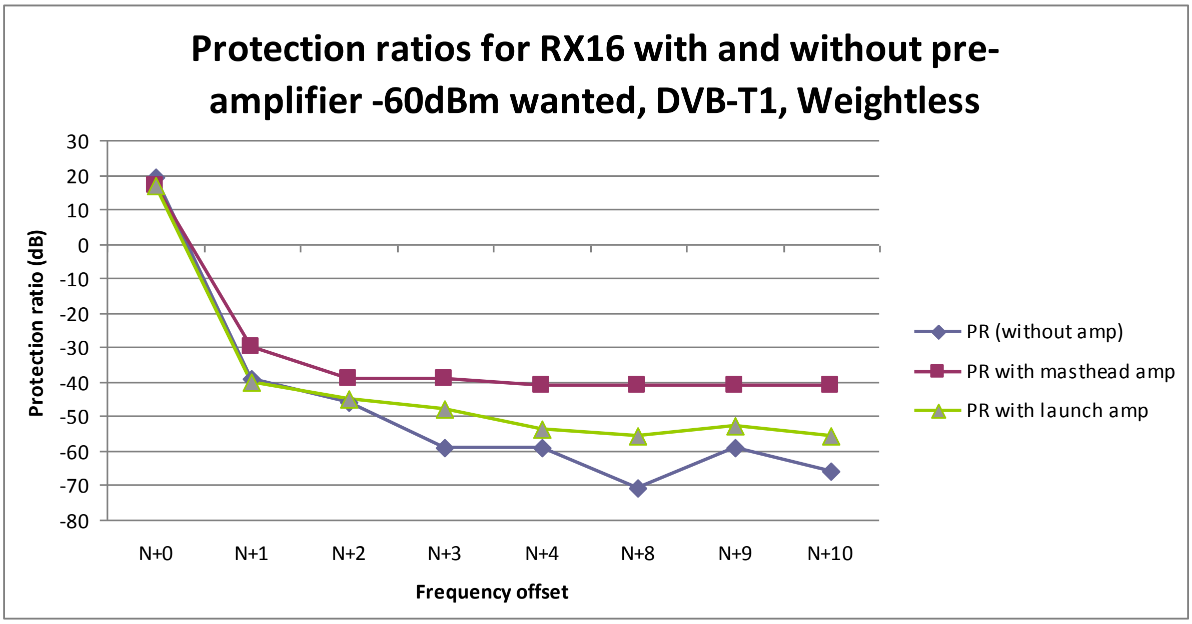

Figure 188 Protection ratio versus frequency offset for Weightless base station at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

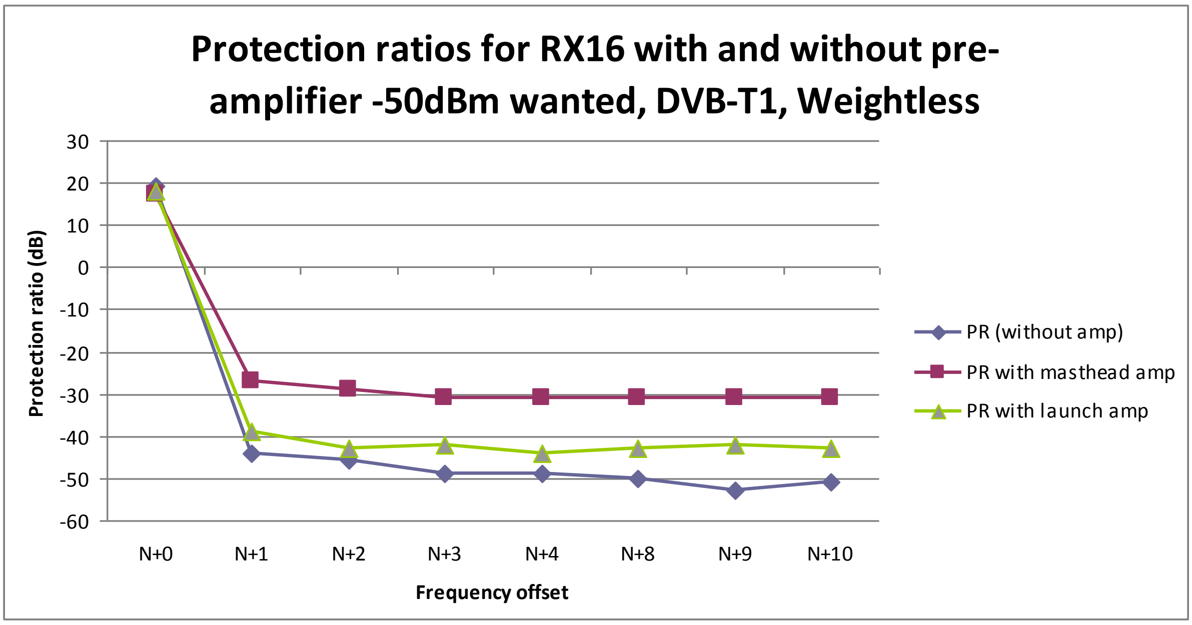

Figure 189 Protection ratio versus frequency offset for Weightless base station at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

C.7 LTE UE full load protection ratios with and without pre-amplification, test receiver 3

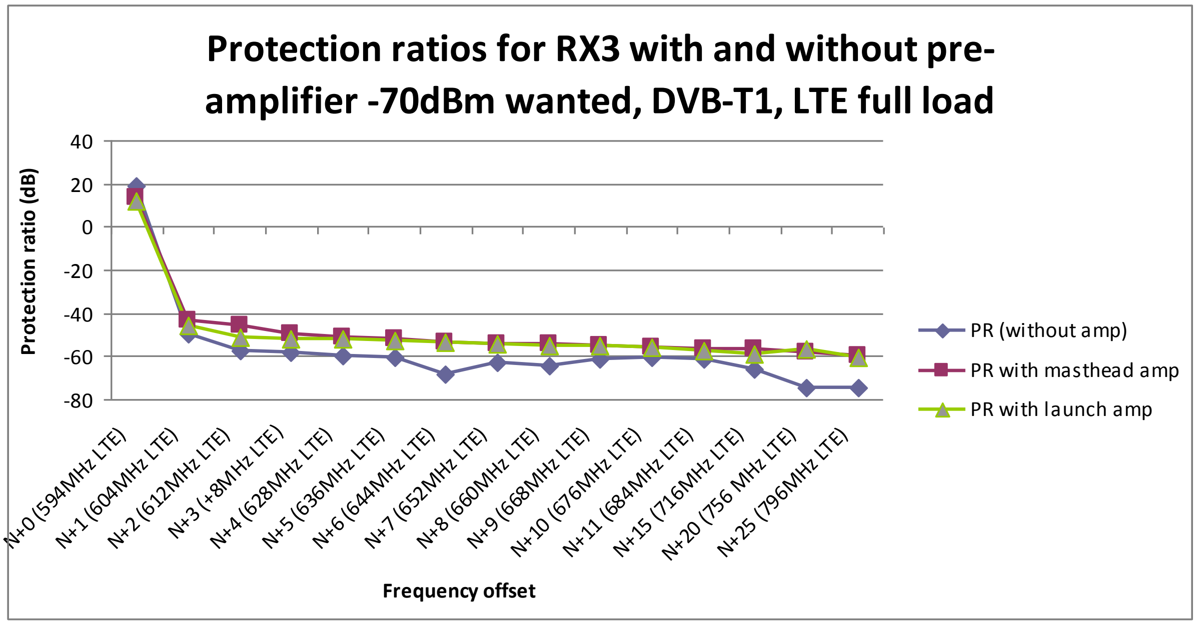

Figure 190 Protection ratio versus frequency offset for LTE UE full load at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

