Paper

Measured Interference of LTE Uplink Signals on DVB-T Channels

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Abstract—Because of the decision, taken during the ITU WRC-07, to allocate the upper part of the so-called digital dividend spectrum for mobile services on a co-primary basis with TV broadcast services, the involved stakeholders have a great interest in avoiding any interference caused by signals transmitted in adjacent bands. In this context the paper presents some experimental results of a study addressed to assess the effects produced by an interferential LTE signal transmitted from a user terminal when it is in proximity of a television antenna that receives DVB-T signals. The study has been conducted in the context of collaboration between Fondazione Ugo Bordoni and ISCTI, the scientific and technical body of the Italian Ministry of Economic Development, using high professional laboratory equipments and considering different experimental simulation test setups. Several simulation scenarios have been analyzed and results in terms of protection ratio and protection distance have been carried out.

Keywords—DVB-T, LTE, TV Interference, UHF Measurements, uplink.

1. Introduction

Mobile telecommunications are currently experiencing the fourth generation technology, whose base is the standard 3GPP Long Term Evolution (LTE), and this is leading to large economical investments as well as innovative technological developments such as new high-speed and high-quality services, convergence towards all-IP networks and very effective radio network performances in terms of spectrum efficiency, peak data rate and latency.

In December 2008, the LTE specification was published as part of Release 8 and the first implementation of the standard was deployed in 2009. The first release of LTE supported radio network delay less than 5 ms and multiple input multiple output (MIMO) antenna techniques achieving rather high data rates. Later on, in December 2009, Release 9 has been introduced improving several functional features that were already present in Release 8.

As a result of these technological developments, improvements in speed and capacity have been made available from telco operators to customers, boosting the market to propose services and applications more and more hungry for bandwidth. On the other hand, the device proliferation like smartphones and tablets, as well as the globally interconnection of devices, envisaged by Internet of Things (IoT), are going to cause, in the next future, a significant data traffic explosion with the consequence that demand could outstrip supply. This consideration is feeding the debate among regulators on how timely cope with technical and regulatory developments which might influencing the allocation, management and use of the radio-frequency spectrum, as witnessed in the last World Radio-communication Conference held in Geneva, Switzerland, in 2012 (WRC-12).

According to the spectrum reforming process, currently in progress all around the world, the frequency bands designated for the new services in Europe are the ones at present used by UMTS and GSM, as well as new bands at 2.6 GHz. However, the best frequency band option to open up these services has been, definitely, the digital dividend portion of the UHF spectrum (from 790 to 862 MHz in ITU Region 1, consisting of Europe, Africa and parts of the Middle East), resulting from the digital switchover (DSO) process from analog to digital television (DTV) that was concluded at the end of the year 2013 in almost all European countries.

Furthermore, during WRC-12 in order to meet the demand of additional bandwidth, it was decided to allocate further UHF spectrum to mobile services. The planned new spectrum allocation involves the frequency band from 694 to 790 MHz, and is proposed to come into force in 2015, in order to enable the conclusion of the necessary technical studies regarding the availability and assignment of the new band, before allowing its use.

As a consequence of these decisions LTE will operate alongside broadcast applications (UHF TV channels) and, for this reason, potential coexistence issues might arise.

The digital TV antenna, as well as LTE user terminals, always receives the wanted signal in the presence of unwanted signals generated by other radio systems. On the basis of the outlined spectrum allocation, a certain number of coexistence scenarios have been identified. Depending on the severity of the interference, this may cause degradation of receiver quality, e.g. artifacts in case of digital TV reception or loss of throughput in case of mobile radio, up to complete failure in receiving the wanted signal. It is a matter of fact that the most important factors, which characterize the influence of this interference, depend on the frequency offset between interferer and victim signals as well as on the power level of both wanted and unwanted signals.

In this paper the considered coexistence scenario involves an LTE transmitter, which acts as interferer on the digital TV receiver. In particular, the adopted LTE equipment is a mobile terminal transmitting an uplink signal in the 832-862 MHz band, where, as described in ECC Decision 09-03 [1], the harmonized ITU Region 1 plan for the digital dividend band has allocated the new mobile services adopting the FDD duplex technique for downlink and uplink communication services, with the uplink one located in the upper part of this band.

Experimental tests have been carried out in the Istituto Superiore delle Comunicazioni e delle Tecnologie dell'Informazione (ISCTI), sound and television broadcasting laboratory of Ministry of Italian Economic Development (MiSE) through high-professional devices, considering several operative setup configurations. The paper will provide, in Section 2, an overview of the uplink LTE transmission and potential influences it could cause on signals transmitted on DVB-T channels, as well as the performance parameters that should be considered for assessing the corresponding interfering effects (protection ratio and protection distance). In Section 3 are illustrated the considered experimental setups, including a short description of interfering and victim signals, the measurement methodology and the features of the most relevant equipment used (DVB-T receivers and MATV masthead amplifiers). Successively in Sections 4 and 5, are reported the resulting measurements carried out during the experimental activity as well as relative considerations about the protection distance, which guarantees the quality of service (QoS) levels required by operators. The paper ends with some conclusive remarks reported in Section 6.

2. LTE Influence on DVB-T Reception: Uplink Analysis

2.1. Overview

Since spectrum-sharing criteria normally depend upon parameters of both interfering and interfered systems, as well as their operating environments, the identification of the appropriate interference protection criteria to be adopted is often a confusing, time-consuming process.

This is due to several regulatory and technical terms used to identify the potential interference, including: permissible interference, accepted interference, harmful interference, protection ratios, allowable performance degradation, interference protection criteria, spectrum sharing criteria, and so on.

In 1990, the ITU-T SG1, with the adoption of Rec. ITU-R SM.669 [2], made an attempt to reduce this complexity by the definition of a matrix of protection ratios for various combinations of interfering and wanted signal modulation types, but the interference protection criteria presented in this Recommendation have become largely obsolete. In fact it is mainly addressed to analog and early digital modulation techniques which are in many cases being supplanted by more complex, digital modulations. Furthermore, efforts are focused primarily on modulation with little regard to radio service requirements or factors linked to the operating frequency.

On the contrary, most spectrum sharing studies today focus primarily on radio services and specific frequency bands. As a result of various compatibility studies conducted within the European Conference of Postal and Telecommunications Administrations (CEPT), the frequency plan, resulting from the decisions approved by the WRC-07, employs a duplex direction that is reversed when compared to the normal European convention. Normally, mobile bands are planned with the uplink (base stations receive/mobile terminals transmit) in the lower band and the downlink (base stations transmit/mobile terminals receive) in the upper band. However, due to concerns regarding interference from mobile transmission to Digital Terrestrial Television (DTT) services operating below 790 MHz, it was decided for the 800 MHz band to reverse the duplex direction, so that the downlink is in the lower band. The reason of this choice is to protect the DVB-T broadcast signal transmitted on UHF channels (in particular on channel 60), from interference produced by the uplink transmission of mobile Electronic Communication Networks (ECN) terminals, which is the most critical aspect for DVB-T receiving systems, due to the unpredictable position of the LTE terminal. Thanks to the adoption of the above mentioned frequency allocation a virtual guard band of 42 MHz is provided. In addition, the remaining 11 MHz duplex gap could be exploited by other unspecified services (see Fig. 1).

