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Summary

This report presents the results of an independent study undertaken by Cobham Technical Services to investigate potential interference from new mobile services in the 800 MHz band into Cable TV and Broadband customer premises equipment.

The work was commissioned by Ofcom in April 2010 and undertaken at Virgin Media's RF/Optical test facility in Birmingham over a seven week period. The Set Top Box (STB) and Cable Modem (CM) equipment assessed in the study, together with the test facility and associated technical support, was kindly made available by Virgin Media for the duration of the study.

The scope of the technical research was discussed with both Ofcom and Virgin Media and a detailed test plan was agreed prior to commencing the study. A radiated measurement programme was then undertaken to determine the potential for interference from Long Term Evolution (LTE) User Equipment (UE) into 9 set top boxes and 12 cable modems for the following scenario:

- A wanted signal level at the device under test of -8 dBmv (-55 dBm), at the lower end of the operating range in the UK of -10 to +10 dBmV;
- 64 QAM modulation for the STBs and 256 QAM modulation for the CMs;
- A simulated UE interferer with a 10 MHz bandwidth QPSK FDD reference channel based on full Resource Block (RB) allocation (50 RBs);
- A maximum UE transmit EIRP of 25 dBm, based on a level of 23 dBm for UE Power Class 3 ±2 dB tolerance, as defined in section 6.2 of ETSI TS 136 521-1 [1];
- Frequency offsets from co-channel (N) to N ± 9 channel separations for the STBs and ±8 MHz for the CMs;
- A separation distance of 1m between the interferer and device under test.

The measurements were repeated to assess the performance from the front, side and back of each STB, and from the front and side of each CM. Interference was taken to be the point of picture failure (PF) for the STBs, or data failure for the CMs.

A sensitivity analysis was undertaken for a limited number of STBs to asses the impact of varying the wanted signal level and for various LTE UE partial resource block allocations.

Finally, five STBs and five CMs were examined with respect to their electromagnetic design, to determine potential weaknesses in the designs and to recommend any improvements. It should be noted that all of the equipment tested was compliant with existing European regulations.

Set Top Box Results

The results show that 7 out of the 9 STBs tested could suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm (23 dBm EIRP ± 2 dB tolerance) at 1m separation distance. Interference was only found to occur when the unwanted LTE signal was co-channel with the wanted CATV signal; no adjacent, local oscillator, or image channel interference was observed.

- Picture failure was generally found to occur at similar interference levels regardless of whether the interference source was radiating at 1m from the front, back or side of the STB under test. However, STB2 only suffered interference from the side while STB4 and STB5 were marginally worse from the back;
- The performance of STB1 was much worse than the other STBs tested, requiring around 21 dB more protection than the next worse case (STB9). It exhibited picture failure at a co-channel LTE UE EIRP of around -3 dBm, with a C/I protection ratio measured at the STB of -26 dB. STB1 was the oldest box tested, manufactured in 2003, and is considered to have the poorest design in terms of electromagnetic compatibility;
- STBs 9, 6 and 2 were found to exhibit PF at a co-channel LTE UE EIRP of 15.76 dBm, 18.71 dBm and 21.06 dBm respectively with the interferer at 1m from the side. STBs 9 and 6 are similar models, which explains their similar performance;
- STBs 4, 5 and 8 were only found to exhibit PF at or near the maximum LTE UE EIRP (24 – 25 dBm). STBs 3 and 7 did not experience PF under any of the test conditions;
- In all cases apart from STB1, PF was only found to occur for frequency offsets of -5 to +5 MHz, when the 10 MHz LTE signal is essentially co-channel and adjacent channel with the wanted signal. No image channel or STB local oscillator interference was found to occur;
- In all cases the Signal-to-Noise / Modulation Error Ratio reported by the STB diagnostics was degraded for frequency offsets from -8 to +8 MHz. Pre-Reed Solomon errors were typically found to occur at SNR of 28 – 24 dB, post-Reed Solomon errors occur at 22 to 20 dB and the STB loses lock completely when the SNR falls below 19 to 17 dB.

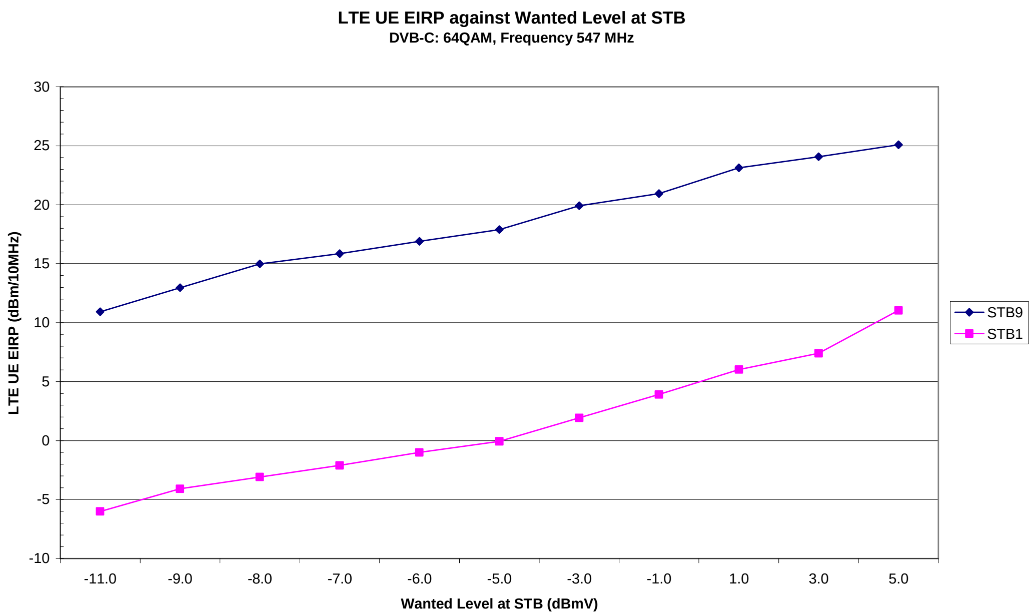
Cable Modem Results

The results show that all 12 of the CMs tested could suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm at 1m separation distance.

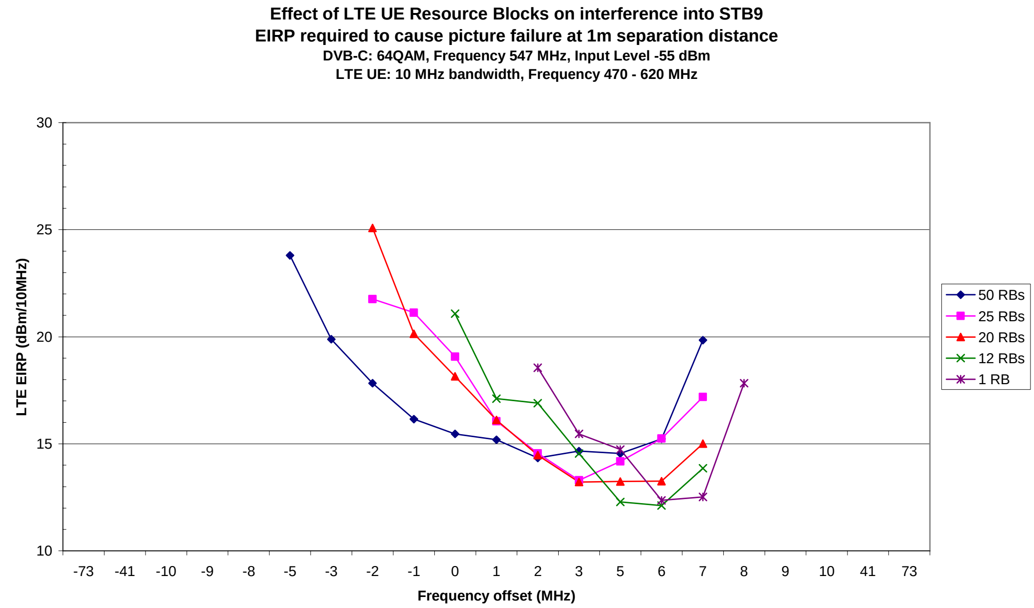
- The CMs under test were generally more prone to interference from the front. Only CM3, CM5 and CM11 exhibited worse performance from the side, with CM11 requiring an additional 11 dB of protection;
- CMs 12 and 9 were found to require the most protection. They exhibited data failure at a co-channel LTE UE EIRP of -13 dBm and -10 dBm respectively with the interferer 1m from the front. These two CMs are similar models from the same manufacturer. CM12 is considered to have the poorest design in terms of electromagnetic compatibility;
- CM1 was found to require the least protection. Data failure occurred at a co-channel LTE UE EIRP of +20 dBm. Performance was similar from both the front and side (within 1 dB). CM1 is considered to have the best design in terms of electromagnetic compatibility;
- For CMs 2, 6, 7, 9, 11 and 12 data failure was found to occur for frequency offsets of -8 to +8 MHz (the maximum range tested).

<u>Sensitivity Analysis</u>

The figure below shows that for every 1 dB increase in wanted signal level, the level of interference required to cause picture failure increases by approximately 1 dB. This suggests that operating the CATV network at higher wanted signal levels could be a useful mitigation measure. The commercial, practical and technical feasibility of such a measure has not been examined.



The figure below shows the effect of reducing the number of LTE UE resource blocks on the EIRP required to cause picture failure. The results show that partial resource block allocations could cause higher levels of interference at the STB. Although the power density across the 10 MHz LTE bandwidth stays constant when the RB allocation is reduced, the peak power increases. Reducing the number of RBs from 50 to 1 increases the required protection ratio by around 3 dB.



Electromagnetic Design

Five set top boxes and five cable modems were reviewed with respect to their electromagnetic (EMC) design, to determine potential weaknesses in the designs and to recommend any design improvements.

All of the STBs were found to have significant rectangular holes (apertures) in the metalwork that can allow unwanted frequencies to pass through which may then couple to sensitive circuitry. Overall the design of STB1 is considered to be the poorest and this is reflected in the test results.

CM12 is considered from an inspection to have the poorest design based on the plastic case and the RF modulation/demodulation circuitry built on the PCB with no additional screening. CM1 was assessed to have the best design, with the RF circuit in a can and with the box having a conductive coating on the inside to provide a faraday cage. Again, these findings are reflected in the test results.

The Concise Report presented by the ETSI CENELEC joint working group at the European Commission Workshop in June 2010 [2] suggests that the radiated immunity of DVB tuners in the frequency range 790 - 862 MHz should be as a minimum 1 V/m in-band and outside this band 3 V/m. Of the nine boxes tested only one failed the suggested limits. As noted above, this STB has poorer EMC design performance that the other STBs reviewed.

The results presented in this study for LTE UE interference into STBs at 1m separation distance suggest that the design of these boxes should be adequate to meet the suggested limits. However, seven out of the nine STBs tested could still suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm at 1m (equivalent to 3 V/m co-channel).

For CM's the results were worse, with only two out of twelve passing the suggested limits and all twelve suffering interference under the test conditions.

Virgin Media comment: These Draft ETSI immunity figures are based on what CPE Vendors who were part of the Digital Dividend Joint Working Group believed were achievable in terms of the redesign of their equipment.

As 23 dBm equates to a transmission level of 2.5 V/m at a separation distance of 1 metre, then an in-band immunity of 1 V/m is unlikely to be enough to offer complete protection from a LTE UE in close proximity, on-channel and transmitting at full power.

The CTS testing does show that STBs 9, 6 and 2 were found to exhibit picture failure at a co-channel LTE UE EIRP of 15.76 dBm (1.1 V/m), 18.71 dBm (1.5 V/m) and 21.06 dBm (2.0 V/m). They do indeed meet the new proposed ETSI standard, but still suffer picture failure at a separation distance of 1 metre with the wanted cable TV signal towards the lower end of the input range. Increasing the separation distance will increase the required UE power to cause a picture failure by 20log(d), where "d" is the separation distance in metres.

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Abbreviations List

CATV	Cable Television
CM	Cable Modem
CMTS	Cable Modem Termination System
DF	Data Failure
DOCSIS	Data-Over-Cable System Interface Specification
DTT	Digital Terrestrial Television
DUT	Device Under Test
ECC	Electronic Communications Committee
EMC	Electromagnetic Compatibility
FDD	Frequency Division Duplex
LTE	Long Term Evolution
MER	Modulation Error Ratio
MFCN	Mobile/Fixed Communications Network
PRBS	Pseudo Random Bit Sequence
PF	Picture Failure
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RMC	Reference Measurement Channel
SC-FDMA	Single Carrier Frequency Division Multiple Access
SNR	Signal-to-Noise Ratio
STB	Set Top Box
UE	User Equipment
VM	Virgin Media

1. Introduction

The CEPT Electronic Communications Committee (ECC), at its 22nd meeting in Vienna, agreed to develop a Decision [3] on the harmonised technical and regulatory conditions for fixed and mobile communications networks operating in the band 790 – 862 MHz. The preferred frequency arrangement is based on Frequency Division Duplex (FDD) technology, with the downlink starting at 791 MHz and the FDD uplink starting at 832 MHz, as shown in the following figure.

791-796	796-801	801-806	806-811	811-816	816-821	821 - 832	832-837	837-842	842-847	847-852	852-857	857-862
Downlink						Duplex gap	Uplink					
30 MHz (6 blocks of 5 MHz)						11 MHz	30 MHz (6 blocks of 5 MHz)					

Figure 1: Likely ECC band plan for 790 – 862 MHz

CEPT Report 30 [4] defines a set of "common and minimal (least restrictive) technical conditions" optimised for, but not limited to, mobile/fixed communications networks (MFCN) in the 790 – 862 MHz band, whilst enabling the protection of broadcasting operating in accordance with GE-06 and other applications. These technical conditions are based on the definition of a block-edge mask consisting of in-block and out-of-block limits depending on frequency offset. These limits were derived based on compatibility studies with Digital Terrestrial Television (DTT) but they did not consider the impact of MFCNs on cable TV (CATV) networks. A number of Regulatory Agencies across Europe have carried out initial tests to determine the potential impact of LTE user terminals operating in the 800 MHz band on CATV Set Top Boxes (STBs) and Cable Modem (CM) equipment. These studies suggest that mobile handsets located close to STBs could cause interference due to limitations in the RF screening of the tuner section.

This report presents the results of radiated testing undertaken at Virgin Media's (VM) optical and RF test facility in Birmingham, UK, to determine the sensitivity of 9 STBs and 12 CMs to LTE UE interference.

The baseline configuration is shown in the table below.

Table 1:
Baseline test configuration

Parameter	Set Top Box	Cable Modem
Maximum LTE UE transmit EIRP[1]	25 dBm	25 dBm
LTE UE Resource Blocks	50	50
Separation distance	1m	1m
Wanted modulation scheme	64 QAM	256 QAM
Wanted signal level	-8 dBmV	-8 dBmV

Measurements were undertaken at a wanted signal level of -8 dBmV, which is at the lower end of the available operating range in the UK of -10 to +10 dBmV (-57 to -37 dBm). In practice 256 QAM modulation would be likely to be operated at wanted levels 6 dB higher than for 64 QAM to overcome reduced robustness to interference in higher order modulation schemes. A sensitivity analysis was undertaken to assess the effects of increasing the wanted signal, and the effects of reducing the number of LTE UE resource blocks.

The STB under test was connected to a standard TV using a 3m SCART lead in order to allow the Picture Failure (PF) point to be observed. Each box was rotated through 90 and 180 degrees to assess interference effects from the front, side and back for a number of frequency offsets from N-9 to N+9 channel separations. Measurements were also undertaken to look at the effect of the LTE UE EIRP on the Signal-to-Noise or Modulation Error Ratio reported by the STB diagnostics.

The CM under test was configured to transmit a data file at 7 Mbps, the maximum supported by the older modems under test, and the effects of the interference on data throughput were monitored.

Finally, a range of STBs and CMs have been examined against current best practice Electromagnetic Compatibility (EMC) design in terms of shielding and bonding etc (see Appendix C). As noted above all equipment tested is compliant with existing European regulations.

[1] Based on a level of 23 dBm for UE Power Class 3 ±2 dB tolerance, as defined in section 6.2 of ETSI TS 136 521-1 [1];

2. Test Set-Up

2.1 Generic Test Set-Up

The generic test set-up for the baseline radiated measurements is shown in Figure 2 below.

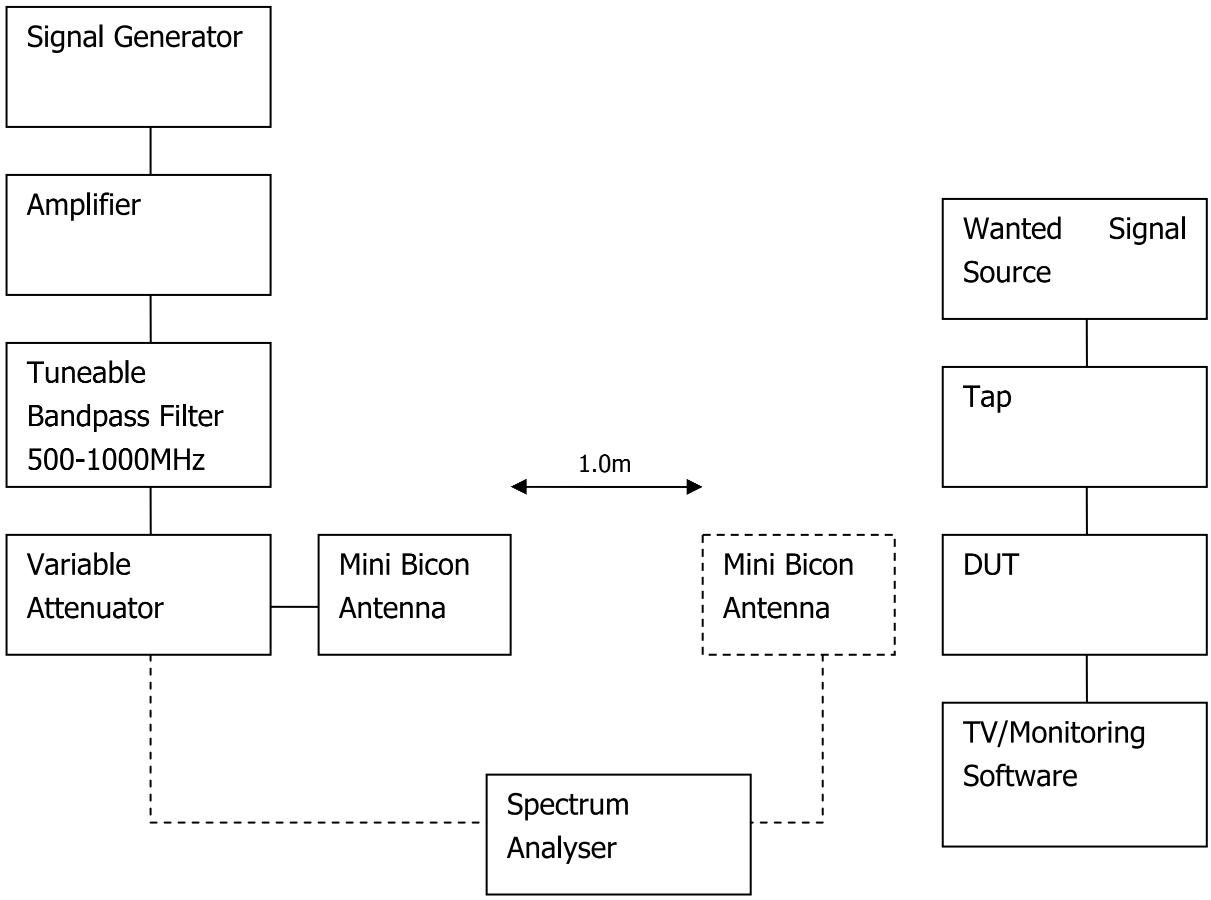

Figure 2: Generic test set-up

The LTE UE transmit antenna was located 1m from the DUT at a height of 0.85m above ground. A second substitution antenna was used to measure the field strength at the facing side of the DUT.

The STB under test was connected to a 42" plasma TV using a 3m SCART lead.

Each set of measurements was repeated with the DUT rotated through 90 and 180 degrees in order to assess interference from the front, side and back of the device.

2.2 Unwanted LTE UE Parameters

The LTE UE uplink signal parameters were based on a Reference Measurement Channel (RMC) using Frequency Division Duplex (FDD) for a full Resource Block (RB) allocation, as described in Annex A of ETSI TS 136 521-1 (3GPP TS 36.521) [1]. Maximum transmit power was based on UE Power Class 3 with 23 dBm ±2 dB tolerance (maximum 25 dBm) as defined in clause 6.2 of TS 136 521-1. The parameters, based on QPSK modulation and 10 MHz channel bandwidth, are shown in Table 2 below.

Table 2:
LTE UE signal parameters

Parameter	Value
Max Output power	25 dBm (23 dBm ±2dB)
Multiple access method	SC-FDMA
Duplex	FDD
Channel bandwidth	10 MHz
Allocated resource blocks	50
Channel modulation	QPSK
Target coding rate	1/3
Sub-frame length	1 ms
Number of occupied sub-carriers	600
Sub-carrier spacing	15 kHz
Code rate	1/3
Number of users	6-8
Data pattern	9 PRBS

These parameters were selected in the absence of an agreed standard for an appropriate LTE interfering signal for different victim systems. A short series of measurements were also performed with partial resource block allocations (25, 20, 12 and 1) as described in section 2.5.1.

A signal generator was used to produce the LTE UE uplink signal with a spectrum mask compliant, as close as practicable, with the SE42 boundary emission mask shown in Table 3.

The generated signal was amplified by an overdriven amplifier to create spectral re-growth and then filtered such that the resultant spectral emission mask conformed as closely as possible to the SE42 FDD LTE UE parameters. The transmit power was controlled using a variable attenuator to step the entire mask up or down, thus maintaining the same Adjacent Channel Interference Ratio (ACIR) throughout the testing, Figure 3

Figure 3: Generation of LTE UE signal

Table 3:
SE42 boundary emission mask for FDD LTE UE uplink

Frequency offset from FDD (lower/upper) block edge	Maximum mean out-of-block power	Measurement bandwidth
FDD downlink upper band edge to -10 MHz from FDD lower block edge	-25 dBm	1 MHz
-10 to -5 MHz from FDD lower block edge	-6 dBm	5 MHz
-5 to 0 MHz from FDD lower block edge	1.6 dBm	5 MHz
0 to +5 MHz from FDD upper block edge	1.6 dBm	5 MHz
+5 to +10 MHz from FDD upper block edge	-6 dBm	5 MHz
+10 MHz from FDD upper block edge to FDD uplink upper band edge	-25 dBm	1 MHz

The measured spectral emissions are shown in Figure 4 below.

