Progress In Electromagnetics Research C, Vol. 17, 1–15, 2010

PERFORMANCE MEASUREMENTS OF A DVB-T SYSTEM AFFECTED BY 5-MHZ GENERIC ADJACENT CHANNEL INTERFERENCE

V. P. Kalogirou, T. H. N. Velivasaki, and C. N. Capsalis

Department of Electrical Engineering
Division of Information Transmission Systems and Material Technology
National Technical University of Athens
9 Iroon Polytecneioy Str. 15772, Athens, Greece

Abstract—With the advent of DVB-T in most European countries, the European Union has decided to end all analogue television broadcasts in its member countries until 2012. This analogue switch-off, as well as the increased spectral efficiency of the DVB-T protocol will create a surplus of spectrum in the UHF band, part of which is to be used by mobile communications systems. In order for this "digital dividend" to be shared efficiently, the coexistence and interference parameters between DVB-T and other services (designated as IMT-Advanced by the International Telecommunications Union) have to be studied. In this paper a generic 5 MHz interfering signal is broadcasted in close proximity to a stationary DVB-T receiver. Various DVB-T parameters are then measured and analyzed for different frequency values and power levels of the interfering signal.

1. INTRODUCTION

Frequency spectrum has always been a commodity of high demand, especially so nowadays with the advent of new broadband mobile services and applications. In particular, the part of the UHF spectrum that has been traditionally allocated to television broadcasting has recently provoked significant controversy as to its future use.

The penetration of the digital television has brought the development of new services into perspective, as the imminent digital switch-off (DSO) from analog to digital broadcasting will vacate a number of frequency channels. More specifically, the Regional

Received 29 August 2010, Accepted 19 October 2010, Scheduled 26 October 2010
Corresponding author: Vasilis P. Kalogirou (vkalo@mail.ntua.gr).

Radiocommunication Conference (RRC-06), which resulted in the Geneva 2006 Agreement (GE06), has planned the digital terrestrial broadcasting service in parts of Regions 1 and 3 (Europe, Africa, and part of Asia), in the frequency bands 174–230 MHz and 470–862 MHz [1]. According to GE06, all participating countries in these Regions are obliged to end their analog TV broadcasting service until 2015, while countries which are EU-members are encouraged to switch off earlier, in 2012 [2]. As the Digital Video Broadcasting-Terrestrial (DVB-T) standard has lower spectrum requirements due to advanced compression and multiplexing techniques, some part of the currently occupied UHF spectrum could be available for new services. This, still unspecified, spectral part is being referred to as the "digital dividend" [3]. The TV frequencies in the UHF band in particular (470–862 MHz) have stimulated the interest of mobile telecommunications operators, as, apart from the possible availability of frequencies, it has favorable propagation characteristics. On the other hand, broadcasters postulate the allocation of this spectrum as well to accommodate additional broadcasting services, since after all, the specific frequency band is allocated to TV broadcasting on a primary basis.

In this paper we attempt to examine the compatibility between the mobile and the DVB-T broadcasting service. To this extent, the situation in which a mobile transceiver (MT) operates in close proximity to a DVB-T receiver is analyzed and measured. A cross-layer approach is utilized, in which measurements of critical values in the physical layer are performed under specific conditions of perceived quality in video/audio services in the end-user layer. This is evaluated manually by the receiver operators, rather than applying more complex techniques of image quality assessment [4].

The purpose of the experiment is to determine the maximum allowable relative power level of the interfering signal, considering MT operation in different parts of the adjacent channel to the broadcasting service. Two different scenarios of receiving conditions (Outdoor reception with Line of Sight (LOS) to the DVB-T transmitter site, and indoor reception (without LOS) are examined). The first scenario corresponds to Fixed Antenna Reception, while the second to Class B Portable reception, as specified by ETSI [5].

