



Study on specification and use of in-line
filters to reduce interference in
broadcast bands from mobile base
stations (SB2122)

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2 Introduction and Scope

Several national Administrations have decided to allocate the 790-862 MHz frequency band (the 800 MHz band) to mobile/fixed communications networks (MFCN), following the switch off of analogue terrestrial television services.

The European Commission issued a Decision (2010/267/UE) on harmonized technical conditions of use of this frequency band in the European Union by MFCNs. This decision is based on studies carried out by the CEPT, the results of which are published in CEPT Reports 30 and 31. These harmonised technical conditions have been derived aiming to reduce the risk of disturbance that the implementation of MFCN in the 790-862 MHz frequency band may cause to Digital Terrestrial Television (DTT) broadcasting services in the lower adjacent band. However, as expressed in the CEPT Report 30, the concept of ‘block edge masks’ used to define these conditions does not always provide the required level of protection for victim services and, in order to resolve these cases of interference, additional mitigation techniques would need to be applied. The EC Decision (Article 2, second paragraph) also states that Member States shall ensure that the new systems in the frequency band 790-862 MHz provide appropriate levels of protection to systems in adjacent bands, e.g. DTT broadcasting services.

In order to provide appropriate levels of protection to DTT services below 790 MHz several measures may be applied, namely:

- Careful network planning by the MFCN operator to avoid situations that may create interference to the reception of DTT signals, including
 - Reducing the transmitted power and adjusting the antenna patterns
 - Using Base Station antenna polarisations that are opposite to that of the appropriate DTT transmitter
 - Using additional RF filtering at MFCN Base Stations
- Use of on-channel, low-power DTT repeaters at MFCN Base Stations

If the above measures do not prove to be sufficient, the additional measure may be applied of providing an in-line filter that may be connected in front of the DTT receiver or receiving antenna amplifier system to reduce the high levels of adjacent channel (out-of-band) interference experienced by DTT receivers in the presence of signals from MFCN (/LTE) base stations.

The study which is the subject of this report examines only some aspects of interference into DTT caused by LTE base stations deployed in the 800MHz band. This study focuses on fixed-antenna, DTT reception and the goal is to define an ‘ideal’ specification for a consumer-grade external filter that could be inserted in line with the TV antenna cable for roof top reception cases to improve rejection of LTE interference *in a majority of cases*, depending on specific local conditions. The aim of this study has been to address the most likely interference situations – based on the same general assumptions as used by CEPT in Report 30 – rather than extreme cases which may need more expensive filters or other mitigation methods. The filter requirements are quite challenging with today’s technology and a relaxed specification filter is also proposed that can still reduce the effects of LTE interference in areas further from the base station.

Other interference scenarios such as indoor portable reception and interference from the UE (user equipment) ideally need to be considered as well, but these aspects are not considered in this report. It is possible that the same filter specification may also be sufficient for these reception conditions, but drawbacks like insertion loss have to be considered as well.

It may be that a higher-selectivity filter is required in the case of a community antenna distribution system serving many users, who can share the higher cost of the device. The requirements of such distribution amplifier filters, dealing with intermodulation issues, are not in the scope of this document.

Further information related to downlink and uplink interferences and related recommended mitigation measures (joint document by DigiTAG, ACT, BNE and EBU) can be found on the DigiTAG website: www.digitag.org

3 References

1. SE42(09)014 Computation of block-edge masks for MCN BS at 790 MHz boundary with DTT.
Reza Karimi, Ofcom, UK, 16 Jan 2009

2. The co-existence of LTE and DTT services at UHF: a field trial, Ofcom, UK, 4th July 2011, http://www.ofcom.org.uk/static/research/co-existence/LTE_DTT_services_at_UHF.pdf
3. CEPT Report 30 <http://www.ero-docdb.dk/Docs/doc98/official/pdf/CEPTREP030.PDF>
4. High Q Filter Studies http://stakeholders.ofcom.org.uk/binaries/consultations/872_876_mhz/annexes/highq.pdf
5. ITU-R draft recommendation: BT.1368 : Draft revision of Recommendation ITU-R BT.1368-8 - Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands <http://www.itu.int/rec/R-REC-BT.1368-9-201112-D/en>
6. ITU-R report: Measurements of Protection Ratios and Overload Thresholds for Broadcast TV Receivers <http://www.itu.int/pub/R-REP-BT.2215-2011>
7. ECC report 148: MEASUREMENTS ON THE PERFORMANCE OF DVB-T RECEIVERS IN THE PRESENCE OF INTERFERENCE FROM THE MOBILE SERVICE (ESPECIALLY FROM LTE) Marseille, June 2010 <http://www.ero-docdb.dk/docs/doc98/official/pdf/ECCRep148.pdf>
8. T2_0591_Ofcom UK earlier filter work
9. T2_0599_Impact of LTE on amplifier intermodulation
10. T2_0600_Conducted measurements on DVB-T interfered with by LTE uplink signals
11. T2_0601_LTE disturbs DVB-T2/T/Cable
12. T2_0606_Potential risk of intermodulation - qualitative case studies
13. T2_0628_ACS Requirement and Filter Models
14. T2-0629_Impact of Attenuation on Coverage

4 Abbreviations

ACS	Adjacent channel selectivity. A measure of receiver performance. It is defined as the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent frequency.
ACLR	Adjacent channel leakage. A measure of transmitter performance. It is defined as the ratio of the transmitted signal power (nominally equal to the power over the signal's passband) to the power of the signal measured at the output of a (nominally rectangular) receiver filter centred on the adjacent channel.
ACIR	Adjacent channel interference ratio. The ratio of the adjacent channel interferer power (P_{AC}) to the interference power (P_I) experienced by the victim. $ACIR = P_{AC}/P_I = SIR/(C/I)$ where SIR and C/I are defined below.
BS	Base Station
CCI	Co-Channel Interference
C/I	Carrier to Interference ratio, sometimes referred to as protection ratio.
FBAR	(Thin) Film bulk acoustic resonator – filter technology; consist of a piezoelectric material sandwiched between two electrodes and acoustically isolated from the surrounding medium
FDD	Frequency Division Duplex – upstream and downstream are in different paired frequencies
LTE	Long-Term Evolution – a 4 th generation mobile communications technology.
MATV	Master Antenna Television – usually a professionally installed system that amplifiers TV signals received from one antenna to a level where it can be distributed by cable to multiple TV outlet points within a building.
MFCN	Mobile/Fixed Communications Network
OFDMA	Orthogonal Frequency Division Multiple Access – a multicarrier modulation scheme used for the LTE downlink (BS)
SAW	Surface acoustic wave – filter technology; electrical signals are converted to a mechanical wave in a device constructed of a piezoelectric crystal or ceramic
SC-FDMA	Single Carrier Frequency Division Multiple Access – a multicarrier modulation scheme used for the LTE uplink (UE). It has a lower peak to average power ratio (PAPR) than OFDMA.
SIR	Signal to interference ratio – in this study it is used to indicate the co-channel protection ratio (C/I) of LTE interference into a DTT signal
UE	User equipment – the mobile terminal or handset

5 Executive summary

With the “digital dividend” spectrum reorganization in Europe, LTE and digital broadcast television bands have become very close neighbours. DTT channel 60 is now separated by only 1MHz from the lowest downlink LTE band. Also the LTE transmissions overlap the frequencies used by cable networks.

This report examines some aspects of interference from LTE to television receivers and proposes various filter masks which might be used as a guide by filter manufacturers to create external filters that could be fitted to mitigate several interference issues into fixed DTT reception. In particular this report covers the broadcast television standards DVB-T and the second-generation DVB-T2. These standards are widely deployed in Europe and throughout the world.

Nine interference scenarios were identified, however due to time considerations only the cases from a LTE base station into fixed DTT reception are considered in detail. Five potential mitigation methods are discussed in section 9; however this report focuses on an external filter at the receiver television end which is generally accepted to be the most effective form of mitigation.

Simulation models were created to re-create the inband and out of band interference case for a TV receiver to show the effects that BS out of band noise can have on overall receiver performance. It was concluded that for the assumption of a BS out-of-band (OOB) noise of -10dBm/10MHz, and ideal adjacent channel selectivity (ACS) required to achieve maximum rejection was 80dB, whilst a relaxed figure of 70dB would still give good rejection in locations further away from the BS.

With this ACS defined, current receiver ACS performance was calculated based on measurements of protection ratios for DVB-T/T2 on various silicon and can tuners. Receiver ACS performance varied from 36dB to 67dB. Some receivers were particularly sensitive to the low data rate so called “LTE idle mode” where the signal power varies rapidly over time. This is thought to be due to the signal power variation affecting the receiver AGC loop. The idealized external filter shape to achieve the necessary overall required ACS was created by combining the existing receiver filter response with the external filter shape using different assumptions on filter transition slope and stopband rejection, to show the range of options available to the filter designer.

Next, four different generic existing receiver filter responses are defined (RXA-RXD) in Figure 17 based on a generic model in Figure 15. Existing receiver filters RXA and RXB are more stringent, and are suitable for poorly behaving receivers. Existing receiver filters RXC and RCD are more appropriate for receivers with better selectivity and the external filter requirements are similarly relaxed.

From these filter responses and the calculated required ACS, LTE-stop filter requirements were derived. Figure 18- Figure 21 show the graphical representation of the required LTE-stop filters for RXA-RXD as well as the combined response of the receiver channel filters and the LTE-stop filter. Table 4 lists the detailed filter specifications that are recommended to be created in this report.

These filter specifications are ideal, and they do not take into account practical implementation issues like connectors and insertion loss. Some studies on the impact of insertion loss on existing DTT coverage are summarized in section 13. All results show that any additional attenuation above 1 dB may lead to severe losses in coverage. Furthermore, relative coverage loss is much higher for portable reception than for fixed reception. Finally, section 14 gives an overview on some filters which are currently on the market, especially in Germany. Many of these filters have a relatively high insertion loss, which is in some cases even higher than specified by the manufacturer.

6 The harmonised 800MHz band plan (Europe)

The harmonised reverse duplex FDD spectrum arrangement following analogue switch off and spectrum re-organisation of DTT channels is shown in Figure 1. The LTE downlink is separated from the top TV channel 60 edge (790MHz) by a guard band of 1MHz. The mobile handset transmission frequencies are separated from channel 60 by 42MHz.

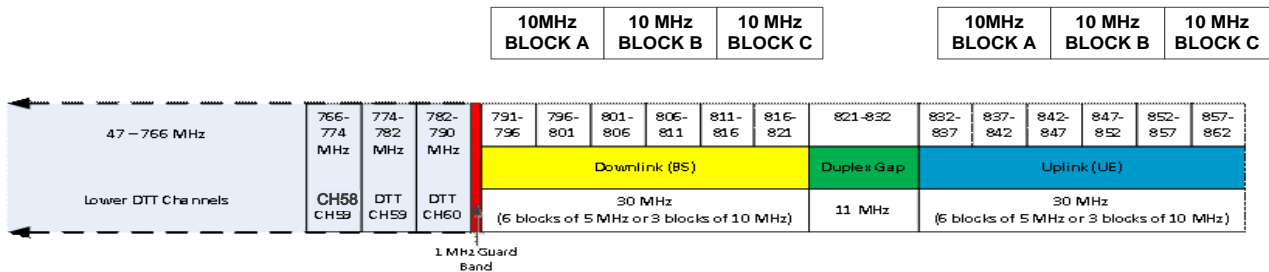


Figure 1 - Harmonised 800MHz digital dividend spectrum organisation

This harmonised frequency band plan will become effective in many European countries – at least in the EU -, when the 800MHz band will be used for mobile services. Currently, this is the case only in a few countries, e.g. in Sweden and Germany, but auctions are planned in other countries for the near future (e.g. The Netherlands, Switzerland, Norway).

7 Receiver behaviour and assumed reception scenarios (DVB-T/T2)

7.1 Receiver protection ratios and overload thresholds

There are two key aspects of DTT receiver behaviour relevant to interference situations.

Protection ratio – is the ratio of wanted/unwanted signal power before reception is affected by the interference – usually this is measured by fixing the wanted signal level and increasing the interference level until picture artefacts start to appear. At low wanted signal levels, this ratio is fixed, so for every dB increase in interference, the wanted signal level also has to be increased by the same amount. Here the receiver is showing ideal linear behaviour. Typically the interferer is several 10s of dB higher than the wanted signal level in these conditions. But in locations where the wanted signal is much stronger, there will be a certain interference level beyond which the receiver cannot maintain this linear behaviour due to non linearities caused by receiver overload as shown in Figure 2.

Tests have shown that some receivers do not behave in this ideal way, particularly when the LTE signal is time varying – such as when it is only carrying a small amount of user data. Some examples of different tuner C/I characteristics along with recommended ways to measure the protection ratio and overload threshold are given in reference 6. Adding an external filter will attenuate the interference signal level thus helping to prevent receiver overload occurring.

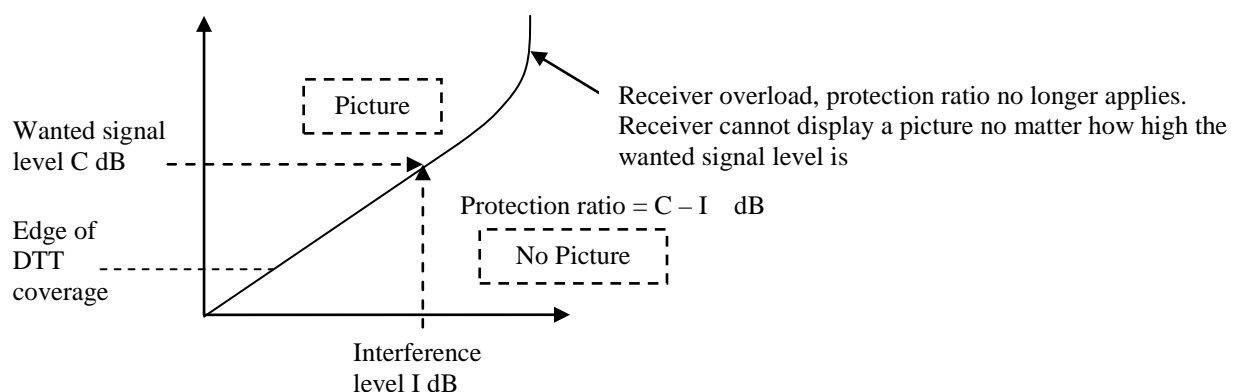


Figure 2 - Protection ratio and overload threshold of an ideal DTT receiver

7.2 Booster Amplifiers

As shown in the reference document 6, DTT receiver adjacent channel selectivity protection ratio and over loading vary as function of frequency offset relative to the DTT wanted signal channel/frequency. The general trend is that the protection ratio and overloading threshold increase with the increase of frequency offsets, and they can be very different for different DTT receivers (tuner type, manufacturer design, etc).

In many real DTT reception installations, DTT signal booster amplifiers are used by DTT users to amplify the DTT wanted signal. Most of the DTT booster power amplifiers installed in the field are the existing ones used for analog TV installed outside on the DTT reception antenna mast or inside the house before the DTT signal splitter box. These DTT power amplifiers were initially designed for covering the whole UHF frequency band from 470-862 MHz, including the sub-band (790-862 MHz) newly allocated to mobile services. When an adjacent channel LTE interference signal is input to a DTT booster power amplifier, due to its non linear behaviour, the power amplification gain as function of frequency offset can be very different compared to the case without an adjacent channel interfering signal - the out of band amplification gain curve is raised following some intermodulation laws. This non linear behaviour of the DTT booster power amplifier will create DTT receiver overloading, not only to the immediate adjacent channels, but also to the far away DTT adjacent channels. The mitigation solution is to install an external filter before the DTT power amplifier to attenuate the LTE interference signal level.

7.3 Effects of intermodulation

Every time a multitude of signals multiplexed in the frequency domain is processed by a non-linear device, such as a wide-band distribution amplifier, intermodulation products are present at the output of that device, due to beats among the input frequencies.

Distribution amplifiers are carefully regulated during the installation phase, in order to minimise intermodulation in normal operational conditions. However, if later on new high level signals (e.g. LTE signals) are received in the same area, intermodulation products significantly increase.

The I/O characteristics of a non-linear amplifier can be modelled as its series expansion truncated at the 3rd order¹, as follows:

$$V_o = k_1 V_i + k_2 V_i^2 + k_3 V_i^3$$

Where

- V_i is the input voltage,
- V_o is the output voltage,
- k_1 is the amplifier gain,
- k_2, k_3 are the 2nd and 3rd order coefficients of the series expansion, and can be calculated from the values of 2nd and 3rd order InterModulation Distortion (IMD) of the amplifier, as declared by the manufacturer or measured in the lab.

3rd order intermodulation products fall at frequencies like $f_1 \pm f_2 \pm f_3$, where f_1, f_2 and f_3 are any of the carriers belonging to the input signals (DVB or LTE): therefore they are potentially affecting all TV channels in the UHF band.

An example is shown in Figure 3. The blue histogram shows that, without LTE signals, a proper regulation of the distribution amplifier allows to limit the intermodulation products about 50 dB below the useful DTT signal level (C/I > 50 dB); instead, in the presence of high level LTE signals (orange histogram), intermodulation products cause the resulting C/I of all DTT signals to be definitely under the reception threshold.

Further studies on the effects of intermodulation can be found in references 9 & 12. It can be seen that the probability of intermodulation products falling into a certain DVB-T channel strongly depends on the specific situation in the area under consideration. The risk of such products increases if intermodulation between mobile signals is taken into account as well.

¹ In case of very high input signal levels, a better approximation could be achieved with a 5th order model.

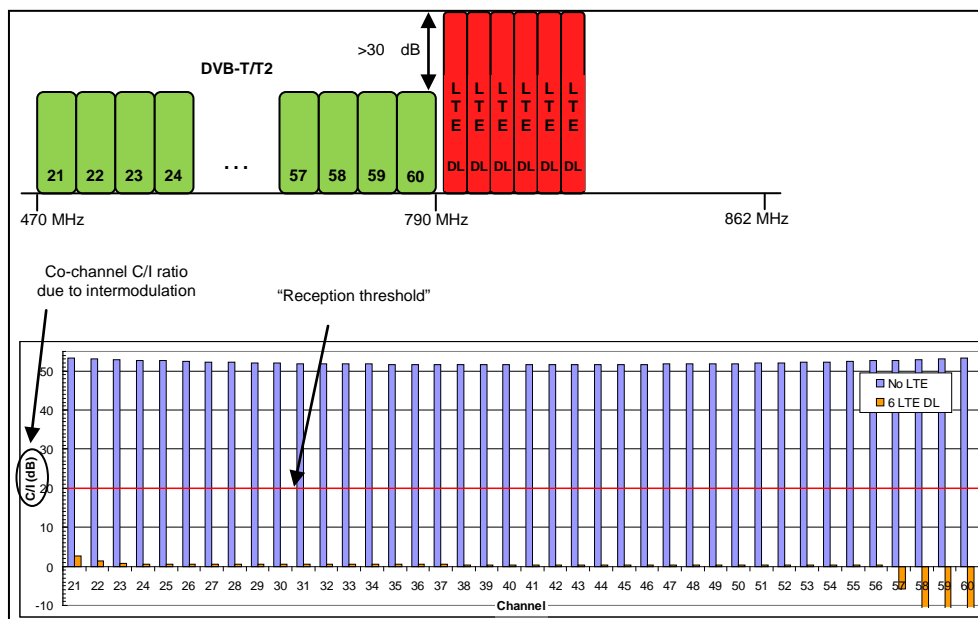


Figure 3 – Example of intermodulation effects generated by a wide-band distribution amplifier in the presence of high level LTE signals

7.4 Assumed reception scenarios

Figure 4 shows some likely cases of interference entry in roof top and indoor portable reception conditions. Figure 5 shows some likely interference entry points in a communal antenna system. Table 1 outlines each case briefly and summarises the extent of its coverage in this study.

