BACHELOR’S THESIS

BACHELOR OF INFORMATION AND COMMUNICATIONS TECHNOLOGY ENGINEERING

Communications Department

2017

JESÚS SANTIAGO FRANCO OROZCO

INTERFERENCE PROTECTION RATIOS FOR THE CO-EXISTENCE OF DTT AND 4G LTE IN THE UHF BAND

MARGENES DE PROTECCIÓN ASOICADAS A INTERFERENCIAS PARA LA CO-EXISTENCA DE LA TDT Y 4G LTE EN LA BANDA DE FFRECUENCIAS UHF

TURKU AMK

TURKU UNIVERSITY OF APPLIED SCIENCES

BACHELOR’S THESIS | ABSTRACT

TURKU UNIVERSITY OF APPLIED SCIENCES

BACHELOR OF INFORMATION AND COMMUNICATIONS TECHNOLOGY ENGINEERING

INFORMATION

2017 | 29 pages

JESÚS SANTIAGO FRANCO OROZCO

INTERFERENCE PROTECTION RATIOS FOR THE CO-EXISTENCE OF DTT AND 4G LTE IN THE UHF BAND

MARGENES DE PROTECCIÓN ASOICADAS A INTERFERENCIAS PARA LA CO-EXISTENCA DE LA TDT Y 4G LTE EN LA BANDA DE FFRECUENCIAS UHF

Nowadays, there is less free range of frequencies for 4G and television. For this reason, this thesis provides a theorical and practical study about two most used of communications standards (DVB-T/T2 and LTE) and interferences in UHF frequency band, thus, reach to get to know what effects can be appear in DTT channel being interfering by LTE channel in two diffirent scenarios. The first with a known signal and the second with a broadcasting signal. And the findings would tells us with how much power level it would be possible to have an adjacent LTE channel to DVB-T/T2 channel.

KEYWORDS:

Ratio protection, interference, adjacent, signal, frequency, channel, IDLE-mode, half-mode, full-mode

CONTENT

APPENDICES

Appendix 1. First Measurements Tests

Appendix 2. Second Measurements Tests

FIGURES

Figure 1. Differences between DVB-T/T2 [2] 5
Figure 2. Resource block parameters for the downlink [4] 7
Figure 3. Downlink OFDM signal generation [5] 7
Figure 4.[6] 10
Figure 5.[7] 11
Figure 6. 14
Figure 7.Variations between OFDMA and SD-FMDA [12] 15
Figure 8.[14] 16
Figure 9. R&S®SFU Broadcast System [15] 17
Figure 10. R&S®ELT TV Analyzer [16] 18
Figure 11. DTU-245 18
Figure 12. DTTV Modulator 18
Figure 13. Sony Bravia 19
Figure 14. Variable Attenuator 19
Figure 15: Power Splitter 19
Figure 16. Indoor Antenna 20
Figure 17. DVB-T2 Known Signal 20
Figure 18. 21
Figure 19. 21
Figure 20. 21
Figure 21. 22

EQUATIONS

Equation 1. Studied Channels 23

TABLES

Table 1. DVB-T2 signal from the DTU generator and center ferequency 786 MHz. 26
Table 3. Diffrence Between Signals Levels by Mode 27
Table 2. Live DTT signal received by an antenna and frequency 538 MHz 27

LIST OF ABBREVIATIONS (OR) SYMBOLS

LTE	Long Term Evolution
DVB-T	Digital Video Broadcasting Terrestial
PLP	Single Physical layer Pipe
LTE	Long Term Evolution
FFT	Fast Fourier Transform
RF	Radio Frequency
QAM	Quadrature Amplitude Modulation
FDD	Frequency Division Duplexing
TDD	Time Division Duplexing
UE	User Equipment
UT	User Terminal
DL	Down Link
UL	Up Link
MIMO	Multple Input Mutiple Output
Mbps	Mega bits per second
PSK	Phase Shift Keying
OFDMA*	Orthogonal Frequency Division Multple Access
SC-FDMA	Single Carrier Frequency Division Multiple Access
TTI	Transmision Time Interval
WCDMA	Wideband Code Diviison Multiple Access
UMTS	Universal Mobile Telecommunicaitons System
FEC	Forward Error Correctons
RB	Resource Block
FSL	Free Space Loss
EIRP	Equivalent Isotopically Radiated Power
IM	Intermodulation
IMD	Intermodulation Distortion

PIM	Passive Intermodulation Distortion
EMI	Electromagnetic Interference
ADI	Adjacent Channel Interference
CCI	Co-Channel Interference
ISI	Inter Symbol Interference
USB	Universal Serial Bus
BNC	Bayonet Neil Concelman
MPEG	Moving Experts Group
PC	Personal Computer
RMS	Root Mean Square
mW	MilliWatts
MLSE	Maximum likelihood sequence estimation
DTTV/DTT	Digital Terrestial Television

1 INTRODUCTION

The thesis covers general theory about DVB-T/T2 and LTE that are communication standards, the theory about effects and possible remedies of interferences.

After that, it is going to measure the protection ratio when there is an adjacent channel on the left and on the right in two different scenarios. The first one with known signal and whoes source is not from broadcasting, and the second one whoes is from broadcasting. Both of them are DVB-T2 because it is wanted to measure the effect which produces LTE signal to DVB-T3 signal. In addion, It is going to explain which material we have operated.

Lastly, it is going to assessed the findings

1.1 A Little of DVB-T/T2 History[1]

From the first days of television until the 1990s, all television broadcasting signals were analogue and it had been not realistic to introduce a digital system because the difficulty of processing was not enough modern. However, with the advance of digital processing methods and the improvement of integrated circuits technology gave way to the possibility of using digital techniques for television feasible.

In 1997 when DVB-T appeared theoretically and was implemented in the in the first countries, for instance: Sweden was the first in 1998 and UK launching their system a year later.

1.2 A Little of LTE History

3G, the previous technology of 4G, has been technology which has had more changes to try improve itself and for this reason LTE was born by the need to ensure the continuity of competitiveness of 3G system for the future, to assure user demand for higher data rates and quality of service, furthermore, it was necessary optimised the packet switch system and reduced complexity because 3G technology could not already offered better features.

2 BACKGROUND

Under this point there is an explanation about the main characteristics and advantages of most communications standards in UHF.

2.1 DVB-T and DVB-T2 Digital Television signal characteristics[1]

2.1.1 FFT size

It allows us converts the signals from time domain to frequency domain, thus it is can analyse it with greater ease. Furthermore, if the signal wants to be sent, it is necessary back to time mode with any signal. On the other hand, the size is defined according to technology, that is to say, when it is used T it is only possible two types of size 2k and 8k. And when it used T2 the range of sizes increase, being xk the number of data in the same window and quantity of data. If it will enhance the amount of points of FFT it could get a better delay tolerance.

2.1.2 FEC

They give the possibility to correct errors when the signal arrives to the receiver because it is added redundancy bits, but the bit rate is decreased and there is a delay rise of each packet.

2.1.3 Extended carried mode

This technique is only available in T2 and it does that data capacity increase a bit. It is not recommendable that has more than two consecutive RF channels, it is better to alternate them.

2.1.4 Guard interval

It is used to guarantee different transmissions do not interfere with another's, doing that relays, echoes and reflections do not affect digital signal. There some possibilities, but we can differentiate two different ways: one of two is to give highest data rete and lowest protection and the other is the opposite (1/32), to offer the best protection and lowest data rate (1/4). A/B, it means that B is total data, being A is control data and the subtract between B-A is useful data to send.

2.1.5 Scattered Pilots

They are symbols with amplitude and phase known by receivers because thus, we can measure what characteristics the channel has in time and frequency and with these measurements to construct estimates of the channel response. There are eight types of pilot patterns.

2.1.6 Standard radio channel models used in DVB-T / T2 testing

It refers the number of symbols there is in T2-frame. There are three constraints imposed: The first is that the maximum frame T2-frame length is 250 ms, the second is that the minimum number of symbols is fixed. And third, in 32K mode the number of symbols is always even. But it depends on what we need it, it will use a shorter value for frame length or longer value for frame length. For instance, with these characteristics (32KE, PP7, 256-QAM, CR=3/5, GI=1/128, Nldpc=64800) the best option is sixty symbol per frame, but that is not always the used by the countries.

2.1.7 Super-frame length

That mode is only used is the minimum super-frame length is more than two frames and other technics items.

2.1.8 A or B Input mode

These modes are used in DVB-T2 but the biggest difference in simple words is that A is more straightforward than B.