2. METHOD

2.1. The DVB-T Signal

The DVB-T protocol allows for a wide variety of operational modes. The OFDM multiplexing can generate either 2 k or 8 k carriers (1705 and 6817 respectively after taking into account the spectrum mask suppression at the channel edges) in the nominal 8 MHz UHF channel bandwidth, while each one of the carriers can be modulated using QPSK, 16-QAM or 64-QAM schemes. To further enhance the reliability of the system, Forward Error Correction (FEC) is applied via punctured convolutional codes with possible code rates of 1/2, 2/3, 3/4, 5/6, and 7/8. The improved robustness of the signal by using a less complex modulation scheme or lower rate codes is however achieved at the expense of the useful data rate transmitted. Furthermore, in order to make the transmitted signal more resilient to multipath propagation and echoes, each OFDM frame incorporates a guard interval of 1/4, 1/8, 1/16, or 1/32 of its nominal duration, during which all echoes of the same signal received can usefully contribute and not act as interference. As with the modulation and coding schemes, the added multipath protection by using high proportion guard intervals (1/4 or 1/8) comes at the expense of the useful bitrate that can be transmitted. By selecting a combination of the above transmission characteristics, each broadcaster can design the transmission network to meet his specific needs in terms of signal robustness, area covered and data rate capacity between a minimum of 4.98 Mbits/sec and a maximum of 31.67 Mbits/sec [6].

The DVB-T signal source in this experiment is the sole multiplex in operation at present in the city of Athens, Greece. It is provided by ERT S. A., the National TV and Radio Broadcaster of Greece, and is transmitted in channel 48 of the UHF Band in Athens and its suburban areas. The current parameters utilized are 8 k Carriers, 1/8 Guard Interval, 16-QAM modulation with 3/4 code rate, offering a nominal data transmission rate of 16.59 Mbits/sec. The signal is broadcasted in a Single Frequency Network of 3 transmitters, all operating in the same channel (48 UHF). It must be noted that at the time of these measurements the DVB network was undergoing a trial period with frequent changes in network parameters and transmitter power levels in order to obtain optimal SFN performance in the service area of Athens.

2.2. The Interfering Signal

The scope of this experiment is the study of the coexistence of a DVB-T broadcasting service and a generic broadband signal representing a mobile communications service. As stated in the introduction, a possible future scenario is the shared use of the UHF band between DVB-T broadcasters and mobile services (characterized by the generic term IMT 2000 by the ITU) in adjacent UHF channels. Since the IMT 2000 incorporates a fair number of different mobile communication standards, and it is possible that even more will be developed in the

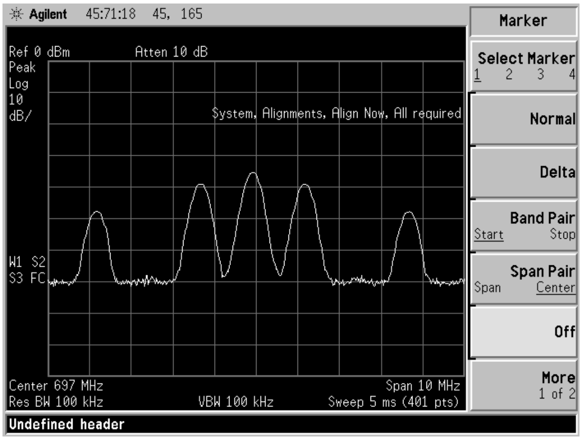

Figure 1. Interfering signal spectrum.

near future, the interfering signal of this experiment was selected as a generic template, and not a specific reproduction of one of the above mentioned standards.

The signal selected to act as interference in this experiment is a series of square pulses with high time of 400 nsec, repeated every 800 nsec (in essence a square wave with period 800 nsec and duty cycle 1/2) which then modulates a cosine carrier at the necessary frequencies near the DVB-T signal. The bandwidth of this signal is 5 MHz (same as the W-CDMA protocol [7]), and no filtering is applied to its spectrum. Although a mobile broadband signal will be subject to strict spectrum mask limitations, especially so if it is to co-exist with a DVB-T broadcast within the UHF band, the absence of filtering in this experiment could represent less than optimal equipment, or the worst case of the outright non-existence of filtering arrays.

The spectrum visualization of the signal is represented in the following Figure 1. It is generated throughout the measurement process using an Agilent MXG N5181A Analog Signal Generator.