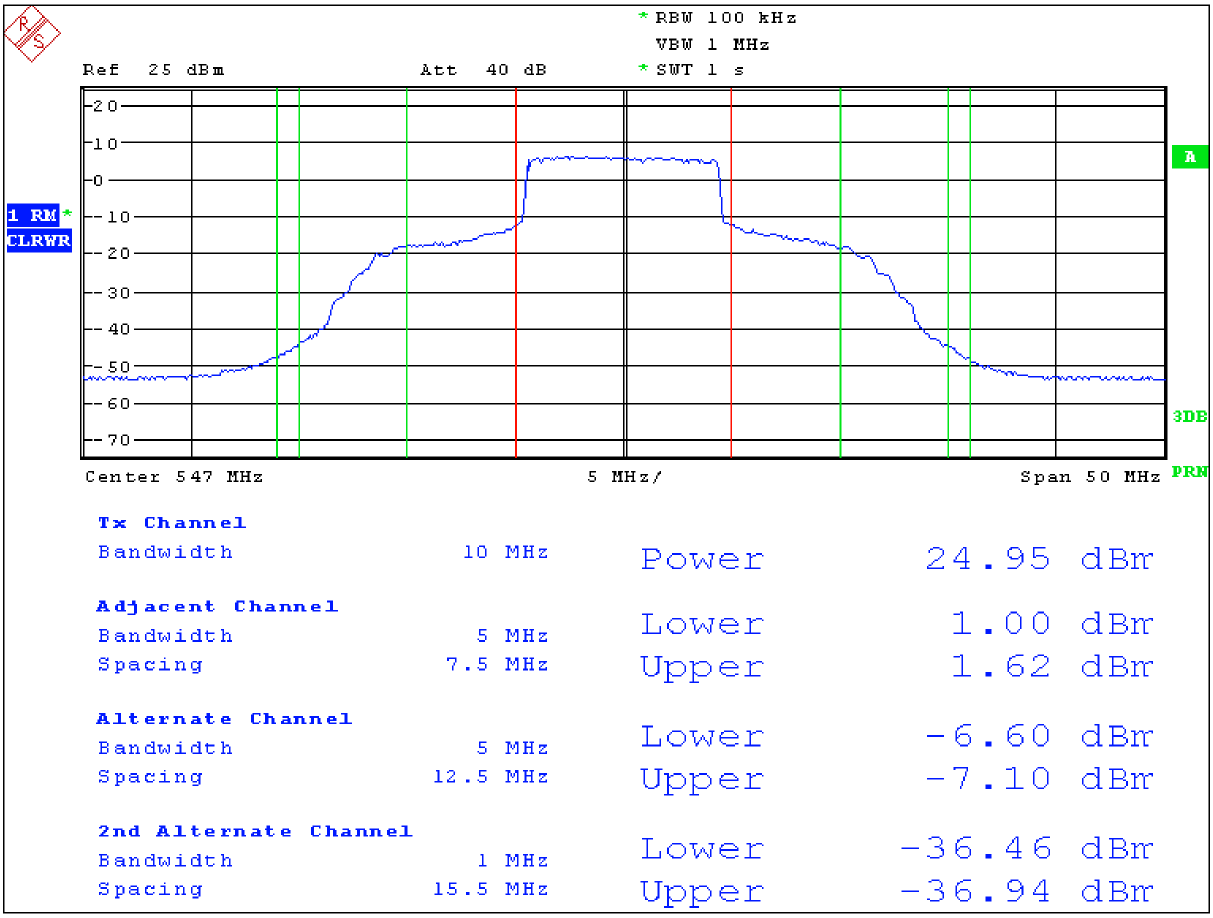

Figure 4: Simulated LTE UE spectrum emission mask for 50 Resource Blocks

2.3 Set-Top Box Parameters

2.3.1 Wanted signal parameters

Due to difficulties encountered by Virgin Media in setting up a test network, the measurements were performed using the live Birmingham cable TV feed for the wanted signal. This operates over the frequency range 107 – 595 MHz and the STB was tuned towards the upper end of this range, at 547 MHz (channel 511). Since the field strength at the STB at the point of picture failure is independent of frequency, the impact of selecting 547 MHz as the wanted frequency should be negligible.

The wanted signal level in a live network can typically vary from -10 to +10 dBmV (-57 to -37 dBm). For the baseline tests the wanted level was set to -8 dBmV (-55 dBm), at the lower end of the operating range.

The wanted DVB-C signal parameters, based on ETSI EN 300 429 [5] using 64 QAM modulation, are shown in Table 4.

Table 4:
Wanted Set Top Box parameters

DVB-C parameter	Value
Input Interface	Single Transport Stream
Modes	Constant Coding and Modulation
Forward error correction	Reed Solomon
Interleaving	Bit interleaving
Modulation	Single Carrier QAM
Modulation Scheme	64 QAM
Symbol Rate	6.952 Msym/sec
Channel bandwidth	8 MHz
Power level at input to STB	-8 dBmV (-55 dBm)

The STB was connected to the tap head using a standard quad screened cable via an isolator and 2-way splitter, as used in a typical UK domestic installation installed over the last two years (see Figure 5).

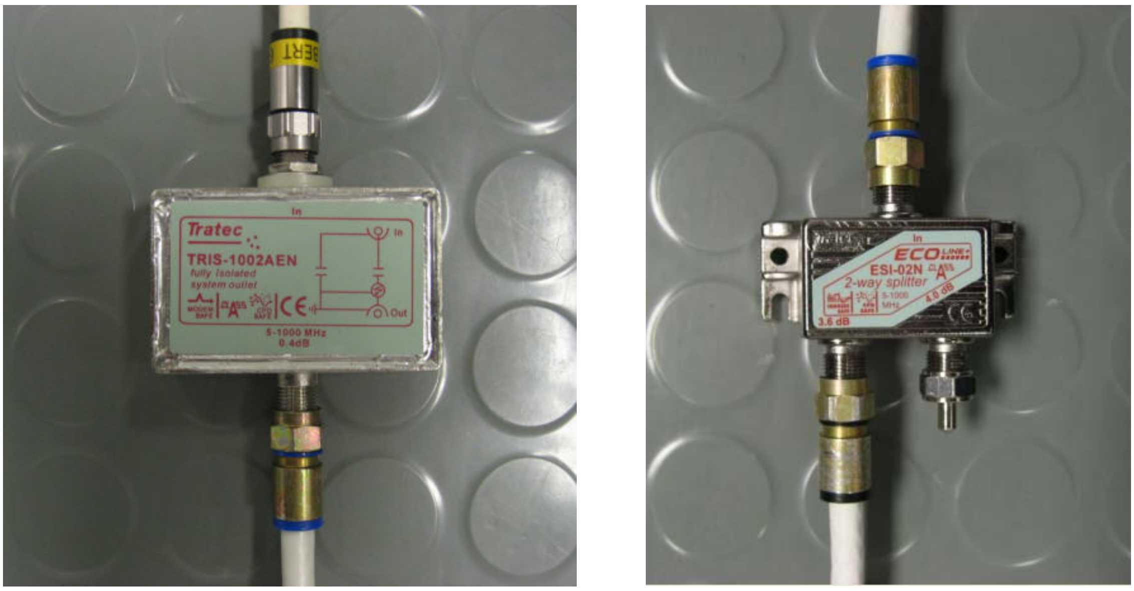

Figure 5: Isolator and splitter used in a standard domestic installation

2.3.2 Interference criterion

2.3.2.1 Picture failure

The received picture was monitored on a standard 42" plasma TV and the Picture Failure (PF) point was identified by visual observation. For the purpose of this report, PF is defined as the point at which the onset of un-correctable errors occurs. This normally results in pixilation effects on the viewed channel or, in more extreme cases, a frozen picture frame. Complete failure, i.e. total loss of reception, can normally be observed with a 1 to 2 dB increase in the interfering signal from the PF point.

Figure 6: Received picture showing the onset of un-correctable errors

2.3.2.2 Diagnostics

The measurements were repeated with the STB placed in diagnostics mode. This allows the Signal-to-Noise Ratio (SNR) or Modulation Error Ratio (MER) to be observed, along with pre- and post-Reed Solomon errors[2].

[2] Reed Solomon is a form of forward error correction. The pre-RS error rate shows the total number of errors, both correctable and un-correctable; the post-RS error rate shows the number of un-correctable errors. The un-correctable errors are manifested as pixilation effects on the viewed channel.

For each orientation of the STB, the LTE UE transmit level was fixed at 25 dBm and the SNR/MER was recorded for various frequency offsets from N-9 to N+9 channel separation. The SNR/MER value at which pre and post-Reed Solomon errors occurred was also recorded.

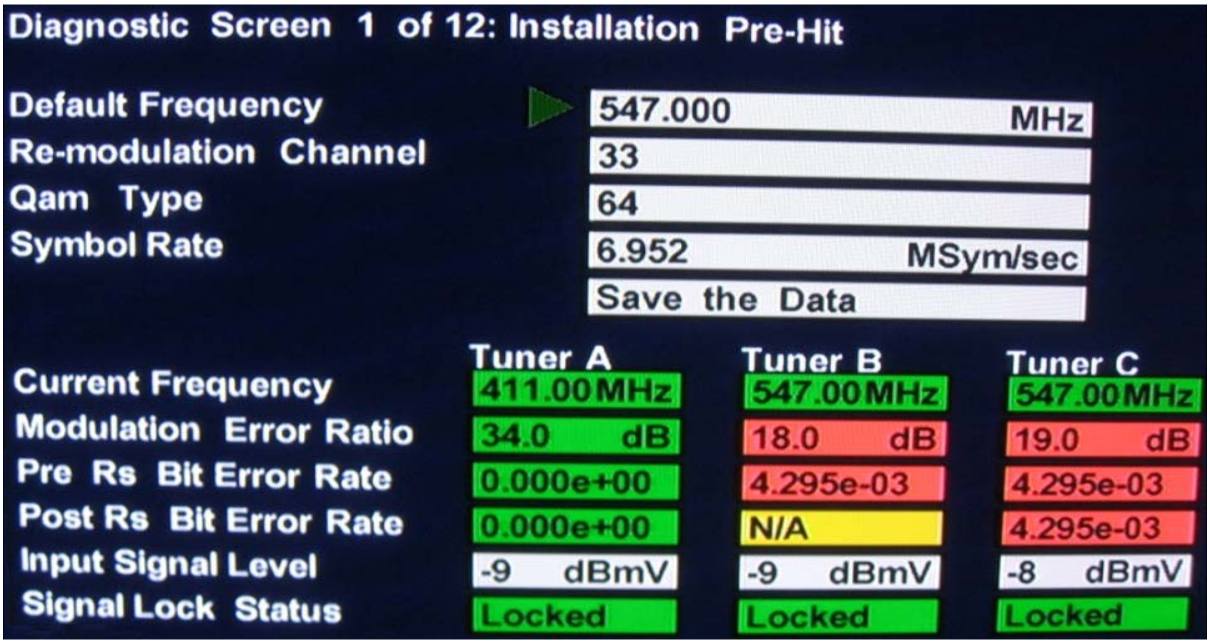

Figure 7: Example diagnostic page showing error statistics

2.3.3 Test method

2.3.3.1 Picture failure

The following procedure was used to determine the level of LTE UE interference required to cause picture failure for each STB under test:

1. Using suitable impedance matching components (75 - 50 Ω), the power of the wanted signal (C) at the STB was recorded using a spectrum analyzer;
2. The frequency of the unwanted LTE UE signal was set to be co-channel with the wanted CATV signal (547 MHz);
3. The level of the unwanted LTE UE signal was initially set to a low value by setting the variable attenuator such that no visible interference effects were observed on the monitor/TV;

4. The level of the unwanted LTE UE signal was increased (by reducing the value of the variable attenuator) to achieve the required degradation in picture quality (PF point) as observed on the monitor/TV;
5. The transmit EIRP of the unwanted LTE UE signal was recorded, together with the level (I) received at the face of the STB, using a spectrum analyzer;
6. The Carrier-to-Interference (C/I) protection ratio was calculated from steps 1 and 5;
7. Steps 3 to 6 were repeated for relative frequency offsets from N-9 to N+9;
8. Steps 1 to 7 were repeated for orientation angles of 90 and 180 degrees.

2.3.3.2 Diagnostics

The following procedure was used to assess the impact of an LTE UE signal with a fixed EIRP of 25 dBm on the SNR/MER reported by the STB diagnostics page:

1. The frequency of the unwanted LTE UE signal was set to be co-channel with the wanted CATV signal (547 MHz);
2. The level of the unwanted LTE UE signal was set to an EIRP of 25 dBm;
3. The SNR/MER reported by the STB diagnostics was recorded;
4. Steps 2 and 3 were repeated for relative frequency offsets from N-9 to N+9;
5. Steps 1 to 4 were repeated for orientation angles of 90 and 180 degrees.

2.4 Cable Modem Parameters

2.4.1 Wanted signal parameters

The cable modem configuration is shown in Figure 8 below. The transmission path consists of the Cable Modem Termination System (CMTS) at the headend and a cable modem at each customer location. Data transfer between the CMTS and CM was simulated using a Spirent SPT-2000A test centre. The data rate was fixed at 7 Mbps, close to the maximum rate supported by the older CMs under test.

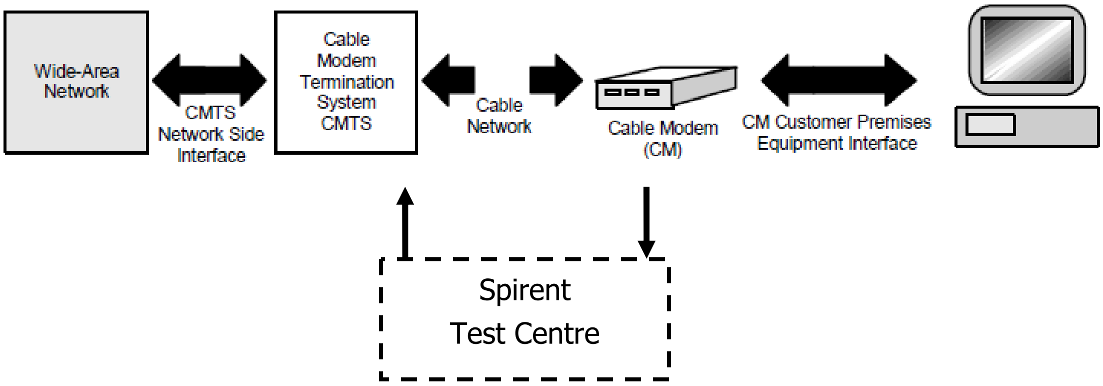

Figure 8: Cable Modem test configuration

The CM parameters were based on the Data-Over-Cable System Interface Specification (DOCSIS) given in ETSI ES 201 488 [6], reproduced below in Table 5 and Table 6.

Although some of the CMs tested were able to support DOCSIS / EURODOCSIS versions 2.0 and 3.0, which provide higher data rate capabilities (particularly in the upstream direction), all of the testing was carried out with a DOCSIS 1.0/1.1 configuration in order to provide a common set of tests. The test parameters are shown in Table 7.

Table 5:
DOCSIS downstream RF channel transmission characteristics

Parameter	Value
Frequency range	Cable system normal downstream operating range is from 50 MHz to as high as 860 MHz. However, the values in this table apply only at frequencies ≥ 88 MHz.
RF channel spacing (design bandwidth)	6 MHz
Transit delay from headend to most distant customer	≤ 0,800 ms (typically much less)
Carrier-to-noise ratio in a 6 MHz band	Not less than 35 dB (see notes 2 and 3)
Carrier-to-Composite triple beat distortion ratio	Not less than 41 dB (see notes 2 and 3)
Carrier-to-Composite second order distortion ratio	Not less than 41 dB (see notes 2 and 3)
Carrier-to-Cross modulation ratio	Not less than 41 dB (see notes 2 and 3)
Carrier-to-any other discrete interference (ingress)	Not less than 41 dB (see notes 2 and 3)
Amplitude ripple	3 dB (see note 2) within the design bandwidth
Group delay ripple in the spectrum occupied by the CMTS	75 ns (see note 2) within the design bandwidth
Micro reflections bound for dominant echo	-20 dBc @ ≤ 1,5 µs, -30 dBc @ > 1,5 µs -10 dBc @ ≤ 0,5 µs, -15 dBc @ ≤ 1,0 µs (see note 2)
Carrier hum modulation	Not greater than -26 dBc (5 %) (see note 2)
Burst noise	Not longer than 25 µs at a 10 Hz average rate (see note 2)
Maximum analog video carrier level at the CM input	17 dBmV
Maximum number of analog carriers	121
NOTE 1: Transmission is from the headend combiner to the CM input at the customer location. NOTE 2: Measurement methods defined in [NCTA] or [CableLabs2]. NOTE 3: Measured relative to a QAM signal that is equal to the nominal video level in the plant.	

Table 6:
DOCSIS upstream RF channel transmission characteristics

Parameter	Value
Frequency range	5 MHz to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	≤ 0,800 ms (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross-modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB (note 2)
Carrier Hum Modulation (CHM)	Not greater than -23 dBc (7,0 %)
Burst noise	Not longer than 10 μs at a 1 kHz average rate for most cases (notes 3 and 4)
Amplitude ripple 5 MHz to 42 MHz	0,5 dB/MHz
Group delay ripple 5 MHz to 42 MHz	200 ns/MHz
Micro-reflections - single echo	-10 dBc @ ≤ 0,5 μs -20 dBc @ ≤ 1,0 μs -30 dBc @ > 1,0 μs
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max
NOTE 1: Transmission is from the CM output at the customer location to the headend. NOTE 2: Ingress avoidance or tolerance techniques may be used to ensure operation in the presence of time-varying discrete ingress signals that could be as high as 10 dBc. The ratios are guaranteed only within the digital carrier channels. NOTE 3: Amplitude and frequency characteristics sufficiently strong to partially or wholly mask the data carrier. NOTE 4: Impulse noise levels more prevalent at lower frequencies (< 15 MHz).	

Table 7:
Wanted Cable Modem parameters

Parameter	Value
Input Interface	Single Transport Stream
Modes	Constant Coding and Modulation
Forward error correction	Reed Solomon
Interleaving	Bit interleaving
Modulation	Single Carrier QAM
Modulation Scheme	256 QAM
Symbol Rate	5.360 Msym/sec
Channel bandwidth	6 MHz
Downstream data rate	7 Mbps
Power level at input to STB	-8 dBmV (-55 dBm)

2.4.2 Interference criterion

The transferred data rate was monitored using the Spirent test centre interface. The interference criterion was taken at the Data Failure (DF) point on the received data stream, as illustrated in Figure 9 below.

The DF point occurs at an increase in unwanted signal level of 1 – 3 dB from the onset of interference.

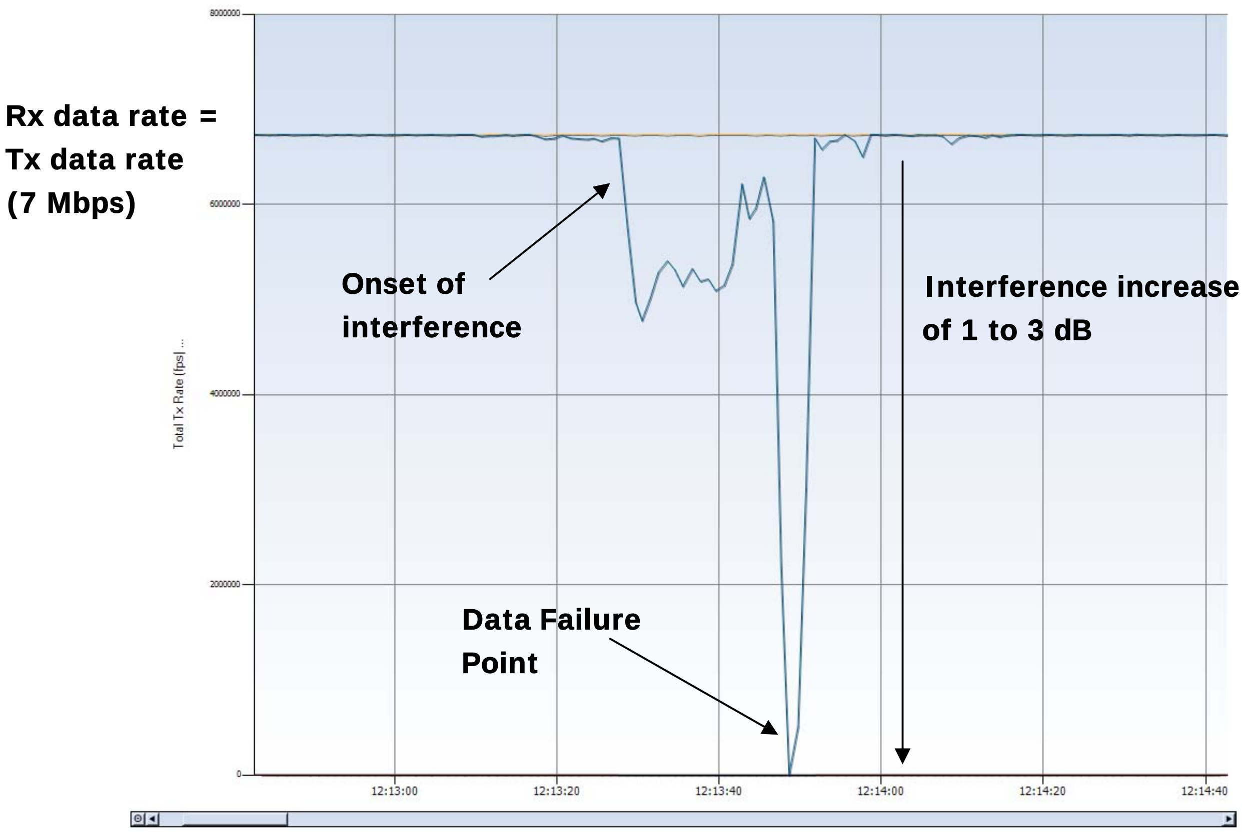

Figure 9: Cable Modem interference criterion

2.4.3 Test method

The following procedure was used to determine the level of LTE UE interference to cause data failure for each CM under test:

1. Using suitable impedance matching components (75 - 50 Ω), the power of the wanted signal (C) at the CM was recorded using a spectrum analyzer;

2. The frequency of the unwanted LTE UE signal was set to be co-channel with the wanted CATV signal (547 MHz);
3. The level of the unwanted LTE UE signal was initially set to a low value by setting the variable attenuator such that no visible interference effects were observed on the transmitted data rate (received data rate = transmit data rate);
4. The level of the unwanted LTE UE signal was increased (by reducing the value of the variable attenuator) to achieve the required degradation in data throughput as observed on the Spirent monitoring interface;
5. The transmit EIRP of the unwanted LTE UE signal was recorded, together with the level (I) received at the face of the CM, using a spectrum analyzer;
6. The Carrier-to-Interference protection ratio was calculated from steps 1 and 5;
7. Steps 3 to 6 were repeated for relative frequency offsets from -8 to +8 MHz;
8. Steps 1 to 7 were repeated for an orientation angle of 90 degrees to the CM.

2.5 Sensitivity Analysis

In addition to the baseline tests described above, additional measurements were made on a subset of STBs to analyse the impact of changing the wanted signal level and reducing the number of LTE UE resource blocks. The test variations are summarised in the table below.

Table 8:
Test Variations

Set Top Box	Baseline	Variation
1, 9	Input level: -8 dBmV LTE UE resource blocks: 50	Input level: -11 to +5 dBmV LTE UE resource blocks: 50
9	Input level: -8 dBmV LTE UE resource blocks: 50	Input level: -8 dBmV LTE UE resource blocks: 1, 12, 20, 25

2.5.1 Partial LTE UE Resource Block allocations

ETSI TS 136 521-1 (Annex A) provides LTE uplink reference channel parameters for partial RB allocations, reproduced in Table 9 below.

Table 9:
Reference channels for 10 MHz QPSK with partial RB allocation

Parameter	Unit	Value	Value	Value	Value
Channel bandwidth	MHz	10	10	10	10
Allocated resource blocks		1	12	20	25
DFT-OFDM Symbols per Sub-Frame		12	12	12	12
Modulation		QPSK	QPSK	QPSK	QPSK
Target Coding rate		1/3	1/3	1/3	1/3
Payload size	Bits	72	1224	1736	2216
Transport block CRC	Bits	24	24	24	24
Number of code blocks per Sub-Frame (Note 1)		1	1	1	1
Code block CRC size	Bits	0	0	0	0
Total number of bits per Sub-Frame	Bits	288	3456	5760	7200
Total symbols per Sub-Frame		144	1728	2880	3600
UE Category		1-5	1-5	1-5	1-5
Note 1: If more than one Code Block is present, an additional CRC sequence of L = 24 Bits is attached to each Code Block (otherwise L = 0 Bit)					

The spectrum emission masks for 1, 12, 20 and 25 RBs produced by the signal generator equipment are shown in Figure 10, compared to the 50 RB baseline. Note that the allocated RBs are contiguous and start from one end of the channel bandwidth, as defined in Annex A.2.2.2 of ETSI TS 136 521.

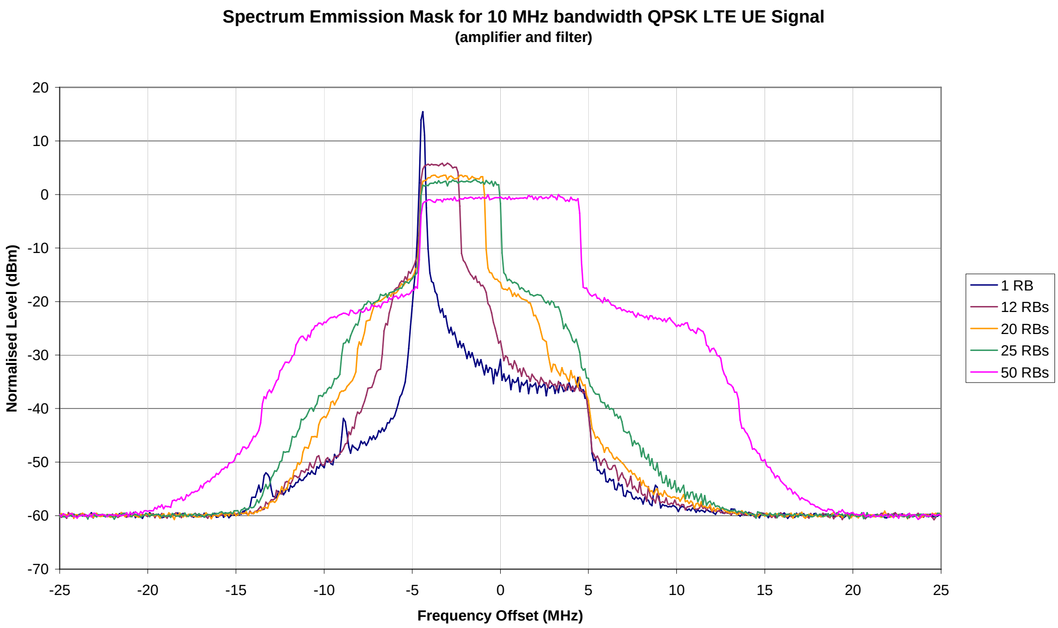

Figure 10: Spectrum emission masks for partial RB allocation

3. Results

3.1 Set-Top Box Results

A total of nine STBs from four different manufacturers were tested, representing a range of different design and model types. The oldest model tested was manufactured in 2003 and the newest in February 2010. The complete results for each STB are included in Appendix A.

