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COgnitive radio systems for efficient sharing of TV white spaces in EUropean context

D4.5
Guidelines for TVWS equipment certification and compliance – final

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Abstract:

D4.5 describes new measurement results for DVB-T receivers and identifies a 'typical' DVB-T receiver that is to be used for future comparison tests. The deliverable describes alternatives for the generation of multi-channel interference signals of different standards such as LTE and WiFi which may lead to test set-ups very close to scenarios in the field.

Deliverable D4.5 provides a high-level view of the process of certification of WSDs. It includes the description of two testbeds: the first one to evaluate the resilience of the existing population of DVB-T/T2 receivers against interference from WSDs, the second testbed for checking the conformance of WSDs with the requirements set by the regulatory authorities.

The first test set-up can be employed by the regulator, the second one can be used by a test centre or the WSD supplier itself, in the case of self-certification.

The guidelines also include a non-exhaustive list of parameters and data to be stored in a special archive for documentation purposes.

Keyword list: Protection ratio measurement, Overload threshold measurement, Typical DVB-T receiver, Multi-channel interference signals, TVWS, WSD, certification.

Executive Summary

This deliverable D4.5 reports the final guidelines for WSD equipment certification and extend the initial set of recommendations reported in the internal deliverable D4.4.

A set of measurements were carried out to establish the resilience of commercial DVB-T/T2 receivers. Investigations were made on the adjacent channel interfering effect of LTE Base Station (BS) and LTE User Equipment (UE) signals into DVB-T reception with iDTV receivers. The results were used to choose a typical iDTV receiver for the COGEU white space device (WSD) certification testbed.

Protection Ratios (PRs) were measured for the wanted DVB-T signal 8k 16QAM 2/3 received over a Gaussian transmission channel and the interfering signal in the adjacent channels N+1 to N+11. Eleven DVB-T receivers were used in the measurements, nine iDTV receivers and two USB-sticks. The PRs median and the 90-%-percentiles for all receivers and for each adjacent channel were calculated. They have different values for LTE-UE and LTE-BS interfering signal.

The PRs for 90% of the iDTV receivers in a Gaussian transmission channel for worst-case LTE-BS interferer are -40 dB in channel N+1 and -42 dB in the channels N+2 to N+9. In adjacent channel N+1 they are unchanged and in adjacent channels beyond N+2, where the noise floor is relevant, up to 13 dB higher than in CEPT/ECC Report 148.

The worst case PRs for 90% of the iDTV receivers in a Gaussian transmission channel for LTE-UE signal as interferer are -10dB in channel N+1 and -22 dB in the channels N+2 to N+9. More than half of the measured iDTV receivers have double conversion, which avoids the image frequency problem in adjacent TV-channel N+9.

A high level signal can interfere to the reception of another signal even if its spectrum does not overlap with the desired signal spectrum, by overloading the receiver front end. Overloading thresholds (Oth) for the DVB-T receivers were also determined. For LTE-BS as interferer 50% of the iDTV receivers are not overloaded for interferer levels below -3 dBm and 90% of the receivers are not overloaded for levels below -5 dBm. The 90% value is close to the values given in CEPT/ECC Report 148 for iDTV receivers in the adjacent channels beyond N+2. The new iDTV receiver 90% overloading threshold for LTE-UE as interferer is at a level below -26 dBm. This value is within the wide range of the values given in CEPT/ECC Report 148. A receiver with parameters close to the 50% PR and Oth values of the investigated receivers was chosen to be used in the COGEU white space device certification testbed.

A new mask for the LTE-UE signal is under discussion. As soon as it will be available, PR values can be recalculated from the measurement results presented here in accordance to the new spectrum mask. Therefore for the time being the LTE-UE PR values measured should not be considered for final planning purposes.

A test set-up was used to evaluate DVB-T/T2 USB receivers and to measure the respective PRs against WiFi interference (IEEE802.11n). The standard failure criterion of ESR5 is used, i.e. visible artefacts during a maximum of 1 second of such 20 second periods.

For WSD certification there are four technical specifications to be tested: RF output power measurement, WSD signal bandwidth, Out-of-block power in the DVB-T channels up to N±3 and WSDs spurious emissions. A testbed and a procedure for WSD certification concerning RF emission characteristics is proposed. The thresholds for these RF parameters are found by measurements of the failure points of the DVB-T/T2 receivers and should not exceed specific limits.

For the measurement of interference of DVB-T signals into WSDs, a simple test set-up provides a wide variety of different, configurable test signals. Based on a modified test instrument, multiple signals can be generated and amplified so that they can characterize the WSD in terms of selectivity, overload and sensitivity.

After several series of tests, the list of parameters that are needed for a sufficient accuracy in certification of TV White Space devices (WSDs) has been reviewed and up-dated.

Finally, the resilience of the DVB-T/T2 receiver population varies typically from country to country depending on the introduction of the DVB-T or DVB-T2 services in this country. To protect legacy receivers (i.e. old DVB-T receivers) which may not have the same selectivity of input signals or the same overload threshold as modern receivers, it could be useful to introduce an additional margin for WSDs, at least in countries where a significant number of legacy receivers is in operation (e.g. UK, I, F D). In countries where DVB-T or DVB-T2 services started over the last 3 or 4 years, this does not seem to be necessary.

For the documentation of the certification process, it is most likely that a repository is set up by the regulator where all the data of each type of WSD that has passed the certification process, are stored. Such central repository seems necessarily independent on the character of the certification process, whether it is self-certification by WSD manufacturers or certification by a central institution.

Table of Contents

1- Introduction

This deliverable D4.5 collects all the results of measurements on the COGEU coexistence evaluation testbed developed in WP4. It addresses the two main use cases:

- White Space Devices (WSDs) interfere with DVB-T signals;
- The interference of DVB-T signals into the WSD link.

Chapter 2 and Chapter 3 describe the test set-up and the measurements that constitute compatibility of WSDs and DVB-T/T2 receivers as primary users. Such a testbed is a prerequisite for the development of specifications for WSDs, and is typically used by the respective regulatory authority or by a test centre entrusted with the specification development.

Chapter 2 includes a comprehensive set of measurements with commercially available DVB-T/T2 receivers, both “silicon type” and “can type" when LTE interference signals over TVWS are present.

Chapter 3 describes PR measurements with a WiFi (IEEE802.11n) signal as interferer and DVB-T/T2 as the wanted signal.

Chapter 4 looks into the problems of the measurement of the resilience of WSDs in the presence of strong DVB-T signals and how such a measurement can be simplified.

Chapter 5 provides recommendations for a testbed for WSD certification that includes RF measurements (e.g. compliance with pre-defined templates) and the control characteristics (e.g. the quality of the communication between the WSD master and the slave device).

Chapter 6 addresses the administrative aspects and summarises the most important points for the documentation, the registration of the WSD and the archiving of test results.

Chapter 7 presents the main conclusions of this Deliverable.

2- Measurement results of interference by LTE secondary users

New investigations were made at IRT on the adjacent channel interfering effect of LTE Base Station (BS) and LTE User Equipment (UE) signals into DVB-T reception. The measurements were a continuation of the IRT-investigations presented to the ITU [7] and the ECC/TG4 [8] in 2009 and 2010. They were necessary, because technology made further progress in the last two years. The results were also used to choose a typical integrated Digital TV (iDTV) receiver for the COGEU white space device (WSD) certification testbed.

The interfering effect of a signal is metered by the protection ratio (PR). The interfering signal out of band spectrum amplitude has upper limits set by a spectrum mask. The worst case PR values are measured when the interfering signal spectrum amplitude is just below the spectrum mask.

It is very difficult if not impossible to shape the interfering signal spectrum to have exactly the shape of the spectrum mask. Every difference in the shapes is influencing the PR value, and therefore the measurement results in distinct laboratories are often different.
The CEPT spectrum masks given in [3] were considered. The LTE signals used in the IRT measurements were shaped to tally best to the spectrum masks at the LTE block edge. Further away in frequency the concordance was less good. The signal noise floor level was lower than the mask limit. In some earlier IRT PR measurements noise was added to the LTE signal in order to raise the base–noise level to the mask-level. Industry representatives protested at the CEPT-ECC organization to that signal shaping, stating that the real life LTE-BS signals are better than the mask, see [4]. Therefore we renounced to add noise to the signals used.

The LTE signal noise floor has a direct influence on the PR in adjacent channels farther than N+3. Would it be close to the spectrum mask, the PR for the channels beyond N+3 would be higher than the values found in the measurements described here. The PR with higher noise floor can be easily calculated from the measured values. The worst-case PR values given here were calculated. They can be recalculated if the spectrum masks will be changed.
PRs were measured for the wanted DVB-T signal 8k 16QAM 2/3 received over a Gaussian transmission channel and the interfering signal in the adjacent channels N+1 to N+11. Eleven DVB-T receivers were used in the measurements, nine iDTV receivers and two USB-sticks.
Using statistical analysis general values can be found. The PR values measured for one sort of receivers at a certain adjacent channel are considered to be Gauss (normal) distributed. The PRs median and the 90-%-percentiles for all receivers and for each adjacent channel were calculated. They have different values for LTE-UE and LTE-BS interfering signal.
The PRs for 90-% of the iDTV receivers in a Gaussian transmission channel for worst-case LTE-BS interferer and 8k 16QAM 2/3 DVB-T mode are -40 dB in channel N+1 and -42 dB in the channels N+2 to N+9. In adjacent channel N+1 they are unchanged and in adjacent channels beyond N+2, where the noise floor is relevant, up to 13 dB higher than in CEPT/ECC Report 148 [1].

The “worst case” PRs for 90-% of the iDTV receivers in a Gaussian transmission channel for LTE-UE signal as interferer are -10dB in channel N+1 and -22 dB in the channels N+2 to N+9.
For the LTE-UE signal as used in the measurements presented here as well as in the measurements for the CEPT/ECC Rep. 148 [1], the PR measured for the newer iDTV receivers in the adjacent channel N+1 is about 8 dB higher. In the other adjacent channels the differences are lower.

More than half of the measured iDTV receivers have double conversion, which avoids the image frequency problem in adjacent TV-channel N+9.
A new mask for the LTE-UE signal is under discussion. As soon as it will be available, PR values can be recalculated from the measurement results presented here in accordance to the

new spectrum mask. Therefore for the time being the LTE-UE PR values measured should not be considered for final planning purposes.

Overloading thresholds (O_{th}) for the DVB-T receivers were also determined. For LTE-BS as interferer 50% of the iDTV receivers are not overloaded for interferer levels below -3 dB_m and 90% of the receivers are not overloaded for levels below -5 dB_m. The 90% value is close to the values given in [1] for iDTV receivers in the adjacent channels beyond N+2.

The new iDTV receiver 90% overloading threshold for LTE-UE as interferer is at a level below -26 dB_m. This value is within the wide range of the values given in [1].

A receiver (#9) with parameters close to the 50% PR and Oth values of the investigated receivers was chosen to be used in the COGEU white space device certification testbed.

For the development of specifications of WSDs there are two governing principles that should be respected under all circumstances:

- The WSD signal should not disturb DVB-T/T2 reception more than a DVB-T/T2 interferer of the same power level, bandwidth and frequency positioning (e.g. protection ratio, overloading threshold)
- The WSD should not require more protection than a DVB-T/T2 receiver

Some WSD transmission system signals interfere stronger to DVB-T/T2 reception than DVB-T/T2 signals due to their pulsed nature. The knowledge of transmitter signal power, bandwidth, unwanted and spurious emissions etc. is not sufficient to estimate the interference level. It has to be measured with a representative DVB-T/T2 receiver. A result of this measurement could be more stringent limits for the out-of-block emissions for WSD-signals with pulsed signals compared to the limits for DVB-T/T2 signals.

2.1- Measurement conditions

2.1.1- Signal parameters and transmission channel

The DVB-T/T2 signal properties are set such that the typical situation in the country in question applies. For instance, the modes that are used in the UK are

- DVB-T: 64QAM/ 8k,
- DVB-T2: 256QAM/ 32k.

For Germany, the mode to be set is

- 16QAM/ 8k for DVB-T.

The respective parameters can be set at the test signal generator.

The LTE interfering signal had following parameters:

LTE-Downlink (BS):

– bandwidth 5 MHz, with all resource blocks (RBs) in all subframes used for data traffic, all with constant (0 dB) transmission power,

LTE-Uplink (UE):

– bandwidth 5 MHz, one sub frame in a radioframe used for traffic (1 ms out of 10 ms), all RBs in the subframe used, thus occupying the whole bandwidth. As a result the transmission power is pulsed with duty cycle 1/10. During the pulse the transmitted power is constant.

The measurements were carried through for the wanted DVB-T signal received in a transmission-channel of Gaussian type.

2.1.2- Failure criteria

Mass consumer DVB-T receivers do not provide an adequate output to measure relevant transmission quality parameters. Due to this reason, a subjective evaluation method called Erroneous-Second-Ratio 5% (ESR_5) was applied. The transmission is considered impaired when:

- more than one artefact in the picture shows up within a time frame of 20 s or
- the picture freezes or is blanked (sync loss)

For more details see ITU Recommendation ITU-R BT.1368 [2], Annex 6, part 2.

2.1.3- Interfering LTE signals

The interfering effect of a signal is metered by the protection ratio. The interfering signal out of band spectrum amplitude has upper limits set by a spectrum mask. The worst case PR values are measured when the interfering signal spectrum amplitude is just below this spectrum mask.

The interfering signal for the measurements was therefore shaped to be close to the spectrum mask. The out-of block spectrum mask (radiation limits) for ECN (Electronic Communication Networks) signals, a generic term for different communication systems like LTE, WiMAX, WiFi and so on, is given for Europe by the CEPT in Report 30 [3] (see also COGEU D4.3 [10]).

2.1.3.1 LTE-Base Station Signal

The LTE-BS signal was generated by a Rohde & Schwarz SMU 200A signal generator. Its output signal spectrum was compared to the CEPT spectrum mask defined in [3]. The LTE-BS signal was shaped to come close to the two inner corners of the spectrum mask by setting the LTE symbol time-domain windowing transition time in the LTE coder in the SMU 200A generator, see **Figure 2-1**. The LTE-BS spectrum mask for a transmitter with of 59 dB_m maximum power is shown as a blue line. The red line is the spectrum of the LTE-BS interfering signal as it was used in the measurement set-up.

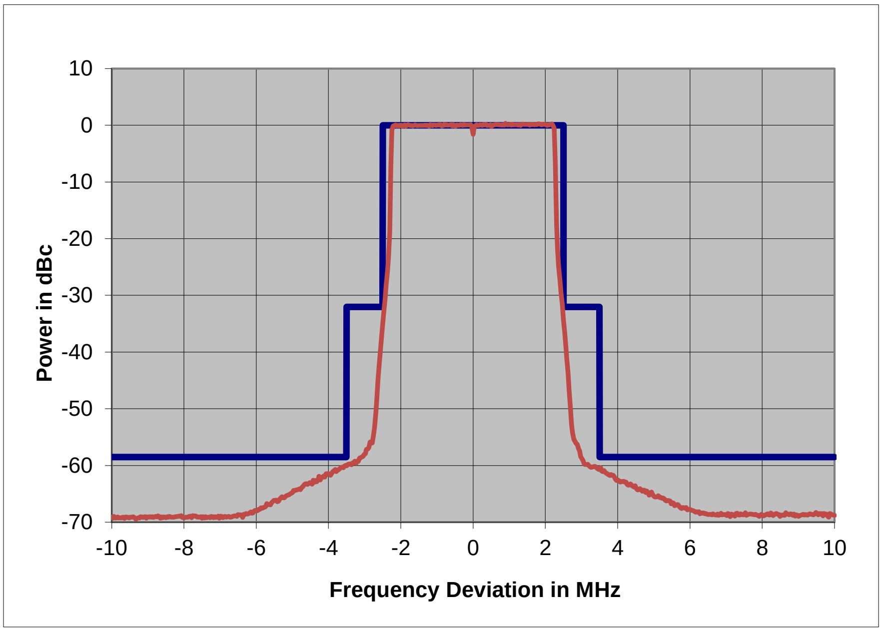

Figure 2-1 LTE-BS interfering signal mask (blue) and spectrum (red)

The base-noise level of the generated LTE signal is lower than the spectrum mask allows. In the IRT PR measurements of 2009 noise was added to the LTE signal in order to raise the base–noise level to the mask-level. The industry protested at the CEPT-ECC organization to that signal shaping, declaring that the real life LTE-BS signals are better than the mask, see [4] (ECC SE43(10)89). Therefore we renounced to add noise for this measurement and let the

LTE signal as is, see **Figure 2-2**. The worst-case PR values can be calculated using the base-noise floor of the mask. They can be recalculated if the spectrum masks will be changed.

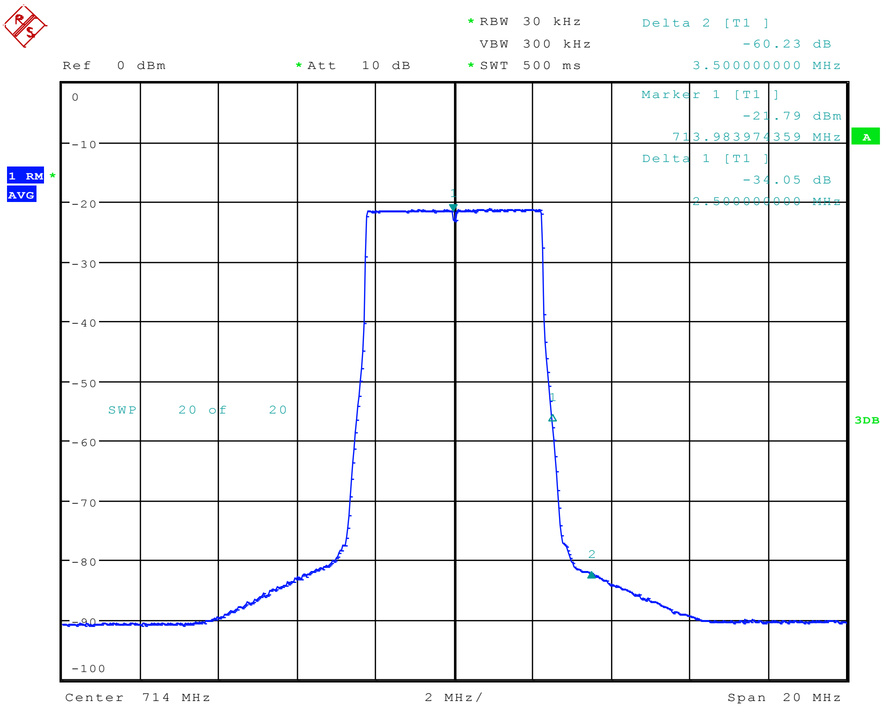

Figure 2-2 LTE-BS interfering signal spectrum

The signal noise level, as seen in **Figure 2-2** is very low, close to the system noise level. To find its true level, the system noise influence has to be considered. In order to do that, the system noise was measured with the spectrum analyzer settings used to measure the LTE-signal spectrum and was found to be -94 dB_m. As the base noise line in the spectrum in **Figure 2-2** is -91 dB_m, the LTE signal must have a constant noise base at -94 dB_m , since the sum of two equal powers is 3 dB higher (hence -91 dB_m). The signal noise-base is about 13 dB lower than the lower spectrum mask limit (see **Figure 2-1**).

The LTE signal noise level has a direct influence on the PR in adjacent channels farther than N+3. Would it be close to the spectrum mask, the PR for the channels beyond N+3 would be 13 dB higher than the values found in these measurements.

2.1.3.2 LTE-User Equipment Signal

The interfering LTE UE signal as generated by the SMU 200A shows much lower signal out of band power levels than allowed by the CEPT ECC [3] spectrum mask. In order to match the mask, the LTE-UE signal was distorted by feeding it to a broadband amplifier (see **Figure 2-5**). If the amplifier is overloaded, the shoulders of the LTE-UE signal are coming up. The amplifier input level was adjusted until the LTE signal spectrum shoulders came close to the inner corner of the spectrum mask (see **Figure 2-3**). This signal deterioration in the nonlinear working amplifier is a natural one, it happens also in the UE power amplifier.

The spectrum mask for an ECN Terminal System (UE) with 23 dB_m transmitting power as given in [3] is shown in **Figure 2-3** as a blue line. The LTE-UE signal spectrum is the red line. The spectrum analyser detector is set to RMS maximum hold.

The signal level in **Figure 2-3** is the transmitted power level during the 1 ms signal transmission (pulse).

