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Improving Measurement Techniques for Testing Digital Broadcasting Systems

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***Abstract*—This paper presents a methodology for efficient measurement of digital broadcasting signals, both with field trials or at the laboratory. The study is focused on measuring the C/N requirement for achieving a threshold BER. A comparison between the traditional techniques and the proposed methodology is analyzed in this work. The key of the methodology presented in this paper is the use of general purpose equipment such as a vector signal analyzer for recording baseband IQ samples.**

***Index Terms*—C/N measurement, field trials, digital broadcasting, measurement system, signal processing.**

I. Introduction

The planning of a measurement campaign for testing a digital broadcasting system includes a number of elements which cover the transmission equipment, spectrum licenses and the measurement system. Usually the availability of all these elements is limited in time and a compromise must be reached between the number of measurement locations and the number and kind of measurements carried out at each location. The wider the variety of measurements carried out at each location the longer the measurement time is and thus a smaller number of measurement locations can be covered.

A key element in the measurement system is the professional receiver used to carry out all the baseband measurements on the received signal. When the digital broadcasting standard used is mature, a number of professional receivers are available from different manufacturers and usually only one of them is used in the measurement system. However the situation is different when testing emerging technologies. In this last case, the professional receiver available usually evolves according to the following steps:

1) A reference software receiver is first implemented and used in computer simulations.
2) These simulations may advise a change in the initial specification of the system, a change which is incorporated at the software receiver and validated.
3) After the system specification is validated using computer simulations with the software reference receiver, equipment manufacturers do the proper with a hardware implementation.
4) The hardware implementations of different manufacturers are cross-validated and used to re-validate the specification in laboratory simulations.
5) Finally field measurements are carried out in order to test the performance of the system under real conditions.

Using this methodology field trials are not really meaningful until reference hardware implementations are available. Furthermore, this hardware implementations are first generation prototypes that may have not been thoroughly validated. This could lead to a situation in which the measurements carried out on the field result inaccurate, and a new measurement campaign could be required.

To overcome the presented disadvantages, this paper presents a measurement technique that both reduces the measurement time required at each location and avoids situations in which measurement campaigns must be extended with further measurements on the field. This technique is based on the use of general purpose equipment such as a vector signal analyzer and an arbitrary waveform generator.

The methodology presented in this paper has been validated with measurements [1] of different digital broadcasting systems such as DRM [2] and DVB-T [3], and it is being used for testing the new generation of digital broadcasting systems such as DVB-T2 [4] and DVB-SH [5]. The paper presents results of applying this methodology to different systems.

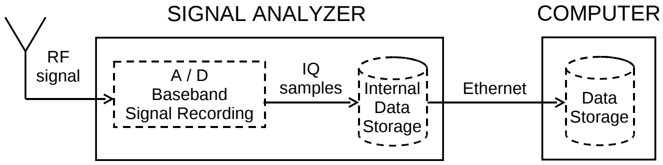
II. Proposed Methodology

A. Signal Acquiring and Recording

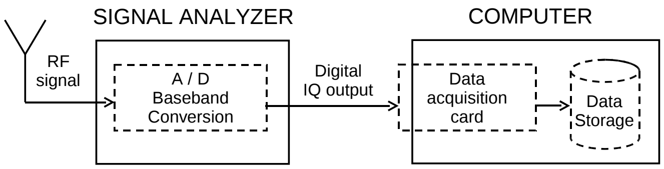
Digital broadcasting signals, received in the coverage area of a transmitter, can be captured with a vector signal analyzer that performs the analog to digital conversion. Received signal is down converted and baseband information is digitalized as IQ samples that can be recorded for further processing.

