Commission for
Communications Regulation

LTE Filter Testing

Analysis of the Effectiveness of Currently Available LTE Filters at Reducing and Eliminating RF Overload in Masthead Amplifiers in the Presence of LTE Signals

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Content

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1 Executive Summary

Long-Term Evolution (LTE) is a new mobile high-speed data technology. It is envisaged that services based upon LTE technology will come online in Ireland in early 2013 and that such services will operate in the radio spectrum from 790 MHz to 862 MHz ('800 MHz Band'). The 800 MHz band is currently used for transmission of analogue television signals but will no longer be used for that purpose following 'Analogue Switch-Off', which is set to occur on 24 October 2012[1].

Households that use legacy wideband roof-top aerials fitted with masthead amplifiers could experience disruption to their television reception following the introduction of services based upon LTE technology, due to a phenomenon known as Radio Frequency (RF) overload.

A survey by ComReg indicates that a sizable number of domestic television reception systems currently in use in the State are at *high risk* of susceptibility to RF overload once services based on LTE technology are rolled-out. Some such systems could experience partial or total loss of received DTT services due to RF overload. However, the problem is easily overcome through the use of appropriate LTE filters which are used to reduce and eliminate RF overload in masthead amplifiers.

This document sets out the results of testing of a representative sample of LTE filters currently available. All testing included worst-case scenarios and test results show that use of an LTE filter offers a significant increase in resilience against RF overload caused by an LTE signal.

ComReg considers that in the vast majority of domestic television reception systems there is no requirement for masthead amplifiers to be installed. In the few situations where a masthead amplifier is required, it should always be used in conjunction with appropriate filtering. For domestic television reception systems that currently have masthead amplifiers installed, consideration should be given to removing the amplifier. If this is not possible, LTE filters may have to be installed should RF overload occur, once services based on LTE technology have been rolled-out. A filter can also be fitted as a precautionary measure against any future possibility of RF overload.

[1] 'Minister Rabbitte announces date for digital TV Switchover' – DCENR, 14 October 2011

2 Introduction

Following Analogue Switch-Off (ASO) in Ireland, on 24 October 2012, off-air reception of free-to-air terrestrial television will be by means of Digital Terrestrial Television (DTT). DTT uses spectrum more efficiently than analogue broadcast transmission. This means that following ASO spectrum which had been required for analogue television transmission will become available for other electronic communications services, such as those based on LTE technology.

In ComReg document 11/60a, Section 10, ComReg identified the possibility of the degradation of reception of DTT once services based on LTE technology are rolled-out due to a phenomenon known as Radio Frequency (RF) overload. ComReg expressed its view that RF overload issues would be best addressed by appropriate use of antennas and filtering at the receiver[2]. RF overload generally occurs in systems that have high gain characteristics such as antenna gain and/or amplification.

Where LTE technology is operated in bands adjacent to the DTT bands, LTE signals may be considered high-powered, relative to a DTT signal and so they can cause RF overload of a domestic DTT television reception systems. In domestic DTT television reception systems, RF overload typically occurs in the masthead amplifier used to boost the lower level DTT signal. This can lead to disruption to or loss of the DTT signal (see Figures C-4 and C-5, in Appendix C, for an example of the type of disruption that may result from RF overload)

Masthead amplifiers have typically been used in geographic regions where the sought after television signals, such as those of UK terrestrial television channels, are too weak to be received otherwise. However, and importantly, masthead amplifiers are *not required* to receive Irish digital terrestrial television channels in most parts of the State. ComReg recommends that masthead amplifiers are not used unless absolutely necessary, especially as they are prone to experiencing RF overload.

In some instances, masthead amplifiers are installed for the purposes of boosting received signals for distribution to more than one television within a home. ComReg recommends against this practice and suggests a better alternative is to use a distribution amplifier with appropriate filtering, in order to prevent RF overload to the domestic television reception system.

[2] 'Response to Consultation and Draft Decision on Multi-band Spectrum Release' – 11/60, 24/08/2011

RF overload of masthead amplifiers, leading to disruption or loss to television reception, can occur in areas where significantly strong radio frequency signals, other than DTT, exist. RF overload has occurred previously throughout the State, caused by various signals outside the operational frequency range of masthead amplifiers that are typically used in domestic television reception systems. However, as many of the masthead amplifiers currently in use do not have the required frequency selectivity or filtering to reject signals in adjacent bands, such as bands where LTE technology is being used, ComReg is of the opinion that incidents of RF overload will increase following ASO and the subsequent introduction of LTE technology. However, there is a means of countering RF overload of masthead amplifiers caused by LTE, by means of LTE filters.

In the UK, testing has been carried out to establish the effectiveness of LTE filters[3].

As indicated in ComReg document 11/60A, RF overload due to the presence of LTE signals is of concern. ComReg tested a representative, but not exhaustive, sample of LTE filters available on the Irish market, additional to those tested in the UK, to determine their effectiveness in reducing RF overload. Work was also conducted to estimate the extent to which such problems could occur.

The findings of the testing conducted by, and on behalf of, ComReg are broadly similar to those found in the UK.

In cases where a masthead amplifier is considered necessary for television reception and overloading occurs, the use of appropriate filtering, installed between the antenna and the masthead amplifier, will alleviate the problem.

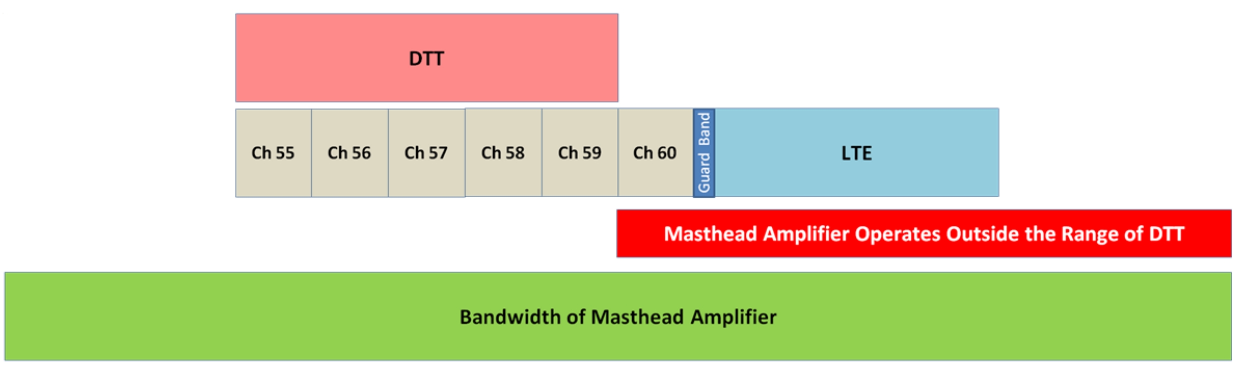

Figure 1 - Illustration of the operating frequency of typical masthead amplifiers operating outside the range of the DTT band.

[3] http://stakeholders.ofcom.org.uk/binaries/consultations/dtt/annexes/Technical-Report.pdf

3 Prevalence of Vulnerable Systems

To determine the prevalence of vulnerable domestic television reception systems, following ASO and the introduction of LTE technology, ComReg conducted a nationwide survey on the extent to which masthead amplifiers are used. The survey focused on urban areas, where the likelihood that of DTT reception systems being close to LTE base stations is at its highest. Visual inspections of DTT reception systems were undertaken and the proportion of households employing masthead amplifiers was identified. Cases where it was not possible to confirm the presence of a masthead amplifier were not included.

An estimate of the proportion of domestic television reception systems that can be considered at *high risk* of RF overload from LTE services was determined. A total of 12,214 domestic television reception systems were surveyed and 59% were found to be using masthead amplifiers. These systems were spread throughout each of the urban areas and not all will be located close to future LTE base stations. The survey was conducted on a nationwide basis and, based on the number of samples taken, it can be considered to be statistically relevant. Please see Appendix B for further information.