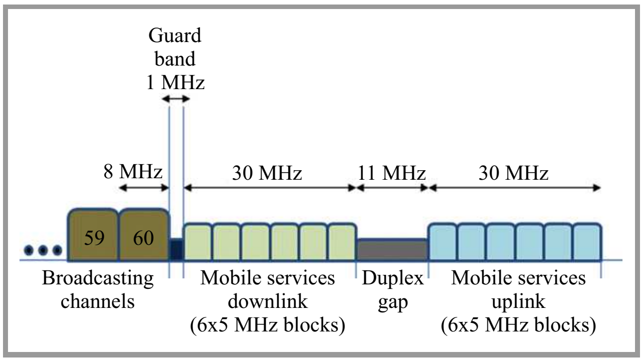

Fig. 1. CEPT channelization proposal for the digital dividend band in case of FDD duplexing technique implementation.

Many studies have been performed to verify the coexistence conditions between LTE downlink and DVB-T signals [3]–[5]. On the contrary, many less studies have been conducted with regard to the interferential effects produced by the LTE uplink signal [4], [5] also because of the higher frequency offset that should theoretically ensure a greater protection. Most of them provide results carried out using computer simulations [6] others consider a limited number of experimental setup configurations [7], [8].

The present work focuses on results obtained through laboratory measurements, referred to the coexistence of DVB-T services, operating in the upper part of the TV UHF band (470–790 MHz), with uplink LTE mobile communication services, operating in the digital dividend band, including an extended set of experimental configurations involving a MATV masthead amplifier. The analysis has been conducted for a selection of reference scenarios, evaluating the Protection Ratio (PR) and the Protection Distance (PD) parameters, with the aim to provide an overview of potential drawbacks resulting from the usage of LTE mobile equipments nearby TV antennas, in order to give an idea of appropriate countermeasures to be adopted to mitigate these undesired effects.

2.2. Protection Ratio Concept

As defined in Report ITU-R BT.2215-4 [9], the PR is the minimum value of the signal-to-interference ratio, usually expressed in decibels, required to obtain a specified reception quality under specified conditions at the receiver input. In this work, the wanted signal is a DVB-T one whilst the unwanted signal is a LTE uplink one.

PR measurements have been carried out for different power levels of the DVB-T signal at the DTT receiver antenna. In this way, it has been possible to simulate the magnitude of the interference in different operating conditions, trying to cover the widest range normally present at the input of the TV sets.

Usually, PR is conditioned by different parameters of the involved signals, i.e. the frequency offset between the wanted and the interfering signals, the power of the victim signal, as well as by the specific receiver features because usually it has different ability to discriminate interfering signals operating on frequencies adjacent to the ones used by the wanted signal. For this reason, the results of the laboratory measurements have been repeated for different typologies of DVB-T receivers, by configuring the LTE signal at different frequency offset from the carrier of the DVB-T channel under test, evaluating, for each of them, the minimum power level of the LTE signal which affects the quality of the DVB-T video signal or, alternatively, a critical value for the BER of the victim signal higher than $2 \cdot 10^{-4}$ after Viterbi decoding or higher than 10^{-11} after Reed-Solomon decoding.

Another relevant parameter to determine the signal QoS is the overloading threshold corresponding to the carrier-to-interference (C/I) ratio value where the TV signal is lost. This parameter was not deeply investigated in this work however some minimal considerations are reported in the conclusions.

2.3. Protection Distance Concept

From a technical point of view, the PD is defined as the minimum spatial distance, expressed in meters, between an interfering device (LTE user equipment, for the uplink analysis conducted in this work) and the receiving antenna of the system to be protected (DVB-T receiver) in order to ensure that the interfering signal power levels at the front-end antenna of the receiver are still low enough to guarantee an acceptable QoS of the wanted signal.

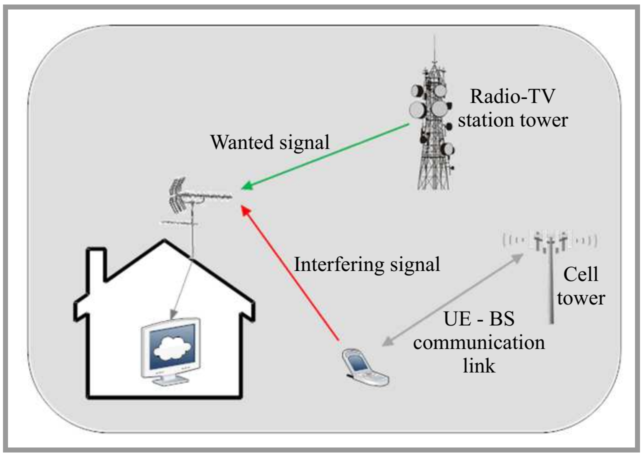

Fig. 2. Reference scenario for evaluating the PD parameter.

Recommendation ITU-R SM.337-5 [10] provides a general method to evaluate this parameter, as well as the frequency separation between the interfering and the victim antennas in order to bind the interfering signal under an acceptable radiated power level. According to this method, the PD can be evaluated under the simplified hypothesis that the LTE mobile terminal is in line-of-sight with the DTT receiving antenna (see Fig. 2) and that the path attenuation of the radio signals can be calculated using the free space propagation model, as it is also suggested in Rec. ITU-R P.525.2 [11].

3. Experimental Scenario

3.1. Experimental Setup

The measurements have been carried out using the experimental setup shown in Fig. 3, in accordance with the method suggested in ECC Report 148 [12]. The DVB-T signal is generated by the Rohde-Schwarz SFU broadcast test system and is modulated by the MPEG-2 transport stream provided by the Rohde-Schwarz DVG generator.

On the other side, the LTE uplink signal is generated by the Rohde-Schwarz SMBV100A vector signal generator. The DVB-T and LTE signals are combined using a directional coupler (Agilent model 775D) operating in the 450–940 MHz frequency band (see Fig. 4), which is able to ensure an effective decoupling of about 60 dB between the two signal generators, if it is used as shown in Fig. 3.

The output of the coupler has an impedance of 50 Ω and needs a 50–75 Ω impedance adapter in order to avoid mismatch reflection to the input of the TV receiver or to the masthead amplifier, in case it is present in the MATV chain.

In the experimental setup option including a masthead amplifier, the output of this device is connected to a variable attenuator in order to simulate the losses of a real TV distribution system in order to guarantee a good DVB-T signal power level (–50 dBm) at the input of the TV receiver.

