A precompliance EMC test-set based on a sampling oscilloscope

A Precompliance EMC Test-Set Based on a Sampling Oscilloscope

Marco Parvis, *Senior Member*, Guido Perrone, *Member*, and Alberto Vallan

***Abstract*—In this paper, a precompliance test-set for the measurement of conducted emissions based on a medium-level sampling oscilloscope and on a fast filtering algorithm is presented. This system has been designed as a low-cost alternative to the typical precompliance test-sets that are based on spectrum analyzers equipped with EMC filters and peak detectors. Experimental examples of the results obtained using a sampling oscilloscope with 8 kbytes of memory are given.**

***Index Terms*—Discrete fourier transform, electromagnetic compatibility, spectral analysis.**

I. Introduction

THE ELECTROMAGNETIC compatibility (EMC) certification is an important issue in the design and fabrication of any electrical device since, in most countries, emission and susceptibility levels must comply with strict regulations. However, EMC full-compliant measurements of both conducted and radiated emissions are rather expensive and require dedicated instrumentation not readily available in most laboratories of small and medium enterprizes. A low-cost precompliance test-set is therefore important to reduce the overall cost, since it allows the repeated characterization of a prototype while still under development and leaves the expensive full-compliant EMC measurements for the final device. The following sections therefore describe a simple test-set arrangement that is based on widely available digital oscilloscopes.

II. Compliance and Precompliance Tests for Conducted Emissions

Compliance tests for conducted emissions are performed in qualified sites according to specific standards. As an example, in Europe, data processing devices must comply with the emission levels defined in the European Norm EN55022 while similar levels are defined in others countries (e.g., FCC15 in USA).

Conducted emission measurements are carried out using the setup defined in the CISPR16 recommendations [1] that is basically composed of a line impedance stabilization network (LISN) and a receiver. The LISN is a passive filter that lets the mains signals feed the equipment-under-test (EUT), while routing the EUT disturbances to the receiver. The CISPR16 recommendations define most of the receiver specifications such as the detector type and the intermediate filter (IF) bandwidth. In particular, for conducted emission measurements in the band B of the spectrum (i.e., from 0.15 MHz to 30 MHz), the recommendations require a quasi-peak detector with a charge time constant of 1 ms and a discharge time constant of 160 ms and a receiver having an IF filter bandwidth of 9 kHz at the -6 dB points.

Regardless of the employed test-set, measurements done using a quasi-peak detector are rather slow, so compliance measurements are often performed in two steps. In the first step, a fast measurement of the emissions against frequency is carried out by using a peak detector. This analysis always overestimates the EUT disturbances since the peak detector response is very sensitive to EUT impulse emissions. In the second step the quasi-peak detector is employed to investigate only the frequencies corresponding to emissions exceeding the limits.

Precompliance measurements are a low-cost solution useful to obtain an estimation of the EUT emissions during prototype development. These measurements are typically carried out with a setup where a spectrum analyzer substitutes for the receiver [2]. Commercially available analyzers are typically equipped with a peak detector and a set of IF filters not suitable for EMC measurements. However, most spectrum analyzer manufacturers, in order to improve their instrument versatility, provide their top-class instruments with an optional quasi-peak detector and an EMC compliant filter.

Completely different approaches, which are based on the acquisition of the EUT emissions, have been recently investigated [3], [4] in order to emulate the receiver behavior. A simple approach is based on a digitizer, that samples the LISN output, and on a numerical processor that performs the spectrum analysis of the acquired signal. The digitizer sampling frequency, which is strictly related to the investigated signal bandwidth, has to be greater than 100 MHz when the full CISPR16 band B needs to be analyzed. Furthermore, the digitizer must be able to store a large amount of samples (typically more than 5 Msamples) because the acquiring process has to be carried out at least for some periods of the mains signal. The acquired samples are then processed by means on an algorithm that emulates the receiver behavior. The spectral content at a generic frequency f_0 is typically obtained in two steps: firstly the signal is filtered by means of a numerical band-pass filter centered at f_0, then a nonlinear algorithm, which acts as a peak or quasi-peak detector, is employed to evaluate the disturbance amplitude at the frequency of interest. These approaches behave quite well, although the digitizer they require is still an expensive device. However, as explained in the next section, under certain circumstances it can be substituted by a digital oscilloscope.

III. Peak Analysis Based on Short Frame Acquisitions

Sampling oscilloscopes are an attractive solution to be employed as high speed digitizers. Top-class oscilloscopes

Manuscript received June 15, 2002; revised March 3, 2003.