The frequency range of masthead amplifiers currently installed includes the adjacent 800 MHz band in which LTE will operate. These devices represent the most likely component to experience RF overload. However, ComReg does not expect that every domestic television reception system included in the figure above will experience future disruption or loss of service due to RF overload. This is because not every domestic television reception system will be close to an LTE base station. ComReg estimates that, in a worst-case scenario, up to 59% domestic television reception systems located in urban areas can be considered at *high risk* of experiencing disruption of television reception due to RF overload.

While ComReg is satisfied that the estimated proportion of domestic television reception systems which are using masthead amplifiers and which are therefore at risk of experiencing RF overload is as stated above, it considers that there are too many variables to accurately predict where and when individual cases of RF overload may occur.

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4 Test Results

4.1 Laboratory Testing

ComReg obtained a number of LTE filters currently available on the market. These were then tested under laboratory conditions in order to assess their suitability to prevent RF overload. The filters used in this testing were as follows[4]:

1. Triax TSBO LTE Filter
2. Johansson 6023 LTE Filter
3. Johansson 6022 LTE Filter

Normalised frequency response profiles for each of these filters can be found in Appendix A.

In the body of the text all equipment used is only referred to in generic terms, i.e. Filter A, Set-Top Box C, Masthead Amplifier B, etc.

All laboratory testing was conducted on ComReg's behalf by Compliance Engineering Ireland Ltd, a test facility accredited to ISO 17020 & 17025[5] by the Irish National Accreditation Board.

4.1.1 Laboratory Test Methodology and Summary

A number of masthead amplifiers, LTE filters and 'Saorview Approved' MPEG4 DVB-T receivers were tested. Testing was designed to identify the receiver and amplifier most susceptible to RF overload. Once identified, this receiver and masthead amplifier combination was then used in the subsequent tests to determine the effectiveness of the LTE filters. This represents the worst case scenario available.

The testing was conducted in three phases:

[4] It should be noted that the filters tested were a representative sample of those available. The list is not exhaustive and does not for example include filters which were tested separately in the UK (see footnote 3)

[5] International standards ISO 17020 & 17025 outline the requirements for the operation of various types of bodies performing inspection and general requirements for the competence of testing and calibration laboratories, respectively.

Phase 1 - Testing of DVB-T receivers to determine which receiver is most susceptible to front-end RF overload in the presence of an LTE signal.

Phase 2 - Testing of masthead amplifiers used in conjunction with the worst performing DVB-T receiver to determine which masthead amplifier is most susceptible to RF overload in the presence of an LTE signal.

Phase 3 - Testing of LTE filters in conjunction with the worst performing receiver and masthead amplifier to determine the effect on system performance in the presence of an LTE signal.

4.1.2 Phase 1 Testing

Each test was conducted using a DVB-T signal (operating on UHF channel 59[6]) at various signal levels, in 10dB steps. The point at which RF overload occurred was determined by varying the LTE signal level (centred on 792.5MHz with 5MHz bandwidth) until picture break-up and/or complete picture loss occurred at the receiver.

[6] UHF Channel 59 is the uppermost UHF channel licensed for use by ComReg for DTT services in the band 470 – 790 MHz in Ireland. According to ComReg documents 11/60, 11/60a, 12/25 and 12/25A, UHF Channel 60 is not being used or planned for use in the first six DTT multiplexes in order to mitigate against any issues that may cause possible SINR degradation to domestic television DTT reception. As such, Channel UHF channel 59 represents the closest channel to the proposed LTE Downlink Bands.

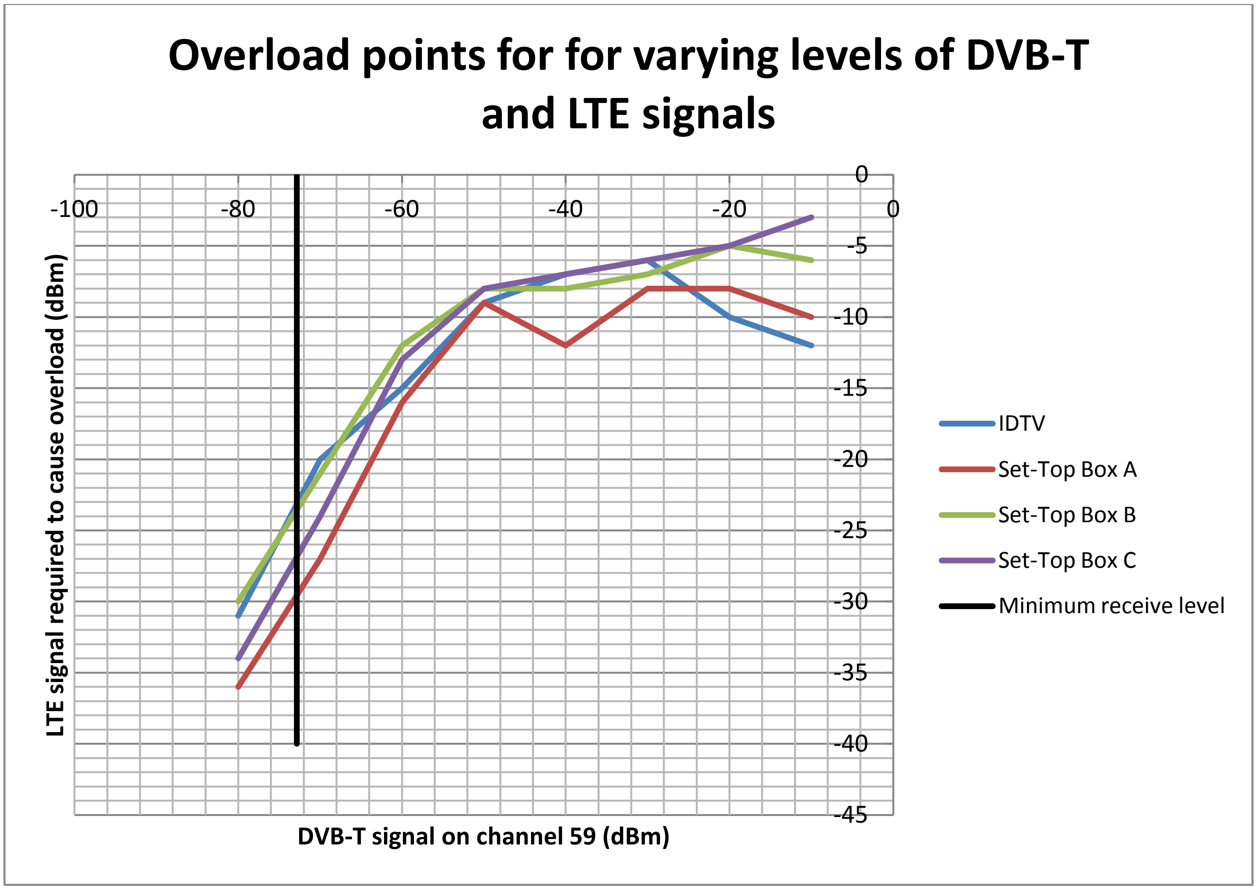

Figure 2 - Performance of DTT receivers

It can be seen from Figure 2 that the Set-Top Box A set-top box was identified as the receiver most susceptible to RF overload under test conditions. Once identified, Phase 2 testing was then conducted using the Set-Top Box A set-top box in conjunction with the various masthead amplifiers acquired.