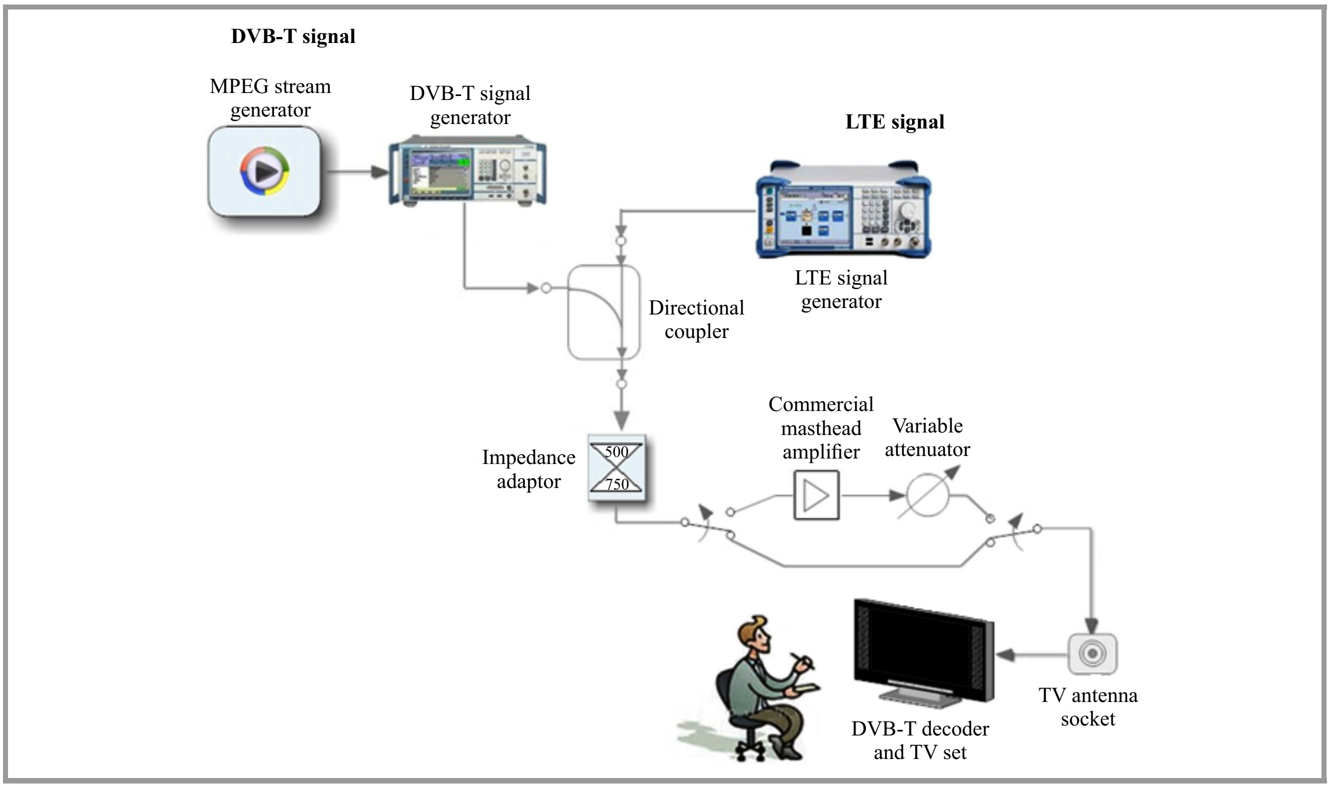

Fig. 3. Functional schematic of the test bed.

Fig. 4. Directional coupler.

3.2. System Parameters Adopted: Interfering and Victim Signals

As above mentioned, in this experimental context the LTE uplink signal acts as the interferer. It has been configured in accordance with the provisions of the WRC-07, and with reference to the regulation fixed by European authorities. According to 3GPP TS 36.211 [13], the LTE signal at 800 MHz is characterized by FDD duplexing technique and the spectrum dedicated to uplink transmissions ranges from 832 to 862 MHz (see Fig. 1).

The adopted frame structure is Type-1, and the transmission scheme for LTE uplink signals is the Single Carrier Frequency Division Multiple Access (SC-FDMA). The main LTE uplink signal frame specifications for the PHY layer are reported in Table 1.

In addition, taking into account of a typical scenario, three different LTE uplink carrier frequencies have been considered: 837 MHz (from 832 to 842), 847 MHz (from 842 to 852) and 857 MHz (from 852 to 862). In any case, for the LTE signal, a traffic load level of 100% has been configured.

Table 1
LTE uplink signal frame specifications for the PHY layer

LTE uplink signal frame parameter	Value
Duplex scheme	FDD
Radio frame structure	Type-1
Duration of radio frame	10 ms
Number of subframes (TTI)	10
Duration of a subframe	1 ms
Number of time-slot per subframe (Resource block or RB)	2
Duration of a time-slot	0.5 ms
Bandwidth of a RB	180 kHz
Number of subcarrier per RB	12
Bandwidth of a subcarrier	15 kHz
Bandwidth for each operator	10 MHz

The victim signal considered in this study is a reference DVB-T one compliant with the ETSI Rec. EN 300 744 [14] whose main features are summarized in Table 2.

Measurements have been carried out for different signal levels at DTT receiver antenna input or at the input of a masthead amplifier, if it is present. QoS of five DVB-T

Table 2
Main settings of the victim signal

Modulation	OFDM sub-carriers	Code rate	Guard interval	Band-width	Data rate
64QAM	8 K	3/4	1/4	8 MHz	22.39 Mb/s

Table 3
TV channel frequencies considered in the experimental setup

DVB-T channel	Central frequency [MHz]	Start frequency [MHz]	End frequency [MHz]
60	786	782	790
59	778	774	782
58	770	766	774
57	762	758	766
56	754	750	758

multiplex channels have been tested spanning from channel 56 up to channel 60 (carrier spacing 8 MHz), as reported in Table 3.

3.3. DVB-T Receivers Typology

During the experimental study, two DVB-T receivers, implementing different tuning techniques (CAN and silicon tuner), have been tested:

- CAN tuner (also known as superheterodyne) is placed in a metal enclosure to prevent interferences and the RF input signal is mixed with a Local Oscillator to obtain an Intermediate Frequency (IF) signal. The superheterodyne architecture used in this kind of tuner leads to an image frequency 72 MHz above the tuned signal;
- Silicon tuner uses Large Scale of Integration (LSI) chips. The receivers using this kind of tuner are not affected by the problem of image frequency, because the input signal is directly converted in base band or in a very low IF.

3.4. MATV Masthead Amplifier Features

Masthead amplifiers are used in television receiving systems to increase the level of signal received at a television set for single or multi user systems. They are mounted on the roof mast or on the roof space, very close to the aerial, and are connected to the TV set by a coaxial cable or a more complex distribution network.
The amplifiers commercially available before the migration of mobile services in the UHF television band show amplification features almost constant up to the end of the digital dividend band (862 MHz), today unnecessary and even harmful, because the presence of unwanted signals could force it to operate in nonlinear mode.