The wanted signal level at the STB was -8 dBmV (-55 dBm) using 64 QAM modulation. The LTE UE uplink signal parameters were based on a 10 MHz FDD reference channel using QPSK modulation and full RB allocation (50 resource blocks). Maximum transmit EIRP was assumed to be +25 dBm in the channel bandwidth (23 dBm ±2 dB tolerance).

Figure 11, Figure 12 and Figure 13 show the LTE UE EIRP required to cause picture failure at a distance of 1m from the front, back and side of the STB under test respectively. Figure 14 through to Figure 19 show the measured field strength at the STB and the required Carrier-to-Interference protection ratio. Figure 20, Figure 21 and Figure 22 show the SNR/MER reported by the STB diagnostics page for the LTE UE transmitting at maximum power.

- Picture failure was generally found to occur at similar interference levels regardless of whether the interference source was radiating at 1m from the front, back or side of the STB under test. However, STB2 only suffered interference from the side while STB4 and STB5 were marginally worse from the back;
- The performance of STB1 was much worse than the other STBs tested, requiring around 21 dB more protection than the next worse case (STB9). It exhibited picture failure at a co-channel LTE UE EIRP of around -3 dBm, with a C/I protection ratio measured at the STB of -26 dB. STB1 was the oldest box tested, manufactured in 2003;
- STBs 9, 6 and 2 were found to exhibit PF at a co-channel LTE UE EIRP of 15.76 dBm, 18.71 dBm and 21.06 dBm respectively with the interferer at 1m from the side. STBs 9 and 6 are similar models, which explains their similar performance;
- STBs 4, 5 and 8 were only found to exhibit PF at or near the maximum LTE UE EIRP (24 – 25 dBm). STBs 3 and 7 did not experience PF under any of the test conditions;
- In all cases apart from STB1, PF was only found to occur for frequency offsets of -5 to +5 MHz, when the 10 MHz LTE signal is essentially co-channel. No image channel or STB local oscillator interference was found to occur;
- In all cases the Signal-to-Noise / Modulation Error Ratio reported by the STB diagnostics was degraded for frequency offsets from -8 to +8 MHz. Pre-Reed Solomon

errors typically occur at SNR of 28 – 24 dB, post-Reed Solomon errors occur at 22 to 20 dB and the STB loses lock completely when the SNR falls below 19 to 17 dB.

The results show that 7 out of the 9 STBs tested could suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm at 1m separation distance. Interference was only found to occur when the unwanted LTE signal was co-channel with the wanted CATV signal; no adjacent, local oscillator or image channel interference was observed.