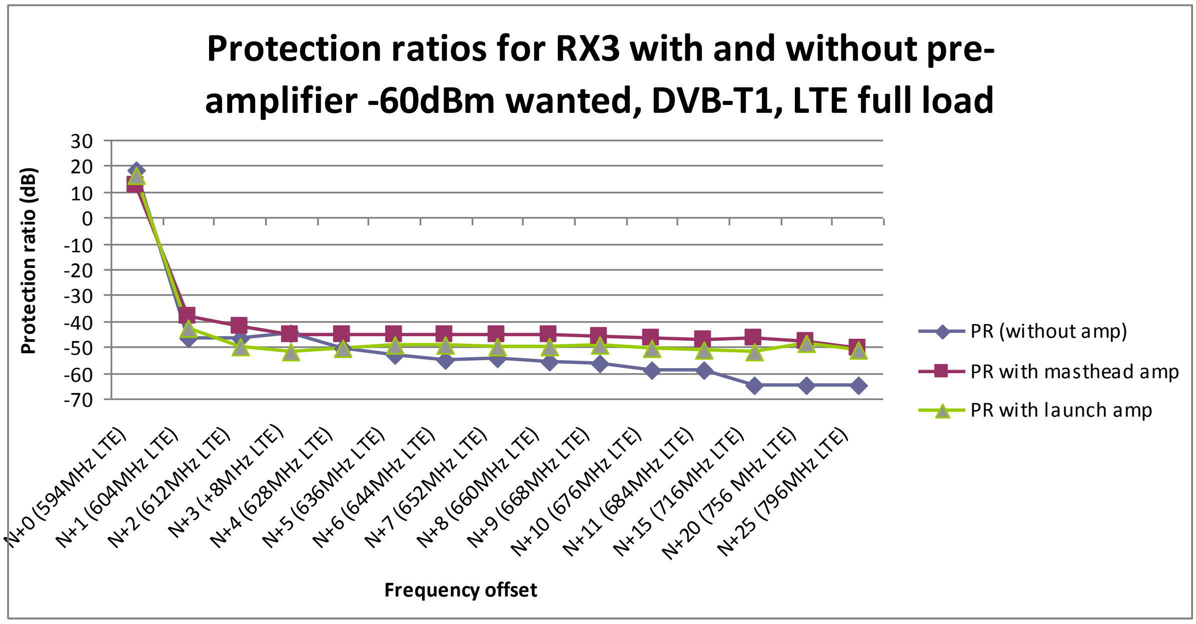

Figure 191 Protection ratio versus frequency offset for LTE UE full load at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

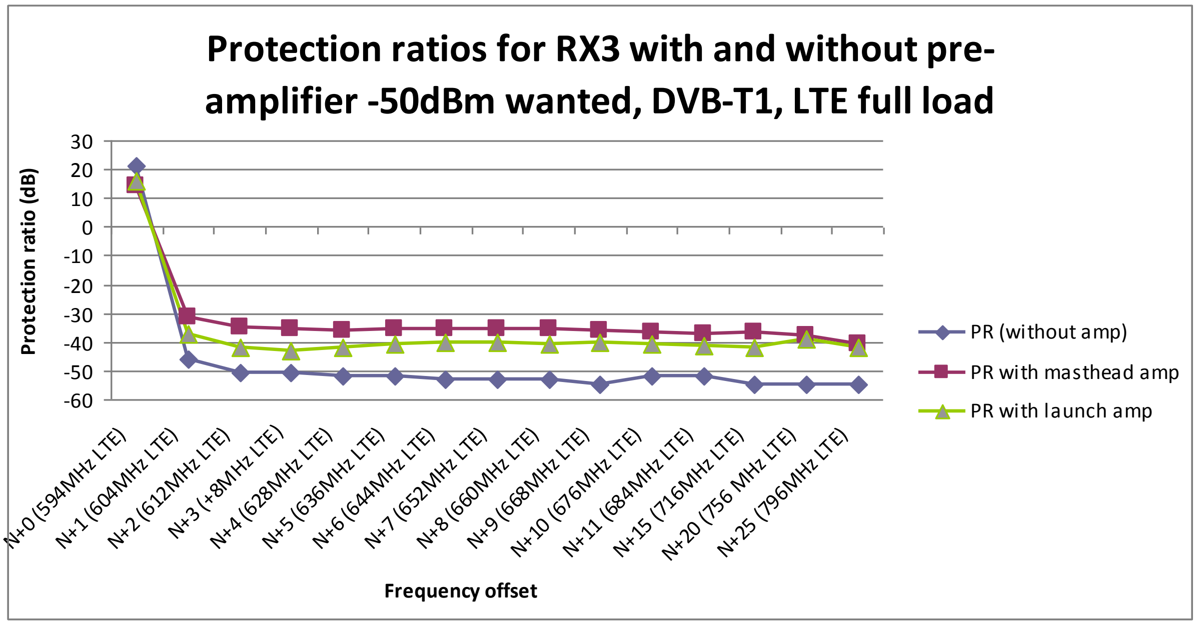

Figure 192 Protection ratio versus frequency offset for LTE UE full load at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

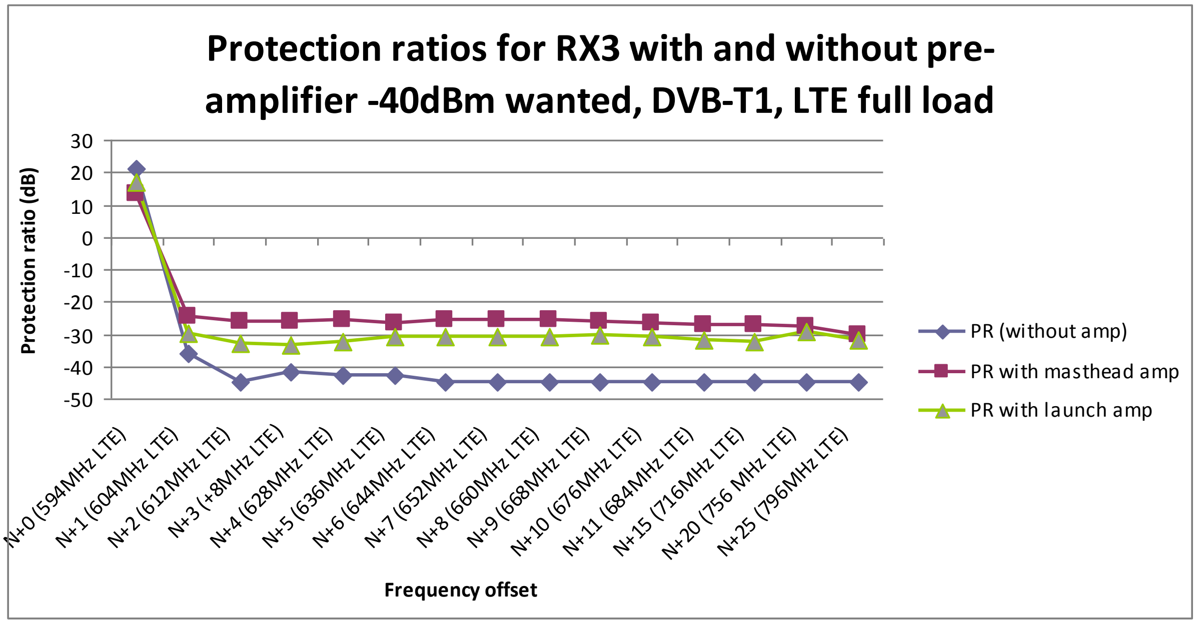

Figure 193 Protection ratio versus frequency offset for LTE UE full load at-40dBm DVB-T1 DTT with and without pre-amplification, RX3

C.8 LTE UE full load protection ratios with and without pre-amplification, test receiver 16

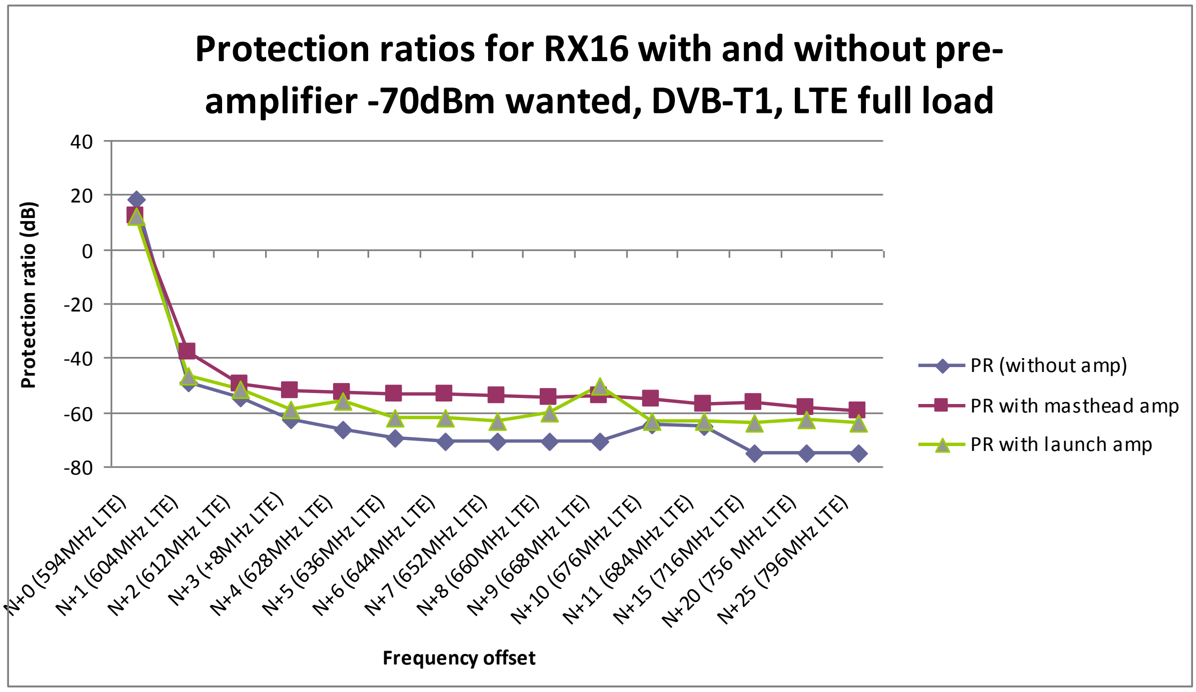

Figure 194 Protection ratio versus frequency offset for LTE UE full load at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