4.1.3 Phase 2 Testing

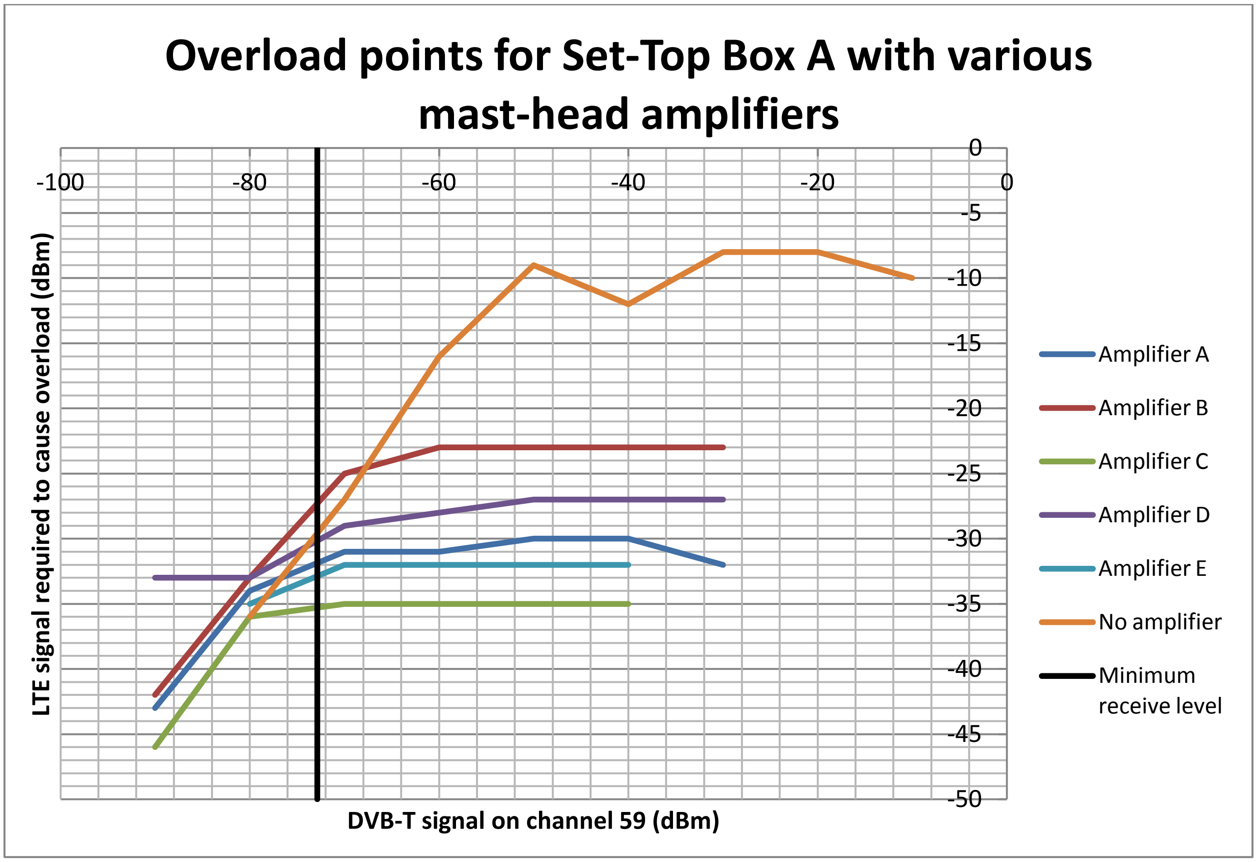

Figure 3 - Performance of Masthead Amplifiers

It can be seen from Figure 3 that Amplifier C was the most susceptible to RF overload. The combination of the Set-Top Box A set-top box and Amplifier C masthead amplifier was then used in Phase 3 testing to assess the performance of the LTE filters.

4.1.4 Phase 3 Testing

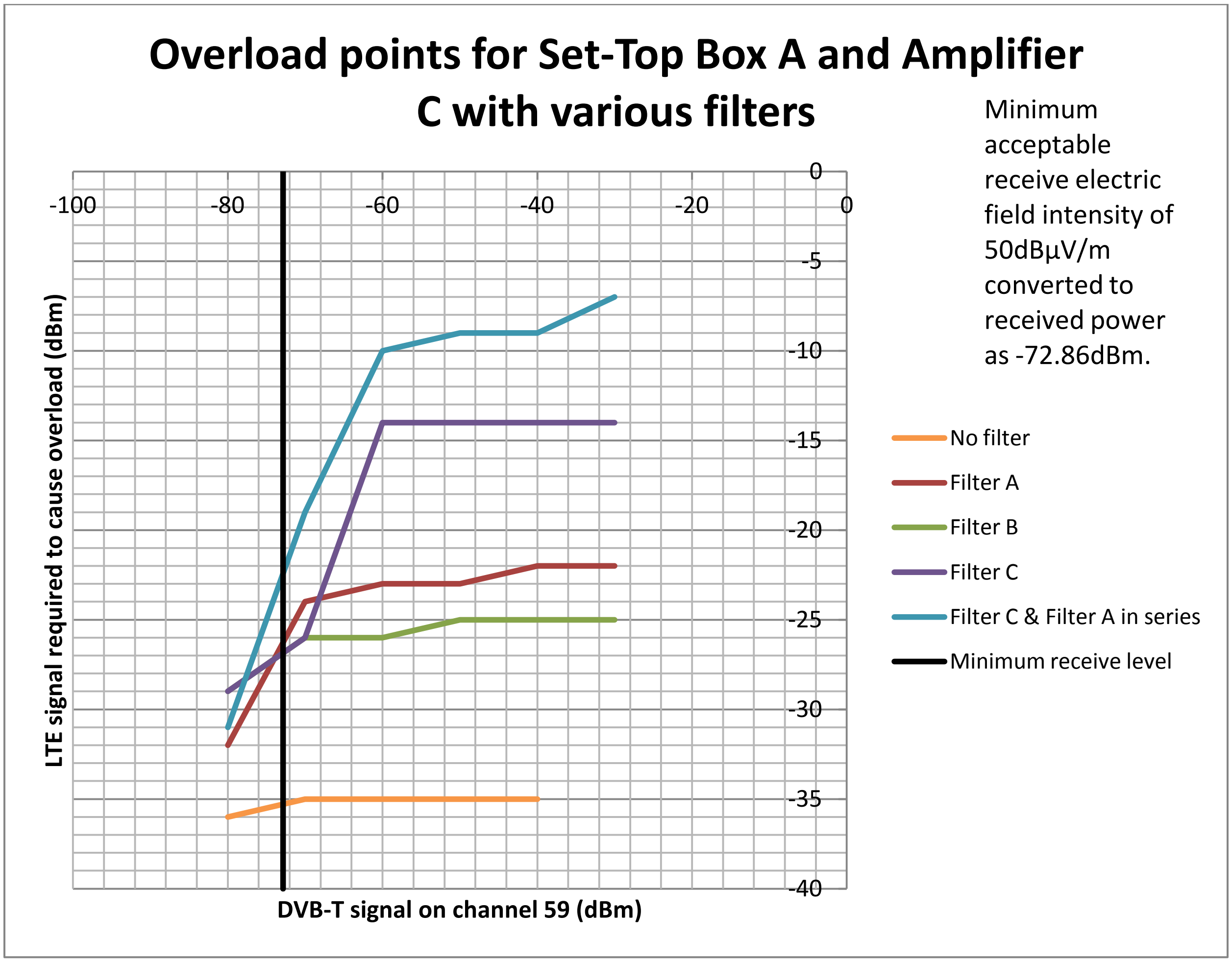

Figure 4 - Performance of DVB-T reception systems using LTE filters

The LTE signal level at which RF overload occurs was then determined with each of the LTE filters introduced to the system. The results outlined in Figure 4 show that all filters offer a significant improvement in performance.

The LTE signal level required to cause RF overload when an LTE filter is used is significantly stronger compared to the worst-case scenario of the Set-Top Box A receiver and Amplifier C masthead amplifier being used *without* an LTE filter.

When the Filter B was used, the LTE signal level needed to be 9dB greater than when no filter was used to cause RF overload. When the Filter A was used, the LTE signal level needed to be 12dB greater than when no filter was used to cause RF overload.

When the Filter C is used, the LTE signal needed to be 21dB greater than when no filter was used to cause RF overload.

For further information on the laboratory testing conducted please see Appendix C.

4.2 Field Testing

In addition to the laboratory testing, outlined in section 4.1, additional tests under 'real-world' conditions were also undertaken. The purpose of this testing was to verify the findings of the laboratory tests that the introduction of appropriate LTE filters will significantly improve the performance of a domestic television reception system under RF overload conditions in the presence of an LTE signal.

It should be noted that while the installation used and results obtained during this testing are broadly representative of the majority of domestic television reception systems considered *high risk* by ComReg there will be slight variances from system to system.

The testing was designed to mimic worst case scenario conditions and the methodology used is outlined in sub-section 4.2.1.

