

Chapter 4

The Television White Space Opportunity in Southern Africa: From Field Measurements to Quantifying White Spaces

Albert A. Lysko, Moshe T. Masonta and David Lloyd Johnson

Abstract The lack of sufficient fixed-line communication infrastructure in African rural areas has resulted in wireless communication being the only cost effective alternative solution for broadband connectivity. However, access to valuable spectrum—specifically sub-1 GHz spectrum—is mostly allocated to broadcasting or mobile telephony. The global digital switch over (DSO) of television (TV) broadcasting systems will see more sub-1 GHz TV band spectrum being made available for the digital dividend and also result in more TV white space (TVWS) spectrum. In order to ensure dynamic and efficient utilization of the TV white space spectrum, there is an increasing trend to use cognitive radiosystems that use geo-location spectrum databases and spectrum sensing as an enabling technology. In this paper, we overview the relevant signals and standards and present field measurement results showing the actual usage of TV bands before the DSO in selected urban and rural areas of Southern Africa. Measurements were conducted using low-cost and high-grade radio instruments. The low-cost spectrum analyser was built in-house using the Universal Software Radio Peripheral (USRP-2) and GNU Radio software. A metric to quantify available TV white space, based on the minimum acceptable field strength, is introduced and applied to quantify the availability of TV white space. Our results show medium spectrum usage in urban areas and very low spectrum usage in rural areas, making TVWS an attractive solution for rural broadband connectivity.

Keywords Measurements · Radio frequency · Southern Africa · Spectrum · Television white spaces

A.A. Lysko (✉) · D.L. Johnson
Council for Scientific and Industrial Research (CSIR) – Meraka,
P O Box 395, 0001 Pretoria, South Africa
e-mail: alysko@csir.co.za

D.L. Johnson
e-mail: djohnson@csir.co.za

M.T. Masonta
Department of Electrical Engineering, Tshwane University of Technology,
Pretoria, South Africa
e-mail: mmasonta@csir.co.za

4.1 Introduction

White spaces refer to portions of licensed radio frequency (RF) spectrum band which are not utilized or are sporadically used at a given time in given geographical location. The amount of available white spaces depends on the incumbent, licensed or primary users (PUs) and can vary according to the PUs activities. Although white spaces can be found within any allocated spectrum band, the current focus is on the television (TV) band where there is ongoing migration from analogue to digital broadcasting or digital switch over (DSO). Thus, white spaces in TV bands are commonly referred to as television white spaces (TVWSs). The International Telecommunication Union (ITU) deadline for DSO in Region 1 countries (which corresponds to Europe, Russia, Africa and the Middle East) is set for June 2015 [1]. The DSO promises efficient spectrum use, increased competition, technology convergence and more spectrum for digital dividend (spectrum freed up in the digital migration process) as well as the exploitation of TVWS for broadband connectivity in rural areas. Unlike the Wi-Fi spectrum, which is above the 2 GHz frequency band, TVWS provides great propagation characteristics which can address Internet connectivity to sparsely populated and remote areas.

In 2008, the Federal Communications Commission (FCC) of the United States (US) announced a decision to open up TVWS for unlicensed or license-exempt use [2]. In order to make such a decision, extensive work commissioned by the FCC has been done in the US which includes spectrum occupancy measurements, consultations and TVWS trials. The same decision was also taken by the Office of Communications (Ofcom) in the United Kingdom [3], and this has created a large amount of interest from the research community on the exploitation of TVWS for broadband access. In Africa, notable activities on TVWS include the TVWS trials in South Africa [4–6], the development of a geo-location spectrum database (GSDB) [7] for the TV band and a number of spectrum occupancy measurement campaigns [8–11] with the aim of quantifying the amount of TVWS in both rural and urban areas. While there are no clear regulatory decisions on how to utilize TVWS in Africa, we believe that these efforts will play a crucial role in supporting the decision making process, especially post the DSO deadline.

In this paper, ultra-high frequency (UHF) TV band spectrum occupancy measurements results conducted in selected Southern African urban and rural areas are presented. This is a follow-up work that was first presented in [8], and now also includes results from the Cape Town area. Specifically, TV band occupancy measurements were conducted using a combination of the Meraka Cognitive Radio Platform and high-grade RF instruments in Southern Africa. In South Africa, spectrum occupancy measurements were conducted in Pretoria and Cape Town in Gauteng (representing a typical urban environment) and in Philipstown in the Northern Cape Province (representing a typical rural environment). In Zambia, spectrum occupancy measurements were conducted in Macha, a rural area in Southern Zambia. As one would expect, our occupancy measurements found that over 40 % of TVWS

is typically available in urban areas, whereas rural areas have over 90% of TVWSs available for broadband connectivity usage.

The remainder of this chapter is organized as follows: Sect. 4.2 provides the TVWS context in South Africa. Section 4.3 presents a detailed methodology used for estimating TVWSs in Southern Africa using the Meraka Cognitive Radio Platform. The detailed methodology used for estimating TVWSs in Cape Town is discussed in Sect. 4.4. Section 4.5 presents the measurement results in order to quantify the amount of TVWS availability in Southern Africa. Some remarks on the optimizing speed and accuracy of measurements are provided in Sect. 4.5. Section 4.7 concludes the chapter.

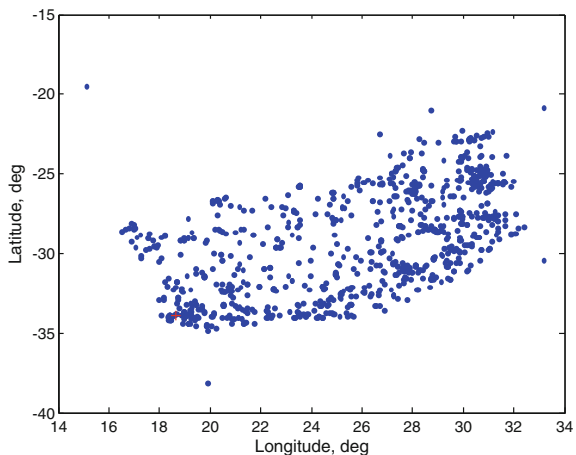
4.2 TV White Space Context in South Africa

This section presents the TVWS context in the South African environment. Like other countries, South Africa is undergoing a national DSO process and is expected to complete this process by June 2015—the deadline set for ITU-R region 1 countries.

4.2.1 Overview of the South African TV Broadcasting Network

South Africa has over 4,000 registry entries in the list of TV programs being transmitted. The location of TV transmitters, as per the listing by the Independent Communications Authority of South Africa (ICASA), is shown in Fig. 4.1. The figure shows an overview of the distribution of TV transmitters around South Africa. It is easy to see that the highest density of the transmitters corresponds to the most populated regions, such as Gauteng, and Western Cape. It is also possible to see that the original

Fig. 4.1 Location of TV transmitters around South Africa. TV transmitters are shown with *blue* dots



data set includes some outliers and, if used for mission critical applications, such as a national geo-location database [7], it must therefore be treated with caution.

On October 3, 2012, South African Communications Minister Dina Pule launched a demonstration of South Africa's digital terrestrial television (DTT) technology in the Northern Cape, ahead of the planned December launch of the country's migration from analogue to digital TV broadcasting. In 2012/2013, South Africa had both analogue and digital broadcasting available in many areas. Analogue broadcasting was available nation-wide, whereas digital broadcasting was introduced in a testing phase in limited areas, prior to the official dual illumination period [12]. Thus, in many locations, especially in the more densely populated areas like Gauteng and Western Cape, TV broadcasting was de-facto in dual illumination mode.

4.2.2 Expected Spectral Masks and Minimum Signal Strength Values for TV Broadcasting in South Africa

In South Africa, analogue transmitters use PAL system I with 8 MHz channel bandwidth similar to what is used in the UK. The digital transmitters use terrestrial digital video broadcasting (DVB-T2) and the DVB hand-held option (DVB-H). This Section deals with describing the signals in the frequency domain and using the information available from the standards and legal documents to derive the metrics to be used as a threshold to identify and quantify the amount of white space.

4.2.2.1 Analogue Broadcasting: PAL-I

With reference to [13], the key parameters of a PAL-I signal are captured in Table 4.1. A schematic representation of the components present in PAL-I spectrum are shown in Fig. 4.2a.

A sample of a measured analogue signal's spectrum is shown in Fig. 4.2b. It is possible to see the following distinct components: video intensity (luma) carrier surrounded with luma spectrum, color representation carrier, audio carrier and NICAM (Near Instantaneous Companded Audio Multiplex) [16]. The NICAM is an optional component, and may be present in some of the spectra measured. The chroma component is optional, as well, but, in the modern world, is present in practically all analogue TV transmissions.

References [17, 18] point to the following information regarding the relevant specifications of a digital method to transmit sound, NICAM:

- Modulation: differentially encoded Quaternary Phase-Shift Keying (QPSK), with bit rate $728 \text{ kbit/s} \pm 1 \text{ part/million}$; one packet sent every millisecond;
- Carrier frequency of $6,552 \text{ MHz} \pm 1 \text{ part/million}$ above the vision carrier frequency;
- The power ratio between the peak vision carrier and the modulated digital signal is approximately 100:1 (20 dB) for systems B, G, H and I;

Table 4.1 Key parameters of PAL-I signal, as per [14–16]

| # | Parameter | Value and unit | Rec. ITU BT/EN |
|---|---|---|----------------|
| 1 | Nominal radio-frequency channel bandwidth | 8 MHz | 1701 |
| 2 | Sound with respect to video carrier | +5.9996 ± 0.0005 MHz | 1701 |
| 3 | Nearest edge of channel relative to vision carrier | 1.25 MHz | 1701 |
| 4 | Nominal width of the main sideband | 5.5 MHz | 1701 |
| 5 | Nominal width of the vestigial sideband (VSB) | 1.25 MHz | 1701 |
| 6 | Minimum attenuation of vestigial sideband | 20 dB at –3.0 MHz and | |
| | | 30 dB at –4.43 MHz ^a | 1701 |
| 7 | Chrominance sub-carrier frequency | 4 433 618.75 Hz ± 1 Hz | 1700 |
| 8 | Type of chrominance sub-carrier modulation | Suppressed-carrier amplitude-modulation of two sub-carriers in quadrature | 1700 |
| 9 | Power ratio between the peak vision carrier and the analogue FM sound carrier | Approximately 10:1 or 10 dB ^b | 300163 |

^a Additional restrictions may apply for a co-channel transmittance of a DVB-T signal

^b However, in the UK with system I this ratio has since been relaxed to 20:1 or 13 dB, bringing the UK in line with Systems B and G within Europe

Note In the case of cable distribution with adjacent channel operation, it is recommended to use a power ratio of approximately 300:1 (25 dB) for PAL system I.

Minimum Field Strength: PAL-I

ITU-R [19] states that the median field strength values for which protection against interference is planned should not be lower than the values shown in Fig. 4.3 and Table 4.2.

The minimum field strength can be used as the threshold to determine whether a channel with analogue PAL-I signal is usable for viewing.

Typical TV Receiver Parameters: PAL-I

Recommendation [20] provides the values for antenna gain and cable loss, as shown in Table 4.3.

The section on calculation of minimum field strength for DVB-T 8 MHz systems in [21] also uses the same antenna gain values for the respective bands, although it

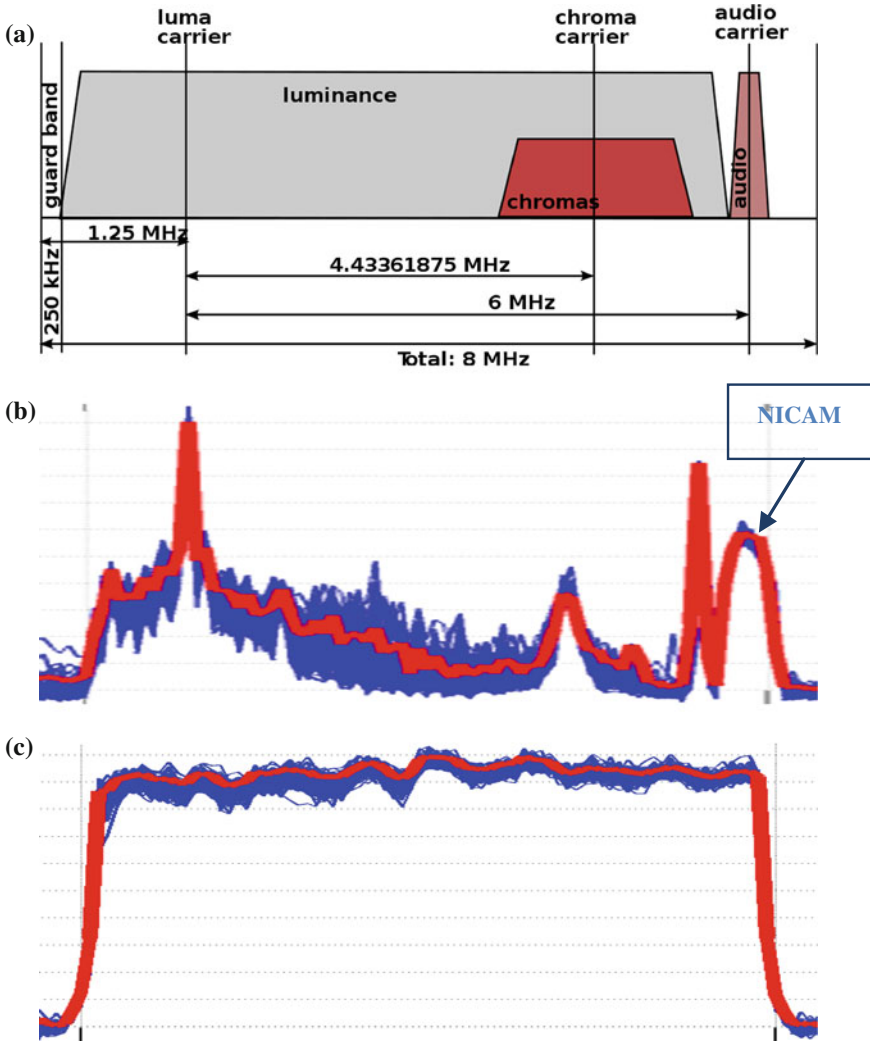


Fig. 4.2 a TV signal's spectrum for PAL system I (Courtesy of <http://en.wikipedia.org/wiki/PAL>); b sample of real world PAL-I spectrum with NICAM; c sample of real world digital spectrum DVB-T2

uses 5 dB cable loss (referred to as *feeder loss*) instead of 4.5 dB. As shown in [21], when considering DVB-T2 8 MHz systems operating at 650 MHz, an antenna gain of 11 dB and feeder loss of 4 dB for the “fixed” roof top scenario is used. In [22] they focus on DVB-T2, at 650 MHz, and also use the same parameters.