The authors are with the Dipartimento di Elettronica, Politecnico di Torino, Torino, Italy (e-mail: alberto.vallan@polito.it).

Digital Object Identifier 10.1109/TIM.2003.816839

are often equipped with large and fast memories and can thus be employed as described in the previous section. On the contrary, most medium-level oscilloscopes are able to acquire a few thousand sequential samples only, and are not able to reconstruct large signal frames.

However, with some limitations, these oscilloscopes can be employed to perform the spectral analysis as required in the CISPR16 recommendation, at least in the peak mode. In fact, if the oscilloscope frame width is as wide as the time response of the numerical band-pass filter, at least one sample of the filtered signal can be obtained and, if several randomly acquired frames are available, it is possible to obtain a set of filtered points that can be employed to estimate the peak of the filtered signal. In this case the quasi-peak detector cannot be implemented because it requires a complete description of the filtered signal. The number of frames that are required to estimate the signal peak is related to the repetition rate of the disturbance signal. In most practical cases, when the disturbances have approximatively the same repetition rate as the mains signals (50 or 60 Hz), experimental tests have shown that a few thousand filtered samples allow for the detection of the signal peak with a maximum error that does not exceed 1 dB.

The frame width required to obtain at least one useful sample of the filtered signal is related to the filter time response. The computation is easy if a finite impulse response (FIR) filter is employed, since in this case the frame has to have at least a number of samples equal the filter order.

Commercial spectrum analyzers typically employ gaussian filters [5] with a bandwidth B_6 of 9 kHz at the -6 dB points, so $h_{f_0}(t)$ can be analytically obtained as [6]

$$\begin{aligned} h_{f_0}(t) &= h'(t)\cdot\left(e^{j2\pi f_0 t}+e^{-j2\pi f_0 t}\right) \\ h'(t) &= \sqrt{2\pi}\sigma e^{-2(\pi\sigma(t-\tau))^2} \end{aligned} \tag{1}$$

where $h'(t)$ is the equivalent low-pass filter impulse response and the parameter σ can be evaluated as

$$\sigma^2 = -\frac{B_6^2}{8\ln\frac{1}{2}}. \tag{2}$$

The constant τ in (1), related to the filter phase response, represents the time shift of the filter impulse response. This can be arbitrarily chosen because the CISPR16 recommendation does not specify any details regarding the phase response of the IF filter. The filter response in (1) has an infinite duration but, as shown in Fig. 1, its amplitude quickly decreases outside the peak zone, so only about 0.3 ms of $h_{f_0}(t)$ need to be taken into account without significantly affecting the filter response.

Therefore, an acquisition 0.3 ms long allows one to obtain at least one sample of the filter output. As an example, if the employed oscilloscope is equipped with 8 ksamples of memory, the maximum sampling rate will be about 26 MHz, and this practically limits the spectral analysis to 10 MHz.

When the entire band has to be investigated, several filters are needed, so the filtering process could require a long time to be performed. The duration of the filtering process can be significantly shortened by employing a filter bank based on the inverse fast Fourier transform (IFFT) algorithm. One sample of all the outputs of a bank of filters having center frequencies $f_k = k\cdot f_s/N, k = 0,\ldots,N-1$ can be concurrently obtained as in [6]–[8]

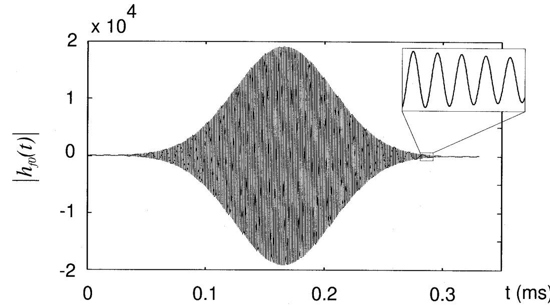

Fig. 1. Impulse response of a CISPR16 compliant bandpass filter.

$$\mathbf{y} = \frac{2N}{f_s}\Re\{\mathrm{IFFT}(\tilde{\mathbf{x}}\cdot\mathbf{h}')\} \tag{3}$$

where $\tilde{\mathbf{x}}$ is the reverse-index version of the input vector $\mathbf{x}$, i.e., $\tilde{x}[0] = x[N-1],\ldots,\tilde{x}[N-1] = x[0]$, $\mathbf{h}'$ is the sampled impulse response of the equivalent low-pass filter, f_s is the sampling frequency and N is an integer power of two. One should note that the IFFT algorithm is here employed because of its numerical advantages in the computation of the filter outputs and not to transform the disturbance signal from the frequency to the time domain.

