Wise-Project Measurement Report:

WSD maximum Power Indoor Measurements in Turku Test Network

A measurement campaign to study the WSD maximum power indoors was organized as part of the Finnish WISE-project. WISE (White space test environment for broadcast frequencies) is a project with the aim to construct an open, cognitive radio geolocation database test bed for studying the use of cognitive radios in the UHF television broadcast bands. This includes simulations, test database, test network and measurement platform. The project partners are Aalto University, Digita, Fairspectrum, Ficora, Nokia, University of Turku, Turku University of Applied Sciences and it is funded by Tekes, the national technology funding organization, as part of a larger cognitive radio Trial-program.

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1. BACKGROUND

When considering the interference caused by a White Space Device (WSD) to the digital terrestrial television (DTT) reception, two cases must be distinguished. Firstly the WSD and the victim DTT-receiver can be separated by a rather large distance. In this case the interference considered is probably a co-channel one and the distance between the WSD location and the DTT reception site is known as the later one is typically the nearest possible pixel of the DTT service area in question. The coupling loss between the devices can be calculated by using the distance and a suitable propagation model.

Secondly the WSD and the victim DTT-receiver can be situated at the same pixel (same location). In this case the interference is typically adjacent channel type as the operation with co-channel is not possible within the DTT service area. Calculating the coupling loss in this case is problematic as nothing is known about the geometry between the WSD and the DTT-receiver, only that they may exist within the same pixel and thus the distance between is smaller than the pixel size. This problem is discussed in the ECC Report 159, prepared by the CEPT SE 43 group, and a proposed solution is to use a reference geometry in the calculations between the devices. Several different reference geometries are proposed for different kind of situations.

In the ECC report 159 the path losses in the reference geometries are calculated as free space losses with certain assumptions of the used antennas. An earlier Wise-project measurement campaign was studying the outdoor portable WSD to fixed rooftop DTT case and this report is studying indoor portable to indoor portable reference geometry. Like in the outdoor campaign both path loss and maximum WSD power to interfere DTT-reception were measured with some parameter variations. From the results it was possible to calculate the protection ratios for different offsets.

2. MEASUREMENT SETUP

2.1 Reference geometry

The used portable indoor reference geometry is shown in Figure 1. Both DTT-reception antenna and the WSD are at 1.5 m height 2m away from each other. The geometry is assuming an omnidirectional antenna for both the WSD and DTT with no polarization discrimination. This was repeated in the measurements both ends using similar omnidirectional antennas with a nominal gain of 2 dBi. In some measurements the DTT-receiving antenna was replaced with an active indoor antenna.

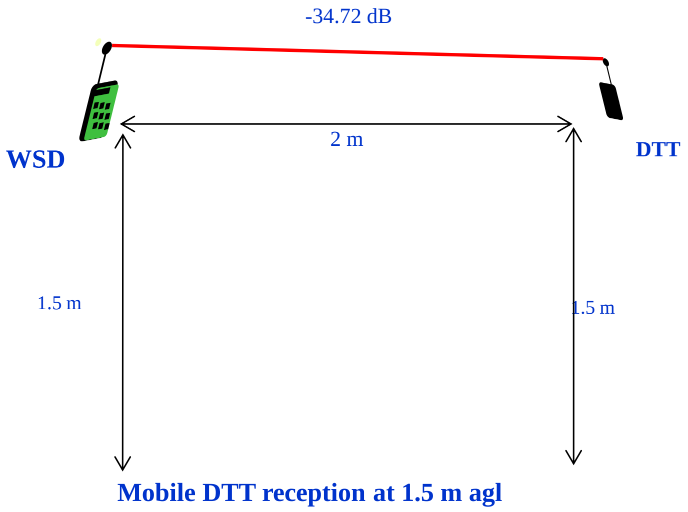

Figure 1. The basic reference geometry used in the measurements

2.2 DTT-signal

Due to the interfering nature of the measurements it is not possible to use operational DTT-signals and therefore a signal from test network was used instead. The Turku test network has several transmitters, but this time a single transmitter in the city centre was used to transmit a DVB-T2 signal.

BS name	VANHA STUDIO
Channel/Frequency	38 / 610,0 MHz
Location	22E15’33’’/60N27’01’’
Mast code	TUT30030
Power ERP	1kW
Antenna height from GL	40m
Polarisation	H

Figure 2 Vanha Studio transmitter

The Vanha Studio transmitter with basic data is shown in Figure 2. A DVB-T2 transmission with two different set of parameters was used. The parameters for a signal to present fixed reception were:

FFT = 32k, extended
GI = 1/32, PP=4
Modulation = 256 QAM, CR = 3/5
Rotated constellation

NorDig requirements C/N = 18.9 dB, sensitivity -80.2 dBm

Parameters to present portable reception were:

FFT =16k, extended
GI = 19/128, PP=2
Modulation = 16 QAM, CR = 2/3
Rotated constellation
NorDig requirements C/N = 11.4 dB, sensitivity -87.7 dBm

The purpose of selecting two modes was the idea that with the better sensitivity of the 16QAM mode it would be possible to do measurements also al lower received signal levels with lower WSD-power. In practice this was not the case as with 16QAM also the interfering power was increasing even if the DTT-signal level was lower. Therefore in the end only few measurements were made with 16QAM.

2.3 Licenses and used frequencies

Test license from Ficora was obtained for the period of the measurements for the WSD-transmitter signals. The used frequencies, channel numbers and offsets from the DVB-T2 channel 610 MHz [ch 38] are shown in Table 1.

Table 1 Used frequencies

Frequency [MHz]	Channel number	N
578	34	-4
586	35	-3
594	36	-2
602	37	-1
610	38	0
682	47	9

The channel 47 is image channel for channel 38. In practice only few measurement were conducted on this frequency as the WSD-power available was not able to produce any errors.

2.4 Equipment

2.4.1 DVB-Receiver

The measurements were done with Sony Bravia KDL-32EX713 TV-set. This is rather modern integrated set with DVB-T2 capability. The same set was used also in the previous outdoor measurement campaign. The Sony set has a sensitivity of -83.3 dBm for the 32k 256QAM 3/5 “fixed” signal in Gaussian channel and a sensitivity of -91.5 dBm for the 16k 16QAM 2/3 “portable” signal in Gaussian channel. These sensitivities were used as a reference levels for planning for the measurement set up. In practice the lowest level was selected so that the TV set was operating 3 dB above the sensitivity. The TV set characteristics were also measured in the lab for different channel conditions (see 3.4).

2.4.2 WSD Tx signal generation

The WSD-signal was simulated with a constant OFDM-signal from a Pro Television PT5780 DVB-T signal generator. This setup was chosen because we were interested especially in the uplink part and with a constant signal the power level measurements could be done very reliably with R&S ETL TV-analyzer. Also the signal bandwidth was 7.6 MHz filling the whole channel. The protection ratio of the simulated WSD-signal towards the DVB-T receivers was measured in all configurations as well as the ACLR of the signal so that the final measurement results of the campaign can be easily scaled to any other signal with known characteristics (ACLR and PR towards DVB-T).

The used signal generator was able to provide output power levels up to +20 dBm, which was considered to be adequate in the indoor conditions and no extra power amplifier was used. A block diagram is shown in Figure 3.

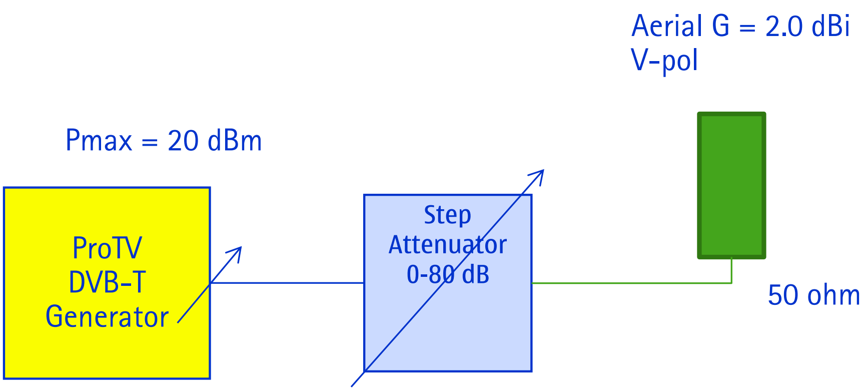

Figure 3 WSD signal generator block diagram

The Tx power levels were measured at the feed point of the antenna. All level measurements were done with R&S ETL TV-Analyzer.