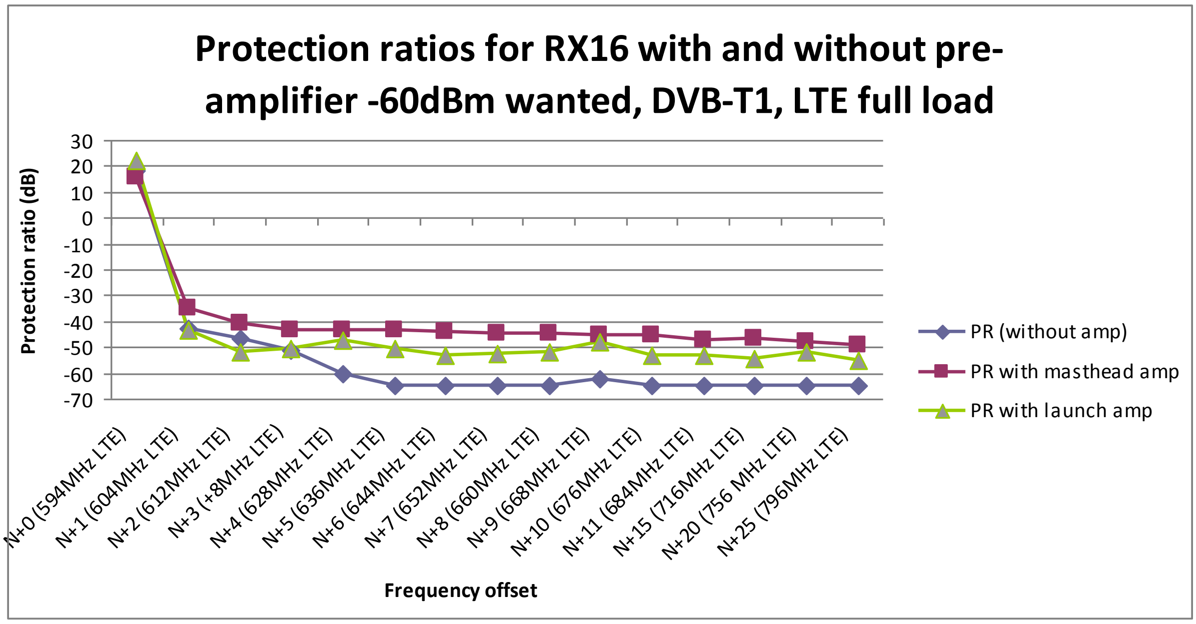

Figure 195 Protection ratio versus frequency offset for LTE UE full load at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

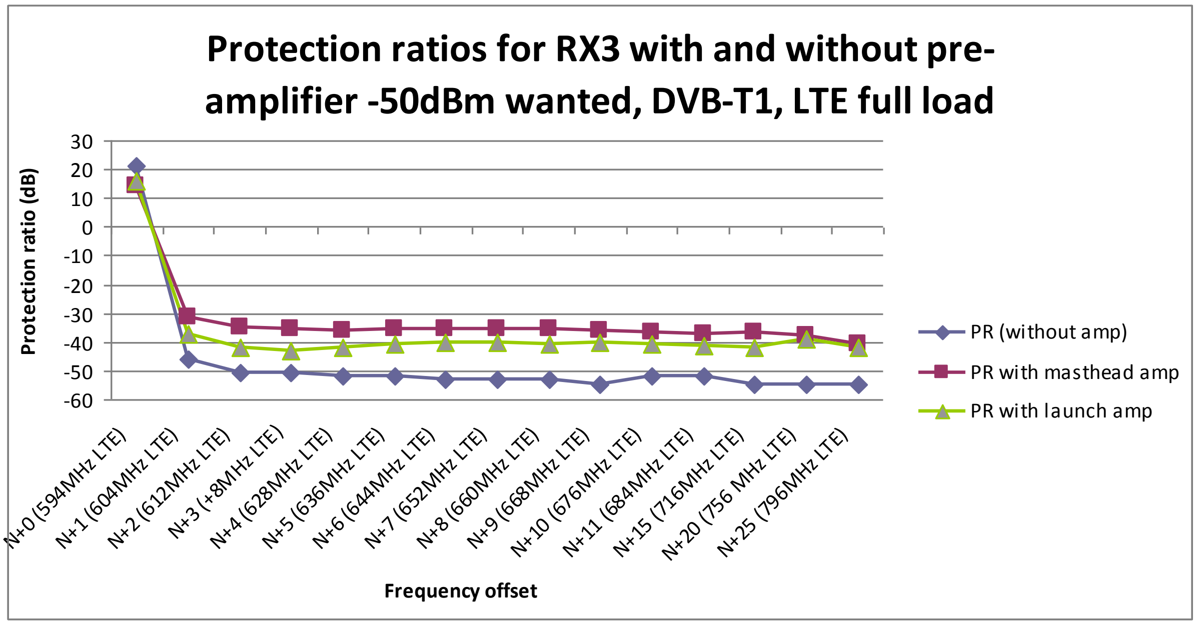

Figure 196 Protection ratio versus frequency offset for LTE UE full load at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

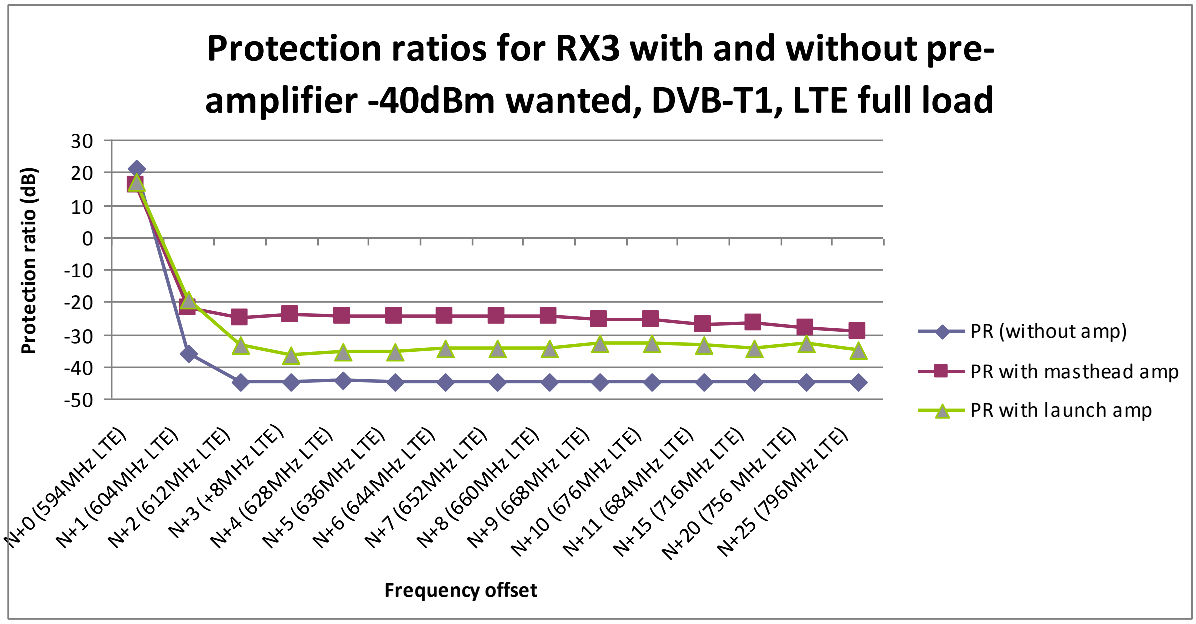

Figure 197 Protection ratio versus frequency offset for LTE UE full load at-40dBm DVB-T1 DTT with and without pre-amplification, RX16