Note on interpretation of antenna gain:

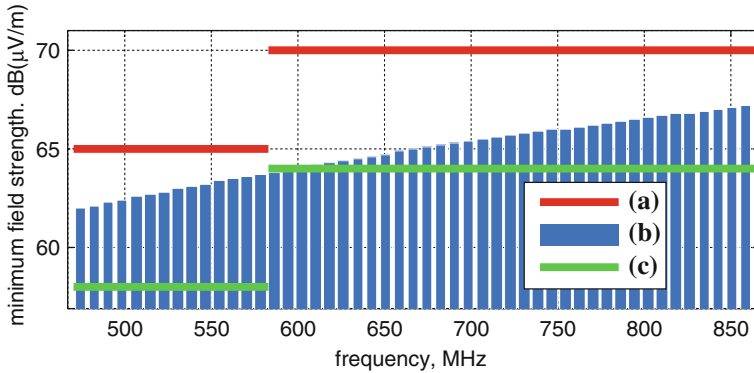


Fig. 4.3 The median and minimum field strength values permissible with and in absence of interference [19]. The bars were calculated based on the formula E_{min} (dB(μ V/m)) = 62 + 20 log($f/474$). The (a)–(c) refer to the respective lines in Table 4.2

Table 4.2 Field strength values (in dB(μ V/m)) recommended for planning analogue TV broadcasting in UHF [19] These values refer to the field strength at a height of 10m above ground level

| Band | | IV | V |
|---|---|-----------------|----------------------|
| Frequency range, MHz | | 470–582 | 582–960 ^a |
| | Scenario | | |
| Medium/ Minimum value, dB(μ V/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 grey block values are calculated using the formula E_{min} (dB(μ V/m)) = 62 + 20 log($f/474$), where f is frequency in MHz; with the result shown in Fig. 4.5. The lines (a) and (c) refer to median field strength values. The lines (b) and (d) refer to minimum field strength values

^a The upper frequency of the band has been changed to 862 MHz, and is planned to be moved to 790MHz, and possibly even lower

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 $G(\text{dBi}) = G(\text{dBd}) + 2.15$ dB).

The grounds for this are as follows:

- Recommendation [20] lists the dipole conversion factor.
- Recommendation [23] lists the values in dBd. The expressions also include a 1.64 correction factor corresponding to a 2.15 dB difference.
- Recommendation [21] lists the values in dBd.
- Report [24] lists the values in dBd, and also proposes an additional correctional factor to take into account the increase in the antenna gain with frequency:

Table 4.3 Typical minimum signal strength, antenna gain, feeder loss per [20]

| Band | IV | V |
|--|---------|----------------------|
| Frequency range, MHz | 470–582 | 582–960 ^a |
| Minimum field strength, dB(μ V/m) | 62 | 67 |
| Antenna gain, dBd | 10 | 12 |
| Cable loss, dB | 3 | 4.5 |
| Dipole conversion factor ^(b) , dB | 20.5 | 25 |

^aThe upper frequency of the band has been changed to 862 MHz, and is planned to be moved to 790 MHz, and possibly even lower

^(b) $20 \log 2\pi/\lambda$

$\text{Corr} = 10 \log_{10}(\text{FA}/\text{FR})$, where FA is the actual frequency being considered and FR is the relevant reference frequency.

Suggested Parameters for Modelling a Typical Fixed Roof Top Antenna Installation

Based on the references indicated and discussions made in the previous section, 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 the frequency in the middle of a channel, in MHz.

The model ensures that the parameters specified by Table 4.3 are satisfied. The resultant curves for the parameters are shown in Fig. 4.4. It is clear that the maximum difference between the difference of gain and loss for the proposed model and [20] is within 0.5 dB. The difference to the other above-mentioned recommendations and to [1] is within 1 dB.

Considerations for TV Receivers

As per [20]:

- “In order to obtain the protection ratios given in [25] the minimum field-strength values given in [19], and meet other frequency planning constraints, the” noise-limited sensitivity of at least -58 dBm in UHF band “for reference receivers for different transmission systems should be met”.
- A principal receiver in UK has the noise-limited sensitivity of -65 dBm in the UHF band.

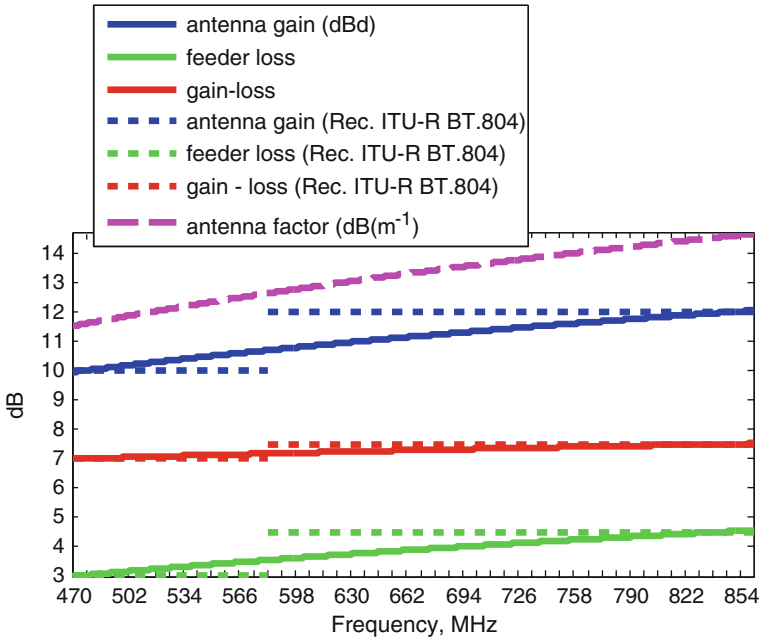


Fig. 4.4 Model curves for the selected specifications for a fixed rooftop antenna installation. The upper scale shows the TV channel number

Estimation of the Minimum Acceptable Power Level

The minimum usable power level is estimated from the minimum field strength given in Sect. 2.2.1.1. The calculations are done in the following sequence:

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 $S = E_{min}^2/120\pi$ [$W\cdot m^{-2}$], where E_{min} [$V\cdot m^{-1}$] is the minimum field strength.
3. Incident power P_i is computed as $P_i = S\cdot A$ [W], and may then be converted into dBW or dBm.

The result of this calculation, based on the model discussed in Sect. 2.2.1.3 is shown in Fig. 4.5. The values shown represent full power (i.e. within the defined signal bandwidth, e.g. 300 kHz around the video carrier for PALI, rather than within the spectrum analyzer’s resolution bandwidth).

Considering that the typical uncertainty in the field measurements is on the order of a few dB, it is possible to say that the minimum required power level for the power incident onto a fixed rooftop TV antenna for PAL-I is about **- 56 dBm**.

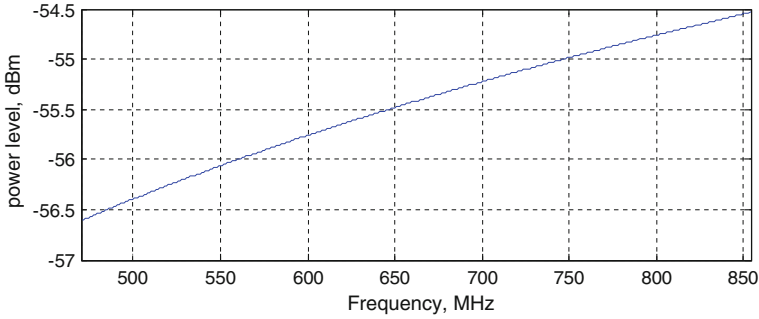


Fig. 4.5 Minimum incident power level at the antenna, corresponding to the minimum field strength for PAL-I reception

4.2.2.2 Digital Broadcasting: DVB-T2

DVB-T2 is based on orthogonal frequency division multiplexing (OFDM). A sample of a measured digital signal's spectrum is shown in Fig. 4.2c. The spectrum is composed of a multitude of tightly packed subcarriers appearing as a continuous, nearly rectangular block. The bandwidth of the “standard” DVB-T2 signals is 7.61 MHz [22, 26]. In South Africa, DVB-T2 is said to currently run in 256 QAM, code rate 3/5, PP4, 32k extended mode, with 1/16 guard interval, resulting in a slightly wider bandwidth of 7.77 MHz.

Minimum Field Strength: DVB-T2

The sample scenarios considered in [22] reveal a minimum equivalent field strength at receiving location at 650 MHz of 45.3 dB(μ V/m) for a fixed scenario, 50.2 dB(μ V/m) for a portable outdoor/urban scenario, and 42.5 dB(μ V/m) for a mobile/rural scenario etc. Just like for the analogue signal, these values are extrapolated over the UHF band by using a logarithmic formula. The main difference is that the mobile and portable etc. scenarios were introduced and are treated differently to a fixed scenario:

for fixed reception: $F_{s1} = F_s + 20 \log_{10}(f_1/f)$, and

for portable and mobile reception: $F_{s1} = F_s + 30 \log_{10}(f_1/f)$,

where F_{s1} is the minimum median field strength for a frequency f_1 using the value of the field strength F_s for the frequency f given, applicable within the Bands IV/V.

Models for Antenna Installation and Resultant Minimum Acceptable Power Level

The same model is used as in Sect. 2.2.1.3.

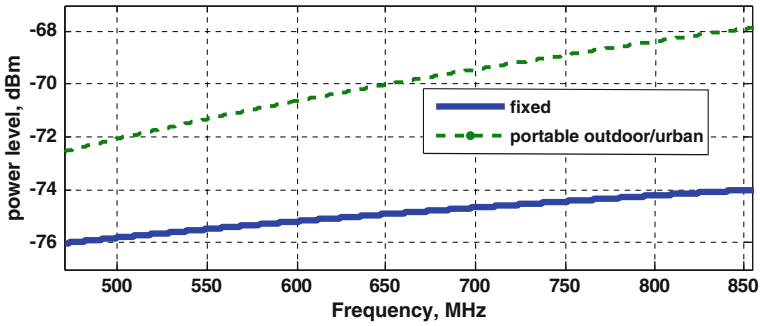
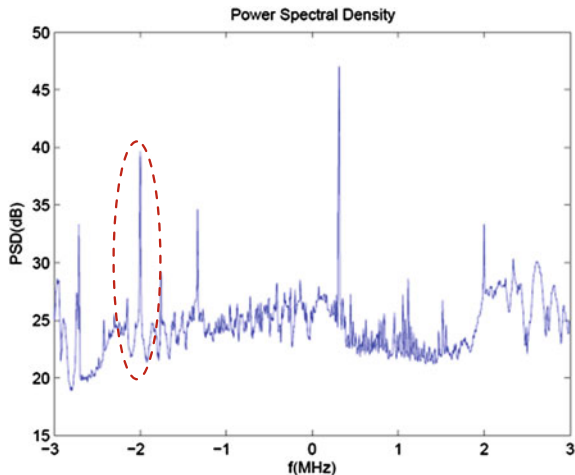


Fig. 4.6 Minimum incident power level at the antenna, corresponding to the minimum field strength for DVB-T2 reception under the “fixed” and “portable outdoor/urban” scenarios

Repeating the same type of calculations as in the case of analogue signals, it is possible to obtain the minimum required incident power level for fixed scenario DTT with a “standard profile” DVB-T2. The result is shown in Fig. 4.6. As it follows from the figure, the minimum required power level for the power incident onto a fixed rooftop TV antenna for DTT is about **-75 dBm**. This figure is expected to be slightly stricter than the one required for the South African mode of DVB-T2 (because the bandwidth of the South African signal is slightly wider).

It may need to be taken into account that a margin additional to this minimum required power level is normally necessary to ensure protection of the primary users, i.e. TV broadcasting.

Fig. 4.7 Received periodogram of a typical TV channel with a wireless microphone signal and narrowband interference signals. The channel centre frequency is converted to the baseband, and the scale of the y-axis is not calibrated. The wireless microphone signal is at $f = -2$ MHz (highlighted), and the other spikes are from unknown emissions [30]



4.2.2.3 Note on Wireless Microphones

Wireless microphones that are used for Public Address systems often also operate in the UHF band and are treated as primary users. Wireless microphones are capable of emitting bandwidths from 50 kHz to 600 kHz [27]. A sample of the spectrum emissions produced by FM wireless microphone is shown in Fig. 4.7. It is clear that this type of transmitter is difficult to detect (e.g. the measurements to capture the spectrums shown were carried with the resolution bandwidth of 1.8 kHz). A number of spectrum measurement scans can also be observed in [28]. The approach currently used by the FCC is to create dedicated channels for wireless microphones and store these in the geo-location spectrum database [29].