2.3. Measurement Setup

The measurement process of this experiment consists of two parts: Field measurements and anechoic chamber. First, two sets of field measurements (outdoor and indoor) of the received DVB-T signal under the effects of the interfering signal at a wide range of relative frequency spacing. Second, precise measurements inside an anechoic chamber of the interfering signal alone.

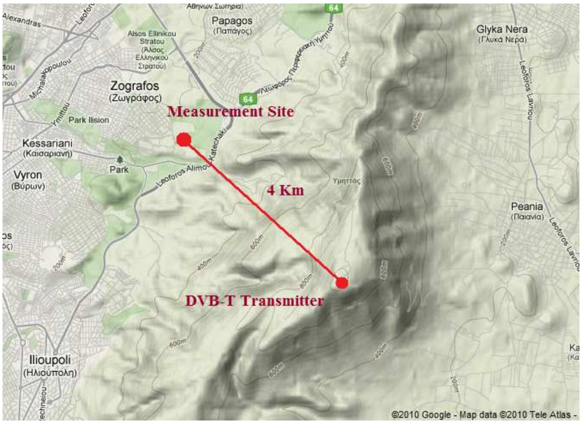

Figure 2. Relative positions of DVB-T transmitter and measurement site.

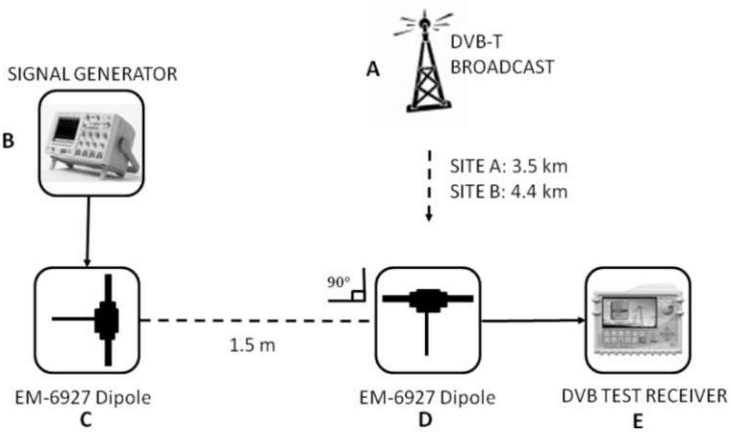

Figure 3. Field measurements setup.

2.3.1. Field Measurements

The first of the two field measurements was conducted on rooftop conditions with direct Line of Sight (LOS) to the nearby DVB-T transmitter site, while the second was conducted indoors, without LOS to the transmitter. Both were carried out at the building of the Electric and Computer Engineering department of the National Technical University of Athens, on a 4th floor rooftop and inside a 2nd floor office respectively. Figure 2 outlines the relative positions of the main transmitter site and the measurement setup in outdoor and indoor conditions respectively, while Figure 3 is the layout of the measurement setup itself, identical in both sets of the experiment.

The measurement setup as outlined above consists of the following: An Agilent MXG N5181A Analog Signal Generator (B) produces the interfering signal by modulating a sine carrier with a 5 MHz bandwidth square pulse. A Promax TV Explorer II+ is used in order to record and analyze the DVB-T signal received (E). This device records the signal power received, the C/N ratio, Bit Error Rate (BER) before and after the outer decoder, Modulation Error Ratio (MER) and various other data. It can also decode the mpeg stream and project a live picture of the broadcasted program. Both the generator and the test receiver were connected to two identical ElectroMetrics EM 6927 tunable dipole antennas (C) and (D), using low-loss coaxial cables. The interferer antenna (C) was situated 1.5 m away from the receiver antenna (D) and at 90° angle to its LOS to the DVB transmitter site. In the indoor setup, the receiver antenna was aimed to the office window, slightly adjusted in order to find the best reception angle, while the interferer antenna was situated 1.5 m away at a 90° angle, exactly as in the outdoor setup. The two antennas were situated at least 5 m away from the rest of the devices and the operators.