The A mode or too known as PLP, it only takes single transport or generic transport in one PLP, they are two different kind of protocol of communication. That mode has the unchanged modulation and codification during transmission.

On the another hand, the B mode carries more than one input stream, which might include both kind of streams, the interleaving is bigger than. And it can offer high-bit rate fixed services and rugged mobile services in the same multiplication too.

2.1.9 Number of sub-slices

Normally, these should be as larger as possible in type two and one slice per T2 frame in type one.

2.1.10 Interleaving parameters

On one hand, the first is an extreme, increasing the number of time interleaving blocks with the same frame length, thus it increases the resistance to impulse interference.

On the other hand, the second option is that increasing the number of TI blocks increases the maximum data rate for physical layer pipe (PLP).

2.1.11 Rotated constellations

It reduces error bit rate because it disappears one of the two axis during transmission and common symbols are reconstructed from the value of single axis of the constellation, by that same axis and a given angle.

2.1.12 Code rate, block length and constellations

Higher code-rates and higher-order constellations both give greater bit rates but require higher signal-to-noise ratios.

2.1.13 Differences between DBV-T/T2[2]

	DVB-T	**DVB-T2** (new/improved options in **bold**)
FEC	Convolutional Coding+Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8	LDPC + BCH 1/2, **3/5**, 2/3, 3/4, **4/5**, 5/6
Modes	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM, **256QAM**
Guard Interval	1/4, 1/8, 1/16, 1/32	1/4, **19/128**, 1/8, **19/256**, 1/16, 1/32, **1/128**
FFT Size	2k, 8k	**1k**, 2k, **4k**, 8k, **16k, 32k**
Scattered Pilots	8% of total	**1%, 2%, 4%**, 8% of total
Continual Pilots	2.0% of total	**0.4%-2.4%** (0.4%-0.8% in 8K-32K)
Bandwidth	6, 7, 8 MHz	**1.7, 5**, 6, 7, 8, **10** MHz
Typical data rate (UK)	24 Mbit/s	**40 Mbit/s**
Max. data rate (@20 dB C/N)	31.7 Mbit/s (using 8 MHz)	**45.5 Mbit/s** (using 8 MHz)
Required C/N ratio (@24 Mbit/s)	16.7 dB	**10.8 dB**

Figure 1. Differences between DVB-T/T2 [2]

2.2 LTE 4th generation mobile system signal characteristics[3]

2.2.1 Acces mode

FDD or TDD with a common 10 ms frame timing but different frame structures, where FDD means a transmission between BS to UE/UT or vice versa where each signal each is sent by the same time but with different frequency, and besides, TDD means the same as above but here, the frequency unchanged ant it uses different slots of time to send signals.

2.2.2 Variable channel bandwidth

There is scalable band, from 1,4 MHz to 20 MHz where they can be view $[1{,}4\ 3\ 5\ 15\ 20]\ \mathrm{MHz}$ and all of them available for FDD and TDD.

2.2.3 **Baseline UE capability**

Normally, it is common used 20 MHz band for UL as well as DL and two and one antennas respectively.

2.2.4 User data rates

DL can get 172.8 Mbps with 2x2 a single user that using MIMO trough 64QAM and 326.4 Mbps with antenna 4x4 MIMO. On the other hand, UL achieves 86.4 Mbps with single link and using 64QAM too.

2.2.5 Downlink Transmission

The multiplexing used in DL transmission is OFDMA inasmuch as it has ample efficiency and lowest latency than the previous technologies, for example WCDMA in UMTS. Here, it uses OFDMA multi-carrier modulation scheme with closely-spaced orthogonal sub-carrier during a determined time. All slots are used as time as frequency in downlink.

The block structure consists of $N_{RB}^{DL} \times N_{SC}^{RB}$subcarriers in the frequency domain and N_{Symbol}^{DL} OFDM symbols in the time domain, where N_{RB}^{DL} denotes the downlink transmission bandwidth, expressed in multiples of N_{SC}^{RB}

In general, there are two kind of channels, traffic channels (TCH) and control channel (CCH). The first of both is used for send data and another for control data, but, in fact they are not used as such because there are wide variety of T/C channels. Among these are the following, besides, under this, it shows how is packet structure. And last part, it reproduces the downlink diagram block.

Configuration	Δf	OFDM symbols per slot	Cyclic prefix length
Normal CP	15 kHz	7	160 for l=0
			144 for l=1…6
Extended CP	15 kHz	6	512 for l=0…5
	7.5 kHz	3	1024 for l=0,1,2

Figure 2. Resource block parameters for the downlink [4]

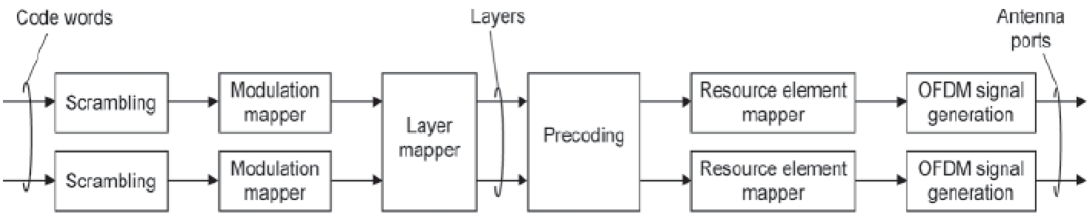


Figure 3. Downlink OFDM signal generation [5]

2.2.6 Uplink transmission

This uses another kind of multiplexing which is SC-FDMA. That is the amount of OFDMA with Transform Fourier (FFT) block previously (just behind Precoding) in order to have flexibility and variability. The uplink resource grid consists of $N_{RB}^{UL} \times N_{SC}^{RB}$ subcarriers in the frequency domain N_{Symbol}^{UL} SC-FDMA symbols in the time domain, where N_{RB}^{UL} denotes de uplink transmission bandwidth, expressed in multiples of N_{SC}^{RB}, it defines the number of subcarriers per 180 kHz RB. The big difference between UL and DL is that in scenery of UL does not always utilise all spectrum such as time as frequency.

2.2.7 DL spatial diversity

Out signal only depends on input signal, in other words, that is open loop Tx diversity, it is for single user and works MIMO up to 4x4 supportable

2.2.8 UL spatial diversity

It may work to open loop Tx diversity, 2x2 multi-user MIMO and optional 2x2 single user MIMO

2.2.9 Transmission time interval and H-ARQ retransmission time

With the first configuration is only one microsecond to each time interval, with the second it is increased to 8 microseconds. It reduces de capacity or effective binary rate; nevertheless, it only works if it is needed, that to say, it is possible receive the same bit packet twice without discard any of them and the state of the packet, wrong or correct is independently. This is useful when appears fast fading and it is possible obtain some packets which are the same.

2.2.10 Frequency hopping

It is observed two possibility cases; intra-TTI between the same frequency where in UL one per 0.5 ms slot and DL one per 66 µs symbol. Inter-TTI has the same delay as across retransmissions.

2.2.11 Bearer Servicies

It supports packet switching, and not circuit switching. Second one needs to keep resources to do the connexion. However, the second one just need a long header to deliver fundamental information.

2.2.12 Unicast scheduling scheme

There are two: Frequency Selective and Frequency Diversity. First, it separates in two bands, one which we want to receive and it will be discarded. And Second, it uses two frequencies to send the same information by frequency hopping.

2.2.13 Multicasting

Enhanced Multimedia Broadcast/Multicast Service (eMBMS) supporting Multicast/Broadcast over single frequency network (MBSFN).

2.3 Radio Interference Phenomens and Parameters

As of now, it analyses the factors which perturb signal during its path. The common word which is used to mention it is known as attenuation, but attenuation is a general term. It can define as any reduction in the strength of the signal. It could be divide in the following categories.

2.3.1 Path Loss

It is the power reduction of Radiofrequency Signal which spreads through space, it is expressed in dB and they depend on:

- Distance from transmitter antenna to receiving antenna.
- Line of the sight between receiving and transmitting antennas.
- Antenna height.

2.3.2 FSL

It is the loss in signal strength of an electromagnetic wave that would result from line of sight path through free space, normally air, with no obstacles nearby to cause reflection or diffraction.

2.3.3 Antenna Characteristics

They are own internal benchmarks of each antenna. Main characteristics os antennas are gain and radiation pattern.