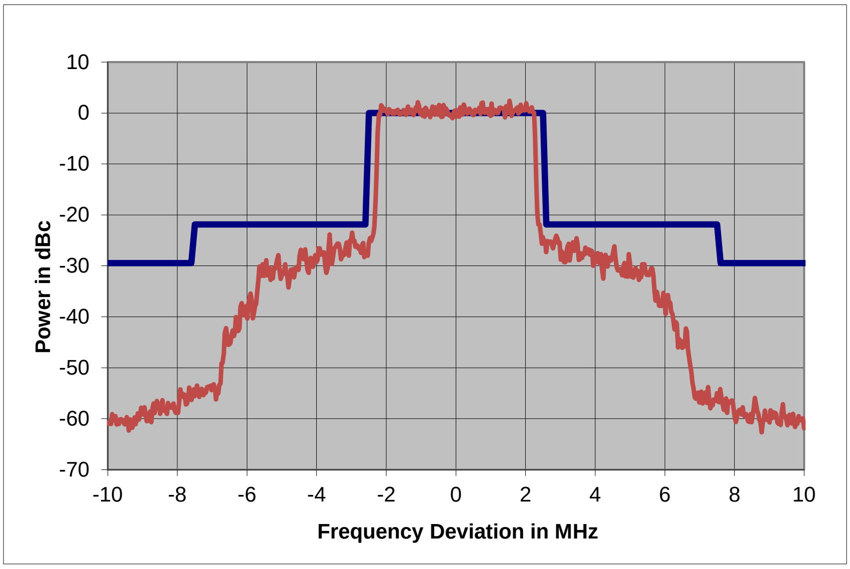

Figure 2-3 Spectrum mask for Electronic Communication Network TS with 23 dB_m power (blue) and LTE-UE signal spectrum (red)

While the LTE-BS signal used for PR measurements is continuous in time, the LTE-UE signal used for measurements has a pulsed nature, as stated in section 2.1. The time variance of the signal, measured with a spectrum analyzer with zero span, is shown in **Figure 2-4**.

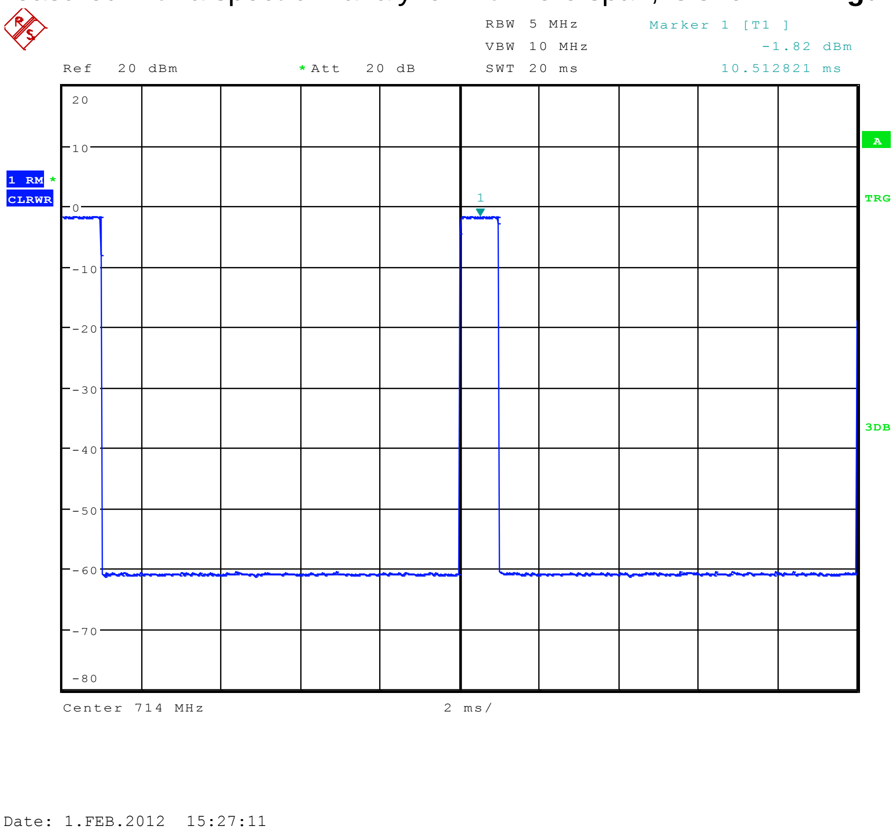

Figure 2-4 LTE-UE interfering signal in time domain, at a level of -10 dB_m

The LTE-UE signal power is defined as the time-average power. For a level setting of –10 dB_m at the SMU 200A generator, the output signal has a maximum power of 0 dB_m, see **Figure 2-4** (there is a 1,8 dB loss in the connection cable).

The LTE-UE signal noise-base is about 30 dB lower than the lower spectrum mask limit (see **Figure 2-3**). For this reason the worst-case PR for channels beyond N+3 are about 30 dB higher than the PR values measured.

2.2- Measurement Set-up

For PR measurements for LTE interferes to DVB-T reception the set-up in **Figure 2-5** was used. A Rohde & Schwarz SFU TV Transmitter generates the wanted DVB-T signal. The LTE-BS and LTE-UE signals are generated by a vector signal generator, the Rohde & Schwarz SMU 200A. The LTE-UE signal spectrum is slightly distorted by the following small signal amplifier (Mini Circuits ZFL 1000LN) to be in accordance with the spectrum mask given in [3], see **Figure 2-3**. For the LTE-BS signal interferer, the small signal amplifier ZFL 1000LN is not used, since the signal spectrum mask has a much lower noise level, see **Figure 2-1**.

The power amplifier increases the interferer signal level to produce interference even at high wanted signal levels and high frequency deviations. The signal spectrum shape and noise level depend on the amplifier input signal level, which is therefore set to a fixed value. A variable attenuator is used to change the interferer signal level for the measurements, in order to let the signal spectrum unchanged.

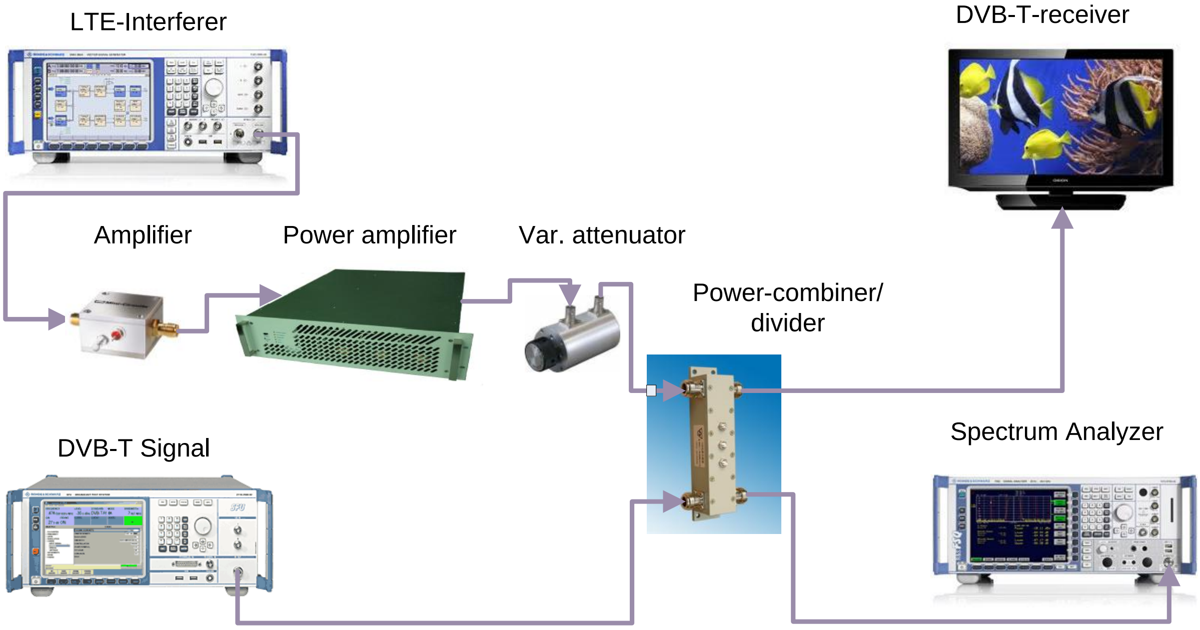

Figure 2-5 Set-up for the PR measurement for LTE interference to DVB-T reception

The interferer signal is merged with the wanted DVB-T signal by a 3-dB-power-combiner/divider. The DVB-T receiver is fed with the sum signal. The decoded DVB-T programme can be viewed on the screen of a TV-monitor. A spectrum analyzer is present for signal control and power measurement purposes.

At the start of the measurements the sensitivity of the DVB-T receiver under test is assessed. For this purpose, the unwanted signal cable is separated from the power combiner and the open combiner port is terminated with 50 Ω. The signal level of the wanted signal is adjusted in such a way that the onset of impairments is found. This threshold signal level Pmin is determined by means of the SFP quality criteria, see Section 2.1-.

The protection ratio measurements are made for wanted signal levels being at least 10 dB above the receiver sensitivity Pmin in order to reduce the impact of the receiver noise on the measurement results. At low DVB-T signal levels the receiver intrinsic noise adds to the LTE-interfering signal influencing the protection ratio values measured. At a signal level of Pmin + 10 dB the measurement error is reduced to 0.4 dB.

2.3- Measurement Results

The LTE BS and LTE UE signals are different and so are the PRs when they are interfering to a DVB-T transmission. The LTE-BS signal is OFDMA modulated and continuous in time [5], whereas the LTE-UE signal is DFT-spread OFDM modulated [6] and pulsed in time (see **Figure 2-4**). The pulsed nature of the LTE-UE signal leads to higher interference and a higher receiver overloading effect compared to the LTE-BS signal.

The PRs were measured for eleven different DVB-T receivers, nine iDTV receivers and two USB-sticks. For every receiver the minimum input power level for good reception Pmin was measured. The PR was then measured successively at signal power level Pmin+10, Pmin+20 etc. up to Pmin +60 dB. At high DVB-T signal levels high interference signal levels are necessary to produce interference, but in most cases receiver overloading is reached first.

The DVB-T-signal's centre frequency was always 714 MHz (TV channel 51). The LTE-signal frequency was set successively to 721,5; 730; 738; 746; 754; 762; 770; 778; 786; 794 and 802 MHz, for a 1MHz gap and to the centre frequencies of the adjacent TV-channels N+2 to N+11.

2.3.1- PR for LTE-BS interferes to DVB-T

The PRs with a LTE-BS signal as interferer for receiver #9 is shown in **Figure 2-6** as an example. In the co-channel the PR is 10 dB, the same as the carrier to noise value C/N and does not depend on the wanted signal level. Starting with the adjacent channel N+1, the PR is independent of the wanted signal level only up to a level of Pmin + 30 dB. For levels above it, the PRs are increasing with the wanted signal level. A receiver overloading takes place.

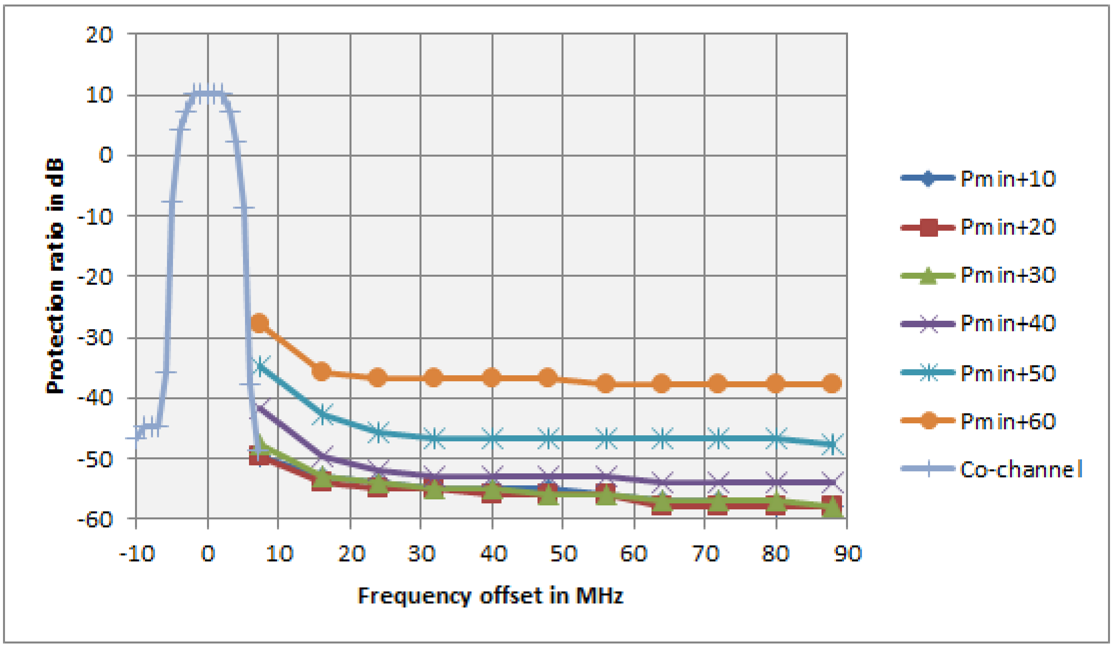

Figure 2-6 Protection ratio for LTE-BS interfering to 8k 16QAM 2/3 DVB-T reception, receiver #9

The PR values measured in the adjacent channels N+1 to N+11 for all receivers at a DVB-T signal level Pmin + 10 dB are given in **Figure 2-7**. They are quite similar one to another excepting USB-stick #2, which is up to 20 dB more sensitive to interference.

The PR values measured for the higher wanted signal levels are not shown here. The measurements were used to find the receiver overloading level and to get more confidence with the Pmin +10 dB results.

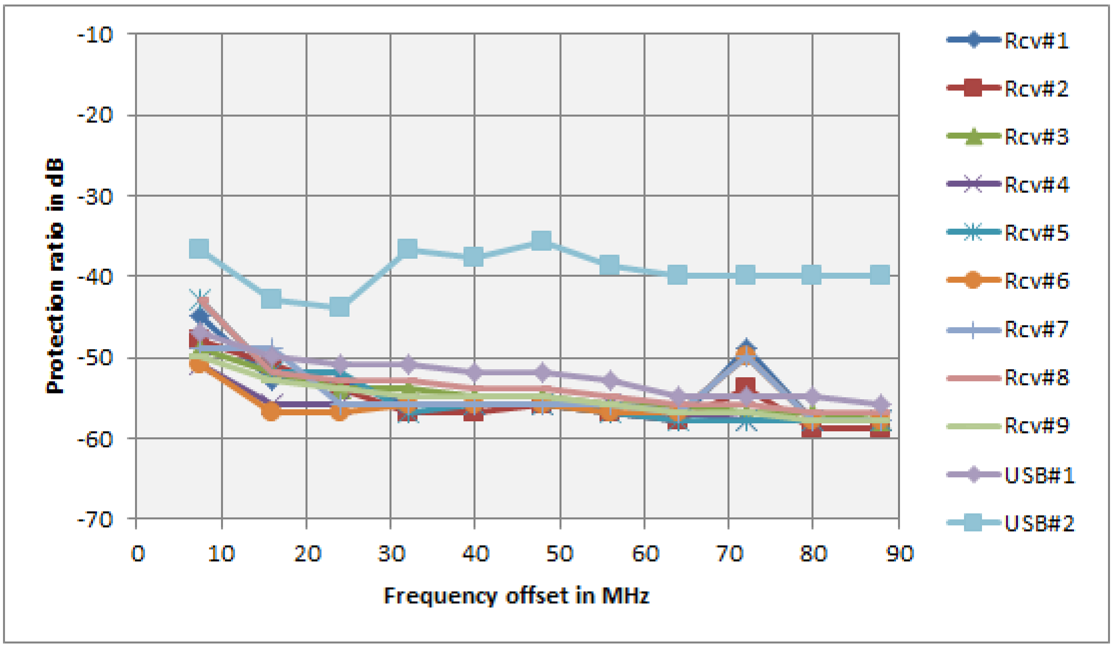

Figure 2-7 Protection ratio for LTE-BS interfering to 8k 16QAM 2/3 DVB-T reception, all receivers at P_{min} + 10 dB

Only four of the nine receivers measured have higher PR values in the image frequency channel N+9 at a frequency offset of 72 MHz. The other receivers have dual frequency conversion tuners with an image frequency which is far away from the received frequency. Starting with adjacent channel N+2 the PR are low, at a value that depends mainly on the interfering signal noise floor.

Using statistical analysis the median (50%) and the 90-% PR-values for each adjacent channel were calculated and are shown in **Figure 2-8** together with the receiver #9 PR values.

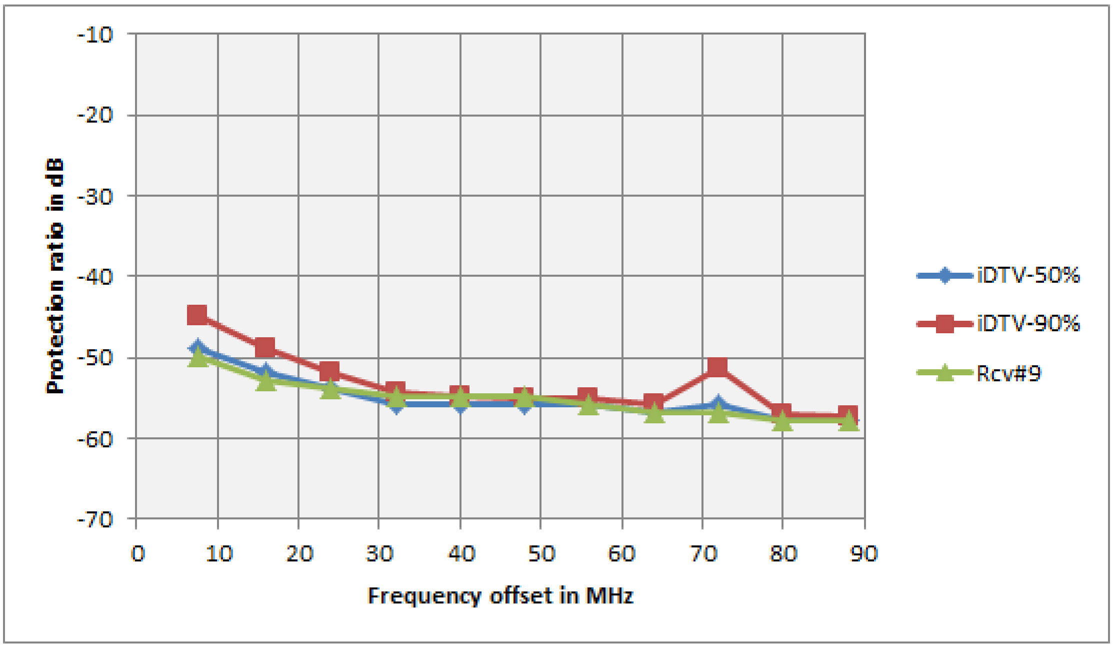

Figure 2-8 LTE-BS protection ratio 50%- and 90%-values for all iDTV receivers and for receiver #9 at wanted signal level P_{min} + 10 dB

In the 90% curve, the image frequency PR increase is visible, in the 50% curve it is not, because 5 of 9 iDTV receivers have dual frequency conversion. It is obvious that the receiver #9 can be considered as representative for the nine iDTV receivers.

The PR values were measured with an interfering LTE-BS signal which is less disturbing than the worst-case signal having a 10 dB higher noise floor (see **Figure 2-1**). The noise floor influences the lower limit of the PR values starting with adjacent channel N+2. In the worst case the lower PR limit is 13 dB higher.

By considering the worst case interferer and the statistical analysis of the measurement results, to make sure that 90-%-of the DVB-T receivers are not interfered by LTE-BS signals, the simplified PR limits in **Table 2-1** should be considered.

Table 2-1 Protection ratio limits for 90-% of iDTV receivers in a Gaussian transmission channel for worst-case LTE-BS interferer and 8k 16 QAM 2/3 DVB-T mode

adjacent channel	N±1	N+2 to N+9	N+10 to N+11
iDTV	-40 dB	-42 dB	-45 dB

For lower quality DVB-T receivers like USB-sticks the PRs are few dB higher.

The worst case PRs are compared in **Figure 2-9** with the PR values given in the CEPT-ECC Report 148 [3] for iDTV receivers and silicon tuner Set-Top-Boxes (STB), measured with a LTE-BS signal similar to that shown in **Figure 2-1**. The PR from [3] were converted for the DVB-T mode 16 QAM 2/3 using Table 4 in [3].