Usually, in order to prevent the amplifier to operate in the nonlinear area, its gain is fixed to a value which allows, at its output and for each DVB-T channel, a signal level adequately lower than the maximum value provided by the manufacturer. This is necessary in order to reduce the potential signal degradation caused by saturation distortion and intermodulation signals production. To this aim, international regulation bodies suggest to use, for each DVB-T channel, the following formula [15], [16]:

$$P_{out} = P_{outmax-ampli}(\text{dBm}) - M(\text{dB}) \quad (1)$$

where: $M(\text{dB}) = 10\log(N-1)$, N = number of received DVB-T channels (2 or more), $P_{outmax-ampli}$ = maximum output power indicated by the manufacturer (usually expressed in dBμV over 75 Ω).

For example, in case of $N = 30$ DVB-T channels, M is equal to 14.6 dB and P_{out} measured for the DVB-T channel having the highest received power level should be fixed at $P_{out} = P_{outmax-ampli}(\text{dBm}) - 14.6$.
In this experimental study, measurements have been carried out using two typical commercial MATV masthead amplifiers, which will be indicated in this work as AMP1 and AMP2, designed to cover UHF band up to 862 MHz. In the following are reported some features of these amplifiers.
AMP1 is a broadband amplifier. Its technical specifications are reported in Table 4. Figure 5 shows the measurement

Table 4
Main parameters of AMP1

Parameter	Value
Noise figure	7.5 dB
Max output	125 dBμV
Minimum gain	10 dB ± 2
Maximum gain	30 dB ± 2
Power supply	12 V_{DC}
Impedance	75 Ω

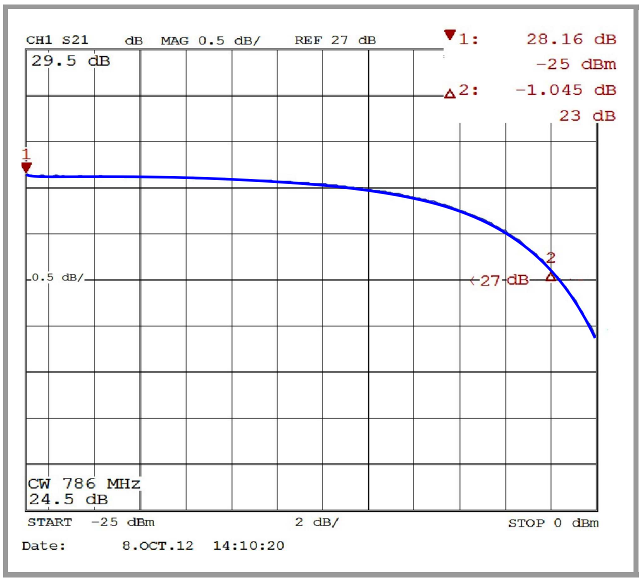

Fig. 5. 1 dB compression point for AMP1.

of 1 dB compression point for AMP1, which occurs in correspondence to an input level of –16.0 dBm and an output level of 11.2 dBm (measurement carried out for a frequency value of 786 MHz and a gain value set to the maximum).

Table 5
Main parameters of AMP2

Parameter	Value
Noise figure	8 dB
Max output	121 dBμV
Minimum gain	30 dB$\pm$2
Maximum gain	53 dB$\pm$2
Power supply	12 V_{DC}
Impedance	75 Ω

AMP2 is a high gain broadband amplifier. Its relevant technical specifications are reported in Table 5. Figure 6 shows the measurement of 1 dB compression point for AMP2. It occurs in correspondence of an input level of –21.5 dBm and an output level of 29.7 dBm (measurement carried out for a frequency value of 786 MHz).

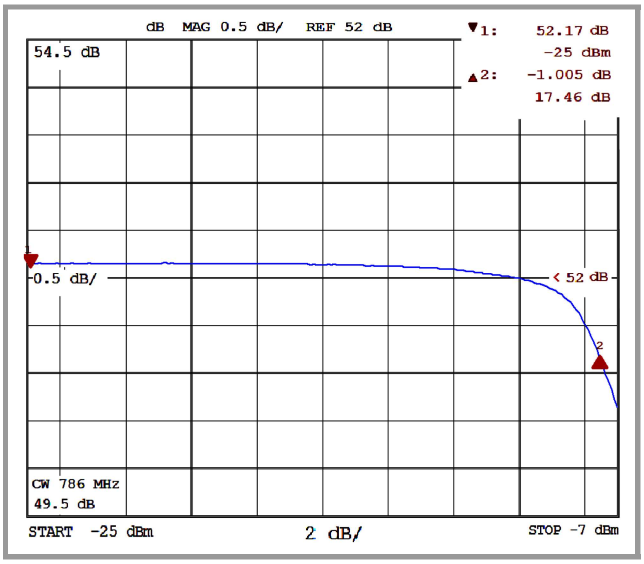

Fig. 6. 1 dB compression point for AMP2.

In order to take into account, as much as possible, of the potential effects of signal degradation due to intermodulation distortion, during the measurements, AMP2 has been set out not only near the maximum gain, but also at 10 dB below the maximum (in practice the signal at the input of the amplifier is first regulated with an attenuation of 10 dB and then amplified with its maximum gain of 52 dB).

3.5. Measurement Methodology

In order to determine the power levels of LTE uplink signal causing quality degradation of DVB-T channels, a proper procedure has been adopted and repeated for each experimental measurement, based on the assessment of the subjective quality of the received TV signal in terms of picture failure (PF). As a preliminary step, the attenuation in dB of all passive elements in the test bed chain has been determined, in order to take them into account during the evaluation of the power levels, of the desired and interfering signals, at the input of the TV receivers or masthead amplifiers as well. Furthermore, a suitable MPEG stream feeding the DVB-T generator and transmitted to the TV receiver has been chosen from the ones available on the MPEG stream generator. After selecting the DVB-T channel to be tested, its power level, the LTE uplink signal carrier frequency and, in case of using the masthead amplifier, its gain value, the power level of the LTE signal has been progressively increased until picture failures of video signal within an interval of 30 s of observation occurred. When this effect appeared, the resulting LTE power level shown on the generator, reduced of the attenuation due to transmission chain passive elements, has been recorded. Note that the reported results depend on the spectral characteristics of the adopted LTE and DVB-T signals as well as on the noise platform introduced by LTE signal generator, which represents a co-channel interference for the DVB-T signal under observation. Any variant of these experimental configurations (e.g. DVB-T signal degradations due to propagation with multiple paths or absence of additional noise), could lead to conclusions different from those obtained in this paper.

