XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

MEASUREMENT OF TRANSMITTER TRANSIENTS WITH WAVELETS

J. Kolakowski
Institute of Radioelectronics
Warsaw University of Technology, Poland

Abstract: The article deals with measurements of signals emitted by a radiocommunication transmitter during transient states. It contains a brief description of measures and measurement methods traditionally used for testing transients. The methods for transmitter behaviour evaluation based on wavelet transform are presented and their features are discussed. The paper contains results of computer simulations as well as measurements of an exemplary transmitter.
Keywords: transient states, radiocommunication measurements

1 INTRODUCTION

The transient behaviour of the transmitter can be defined as the time-dependency of transmitter frequency, power and spectrum when the RF output power is switched on and off. In case of vast majority of contemporary radiocommunication systems frequent switching of transmitters is the essence of the system operation. Cellular TDMA networks are obvious examples of the system working in this manner.

During transient states the RF power and the carrier frequency are changing towards their nominal values. Moreover a rapid growth of RF power makes the output signal spectrum broader. Due to these phenomena the transmitter may be a source of interference covering adjacent channels. Extending the signal changes in time can diminish the level of out-of-band interference but also decreases the efficiency of spectrum usage.

Electromagnetic environment pollution and effective spectrum utilisation are main reasons for testing transients.

2 PARAMETERS AND METHODS TRADITIONALLY USED FOR EVALUATION OF TRANSIENTS

Testing transients is required by many international specifications dealing with measurements of radiocommunication transmitters. These standards define measurement methods and test arrangements as well as limits for obtained results. The most popular European standards have been worked out by ETSI. Each of them concerns specified kind of equipment. Testing transients in almost all specifications is connected with investigation of a signal spectrum and determination of RF power and carrier frequency plots as a function of time [5][6]. These plots are the basis for evaluation of power and frequency behaviour and sometimes they are used for determination of other parameters e.g. attack and release times [5].

Transient power and transient frequency plots are usually measured with the use of RF detectors and test discriminators. Test discriminator should fulfil stringent requirements. Its dynamic range should be wider than 30 dB; it should operate in a broad frequency range and have a very fast response. Frequency deviations as fast as 1 MHz/ms should be properly measured [5].

Evaluation of carrier frequency is closely related to RF power behaviour. If the power crosses predefined threshold value (e.g. –30 dB below the steady state value) the signal frequency should conform to the strictly defined mask. Frequency limits depend on time and finally reach values defined for steady state conditions (usually less than +/-3 kHz). Investigation of RF power behaviour is more detailed. Besides checking a maximum power value and a compliance with the power mask some standards put limit on the slopes of the signal envelope order to detect too fast changes of power.

Another aspect of transients is connected with RF power delivered to the adjacent channels. Generally, the point of this test is to catch a peak value of RF power detected in adjacent channels during transient state. The signal is measured at the output of the strictly defined band-pass filter tuned to the nominal frequency of the adjacent channel. Evaluation concerns the ratio of powers detected in main and adjacent channels.

3 APPLICATION OF WAVELET TRANSFORM FOR MEASURING TRANSIENTS

Traditional methods require implementation of complex test arrangements. Great advances in computer equipment and DSP processors are stimuli for development of measurement methods based on signal processing. The paper presents opportunities created by wavelet transform for evaluation of transmitter transient behaviour. Transient frequency can be determined by analysing location of wavelet transform modulus in time-frequency plane. Calculated time-frequency representation can be used for improvement of a signal to noise ratio (SNR). It can be achieved by thresholding of wavelet coefficients and signal reconstruction.

Better SNR decreases uncertainties of envelope power and transient adjacent channel power determination. Adjacent channel power can be evaluated by filtering the signal in time domain. Digital band-pass filter should have strictly defined transfer function and should be tuned to the adjacent channel frequency.