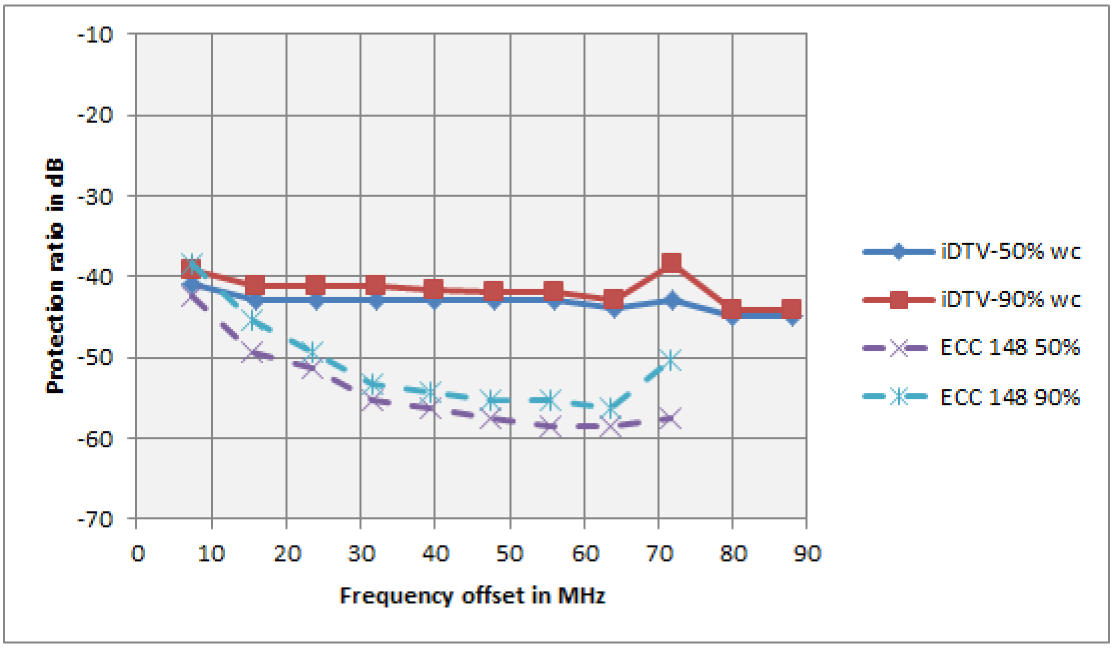

Figure 2-9 LTE-BS worst case PR 50%- and 90%-values for all iDTV receivers measured and for iDTV receivers and silicon tuner STB given in CEPT ECC Rep 148 [3], at interference to 16 QAM 2/3 DVB-T signal reception, at wanted signal level P_{min} + 10 dB

The 90% worst-case PRs for present iDTV receivers are more constant with frequency, equal to the old values in adjacent channel N+1 and up to 13 dB higher in adjacent channels beyond N+2, where the noise floor is relevant.

2.3.2- PR for LTE-UE interferes to DVB-T

In **Figure 2-10** the PR to LTE-UE for iDTV receiver #9 is shown as an example. In the co-channel the PR is 13 dB and does not depend on the wanted signal level. Starting with adjacent channel N+2, the PR is dependent of the wanted signal level, because a receiver tuner overloading takes place. The highest PR of -8 dB was measured in the adjacent channels N±1. The PR values for the adjacent channels N+3 to N+11 are spread over a large value range (40 dB).

Looking at **Figure 2-10** it is evident, that overloading starts below the wanted signal level of Pmin+20 dB.

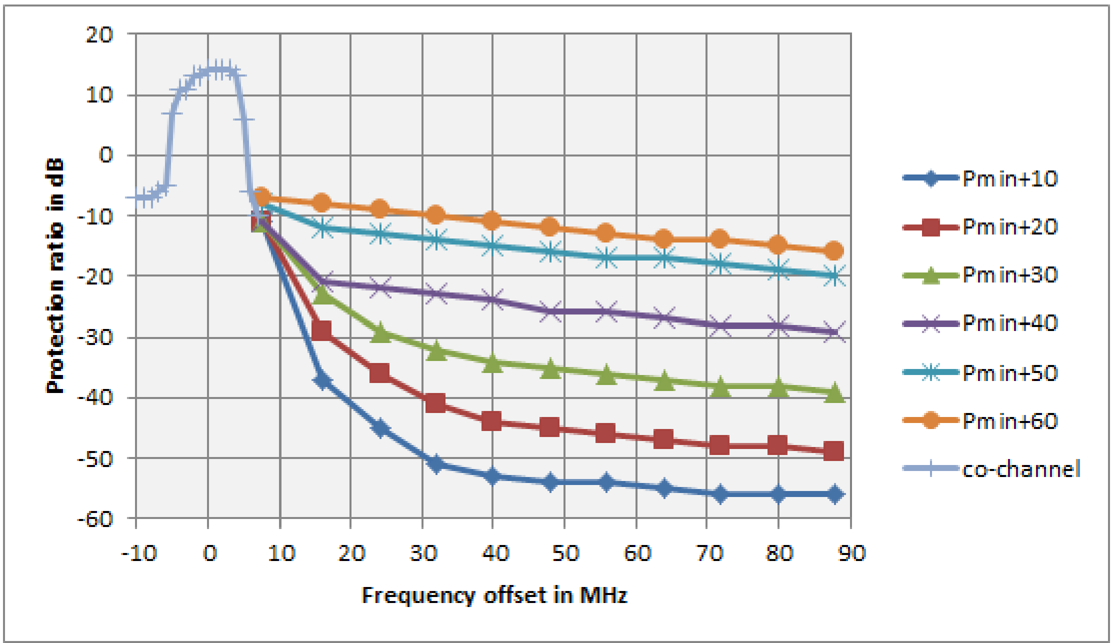

Figure 2-10 Protection Ratio values for LTE-UE interfering to DVB-T reception, mode 16 QAM 2/3, receiver #9

The PR values measured in the adjacent channels N+1 to N+11 at a wanted signal level of P_{min}+10 for all receivers are shown in **Figure 2-11**. The values are quite similar to each other, excepting for the USB-sticks, which are 20 to 30 dB more sensitive to interference. Here too it is obvious that only 4 of 9 iDTV receivers have an image frequency problem at an offset of 72 MHz.

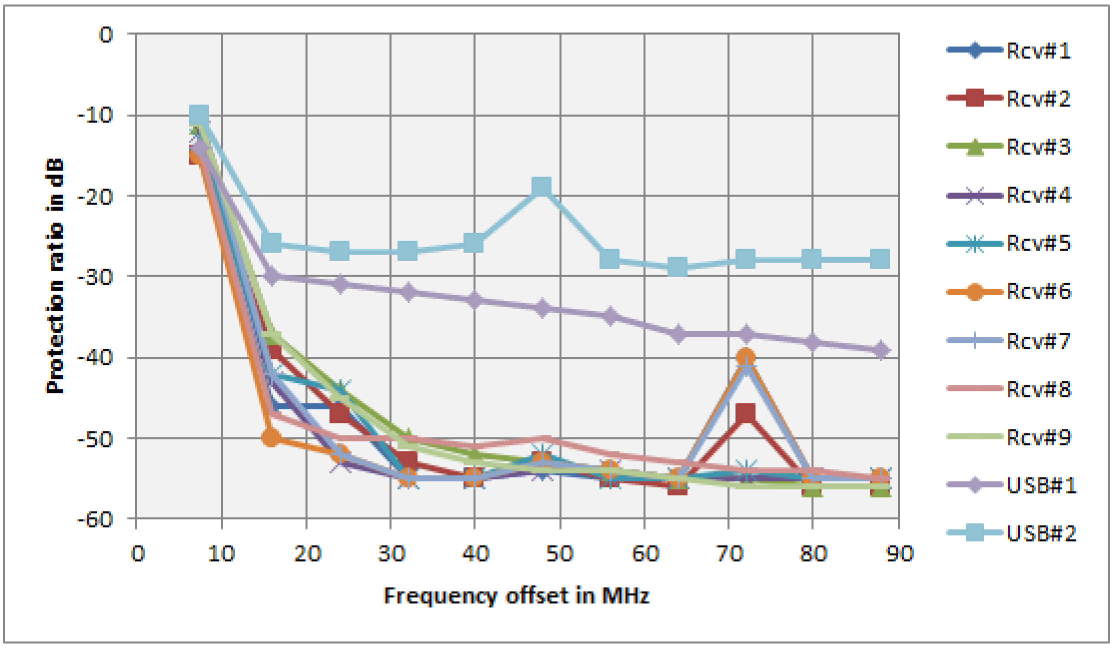

Figure 2-11 Protection Ratio for LTE-UE interfering to DVB-T mode 16 QAM 2/3 reception, all receivers at wanted signal level P_{min} + 10 dB

The PR median and the 90-%-percentiles for all iDTV receivers and for each adjacent channel were calculated and are shown in **Figure 2-12**, together with the receiver #9 PR values.

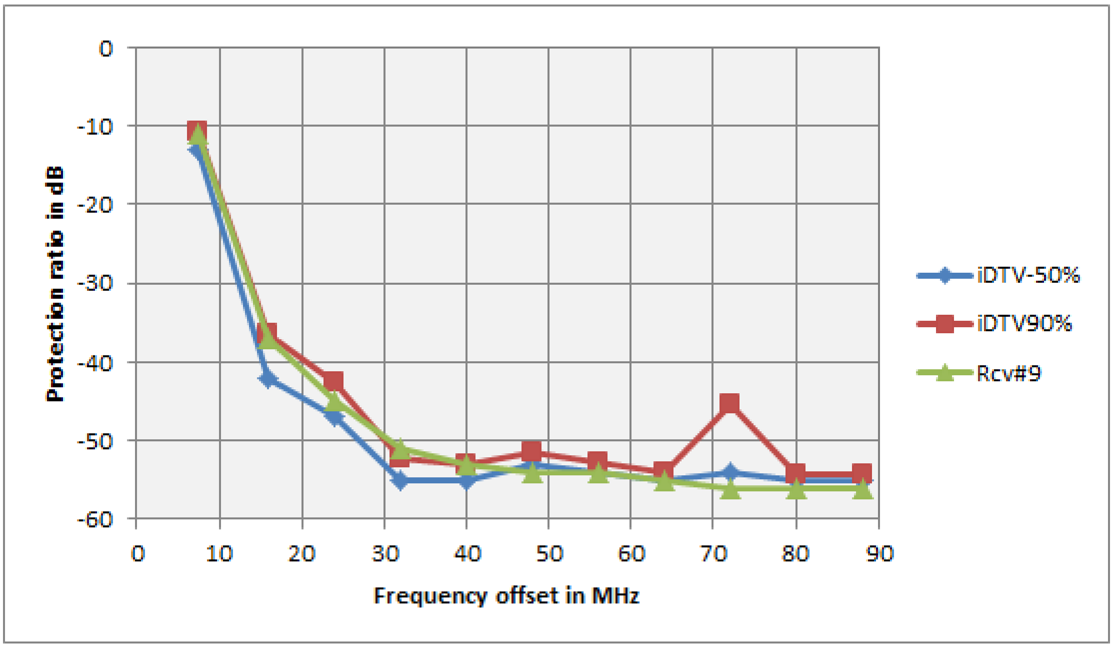

Figure 2-12 LTE-UE Protection Ratio 50%- and 90%-values for all iDTV receivers and for receiver #9 at wanted signal level P_{min} + 10 dB

It is obvious that the receiver #9 can be considered as representative for the group of iDTV receivers taken for measurements.

The LTE-UE PRs measured were compared in Figure 2-13 with the PR values given in the CEPT-ECC Report 148 [3] for iDTV receivers and silicon tuner STB. The PR values from [3] were converted for the DVB-T mode 16 QAM 2/3. In adjacent channel N+1 the PR for the newer iDTV receivers is about 8 dB higher, in the other adjacent channels the values are closer.

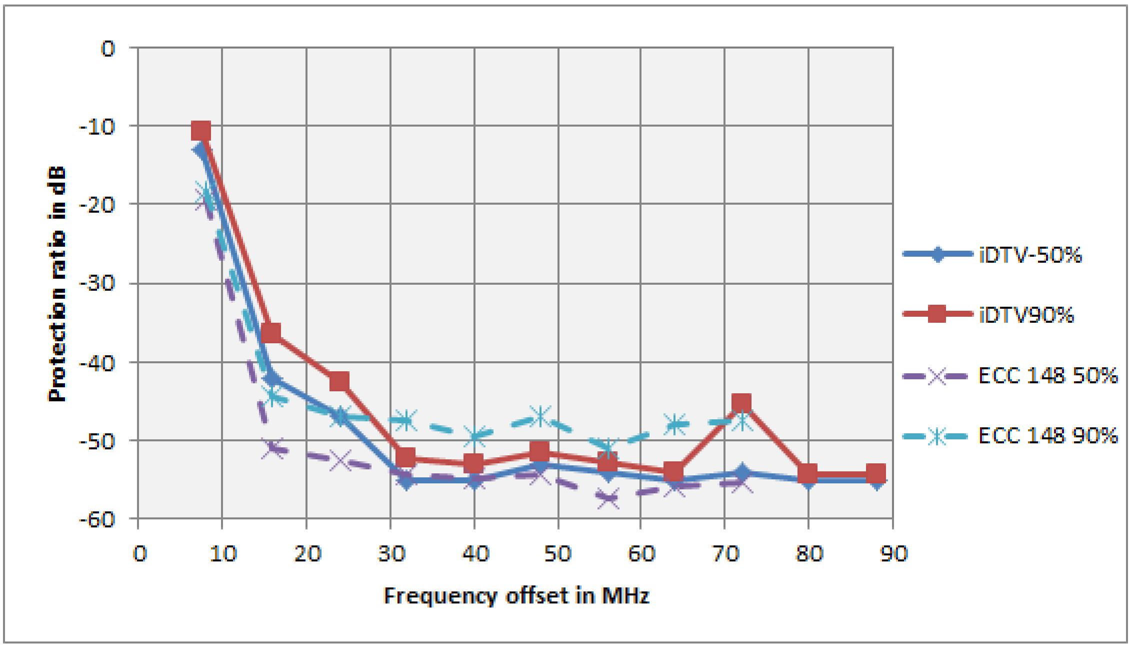

Figure 2-13 LTE-UE PR 50%- and 90%-values for all iDTV receivers measured and for silicon tuner STB given in CEPT ECC Rep 148 [3], at interference to 16 QAM 2/3 DVB-T signal reception at wanted signal level P_{min} + 10 dB

It has to be stressed that the PR measurements here and in [3] were made with a LTE-UE signal having a noise floor 30 dB below the spectrum mask as it is defined at the moment, see **Figure 2-3**. For the worst-case LTE-UE signal the PRs would be 30 dB higher than the values measured, as shown in **Figure 2-14**.

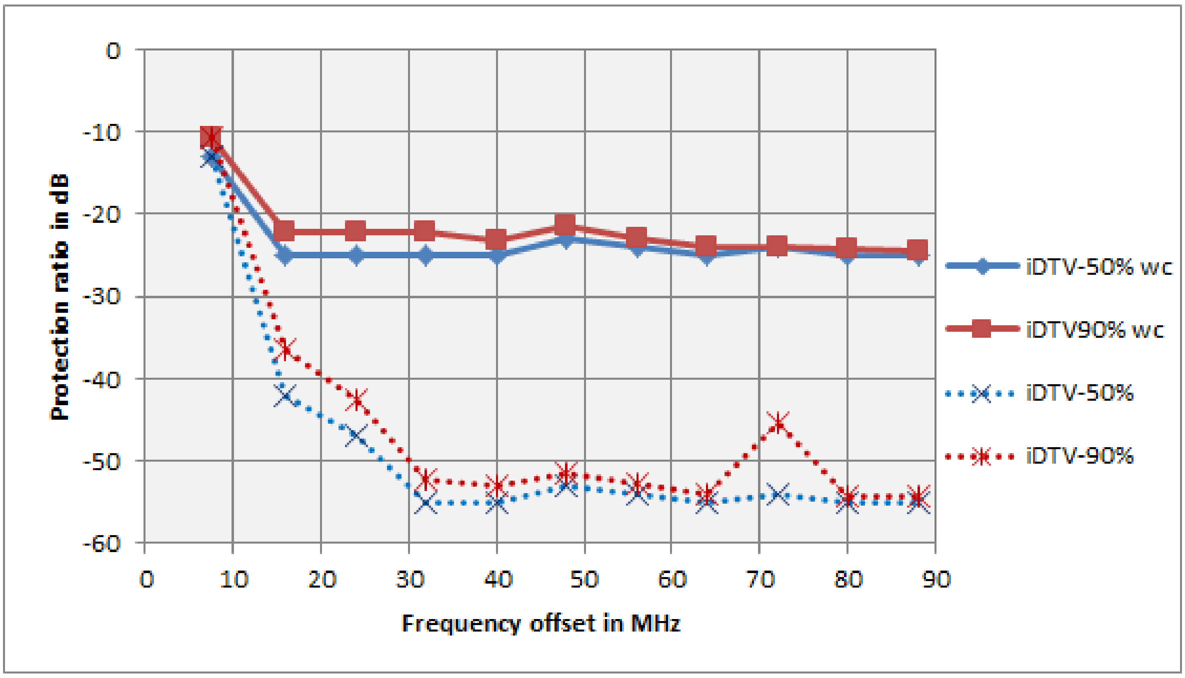

Figure 2-14 LTE-UE PR 50%- and 90%-values for all iDTV receivers as measured and for a worst-case interferer, at interference to 16 QAM 2/3 DVB-T signal reception at wanted signal level P_{min} + 10 dB

The worst case PR values are also given in **Table 2-2**.

Table 2-2 Protection ratio limits in dB in a Gaussian transmission channel for LTE interferer and 8k 16 QAM 2/3 DVB-T mode for the reference receiver

adjacent channel	N±1	N+2 to N+9
LTE-UE PR in dB	-10	-22*

*exact values have to be set in accordance with the final spectrum mask

The industry does not consider the signal spectrum mask in **Figure 2-3** to be realistic [4]. Another, a realistic mask should be defined and after that realistic PRs can be calculated from the measurement results presented here. Therefore for the time being no realistic PRs can be given to be considered for planning purposes.

2.4- Overloading threshold

A low level signal can interfere into the reception of another signal by adding itself to the desired signal, if their spectrums overlap. A high level signal can interfere to the reception of another signal even it its spectrum does not overlap with the desired signal spectrum, by overloading the receiver front end.

While measuring the protection ratios at wanted signal levels 10 dB to 60 dB above the receiver sensitivity power level Pmin, the level of the unwanted signal "I" at the threshold of good reception (according to the SFP criterion, see Section 2.1-) was recorded. From the variation of the interfering signal level "I" as a function of the wanted signal level "C" as shown in Figure 5.1, the level of the interfering signal "I" at which receiver overloading starts to happen can be determined. As long as "I" increase linearly with "C", the receiver linear tuner function is prevailing. Overloading becomes relevant when the increase of I becomes smaller than that of "C". The tuner behaviour becomes nonlinear.

2.4.1- Overloading threshold for LTE-BS interferes to DVB-T

In **Figure 2-15** the interference signal level variation as a function of the wanted signal level for iDTV receiver #9 is shown as an example. The interferer signal frequency is set successively in the adjacent channels N+1 to N+11.

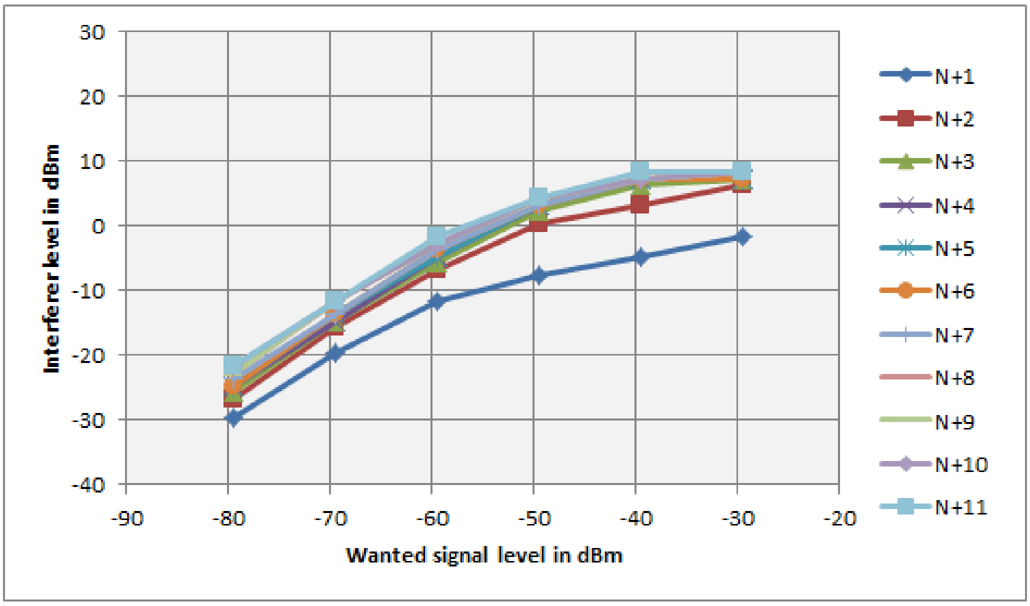

Figure 2-15 Interfering signal LTE-BS level in the adjacent channels as a function of the wanted signal level at receiver input, measured at the threshold for good reception (SFP) receiver #9, DVB-T mode 16QAM 2/3

In the adjacent channel N+1 the LTE signal out of channel power is determinant for the interferer signal level variation, overloading is secondary. Starting with adjacent channel N+2 the effect of the receiver front end nonlinearity is predominant. The start of nonlinearity is considered to be at the tuner 1-dB compression point. It is the point where the curve "I" as function of "C" drops 1 dB below the ideal linear variation. For the receiver #9 in **Figure 2-15** this point is at an interferer level of about 0 dBm.