The commercial DVB signal received occupies the channel 48 of the UHF band (686–694 MHz), while the interfering signal frequency was initially set at 695 MHz and was increased by 1 MHz increments up to 705 MHz. At each step, the interfering signal power level was adjusted in order to identify the value necessary to disrupt the DVB service. More specifically, the decoded mpeg stream was observed by the operators until the distortion occurred was enough to render the service unviewable. This could include a large number of visual block errors, motion distortion, audio fading or even complete loss of mpeg stream synchronization. The power level of the interfering signal generator was adjusted in 1 dBm increments, and the last possible step before severe visual or audio degradation was identified. In most cases, a single 1 dBm step further than this point resulted in long blackouts of the visual component or even total loss of the mpeg stream. This value was recorded in order to be later used inside the anechoic chamber. Next, 20 measurement cycles were performed by the DVB-T test receiver (E). Each cycle had a 15-second duration, during which the receiver recorded the average values of signal level, C/N, BER and MER. In addition, a single measurement cycle was executed with the interferer being inactive, in order to obtain reference values for the DVB-T signal to be used for C/I calculations. In total, 21 cycles for each of the 11 different interferer frequencies were carried out outdoors, as well as an equal number indoors. The last measurements at 705 MHz were carried out with the Agilent MXG N5181A generator operating above 95% power. Any attempts to perform the measurements with the interfering signal at 706 MHz or more failed because the generator could not provide enough output power to disrupt the DVB-T service.

The next measurement phase is aimed at studying the effects of an interfering signal in a fixed frequency but of variable power, near the edge of the adjacent channel to the DVB-T broadcast. The interfering signal generator was set to the frequency of 697 MHz, as it is the closest central frequency outside the UHF channel 48 that a 5 MHz bandwidth signal can be transmitted without compromising the 694 MHz border of the UHF channel. The interferer's power was adjusted from the level of minimal effect on the DVB measured values, up to the point of complete failure of the receiver to identify a valid DVB-T signal. User-perceived layer quality was irrelevant in this segment: as long as the receiver could recognize a DVB signal and record its values, the measurements were carried out, even if the decoding of video and audio was impossible. As before, 20 measurement cycles were carried out at each instance, for a total of 18 power levels outdoors, and another 20 cycles for 18 power levels indoors.

During all the above measurement cycles, the device operators were situated at least 5 m away from the antennas and there were no moving people close to the setup, in order to minimize the time variability of the channel. Further away than these 5 m however, normal office activity was present, including personnel movement and doors opening and closing.

2.3.2. Anechoic Chamber Measurements

The purpose of the procedure inside the anechoic chamber is the exact measurement of the interfering signal in the absence of the DVB-T broadcast and other unspecified degradation factors. Since the DVB test receiver can only record values that relate to the DVB signal, it was necessary to isolate the interfering signal in order to extract the exact power level at the receiver device. Having measured this value, it is then possible to calculate the required protection ratio between the two signals for each carrier frequency of the interfering signal.

This step of the experiment was conducted in the semi-anechoic chamber of the Electrical and Computer Engineering department of the National Technical University of Athens. The device setup was identical to the outdoor and indoor measurements regarding both the orientation of the antennas and the 1.5 m distance between them, as shown in Figure 4. The DVB test receiver was replaced with an Agilent E4403B ESA-L Spectrum Analyzer (F), while the necessary infrastructure components (cables, connectors, and mounting tripods) were the exact ones used in the outdoor setup.

The signal generator was set to the previously recorded frequencies and the corresponding threshold power levels, and the spectrum analyzer was used to measure the signal power level at the receiving point. Each value recorded by the spectrum analyzer was averaged during 10-second sampling intervals, in order to eliminate time variability phenomena.

The results of this procedure are the interference (I) values used in the next section whenever a C/I ratio is mentioned.

3. RESULTS

In this section, the data collected in the above experimental procedures are presented in charts as functions of either the interference power level or the interfering signal frequency.

