REPORT

on

Field measurements done on operational TVWS trial network in Tygerberg

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Revision 0 – first draft

Revision 0.1 – added extra appendices to take into consideration a correction factor (10 dB for digital signals; more for analog signals)

Revision 0.2 – added extra text to take into account detector corrections

Revision 1 – addressed comments from Google and unified filed measurensts sections

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EXECUTIVE SUMMARY

CSIR Meraka Institute together with its partners; TENET, e-Schools Network, WAPA and Google, was given permission by the Independent Communications Authority of South Africa (ICASA) to conduct a trial for TV White Spaces (TVWS) in the Western Cape. The trial was conducted over a six month period, starting from March 2013.

The objectives of the trial were to demonstrate that TVWS can be used to deliver affordable broadband Internet services without interfering with TV reception and to obtain regulatory support for TV white spaces technology and the use of TV white spaces for the delivery of broadband. A spin-off of the trial is an increased awareness of the potential for TVWS technology in South Africa and across the continent.

The TVWS trial network delivered broadband Internet service to ten schools within a 10 kilometer radius of Stellenbosch University Faculty of Medicine and Health Sciences' hospital in Tygerburg. It consists of three base stations (BSs) located at the hospital and serving three sectors. A terminal radio (TR) was installed at each of the ten schools that participated in the trial.

In order to achieve the objective of delivering the affordable broadband Internet services without interfering with TV reception, CSIR Meraka Institute completed the following:

1. Identified the availabile TV white spaces by analysis based on existing data and measurements taken prior to trial network deployment.
2. Tested a BS and a TR in the laboratory to ensure that they have correct spectrum power mask and that they exhibit the correct behavior.
3. Estimated the protection ratios in terms of the TV White spaces devices (WSD) and TV performance parameters;
4. Monitored for no-compliance during operation following prevailing international best practices. This included recording coordinates and signal strengths across all channels using a spectrum analyser at a minimum of 3 points around each trial location
5. Implemented measures to ensure non-interference to incumbent broadcasts by developing an interference management protocol [14] detailing what needs to happen and within what time, in case of interference.

Eight channels were identified as candidates for TV white spaces transmission and after consultations with the regulator, six channels were recommended for use during the trial.

The laboratory tests confirmed spectral mask of the WSDs were within the 8 MHz of the TV channel and power output within specifications for both the BS and TR. Spectral emmissions were also confirmed to be well contained after a firmware upgrade.

A laboratory estimation of the protection ratio established the acceptable levels of WSD transmission signals on adjacent channels to analogue TV transmissions.

A field setup was made to investigate interference to adjancent channels based on the protection ratios as established by the laboratory estimation done by CSIR Merak Institute. A series of spectrum measurement scans were done around all the schools participating in the TVWS network. The analysis of the results indicates the possibility of interference when WSD is operated on the channel to the left-hand side of analogue TV . The possible radius within which the can be a possibility of interference was not more than 200m in all cases where there was a strong enough TV signal.

A dedicated monitoring system was also set up to continuously log the spectrum emissions by the BSs, at the BS site at the roof of Tygerberg hospital. Initially, this was to assist identification of any potential problems with the TVWS network. A by-product of this spectrum monitoring was identification of the Internet usage patterns, quantifiable per sector of the network.

Based on the analysis on the field measurement done during the trial and on that no cases of possible interference were reported it is possible to conclude that WSDs that have similar spectral masks and EIRP level to the ones tested in this trial will be able to offer broadband Internet services without causing interference. It is further observed that there maybe cases where the transmission power of the devices may need to be reduced if the TVWS network is deployed in densely populated areas where TV can be viewed within 200m of the WSD. The case of co-existence with DVT-T2 was estimated but not tested in this trial.

LIST OF ABBREVIATIONS

BS – base station

PR – protection ratio

RF – radio frequency

RX – receiver/reception

TR – terminal radio

TV – television

TX – transmitter/transmission

TVWS – TV white space

UHF – ultra high frequencies

VHF – very high frequencies

WS – white space

WSD – white space device

WSN – white space network

1 INTRODUCTION AND BACKGROUND

1.1 Background on the project

A group of partners, consisting of TENET, CSIR Meraka Institute, e-Schools Network, WAPA, Carlson Wireless and Google, conducted a trial for TV White Spaces (TVWS) in the Western Cape over a six month period, starting from March 2013. The trial network involved 10 schools.

The objective of the trials was to demonstrate that TVWS can be used to deliver affordable broadband and Internet services without interfering with TV reception and to increase awareness of the potential for TVWS technology in South Africa and across the continent.

The TVWS trial network in this trial delivers broadband Internet service to ten schools within a 10 kilometer radius of Stellenbosch University Faculty of Medicine and Health Sciences' hospital in Tygerburg. It consists of three base stations (BSs) located at the hospital and serving three sectors. A terminal radio (TR) was installed at each of the ten schools that participated in the trial.

The role of CSIR Meraka Institute was to perform spectrum field measurements to demonstrate non-interference. This document provides a detailed results of tasks undertaken to ensure that trial network does not cause interference to the TV reception and make conclusions on the achievements of the first objective of the trial based on all the above measures that have been put in place to achieve the objective.

1.2 Background on TVWS

The terrestrial TV broadcasting networks have been traditionally planned as fixed multi-frequency networks to reduce self interference and to facilitate international frequency coordination. This creates locations within a country where particular UHF channels are not used in order to avoid interference to TV services in adjacent regions. Further, in certain locations, such as in rural and small cities, there are fewer TV services, leaving even more spectrum unused.

TVWS refers to the unused spectrum in the TV spectrum bands at a specific geographical location, that can be used for alternative wireless communication services. The amount and exact frequency vary from one location to another.

TVWS are of a particular interest due to the good propagation properties at VHF and UHF frequency bands and due to availability of underused spectrum, confirmed by multiple international [1]-[5] and local [6]-[10], [12] studies.

A white space device (WSD), as a secondary user of spectrum, communicates with the TVWS geospatial database and switch to the required frequency band. For the WSD to operate without interfering with primary users, protection criteria are required. For a network of such devices to operate, additional criteria may be needed. A WSD can either be a BS (BS) or a terminal radio (TR)

In this trial, devices having different form-factor and said to have different firmware were used as BSs (BS) and terminal radios (TR). More details may be found in [11].

2 DESCRIPTION OF THE TRIALS NETWORK

2.1 Overview of the TV network in Tygerberg

There are a number of broadcasting transmitter sites around Cape Town [15]. The main site is Tygerberg, with the strongest of the TV signals in Cape Town. Tygerberg carries a number of operational and planned transmitters as shown in Table 1. The rest of the sites are shown in Figure 1.

Table 1. TV transmitters in Tygerberg

Services	Frequency, MHz	Channel no	Offset	ERP, kW	Polarization
SABC 2	479.25	22	-20	2	V
SABC 1	511.25	26	-20	2	V
Planned Mobile digital Terrestrial TV multiplex	530	28		2	V
MNET	543.25	30	-20	1	V
Planned Digital Terrestrial TV multiplex 3	562	32		1.9999	V
SABC3	575.25	34	-20	2	V
Digital Terrestrial TV multiplex 1	610	38		2	V
CSN	639.25	42	-20	1	V
eTV	671.25	46	-20	2	V
Digital Terrestrial TV multiplex 2	706	50		2	V
Cape TV	839.25	67	-20	2	V

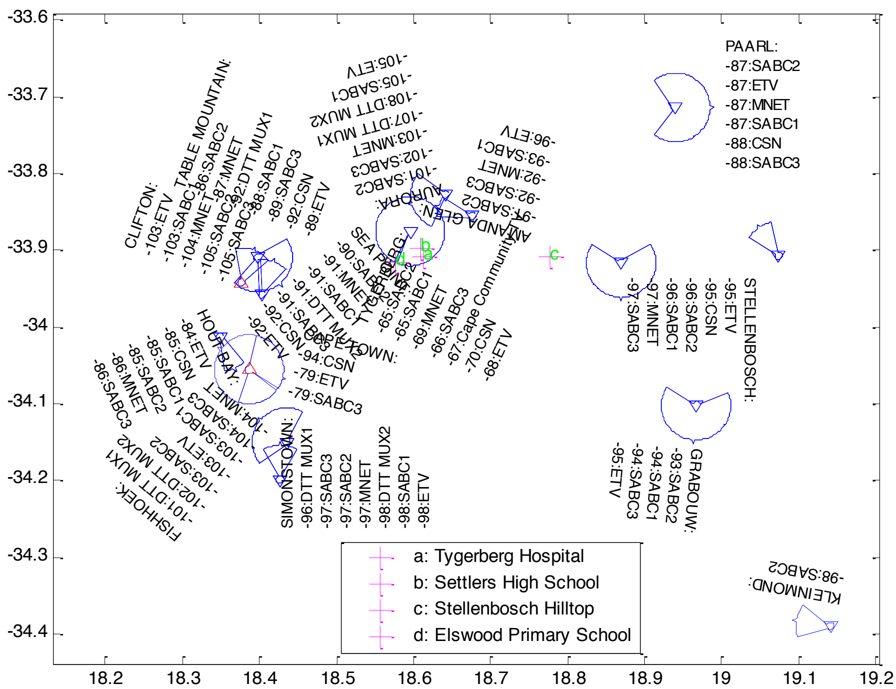


Figure 1: TV transmitters and the directions of radiation

2.2 TVWS network overview

The TVWS network set up in Tygerberg includes 3 BSs serving 3 sectors, as specified in

Table 2. The BSs are installed on the roof of Tygerberg hospital (Stellenbosch University Medical School, Francie van Zijlrylaan, Parow, 7500). The schematic view of the setup is shown Figure 2. The setup includes power supply and Internet connection for the BSs. There is a remotely controlled power switch enabling to turn any BS on and off individually.

Table 2: TVWS BSs on the roof of Tygerberg

Device id	*Sector*	*Location*	*Lati-tude, deg*	*Longi-tude, deg*	*Link (km)*	*TV ch.*	*Ant Hei-ght (m)*	*Ant Az, deg*	*Ant Gain , dB*	*Pola-rizati-on*
CSB00032	Sector 1	Tygerberg	-33.908	18.6125	n/a	23	45	35	10	V
CSB00028	Sector 2	Tygerberg	-33.908	18.6125	n/a	27	45	301	10	V
CSB00026	Sector 3	Tygerberg	-33.908	18.6125	n/a	33	45	238	10	V

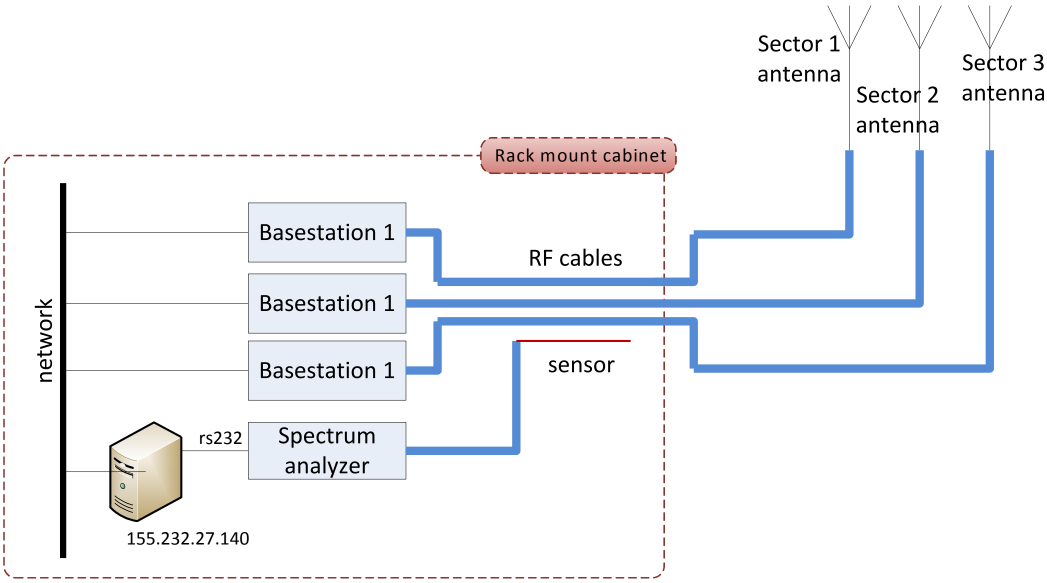


Figure 2: Schematic representation the BSs setup

The areas covered by the different sectors are shown in Figure 3. The colours; green, red and amber, correspond to three sectors, each served by a BS. The coverage is non-radial due to the topology of the landscape. Each sector uses a separate channel to maximize the signal to noise ratio (SNR) and thus the performance of the network.