4.2.1 Field Testing Methodology and Summary

A domestic television reception system was selected that is currently used to receive DTT signals from Three Rock Mountain for the testing as it was considered to be broadly representative of the majority of installations currently in use. The system was not installed or modified by ComReg for the purposes of the testing outlined below; the only change made was the introduction of an LTE filter when required during testing.

At the time of testing the highest DTT channel in use in Three Rock was Channel 58.

The selected domestic television reception system is at a distance of 31.8km from the DTT transmitter on Three Rock Mountain and is comprised of a seven element Yagi antenna with a 25dB gain masthead amplifier. The antenna is mounted on an external pole to the rear of the property and the amplifier is situated in the attic of the house.

In order to conduct the required tests an approximation of an LTE base station operating at the maximum permissible EIRP of 59 dBm was erected at distances of 10 metres, 20 metres and 30 metres from the Yagi antenna. The LTE base station consisted of an Anritsu MS2692A Signal Analyser/Vector Signal Generator used with a Schaffner CBA 9433 power amplifier connected to an Alpha Wireless 3141 LTE Base Station Antenna. The LTE base station antenna was placed in-line with the point of the maximum gain of the television antenna. Both antennas were at the same height. As it is highly unlikely that an LTE base station antenna will be located closer than 10 metres to a domestic television reception antenna, no testing was conducted closer than this distance.

Before commencing testing, baseline performance of the television reception system was established. Using the Triax TR112Set-Top Box A ‘Manual Installation’ software menu it was noted that ‘Signal Quality’ was 100% and the ‘Signal Level’ was 90%. This is representative of the system in normal operation.

At the beginning and end of each test the power level of the LTE signal was confirmed using a watt-meter and a Rohde & Schwarz CMS 52 radiocommunications test set.

Figure 5 - Set-Top Box A Setup Menu Under Normal Operating Conditions

4.2.2 Testing at 10 metres

With the introduction of an LTE signal centred on 792.5 MHz, the LTE channel closest to the DTT band, there was complete loss of signal, with ‘Signal Quality and ‘Signal Level’ both at 0%.

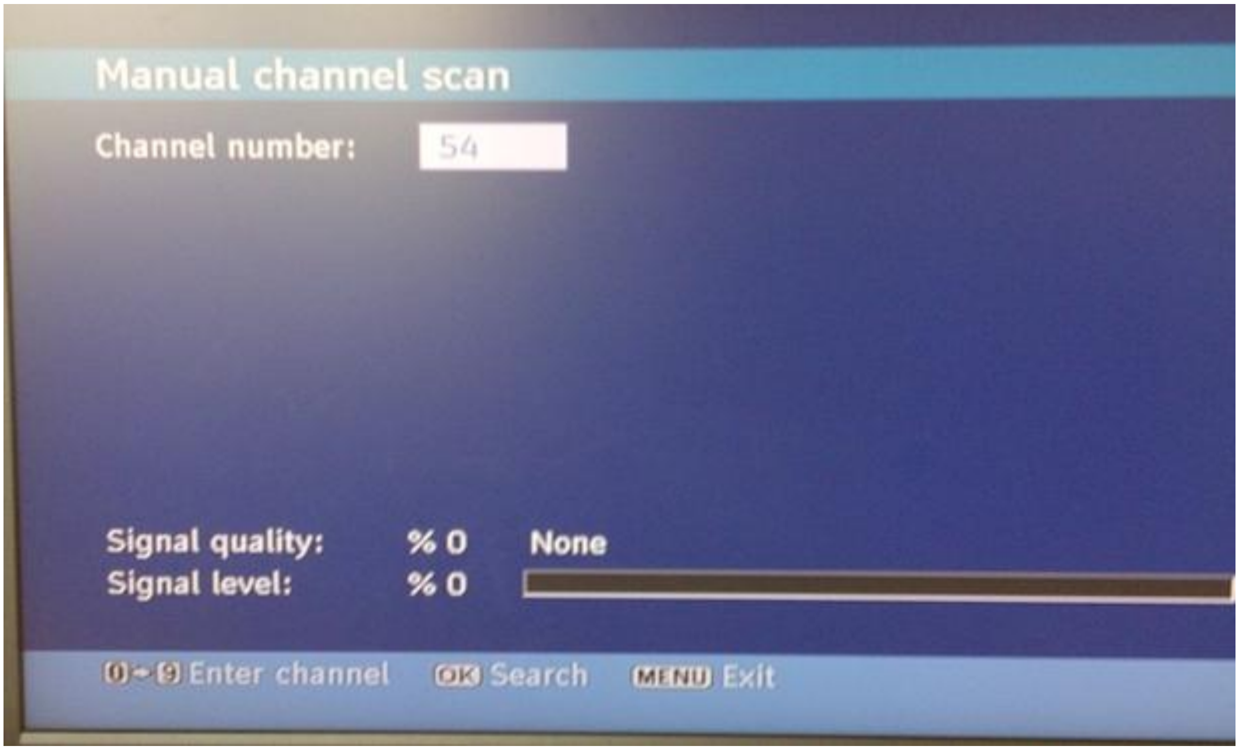

Figure 6 - Set-Top Box A Setup Menu with Masthead Amplifier in RF Overload Conditions

Each LTE filter under test was then used individually to determine its effectiveness. When Filter C was used both ‘Signal Quality’ and ‘Signal Level’ returned to the normal operating state – i.e. ‘Signal Quality’ and ‘Signal Level’ reverted to established baseline levels of approximately 100% and 90%, respectively. The other LTE filters under test did not restore the system to its normal operating state. However, based on the laboratory testing, combining the Filter A and Filter B in series should provide an equivalent attenuation Filter C of 21dB. When the Filter A and Filter B were installed together in series the system was restored to its normal operating state.

4.2.3 Testing at 20 metres

This test was then repeated at a distance of 20 metres. With the LTE signal present and no filter used there was a clear degradation of the receiver 'Signal Quality' and 'Signal Level'. 'Signal Quality' was recorded at 25% and 'Signal Level' was recorded at 91%. Pixelation was evident at all times and there was occasional complete loss of picture and sound. The introduction of each filter individually restored the system to its normal operating state.

4.2.4 Testing at 30 metres

At a distance of 30 metres, with the LTE signal on air and no filter in use, the picture and sound quality were good for the most part but sporadic picture freezing and pixelation was noted. 'Signal Quality' was recorded at 70% and 'Signal Level' was recorded at 92%. The introduction of each LTE filter individually restored the system to its normal operating state.

All instances of RF overload experienced were thus eliminated through the use of appropriate filtering. See Table 1 below for a summary of findings. In all cases (including worst case scenario conditions) it was possible to prevent loss of signal or degradation of quality due to RF overload through the use of appropriate filtering.

Table 1 - Summary of Test Results

Distance	No Filter	Filter C	Filter A	Filter B
10 metres	Complete Loss of Signal Quality	Normal Operation Restored	No Perceivable Improvement	No Perceivable Improvement
20 metres	Partial Loss of Signal Quality – Content Unwatchable	Normal Operation Restored	Normal Operation Restored	Normal Operation Restored
30 metres	Partial Loss of Signal Quality – Content Disrupted but Watchable	Normal Operation Restored	Normal Operation Restored	Normal Operation Restored

5 Conclusion

Based on a survey conducted by ComReg, there are a sizable number of domestic television reception systems currently in use in the State that ComReg believes are at *high risk* of susceptibility to RF overload in the future presence of LTE signals. Once LTE services are rolled-out, such systems could experience partial or total loss of received DTT services due RF overload. However, this problem can be easily overcome through the removal of the masthead amplifier or through the use of appropriate filtering in cases where amplification is necessary.

The vast majority of masthead amplifiers are not sufficiently frequency selective and, therefore, receive signals from adjacent bands. These adjacent-band signals, if of sufficient signal strength, can cause RF overloading. The roll-out of electronic communications service based on LTE technology will make DTT masthead amplifiers more vulnerable to RF overload than is currently the case, as LTE technology will operate in the 800MHz band which is within the frequency range of most, if not all, masthead amplifiers currently in use.

Testing of a representative sample of the LTE filters currently available has demonstrated that they perform as specified by the manufacturer and under laboratory and 'real-world' conditions they have proven capable of eliminating RF overload in masthead amplifiers (though in the more extreme test scenarios, not all of the filters were equally capable of eliminating the RF overload). With the exception of RF overload, no other electromagnetic phenomena capable of disrupting DTT services were noted during any phase of the testing.