7.4.1 Fixed rooftop and indoor portable

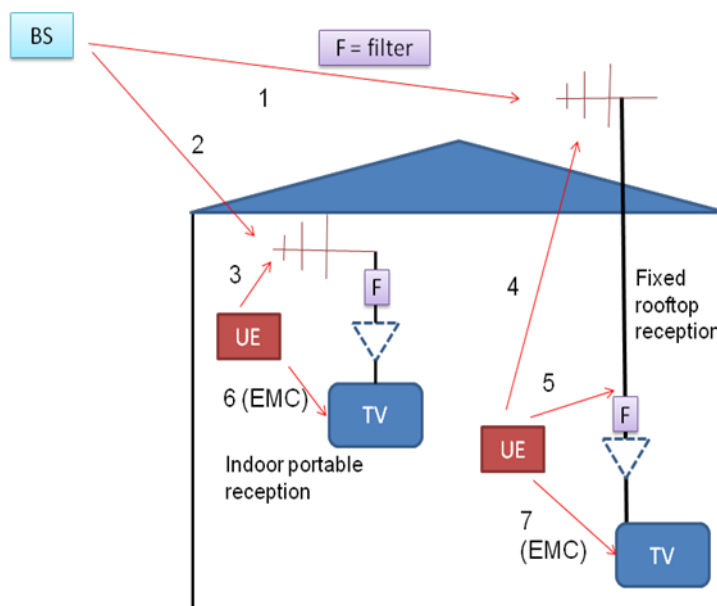


Figure 4 Possible interference entry points for rooftop and indoor portable reception showing location of the external filter

7.4.2 Communal antenna system (MATV)

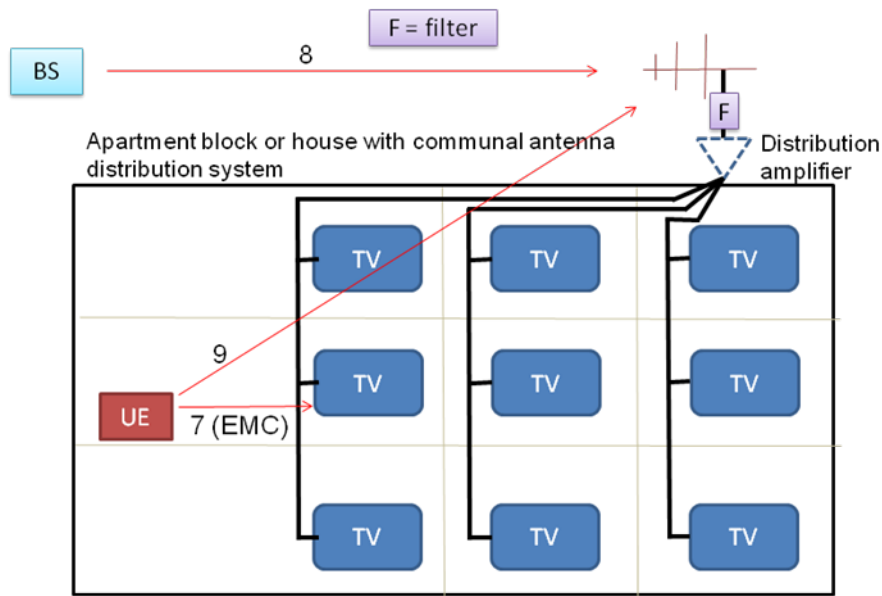


Figure 5 - Possible interference entry points for communal antenna system showing location of the external filter

7.4.3 Reception without booster or mast head amplifiers.

In some situations the DTT signal is strong enough to be received either externally or internally via a portable antenna without any additional amplification. At the very edge of coverage area, the DTT signal will be received if it is greater than the sensitivity limit of the DTT receiver which is defined as:

$$C \text{ (dBm)} = 30 + 10\log_{10}(KTB) + C/N + NF \quad (1)$$

Where

K = Boltzmann's constant $1.38 \times 10^{-23} \text{ J/K}$

B = DTT signal bandwidth in Hz (7.61MHz for DVB-T)

T = temperature in degrees Kelvin (290°)

C/N = required C/N ratio in dB for reception in the particular DTT mode being used

NF = noise figure of DTT receiver in dB – typically 7dB is used in planning.

Any additional losses due to the antenna feeder cable, poor quality connections, or the insertion loss of the external filter will increase the required signal level for reception at the antenna input, thus reducing the coverage area unless a higher gain antenna or a low noise booster/mast head amplifier is used to compensate. Thus for receivers operating right on the limit of DTT coverage, the addition of an external filter insertion loss is likely to require the installation of some other compensation such as an amplifier, a higher gain antenna, or a receiver with a lower noise figure.

But for fixed DTT reception and for locations closer to the DTT transmitter where the signal strength is higher, the DTT receiver will be operating say X dB above the minimum sensitivity level, so the addition of an external filter may not require other compensating measures if the insertion loss of the filter is less than X dB.

In a similar way this may be the case also for portable indoor reception - but not necessarily. In this case, field strength at a certain receiving place might be lower than at another place relatively close by, e.g. due to higher wall losses, reception in a room on the opposite site of the building or shielding by other buildings. Another important aspect is that all multiplexes are received at one particular antenna location - which (e.g. due to standing waves in the room) usually is not at the optimum position for any multiplex, at least not for all multiplexes. Therefore, the field strength at the receiver is lower than it could be if antenna location would be optimal for this particular channel.

Hence, "coverage edge" of portable indoor reception strongly depends on local conditions and could be even close to the transmitter site.

7.4.4 Use of booster/mast head or distribution amplifiers to improve weak signal reception in roof top, indoor portable or communal antenna systems.

As explained above, in areas where a received signal is weak the overall link budget analysis becomes limited by the overall noise in the system as long as there is no interference. In this case we have a standard planning value for the noise figure of a TV tuner of 7dB. This value then sets the limit on weak signal reception capability when taken into account with the antenna gain and any loss in the connecting cable between the antenna and the tuner.

Amplifiers are frequently used in communal MATV systems to amplify the received signal and distribute it around multiple dwellings as shown in Figure 5, but they also have an important role to boost the received signal in normal domestic systems operating in weak signal reception areas (Figure 4). If properly employed they can make weak signal reception possible some way beyond the normal planned TV coverage.

Masthead/booster amplifiers may improve the overall noise figure, provided that its own noise figure is very low and its gain sufficiently high. On the other hand, the amount of amplifier gain required should not be excessive as now the overall dynamic range of the total system is reduced by this extra gain in terms of the overload level going into the TV. This reduction in dynamic range requires careful consideration when receiving any weak TV signal in the presence of strong signals both TV and others. Simple filtering or controlled multiple frequency selective levelling of the multiple signals in the case of an MATV system may become essential.

The best place to insert any protective LTE mitigation filters in these low noise reception systems is at the input of the amplifier. There may even be optimisation approaches where filters can be used in cascade at the input or one at the input to the amplifier and another directly at the TV tuner to help reduce any residual pickup which may occur on the down lead cable if it is exposed to significant levels of RF interference.

The reason for requiring filters with minimum practical insertion loss on the desired channel is set by these noise figure and service area planning considerations. In all these cases any losses in the desired channel by the filtering before the antenna amplifier or tuner will add directly to the effective noise figure of the first amplifier or tuner.

In areas where there is a stronger received signal and reception is not limited by severe multipath conditions, it may be possible to tolerate higher filter insertion losses.

For the technical background and classical analysis background for a cascaded chain of amplifiers with varying noise figures and gains please refer to: http://en.wikipedia.org/wiki/Noise_figure.

Interference case	Description	Considered in Study?	Result
1	BS signal received directly by roof top antenna that may not necessarily be pointing directly towards BS. No mast head amplifier is fitted.	Yes	Some filter specification work has been carried out
1.1	BS signal received directly by roof top antenna that may not necessarily be pointing directly towards BS. Mast head amplifier is fitted (not shown in figure).	Yes (briefly)	Filter should be fitted before the mast head amplifier to avoid overloading active circuitry, so a different temperature and environmental specification would be needed for outdoor usage. The mast head amplifier noise figure needs to be low enough to overcome insertion loss of filter if operating at the edge of DTT coverage.
1.2	BS signal received directly by roof top antenna that may not necessarily be pointing directly towards BS. Booster amplifier is fitted indoors near TV.	Yes (briefly)	Filter should be fitted before the booster amplifier to avoid overloading active circuitry. The booster amplifier noise figure needs to be low enough to overcome insertion loss of filter if operating at the edge of DTT coverage.
2	BS signal reaches indoor portable antenna.	No	One problem is that indoor active antennas do not allow a filter to be inserted before the active circuitry, so an external filter is not a suitable mitigation measure in this case. "Coverage edge" depends on local conditions, especially taking into account that all multiplexes are received by an antenna at a single location, i.e. not at its optimal position for each channel.
3	UE signal directly into indoor portable antenna	No	Case needs re-examining after the filter specification is fixed because the filter specification may be sufficient to cover this case too
4	UE signal directly into rooftop antenna	No	Case needs re-examining after the filter specification is fixed because the filter specification may be sufficient to cover this case too
5	UE signal into cable between antenna and filter	No	Case needs re-examining after the filter specification is fixed because the filter specification may be sufficient to cover this case too
6	UE signal directly into TV set connected to portable antenna	No	This is an EMC issue not a filter issue
7	UE signal directly into TV set connected to rooftop/communal antenna	No	This is an EMC issue not a filter issue
8	BS signal directly into roof top antenna connected to MATV distribution amplifier causing intermodulation problems	Yes (briefly)	Some simulations of intermodulation effects have shown this to be a serious problem. Case needs re-examining after the filter specification is fixed because the filter specification may be sufficient to cover this case too. However in the cases of professional installations a more expensive and capable filter can be deployed if the filter in this study is insufficient.
9	UE signal directly into rooftop antenna connected to distribution amplifier causing intermodulation problems	No	Case needs re-examining after the filter specification is fixed because the filter specification may be sufficient to cover this case too

Table 1 - Interference Cases Considered in Study

8 Assumed transmission scenarios (mobile systems/ LTE)

8.1 Structure of the LTE BS signal

The LTE BS signal uses OFDMA modulation and the UE uses SC-FDMA. Both signals use a framing structure which is extremely flexible, allowing the user data to be allocated to different subcarriers in both time and frequency. In the BS, the actual allocations will vary with the type of scheduling algorithms used, so this will be BS vendor dependent. When the BS is operating at full traffic load, all the available subcarriers in every available symbol can be used (some carriers are used for control data and synchronisation). But when the BS is operating under lighter loads, only a few data subcarriers will be occupied, and this can cause the power of the LTE signal to vary rapidly in time in a scheduler dependent manner.

At the present time there is very little published data on real LTE signals. The main signals used in the receiver industry for testing (including the receiver performance figures in this report) are based on some early recordings of a real BS operating in a test mode where the traffic loading could be varied from nearly 0% to 100%. The first 40ms of the so called "LTE BS idle" signal (filename LTE_BS-idle_V2.wv) has been analysed (see Figure 6 & Figure 7) and shows that there is a very small amount of data traffic being sent, but most of the waveform consists of synchronisation and broadcast signals. The power variation can be seen on a linear scale in the top of the figures. Note that the actual recorded signal is much longer than these 40ms sections, so the actual receiver protection ratios measured with the full recorded signal will differ on some receivers compared with just using the first 40msec repeated in a loop.

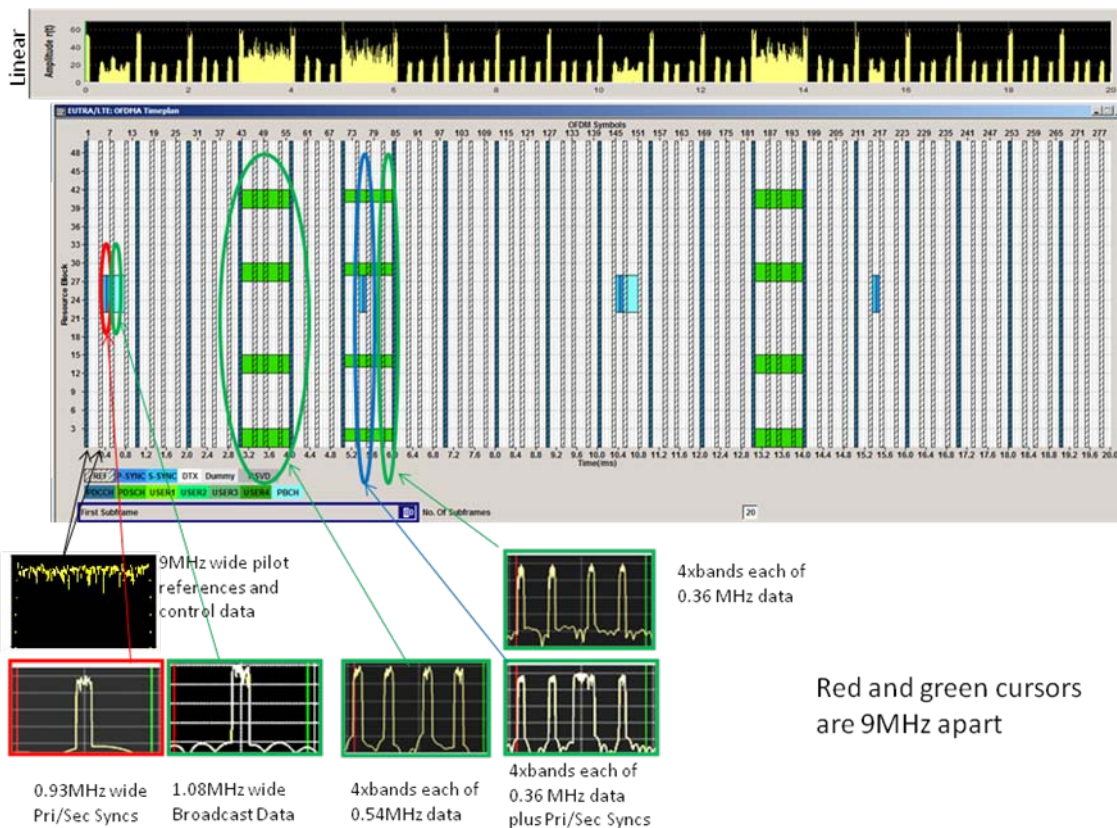


Figure 6 - Analysed BS Signal Characteristics ~0% Traffic Loading 0-20ms

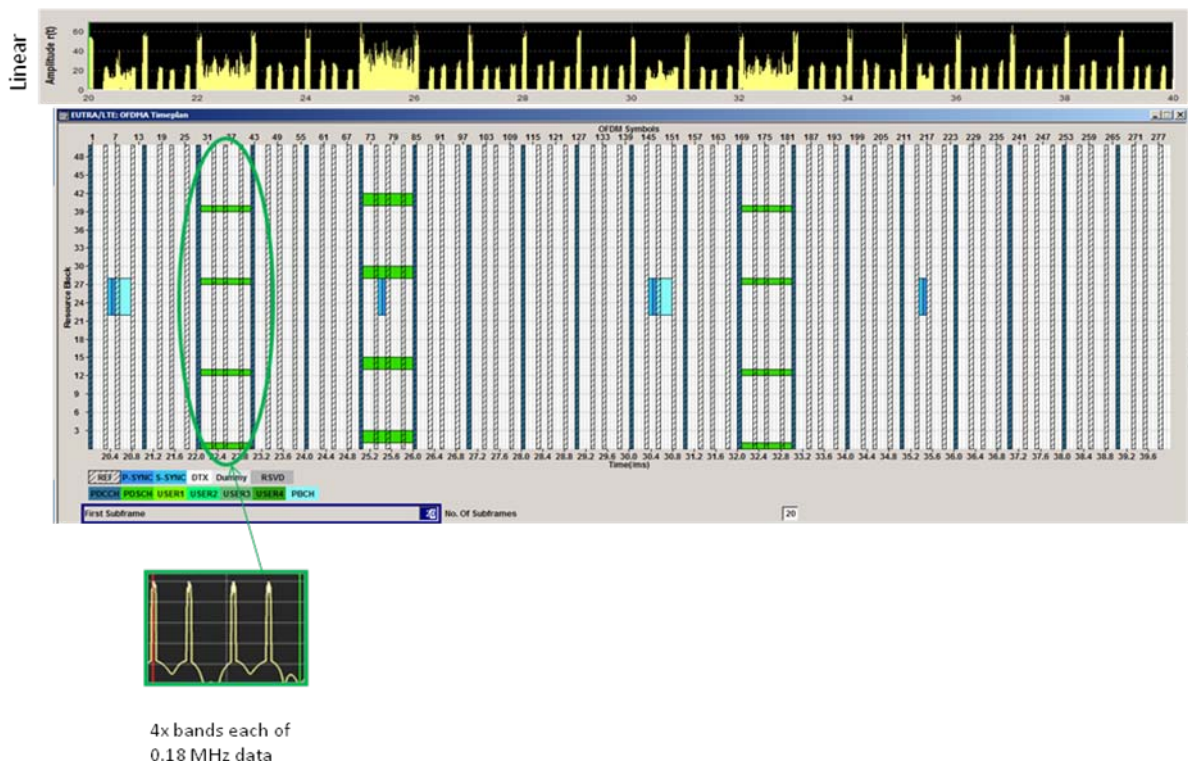


Figure 7 - Analysed BS Signal Characteristics ~0% Traffic Loading 20-40ms

The structure of an LTE BS signal operating in true idle mode (zero data) has also been calculated according to the LTE standard and is shown in Figure 9, Figure 10 and Figure 11. The sequence repeats after 40msec. The following configuration is assumed

- 10 MHz channel
- 2x20 W BS configuration
- Idle mode, no data traffic
- The duration of an OFDM symbol is 71.42 μ s

A key to the various LTE signals active in the figures is given in Table 2 below. The basic radio frame structure is shown in Figure 8.