Specifications for TVWS terminating radios are shown Table 3. The WSDs operated in TDMA mode. The WSDs were specified to output up to +30dBm of power and be able to switch to any of the TV channels in the broadcast UHF band [11]. However, laboratory measurements show output of up to +25 dBm, which was decreasing with increase in frequency. Drastical drop was observed from channel 50 onwards.

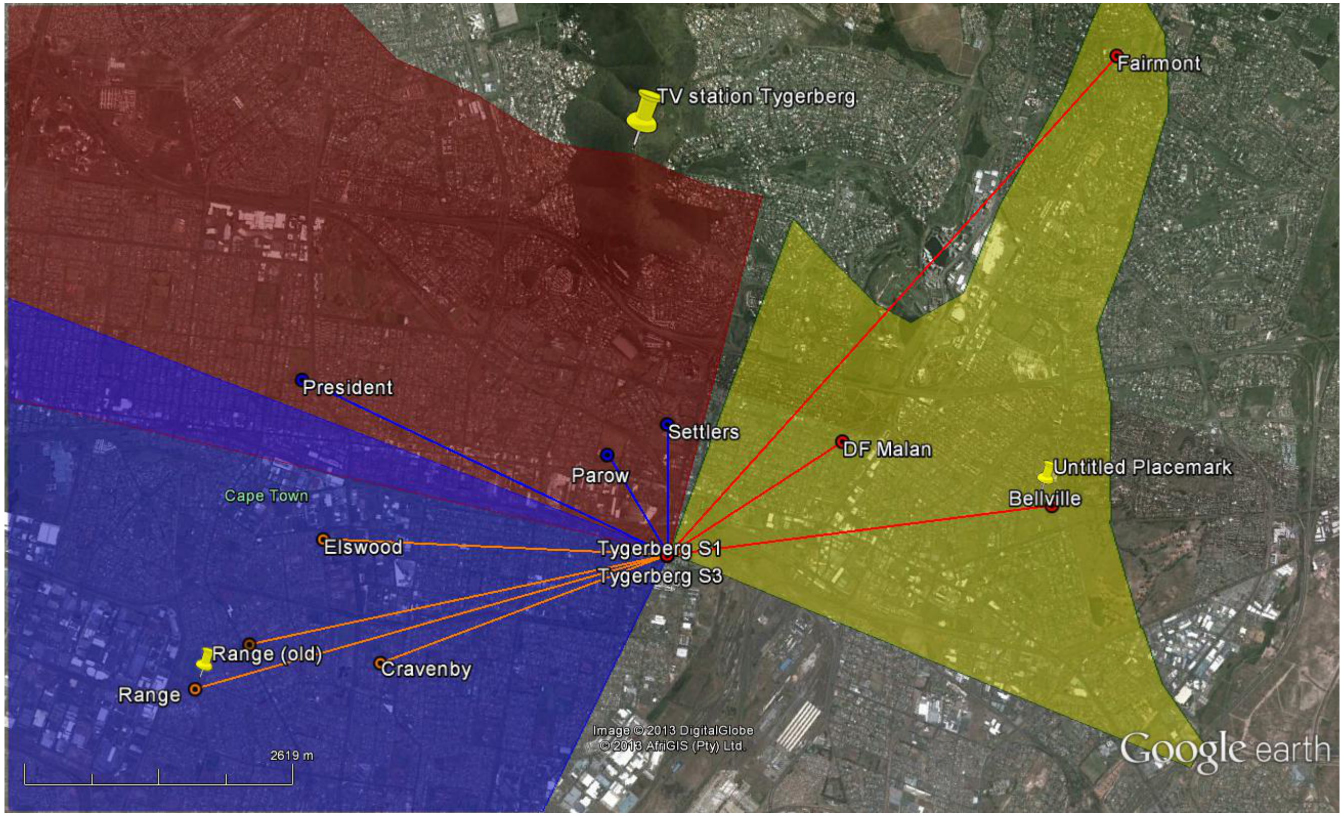


Figure 3. Location of nodes and coverage by the WS network. The three colours correspond to 3 sectors, each served by its own BS. The coverage is non-radial due to the topology of the landscape.

Table 3. Key parameters of the WS network nodes including BSs and terminals at schools

Device id	*Sector*	*Location*	*Lati-tude, deg*	*Longi-tude, deg*	*Link (km)*	*TV ch.*	*Ant Hei-ght (m)*	*Ant Az, deg*	*Ant Gain, dB*	*Polarization*
CST00027	Sector 1	DF Malan - DF Malan High School, Frans Conradie Drive, Bellville, 7530	-33.894	18.6261	2.03	23	8	219	11	V
CST00039	Sector 1	Bellville - Bellville High School, Omnia lane (North Street), Bellville, 7530	-33.893	18.6491	3.77	23	8	244	11	V
CST00025	Sector 1	Fairmont - Fairmont High School, Med Way, Durbell, Durbanville, 7550	-33.854	18.6410	6.55	23	12	204	11	V
CST00040	Sector 2	Settlers - Settlers High School, Settlers Road, Off Mike Pienaar Boulevard, Bellville, 7530	-33.897	18.6081	1.27	27	12	161	11	V
CST00035	Sector 2	Parow - Parow High School, Toner Street South, Parow, 7500	-33.902	18.6031	1.1	27	12	127	11	V
CST00036	Sector 2	President - High School President, Versfeld Street, Goodwood, 7460	-33.904	18.5697	3.99	27	12	97	11	V
CST00029	Sector 3	Cravenby - Cravenby Combined Schools, School Street, Cravenby, 7490	-33.925	18.5873	2.98	33	10	50	11	V
CST00033	Sector 3	Elswood - Elswood High School, Epping Avenue, Elsies Rivier, 7490	-33.916	18.5773	3.38	33	8	74	11	V
CST00031	Sector 3	Norwood - Norwood Central Primary School, 21st Avenue, Norwood, 7490	-33.927	18.5734	4.19	33	8	60	11	V
CST00037	Sector 3	Range - Range High School, Balvenie Avenue, The Range, 7490	-33.932	18.5695	4.15	33	8	56	11	V

3 SIGNAL IDENTIFICATION AND MEASUREMENTS

One of the key activities in ensuring that the trial network does not cause interference to TV reception is to measure signal strengths of all expected wireless technologies operating in the designated spectrum. In particular the interest is in analogue terrestrial TV broadcasting, digital terrestrial TV broadcasting and TVWS devices.

3.1 Analogue terrestrial broadcasting signal

Analogue terrestrial broadcasting uses PAL-I system with 8 MHz channel bandwidth. Various components of PAL-I sytem spectrum are shown in Figure 4 and illustrated by a sample of measured signal in

Figure 5.

The signal consists of video intensity or luma carrier, color represatation or chroma carrier and audio carrier. The signal may optionally also consists of Near Instantaneous Companded Audio Multiplex (NICAM), which would be 6.552 MHz from the video carrier. Full specification of the PAL-I system can be found in [21], [25], and [23].

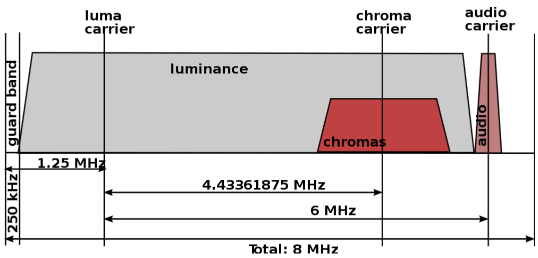


Figure 4: Spectrum components for PAL-I system

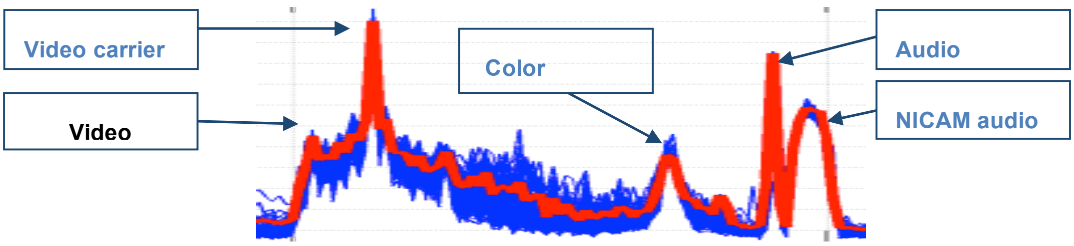


Figure 5: Sample of measured PAL-I system

Table 4: Field strength values (in dB(μV/m)) recommended for planning analogue TV broadcasting in UHF

Frequency range, MHz			470 to 582	582 to 960
	Scenario			
Medium / Minimum value, dB(μV/m)	(a)	Urban area	65	70
	(b)	Urban area with no interference	62 (at 474 MHz)	67 (at 842 MHz)
	(c)	Area with better receivers and antennas	58	64
	(d)	Area with better receivers and antennas and no interference	52	58

The protection criteria against interference are discussed in [19]. The recommended minimum field strength values are given in Table 4 for various scenarios. This information was used as the threshold to determine whether a channel with analogue PAL-I signal is usable for viewing.

The ITU-R recommendation in [17] specifies values for antennae gain and cable loss. The recommended values are shown in **Error! Reference source not found.**.

Table 5. Typical minimum signal strength, antenna gain and feeder loss

Band	**IV**	**V**
Frequency range, MHz	**470 to 582**	**582 to 960**
Minimum field strength, dB(μV/m)	62	67
Antenna gain, dBd	10	12
Cable loss, dB	3	4.5
Dipole conversion factor, dB (conversion formula is 20 log 2π/λ)	20.5	25

In [27] the same antenna gain values for the respective bands are used, although 5 dB is used for cable loss or feeder loss instead of 4.5 dB.

The ITU-R recommendations in [28] and [29], when considering DVB-T2 8 MHz system operating at 650 MHz, uses antenna gain of 11 dBd and feeder loss of 4 dB for the “fixed” roof top scenario.

The antenna gain is interpreted to be in dBd (with respect to a half-wave dipole) rather than dBi (with respect to an isotropic radiator), where the two are related as G(dBi) = G(dBd) + 2.15dB.

Based on the references indicated and discussions made above, the following is considered as a model for the fixed rooftop antenna installation:

- Antenna gain, $G = 10 + 8\log_{10}(f/474)$,
- Feeder loss, $L=3 + 6\log_{10}(f/474)$,
  where f is frequency of in the middle of a channel, in MHz.

The model ensures that the minimum signal strength, antenna gain and feeder loss shown in Table 5 are satisfied. Figure 6 show computed curves for the model. The maximum difference between gain and loss for the proposed model and and values in [17] is within 0.5 dB.

3.1.1 Protection for TV receivers

To achieve required protection criteria from determination in [17], [18] and [19], the noise-limited sensitivity of at least -58 dBm in the broadcasting UHF band is required. In the United Kingdom, the value is set at -65 dBm.

3.1.2 Minimum acceptable power level

Calculations for minimum usable power level are carried out as follows:

1. Unit-less antenna gain G is converted into antenna aperture area $A = G\lambda^2/4/\pi$ [m^2], where λ is wavelength;
2. The incident flux S is computed as $S = E_{min}^2/120/\pi$ [W·m^{-2}], where E_{min} [V·m^{-1}] is the minimum field strength.
3. Incident power P_i is computed as $P_i = S \cdot A$ [W].