4. Experimental Results for the Protection Ratio

As above mentioned, on the basis of the described experimental scenario, two different TV receivers have been used for carrying out the laboratory measurements, the first one operating with a CAN tuner (TV RX1) and the second one with a silicon tuner (TV RX2). These measurements have been performed in absence and presence of two different masthead amplifiers, with the three following configurations:

- configuration A1 – amplifier 1 (AMP1) with a gain of 30 dB (max. allowed),
- configuration A2 – amplifier 2 (AMP2) with a gain of 52 dB (max. allowed),
- configuration A3 – amplifier 2 (AMP2) with a gain of 42 dB.

The measurements have been repeated for each TV receiver with DVB-T power level settings specified in Table 6.
The larger number of measurements carried out in presence of the masthead amplifier was necessary to have a better discrimination of the intermodulation effects due to the amplifier nonlinearities when the DVB-T signal power level is stepping up.
For each configuration, the protection ratio and the protection distance have been evaluated.

Table 6
DVB-T Power levels fixed in correspondence of measurements points

Case	DVB–T Power levels [dBm]	Measurement point
Without masthead amplifier	–35 (max. permitted) –50 –65 (min. permitted)	TV receiver input
With masthead amplifier	–35 (max. permitted) –45 –55 –65 –75 (min. permitted)	Masthead amplifier input

4.1. Measurements in Absence of Masthead Amplifier

In absence of the masthead amplifier, the results obtained with TV RX 1 (equipped with CAN tuner) highlight the presence of an image frequency signal effect 72 MHz below the LTE signal carrier. This impairment may significantly affect the quality of the tuned DVB-T signal, causing the above mentioned picture failures on the video image.
The degradation of DVB-T signal QoS, for the channel influenced by this effect, occurs in presence of an LTE signal power level about 20 dB below the ones noticed for channels not affected by the image frequency impairment. Specifically, for DVB-T signal power levels close to the sensitivity threshold of the receiver, the PR parameter assumes a constant value around –55 dB.

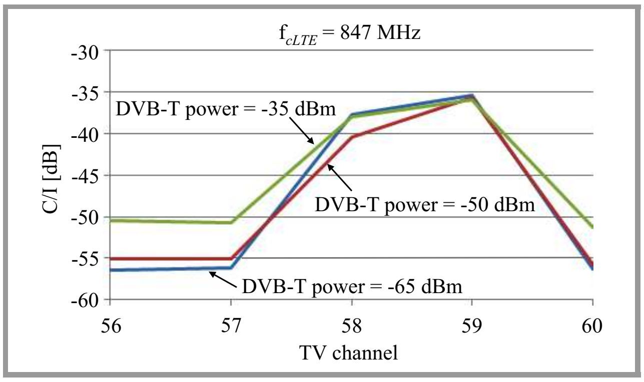

Fig. 7. PR measurements using TV RX1 and LTE signal at $f_{cLTE} = 847$ MHz, for different values of DVB-T power, without masthead amplifier.

Depending on the carrier frequency of LTE uplink interferer signal, the effects of the image channel moves from DVB-T channels 57 (central frequency 762 MHz) and 58 (central frequency 770 MHz), in correspondence of an LTE carrier frequency of 837 MHz, to channels 58 and 59 (central frequency respectively at 770 and 778 MHz, see Fig. 7), with an LTE carrier frequency of 847 MHz, up to channels 59 and 60 (central frequency respectively at 778 and 786 MHz) with an LTE carrier frequency of 857 MHz. These effects are shown in Fig. 8 for a DVB-T signal power level fixed at –50 dBm and become even more evident for decreasing values of the DVB-T signal power level (see Fig. 7).

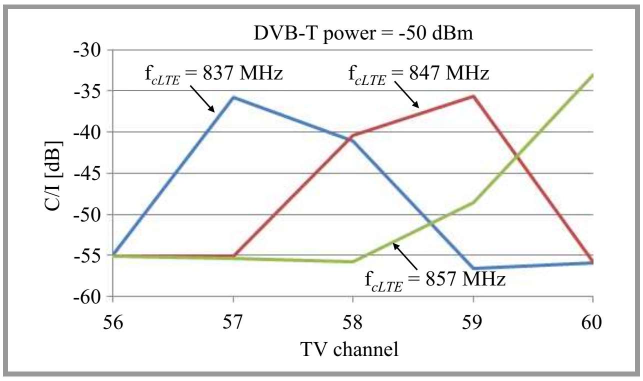

Fig. 8. PR measurements using TV RX1 and –50 dBm DVB-T power level, for different values of f_{cLTE}, without masthead amplifier.

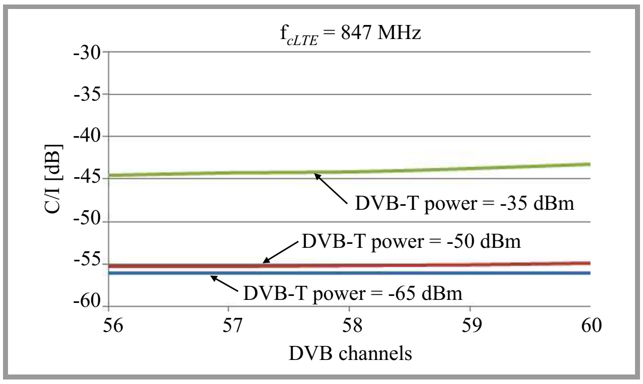

Fig. 9. PR measurements using TV RX2 and LTE signal at $f_{cLTE} = 847$ MHz, for different values of DVB-T power levels, without masthead amplifier.

On the contrary, experimental results obtained with the TV RX 2 receiver (equipped with silicon tuner) show that the interference effects are negligible. In particular, the LTE signal power levels that cause impairments on the DVB-T signal are quite high, as it is evident in Fig. 9, and therefore the reduction of DVB-T signal QoS is evident only in specific environmental conditions, for example when the LTE user terminal is very close to the aerial.

4.2. Measurements with TV RX1 and Masthead Amplifiers

In this experimental setup a masthead amplifier is introduced in the test bed chain after LTE and DVB-T signals have been combined. Two different amplifiers (AMP1 and AMP2) have been used, operating in the above mentioned three different experimental configurations (A1, A2 and A3). Results have been carried out for both TV RX1 and TV RX2. In this section the results with TV RX1 are illustrated.
In configuration A1, the effects of the image frequency are more evident for low power levels of the DVB-T signal

(less than –50 dBm), with an increase of the protection ratio of about 20 dB. For higher power levels of the victim signal (i.e. –35 or –45 dBm), because of approaching the nonlinear behavior (saturation) of the amplifier, the effects of the image channel are less noticeable (Fig. 10).

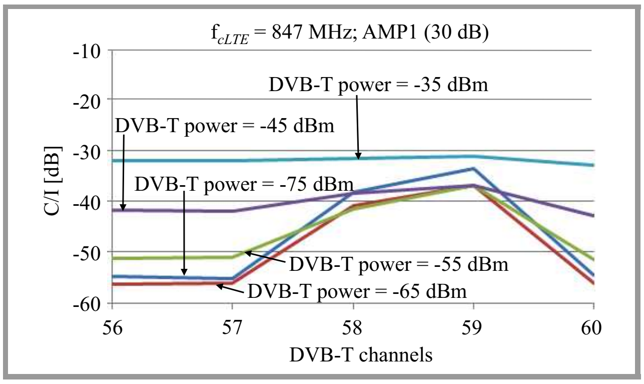

Fig. 10. PR measurements using TV RX1, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP1 (gain = 30 dB).