It is ComReg's opinion that in the vast majority of domestic television reception systems there is no requirement for masthead amplifiers. In the minority of situations where the use of amplification is required it should always be used in conjunction with appropriate filtering. For domestic television reception systems that currently have masthead amplifiers installed, consideration should be given to removing the amplifier. If this is not possible, LTE filters may need to be installed should RF overload occur once LTE services are rolled-out.

Appendix A - LTE Filter Frequency Response Profiles

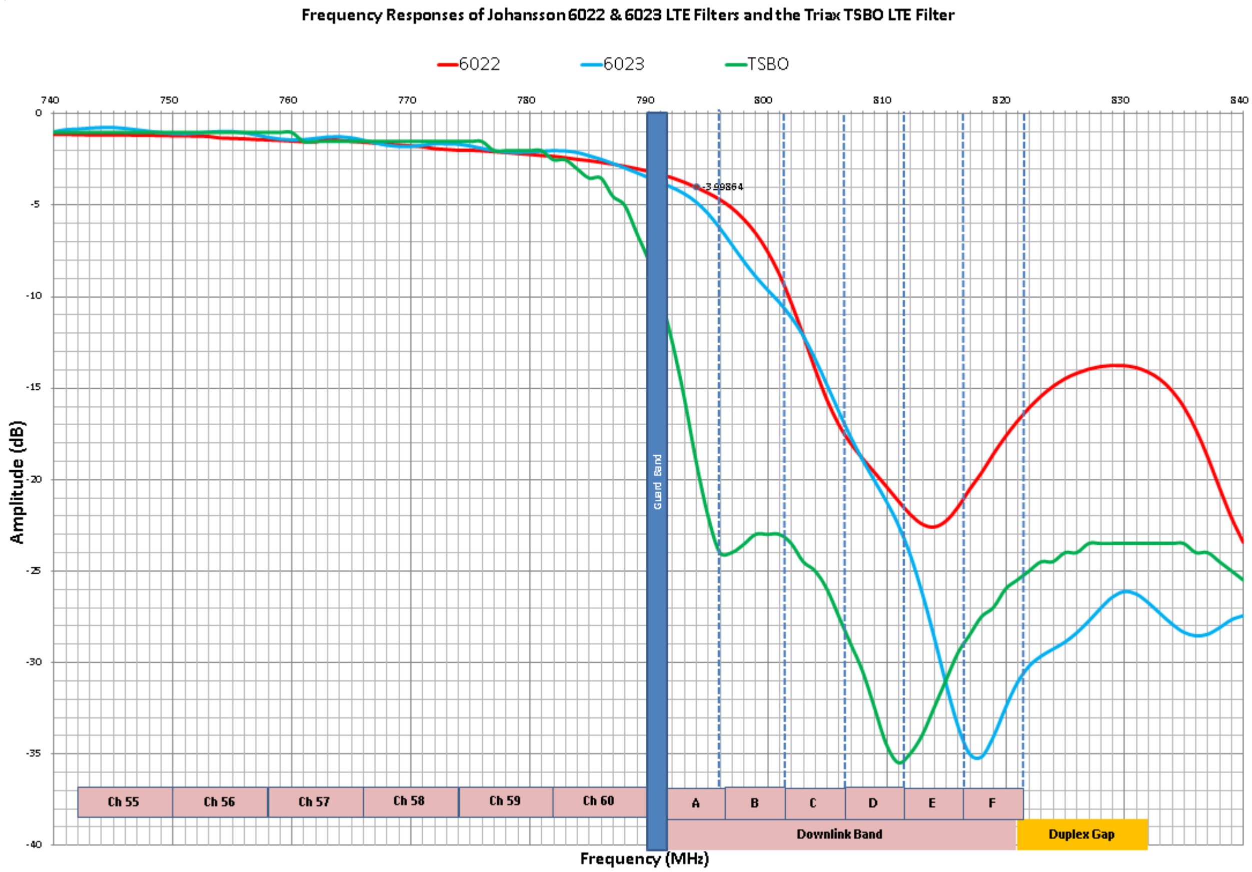

Figure A-1 - Normalised Frequency Responses of Johansson 6022 & 6023 LTE Filters and the Triax TSBO LTE Filter

Appendix B - Statistical Relevance

The survey referred to in section 3 was found to have a Margin of Error of 0.86819% with a confidence level of 95%. Below are the calculations made to determine this value.

The Margin of Error (MoE) with a confidence level of 95%:

$$MoE \cong 0.98\sqrt{\frac{1}{n}} = y$$

For this survey, the MoE is:

$$MoE \cong 0.98\sqrt{\frac{1}{12{,}214}} = 0.88674\%$$

The Finite Population Correction factor is:

$$FPC = \sqrt{\frac{N-n}{N-1}}$$

where:

N is the total population

n is the number of sample taken

The value of N is obtained by adding the total of “Irish Terrestrial” and “Multi Terrestrial” homes (homes which receive Irish channels only, and those which receive both Irish and UK channels, via an aerial or Irish DTT service) given in Figure 5.1.1 of ComReg document 12/62R. This value represents the number of homes in Ireland that are known to have domestic television reception systems that use aerials, which are capable of being used to receive DTT services.

Further data is given in Document 12/62R that accounts for additional homes that have cable or satellite systems installed. However, it is not clear from the figures given whether these additional homes also have domestic television reception systems installed that use aerials that are capable of being used to receive DTT services. As a result, they have been excluded from the population figure, *N*. This has the effect of increasing the margin of error slightly.

For this survey the FPC is:

$$FPC = \sqrt{\frac{295{,}000 - 12{,}214}{295{,}000 - 1}} = 0.97908$$

Including the Finite Population Correction factor, the Margin of Error with a confidence level of 95% for this survey is:

$$MoE = 0.98\sqrt{\frac{1}{n}} \times FPC = 0.88674\% \times 0.97908 = 0.86819\%$$

Appendix C - Laboratory Testing

Equipment Used:

- ProVision MPEG4 DTT Modulator
- Rohde & Schwarz SMB V100A Vector Signal Generator
- Triax TR112 Saorview Approved Set Top Box
- Walker WP12 DTB-4 Saorview Approved Set Top Box
- Digihome Saorview Approved Set Top Box
- Silvercrest DVB-T Compliant Television with integrated DTT tuner
- Wolsey WFAV Masthead Amplifier
- Proception 27dB Gain Masthead Amplifier
- Proception 16dB Gain Masthead Amplifier
- FTE Masthead Amplifier
- Labgear 25dB Gain Masthead Amplifier
- Anritsu MS2726C Spectrum Master (with calibrated directional coupler)

The correct operation of all equipment being used during testing was confirmed prior to the commencement of tests.

Equipment Layout:

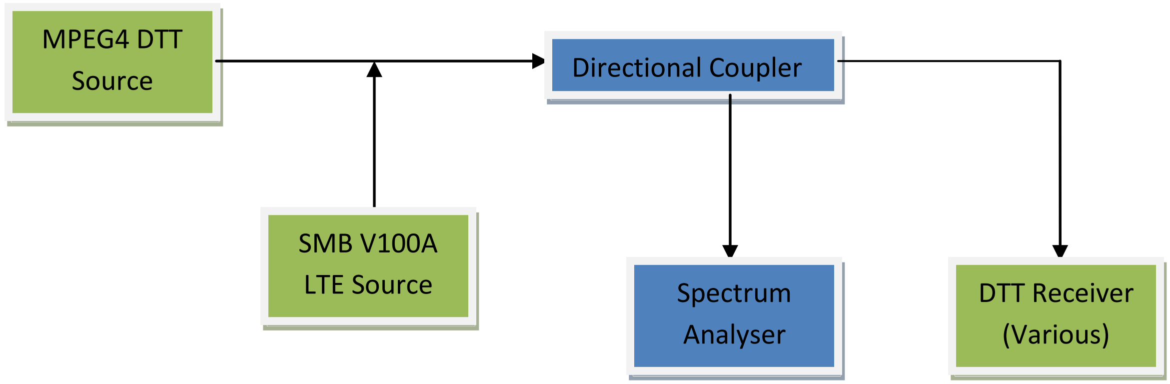

Figure C-1 - Block diagram of the test setup or the purposes of assessing receiver performance. The items highlighted in blue were solely in circuit to ensure levels at the input of the amplifier were correct and played no integral part in the testing.