2.4.3 Receiving and transmitting antennas

In the basic measurement setup similar professional 2 dBi D470-860FN1 omnidirectional antennas from Aerial Oy were used. These were set to 1.5 m height on wooden tripods with the feeding cables downwards from the bottom of the antennas. The setup is shown in Figure 4.

The antennas are specified for entire UHF broadcasting band, but the radiations patterns vary slightly over the band. Both horizontal and vertical patters at three different frequencies have been measured. The results are shown in Figure 5. Overall in indoor conditions with rather small rooms it is very difficult to distinguish between the antenna gain to certain direction at a given frequency and the effects of the radio channel. Therefore in the measurements a direct coupling between the antennas was measured instead of the path loss. A nominal path loss can obviously be calculated by subtracting the nominal antenna gains from the measured coupling, but the validity of this kind of result is questionable.

In the measurements the antennas were kept in fixed angular position towards each other, so that the same sides were always facing each other.

Figure 4 Basic Tx and Rx antenna setup

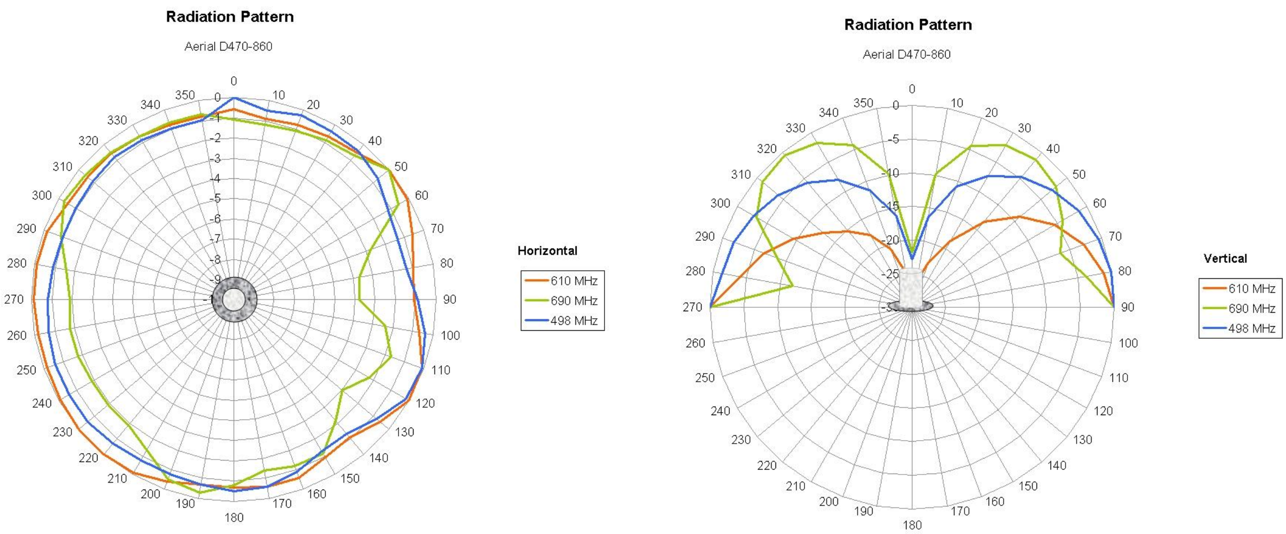

Figure 5 Horizontal and vertical radiation patterns of the Aerial D470-860 antennas

In a few measurements the receiving omnidirectional antenna was replaced with an active antenna. The type was a very common cheap Biltema 24-811. When the antenna was opened and the construction of the antenna investigated, it was found that this is a typical simple and cheap consumer active antenna, where the quality of the RF-design is not very high. Thus it was thought that this kind of antenna could really represent an average active indoor antenna, what an average consumer could buy, even if the type has been replaced in the Biltema selection with a newer type. The active antenna is shown in Figure 6. An external 5 V supply was used to feed the 5V DC-power to the antenna. When the coupling between the antennas was compared to the fully passive case, it was found that the coupling loss was decreasing by some 10 to 15 dB. It is probable that the gain of the antenna element itself is lower than the 2dBi omni antenna, but this is compensated by the gain of the amplifier. This is probably in the order of 15 to 20 dB. No data on the antenna gain or noise figure is available.

Figure 6 Active antenna attached to a tripod

2.4.4 Measurement devices

All the power and spectrum measurements were done with Rohde&Schwarz ETL TV-Analyser. With this device it is very easy to measure accurately the channel power of a DVB-T2 signal as well as make normal spectrum measurements. The device has separate inputs for 50 and 75 ohms. ETL was used also for all laboratory protection ratio and ACLR measurements.

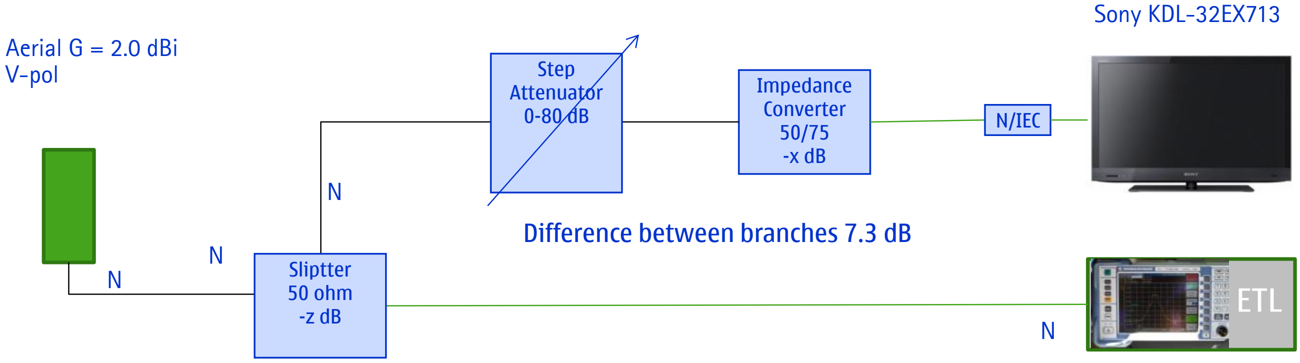

Figure 7 Receiving setup

The general setup for the reception side is shown in Figure 7. The received power from the antenna was split to two branches so that constant monitoring of the wanted signal power

(DVB-T2) and the WSD interference was possible. This was slightly limiting the available power, but it was beneficial not to change the connection during the measurements. The basic attenuation difference between the branches was measured first by replacing the TV set with the 75 Ω input of the ETL and reading the corresponding power levels of the same signal. The TV signal was also adjusted by the step attenuator to the wanted level, which was typically 3 dB above the sensitivity. The full reception side setup is shown in Figure 8.

Figure 8 R&S ETL and the used TV-set.

With the ETL it is also possible to do sweep measurements on the antenna coupling as the ETL includes a tracking generator. In these measurements the ProTV WSD-source was replaced by the ETL tracking generator output.

2.5 Accuracy of the measurements

In general the measurements were performed so that power levels and attenuations were adjusted with 1 dB steps. The power readings from the ETL were recorded with one decimal and the calculations were performed with same resolution. Overall it can be said that the true accuracy of the measurements and results is probably within a few dB.

3. FIELD MEASUREMENTS

3.1 Location

All the measurements were done in two buildings located at Sepänkatu 1, Turku, Finland. This is an old school built in the 1960’s and 70’s and used currently by the Turku University of Applied Sciences. The construction is brick and concrete and the windows are without any metallised shielding, so DTT-transmissions penetrate much better in this type of building as in modern office building. The rooms were classrooms with some space available for the antennas and moving them. The following rooms were used:

“Muotoilutila” A small rooftop space used for project work.
L229 Class room in L-wing, second floor

C20 Class room in C-wing, second floor
L321 Class room in L-wing, third floor

The “Muotoilutila” is a small room on top of the C-wing and has a window towards the transmitter. All other rooms have windows 90 degrees off from the transmitter direction, so no direct signal was received, all coming via reflexions. The location is shown in Figure 9.