3.1. Interference with Variable Frequency

The minimum C/I required to maintain acceptable picture and sound quality for each interfering signal frequency is presented in the following Figure 5. The C/I value is derived from the DVB-T power level that was measured in the field setup, and the corresponding interference level that was measured in the anechoic chamber, as described previously.

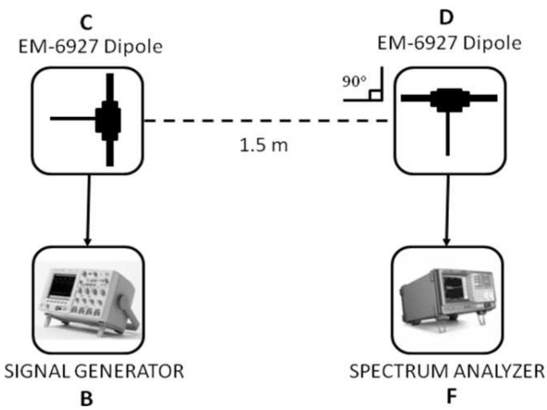

Figure 4. Anechoic chamber measurement setup.

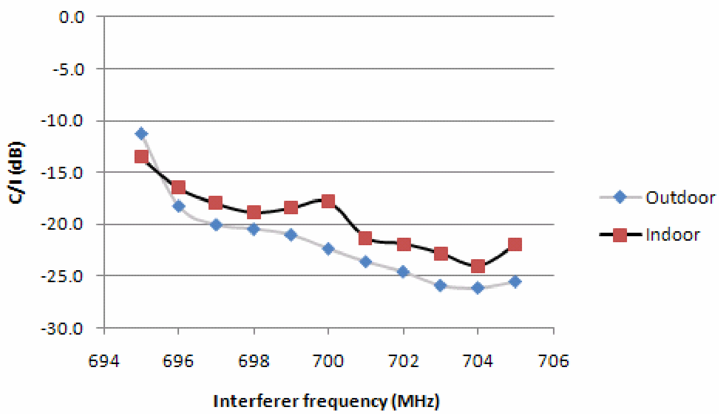

Figure 5. C/I to interferer frequency chart.

The outdoor C/I with the interferer at 69 MHz should be lower than the respective indoor value, as is evident by the trends of both the curves. This discrepancy in the measurement data is most likely a measurement error during the initial evaluation of the DVB-T signal level without the interferer active. One possible explanation for such an error could be a temporary decrease of transmitter power at one of the 3 DVB-T transmitter sites in Athens. Other than that, the C/I progression exhibits a gradual decrease, both in the outdoor and indoor situations. However, when the interfering signal is broadcast at 700 MHz it produces a notable increase in interference potential in indoor reception conditions. This increase is most likely the result of a personnel and/or equipment moving in the same office as the measurement setup. Although care was taken that no movement should occur at least 5 m away from the setup, it is possible that persons or objects with a big flat surface (such as a door or a drawing board) moving beyond that range could have a detrimental effect in the receiving conditions in an indoor Rayleigh-type channel for long enough to affect a single measurement set. Also worth mentioning is that in the final measurement sets for both indoor and outdoor setups, with the interfering signal centered at 705 MHz, there is a significant and unexpected increase in the required C/I to maintain acceptable service level. Given that the interferer center frequency is being progressively moved "away" from the DVB-T channel (686–694 MHz), a lower C/I for 705 MHz than 704 MHz should be expected, instead of the higher one that was measured. The reason for this apparent discrepancy is the internal amplifier of the Agilent MXG N5181A signal generator that was used as the source of the interfering signal. As the interferer signal frequency progressed further away of the wanted DVB-T channel (686–694 MHz) it was necessary to progressively increase the power output of the signal generator in order to disrupt the DVB-T service. The last measurement sets were carried out at 705 MHz, because at 706 MHz the signal generator was unable to disrupt the DVB-T signal even while operating at 100% output. The measurements at 705 MHz were carried out with the signal generator operating near its maximum power output and possible non-linear phenomena due to this might have caused the error in the interference level measurements.