RS	Reference signal - used for receiver channel estimation, they are subcarriers with known phase and amplitude spaced every 6 carrier locations and every 2 symbols per 0.5msec slot (7 symbols)
BCH	Broadcast signal. This occupies 72 subcarriers in the centre of the channel, and is sent in the first 4 OFDM symbols of slot#1.
S-SCH	Secondary synchronisation signal – transmitted twice per 10ms radio frame
P-SCH	Primary synchronisation signal – transmitted twice per 10ms radio frame

Table 2 - Key to LTE signal names used in this section

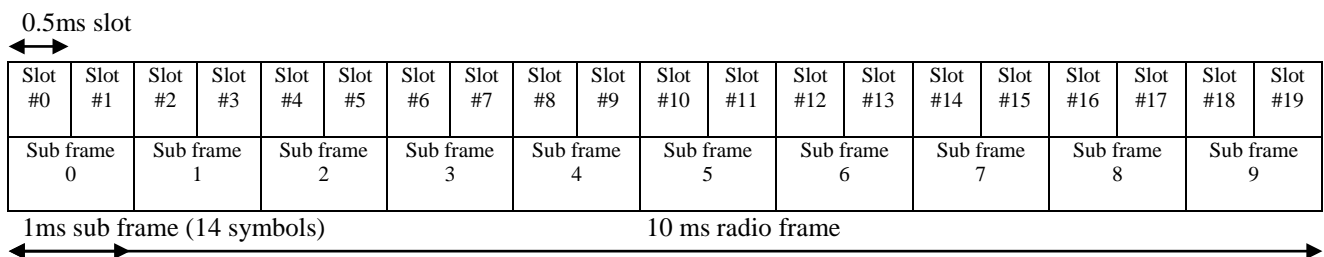


Figure 8 - LTE Frame Structure

E Node B Ptx Model over a 40 ms period (14x40=560 OFDM symbols)
Assumptions: Idle Mode. 10MHz bandwidth. 2 Antenna Ports. 2 x 43dBm/600 as Power per RS RE. 0dB power offsets for P-BCH/P-SCH/S-SCH, PA and PB

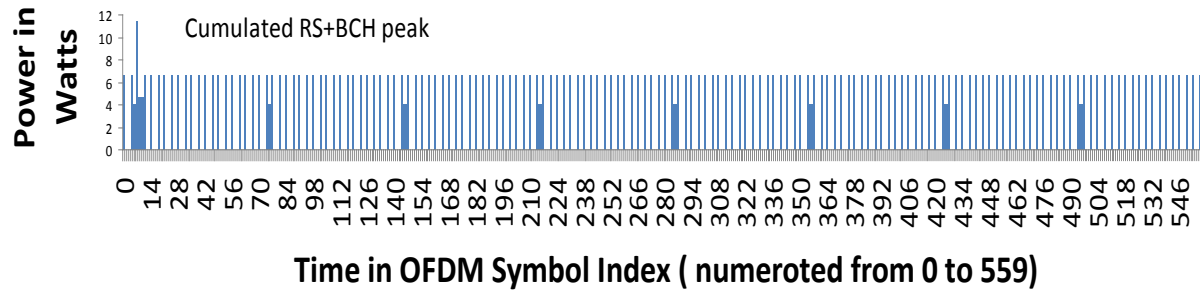


Figure 9 - LTE800 BS Idle mode Tx Power Variation over 40msec

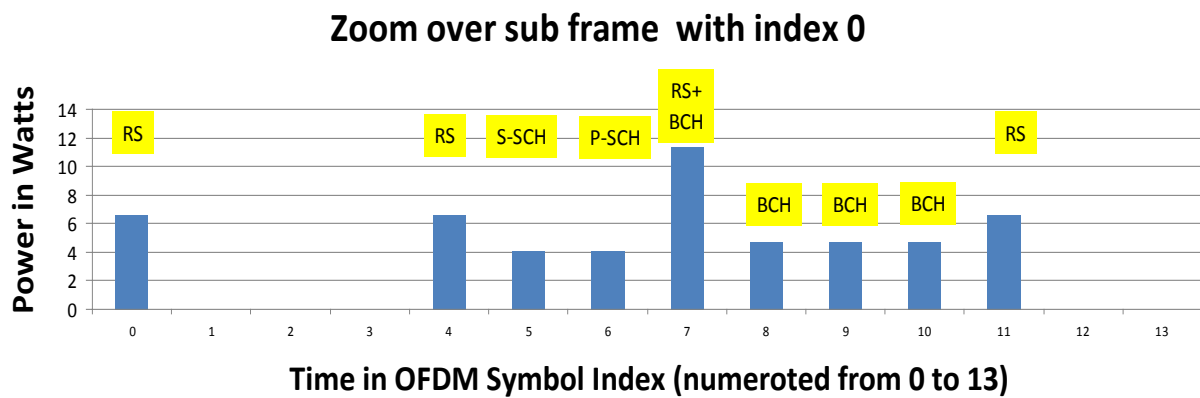


Figure 10 – Zoom in over a 1msec sub frame with index 0

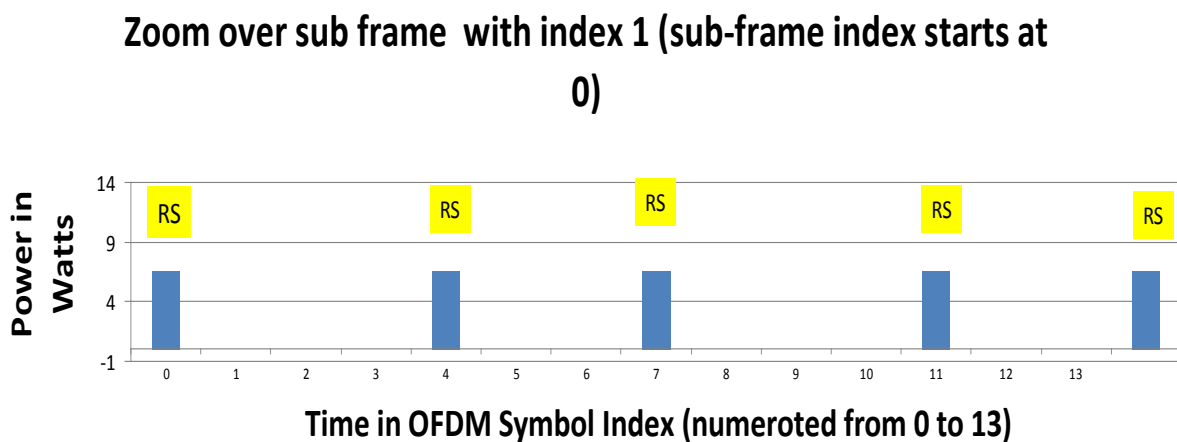


Figure 11 – Zoom in over a 1msec sub frame with index 1 onwards

Note that these diagrams are for a BS power of 2x20W, but a real LTE BS can use 2 x 40W. In this case the LTE BS transmitter power level indicated in figures Figure 9, Figure 10 & Figure 11 will be doubled.

9 Mitigation methods

9.1 External filtering at receiver end

Adding a low pass inline filter between the TV antenna and TV tuner input is currently the most effective solution when the highest TV channel is below channel 59/60. Any such filter should be added before the first active component in the receiving chain, usually a broadband amplifier. However if the highest wanted TV channel is in the CH59/CH60 range, the limitations on the slope of the filter roll off when the cut-off is set to 790MHz (top edge of channel 60), means most filters cannot reach their stop band attenuation at a frequency below the lower edge of the LTE signal in block A.

Reducing the filter cut-off frequency below 790MHz increases the amount of LTE interference rejection at the cost of increasing tilt and insertion loss across the wanted channels below 790MHz (ref. 8), which if operating at the edge of coverage, could result in loss of reception (ref. 14).

In case that an active indoor or outdoor antenna is used, there is no way for the user insert any kind of filter between the antenna itself and the low-noise amplifier. Such antennas may need to be replaced, in case that new models are on the market with filters integrated and/or being part of the rf-design of the antenna (see also section 9.2 below).

The maximum filter attenuation required also depends upon the BS out of band noise limits. If the out of band noise is very low, then the receiver is most affected by the adjacent channel interference power, so a good filter rejection can result in good rejection of the LTE interference. However if the BS out of band noise falling in band to the wanted TV signal is too high, this can dominate the total noise/interference seen by the receiver, and there is no advantage to having a filter with very high stop band attenuation. These tradeoffs are simulated in this study – see section 10.

9.2 Antenna with built in filtering

Roof top outdoor and indoor portable antennas can be designed to have a natural roll-off at 790MHz without the use of active circuitry, which helps to reduce the amount of interference reaching the input of booster amplifiers or TV tuners. However, this means that an existing antenna needs to be replaced.

9.3 Filtering at base station

Reducing the out of band emissions at the base station can be effective if the out of band emissions are dominating the overall receiver performance. Reducing the BS out of band emissions enables the full benefit of fitting an external filter to a DTT receiver with a good adjacent channel protection ratio.

9.4 On channel gap fillers

These devices are typically co-sited with the BS. They receive the DTT signal and re-transmit on the same RF frequency with very small delays in the order of 10µs, in order to boost the SINR of the DTT signal. Receive to transmit isolation is important for these devices to work correctly which might require attention to antenna positions. Echo cancellation techniques also help to improve isolation. Multiple channel gap fillers may be needed in certain places. The use of gap fillers is currently being studied by Ofcom in the UK – see ref. 2.

On the other hand, experience from several field trials and measurements e.g. in Germany and in Austria shows that the applicability of this method strongly depends on several factors, e.g. on network type, modulation scheme (including guard interval), reception mode and surrounding environment (echo situation). This practical experience shows that with single-frequency networks and omni-directional receiving antennas there are almost always locations for which coverage is improved, whereas for others coverage is worse. Furthermore, so far on-channel gap fillers are often used to serve (totally) uncovered areas, with no intention to work in an ‘SFN mode’.

9.5 Reduction in BS power levels

Reducing the BS power level is another way to mitigate interference from LTE BS, particularly for the worst case interferer of LTE Block A in areas where many homes are affected. This method is used in some countries where the interferer is adjacent to the DTT channel. An adjustment of a BS antenna in order to reduce BS power levels into a certain direction or area could be treated as a sub-category of this method.

However power reduction may reduce the coverage of the BS.

9.6 Antenna polarisation discrimination

This technique uses different polarisations of the BS and DTT signals to achieve additional rejection of the LTE BS signal in the DTT receiver if the DTT signal is received via a roof top aerial. This type of discrimination is only valid within the main lobe of the DTT antenna pattern. Initial studies of antenna polarisation discrimination had assumed 16dB attenuation within the main DTT lobe but measurements of real DTT antennas have shown this to be much more variable (ref. 2). Furthermore the use of slant polarisation MIMO in LTE BS means the BS to DTT polarisation is limited to 45° , reducing the effectiveness of this approach to around 3dB, so 3dB has been used in the simulations in this study.

The use of any polarisation for mitigation purposes is limited to fixed DTT reception, only.

10Roof top reception study

10.1 Explanation of simulation model

The purpose of the simulation (ref. 13) was to estimate the overall adjacent channel selectivity (ACS) requirement for the combination of the receiver+external filter for a range of different BS out of band noise levels and distances of the TV antenna from the BS. Due to BS out of band noise falling in band on to the DTT wanted channel, there is a point where increasing the ACS of the receiver + external filter has no effect on reducing the TV to BS minimum distance. The aim of the simulation was to find the best tradeoff between these factors to avoid over specifying the filter. This simulation model is based on a calculation in ref.1, estimating the minimum distance of the TV antenna from the central BS when operating within a group of seven BS located at the edge of DTT coverage area with a wanted signal level of -77 dBm. The TV antenna to TV transmitter distance is fixed at 32 km, and the position of the TV antenna is moved in a grid around the BS calculating the received SINR for each position. The minimum distance is defined as when the received SINR drops by 0.5dB from the required values of 18dB, 21dB and 23dB. Assumptions for the simulations and the simulation results are shown in “Annex A – Simulation assumptions and results”.

The intention of all these simulations was to provide results for very general cases, following same guidelines and based on same parameters as provided in ref 1. These are not necessarily the worst case receiver scenario. In reality, there are many other factors which may need additional consideration, e.g. with respect to real ERP values, antenna heights as well as horizontal and vertical antenna diagrams of existing (complex) antenna systems of broadcasting transmitters. An additional issue might be the use of MIMO or of adaptive antenna systems/beamforming at some or all BS. Furthermore, the simulations do not account of non-ideal parameters such as variations in receiving antennas which have been reported in Ref. 2 (Ofcom field trial).

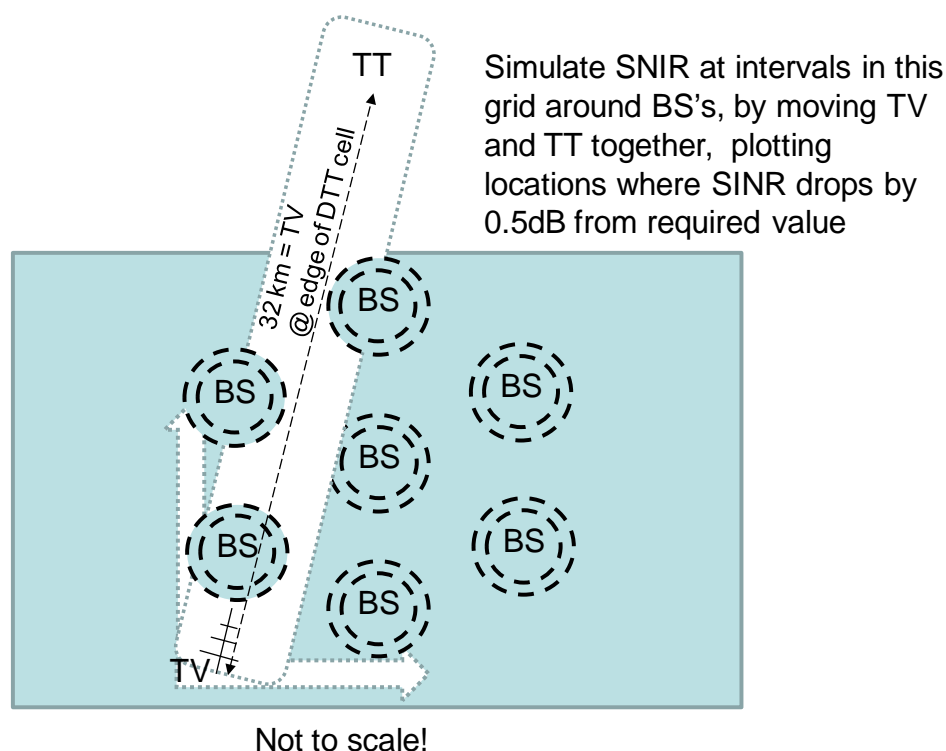


Figure 12 - Simulation of different TV locations around the central BS

The ideal ACS is recorded for each simulation condition shown in the Annex, along with the ACS that would still give some useful improvement. These are summarised in the table below.

	ACS to achieve maximum rejection dB			
BS Out of Band Noise dBm/10MHz	SINR = 18dB degraded to 17.5dB	SINR = 21dB degraded to 20.5dB	SINR=23 dB degraded to 22.5dB	SINR=21 dB degraded to 18dB
0	70(60)	70(60)	80 (70)	70(60)
-10	80(70)	80(70)	80(70)	80(70)
-20	90(80)	90(80)	90(70)	

Table 3 Summary of ideal (useful) ACS requirement (receiver + filter)

10.2 Consideration of receiver overload in these simulations.

In the above simulations the receivers have been operating at the edge of coverage area with a wanted signal of $C = -77$ dBm/8MHz. Measurements of the C/I characteristics of a small number of receivers shown in Figure 13 & Figure 14 show that receiver overload² didn't occur until the interference reached a minimum of -17 dBm. The best protection ratio measurement for CH60 shown in Figure 14 is -37.9 dB (Rx1). Thus even with the best receiver, the protection ratio limit would be reached when the interference reached $-77 + 37.9 = -39.1$ dBm. Based on these limited measurements, the limiting factor at the edge of coverage for well behaved receivers³ is more likely to be protection ratio than receiver overload so the simulations do not need to take overload into account. However in locations closer to the DTT transmitter where the wanted signal is stronger (possibly in cities), receiver overload needs to be considered. This scenario is not explicitly addressed in this study but receiver overload will still be improved by adding the external filter to reduce the interference power level.

10.3 Conclusions

The conclusion from these limited simulations at the edge of coverage area is that an overall 80 dB ACS will minimise the number of receivers affected without overdesigning the filter, assuming the base station out of band noise can meet the -10 dBm/10MHz assumption which is expected to be achievable and in some cases exceeded by current base station designs. However if this proves too difficult to economically implement with today's filter technology, a 70 dB ACS will still give a useful improvement particularly in areas further away from the BS.

² Receiver overload occurs when the C/I characteristic of the receiver substantially departs from the normal linear 1:1 slope.

³ Some receivers have been observed to behave in a non-linear fashion (even at low levels of wanted signal and interference) when the LTE interference signal power changes rapidly with time – the so called BS idle condition.

11 Current receiver performance

There are several industry measurement studies showing receiver protection ratios and overload thresholds with a range of wanted signal levels in the presence of an LTE BS with different traffic loadings (refs 2,5,6,7). Additional measurements for DVB-T and DVB-T2 are shown in “Annex B – Receiver measurements”. Some early measurements of (8K DVB-T 16QAM CR 2/3) with simulated LTE-UE like waveforms are also given in ref. 10.

Receiver ACS performance for interference into channel 60 varied from 36.4dB to 67.3dB on the receivers measured in the annex. Some receivers were particularly sensitive to the time variation on the LTE idle mode interferer (Rx8, Rx10 & Rx12).

11.1 Receiver C/I characteristics (DVB-T2)

The C/I characteristics of the receivers for channel 60 are plotted below to show the effects of receiver overload. Note the lower overload threshold on some receivers when interfered with by the LTE BS Idle signal.

