Measuring Transmitter Attack Time through Time-Frequency Representations

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Abstract: - Power and carrier frequency transients are very common in modern wireless transmitters. Transients can be responsible for harmful interference on transmitting and receiving devices operating on adjacent channels. This is the reason why the standard issued by the European Telecommunication Standard Institute (ETSI) on electromagnetic compatibility and radio spectrum matters includes a section dedicated to wireless transmitter transient behavior and related measurements. In particular, it imposes constraints on the duration of the transmitter attack time and proposes a measurement setup that involves several instruments to measure it. The paper presents the results of experiments carried out on a wireless transmitter, in which the transmitter attack time is measured by means of a method proposed by the authors. The method is based on digital signal processing and exploits time-frequency representations to extract the instantaneous power and frequency trajectories of the signal emitted by the transmitter under test, thus needing only a digital storage oscilloscope and a processing unit to operate.

Key-Words: transmitter testing, transmitter transient measurement, time-frequency representations, short-time Fourier transform, chirplet transform, electromagnetic compatibility (EMC), wireless communication systems.

1 Introduction

Power and frequency transients occur any time a wireless transmitter is switched on. Very often, they can also be experienced during the typical functioning of a transmitter. This is the case, for example, of transmitters employed in communication systems which involve bursty transmission. As a further example, there are communication systems based on TDMA (Time Division Multiple Access), as well as spread spectrum communication systems, which involve quick and frequent changes in transmitted power, with the aim of minimizing battery consumption; not to mention systems based on FDMA (Frequency Division Multiple Access), whose transmitters regularly switch from one frequency channel to another.

Power and frequency transients in wireless transmitters have to be carefully dealt with. They can, in fact, possibly determine interference on other transmitting and receiving devices which are operating in adjacent frequency bands. This is the reason why the standard issued by the European Telecommunication Standard Institute (ETSI) on electromagnetic compatibility and radio spectrum matters includes a section on wireless transmitter transient behavior and related measurements [1].

ETSI standard [1] imposes constraints on the duration of the transmitter attack time, i.e. the time it takes to switch its output power on. Specifically,
the standard defines the transmitter attack time as a function of power and frequency transients, fixes its maximum tolerated duration, and suggests a measurement setup to evaluate the transmitter attack time. The standard measurement setup is sketched in Fig. 1. It involves the use of several instruments, such as a spectrum analyzer (which may be substituted by an RF detector), an FM modulation meter, and a storage oscilloscope. Some major manufacturers have proposed the use of vector signal analyzers (VSA) or real-time spectrum analyzers (RTSA), which are equipped with demodulation capability, to measure transmitter transients with a single instrument and simultaneously display amplitude and frequency versus time [2]-[4]. Such instruments, however, either need to demodulate the signal to be able to measure the transmitter transient (and therefore need to get some information on the transmitted signal, such as carrier frequency and modulation type) or are very expensive.

The measurement method adopted in the experiments was originally presented by the same authors in [11] as an alternative to the solution proposed in [1] to measure transmitter attack time. It only needs to get the samples of the transmitter output signals from a DSO. The method exploits digital-signal processing, based on time-frequency representations (TFR’s) [5] and optimal sampling strategies [6]. The method measures both power and frequency transients by operating in the time-frequency domain, and thus requires no signal demodulation. Moreover, it minimizes the number of samples to be acquired and processed, thanks to the use of optimal sampling strategies, and doesn’t need several instruments, unlike the measurement setup recommended by the standard.

The paper is organized as follows. The measurement method is presented in Section 2, along with the choice of optimal TFR parameters. The measurement setup and results of experiments on a real wireless transmitter are given in Section 3. Finally, Section 4 presents the conclusions.

2 Measurement method

In this section, the measurement method is presented and the optimal values of the TFR parameters are given. Further details can be found in [11].

The measurement method consists in three steps: (i) optimal sample rate selection and signal digitization, (ii) TFR application to gain instantaneous power and frequency trajectories, and (iii) measurement of power and frequency transients.

2.1 Signal digitization

First, the transmitted signal has to be digitized by the DSO at the sample rate provided by one of the algorithms presented in [6]. In particular, the algorithm receives in input some information on the signal, such as its bandwidth and carrier frequency, and then outputs the minimum sample rate, $f_s$, that satisfies user’s requirement in terms of spectral allocation of the sampled signal. It is so possible to digitally downconvert the input signal thanks to a sampling frequency much lower than the carrier frequency, with consequent benefits in terms of frequency resolution. Equivalently, it is possible to
analyze a larger time interval, given the number of samples.

2.2 TFR application

To evaluate instantaneous power and frequency trajectories, a TFR has to be preliminarily applied. A linear TFR should, in particular, be chosen in order to avoid cross terms peculiar to quadratic ones [4]. Two linear TFR’s have been considered, and related results compared: the short-time Fourier transform (STFT) [4], and a modified version of the chirplet transform (CT) [6],[7].

The discrete STFT of the digitized signal \( s(k) \), \( \text{STFT}_s(m,n) \) is evaluated according to

\[
\text{STFT}_s(m,n) = \sum_{k=0}^{N-1} w(k-n)s(k)e^{-j2\pi \frac{m}{N} k}
\]  

(1)

where \( w(k) \) is the window function, and \( N \) is the number of samples on which \( \text{STFT}_s \) is performed; \( k \) stands for the discrete-time variable.

The signal \( s(k) \) is divided into a number of segments, each of which, weighted by the window function \( w(k) \), is treated separately in order to evaluate its spectral content. Expression (1) is computed via a fast Fourier transform (FFT)-based algorithm; the results are then taken in modulus and squared in order to attain the so-called spectrogram. In the presence of discrete-time signals, the spectrogram is represented by means of a matrix; row index is connected to frequency, while column index represents time. By visualizing the matrix along a time-frequency plane, the evolution versus time of the power spectral contents of the analyzed signal can be observed.