The following chart (Figure 6) shows the BER after the Viterbi decoder in the receiver (VBER) for each frequency of the interfering signal. The inconsistency of the VBER measurements is due to the fact that the measurements are carried out near the threshold of visibility of the DVB-T signal and as such, the erroneous packets received are too random to allow for a stable VBER output. However, the two linear trend lines in the chart show that the indoor reception can suffers fewer errors until the threshold of visibility is reached, particularly when the interferer operates nearer to the edge of the DVB-T channel. This higher susceptibility of the indoor signal is caused by the Rayleigh character of the propagation path, with no prominent LOS signal received, as opposed to the Ricean outdoor channel [8]. The presence of a strong direct reception (as in an outdoor Ricean channel) does indeed give some robustness, especially as the interferer frequency moves away from the DVB-T channel edge.

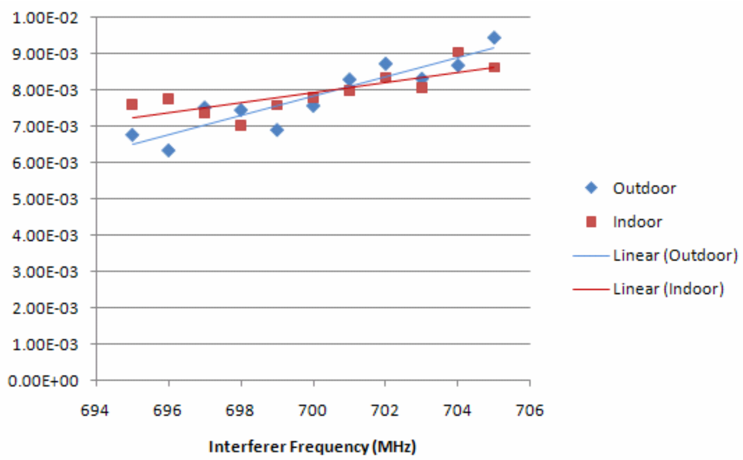

Figure 6. VBER to interferer frequency chart.

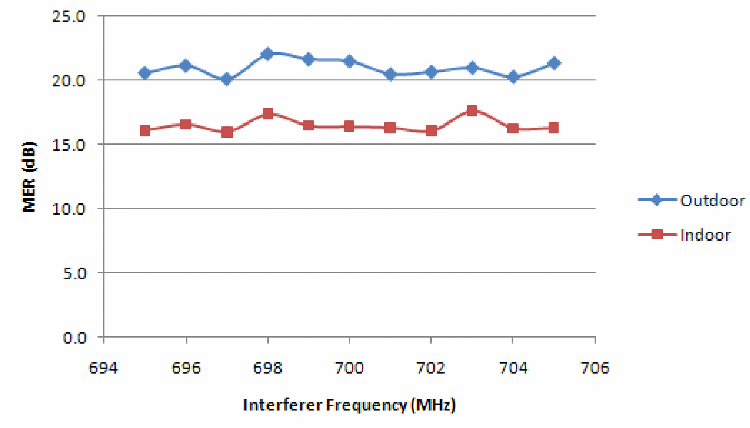

Figure 7. MER to interferer frequency chart.

An interesting observation of the VBER measurements is that the receiver is able to decode the DVB service with no apparent visual degradation well below the "Quasi-error free" point of $2 * 10^{-4}$ error rate, as universally specified for DVB-T [5, 6].

The Modulation Error Ratio (MER) measured remains relatively stable at the failure points, as expected. In outdoor reception the average MER at the loss of visual quality point is approximately 4 dB than indoors, as shown in Figure 7. It must be noted that the difference in MER remains almost constantly at this value, despite the fact that both signals have reached the threshold of visual loss of service. This can be explained by the strong presence of the LOS signal in the outdoor reception environment that adds to the average MER value measured despite the interference that causes the loss of visual quality.

The MER value can be measured accurately near the threshold visibility, (and in some cases even after visual degradation) and as such, it is a good indicator of imminent decoder failure. Unlike the BER measurements (CBER and VBER) that get progressively inaccurate near the threshold of visibility (evident in Figure 6), MER can offer better insight of the nature of the particular interference problems that are present. MER monitoring has been gaining popularity as an important tool to assess service quality in the presence of interference [9].