C.9 LTE UE half load protection ratios with and without pre-amplification, test receiver 3

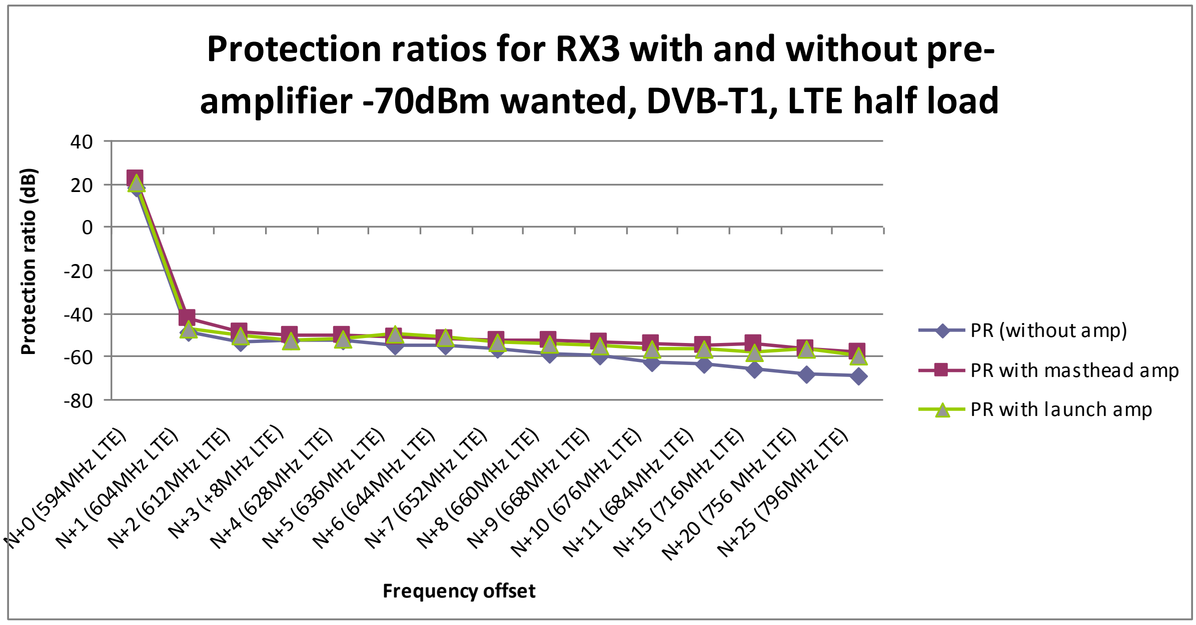

Figure 198 Protection ratio versus frequency offset for LTE UE half load at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

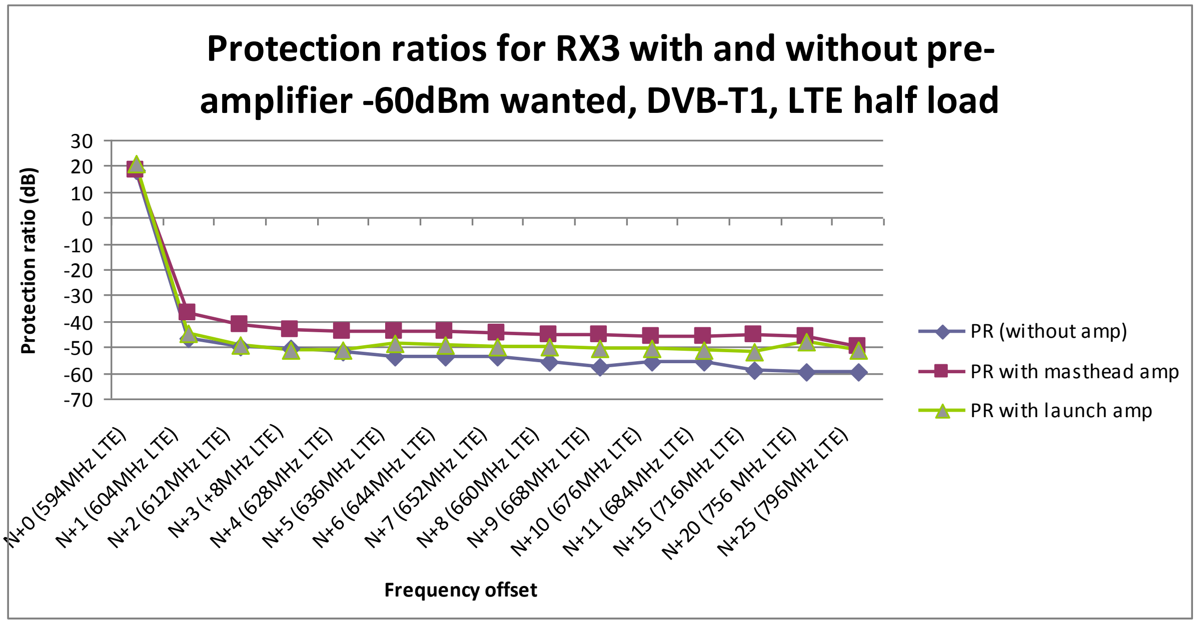

Figure 199 Protection ratio versus frequency offset for LTE UE half load at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

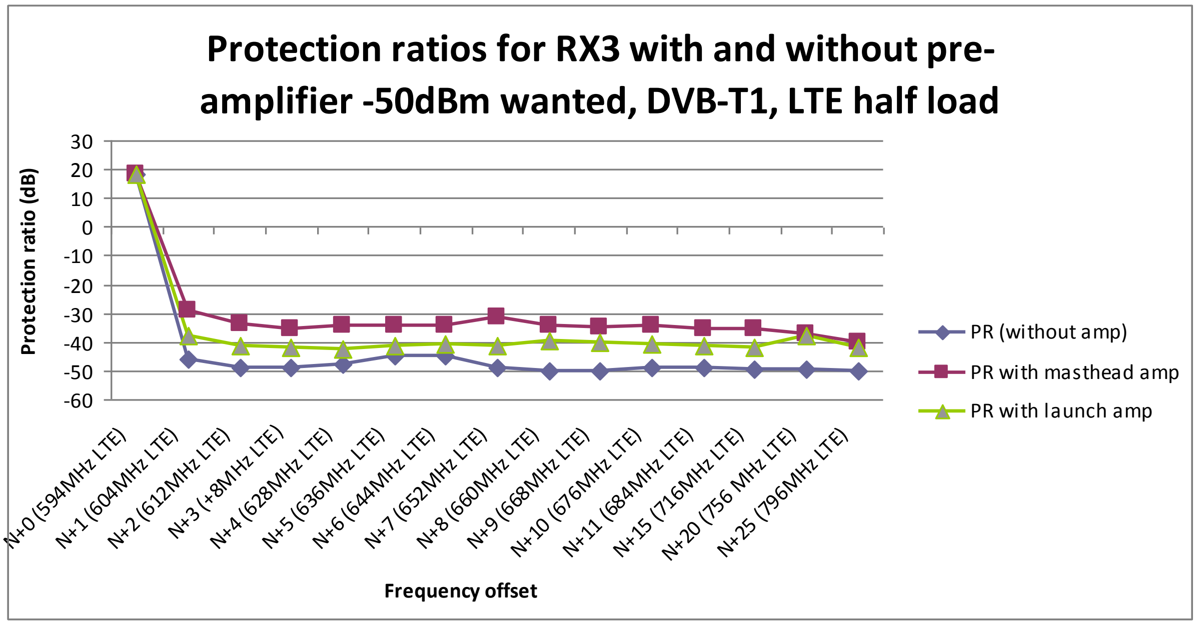

Figure 200 Protection ratio versus frequency offset for LTE UE half load at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