There are a number of key aspects to be considered when using this equipment for recording baseband IQ samples:

- Equipment bandwidth is fitted to cover whole signal frequency occupancy, also considering possible sidebands effects (10 MHz bandwidth is commonly used for 8 MHz digital television systems).
- Both electronic noise in equipment circuits (usually characterized as dBm/Hz) and quantization levels used in digitalization influence recorded signal quality (14 or 16 bits/sample are commonly used to minimize signal degradation). This quality should be better than the one expected for the professional hardware receiver in order to not influence further results.

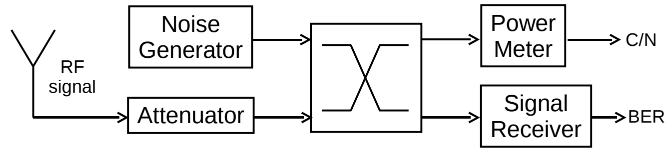


(a) In the equipment

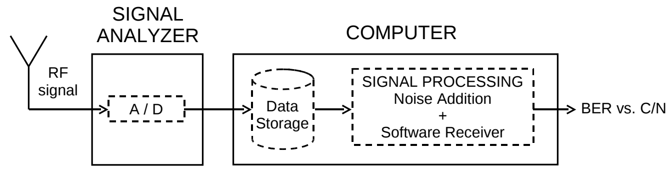


(b) In a computer

Fig. 1. Recording baseband IQ samples



(a) Traditional methodology



(b) Signal processing methodology

Fig. 2. Measuring minimum C/N requirement

- Time records for signal acquiring must be defined considering the type of studies to perform and the reception scenario. Record lengths may be different in urban portable studies of signal strength variability and in rural mobile studies of Doppler spread. Signal bit rate also defines minimum record length because capturing time must be long enough to achieve threshold BER values associated to Quasi-Error-Free reception condition. Moreover, processing methodologies for parameter values averaging also influence minimum record lengths.
- Signal processing and analysis is not required at capturing equipment, but high capacity storage memories with high transfer bit rates are necessary for signal recording.

Basically, there are two options for recording IQ samples using vector signal analyzers available at the market. The first one (Fig. 1(a)) consist on stand-alone equipment that stores a limited time capture in their internal memory. This time capture can be later dumped to the internal hard disk and downloaded to a PC. The second option (Fig. 1(b)) consists on combining a vector signal analyzer with continuous digital IQ output with a data acquisition card installed on a PC, thus allowing for a longer time capture. In the case of digital TV signals, a 10 MHz capture bandwidth can be used requiring typically a 51.2 MB/s data transfer rate on the PCI bus, which is reasonable.

B. Processing the Recorded Signal

The resulting data from a measurement campaign would be a set of files with the received signal recorded as baseband IQ samples. This signal can be later used at the laboratory with no time constraints. Furthermore, any of the measurements taken at any location can be later reproduced the number of times desired to carry out new measurements using different receivers or new upgrades of the same receiver.

When no professional hardware receivers are available at the time of the campaign, the reference software receiver can be used to read the file with IQ samples as the input data. When hardware receivers become available, the recorded data can be used to reproduce the reception conditions without carrying out a new measurement campaign.

In order to perform the measurements with hardware receivers, an arbitrary waveform generator must be used. This equipment performs the digital to analog conversion and up converts the signal to the RF channel. When choosing an arbitrary waveform generator, it is important to take into account the same considerations already presented for the vector signal analyzer.

C. Measuring Minimum C/N Requirement

One key parameter for testing the performance of a digital broadcasting system is the minimum C/N (RF signal to noise ratio) requirement for achieving a threshold BER equivalent to Quasi-Error-Free (QEF) condition to the end user. This C/N requirement is one of the most important parameters used when planning a digital broadcasting service in a coverage area.

When a professional test receiver is used to measure the minimum C/N requirement of an emerging broadcasting system, two techniques are traditionally used [6]–[8] as shown in Fig. 2(a):

- Use a variable attenuator to decrease the C/N ratio in successive steps until the threshold BER is reached.
- Use a AWGN variable noise generator to decrease the C/N ratio and carry out a procedure similar to the previous one. This technique has the advantage that a minimum signal level is guaranteed at the receiver input.

