Abstract

This paper presents some laboratory tests carried out to measure the BER degradation caused by an analogue PAL-G television interference on a COFDM 8K digital television signal. The tests made include co-channel and both upper and lower adjacent channel interference situations. Recently this year, the ITU-R has presented some protection ratios to be sought when planning DVB-T networks. The results of the work presented here include a wider range of power ratios and their effect on the BER rather than the limit protection values. The new digital services will share the same frequency bands as the conventional analogue television so the exact characterization of mutual interference is a major concern of broadcasters during the transition period when both systems have to co-exist.

1. INTRODUCTION

DVB-T [1][2] networks are currently operational in some European countries. One of the major concerns of broadcasters in countries like Spain is the compatibility of the new DVB-T and the analogue system sharing the same frequency bands over common service areas.

Some protection ratios have been recently proposed by the ITU-R on the Rec. BT.1368-2 [3]. Table I summarizes the protection ratios to be guaranteed in three interference scenarios, i.e. co-channel, upper adjacent channel and lower adjacent channel interferers.

<table>
<thead>
<tr>
<th>Unwanted signal</th>
<th>Wanted signal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analogue PAL G</strong></td>
<td><strong>Wanted signal DVB-T</strong></td>
</tr>
<tr>
<td>CO-CHANNEL</td>
<td>3 dB</td>
</tr>
<tr>
<td>(N+1)</td>
<td>-38 dB</td>
</tr>
<tr>
<td>(N-1)</td>
<td>non defined</td>
</tr>
<tr>
<td><strong>DVB-T</strong></td>
<td><strong>Wanted signal PAL - G</strong></td>
</tr>
<tr>
<td>CO-CHANNEL</td>
<td>40 dB</td>
</tr>
<tr>
<td>(N+1)</td>
<td>-5 dB</td>
</tr>
<tr>
<td>(N-1)</td>
<td>-5 dB</td>
</tr>
</tbody>
</table>

Table I. Protection ratios suggested by the ITU-R

The measurements presented here try to specifically evaluate the degradation caused by analogue television interference on the DVB-T reception quality.

Some interference measurements had already been carried out in former measurement campaigns which were designed mostly to test the DVB-T behavior under different reception conditions [4] and to survey the interference degradation caused by DVB-T on the analogue PAL-G signal quality [5].

The results of those tests showed that the adjacent channel interference degradation on the analogue signal caused by the DVB-T spectrum could be avoided if the desired to undesired power ratio was kept higher than -5 dB. Considering the reduction of the transmitter power for similar service areas on the digital networks the compatibility on adjacent channels seems feasible with an acceptable degradation of the analogue picture quality.

The measurements presented here try to specifically evaluate the degradation caused by analogue television interference on the DVB-T reception quality.

This paper will describe the measurement equipment and techniques to show the applicability of the results. Further on, the whole set of measurements will be summarized on different curves and tables. Finally and considering all the results obtained, some conclusions will be proposed as well as some outlines of present and future works.

2. TARGETS

This work will focus on the effect of analogue PAL-G interference (either co-channel and adjacent channel) on the quality of reception of COFDM–8K signals.
In order to obtain both accurate and useful results for real planning, the first target was to corroborate the values given by the ITU-R. Network planning should comply to those protection ratios 99% of the time. Nevertheless, the effect of power ratios which are below the limit is not shown by the Rec BT 1368-2.

As a consequence, the second target of these measurements was to explore the behavior of the BER for power ratios below the maximum threshold. The result would be a set of curves showing the range of power ratios expected on real networks rather than the maximum ratios stated by the ITU-R.

Three different situations were to be tested:

- Lower adjacent channel analogue interference
- Co-channel analogue interference
- Upper adjacent channel analogue interference

As mentioned before, these scenarios have to be carefully studied to minimize the problems that broadcasters will have to face when implementing digital broadcasting networks during the transition period previous to a fully digital environment. The selection of the frequencies to be tested was done according to the criteria adopted by European countries like Spain where the upper UHF is going to be used for the introduction of the digital services.

It should also be noted that lower and upper adjacent channels to an analogue emission have become candidates to allocate new digital emissions inside the overcrowded UHF band in Europe. Therefore, the adjacent channel disturbances could easily appear at the first stages of the digital network implementation process [6][7].

3. MEASUREMENT TECHNIQUES

3.1 Measurement Equipment

The BER data presented on this paper have been obtained using the measurement system showed on figure 1. The equipment used has been chosen with the aim of obtaining data to be used on real network planning.

The signals tested were generated by real (already operative as part of different networks) broadcasting equipment:

- DVB-T modulator and channel converter. It meets the DVB-T specifications [1] and is capable of generating a COFDM 8K spectrum on any channel of the UHF band. The DVB-T mode used during these tests is COFDM 8K, 64 QAM, 1/4 guard interval and 2/3 convolutional coding. The input baseband information stream was a live MPEG-TS.

- Analogue PAL-G modulator and channel converter. The output of this modulator was an analogue TV signal on Channel 68 (center frequency 850 MHz). The video source was created by a test pattern generator. Both modulator and test pattern source are broadcasting equipment used on real analogue networks. Other PAL G signal parameters are shown on table II.