The result of this calculation, based on our model, is shown in Figure 7.

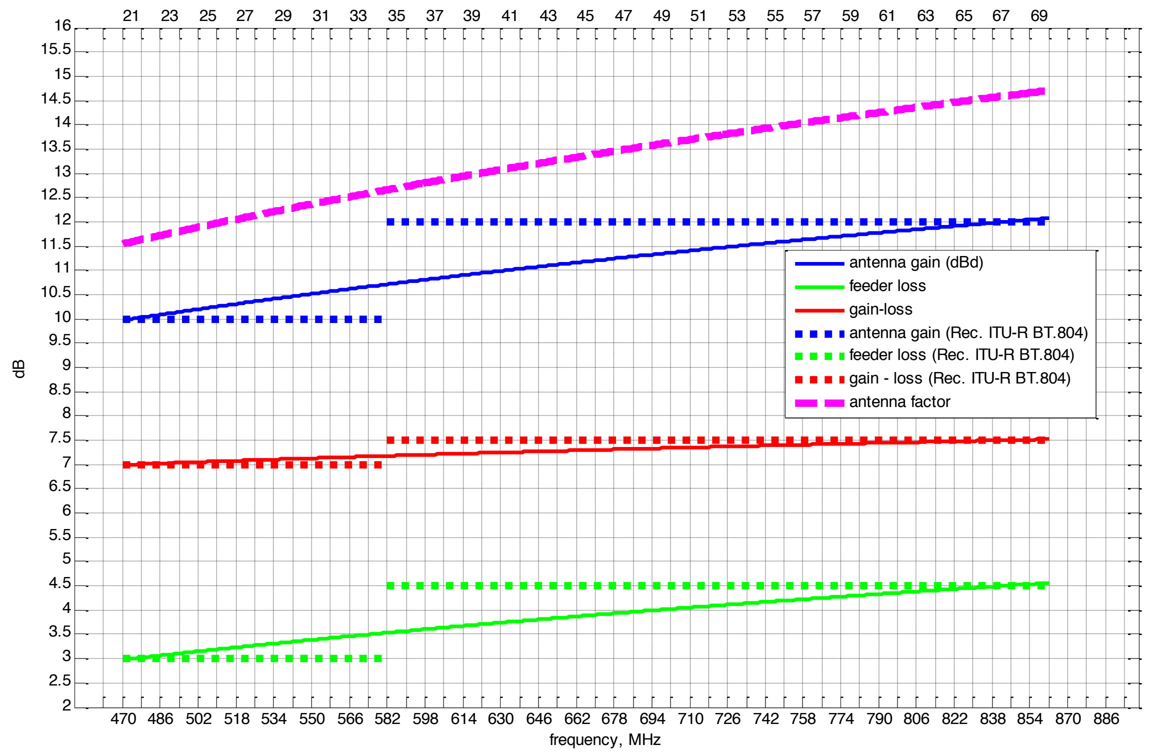


Figure 6: Model curves for the selected specifications for a fixed rooftop antenna installation

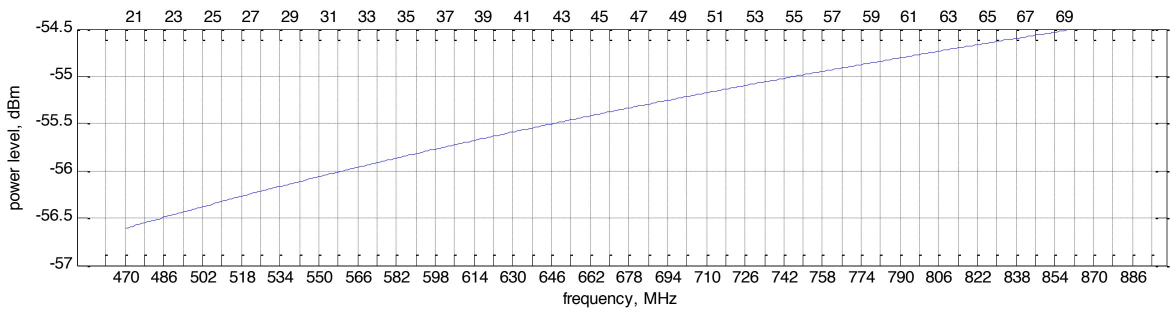


Figure 7. Minimum incident power level at the antenna, corresponding to the minimum field strength.

3.2 Digital video broadcasting

The theoretical spectrum mask for DVB-T2 is shown in Figure 8 for different modes of operation. DVB-T2 is based on orthogonal frequency division multiplexing (OFDM). A sample of a measured digital signal's spectrum is shown in Figure 9. The spectrum is composed of a multitude of tightly packed subcarriers appearing as a continuous, nearly rectangular block, taking a bandwidth of 7.61 MHz [30], [31].

3.2.1 Minimum field strength

The sample scenarios considered in Rec. ITU-R BT.2254 give min equivalent field strength at receiving location as 45.3 dB(μV/m) for fixed scenario, 50.2 dB(μV/m) for portable outdoor/urban, 42.5 dB(μV/m) for mobile/rural etc.

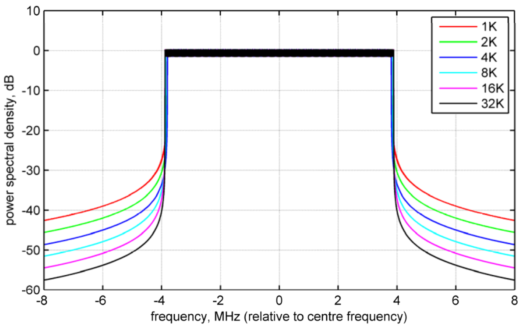


Figure 8: Theoretical spectrum mask for DVB-T2 spectrum for guard-interval fraction 1/8 for 8 MHz channels

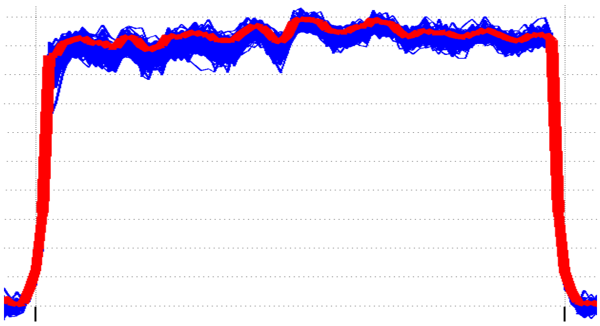


Figure 9: Sample of off-the-air measured digital spectrum DVB-T2

3.2.2 Model for a fixed rooftop antenna installation

The same model used for analogue terrestrial broadcasting is used for DVB-T2 fixed rooftop antenna installation.

3.3 TVWS signals

TVWS users are considered secondary users and is a potential interferer to the terrestrial TV broadcasting signals. The devices used in the trial are based on Time Division Multiple Access (TDMA). Figure 10 shows measured spectrum mask for WSD [11], the results are sumarised in Table 6.

The bandwidth estimations made using a different set up shown in Appendix C of [11] confirm the trends and indicate that the roll-off rate is around 100 dB/MHz. However, as shown in [11], due to limitations of the measurement equipment, it is difficult to extrapolate this roll off to beyond 60 dB below the signal level.

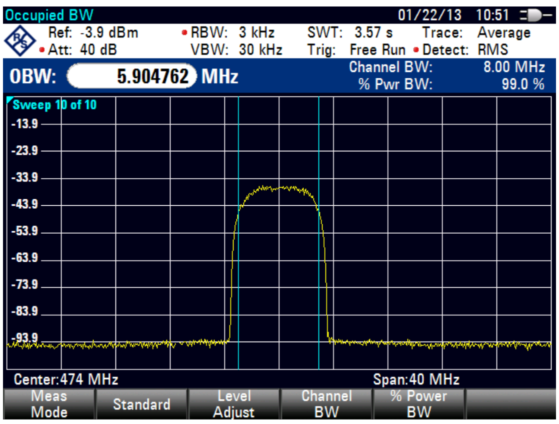


Figure 10: Sample of measured occupied bandwidth for WSD

Table 6: Occupied bandwidth measurements for selected operation channels

Percentage of power witin the 8 MHz channel (%)	Equivalent measurement level, dB	Occupied bandwidth from an 8 MHz channel, MHz
90	-10	4.507937 ± 0.033
99	-20	5.904762 ± 0.033
99.9	-30	6.476190 ± 0.033
99.99	-40	7

4 LABORATORY ESTIMATION OF PROTECTION RATIO

This section discusses the laboratory testing done to confirm general non-interference and estimate the boundaries of interference-free operation.

The work described in this section refers to testing the TV sets/receivers to statistically characterise their properties, and to quantify the quality of the picture with respect to the strength of the WSD signal[1] present in the same or adjacent TV channel.

The measurements reported in [11] have confirmed that the WSDs operated well enough to be used in a limited field trial. The following measurements and analysis were done:

1. Laboratory measurements to validate the equipment for trial operation, including selected electromagnetic compatibility (EMC) and electromagnetic interference (EMI) tests.
2. Transmission spectral mask during normal operation, to ensure that the spectrum of transmitted signals is well within the bounds of an 8 MHz wide TV channel, and that the power output is within the specifications stated.
3. Spectral emissions during transient processes (e.g. compliance to master-slave behavioural pattern, including during the start-up).
4. Power output versus TV channel number, to confirm that the WSD is usable within the full UHF frequency band.

4.1 TV picture quality definition

The picture quality was graded by manually observing the picture displayed by the sample TV sets. The figure of merit selected for the evaluation is based on the he CCIR five grade scale, as per CCIR Recommendation 500-1 (Kyoto, 1978), indicated in Table 7.

Table 7. CCIR picture assessment scale

Grade	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Examples of the pictures quality for some of the grades are shown in Figure 11.

Most of the estimations were done as a mean opinion score from a team of 2 to 3 people.

[1] The results of a study for the opposite effects, where the TVWS link was subjected to interference by analogues TV are shown in Section **Error! Reference source not found.**.

a) b)

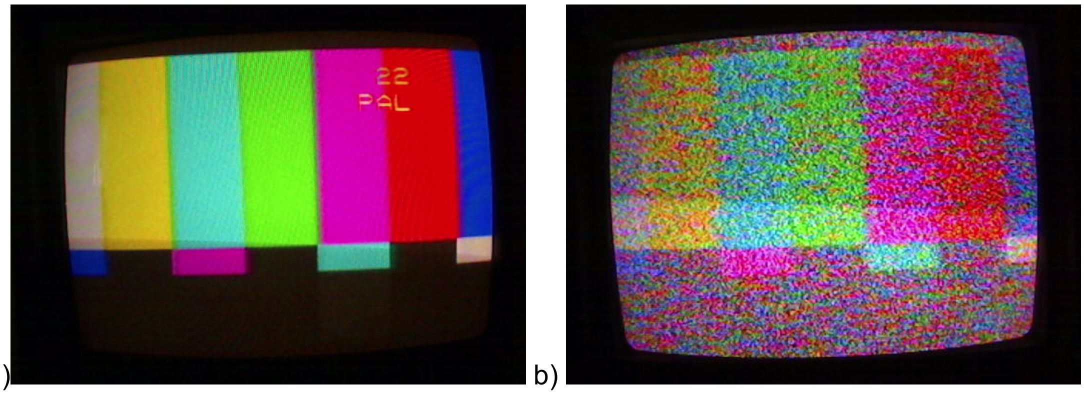


Figure 11. Samples of picture quality scale: a) grade 5 - excellent quality / imperceptible impairment, b) grade 1 – bad quality / very annoying impairments.