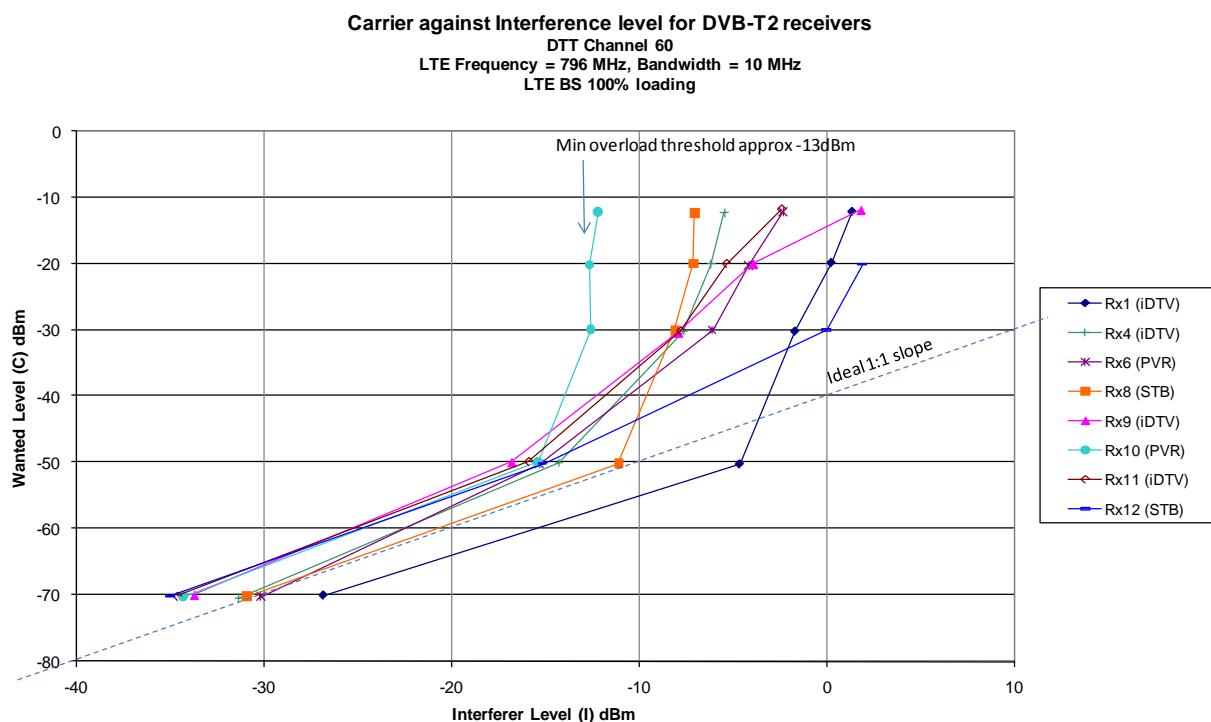


Figure 13 - C vs. I curves for channel 60 DVB-T2 with 100% LTE traffic loading in LTE block A

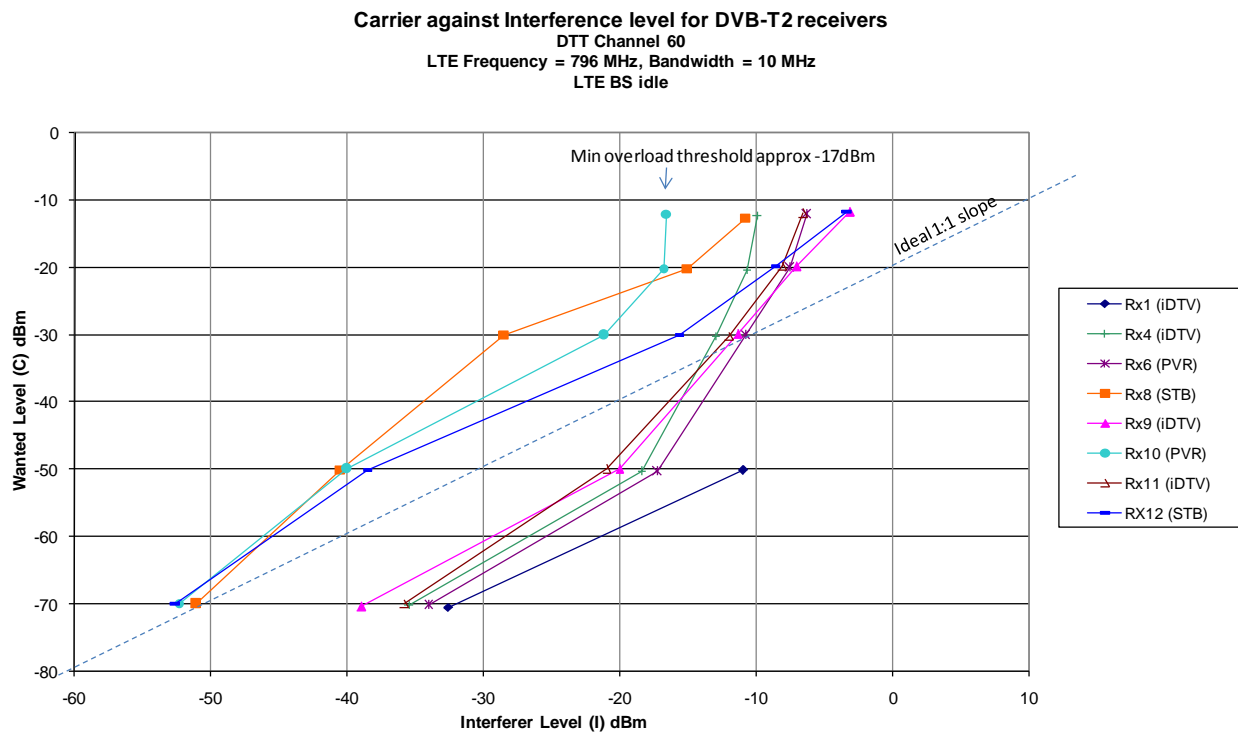


Figure 14 - C vs. I curves for channel 60 DVB-T2 with LTE idle traffic loading in LTE block A

12 Ideal filter specifications and technologies

12.1 Ideal filter specifications

Based on the simulation results, if the BS OOB power is in the range -10dBm/MHz – a figure thought to be realistic for most BS implementations, an overall receiver + external filter ACS of around 80dB is a reasonable target for the upper level of performance. Lower ACS values will make filter implementations easier and would be adequate in some areas further away from the BS. Feedback from filter manufacturers on cost and technical feasibility is needed for the next step. Some details of the different filter technologies are included in the next section.

The ACS of receivers can be determined from measurements, but the required ACS and shape of the external filter depends upon the shape of the existing receiver filter. In the absence of data on specific receiver channel filter shapes some estimates of required filter performance have been made based on known SAW filter characteristics use in typical can tuners, as well as some generic curves to which existing receiver filters can be matched in the case of silicon tuners.

A simple generic filter model is shown in Figure 15.

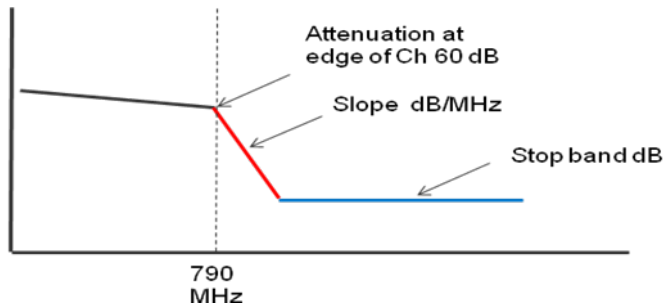


Figure 15 – Simple generic filter model

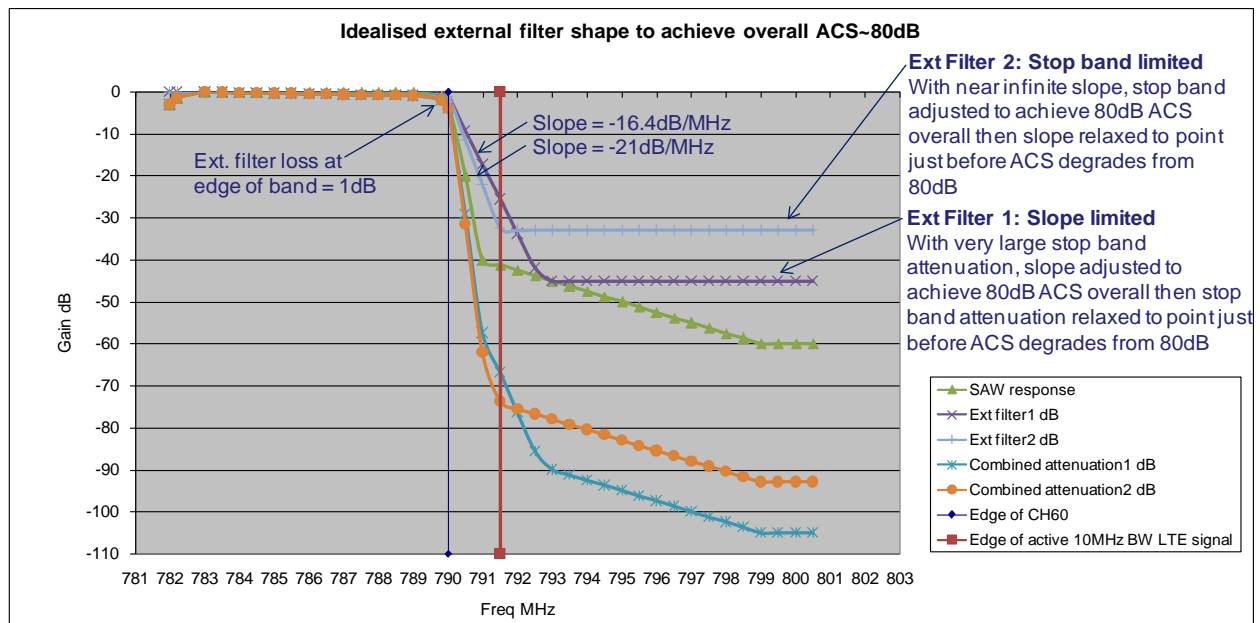


Figure 16 – Example showing two different external filter options to achieve an overall filter+receiver ACS of 80dB when the existing receiver filter is an x6966 SAW filter.

Figure 17 shows some generic existing receiver filter frequency responses drawn alongside the known x6966 filter response for comparison. These generic curves assume a linear tilt across the passband with 1dB attenuation at

790MHz. The associated external filter responses⁴ to obtain an overall ACS of 80dB are shown in Table 4. The external filters required for the poorer performing receivers A and B roughly fall either side of those required by the SAW filter, whilst the external filters for receivers C & D (which have better selectivity) have much less stringent specifications as expected.

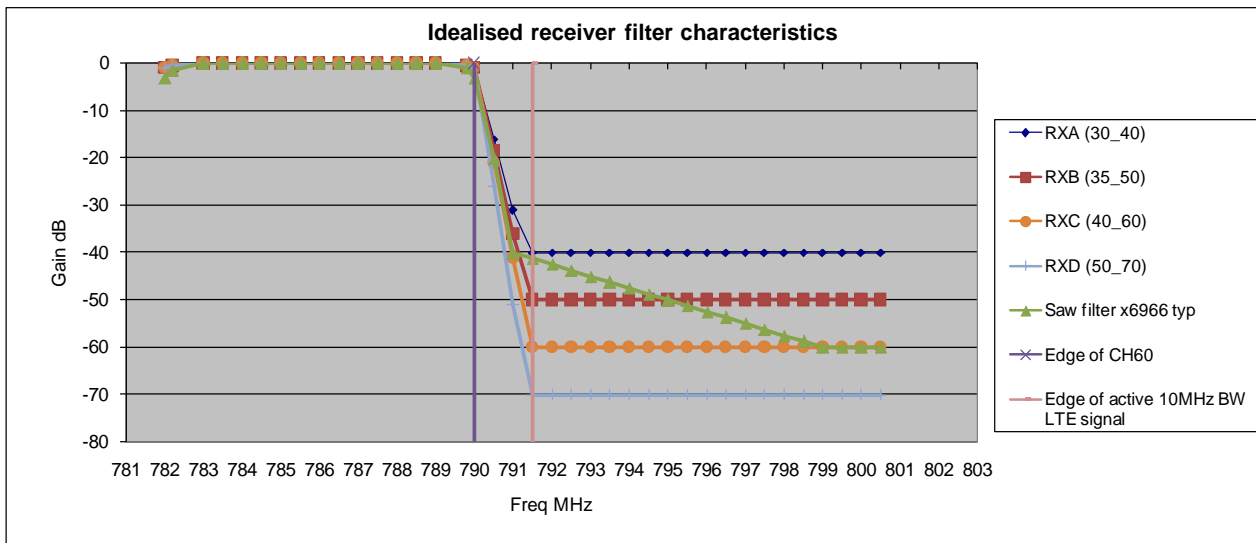


Figure 17 – Generic existing receiver filter assumptions shown alongside the x6966 SAW filter.

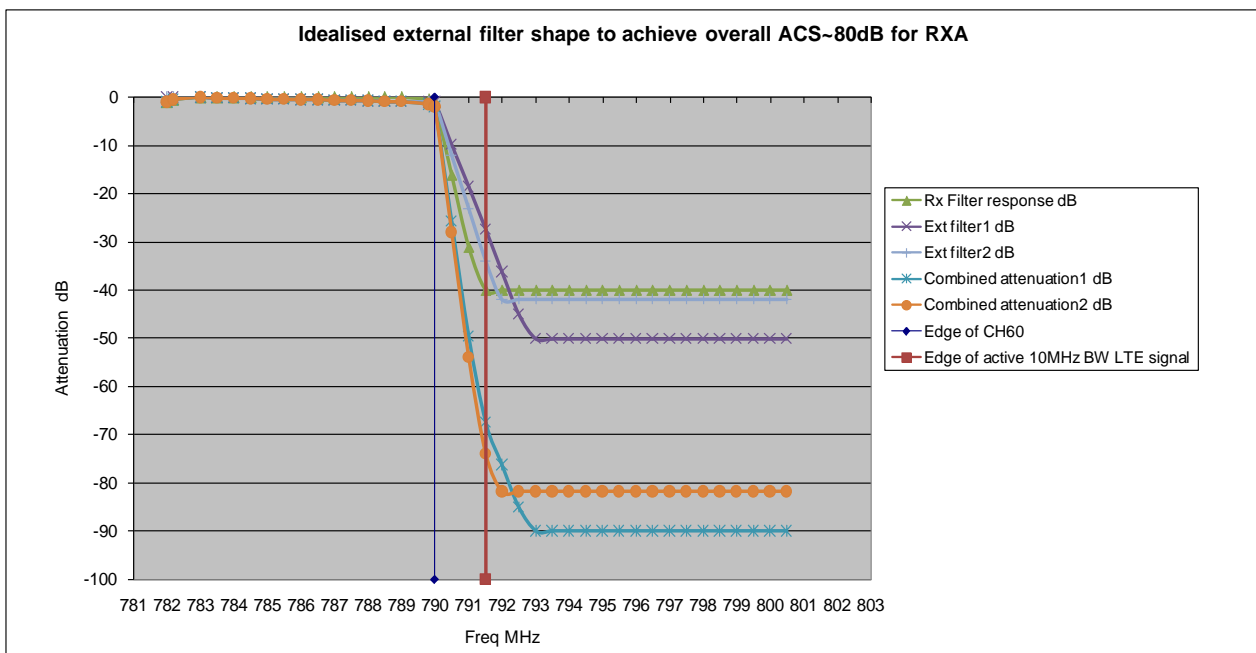


Figure 18 - Required external filter for overall ACS of 80dB assuming existing receiver filter = generic RXA

⁴ Note that all the external filter ACS calculations in this section have assumed a 10MHz LTE interferer adjacent to channel 60, with a 1MHz guard band. The ACS calculations assume the first LTE subcarrier is 1.5MHz away from the top of CH60. For 5MHz LTE signals, this reduces to 1.25MHz giving slightly different results.

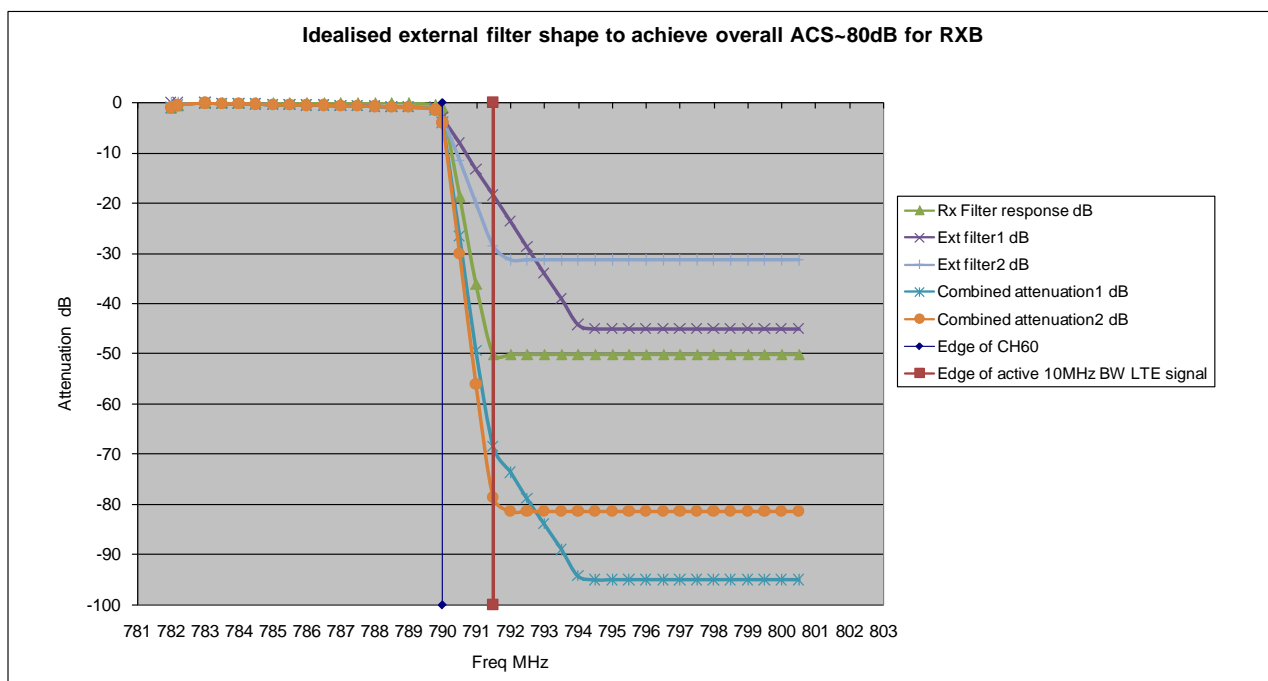


Figure 19 – Required external filter for overall ACS of 80dB assuming existing receiver filter = generic RXB

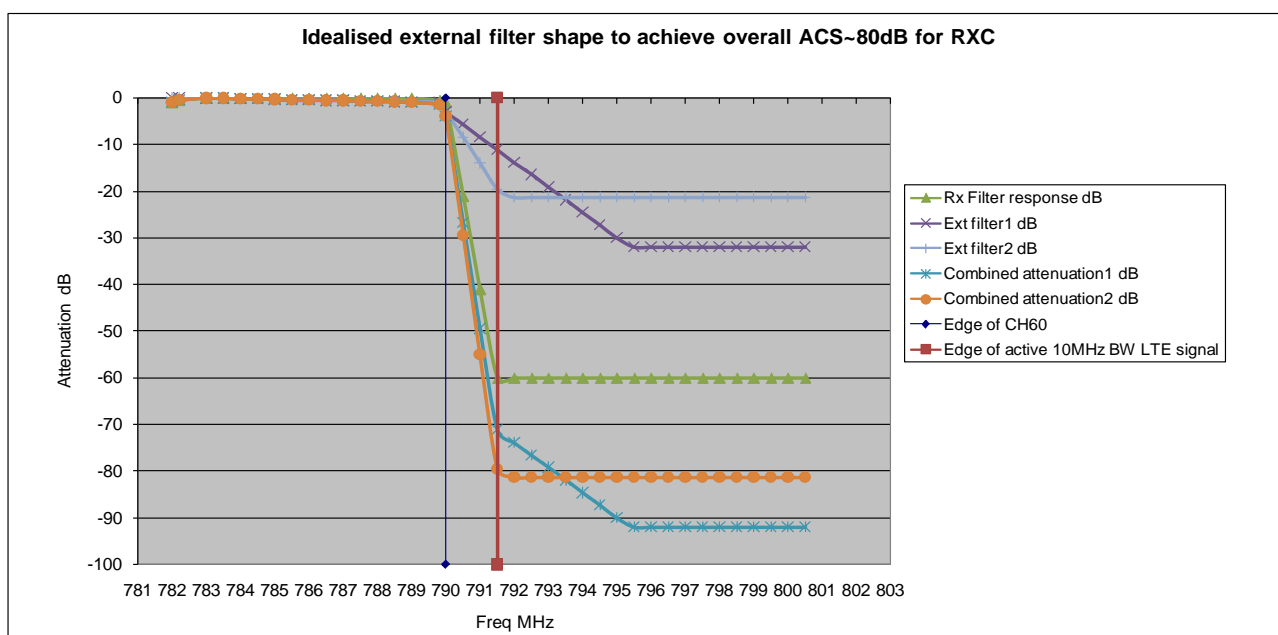


Figure 20 – Required external filter for overall ACS of 80dB assuming existing receiver filter = generic RXC