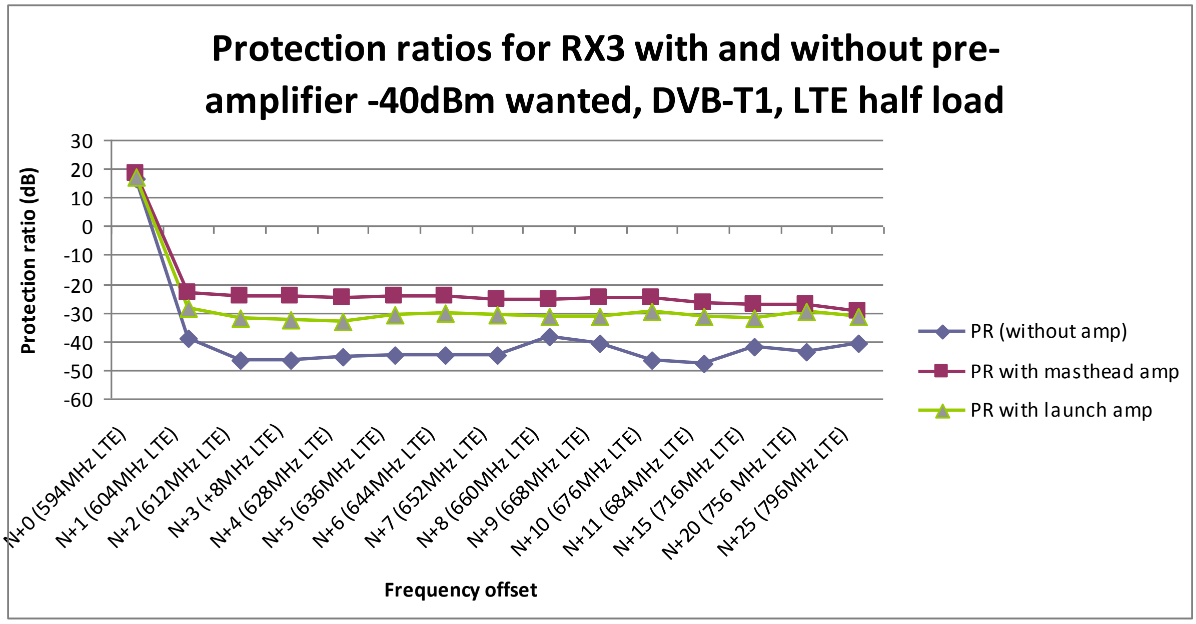

Figure 201 Protection ratio versus frequency offset for LTE UE half load at-40dBm DVB-T1 DTT with and without pre-amplification, RX3

C.10 LTE UE half load protection ratios with and without pre-amplification, test receiver 16

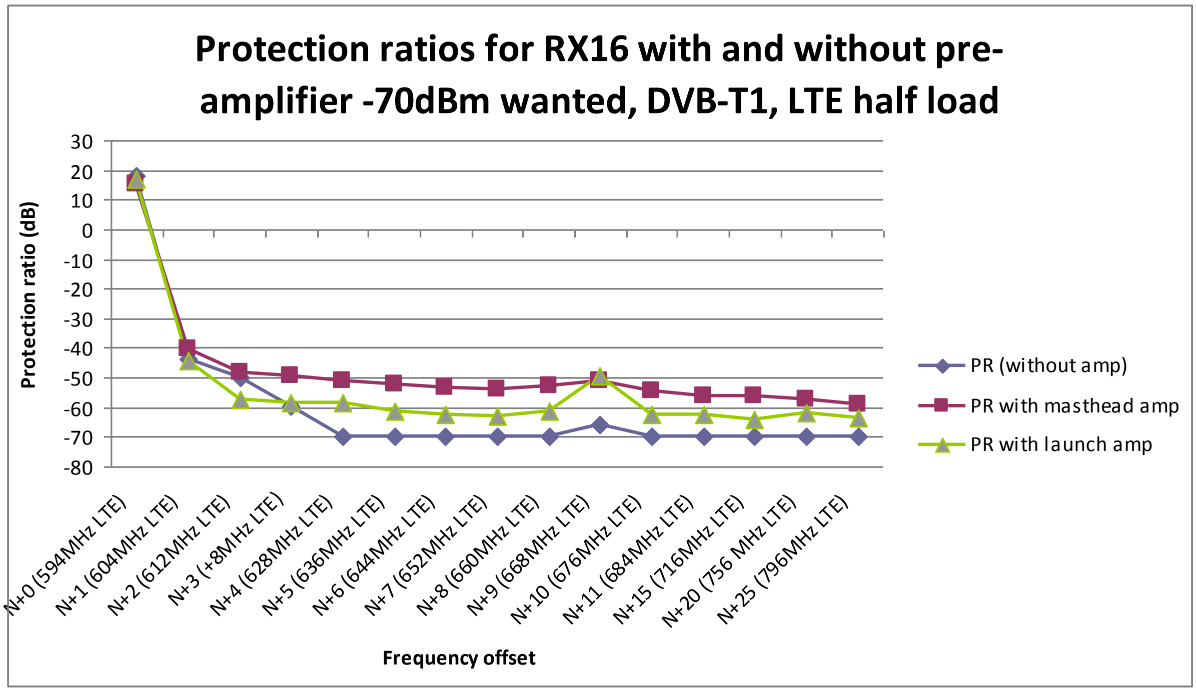

Figure 202 Protection ratio versus frequency offset for LTE UE half load at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

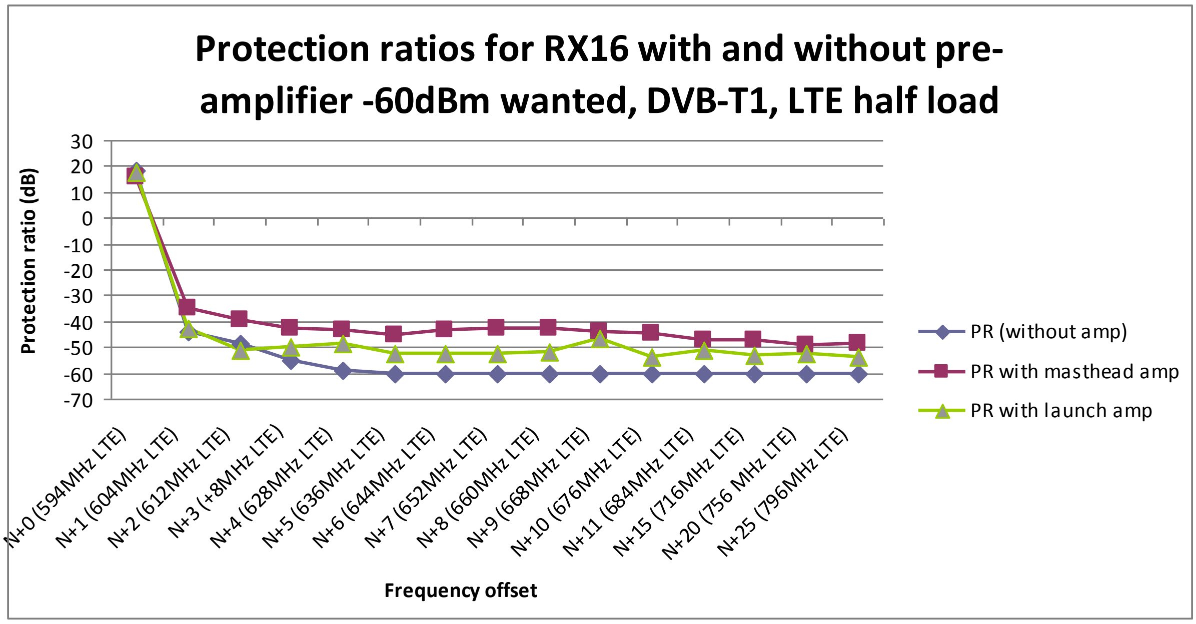

Figure 203 Protection ratio versus frequency offset for LTE UE half load at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