The spectral profiles of the expected types of signals have now been considered to a degree sufficient for visual recognition from a spectrum scan made with a typical set up consisting of a spectrum analyzer connected to an antenna. The next step is to take a deeper look at some of the options possible for making spectral scans.

4.3 White Space Measurement Configuration Using the Meraka Cognitive Radio Platform

The aim of our measurements was to scan the VHF/UHF spectrum bands, i.e. from about 50 MHz–1 GHz, using a low-cost spectrum analyser based on the Ettus USRP2. We conducted the frequency scan in two different places within South Africa. One of these measurements was carried out in Pretoria (an urban area in South Africa) and the other one in Philipstown (a rural area in the Northern Cape Province).

Solutions that provide acceptable spectrum scan results using low-cost equipment are crucial if scientists in African countries, that can't afford high-grade costly scientific equipment, are to contribute to the global picture of available white space spectrum. The Ettus USRP-based spectrum analyser presented here as well as other solutions such as those based on the ASCII-32 device [10] used in Malawi are crucial to fulfill this aim.

4.3.1 Known TV Transmitters Around the Test Sites

The list of TV transmitters in Pretoria and Philipstown are shown in Tables 4.4 and 4.5, respectively. These tables were generated using data from an updated terrestrial broadcasting frequency plan of 2013 published in government gazette no 36321 by Independent Communications Authority of South Africa (ICASA) on 2nd April 2013 [31]. According to ICASA's 2013 terrestrial broadcasting frequency plan, there were no live DTT transmissions in Pretoria and Philipstown.

Table 4.4 Known broadcasting transmitters around Pretoria East

| Location and coordinates | Service | Status | Ch. no | Frequency (MHz) | ERP (kW) |
|---|--|-------------|--------|-----------------|----------|
| Pretoria (S 25° 41' 21" E 27° 29' 02") | M-Net | Operational | 21 | 470 | 84.6 |
| | CSN | Operational | 25 | 502 | 28.2 |
| | e.tv | Operational | 29 | 534 | 138 |
| <i>Note</i> | <i>SABC 1, 2 and 3 broadcast from the VHF channels 8, 5 and 11 (all at 100 kW ERP) from the Pretoria transmitter</i> | | | | |
| Menlo Park (S 25° 46' 16" E 28° 16' 05") | SABC 2 | Operational | 53 | 726 | 0.04 |
| | SABC 1 | Operational | 57 | 758 | 0.04 |
| | SABC 3 | Operational | 65 | 822 | 0.04 |
| | M-Net | Operational | 61 | 790 | 0.04 |
| | CSN | Operational | 44 | 654 | 0.04 |
| | e.tv | Operational | 48 | 686 | 0.04 |
| Sunnyside (S 25° 45' 58" E 28° 12' 21") | SABC 2 | Operational | 55 | 742 | 1 |
| | SABC 1 | Operational | 63 | 806 | 1 |
| | SABC 3 | Operational | 59 | 774 | 1 |
| | M-Net | Operational | 67 | 833 | 1 |
| | CSN | Operational | 46 | 670 | 1 |
| | e.tv | Operational | 38 | 606 | 1 |
| | TSHW | Operational | 27 | 518 | 1 |
| Pretoria-North (S 25° 41' 29" E 28° 10' 02") | SABC 2 | Operational | 40 | 622 | 0.05 |
| | SABC 1 | Operational | 52 | 718 | 0.05 |
| | SABC 3 | Operational | 46 | 670 | 0.05 |
| | M-Net | Operational | 50 | 702 | 0.125 |
| | CSN | Operational | 56 | 750 | 0.12 |
| | e.tv | Operational | 37 | 598 | 0.05 |

Table 4.5 Known TV broadcast transmitters around Philipstown

| Service | Status | Ch. no | Frequency (MHz) | ERP (kW) |
|---------|-------------|--------|-----------------|----------|
| SABC 2 | Operational | 26 | 510 | 0.004 |
| SABC 1 | Operational | 22 | 478 | 0.004 |
| SABC 3 | Operational | 30 | 542 | 0.004 |
| e.tv | Operational | 34 | 574 | 0.004 |

4.3.2 Meraka Cognitive Radio Platform

The Meraka Cognitive Radio Platform (MCRP), operating as a low-cost spectrum analyser, was used to conduct RF spectrum measurements in both urban and rural areas of South Africa. The MCRP is shown in Fig. 4.8. The platform consists of four

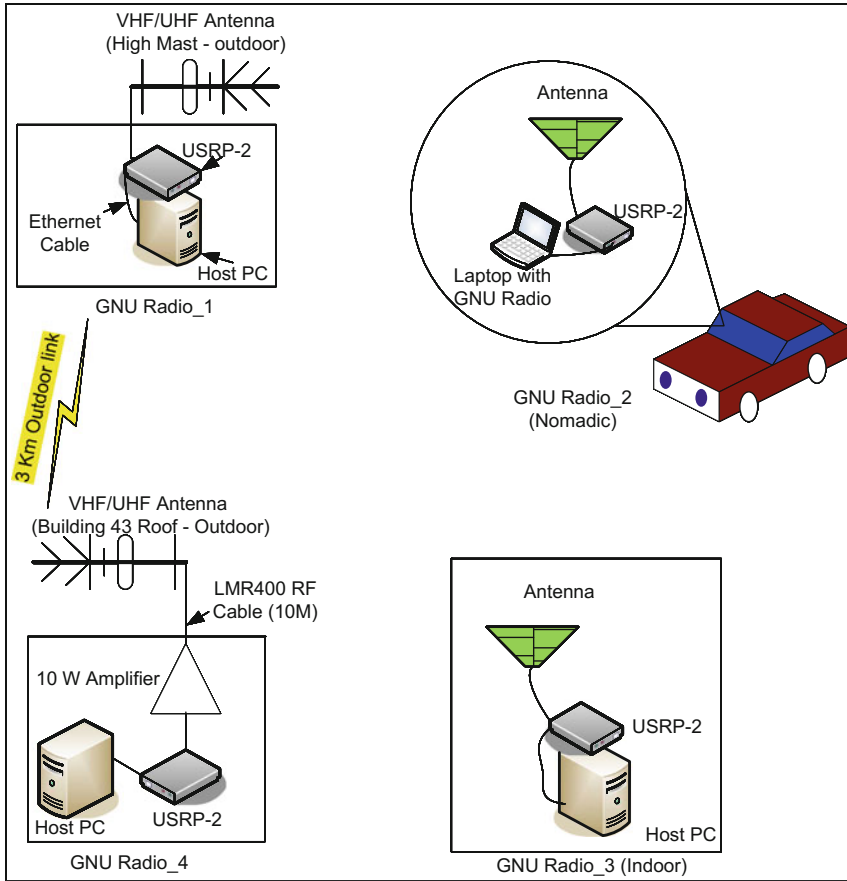


Fig. 4.8 The Meraka Cognitive Radio Platform [8]

nodes, and each node is connected to the Internet using the Ethernet cable (when in a fixed environment). One of these nodes can operate as a hand-held or standalone receiver or transmitter using a laptop with GNU Radio software. A single fixed node is built up of three major hardware components: (i) a high speed computer (powered by 2.60 GHz Dual Core Intel Pentium Processor, 2 GB memory and 500 GB hard-drive), (ii) version two of the Universal Software Radio Peripheral (USRP-2) package (with a single WBX daughter-board) and (iii) an antenna.

The USRP-2 is composed of a motherboard and one or few daughter-boards. The USRP-2 is a flexible Software Defined Radio (SDR) device developed by Ettus Research LLC [32]. The SDR is a radio communication system where components that would have typically been implemented in hardware are implemented using software. The motherboard performs baseband processing while the daughter-boards

provide the RF front-end part of the radio. The MCRP is built on WBX daughterboards with the transceiver covering the 50 MHz–2.2 GHz frequency range.

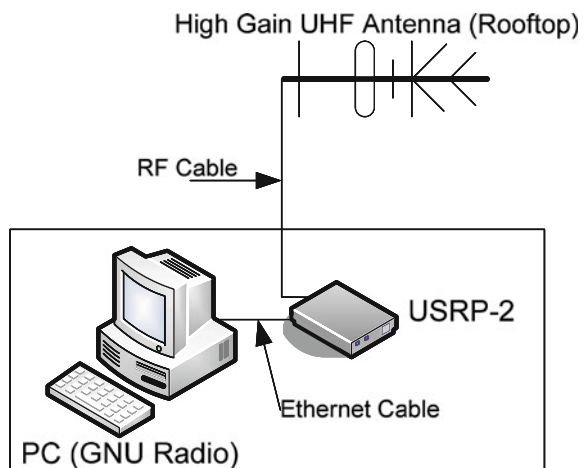
The MRCP is suitable for conducting experimental research studies in wireless communications. Typical functions include spectrum monitoring, a low-cost spectrum analyser and two way communication between nodes. Depending on the nature of an experiment, a 1 W amplifier can be used to boost the signal during the transmission (at unlicensed bands). An amplifier proved to be important for long distance transmission experiments since the USRP-2 is limited to 100 mW output power. As shown in the Fig. 4.8, two nodes are used for outdoor 3 km link where either node can receive or transmit in a selected frequency channel.

During the field spectrum measurements exercise, one fixed node was used for Pretoria measurements and the other nomadic node was used as a handheld spectrum analyser for Philipstown measurements. For fixed installations, a high gain Ellies VHF/UHF Combo antenna with 15 elements was used and for nomadic measurements an Ettus log-periodic 6 dBi PCB-based antenna was used. Detailed setups for each measurement are discussed in the following subsections.

4.3.2.1 Pretoria Measurements

For the Pretoria scans, an 8 dBi log periodic high gain Ellies antenna was used on a rooftop. We used a directional antenna that connected directly to the fixed MCRN equipment as shown in Fig. 4.9. Measurements were collected in one direction since the antenna was fixed. This placed the antenna at around 5 m above the ground. In Pretoria, an outdoor CR node was used for the spectrum scan, which ran for more than a week. Figure 4.10 shows a map of Pretoria containing the point where measurements were carried out and the four locations where known TV broadcasting transmitters are located.

Fig. 4.9 Setup for Pretoria RF Measurements



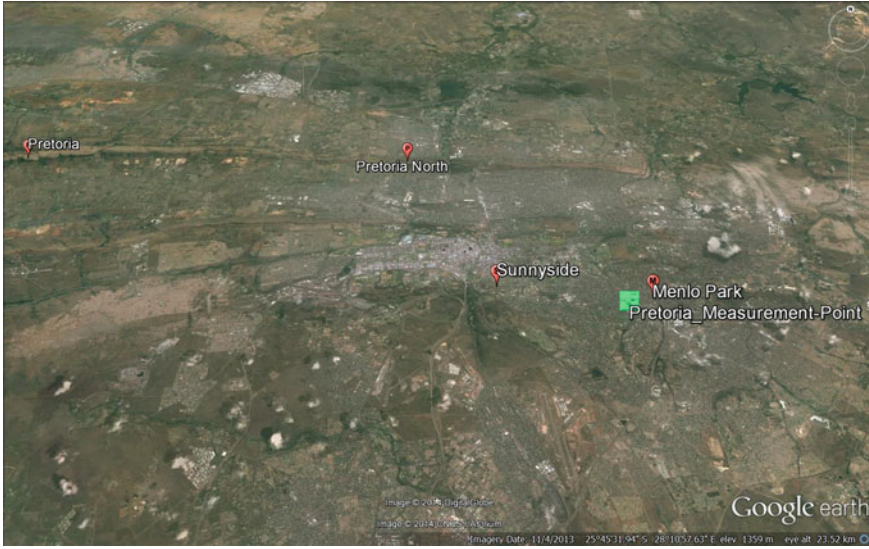


Fig. 4.10 Map of Pretoria showing known TV broadcasting transmitters and the location where measurements were collected

4.3.2.2 Philipstown

In Philipstown, measurements were collected at the location denoted by the following coordinates: S 30° 26' 09.05", E 24° 28' 22.42" E. The known TV broadcasting transmitter in Philipstown is located within a kilometer from the point where measurements were done, as shown in Fig.4.11. Nomadic or handheld equipment was used for the spectrum scans which were collected for a few minutes in three different directions at 90° to each other.

4.3.2.3 Macha Measurements

In Macha, measurements were conducted at the location: S 16° 25' 31.63", E 26° 47' 00.81". The nearest known TV transmitter to Macha is located in Pemba, which is about 60 Km away from the point where frequency measurements were conducted as shown in Fig. 4.12. In Zambia, there are eight private broadcasters and 1 public broadcaster, Zambia National Broadcasting Corporation (ZNBC). ZNBC is authorized to broadcast nationwide, while others are restricted to a defined transmission coverage area of around (100–150 km) in radius [33]. In order to expand TV coverage in rural areas, the ZNBC signal is transmitted via satellite and then received in a number of rural districts where it is re-distributed using local terrestrial TV transmitters. By 2010, it was estimated that about 65 % of Zambian population were able to receive the ZNBC terrestrial TV signal [33]. Figure 4.13 shows how nomadic equipment was



Fig. 4.11 Map of Philipstown showing known TV broadcasting transmitters and location where measurements were collected



Fig. 4.12 Map of Macha, Zambia showing location where measurements were taken and location of TV transmitter

setup for rural spectrum measurements. Philipstown and Macha measurements were taken at human height level (1.5 m) with handheld EttusUHF antenna, LP0410 Log Periodic antenna (400MHz–1 GHz) with 5–6dBi gain. In all measurements where the MCRP was used, multiple consecutive scans were done using 800 kHz bandwidth and Fast Fourier Transform (FFT) size of 2,042. The data was post-processed and FFT bins were averaged to 25 kHz buckets.