In configuration A2 the effects of the image frequency are still evident. In this case, however, the impact is limited to very low values of DVB-T signal power levels (around –70 dBm), since for higher values the consequences of the saturation condition of the amplifier are very considerable. In fact, the behavior is strongly influenced by the amplifier: as soon as the LTE signal at its input exceeds a specific threshold power level (around –35 dBm), the amplifier starts operating in the nonlinear area, consequently resulting in a significant reduction of the video signal quality (Fig. 11).

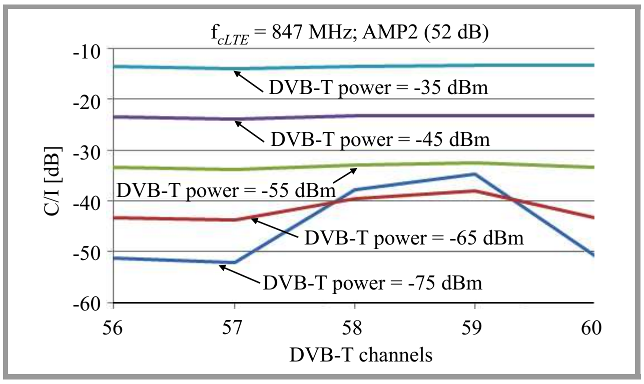

Fig. 11. PR measurements using TV RX1, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP2 (gain = 52 dB).

Finally, using the A3 configuration, the result is similar to the one obtained with the amplifier at the maximum gain. However, in this case, the DVB-T signal is more protected because, for same power levels of a DVB-T signal at the input of the amplifier, the protection ratios are 10 dB lower of one's obtained in configuration A2. In this case it was not possible to perform measurements with the DVB-T sig-

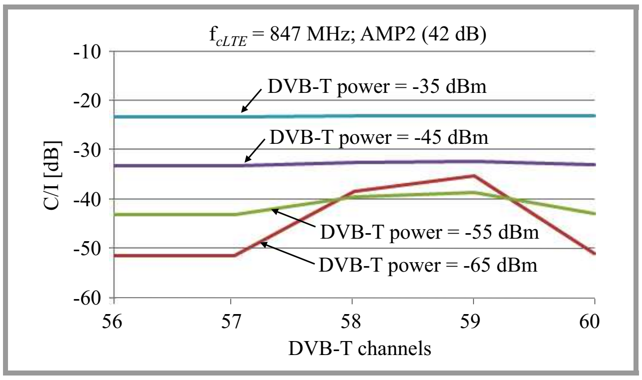

Fig. 12. PR measurements using TV RX1, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP2 (gain = 42 dB).

nal power equal to −75 dBm, because at the output of the amplifier the signal resulted severely corrupted even in absence of the interfering LTE signal due to the presence of comparable power levels of device noise (see Fig. 12).
As a conclusive analysis concerning the TV RX1 receiver, Figs. 13 and 14 illustrate a comparison between LTE and DVB-T signal power level measurements in presence and absence of masthead amplifiers. The analysis is referred to an LTE signal centered at 847 MHz and considering the DVB-T signals received on channels 59 and 60.

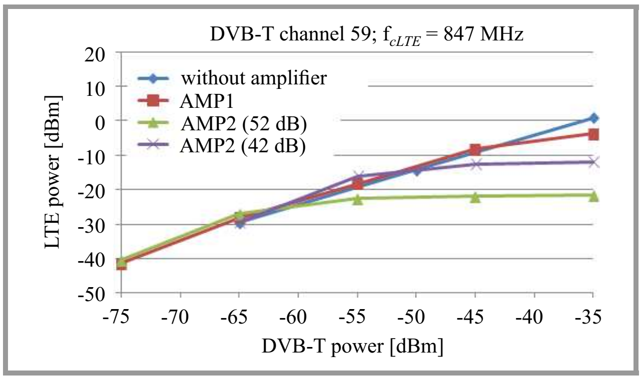

Fig. 13. LTE power level causing interference vs. DVB-T power level in presence and absence of the masthead amplifier, using TV RX1, for DVB-T channel 59 and f_{cLTE} = 847 MHz.

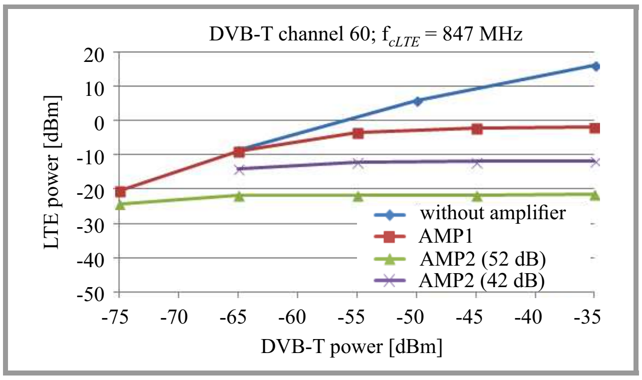

Fig. 14. LTE power level causing interference vs. DVB-T power level in presence and absence of the masthead amplifier, using TV RX1, for DVB-T channel 60 and f_{cLTE} = 847 MHz.

The resulting curves provide a clear evidence of the nonlinear effects of the amplifiers and the corresponding values of LTE signal power levels causing this harmful condition.

4.3. Measurements with TV RX2 and Masthead Amplifiers

Also in this case, the analysis has been conducted adopting the above mentioned three different experimental configurations (A1, A2, A3) for AMP1 and AMP2 in combination with the TV RX2 receiver. The test results illustrated in the graphs reported in Figs. 15, 16 and 17 show a uniform behavior in terms of protection ratio for any considered DVB-T signal power level, regardless of the considered TV channel.

However, the LTE signal power level that causes QoS degradation increases with the power level of the DVB-T received signal, reaching the highest levels for DVB-T signal powers of –35 and –45 dBm. The latter two experimental configurations lead to poorly significant results. In fact, as shown in the next section, for such values of the interferer signal the mobile terminal should be located very close to the antenna TV (few centimeters, not in far field condition) in order to originate a perceptible interference.

As for TV RX1, even in this case an analysis illustrating

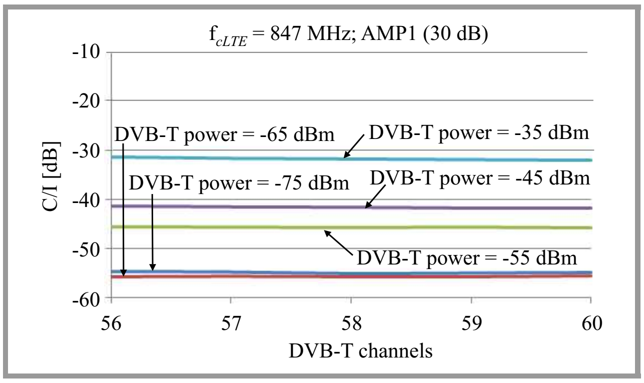

Fig. 15. PR measurements using TV RX2, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP1 (gain = 30 dB).