Both of these techniques requires a measurement time in each step long enough for the receiver to re-synchronize and for receiving a number of bits large enough to measure the BER.

Using the signal recording technique depicted in Fig. 2(b), the measurement time is drastically reduced since the time capture can be as short as one of the steps of the traditional methodology. This recorded signal would be later analyzed at the laboratory modifying the C/N ratio.

Another advantage of this technique is that BER measurements for different C/N ratios are taken under exactly the same channel state. This is not possible with the traditional techniques since the channel can change from one step to the other.

The C/N modification on the recorded signal can be carried out by software, as explained in section II-D ahead, thus avoiding the need for a variable attenuator or a variable noise generator.

Stored data provides information about received RF signal power level. This signal can be distorted with digital signal processing techniques, adding increasing variable noise that simulates decreasing C/N values for receiving signals. This distorted signal can be analyzed by means of a software-based receiver, obtaining BER measurements for corresponding C/N values. Therefore, with this methodology minimum C/N requirement is achieved when BER parameter reaches the QEF condition.

D. Additive White Gaussian Noise Generation by Software

Gaussian pseudo-random numbers can be generated given a source of uniform pseudo-random numbers in different ways [9]. One important method is the polar form of the Box-Muller [10] transformation as follows.

Given u and v, independent and uniformly distributed in the closed interval $[-1, +1]$, and let $s = u^2 + v^2$, if $s = 0$ or $s \geq 1$ then a new pair (u, v) is obtained, else the noise sample $z = I + j \cdot Q$ is calculated as:

$$I = u \cdot \sqrt{\frac{-2 \cdot \ln s}{s}} \quad (1)$$

$$Q = v \cdot \sqrt{\frac{-2 \cdot \ln s}{s}} \quad (2)$$

The resulting AWGN has mean 0 and variance 1 but, in order to achieve the desired C/N ratio, the noise sample z must be multiplied by the new standard deviation σ before being added to the signal sample. Given a signal power S and a C/N ratio in dB, the standard deviation σ of the noise signal can be calculated as shown in (3).

$$\sigma = \sqrt{\frac{S \cdot 10^{-\frac{C/N}{10}} \cdot \frac{BW}{F_s}}{2}} \quad (3)$$

The $\frac{BW}{F_s}$ factor accounts for the receiver bandwidth BW used for C/N calculation, where F_s is the sampling frequency of the complex signal.

III. Results

The methodology proposed has been tested with terrestrial digital video broadcasting signals using both the mature DVB-T system and the emerging DVB-T2 system.

On the one hand, real signals have been tested performing C/N threshold calculation on the field using the typical procedure setup shown in Fig. 2(a). On the other hand, the signals have also been acquired and recorded as baseband IQ samples. This recorded samples have been processed with addition of Gaussian noise as explained in section II-D, then signal parameters have been measured with software based DVB-T and DVB-T2 receivers using the setup shown in Fig. 2(b).

A. Mature DVB-T System

C/N and BER measurements have been carried out using both the traditional and the proposed methodologies with a DVB-T signal captured on the field.

Professional equipment have been used to measure BER and to increase the noise level as explained for the case of traditional methodology. For the proposed methodology a signal vector analyzer has been used to capture the IQ samples and a professional DVB-T/H software receiver [11] for adding Gaussian noise and computing the BER.

The noise level has been modified in order to obtain C/N variations from 15 dB to 35 dB. BER measurement has been taken before the Viterbi decoder by comparing input and output bits at the decoder. Results are presented in Fig. 3.

Using this mature technology with well known equipment both setups provide similar results, so the proposed methodology is valid and can be used for testing system performance when reduced measurement time is required in field trials or laboratory tests.

