TESTING LTE SIGNAL INTERFERENCE IN DIGITAL TV RECEPTION IN UHF BAND

Concern over LTE interference in digital TV operating in adjacent bands has been growing recently, calling for enhanced planning over the use of digital dividends by mobile broadband.

SET - the Brazilian Society for Television Engineering has been studying the topic and has been following up closely on the work done in other countries and by ITU. In 2013, it provided the Ministry of Communications and Anatel (Brazilian Telecommunications Regulatory Agency) with extensive interaction with companies and regulators from countries as the United Kingdom, Japan, and Germany. It also promoted two in-depth technical seminars, with participants from the Ministry of Communications of Japan, the Ministry of Communications and Anatel.

The present paper provides a summary and an analysis of lab testing performed by Mackenzie University in order to determine the relationship between Digital TV in the 470 - 698 MHz and mobile LTE systems in the 700 MHz band. Tests were commissioned by SET, the Brazilian Society for Television Engineering, and were carried out over a 7-month period in 2013. With these tests, SET intended to contribute to society as a whole and particularly to the broadcasting industry in order to ensure that mobile broadband may be offered to the public, without depriving it from access to open air TV.

Interference is a physical electromagnetic phenomenon that takes place whenever adjacent bandwidths are used by different services. It derives from differences in strength values, out-of-band or spurious emissions and depends on the characteristics of the service and of the corresponding equipment. ITU defines three types of interference:

1- Allowed: quantitative levels established in its regulation for sharing and coordination;
2- Acceptable: levels beyond the allowed limit, but agreed upon by two or more countries for the purpose of a specific coordination;
3- Harmful: one that either degrades, prevents or interrupts a broadcasting service.

In the case of digital TV reception, harmful interference means an interruption in the reception of programs, frozen images or a black screen.

In the testing done at Mackenzie and in the current paper, the term "interference" will always refer to harmful interference.

At the tests done at Mackenzie University, protection ratio levels and saturation limits that define co-existence between the LTE and Digital TV systems in adjacent bandwidths have been measured for the most common TV reception systems in use in Brazil.

The "protection ratio" and "overloading (saturation) threshold" levels obtained are specific to the Brazilian case, as they express the ratio between the ISDB-T reception base installed and (i) the frequency arrangement, (ii) the width of the guard band, (iii) the power levels (iv) the emission mask and (v) other specifications to be observed by LTE systems, as per ANATEL Resolution no. 625/2013[1]. During the measurement of these values, which define the conditions of co-existence,

[1] **RESOLUÇÃO Nº 625, DE 11 DE NOVEMBRO DE 2013 -** Approves the Rules of Usage of the 698 MHz a 806 MHz band.

characterizing receivers was an essential stage of the work, as it allowed to quantify performance degradation for the most common receivers on the national market, in case of interference signals in an adjacent bandwidth.

These results show that, with the aim of allowing for a harmonic co-existence between LTE in the 700MHz band and TV in the 470 - 698 MHz, the 3GPP specifications are not sufficient; they shall be significantly tighter for both base stations and handsets. Consequently, it is necessary to make adjustments in the LTE specifications defined by ANATEL Resolution no. 625/2013, as they based on the 3GPP ones. A series of mitigation procedures has to be defined as well in order to avoid or solve harmful interference cases on Digital TV deriving from LTE emissions.

The first mitigation measures are the installation of filters in Digital TV receivers and in LTE RBS transmitters. The installation of a filter in RBS transmitters aims to reduce – as much as possible – all interfering emissions. On the other hand, the installation of filters in DTV receivers aims to enhance its protection against interference.

Nevertheless, the identification of receivers and a large set of tests on conditions for co-existence carried out by Mackenzie allow us to say that:

- Given the LTE ERP power levels and the ACLR uplink and downlink values foreseen in ANATEL Resolution no. 625/2013, the instalation of filters exclusively in the LTE RBS is not sufficient for solving critical cases of interference.
- Given the typical values for antennas and amplifiers used in Digital TV reception, the inclusion of filters exclusively in TV reception will not be sufficient for solving the critical cases of interference.