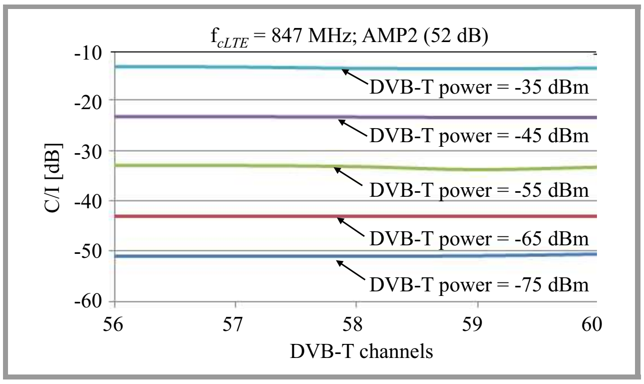

Fig. 16. PR measurements using TV RX2, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP2 (gain = 52 dB).

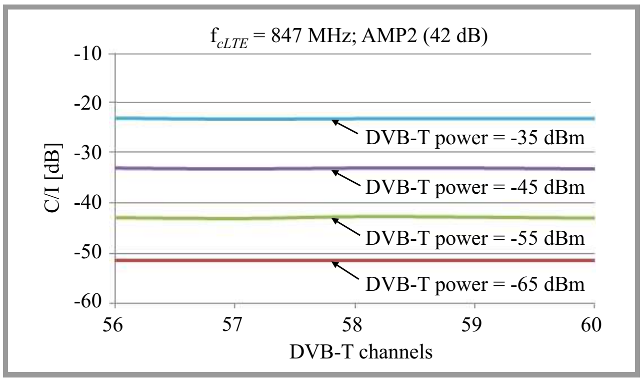

Fig. 17. PR measurements using TV RX2, LTE signal at f_{cLTE} = 847 MHz, for different values of DVB-T power levels, with AMP2 (gain = 42 dB).

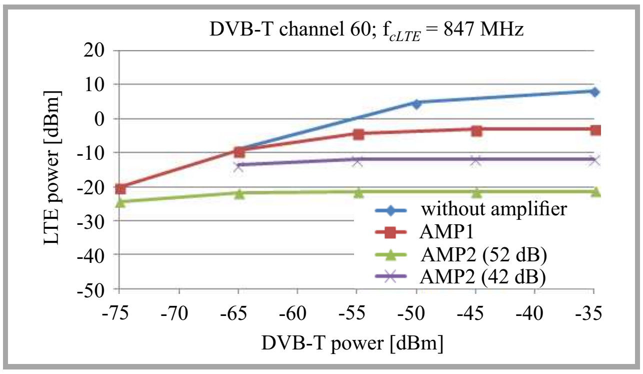

Fig. 18. LTE power level causing interference vs. DVB-T power level in presence and absence of the masthead amplifier, using TV RX2, for DVB-T channel 60 and f_{cLTE} = 847 MHz.

the lowest LTE power levels causing interferential effects at different power levels of DVB-T signal (channel 60), with and without masthead amplifiers, has been provided (see Fig. 18). From this graph nonlinear effects of the amplifiers and saturation points are evident and it is clear how the presence of an amplifier affects the QoS of a DVB-T system in presence of LTE uplink signals. As a consequence of the C/I flat trend highlighted in Figs. 15, 16 and 17, a very similar behavior has been noticed also for all the others considered TV channels.

5. Protection Distances Based on Experimental Results

With the goal to assess the impact of the mutual position of the mobile terminal with respect to the receiving antenna of a TV set, the protection distance parameter between an LTE mobile terminal and a DVB-T antenna has been measured in some of the above considered experimental scenarios.

For this analysis it has been assumed the experimental conditions mentioned in Subsection 2.2 (the mobile user equipment is in Line-Of-Sight with the receiving DTT antenna and the path attenuation can be calculated using the free space propagation model [11]), adopting the LTE mobile terminal and the DVB-T receiver antenna parameters reported in Table 7 (as suggested in the Rec. ITU-R BT.419-3 [17]).

Table 7
LTE UE and DVB-T antenna parameters

Parameter	Value
Max TX power	23 dBm
UE antenna gain	–3 dBi
RX antenna gain (DVB-T)	9.15 dBi
UE antenna pattern	Omnidirectional

In this context, three case studies have been analyzed:

Case 1 – TV RX1 without amplifier and LTE carrier frequency at 837 MHz.

In this case, as illustrated in Fig. 19 the protection distance ranges from less than one meter up to about 20 m. In particular, the worst condition is detected in correspondence of the image frequency, with a DVB-T signal power level equal to –65 dBm. It should be taken into account that values less than one meter are considered as approximated extrapolation of free space far field behavior.

Case 2 – TV RX1 using AMP2 with a gain fixed at 52 dB and LTE carrier frequency at 847 MHz.

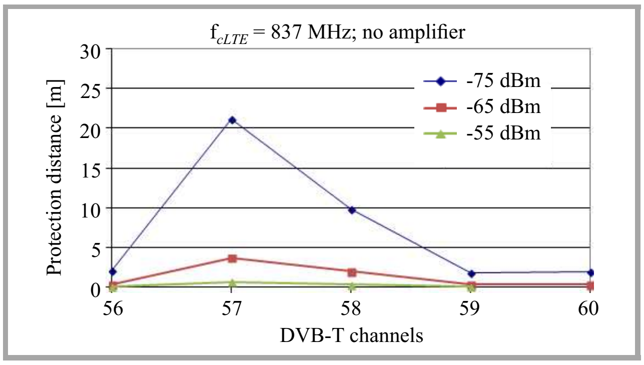

Fig. 19. Protection distance for different DVB-T channels and power levels, at $f_{cLTE} = 837$ MHz, using CAN TV receiver, without masthead amplifier.

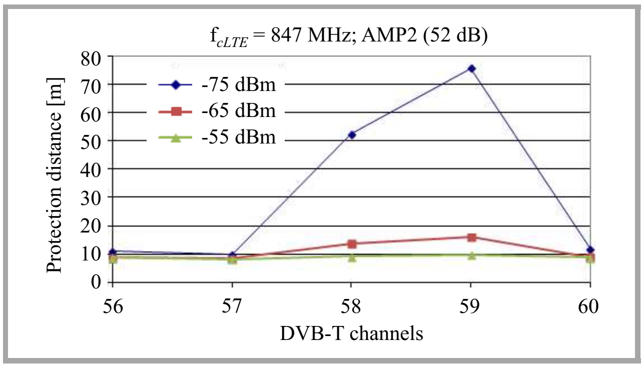

Fig. 20. Protection distance for different DVB-T channels and power levels, at $f_{cLTE} = 847$ MHz, using CAN TV receiver, with AMP2.