In **Figure 2-16** the interference signal level as a function of the wanted signal level at receiver input is shown for all receivers, for the interferer frequency in adjacent channel N+7.

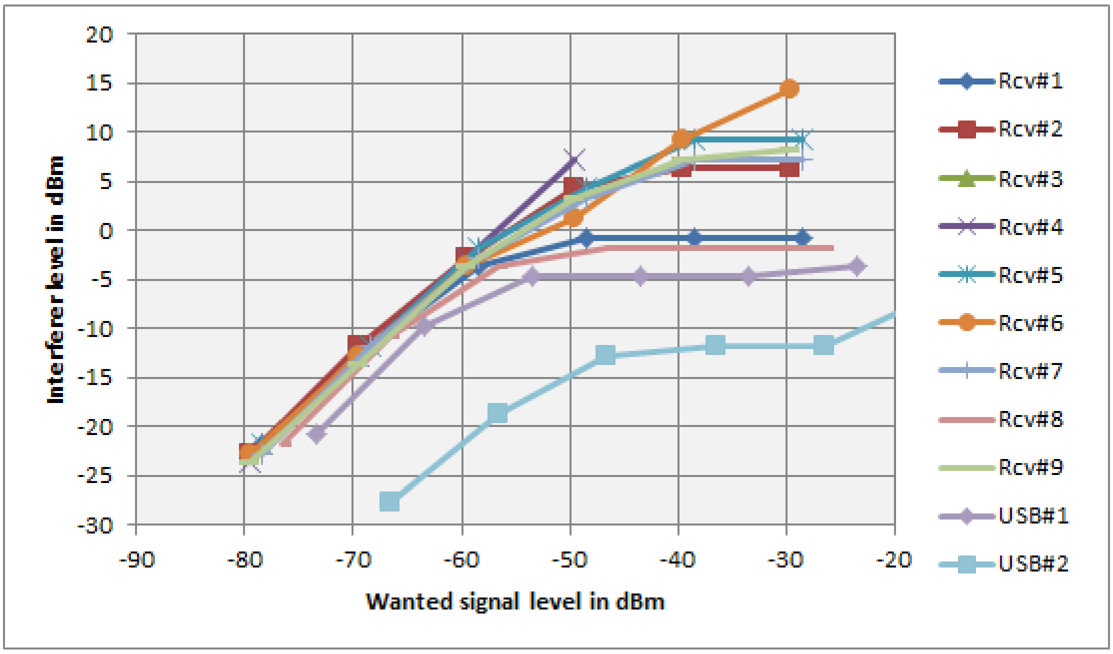

Figure 2-16 Interfering signal LTE-BS level in the adjacent channel N+7as a function of the wanted signal level measured at the threshold for good reception (SFP)
all receivers, DVB-T mode 16QAM 2/3

The USB-stick receiver #2 is the least resistant to overloading. The iDTV receivers are showing nonlinear behaviour for an interferer level above -10 dB_m.

The median variation of the interferer level variation for the nine iDTV receivers measured is shown in the diagram in **Figure 2-17**. The receiver #9 data fits well to it, so that receiver #9 is well suited to represent the iDTV receiver group measured.

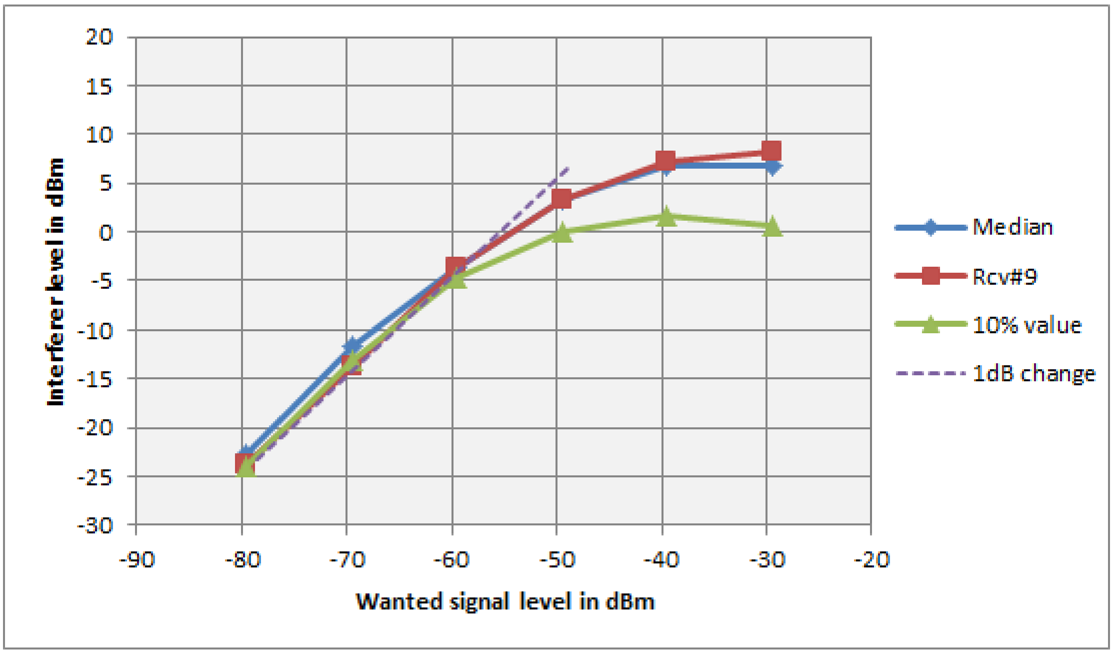

Figure 2-17 Interfering signal LTE-BS level in the adjacent channel N+7as a function of the wanted signal level measured at the threshold for good reception, median value and overloading threshold all iDTV receivers, DVB-T mode 16QAM 2/3

The iDTV receivers interfering signal level variations as a function of the wanted signal level in the adjacent channels beyond N+2 are quite similar to each other. Therefore the median (50%) and the 10% functions are very close to each other and so are their 1 dB compression points (Overloading threshold O_{th}).

Note: 90% of the receivers do not show overloading for interference levels up to the 10% O_{th} value.

For the iDTV receivers the overloading threshold is about -3 dB_m for the median. The O_{th} 10%-value is -5 dB_m (see **Figure 2-17**). It is close to the values given in [1] for iDTV receivers in the adjacent channels beyond N+2, see **Table 2-3**. The DVB-T mode has little influence on the overloading threshold.

Table 2-3 Overloading thresholds in ECC Rec 148 [1] shown here for comparison:

DVB-T O_{th} for 64-QAM 2/3 DVB-T signal (LTE BS, Constant Average Power)									
Channel edge separation (MHz)	**O_{th} (dBm)**								
	90th			**50th**			**10th**		
	Can STB/iDTV	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**
1	-1	-2	-3	-9	-8	-17	-13	-13	-26
9	3	4	0	-3	-1	-13	-8	-7	-22
17	4	7	0	-2	2	-7	-19	-6	-18
25	1	8	0	-8	4	-6	-13	-6	-14
33	1	6	0	-4	4	-5	-8	-6	-14
41	7	8	0	-2	3	-5	-6	-5	-14
49	9	5	0	0	1	-5	-5	-4	-14
57	9	5	0	1	1	-3	-5	-4	-13
65	8	6	0	2	2	-11	-3	-6	-16

Table 5b: DVB-T O_{th} values in the presence of a time-constant LTE BS interfering signal in a Gaussian channel environment at the 10^{th}, 50^{th} and 90^{th} percentile: comparison between can-tuners and silicon-tuners.[4]

2.4.2- Overloading threshold for LTE-UE interferes to DVB-T

In **Figure 2-18** the interference LTE-UE signal level variation with the wanted signal level at the receiver input, measured at the threshold for good reception, is shown for receiver #9. The measurements were made with the LTE UE signal with a spectrum as shown in **Figure 2-3** and time variation as shown in **Figure 2-4**.

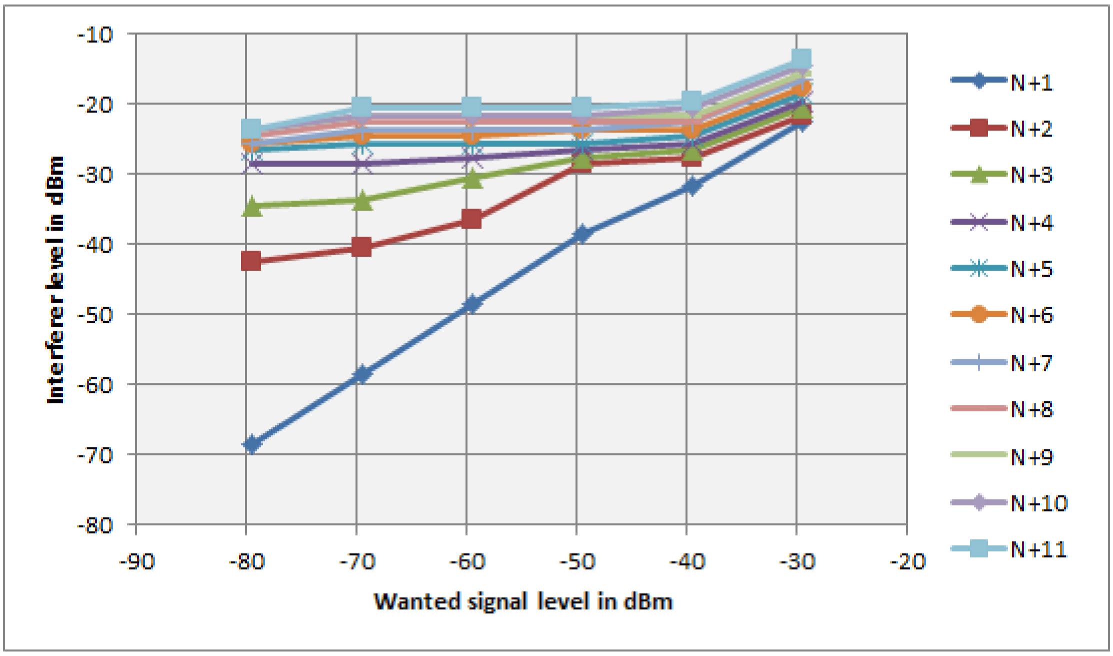

Figure 2-18 LTE-UE interferer signal level in the adjacent channels as a function of the wanted signal level at receiver input, measured at the threshold for good reception (SFP) receiver #9, DVB-T mode 16QAM 2/3

In the adjacent channels N+1, N+2 and N+3 the LTE signal out of channel power has more effect on the interferer signal level variation than overloading. Starting with adjacent channel N+4 the effect of the receiver front end nonlinearity is predominant.

It is not possible for this receiver to find the overloading threshold. The linear variation part of the diagram with slope 1 is missing. It means that the overloading threshold is below -30 dB_m, but it is unknown how far below. This receiver is very sensitive to pulsed signals.

In **Figure 2-19** the interference signal level variation with wanted signal level at the receiver input is shown for all receivers, for a frequency in the adjacent channel N+7.

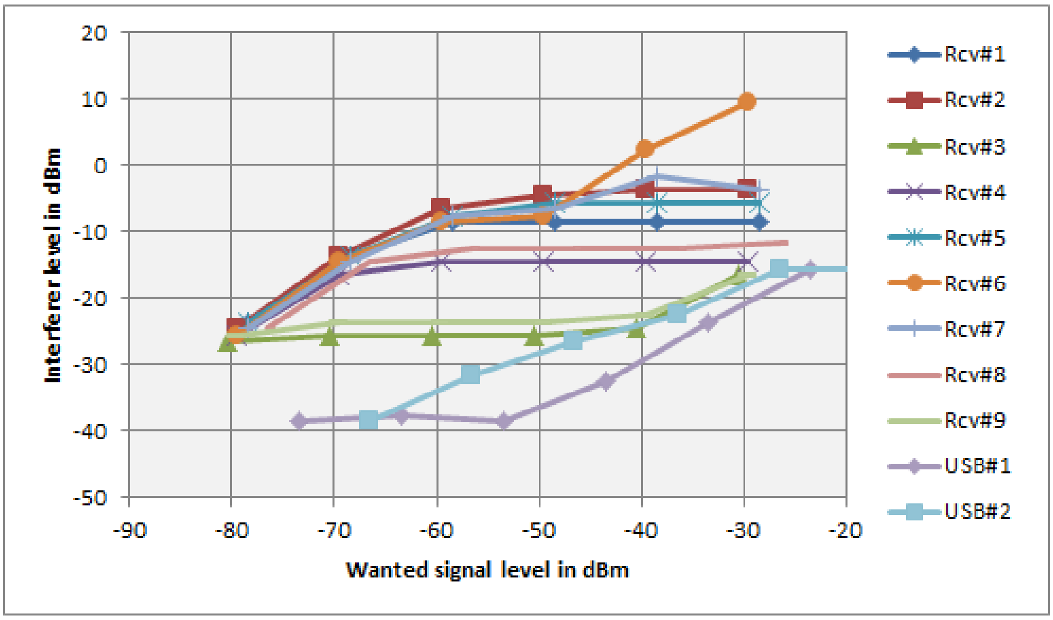

Figure 2-19 LTE-UE interferer signal level in the adjacent channel N+7 as a function of the wanted signal level, measured at the threshold for good reception all receivers, DVB-T mode 16QAM 2/3

The overloading threshold is lower than the one for LTE-BS signals. One reason is that the LTE UE interferer signal level plotted is the time averaged one. During the active LTE UE signal pulse the signal level is 10 dB higher (see Section 2.1.3.2). The other reason is that receivers are more sensitive to pulsed interferers.

The overloading threshold level for seven iDTV receivers is in the range -10 to -15 dB_m, whereas for LTE-BS it is -3 dB_m. The USB-stick receivers are the first to be overloaded. The iDTV receivers #3 and #9 have also lower overloading thresholds compared to the other iDTV receivers.

The median and the 10% value for the 9 iDTV receivers are shown in the diagram in **Figure 2-20**. For 50% of the iDTV receivers the overloading threshold is -13 dB_m. The 10% overloading threshold cannot be determined. Anyway it is below -26 dB_m.

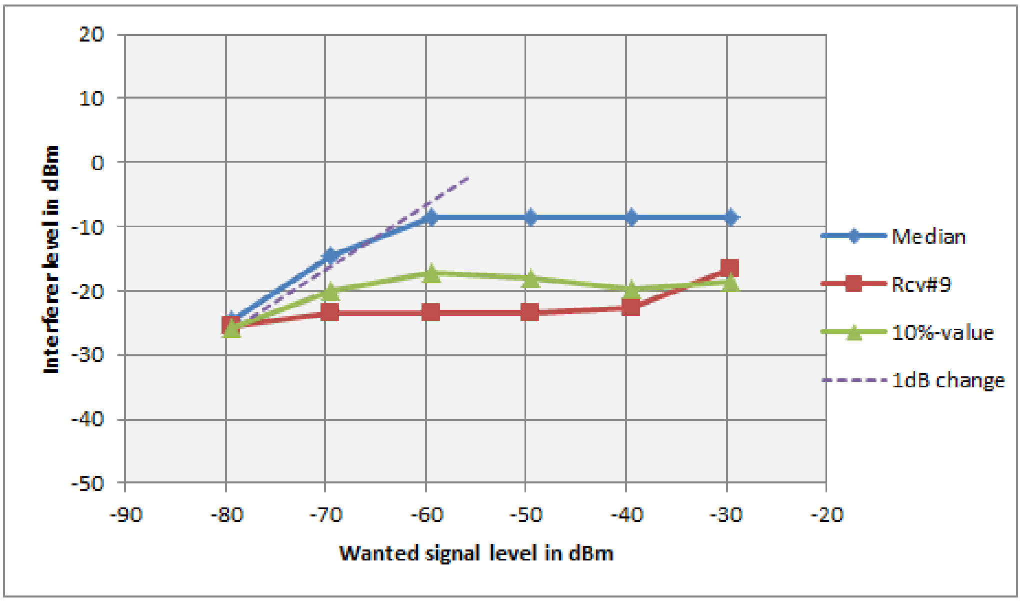

Figure 2-20 Overloading threshold 50% and 10% value for iDTV receivers and for receiver #9, in the adjacent channel N+7, for LTE-UE interfering to DVB-T mode 16 QAM 2/3 reception.

In **Figure 2-20** the performance of receiver #9, chosen to be representative for the 9 iDTV receivers measured, is also shown. Its interferer signal upper level limit is 13 dB lower than that of the median value. This is the only situation in which the receiver #9 diverges from the idTV receiver median values. Its interferer signal level variation is close to the 10% curve. It means that if receiver #9 is not overloaded, 90% of the iDTV receivers will also not be overloaded.

The comparison with the overloading thresholds given in ECC Rec 148 [1] is difficult, see **Table 2-4**. The results are presented as large ranges.

Table 2-4 Overloading thresholds in ECC Rec 148 [1] for comparison:

DVB-T O_{th} for 64-QAM 2/3 DVB-T signal (LTE UE TPC off)									
Channel edge separation (MHz)	O_{th} (dBm)								
	90th			50th			10th		
	Can STB/iDTV	Silicon STB/iDTV	Silicon USB	Can STB/iDTV	Silicon STB/iDTV	Silicon USB	Can STB/iDTV	Silicon STB/iDTV	Silicon USB
1.5	-11 … 2	-14 … -9	-3	-16 … -11	-16 … -16	-15	-21 … -19	-23 … -17	-27
9.5	1 … 7	-10 … 9	-13	-6 … -2	-28 … 2	-30	-18 … -4	-46 … -5	-47
17.5	0 … 7	-5 … 12	-15	-16 … -10	-26 … 5	-32	-31 … -26	-47 … -2	-49
25.5	-7 … -6	-5 … 9	-18	-13 … -9	-25 … 2	-30	-19 … -11	-44 … -6	-42
33.5	-1 … 0	-5 … 10	-19	-9 … -4	-24 … 3	-30	-17 … -7	-43 … -5	-41
41.5	0 … 9	-16 … 7	-13	-9 … -2	-25 … 0	-25	-18 … -7	-41 … -7	-37
49.5	6 … 11	-3 … 13	-13	-3 … 2	-21 … 4	-25	-16 … -3	-39 ... -5	-37
57.5	4 … 10	-12 … 11	-17	-4 … 2	-21 … 2	-28	-16 … -3	-35 … -7	-39
65.5	5 … 10	-13 … 8	-10	-2 … 4	-23 … -1	-25	-9 … -3	-32 … -10	-40

Table 7b: DVB-T O_{th} values in the presence of a LTE UE interfering signal without TPC in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners. [4]

Channel N+7 corresponds to a channel edge separation of about 49.5 MHz. The 50% O_{th} measured here as -13 dB_m is in [1] in the range of -21 dB_m to 4 dB_m as given in **Table 2-4** for silicon STB/iDTV. The 10% O_{th} measured for the 9 iDTV receivers is below -26 dB_m. In [1] in **Table 2-4** the value range is -39 dB_m to -5 dB_m.

The new O_{th} values for LTE-UE as interferer were found within the range of the values given in [1].

2.5- Threshold parameters for compliance measurements with reference receiver

Receiver #9 has been chosen to represent the iDTV receivers in CogEU White Space Device (WSD) compliance tests. For a WSD using the LTE communication system, in order to comply, the protection ratios measured in a Gaussian channel with a wanted DVB-T signal mode 16 QAM 2/3 should be below the values given in **Table 2-5**.

Table 2-5 Protection ratio limits in dB in a Gaussian transmission channel for LTE interferer and 8k 16 QAM 2/3 DVB-T mode for the reference receiver

adjacent channel	N±1	N+2 to N+3	N+4 to N+8	N+9
LTE-BS PR in dB	-40	-42	-42	-42
LTE-UE PR in dB	-10	-22 to -40*	-22 to -52*	-22 to -45*

*exact values have to be set in accordance with the interfering LTE-UE signal spectrum

The reference receiver should not be overloaded at an interferer signal level lower than the values given in **Table 2-6**.

Table 2-6 10% overloading threshold for reference (receiver #9)

Interferer	LTE-BS	LTE-UE
10 % Overloading threshold in dB_m	-5	-26

3- Measurement results of interference by WiFi secondary users

3.1- Testbed 1

A simplified test set-up was used to evaluate a new DVB-T/T2 USB receiver and to measure the respective protection ratios. The aim is to establish if a test environment for WSDs can be proposed that includes only a minimum number of test instruments to enable self-certification through specified test signals.

3.1.1- Signal parameters and transmission channel

For these sample measurements, a DVB-T signal in channel 34 (centre frequency 578 MHz) carries a video programme with a bit rate of 4.5 Mbps plus null packets for stuffing. The video sequence is an endless loop with a period duration of 20 seconds.
The mode of the DVB-T signal is the same as on German DVB-T networks: 8k, 16QAM, CR 2/3, GI 1/4, in a 8 MHz channel.