2.3.4 System Characteristics

Main system parameters in transmitter and receiver sites are:

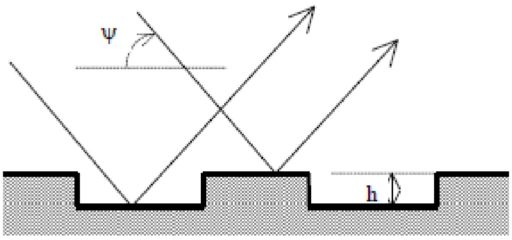
- Receiver sensibility with which it is possible to know the minimum radiofrequency signal power level required at the input of receiver for certain performance. It depends on the effect which the noise cause around the system.
- EIRP. It is the amount of power that would emit a theoretical isotropic antenna to produce the power density in the maximum direction gain of antenna.

2.3.5 Signal Fading

Several physical phenomenas affect the radio signal propagating from the transmitter antenna to the receiving antenna. These cause signal attenuation and different fading effects.

2.3.6 Reflection

It is the change in direction of a wavefront at an interface between two different mediums without enter on the second medium, then the wavefront does not shift to the second medium and it is reflected with exactly the same incidence angle (Ψ). There are two kinds of surfaces according to reflection, smooth surface or rough surface. It depends on the angle of incidence and the surfer roughness. Normally our signal is the sum of reflected components.



$$\sigma_h < \frac{\lambda}{8\sin(\Psi)}$$

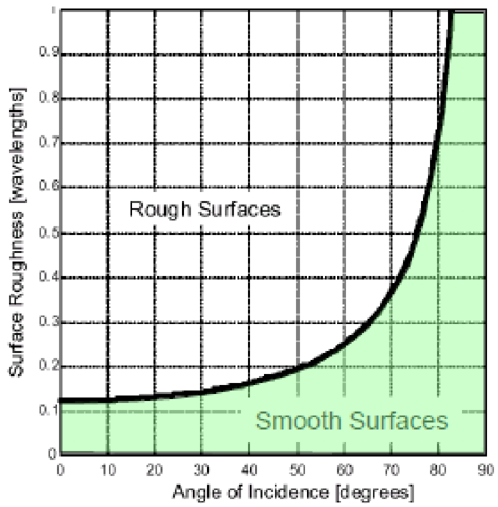


Figure 4.[6]

2.3.7 Refraction

It is the natural extension of above section when there is change of medium; the phenomenon refers to the change in direction of wave propagation due to change in its transmission medium. That is remarkable because signal sometimes crosses the Ionosphere (from 60 km to 1,000 km high) as a result it can move through that atmospheric layer.

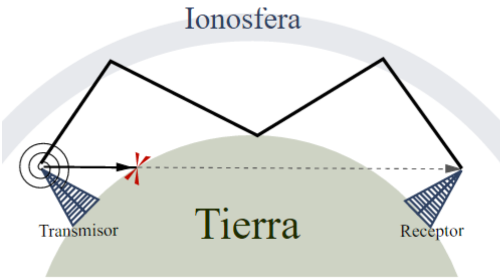


Figure 5.[7]

2.3.8 Surface Wave

That is only happen when the wave is between 10khz and 30Mhz.

2.3.9 Weather Conditions

Attenuation of Atmospheric, Hydrometeors and Vegetation belong between 400MHz to 900 MHz and are not too much strong. They are considered as different kind of noises also

2.3.10 **Fading**[8]

It is possible differentiate two terms; fast and slow fading. They refer to the rate at which the phase and magnitude change imposed by the channel on the signal changes. The coherence time (mathematic expression comes after) measure of the minimum time required for the magnitude change or phase change of the channel to become uncorrelated from its previous value.

- ***Slow fading/shadowing***

It arises when the coherence time of the channel is large relative to the delay requirement of the application. With this regime, the phase and amplitude change imposed by the channel can be considered approximately constant over the period of use. Slow fading can be caused by events such as shadowing.

- ***Fast fading***

Occurs when the coherence time of the channel is small relative to the delay requirement of the application. In this case, the amplitude and phase change imposed by the channel varies considerably over the period of use.

In a fast-fading channel, the transmitter may take advantage of the variations in the channel conditions using time diversity to help increase robustness of the communication to a temporary deep fade. Although a deep fade may temporarily erase some of the information transmitted, use of an error-correcting code coupled with successfully transmitted bits during other time instances (interleaving) can allow for the erased bits to be recovered. In a slow-fading channel, it is not possible to use time diversity because the transmitter sees only a single realization of the channel within its delay constraint. A deep fade therefore lasts the entire duration of transmission and cannot be mitigated using coding.

2.3.11 Interferences/ Noise/ Scattering

Mostly, interferences are anything which modify and/or disrupt the signals as they are travel along a channel between a source and receiver, which is why, such analysis need not pretended establish a fix manner how to describe the interferences.

- ***Noise*** *[9]*

Which its name implies, consists of any undesired signal in a communication system. It has been included noise as type of interference not to make many subdivisions and it will be more easy to explain for us. For our discussion, noise is broken down into two categories and not four how is said in [6] because we considered Crosstalk as another type that deserves to be discussed separately and impulse noise can be an example of EMI.

- *Thermal noise:* It occurs in all different transmission media and communication equipment and arises form random electronic motion. Its function which describes its distribution of energy is known as Gaussian distribution of levels motion. It is noted that it has a flat frequency response and its effect is different by how bandwidth varies.

Δf	180 kHz	200 kHz	1 MHz	2 MHz	3.84 MHz	8 MHz	20 MHz
Thermal noise power	-121.45 dBm	−121 dBm	−114 dBm	−111 dBm	−108 dBm	−104 dBm	−101 dBm
Note	One LTE resource block	GSM channel	Bluetooth channel	Comercial GPS channel	UMTS channel	DVB channel	WLAN−101 dBm

- *(IM) noise:* In fact, it can be active (IMD) or passive (PIM). Normally, the first is generated by active element as frequencies mixer in superheterodyne receivers. On the other hand, PIM are caused by passive components, being the material with which is fabricated, or even, the age or some defect thereof.
- *Impulsive noise:* It is consisting in irregular pulses of short duration and relatively high amplitude

- ***EMI***

Also called radio frequency interference and by ITU (International Communication Union) is *«The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy».* [10]

All electronic apparatus radiate electromagnetic fields which pollutes the radio spectrum and is called man made noise. The easiest manner to prevent EMI is at the beginning of design, but that is not always possible, normally, the components come assembled and it is necessary very special staff to make it. Others possibilities are, for instance, shield sensitive modules or add new of them with different functions which will can resolve the problem.

- ***Doppler***[11]

The Doppler effect is well known as the connexion with the variation which occurs in the frequency of a phenomenon when the source moves at a certain speed with respect to the observer. That is to say, the carrier frequency suffers an offset equal to: $fd=v/\lambda$ for one path.

If we have a terminal that is moving in environment with multiple paths of propagation, each pathway has own trajectory described as $cos(\varphi)v/\lambda$, being φ the angle of each signal impinging which has a frequency displacement.

At the end, power spectrum of the received signal can have dispersed such as the next figure:

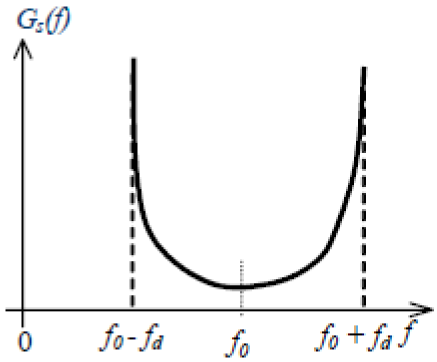


Figure 6.

- ***ACI***

Basically, they are power level spurious originated in signals by parallel channels, for example by CH-B and CH-C. It occurs for two reasons.

First, CH-A receives some emissions from both channel due to its "roll off" of selectivity filters are designed to select a channel ant not two or three of them then do not eliminate a signal completely. Second, due to intermodulation in CH-B and CH-C amplifiers, which cause the transmitted spectrum to spread beyond what was intended. The problem of signal interference on adjacent bands can be mitigated by selective filters in the receiver, and the problem of signal fades can be mitigated by engineering techniques such as power control, channel coding, intertwined or diversity.

- ***CCI – Crosstalk***

The co-channel interference arises in the cellular mobile networks owing to this phenomenon of frequency reuse. Thus, besides the intended signal from within the cell, signals at the same frequencies (co-channel signals) arrive at the receiver from the undesired transmitters located (far away) in some other cells and lead to deterioration in receiver performance. To prevent this problem, each slot must work with orthogonal radio resources. This is one of the reasons that LTE is used OFDMA in DL and SC-FDMA in UL.