In critical cases, a combination between the use of filters in TV receivers and in RBS transmitters will be necessary but not sufficient, requiring additional mitigation measures such as: (i) reduction in RBS transmission power; (ii) changes in TV reception and even (iii) increase of the width of the guard band

The reduction in harmful interferences, including changes in TV reception systems, is critical, as it affects the whole installed .

Resources required for minimizing the impact for viewers are not limited to the development and manufacturing of filters, but include the availability of qualified labor force, trained in significantly altering the reception system, including: (i) the substitution of electronics and amplifiers, (ii) inclusion of filters, (iii) re-directing and substituting TV reception antennas, (iv) installation of appropriate infrastructure and wiring and, finally, (v) the substitution of simple internal reception systems for more complex reception systems, with external or collective antennas.

SET will continue to study and measure the parameters that identify the co-existence between Digital TV systems and mobile broadband systems. A complete version of the report and the additional remarks made by SET on the results of the tests carried out so far can be found in the annex.

REMARKS BY SET ON
TESTING LTE SIGNAL INTERFERENCE IN DIGITAL TV RECEPTION IN UHF BAND

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1. Introduction

The report attached has been prepared by Mackenzie University, at the request of SET, after seven months of tests, the faithful application of the methodology recommended by ITU and a careful analysis of data. The tests have allowed to check the protection ratios and the overloading threshold that identify the interference threshold between 4G/LTE and the Digital TV system.

The aim of this test was to determine the protection ratio and the practical saturation threshold, taking into account the characteristics of the Brazilian terrestrial digital TV system and the parameters established under ANATEL Resolution no. 625/2013, such as the arrangement of frequencies, the RBS transmission power and that of the user terminal, as well as the levels of out-of-band and spurious emissions.

Identifying the interference caused by TV signals in LTE mobile terminals and radio base stations – which also must be considered in the analysis of co-existence scenarios – has not been included in the scope of the SET and Mackenzie University study. With regards to TV reception, the tests do not include the analysis of one-seg mobile reception.

The current analysis is based on the assumption – in line with international service co-existence rules – that mobile broadband operations in the 700MHz bandwidth cannot interfere with existing digital TV transmission and reception systems.

2. Concepts

2.1 Tuner

Currently, digital TV receivers available in the Brazilian Market feature two different tuner technologies.

- **Silicon tuners** are tuners in which the whole processing is implemented in an integrated circuit mounted directly on the receiver's mainboard.
- **Can tuners** are classic super-heterodyne tuners, built from discrete components housed in a metallic box in order to minimize interference by external RF signals.

2.2 Receiver characterization

The **receiver characterization** consist in a set of measures for verifying the functioning of the receiver and its compliance with relevant ABNT Standards[2] , which encompass the measurement of the minimum and maximum signal level and the measurement of the co-channel and the adjacent channel protection ratio of ISDB-T signals.

2.3 Adjacent channel selectivity (ACS)

Adjacent channel selectivity (**ACS**) is an index that refers to a receiver's capacity to receive energy from the channel and to reject adjacent frequency interference.

[2] ABNT - Technical Standard Brazilian Association

2.4 *Adjacent Channel Leakage Ratio* (ACLR)

The ***Adjacent Channel Leakage Ratio*** (**ACLR**) is the performance measurement of a transmitter associated to the capacity to supress energy in the adjacent channel. The ACLR is defined as the ratio, in dB, of the average power of the generated signal integrated into its designated bandwidth, to the average level of emissions in the adjacent channel.

2.5 Overload threshold (Oth)

The **Overload threshold (Oth)** is the maximum level of interfering power tolerated at the entrance of the receiver that still allows for stable TV reception.

2.6 Protection ratio

In this context, the **protection ration (PR)** is the minimum value of the ratio of the desired/interfering (D/I) signal required for maintaining the quality of TV reception, i.e., represents the “acapability” of a receiver to protect itself against interfering signals.