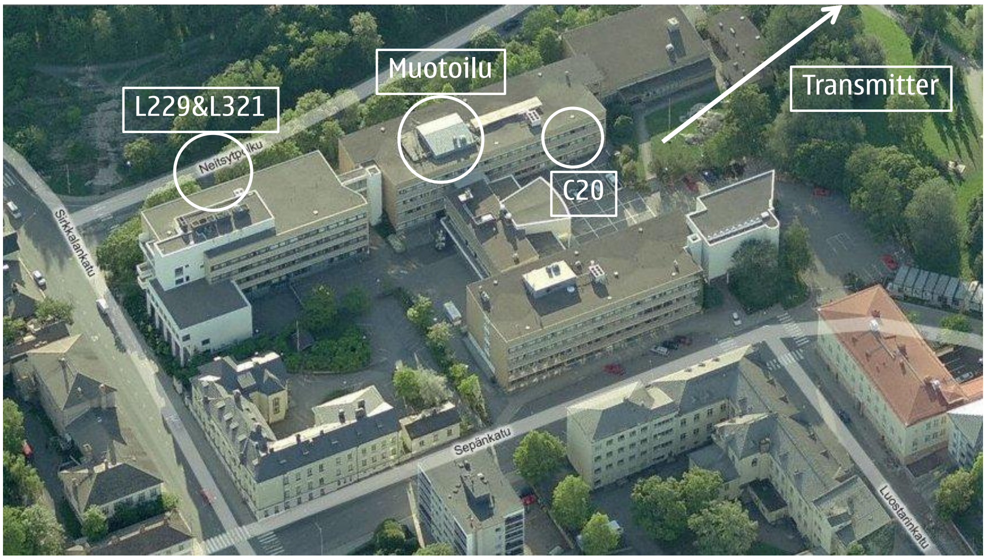

Figure 9 Measurement location and the used rooms

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3.2 Antenna coupling

Antenna coupling was measured in different rooms by feeding the WSD Tx-antenna with known fixed power and then measuring the received power at the Rx-antenna output connector. The measurement was repeated with the different frequencies in use. All the cable losses etc. were compensated and the coupling loss from Tx-antenna input to the Rx-antenna output was calculated. Results from different rooms at the distance of 2m are shown in Table 2 and in Figure 10.

Table 2 Coupling loss at 2m in different rooms

Freq.	Coupling loss [dB] at 2m in room			
[MHz]	Muo	L229	C20	L321
682	37.7	35.1	31.9	31.2
610	29.3	32.9	41.3	34.1
602	31.3	33.3	32.3	33.1
594	32.9	31.6	29.7	34.4
586	33.3	32.0	29.0	32.3
578	34.8	35.2	28.9	28.2

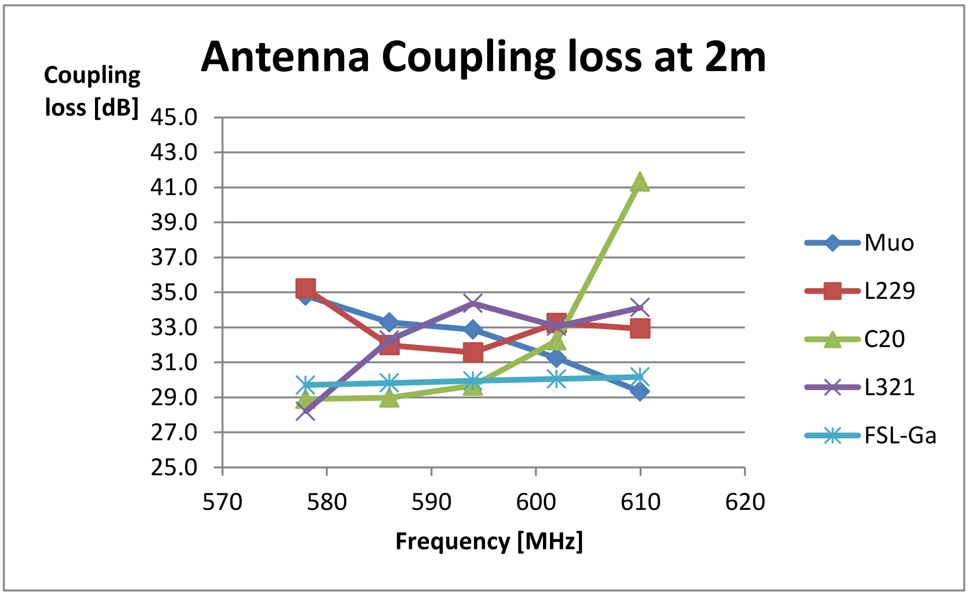

Figure 10 Coupling loss at 2m

In Figure 10 also a curve based on free space loss and the nominal antenna gains is shown for comparison.

Overall it can be said that the coupling between the antennas is very dependent on the frequency and the reflexions in the room. Movements in the room are clearly changing the coupling. In most of the measurement points at 2m distance the coupling loss was somewhat more than what would be expected based on the free space loss model.

Coupling was studied also with a sweep measurement with the ETL tracking generator. Results from the L229 with two different spans are shown in Figure 11.

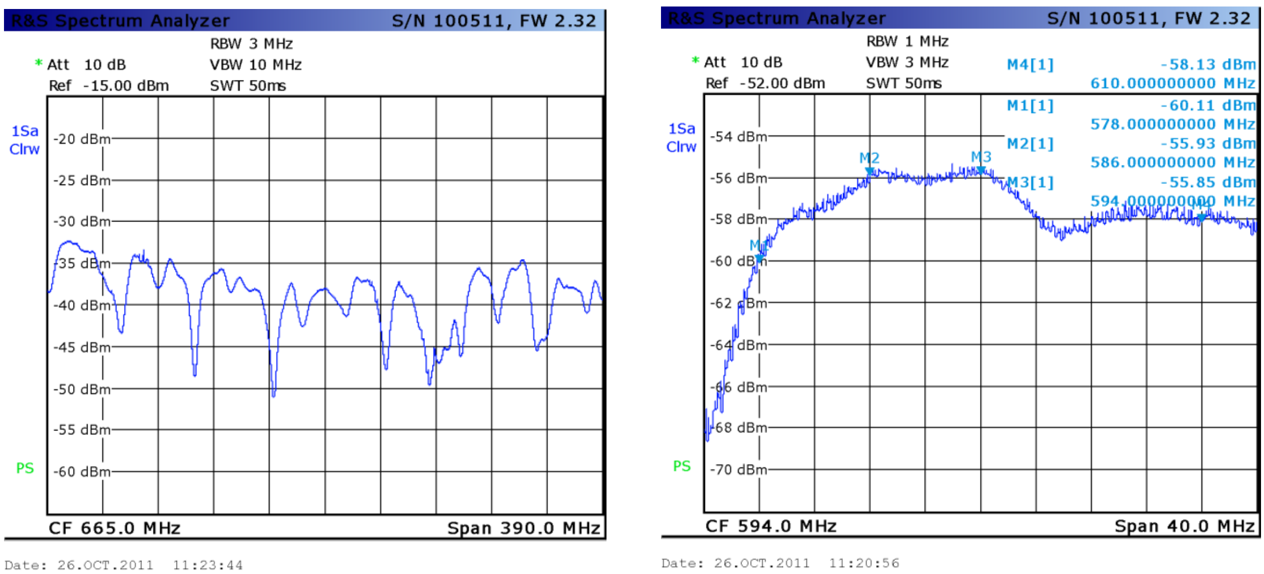

Figure 11 Sweep coupling loss measurements in L229 at 2m with 390 MHz and 40 MHz spans

Similar sweep for the room C20 are shown in Figure 12. As can be seen there are deep notches in the frequency response, overall difference being in the order of 30 dB, although not in the frequency range the WSD-signal was investigated.