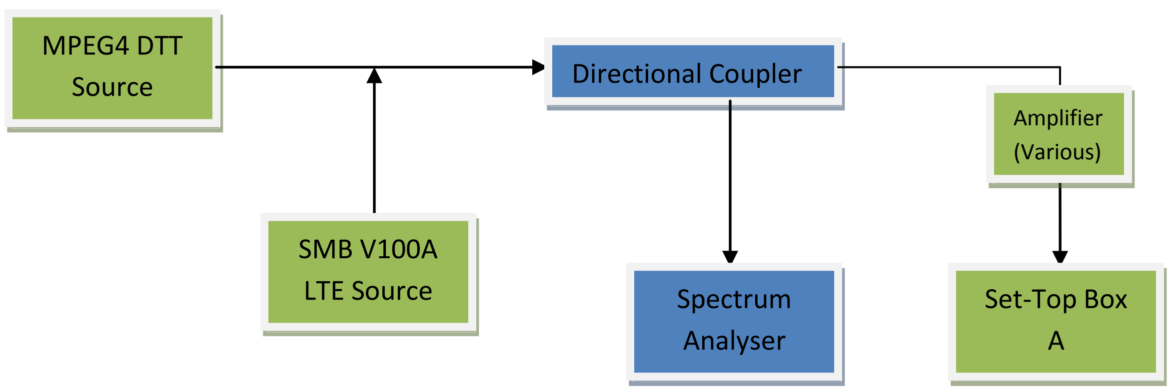

Figure C-2 - Block diagram of the test setup for the purposes of assessing amplifier performance. The items highlighted in blue were solely in circuit to ensure levels at the input of the amplifier were correct and played no integral part in the testing.

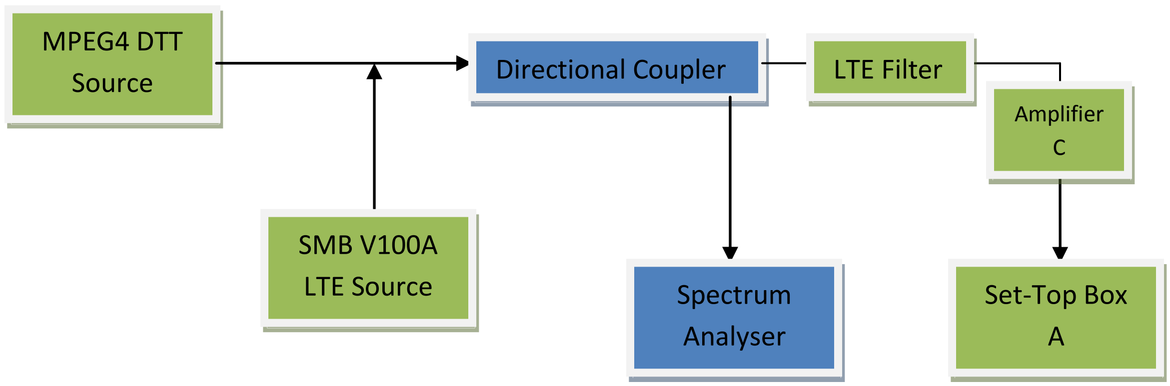

Figure C-3 - Block diagram of the test setup for the purposes of assessing filter performance. The items highlighted in blue were solely in circuit to ensure levels at the input of the amplifier were correct and played no integral part in the testing.

Test Methodology:

Assessment of the performance of the DTT receivers and the masthead amplifiers was conducted to establish the susceptibility of each device to RF overload in the presence of an LTE signal.

To determine the performance of the DTT receivers the test set up shown in Figure C-1 was used. The point at which RF overload of the receiver front-end begins to degrade the quality of the DTT signal was determined as the point at which there was disruption to the picture and/or sound of the content being received. An example of this is shown below in Figure C-4 and Figure C-5.

When the DTT signal was confirmed to be at the required level with stable picture and sound reception on the television, an LTE signal on Downlink Band Channel A was introduced. The amplitude of this signal was gradually increased until disruption of the wanted DTT signal was confirmed visually. See Figure C-5 for example.

This disruption was confirmed to be as a result of RF overload as the introduction of a filter relieved the disturbance to the system. Had the cause of the disruption been due to in-band spurious emissions from the LTE signal, the introduction of a filter to the system would have had no effect.

Figure C-4 - Normal quality reception with no disruption present, this image was captured with no LTE signal present.

Figure C-5 – Disruption to DTT signal as a result of RF overload in the presence of LTE signal.

This test was repeated for all ‘Saorview approved’ receivers and for all amplifiers acquired. As there was a loss of 21dB through the directional coupler, the measured values were corrected as shown in the tables below:

Table 2 - iDTV Receiver

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
-12	-10	-33	-34
-10	-20	-31	-41
-6	-30	-27	-51
-7	-40	-28	-61
-9	-50	-30	-71
-15	-60	-36	-81
-20	-70	-41	-91
-31	-80	-52	-101

Table 3 - Set-Top Box A

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
-10	-10	-31	-31
-8	-20	-29	-41
-8	-30	-29	-51
-12	-40	-33	-61
-9	-50	-30	-71
-16	-60	-37	-81
-27	-70	-48	-91
-36	-80	-57	-101

Table 4 - Set-Top Box B

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
-6	-10	-27	-31
-5	-20	-26	-41
-7	-30	-28	-51
-8	-40	-29	-61
-8	-50	-29	-71
-12	-60	-33	-81
-21	-70	-42	-91
-30	-80	-51	-101

Table 5 Set-Top Box C

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
-3	-10	-24	-31
-5	-20	-26	-41
-6	-30	-27	-51
-7	-40	-28	-61
-8	-50	-29	-71
-13	-60	-34	-81
-24	-70	-45	-91
-34	-80	-55	-101

From the above results it was determined that the Set-Top Box A 'Saorview Approved' Set-Top Box was the device most susceptible to RF overload. This is illustrated in the Figure C-6.