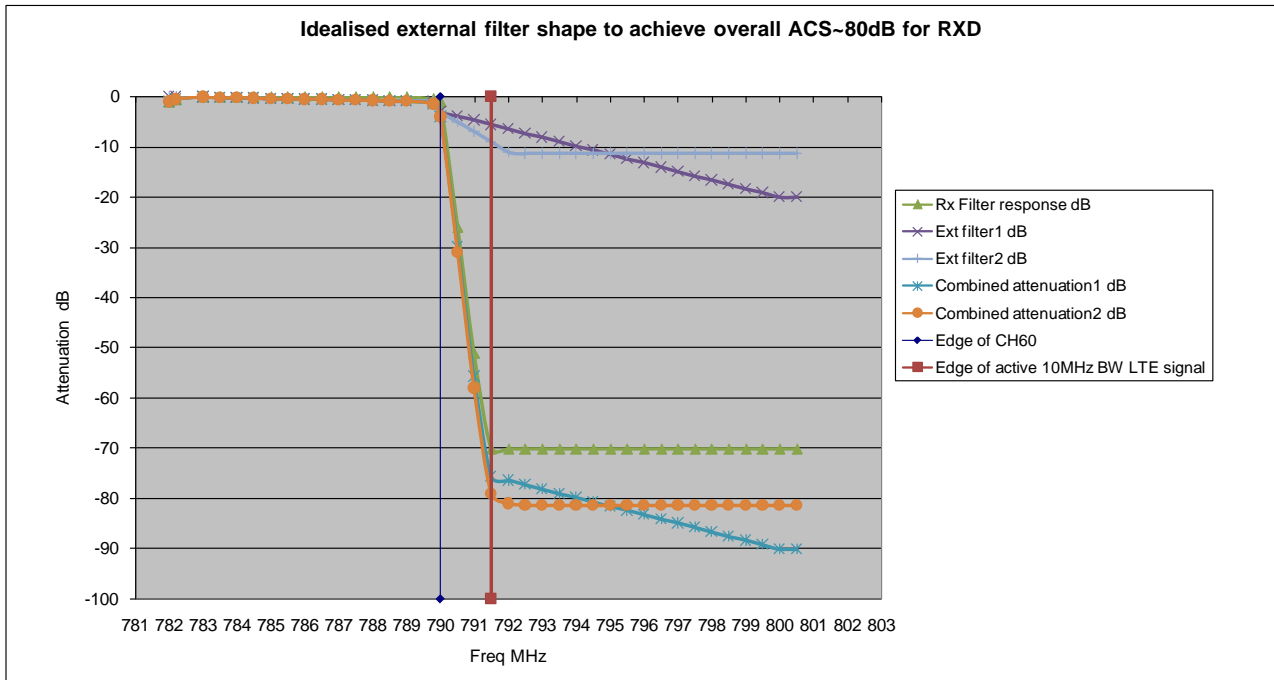


Figure 21 – Required external filter for overall ACS of 80dB assuming existing receiver filter = generic RXD

Assumed existing receiver filter response: (slope_stop band)	Slope Limited		Stop Band Limited	
	Slope dB/MHz	Stop band dBc	Slope dB/MHz	Stop band dBc
RXA (30_40)	-17.6	-50.0	-22.0	-41.8
RXB (35_50)	-10.3	-45.0	-17.0	-31.3
RXC (40_60)	-5.4	-32.0	-11.0	-21.3
RXD (50_70)	-1.7	-20.0	-4.0	-11.3
X6966 SAW filter	-16.4	-45	-21	-33

Table 4 – Required ‘ideal’ external filter characteristics to achieve overall 80dB ACS

12.2 ‘Useful’ filter specifications

Table 5 repeats the calculation but with a target of 70dB ACS instead of 80dB ACS, representing more relaxed filter requirements that would still give a useful amount of LTE rejection particularly in locations further away from the BS. The associated plots are shown in Figure 22 to Figure 25.

Assumed existing receiver filter response: (slope_stop band)	Slope Limited		Stop Band Limited	
	Slope dB/MHz	Stop band dBc	Slope dB/MHz	Stop band dBc
RXA (30_40)	-11.5	-43	-26	-41.3
RXB (35_50)	-5.4	-31	-10.7	-21.3
RXC (40_60)	-1.8	-16	-4.1	-11.3
RXD (50_70)	N/A	N/A	N/A	N/A
X6966 SAW filter	-10.4	-34	-5	-23

Table 5 – Required ‘useful’ external filter characteristics to achieve overall 70dB ACS

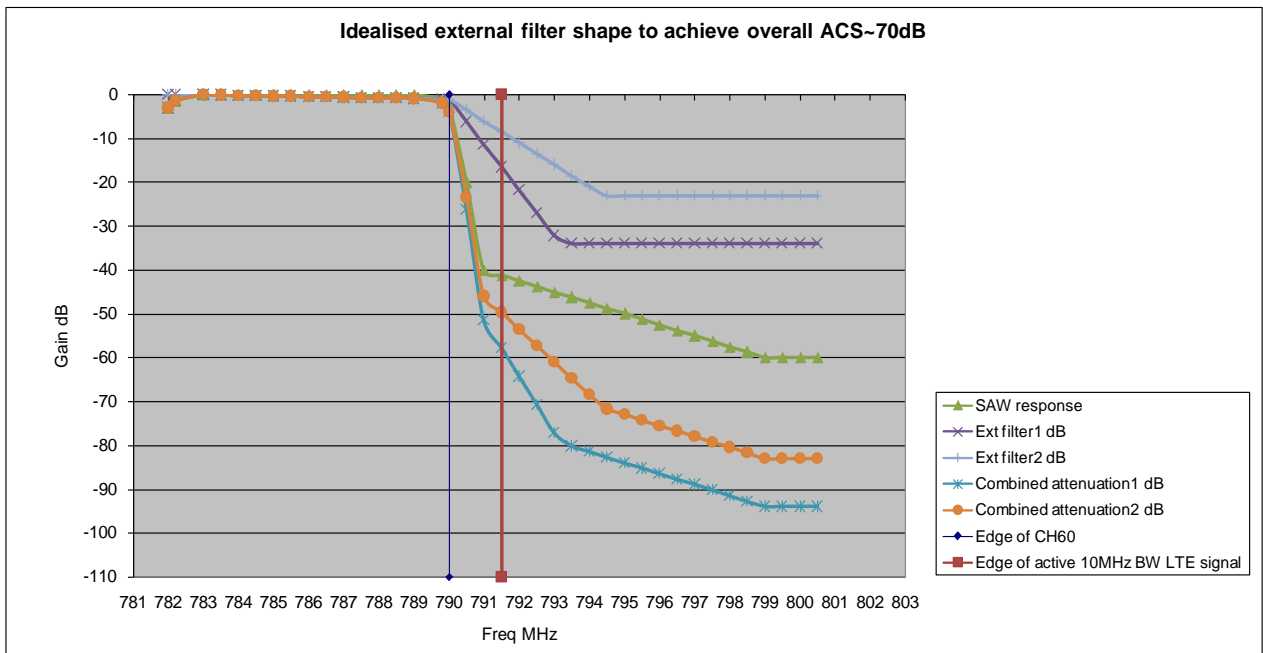


Figure 22 – Example showing two different external filter options to achieve an overall filter+receiver ACS of 70dB when the existing receiver filter is an x6966 SAW filter.

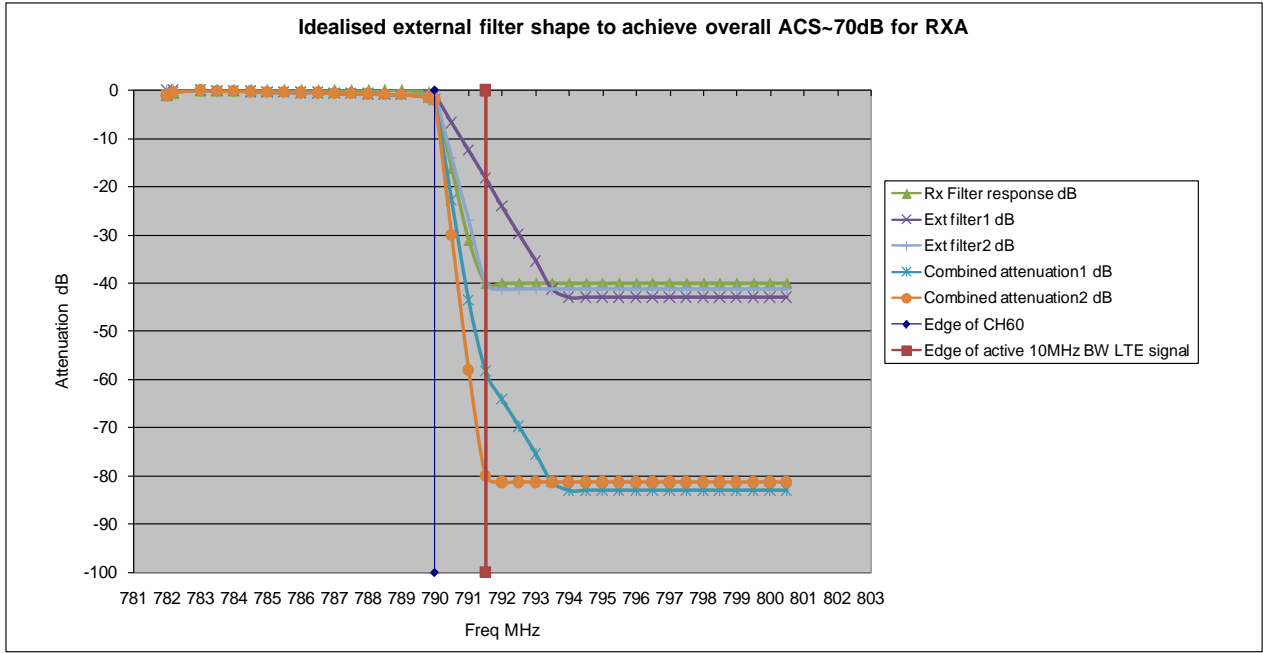


Figure 23 – Required external filter for overall ACS of 70dB assuming existing receiver filter = generic RXA

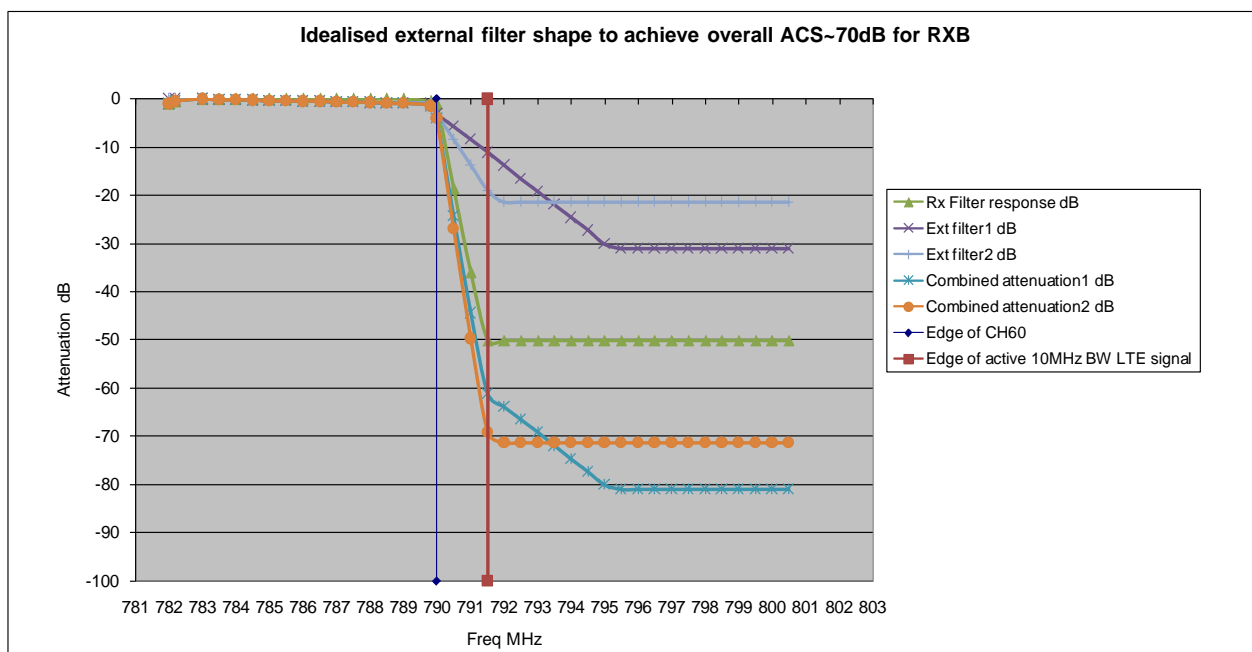


Figure 24 – Required external filter for overall ACS of 70dB assuming existing receiver filter = generic RXB

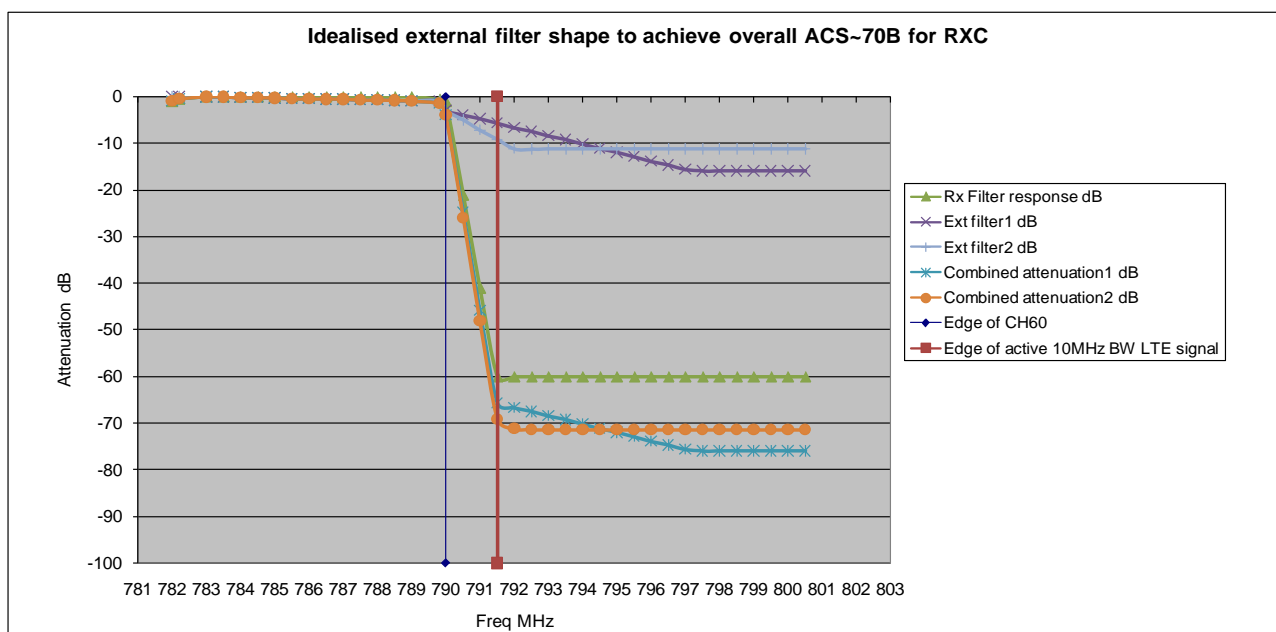


Figure 25 – Required external filter for overall ACS of 70dB assuming existing receiver filter = generic RXC

12.3 Filter technology overview

Filters can be made in several technologies. Each technology has its own set of capabilities and an inherent ease of readying for production. At the simplest level we have discrete component inductors and capacitors in classical LC filters. For frequencies at the top end of the UHF TV band we are reaching the point where physical layout of components and coupling between them starts to take over.

At these frequencies around 800-900MHz we also find that classical discrete components on a composite circuit board become significant in size when compared with a wavelength. The net result is that component losses tend to become dominant and simplistic approaches which can be used at lower frequencies are no longer possible, but we are not yet high enough in frequency for a full transition to microwave techniques.

The compromises in filter designs which are essential to provide consumer acceptable packages are considerable. We require that all TV channels should be passed with minimal loss. We also require the maximum possible suppression of the unwanted signals which can start about 1.5 MHz above the top edge of the TV channels. The transition from pass band to stop band is in the worst case only 1.5 in 790 MHz or a bit less than 0.2% change in frequency.

This is a very difficult requirement in both the achieving of a good suppression but also in maintaining a good stability with changes in temperature even in a domestic environment.

Some available technologies and their manufacturing issues are described below

12.3.1 Discrete LC

Discrete LC which is able to provide good basic rejection with careful PCB layout and screening but the inherent component losses will almost certainly lead to a pronounced spreading of the transition region so that some significant losses may be inevitable on wanted channels. In the case where the wanted TV channels in an area are well below the LTE then these filters may be perfectly adequate and will be the cheapest and quickest to market in a compact format.

12.3.2 Ceramic resonator

Ceramic resonator technologies can be used to enhance the performance of the simple discrete filter. However to get the full advantage of this technology will require a thorough knowledge of their behaviour and component placement and board layout. The PCB itself will start to take over in terms of stray capacitance and coupling lead inductances. The Q factor of these components is very significantly higher than of standard discretises so a considerable improvement up to our targets should be possible.

12.3.3 SAW

The next step is to items requiring significant up front tooling costs. The first of these is SAW technology. SAW filters are certainly possible at these frequencies. They are however usually characterised with insertion losses of many dBs in the wanted signal. They also are usually able to provide unwanted signal attenuation above 40 dB relative to wanted signal fairly rapidly. They provide rapid transitions when seen in IF strips at 36MHz but when you scale this by a factor of 20 in frequency the compromises become significant. So SAW is perhaps not the way to go but has some possibilities if very high volumes and a lot of up front development work is done.

12.3.4 FBAR etc.

We then have possibilities which are much more like making physical structures actually in the silicon and other materials that is used for IC manufacture. These are techniques where the companies with the capability guard the use heavily with patents. There are significant upfront costs and intellectual property rights issues that would have to be overcome before viable domestic products would appear. These technologies are certainly capable of providing very high performance in these frequencies and are well known to the mobile phone industries where they are used extensively in the duplexers for handsets, however their suitability for this application requires further investigation.

12.3.5 Cavity filters

Finally we have the use of physical “plumbing” mechanical techniques. These can supplement the performance of filters or we can actually implement filters as components made from tuned circuit elements consisting of real coupled transmission lines or their electrical and mechanical analogue in the shape of resonant cavities in metal. There is certainly scope in the design of rooftop antenna antennas feed systems to incorporate frequency selective notches using both of these techniques. Perhaps this is the design technique for the future rooftop antenna. Please note the inherent losses in standard coaxial cables are so high that reactive notch stubs made from coaxial cable have an excessively wide frequency characteristic in this application, but can be very effective and extremely cheap to make if you a good frequency separation say lower band 5 wanted signals around 500 MHz to 600 MHz and LTE at 796MHz.

The compromise is that the element sizes in metal are a bit too big at these frequencies to be friendly in a domestic environment. They are however perfectly adequate for housing in enclosures in a roof space or wiring cabinets at the head ends of MATV systems. They typically end up as looking like blocks of metal the size of shoebox and are several kilos in weight. Their performance can be extremely good and satisfy our requirements easily. They have not traditionally been production engineered in a way which suits mass production so there may still be some new challenges to overcome for volume production.

12.3.6 Connectors

Most of the filters which are currently on the market come with F-type connectors (see also section 14), whereas almost all DTT receivers or TV have IEC connectors. For some of the filters listed in section 14, F-connectors and/or filter dimensions are an integral part of the filter design. However, for larger volumes a re-design might be appropriate in order to avoid additional adaptors.