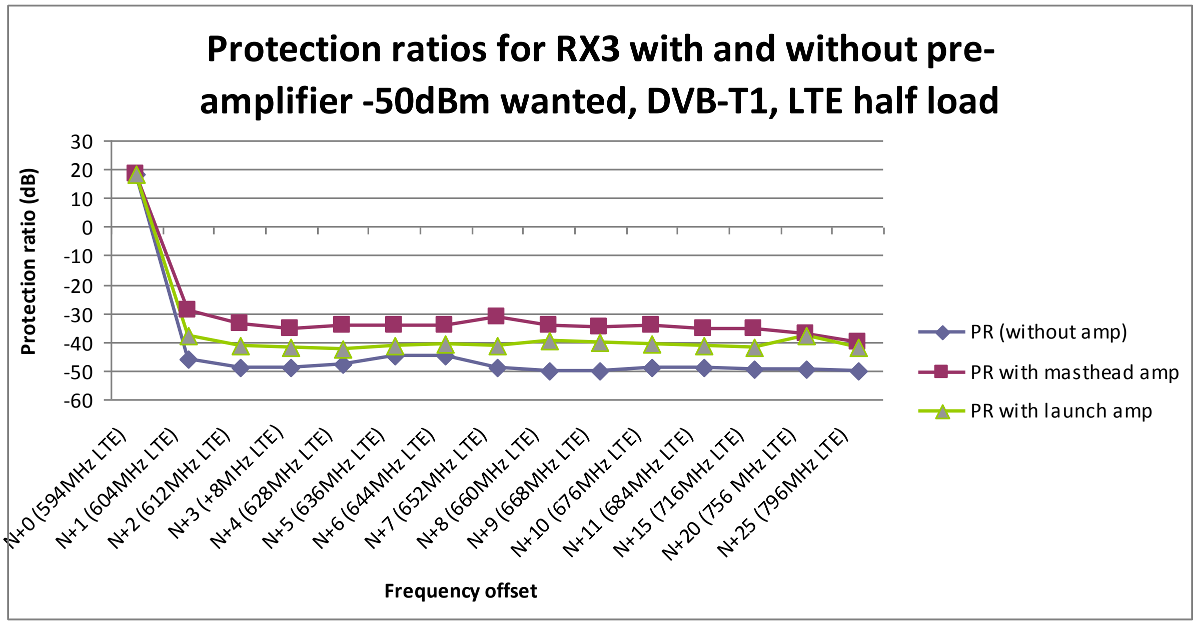

Figure 204 Protection ratio versus frequency offset for LTE UE half load at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

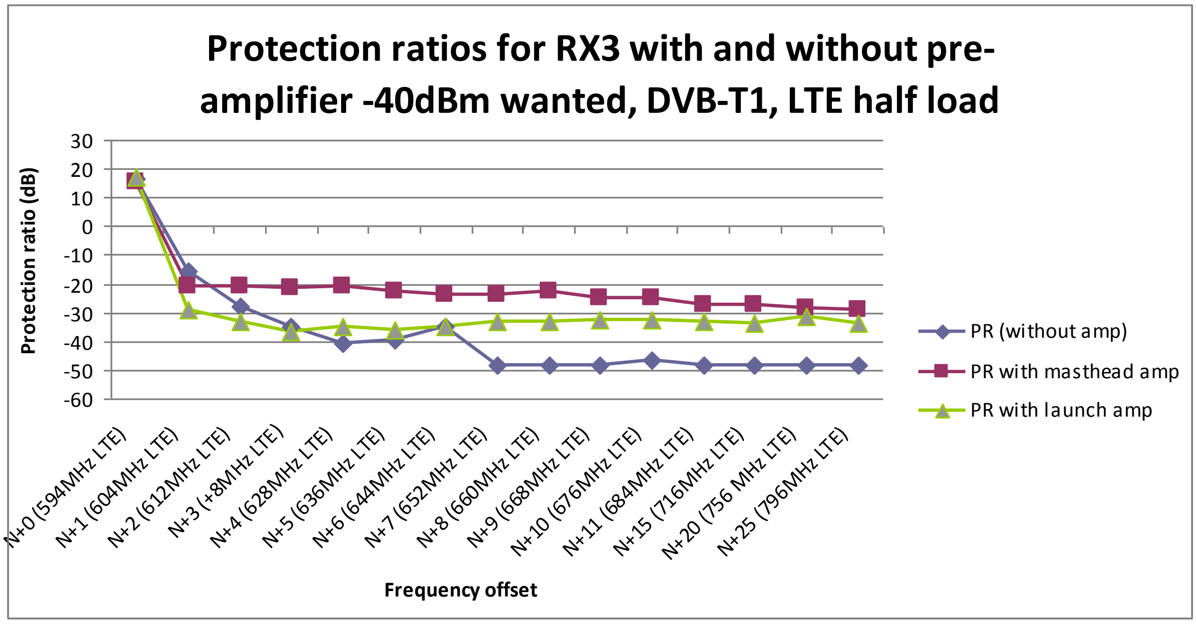

Figure 205 Protection ratio versus frequency offset for LTE UE full load at-40dBm DVB-T1 DTT with and without pre-amplification, RX16

C.11 LTE UE idle mode protection ratios with and without pre-amplification, test receiver 3

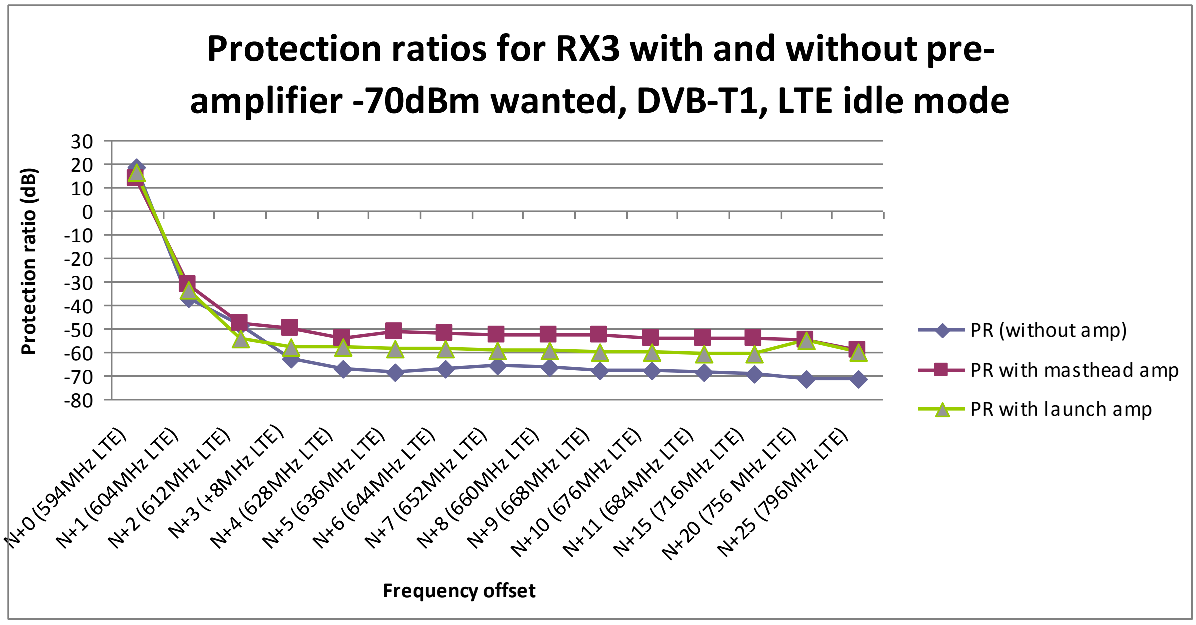

Figure 206 Protection ratio versus frequency offset for LTE UE idle mode at-70dBm DVB-T1 DTT with and without pre-amplification, RX3

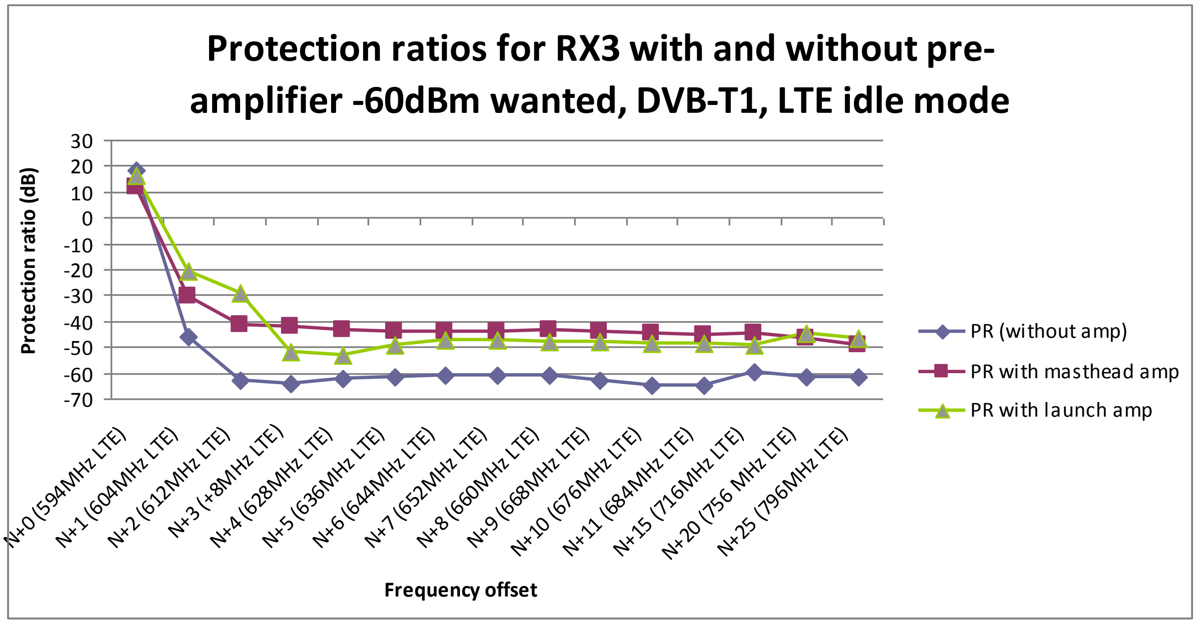

Figure 207 Protection ratio versus frequency offset for LTE UE full load at-60dBm DVB-T1 DTT with and without pre-amplification, RX3