4.2 Laboratory set up and methodology

The laboratory set up is shown in Figure 12. The upper signal chain starts with a source of composite video signal. A DVD player playing a DVD with pre-recorded standard video pattern, was used as the source of composite video signal. This composite video signal was then fed into a radio frequency (RF) modulator, which outputs a modulated video signal. For convenience and also to minimize loss in the cables, most the modulator was set to and tests were done at the TV channels 21 to 23. This signal is then passed through an electronically controlled digital attenuator (range 0 to 31.5 dB, with step 0.5 dB). From the attenuator, the signal is enters a splitter (a resistive splitter with 6 dB loss per arm), which was used as a combiner.

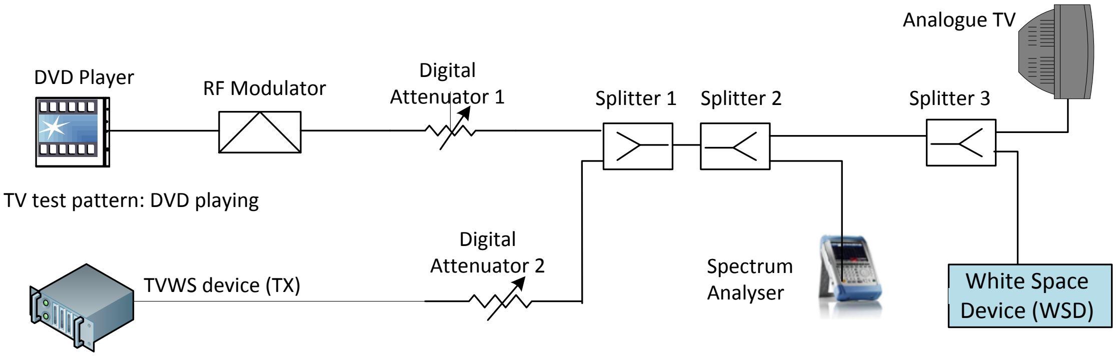


Figure 12. Block diagram of the set up used for the laboratory measurements.

The other arm of the combiner is fed, through another digital attenuator (with range 0 to 71 dB, with step 1 dB), with a signal from WSD set to transmit continuously. At the combiner, the two signals are added together, as it would happen if the signals were sent/broadcast through a common media, air.

The next splitter (with the same characteristics as the previous one) splits the signals into two equal portions. The measured half fed into a spectrum analyser N9912A. The other arm of the splitter sends the signal to the next splitter.

This last splitter splits the signal equally between a TV receiver and a WSD functioning as a receiver.

Note:

Unless specifically stated, the results are presented in terms of the signal level rather than integral signal power.

4.2.1 Test cases

The measurement set up permits the following main test configurations:

1. Measuring the characteristics of TV receiver
2. Measuring the characteristics of WSD link
3. Characterising co-existence of WSD and TV, including
    a. Co-channel interference by WSD to TV reception
    b. Co-channel interference by TV signal to WSD link performance
    c. Adjacent channel interference by WSD to TV reception for left hand side and right hand side adjacent channels

Case 1: co-channel interference by WSD to TV signal

The picture quality started to become acceptable with WSD being lower than the TV signal's strength by at least 30 dB.

Case 2: Adjacent channel interference by WSD to TV signal

The TV signal level was kept at around -51.3 dBm and WSD signal strength was varied using the digital attenuator 2, repeated several times.

The results are summarized in Figure 13. It is for example possible to see that to achieve the level 5 TV picture quality ("excellent"), one is required to have WSD signal at least 6.3 dB ± 3.8 dB lower than the TV signal. Using the relationship,

$$\mathrm{PR(power)} = \mathrm{PR(level)} + 10\log_{10}\left(\frac{\mathrm{BW1}}{\mathrm{BW2}}\right),$$

where PR(power) is the protection ratio in terms of the total/integral signal power, PR(level) is the protection ratio in terms of the signal strengths (as defined in this Section), BW1 is the bandwidth of the protected TV signal (~300 kHz) and BW2 is the bandwidth of the WSD signal. With this relationship, the PR(level) obtained in this section may then be translated into integral power based protection ratio PR(power), the metric more comparable to ITU-R recommendations.

For comparison, the PR for PAL-I agaist DVB-T signal in adjacent band is -5 dB. The respective value for the WSD equals $+6.3 + 10\log_{10}(250\mathrm{kHz}/5.9\mathrm{MHz}) = \text{-}7.4\ \mathrm{dB}$. This indicates that the obtained results permit WSD transmissions stronger by 2.4 dB for the left-hand-side (N-1) WSD channel and stronger by 8.6 dB for the right-hand-side (N+1) WSD channel.

Note 1

From the theoretical point of view, the possibility of relaxing PRs is attributed to the spectrum of WSD being narrower than the spectrum of DVB-T. The ratio of the two leads to 10log10(7.61MHz/5.9MHz)=1.1 dB, which is nearly half of the difference (2.4 dB) found.

Note 2

One may however notice that the signal strength levels at the TV input were relatively low, compared to the -39 dBm used as a reference in several ITU-R Recommendations. It is possible that the low TV signal levels restricted the ability of TV sets to combat the adjacent channel interference and thus the protection ratios could possibly be relaxed further.

Table 8. Estimation of sensitivity of two sample TV sets (one made by Samsung and another by JVC). The level and mean value refer to the values measured for a specific resolution bandwidth. The total power refers to the integral power over 300 kHz bandwidth around the visual carrier.

TV picture quality level	Attenuator setting, dB		Level, dBm		Mean value	Difference to level 5	Total power
	Samsung	JVC	Samsung	JVC	dBm	dB	dBm
5 (excellent)	0		-74.4		**-74.4**	0	-56.5
4 (good)	3	10	-77.4	-84.4	**-80.9**	6.5	-63
3 (fair)	6	13	-80.4	-87.4	**-83.9**	9.5	-66
2 (poor)	10	17	-84.4	-91.4	**-87.9**	13.5	-70
1 (bad)	15	22	-89.4	-96.4	**-92.9**	18.5	-75
complete loss of picture		37		-111.4	**-111.4**	37	-93.5
switch off	40		-114.4		**-114.4**	40	-96.5

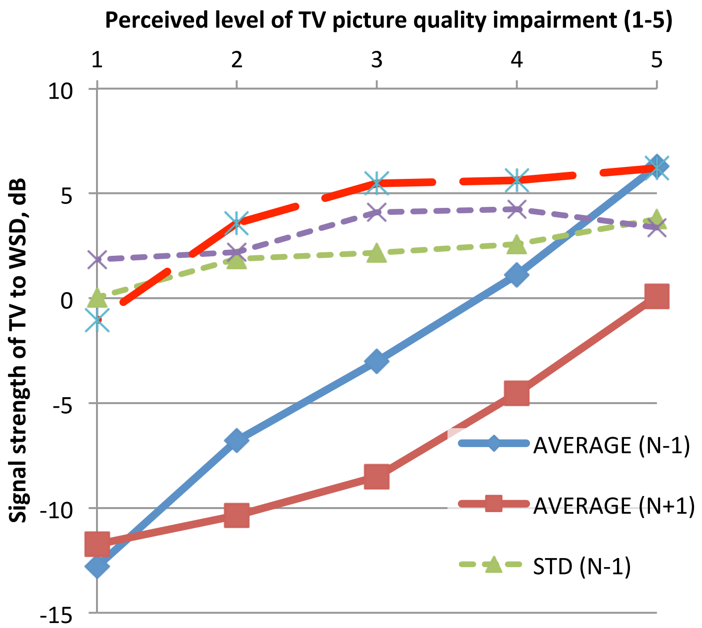


Figure 13. Protection ratios ("AVERAGE") required to achieve specific perceived levels of TV picture quality, and respective uncertainties ("STD") for the WSD in the left hand side adjacent TV channel (*N*-1) and right hand side adjacent TV channel (*N*+1).

4.2.2 Conclusions

In order to achieve protection for analogue TV broadcasting, the maximum amplitude of the video carrier of the TV signal should exceed the maximum amplitude of the flat top portion of the WSD signal by at least

- 6.3 dB ± 3.8 dB for level 5 quality for WSD being in the left-hand-side adjacent channel (N-1);
- 0.1 dB ± 3.4 dB for level 5 quality for WSD being in the right-hand-side adjacent channel (N+1);

- 1.1 dB ± 2.6 dB for level 4 quality for WSD being in the left-hand-side adjacent channel (N-1);
- -4.5 dB ± 4.2 dB for level 4 quality for WSD being in the right-hand-side adjacent channel (N+1).

with more details shown in Figure 13. These figures may be translated into the PRs in terms of the total power in the signals:

- -7.4 dB ± 3.8 dB for level 5 quality for WSD being in the left-hand-side adjacent channel (N-1);
- -13.6 dB ± 3.4 dB for level 5 quality for WSD being in the right-hand-side adjacent channel (N+1);
- -12.6 dB ± 2.6 dB for level 4 quality for WSD being in the left-hand-side adjacent channel (N-1);
- -18.2 dB ± 4.2 dB for level 4 quality for WSD being in the right-hand-side adjacent channel (N+1).

It may be noted that the PR estimaitons were done on a relatively low level of the reference TV signal. It is thus likely that the PR ratios could be relaxed even more, compared to the PR stated in [27] for protecting PAL signal against DVB-T transmissions in an adjacent channel.

It should however be noted that the the metric for the WSD in right hand side adjacent channel may be less accurate as it does not consider the interference to audio carrier and to NICAM.

5 FIELD MEASUREMENTS

The measurements of the field strength distribution due to TV stations and operation of TVWS network have been carried out, as a part of a study to confirm non-interference to the primary users of this spectrum by the TVWS wireless network. The results from this campaign, especially the levels of the WSD signals and TV signals in adjacent channels, are to be used as inputs to quantify non-interference.

An additional goal of the measurements was to confirm the correct spectrum mask transmitted by each WSD in the network.

5.1 Measurement setup and methodology

5.1.1 Measurement set up

The set up used for the measurement can be seen in multiple pictures available in Volume 2 of the report. The measurement part of the setup includes the monitoring antenna R&S HK033, connected with a cable to the receiver R&S ESVD, as illustrated in **Error! Reference source not found.**. The receiver is controlled by a notebook, which also collects the data. Except for the roof of the Tygerberg hospital, the whole setup was mounted on a man lifter. When this man lifter is fully expanded and the antenna is about 13 m above the ground level.

<u>Note</u>

Although, following a number of international standards, it is more customary to use 10 m as the reference height, several sites required a higher positioning of the receiver antenna in order to be able to receive signal over the surrounding buildings/structures. Thus, the 13 m height was used instead.

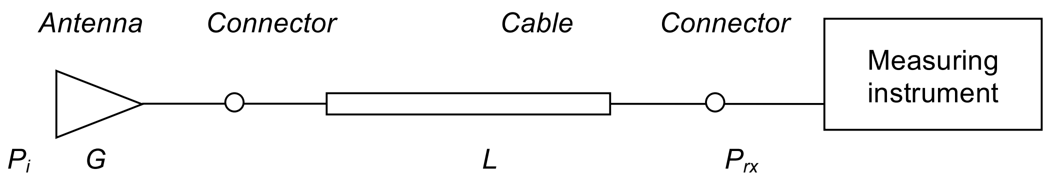


Figure 14. Signal path in the measurement chain: from incident power Pi to the signal measured by the instrument Prx. The antenna is R&S HK033. The measuring instrument is R&S ESVD.

The signal measured by the instrument equals $P_{rx} = P_i + G - L$, where G is antenna gain, L is the loss in the cable, P_i is the incident power, and all quantities are in dB. It is assumed that the connectors do influence the results in a negligible manner, e.g. compared to the uncertainty in the measurement due to the fading.

5.1.2 Settings for ESVD

The ESVD settings were similar to the previous measurement campaign [10], except for a slightly wider frequency range used at most of the sites.

Most of the scans were from 450 MHz to 900 MHz (i.e. 450 MHz). A few initial scans were performed with slightly narrower band.