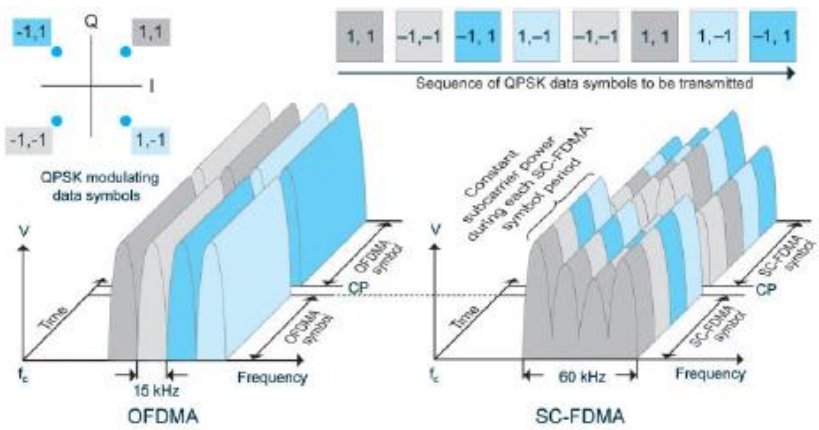


Figure 7.Variations between OFDMA and SD-FMDA [12]

Sometimes, working with orthogonal radio resources is not enough, when it is talk about Co channel interference, it is left out the difference between amplitude power which has each channel. Further on, it is explaining how this happen and it is show the results obtained.

- ***ISI*** *[13]*

This category of interference distorts the received signal, it is manifested in the temporal spreading and consequent overlap of individual pulses to the degree that the receiver cannot reliably distinguish between changes of state, that is, between individual signals elements.

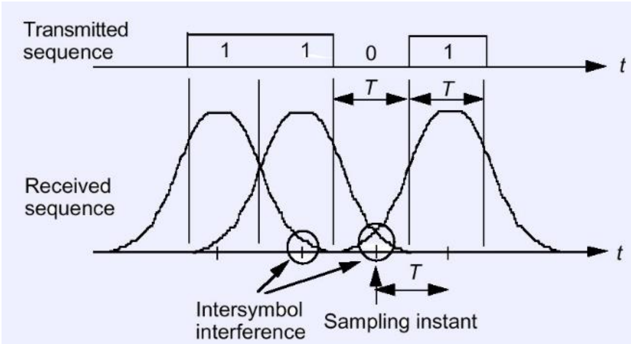


Figure 8.[14]

One of the methods to decrease wherever possible this type of intrusion is design the system with short impulse responses that are short enough to reduce the possibility of signals crossing over to other symbols within the transmission. An additional hardware solution is to add an equalizer that might work as an inverse filter because that removes the channel effects and increases the ability to receive signals. Last hardware solution is to put a raised cosine filter due to its capacity to minimise Inter-Symbol Interference.

On the other hand, there are some software solution as for example to separate symbols through guard bands then, it prevents from being received out of order or cluttered. Further instance is a MLSE is a mathematical algorithm to extract useful data of noisy data stream.

3 LABORATORY MEASSUREMENTS

3.1 Equipment used in Measurements

This section describes the equipment and accessories which were used to build up the test system for DTT an LTE protection ratio measurements.

3.1.1 R&S®SFU Broadcast System [15]

The R&S®SFU broadcast test system is a multi-standard signal generator that is used worldwide. It provides a platform that supports all conventional TV and audio broadcasting standards and is used as a reference signal source. It will allow us to generate a DVB-T2 signal directly with internal parameters or recreate a LTE signal by means a .WV file. On the one hand, Internal features could change with the first parameter, and visualize almost all of them. But, on the other hand, it is only possible modify two own internal features when the signal is created from in a file, frequency and power.

Figure 9. R&S®SFU Broadcast System [15]

3.1.2 **R&S®ELT TV Analyzer [16]**

The R&S®ETL TV analyzer stands for all-in-one. The R&S®ETL combines the functionality of a TV and FM (radio) signal analyzer, a video and MPEG TS analyzer and a spectrum analyzer in a single instrument. It has been possible measure the different power levels accurately and show us the parameters which are not easy to display theoretically. Among those are the Power Signal or Channel Level which is sum of each Orthogonal Frequency Digital sample, bandwidth of the same, BER, constellation, frequency response… And of course, R&S®ETL TV analyzer was useful to make the measurements and extracts the margins of protection ratio.

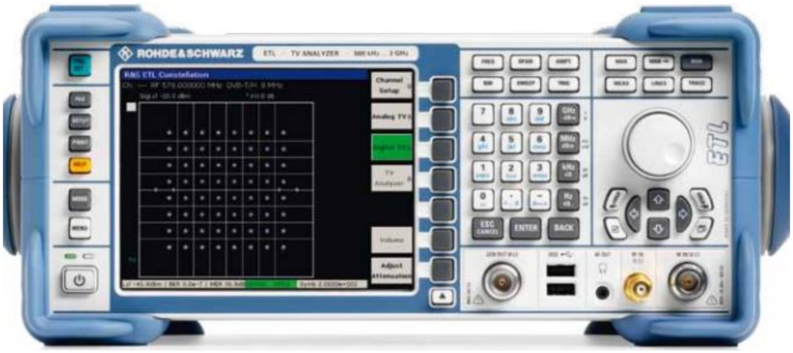


Figure 10. R&S®ELT TV Analyzer [16]

3.1.3 DTU-245 [17] [18]

This compact USB adapter or player was used to capture and generate MPEG-2 (DVB-ASI) transport streams enabled by StreamXpress software through USB and then, to deliver the data stream to DTTV modulator by BNC connector. The control was a PC with static IP to can establish the connexion between the PC and the modulator.

Figure 11. DTU-245

3.1.4 DTTV Modulator [19]

NetMod-DTTV broadcast modulator has been designed to provide a cost effective and high quality solution for broadcast network operators, system integrators and transmitter manufacturers aiming to deploy digital TV services over DVB-T, DVB-H or DVB-T2 networks in MFN or SFN environments. It collects the stream data in MPEG-2 TS input port that come from DTU-245. After, the stream is modulated to send through RF channel.

Figure 12. DTTV Modulator

3.1.5 Sony Bravia TV

This smart TV was utilized in the signal visualization to check in which moments the channel experienced disturbances or the reverse, can say everything is correct. For instance, it was employed as receiver to verify the field measurement of protection ratio between DVB-T2 and LTE.

Figure 13. Sony Bravia

3.1.6 8494B, 8495B and 8496B variable attenuators

They were useful as much to fix reference constant power levels as to search which power level was the most suitable to each moment. It operated with *8494B* to reduce power level one dB at a time. Instead, it worked with *8495B and 8496B* to reduce power level ten dB at a time. It is added the datasheet in the references [20]

Figure 14. Variable Attenuator

3.1.7 Power Splitter

Generally, splitters are for divide the signal, but it was used to add two different signals in the same cable channel at the beginning, and hereinafter, to separate both of them. It is added the datasheet in the references [21]

Figure 15: Power Splitter

3.1.8 Indoor Antenna

Figure 16. Indoor Antenna

The antenna located in the left, has been used to realize the measurements of the band UHF frequencies. It is clearly appreciated that this device, is an indoor antenna. During the second measuring process, also known as the validation method, the antenna was invariable and fixed, located in a place next to the window and not in the center of the laboratory.