The protection ratio in an adjacent channel (PR(Δf)) is a function of the co-channel protection ratio (PRO), of the selectivity of the adjacent channel of the interfered receiver (ACS – Adjacent Channel Selectivity) and the ratio between unwanted emissions from the interfering transmitter over the adjacent channel (ACLR – Adjacent Channel Leakage Ratio). This definition can be found in Appendix 3 of Annex 2 of Recommendation ITU-R BT.1368-10:

$$PR(\Delta f) = PR_0 + 10\log\left(10^{\frac{-ACS}{10}} + 10^{\frac{-ACLR}{10}}\right)$$

3. Test structure

3.1 Measurement procedures and criteria

Results were obtained from a sample containing six receivers that properly represent the national market, with can-tuner and silicone-tuner front-ends and included an evaluation of the whole UHF bandwidth, totaling over 3,000 measurements.

The evaluation has included LTE downlink tests operating with three adjacent channels with 15MHz occupation, in the Carrier Aggregation mode, occupying the 758 to 803 MHz bandwidth and a 100% load. For the mobile terminal interference tests, a 15 MHz channel was used, occupying the 703 to 718 MHz bandwidth, in the pulse mode, with a 10% load.

All signals were simulated by an LTE signal generator with a much higher out-of-band and ACLR emissions than the one foreseen in ANATEL Resolution 625/2013, requiring a compensation for the results, so as to reflect the parameters specified by ANATEL.

The threshold perception method was used as a TV signal failure criterion, as foreseen in recommendation ITU-R BT.1368, which is equivalent to an image quality in which no more than one error is perceived during a sixty-second observation period.

3.2 Interference scenarios

Mackenzie University also analyses several cases of TV signal reception for different configurations of antenna installations, both in house holds and buildings. These scenarios are based on Report ITU-R BT.2247-2 (Part B), replacing the LTE emission parameters for Japan by those specified in ANATEL Resolution no. 625/2013.

Table 1 presents the five scenarios that represent the reception conditions that are most typical to Brazil, out of the 15 scenarios for ISDB-T reception systems described in the report mentioned above.

Table 1: Brazilian typical reception conditions

TV reception systems (470-698 MHz)	Distance between TV antenna and LTE system		Amplifier gain - loss (dB)
	Mobile Terminal	Radio Base Station (m)	
Household with external antenna	22	214	0
Household with external antenna and booster			12
Household with internal passive antenna	0,7	269	0
Household with amplified internal antenna			25
Building with communal DTV antenna, co-localized with the BS LTE antenna.	-	3	20

3.3 LTE signal power

The starting point for identifying the critical cases of co-existence and the specifications of mitigation measures is the power of the LTE signal established at the entrance of the TV receiver.

Calculations for the power of the LTE signal that reaches the TV receiver are based on the characteristics of the transmission and the reception systems involved and the Minimum Coupling Loss geometry between transmission and reception.

The levels calculated for the Brazilian scenario are summarized in Table 2:

Table 2: Maximum power of LTE signal

TV reception systems (470-698 MHz)	Maximum power of interfering signal (dBm)	
	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Household with external antenna	-28.1	-8.2
Household with external and booster	-12.1	7.8
Household with passive internal antenna	-6.8	-30.4
Household with amplified internal antenna	18.2	-5.4
Building with communal DTV antenna, co-localized with the BS LTE antenna.	-	30.9

4. Test results

4.1 Types of interference

The introduction of 4G/LTE services in the higher UHF bandwidth has an impact on the reception of Digital TV signals. Can-tuner or silicon-tuner synthesizer technologies imply in different kinds of susceptibility to different types of interference. A summary of the effects observed in the laboratory is presented in Table 3.

Table 3: Characteristics of interference in Digital TV

Type of interference	Interfering signal	Most affected TV channels
Image frequency	LTE radio base station	47 to 51
	LTE mobile terminal	38 to 45
Adjacent frequency	Mobile terminal (UE)	46 to 51
Saturation	Both	14 to 51

By individually analyzing the receivers and different UHF channels in the Mackenzie test results, a very significant IF frequency beat effect is noticed among front end and can tuner receivers, which is not found for silicon tuners. Channels 38 to 45 are affected by the uplink IF and channels 47 to 51, by the downlink IF. In both cases, the performance loss is 25 to 30 dB.

4.2 Protection Ratio

The measured protection ratios and their corrected values for the real equipment scenario, in compliance with the specifications of ANATEL Resolution no. 625/2013, are summarized in Table 4, considering a Digital TV signal at -77dBm.