The R&S ESVD was used as the measuring instrument. Due to the limited memory of instrument, the whole band (450 MHz – 900 MHz) was split into sub-bands measured one by one, increasing the frequency. The key specifications for the measurements are given below, in the form of human-readable commands sent to the instrument:

SCAN:FREQUENCY:STEPSIZE 100 kHz;
SCAN:RECEIVER:DETECTOR PEAK;
SCAN:RECEIVER:BANDWIDTH:IF 10 kHz[2]*;*
SCAN:RECEIVER:MEASUREMENT:TIME 100 ms;
SCAN:RECEIVER:ATTENUATION:AUTO On;
SCAN:RECEIVER:ATTENUATION:MODE LowNoise;
SCAN:RECEIVER:Range 60 dB;
SCAN:RECEIVER:PreAMPLIFIER ON;

5.1.3 Calculation of incident field strength from received voltage

The field incident onto an antenna E_i [dB(μV/m)] was computed as a sum of the voltage measured by the receiver V_{rx} [dB(μV)], antenna factor AF [dB(m^{-1})] and losses in the cable L [dB]:

$$E_i = V_{rx} + \mathrm{AF} + L$$

The antenna factor was computed as a function of wavelength λ [m] and unitless antenna gain *G* as:

$$AF = \frac{9.73}{\lambda\sqrt{G}}, \qquad AF(dB) = 20 \cdot \log_{10}\left(\frac{9.73}{\lambda\sqrt{G}}\right)$$

It can be seen that the uncertainty, given in dB, in the value of the gain, will translate into the same uncertainty in the antenna factor. For this reason, corrections in the antenna gain, cable loss, tdetectator type and IF bandwidth influence are carried out as follows

5.1.4 Calibration factors

The following factors have been addressed by the calibration: antenna gain, cable loss, detector type and the influence of IF bandwidth.

Antenna and cable

Before the signals are measured by the instruments, they are received by an antenna, and passed through an RF cable. As these devices influence the results of the measurements, all of them require characterization.

The losses in the cables have been measured and the result is shown in **Figure 15**. The curved denoted with "filtered" are the ones applied to the spectrum measurements, and have been obtained by applying a running average filter to the actually measured values. The filtering has been done to reduce the measurement noise.

[2] The instrument used 10 kHz IF bandwidth.

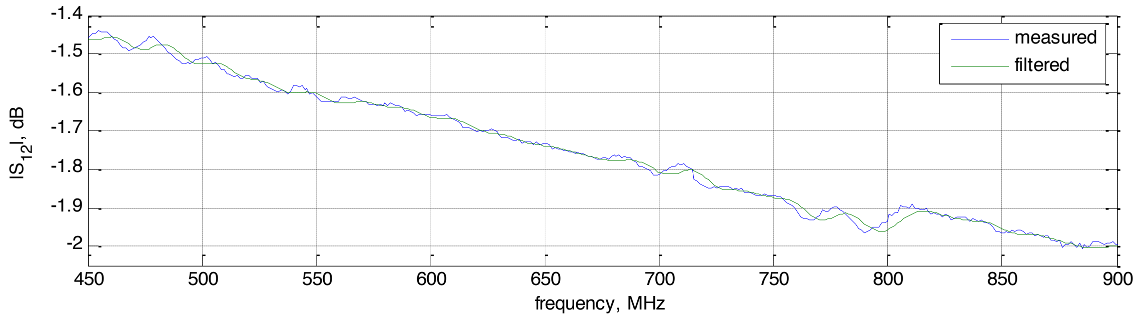


Figure 15. Measured loss in the cables *L*=-|S12|. Uncertainty, per N9912A's specifications, is 0.15 dB

The antenna gain for the antenna R&S HK033 is specified to be 2 dBi ± 1.5 dB. It may also be noted that the antenna gain is fully compensates for the loss in the cable.

The VSWR of the antenna is stated to be below 2.4 dB. This may be translated into an equivalent insertion loss uncertainty of up to 0.8 dB. The VSWR of the receiver ESVD is stated to be below 2, translating into a maximum equivalent insertion loss or uncertainty of 0.5 dB. In addition, the measurement error, for the target temperature range (0 to 55 deg C) is stated to be below 1 dB. The VSWR of the cable is ignored. The overall uncertainty budget is shown in

Table 9. The optimisation of the uncertainties by considering input mismatches as an equivalent insertion loss equal to the half of its maximum value, permitted to reduce the measurement uncertainty by 0.65 dB.

Table 9. Analysis and optimisation of measurement uncertainties. The non-unitary VSWR were converted into an equivalent insertion loss with half the original uncertainty.

	Original uncertainty budget	
Source of uncertainty	**Gain value, dB**	**Uncertainty, dB**
Antenna's gain	+2	1.5
Antenna's mismatch	VSWR<2.4, i.e. Insertion loss	0.8
Cable loss	-1.55 dB	0.15+0.1
Receiver's input mismatch	VSWR<2, i.e. Insertion loss	0.5
Receiver's measurement		1
TOTALS	**0.45 dB**	**4.05**

Thus, for simplicity, a system comprised of the antenna and the cable connecting it to the receiver, may be characterized by the overall gain of -0.2 dB ± 3.4 dB in the middle of the band of interest, i.e. at 522 MHz. However, to reduce the uncertainty, the plots of the spectrum scans provided do not use this simplification and take the frequency dependence shown in Figure 15 into account.

The sensitivity of the R&S HK033 and effect of the losses in the cable may be expressed via the antenna factor, as shown in Figure 16.

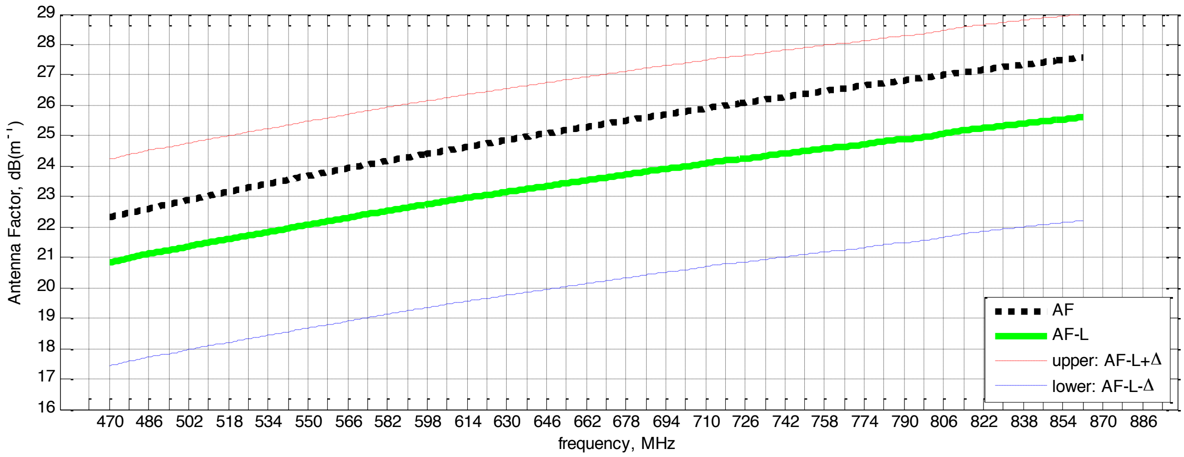


Figure 16. Antenna factor for R&S HK033 (AF), influence of cable loss (L), and uncertainties (Δ). The dashed curves indicate bounds due to the total uncertainty, Δ=1.8 dB.

IF bandwidth and detector type

The correction factors for transforming the power calculated from the measured results into the RMS power are summarized in Table 10. Table 11 shows the correction factor for the ESVD readings. The total correction factor for the ESVD readings is 5.71 dB.

The correction factors for different types of signals, to convert from the readings done in the peak detector mode of ESVD into RMS value, are shown in Table 12. The uncertainty was estimated based on the observation of the fluctuation in the measured results.

Table 10: Correction factors for adjusting readings from the bands to convert from the Peak detector to RMS detector

Signal	Correction Factor, dB	Uncertainty, dB
DVB-T2	+10	0.5
Strong PAL-I signal > -70 dBm @ RBW=10kHz	+18.5	2.1
Weak PAL-I signal < -70 dBm @ RBW=10kHz	See **Error! Reference source not found.**	3
WSD	+10	0.5

Table 11: Correction factor for the ESVD readings

Signal	Field strength, dBμV		Calibration
	ESVD	FSH4	Factor
Noise floor	30.29	24.18	-6.11
BPSK	71.72	66.	-5.72
QPSK	71.71	66.	-5.71
QAM16	69.18	63.47	-5.71

Table 12: Correction factors for adjusting readings from the bands to convert from the Peak detector to RMS detector

Media	Calibration Factor, dB	Uncertainty, dB
DVB-T2	-7.22	0.5
PAL-I	-0.11	0.5
WSD	-5.71	0.5

5.2 Summary of the scans – locations, timing and other parameters

In doing the field measurements, care was taken to differentaiate TV signal and WSD signal from any other signals. Thus, for each school, three locations were selected for measurements and for each location, two sets of measurements were recorded. The first set was when both the BS and TR at the schools were operating. The other was for when the BS and TR at the school were off..

The most reliable results come from the line of sight measurements around the maximum of the main beam of a transmitting antenna. The following sites are considered to offer the line of sight measurements around the maximum of the main beam of a transmitting antenna:

- Receiving from WSD transmitter at Range
    - Measurement point #1 at Range - the school building and surrounding structures are low and the tall trees are few, so the TV signal may be expected to be about the same in all of the measurement points.
    - All measurement points at Cravenby, Norwood and Elswood - The buildings were low, but the trees at two measurement locations at Cravenby were tall and could be expected to affect the measurement results for TV signal strength.

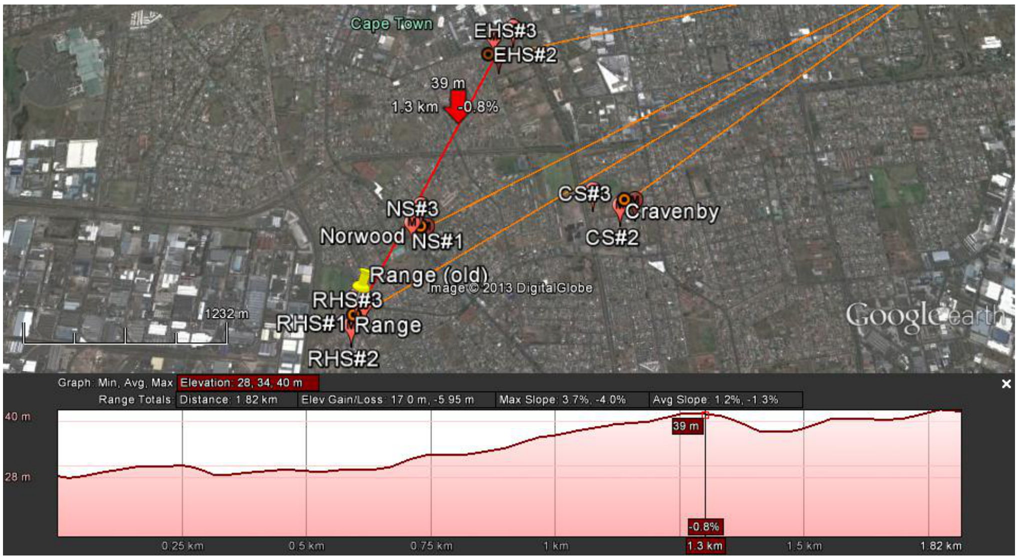


Figure 17: Suitable elevation profile for the signal from Range

- Receiving from WSD transmitter at President

- All measurement points at Parow and Settlers - measurement point #3 at Settlers was much lower and the signal could be missed there.