IV. Experimental Results

Fig. 2 shows the experimental test-set used to measure the disturbances in three different conditions. The test-set is composed of a low-pass filter, the sampling oscilloscope, a personal computer (PC), and a spectrum analyzer which is employed as the reference instrument. The spectrum analyzer is an HP 8591E equipped with the EMC option. The analyzer has been set to perform the spectral analysis from 150 kHz to 10 MHz, with a CISPR16 compliant 9-kHz IF filter and a peak detector. The sweep rate of the analyzer has been set to 30 s in order to allow its IF filter to work with quasi-steady signals.

The sampling oscilloscope is an HP54505B, which has a resolution of 8 bits and is able to acquire up to 8000 samples in real-time mode. In order to acquire frames with a duration of 0.3 ms, the oscilloscope sampling frequency has been set to 25 MHz. This has limited the emission analysis to a maximum frequency of about 10 MHz. The input signal has been therefore filtered to reduce the aliasing effects using a second order low-pass filter with a cut-off frequency of about 10 MHz. The spectrum analyzer has been connected in parallel to the oscilloscope so that both instruments measure the same signal.

The frames acquired by the oscilloscope are sent to the PC, extended to 8192 samples with null samples and processed according to (3) by employing a gaussian filter with a bandwidth of 9 kHz at the -6 dB points. Eventually, the maximum value of each filter output is taken as the peak estimation of the disturbance signal spectrum at the filter central frequency. In these conditions, the proposed system provides 4192 points of the signal spectrum equally spaced up to the Nyquist frequency. These values are eventually decimated to obtain about 400 equispaced points to be compared with the 401 points provided

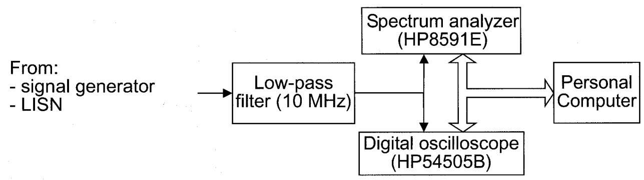

Fig. 2. Comparison test-set.

by the spectrum analyzer. The algorithm runs on a Pentium III based computer and the computational time is negligible with respect to the acquisition time.

A. Test #1: Synthesized Signal Analysis

An arbitrary signal generator (HP33120A) has been employed to test the proposed system performance with a reproducible and known signal. The synthesized signal [Fig. 3(a)] is an approximation of the typical conducted emissions generated by a dimmer regulator.

Two thousand frames have been randomly acquired in about 10 minutes and processed as described in the previous section. Fig. 3(b) shows the experimental results obtained with the spectrum analyzer and with the proposed system. The difference between the results [Fig. 3(c)], is below ± 2 dB. The standard deviation of the results obtained with the oscilloscope-based system over 10 measured spectra, is below 0.6 dB up to 7 MHz and reaches 1.5 dB at 10 MHz.

B. Test #2: Personal Computer Emission Analysis

In this case a commercial LISN has been used to isolate the emissions of a commercial personal computer. Also in this case 2000 frames of the disturbance signals have been acquired and processed. The spectra in Fig. 4 show an overall good agreement and their point-by-point difference mainly comes from the different durations of the two measurement processes, since the disturbance spectrum is time dependent. The figure shows that the disturbance spectrum, which has been obtained with a peak detector, never exceed the band B limit. This is an example where the quasi-peak detector is unnecessary, thus avoiding the necessity of using more costly equipment.

C. Test #3: Dimmer Regulator Emission Analysis

In the third example the LISN has been used to isolate the emissions of a commercial dimmer that feeds a resistive load. The disturbance signal [Fig. 5(a)] has the same frequency as the mains signals and the disturbance energy is concentrated in two short time intervals per period. In this case the signal can be completely described by acquiring only two frames corresponding to the cross-over points of the mains signal so that the 2000 acquisitions can be simulated by shifting the acquired data so that the spike appears in different positions within the frame itself. Fig. 5(b) shows the spectra obtained with the proposed test-set and with the spectrum analyzer. The figure shows that there is a good agreement between the results up to about 3 MHz, while the spectrum obtained with the oscilloscope overestimates the spectrum at higher frequencies. This phenomenon is mainly related to the oscilloscope input noise. The noise contribution can be easily estimated by performing the spectrum analysis when the oscilloscope input is shorted. Fig. 5(b) shows that the noise