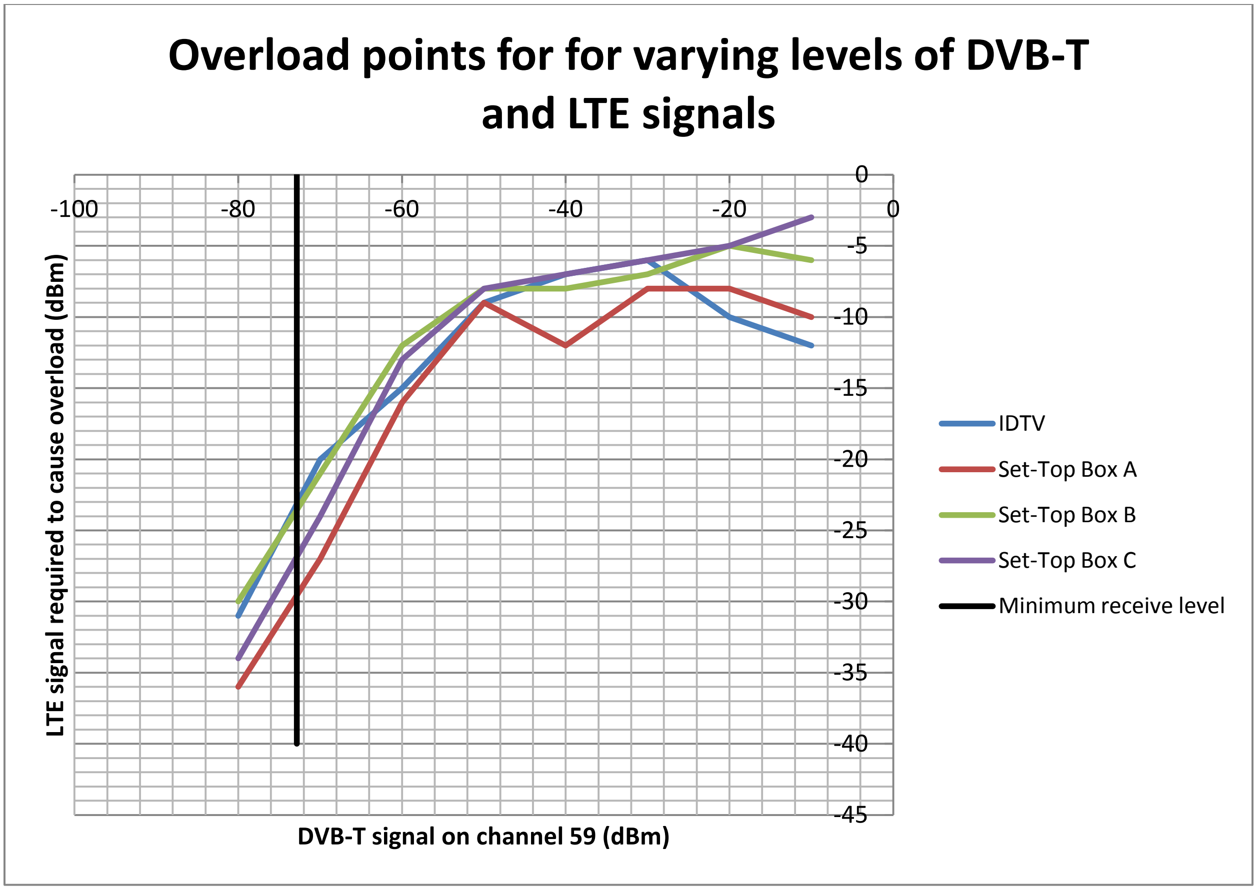

Figure C-6 – Performance of Receivers Graphically Represented

The same test was then completed, using the set top box identified as most susceptible to RF overload, with an amplifier in circuit to determine the worst case scenario conditions. The results obtained were as follows.

Table 6 - Set-Top Box A Receiver with Amplifier A

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-32	-30	-53	-51
-30	-40	-51	-61
-30	-50	-51	-71
-31	-60	-52	-81
-31	-70	-52	-91
-34	-80	-55	-101
-43	-90	-64	-111

Table 7 - Set-Top Box A Receiver with Amplifier B

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-23	-30	-44	-51
-23	-40	-44	-61
-23	-50	-44	-71
-23	-60	-44	-81
-25	-70	-46	-91
-33	-80	-54	-101
-42	-90	-63	-111

Table 8 - Set-Top Box A Receiver with Amplifier C

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
N/A	-30	O/L DTT Only	-51
-35	-40	-56	-61
-35	-50	-56	-71
-35	-60	-56	-81
-35	-70	-56	-91
-36	-80	-57	-101
-46	-90	-67	-111

Table 9 - Set-Top Box A Receiver with Amplifier D

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-27	-30	-48	-51
-27	-40	-48	-61
-27	-50	-48	-71
-28	-60	-49	-81
-29	-70	-50	-91
-33	-80	-54	-101
-33	-90	-54	-111

Table 10 - Set-Top Box A Receiver with Amplifier E

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
N/A	-30	O/L DTT Only	-51
-32	-40	-53	-61
-32	-50	-53	-71
-32	-60	-53	-81
-32	-70	-53	-91
-35	-80	-56	-101

Amplifier C was identified as the device most susceptible to RF overload and was then used with the Set-Top Box A set top box to test the effectiveness of the filters. The combined results have been entered in the following graph for clarity.

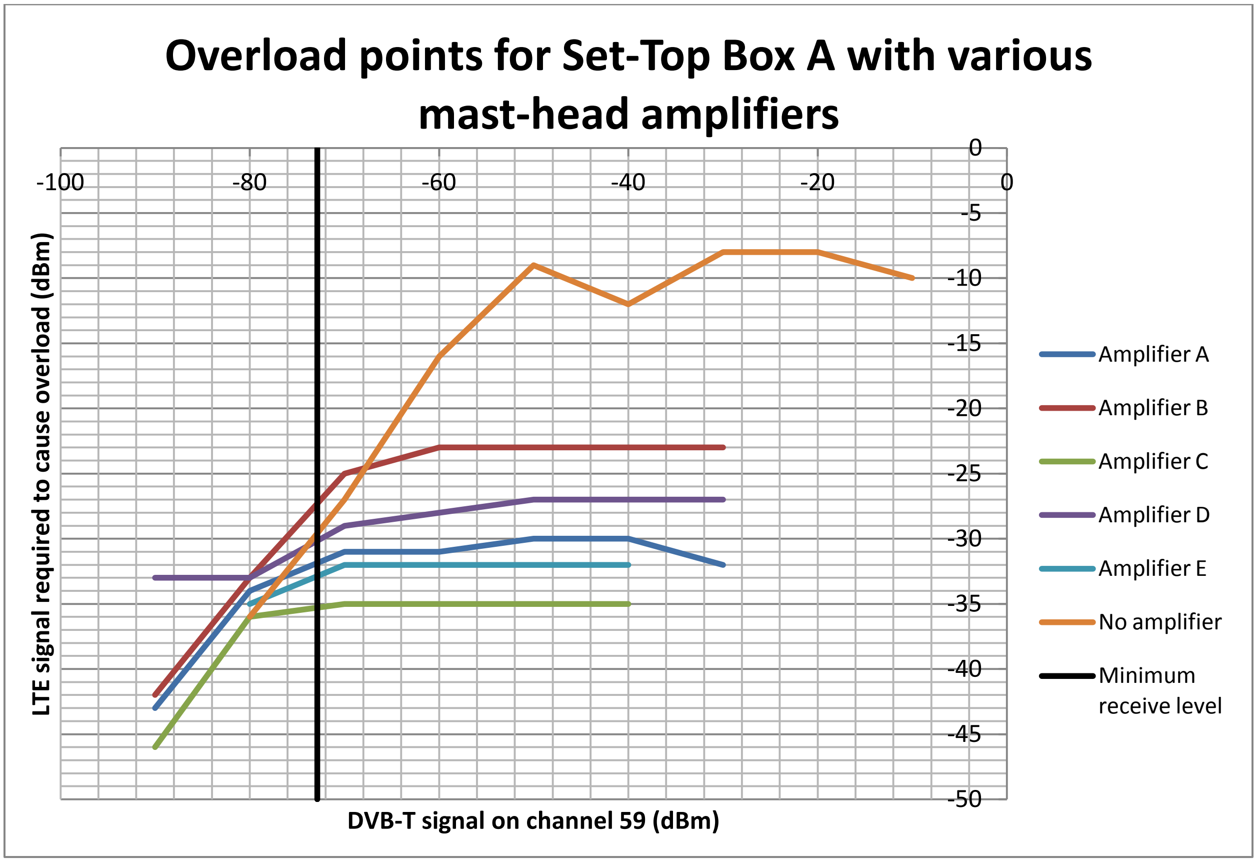

Figure C-7 – Performance of Masthead Amplifiers Graphically Represented

Results:

Having determined the worst case scenario conditions, the equipment was set up as per Figure C-3 above in order to test the effectiveness of the LTE filters under test at preventing RF overload from occurring in the masthead amplifier being used.

This was done in the same manner as before with the DTT signal being confirmed at predefined levels between -110dBm and -10dBm. The LTE signal was then introduced and increased in power until disruption of the received signal was noted. The results obtained are outlined below.