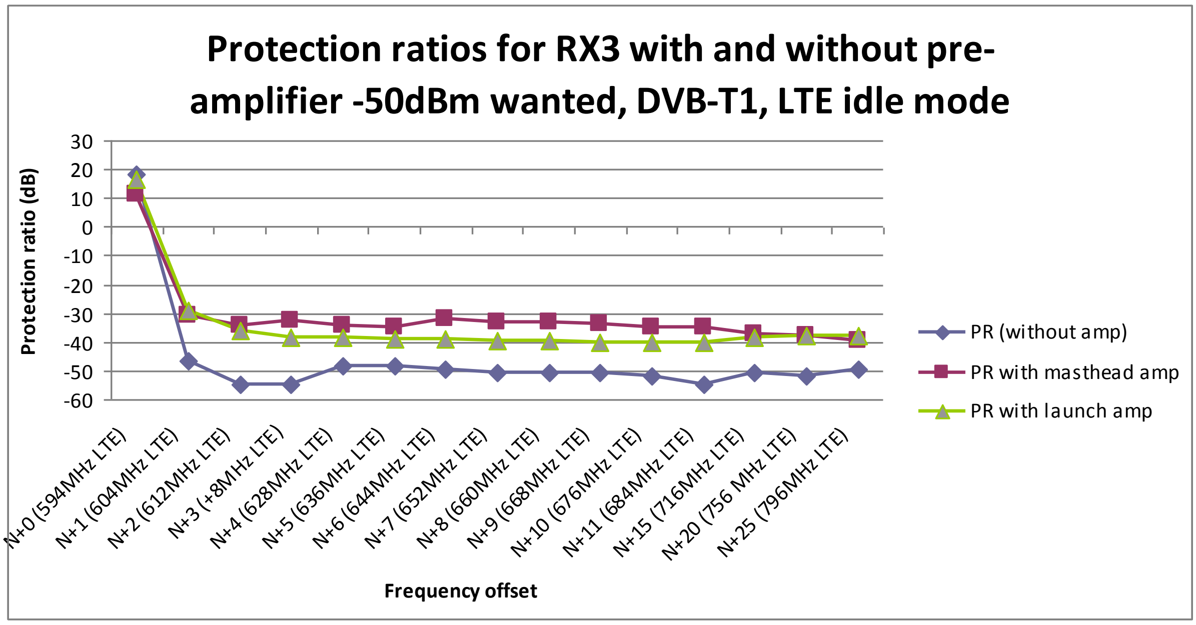

Figure 208 Protection ratio versus frequency offset for LTE UE idle mode at-50dBm DVB-T1 DTT with and without pre-amplification, RX3

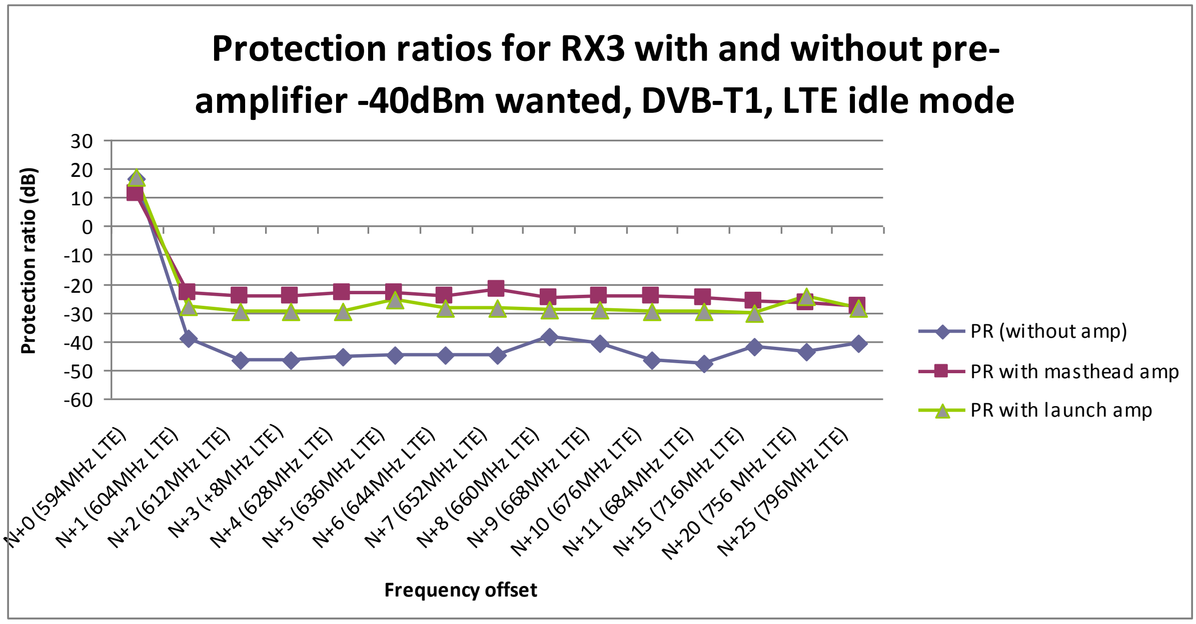

Figure 209 Protection ratio versus frequency offset for LTE UE idle mode at-40dBm DVB-T1 DTT with and without pre-amplification, RX3

C.12 LTE UE idle mode protection ratios with and without pre-amplification, test receiver 16

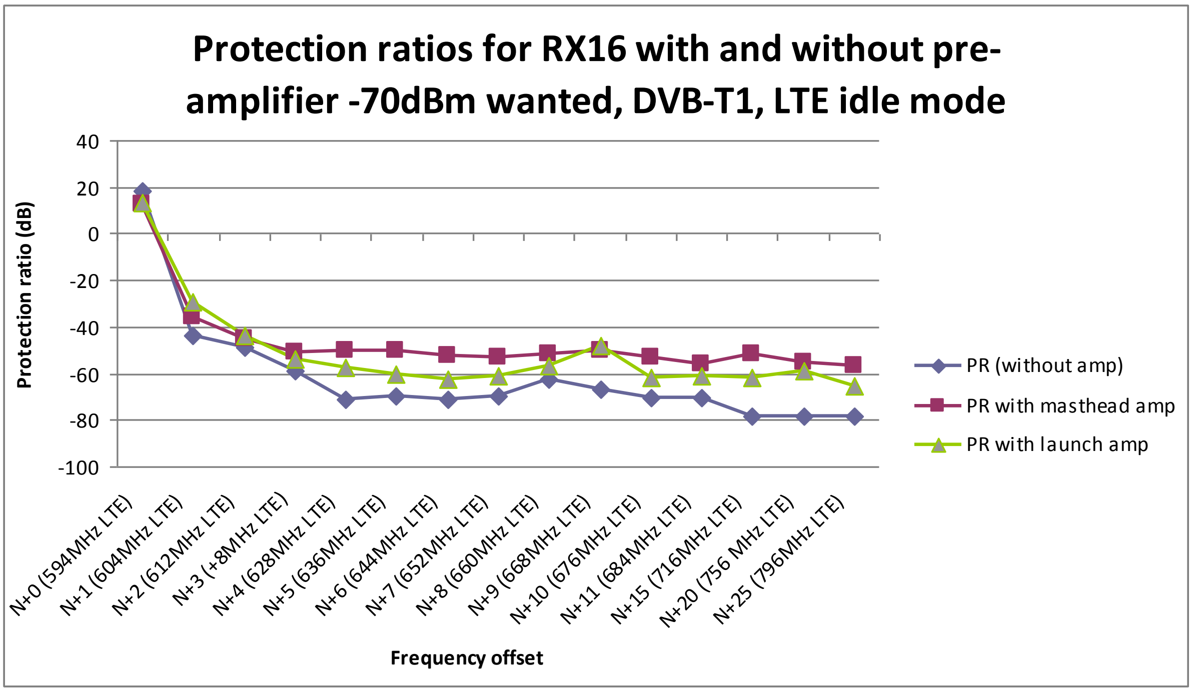

Figure 210 Protection ratio versus frequency offset for LTE UE idle mode at-70dBm DVB-T1 DTT with and without pre-amplification, RX16