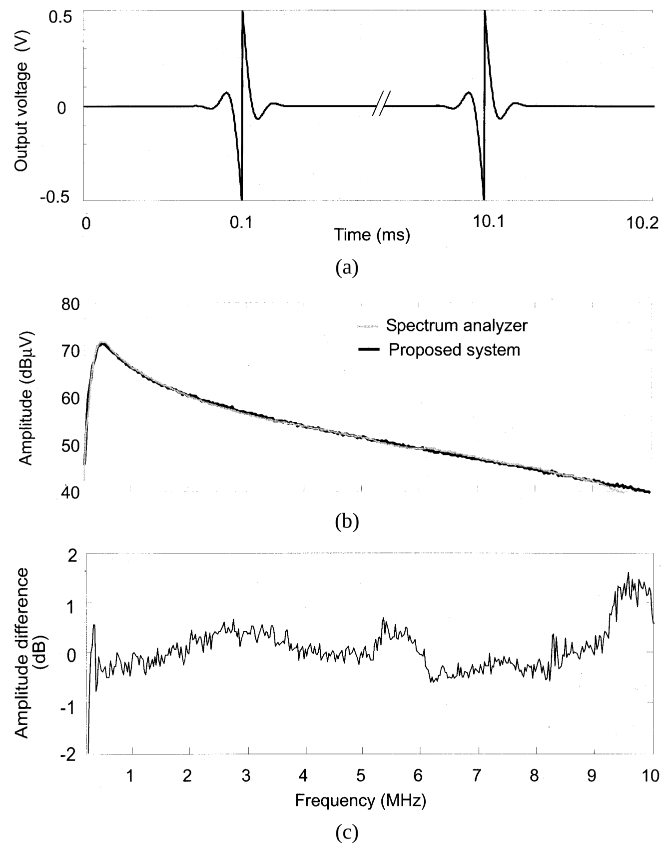

Fig. 3. (a) Synthesized signal; (b) spectra obtained by the proposed test-set and by the spectrum analyzer; (c) spectrum difference.

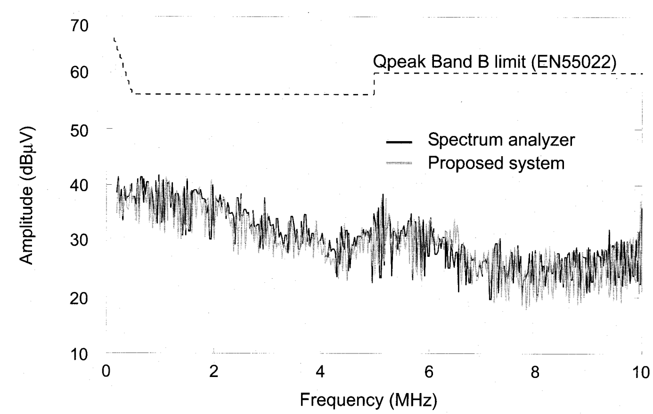

Fig. 4. Conducted emissions of a personal computer.

reaches 40-dBμV amplitude and produces a nonnegligible effect on the measured spectrum in the range of 3 to 7 MHz. However, this does not impair the overall performance since the noise level is far below the band B level in this frequency range.

In this example the peak spectrum exceeds the band B limit at low frequencies, so further tests have to be performed with a spectrum analyzer equipped with a quasi-peak detector to asses the DUT conformity. One should note that, in this specific condition, since a complete description of the disturbance signal is available, it would be possible to employ the proposed test-set not only to estimate the spectrum peak, but also to estimate the quasi-peak spectrum by employing a numerical algorithm similar to the one described in [4].