On the other hand, performance of IEC-connectors is worse than F-connectors with respect to EMC issues. An option to minimize this effect might be a fly-lead with an integrated filter.

13 Insertion loss study

13.1 Introduction

Any device which is inserted into an existing receiving chain causes an additional attenuation, often called “insertion loss”. Such losses have an impact on coverage of existing networks and need to be taken into account for DVB-T/T2 network planning in the future, e.g. as an increase of the receiver noise figure.

In a first attempt, the amount of potential losses in coverage has been studied for different networks in Germany, covering the impact on:

- Coverage by a single transmitter, with reception “focus” mainly in densely populated area
- Single-frequency networks (SFN), with reception “focus” in densely populated area as well as in rural area
- Fixed reception as well as on portable indoor reception
- Population coverage and on area coverage (for outdoor/mobile coverage), for location probability above 95%.

13.2 Case study

In all cases, a typical standard prediction⁵ has been used as a reference (‘basis’), in line with predictions agreed by all regional DVB-T projects in Germany and provided to the public, e.g. on web site “www.ueberallfernsehen.de”.

Different networks were studied, e.g.

- Nuernberg, channel 60, single transmitter, “focus” on densely populated area but surrounded by rural area
- Five multiplexes are in operation which can be received portable indoor in Nürnberg as well as in other big cities close by, e.g. in Erlangen and Fürth. Amongst them is channel 60, carrying 4 commercial programs.
- Rhein-Main, channel 59, SFN, “focus” on densely populated area
- Six multiplexes are in operation in the Rhein-Main area, which can be received portable indoor in several larger cities like Wiesbaden, Mainz and Frankfurt/Main. Population in the entire area is more than 6 millions.
- Berlin, channel 59, SFN (two transmitters), “focus” on densely populated area
- Nine multiplexes are in operation in Berlin, covering an area of about 5 million people portable indoor. The SFN consists of two transmitters, where the main one is in the city centre (antenna height about 350m). Two scenarios were studied, differing in the ERP for both transmitters.
- Karlsruhe, channel 60, SFN (three transmitters), “focus” on densely populated as well as rural area
- Three transmitters are in operation in south-west of Germany, covering the entire allotment area as contained in the GE06 Digital Plan with fixed reception, as well as almost all bigger cities in this area portable indoor.
- Sauerland, channel 60, SFN (three transmitters), “focus” on rural area. All three transmitters are at relatively high locations, covering a mainly rural, mountainous area (up to 1000m).

As an example, Figure 26, Figure 27 & Figure 28 below provides some insight view into what happens for portable reception and where losses occur. It can be clearly seen that there is no common coverage area, and that “edge of coverage” does not exist.

⁵ in line with those predictions provided on official web sites in order to inform the public

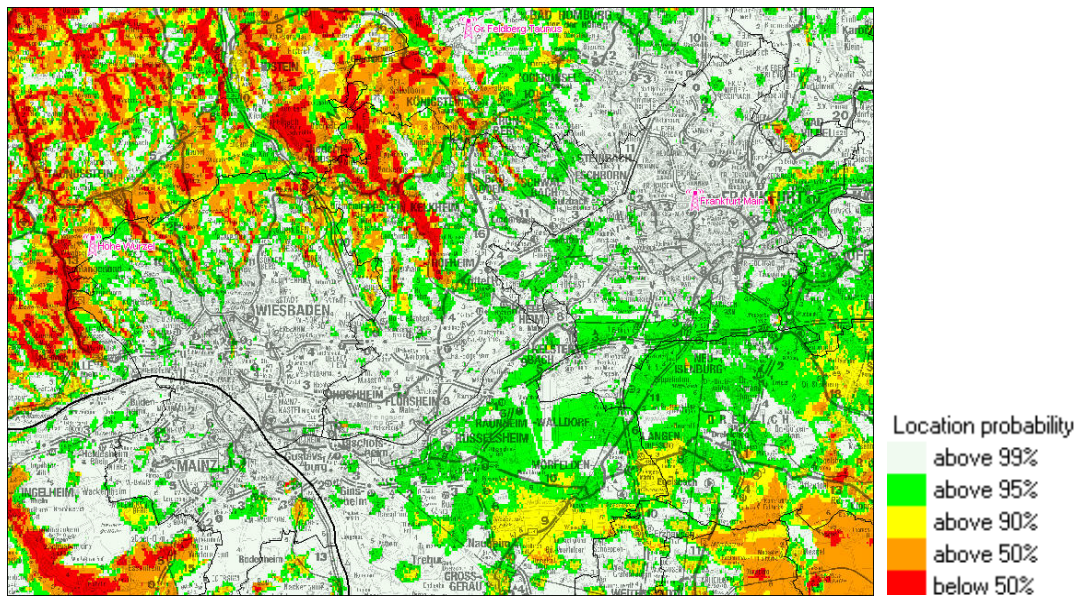


Figure 26 - Main CH59, portable indoor reception, prediction for standard parameters

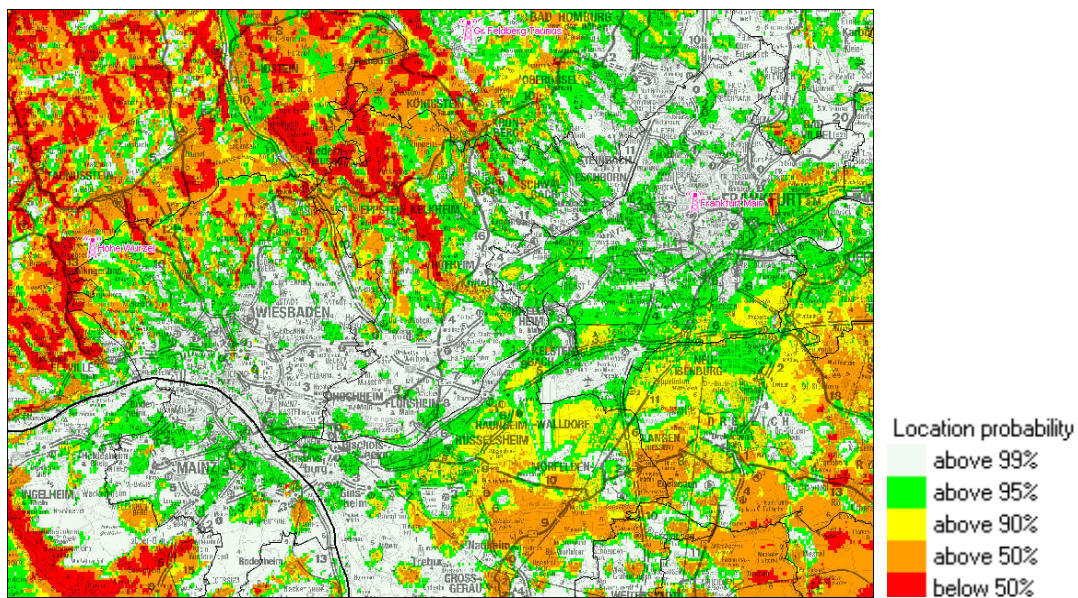


Figure 27 - Main CH59, portable indoor reception, prediction for 3dB of additional attenuation

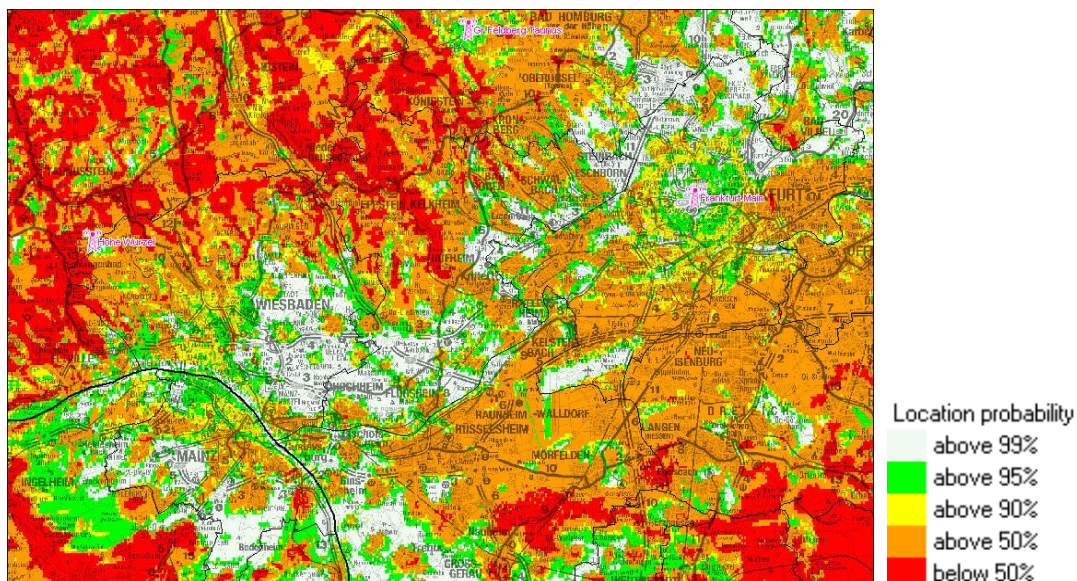


Figure 28 - Rhein-Main CH59, portable indoor reception, prediction for 10dB of additional attenuation

The results can be found in Figure 29 & Figure 30 for a location probability of 95% and fixed reception as well as portable indoor reception of DVB-T. Both figures provide a good overview on “impact ranges” of additional losses on population coverage.

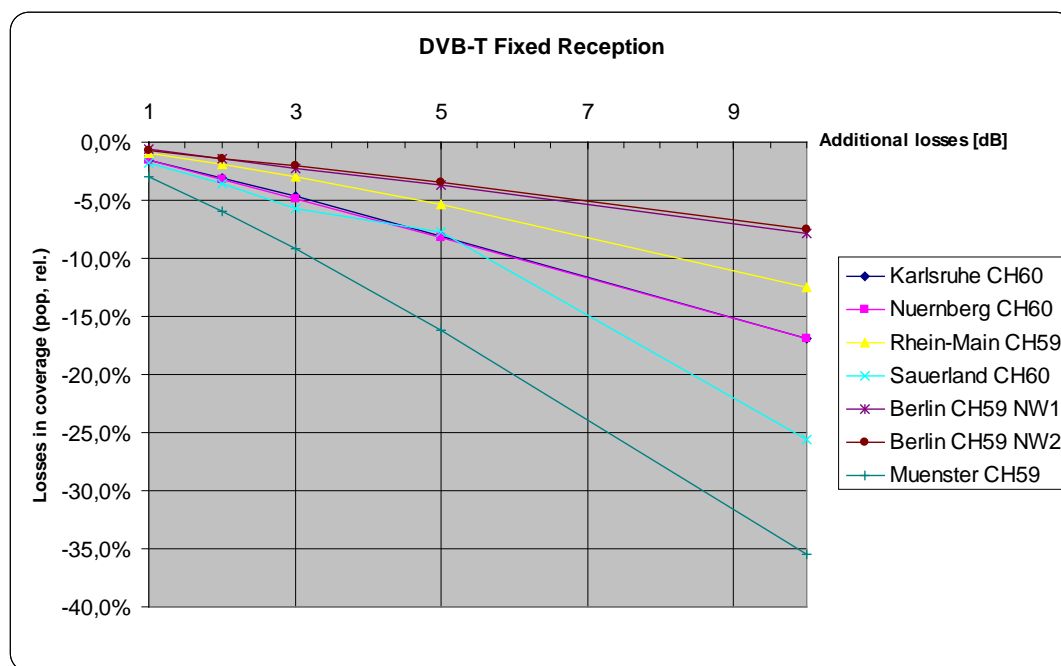


Figure 29 - Results for fixed reception for different areas/networks

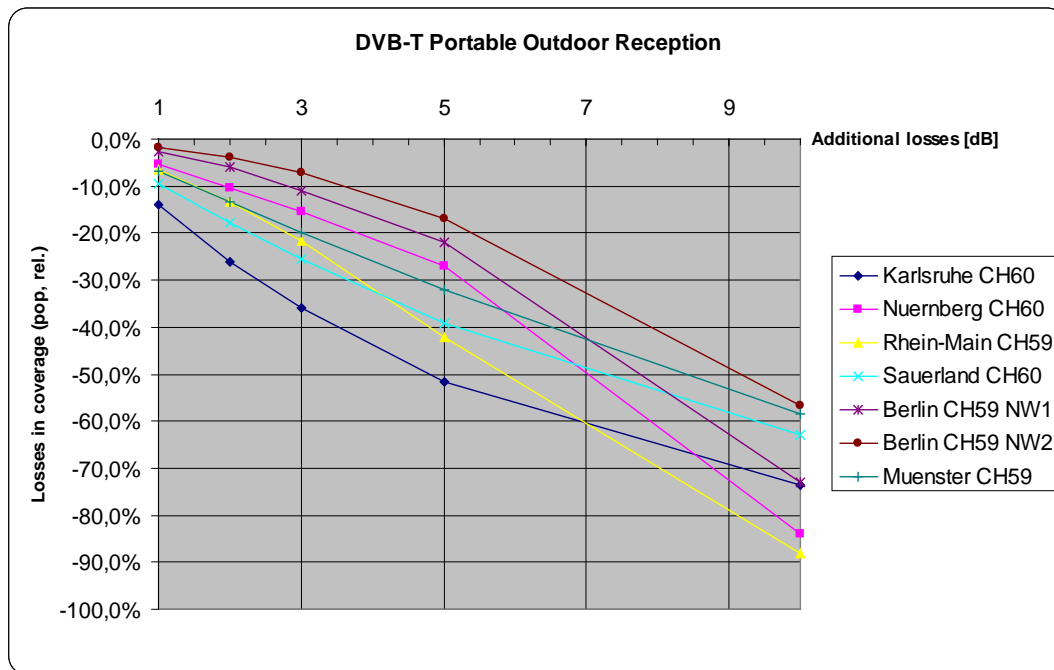


Figure 30 - Results for portable outdoor reception for different areas/networks

13.3 Summary

From all results presented, it can be seen that any additional attenuation above 1 dB may lead to severe losses in coverage, especially (but not limited to) for portable DVB-T/T2 reception.

There is a common trend in all results: relative coverage loss is much higher for portable reception than for fixed reception (e.g. compare Figure 29 with Figure 30). An obvious reason is that portable coverage is provided (mainly) in densely populated areas, whereas fixed reception covers areas with (much) lower population density as well. Other reasons might be

- Location of transmitters and vertical antenna patterns
- General “nature” of portable coverage, i.e. that there are many weak points even inside the coverage area (if shadowing by a large building occurs and reception is provided only by reflections)

More studies are needed, e.g. for other types of DTT networks.

All predictions for portable indoor were made for reception of a single multiplex, only. Due to diffraction/reflection varying with frequency and resulting in different location of field strength maxima for different channels, it can be expected that changes for a certain channel may lead to consequences with respect to concrete antenna location, e.g. that no single point can be found anymore where all channels can be received.

Information in this section is based on ref. 14.

14 Survey of existing filter solutions

The aim of this section is to provide some information on filters which are sold in order to improve protection of DVB-T equipment against interferences from LTE downlink and/or uplink signals.

Table 6 gives an overview on filters which are currently available on the German market.

Item	Specifications							costs €/unit	measure- ments
	pass band [MHz]	stop band [MHz]	insertion loss [dB]	rejection	dimensions [mm]	connectors	DC pass		
1	0.3 - 790	822 - 1000	≤ 1.0 (5-700MHz), ≤ 3.0 (700-790MHz)	> 50 dB	Ø 21, length 73	F-type (m/f)		about 12	yes
2	0.3 - 782	814 - 1000	≤ 1.0 (5-700MHz), ≤ 3.0 (700-784MHz)	> 50 dB	Ø 21, length 73	F-type (m/f)		about 12	yes
3	0.3 - 777	806 - 1000	≤ 1.0 (5-700MHz), ≤ 3.0 (700-774MHz)	> 50 dB	Ø 21, length 73	F-type (m/f)		about 12	yes
4	0.3 - 766	798 - 1000	≤ 1.0 (5-700MHz), ≤ 3.0 (700-766MHz)	> 50 dB	Ø 21, length 73	F-type (m/f)		about 12	yes
5	0.3 - 758	790 - 1000	≤ 1.0 (5-700MHz), ≤ 3.0 (700-758MHz)	> 50 dB	Ø 21, length 73	F-type (m/f)		about 12	yes
6	0 - 790	820 - 2700	≤ 2.0	40 dB	16 *30 *46	IEC, DIN 45325		about 30	no
7	0 - 744	804 - 2700	≤ 2.0	40 dB	16 *30 *46	IEC, DIN 45325		about 30	no
8	5 - 780	790 - 2050	≤ 1.0	max. 50 dB		F-type (m/f)	yes	about 16	yes*
9	0.1 - 790	800 - 2200	≤ 1.0	> 45 dB	59 *17 * 17	F-type (m/f)	yes	about 13	
10	5 - 780	800 - 2200	about 1.0	above 40 dB	59 *17 * 17	F-type (m/f)	yes	about 13	yes*
11	5 - 790	822 - 1000	typ. 1.0	typ. 50 dB	Ø 25, length 75	F-type (m/f)		about 16	

Table 6 - Overview on filters available on the German market

Notes:

- Some of the filter models are very similar, so they seem to be from the same manufacturer
- Currently, all measurements were made on a very limited number of devices, i.e. one to four.
- All measurements were carried out under lab conditions, i.e. any environmental impact has not been studied.
- The last column of Table 6 indicates that measured insertion loss was much bigger than specified.
- Most of the items come with F-type connectors. Therefore, additional losses need to be taken into account for adaptors.

In the following, some information is provided for a few items/filters listed in Table 6.

Item #1 of Table 6

This filter comes in five different models, with different cut-off frequencies and following specifications. Two different filters of the model with highest cut-off frequency /790 MHz) were measured. The difference between both was negligible, and results are shown in Figure 31. According to these measurements, insertion loss below channel 60 is about 1.5 dB at 770 MHz (channel 58) and about 1 dB at 746 MHz (channel 55).

A group delay of +40 to -50ns has been measured. Taking into account a symbol duration of 224 μ s (2k FFT) or 896 μ s (8k), no signal distortions are expected for DVB-T reception.

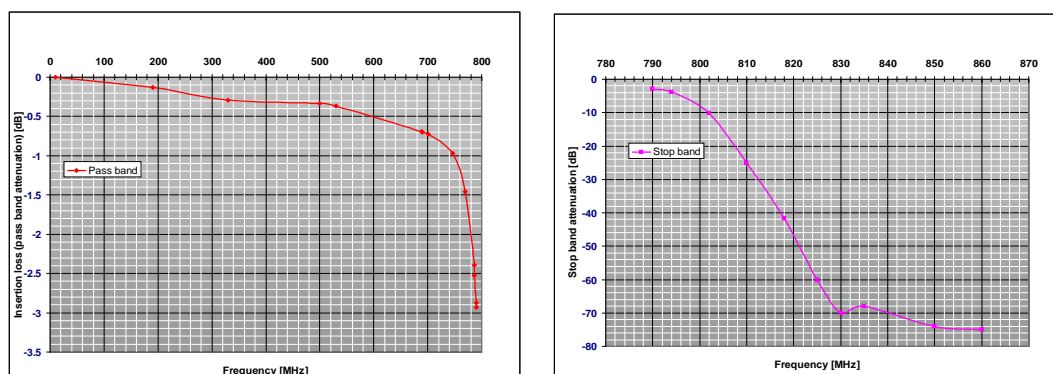


Figure 31 - Attenuation in pass band (left; insertion loss) and in stop band (right, rejection) for item #1

Item #10 of Table 6

This filter is quite similar to item #9, and one filter has been measured.