<table>
<thead>
<tr>
<th>Video Bandwidth</th>
<th>5 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio subcarrier</td>
<td>5.5 MHz from video carrier</td>
</tr>
<tr>
<td>Audio Carrier Level</td>
<td>10 dB below video</td>
</tr>
<tr>
<td>UHF Channel Bandwidth</td>
<td>8 MHz</td>
</tr>
</tbody>
</table>

Table II. PAL-G parameters

![Figure 1. Measurement System](image-url)
Both analogue and digital transmitted power levels were measured after the variable attenuators shown on figure 1. The COFDM signal power measurements have been carried out using a vector signal analyzer that was able to automatically integrate the power across the 7.6 MHz bandwidth of the DVB-T 8K mode.

A conventional spectrum analyzer could also have been used, but in that case a bandwidth correction factor should have to be applied [8]. The analogue power was measured as the peak average power during sync tip period.

Several decoding equipment was used to decode and measure the DVB-T MPEG-TS information stream as shown in figure 2. In order to obtain data applicable to any standard DVB-T receiver, all the measurements were carried out using two different COFDM decoder chipsets on development board kits. These development boards include the tuning, OFDM demodulation and forward error correction blocks according to the DVB-T standards. The output of this decoding sets is a standard MPEG-TS. The minimum C/N required by those receivers was measured to be around 20 dB (COFDM 8K, guard interval 1/4, 2/3 convolutional code) which is a typical value for domestic receivers. No pre-amplifiers were used in the test.

### 3.2 Measurement techniques

The measurement system outlined on figures 1 and 2 allowed to take the following measurements:

- Power ratios between digital and analogue signals
- Bit Error Rate after Viterbi decoding

The BER has been measured using the so called “in service” method. This procedure is based on the error detection and correction that is made at the Reed-Solomon decoding stage. Under proper reception conditions, when the received signal is strong enough and distortion caused by multipath, interference, etc, are negligible, the Reed Solomon decoder is able to detect and correct the errors on the information stream.

On the other hand, if the received signal is too weak or the distortions are high enough, burst errors overload the Reed Solomon algorithm and the bit error rate will be higher than $2 \times 10^{-4}$ (quasi error free condition).

The BER is obtained comparing the input and output streams of the Reed Solomon decoder. This estimation is considered accurate up to $10^{-3}$ and higher values should not be supposed reliable [9].

The main advantage of this method is the ability of taking BER measurements while decoding “on air” signals and does not require either PRBS generation or BER measurement equipment.

All the error measurements presented on this paper were made by accessing internal registers of the Reed Solomon stage of both COFDM chipset development boards. Once the measurement system had been set up, the output power of each modulator was adjusted by means of the variable attenuators and the resulting BER was measured several times in order to obtain an average value for the selected power ratio.

![Figure 2: COFDM decoding and BER measurement system](image-url)
3.3 Power considerations
In order to obtain power ratios of wanted vs. unwanted signals, the received input power of the wanted signal (DVB-T) has to be kept constant all over the tests and the different ratios will be obtained by changing the unwanted signal level. The value adopted during these tests was –60 dBm following the recommendations given by ITU-R [3].

4. RESULTS AND DISCUSSION
The results in this section are presented according to three different interference scenarios, i.e., co-channel, upper and lower adjacent channel interference.

4.1 Co-channel Interference
For all the co-channel interference measurements both transmitters, analogue and digital, were configured to place each spectrum centered on UHF channel 68 (center frequency 850 MHz).

Figure 3 shows the results obtained. Desired-to-Undesired (D/U) power ratios are plotted on the horizontal axis. The values are expressed in decibels as:

\[
\text{Power Ratio} = 10 \log \frac{\text{DVB-T Signal (7,6 MHz BW)}}{\text{PAL - G Video Carrier}}
\]

As expected, the number of erroneous bits increases when the power level of the analogue interferer is made higher. It comes clear from the curve that only values below 6 dB cause considerable degradation on the digital stream quality. Nevertheless, it should be noted that the quasi error free condition is achieved for values above than 4.5 dB.

The continuous line on the same graph represents the exponential interpolation curve that comes out from the whole co-channel interference measurement set. This continuous line expresses graphically the relationship between the BER and the wanted-unwanted signal power ratio.

The first conclusion that arises from the curve obtained is the ability of the COFDM modulation to cope with analogue co-channel interference. A standard DVB-T receiver would be able to decode the MPEG-TS with no noticeable degradation in video and audio quality if the power ratio is higher than 4 dB.

The ITU-R recommendation BT 1368-2 gives a protection ratio of 3 decibels for a co-channel PAL interference when the wanted signal is a DVB-T whereas the results presented here show an slightly higher value. On the other hand, if the 3 dB ratio is set at the receiver input the measured BER is \(6 \times 10^{-4}\).

Table III shows the comparison between obtained results and ITU-R recommended value.