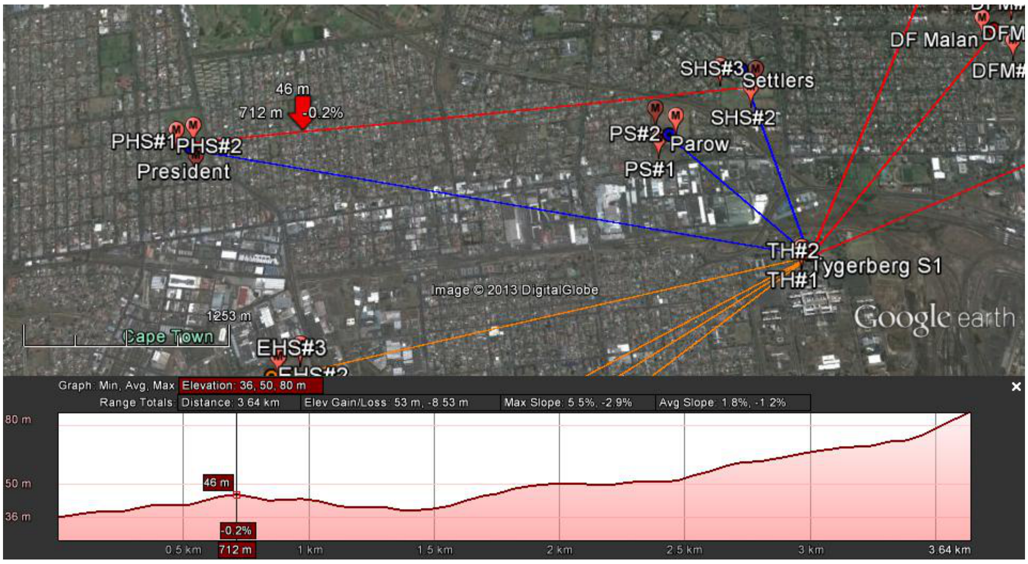
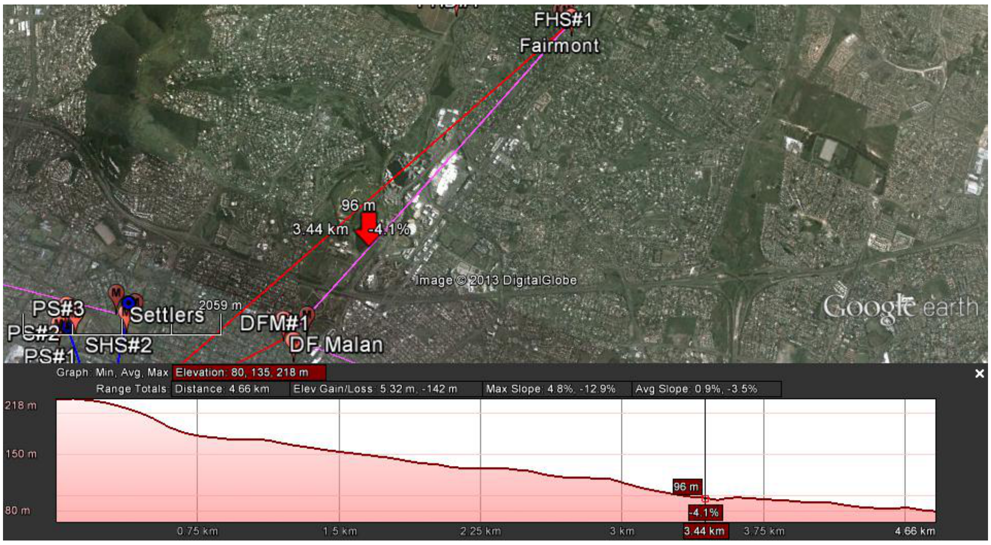


Figure 18: Signal from President

- Receiving from WSD transmitter at Settlers
  - Measurement point # 2 at Settlers
- Receiving from WSD transmitter at Bellville
  - Measurement point # 3 at Bellville
- Receiving from WSD transmitter at Fairmont
  - All measurement points at DF Malan



  - All measurement points at Bellville (although the angle off the direction of the maximum signal strength is large, around 30 deg; thus, it is possible to expect signal attenuation more than 3 dB)

There was however no noticeable difference between the signals at these locations an other measurements sorounding them.

5.3 Results

The methodology used initially resembled that used for determining the protection ratios in the laboratory tests, where the amplitude value rather than the total power was used for the measurements. The values were then processed to remove the antenna gain and cable loss, resulting in obtaining the power incident upon the antenna. The result is illustrated with Figure 19.

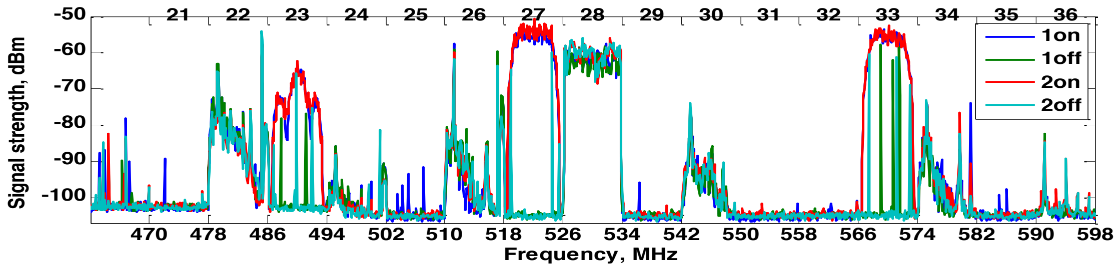


Figure 19: Spectrum measured at the roof of Tygerberg hospital, at the locations #1 and #2

The integral of the power in the spectrum of the video intensity signal (bandwidth of 300 kHz centered at 1.25 MHz to the right of the left boundary of the TV channel) is recorded as the TV signal strength level, Stv. The integral of the power in the spectrum of WSD signal (within the bandwidth of 7 MHz) was recorded as the WSD signal strength, Swsd. The difference of the values, Stv - Swsd, was then compared against the protection ratio value, PR, derived from the laboratory tests, leading to the safety margin ratio dPR= Stv - Swsd PR. The PR value used for a potential interferer in the channel adjacent and to the left (N 1) of the TV channel (N) was 8 dB. The PR value used for a potential interferer in the channel adjacent and to the right (N+1) of the TV channel (N) was 14 dB. The uncertainty of these values is on the order of ±4.5 dB. The difference between the measured ratio and the required protection ratio, dPR, was then used to estimate the interference distance , as Rinterf =D•10-dPR/20, assuming free space propagation. The variable D is the distance from the WSD antenna to the measurement site.

Figure 20 shows a summarized presentation of the measurement results, permitting to compare the strength of WSD signal to the strength of TV signal in adjacent channels In the analysis, it has been assumed that the likelihood of interference from WSD to the TV channels adjacent to the operational WSD channels is much greater than the likelihood of interference to the TV channels further away. Thus, the analysis was done at the N±1 channels only.

It is easy to observe that the WSD signal distribution indicates maximum strength within the respective sectors. For example, the WSD signal is the strongest for locations 10-18 corresponding to Sector 2, as shown in Figure 20b. The WSD signal is very strong in locations 31 and 32 corresponding to the measurement site at the roof of the Tygerberg hospital, as this location is very close (about 50 m away) from the location of the BS antennas. Still, one can observe that the WSD signal for channel 23 is significantly lower than the WSD signal for channels 27 and 33, as the WSD BS antenna for Sector 1 points in a significantly different direction.

The distribution of TV signals seems to be relatively uniform, with deviations in the signal strength typically within ±10 dB. There is however an exception for channel 32, where the field strength deviates significantly more. By analyzing the field strength versus time, it was concluded that it is most likely that this channel was being under test by broadcasters, where the transmissions on this channel were on in the beginning of the data collection period, and then off for most of the time.

The data have then been processed on per-TV-channel basis, using the concept of protection ratios overviewed in Section **Error! Reference source not found.**. A qualitative study can already be done from Figure 20 by considering the difference between the TV and WSD signal strength. As per Section **Error! Reference source not found.**, in order to permit non-interfering co-existence of WSD and TV at a point where measurement is made, the strength of WSD signal should not exceed the strength of TV signal by more than

- 5 dB (if one used DVB-T criterion) or
- by more than 8dB for WSD signal being on the left-hand-side of the TV signal and
- 14 dB for WSD signal being on the right-hand-side of the TV signal.

At the same time, one needs to take into consideration that application of protection ratios will make solid sense only at the locations where the strength of TV signal is sufficient for viewing TV. The minimum required field strength for TV signal is around 65 dBμV/m (a more detailed criterion is described earlier and applied in

Table 14). For example, with this in mind, TV signal in channel 24 is not viewable, whilst the channels 22 and 26 offer on-average the strongest TV signal. TV signals below approximately 65 dBμV/m are considered as not requiring protection.

Analyzing the TV channels adjacent to WSD channels, one by one it is possible to see that

- channel 22: protection ratio are well satisfied, as the TV signal is stronger than WSD signal everywhere, except at location 3;
- channel 24: TV signal is below the required minimum viewable level;
- channel 26: There is a possibility of interference at locations 31 and 32. Also, the ratio of TV and WSD signals needs to be checked at the location 15;
- channel 28: only locations 31 and 32 may need to be verified for the presence of interference; however, the digital TV has much higher tolerance to interference (the protection ratio of around -30 dB for DVB-T2 interfered with by DVB-T2), thus one should be able to consider this channel as free of interference;
- channel 32: broadcasting was not operational for most of the time, so it is difficult to estimate probability of interference; out of a few times, where the broadcasting was operational, only the location 28 may need a more detailed analysis;
- channel 34: the locations 22, 23, 26, 28, 30-32 need a more detailed analysis.

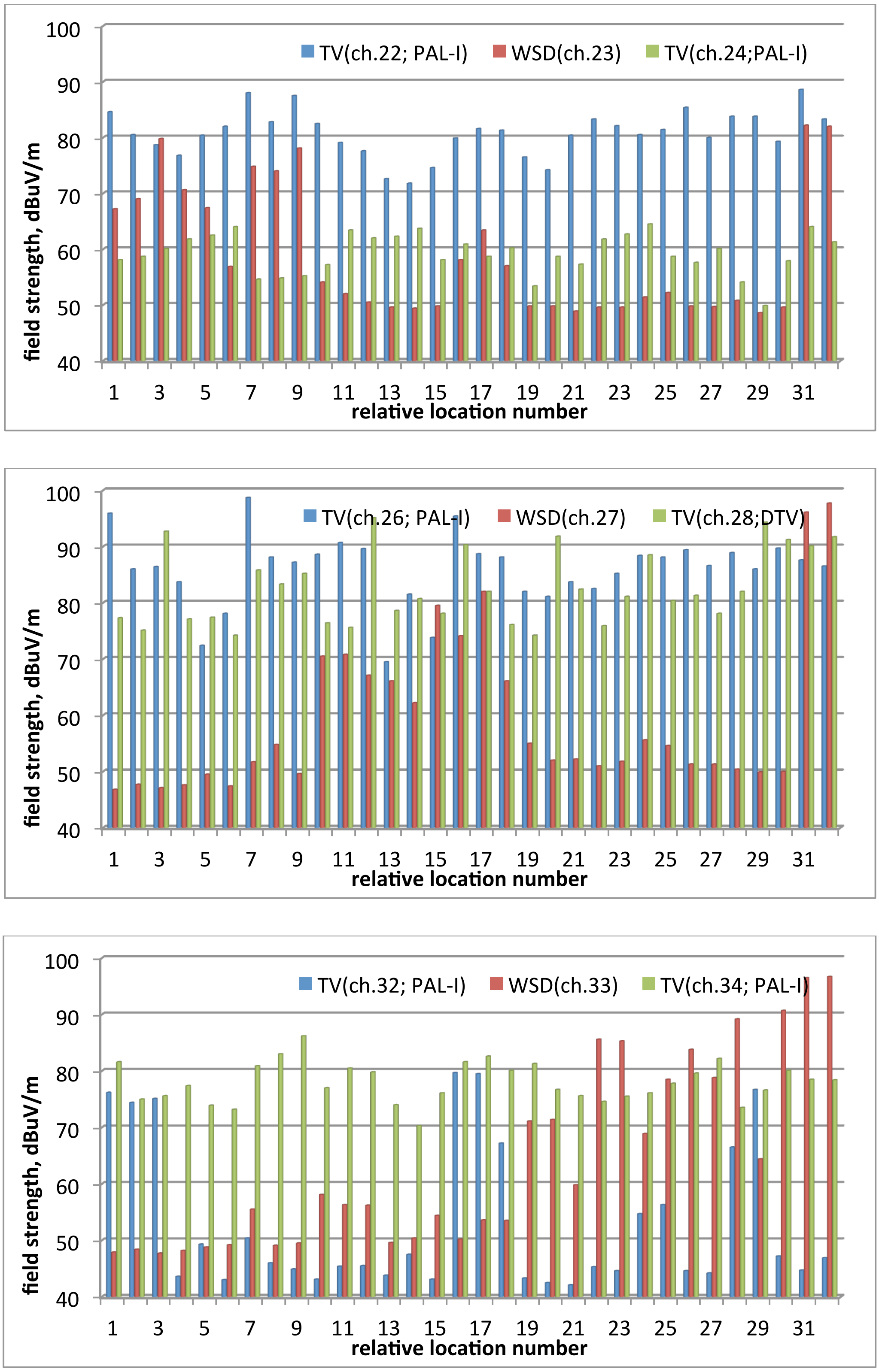


Figure 20. Integral field strength for all measurement locations. Only *ON* states are shown. Relative location number sequence correspond to the presentation given in