4.4 White Space Measurement Configuration for the TV White Space Trial InTygerberg Near Cape Town

As a part of initiation of the TV White Space trial in Cape Town [4], measurements were made to estimate availability of the spectrum in the Ultra-High Frequency (UHF) band around Tygerberg, Cape Town, South Africa Fig.4.13.

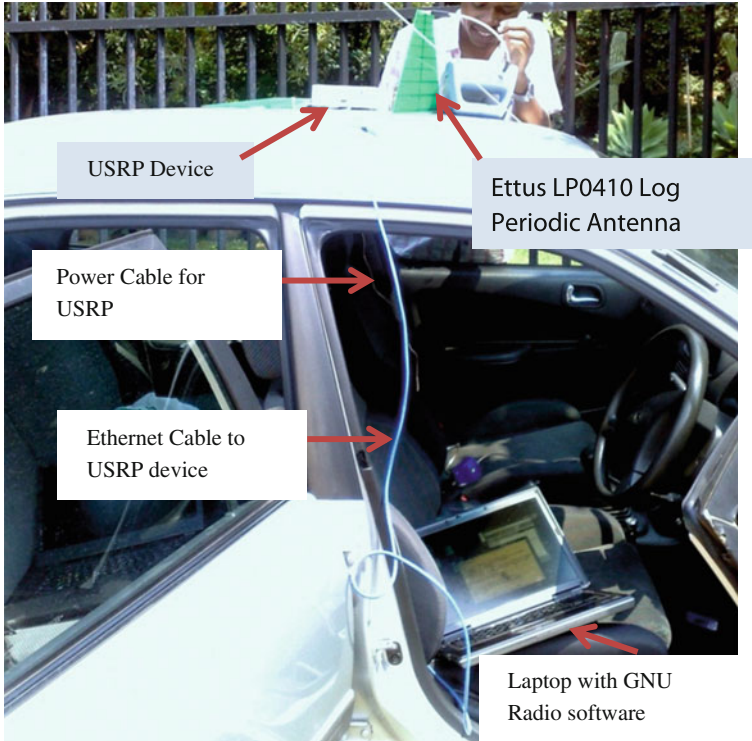


Fig. 4.13 Setup of nomadic node for outdoor remote feald scan

4.4.1 Known TV Transmitters Around the Test Site

The list of TV transmitters in Tygerberg is shown in Table 4.6. However, as it will be clear from the measurement results, there are also TV signals received in Tygerberg, which do not seem to originate from these transmitters.

The following should be considered when considering the data presented in Table 4.6:

- The Tygerberg site is located at S 33° 52' 31", E 18° 35' 44" at height 75 m, and an omnidirectional antenna with vertical polarization was used for measurements.
- Channel 38 shown in Table 4.6 was historical allocated to Cape Community TV but the current active allocation is for DTT MUX 1.
- Channel 28 is said to be allocated to mobile DTV, channels 65 and 66 to NEOTEL, and the frequency range 820–846 MHz to Studio Transmitter Links (STL). The frequencies for STL and NEOTEL overlap.

It should also be noted that Digital Dividend 1 will affect frequencies above 790 MHz. In addition, there are provisional plans to implement Digital Dividend 2 affecting the frequencies above 694 MHz [31].

Figure 4.14 shows the indicative information about the TV transmitters near the four test sites. The transmitters shown were selected using the following criteria: distance less than 300 km, operational status being “Active” and the signal strength at the location of Tygerberg hospital estimated to be more than -115 dBm. The estimation was based on the effective radiated power (ERP) and free space propagation loss [9] and did not include the influence of the actual landscape or radiation pattern.

Figure 4.15 shows the location where spectrum measurements were conducted in the Cape Town area. Information on the Cape Town measurement sites and some brief measurement details are provided in Table 4.7.

Table 4.6 TV programs in from the transmitter in Tygerberg

| Service | Status | Ch. no | Frequency, MHz | ERP, kW |
|----------|-------------|--------|----------------|---------|
| SABC2 | Operational | 22 | 479.25 | 2 |
| SABC1 | Operational | 26 | 511.25 | 2 |
| MNET | Operational | 30 | 543.25 | 1 |
| SABC3 | Operational | 34 | 575.25 | 2 |
| DTT MUX1 | Operational | 38 | 610 | 2 |
| CSN | Operational | 42 | 639.25 | 1 |
| ETV | Operational | 46 | 671.25 | 2 |
| DTT MUX2 | Operational | 50 | 706 | 2 |

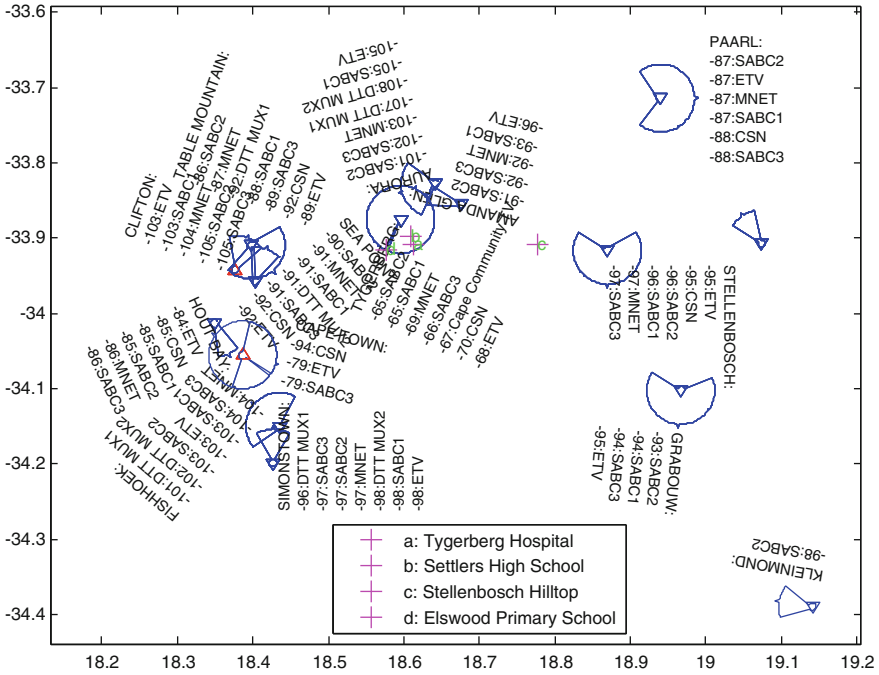


Fig. 4.14 Indication of the location and specifications of nearby TV transmitters and the directions of their radiation. The small spike on the *blue* antenna radiation pattern curves shows the direction of the main beam. The width of the *round* portion shows the beam width of the antenna beam. The *omnidirectional* patterns are shown as *circles* with an arbitrary direction of the main beam. The text includes the name of the TV station, approximate value of the signal received at the Tygetberg hospital (in dBm; estimated using free space loss formula), and the name of the service. The *blue flat-top* and *red flat-bottom* triangles correspond to the *vertical* and *horizontal* polarizations, respectively. The locations of the four test sites are also shown, as *magenta* crosses

4.4.2 Measurement Set-Ups

In Cape Town, some of the measurements were done using a set up schematically illustrated in Fig. 4.16.

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.

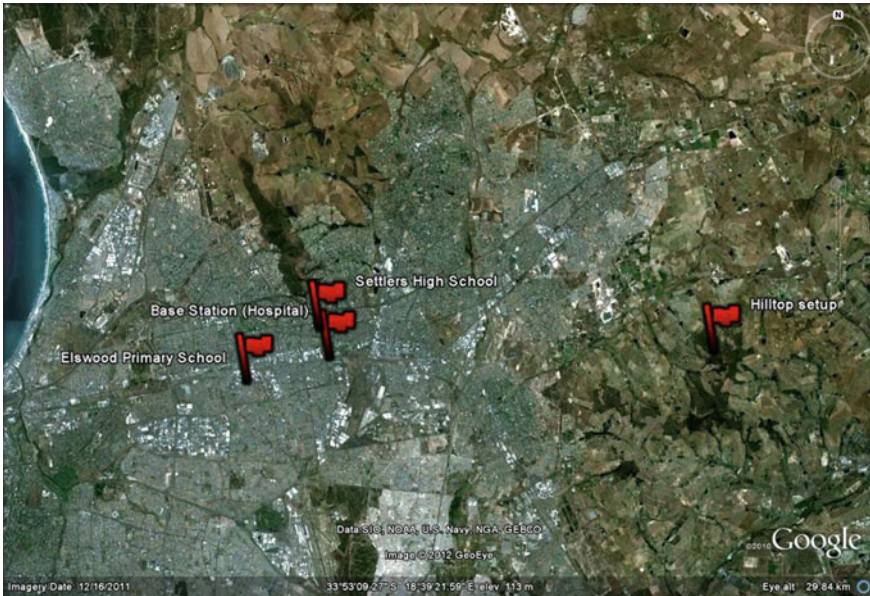


Fig. 4.15 Location of the test sites in Cape Town area

Table 4.7 Information on the measurement sites and brief measurement details

| Site | GPS | Comment |
|------------------------|---------------------------------------|---|
| Tygerberg Hospital | −33.90799, 18.61252 | 24 h run; 150+ scans of full UHF band |
| Settlers High School | −33.89764, 18.60821 | Short run |
| Stellenbosch Hilltop | −33.90778, 18.77782 476 m altitude | Short run; had to switch from FSH6 to PR100 due to interference; directional information was obtained |
| Elswood Primary School | −33.91632, 18.57716 49 m altitude | Short run; Two antenna elements fall off down during the measurement due to wind; obtained 3+2 scans |

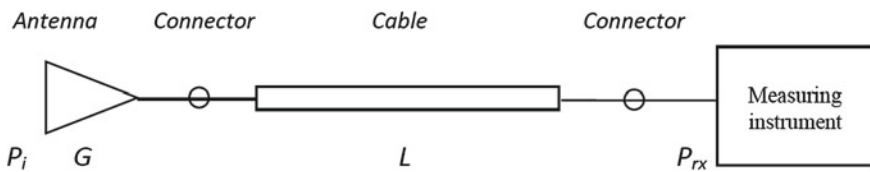


Fig. 4.16 Signal path in the measurement chain: from incident power P_i , through the antenna gain G and cable loss L , to the signal measured by the instrument, P_{rx}

4.4.2.1 Equipment Used

The 24 h long series of measurements on top of the Tygerberg hospital were performed using an R&S ESVD test receiver with a R&S HK033 omnidirectional coaxial dipole antenna.