Frequency Range: 470-860 MHz

Brand: Aerial Oy antenna

3.2 Used Signals and Spectrum

3.2.1 DVB-T2 known

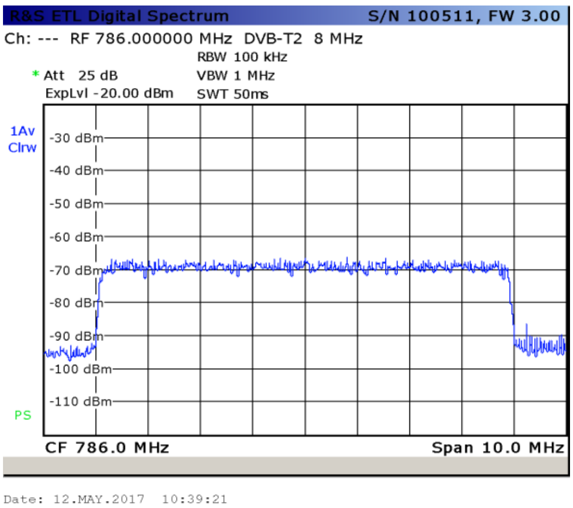


Figure 17. DVB-T2 Known Signal

Parameters T2-Known-Signal	
Source Power Level	-10 dBm
Receiver Power Level	-50 dBm
BW	8 MHz
FFT size	32 K Ext
Guard interval	1/128
Modulation	654-QAM
Fc	786 MHz
Code rate	4/5
Scattered Piots	PP7

3.2.2 LTE-DL Signal Full Mode

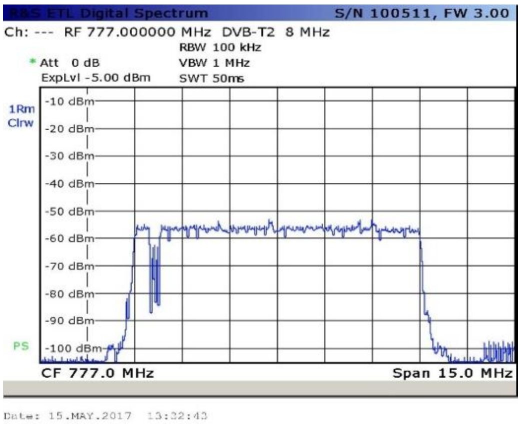


Figure 18.

The three signals have the same parameters	
Source Power Level	10 dBm
Receiver Power Level	Variable
BW	10 MHz
FFT size	1024
Number of Resource Bloks	50
Occupied Channel BW	9.015 MHz
DL BW efficiency	90%

3.2.3 LTE-DL Signal Half Mode

Apparently, full mode and half mode are by no means equal, but it will be view how in the protection ratio are very similar.

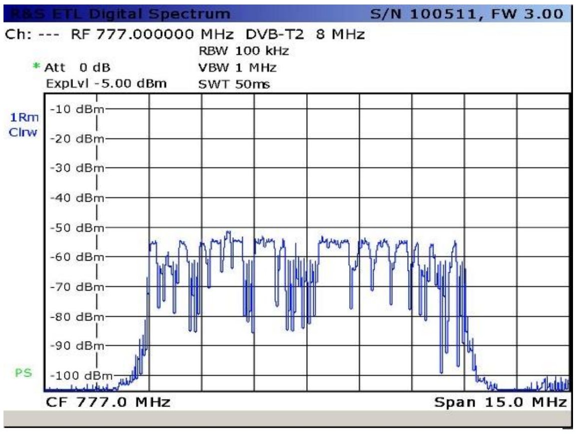


Figure 19.

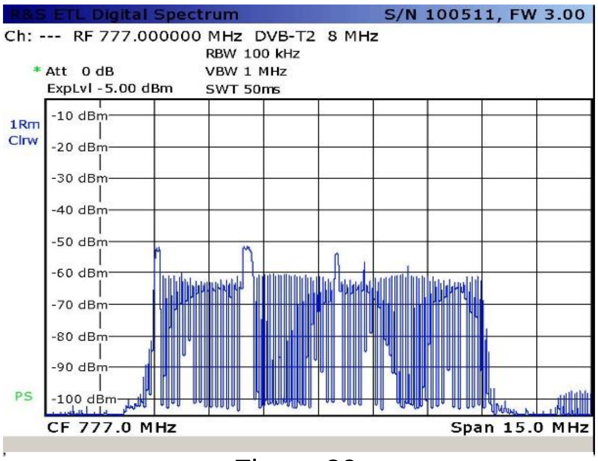


Figure 20.

3.2.4 LTE-DL Signal IDLE Mode

Evidently, that signal is much more different to other signals. This case is more normal than we think because, for instance the system is some empty or unproductive at nights or other special hours over day.

3.2.5 Spectrum of Turku

This is the radioelectric spectrum of Turku, where we can appreciate the different response of the channels in real world, the difference on amplitude and form between T2-signals or T2-channels, also, between LTE-channel to DVB-T2 channel.

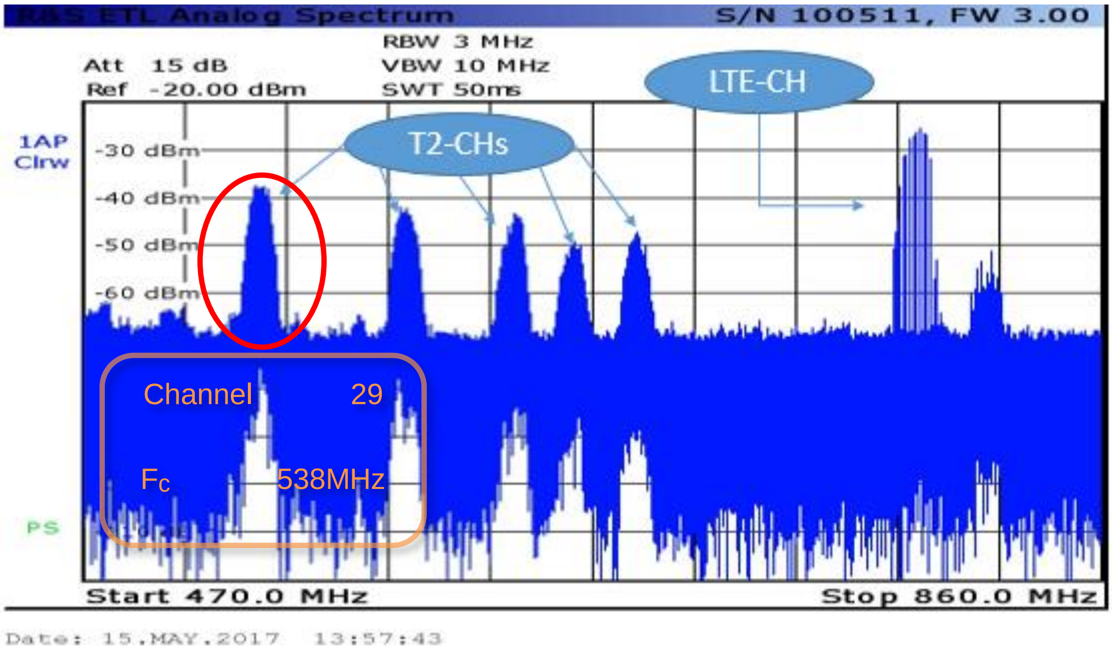
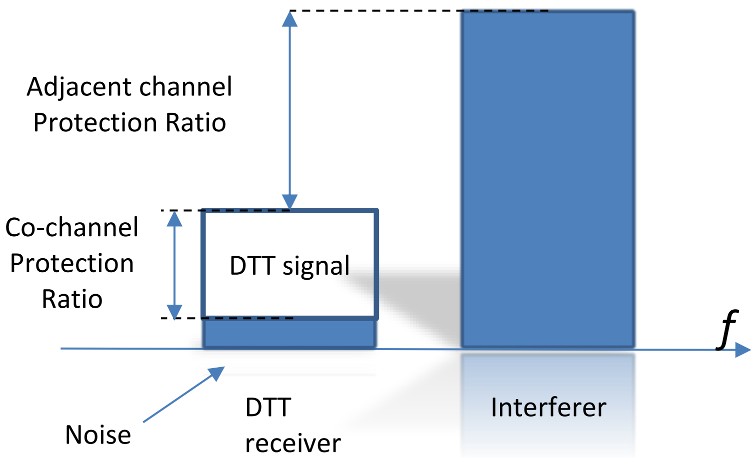


Figure 21.

3.3 DVB-T2 Adjacent Channel Protection Ratio Measurement

Protection ratio is the minimum difference between the desired $X_1(f)$ and not desired $X_2(f)$ signal, expressed in dB [dBm-dBm=dB] , at the receiver's input in order to meet a given quality requirement.



3.3.1 Methodology

During this section, the following topic will be discussed, the different ratios protection for five adjacent channels which will be both above and below the channel number N.

This method consists in the following. First, select a channel N from a given frequency; in this case, 786 MHz was the channel central frequency chosen and 538 MHz was the central frequency of the channel we validate the first measures. However, both have the same process. This channel will stay stable and will not change because it is necessary to wait until having a response by each adjacent channel. The adjacent channels will be the followings:

$$\sum_{i=-5}^{n=5} N + i, \forall\, i \neq 0$$

Equation 1. Studied Channels

Second, for the realization of the measures, an entry power of the receptor is already given to the television as well as the spectrum *analyzer*. The power level chosen is -50 dBm, in other words, 0.01 mW. This value has been chosen because it is considered not to be a high level for the signal receptors as well as not too low so it can be inhibited by the defects of the components used. Some examples of this components can be, wires, splitters, attenuators, connectors… The description, the blocks diagram, the system assembling will be discussed in the following pages.