Table 11 - Set-Top Box A with Amplifier C and Filter A

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-22	-30	-43	-51
-22	-40	-43	-61
-23	-50	-44	-71
-23	-60	-44	-81
-24	-70	-45	-91
-32	-80	-53	-101
-38	-88	-59	-109

Table 12 - Set-Top Box A with Amplifier C and Filter B

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-25	-30	-46	-51
-25	-40	-46	-61
-25	-50	-46	-71
-26	-60	-47	-81
-26	-70	-47	-91
-29	-80	-50	-101
-42	-88	-63	-109

Table 13 - Set-Top Box A with Amplifier C and Filter C

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-14	-30	-35	-51
-14	-40	-35	-61
-14	-50	-35	-71
-14	-60	-35	-81
-26	-70	-47	-91
-29	-80	-50	-101
-36	-89	-57	-110

Table 14 - Set-Top Box A with Amplifier C and Filter C & Filter A in series

Corrected LTE (dBm)	Corrected DTT (dBm)	Measured LTE (dBm)	Measured DTT (dBm)
N/A	-10	O/L DTT Only	-31
N/A	-20	O/L DTT Only	-41
-7	-30	-28	-51
-9	-40	-30	-61
-9	-50	-30	-71
-10	-60	-31	-81
-19	-70	-40	-91
-31	-80	-52	-101
-31	-85	-52	-106

It was observed that the amplifiers were being overloaded by the DTT signal only, i.e. without the LTE signal present, for levels of -20dBm and above. In all cases the introduction of an LTE filter offered a significant improvement over the use of a non-filtered amplifier. The results have been combined in Figure C-8 for clarity.

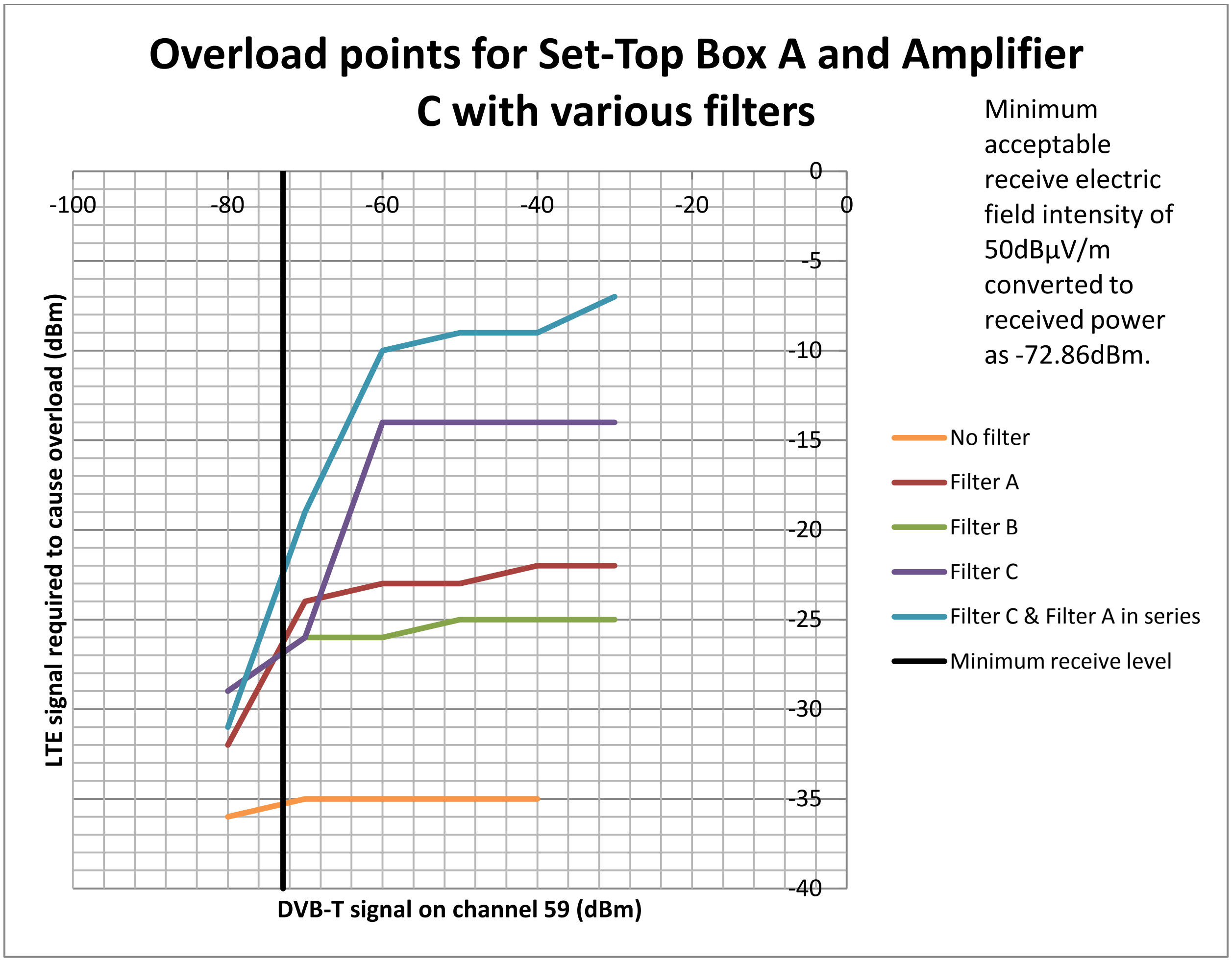

Figure C-8 – Performance of Filters Graphically Represented

Appendix D - Field Testing

Equipment Used:

- Anritsu MS2692A Signal Analyser/Vector Signal Generator
- Schaffner CBA 9433 Power Amplifier
- Alpha Wireless 3141 LTE Base Station Antenna
- Alpha Wireless 3142 LTE Base Station Antenna
- Stella Doradus LTE Base Station Antenna
- Bird Termination Watt Meter
- Rohde & Schwarz SMC 100A Signal Generator
- Rohde & Schwarz CMS 52 Radiocommunications Test Set
- Anritsu MS2726C Spectrum Master
- Rohde & Schwarz PR100 Receiver
- Telescopic Mast

Equipment Layout:

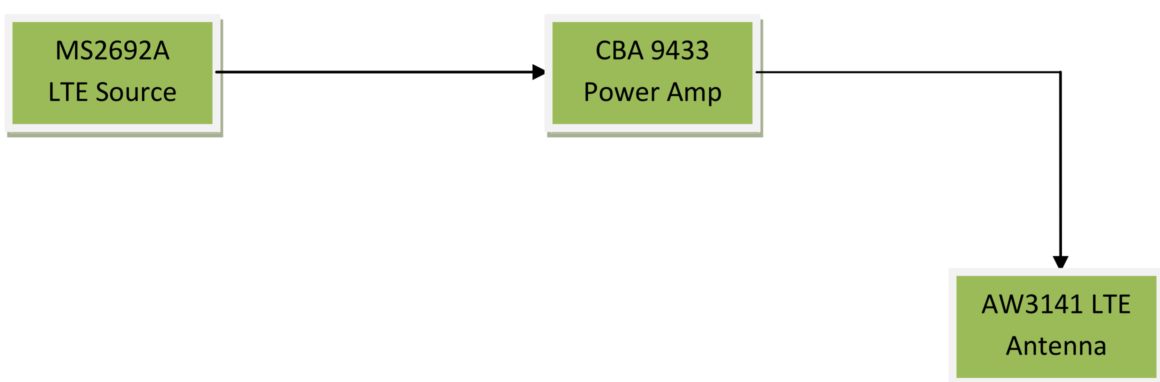

Figure D-1 - Block diagram of the test setup for the purposes of assessing amplifier performance.

The AW3142 LTE Base Station Antenna was chosen for use during the testing as it is representative of the type of antenna that will likely be used in the event of LTE roll out and offered the highest gain figure which minimised possible distortion of the LTE signals due to the reduced power output required from the amplifier.

The proper functioning of all equipment and the levels of all signals were confirmed at the beginning and end of each test to ensure consistency. The off-air LTE signals were also monitored using an Anritsu MS2726C Spectrum Master to ensure levels were consistent and present at all stages of testing.

See Table 14 below for a summary of findings, in all cases (under worst case scenario conditions) it was possible to prevent loss of signal or quality due to RF overload.

Table 15 - Summary of Test Results

Distance	No Filter	Filter C	Filter A	Filter B
10 metres	Complete Loss of Signal Quality	Normal Operation Restored	No Perceivable Improvement	No Perceivable Improvement
20 metres	Partial Loss of Signal Quality – Content Unwatchable	Normal Operation Restored	Normal Operation Restored	Normal Operation Restored
30 metres	Partial Loss of Signal Quality – Content Disrupted but Watchable	Normal Operation Restored	Normal Operation Restored	Normal Operation Restored