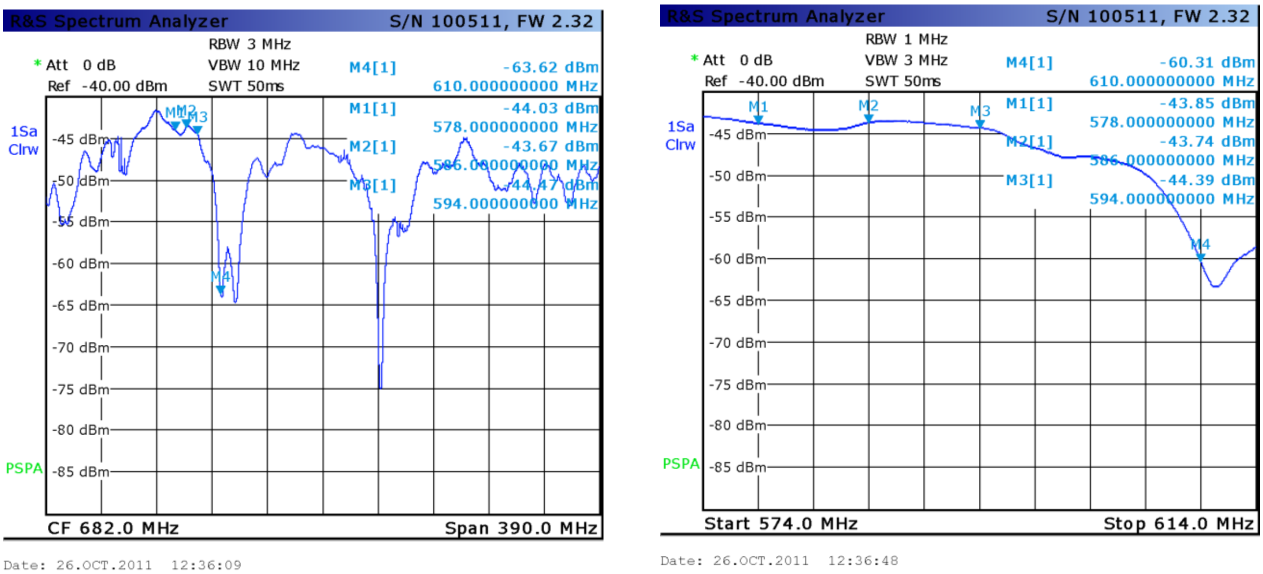

Figure 12 Sweep coupling loss measurements in C20 at 2m with 390 MHz and 40 MHz spans

Sweep measurements for the room L321 are shown in Figure 13. In this case the test frequencies are all within a 5 dB window, but on other frequencies deep 20 dB notches occur.

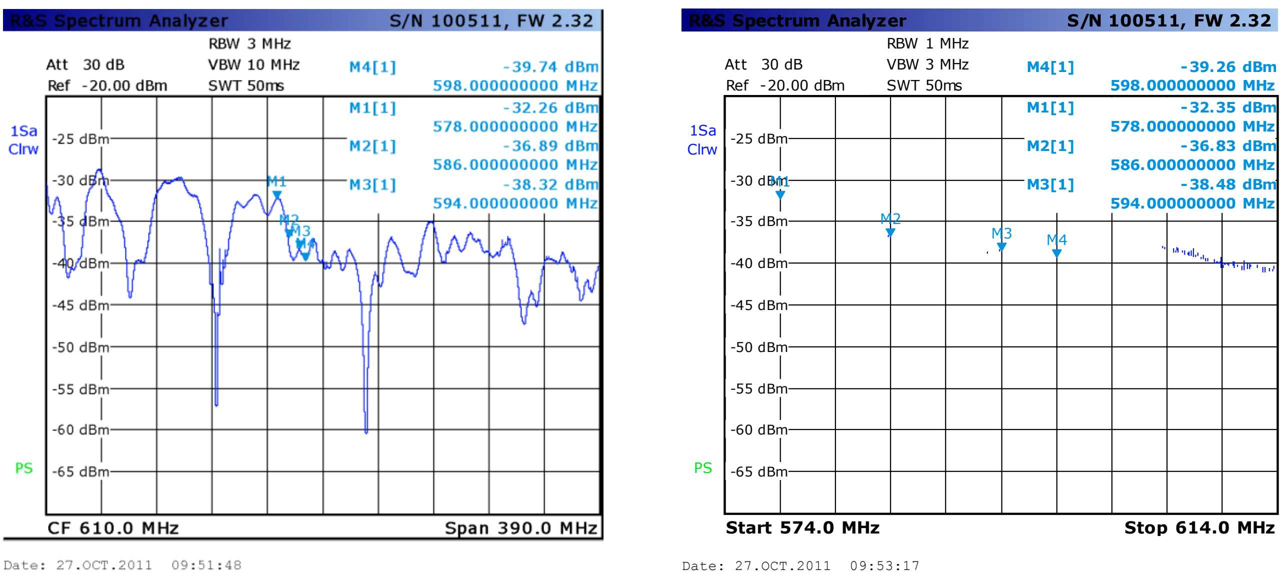

Figure 13 Sweep coupling loss measurements in L321 at 2m with 390 MHz and 40 MHz spans

As can be seen from all the 2m measurement data, the coupling between the antennas indoors is a very complex issue, where the environment, radiation patterns and frequency all play a role.

Studies in the antenna coupling continued by changing the distance between the antennas. This was done in room L229 at a frequency of 610 MHz and with antenna separations of 2m, 4m, 6.45 m and 8.15m, the last being in a corridor just behind a wall. Results are shown in Table 3 and Figure 14.

Table 3 Coupling loss in L229 at 610 MHz with different distances

d [m]	Loss [dB] L229
2	32.9
4	50.3
6.45	36.2
8.15	40.9

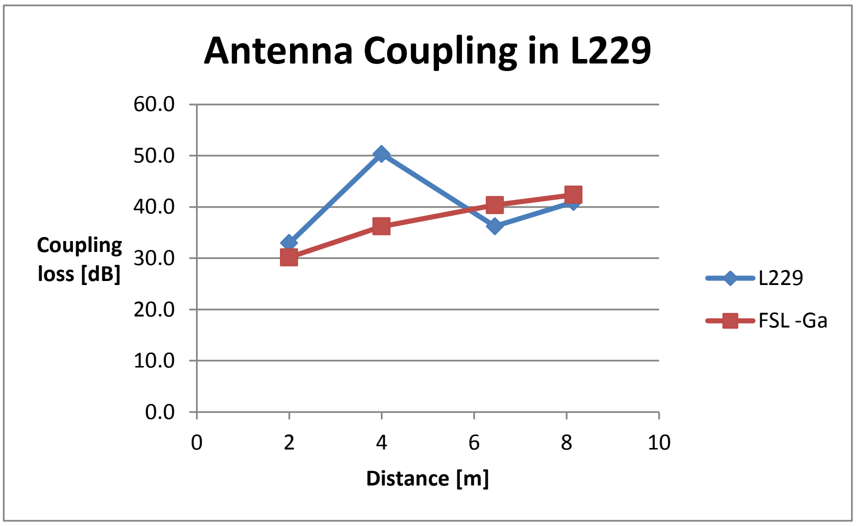

Figure 14 Coupling loss in L229 at 610 MHz with different distances

It is interesting to note that the highest loss is at 4 m distance. Probably at this distance and frequency one of the deep notches found in the sweep measurement occur. Even if the last measurement point at 8.15 m was behind a brick wall and some wooden lockers the loss is not significantly higher showing that the wall attenuation in this case was not significant. Theoretically the loss increases by 12 dB when the distance increases from 2m to 8 m.

Antenna coupling was also measured with the active antenna. This was done in L320 at two different antenna separations 2m and 9.75m. In the longer distance the WSD Tx antenna was changed from the 2dBi omni antenna to a Completech 12dBi Yagi mainly to boost the available WSD-power. Both point frequency measurements and sweep measurements were done. In addition logs of the coupling were recorded while there was movement in the room to demonstrate how much moving people around the antenna can affect the coupling of the antennas.

Numerical results are shown in Table 4 and corresponding curves are shown in Figure 15.

Table 4 Coupling loss of the active antenna at 2m in room L321

Freq. [MHz]	Room L321 2m	2m Active	2m FSL-Ga	9.7m Active	9.7m FSL-Ga
610	34.1	24.5	30.2	26.3	33.9
602	33.1	21.4	30.1	26.5	33.8
594	34.4	20.7	29.9	26.8	33.7
586	32.3	21.5	29.8	24.3	33.6
578	28.2	18.4	29.7	27.2	33.5

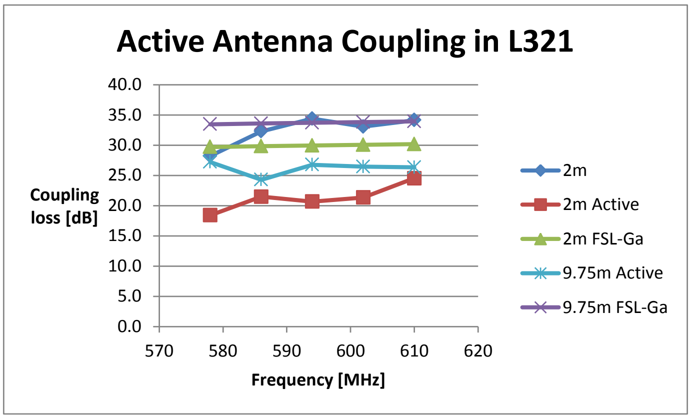

Figure 15 Coupling loss of the active antenna at 2m in room L321

As can be seen there is a 10 to 15 gain due to the active antenna compared to the passive 2dBi omni antenna. The FSL-figures are just for comparison and are giving a theoretical coupling based on the free space loss and nominal antenna gains. Note that in the 2m measurement the nominal gains are 2x2dBi and in the 9.75m measurement 2dB+12dBi.