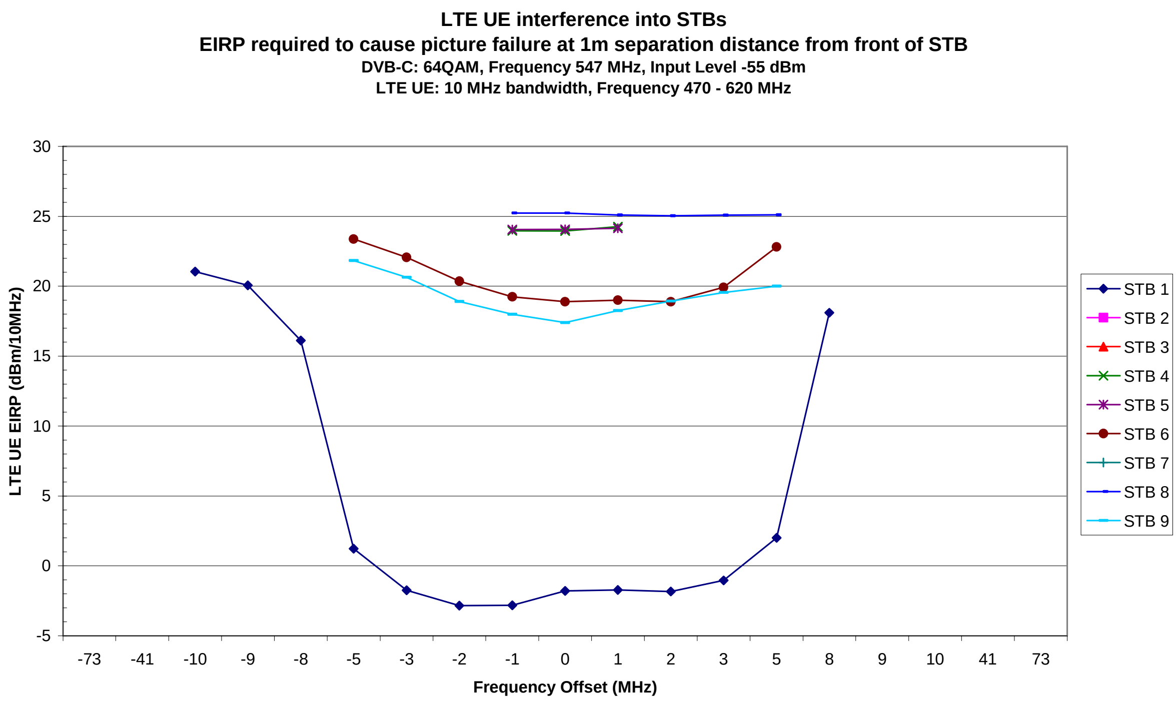

Figure 11: Transmit EIRP to cause picture failure at 1m from front of STB

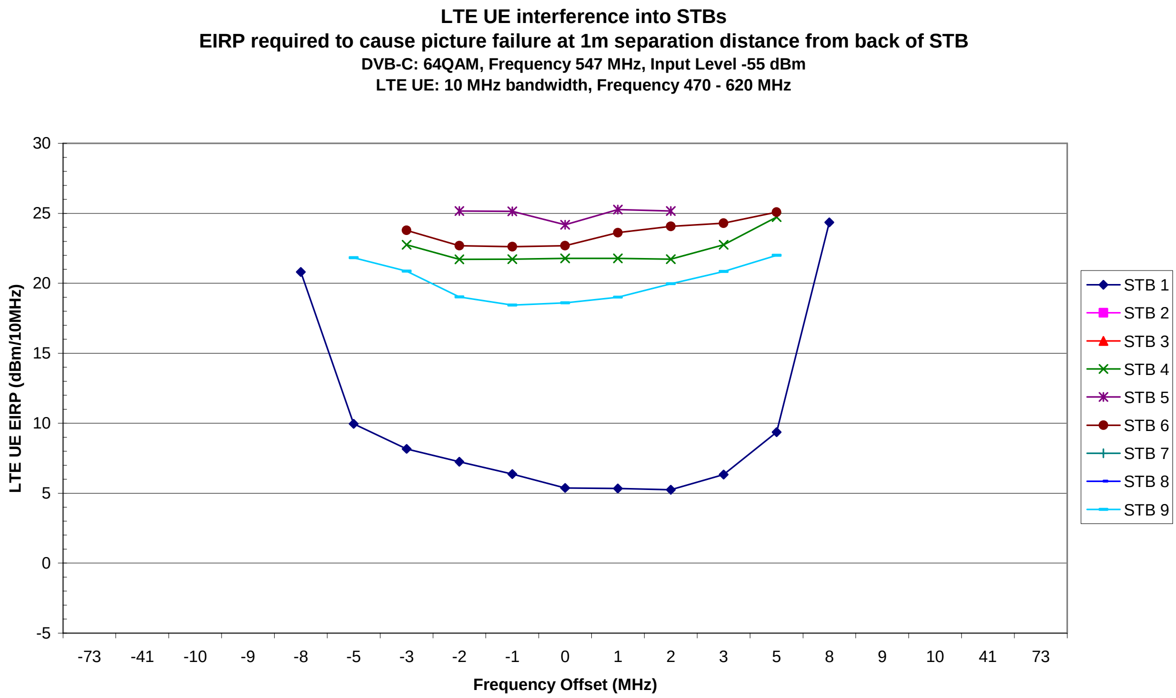

Figure 12: Transmit EIRP to cause picture failure at 1m from back of STB

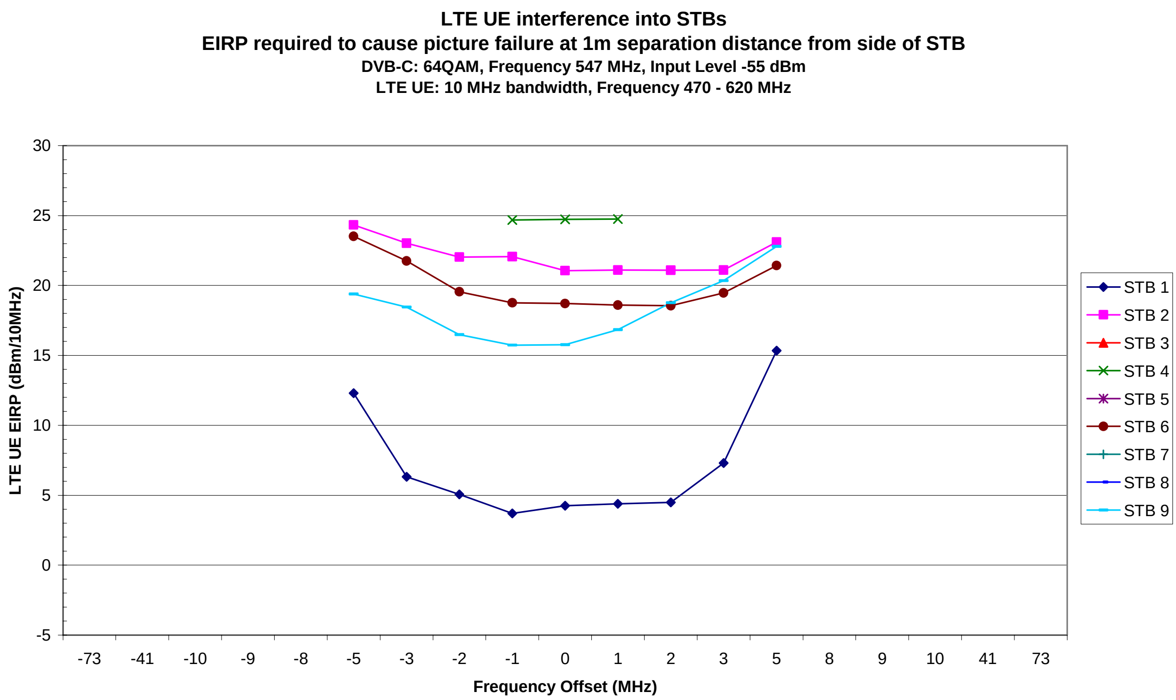

Figure 13: Transmit EIRP to cause picture failure at 1m from side of STB

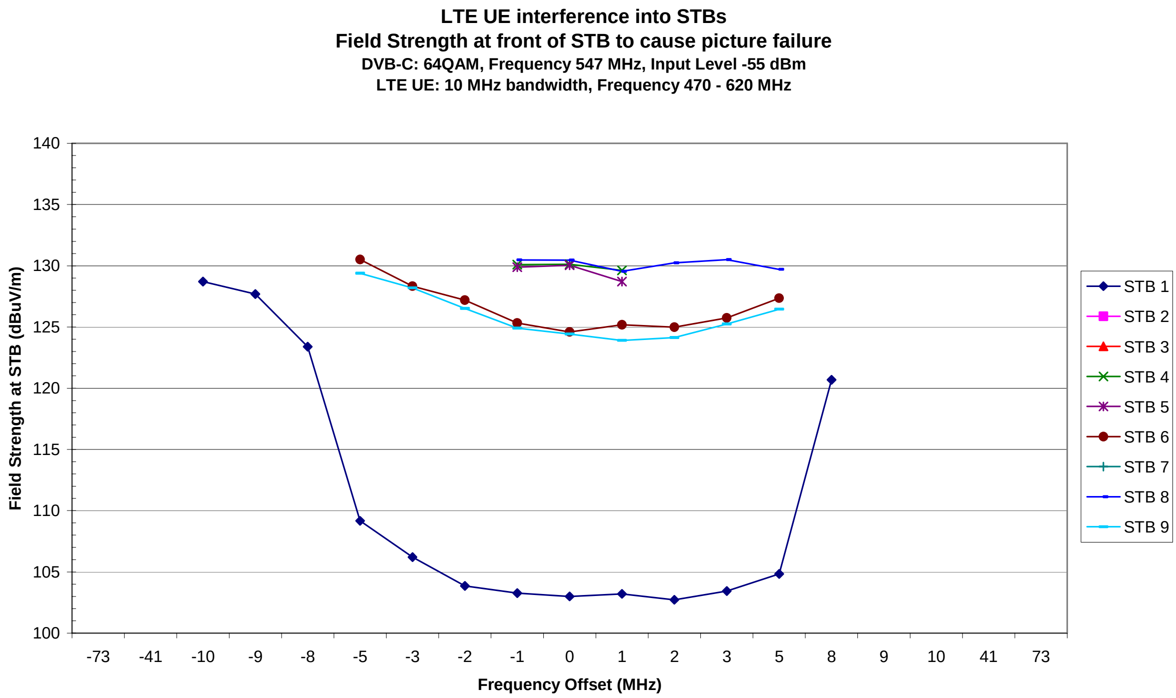

Figure 14: Field Strength measured at front of STB at picture failure

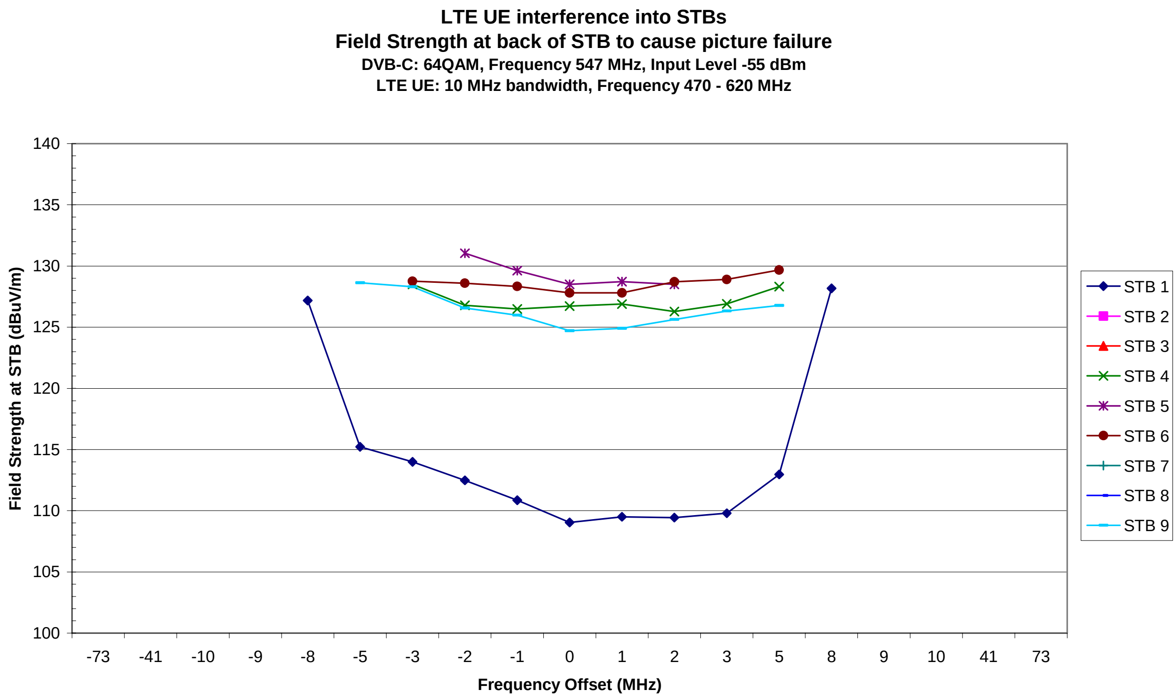

Figure 15: Field Strength measured at back of STB at picture failure

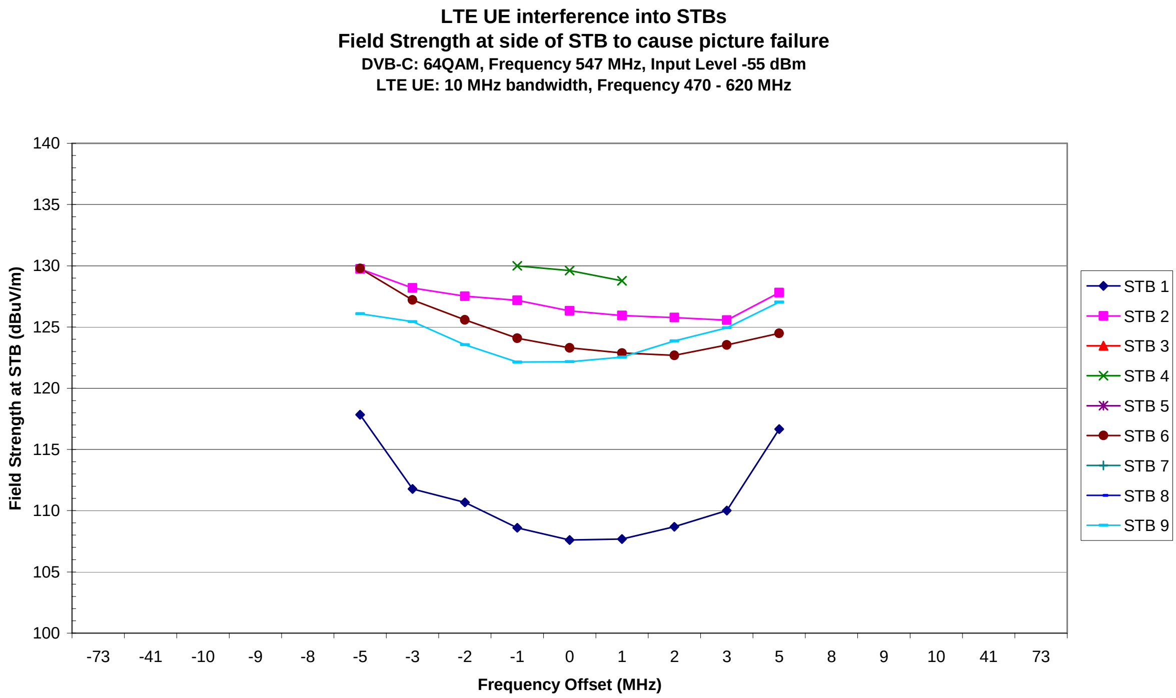

Figure 16: Field Strength measured at side of STB at picture failure

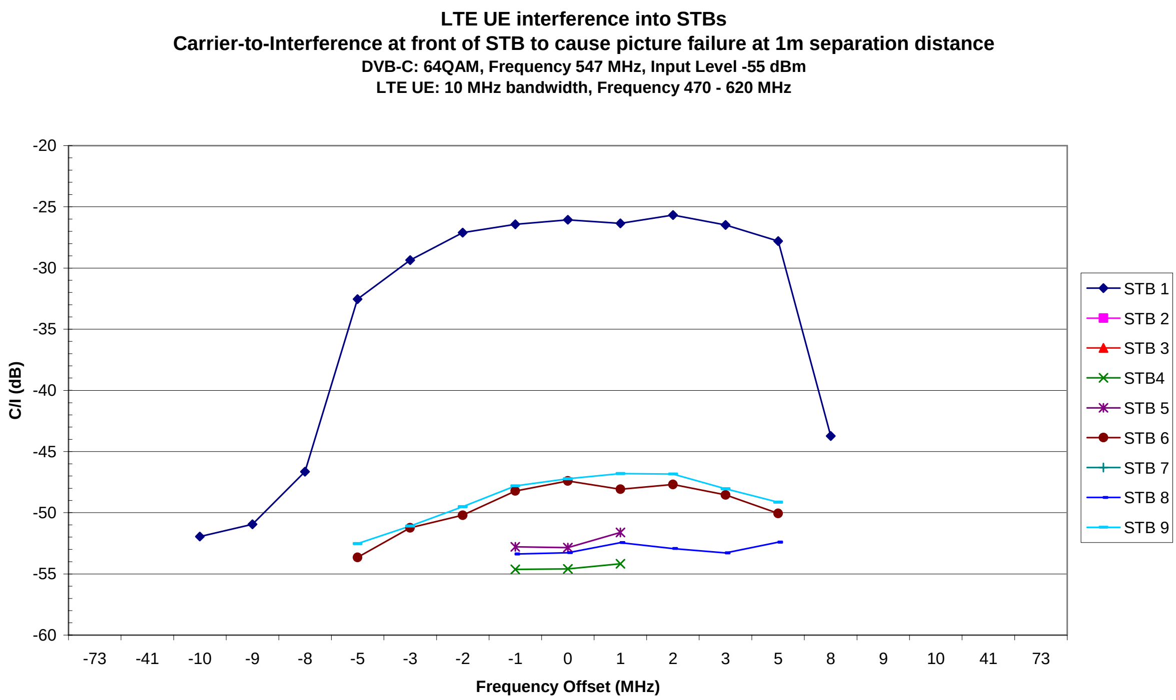

Figure 17: C/I protection ratio for LTE interferer at 1m from front of STB

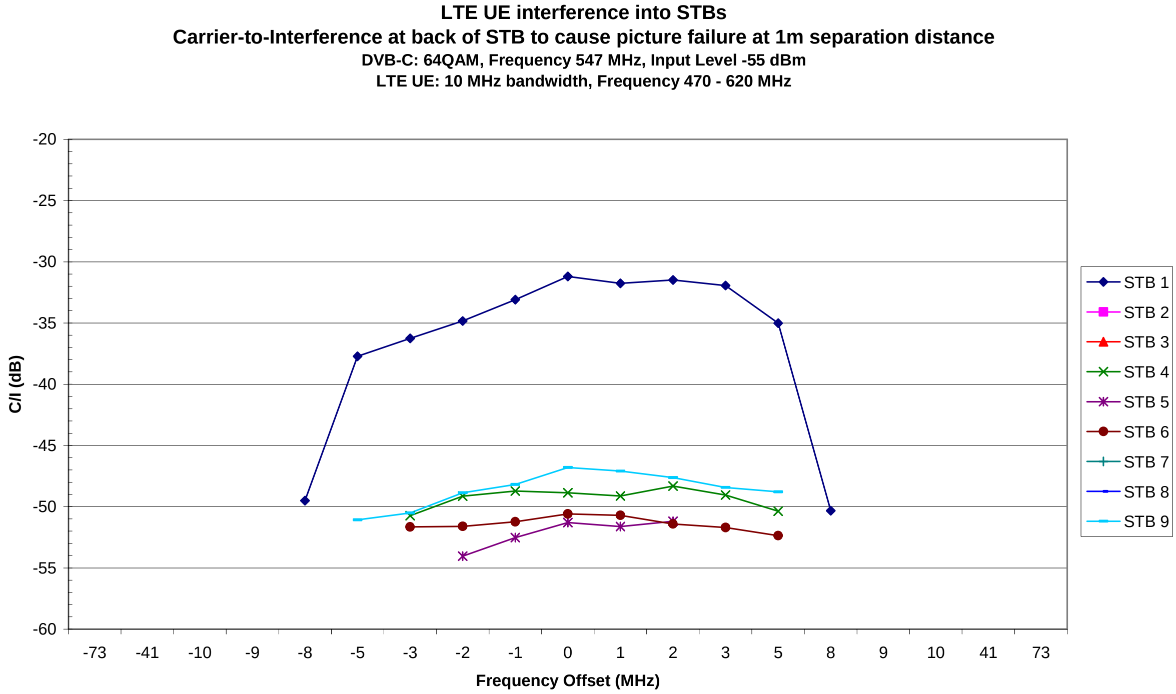

Figure 18: C/I protection ratio for LTE interferer at 1m from back of STB

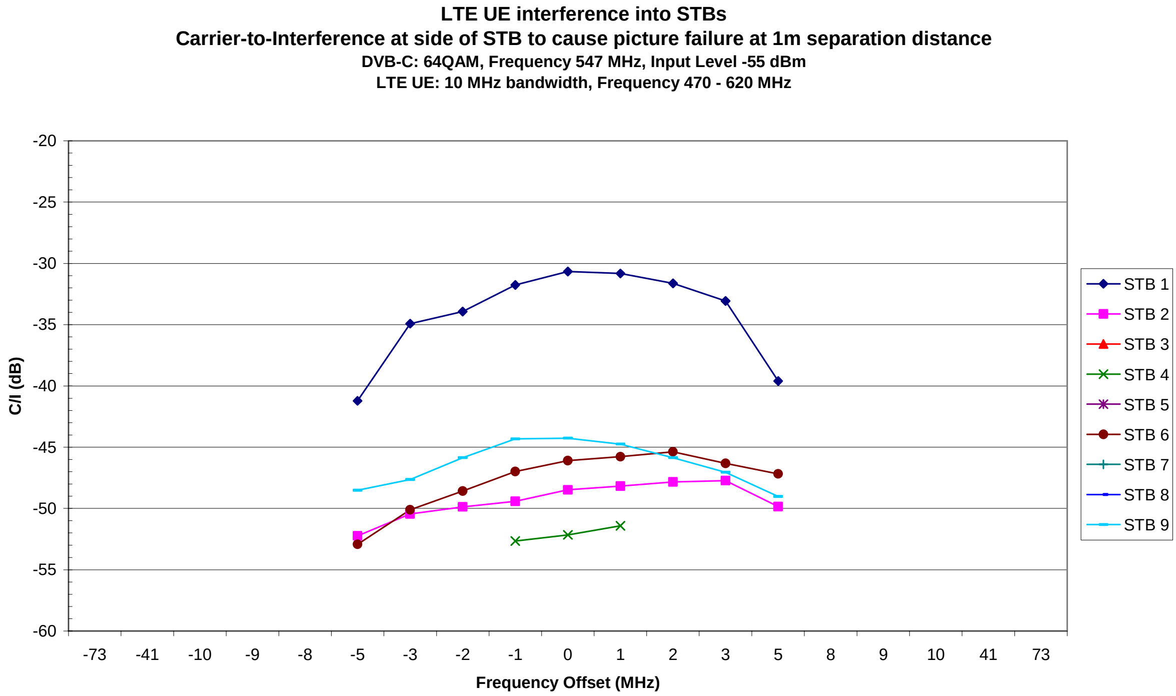

Figure 19: C/I protection ratio for LTE interferer at 1m from side of STB

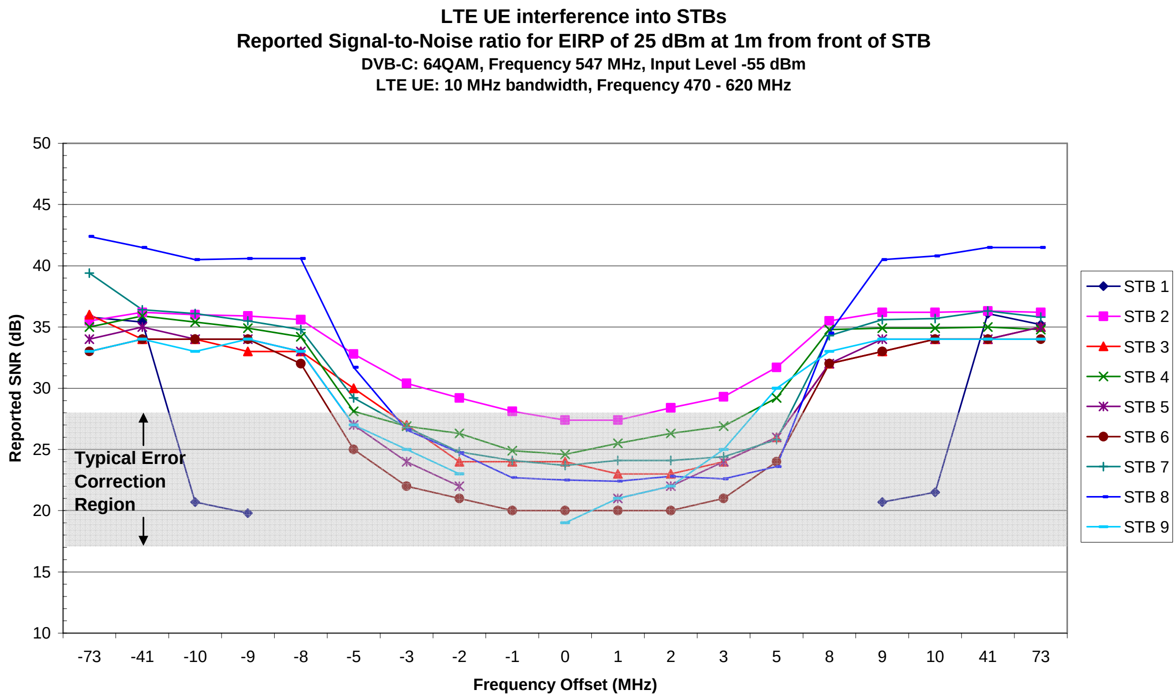

Figure 20: Reported SNR for LTE interferer at 1m from front of STB

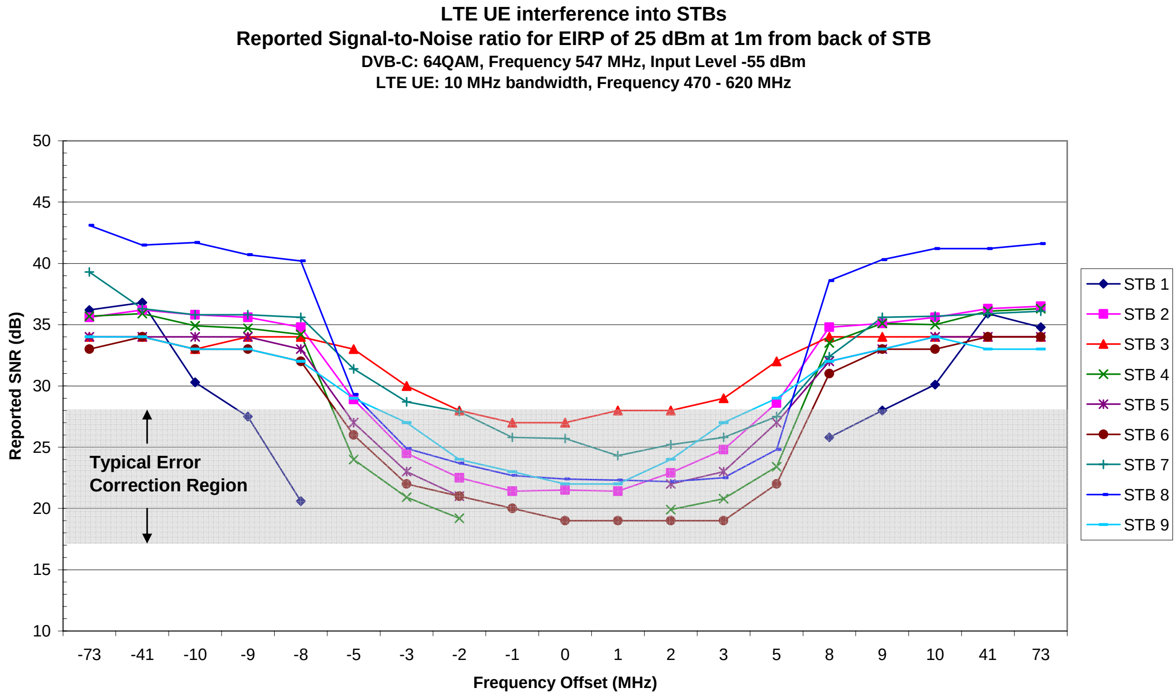

Figure 21: Report SNR for LTE interferer at 1m from back of STB

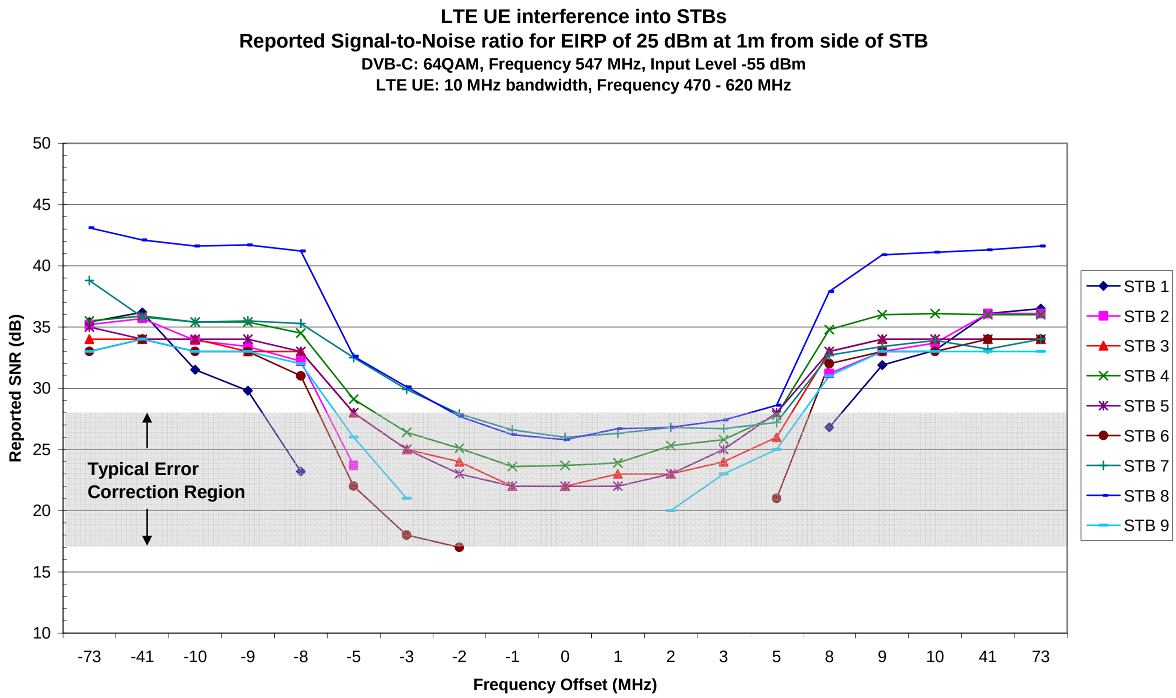

Figure 22: Reported SNR for LTE interferer at 1m from side of STB

3.2 Cable Modem Results

A total of twelve CMs from four different manufacturers were tested, representing a range of different design and model types. The complete results for each CM are included in Appendix B.

Although some of the modems were able to support the latest DOCSIS 3.0 standard, the earlier models tested were only able to support DOCSIS 1.0/1.1. Therefore, all tests were carried out with DOCSIS 1.0 configuration using the parameters given in Table 7 in order to provide a common set of results. The wanted signal level at the CM was -8 dBmV (-55 dBm) using 256 QAM modulation. It should be noted that in practice, 256 QAM is likely to be operated at wanted levels 6 dB higher than for 64 QAM to overcome reduced robustness to interference in higher order modulation schemes. This could be expected to produce a corresponding improvement of 6 dB in the cable modem results.

The LTE UE uplink signal parameters were based on a 10 MHz FDD reference channel using QPSK modulation and full RB allocation (50 resource blocks). Maximum transmit EIRP was assumed to be +25 dBm in the channel bandwidth (23 dBm ±2 dB tolerance).

Figure 23 and Figure 24 show the LTE UE EIRP required to cause data failure at a distance of 1m from the front and side of the CM under test respectively. Figure 25 through to Figure 28 show the measured field strength at the CM and the required Carrier-to-Interference protection ratio.

- The CMs under test were generally more prone to interference from the front. Only CMs 3, 5 and 11 exhibited worse performance from the side, with CM11 requiring an additional 11 dB of protection;
- CMs 12 and 9 were found to require the most protection. They exhibited data failure at a co-channel LTE UE EIRP of -13 dBm and -10 dBm respectively with the interferer 1m from the front. These two CMs are similar models from the same manufacturer;
- CM1 was found to require the least protection. Data failure occurred at a co-channel LTE UE EIRP of +20 dBm. Performance was similar from both the front and side (within 1 dB);
- For CM2, 6, 7, 9, 11 and 12 data failure was found to occur for frequency offsets of -8 to +8 MHz (the maximum range tested).

The results show that all 12 of the CMs tested could suffer interference from a LTE UE handset operating at, or near, the maximum permissible transmit power of +25 dBm.