Table 14. Locations 1-9 are served by Sector 1 BS. Locations 10-18 are served by Sector 2 BS. The rest of locations (19-32) are served by Sector 3 BS. Locations 31 and 32 are the measurement site on the roof of Tygerberg hospital, very near (about 50 m away from) the base station antennas.

In order to perform the interference analysis at the locations outside of the discrete set of measurement points, the estimated ratios of the TV signal strength to WSD signal strength at those measurement points are then used to guess the characteristic distance from the WSD antenna (the distance starting from which the non-interference may be guaranteed with high degree of probability). This is done by approximating the signal strength along the line from the WSD antenna through the measurement point, using free space propagation formula. This assumption is based on the physics of the wave propagation, where the signal strength decreases with the increasing the distance from the source. The slowest expected rate of signal decay is the free space propagation model, where the signal strength E decreases inversely proportionally to the distance R from the source of the signal (here, the WSD antenna): $E \sim R^{-1}$. In practice, the influence of environment (landscape, vegetation, buildings) and lossy ground lead to a faster decay in the signal strength. Thus, the free space model may be used as an upper bound for the maximum expected signal strength.

This is implemented as follows: The difference between the measured ratio of TV signal strength S_{TV} and WSD signal strength S_{WSD} are used to compute the protection ratio margin (dPR), i.e. the difference between the obtained, $S_{TV} - S_{WSD}$, and required, PR, protection ratios: $dPR = (S_{TV} - S_{WSD}) - PR$. If the calculated dPR is negative, then the required protection ratio is not satisfied at the measurement site and one can expect that the required protection ratio will be satisfied at a distance further away from the WSD antenna than the measurement site. Otherwise, if the dPR is positive, one may expect that the required protection ratio was already satisfied at some distance closer to the WSD antenna than the location of the measurement site. Assuming free space propagation mode, this distance, where the required protection ratio is satisfied with zero margin, may be estimated as $R_{interf} = D \cdot 10^{-dPR/20}$. The variable D here is the distance from the WSD antenna to the measurement site. Outside of this range (R_{interf}) the interference is very unlikely.

5.3.1 Case study – Tygerberg hospital

The results for the BS were found to indicate the strongest likelihood of interference. Thus, they are analysed in detail. The measurement set up is shown in **Error! Reference source not found.**. The key features are:

- Approximately 50 m distance between the BS antennas (as read off Google Earth images) and direct line of sight from the base station's antennas to the test point.
- Sector 3 antenna directed towards the test point.
- Negligible height difference between the antennas.
- Two locations of antenna on the roof were used for the measurements, a few meters apart. This was done to compensate for shadowing by the structures on the roof.
- 2 full frequency scans were done at each location (BS on and BS off).

Figure 21. Measurement configuration for the roof of Tygerberg hospital: a) overview of the links, b) measurement set up (the dashed arrow points to the exact location on the roof), c) close up of the relevant roof structures (the red line shows the distance between the measurement set up and the BS antennas).

The results obtained are summarized in **Error! Reference source not found.**, indicating that the interference is very limited and is likely to be restricted to 160 m radius for the main beam of the BS antenna in Sector 3, pointing away from the building, over an open area. The interference was found unlikely for the other channels.

Table 13. The results of the base station case study: signal strength for the TV signals in the channels 22, 24, 26, 28, 32 and 34, compared against the respective signal strengths fotr the adjacent interferer (WSD) channels 23, 27 and 33. The red entries denote TV signal below min vieable threshold of approximately 65 dBμV/m. The diagonally crossed entries are for the cases where the TV signal is too low for PR calculations to be necessary. It may be necessary to note that there is a slight (under 5%) difference in the values shown in this table and in the respective values shown in

Table 14. This is due to the choice of 65 dBμV/m instead of more refined threshold used for

Table 14.

	TV ch #	S_{TV} (*N*-1: Upper): S_U	S_{WSD} (*N*): S_0	S_{TV}(*N*+1: Lower): S_L	S_U-S_0 (PR of -14 dB)	R_{interf}	S_L-S_0 (PR of -8 dB)	R_{interf}	***Comment***
unit		**dBμV/m**			**dB**	**m**	**dB**	**m**	
Field strength, dBuV/m	23	88.6	82.2	64	6.4	**4.9**	-18.2	**165**	Ch.23: 6.4 > -14 → OK Ch.25: TV signal low
	27	87.6	96.1	90.1	-8.5	**27**	-6	**41**	Ch.26: need only 27m Ch.28: need only 41m
	33	44.7	96.5	78.5	-51.8	**3960**	-18	**160**	Ch.32: TV signal low Ch.34: need 160m

The conclusion drawn from this case study were that interference to TV broadcasting is well contained within ~160 m from the base station (antennas point away from the nearest building 30 m away).

5.3.2 All results processed

The overview of results is shown in

Table 14. It has several main parts:

- The left hand side 3 columns indicate the measurement site parameters.
- The next series of columns (5 columns corresponding to different TV channels adjacent to respective used TVWS channels) indicate how strong the TV signal is compared to the specified minimum signal strength suitable for viewing.
- The next series of columns (5 columns for one protection ratio metric and 5 columns for alternative protection ratio metric) specifies the margin achieved in terms of the protection ratio. The ratios data for the approximate DVB-T based protection ratios (applied here to substitute for WSD PRs) is given separately from the ratios data based on the laboratory tests done specifically for WSDs.
- The last set of columns (5 columns for one protection ratio metric and 5 columns for alternative protection ratio metric) shows the distances beyond which there is guaranteed non-interference. The values in this part of the table show the distances[3] (in meters) at which the ratio between the TV signal and WSD signal in an adjacent band, reach an acceptable level, i.e. the level of TV signal exceeds the level of WSD signal plus protection ratio. This is because, after this relatively short distance (as compared to the typical distances to a TV station) is passed, the WSD's signal strength continues to decay and it is thus unlikely that the interference would occur.

The following notations are used to highlight the behavior trends in the data:

- **Blocks of thick line** indicate that the channel used by WSD at school is adjacent to the respective TV channels.
- The washed-out numbers in the distances columns have low probability of validity, as the TV signal strength is below the required minimum threshold.
- **Bold font with red background** is used for the values where the TV signal may exceed the minimum required strength whilst the protection ratio is not satisfied.

5.3.3 Analysis of data

Analysis of the data shown in the table indicates the following:

- TV signals are strong in most of the locations and channels. The channel 32 is an exception. Also, the signal measured at Tygerberg hospital seems to be weaker[4] than at most of the locations.
- The protection ratios are satisfied for most of the locations and channels. As the measurement points are typically surrounding the WSD, this result indicates that the interference is well contained at most of the locations.
  - The few exceptions are for channels 24 and 32 but only where the TV signal is too low for quality viewing.
  - The only considerable exception is
    - Range, point #1

[3] Estimated as follows: the protection ratio margin, dPR, i.e. the difference between the measured ratio and the required PR, is used to estimate the interference radius R_{interf} as $R_{interf}=D\cdot 10^{-dPR/20}$, assuming free space propagation. The variable D is the distance from the WSD TR antenna to the measurement site.

[4] This may have been due to the change in the antenna used for the measurements and will require further verification.

but *the TV signal there is just marginally higher than the minimum required value. Considering that the measurements were done at 13 m above the ground, whilst the low profile buildings in that area do not seem to raise their antennas above 5 m above the ground, it is most likely*[5] *that the TV signal at the level of a domestic TV antenna on the roof of a house will receive a much lower level of TV signal than the one measured in our set up. Such a low TV signal will be considered as too low for quality TV viewing*.

- Few entries with red background showing potential non-compliance are discussed as follows:
  - President, point #3, ch.26:
    - This exception is absent if one applies WSD PRs.
    - The TV signal measured at 13 m above the ground is on the margin of sufficient strength, i.e. it is unlikely that the signal is viewable using antennas at 5 m above the ground.
    - The distance is 106 m, or bare 39 m for the WSD PRs, means that the interference, if any, if well contained to the perimeter of the school.
  - Elswood, two points, ch. 34:
    - The TV signal is too low to be viewable for most of the points. The same arguments apply.
  - Range, points #1, 3 and 3, ch-s 32, 34:
    - TV signal is too low or only marginally above the threshold. The same arguments apply.
  - Tygerberg hospital roof, chs 24, 26, 34:
    - Channel 24: TV signal is just marginally higher than the threshold. The same arguments (except height) apply.
    - Channel 26: The PR for WSD is satisfied, unlike the one for DVB-T.
    - Channel 34: The WSD signal is very strong because WSD antenna for Sector 3 points towards the measurement site and is only 50 m away. Nevertheless, the interference is very limited
- The digital transmission on channel 28 seems well protected (both TV signal is strong and protection ratio is strong), indicating that the upcoming conversion to digital broadcasting may open more opportunities for the TVWS.
- The protection ratios (PRs) derived from the laboratory measurements specifically for the interference from WSD to PAL-I broadcasting, result in about 1.3 to 4 times smaller radius of the zone with interference than the PRs obtained for a wider bandwidth of DVB-T/2.
  - This can be easily supported by considering the following arguments:
  - Assuming that the protection ratio for DVB-T may be converted into the protection for WSD, the difference, due to the difference in bandwidths, is $10 \cdot \log_{10}(7.61/5.9)=1.1$ dB. This value gives $10^{1.1/10}=1.3$ times lower range where interference is likely

[5] ITU Recommendation [32] discusses details on the decrease of the TV signal with height of antenna installation for built-up areas.

- Comparing the PR for the entry # 1 against the entries # 5 and 6 leads to an even greater differences (3 dB and 9 dB, respectively), offering even greater reduction in the range (between 2 to 8 times).
  - One may however need to take into account that the PR derived for WSD being in the right-hand-side adjacent channel to TV may be insufficient because the protection for audio has not been tested.
- For most cases, the interference radius is less than 100 m. Thus, the interference from the TRs, if any, is most likely limited to the premises of the schools it is installed at. However, considering the installations with WSD directional antennas mostly facing away from the school buildings, and over some open space, the interference to any TV in the school is also highly unlikely.