Additionally, it is convenient to calibrate and check the losses in which every element of the system introduces. Also, it is important to compare them with each corresponding datasheet. In addition, when elaborating this process, it has to be taken into account that the changes are not instantaneously done and it will be needed around thirty seconds, but preferably sixty seconds of waiting in order to make the visual subjective decision of the picture quality; failures or no failures.

The measurement consists of the following; to increase the interferer LTE power *(N±i),* this is done by reducing the attenuator variable gain, which means, keeping the channel N DTT power as a constant. The power will increase from decibel to decibel until reaching a decibel level which would stop not stop completely but cause falures in some pixels of the picture. This is the protection ratio threshold where LTE signal starts to interfere the DTT reception and this effect is known as adjacent channel interference. According to the ITU, this value varies depending on the characteristics of signals and receiving apparatus like iDTV, STB etc…. For instance, the ratios is not going to be the same for different channels *(N±i),* neither will be the same for a same channel, because the signal suffers of different energetic states thru time. For example, this can be explained with the number of users who are utilizing the range of the spectrum by channel *(N±i)* because it has not always the same throughput at the same time (one hundred perfect of usage. fifty per cent of usage or IDLE mode)

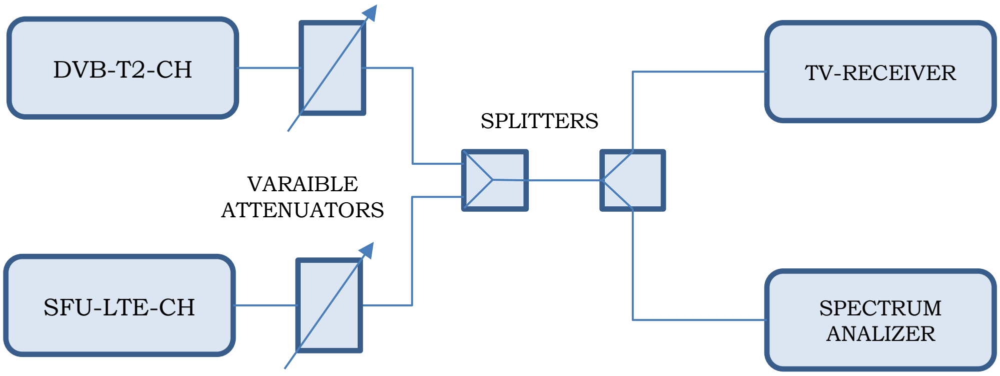
Once the signal power level has been found *N±i,* which will interfere in signal N, it would be necessary to decrease the attenuator one decibel. When the signal is stabilized and there are no adjacent channel interferences in the channel N, it will be necessary to calculate the difference of the amplitudes between signals. There are two different ways to calculate the value. First, it is possible to do this by counting the *Spectrum Analyzer* squares of the and doing a close eye view into the measure; thus, looking for the SPAN size. On the other hand, the second way will be, using the markets which are able by the *Spectrum Analyzer*. This last, will be the best and more precise form to calculate the value. Additionally, to reduce the variation of the maximums and minimums, the tools "*Average*" and/or "*RMS*" are the more used on "*Trace"* mode. This process provides a better result that the options mentioned before. This last ELT which is the analyser device characteristic creates a better confidence interval, which will change from ±5 dB to ±1by a high percentage of the measurements performed.

3.4 Measurement System block Diagrams

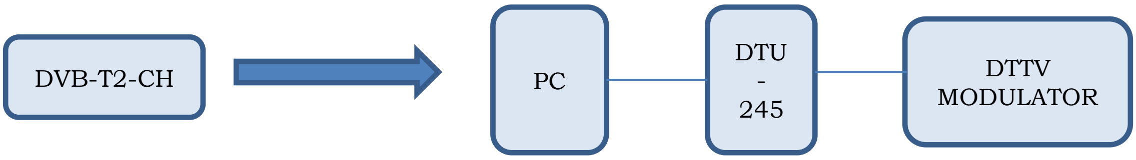
The measurement system is described with three separate block diagrams : Transmitter, passive and receivers elements.

3.4.1 DTT-LTE Protection Ratio Measurement system block diagram

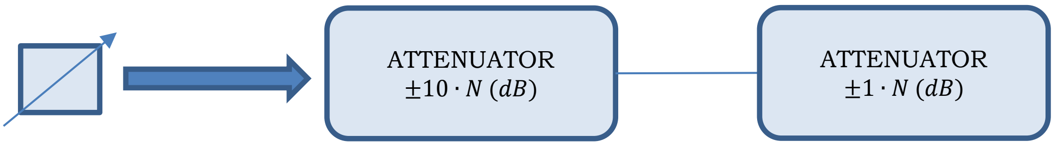
The tv picture content test file (MPEG-2) is selected in the the PC and the serial signal stream (DVB ASI) is created in the stream player DTU-24. The modulating stream is fed to the modulator which creates the rf carrier signal (DTT channel center frequency) and DVB-T2 modulation. Interfering LTE signal comes from the SFU generator. DTT and LTE signals are combined in the first splitter and then devided in the splitter to the iDTV, Device Under Test (DUT) and DTV analyses in paralle. Block diagrams of the entire systems and detailed sub parts are presented under.



DVB-T2 signal generation by pc, stream palyer and DVB-T2 modulator

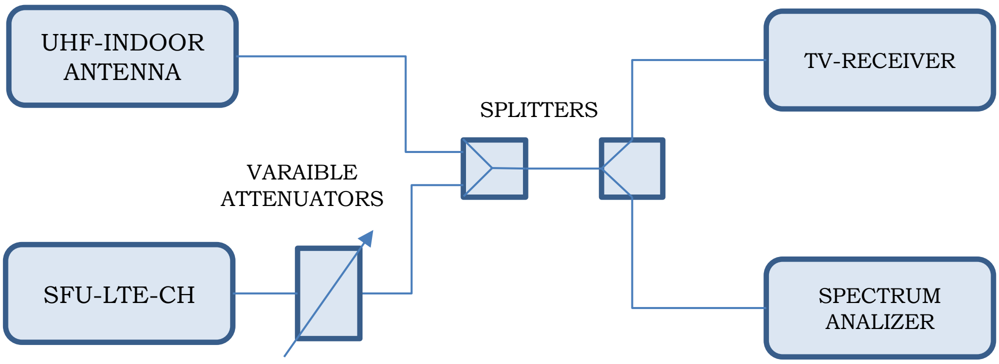


The variable attenuator, is formed by two variable attenuators. The first one, reduces the signal amplitude by ten decibels when it does a turn on the wheel. The latter, reduces the signal by one decibel; therefore, the outcome is more precise.



3.4.2 Block Diagram to Validate Protection Ratio

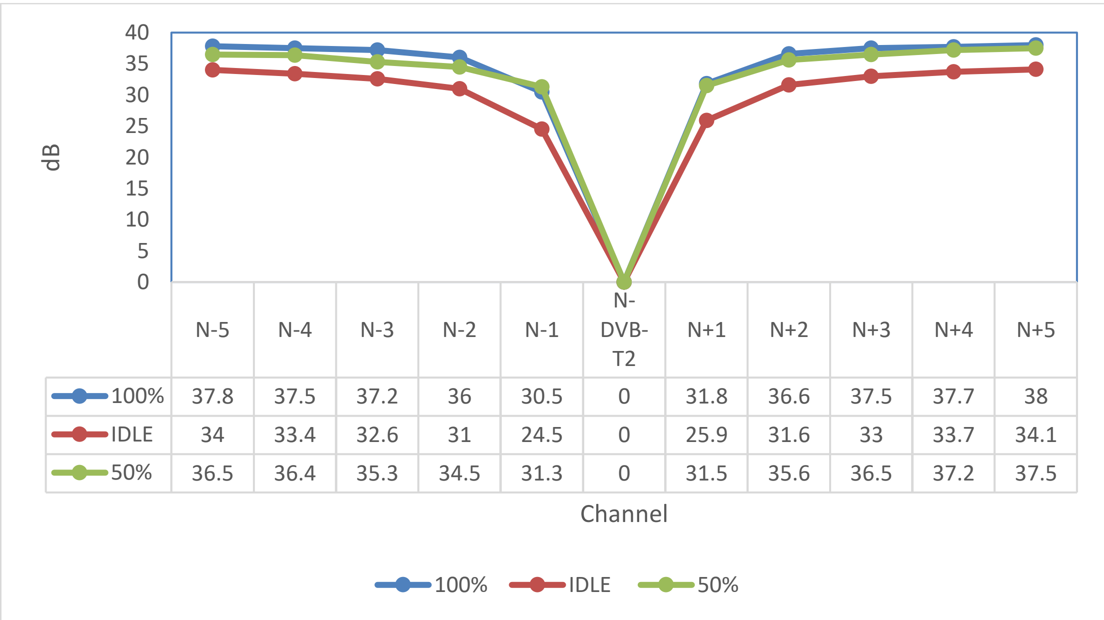
This last block diagram, is utilized in the measurement validation process. In other words, it validates by a more realistic form than the results obtained in the previous processes. Thus, it would be a more efficient on a real life scenario. The difference now is, the DVB-T2 signal is not a known test stream instead it is live tv content. TV signal is captured by the indoor antenna, which captures just a part of the radio electric spectrum in which it is located. Usually between the 470 MHz y los 860 MHz, an example would be, a television channel.