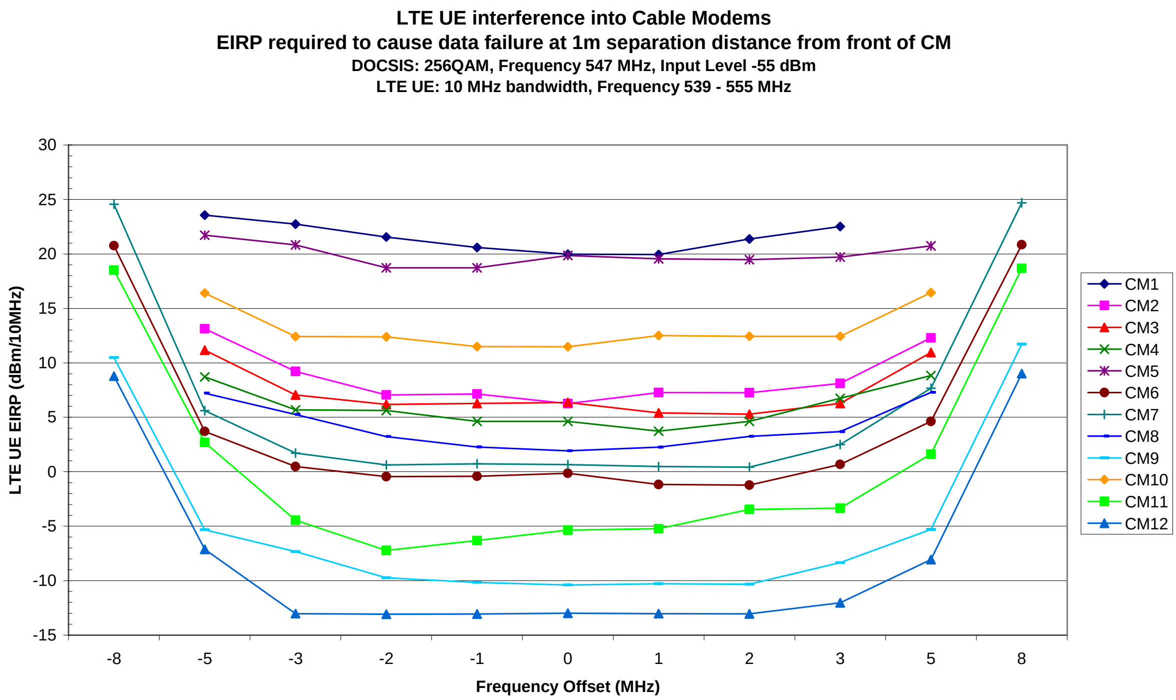

Figure 23: Transmit EIRP to cause data failure at 1m from front of CM

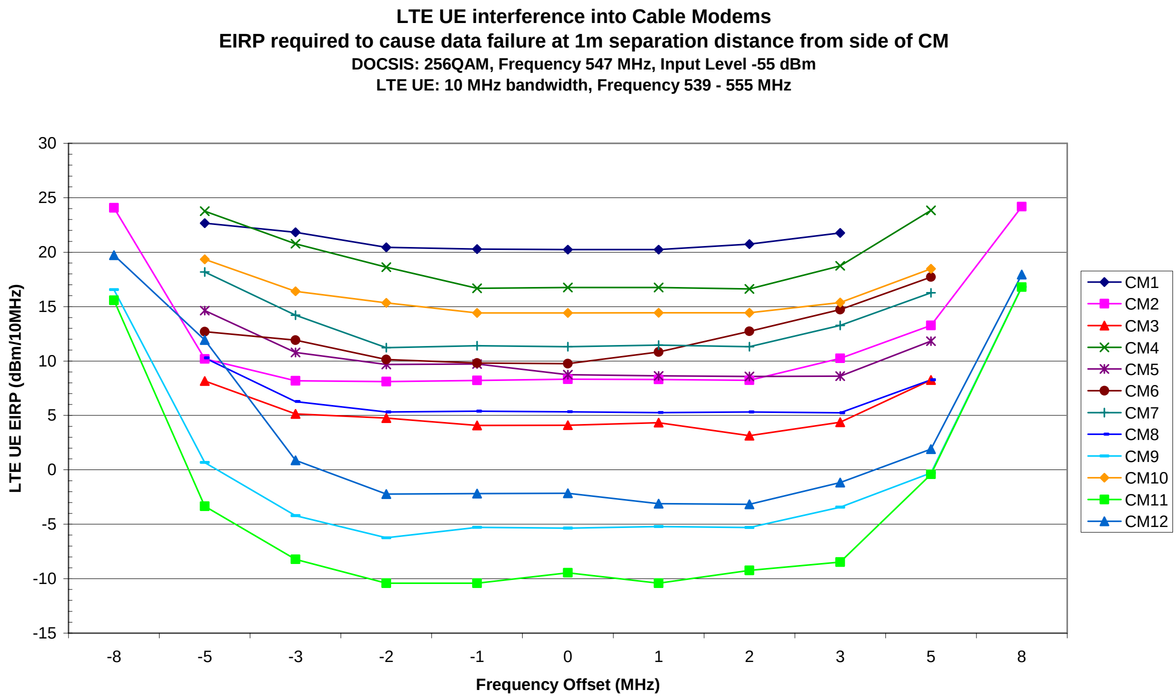

Figure 24: Transmit EIRP to cause data failure at 1m from side of CM

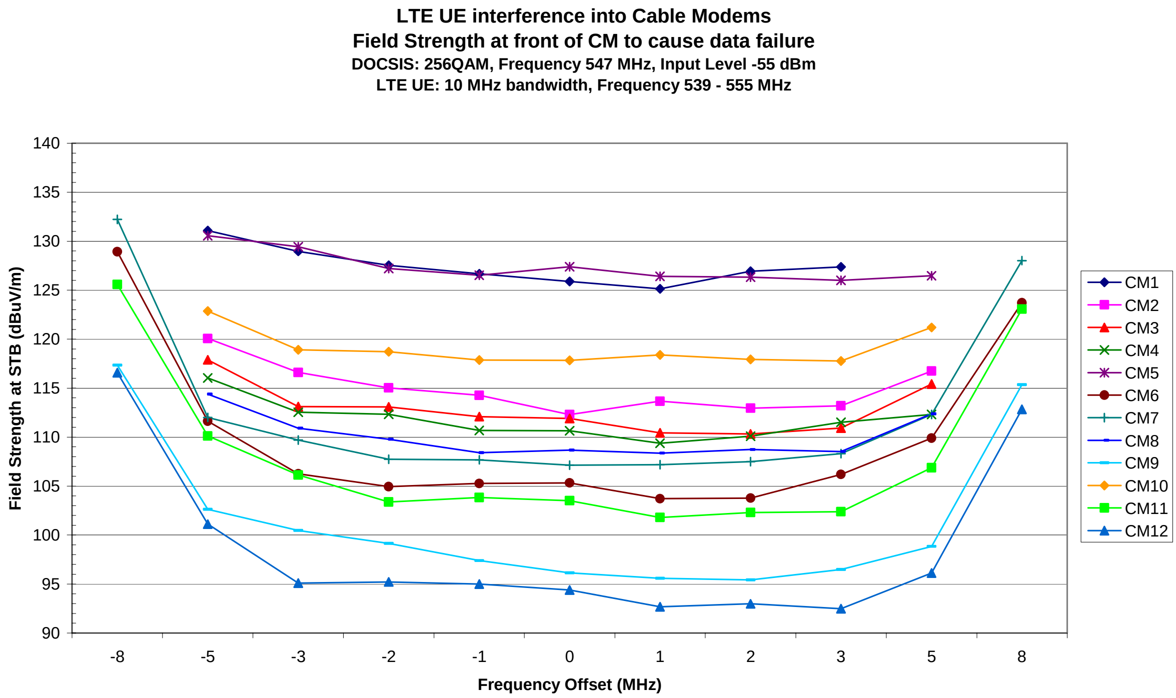

Figure 25: Field Strength measured at front of CM at data failure point

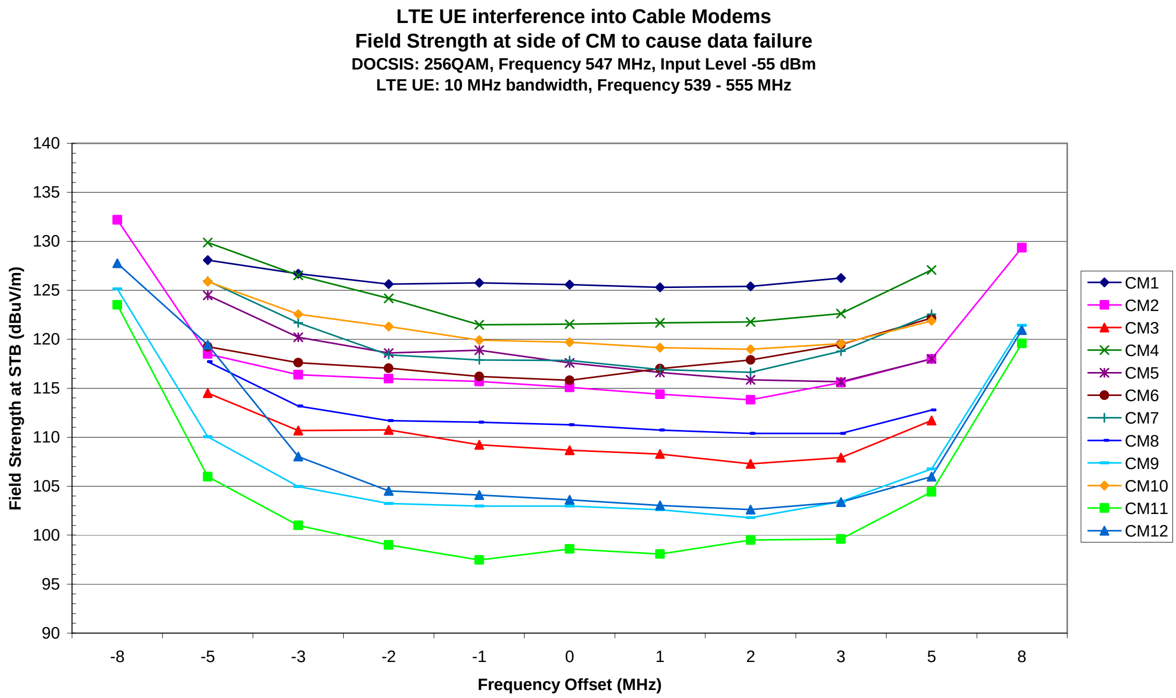

Figure 26: Field Strength measured at side of CM at data failure point

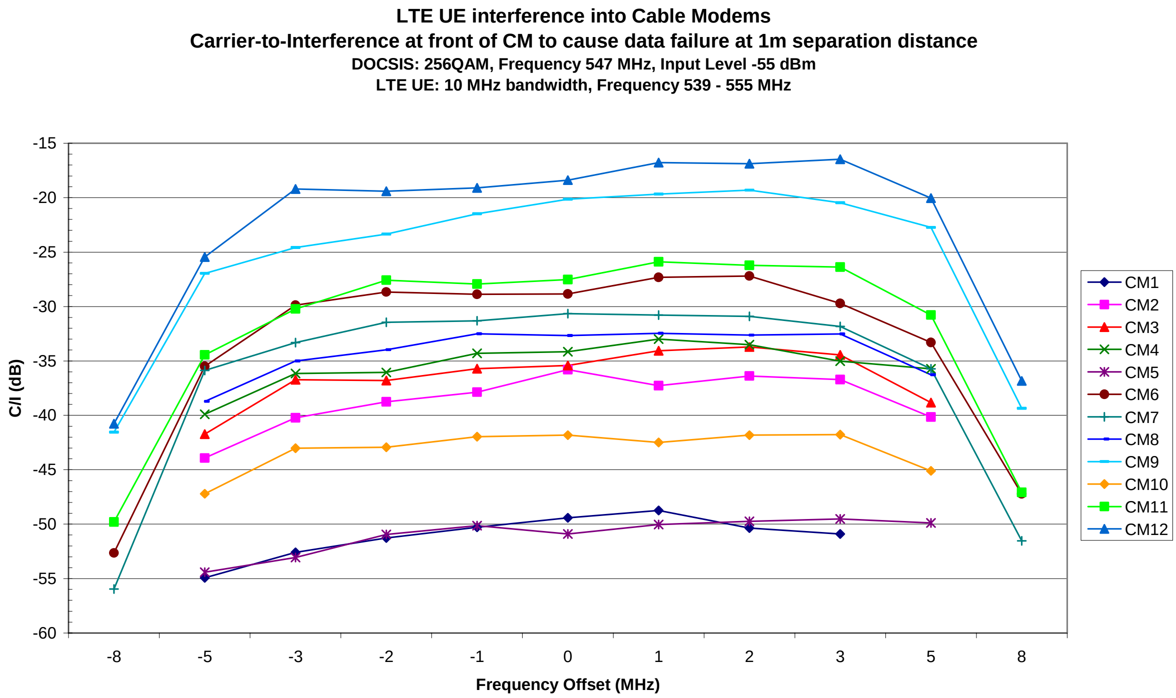

Figure 27: C/I protection ratio for LTE interferer at 1m from front of CM

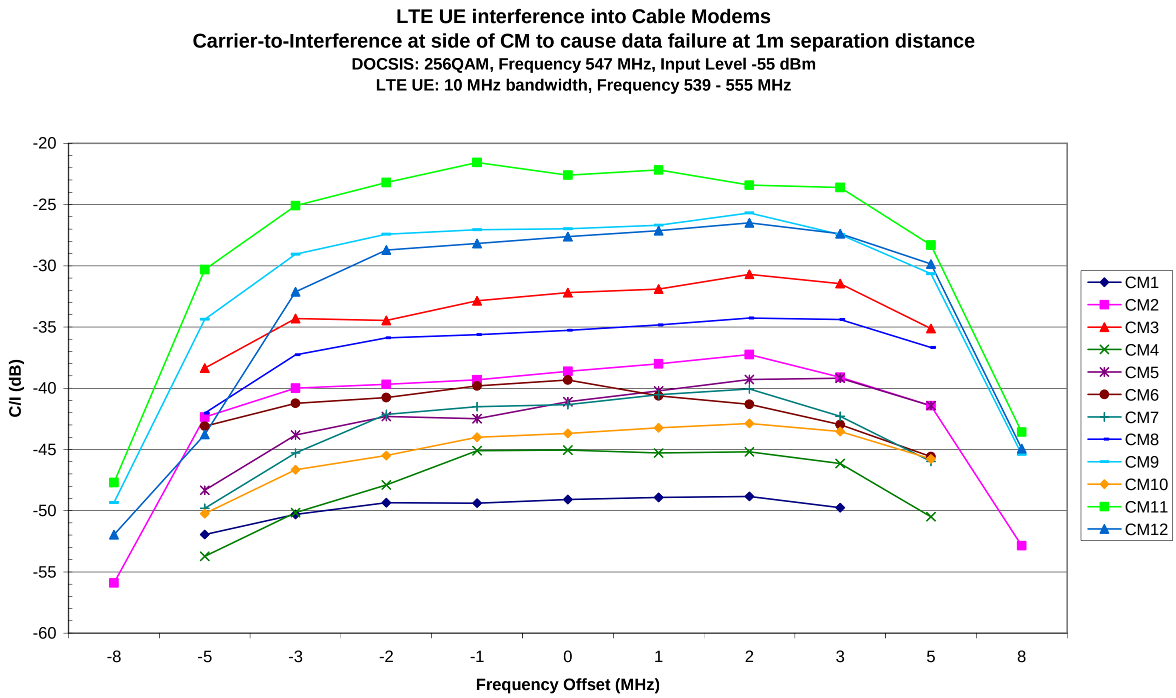

Figure 28: C/I protection ratio for LTE interferer at 1m from side of CM

3.3 Sensitivity Analysis

3.3.1 Wanted signal level

Figure 29 below shows the effect of increasing the wanted signal level for STB9 and STB1. The results show that for every 1 dB increase in wanted signal level, the level of interference required to cause picture failure increases by approximately 1 dB. This suggests that operating the CATV network at higher wanted signal levels could be a useful mitigation measure against future LTE UE interference. The commercial, practical and technical feasibility of such a measure has not been examined.

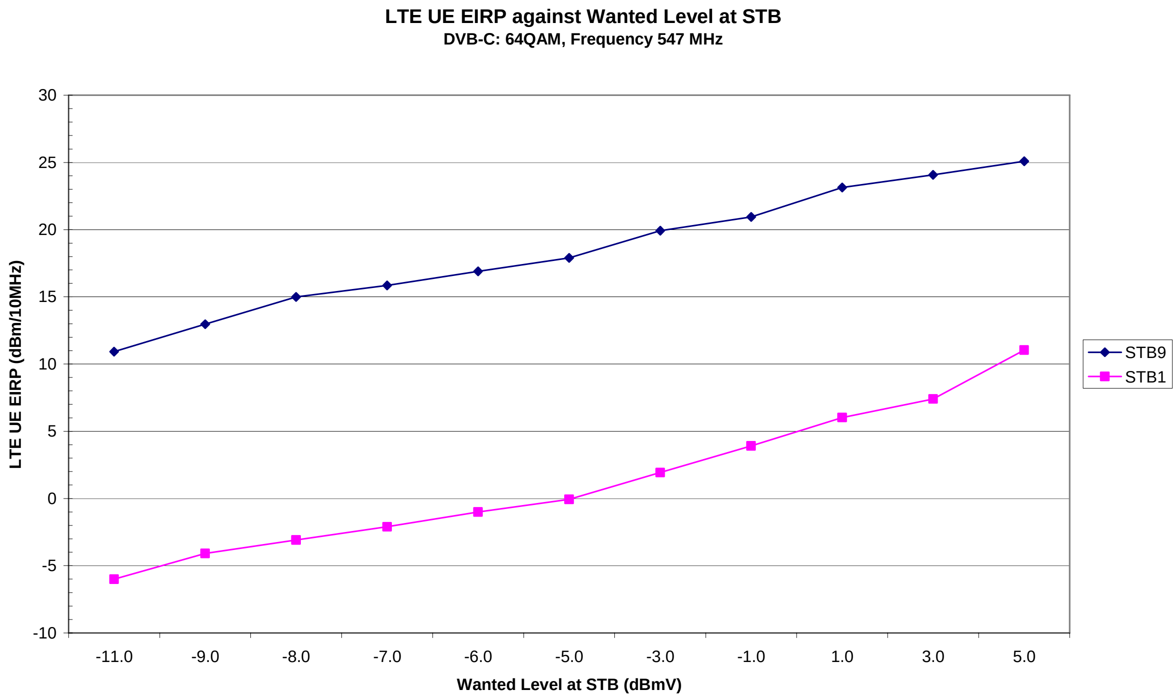

Figure 29: Effect of changing wanted signal level at input to STB

3.3.2 Partial resource block allocations

Figure 30 shows the effect of reducing the number of LTE UE resource blocks on the EIRP required to cause PF for STB9. Figure 31 shows the corresponding C/I protection ratio at the STB.

The results show that partial resource block allocations could cause higher levels of interference at the STB. Although the power density averaged over the 10 MHz LTE bandwidth stays constant when the RB allocation is reduced, the peak power increases as shown in the spectrum emission plots in Figure 10. Reducing the number of resource blocks from 50 to 1 increases the required C/I protection ratio by around 3 dB.

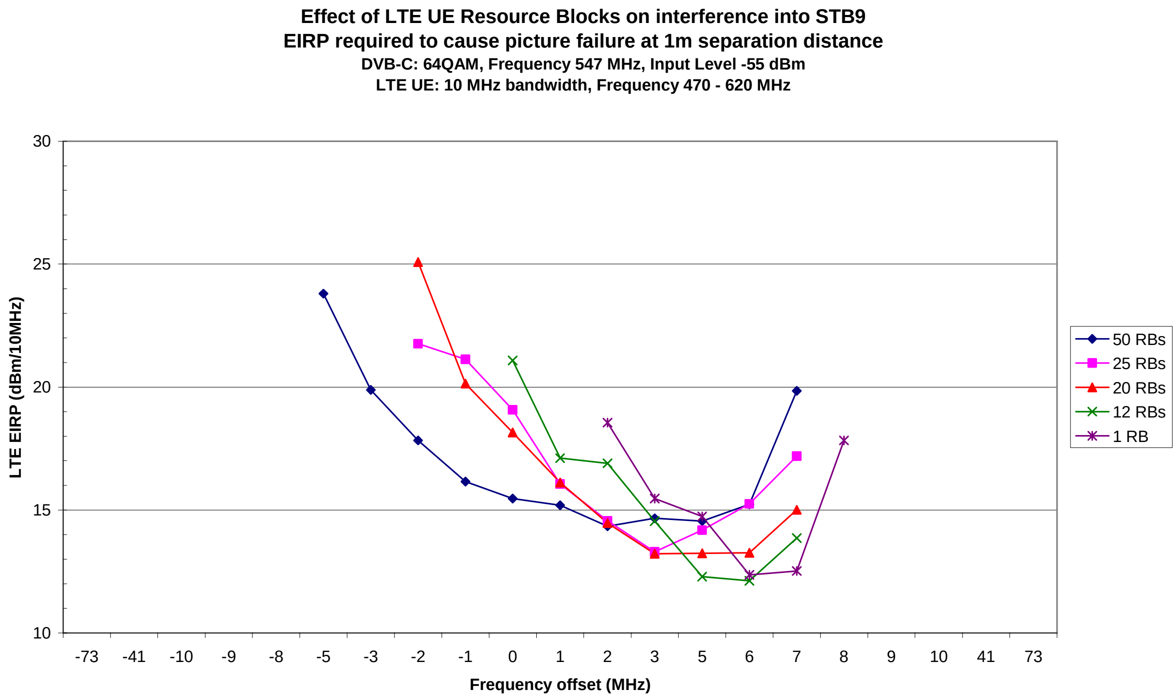

Figure 30: LTE UE EIRP for partial Resource Block allocations

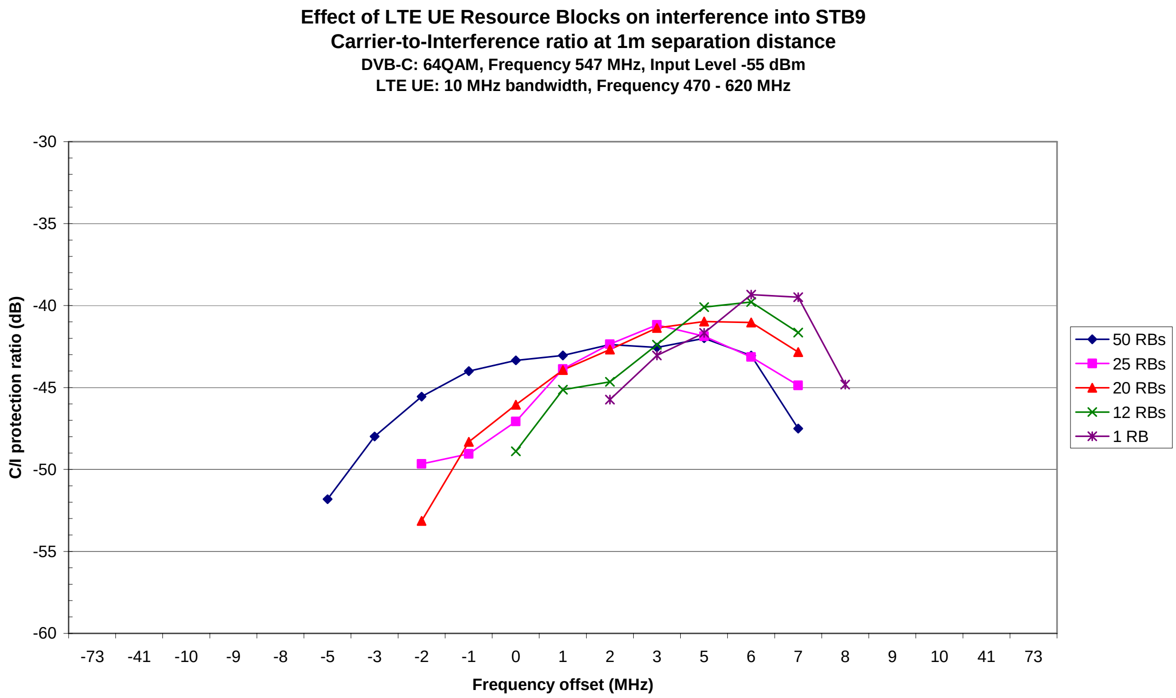

Figure 31: C/I protection ratio for partial Resource Block allocations

From Figure 30 it can be seen that the highest levels of interference occur for frequency offsets of +5 to +7 MHz for 1 RB allocation. This is because, with the static LTE characteristics used, the interference peak occurs at the lower end of the LTE UE channel, and is therefore only co-frequency with the centre of the wanted CATV channel for frequency offsets greater than 4.5 MHz, as illustrated in the figure below.

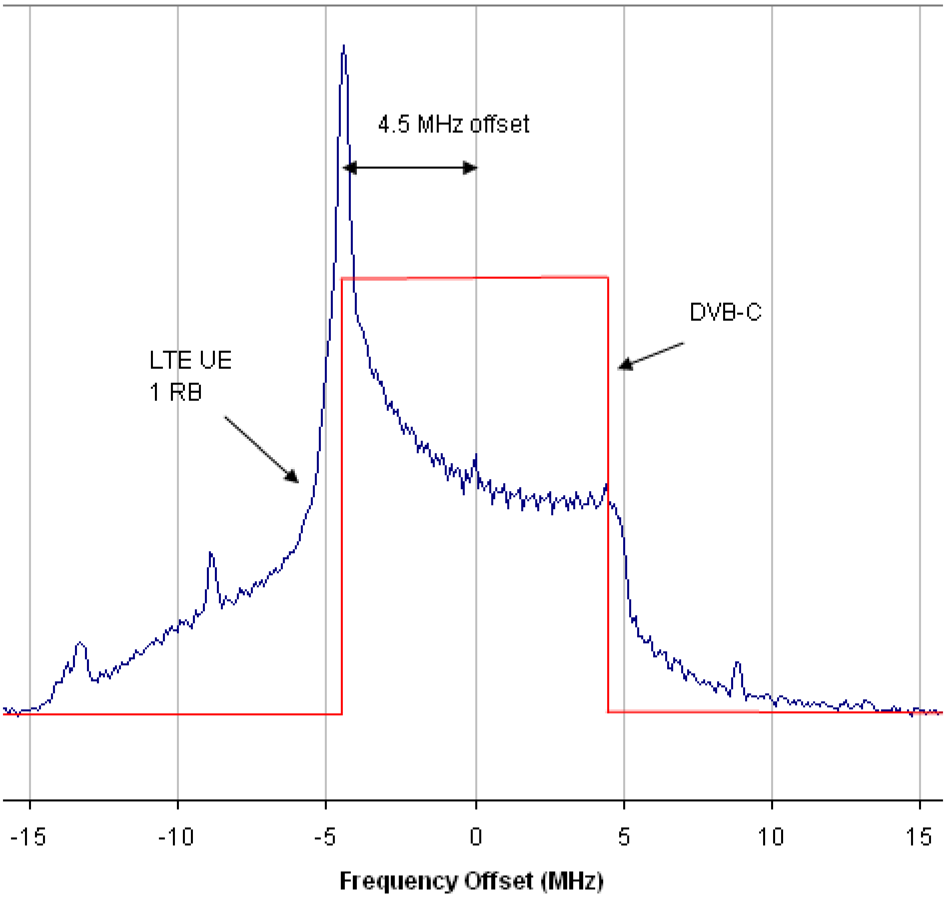

Figure 32: Relative frequency offset for single resource block allocation

4. Electromagnetic Design

Five set top boxes and five cable modems were reviewed with respect to their electromagnetic design, to determine potential weaknesses in the designs and to recommend any design improvements. The full analysis is included in Appendix C.

In the following sections, "slots" and "apertures" are generally rectangular holes in the metalwork, that may be covered by plastic for specific connectors (not grids of small cooling holes) that allow unwanted frequencies to pass through which may then couple to sensitive circuitry.

4.1 Set Top Box Design

The five STBs reviewed were identified as 1, 5, 6, 8 and 9. The boxes are similar in size and shape, however STBs 1 and 8 do not contain recordable disk drive units. STBs 6 and 9 were identical from a visual internal inspection. Overall the design of STB1 is considered to be the poorest.

The EMC design approach applied to all of the units is to provide a screened metal compartment, with the front panel being plastic and containing the user controls. All electrical interfaces for power, RF input and output and data are mounted on the back panel. Smart card reader slots are located either on the front or the rear panels.

STBs 6 and 9 are identical in design using good bonding to provide a faraday cage around the electronics. The other three units, although following a similar approach, are not considered to be likely to achieve such good contact between the lid and the base impacting on the screening efficiency.

There are significant slots on all of the units, particularly at the front panel for the ribbon cable for the controls. In some instances there are slots which serve no purpose. The rear panel on all units presents some slots where plastic power connectors and other connectors are mounted. Ethernet and USB connectors generally have contact fingers to provide bonding. SCART connectors, although bonded by one or two screws, still leave slots where RF could couple in. The RF signal interface in all cases is bonded to the chassis with the RF circuits in a screening can mounted on the PCB.

It should be noted that the tests were carried out at 547 MHz due to the limitation of using the live Birmingham TV feed at the test facility. At 790 - 862 MHz the wavelength is shorter, which may result in more efficient coupling through slots and apertures in the cases and also to PCB tracks. This may result in less immunity. Coupling through interface cabling to the units is considered to be low risk at the higher frequencies.

4.2 Cable Modem Design

The five CMs reviewed were identified as 1, 3, 10, 11 and 12. Four of the units were similar, but CM10 combined an RF router.

CM12 is considered from an inspection to have the poorest design based on the plastic case and the RF modulation/demodulation circuitry built on the PCB with no additional screening. CM1 was assessed to have the best design, with the RF circuit in a can and with the box having a conductive coating on the inside to provide a faraday cage. The remaining three units are all of similar design, housed in similar plastic boxes, with the design order of preference being CM3, CM10 and CM11.

Design improvements are limited to conductive coating of the boxes to provide a faraday screen with associated bonding of interface RF and data connectors to the faraday screen. Where RF circuits are not screened improvements should be possible with screening cans. PCB routing, track lengths and decoupling cannot be assessed but is an area where performance improvements may be possible, but are difficult to quantify.

4.3 Implications of Proposed Radiated Immunity Test Levels

Draft ETSI TR DD v1.0.0 (2010-06) [2] suggests that the radiated immunity of DVB tuners in the frequency range 790 - 862 MHz should be 1 V/m in-band and outside this band 3 V/m.

The results presented in this study for LTE UE interference into STBs at 1m separation distance suggest that the design of these boxes should be adequate to meet the suggested limits. Of the nine boxes tested only one failed the suggested limits, with results significantly worse than the other STBs tested. As noted above, this STB has poorer EMC design performance than the other STBs reviewed.

For CM’s the results were worse, with only two out of twelve passing the suggested limits.

The primary difference in design is that STBs use a screened box approach with the RF section in a screened can, whereas CM’s generally have no overall screen and, in the worst cases, no or limited screening for the RF section. One of the two CM’s that passed the suggested limit has an internal conductive coating to provide overall screening. It is considered that where the RF design includes a good screening can, that the coupling of unwanted RF may be through the PCB adjacent to the RF tuner. If this is the case the design options are to provide improved screening or to improve the RF isolation at the PCB for the CMs.

5. Conclusions

Radiated measurements were undertaken at Virgin Media's RF/Optical test facility to establish the potential for Long Term Evolution User Equipment interference into 9 set top boxes and 12 cable modems in use in the UK.

The following test scenario was assumed:

- A wanted signal level at the device under test of -8 dBmv (-55 dBm), at the lower end of the operating range in the UK of -10 to +10 dBmV;
- 64 QAM modulation for the STBs and 256 QAM modulation for the CMs;
- A UE interferer with a 10 MHz bandwidth QPSK FDD reference channel based on full Resource Block allocation;
- A maximum UE transmit EIRP of +25 dBm, based on a level of +23 dBm for UE Power Class 3 ±2 dB tolerance, as defined in section 6.2 of ETSI TS 136 521-1 [1];
- Frequency offsets from co-channel (N) to N ± 9 channel separations for the STBs and ±8 MHz for the CMs;
- A separation distance of 1m between the interferer and device under test.

For the above assumptions, the results show that 7 out of the 9 STBs tested could suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm at 1m separation distance:

- STB1 was found to require the most protection from interference. It exhibited picture failure at a co-channel LTE UE EIRP of around -3 dBm, with a C/I protection ratio measured at the STB of -26 dB. The performance of STB1 was much worse than the other STBs tested, requiring around 21 dB more protection than the next worse case (STB9). STB1 was the oldest box tested, manufactured in 2003, and is considered to have the poorest design in terms of electromagnetic compatibility;
- STBs 4, 5 and 8 were only found to exhibit PF at or near the maximum LTE UE EIRP (24 – 25 dBm). STBs 3 and 7 did not experience PF under any of the test conditions;
- No adjacent, local oscillator, or image channel interference was observed for any of the STBs tested.

The results show that all 12 of the CMs tested could suffer interference from a LTE UE handset operating at the maximum permissible transmit power of +25 dBm at 1m separation distance:

- CMs 12 and 9 were found to require the most protection. They exhibited data failure at a co-channel LTE UE EIRP of -13 dBm and -10 dBm respectively, with a C/I protection ratio measured at the CM of -17 dB and -20 dB respectively. These two CMs are similar models from the same manufacturer. CM12 is considered to have the poorest design in terms of electromagnetic compatibility;
- CM1 was found to require the least protection. Data failure occurred at a co-channel LTE UE EIRP of +20 dBm. Performance was similar from both the front and side (within 1 dB). CM1 is considered to have the best design in terms of electromagnetic compatibility.

It should be noted that for the cable modem testing 256 QAM modulation was used with a wanted signal level of -8 dBmV. In practice, 256 QAM modulation is likely to be operated at wanted levels 6 dB higher than for 64 QAM to overcome reduced robustness to interference in higher order modulation schemes. This could be expected to produce a corresponding improvement of 6 dB in the cable modem results.

The sensitivity analysis shows that increasing the wanted signal level by 1 dB results in a comparable increase in the LTE UE level required to cause interference to the STB. This suggests that operating the CATV network at higher wanted signal levels could be a useful mitigation measure.

Picture failure was generally only found to occur for frequency offsets of -5 to +5 MHz, when the 10 MHz LTE signal is essentially co-channel. This suggests that, for the majority of STBs, interference can be avoided if there is a 5 MHz guard band between the CATV and LTE UE centre frequencies.

The sensitivity analysis shows that partial LTE UE resource block allocations could cause higher levels of interference at the STB. Although the power density across the 10 MHz LTE bandwidth stays constant when the RB allocation is reduced, the peak power increases. Reducing the number of RBs from 50 to 1 increases the required protection ratio by around 3 dB.

A representative sample of STB and CM equipment was examined in terms of electromagnetic design. All of the STBs were found to have significant rectangular holes (apertures) in the metalwork that can allow unwanted frequencies to pass through which may then couple to sensitive circuitry. Overall the design of STB1 is considered to be the poorest and this is reflected in the test results.

Of the cable modems examined, CM12 is considered to have the poorest design based on the plastic case and the RF modulation/demodulation circuitry built on the PCB with no additional screening. CM1 was assessed to have the best design, with the RF circuit in a can and with the box having a conductive coating on the inside to provide a faraday cage. Again, these findings are reflected in the test results.

Draft ETSI TR DD v1.0.0 (2010-06) [2] suggests that the radiated immunity of DVB tuners in the frequency range 790 - 862 MHz should be 1 V/m in-band and outside this band 3 V/m.

The results presented in this study for LTE UE interference into STBs at 1m separation distance suggest that the design of these boxes should be adequate to meet the suggested limits. Of the nine boxes tested only one failed the suggested limits. As noted above, this STB has poorer EMC design performance than the other STBs reviewed.

For CM's the results were worse, with only two out of twelve passing the suggested limits.

It is evident from the EMC design review that some simple measures could be taken to improve the resilience of new CM equipment to LTE UE interference, such as additional screening of the RF circuitry. Alternatively, broadband data services could be located at the lower end of the operational CATV frequency range, away from the 832 – 862 MHz band. The technical, practical and commercial feasibility of these measures has not been examined.

6. References

[1] ETSI TS 136 521-1 v8.4.0 (2010-04). LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Conformance testing

[2] Draft ETSI TR DD v1.0.0 (2010-06): The concise report of the CENELEC/ETSI Joint Working Group on the digital dividend.

[3] ERC/DEC/(09)03 on "harmonised conditions for mobile/fixed communications networks (MFCN) operating in the band 790 – 862 MHz". 30th Oct 2009.

[4] CEPT Report 30 on "the identification of common and minimal (least restrictive) technical conditions for 790 – 862 MHz for the digital dividend in the European Union". 30th Oct 2009.