The scans were done from 470–854 MHz (i.e. 384 MHz or 48 television channels). The R&S ESVD was used as the measuring instrument. Due to the limited memory of instrument, the whole band (470–854 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 100kHz;
SCAN:RECEIVER:DETECTOR PEAK;
SCAN:RECEIVER:BANDWIDTH:IF 10kHz;
SCAN:RECEIVER:MEASUREMENT:TIME 100ms;
SCAN:RECEIVER:ATTENUATION:AUTO On;
SCAN:RECEIVER:ATTENUATION:MODE LowNoise;
SCAN:RECEIVER:Range 60dB;
SCAN:RECEIVER:PreAMPLIFIER ON;
```

A few initial scans were performed with the preamplifier off (approximately 10 dB gain difference). This was been taken into account in processing the data acquired.

Note on Timing: Total data collected covers a period of 24h 20min. The time-dependent plots and statistical characterisation use 23h 2min selected from the middle of this data set (approximately, from 29-Aug-2012 16:26:01 to 30-Aug-2012 15:18:52). The selection was done mainly to simplify the data processing (as one hour of data was lost due to a power failure at the measurement site).

One full frequency scan from 470–854 MHz took on average around 9min. Each such scan was composed of scanning through 10 sub-bands.

The rest of the measurements were done using R&S FSH6 portable spectrum analyzer, and R&S PR100 portable receiver. The antennas were always set to receive vertical polarization.

4.4.2.2 Correction Factors

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 Fig. 4.17: The curves denoted with “filtered” are the ones applied to the spectrum measurements. They were been obtained by applying a running average filter to the actually measured values. The filtering has been done to reduce the measurement noise.

The antenna gain for R&S antenna HK033 is specified to be 2 dBi \pm 1.5 dB. As discussed in Sect. 4.4.2.3, the other antenna used in some of the measurements, i.e. the

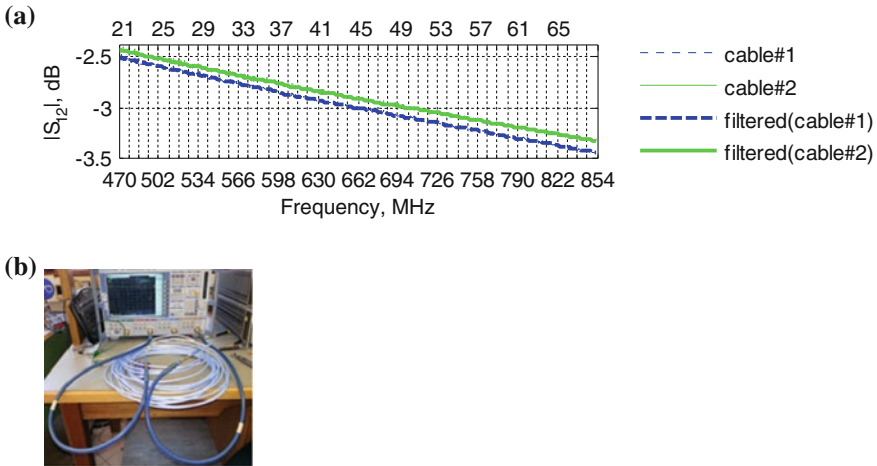


Fig. 4.17 a Measured loss in the cables $|S_{12}|$, and b measurement set up

antennas ST4, has a deep null covering several TV channels, significantly reducing the sensitivity in those bands (around 622–672 MHz, corresponding to TV channels 40–46, where the gain drops to as low as -20 dBi, thus reducing the sensitivity by 15–20 dB). This is applicable to the measurements done at the two schools.

It may be noted that the antenna gain nearly compensates for the loss in the cable.

4.4.2.3 Note on the Challenges with Using the Antenna AntennaCraft ST4

In order to ensure validity and tractability of measurements, the antennas used for the spectrum scans have been characterized. The wire discone antenna ST4 made by AntennaCraft was found to have expected features in its gain pattern. In particular, it was found that even for the horizontal plane radiation pattern, the results indicate a significant drop in the antenna gain, most pronounced at the frequency bands centered around 540–690 MHz. This was first identified from a numerical model using WIPL-D software [34, 35], and then confirmed with the open range antenna gain pattern measurements. A summary of the results of this study are shown in Fig. 4.18, where it is easy to observe a significant drop in the sensitivity of the system using ST4.

As some of the measurements shown in Fig. 4.18, were made using this antenna, the appropriate corrections have been introduced. Unfortunately, due to the low sensitivity of the system around the two identified frequency bands, the corrections also, in effect, raise the measurement noise floor around those areas.

Further examination indicated that the influence of wind or inaccurate vertical positioning of the antenna could be a significant contributing factor as well. It was found that the antenna gain variation in the vertical (elevation) plane may cause significant and frequency dependent variation in signal strength received from the

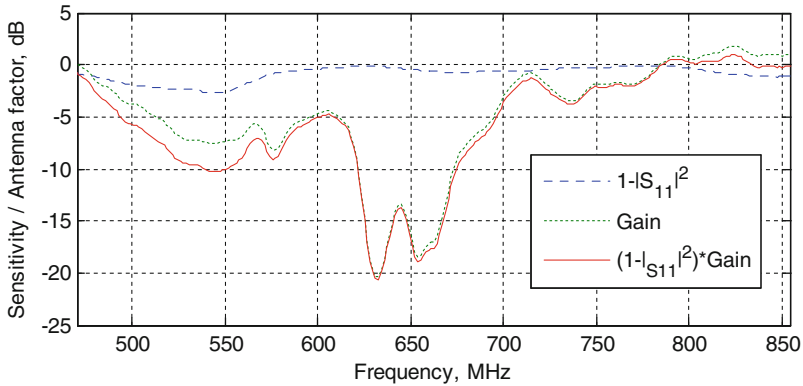


Fig. 4.18 Change in the partial system sensitivity function (shown with *red solid line*) due to the behaviour of the Gain and mismatch factor $(1 - |S_{11}|^2)$ of the wire disc antenna ST4

antenna. For example, a -15 to 15 deg movements due to wind can cause up to 25 dB variation in the read level of the incident signal (from -20 to $+5$ dB_i).

The above-mentioned findings indicate a need for strict requirements on the necessity to ensure a rigid mounting of the antenna as well as a good alignment to the vertical orientation.

4.4.3 Measurement Results

The location (via Google Earth) of the measurement set up and the pictures from setting up the measurements are shown in Fig. 4.19a–d.

As it can be seen from 4.19b, there should be very little blockage to the measurements. The only blockage is due to the two towers on the sides of the building. The choice of not using one of those towers (which would have been a more ideal location) was dictated by the safety considerations of transporting the heavy equipment across the roof.

4.5 Quantifying the Amount of TVWS

This section presents the results for all the spectrum measurements conducted using the two equipment discussed in the previous sections.

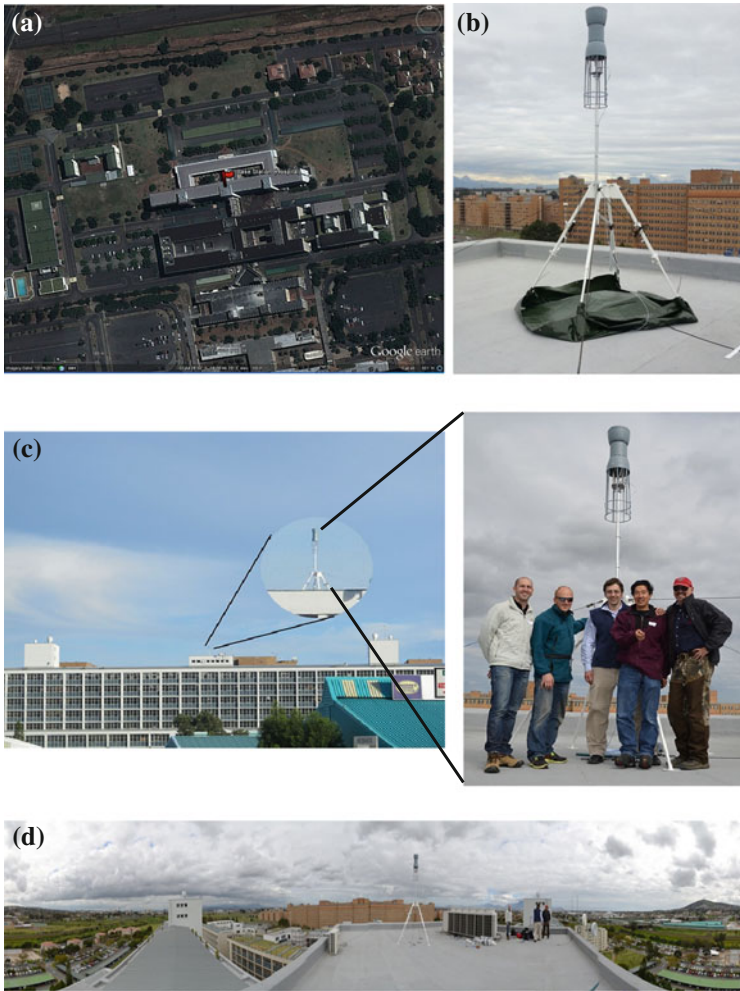


Fig. 4.19 **a** Top view at the measurement location; **b** measurement set up composed of the R&S HK033 antenna mounted on a tripod and connected to a computer controlled receiver (under the rain-proof cover); **c** side view at the measurement set up; **d** panoramic view from the location of the set up

4.5.1 Philipstown

Figure 4.20 shows the TV UHF band scan results performed in Philipstown. According to the national terrestrial broadcasting frequency plan of 2013 [31], there are only 4 TV stations in the area which occupy channels 22 (at 478 MHz), 26 (at 510 MHz), 30 (at 542 MHz) and 34 (at 574 MHz). However, due to the very low transmit power, only one channel (#34) was detected by equipment. With only four channels being

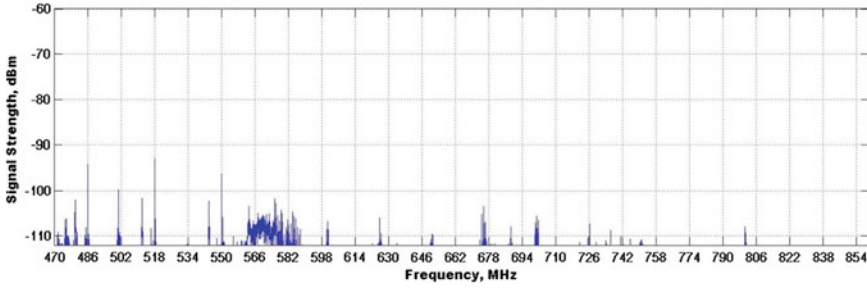


Fig. 4.20 Spectrum activity results in rural Philipstown, South Africa (relative vertical scale)

allocated, out of possible 29 channels (between 470 and 694 MHz band), it is clear that there is over 80 % of TVWS spectrum which can also be available post the DSO process in 2015.

4.5.2 Macha

In Zambia, ZNBC has only one TV channel which covers over 65 % of the population. Most of the private broadcasting channels are not covering the rural or remote areas. While we could not find the actual channels used at Pemba TV transmitter, which is the nearest transmitter to Macha, our results shows some activities between 470 and 590 MHz. Other than those channels, TVWS availability in Macha rural area is over 90 % as shown in Fig. 4.21.

4.5.3 Pretoria

Unlike in rural areas, spectrum occupancy in urban areas is much higher mainly due to a high number of TV transmitters needed to provide quality viewing for the greater population. Although some transmitters used low power, there is no channel reuse

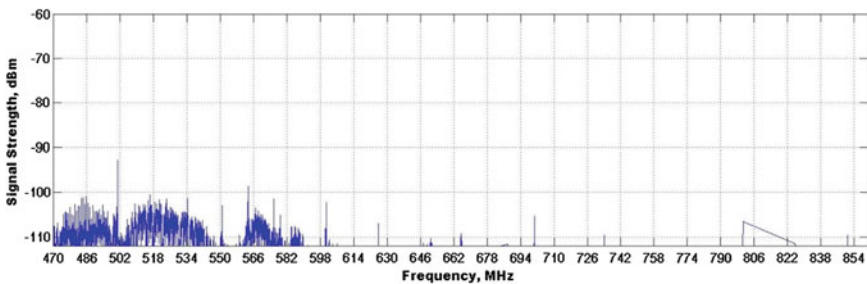


Fig. 4.21 Spectrum activity results in rural Macha, Zambia (relative vertical scale)

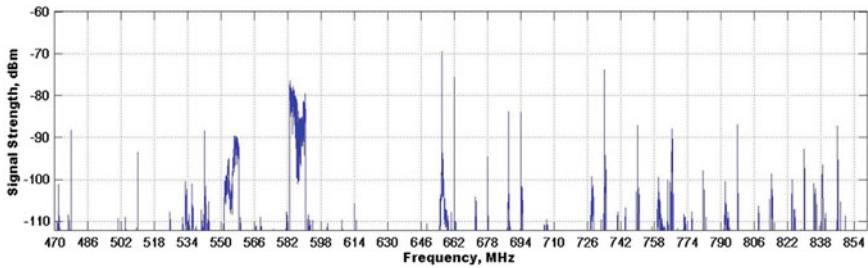


Fig. 4.22 Spectrum activity results in Pretoria West (relative vertical scale)

within the Pretoria area as shown in Table 4.4. Out of possible 29 UHF channels, a total of 22 channels were used for TV broadcast around Pretoria (there are also three high power VHF transmitters). As shown in Fig. 4.22, there are many activities which were detected during our spectrum measurements. It is important to note that measurements in Pretoria lasted for more than 24h since the equipment was fixed with a roof-top antenna. Based on our measurements and number of channels already used for broadcasting, TVWS availability in Pretoria can be estimated to be over 40%. However, this number can even be greater, depending on the location, especially since most of the existing transmitters are using low power.

4.5.4 Tygerberg

As a part of initiating the TV White Space trials in Cape Town, more specifically in Tygerberg, an urban area, the spectrum availability was measured at four locations. Most of the discussions are derived from the measurements made on the roof of Tygerberg hospital, where the spectrum scan was run for 24h and used only calibrated professional grade equipment.

4.5.4.1 Samples of Spectrum Scans Sade at the Tygerberg Hospital Roof

This subsection discusses the raw results of the measurements.

Note on Data Presentation

The plots shown in the next several pages show the frequency spectrum use in the following form:

- The **upper plot** displays all the received spectra measurements (in blue) as well as the maximums over the 3-hourly averaged values (in red). The latter plot was