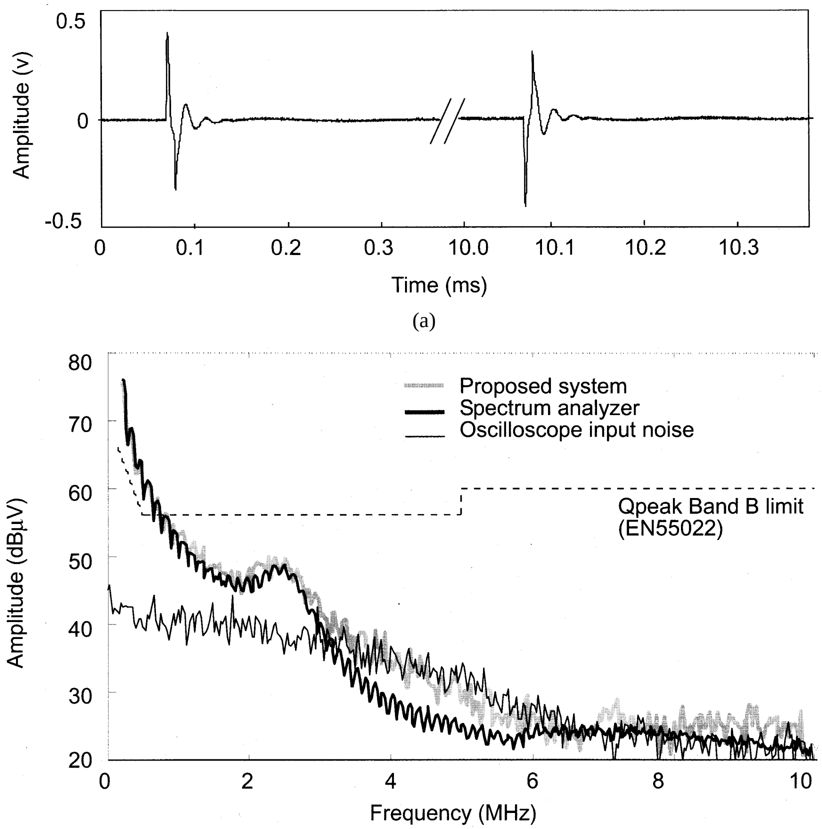

Fig. 5. (a) Conducted emissions of a dimmer regulator in the time domain and (b) in the frequency domain.

V. Conclusion

Precompliance measurements for conducted emissions can be conveniently obtained by employing a widely-available, low-cost digital oscilloscope coupled to a PC, thus avoiding the use of either costly digitizers or spectrum analyzers with EMC options. A test-set based on low resolution (8 bit) low frame memory (8–32 ksamples) oscilloscopes allows one to obtain an estimation of the peak spectrum, but not always the quasi-peak estimation. However, such an estimation can be obtained in specific circumstances that commonly arise.

An arrangement of the proposed test-set has been employed to verify the performance in three cases representative of several common conditions. The test results have confirmed that the difference with respect to costly spectrum analyzers is rather small and that the proposed solution can be used as a low-cost alternative to a spectrum analyzer equipped with IF filters compliant with the CISPR16 recommendations.

References

[1] *Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods*, CISPR16, 1999.
[2] *Making Precompliance Conducted and Radiated Emission Measurements With EMC Analizers*, Agilent Technologies, doc. AN 1328, 1999.
[3] F. Avallone, M. D'Apuzzo, and C. De Capua, "A digital measurement technique for EMI tests on variable speed drives," in *Proc. IEEE Instrum. Meas. Conf.*, Brussels, Belgium, 1996, pp. 1114–1118.
[4] C. De Capua and C. Landi, "A digital measurement station for RF conducted emissions monitoring," *IEEE Trans. Instrum. Meas.*, vol. 51, pp. 1363–1366, Dec. 2002.
[5] A. D. Helfrick, *Electrical Spectrum and Network Analyzers*. San Diego, CA: Academic, 1991.
[6] M. Parvis, G. Perrone, and A. Vallan, "A precompliance EMC test-set based on a sampling oscilloscope," in *Proc. 19th IEEE Instrumentation and Measurement Conf.*, Anchorage, AK, 2002, pp. 1197–1201.
[7] K. Shenoi, *Digital Signal Processing in Telecommunication*. Englewood Cliffs, NJ: Prentice-Hall, 1995.
[8] P. P. Vaidyanathan, *Multirate Systems and Filter Banks*, ser. Signal Processing Series. Englewood Cliffs, NJ: Prentice-Hall, 1993.

Marco Parvis (SM'01) was born in Italy in 1958. He received the M.S. degree in electrical engineering and the Ph.D. degree in metrology from the Politecnico di Torino, Torino, Italy.

Currently, he is a Professor of electronic measurements at the Politecnico di Torino. His main fields of interest are intelligent instrumentation, signal processing, and biomedical measurements. He is presently working on new sensors for mechanical and chemical quantities and on the development of distributed measuring systems.

Guido Perrone (M'98) was born in Italy in 1965. He received the Ph.D. in electromagnetics from the Politecnico di Torino, Torino, Italy

He is currently an Assistant Professor at the Politecnico di Torino, lecturing on basic electromagnetics, electromagnetic compatibility, and optical devices. His research activity is mainly in the design of optical components for RF telecommunication applications.

Dr. Perrone is member of the Optical Society of America.

Alberto Vallan was born in Italy in 1967. He received the M.S. degree in electronic engineering from the Politecnico di Torino, Torino, Italy, and the Ph.D. degree in electronic instrumentation from the Universitá de Brescia, Brescia, Italy.

He is currently an Assistant Professor at the Electronics Department, Politecnico di Torino. His main fields of interest are power measurement in distorted environments, development of sensors for physical and chemical quantities, and intelligent measurement systems.