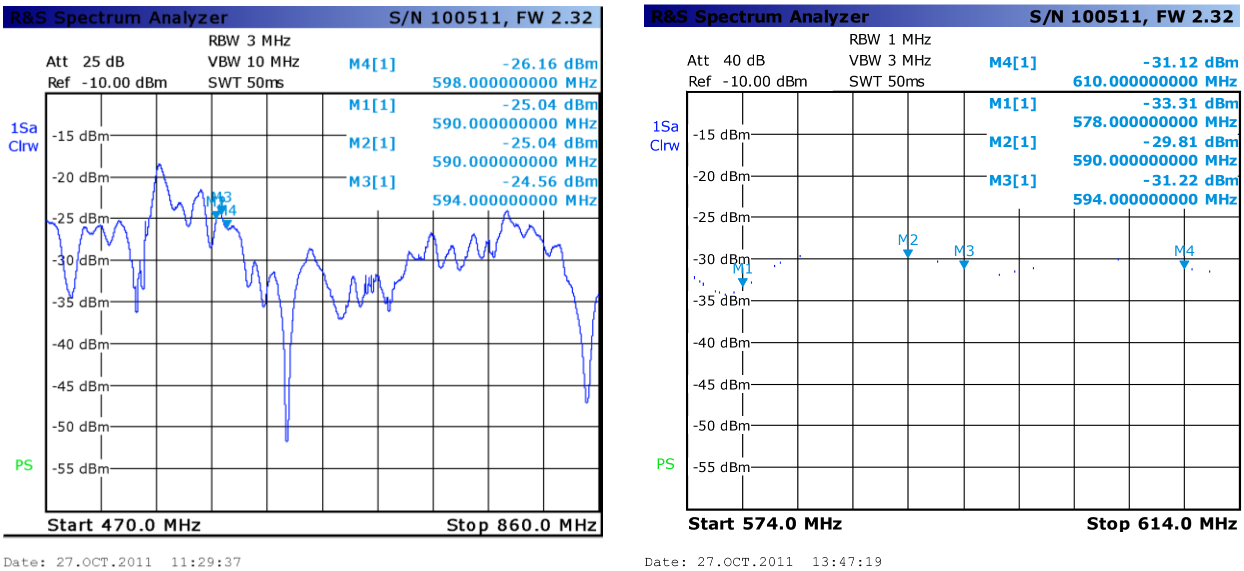

Figure 16 Sweep coupling loss measurements with active antenna in L321 at 2m with 390 MHz and 40 MHz spans

The results of the sweep measurement shown in Figure 16 are very similar to the passive antenna sweep measurements in the same room with deep notches in the frequency response.

The movement log is shown in Figure 17. Logging of the received power happened once in a second with the ETL. First there was no movement in the room and then the number of people and activity level was gradually increasing and then slowing down before stopping.

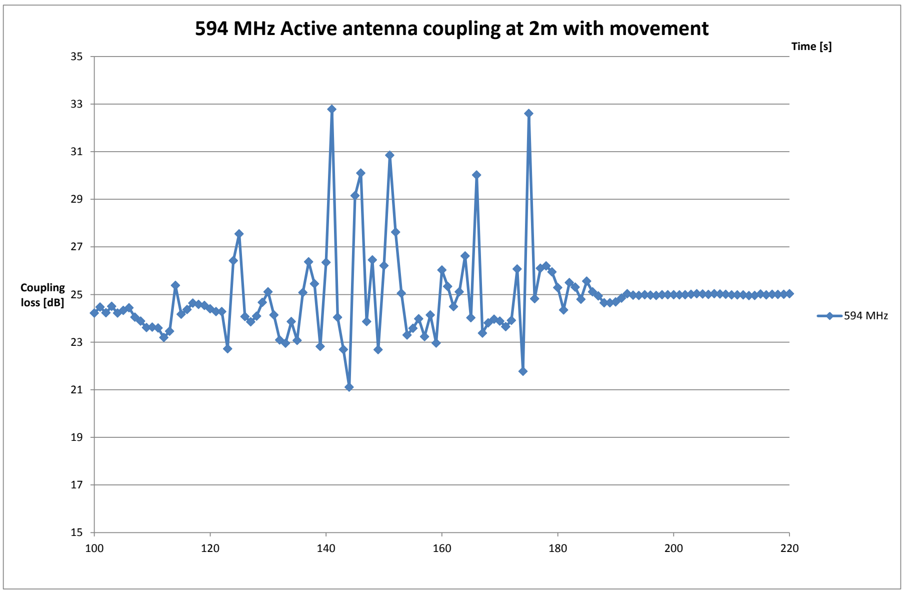

Figure 17 Log of received power vs. time with people moving around the antenna

It is interesting to see that the movements are producing variations of more than 10 dB, mostly these are increasing the loss, but in some cases decreases happen.

3.3 WSD maximum power and protection ratios

3.3.1 DTT-signal level selection

These measurements studied the maximum possible WSD-power in the reference geometry before the received picture failed. Most of the measurements were done close to the sensitivity limit corresponding the situation where the DTT-receiver is located at the edge of the service area or in difficult indoor conditions otherwise. Placement of the receiving antenna within the room was selected so that enough signal power was available for measurement setup, which divided the power to two branches as shown in Figure 7. Next the receiver sensitivity level was searched by increasing the attenuation in the TV-branch with the step attenuator until picture failure. After that the signal level was increased by 1 dB, so that no errors we observed in the picture and this was taken as the sensitivity level in the channel conditions of the receiver location. From this level the wanted measurement level was reached by increasing the signal level with 3dB. In some cases higher signal level was used, but typically this was not possible due to the limitations in the available WSD-power.

Choosing a 3 dB higher level than the receiver sensitivity matches quite nicely with the minimum planning field strengths. When studying the indoor reception variants of the table 1 of the ECC report 159 it can be seen that the link budgets are calculated for receiver sensitivity levels, but using certain assumptions of the noise figure and required C/N for the indoor channel conditions. Practical receivers tend to have better performance due to the lower noise figure and better C/N performance. For example looking the “portable indoor reception urban” variant from the table we see that this is planned for 16QAM 2/3 and requires 71 dBµV/m median field strength at 1.5 m height outside. As the total margin is 12.8 dB, the minimum FS outside at 1.5 m is 58.2 dBµV/m. This corresponds isotropic power of -75.3 dBm and with the wall loss of 8 dB, the isotropic power inside is -83.3 dBm. With 2.15 dBi antenna the received power is -81.15 dBm. The receiver used in the measurements have a sensitivity of about -88 dBm for this mode, so choosing a point 3 dB from the sensitivity (-85 dBm) would still be less than the planning minimum. The table 1 in ECC report 159 do not have any examples for DVB-T2 indoor reception, but the same principle can be applied.

3.3.2 Signal conditions in the test rooms

The measurements were done in four different rooms as explained in 3.1. In all rooms the DTT-reception antenna location was optimised so that enough power was available for the test system with the power divider and two branches. Next the spectrum and impulse response were recorded so that an understanding of the receiving conditions was obtained.