3.2. Interference with Variable Power Level at Fixed Frequency

The interfering signal is centered at 697 MHz as described in the method section and its power level varies, starting at the point the interference starts to affect the BER on the DVB-T receiver. The minimum required C/I (with the interferer at 697 MHz) at the visual threshold level is found in Figure 5: −20.1 dB for the outdoor reception and −17.8 dBm for the indoor reception.

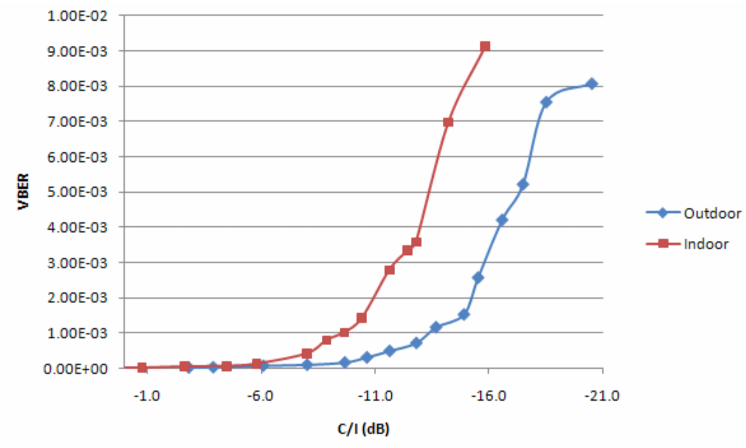

Figure 8. VBER in relation to C/I levels.

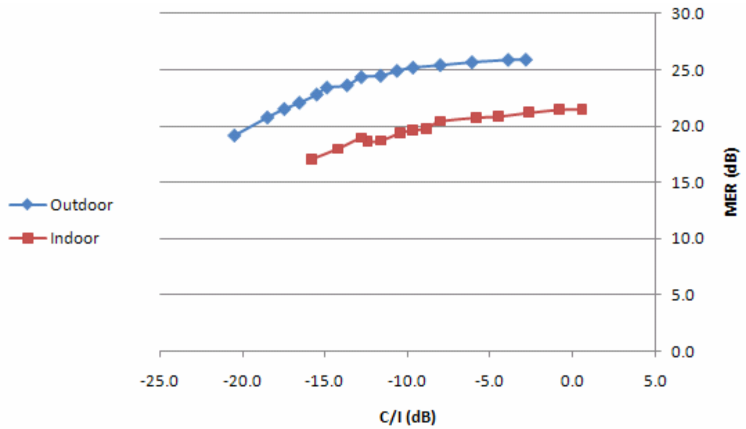

Figure 9. MER in relation to C/I levels.

Figures 8 and 9 show the expected higher tolerance of the outdoor LOS receiver to the increase of interference power level. It must be noted that the charts are drawn up to the visual failure point of the DVB-T signal. The receiver was able to continue recording of DVB parameters for even higher interference, but due to very high number of errors in the DVB reception, the VBER readings were erratic and unsuitable for any further analysis.

Once again it is observed that the receiver is able to go way below the "quasi-error free" VBER point of $2 * 10^{-4}$, as the threshold of visibility is reached at a VBER value of $9 * 10^{-3}$.

4. DISCUSSION

The preferred method for establishing the threshold of visibility in this study is manual observation of the decoded signal in order to spot visual artifacts and/or sound distortion in the timeframe of a few seconds. Although more complex methods for assessing the quality of the decoded signal are often employed, most notably VQM [4, 10, 11], and ESR_5 (Erroneous Second Ratio) [12, 13], the operator observed loss of visual quality was deemed adequate for the needs of this experiment.

The C/I values obtained from the measurement campaign differ significantly from the ITU specified for DVB-T to DVB-T and analog to DVB-T interference [5, 14], so it will be necessary to establish new set of protection ratios for each type of service that may be required to co-exist with DVB-T in the UHF band in the future. The European Conference of Postal and Telecommunications Administrations (CEPT) has already begun to address this issue both in regulatory and technical basis for its European members ([15, 16]) and final decisions are expected in the near future. As such, further research and experiments are required on the specific technical details of coexistence between DVB-T and any other services that may be allowed to share the UHF band.