The selectivity values of the Digital TV receiver for the adjacent channel (ACS) and the corrected protection ratio (PR') shown in Table 4 were calculated as per the definition contained in Appendix 3 of Annex 2 of Recommendation ITU-R BT.1368-10, presented earlier. Additionally, the ACLR values foreseen under ANATEL Resolution 625/2013 have also been considered, as well as the 3GPP TS 136.101 and TS 135.104 specifications, respectively, of - 49.2 dB for the LTE mobile terminal and 64.2 dB for the radio base station.

Table 4: Protection ratios and ACS

Channel	LTE Mobile Terminal (703-748 MHz)			LTE Radio Base Station (758-803 MHz)		
	PR Measured (dB)	PR' Corrected (dB)	ACS (dB)	PR Measured (dB)	PR' Corrected (dB)	ACS (dB)
38 to 45	-50	-36	64	-55	-50	68
47 to 50	-49	-35	62	-38	-38	51
51	-41	-35	54	-37	-37	49
Other UHF Channels	-66	-36	79	-58	-51	70

4.3 Overloading threshold

The protection ratio is applicable to cases in which the power of the interfering signal is less than the strength of the signal corresponding corresponding ti the overloading threshold. The overloading threshold, on the other hand, is an exclusive characteristic of the Digital TV receiver and does not depend on the interference signal's ACLR.

The overloading threshold values measured by Mackenzie are summarized in Table 5.

Table 5: Overloading threshold (Oth)

Overloading threshold	LTE Radio Base Station (758-803 MHz)	LTE Mobile Terminal (703-748 MHz)
Oth (dBm)	-6 to 0	-29 to 7

Overload values for ISDB-T_B signals in Digital TV receivers are defined in the ABNT standard NBR 15604 (sub-section 7.2.5) at -20 dBm. Nevertheless, the values measured by Mackenzie are about 15 dB better, i.e., less susceptible to interference than the standard values.

Nevertheless, it is worth highlighting that a low cost digital converter that fully complies with the Brazilian ABNT standard NBR 15604 – without performance variations compared to the specified ones – will be much more strongly affected by interference. This aspect calls for caution, since this kind of equipment usually is set up in low-income households, with greater interest in open-air TV reception.

5. Co-existence

5.1 Required protection ratio

Based on the levels of interfering power on Table 2, a required protection ratio can be calculated so as ensure co-existence. It is assumed that the power received from the Digital TV signal matches the reception threshold defined by ABNT standart NBR 15604, i.e., - 77dBm, so as to preserve the coverage area of the TV station.

The ratio 'desired / interfering signal' derived from the Mackenzie University scenarios is presented in Table 6 below:

Table 6: Required protection ratio

TV reception system (470-698 MHz)	Required protection ratio (dB)	
	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Household with external antenna	-48.9	-68.8
Household with external antenna and Booster	-64.9	-84.8
Household with passive internal antenna	-70.2	-46.6
Household with amplified internal antenna	-95.2	-71.6
Building with communal DTV antenna, co-localized with the LTE BS antenna	-	-107.9

5.2 Measured protection ratio x Required protection ratio

The required protection ratio to enable co-existence indicates a need for reducing out-of-band emissions, as the level of the LTE signal in the analyzed scenarios is higher than the acceptable interference value, identified by the protection ratio measured in the laboratory.

In order to ensure the required protection ratios, the Adjacent Channel Selectivity (ACS) of the interfered TV receiver must be improved and the Adjacent Channel Leakage Ratio (ACLR) must be reduced, preferably through additional filters. In order to calculate the required ACS and ACLR values, the definition contained in Appendix 3 of Annex 2 of the Recommendation ITU-R BT1368-10 is be used again.

The results presented in Table 7 take into account that the **co-channel** protection ratios measured by Mackenzie University are, respectively, 12.5 dB for radio base station and 13.5 dB for the mobile terminal, and assume that the same value applies to ACS and ACLR.