obtained by computing averages over all values of time with a running window of 3 h, at each frequency; after this, a maximum was found of these values, again individual for each frequency. Thus computed average value shows the presence of systematically available signals in the bands versus more sporadic signals.

- *For the 3 h averaged values:* It may be noted that if TV station broadcasts only for very short time (and the transmitter is transmitting during the time only), e.g. only 1 h over any given 3 h time interval, the value will be displayed with a magnitude reduced by the ratio of the duration of the program to the 3 h reference frame. For example, a 45 min long transmission will have 1/4th of the true value and thus the displayed magnitude which is 6 dB lower than actually present. Such programs may be identified by considering this upper plot against the 3rd plots with time representation (waterfall plot). In addition, one may expect a peak at that frequency in the 2nd plot, as well.
- It was possible to increase the noise floor, by at least 10 dB, but at an expense of setting a narrower IF bandwidth and thus much longer scanning time—a much longer scanning time would result in the possibility of missing shorter transmissions.
- The top of the plot shows the TV channel numbers.
- Around the top of the plot, there are also crosses (x) to indicate the frequencies registered for some TV transmitters which could be visible in the measurements (e.g. as full-fledged profiles of signals or just weak signals).

It may be noted that the reference frequency (stated in the ICASA documents for a particular TV transmitter) for the fully visible profiles of analogue signal correspond to the visual carrier and are usually 1.25 MHz to the right from the start of the particular TV channel (e.g. TV channel 21 starts at 470 MHz, and so the visual carrier may be expected to be around 471.25 MHz, possibly with a small offset used to minimize interference in large analogue TV broadcasting networks).

It may be noted that the reference frequency for a digital signal usually corresponds to the middle of the TV channel.

The associated texts tell the estimated signal strength value (in dBm) as well as the name of the station, polarization (V for vertical and H for horizontal), and the program it transmits. As it has been mentioned in the earlier Sect. 4.4.1 on the current frequency allocations around the area of interest, the estimated received power is calculated using the propagation loss derived from the free space loss formula. This simple formula disregards the antenna's radiation pattern and landscape elevation profile. In addition, the computed values relate to the total power of TV signal, whilst the measured values are based on the IF bandwidth of 10 kHz (this gives over 10 dB difference for analogue TV signal's video carrier occupying at least 100–500 kHz, and even more for digital signals). Thus, the numbers shown in this text can only be used as a guideline, and cannot be compared to most of the measurements directly.

- The **2nd** plot displays the uncertainty in the measured mean value. This was computed as a standard deviation from the raw data, at each frequency, using the

time series. A high value, e.g. above 5 dB, may indicate presence of significant occasional transmissions made or presence of quiet periods.

- The **3rd** plot displays the time variation of the signals at each frequency, shown as a temperature plot. As in the previous plots, the horizontal axis shows the frequency. The vertical axis shows the time of the day (from the beginning of the measurement, before 6PM until the end of the measurement, after 3PM on the next day). The colour of the data indicates the signal strength observed during that time at a specific frequency, e.g. red corresponds to strong signals and blue to weak signals. The colour scale is shown under this plot. It is possible to see that some signals are present on continuous basis (e.g. much of the signals in 22nd and 26th channels), whilst some signals are transmitted occasionally (e.g. signal visible in the portions of channels 27 and 31).
 - It may be noted that the colour scale on this plot has been selected to saturate strong signals (as they are already visible well), and highlight medium range signals.
 - The plot uses approximation of the spectral content being constant within one step of time (~9 min).
- The **4th** plot shows occupancy of each individual frequency resolved, indicating how much use a particular channel is estimated to be used, in percents, over the entire measurement period. This quantify is computed as a ratio of the number of times the signal exceeds a pre-defined threshold to the total number of samples (154). Three thresholds were used: -95 dBm, -90 dBm, and -80 dBm.

Sample of scans—channels 27–32

The scan results shown in Fig. 4.23 indicate that TV channels 27, 29, 31 and 32 were not actively used, channel 28 is used for digital transmission (for mobile communication needs) and channel 30 (likely, MNET) has a weak (likely unusable) TV signal. The occasional peaks present in the channels 27, 29, 31 and 32 are likely to be due to narrow-band analogue transmissions. It is possible that the signals in the channels 29 and 31 are paired.

It is also possible to see that the analogue TV transmission in channel 26 (shown only partly) has NICAM sound, in addition to the normal audio component.

Sample of scans—channels 33–38

In Fig. 4.24, the plots indicates that channels 34 (SABC3) and 38 (DTT MUX 1 or Cape TV) are definitely used, by analogue and digital transmissions, respectively. The channels 33 and 35 seem to be mostly available. The channels 36 and 37 have low level signals/traces of what appears to be TV signal(s) from far away transmitter(s).

It may also be noted that the analogue TV transmission in the channel 34 does not have NICAM sound.

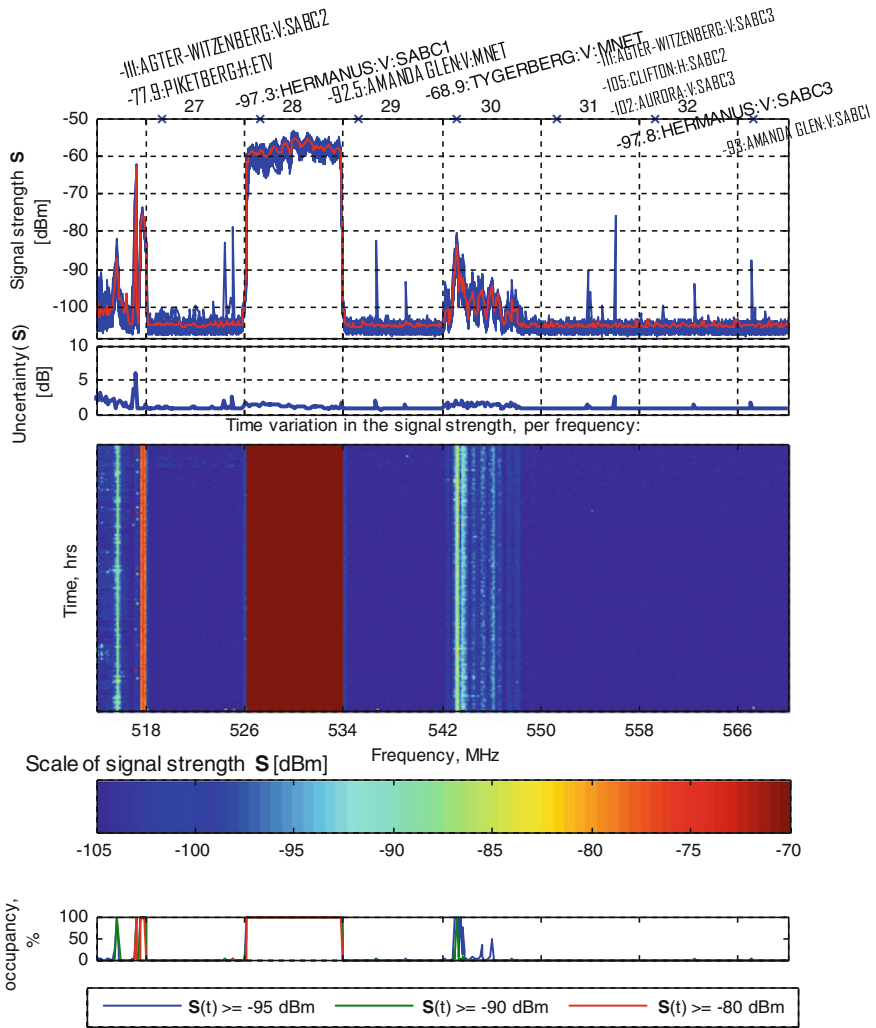


Fig. 4.23 Spectrum activity results for Tygerberg hospital roof: TV channels 27–32

The spectrum activity plot in the upper part of Fig. 4.24 may be compared to an equivalent plot based on measurements made in May 2013, approximately 8 months after the first round of the measurements. The latter plot is shown in Fig. 4.25. The interpretation of the data in this plot requires taking the following into account:

- Unlike the much longer measurements used for Fig. 4.24, this new set of data is based on two rounds of just 3 frequency scans over a total period of less than 30 min.

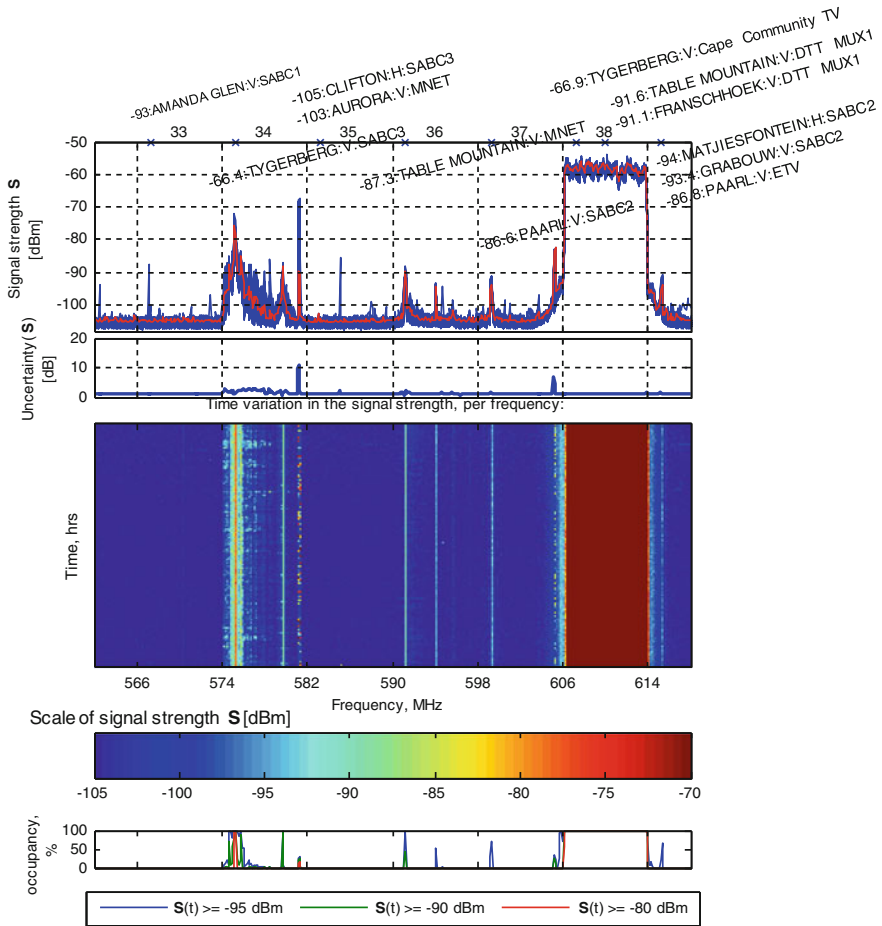


Fig. 4.24 Spectrum activity results for Tygerberg hospital roof: TV channels 33–38 in Aug 2012

- The plot displays all the received spectra measurements, i.e. 3 scans made over 27 min long period (in green) as well as the two averages over the duration of the scans (in red).
 - Each spectrum scan has been converted from the received voltage in $\text{dB}\mu\text{V}$ into received power in dBm and then into the strength of the incident electric field in $\text{dB}(\mu\text{V}/\text{m})$, as discussed in Sect. 4.6.1.
 - One curve corresponds to the mean value of the scans for the scenario when a transmitter(TR) is on and transmitting.
 - Another curve corresponds to the mean value for the TR being off and silent.
 - Mean values are based on the three data points, for most of the measurements.
 - The top of the plot shows the TV channel numbers, as well as lists some of the TV transmissions that may be seen in the measurement. The propagation

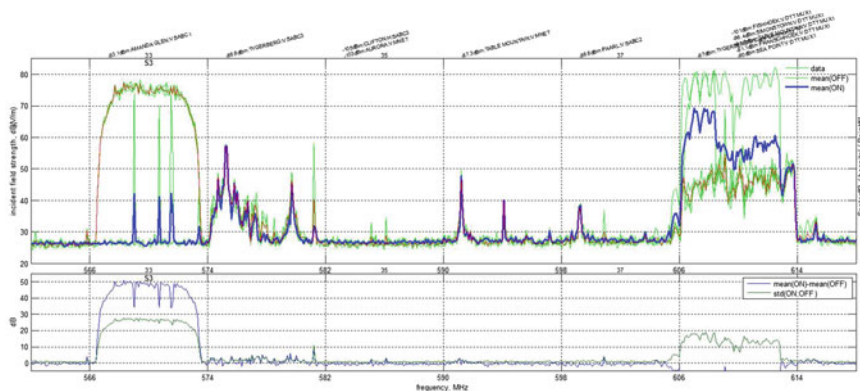


Fig. 4.25 Spectrum activity results for Tygerberg hospital roof: TV channels 33–38, in May 2013

loss was estimated using the free space loss formula disregarding the antenna’s radiation pattern and elevation profile. Thus, the numbers can only be used as a guideline, and cannot be compared to most of the measurements directly.

Comparing the plots in Figs. 4.24 and 4.25, one may find that the plots are effectively the same for the contributions due to the most of TV broadcasting channels (except the channel 38). They remain essentially the same. In May 2013, the channel 38 was being tested by SENTECH and so it was periodically switched on and off. Thus, the scanned values were different.

The spectrum in the channel 33 is an overlap of 6 scans, of which 3 are for a recently introduced transmitter being on and other 3 for the same transmitter being off. It is possible to see that when the transmitter is off, there are some other signals (3 peaks) present in the band. It was checked against the ICASA frequency allocation tables and no legal allocations (except for the TV broadcasting) were found for this channeling this geographic area.