3.1.2- Failure criteria

The standard failure criterion of ESR_5 is used, i.e. visible artefacts during a maximum of 1 second of such 20 second periods.

3.1.3- Interfering WiFi signal

The interfering signal is a WiFi Base station signal (IEEE802.11n) as shown in **Figure 3-1**. The signal is loaded into the ARB (arbitrary waveform generator) that is integrated into the DVB-T test signal generator. It can be frequency-shifted between n-4 and n+4, i.e. it is especially suited for adjacent channel measurements.
The power level of the interfering signal is adjusted independently of the power level of the wanted (DVB-T) signal.

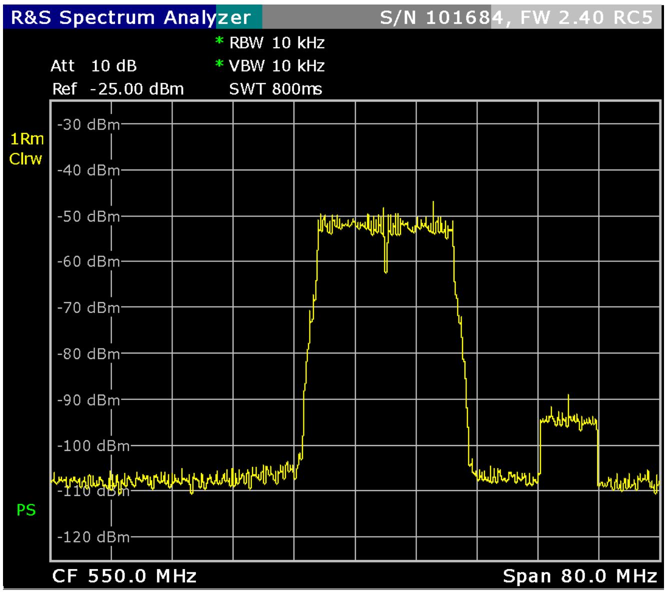

Figure 3-1 Spectrum of IEEE 802.11n signal and DVB-T signal

3.1.4- Measurement set-up

For these preliminary measurements the SFU test signal generator is used as a signal source for the DVB-T signal. The incorporated ARB generator is loaded with the 802.11n base station waveform (**Figure 3-2**).
The DVB-T USB receiver is installed on a notebook and the display of this notebook is used for the assessment of the video quality.
A protocol analyser cannot be connected in this case since the receiver does not provide any intermediate output of the MPEG2 Transport Stream.

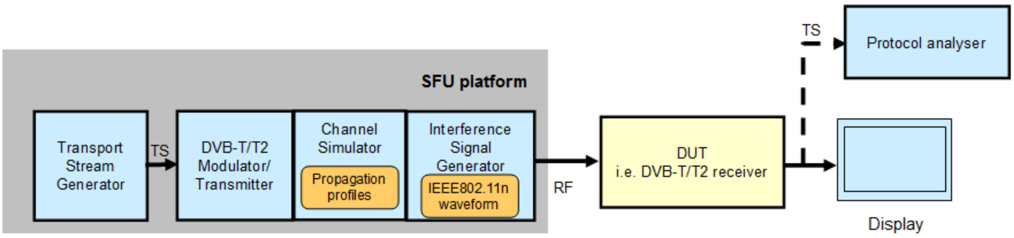

Figure 3-2 Set-up for the PR measurement for WiFi interference to DVB-T reception.

3.1.5- Measurement results

The table below show a first set of results which comply mainly with the results measured by IRT in section 2.3-.
The minimum input power for the USB receiver was measured as -86 dBm. Measurements were carried out for Pmin + 6 dB, + 20 dB and + 40 dB.
If the power level of the DVB-T signal is set to more than -60 dBm, protection ratios cannot be measured beyond a range of approximately -10 dB to dB because the linearity of the output signal of the test signal generator is not guaranteed. In this case, only independent amplification of the interference signal as provided in the IRT set-up, works appropriately.

Protection ratio C/I:													
DVB-T 8k 16QAM 2/3 1/4	Input level at receiver	Channel	Centre frequency DVB-T	Centre frequency WiFi signal (Interferer)/ MHz									
	dBm		MHz	-32	-24	-16	-8	0	8	16	24	32	MHz
Pmin+6dB	-80	34	578	-40	-37	-36	10	12	9	-34	-33	-42	dB
Pmin+20dB	-66	34	578	-51	-47	-33	5	7	5	-33	-47	-48	dB
Pmin+40dB	-46	34	578				5	8	5				dB

Table 3-1 Protection ratios when IEEE 802.11n signal interferes with DVB-T signal

The results listed in **Table 3-1** are depicted in **Figure 3-3**. In addition, the results of a DVB-T2 signal of a similar mode (same parameters, pilot Pattern PP1) are included in the diagram. Apparently, the DVB-T2 signal is more resilient when the interference signal is close in frequency.

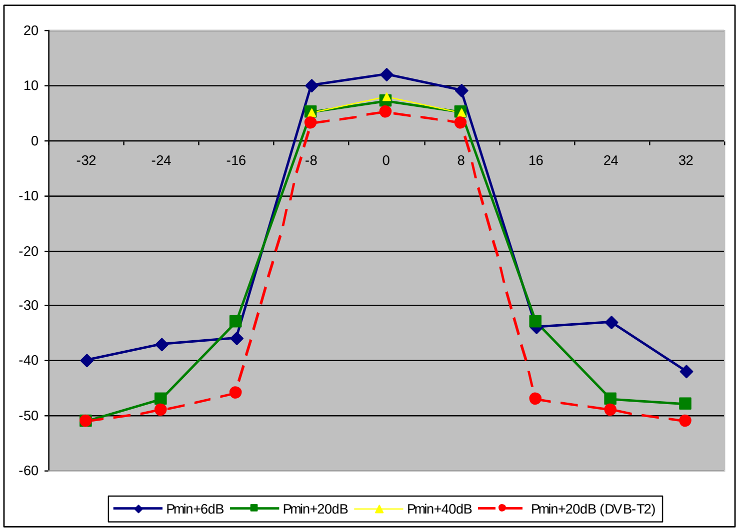

Figure 3-3 Protection ratios when IEEE 802.11n signal interferes with DVB-T (and DVB-T2) signal

3.1.6- Extension of test signal configuration

The cable load generator which is described in more detail in section 4.1- can also be used for the generation of multiple WSD signals which are then used to test a DVB-T receiver.

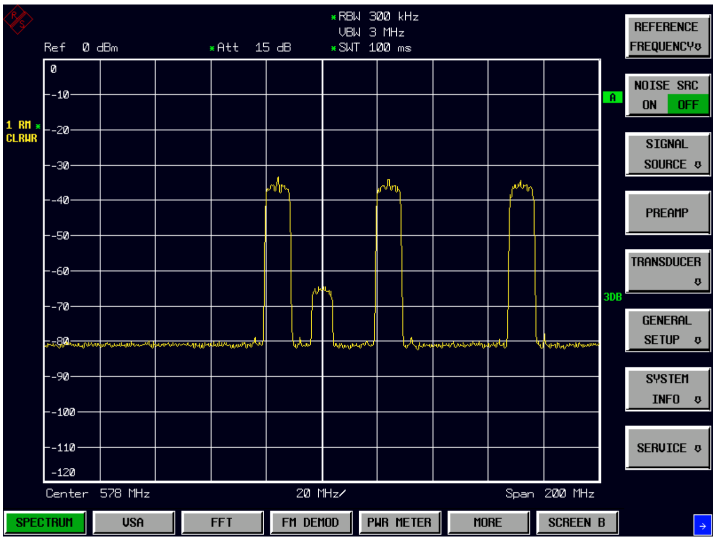

Figure 3-4 DVB-T signal between several LTE BS signals

In **Figure 3-4**, the wanted DVB-T signal is set up between three LTE base station signals (bandwidth 10 MHz) whose power levels are significantly higher.
A multi-channel test signal as in **Figure 3-4** would allow for a comprehensive overview measurement under worst case conditions. The test set-up enables the users to adapt the channel occupation around their own needs. In any case, it provides the flexibility required for such a testbed. The user interface for configuring these channels is depicted in **Figure 3-5**.

3.1.7- Conclusion

The test set-up that uses only one generator that provide the wanted signal and the interference signal works satisfactorily for the channels n-4 to n+4 with some limitations on the input power for the receiver under test.

This allows for a quick assessment of the resilience to adjacent channel interference under normal reception conditions but not for the measurement of overload thresholds.

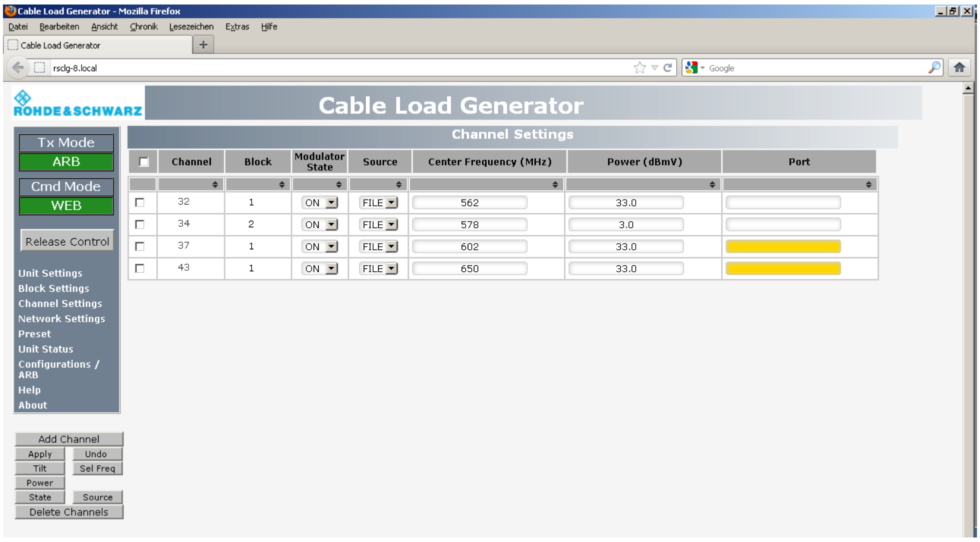

Figure 3-5 User interface of cable load generator.

3.2- Testbed 2

The current section descibes two experiments that where conducted using a DVB-T signal as the carrier or wanted signal and a Wi-Fi signal as the interference or unwanted signal.

3.2.1- Experimental System Setup

In order to generate the DVB-T signal a DVB-T modulator was used. The following table defines the the transmitted DVB-T signal characteristics:

DVB-T Signal Characteristics	
Constellation	64-QAM
Channel BW	8MHz
Code Rate	¼
Guard Interval	½
Number of Carriers	8k
Frequency	698 MHz

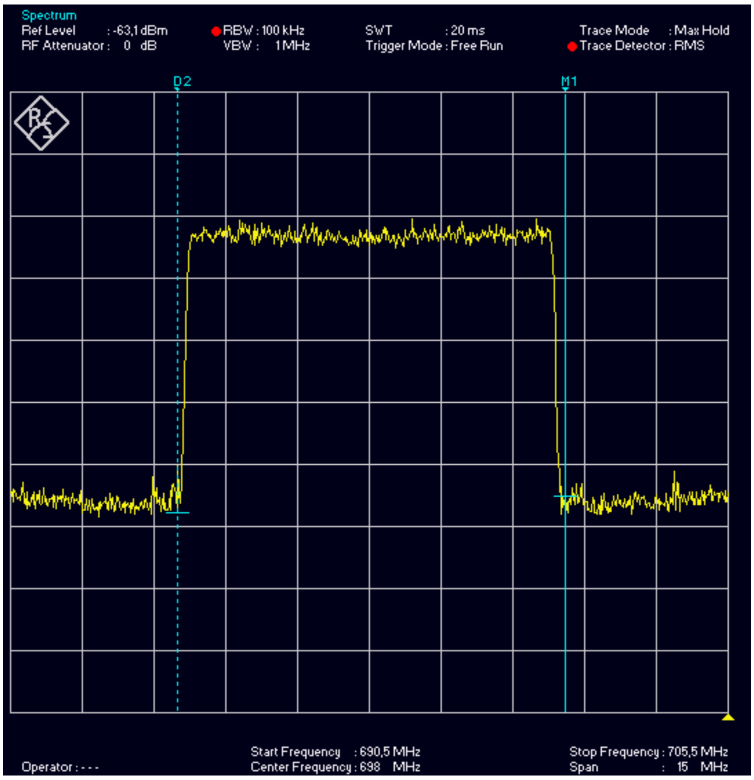

Figure 3-6: DVB-T Signal (Carrier)

In the experimnetal setup of interest, a WiFi signal was used as the interfering signal. The following table defines the the WiFi interfering signal Characteristics:

802.11 Signal Characteristics	
Technology	802.11 g
Channel BW	5MHz
Frequency	VHF - UHF

The transmit power and the center frequency of the interfering signal is adjusted accordingly to the experimental setup requirements.

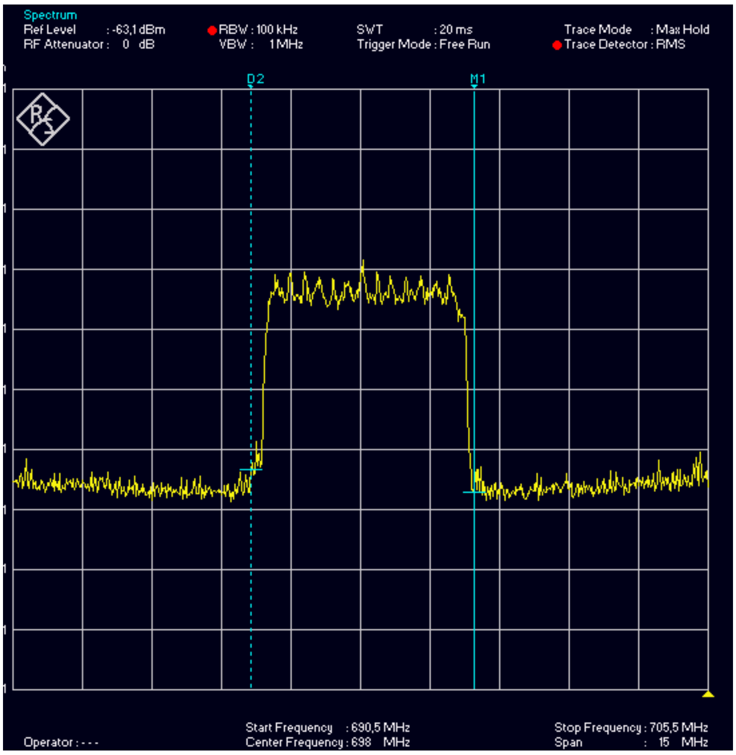

Figure 3-7: Wi-Fi Signal (Interference)

3.2.2- Measured Parameters

During the experimental setup a number of parameters were recorded. These parameters describe both the experimental setup and the effect of the interfering signal (802.11) on the wanted signal (DVB-T). Parameters include C/I and MER degradation. Measurements in the form of eye diagram and constellation diagrams are also presented describing the effect of the interfering effect on the received DVB-T signal.

The **Modulation Error Ratio** or **MER** is a measure to quantify the performance of a digital radio transmitter or receiver in a communications system using digital modulation. For the current set of experiments a 64-QAM modulation for the DVB-T transmitted signal was used.

Various imperfections in the implementation or environment cause deviation of the constellation points. In the current environment the main reason that the actual constellation points deviate from the ideal locations is due to the presence of the interference signal that is being injected into the DVB-T signal channel. A higher MER figure indicates better performance. The measurements are expressed in MER degradation which is the degradation of the measured MER in dB in relation to the MER when there is no interference present.

The **eye diagram** is an intuitive graphical representation of communication signals. The quality of these signals can be judged from the appearance of the eye.

A **constellation diagram** is a representation of a signal modulated by a digital modulation scheme. It displays the signal as a two-dimensional scatter diagram in the complex plane at symbol sampling instants. In a more abstract sense, it represents the possible symbols that may be selected by a given modulation scheme as points in the complex plane. Measured constellation diagrams can be used to recognize the type of interference and distortion in a signal.

3.2.3- Measurement scenarios

Two type of measurement scenarios have been investigated. The first scenario captures the effect when an interfering signal gradualy overlaps a DVB-T signal. The second scenario captures the interference effect when the two signals are instantaneously overalapping.

3.2.4- Gradually overlapping test scenario

This experiment has been designed in order to test the behavior of a DVB-T received signal when an interfering Wi-Fi signal gradually overlaps the DVB-T channel. The power of the interferer is constant during this set of measurements and thus the C/I is constant (12dB). The Wi-Fi signal gradually moves into the DVB-T signal in 2 MHz steps and at every step a set of measurements is carried out. In this experiment the C/I_{ov} is defined as the DVB-T Carrier signal (C) to the Interference – overlapping signal (I_{ov}), at any given position.

During the experiments, as can be seen from Figure 3-8, the I_{ov} is the interferer signal that overlaps the DVB-T Carrier (C) signal. As presented in Table 3-2, the I_{ov} Bandwidth in MHz is the amount of interferer signal that overlaps the Carrier signal, in this case the DVB-T signal.

The obtained results are presented in MER degradation figures in relation to C/I_{ov} and C/I_{ov} Bandwidth.

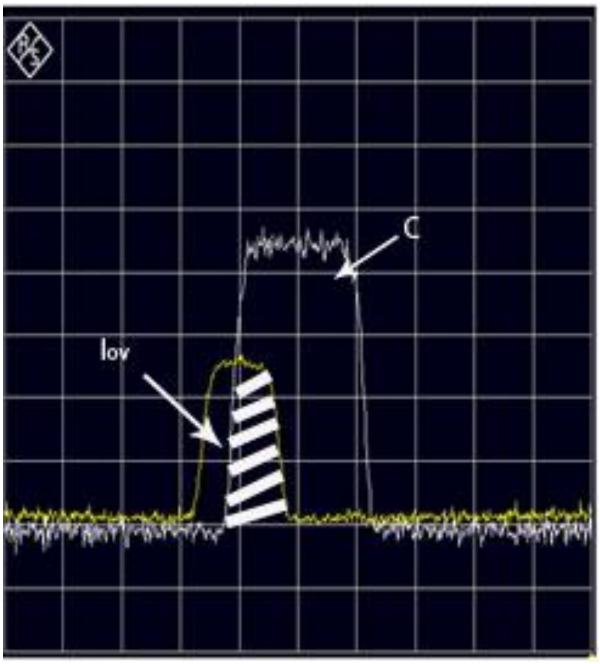

Figure 3-8: I_{ov} overlapping the carrier.