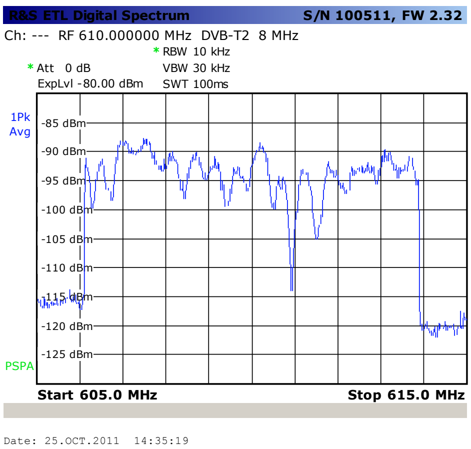

Figure 18 Received DTT-spectrum at 610 MHz in Muotoilutila-room

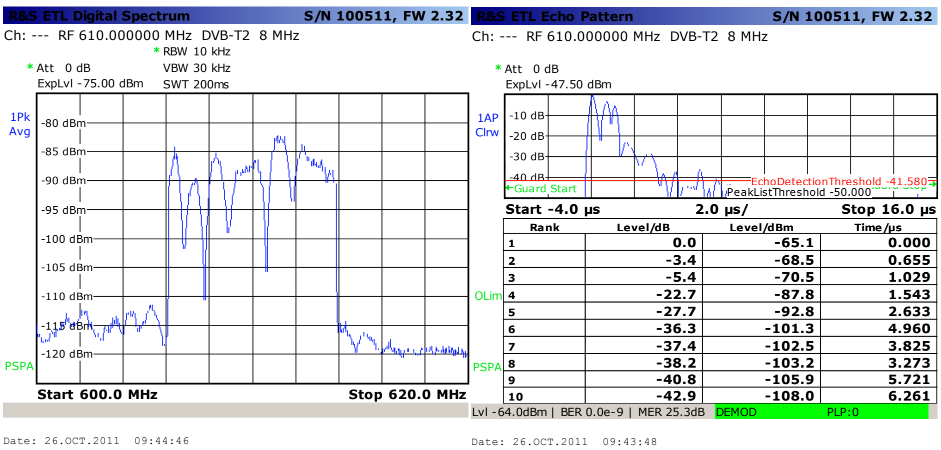

Figure 19 Received DTT-signal spectrum and impulse response at 610 MHz in L229

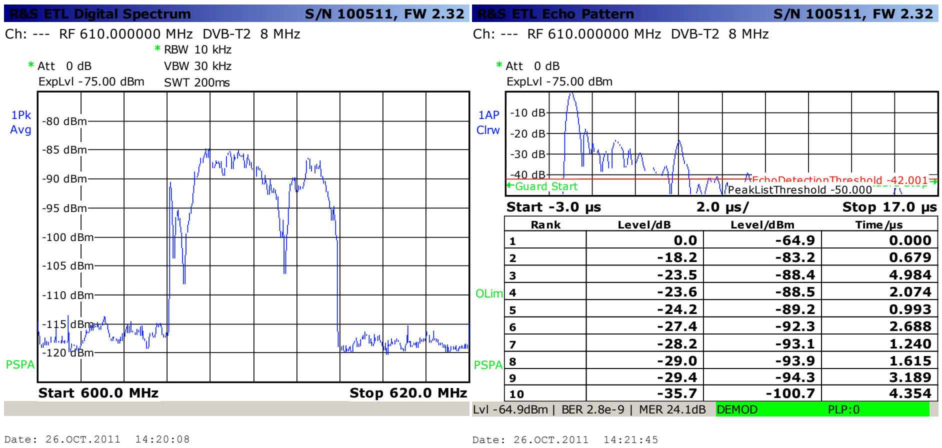

Figure 20 Received DTT-signal spectrum and impulse response at 610 MHz in C20

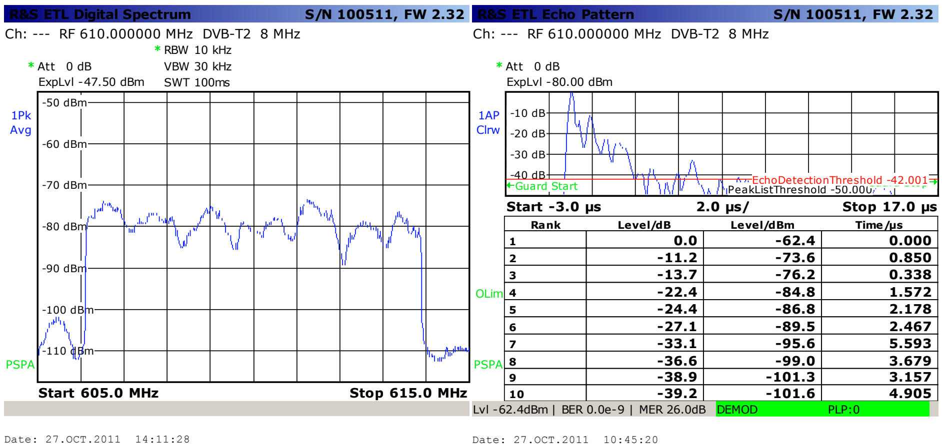

Figure 21 Received DTT-signal spectrum and impulse response at 610 MHz in L321

All rooms except the “Muotoilutila” at the roof top had only indirect signals coming in.

3.3.3 Maximum WSD-power

The measurements were done at co-channel, N-1, N-2, N-3 and N-4 in all four rooms. In some cases also N+9 was tested, but in general the required WSD Tx-power to cause any errors was too high to be achieved as the receiver had very good performance at the image channel. For similar reason most of the results are with 256QAM.

In the maximum WSD-power measurement WSD Tx-power was increased until errors were detected in the picture and then decreased by 1 dB step so that no errors were visible during an observation period of several tens of seconds (roughly the ESR5 criterion). After that the WSD power level was measured both at the transmitter side and on the receiver side. It should be noted that the measured WSD Tx-power must be corrected by the total attenuation of 13.2 dB of the TV-branch of the measurement setup (see Figure 7) to get the true corresponding WSD EIRP which would cause the same effect when the TV-set is connected directly to the TV-set. From the measured interference power it was possible also to calculate the protection ratio (PR) as the DTT-signal level was known.

Table 5 Maximum measured WSD power at 2m with 256QAM

Freq. [MHz]	Max WSD EIRP [dBm] in room Muo	L229	C20	L321	256QAM L321 Act	Average
610	-64.6	-59.6	-54.6	-57.6	-58.6	-59.0
602	-15.6	-6.6	-6.6	-3.6	-8.6	-8.2
594	-1.5	3.5	-4.5	6.5	0.5	0.9
586	0.4	5.4	-1.6	6.4	2.4	2.6
578	2.5	6.5	-1.5	6.5	-0.5	2.7

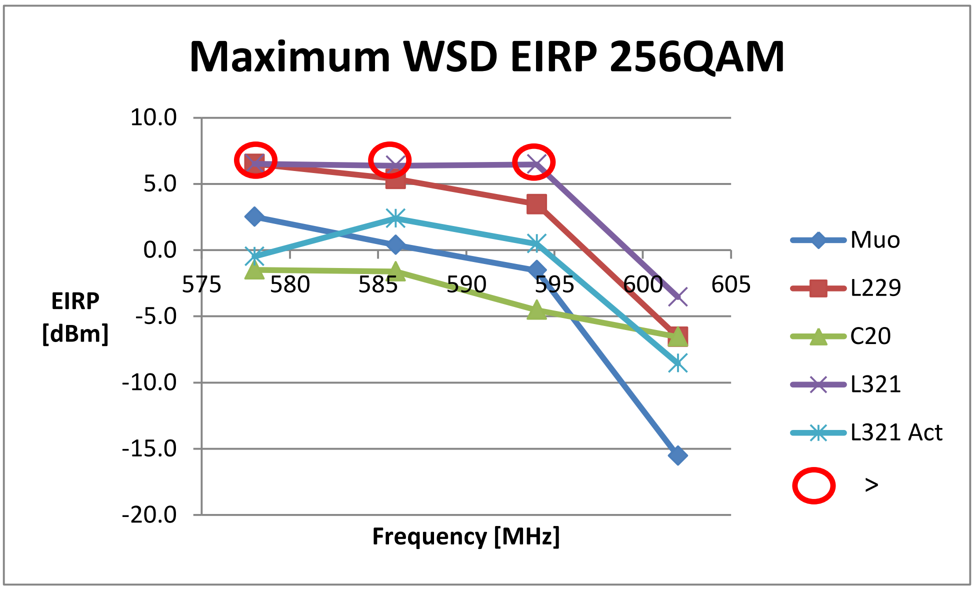

Figure 22 Maximum measured WSD power at 2m with 256QAM

The basic results at the 2m reference geometry with 256 QAM T2 signal are shown in Table 5 and Figure 22. Note that the figure does not have co-channel points included. In the table also an average value over all the rooms is included. It is interesting to note that the active antenna is close to the average, but if the active antenna performance is compared with passive antenna in the same room (L321), the results are about 5 dB worse. This is understandable as the coupling between the antennas is much higher (more than 10 dB) due to the amplifier. Points marked with red circle are minimum values, the true value can be higher as no errors were observed.