4.5.4.2 Summary of the Results

The results are summarized in Fig. 4.26. The four upper plots show the individual spectrum activity per location. The lowest plot shows an overlap of those plots, to highlight the good correlation between the scans obtained around Tygerberg area.

The good correlation between the results measured in different parts of Tygerberg and even from the hilltop in Stellenbosch indicated that the shadowing effects did not disturb the measurements and the spectrum scans obtained may be used as a reliable source of data to estimate spectrum availability.

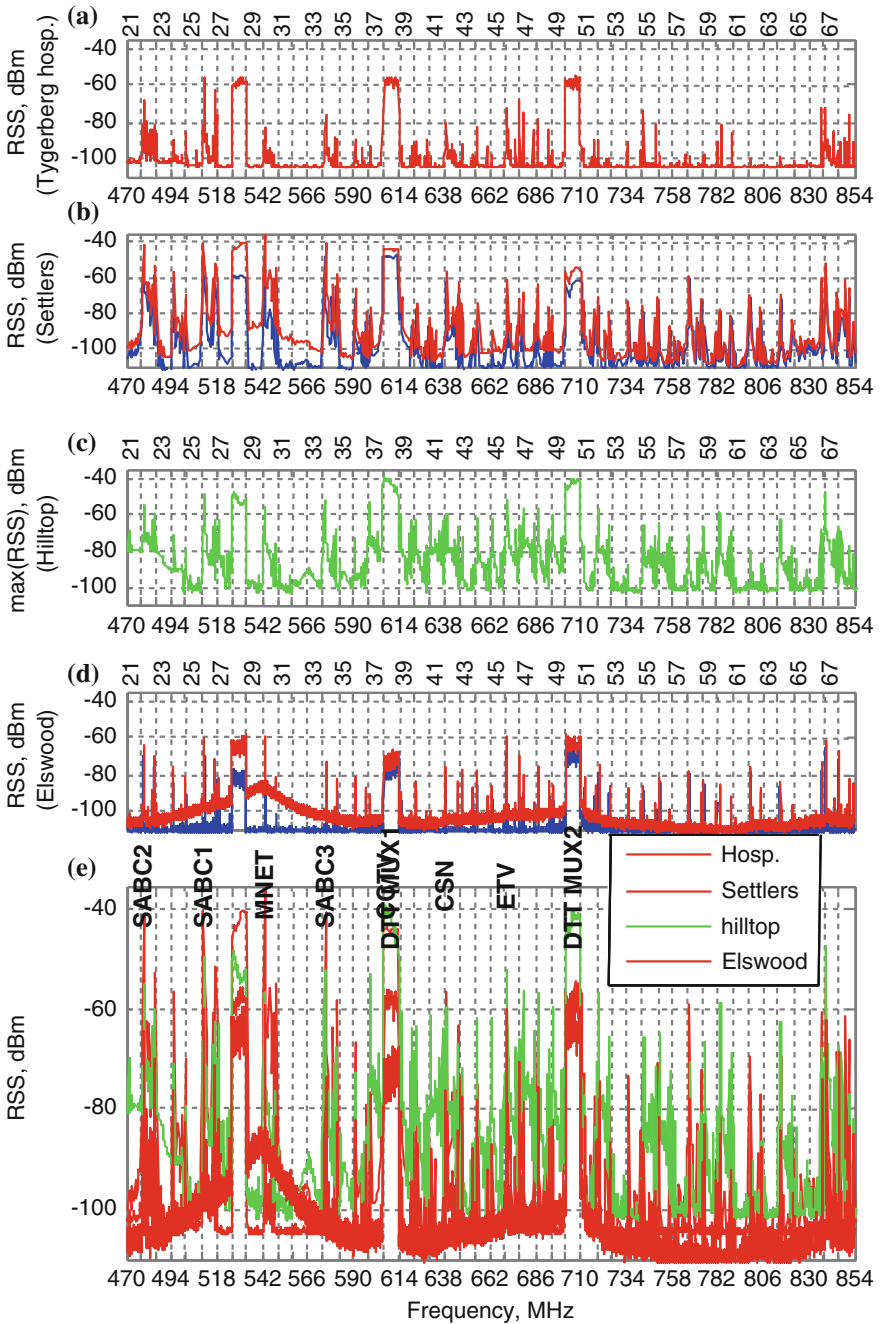


Fig. 4.26 Spectrum activity comparisons for four locations near Tygerberg, Cape Town, South Africa. The four upper plots correspond to the measurements done **a** at the roof of Tygerberg hospital, **b** at Settlers High School, **c** at a hilltop near Stellenbosch, **d** at Elswood Primary School, **e** overlaps of plots **a-d**

4.5.5 Notes on Criteria for Evaluation of Spectrum Availability

Determination of availability of a channel may be made using a number of various criteria. Disregarding the more advanced and accurate but computationally very demanding approaches, such as the ones based on singular value decomposition, the following discussions may be made.

In Fig. 4.27, each plot shows a histogram illustrating the occupancy of a channel. The horizontal scale is for the signal strength and maps strengths from -115 dBm to -50 dBm (the values are not shown in order to keep the picture clearer). The vertical axis is in logarithmic scale, showing the number of times the signal in the band had this (corresponding to the respective value on the horizontal axis) level. This presentation permits illustrative interpretation of the availability. For example, the channels 21, 29, 53 and 61 have only low level present in them, and never encountered a high level signal. This may be interpreted as availability of these channels. On the contrary, the channel 22 has nearly uniform occurrence of low and high signal levels, and can thus be considered as busy.

The simplest way to estimate the availability is by using a threshold of a pre-defined level. Several thresholds were tested. One was based on the maximum value of the signal observed in a given TV channel. Another threshold was based on the mean value of the signal observed in a given TV channel. Also, for a reference purpose, a metric based on the minimum value of the signal observed in a given channel was also applied. The results, based on the Tygerberg hospital roof measurements, are shown in Figs. 4.28 and 4.29.

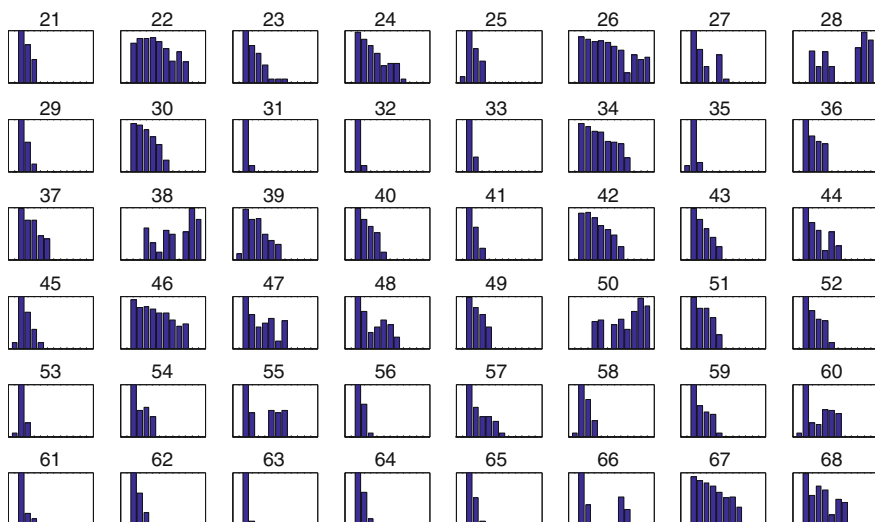


Fig. 4.27 Distributions of occupancy, per TV channel

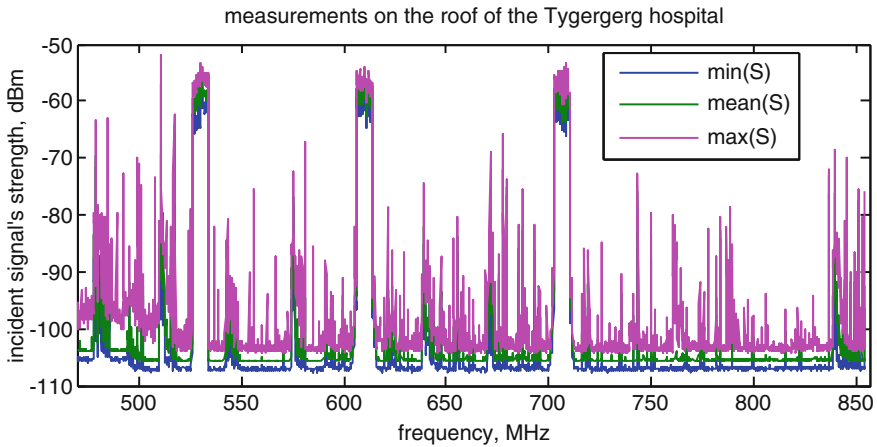


Fig. 4.28 Signal strength versus frequency (via different metrics: minimum, average and maximum levels of the signal detected over time in each frequency band resolved by the receiver)

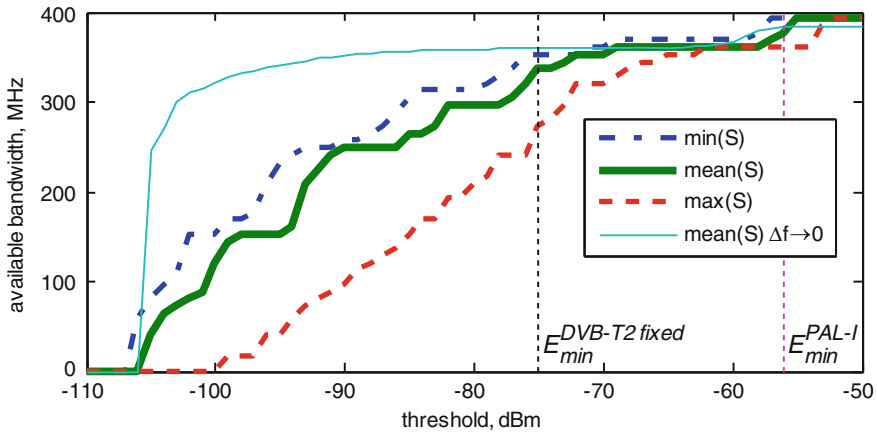


Fig. 4.29 Availability of spectrum in TV bands around Tygerberg hospital in August 2012, estimated using different threshold types, based on the minimum, mean and maximum values of the signal observed at each 8 MHz wide TV channel (except for the curve ‘mean(S) $\Delta f \rightarrow 0$ ’ calculated using 100 kHz wide channel width)

Figure 4.28 illustrates the effect of different metrics used for the processing the spectral signature in time domain. It affects the perceived noise floor as well as the perceived maximum level of the signal. It may also be noticed that the quantity of the effect differs for the analogue and digital signals, likely due to the way the receiver measures the signal using its swept narrowband filters.

Figure 4.29 shows the availability of the spectrum calculated from the data shown in Fig. 4.28. There are several observations and conclusions which may be made from the plot in Fig. 4.29:

- The ‘minimum acceptable signal strength’ indicators derived in Sects. 2.2.1.5 and 2.2.2.2 for PAL-I and DVB-T2, respectively, yield huge amounts of the white space available, on the order of 336–376 MHz, or 86–96 % (the first number is given for DVB-T2 fixed scenario and the other number is given for the PAL-I fixed scenario). Even with an additional margin of 10 dB, there is still over 43–92 % of the TV spectrum that is available.
- Introduction of digital terrestrial television reduces the amount of white space available, because of the better sensitivity afforded by the digital receivers. However, the quantity of the spectrum available for local reuse will still be significant.
- The curve ‘mean(S) $\Delta f \rightarrow 0$ ’ shows the availability of the spectrum, when the width of a channel is very small (here, it is equal to the frequency step of the receiver, or 100 kHz). This curve may be interpreted as an upper limit for the amount of spectrum without much obvious activities (and also including the gaps in the spectrum signatures from the valid users).
 - This curve is well above the equivalent curve ‘mean(S)’ for 8 MHz wide channel, but the difference is reduced with the growth in the level of the threshold.
 - Around the noise floor, the curves converge due to high uncertainty in the measured values.
- Using the worst case scenario of a threshold, i.e. the maximum value of the signal observed in a TV channel (curve ‘max(S)’) still shows a very large amount of white space.

Comparing the relatively densely occupied spectrum shown in Fig. 4.28 against the measurements done in more rural areas, like those from Sects. 4.5.1 and 4.5.2, reveals an abundance of TV white space spectrum relative to urban areas such as Cape Town.

4.6 Notes for Optimizing Measurements

As discussed in 4.4.2.3, it may be important to ensure the correct choice of antenna and the antenna mounting.

Depending on the instrumentation available, one may need to calibrate the measurement set up against a reference. For example, the commonly accepted correct method of measuring power is using RMS (root mean square) detector. Some, especially older, instruments may not have a RMS detector available. If so, one may need to calibrate the instrument against another, reference instrument. A comparison of the measurement results using different spectrum analyzers is shown in Fig. 4.30. It should however be noted that the calibration factor may depend on the type of signal being measured.

Considering that the spectrum scans normally consume significant time, it may be desirable to optimise the overall measurement time by reducing the measurement time set in the measuring instrument. This is especially applicable to the older instruments. In order to minimize the measurement time whilst keeping sufficient accuracy of signal presentation, a study was done on the effect of measurement (integration)

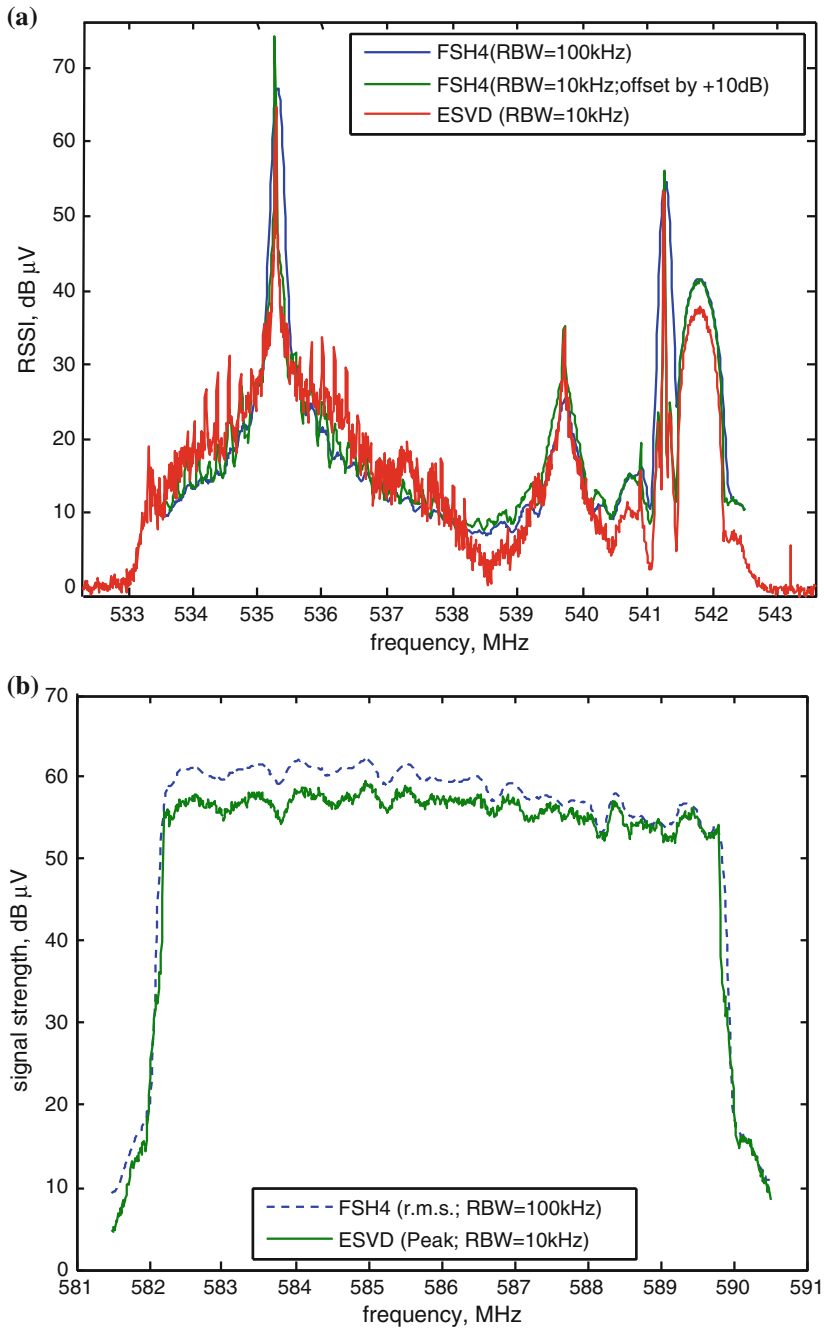
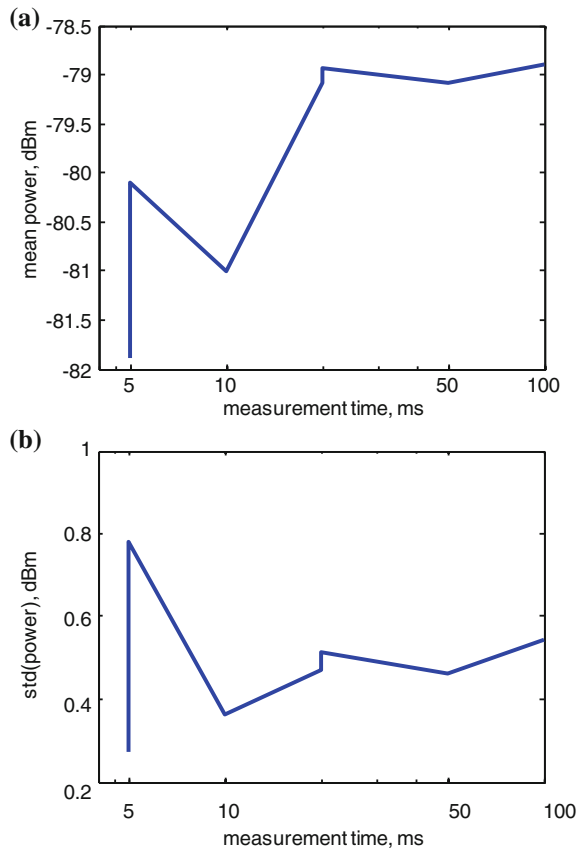


Fig. 4.30 Spectrum of **a** analogue PAL-I and **b** digital broadcasting signals, as measured by FSH4 with RMS detector and resolution bandwidth (RBW) of 100kHz, and ESDV with Peak detector and RBW of 10kHz

Fig. 4.31 Average total power (a) and its standard deviation (b) versus measurement time



time on the result of the measurement with R&S ESVD test receiver using the PEAK detector. A live digital terrestrial television (DTT) broadcast was used as a reference signal, whilst it was measured using different values of detector *measurement time*. The plots for the variation in the average power measured using Peak detector and respective standard deviation in the data sets are show in Fig.4.31. The standard deviation remains about the same (determined by the source DTV signal), whilst the measured average of the peak grows slowly and stabilizes at 20ms. It may be concluded that 20ms, is sufficient time for an accurate measurement (within the uncertainty of the measurement).

4.6.1 Correspondence Between Incident Power and Incident Field Strength

The results stated for the Tygerberg measurements have been presented in terms of the incident power, in dBm. This quantity reflects the power of a signal incident from the

air onto the antenna and, as per Sect. 4.4.2, is calculated by subtracting the gain of the antenna and adding the loss in the cable to the values measured by a spectrum analyser.