A/A[1]	C/I $_{ov}$ dB	I_{ov} Bandwidth (MHz)	MER Degradation (dB)
1	19.6	0.5	-3.6
2	13.8	2.5	-15
3	11.8	4.5	-18.2
4	11	5	-18.8

Table 3-2: 1st measurement set results

[1] A/A: Amplitude of wanted signal / Amaplitude of unwanted signal

Interference Centre Frequency 692MHz

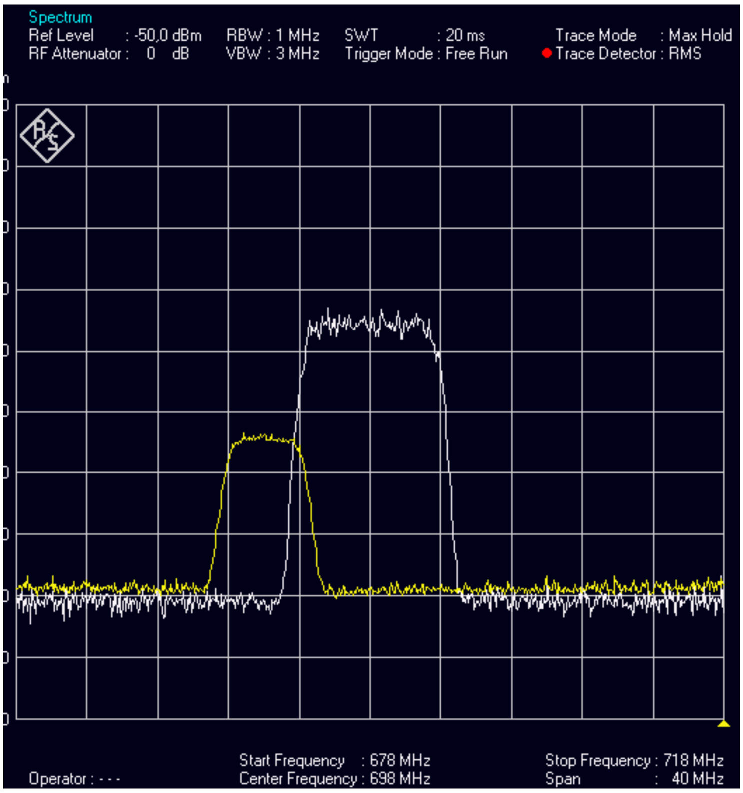

Figure 3-9: Spectrum for measurement 1

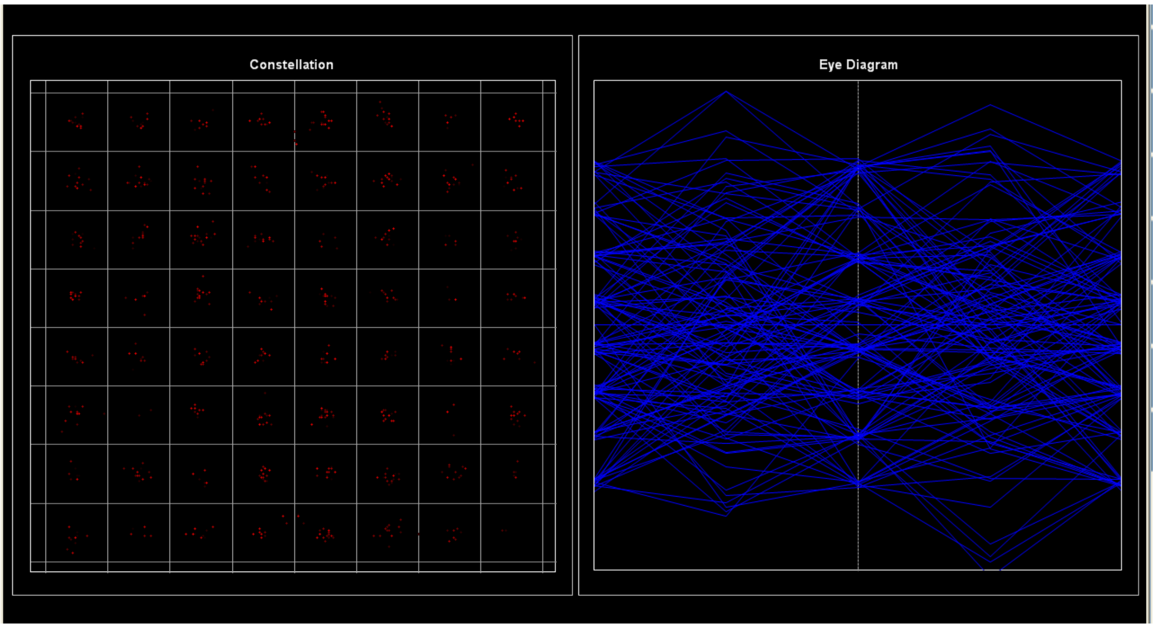

Figure 3-10: Diagrams for measurement 1

Interference Centre Frequency 694MHz

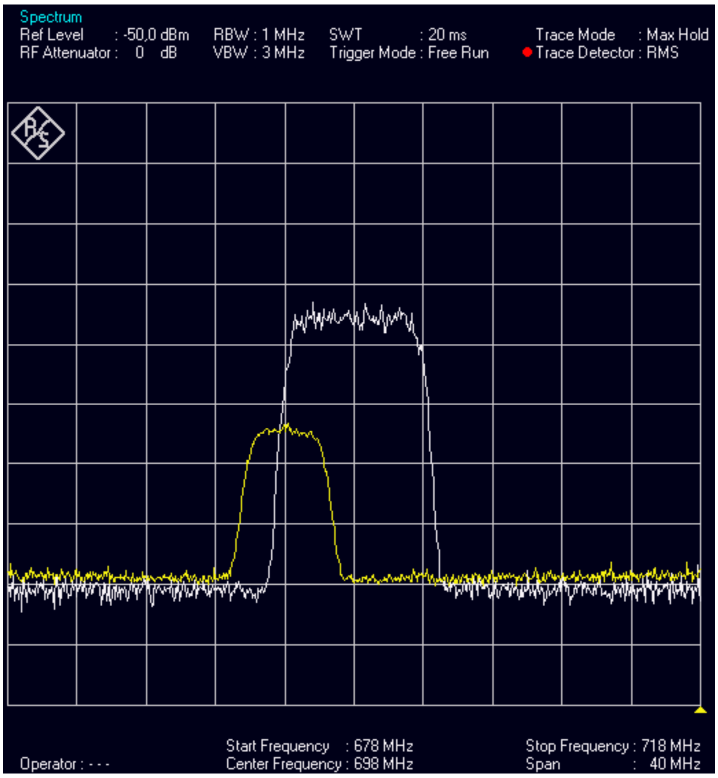

Figure 3-11: Spectrum for measurement 2

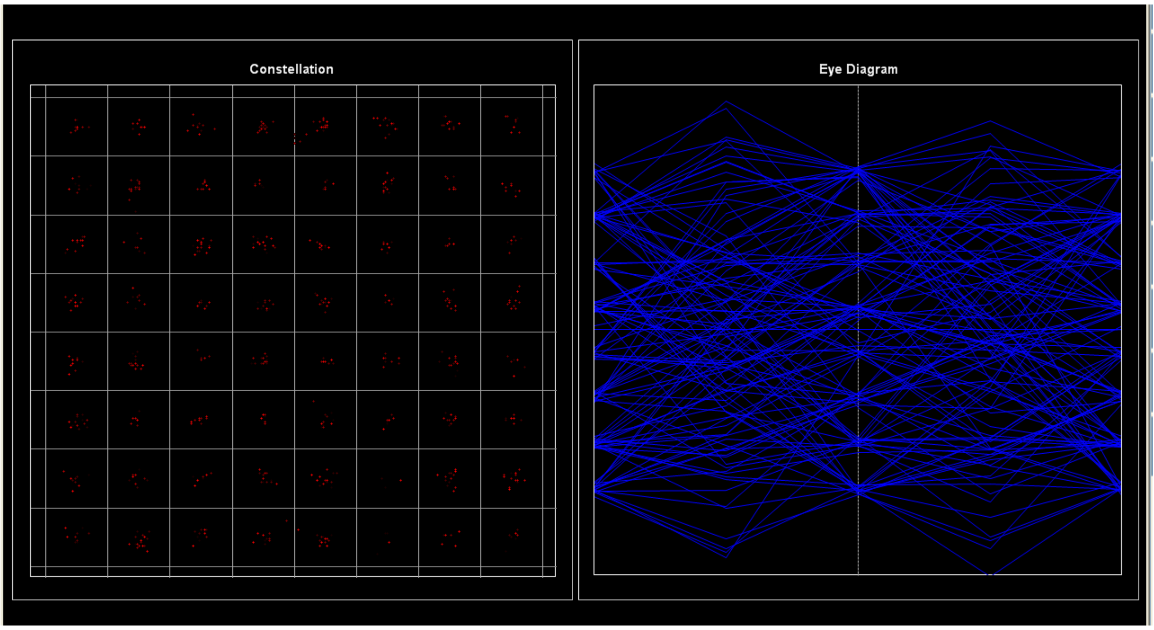

Figure 3-12: Diagrams for measurement 2

Interference Centre Frequency 696MHz

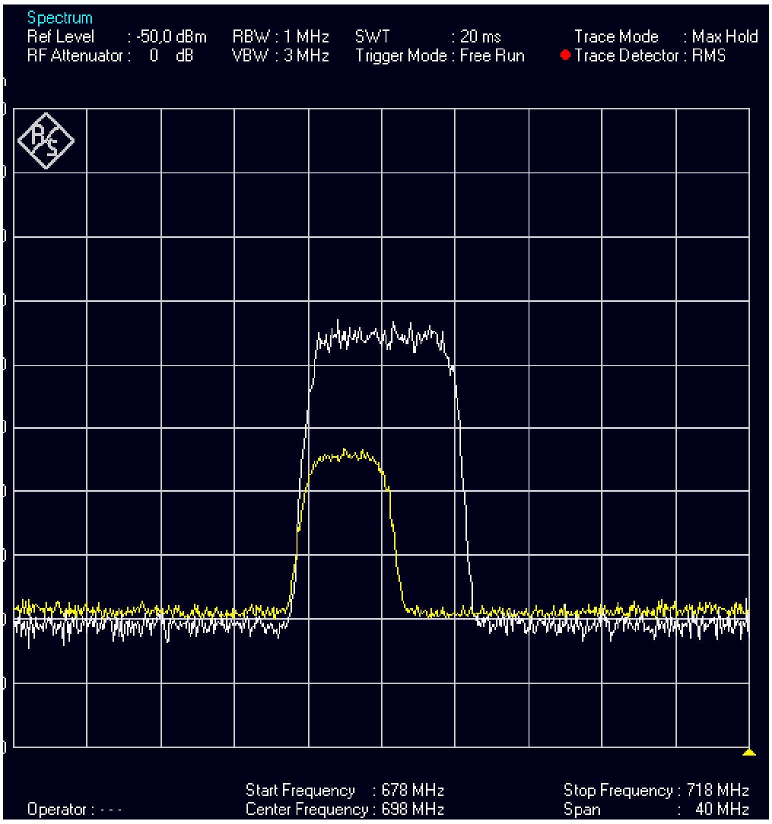

Figure 3-13: Spectrum for measurement 3

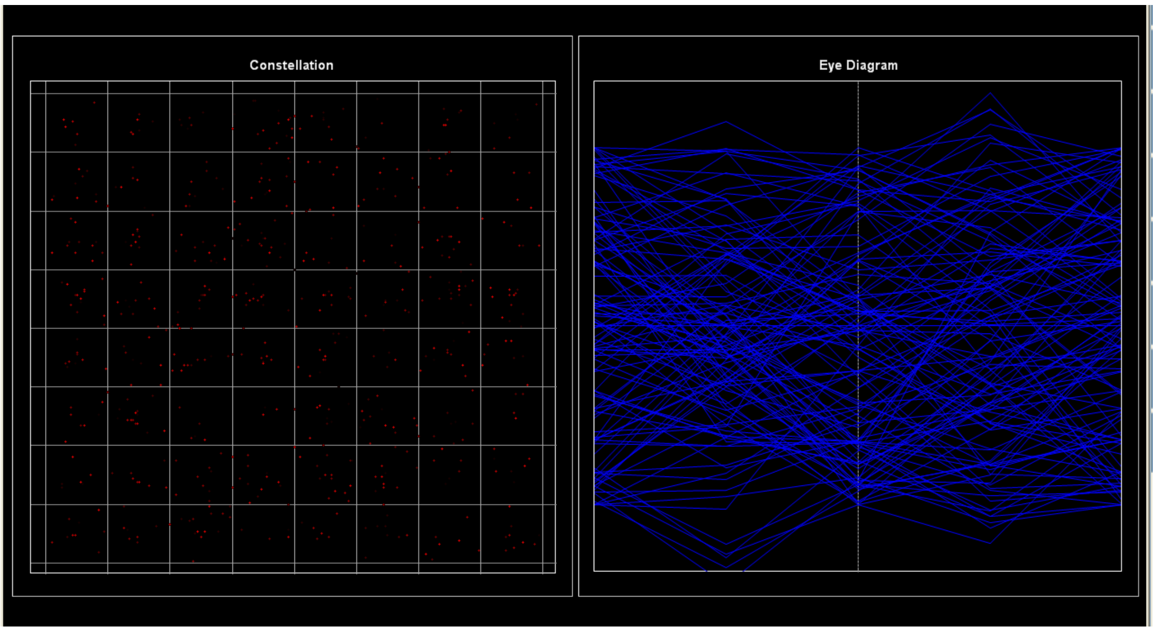

Figure 3-14: Diagrams for measurement 3

Interference Centre Frequency 698MHz

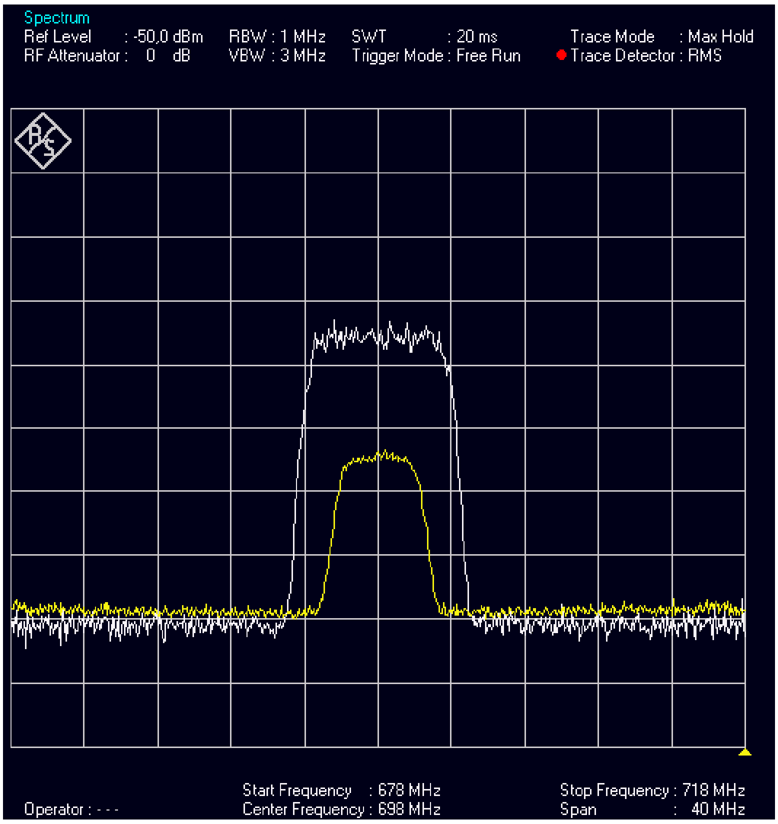

Figure 3-15: Spectrum for measurement 4

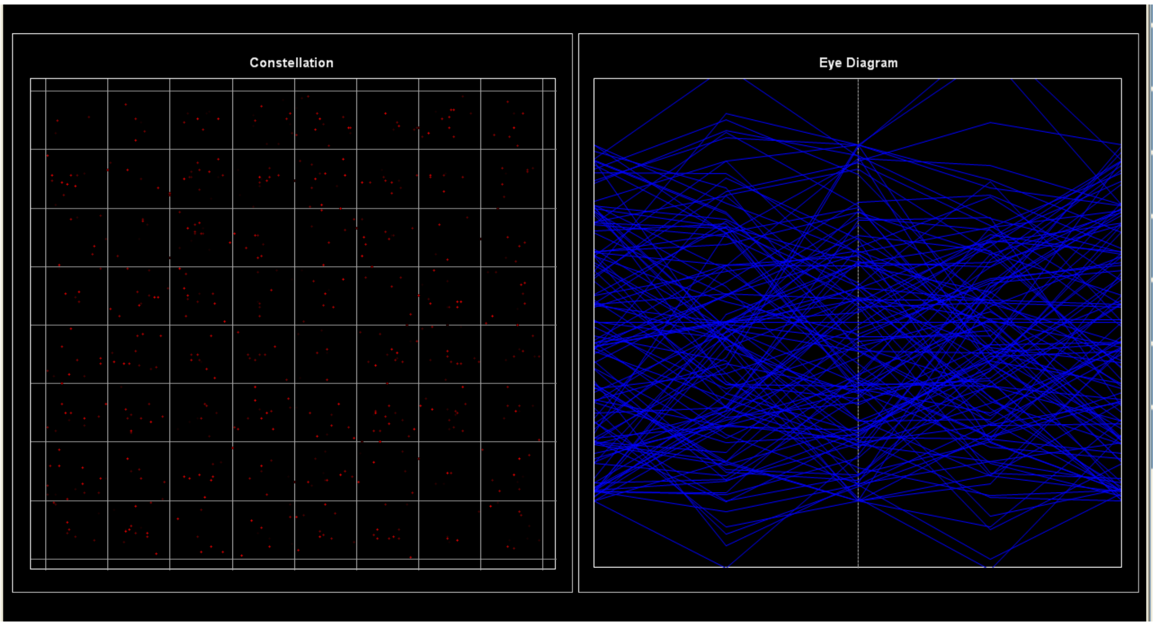

Figure 3-16: for measurement 4

From this set of measurements it is clear that the level of interference and distortion to the DVB-T signal is determined by the positions of the centre frequency of the interfering signal and the wanted signal's centre frequency. For a given bandwidth and spectrum mask this determines the overlapping spectrum. As the interfering signal moves closer to the DVB-T centre frequency the interference effect becomes more severe and visible to the DVB-T reception.

For the case where the interfering signal overlaps 0.5MHz the DVB-T signals, there is MER degradation of 3.6 dB. When the interfering signal overlaps by 2.5MHz the DVB-T signal, there is a difference to MER by -15dB and visible constellation point's scarcity.

In the case of 4.5MHz and 5MHz overlapping there is severe degradation to the MER.

3.2.5- Co-channel Interference test scenario

During this test the behaviour of a DVB-T received signal under co-channel interference was investigated (100% overlap of the two signals). The interference signal is a Wi-Fi signal operating in the same centre frequency of 698MHz with a 5MHz bandwidth. The interferer power is adjustable and is increased by 2dBm for consecutive measurements.

A/A	C/I (dB)	MER Degradation (dB)
1	17.4	-12
2	15.4	-14.4
3	13.4	-16
4	11.4	-19.2
5	9.4	-21.3
6	7.4	-23.8

Table 3-3: 2nd measurement set results

During this set of experiments 6 measurements where conducted. During the measurement the Wi-Fi power was increased by 2dBm steps. The results are described again through the measured MER degradation. Constellation and eye diagram are also presented to visually observe the distortion caused to the received signal.