<table>
<thead>
<tr>
<th>Protection Ratio</th>
<th>Measured BER for a 3 dB ratio</th>
<th>Measured Protection Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITU-R BT 1368-2</td>
<td>6 (\times 10^{-4})</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

Table III. Co-channel protection ratios

4.2 Upper adjacent Channel Interference
The amount of interference created by an adjacent channel emission on a wanted signal depends on the transmitter
output power mask, which usually depends on the quality of the filters before the radiation systems. The technical specifications given by the manufacturer of the PAL modulator used during these tests ensure an harmonics and spurious radiation out of channel below 60 dB.

In order to obtain the values for this scenario, the DVB-T modulator was configured to output a COFDM spectrum on the UHF channel 67. The center frequency of this channel is 842 MHz. The PAL-G baseband signal was up-converted to Channel 68.

The results of the BER measurements for the upper adjacent channel interference are shown on figure 4. The vertical axis shows the BER measured before the Reed-Solomon decoder. The horizontal axis shows the ratio of wanted (DVB-T) and unwanted (PAL-G) signals.

On figure 4, the discrete points are mean values of several measurements made with both COFDM 8K chipsets for a certain power ratio of the analogue and digital signals. The continuous line is the mathematical interpolation from those measurements and shows the variation of the BER along the whole range of power ratios.

![Figure 4](image)

**Figure 4.** Upper adjacent channel D/U Power Ratio (DVB-T/ PAL) vs BER after Viterbi decoding

As it comes clear from figure 4, at ratios higher than -34 dB the effect on the information stream quality is negligible. In fact, the measured BER is almost zero. The BER increases sharply for D/U ratios lower than -37 dB, past the quasi error free condition.

Those results agree with the protection ratios suggested by the ITU-R , which gives a protection ratio of –38 dB to be sought when planning DVB-T services.

The robustness of the COFDM 8K modulation against upper adjacent channel interference ensures the suitability of the adjacent channels to analogue allocations for initial introduction. On the other hand, such low values indicate that the real constraint on the simulcast environment is the protection of existing analogue television services.

### 4.3 Lower adjacent Channel Interference

The same methodology has been followed to measure the lower adjacent channel interference. The out-of-band harmonics and spurious radiation (<60 dB) from the analogue transmitter are also applicable to the measurements shown in this section. The DVB-T spectrum was placed on channel 69 (858 MHz) and the analogue PAL-G on channel 68 (850 MHz).

Obtained results are displayed on figure 5. In the same way as former graphs, the discrete points represent the mean value of a representative amount of BER measurements made using the two chipsets under the same power ratio conditions. The continuous line again represents the exponential interpolation of the whole set of measurements.

![Figure 5](image)

**Figure 5.** Lower adjacent channel D/U Power Ratio (DVB-T/ PAL) vs BER after Viterbi decoding

The vertical axis indicates BER values measured before the Reed Solomon stage, and the horizontal one represents the power ratios of digital and analogue signals calculated following the expression mentioned before.

According to the BT 1368-2 no values have been specified for the upper adjacent channel PAL G interference scenario by the ITU-R so far. The figures obtained in these measurements give a protection ratio of –43 decibels (Table IV).

The measured lower protection ratios required to protect lower adjacent channel interference are expectable if the asymmetrical shape of the spectrum of the PAL G signal is...
considered. Power ratios higher than –39 dB do not cause any BER degradation. Values between –39 and –43 dB increase the number of errors in the MPEG-TS.

<table>
<thead>
<tr>
<th>Protection Ratio ITU-R BT 1368-2</th>
<th>Measured Protection Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>No value specified</td>
<td>-43 dB</td>
</tr>
</tbody>
</table>

Table IV. Lower adjacent channel protection ratios

5. CONCLUSIONS

The work presented in this paper aimed at modeling the variation of the bit error rate of the MPEG-TS in a DVB-T signal when an analogue PAL television interference is present.

The DVB-T mode tested during these laboratory measurements has been COFDM 8K, 64 QAM, 1/4 guard interval, and 2/3 convolutional coding rate. This particular mode is the one being used on the DVB-T networks that have already become fully operational in Europe.

The ITU-R has published some protection ratios to be sought when planning the DVB-T services. The data presented on the BT-13682-2 are not completed in some cases yet (lower adjacent channel PAL-G interference) and do not show the variation of the BER with power ratios (wanted/unwanted) lower than the protection ratio (power ratio for QEF condition).

The results of the measurements presented here are some curves that show the effect on the MPEG-TS bit error rate under three different interference situations: co-channel, upper adjacent channel and lower adjacent channel interferences. The most remarkable result is the confirmation of the excellent behavior of the COFDM 8K system under interference situations, even if a considerable high co-channel interference is present. The results agree with values recommended by the ITU-R as shown in table V.

<table>
<thead>
<tr>
<th>Unwanted signal</th>
<th>Wanted signal DVB-T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UIT-R</td>
</tr>
<tr>
<td>Analogue PAL-G</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>(N+1)</td>
</tr>
<tr>
<td></td>
<td>(N-1)</td>
</tr>
</tbody>
</table>

Table V. Comparison between measured and UIT-R values

Further work needs to be done in order to test different DVB-T modes and single frequency networks that could be used in future planning. Such measurements are now being planned and include both laboratory and field tests.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