3.5 Results

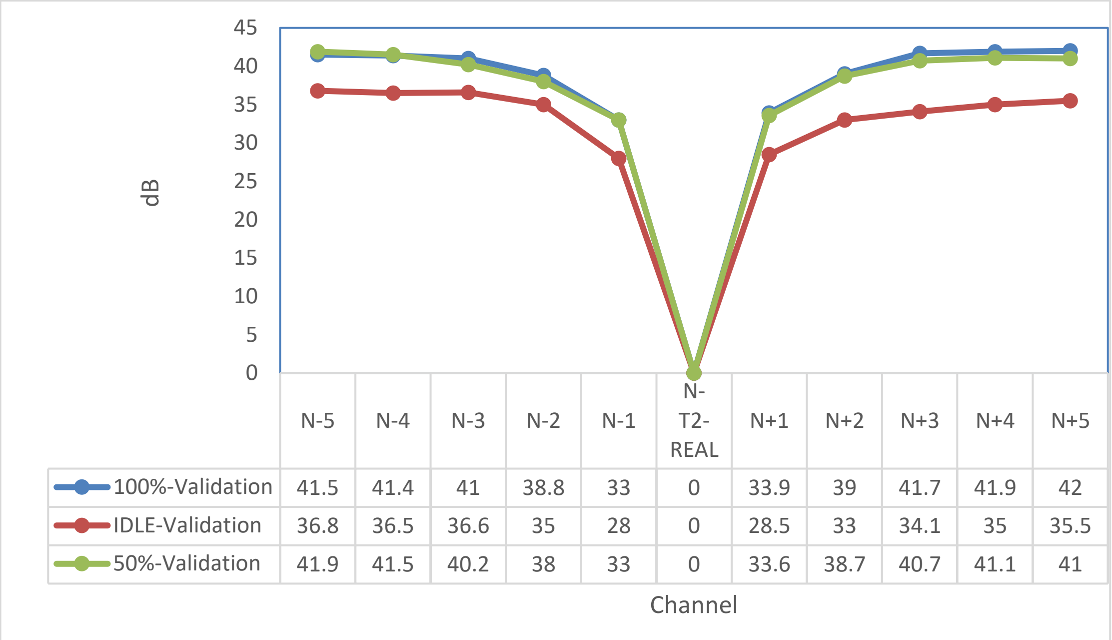
3.5.1 First and Second/Validation Round of Measurements

The calculated Protection Ratios are presented under. Corresponding excel sheet are in appendix 1 and 2.



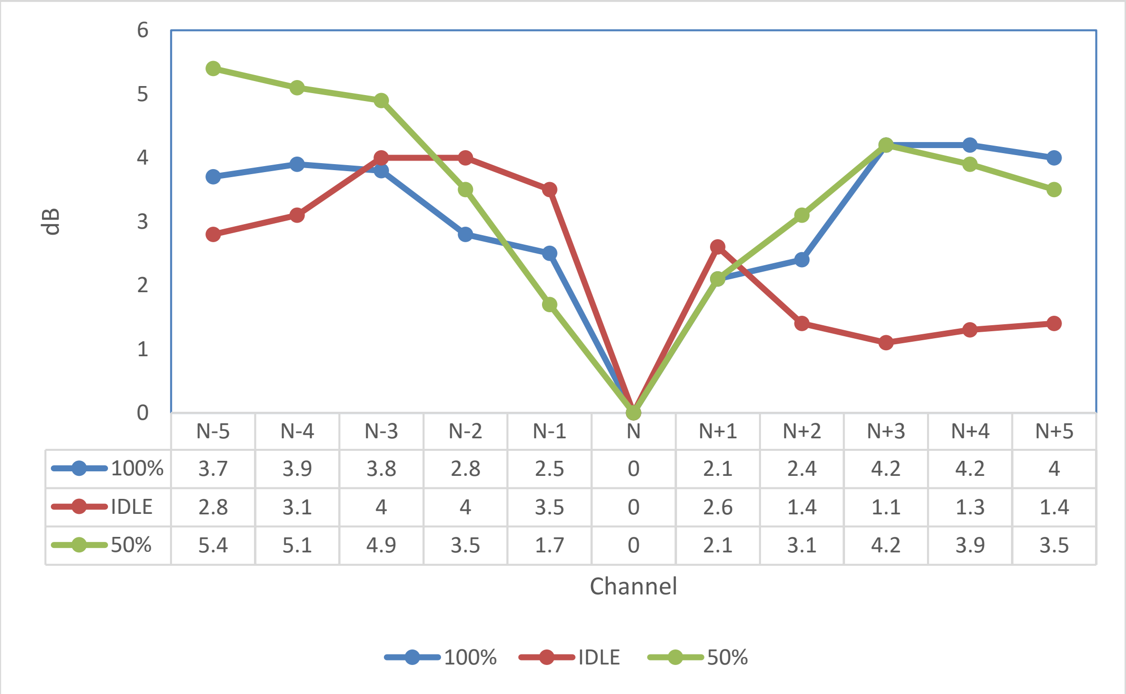
	N-5	N-4	N-3	N-2	N-1	N-DVB-T2	N+1	N+2	N+3	N+4	N+5
100%	37.8	37.5	37.2	36	30.5	0	31.8	36.6	37.5	37.7	38
IDLE	34	33.4	32.6	31	24.5	0	25.9	31.6	33	33.7	34.1
50%	36.5	36.4	35.3	34.5	31.3	0	31.5	35.6	36.5	37.2	37.5

Table 1. DVB-T2 signal from the DTU generator and center ferequency 786 MHz.



	N-5	N-4	N-3	N-2	N-1	N-T2-REAL	N+1	N+2	N+3	N+4	N+5
100%-Validation	41.5	41.4	41	38.8	33	0	33.9	39	41.7	41.9	42
IDLE-Validation	36.8	36.5	36.6	35	28	0	28.5	33	34.1	35	35.5
50%-Validation	41.9	41.5	40.2	38	33	0	33.6	38.7	40.7	41.1	41

Table 3. Live DTT signal received by an antenna and frequency 538 MHz



	N-5	N-4	N-3	N-2	N-1	N	N+1	N+2	N+3	N+4	N+5
100%	3.7	3.9	3.8	2.8	2.5	0	2.1	2.4	4.2	4.2	4
IDLE	2.8	3.1	4	4	3.5	0	2.6	1.4	1.1	1.3	1.4
50%	5.4	5.1	4.9	3.5	1.7	0	2.1	3.1	4.2	3.9	3.5

Table 2. Diffrence Between Signals Levels by Mode

3.5.2 Analysys Results

It seems that the obtained results are the ones expected, the IDLE mode has a protection ratio lower than half and full mode, nonetheless, the difference is quite detectable between these two last modes. In other words, the difference between the two modes exists, yet it is minimum for compering scenario A with the resource consumption of 50% and B scenario with the resource consumption of 100%. This happens with both the measures of a known signal as well as with a signal transmitted by a broadcasting diffusion evidently.

In second place, the protection ratio stabilizes as the distance increases from the N channel from above and below. In other words, it tends to have a fixed value, which in an extreme scenario, will decrease due to the saturation excess induced to the increase on the interfering signal level.

Last, and possibly the most surprising result is the difference between the two measurments series used during the protection ratios obtention and the second serie, in which the previous results were validated. As a result, the average will then will be the difference higher than 2 dB having as an input power lever -50 dBm in the both cases. Show Table 3.