C/I: 17.4 dB

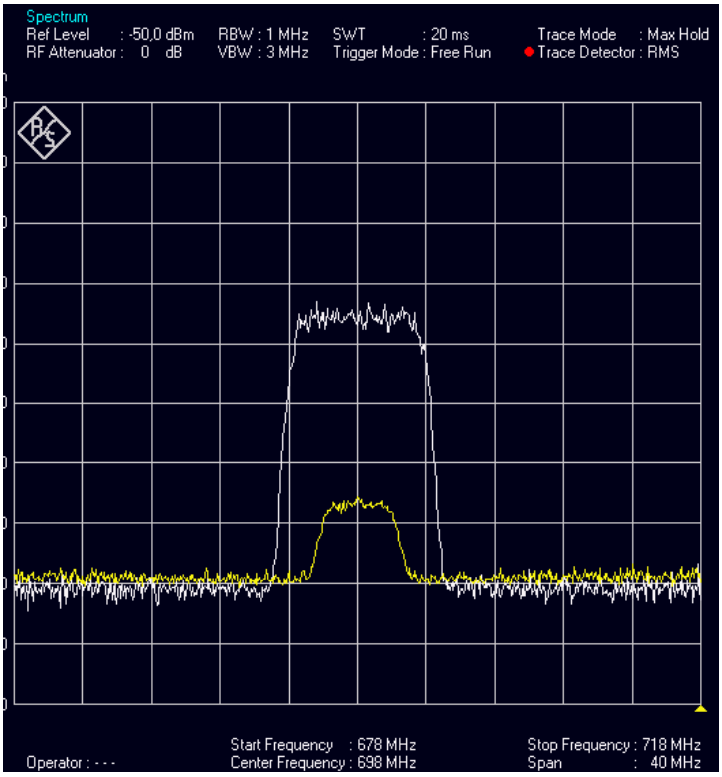

Figure 3-17: Spectrum for measurement 1

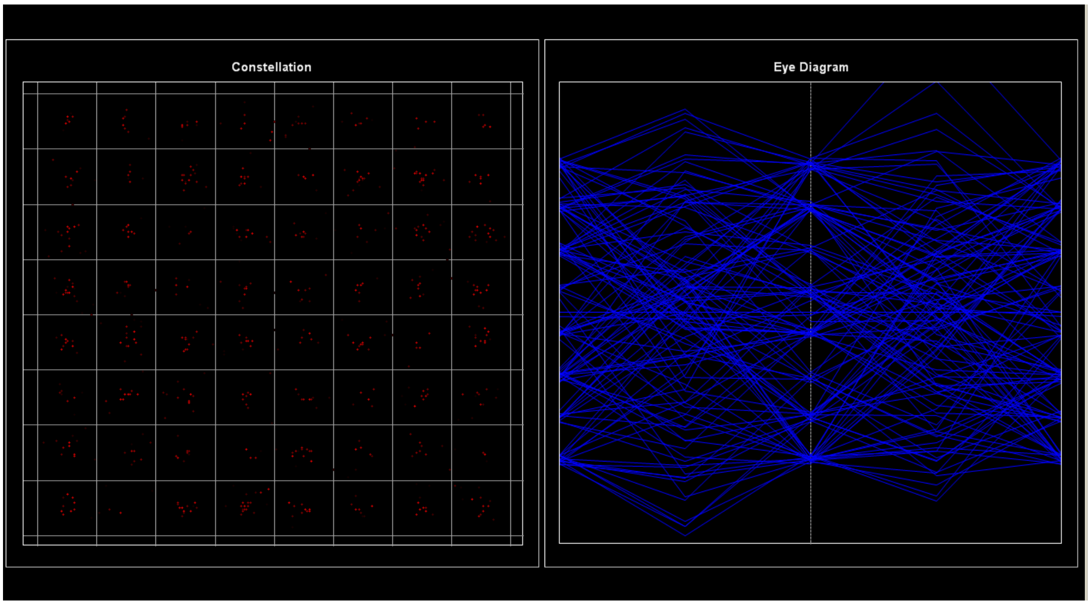

Figure 3-18: Diagrams for measurement 1

C/1: 15.4 dB

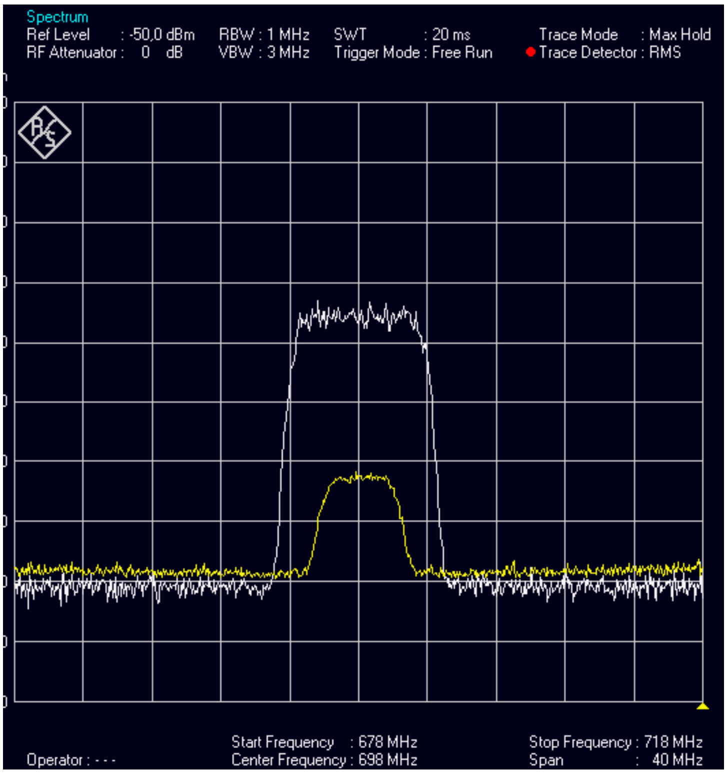

Figure 3-19: Spectrum for measurement 2

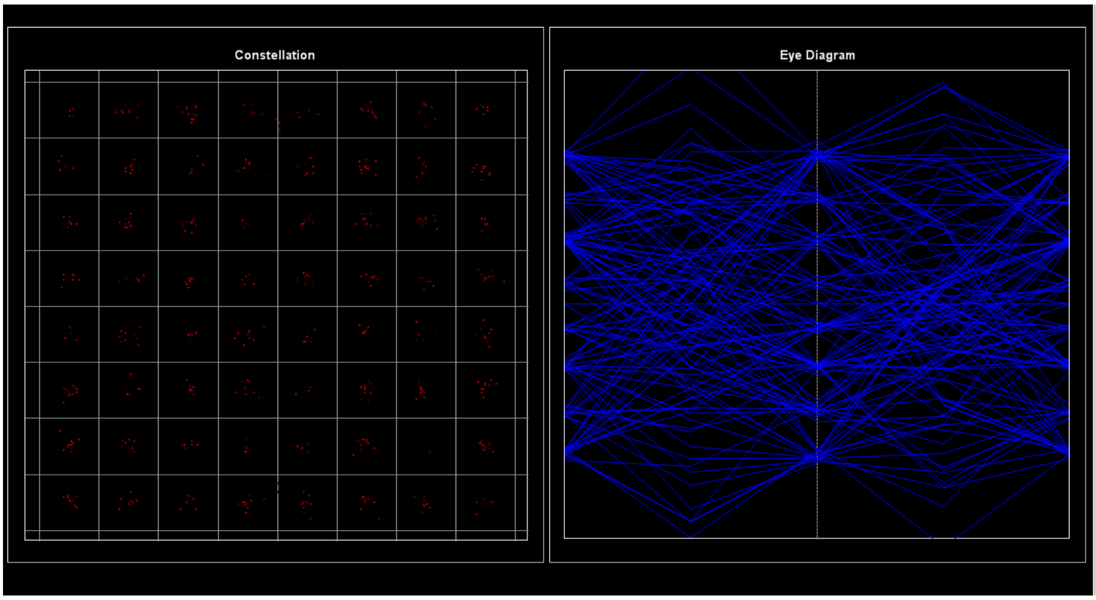

Figure 3-20: Diagrams for measurement 2

C/1: 13.4 dB

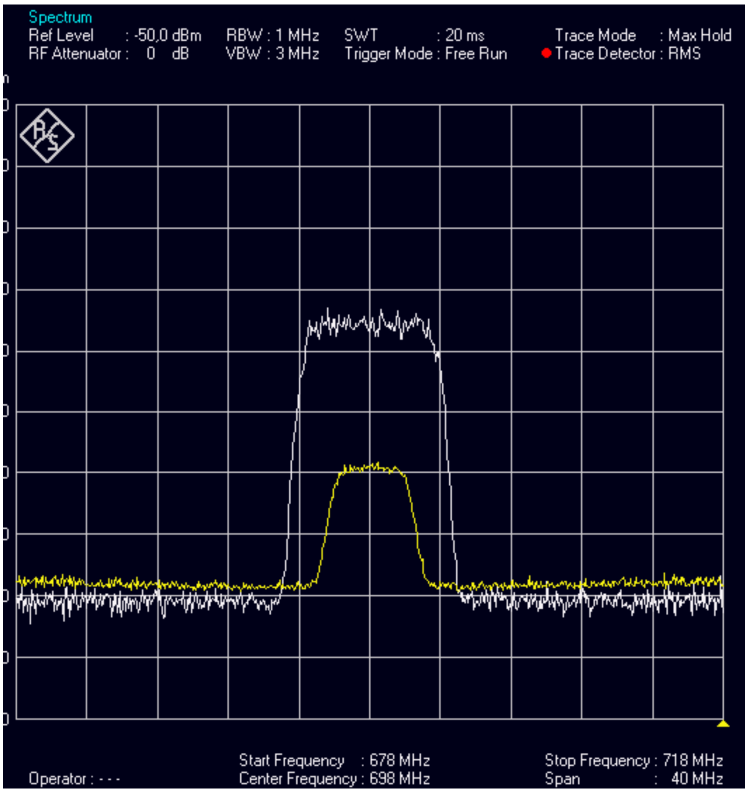

Figure 3-21: Spectrum for measurement 3

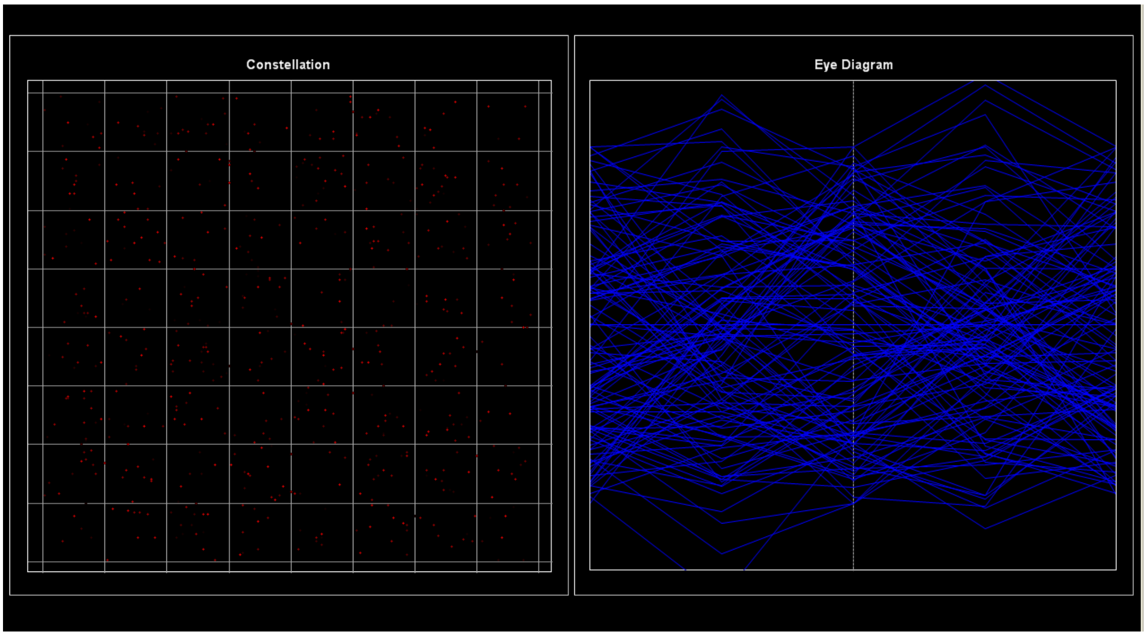

Figure 3-22: Diagrams for measurement 3

C/I: 11.4 dB

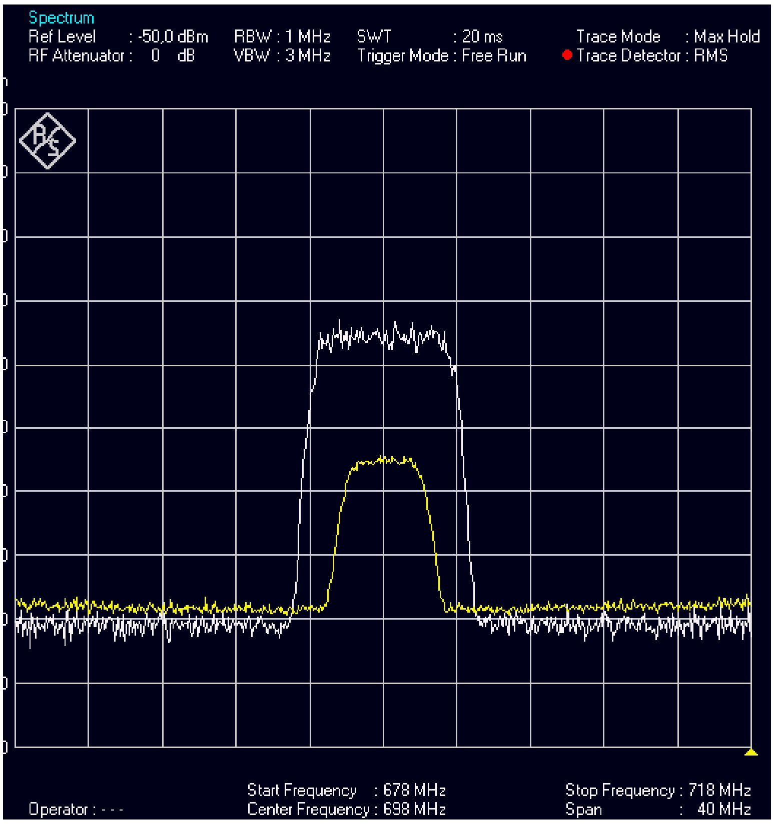

Figure 3-23: Spectrum for measurement 4

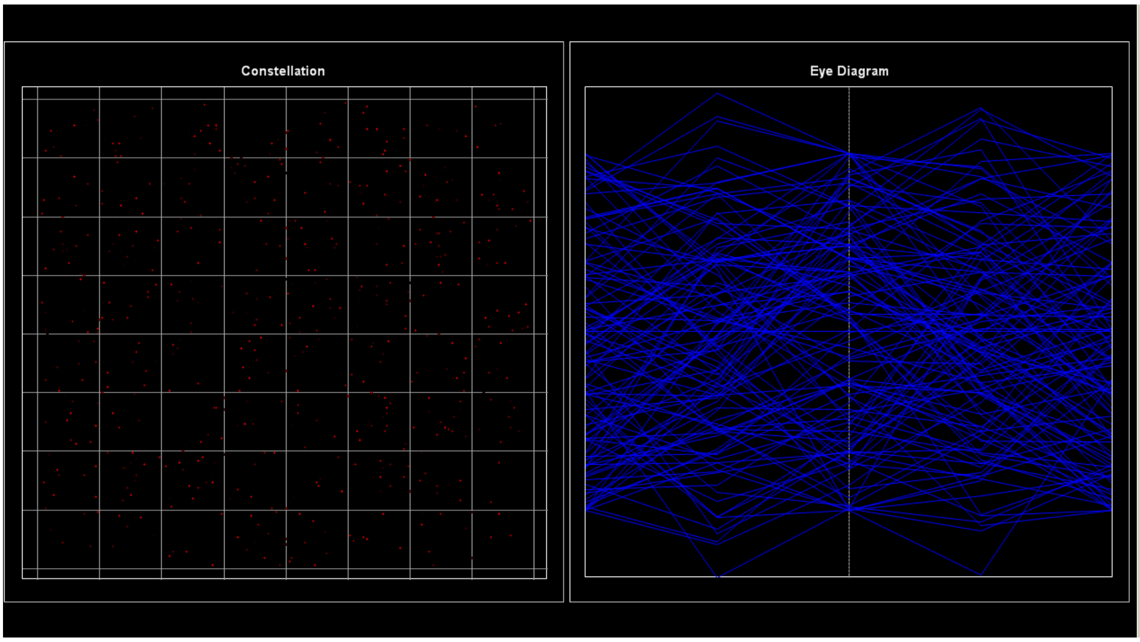

Figure 3-24: Diagrams for measurement 4

C/I: 9.4 dB

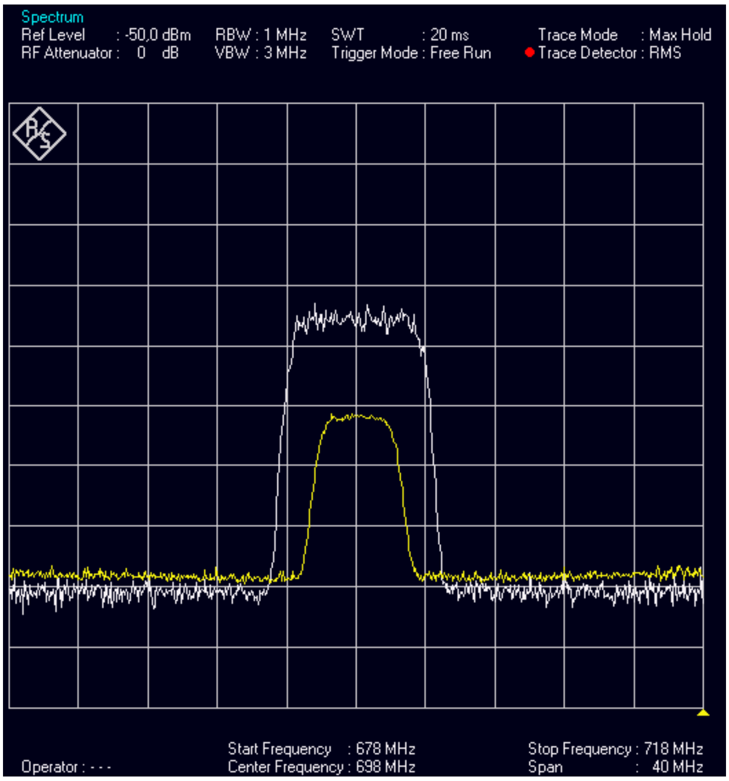

Figure 3-25: Spectrum for measurement 5

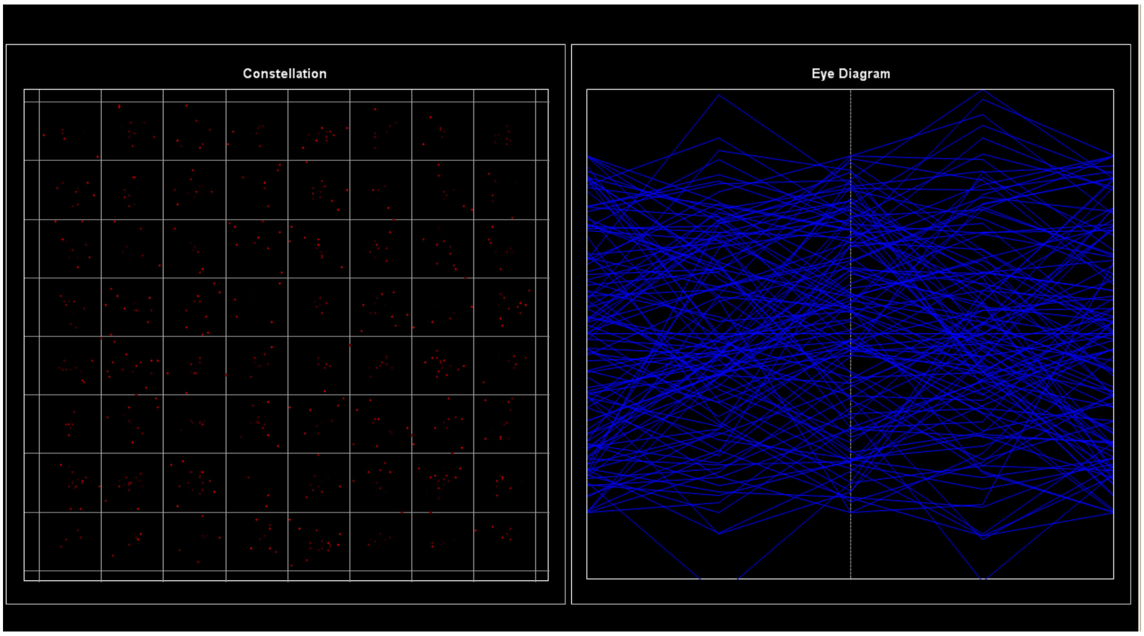

Figure 3-26: Diagrams for measurement 5

C/I: 7.4 dB

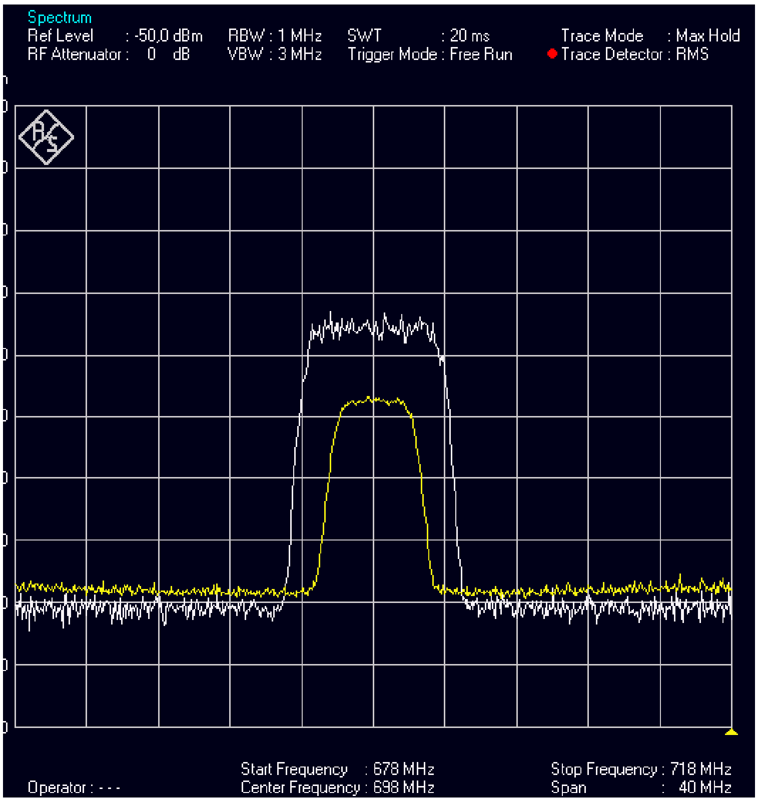

Figure 3-27: Spectrum for measurement 6

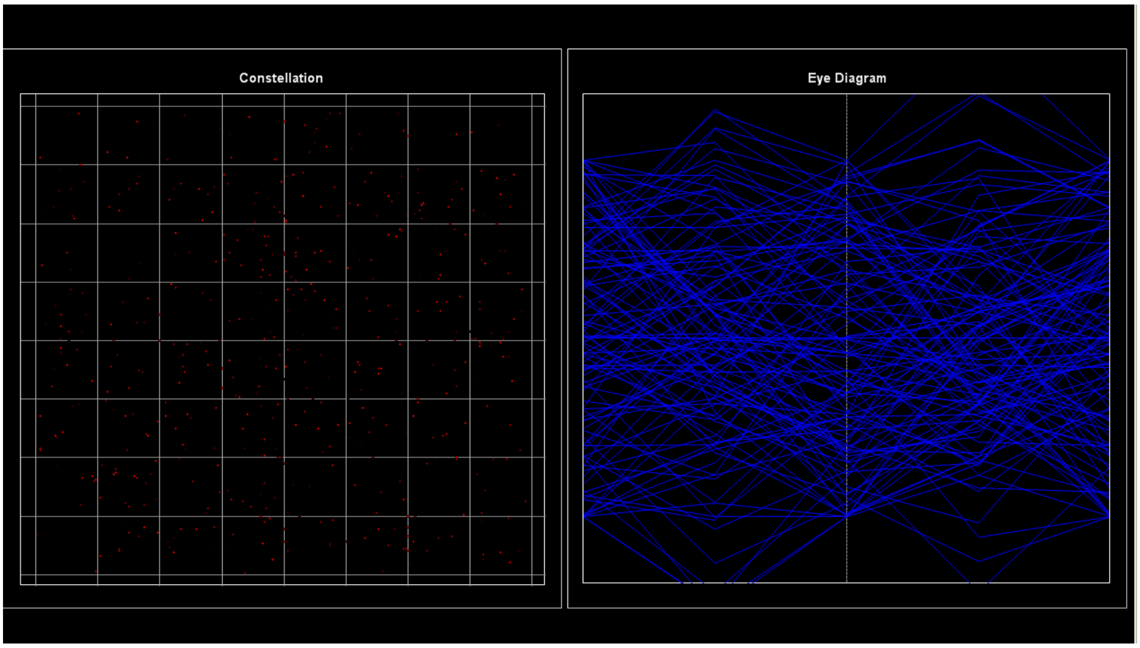

Figure 3-28: Diagrams for measurement 6

3.2.6- Conclusion

During this experiment it was shown that co-channel interference, in this case from a Wi-Fi technology, can affect a DVB-T signal. Obtained results suggest that if the C/I drops below 14dB there is severe distortion to the channel and thus to the transmitted content.