The modified version of CT is calculated, in accordance to [7], as

\[
\text{CT}_s(m,n) = \sum_{k=0}^{N-1} g(k-n)s(k)e^{-j2\pi \frac{m}{N} k}
\]  

(2)

where \( g(k) \) is a modulated Gaussian window given by

\[
g(k) = \frac{1}{\sqrt{2\pi a}} e^{-\frac{1}{2} \left( \frac{k}{a} \right)^2} e^{-j2\pi \frac{3}{N} \frac{(k - c)^2}{2a^2}}
\]  

(3)

in which \( a, b, \) and \( c \) are respectively the scaling factor, bending, and chirping factor, whereas \( T \) is the sample period characterizing the acquired signal.

As with regard to STFT, modified CT in (2) is computed via an FFT-based algorithm, and results are taken in modulus and squared in order to achieve the evolution versus time of the power spectral contents of the analyzed signal.

2.3 Transient measurement

ETSI standard [1] defines transmitter attack time, \( t_a \), as the maximum between power and frequency transient durations, defined, respectively, as:

\( a \) the time which elapses between the initiation of the "transmitter on" function and the moment when the transmitter output power has reached a level 1 dB below or 1.5 dB above the steady state power, \( P_s \), and maintains a level within +1,5 dB/-1 dB from \( P_s \);

\( b \) the time which elapses between the initiation of the "transmitter on" function and the moment after which the frequency of the carrier always remains within ±1 kHz of its steady state frequency, \( f_c \).

The standard prescribes that \( t_a \) shall not exceed 25 ms.

Instantaneous power and frequency trajectories are evaluated by suitably processing the matrix obtained at the end of the previous step. Instantaneous power of the signal as a function of time can, in particular, be calculated by summing the values along each column of the matrix, and multiplying the result by the frequency resolution, which is equal to \( (NT)^{-1} \). As the maximum value of the power spectrum is, in each time instant, associated to the instantaneous frequency of the signal [8], the frequency trajectory can be evaluated by applying a proper peak location algorithm to the matrix [8],[9]. Specifically, for each column, the row index in correspondence of which the power spectrum reaches its maximum is collected in an array, which consequently accounts for the evolution versus time of the frequency of the analyzed signal. No demodulation is thus needed to gain the desired instantaneous power and frequency trajectories. Transmitter attack time is finally measured according to what stated in \( a \) and \( b \).

2.4 Optimal choice of TFR parameters

As the performance of TFR’s largely depend on the choice of their parameters, particular attention must be paid in this task. The authors have experimentally singled out the best set of parameters for both the STFT and the CT [11].

A digitally synthesized signal whose characteristics are adherent to the sample transients shown in [1] was generated by means of an arbitrary waveform generator, and acquired through a DSO. The acquired samples were then processed several times, for different combination of the STFT and CT parameters, and their best combination were singled out as those minimizing the root mean square error between the reconstructed
instantaneous power and frequency trajectories and those (known) of the test signal [11].

4. Experiments on a real transmitter

Experiments to measure transmitter attack time by means of the proposed method have been carried out on a real transmitter. The transmitter under test has been set to a steady state carrier frequency $f_c$ equal to 30.817 MHz. Its output signal has been sampled at 250 kS/s, so as to center the sampled signal at 67 kHz. In order to acquire the whole power and frequency transients, a short pre-trigger has been set on the DSO. The adopted measurement test-bed is shown in Fig. 2.

Experimental results are shown in Fig. 3. In detail, Fig. 3a gives the acquired signal; Fig. 3b and Fig. 3c show the frequency and power trajectories extracted through the STFT; Fig. 3d and Fig. 3e show instantaneous power and frequency trajectories provided by the method, when CT is applied.

Experiments have been carried out also with a steady state carrier frequency $f_c$ of the transmitter under test equal to 31.827 MHz. Results are presented in Fig. 4 and organized in the same way as in Fig. 3.

As in [11], the results show that attack time is basically determined by the duration of the frequency transient. No significant discrepancy in the results emerges when the adopted TFR is either CT or STFT; differences between related results are, in fact, within 2%. Thus, STFT has to be preferred, since its computational burden is much lower than that of CT.

5. Conclusions

The paper has presented the results of transmitter attack time measurements performed on a wireless commercial transmitter. The adopted measurement method represents an alternative to that suggested by ETSI in [1], and was introduced in [11]. It is a digital-signal processing method, based on linear TFR’s, which simultaneously measures power and frequency transients, and requires neither signal demodulation, nor costly special-purpose instrumentation.

Experimental results have shown the efficacy of the method in measuring instantaneous power and frequency trajectories with low cost instrumentation, compared to the number of instruments needed to implement the measurements setup suggested in [1]. In fact, transmitter attack time measurements carried out on a commercial wireless transmitter, utilizing either the STFT or the CT, provide concurring results, with differences between the measurement output within 2%.
Fig. 3. Results of the measurements on the transmitter with carrier frequency equal to 30.817 MHz.

Fig. 4. Results of the measurements on the transmitter with carrier frequency equal to 31.827 MHz.
References:

[1] “Electromagnetic compatibility and Radio spectrum Matters (ERM); Land mobile service; Radio equipment intended for the transmission of data (and/or speech) using constant or non-constant envelope modulation and having an antenna connector; Part 1: Technical characteristics and methods of measurement”, ETSI EN 300 113-1 v.1.5.1, September 2003.