[5] ETSI EN 300 429: Digital Video Broadcasting: Framing structure, channel coding and modulation for cable systems.

[6] ETSI ES 201 488-2: Access and Terminals; Data Over Cable Systems; Part2: Radio Frequency Interface Specification.

Appendix A
Detailed Set Top Box Test Results

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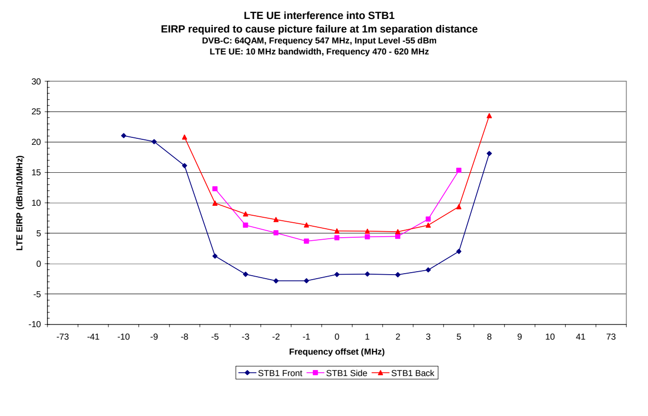
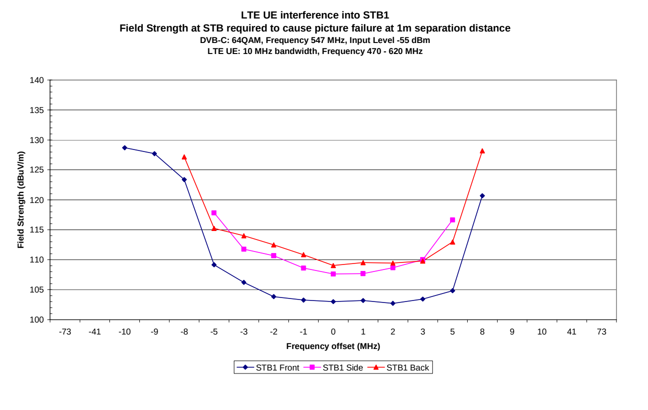
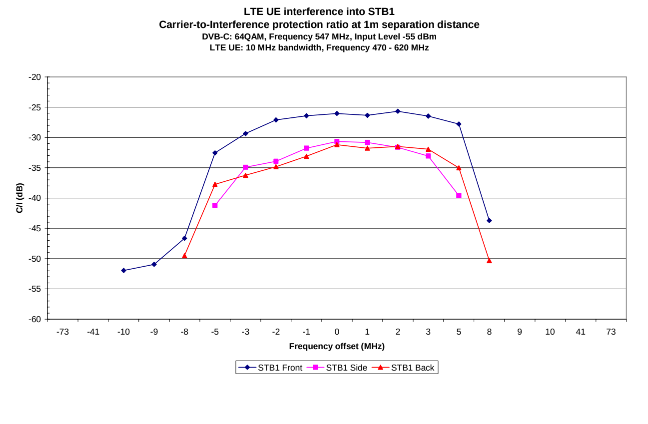
A.1. Set Top Box 1



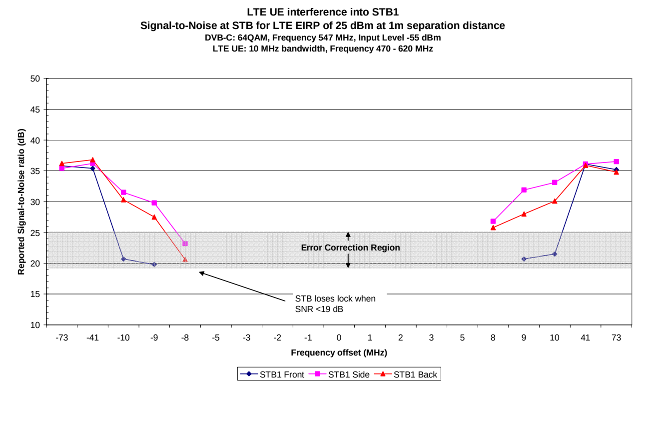
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



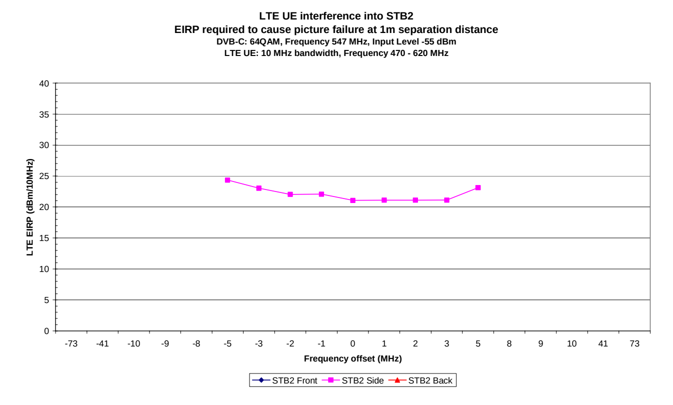
c) Carrier-to-Interference Protection Ratio



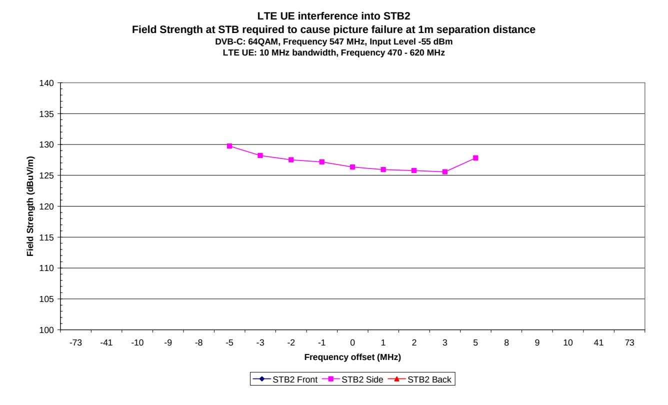
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 33: Detailed Results for STB 1

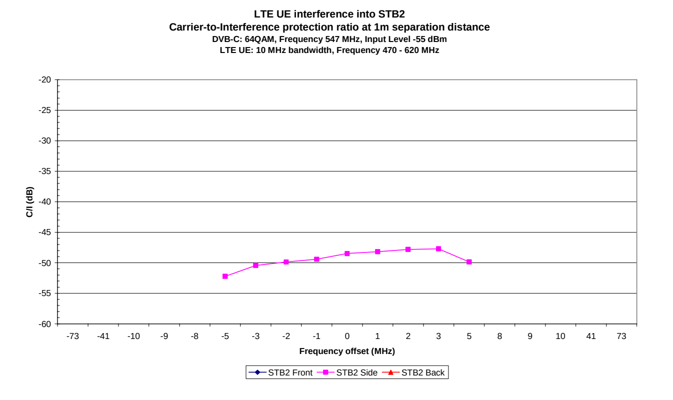
A.2. Set Top Box 2



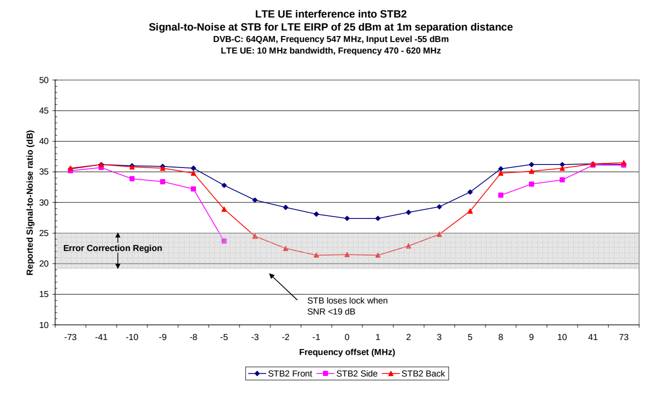
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



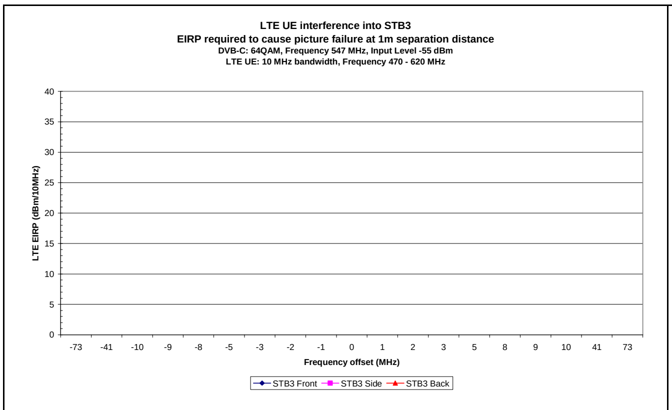
c) Carrier-to-Interference Protection Ratio



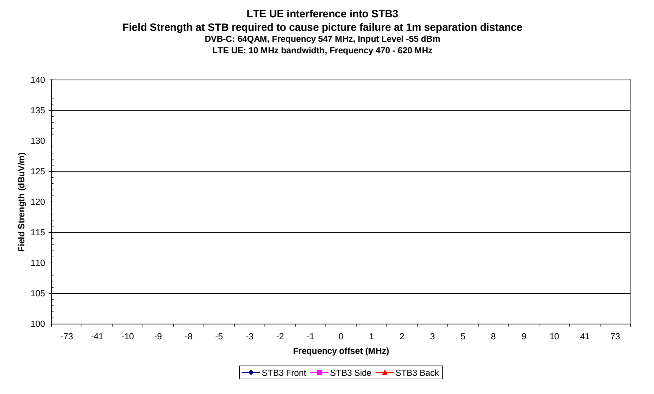
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 34: Detailed Results for STB 2

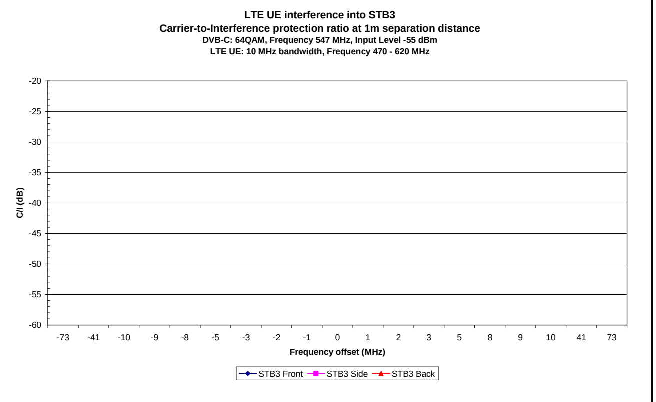
A.3. Set Top Box 3



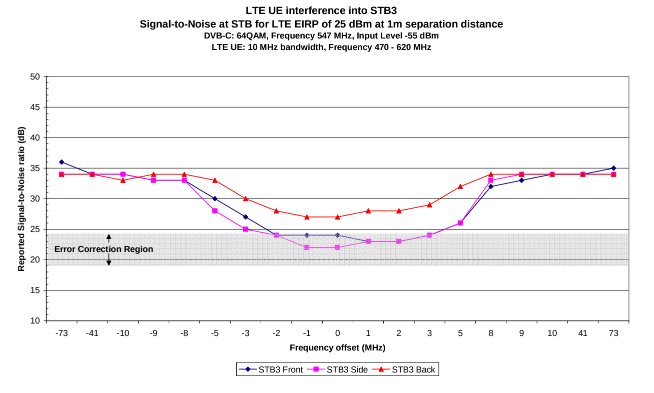
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



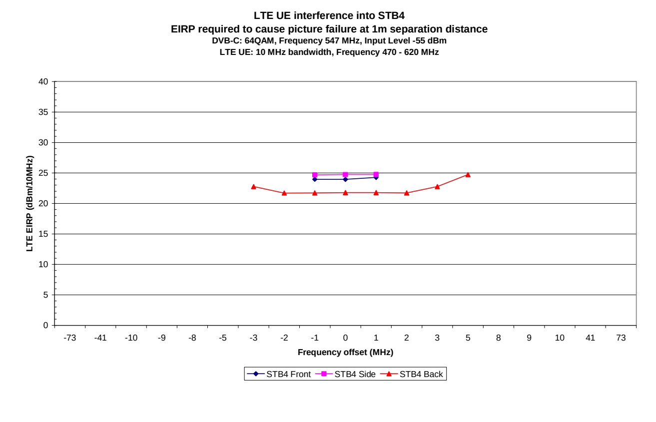
c) Carrier-to-Interference Protection Ratio



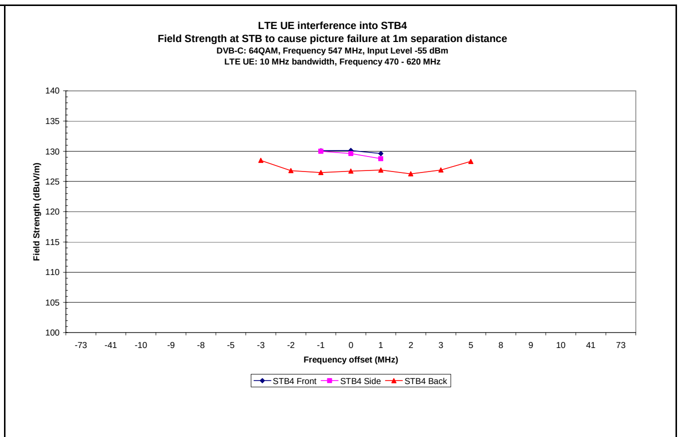
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 35: Detailed Results for STB 3

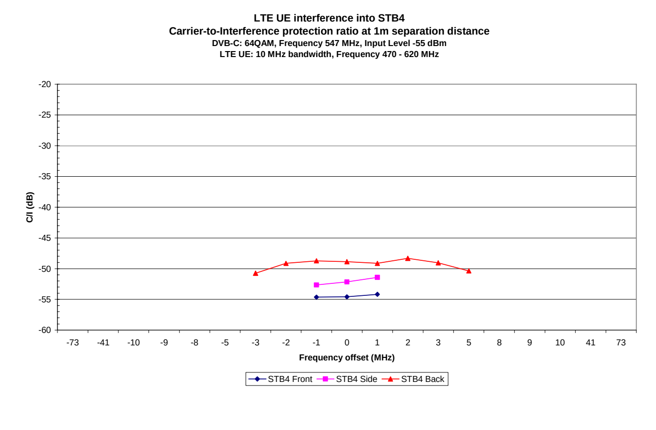
A.4. Set Top Box 4



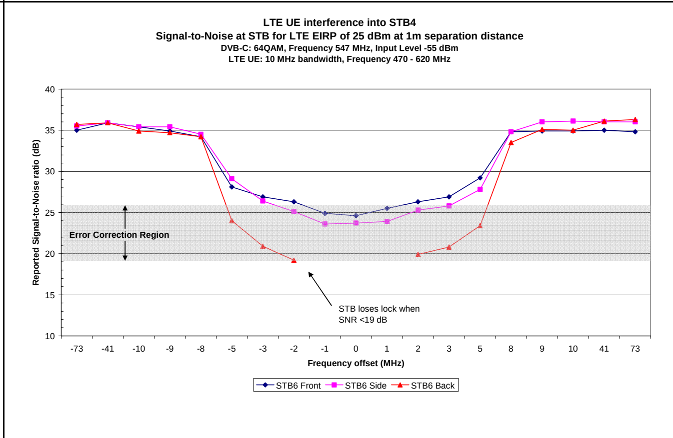
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



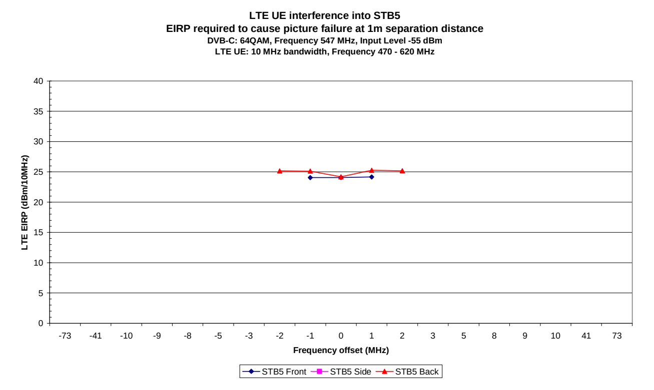
c) Carrier-to-Interference Protection Ratio



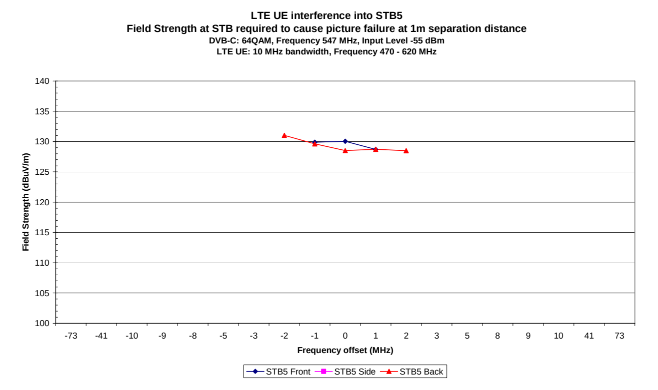
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 36: Detailed Results for STB 4

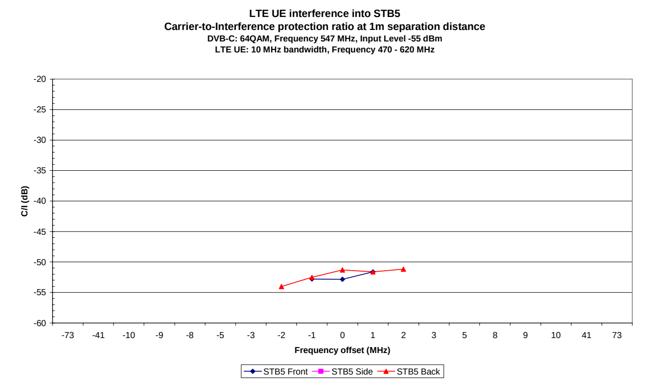
A.5. Set Top Box 5



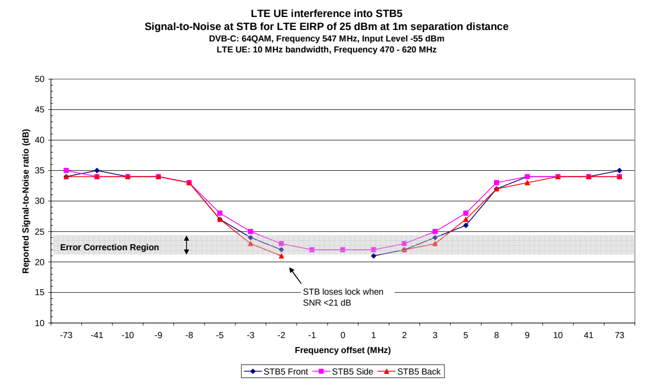
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



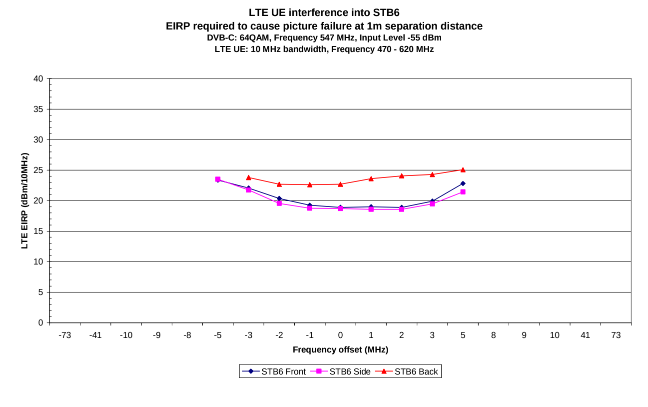
c) Carrier-to-Interference Protection Ratio



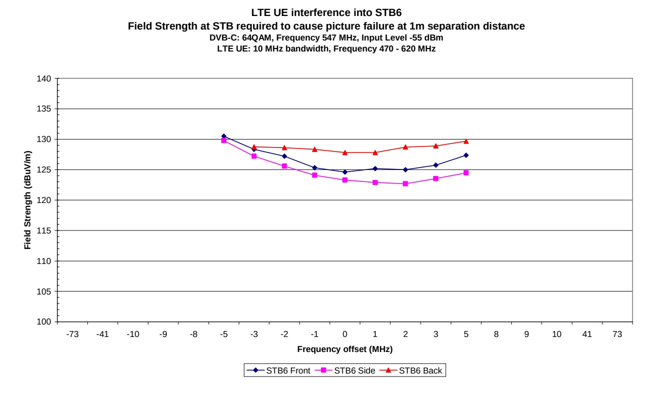
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 37: Detailed Results for STB 5

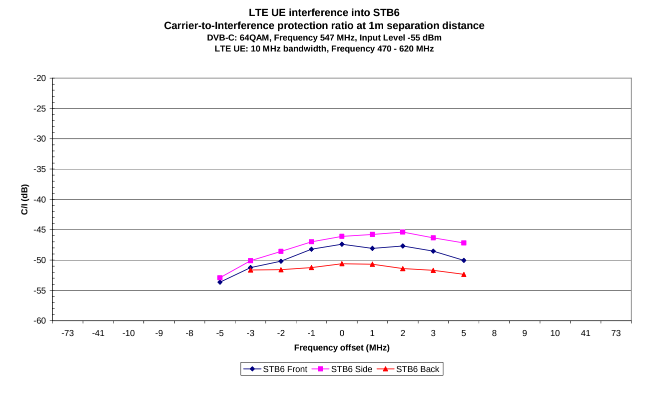
A.6. Set Top Box 6



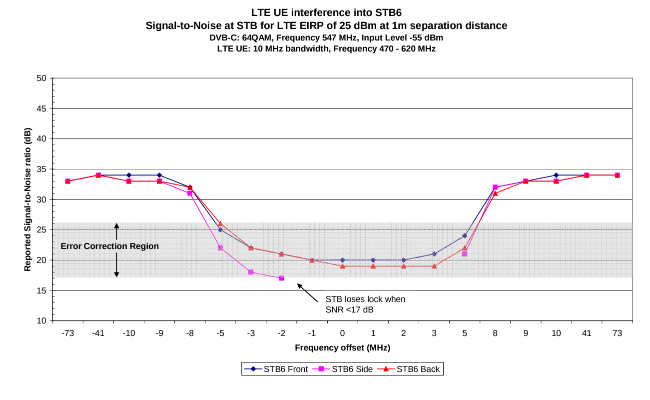
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



c) Carrier-to-Interference Protection Ratio



d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 38: Detailed Results for STB 6