REFERENCES

[1] https://www.electronics-notes.com/articles/audio-video/broadcast-tv-television/what-is-dvb-t2-basics-tutorial.php

[2] http://www.etsi.org/deliver/etsi_ts/102800_102899/102831/01.02.01_60/ts_102831v010201p.pdf

[3] https://www.dvb.org/resources/public/factsheets/dvb-t2_factsheet.pdf

[4] LTE and the Evolution to 4G Wireless, Design and Measurement Challenges, Second Edition

[5] ESTI de Telecomunicación. Universidad Politécnica de Valencia, Transparencies of Moble Communications

[6] LTE and the Evolution to 4G Wireless, Design and Measurement Challenges, Second Edition, Figure 3.2-8.

[7] ESTI de Telecomunicación. Universidad Politécnica de Valencia, Transparencies Radiocomunicaciones

[8] ESTI de Telecomunicación. Universidad Politécnica de Valencia, Transparencies Radiocomunicaciones

[9] Tse, David; Viswanath, Pramod (2006). *Fundamentals of Wireless Communication* (4 ed.). Cambridge [Eng.]: Cambridge University Press.. ISBN 0521845270.

[10] http://www.ie.itcr.ac.cr/acotoc/Maestria_en_Computacion/Sistemas_de_Comunicacion_II/Material/Biblio5.pdf

[11] ITU Radio Regulations, Section IV. Radio Stations and Systems – Article 1.166, definition: *interference*

[12] ftp://www2.esuhsd.org/science/Q1000XX/p_subunit_1/059_doppler.pdf

[13] LTE and the Evolution to 4G Wireless, Design and Measurement Challenges, Second Edition, Figure 2.3-1

[14] https://www.its.bldrdoc.gov/fs-1037/dir-019/_2849.htm

[15] http://technews365.info/intersymbol-interference/#prettyPhoto/0/

[16] https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_manuals/gb_7/sfu_2/SFU_GettingStarted_en_18.pdf

[17] https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/ETL_bro_en.pdf

[18] http://www.dektec.com/Products/Usb/DTU-245/

[19] http://www.dektec.com/Products/Usb/DTU-245/downloads/DTU-245%20Leaflet.pdf

[20] https://www.advanceddigital.ca/content/NetMod-DTTV.pdf

[21] https://www.atecorp.com/ATECorp/media/pdfs/data-sheets/Agilent-8494-95-96AB_Manual.pdf

[22] https://www.minicircuits.com/pdfs/ZAPD-2-252+.pdf

APENDICIES: MEASURED VALUES, EXCEL SHEETS

1. First Measurements Tests

a. 100 % Mode:

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N- DVB-T2	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	746	754	762	770	777	786	795	802	810	818	826
P_in_T2_CH (dBm)						-10					
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
P_T2_CH (dBm)_out						-50					
P_LTE_CH (dBm)_out	-12.2	-12.5	-12.8	-14	-19.5		-18.2	-13.4	-12.5	-12.3	-12
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-9	-9	-9	-12	-20		-18	-12	-9	-8	-8
	-37.8	-37.5	-37.2	-36	-30.5		-31.8	-36.6	-37.5	-37.7	-38
PR (Lab)	37.8	37.5	37.2	36	30.5	0	31.8	36.6	37.5	37.7	38

b. 50 % Mode

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N- DVB-T2	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	746	754	762	770	777	786	795	802	810	818	826
P_in_T2_CH (dBm)						-10					
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-11	-11	-13	-15	-19		-17	-13	-12	-10	-9
P_T2_CH (dBm)_out						-50					
P_LTE_CH (dBm)_out	-13.5	-13.6	-14.7	-15.5	-18.7		-18.5	-14.4	-13.5	-12.8	-12.5
	-36.5	-36.4	-35.3	-34.5	-31.3		-31.5	-35.6	-36.5	-37.2	-37.5
PR (Lab)	36.5	36.4	35.3	34.5	31.3	0	31.5	35.6	36.5	37.2	37.5

c. IDLE Mode

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N- DVB-T2	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	746	754	762	770	777	786	795	802	810	818	826
P_in_T2_CH (dBm)						-10					
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-9	-9	-10	-11	-17		-19	-11	-11	-10	-10
P_T2_CH (dBm)_out						-50					
P_LTE_CH (dBm)_out	-16	-16.6	-17.4	-19	-25.5		-24.1	-18.4	-17	-16.3	-15.9
	-34	-33.4	-32.6	-31	-24.5		-25.9	-31.6	-33	-33.7	-34.1
PR (Lab)	34	33.4	32.6	31	24.5	0	25.9	31.6	33	33.7	34.1

2. Second Measurements Tests

a. 100 % Mode

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N-T2-REAL	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	498	506	514	522	529	538	547	554	562	570	578
P_in_T2_CH (dBm)											
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-9	-9	-9	-12	-20		-18	-12	-9	-8	-8
P_T2_CH (dBm)_out						-50					
P_LTE_CH (dBm)_out	-11.2	-11.5	-11.9	-14.5	-22.3		-21	-14	-10.5	-10.2	-10
	-38.8	-38.5	-38.1	-35.5	-27.7		-29	-36	-39.5	-39.8	-40
PR Validation (Lab)	38.8	38.5	38.1	35.5	27.7	-30	29	36	39.5	39.8	40
OKaY/ No okay	okay	okay	okay	okay	okay	-	okay	okay	okay	okay	okay
Signal level %	100	100	100	100	100		97	100	100	100	100
Signal quality %	97	97	97	97	96		97	96	96	96	96
New_Variable_Attenuator	-6	-6	-6	-9	-14		-14	-9	-7	-6	-5
New PR (Lab)	41.5	41.4	41	38.8	33	0	33.9	39	41.7	41.9	42
Difference PR	2.7	2.9	2.9	3.3	5.3		4.9	3	2.2	2.1	2
Signal level %	28	31	18	38	1		10	14	22	25	12
Signal quality %	96	97	96	96	94		97	96	95	96	96

b. 50 % Mode

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N- DVB-T2	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	498	506	514	522	529	538	547	554	562	570	578
P_in_T2_CH (dBm)											
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-9	-9	-9	-12	-20		-18	-12	-9	-8	-8
	-38	-37.9	-37.3	-34.1	-27		-28.1	-34.6	-37.7	-38.5	-38
PR Validation (Lab)	38	37.9	37.3	34.1	27	-30	28.1	34.6	37.7	38.5	38
OKaY/ No okay	okay	okay	okay	okay	okay	-	okay	okay	okay	okay	okay
Signal level %	100	100	100	100	100		87	100	99	87	99
Signal quality %	97	97	97	96	98		97	96	96	96	97
New_Variable_Attenuator	-5	-5	-6	-8	-13		-13	-9	-6	-5	-5
New PR (Lab)	41.9	41.5	40.2	38	33	0	33.6	38.7	40.7	41.1	41
Difference PR	3.9	3.6	2.9	3.9	6		5.5	4.1	3	2.6	3
Signal level %	10	8	25	40	37		5	20	16	2	23
Signal quality %	95	96	96	97	97		96	95	95	96	96

c. IDLE Mode

BW DVB-T2-CH (MHz)	8										
BW-LTE-CH (MHz)	10										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Channel	N-5	N-4	N-3	N-2	N-1	N- DVB-T2	N+1	N+2	N+3	N+4	N+5
Fc (MHz)	498	506	514	522	529	538	547	554	562	570	578
P_in_T2_CH (dBm)											
P_in_LTE_CH (dBm)	10	10	10	10	10		10	10	10	10	10
Variable Attenuator (dB)						-30					
Variable Attenuator (dB)	-9	-9	-9	-12	-20		-18	-12	-9	-8	-8
	-32.6	-32.5	-32	-27.9	-20		-22	-29.5	-31.7	-32.5	-33
PR Validation (Lab)	32.6	32.5	32	27.9	20	-30	22	29.5	31.7	32.5	33
OKaY/ No okay	okay	okay	okay	okay	okay	-	okay	okay	okay	okay	okay
Signal level %	100	100	100	100	100		100	100	100	100	99
Signal quality %	97	97	97	96	98		97	96	96	96	97
New_Variable_Attenuator	-4	-4	-5	-7	-13		-12	-8	-6	-4	-3
New PR (Lab)	36.8	36.5	36.6	35	28	0	28.5	33	34.1	35	35.5
Difference PR	4.2	4	4.6	7.1	8		6.5	3.5	2.4	2.5	2.5
Signal level %	30	27	25	45	50		14	40	73	19	23
Signal quality %	97	97	96	96	97		96	96	96	96	96