Measured insertion loss up to channel 39 might be acceptable, but it is very high e.g. around channel 50 and especially above channel 56 (see Figure 32).

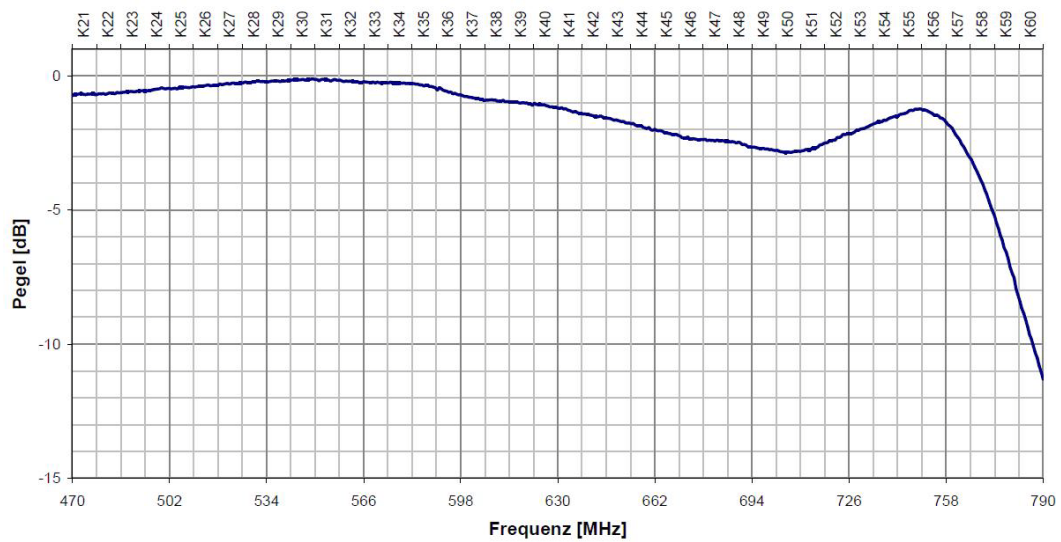


Figure 32 - Insertion loss (y-axis) vs. frequency (x-axis, in MHz) for item #10

15 Further study items

This report covers only an initial study of filter characteristics that might be helpful in mitigating the effects of interference from LTE base stations on the coverage of digital TV terrestrial broadcasts. Several areas were identified for further study to confirm the practical viability of the measures put forward in this study. These areas are:

1. Discussions with filter manufacturers to gain feedback on the feasibility of the proposed filter responses, and to trade-off performance vs. cost. One issue that needs careful consideration is the effect of the tuner input return loss on the filter loading.
2. Tests of prototype filters on a range of receivers and under different reception conditions.
3. Complement the ideal filter characteristics provided in Table 4 by other important parameters like insertion loss and pass band ripple, in order to derive filter specifications for cases studied so far.
4. Check whether the resulting filter specification is suitable for the other interference scenarios shown in Table 1. Specific items need careful consideration, e.g. overall noise figure, insertion loss and overloading.
5. Further studies are needed on intermodulation.
6. Further studies are needed around how to avoid/minimize confusion of customers if a channel close to channel 60 is to be used in a certain area in the future – e.g. for migration purposes, but filters with a certain attenuation for that channel were provided in order to solve interference problems in lower channels.
7. The effect of overloading in booster amplifiers needs further study because recent field experience is showing this to be a particularly common problem. Often these are old designs left over from analogue TV days which have not caused problems to DTT reception until they are subject to higher levels of interference.

16 Conclusions

This initial study has examined some aspects of interference into fixed DTT receivers caused by LTE base stations deployed in the 800MHz digital dividend band in Europe. An ‘ideal’ specification for a consumer grade external filter has been determined that could be inserted in line with the TV antenna cable for roof top reception cases to improve rejection of LTE interference in a majority of cases, depending on specific local conditions. The aim has been to address the most likely interference situations – based on the same general assumptions as used by CEPT in Report 30 – rather than extreme cases which may need more expensive filters or other mitigation methods. The filter requirements are quite challenging with today’s technology and a relaxed specification filter is also proposed that can still reduce the effects of LTE interference in areas further from the base station.

Other interference scenarios, such as indoor portable reception and interference from the user/consumer terminal have not been considered in this study. It may be that the same filter specification may be sufficient in such reception conditions, but drawbacks such as insertion loss need to be seriously considered.

For community antenna distribution systems, it is likely that a higher-selectivity filter is required but at least the higher cost of such a device might be shared amongst the community of users. The requirements of such filters (and associated distribution amplifiers) have not been considered in this study.

Areas of further work have also been identified that are necessary in order to confirm the practical viability of the mitigation measures proposed in this document.

It must be stressed that the use of in-line filters to reduce high-levels of adjacent channel interference from LTE base stations is only one of many mitigation measures that may be necessary to ensure that DTT coverage is not significantly impaired. Most of the other measures require the direct involvement of the Mobile/Fixed Network Operator.

17 Annex A – Simulation assumptions and results

Parameter	Value
BS EIRP	64dBm/10 MHz (Urban)
BS antenna height	30 m (Urban)
BS Antenna tilt	-4°
BS elevation antenna gain pattern	See Figure 33
Frequency	790 MHz
TV Tower (TT) EIRP	72dBm/8 MHz (Urban)
TT Antenna height	100 m (Urban)
TT Elevation antenna gain pattern	See Figure 34
TT distance to TV Rx	32 km (edge of cell)
TV Rx NF	7 dB
TV Rx noise bandwidth	7.6 MHz
TV antenna height	10m
TV antenna gain	7dBi (including feeder losses of 5dB)
TV antenna tilt	0°
TV azimuth/Elevation antenna gain pattern	See Figure 35
Min TV Rx SINR requirement	18 dB, 21 dB & 23dB
TV antenna polarisation discrimination	-3 dB (due to use of LTE MIMO with 45deg. slant polarisation), see Figure 36

Table 7 - Assumptions for simulation model

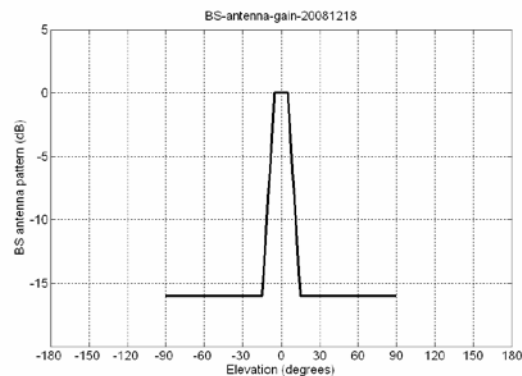


Figure 33 - BS antenna pattern (elevation)

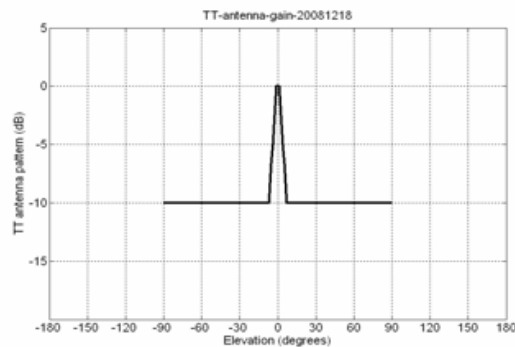


Figure 34 - TT antenna pattern (elevation)

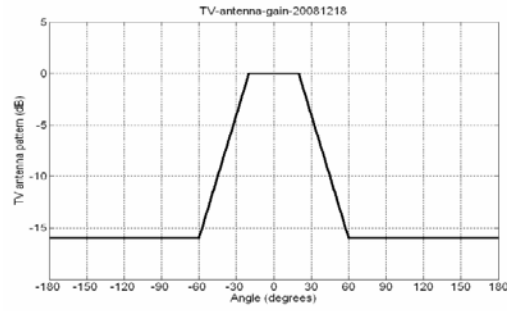


Figure 35 - TV antenna pattern elevation+azimuth

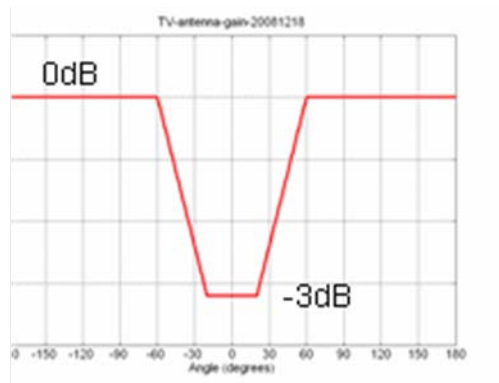


Figure 36 - TV antenna pattern polarisation discrimination assuming LTE MIMO 45° slant polarisation

17.1 Propagation models used

These models were based on the same models (Hata urban for mobile & P.1546 for DTT) as used in ref. 1

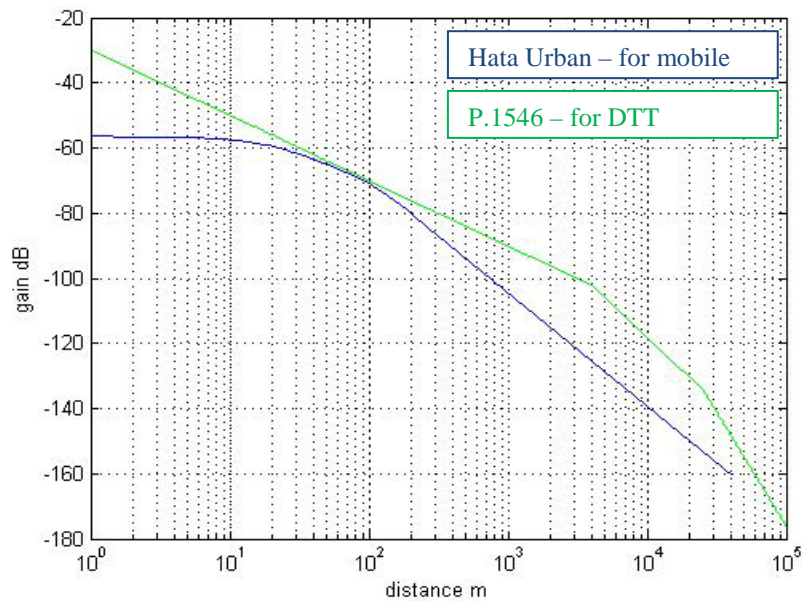


Figure 37 - Propagation models used in simulation

17.2 Simulation results for 0.5dB degradation of SINR @18dB

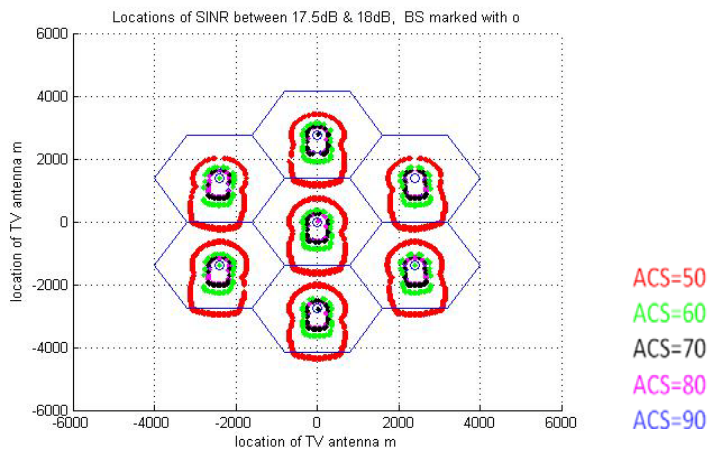


Figure 38 – Simulation results for BS OOB = 0dBm/10MHz

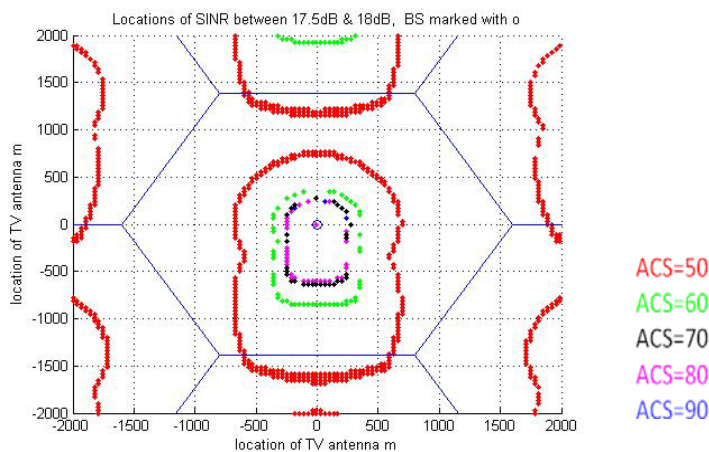


Figure 39 – Simulation results for BS OOB = 0dBm/10MHz for centre BS. ACS=70dB ideal, 60dB useful

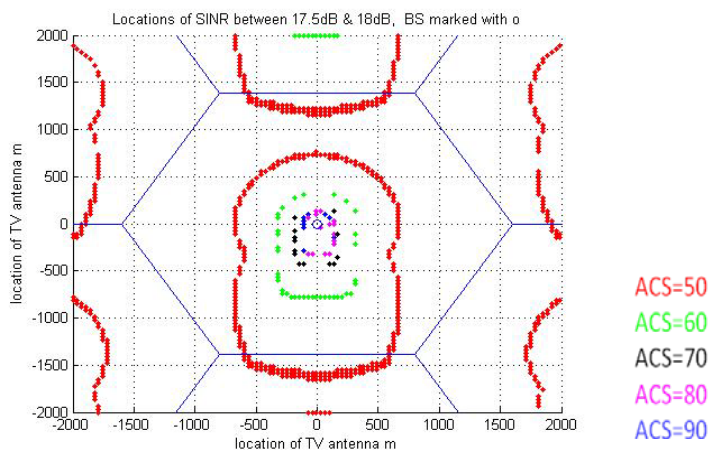


Figure 40 – Simulation results for BS OOB = -10dBm/10MHz for centre BS. ACS=80dB ideal, 70dB useful

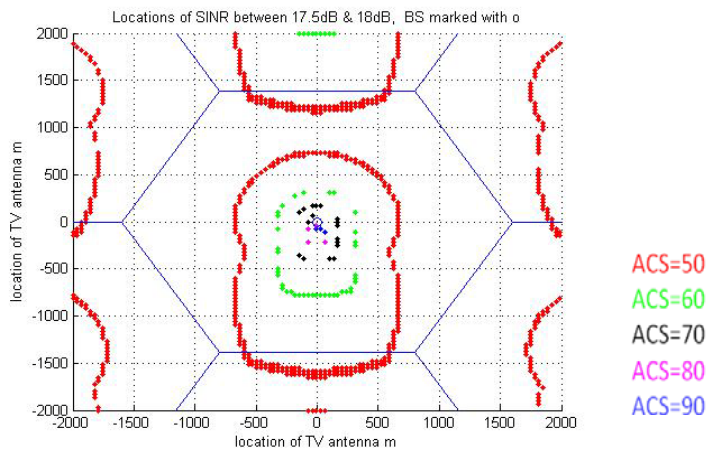


Figure 41 – Simulation results for BS OOB = -20dBm/10MHz for centre BS.

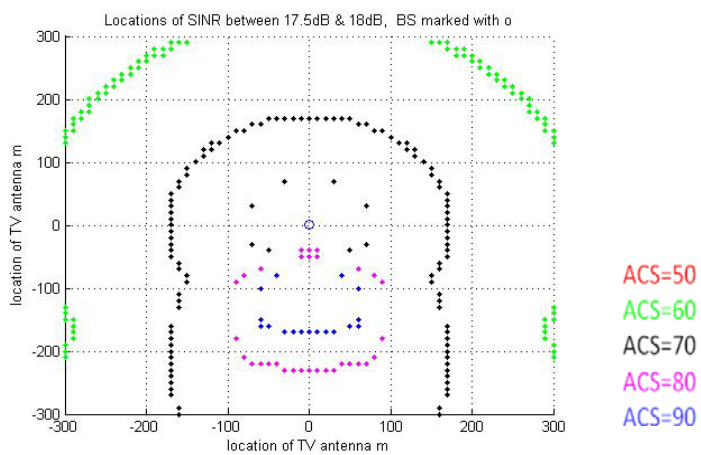


Figure 42 –Simulation results for BS OOB = -20dBm/10MHz – zoom on centre BS. ACS=90dB ideal, 80dB useful

17.3 Simulation results for 0.5dB degradation of SINR @21dB

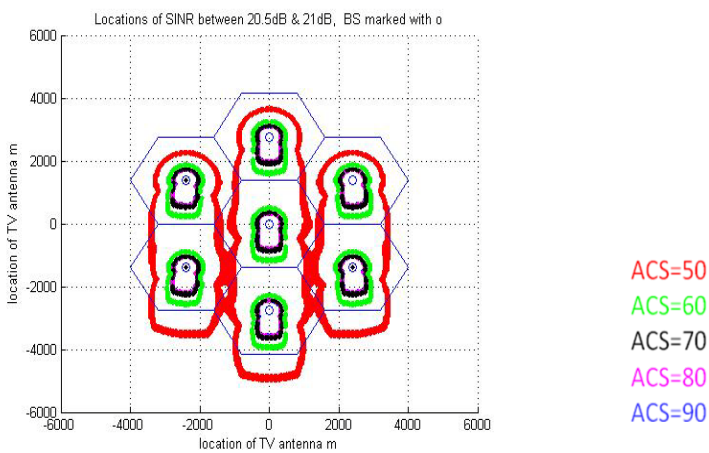


Figure 43 – Simulation results for BS OOB = 0dBm/10MHz

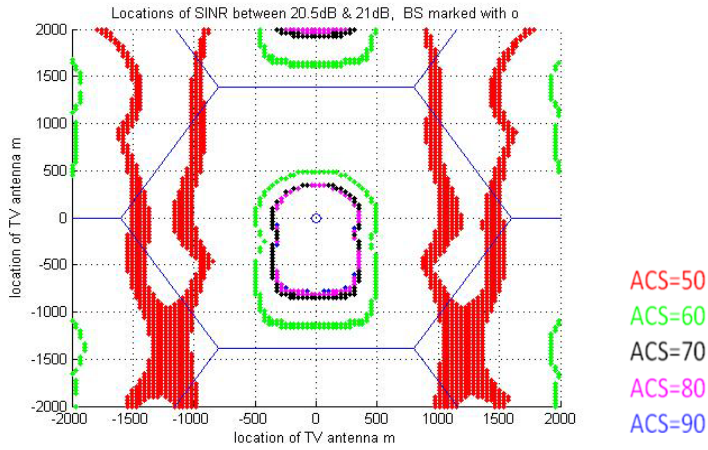


Figure 44 – Simulation results for BS OOB = 0dBm/10MHz for centre BS. ACS=70dB ideal, 60dB useful