In room L321 the effect of DTT-level and distance of the antennas was studied with the active antenna. The basic measurements have all been done at +3dB above the sensitivity level. Now with the active antenna enough power was available so that the DV-T2 signal level at the TV-set input was raised by 10 dB to a level of +13dB above the sensitivity level. The results are shown in Table 6 and Figure 23. As can be seen the increase in distance between the WSD and DTT-reception antenna was increasing the maximum WSD power by 6 dB. Level increase in the TV-set input by 10 dB was increasing the WSD power by 3 dB.

Table 6 Maximum WSD power in L321

Freq. [MHz]	Max WSD EIRP [dBm] in L321 2m	9.75m	+13dB
610	-58.6	-56.6	-55.6
602	-8.6	-2.6	-5.6
594	0.5	6.5	3.5
586	2.4	6.4	5.4
578	-0.5	6.5	2.5

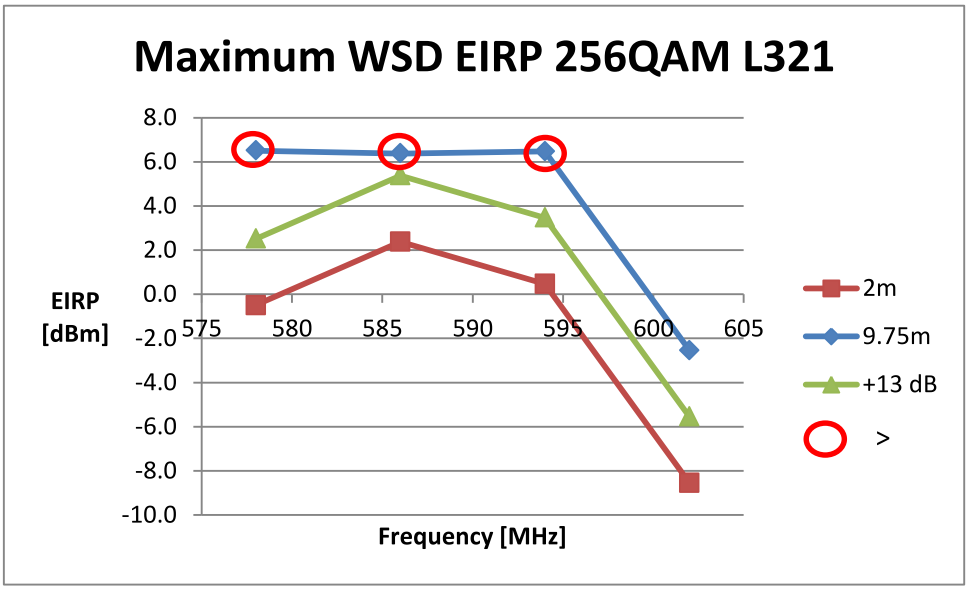

Figure 23 Maximum WSD power in L321

As a conclusion of the WSD maximum power measurement results, it can be said that the results are complex in a similar way than the antenna coupling results were. The radio channel indoors between the WSD and DTT as well channel from outdoor DTT Tx to indoor DTT Rx are affected by many factors.

3.3.4 Protection ratios

The protection ratios were calculated from the measured WSD- and DTT-powers at the TV-set input. Results are shown in Table 7.

Table 7 Protection ratios with 256QAM

Freq. [MHz]	Protection ratio with 32k 256QAM 3/5 in room Muo 2m	L229 2m	L229 2m +6dB	C20 2m	C20 6.8m	L321 2m	L321 2m Active	L321 2m Active +10 dB	L321 9.7m Active +10dB
610	-23.5	-23.6	-21.5	-22.8	-25.3	-23.8	-24.1	-20.9	-23.5
602	25.6	28.6	31.5	35.0	24.8	30.7	29.3	32.0	30.5
594	39.5	40.8	42.0	40.9	28.7	38.9	39.9	43.2	38.2
586	41.9	42.5	42.3	42.9	36.6	40.1	40.5	44.0	40.6
578	43.0	40.1	39.9	43.9	38.2	44.5	41.6	44.8	35.9

Cells marked with grey background are points, where the available WSD-power was not enough to cause any errors, so the calculated PR-value is a minimum and the real value can be higher. The results are shown graphically in Figure 24. Here the unreliable data points are marked with red circles.

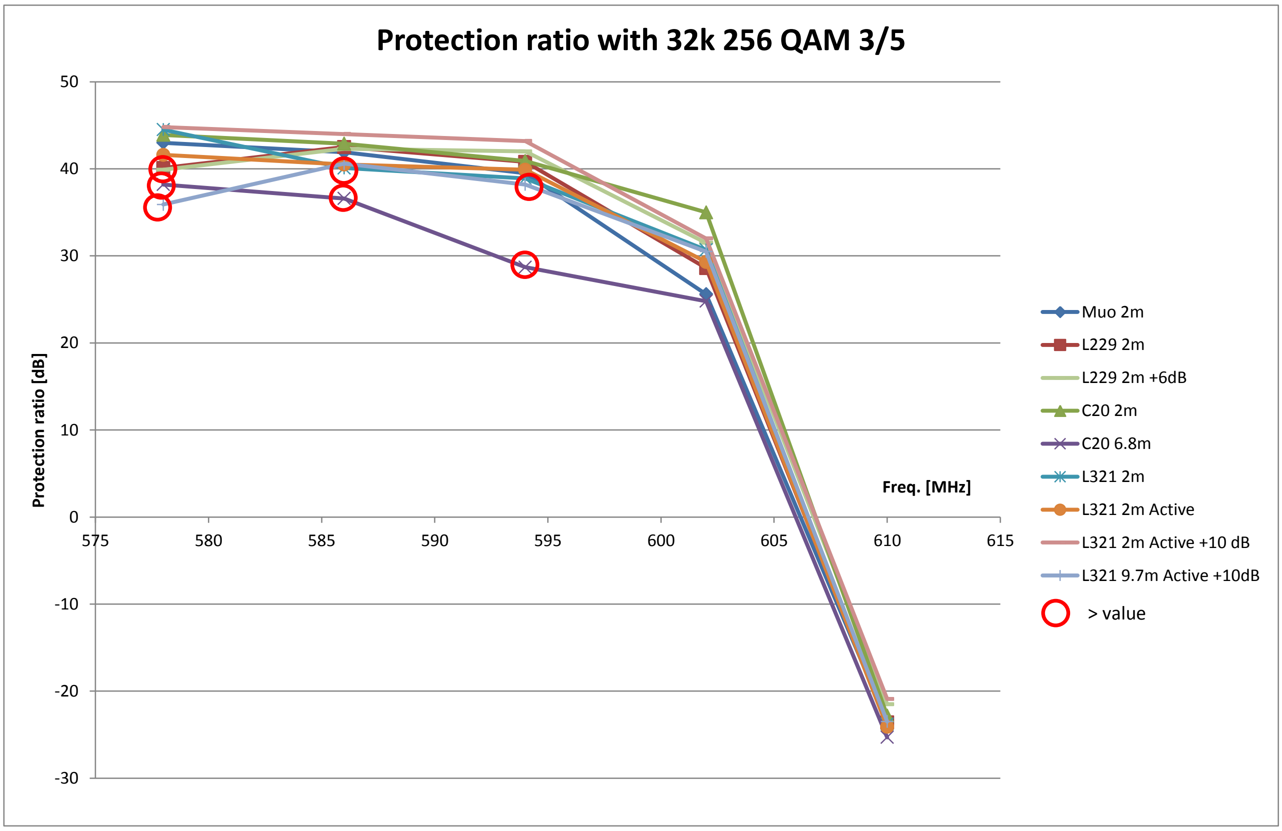

Figure 24 Protection ratios with 256QAM

The protection ratio values are rather consistent if the unreliable points are excluded. Greatest spread is in the values at N-1 (602 MHz). On average co-channel value is between -20 and -25 dB, on N-1 between 25 and 35 dB, on N-2 between 39 and 42 dB, on N-3 and N-4 between 40 and 45 dB. The variations are at least partly due to the channel conditions in the different locations. Average values are shown in Table 8. On 16 QAM there were too few measurement points for a reliable result analysis.