3.1 Transmitter signal features

Transmitter output signal features strongly influence signal processing procedures. Usually we deal with a narrowband emission at high frequencies. Transmitter output signal can be modelled by the following equation.

$$s(t) = a(t)\cos(f(t)) \tag{1}$$

Measurement practice shows that usually *a(t)* and *cos((t))* spectra can be treated as separated in frequency and corresponding analytical signal can be expressed by equation [4]:

$$s\ \ (t) = a(t)e^{jf(t)} \tag{2}$$

Instantaneous envelope power *a(t)* and frequency f_i can be defined as:

$$a(t) = \left|s_a(t)\right| \tag{3}$$

$$f_i = \frac{1}{2p}\frac{df_a}{dt} \tag{4}$$

It is worth to note that during a measurement signal is usually down-converted. Resulting signal frequency should be chosen very carefully in order not to violate relations between spectra mentioned above.

Amplitude of signals emitted during transient states can vary in the range of a few tens of decibels (from noise level to maximum transmitter power). The problem of dynamic range arises in case of equipment with integral antenna. Coupling device used for signal acquisition can introduce attenuation resulting in deterioration signal-to-noise ratio.

3.2 Wavelet transform

Wavelet transform (5) converts time-domain signal *f(t)* to its time-scale representation *Wf(u,s)*.

$$Wf(u,s) = \int f(t)\frac{1}{\sqrt{s}}y^{*}\left(\frac{t-u}{s}\right)dt \tag{5}$$

Function ψ is often called a mother wavelet, variables: u, s correspond to shift in time and scale respectively. Usually energy of mother wavelet is concentrated in the certain region in time-frequency plane. Scaling the mother wavelet corresponds to changing its localisation in frequency domain so the scale value corresponds to frequency value. Time-frequency signal energy density can be expressed by scalogram - squared modulus of the wavelet transform

Signal can be reconstructed from its wavelet transform. Appropriate equations are presented below.

$$f(t) = \frac{1}{C_y} \int_0^{\infty} \int_{-\infty}^{\infty} Wf(u,s) \frac{1}{\sqrt{s}} y\left(\frac{t-u}{s}\right) du \frac{ds}{s^2} \tag{6}$$

where $$C_y = \int_0^{\infty} \frac{|\hat{y}(w)|^2}{w} dw \tag{7}$$

$\hat{y}$ - Fourier transform of y

Equations mentioned so far describe continuous version of the wavelet transform. Computer calculations require discretisation in time and scale domains. Discretisation should be done carefully because it influences time and frequency resolutions. Moreover it should provide precise signal reconstruction. Both aspects are covered by wavelet frame theory [1][2].

3.3 Transient frequency determination

Simulations and measurements described in the paper have been done with the use of Gabor wavelet (8) (figure 1).

$$y(t) = g(t)e^{-jht} \tag{8}$$

where *g(t)* is a Gaussian window:

$$g(t) = \frac{1}{\left(s^2 p\right)^{\frac{1}{4}}} e^{-\frac{t^2}{2s^2}} \tag{9}$$

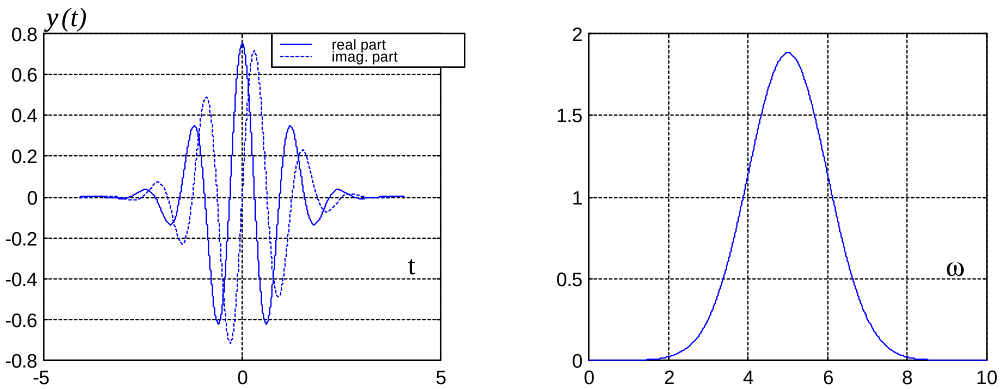

Figure 1. Gabor wavelet in time and frequency domains (h=5, s=1).