A.7. Set Top Box 7

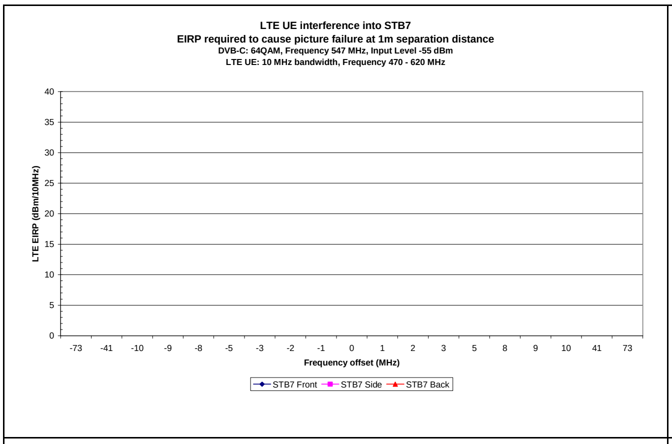
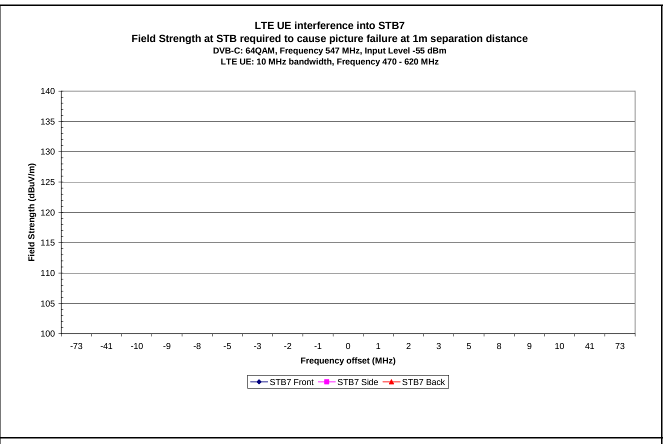
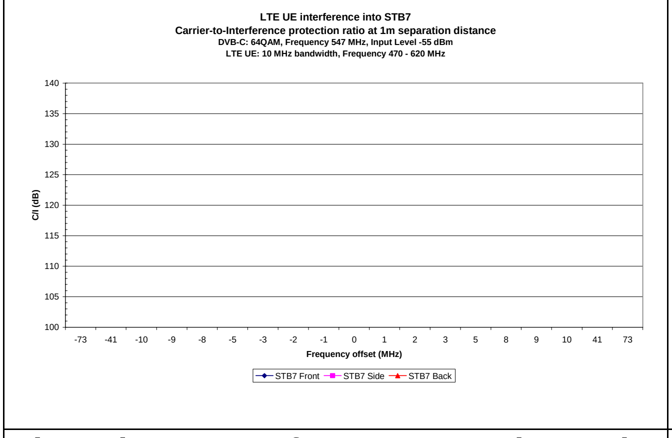
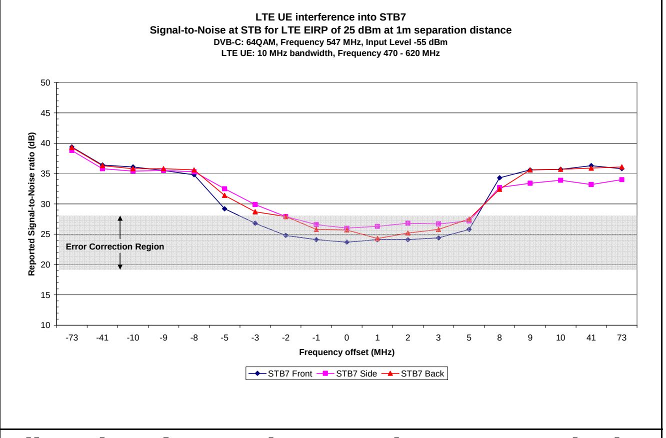
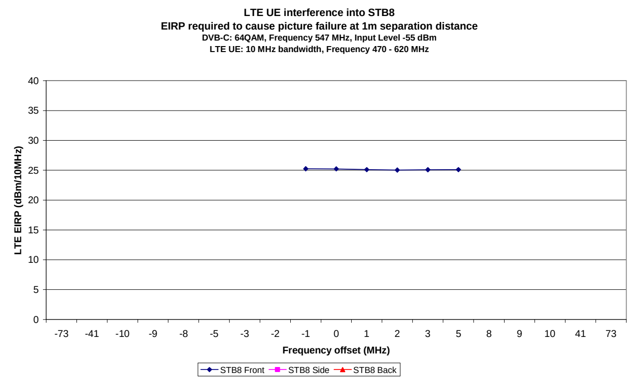
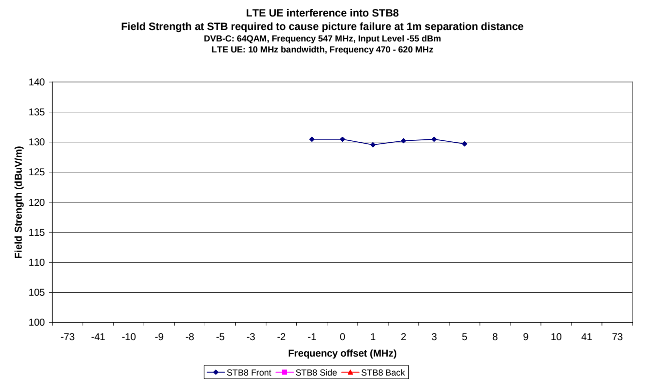
	
a) LTE EIRP at Picture Failure Point	**b) Field Strength at STB at Picture Failure Point**
	
c) Carrier-to-Interference Protection Ratio	**d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP**

Figure 39: Detailed Results for STB 7

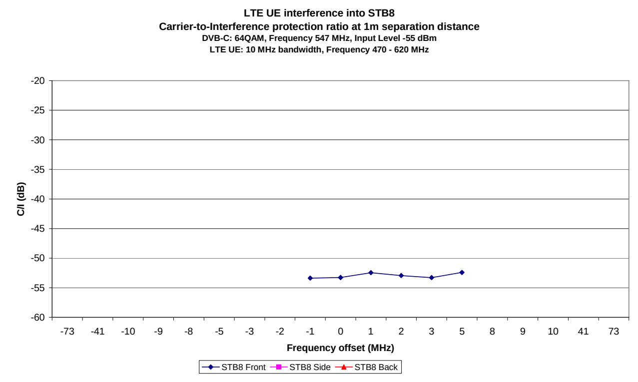
A.8. Set Top Box 8



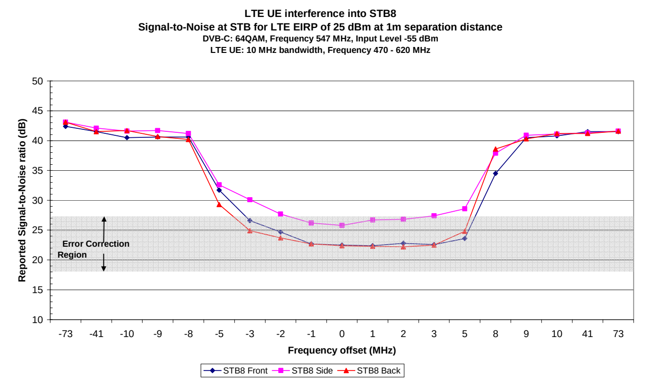
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



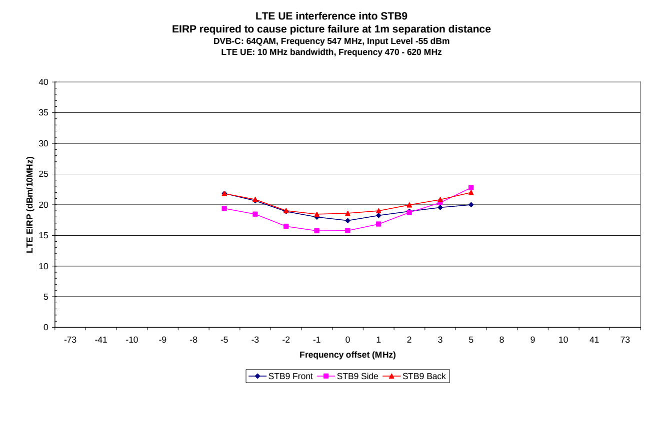
c) Carrier-to-Interference Protection Ratio



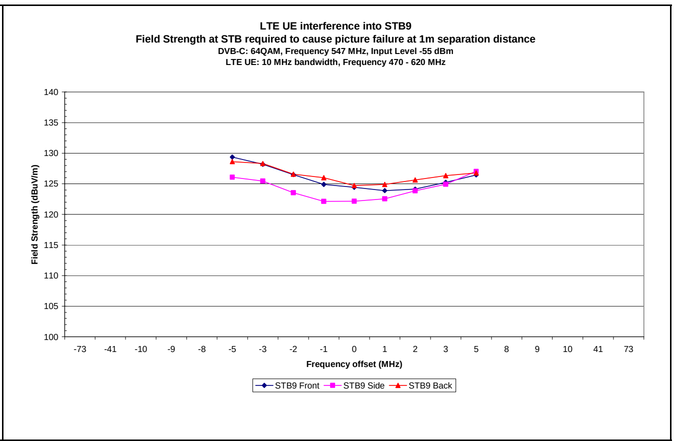
d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 40: Detailed Results for STB 8

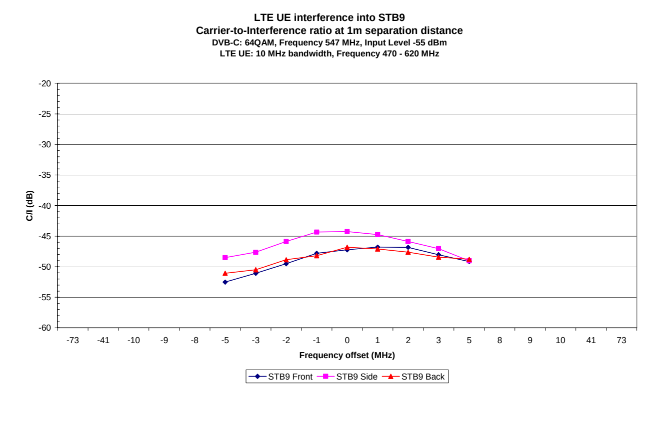
A.9. Set Top Box 9



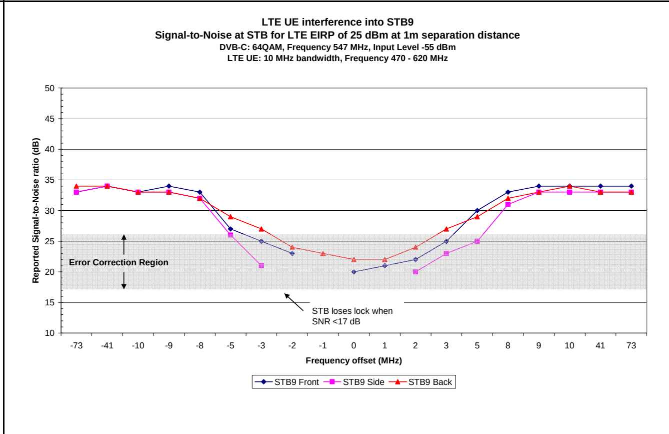
a) LTE EIRP at Picture Failure Point



b) Field Strength at STB at Picture Failure Point



c) Carrier-to-Interference Protection Ratio



d) Signal-to-Noise Ratio reported by diagnostics for maximum EIRP

Figure 41: Detailed Results for STB 9

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Appendix B
Detailed Cable Modem Test Results

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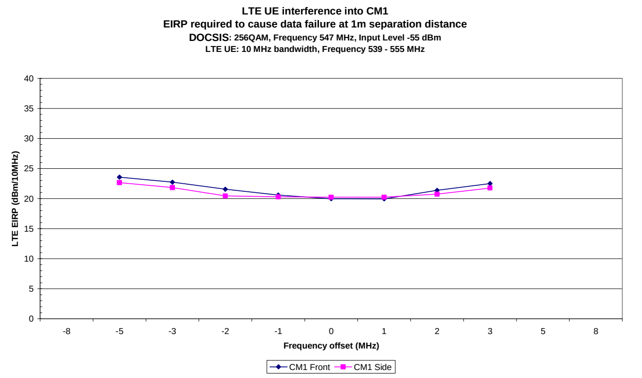
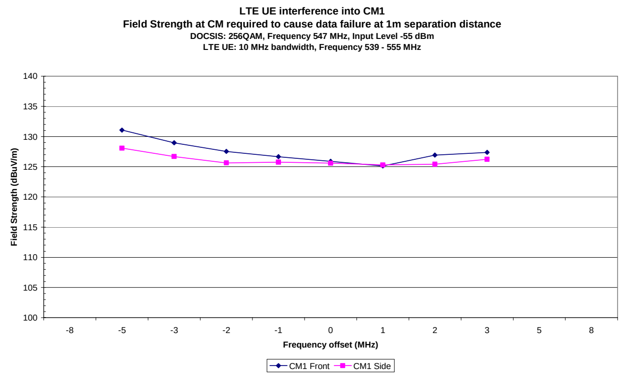
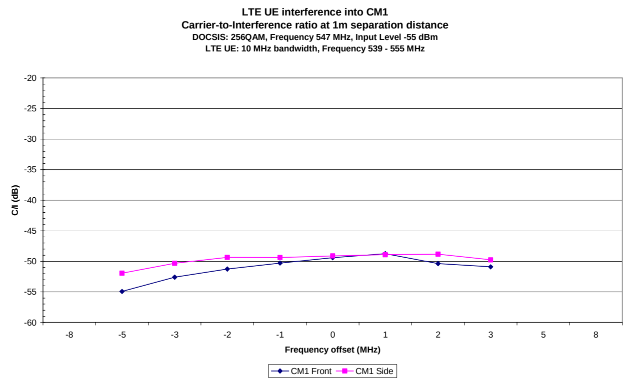
B.1. Cable Modem 1



a) LTE EIRP at Data Failure Point



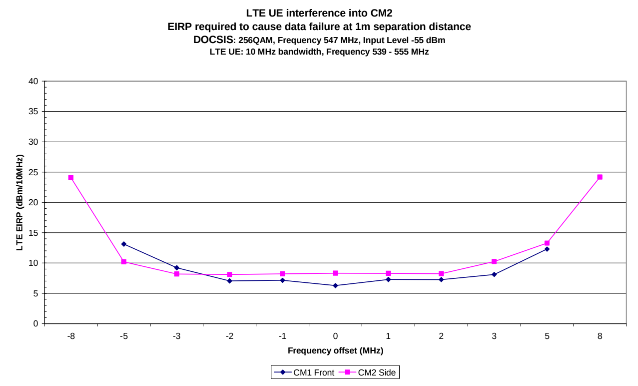
b) Field Strength at CM at Data Failure Point



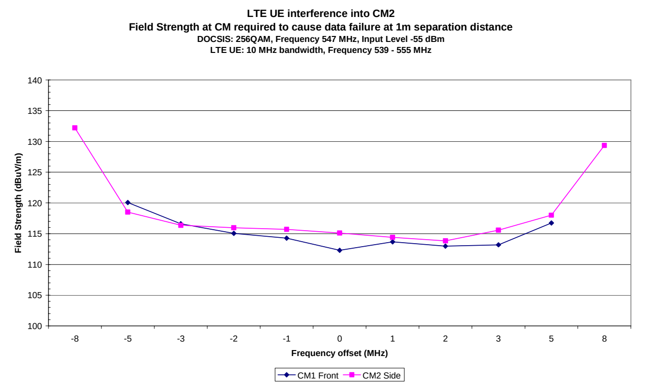
c) Carrier-to-Interference Protection Ratio

Figure 42: Detailed Results for CM 1

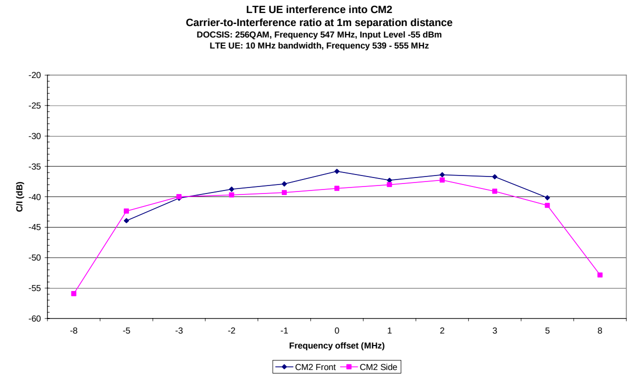
B.2. Cable Modem 2



a) LTE EIRP at Data Failure Point



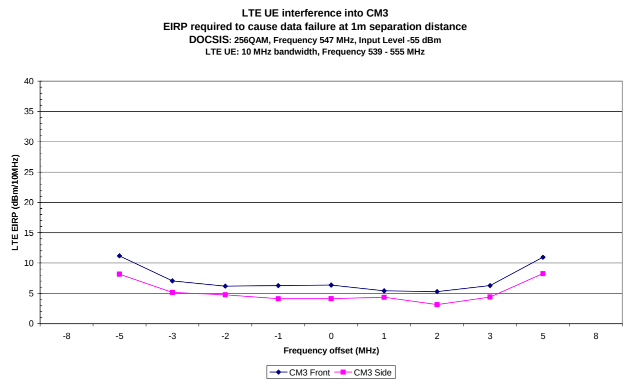
b) Field Strength at CM at Data Failure Point



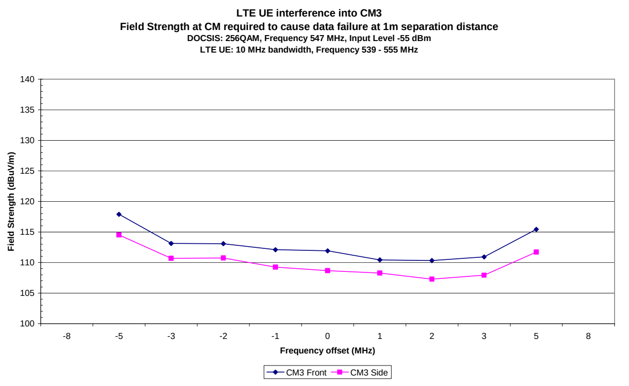
c) Carrier-to-Interference Protection Ratio

Figure 43: Detailed Results for CM 2

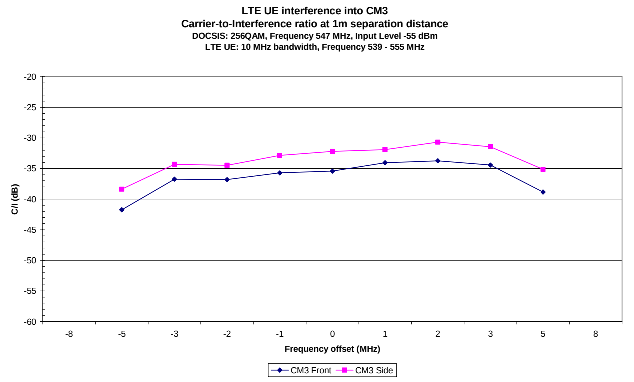
B.3. Cable Modem 3



a) LTE EIRP at Data Failure Point



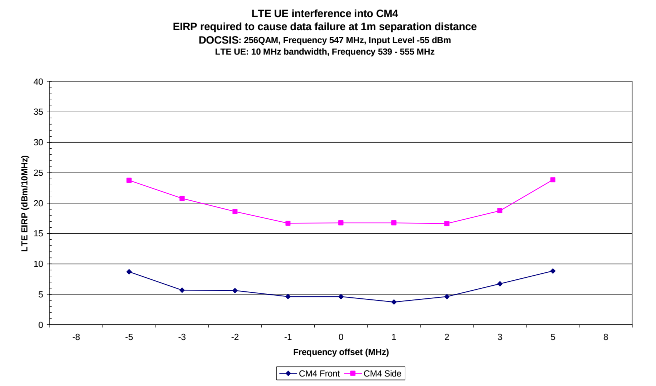
b) Field Strength at CM at Data Failure Point



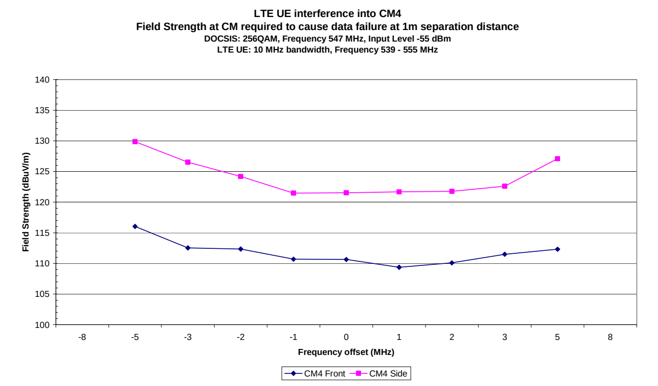
c) Carrier-to-Interference Protection Ratio

Figure 44: Detailed Results for CM 3

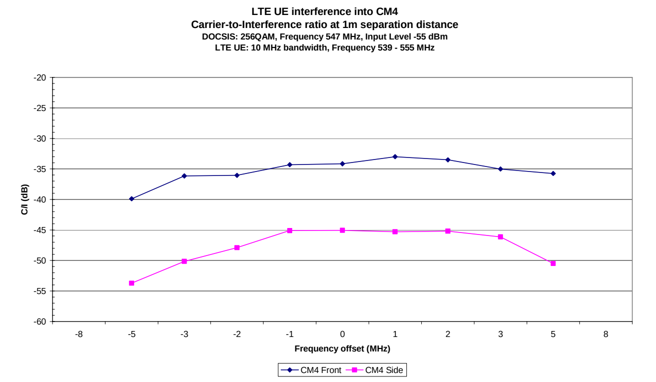
B.4. Cable Modem 4



a) LTE EIRP at Data Failure Point



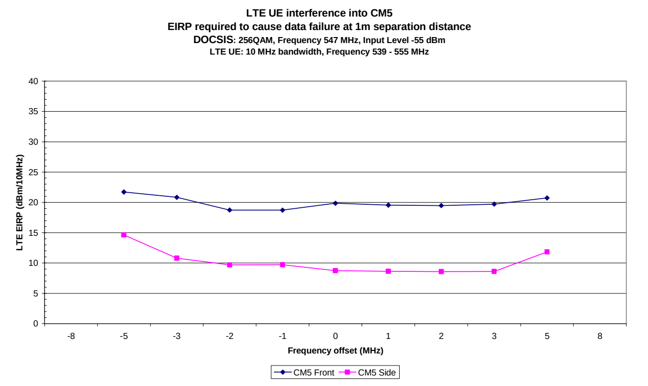
b) Field Strength at CM at Data Failure Point



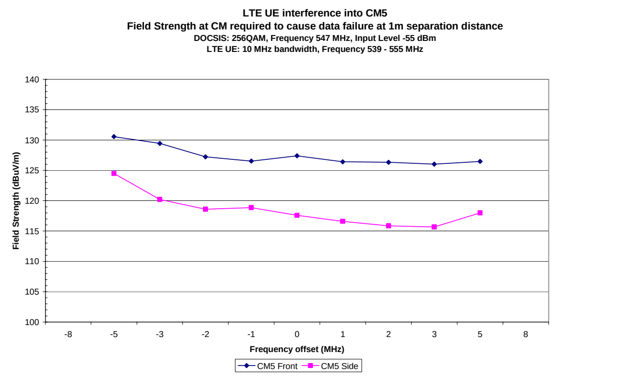
c) Carrier-to-Interference Protection Ratio

Figure 45: Detailed Results for CM 4

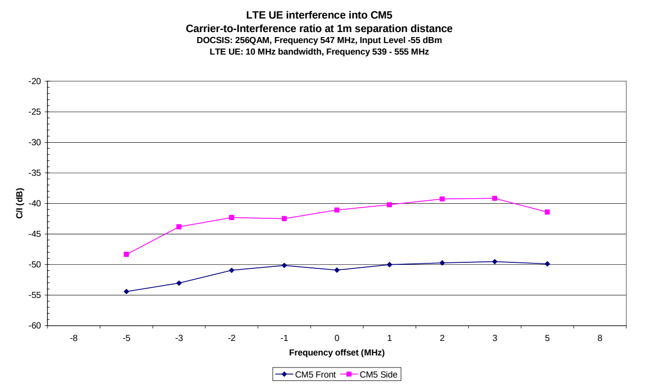
B.5. Cable Modem 5



a) LTE EIRP at Data Failure Point



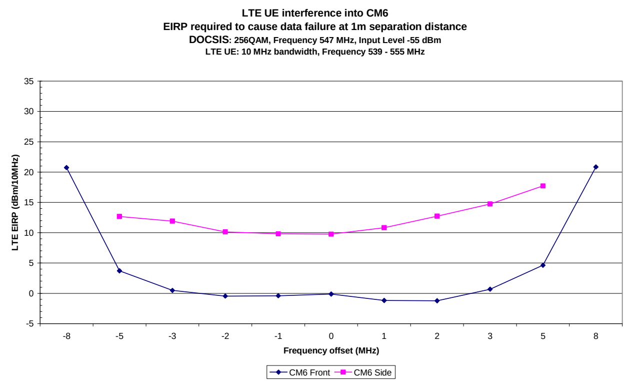
b) Field Strength at CM at Data Failure Point



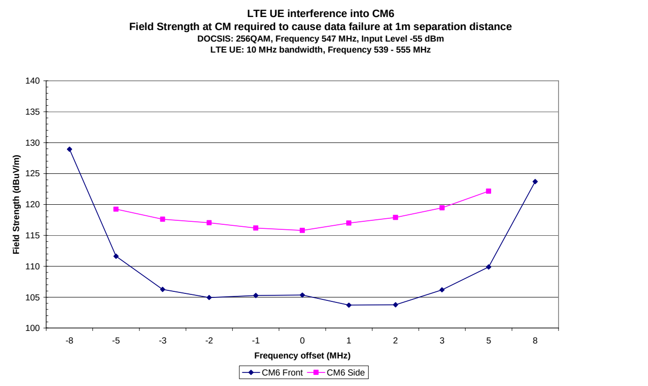
c) Carrier-to-Interference Protection Ratio