Table 8 Average protection ratios with 256QAM

Freq. [MHz]	Average PR [dB] 32k 256QAM 3/5
610	-23.2
602	29.8
594	40.4
586	41.9
578	41.9

3.4 Lab measurements

Some laboratory measurement were made after the field testing to calibrate the measurement setup as well as to get information on the DTT-receiver performance in controlled environment.

3.4.1 C/N-performance

These measurements were done in the order to help to understand how difficult the channels in the field were. First the sensitivity of the DTT-receiver with 32k 256QAM 3/5 DVB-T2 signal was found to be -83.3 dBm. Next the required C/N with different standard channel models was measured at different input levels. The results can be seen in Table 9.

Table 9 DTT-receiver C/N-performance with 256QAM

Sony KDL-32EX713 1/32 32k 256QAM 3/5 Extended			Pmin -83.3
Input level [dBm]	C/N Gauss [dB]	C/N Ricean [dB]	C/N Rayleigh [dB]
-50	17.4	18	20
-60	17.5	18	20
-70	17.7	18.2	20.5
-77	18.6	19.3	24.2
-80	20.2	21.4	29

Comparable to the field measurements are the values of -80 and -77 dBm as most of the input levels were around these values. As can be seen the measured co-channel protection ratios in the field (-20 to -25 dB) match fairly well with the lab C/N measurements if the channel is considered to be something close to Rayleigh or Ricean channel.

For 16QAM similar results are shown in Table 10. The sensitivity was found to be -91.5 dBm. Unfortunately very few co-channel protection ration measurements were made with 16QAM (lack of WSD-power to cause errors), but the few results between -11.4 and 14.4 are in line with the low input level values of the laboratory measurements.

Table 10 DTT-receiver C/N-performance with 16QAM in the laboratory

Sony KDL-32EX713 19/128 16k 16QAM 2/3 Extended			Pmin -91.5
Input level [dBm]	C/N Gauss [dB]	C/N Ricean [dB]	C/N Rayleigh [dB]
-60	9.3	10	12.2
-70	9.3	10	12.2
-80	9.7	10.3	12.8
-86	10.8	11.3	16
-89	13.3	15	nw

3.4.2 Protection ratios

Protection ratios with the same WSD-interferer signal as in the field were repeated in the laboratory with Gaussian channel conditions at the same approximate DTT-receiver input levels as in the field. The results are shown in Table 11.

Table 11 Protection ratios with 256QAM in the laboratory

PR from T to T2 T2 Mode	f [MHz]	Input level [dBm] -77	 -67
1/32 32k 256QAM	610	-19.5	-18.4
3/5 Extended	602	33.6	34.5
	594	44.5	45.6
	586	46.4	48.5
	578	47.6	49.6
	682	51.9	53

As can be seen the obtained protection ratios are somewhat better than the average results measured in the field (see Table 8). The difference is due to the more challenging channel conditions. The used DVB-T2 signal was with the extended spectrum and therefore it was interesting to see if there would be any difference in the PR with the extension on or off. This was tested at N-1 (602 MHz). The found difference was 1 dB, the extended version demanding more protection.

3.5 Comparison of the measured and calculated WSD-powers

The measured WSD-power levels can be compared to the theoretically calculated maximum allowed WSD-power levels. The calculation can be based on the methods presented in the ECC report 159 and some further contributions under discussion in the CEPT SE43 group. However, one should note that the calculated power levels and the measured ones are not directly comparable as in the measurements the WSD-power was increased to the point after which errors start to appear and the calculated maximum WSD-power is supposed to have certain margin before errors. Comparison will give some insight to the practical margins and also to the validity of the assumed reference geometry and how it can be applied.

In calculating the maximum power for the indoor to indoor case there are, however, some problems. In the ECC report 159 table 1 there is no directly similar reception variant as was used in the field test. Therefore there is no straightforward way of selecting a suitable minimum median field strength value from the table and to calculate or simulate the corresponding E_{imed} with a given (say 0.1%) location probability reduction. One possible way of getting an appropriate value is to use the value of E_{wmed} 61 dBµV/m for outdoor portable reception as a basis. Obviously the reference field strength for indoor reception is higher, but this is typically given as the outdoor field strength planning value and when taking into account building penetration losses the resulting indoor field strength is close to the outdoor value. The corresponding E_{imed} is 12.7 dBµV/m, which will correspond to an isotropic interference power of -120 dBm. In general the reception link budgets are typically calculated as noise limited and another way of assessing the allowed interference level at the coverage edge is to use the required I/N directly. If the -20 dB value is used, the isotropic WSD-power would be around -125 dBm. Both values can be used for comparison.

The WSD maximum powers can be calculated by adding to the isotropic power the influence of free space loss. No polarisation discrimination is assumed here. The result obtained is valid for the co-channel case and for the adjacent channels it is corrected by the protection ratios PR(0)-PR(N-X). The used protection ratios are the average values obtained in the field measurements.

Table 12 Comparing the measured and calculated WSD power values

Coverage edge WSD ch	Freq. [MHz]	Pi 1 [dBm]	Pi 2 [dBm]	FSL [dB]	PR [dB]	P WSD 1 [dBm]	P WSD 2 [dBm]	Measured [dBm]	Margin 1 [dB]	Margin 2 [dB]
N	610	-120.0	-125.0	-34.2	23.2	-85.8	-90.8	-59.0	26.9	31.9
N-1	602	-120.0	-125.0	-34.1	-29.8	-32.9	-37.9	-8.2	24.8	29.8
N-2	594	-120.0	-125.0	-33.9	-40.4	-22.4	-27.4	0.9	23.3	28.3
N-3	586	-120.0	-125.0	-33.8	-41.9	-21.1	-26.1	2.6	23.7	28.7
N-4	578	-120.0	-125.0	-33.7	-41.9	-21.1	-26.1	2.7	23.8	28.8

The calculated margins are shown in Table 12. The 5 dB difference between margin 1 and margin 2 is self-evident as the allowed isotropic powers were differing by 5 dB. What is interesting is that the margins seem to be rather consistent on channels N-1 to N-4 the co-channel differing more. Margin 2, which is based on the -20 dB I/N requirement seems to be closer to the 30 dB mark than 20 dB. Overall it seems that the calculated maximum powers would have a large margin when compared to the practical case in the field. Still it should be noted that the resulting WSD-powers, even without any margin, are only in the order of 0 dBm and thus the practical powers for operating a WSD in close proximity of DTT indoor receiver is difficult.

4. CONCLUSIONS

The measurement campaign studied the 2m reference geometry between WSD and DTT-receiver in indoor conditions. One part was the coupling between the WSD-antenna and the DTT-receiver antenna. It was shown that the coupling between the antennas is varying quite a lot due to the complex radio propagation indoors. This is affected by the antenna radiation patters, reflections from objects nearby, possible obstacles between the antennas, people moving in the room etc. All the components are frequency dependent, which means that there are also great variations in the coupling between channels. All this means that a simple model based on the antenna gains and free space loss will only give an approximation of the situation. Nevertheless in most of the cases the measured coupling was smaller (loss higher) than FSL-based coupling although at some points also higher coupling values were seen. This indicates that the reference geometry is useful even if not accurate to the detail.

On the DTT-reception most of the studies were done at a level of +3 dB over the observed sensitivity level. It was seen that the sensitivity level in the field was higher (less sensitive) than measured in the laboratory with Gaussian channel. On the other hand the sensitivity values in the field match quite well with the laboratory measured Ricean or Rayleigh channel values.

With maximum WSD-power measurement it was possible to estimate how the theoretically calculated WSD maximum power values, based on the reference geometry, match with the field experience. The measured values are obviously varying like the coupling between the antennas, but it seems that there is a good margin between the calculated value and measured vale (note that they are not directly comparable values, there should be a margin). The calculation in this case is more like an estimation as accurate interference field strength values were not available.

Based on the measured powers the protection ratios were calculated and found to be rather consistent over the various locations and also match quite well with the laboratory measurements when bearing in mind the more difficult channel condition of the field case.

Overall the 2m reference geometry indoors may well be used in calculating the maximum power. It is true that there are large variations, and other geometries could be used but on the other hand it can be said that this as good as any other presenting the situation where both WSD and DTT-receiver are in the same room. In most cases the path loss seems to be higher than given by the reference geometry, only in few points lower loss was observed. Brief testing with an active antenna was not showing any alarming effects. Even if the distances were short the DTT-receiver overload threshold was not reached, the protection ratios limiting the WSD-power before.