B. Emerging DVB-T2 System

A signal obtained from DVB-T2 field trials [12] at Seville (Spain) has been used to present the advantages of the proposed methodology for the evaluation of emerging digital broadcasting systems.

C/N and BER before BCH measurements have been carried out using the traditional methodology with prototype equipment. In each measurement location IQ samples of the signal were also recorded using a vector signal analyzer in order to later apply the proposed methodology. Results are presented in Fig. 4.

The DVB-T2 prototype software receiver uses the received bits before adding the noise in order to compare them with those obtained with the noisy signal, thus providing a precise BER measurement in a wide range of values.

From Fig. 4 a difference of about 3 dB is obtained in the C/N ratio required for achieving a threshold BER of 10^{-7} before BCH decoder. This is due to a problem with the initial implementation of the prototype hardware receiver. With the proposed methodology, the correct C/N ratios have been calculated later without the need of carrying out a new measurement campaign.

IV. Conclusions

Field trials or laboratory measurements of digital broadcasting systems performance can be carried out with one vector signal analyzer, instead of using professional test receivers for each broadcasting system.

Traditional techniques for measuring C/N thresholds require attenuators and noise generators. Described technique requires only one equipment and reduces drastically the measurement time.

With this methodology, the received signal is acquired and baseband IQ samples are recorded. Calculation of C/N values for QEF condition can be performed with signal processing algorithms, adding noise to recorded samples.

System performance results obtained with the software-based setup are similar to those obtained with a traditional setup.

Another advantage of the proposed methodology is its use for evaluating emerging digital broadcasting systems. When the technology is not mature, hardware prototypes may have implementation problems that could invalidate all the measurements carried out. With the proposed methodology, the IQ samples of the signals are recorded and can be used later to obtain the correct values without requiring a new measurement campaign.

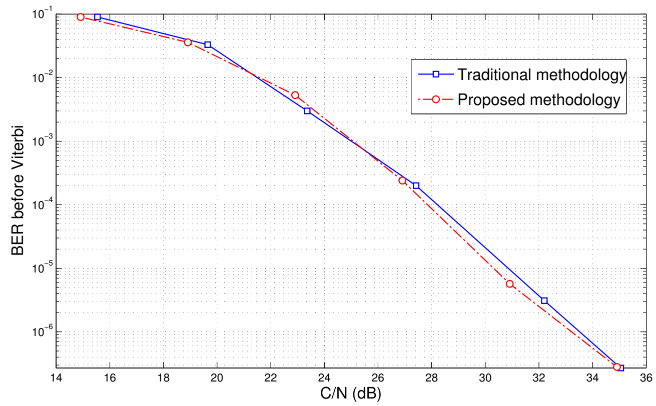


Fig. 3. Validation of the proposed methodology using DVB-T signals (8k, 64QAM, 1/4 guard interval, 2/3 code rate)

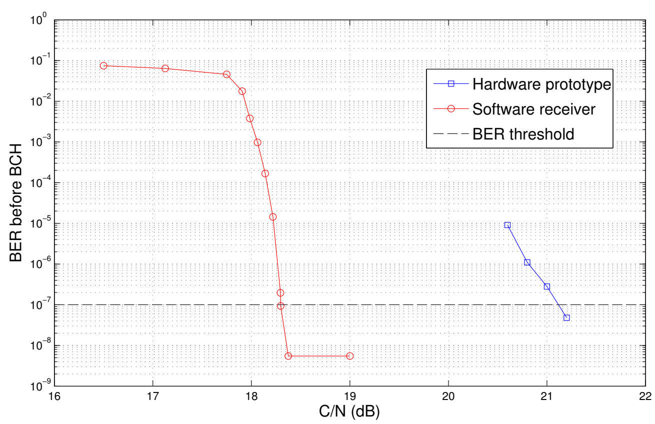


Fig. 4. Advantages of the proposed methodology using DVB-T2 signals (32k, 256QAM, 1/128 guard interval, 3/5 code rate)

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