Table 7: ACS and ACLR values required to enable co-existence

TV reception system (470-698 MHz)	Required ACS and ACLR value (dB)	
	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Household with external antenna	65.4	84.3
Household with external antenna e Booster	81.4	100.3
Householdv with passive internal antenna	86.7	62.1
Household with amplified internal antenna	111.7	87.1
Building with communal DTV antenna, co-localized with the LTE BS antenna	-	123.4

It should be noticed that, even though ACS and ACLR values do not necessarily need to be equal, the minimum ACS value – which can be calculated by assuming ACLR as infinite (ideal transmitter) – and the minimum ACLR value – which can be calculated by assuming ACS as infinite (ideal receiver) – will be only 3 dB lower than the values shown in Table 6.

This is a very significant outcome, since a small reduction in the performance requirement in LTE emissions – both at the radio base station, as well as at the mobile terminal – leads to a large increase in filter requirements at the entrance of TV sets and may turn their construction either technically or economically unfeasible.

5.3 Filter specifications for DTV receivers

Initially, it was considered the demand for specifications for filters in order to enable co-existence in each analyzed scenario, without any other change in the viewer's reception systems.

The required ACS and ACLR values define the improvements required regarding the selectivity of Digital TV receivers and the unwanted emissions of LTE Radio Base Stations and MobileTerminals.

The ACS reference value, which represents the performance of today's TV-sets, is based on the values measured by Mackenzie University, as per Table 8.

Table 8: ACS reference values for TV sets

TV reception system (470-698 MHz)	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
PR measured for channel 51 (dB)	-41	-37
ACLR of Mackenzie setup (dB)	98	100
Calculated ACS (dB)	54	49

The ACS level can be improved by using a TV reception filter. Table 9 indicates the filter attenuation required for Digital TV receivers in the foreseen guard band in order to reject interference and maintain the quality of Digital TV reception in each one of the reception types considered by the Mackenzie University study.

Table 9: Filter attenuation required for Digital TV receivers for the usage cases considered

TV reception system (470-698 MHz)	Filter attenuation **by 5 MHz** (dB)	Filter attenuation **by 60MHz** (dB)
	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Household with external antenna	11	35
Household with external antenna e Booster	27	51
Household with passive internal antenna	32	13
Household with amplified internal antenna	57	38
Building with communal DTV antenna, co-localized with the LTE BS antenna	-	74

Ideally, the attenuation caused by the insertion of a TV reception filter on the 470-698 MHz bandwidth should be limited to 1 dB, so as not to significantly degrade TV coverage. It should be noticed that, in the case of amplified reception systems, such filter should be inserted before the amplification of the antenna signal, thus implying in the substitution of reception antennas with integrated amplification.

As an additional counter-measure in TV systems, adding a filter before the amplifier to avoid saturation should be considered, as well as adding one more filter between the amplifier and the TV receiver.

5.4 Attenuation of out-of-band emissions for LTE mobile terminals (UE) and base stations

On the other hand, the ACLR reference level of LTE systems is defined in ANATEL Resolution no. 625/2013, as per Table 10.

Table 10: ACLR reference values defined in ANATEL Resolution no. 625/2013

TV reception system (470-698 MHz)	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Maximum power (dBm)	23	46
Unwanted emissions (dBm/6 MHz)	-26	-18
Resolution ACLR (dB)	49	64

Table 11 shows the attenuation required for unwanted emissions of LTE signals, OOBE – Out-of-band Emissions, in order to improve the ACLR required for safeguarding the quality of Digital TV reception.

Table 11: Required attenuation of unwanted emissions from LTE transmitters for the usage cases considered

TV reception system (470-698 MHz)	OOBE attenuation **by 5 MHz** (dB)	OOBE attenuation **by 60MHz** (dB)
	LTE Mobile Terminal (703-748 MHz)	LTE Radio Base Station (758-803 MHz)
Household with external antenna	16	20
Household with external antenna and	32	36
Household with passive internal antenna	37	0
Household with amplified internal antenna	62	23
Building with communal DTV antenna, co-localized with the LTE BS antenna	-	59

5.5 Interference mitigation

Introducing filters as an interference mitigation technique aims to reduce out-of-band emissions in order to improve the performance of the corresponding transmission and reception systems. It should be noticed that, as the protection ratio depends simultaneously on ACS and ACLR values, filtering established in sub-sections 5.4 and 5.5 is complementary and must be applied simultaneously in order to enable co-existence in the scenarios considered herein.