4- Testing WSDs for interference by primary users

For the measurement of interference of DVB-T signals into WSDs, a simple test set-up provides a wide variety of different, configurable test signals. Based on a modified test instrument, multiple signals can be generated and amplified so that they can characterize the WSD in terms of selectivity, overload and sensitivity.

4.1- Simplified test set-up for testing WSDs

The Cable Load Generator CLG was originally designed to simulate heavily loaded cable networks with many channels. The channels can carry analogue or digital TV signals or other waveforms. The output signals are used to test cable TV receivers and similar equipment.
In the course of COGEU, R&S has modified such a cable load generator so that it can output a multitude of DVB-T signals for the testing of WSDs, or a multitude of signals of secondary services such as WiFi, LTE etc. for testing DVB-T receivers.
In the following sub-sections some possible test signals are described which may serve as a starting point for a proposal on test signals for WSDs.

4.2- Definitions of interference signals

Figure 4-1 shows a possible test signal for WSDs. It contains the LTE base station signal of the device under test (DUT) and three DVB-T signals of different power levels.

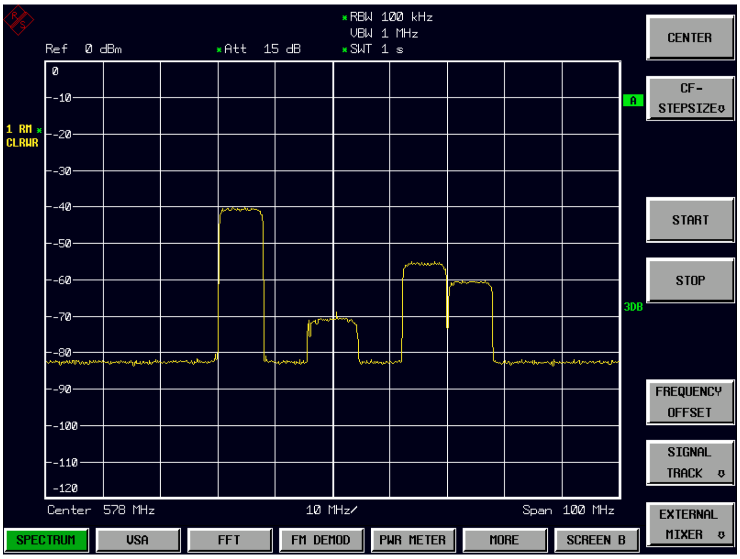

Figure 4-1 Spectrum of test signal: LTE with 3 DVB-T signals.

The configuration is arranged according to **Figure 4-2** by defining two groups (blocks) of channels. The first block contains the three DVB-T signals in channel 32, 36 and 37. The second block is configured for the wanted LTE signal. The output power for each channel can be set individually, in this case the power level of the interfering DVB-T signals is higher than that of the wanted LTE signal, but all three are different.

The output power for each channel is given in 'dB mV at 75 Ohm' which can be converted into 'dBm at 50 Ohm'. When considering the loss of 75/ 50 Ohm matching (approx. 5.7 dB), 33 dB mV translate into -21.5 dBm.

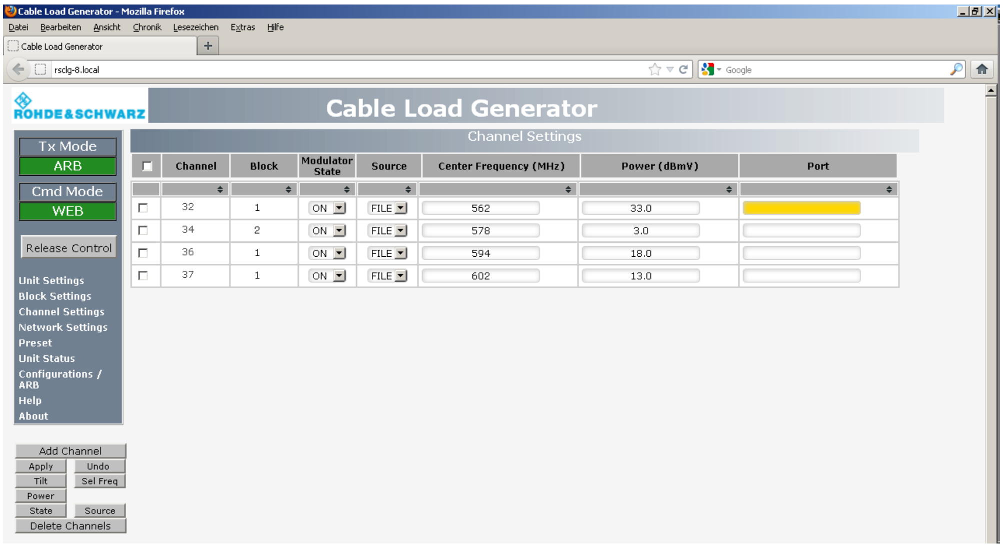

Figure 4-2 User interface for configuration of cable load generator

Table 4-1 Settings for wanted and unwanted signals

Type of signal	Channel	Relative channel numbering	Centre frequency MHz	Bandwidth MHz	Power level dB mV
LTE BS (wanted signal)	34 (partly occupying ch 33 and ch 35)	n	578	10	3
DVB-T	32	n-2	562	8	33
DVB-T	36	n+2	594	8	18
DVB-T	37	n+3	602	8	13

4.3- Failure criterion for quality of WSD signals

The definition of the failure criterion needs to take into account which parameters are accessible in a WSD. Investigations on the testbed are necessary to establish if more than the usual information on throughput and packet loss rate is available.

One criterion that could serve as a fall-back solution is the ESR_5 criterion used for the assessment of the link quality in a DVB-T system. Provided that the WSD receives a video sequence, the threshold for visibility of distortions in the picture can be identified in a similar way as in the testing of DVB-T receivers.

5- Recommendations for a testbed for WSD certification

For certification of a new WSD the tools describes so far are too complex and laborious for each certification. Instead the regulator derives a set of parameters out of the results which are easy to measure in a certification facility and can guarantee an interference free coexistence of incumbents and WSDs.

For WSD certification there are two categories of technical specifications to be tested:

- RF emission characteristics
- Control characteristics

5.1- Testbed for WSD certification: RF emission characteristics

The following RF emission characteristics can be measured with the testbed in **Figure 5-1** :

- Power
- Bandwidth
- Out-of-block power in the DVB-T channels up to N±3
- Spurious emissions

The thresholds for these parameters are found by measurements of the failure points of the DVB-T/T2 receivers and should not exceed specific limits. The limits for the parameters are set as part of a specification:

- for the maximum signal power by the national regulation authority
- for the out-of-band emissions in an European Electromagnetic Compatibility Norm [13] and in the WSD transmission system norm (e.g. for LTE 3GPP TS 36101 and TS 36104)
- for the spurious emissions in an European Electromagnetic Compatibility Norm [13] and in the WSD transmission system norm (e.g. for LTE 3GPP TS 36101 and TS 36104)
- for the overloading threshold in the CEPT ECC Rep 148 [1]

The limits given in [13] are for DVB-T transmitters. The standards are also applicable for WSD-transmission systems similar to DVB-T, with time-invariant spectrum power density in the necessary bandwidth (e.g. LTE NodeB). As WSD are used in the same frequency band as secondary users, they should comply with these limits.

In chapters 2 to 4 limits like protection ratios and overload thresholds were measured for WSD interfering to DTT and vice versa. As long as the measured limits do not exceed the limits for DVB-T/DVB-T systems the standards are applicable. If the found parameters for WSD/DVB-T systems are worse than for DVB-T/DVB-T systems, the standards are applicable as well but the limits in the standards may then be toughened accordingly.

It is also possible that the regulation authorities will emit new regulations for specific equipment.

For transmission systems with time variant power spectrum density (e.g. LTE terminal equipment) supplementary interference measurements are necessary.

It has to be tested that the WSD signal is not disturbing DVB-T reception more than a DVB-T signal does. Some supplementary disturbance is caused by the out-of-band emissions of the WSD. The pulsing WSD-signal in the necessary bandwidth can provoke overloading.

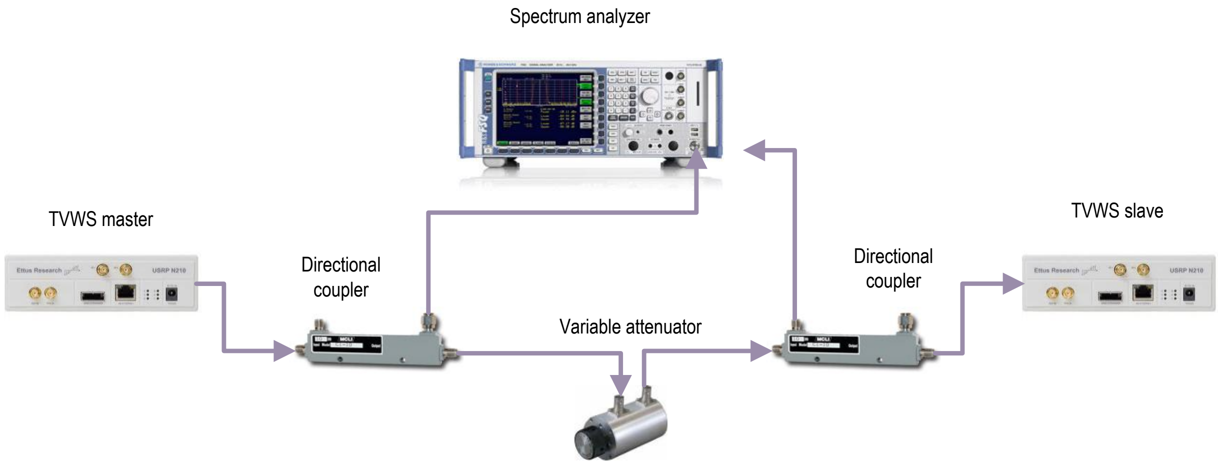

Figure 5-1 Testbed for WSD certification concerning RF emission characteristics

First, it has to be checked that the protection ratio (PR) for WSD signal interfering with to DVB-T is less or equal to the PR for DVB-T signal interfering with to DVB-T. If this is not the case, the out-of-band emission level limit has to be reduced accordingly.

Second, it has to be tested if the WSD signal overloads DVB-T receiver at lower levels than a DVB-T signal. If true, the WSD signal allowed peak power has to be reduced accordingly.

5.1.1- RF output power measurement

For the measurements a WSD master and a WSD slave device have to be available. They should be connected via an attenuator and should communicate, see **Figure 5-1** . Their parameters have to be set to transmit maximum power.
A directional coupler on the master side allows the measurement of the master transmitted power. Similarly a directional coupler on the slave side allows the measurement of the slave transmitter power. The attenuator has to be set in accordance with the selected Gaussian transmission channel attenuation.
The power is measured with a spectrum analyzer (SA) that can measure channel power, with the following settings:

- Centre frequency: WSD signal centre frequency
- Span 20 MHz
- Resolution bandwidth 100 kHz
- Video bandwidth 300 kHz
- Trace max hold
- Detector RMS

The SA power measurement limits should be set to the WSD signal bandwidth. When the trace is stable the SA displays the rf-output power. Correction should be made for the directional coupler attenuation. The power measurement has to be done for the master and for the slave WSD. The power has to be below the limits discussed as above in section 5.1-.

If the WSDs are using only a part of the allocated frequency band in a variable spectrum position, the measurement method is different. The SA is set as follows:

- Centre frequency: WSD signal centre frequency
- Zero span
- Resolution bandwidth is WSD signal bandwidth

- Video bandwidth is WSD signal bandwidth
- Trace max hold
- Detector RMS
- Sweep time chosen to see 20 bursts

Take at least 5 single sweeps and look for the highest pulse. Its power averaged over time is the maximum signal power.

The test has to be done near the lower and the upper frequency band permitted for operation.

5.1.2- Signal bandwidth

A WSD master and a WSD slave device connected as stated in 5.1.1- have to be set to communicate in a characteristic way, in the same way as in 5.1.1-. A spectrum analyzer with the following settings:

- Centre frequency: WSD signal centre frequency
- Span 20 MHz
- Resolution bandwidth 100 kHz
- Video bandwidth 300 kHz
- Trace max hold
- Detector peak

will provide a sweep. The bandwidth can be calculated by the SA (99%) or can be approximated as the difference of the frequencies where the signal power density is 20 dB less than the average power density in between these points.

5.1.3- Out-of-block power in the DVB-T channels up to N±3

The set-up is the same as in 5.1.1-. Master and slave WSD have to communicate with maximum power. The SA settings are slightly different:

- Centre frequency of channel N±1, N±2, N±3
- Span 20 MHz
- Resolution bandwidth 100 kHz
- Video bandwidth 300 kHz
- Trace max hold
- Detector rms

The SA sensitivity should be high by using a preamplifier, by reducing the input attenuation and optimizing the reference level setting, so that the noise floor is at least 12 dB below the power limits.
The SA power measurement frequency limits should be set successively to the DTV-channel N±1, N±2, or N±3 limits. When the max-hold trace is stable the SA displays the rf-output power in the respective adjacent channel. Correction should be made for the directional coupler attenuation.
The power in the adjacent channels should be below the limits discussed in chapter 5.1-.

5.1.4- Spurious emissions

The set-up is again the same as in 5.1.1-. Master and slave WSD have to communicate with maximum power. The SA sensitivity should be high so that the noise floor is at least 12 dB below the power limits.
The emissions should be measured over the frequency range 30 MHz to 6 GHz.

In the frequency range 30 MHz to 1 GHz, the SA settings are:

- Resolution bandwidth 100 kHz
- Video bandwidth 300 kHz
- Trace max hold
- Detector peak
- Sweep time such that for each frequency step, measurement time is longer than two WSD transmissions

In the frequency range 1 GHz to 6 GHz, the SA settings are:

- Resolution bandwidth 1 MHz
- Video bandwidth 3 MHz
- Trace max hold
- Detector peak
- Sweep time such that for each frequency step, measurement time is longer than two WSD transmissions

The power in the whole frequency range should be below the limits discussed in chapter 5.1-.

5.2- Testbed for WSD certification: control characteristics

Besides the RF parameters there are another groups of factors required for a WSD to operate without causing interference. One group of such factors are considering the performance and control of a WSD that operates in a specific scenario. A WSD operates in master/slave setup since it requires a Tx/Rx channel to transmit and receive data. More specifically a WSD must have a number of capabilities depending on the mode that is operating on.

For a Master WSD:

- Communicate with Broker entity
- Communicate with Geolocation DB
- Communicate with all slave WSDs
- Remote Control of slave WSDs
- Force a new configuration if and when needed
- An accurate positioning mechanism

For a Slave WSD:

- Communicate with Master WSD
- Adjust its operation configuration
- Communicate and transmit performance data to the Master WSD
- An accurate positioning mechanism to report its position in frequent intervals.
- Safety mechanism for not allowing the WSD to operate if is unable to obtain or apply the configuration from a master WSD.

The aforementioned characteristics are very important for any WSD in order to be allowed to operate and not cause any thread to primary and secondary systems.

6- Documentation of certification results

The documentation of the certification measurement results should contain at least the following points:

- WSD type and description of equipment and its capabilities (to be derived from the specification of the WSD)
- Test signals for WSD link (typically WiFi or LTE, including versions, standards, etc.)
- Error criterion
- Pass thresholds
- Certifying institution
- Certification number (under which all documentation can be retrieved)

The regulatory authorities are likely to decide on certain formats for the documentation of results. They will probably set up a separate database where all WSD test results are collected.

Finally, the resilience of the DVB-T/T2 receiver population varies typically from country to country depending on the introduction of the DVB-T or DVB-T2 services in this country. To protect legacy receivers (i.e. old DVB-T receivers) which may not have the same selectivity of input signals or the same overload threshold as modern receivers, it could be useful to introduce an additional margin for WSDs, at least in countries where a significant number of legacy receivers is in operation (e.g. UK, I, F D). In countries where DVB-T or DVB-T2 services started over the last 3 or 4 years, this does not seem to be necessary.

7- Conclusions

The results of the measurements in WP4 and the recommendations for test conditions which are derived from these results form the main output the work in WP4. They are completed by the recommended procedures for the certification of WSDs, including proposals for testbed set-ups, and the main points for documentation of the test results.

The experience gained during the measurement campaign led to an additional iteration of the definition of recommendations for interference measurements.

With the equipment and testbeds available now, a suitable set of test cases can be selected from a great diversity of test scenarios.

The challenge to reduce the number of required tests to a minimum so that certification of WSDs can be done in an inexpensive, cost-effective way, is addressed in this deliverable.

8- References

[1] CEPT/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

[2] RECOMMENDATION ITU-R BT.1368-6: “Planning criteria for digital terrestrial television services in the VHF/UHF bands”

[3] CEPT/ECC: “The identification of common and minimal (least restrictive) technical conditions for 790 – 862 MHz for the digital dividend in the European Union” CEPT Report 30, October 2009

[4] Nokia: “Comments on the spectrum mask used in the protection ratio measurements”, CEPT/ECC, Doc. SE43(10)89, 6th Meeting of SE43, June 2010, Mainz, Germany

[5] 3GPP TS 36.104 V8.5.0 “Base Station (BS) radio transmission and reception”

[6] 3GPP TS 36.101 V8.5.1 “User Equipment (UE) radio transmission and reception”

[7] NDR/ZDF: “Further studies on the compatibility between LTE and DVB-T systems in co- and adjacent-channel configuration”, ITU, JTG 5-6, Doc. 5-6/125-E, 12 Nov 2009

[8] ARD/ZDF/IRT: “Protection Ratios for LTE-BS and LTE-UE interference into DVB-T”, CEPT ECC Doc TG4(10) 322, January 7th, 2010

[9] COGEU: Deliverable D4.4 'Guidelines for TVWS equipment certification and compliance – initial'; May 2012.

[10] COGEU: D4.3 'Testbed for coexistence evaluation'; October 2011.

[11] OFCOM: VNS 2188 – Voluntary National Specification 2188; White space devices operating in the 470 MHz to 790 MHz band; November 2012.

[12] OFCOM: IR 2088 – UK Interface Requirement 2088; White space devices operating in the 470 MHz to 790 MHz band; November 2012.

[13] ETSI EN 302 296-2 V1.2.1 (2011-05): Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the digital television broadcast service, Terrestrial (DVB-T).

9- List of Tables

10- List of Figures

11- List of Abbreviations

3GPP	3rd Generation Partnership Project
AGC	Automatic Gain Control
AWGN	Additive White Gaussian Noise
C/N, CNR	Carrier-to-noise (ratio)
CEPT	Conference of European Postal & Telecommunications
CR	Cognitive Radio
DVB-H	Digital Video Broadcasting - Handheld
DVB-T	Digital Video Broadcasting - Terrestrial
DTT	Digital Terrestrial Television
DTV	Digital Television
ED	Energy detector
EN	European Norm
ETSI	European Telecommunications Standards Institute
EU	European Union
FFT	Fast Fourier Transformation
GI	Guard Interval
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
PMSE	Programme Making and Special Events
PR	Protection Ratio
PRBS	Pseudo Random Binary Sequence
PU	Primary users
RF	Radio Frequency
SDR	Software Defined Radio
TPS	Transmission Parameter Signalling
TU6	Typical Urban 6 paths (propagation profile)
TV	Television
TVWS	TV White Spaces
UHF	Ultra High Frequency
WLAN	Wireless Local Area Network
WM	Wireless Microphone
WP	Work Package
WSD	White Space Device