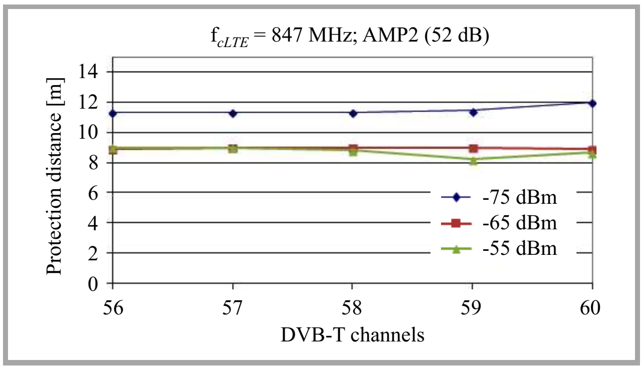

Fig. 21. Protection distance for different DVB-T channels and power levels, at $f_{cLTE} = 847$ MHz, using silicon TV receiver, with AMP2.

In this case, as shown in Fig. 20, the protection distance ranges from less than 10 m up to about 75 meters. The worst condition is still detected in correspondence of the image frequency and for DVB-T signal power level equal to –75 dBm.

Case 3 – TV RX2 using AMP2 with a gain fixed at 52 dB and LTE carrier frequency at 847 MHz.

In this case, as illustrated in Fig. 21, the protection distance is around 10 meters for all channels and all considered DVB-T power levels. Similar results have been assessed for 837 and 857 MHz LTE carriers.

6. Conclusions

In the present study the problem of coexistence of DVB-T and LTE mobile communication systems operating in contiguous UHF frequency bands has been analyzed.

In particular, it has been investigated the interference effect that an LTE uplink transmission might produce on the TV broadcasting service in specific scenarios, by means of the evaluation of protection ratio and protection distance parameters referred to experimental simulation laboratory setups representing real operative situations.

The obtained results highlighted that the TV receiver features, as well as the presence or absence of a masthead amplifier in the receiving chain, may heavily influence, in specific circumstances, the DVB-T signal QoS perceived by the user. More in detail, for the protection ratio, the results can be synthesized as follows.

In absence of the masthead amplifier, the CAN TV receiver determines the presence of an image frequency contribution on DVB-T channels 57–60, depending on the LTE signal carrier ranging from 837 to 857 MHz, with a consequential increasing of the PR of about 20 dB for the channel influenced by this effect. On the contrary, this result does not occur for the silicon TV receiver where, only in presence of DVB-T signal power levels close to the minimum allowed or in presence of quite high LTE signal power levels, reachable in extremely rare conditions

(LTE mobile terminal located very close to the UHF TV antenna), the reduction of DVB-T signal QoS is relevant, independently from the considered TV channel;

In presence of the masthead amplifier, it has been observed a behavior similar to the one described in the previous case, until the power levels of the victim signal are under a threshold value, inversely proportional to the gain of the amplifier. Once this value is exceeded, the nonlinearity characteristic effects of the amplifier become predominant and the picture failure of the video signal appears even for very low power levels of the interfering LTE signal gathered by TV antenna. It must be underlined that in this case the signal degradation affects almost all DVB-T channels and not only a specific one. Furthermore the increase of the power level of the LTE interference signal of a few decimal of dB (0.2 to 0.5) leads to completely break down the TV signal, reaching the condition of overloading threshold.

About the protection distance parameter, it can be deducted that the lower is the received DVB-T signal power level the higher should be the distance of the LTE transmitter from the receiving UHF TV antenna in order to avoid interference, mainly in correspondence of the channel that is influenced by the image frequency, if the TV set equipped with a CAN tuner is considered. This effect is even more emphasized in presence of a masthead amplifier when, the previous distance, is in the order of tens of meters, depending on the gain of the amplifier. Obviously, in case of a TV set equipped with a silicon tuner, due to the absence of image frequency effect, the protection distance behavior is almost constant for all considered DVB-T channels, with a slight worsening in case of DVB-T power levels close to the minimum allowed values at the input of masthead amplifier. From these results it is clear that some interference problems exist, which could be mitigated by adopting appropriate countermeasures including the installation of a low pass filter in the head-end of the MATV plant.

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References

[1] "ECC Decision of 30 October 2009 on harmonised conditions for mobile/fixed communications networks (MFCN) operating in the band 790-862 MHz", Electronic Communications Committee, Oct. 2009.

[2] Rec. ITU-R SM.669, Protection Ratios for Spectrum Sharing Investigations, 1990.

[3] I. Parker and S. Munday, "Assessment of LTE 800 MHz Base Station Interference into DTT Receivers", ERA Tech. Rep. no. 2011-0351, Survey, UK, Jul. 2011.

[4] N. Cardona, "Coexistence of broadcast and mobile technologies in digital dividend band", in *IEEE BTS Gold Worksh.*, Brasov, Romania, 2014.

[5] B. Randhawa, J. Parker, and S. Antwi, "LTE Interference into Domestic Digital Television Systems", Cobham Technical Services, ERA Technology RF and EMC Group, Rep. no. 2010-0026, Jan. 2010.

[6] I. Cho, I. Lee, and Y. Park, "Study on coexistence between long term evolution and digital broadcasting services", *Int. J. Adv. Sci. Technol.*, vol. 38, Jan. 2012.

[7] K. Sakic and M. Gosta, "Measurements on the influence of the LTE System on DVB-T reception", in *Proc. 54th Int. Symp. ELMAR 2012*, Zadar, Croatia, 2012.

[8] "Dynamics of 3GPP LTE uplink: 800 MHz DTT and LTE coexistence", Real Wireless Tech. Rep., ver. 5.0, Feb. 2012.

[9] Rep. ITU-R BT.2215-4, Measurement of protection ratios and overload thresholds for broadcast TV receivers, Nov. 2014.

[10] Rec. ITU-R SM.337-5, Frequency and distance separations, 2007.

[11] Rec. ITU-R P.525.2, Calculation of Free-Space Attenuation, 1994.

[12] ECC Report 148, "Measurements on the performance of DVB-T receivers in the presence of interference from the mobile service (especially from LTE)", Jun. 2010.

[13] 3GPP TS 36.211 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 12).

[14] ETSI EN 300 744 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television, 2015.

[15] EN 50083-8:2013 Cable networks for television signals, sound signals and interactive services – Part 8: Electromagnetic Compatibility for Networks.

[16] EN 50083-5:2002 Cable networks for television signals, sound signals and interactive services – PART 5: Headend Equipment.

[17] Rec. ITU-R BT.419-3, Directivity and Polarization of Antennas in the Reception of Television Broadcasting, 1992.

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