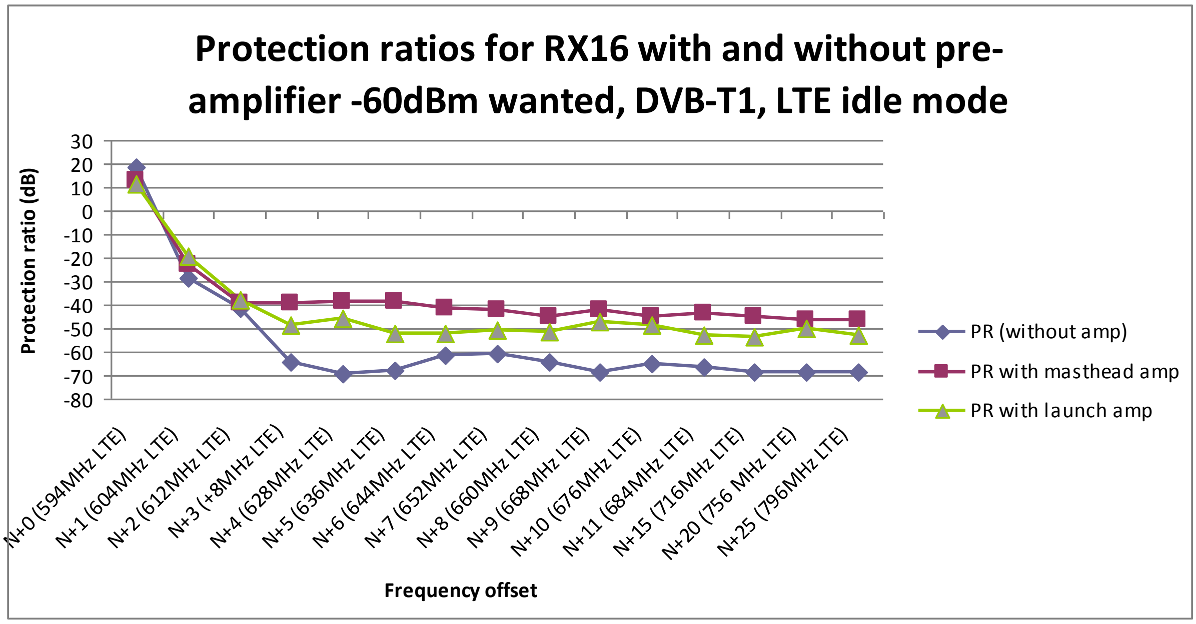

Figure 211 Protection ratio versus frequency offset for LTE UE full load at-60dBm DVB-T1 DTT with and without pre-amplification, RX16

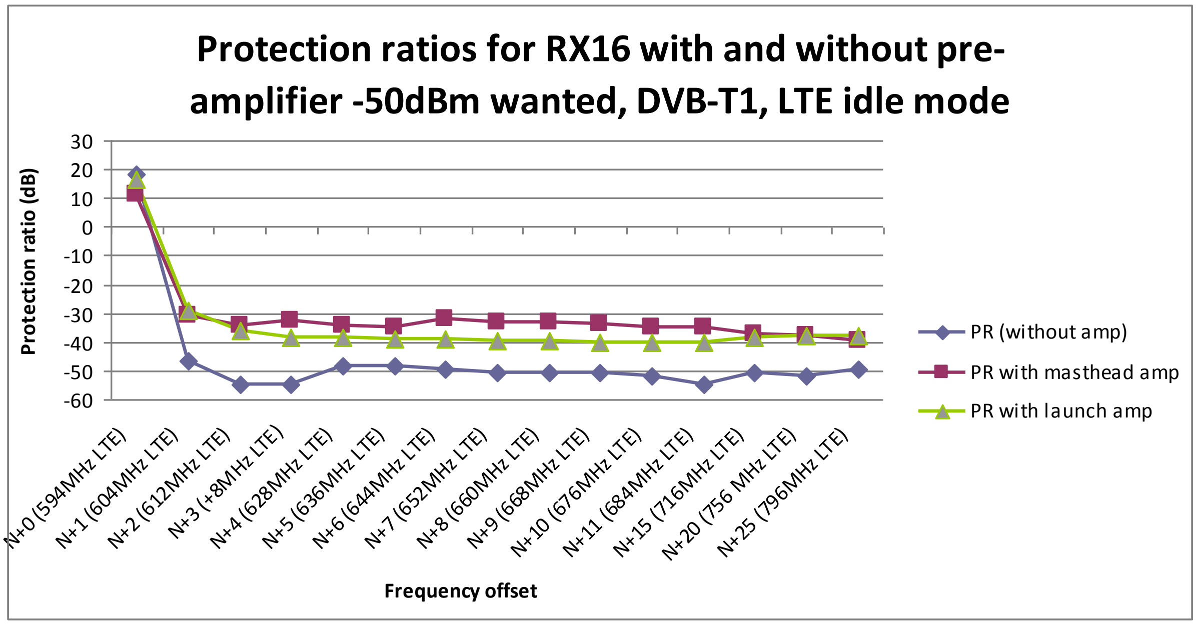

Figure 212 Protection ratio versus frequency offset for LTE UE idle mode at-50dBm DVB-T1 DTT with and without pre-amplification, RX16

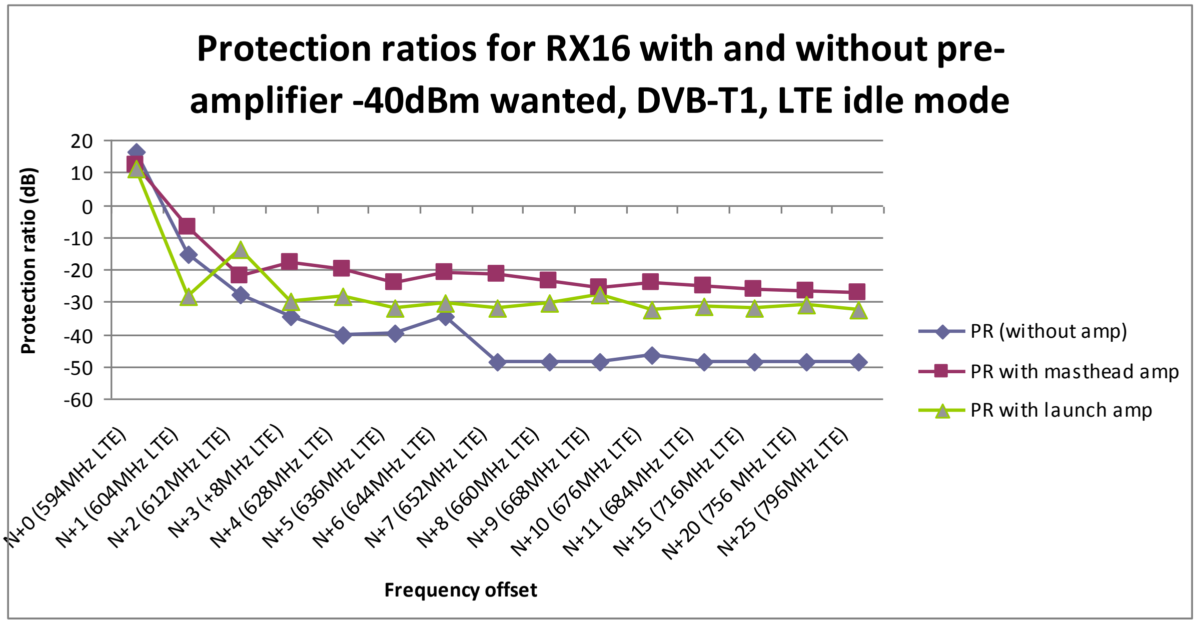

Figure 213 Protection ratio versus frequency offset for LTE UE idle mode at-40dBm DVB-T1 DTT with and without pre-amplification, RX16