5.3.4 Summary

Processing of the results of the measurements indicate that the interference, if any, is, most likely contained within the premises of the schools, about 50-200 m from WSD. This implies the following:

- the relatively short distances from WSD may help to explain and support absence of registered interference complaints;
- these values may however be high enough to become of concern for non-regulated installations of TVWS devices using similar levels of power (EIRP). The latter also highlights that proper planning and possibly network certification/licensing are likely to be needed for TVWS networks using levels of power (EIRP) similar to the ones used in this trial network (i.e. EIRP of about 5W).
- For large scale TVWS deployments, it may be important to restrict the maximum EIRP. In order to realize such networks physically, one may need to implement the networks as mesh networks, reducing the distances between nodes and thus reducing the maximum required transmitter power.
- It is also possible to recommend the use of TVWS for low power / short range devices, as these are expected to be able to operate without causing any noticeable interference. As the WSD antennas are high gain and most of the WSD antenna installations point the antenna away from the buildings, the likelihood of interference to the school premises is also low.

- The coverage by digital TV in channel 28 is strong in all of the locations, thus ensuring a high PR everywhere. This indicates that the possibility of co-existence between WSD and DTV, at least within the specifications of the WSD and antennas as used in this trial.

Table 14. The non-interference distances (in meters), per TV channel, for each of the measurement locations. The critical entries are shown with red background.

			TV signal strength margin = E(TV) - Emin, dB					
Type of protection ratios applied								
Protected TV channel			22	24	26	28	32	34
Signal in the protected channel			PAL-I	PAL-I	PAL-I	DMT1	PAL-I	PAL-I
Emin,dB(µV/m)/Potential interferer's ch.			62.1	62.4	62.7	40	62.1	63.7
Sector	Place	Point						
1	Bellville HS	1	23	-4	33	37	14	18
1	Bellville HS	2	18	-4	23	35	12	11
1	Bellville HS	3	17	-2	24	53	13	12
1	DF Malan HS	1	15	-1	21	37	-19	14
1	DF Malan HS	2	18	0	10	37	-13	10
1	DF Malan HS	3	20	2	15	34	-19	10
1	Fairmont HS	1	26	-8	36	46	-12	17
1	Fairmont HS	2	21	-8	25	43	-16	19
1	Fairmont HS	3	25	-7	25	45	-17	23
2	Parow	1	20	-5	26	36	-19	13
2	Parow	2	17	1	28	36	-17	17
2	Parow	3	16	0	27	55	-17	16
2	President	1	11	0	7	39	-18	10
2	President	2	10	1	19	41	-15	7
2	President	3	13	-4	11	38	-19	12
2	Settlers HS	1	18	-2	33	50	18	18
2	Settlers HS	2	20	-4	26	42	17	19
2	Settlers HS	3	19	-2	25	36	5	16
3	Cravenby	1	14	-9	19	34	-19	18
3	Cravenby	2	12	-4	18	52	-20	13
3	Cravenby	3	18	-5	21	42	-20	12
3	Elswood HS	1	21	-1	20	36	-17	11
3	Elswood HS	2	20	0	23	41	-18	12
3	Elswood HS	3	18	2	26	49	-7	12
3	Norwood	1	19	-4	25	40	-6	14
3	Norwood	2	23	-5	27	41	-18	16
3	Norwood	3	18	-2	24	38	-18	19
3	Range HS	1	22	-8	26	42	4	10
3	Range HS	2	22	-13	23	54	15	13
3	Range HS	3	17	-5	27	51	-15	16
3	Tygerberg hospital	1	27	2	25	50	-17	15
3	Tygerberg hospital	2	21	-1	24	52	-15	15

			Protection ratio margin = E(TV) - E(WSD) - PR, dB											
Type of protection ratios applied			DVB-T PRs						WSD PRs					
Protected TV channel			22	24	26	28	32	34	22	24	26	28	32	34
Signal in the protected channel			PAL-I	PAL-I	PAL-I	DMT1	PAL-I	PAL-I	PAL-I	PAL-I	PAL-I	DMT1	PAL-I	PAL-I
Emin,dB(µV/m)/Potential interferer's ch.			23	23	27	27	33	33	23	23	27	27	33	33
Sector	Place	Point												
1	Bellville HS	1	22	-4	54	83	33	39	31	-1	63		42	41
1	Bellville HS	2	17	-5	43	80	31	32	25	-3	52		40	34
1	Bellville HS	3	4	-15	44	98	32	33	13	-12	53		41	36
1	DF Malan HS	1	11	-4	41	82	0	34	20	-1	50		9	37
1	DF Malan HS	2	18	0	28	80	6	30	27	3	37		14	33
1	DF Malan HS	3	30	12	36	79	-1	29	39	15	44		8	32
1	Fairmont HS	1	18	-15	52	90	0	30	27	-12	61		9	33
1	Fairmont HS	2	14	-14	38	88	2	39	23	-11	47		11	42
1	Fairmont HS	3	14	-18	43	90	0	42	23	-15	51		9	44
2	Parow	1	33	8	23	57	-10	24	42	11	32		-1	27
2	Parow	2	32	16	25	56	-6	29	41	19	34		3	32
2	Parow	3	32	17	28	79	-6	29	41	19	36		3	31
2	President	1	28	18	8	64	-1	29	37	20	17		8	32
2	President	2	27	19	24	70	2	25	36	22	33		11	28
2	President	3	30	13	-1	50	-6	27	39	16	8		2	29
2	Settlers HS	1	27	8	26	67	35	36	36	11	35		43	39
2	Settlers HS	2	23	0	12	51	31	34	32	3	20		40	37
2	Settlers HS	3	29	8	27	61	19	32	38	11	36		27	34
3	Cravenby	1	32	9	32	71	-23	15	40	11	41		-14	18
3	Cravenby	2	29	14	34	92	-24	10	38	17	43		-15	13
3	Cravenby	3	37	13	37	82	-13	21	45	16	45		-4	24
3	Elswood HS	1	39	17	37	78	-35	-6	47	20	45		-27	-3
3	Elswood HS	2	38	18	38	81	-36	-5	46	21	47		-27	-2
3	Elswood HS	3	34	18	38	85	-9	12	43	21	47		0	15
3	Norwood	1	34	12	39	78	-17	4	43	14	47		-8	7
3	Norwood	2	41	13	43	82	-34	1	49	16	52		-25	4
3	Norwood	3	35	15	40	79	-30	8	44	18	49		-21	11
3	Range HS	1	38	8	44	84	-18	-11	47	11	52		-9	-8
3	Range HS	2	40	6	41	97	17	17	49	9	50		26	20
3	Range HS	3	35	13	45	93	-39	-6	43	16	53		-30	-3
3	Tygerberg hospital	1	11	-13	-4	45	-47	-13	20	-10	5		-38	-10
3	Tygerberg hospital	2	6	-16	-6	45	-45	-13	15	-13	3		-36	-11

			Distances (m)											
Type of protection ratios applied			DVB-T PRs						WSD PRs					
Protected TV channel			22	24	26	28	32	34	22	24	26	28	32	34
Signal in the protected channel			PAL-I	PAL-I	PAL-I	DMT1	PAL-I	PAL-I	PAL-I	PAL-I	PAL-I	DMT1	PAL-I	PAL-I
Emin,dB(µV/m)/Potential interferer's ch.			23	23	27	27	33	33	23	23	27	27	33	33
Sector	Place	Point												
1	Bellville HS	1	9	183	0	0.1	2	1	3	133	0		1	1
1	Bellville HS	2	27	328	1	0.2	5	5	10	239	0		2	3
1	Bellville HS	3	42	359	0	0.0	2	1	15	262	0		1	1
1	DF Malan HS	1	25	142	1	0.1	88	2	9	104	0		32	1
1	DF Malan HS	2	21	165	7	0.2	89	5	8	121	2		32	4
1	DF Malan HS	3	6	51	3	0.3	235	7	2	37	1		86	5
1	Fairmont HS	1	3	138	0	0.0	24	1	1	101	0		9	1
1	Fairmont HS	2	17	426	1	0.1	67	1	6	311	0		24	1
1	Fairmont HS	3	26	1076	1	0.1	131	1	10	786	0		48	1
2	Parow	1	2	42	7	1.7	338	7	1	31	3		124	5
2	Parow	2	2	13	5	1.6	176	3	1	10	2		64	2
2	Parow	3	4	24	7	0.2	314	6	1	18	3		115	4
2	President	1	5	15	43	0.9	125	4	2	11	16		46	3
2	President	2	6	15	8	0.5	106	8	2	11	3		39	6
2	President	3	3	21	106	3.6	202	5	1	15	39		74	3
2	Settlers HS	1	5	40	5	0.5	2	1	2	29	2		1	1
2	Settlers HS	2	12	167	45	5.5	5	3	4	122	16		2	3
2	Settlers HS	3	5	60	7	1.6	18	4	2	44	3		7	3
3	Cravenby	1	2	30	2	0.3	1118	14	1	22	1		409	10
3	Cravenby	2	3	19	2	0.0	1457	28	1	14	1		533	21
3	Cravenby	3	3	46	3	0.2	928	20	1	34	1		340	14
3	Elswood HS	1	1	12	1	0.2	4890	168	0	8	0		1790	122
3	Elswood HS	2	1	10	1	0.1	4937	141	0	7	0		1807	103
3	Elswood HS	3	4	27	3	0.2	632	54	2	20	1		231	39
3	Norwood	1	1	18	1	0.1	478	40	0	13	0		175	29
3	Norwood	2	1	14	0	0.1	3128	56	0	10	0		1145	41
3	Norwood	3	1	15	1	0.1	2627	33	1	11	0		962	24
3	Range HS	1	1	25	0	0.1	491	219	0	18	0		180	160
3	Range HS	2	1	53	1	0.0	15	15	0	39	0		5	11
3	Range HS	3	1	14	0	0.0	5637	128	0	11	0		2064	93
3	Tygerberg hospital	1	14	233	76	3.2	11158	228	5	170	28		4084	166
3	Tygerberg hospital	2	27	335	112	3.5	9558	254	10	245	41		3499	186

6 CONCLUSIONS

Several different type of field measurements were completed to consider key aspects of white space network operation and possible inteference on the reception of TV broadcasting. In this document we presented analysis of the results from those field measurements.

During the field measurement the three sectors were operating on channels 23, 27 and 33. We analysed the TV channels adjacent to WSD channels and the following were observed:

- For WSD channel 23
  - channel 22: protection ratio are well satisfied,
  - channel 24: TV signal is below the required minimum viewable level.
- For WSD channel 27
  - channel 26: protection ratio was almost always satisfied except at one of the measurement locations at President, however the interference can be contained within 32m of the WSD.
  - channel 28: This is a digital TV channel, the protection ratio was not derived for it, it is however assumed to be satisfied.
- For WSD channel 33
  - channel 32: broadcasting was not operational for most of the time, so it is difficult to estimate probability of interference;
  - channel 34: protection ratio is satisfied at two of the schools and not always satisfied at Elswood, Range and at the BS. In all these cases, the possible interference can be contained within 186m of the WSD.

The protection ratios used for above observations were those derived and presented in section 4 of this document. For the above observations, the picture level quality level assumed is 5. The possible interference radius was calculated using the following fomula:

$$R = D.10^{\left({dPR}/{20}\right)}$$

Where *D* is the distance from the WSD antenna to the measurement site and *dPR* is the difference between the measured PR and the required PR. Measured PR is the difference between TV signal and WSD signal.

We can therefore conclude that for any analogue with sufficiently strong signal:

- WSD can be operated on the adjacent channel on its right-hand side without causing interference.
- WSD maybe operated on the adjacent channel on its left-hand side without causing interference, however if transmission power of the WSD is kept at the maximum there maybe a possibility of causing interference within the 200m radius of the WSD.

On the basis of the above observations, we recommend that a geo-location database be used for TVWS networks. The database must be able to estimate protection ratios for each of the adjacent channels and provide transmission power levels to the WSDs for each of the available channels.

We further recommend that a study to determine protection ratios for digital TV channels be undertaken before the digital analogue dual illumination commences.

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