This study is an attempt to obtain a set of generic reference values to be used in future measurement campaigns of compatibility between DVB-T broadcasts in the UHF bands, and a wide range of personal mobile services, under the generic characterization of IMT-Advanced (successor of IMT-2000) by ITU [17]. This measurement campaign utilized a generic unsuppressed w-cdma base signal as the source of interference, though a number of other signals can be utilized to simulate specific conditions of DVB-T and other services coexisting and sharing the "digital dividend" [18, 19].

REFERENCES

1. ITU, "Final acts of the regional radiocommunication conference for planning of the digital terrestrial broadcasting service in parts of regions 1 and 3, in the frequency bands 174–230 MHz and 470–862 MHz (RRC-06)," 2006.
2. Commission of the European Communities, "Communication from the Commission to the Council, the European Parliament, the European Economic, and Social Committee and the Committee of the Regions on accelerating the transition from analogue to digital broadcasting," Brussels, 2005.
3. RSPG07-161, "RSPG opinion on EU spectrum policy implications of the digital dividend," 2007.
4. Bertocco, M., M. Farias, D. Fortin, and A. Sona, "Cross-layer measurement for the analysis of a DVB-T system performances at the end user level," *Proc. of IMTC 2006 — Instrumentation and Measurement Technology Conference*, Sorrento, Italy, Apr. 24–27, 2006.
5. Digital Video Broadcasting (DVB); Implementation guidelines for DVB terrestrial services; Transmission aspects. ETSI Technical Report 101 190 V1.2.1, 2004.
6. Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television. ETSI European Standard (Telecommunication series) 300 744 V1.6.1 2008-09.
7. 3GPP, Spreading and Modulation (FDD), ETSI TS 125 213 V9.1.0 (2010-01).
8. "Probability Distributions Relevant to Radiowave Propagation Modeling," ITU-R P. 1057, 1994.
9. Bertocco, M., M. Farias, D. Fortin, and A. Sona, "Cross-layer measurement for the analysis of DVB-T system performance," *IEEE Transactions on Instrumentation and Measurement*, 2008.
10. Wolf, S. and M. Pinson, "Video quality measurement techniques," US Department of Commerce, National Telecommunications and Information Administration Report, 02-932.
11. Angrisani, L., M. Farias, D. Fortin, and A. Sona, "Performance assessment and optimization of DVB-T systems affected by in-channel interference," *IEEE Instrumentation and Measurement Technology Conference Warsaw*, Poland, May 1–3, 2007
12. Martínez, A., et al. "Analysis of the DVB-T signal variation for indoor portable reception," *IEEE Transactions on Broadcasting*, 2009.

13. ITU-R, "The ESR5 criterion for the assessment of DVB-T transmission quality," ITU-R, Document 6E/64-E, Apr. 2004.
14. "Planning criteria for digital terrestrial television services in the VHF/UHF bands," Rec. ITU-R BT 1368, ITU-R P. 1057, 2003.
15. CEPT-ECC, "Report from CEPT to the European Commission in response to the Mandate on the identification of common and minimal (least restrictive) technical conditions for 790–862 MHz for the digital dividend in the European Union," CEPT Report 30, Oct. 2009.
16. CEPT-ECC, "Report from CEPT to the European Commission in response to the Mandate on technical considerations regarding harmonisation options for the digital dividend in the European Union," CEPT Report 31, Oct. 2009.
17. ITU-R, "ITU global standard for international mobile telecommunications 'IMT-advanced'," 2010.
18. Bendov, O., "Limits on fixed broadband devices for interference-free operation in the DTV spectrum," *IEEE Transactions on Broadcasting*, 2007.
19. Setiawan, D., D. Gunawan, and D. Sirat, "Interference analysis of guard band and geographical separation between DVB-T and E-UTRA in digital dividend UHF band," *International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME)*, 1–6, 2009.