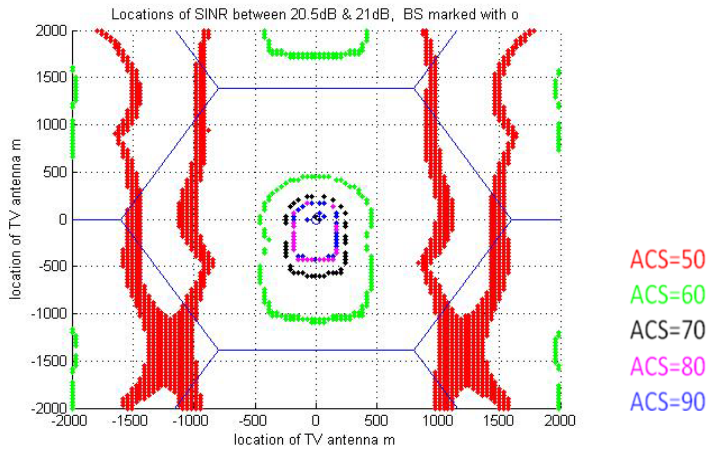


Figure 45 – Simulation results for BS OOB = -10dBm/10MHz for centre BS. ACS=80dB ideal, 70dB useful

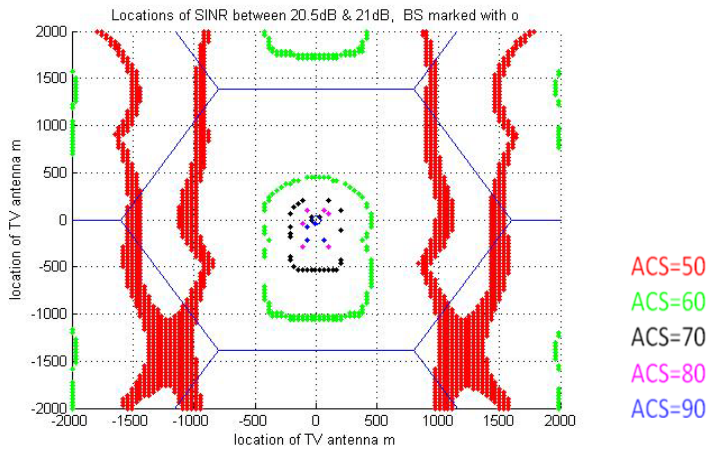


Figure 46 – Simulation results for BS OOB = -20dBm/10MHz for centre BS

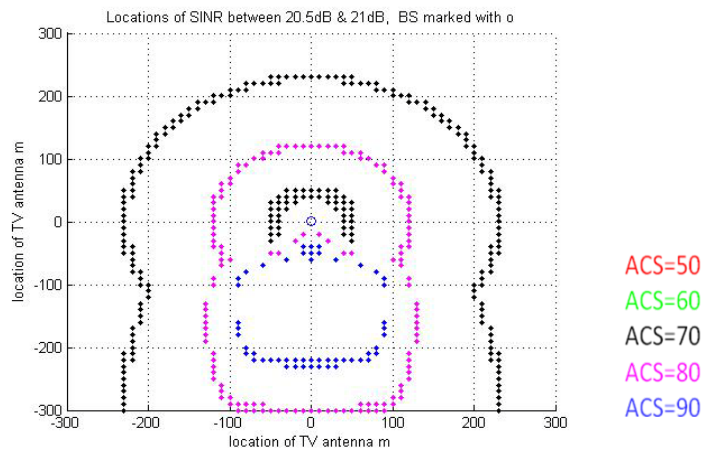


Figure 47 – Simulation results for BS OOB = -20dBm/10MHz – zoom on centre BS. ACS=90dB ideal, 80dB useful

17.4 Simulation results for 0.5dB degradation of SINR @23dB

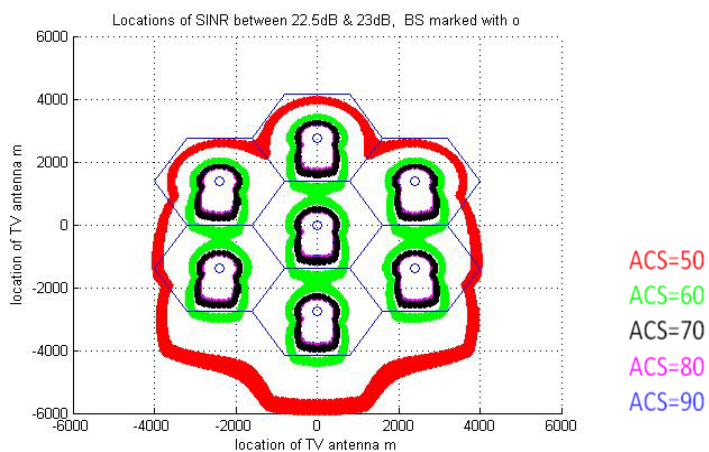


Figure 48 – Simulation results for BS OOB = 0dBm/10MHz

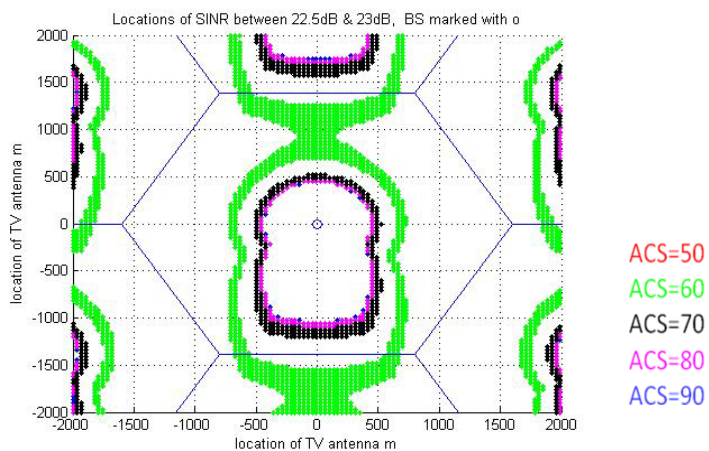


Figure 49 – Simulation results for BS OOB = 0dBm/10MHz for centre BS. ACS 80dB ideal, 70dB useful

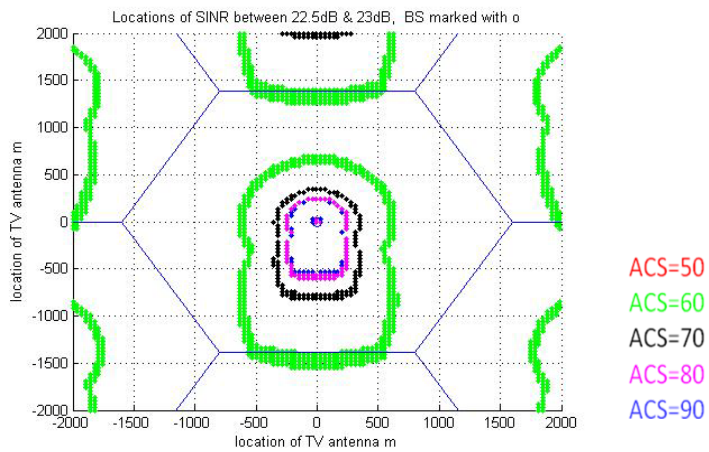


Figure 50 – Simulation results for BS OOB = -10dBm/10MHz for centre BS. ACS=80dB ideal, 70dB useful

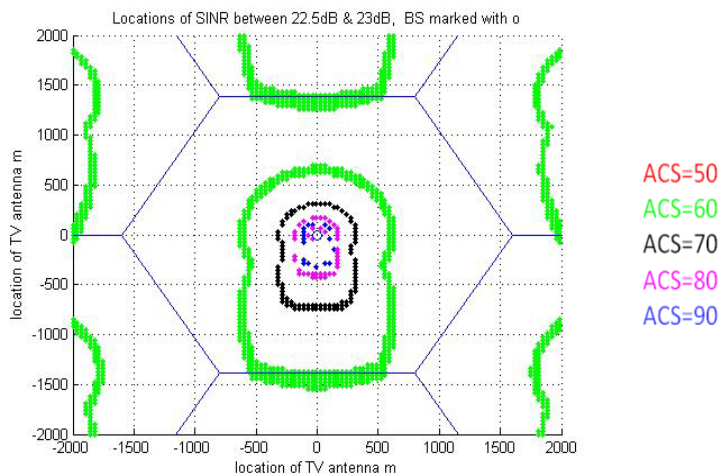


Figure 51 – Simulation results for BS OOB = -20dBm/10MHz for centre BS. ACS=90dB ideal, 70dB useful

17.5 Simulation results for 3dB degradation of SINR@21dB

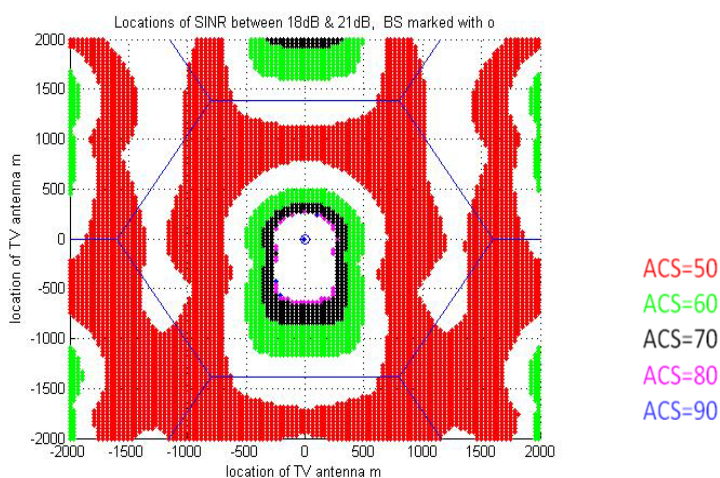


Figure 52 – Simulation results for BS OOB = 0dBm/10MHz for centre BS. ACS=70dB ideal, 60dB useful

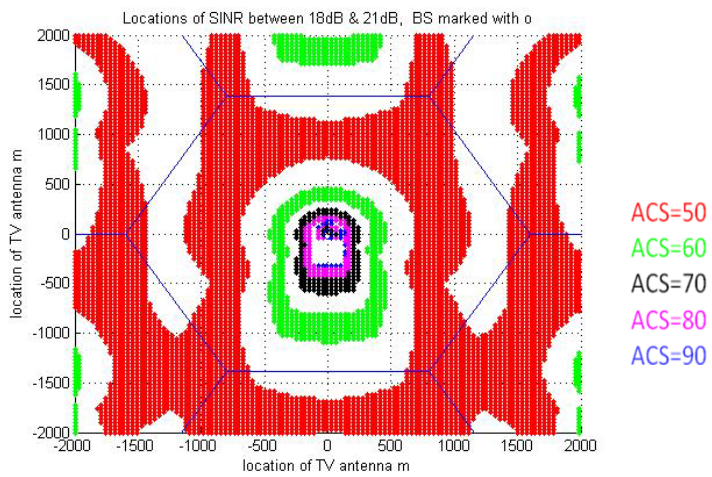


Figure 53 – Simulation results for BS OOB = -10dBm/10MHz for centre BS. ACS=80dB ideal, 70dB useful

18 Annex B – Receiver measurements

The tables below are limited to protection ratio measurement results at low wanted signal levels representing the situation at the edge of coverage area, made on a small set of receivers with LTE interference in nearby channels with traffic loadings of ~0% (idle) and 100%, using recorded waveforms from a real BS operating in test mode which have been further filtered to reduce the artefacts of the recording process.

18.1 ACLR measurements

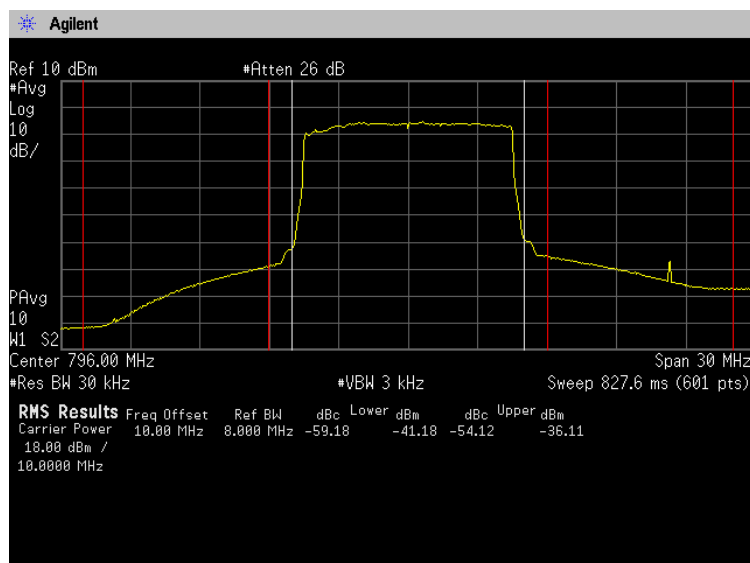


Figure 54 - ACLR measurement for 100% LTE traffic loading

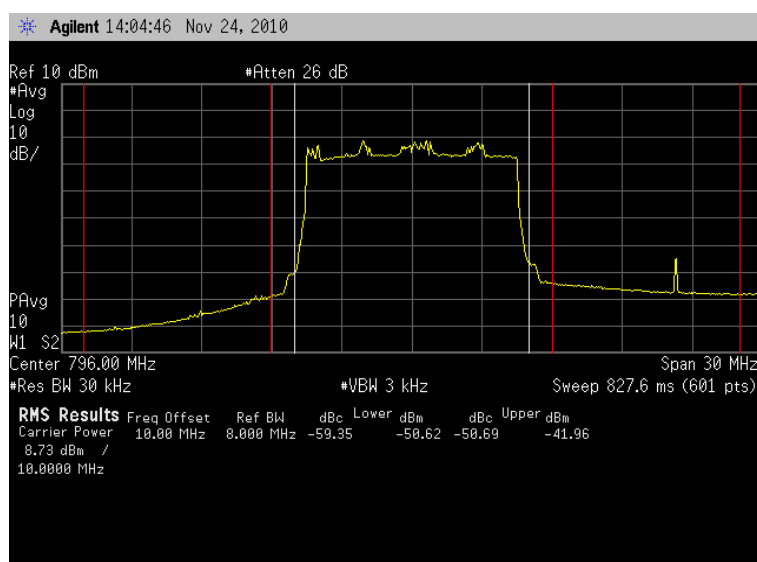


Figure 55 - ACLR measurement for 0% idle LTE traffic loading

Note the ACLR for channels 57-59 was estimated from Figure 54 (100% traffic loading) as 75dB and from Figure 55 (idle mode) as 70dB. The ACLR into channel 60 was set at the CEPT report 30 limit of 59dB as measured in these figures.

18.2 Protection ratio measurements

In these measurements the DVB-T/T2 modes were those used in the UK DTT network for fixed reception.

- DVB-T: 8K, 64QAM, 2/3, 1/32.
- DVB-T2: 32KE, 256QAM, 2/3, 1/128, ROT, No TR, Lf=60 symbols

Note that the DVB-T2 measurements used the extended carrier mode, making them slightly more vulnerable to N+1 adjacent channel interference, so they cannot be directly compared with the DVB-T results.

TV Channel	RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11 (can)	RX12 (si)
60	-43.2	-39.1	-40.0	-39.3	-36.2	-36.0	-35.5	-35.1
59	-49.2	-45.8	-51.7	-43.8	-45.2	-47.7	-40.2	-46.6
58	-50.3	-44.3	-53.7	-44.2	-46.2	-49.7	-49.6	-49.0
57	-51.4	-42.5	-65.7	-44.3	-49.3	-51.4	-40.2	-50.9

Table 8 - DVB-T2 receiver protection ratios with 100% LTE traffic loading and wanted signal level -70dBm

TV Channel	RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11 (can)	RX12 (si)
60	-37.9	-34.6	-36.1	-18.9	-31.4	-17.6	-34.1	-17.5
59	-41.8	-43.0	-47.9	-22.7	-43.0	-24.0	-35.5	-23.5
58	-43.8	-41.2	-50.8	-23.0	-45.9	-30.3	-40.5	-30.1
57	-44.9	-44.0	-61.9	-24.8	-52.1	-33.8	-43.6	-35.6

Table 9 - DVB-T2 receiver protection ratios with LTE idle traffic loading and wanted signal level -70dBm

TV Channel	RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11 (can)	RX12 (si)
60		-41.5	-43.0	-44.1				
59		-44.2	-54.9	-45.9				
58		-50.5	-56.1	-46.7				
57		-52.5	-68.2	-47.8				

Table 10 - DVB-T receiver protection ratios with 100% LTE traffic loading and wanted signal level -70dBm

TV Channel	RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11 (can)	RX12 (si)
60		-33.3	-38.7	-19.1		-16.1		
59		-40.0	-48.4	-21.1		-21.8		
58		-44.0	-50.6	-21.8		-24.9		
57		-50.0	-61.0	-25.0		-27.0		

Table 11 - DVB-T receiver protection ratios with LTE idle traffic loading and wanted signal level -70dBm

18.3 Receiver ACS

The receiver ACS values in the table below were calculated from the measured protection ratios as follows:

$$ACS = [(C/I)/SIR - ACLR^{-1}]^{-1} \quad \text{where}$$

C/I = measured protection ratio (in this case at C=-70dBm)

SIR = measured co-channel protection ratio shown in the tables below

ACLR = measured adjacent channel leakage ratio

		ACS @ C=-70dBm							
ACLR @ -18dBm/10MHz		RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11(can)	RX12 (si)
dBc	CCI SIR dB:	15.4	21.0	18.3	17.2	18.8	19.0	20.0	21.4
	TV Channel								
59.2	60	67.3		65.5	59.8	57.1	57.0	57.8	59.9
75.0	59	65.0	67.5	71.6	61.2	64.4	67.3	60.3	68.9
75.0	58	66.2	65.8	75.0	61.6	65.4	69.8	71.0	72.2
75.0	57	67.5	63.8		61.8	69.1	72.2	60.3	75.6

Table 12 - DVB-T2 receiver ACS performance with 100% LTE traffic loading and wanted signal level -70dBm

		ACS @ C=-70dBm							
ACLR @ -18dBm/10MHz		RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11(can)	RX12 (si)
dBc	CCI SIR dB:	17.2	18.0	16.5	17.9	18.3	18.8	19.1	19.4
	TV Channel								
59.4	60	57.1	53.7	53.7	36.7	50.2	36.4	54.4	36.8
70.0	59	59.4	61.6	65.7	40.6	61.9	42.8	54.8	42.8
70.0	58	61.7	59.6	70.7	40.8	65.5	49.2	60.0	49.5
70.0	57	62.9	62.7		42.6		52.7	63.6	55.1

Table 13 - DVB-T2 receiver ACS performance with LTE idle traffic loading and wanted signal level -70dBm

		ACS @ C=-70dBm							
ACLR @ -18dBm/10MHz		RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11(can)	RX12 (si)
dBc	CCI SIR dB:		14.6	18.2	15.5				
	TV Channel								
59.2	60		59.2						
75.0	59		58.9	77.4	61.7				
75.0	58		65.6	82.1	62.4				
75.0	57		67.9		63.6				

Table 14 - DVB-T receiver ACS performance with 100% LTE traffic loading and wanted signal level -70dBm

		ACS @ C=-70dBm							
ACLR @ -18dBm/ 10MHz		RX1 (si)	RX4 (can)	RX6 (si)	RX8 (si)	RX9 (can)	RX10 (si)	RX11 (can)	RX12 (si)
dBc	CCI SIR dB:		18.2	20.6	19.4				
	TV Channel								
59.4	60		52.2		38.5				
70.0	59		58.3	76.7	40.4				
70.0	58		62.4	70.3	41.2				
70.0	57		69.2	73.6	44.3				

Table 15 - DVB-T receiver ACS performance with LTE idle traffic loading and wanted signal level -70dBm