In critical cases, in addition to filters, mitigation measures reducing the required protection ratio and, therefore, reducing the ACS and ACLR requirements must be considered as well. Tables 9 and 11 show that the most severe cases of interference are caused by (i) radio base stations in receptions with TV signal amplification, especially community antennae and (ii) LTE mobile terminals in internal reception systems for digital TV.

5.5.1 LTE base station x reception with TV signal amplification

In order to allow the co-existence of the services considered herein, filter specifications must take into account their feasibility, both in terms of size and manufacturing costs. The Japanese studies presented in Part B of the Report ITU-R BT.2247 feature a practical limit for TV filters at a maximum attenuation of 30 dB

Even though the addition of filters at the receptor is a necessary mitigation measure, it has a negative impact on TV reception, especially in (i) attenuating the TV signal as the result of a loss in filter insertion and (ii) the degradation of MER – Modulation Error Ratio, i.e., signal quality. Because it is located at the bandwidth limit, channel 51 (692 to 698 MHz) is the most affected one, and should be preserved by determining reception filters capable of ensuring its use for broadcasting, without coverage reduction.

In case the filtering of out-of-band emissions (OOBE) from the radio base station highlighted in red in Table 11 is not feasible, additional mitigation techniques must be implemented. In opposition to filtering, these techniques attempt to reduce the strength of the LTE signal at the entrance of the TV receptor, through the int inrvention in the corresponding irradiating systems.

In order to achieve such result, the position, height, patten and direction of the LTE transmission antennae can be changed. Likewise, similar measures can be implemented at the affected homes. Nevertheless, this is a more costly and time-consuming process, as it requires a case by case analysis of the interference scenario and may involve a change of antennae or substituting the whole reception system.

An additional measure with a similar effect is reducing the strength of the mobile bandwidth signal and increasing the strength of the DTV transmission. As co-existence free from harmful interference depends on the ratio between the strength of the TV signal and the mobile broadband signal, at locations with a weak TV signal, the tolerated limit for interference is also smaller.

5.5.2 LTE mobile terminal (UE) x Reception with internal antenna

Interaction between the mobile terminal and TV reception based on an internal antenna is a major challenge to co-existence. The outcomes of the protection ratios measured by Mackenzie University, as well as the specifications for filters and out-of-band emissions calculated by SET show that environments free from harmful interference can not be established inside homes that depend on an amplified internal antenna for receiving TV signals. The strength of the LTE terminal signal varies according to different factors and, especially, according to the strength of the signal received from the radio base station,   and it may impact TV signal reception in a dynamic way.

On the other hand, according to the studies presented by Japan to ITU-RStudy Group 6, , it is not practical to obtain filters with attenuations above 10 dB at 703 MHz, that is, in the 5 MHz guard band. Therefore, a feasible alternative would be a complete review of the reception system, eliminating the internal antenna reception and changing it for an external reception at household or for community antennae on affected buildings, knowing beforehand that this is a complex and costly process, as it requires a specialized case by case study, in addition to installing an often inexistent infrastructure and wiring.

In order to allow for co-existence, it also is necessary to address ACLR reduction at LTE user terminals. CEPT has recently decided to limit out-of-band emissions from user terminals to -40 to -46 dBm/ 8 MHz for 10 MHz IMT channels, with the uplink starting at 703 MHz. Additional discussions over its impact on costs and performance by limiting the out-of-band emissions of user terminals, at the light of the research and development activities currently under way, will be held at the next CEPT meeting on the topic, scheduled for late April. Despite being insufficient as an isolated measure, specifications for a more rigid envelopment contribute to reducing the incidence of harmful interference and should also be considered for the Brazilian case.

Nevertheless, acknowledging that there is a feasible performance limit for the terminal, an increase in the guard band is proposed as a complementary measure, which would allow to reduce the strength of the interfering signal for frequencies below 698 MHz and improve the technical and commercial feasibility for TV filters with the necessary rejection.