Figure 46: Detailed Results for CM 5

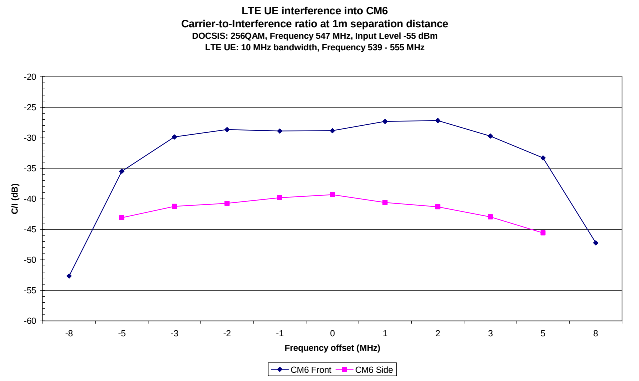
B.6. Cable Modem 6



a) LTE EIRP at Data Failure Point



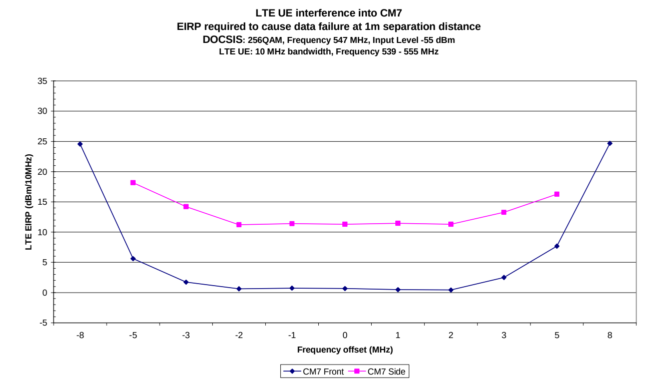
b) Field Strength at CM at Data Failure Point



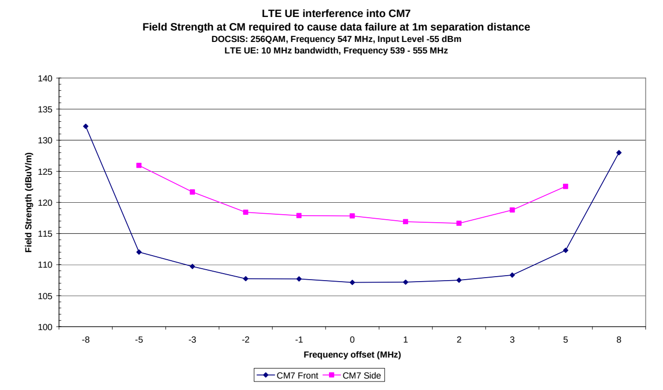
c) Carrier-to-Interference Protection Ratio

Figure 47: Detailed Results for CM 6

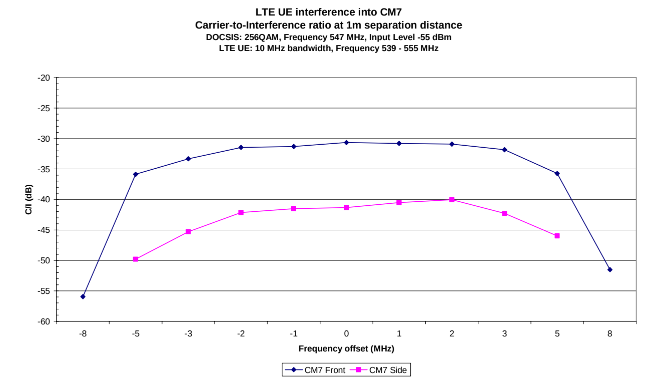
B.7. Cable Modem 7



a) LTE EIRP at Data Failure Point



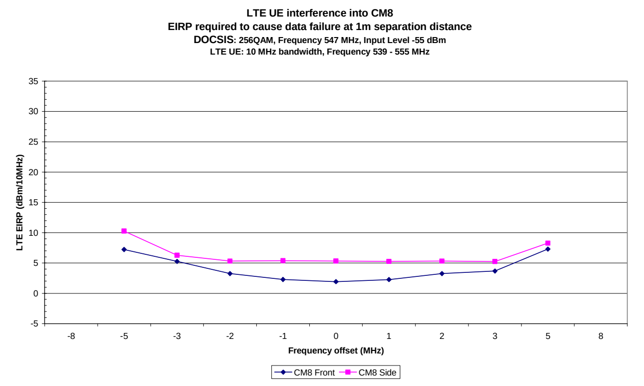
b) Field Strength at CM at Data Failure Point



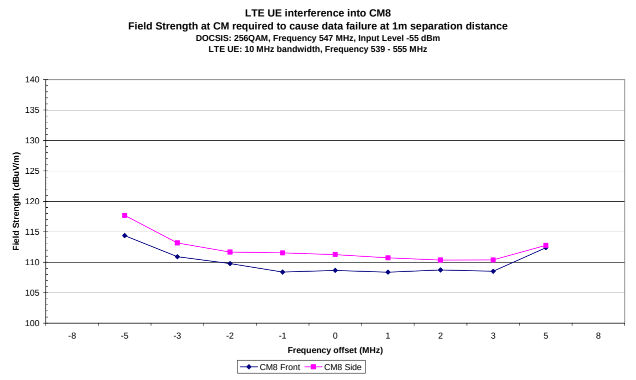
c) Carrier-to-Interference Protection Ratio

Figure 48: Detailed Results for CM 7

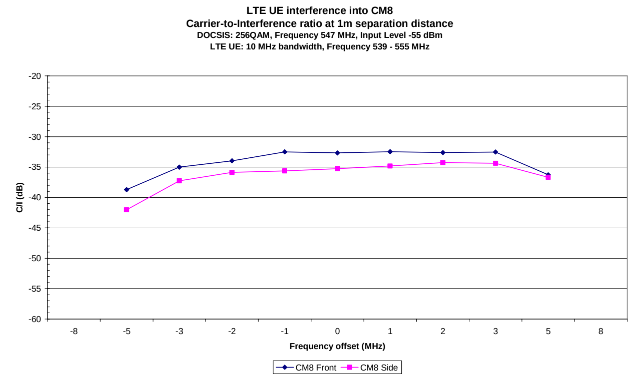
B.8. Cable Modem 8



a) LTE EIRP at Data Failure Point



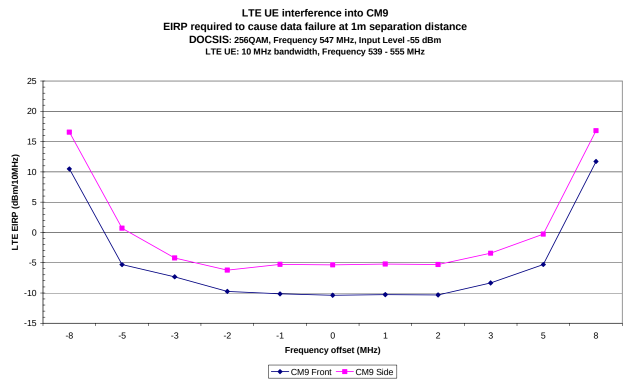
b) Field Strength at CM at Data Failure Point



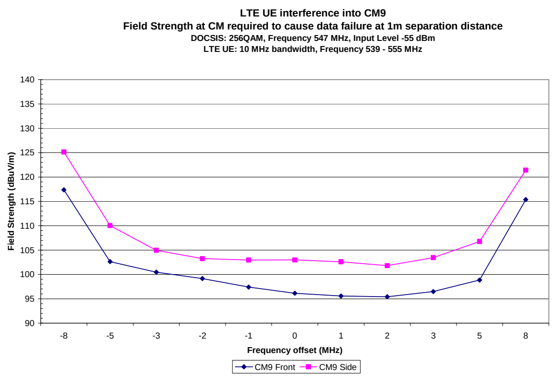
c) Carrier-to-Interference Protection Ratio

Figure 49: Detailed Results for CM 8

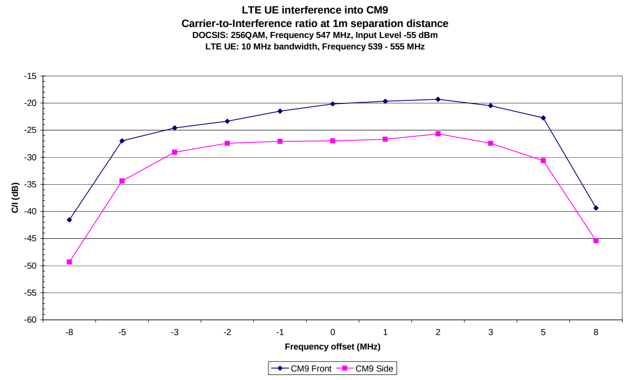
B.9. Cable Modem 9



a) LTE EIRP at Data Failure Point



b) Field Strength at CM at Data Failure Point



c) Carrier-to-Interference Protection Ratio

Figure 50: Detailed Results for CM 9

B.10. Cable Modem 10

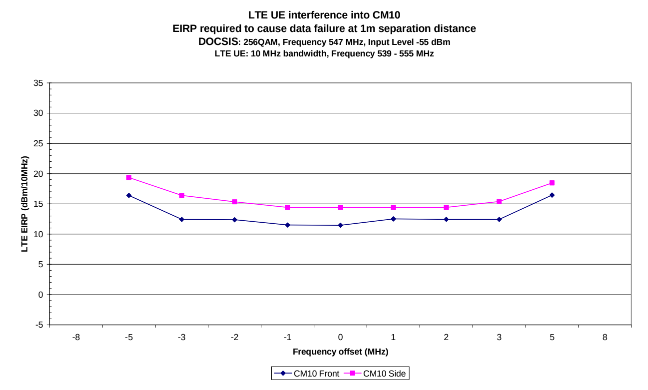
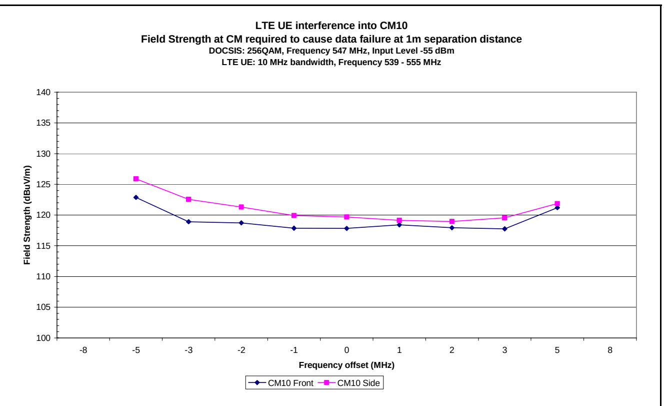
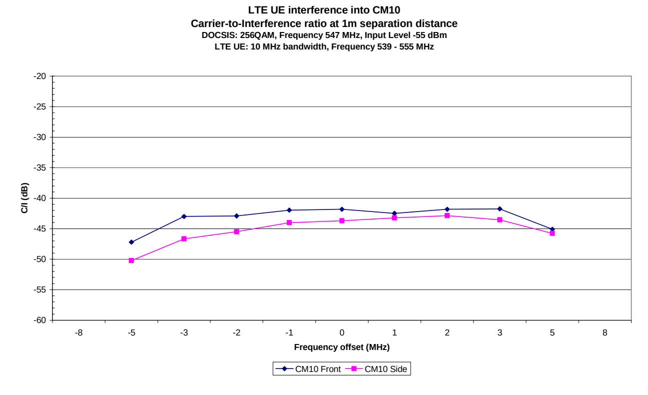
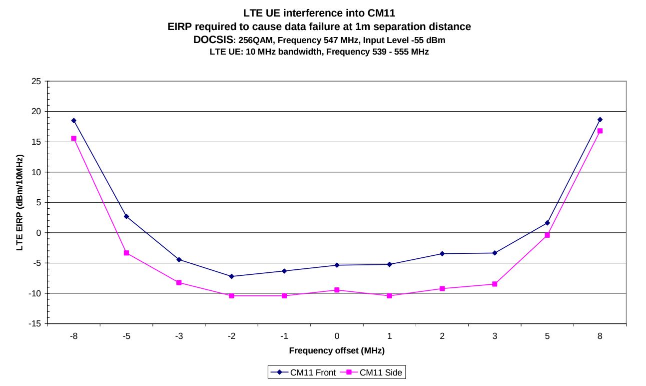
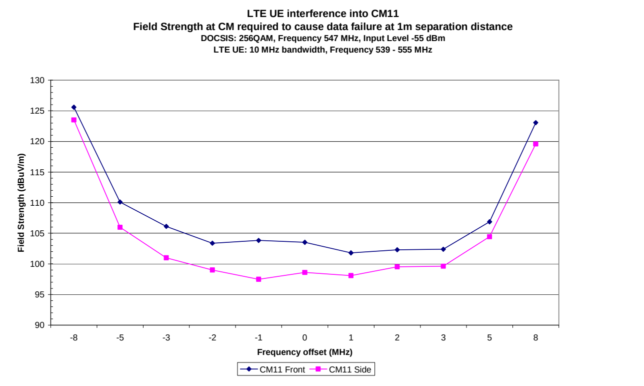
	
a) LTE EIRP at Data Failure Point	**b) Field Strength at CM at Data Failure Point**
	
c) Carrier-to-Interference Protection Ratio	

Figure 51: Detailed Results for CM 10

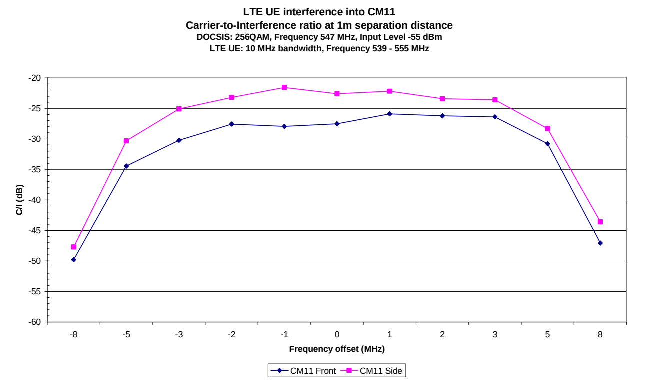
B.11. Cable Modem 11



a) LTE EIRP at Data Failure Point



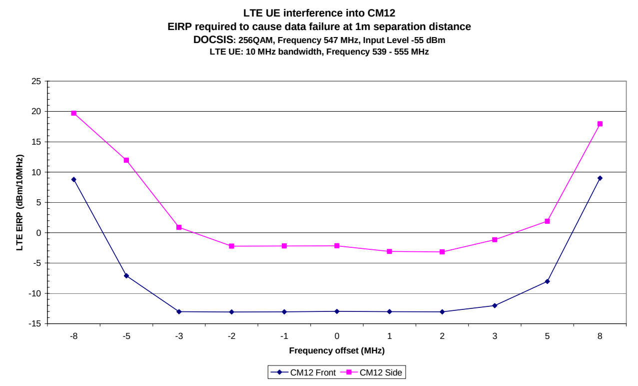
b) Field Strength at CM at Data Failure Point



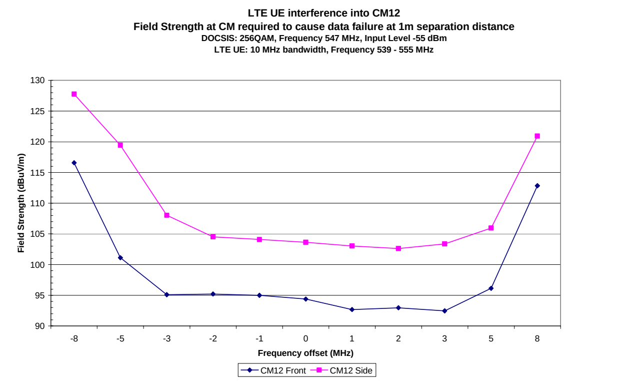
c) Carrier-to-Interference Protection Ratio

Figure 52: Detailed Results for CM 11

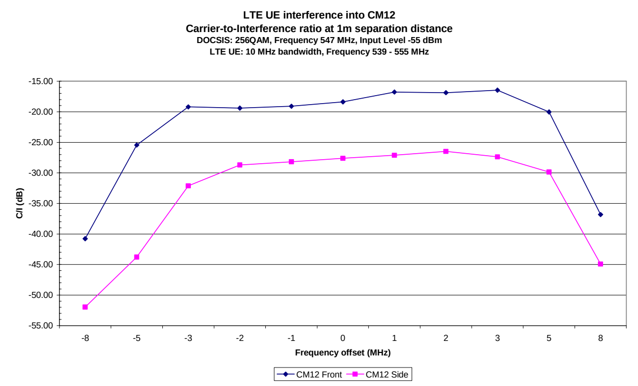
B.12. Cable Modem 12



a) LTE EIRP at Data Failure Point



b) Field Strength at CM at Data Failure Point



c) Carrier-to-Interference Protection Ratio

Figure 53: Detailed Results for CM 12

Appendix C
Electromagnetic Design of Set Top Box and Cable Modems

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C.1. Introduction

In this appendix, five Set Top Boxes and five Cable Modems were reviewed with respect to their electromagnetic (EMC) design, to determine potential weaknesses in the designs and to recommend any design improvements. The design of the RF sections and the PCB cannot be assessed from a visual assessment, most of the tracking being on internal PCB layers.

In the following sections, reference to "finger stock" relates to a method of improving the contact between two metal sections to optimise screening by using shaped spring metal sections on one surface. "Slots" and "apertures" are generally rectangular holes in the metalwork, that may be covered by plastic for specific connectors (not grids of small cooling holes) that allow unwanted frequencies to pass through which may then couple to sensitive circuitry.

C.2. Electromagnetic Design of Set Top Boxes

The five STBs reviewed were identified as 1, 5, 6, 8 and 9. The boxes were similar however STBs 1 and 8 did not contain recordable disk drive units. STBs 6 and 9 were identical from a visual internal inspection.

The EMC design approach applied to all of the units was to provide a screened metal compartment, with the front panel being plastic and containing the user controls. All electrical interfaces for power, RF input and output and data were mounted on the back panel. Smart card reader slots were located either on the front or the rear panels.

C.2.1. STB 6

The base, front and the two sides are formed from a single metal sheet; the right side has a slot for access to the DVD but is closed off with a metal plate bolted to the primary structure with eight bolts. There is a slot in the front panel for the ribbon cable to pass through to the controls (60 x 15 mm) with a smaller slot (10 x 35 mm) that has no purpose. The rear metal section is keyed in and bolted to the primary structure with the connectors mounted between the PCB and the rear panel. The input RF connector is solidly bolted to the rear panel which in turn is in contact with the internal RF screened box containing the demodulator. USB, Ethernet, HDMI and SATA connectors have RF fingers to provide earthing to the panel, the TV and Antenna plate has one screw securing it to the panel and providing an earth reference. The SCART connectors although bolted to the rear panel still present a slot, as does the power connector (20 x 20 mm). All metal parts are bonded together through the unpainted inner surfaces. There is RF finger stock fabricated around all four sides to ensure that the lid section makes good metal to metal contact. The outer of the unit is painted black and is non conductive.

There is a single PCB at the base of the unit containing all the RF and data processing electronics with a power supply unit mounted on the left hand side.

The basic design of the screened box is reasonable, but is limited by the slots produced by the various connections such as the SCART connectors and the card reader slot at the rear and the ribbon cable at the front panel.

C.2.2. STB 9

This unit was internally identical to STB 6, with identical slots and screening applied. The only difference was that the outer surfaces were painted silver.

The design of this STB should result in similar performance to STB 6

C.2.3. STB 1

The basic construction of this unit was similar to STB 6 but with the rear panel integral with the base. There was however no finger stock fabricated around the lid hence contact to the lid was limited to a 2 mm wide bent metal section. Connectors were bonded to the rear panel except for the TV/Antenna connectors. The SCART connectors appeared to have better bonding to the panel but still left a slot.

There was a single PCB for processing with a power supply on the left hand side. The power interface cables ran diagonally across the main PCB which is not good practice. It was noted that there were a number of cans on the PCB but without lids. The RF demodulator interface box contained the RF coaxial input bolted to the rear panel and also contained the TV output and antenna connections into the same RF box, which might impact on the isolation achieved. The RF box connections to the PCB were 8 mm long which may impact on performance.

The screening design was not ideal due to the very small area of peripheral contact between the lid and the base with no guarantee that significant peripheral contact could be made. The RF box which contains both the cable input and the TV output may compromise the performance. Other slots may also compromise the performance as for other STBs.

C.2.4. STB 5

The base and the four sides were fabricated from a single metal sheet. The two sides contained 15 x 15 mm holes with 10 mm metal wall between the holes. The side sections were only approximately 60% of the side height resulting in no contact to the lid at the sides. The lid overlap at the sides covered the gaps, but the degree of continuous contact between base and lid was probably poor. There were a number of large slots on the front panel (70 x 25 and two off 100 x 10 mm). For the rear connector panel, connectors were mounted in a similar manner to other STBs. The lid contact was enhanced at the rear with finger stock along 60% of the rear panel and one RF finger at each corner so that the lid contacted the side panel.

The screening design of this STB was considered to be poor, with contact guarantee being limited.

C.2.5. STB 8

A similar screening design has been applied, with all four sides making some undefined contact to the lid because no finger stock mating facilities are provided. It was observed that the silver painting applied to the outside had also been applied to the inside of the lid where it contacts the front of the box clean metal. Connectors were provided with some contacts or bolts to the rear panel, however slots still exist.

The RF section has two boxes, connected by a miniature coaxial cable earthed to the boxes at both ends. The second box has a sandwich RF gasket to provide earth contact to the lid. The second screened box has a section at the end that is not within the screened section of the can.

The screening on this unit is compromised due to a painted surface and as a result of lid contact that cannot be guaranteed.

C.2.6. STB Summary

The basic design of the five units was similar. STBs 6 and 9 were identical in design using good bonding to provide a faraday cage around the electronics. The other three units, although following a similar approach, were not considered to be likely to achieve such good contact between the lid and the base impacting on the screening efficiency.

There were significant slots on all of the units, particularly at the front panel for the ribbon cable for the controls. In some instances there were slots which served no purpose. The rear panel on all units presented some slots where plastic power connectors and other connectors were mounted. Ethernet and USB connectors generally had contact fingers to provide bonding. SCART connectors, although bonded by one or two screws, still left slots where RF could couple in. The RF signal interface in all cases was bonded to the chassis with the RF circuits in a screening can mounted on the PCB.

Overall the design of STB 1 was considered to be the poorest.

Design improvements to the case screening could be completed; however, the holes and slots for connectors and cables would be the limiting factor to any further improvement. Further investigation into the sensitive circuits and the coupling paths should be carried out to identify where design improvements would be positive

C.3. Electromagnetic Design of Cable Modems

The design of five units was reviewed. Four of the units were similar, being identified as CMs 1, 3, 11 and 12. CM 10 combined an RF router.

C.3.1. CM 12

This was physically the smallest unit. It was manufactured in plastic with RF coaxial connector mounted directly on the PCB. The coaxial connector was an 8 mm cube with the earth connected to the PCB at four corners. There was no RF modulator/demodulator box. The modem components were mounted adjacent to the connector on the PCB with no screening cans. The only other electrical interfaces were the DC power and the Ethernet connector which were both plastic and connected to the PCB.

There was no screening design applied to this unit to protect the front end.

C.3.2. CM 11

This CM was built into a plastic box with all interfaces directly to the PCB. The RF interface connected into an input block 15 x 30 x 10 mm with six connections to the PCB earth plane. There was an additional screened can adjacent to the input can approximately 40 x 30 x 2 mm; this can was not continuous and the end adjacent to the RF block was open. There were very few connections to the earth plane.

The design provides front end protection for the modulator/demodulator circuits through screening; however the open ended screening can was not ideal.

C.3.3. CM 3

Although of plastic construction, the connector interface panel at the rear contained a metal plate where the RF connector is bolted and the Ethernet connector has metal contact. The USB connector metal surround was not connected to the metal plate. The RF connector has an integral modulator/demodulator metal can which is connected at the corners to the PCB ground plane. There is an additional screening can on the PCB.

Care has been exercised in the earthing and the screening of sensitive circuitry.

C.3.4. CM 10

This unit is the more complex because of the radio router interface. The radio section is remote from the RF input stage, however the radio router coaxial feeder to one of the printed internal antennas does run above the RF screening can containing the front end processing circuits. The modem construction was a plastic box with the RF section mounted on the PCB and connected to the ground plane.

C.3.5. CM 1

This was the larger of the CMs and was earlier technology based on the discrete components. There was a metal end plate with the RF input connected to it and to the Ethernet connector in contact through finger stock. The end plate was formed as an L-section to partly cover the base. The inside of the plastic unit had been conductively coated and the case was designed to ensure that there was conductive contact between the sides of the unit.

C.3.6. CM Summary

CM 12 was considered from an inspection to have the poorest design based on the plastic case and the RF modulation/demodulation circuitry built on the PCB with no additional screening. CM 1 was assessed to have the best design, with the RF circuit in a can and with the box having a conductive coating on the inside to provide a faraday cage. The remaining three were all similar using plastic boxes, the design order of preference being CM 3, CM 10 and CM 11.

Design improvements are limited to conductive coating of the boxes to provide a faraday screen with associated bonding of interface RF and data connectors to the faraday screen. Where RF circuits are not screened improvements should be possible with screening cans. PCB routing, track lengths and decoupling cannot be assessed but is an area where performance improvements may be possible, although this is a complex route with unknown gains.