It may however be noted that the broadcasting regulations specify the minimum acceptable value of the field strength rather than the power. As an equivalent alternative to the equation shown in Sect. 4.4.2, the field incident onto an antenna [dB(μ V/m)] may be computed as a sum of the voltage measured by the receiver [dB(μ V)], antenna factor AF [dB(m^{-1})] and losses in the cable [dB]:

$$E_i = V_{rx} + AF + L, .$$

where voltage measured by the receiver is related (for a 50Ω transmission line) to the power measured by the same receiver as

$$V_{rx} = P_{rx} + 107dB.$$

The antenna factor may be computed as a function of wavelength λ [m] and unitless antenna gain G_u as

$$AF_u = \frac{9.73}{\sqrt{G_u}}, \quad AF \text{ (dB)} = 20 \cdot \log_{10} \left(\frac{9.73}{\sqrt{G_u}} \right), \quad G \text{ (dB)} = 10 \cdot \log_{10} (G_u)$$

As a note, one may easily notice that the uncertainty in the value of the gain, given in dB, will translate into the same uncertainty in the antenna factor and field strength.

These formulas may be for example applied to the antenna used for the measurements on the roof of Tygerberg hospital. Considering that the antenna gain for R&S antenna HK033 is specified to be $2\text{dBi} \pm 1.5\text{dB}$, the antenna factor may be calculated and the result is plotted in Fig. 4.32.

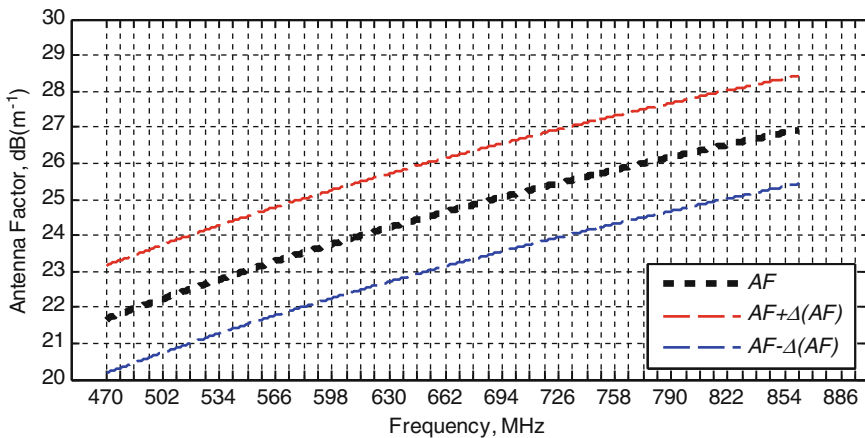


Fig. 4.32 Antenna factor computed for the antenna R&S HK033, together with the *upper* and *lower* bounds based on the specification of the uncertainty in the gain

4.7 Conclusion

In this chapter we have introduced a standards-based metric for quantifying the amount of available TV white space. Spectrum scans reveal an abundance of TV white space bandwidth, especially in rural areas, that may be used for broadband or machine-to-machine (M2M) communications in Africa. The urban areas may offer at least 40 % of the UHF spectrum to low RF power TVWS applications. The rural areas are likely to offer more than 90 % of the UHF spectrum. The spectrum scan measurements were carried out during the current dual-illumination period and even more TVWS will be released after the global digital switch over (DSO). This study serves as a starting point towards informing the development of fully operational TV white space networks for broadband or M2M connectivity. It is likely that rural areas will be a specific target of TV white space broadband networks as they provide excellent propagation characteristics for reaching sparsely populated regions with large distances between population settlements. There are ongoing research efforts towards understanding the TVWS ecosystem in South Africa through TVWS trials and a planned countrywide study of TVWS availability and these studies will ultimately culminate in new regulation on spectrum use in TV white spaces in South Africa -most likely in early 2015.

References

1. ITU, Final acts of the regional radiocommunication conference - GE06, International Telecommunications Union - Radio Sector, Switzerland, Geneva (2006)
2. FCC, Second report and order and memorandum opinion and order in the matter of: unlicensed operation in the tv broadcast bands, ET Docket No. 08–260, Federal Communications Commission, Washington, DC, United States (2008)
3. Ofcom, TV white spaces: approach to coexistence - technical analysis, Office of Communications, London, United Kingdom (2013)
4. TENET, The Cape Town TV white spaces trial, Available: <http://www.tenet.ac.za/tvws>. (2013) Accessed 14 March 2014
5. Mikeka, C., Thodi, M., Mlatho, J., Pinifolo, J., Kondwani, D., Momba, L., Zennaro, M., Moret, A.: Malawi television white spaces (TVWS) pilot network performance analysis. *J. Wirel. Networking Commun.* **4**(1), 26–32 (2014)
6. Haji, M. A.: Licensing of TV white space networks in Kenya, Geneva, Switzerland: Presented at ITU-R SG1 Workshop: Spectrum management issues on the use of white spaces by cognitive radio systems (2014)
7. Mfupe, L., Montsi, L., Mzyece, M., Mekuria, F.: Enabling dynamic spectrum access through location aware spectrum databases. In: *IEEE Africon*, Mauritius, 9–12 Sept 2013
8. Masonta, M., Johnson, D. L., Mzyece, M.: The White Space Opportunity in Southern Africa: Measurements with Meraka Cognitive Radio Platform, Springer Lecture Notes, Popescu-Zeletin et al. (Eds.), vol. 92, Part 1, pp. 6–73 (2012)
9. Lysko, A. A., Masonta, M., Johnson, D. L., Venter, H.: FSL based estimation of white space availability in UHF TV bands in Bergvliet, South Africa, in *SATNAC* (2012)

10. Zennaro, M., Pietrosevoli, E., Mlatho, J., Thodi, M., Mikeka, C.: An assessment study on white spaces in Malawi using affordable tools. In: IEEE Global Humanitarian Technology Conference, Seattle, USA (2012)
11. Kagarura, G.M., Okello, D., Akol, R.N.: Evaluation of spectrum occupancy: a case for cognitive radio in Uganda. In: IEEE 9th International Conference on Mobile Ad-hoc and Sensor Networks, Dalian, China (2013)
12. Masonta, M., Mekuria, F., Mzyece, M.: Analysis of ICASA broadcasting frequency plan for possible use of TV white space for broadband access. In: Southern Africa Telecommunication Networks and Applications Conference (SATNAC), Stellenbosch, South Africa (2013)
13. ITU-R, Conventional analogue television systems, Recommendation ITU-R BT.470-7, Geneva (2005)
14. ITU-R, Characteristics of radiated signals of conventional analogue television systems, Recommendation ITU-R BT.1701-1, Geneva (2005)
15. ITU-R, Characteristics of composite video signals for conventional analogue television systems, Recommendation ITU-R BT.1700, Geneva (2005)
16. ETSI, Television systems; NICAM 728: transmission of two-channel digital sound with terrestrial television systems B, G, H, I, K1 and L', ETSI EN 300 163 V1.2.1 (1998–2003) (1998)
17. ITU-R, Television systems; NICAM 728: transmission of two-channel digital sound with terrestrial television systems B, G, H, I, K1 and L, ETSI EN 300 163 V1.2.1 (1998)
18. ITU-R, Transmission of multisound in terrestrial television systems PAL B, D1, G, H and I, and SECAM D, K, K1 and L', Recommendation ITU-R BS.707-4, Geneva (1998)
19. ITU-R, Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service, Recommendation ITU-R BT.417-5, Geneva (2002)
20. ITU-R, Characteristics of TV receivers essential for frequency planning with PAL/SECAM/NTSC television systems, Recommendation ITU-R BT.804, Geneva (1992)
21. ITU, Planning criteria, including protection ratios, for second generation of digital terrestrial television broadcasting systems in the VHF/UHF bands, Recommendation BT.2033-0, Geneva (2013)
22. EBU, Frequency & network planning aspects of DVB-T2, Tech 3348 r3, Geneva (2013)
23. ITU-R, Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands, Recommendation ITU-R BT.1368-10, Geneva (2013)
24. ITU-R, Frequency and network planning aspects of DVB-T2, Report ITU-R BT.2254, Geneva (2012)
25. ITU-R, Radio-frequency protection ratios for AM vestigial sideband terrestrial television systems interfered with by unwanted analogue vision signals and their associated sound signals, Recommendation ITU-R BT.655-7, Geneva (2004)
26. Fischer, W.: Digital Television: A Practical Guide for Engineers. Springer, Berlin (2004)
27. ETSI, Electromagnetic compatibility and radio spectrum matters (ERM); wireless microphones in the 25 MHz to 3 GHz frequency range; Part 1: technical characteristics and methods of measurement, ETSI EN 300 422-1 V1.3.2 (2008–03) (2008)
28. Ofcom, Spectrum efficiency of wireless microphones (Final Report) 2202/DWM/R/2/2.0, 2010. Available: <http://stakeholders.ofcom.org.uk/binaries/research/technology-research/sewm/finalreport.pdf> (2010) Accessed 19 May 2014
29. Shellhammer, S., Sadek, A.K., Zhang, W.: Technical challenges for cognitive radio in the TV white space spectrum. In: Information Theory and Application (ITA) Workshop, San Diego, CA, USA (2009)
30. Sun, H., Zhang, T., Zhang, W.: Separating the wheat from the chaff: sensing wireless microphones in TVWS, [arXiv:1205.2141v1](https://arxiv.org/abs/1205.2141v1) [cs.IT] (2012)
31. ICASA, Final terrestrial broadcasting frequency plan 2013, Government Gazette. 36321, South Africa (2013)
32. Ettus Research, USRP family of products, Ettus REsearch, 2014. Available: <http://home.ettus.com/> Accessed 21 May 2014
33. Habeenzu, S.: Zambia ICT sector performance review 2009/2010: towards evidence-based ICT policy and Regulation. Research ICT Africa **2**(17), 1–38 (2010)

34. Kolundzija, B., Ognjanovic, J.S., Sakar, T.K.: WIPL-D: Electromagnetic modeling of composite metallic and dielectric structures. Software and User's Manual, Artech House Publishers, Boston (2000)
35. Lysko, A.A.: New mom code incorporating multiple domain basis functions. In: XXXth URSI General Assembly and Scientific Symposium (URSI GASS 2011), Istanbul, Turkey (2011)