Location of the scalogram ridges depends on instantaneous frequency of the signal (4) Precise description of this relation can be found in [2][3]. It can be proved [2] that uncertainty of instantaneous frequency estimation of the signal (1) depends on behaviour of amplitude *a(t)* and phase *F(t)*. The errors become negligible when

$$h^2 \frac{|f''(u)|}{|f'(u)|^2} << 1 \tag{10}$$

$$\frac{h^2}{|f'(u)|} \frac{|a''(u)|}{|a(u)|} << 1 \tag{11}$$

where h is a Gabor wavelet parameter (8).

These relations are easier to fulfil if the instantaneous frequency is higher. Moreover higher frequency allow for faster changes of frequency and amplitude. Equations do not provide quantitative description of frequency determination errors. It can be achieved by means of computer simulations.

3.4 Measurement of signals in noisy environment

Application of wavelet transform can significantly improve signal to noise ratio and thus decrease uncertainty of measurement in case of weak noisy signals (e.g. signals from low power integral antenna devices).

The first step of the de-noising process results in time–scale representation of the signal. The wavelet coefficients are then selected and modified in order to diminish influence of interference. At least the signal is reconstructed from modified time-scale representation. The simplest methods of modification use various ways of wavelet coefficient thresholding [2]. According to hard thresholding method all coefficients lying below the threshold are set to zero. In case of soft thresholding signal modification depends on relation between the threshold and coefficient value. More sophisticated solutions eliminate wavelet transform coefficients lying outside the ridge regions.

The advantage of such de-noising methods originates from the fact that apart from traditional filtering the method can limit the noise in the signal bandwidth.

4 SIMULATIONS AND MEASUREMENTS

4.1 Computer simulations

Results presented below concern only a few problems that can be encountered when implementing proposed methods: capability of the method to measure signals with fast frequency changes and effectiveness of noise reduction.

Calculations have been made for a test signal with sinusoidal frequency modulation (normalised frequency deviation – 0.1). Mean square error (MSE) of the evaluated modulation signal as a function of signal and modulating signal frequencies is presented in figure 2.

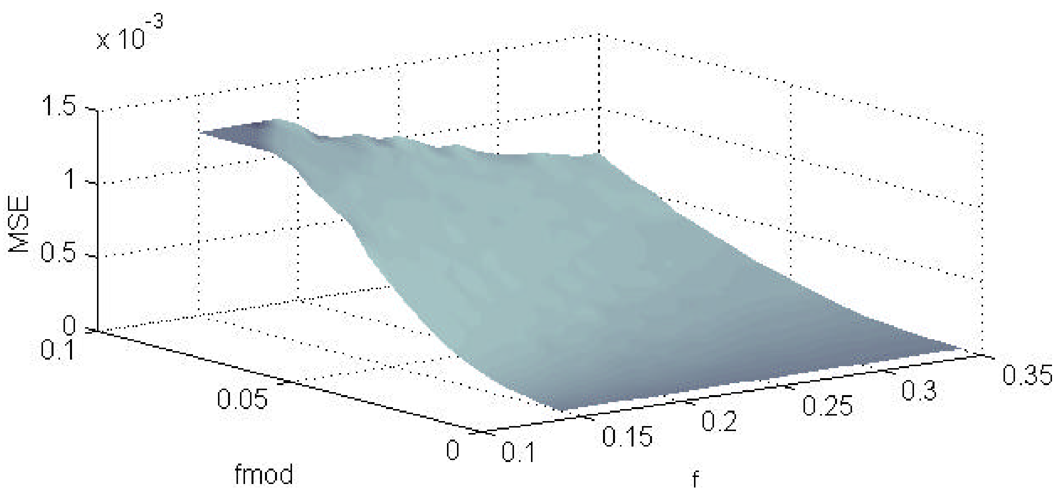

Figure 2. Mean square error (MSE) versus signal and modulating signal normalised frequencies.

Results confirm theoretical analysis (11,12). The higher frequency of the signal the lower errors we can expect.

Effectiveness of noise reduction procedures utilising wavelet coefficient thresholding strongly depends on threshold value. The threshold can be evaluated using noise parameters (variance) [2], which should be calculated from measurement data. An exemplary increase in SNR of a signal with SNR=10 dB is presented in figure 3. Such test can also be used for evaluation of optimum threshold value.

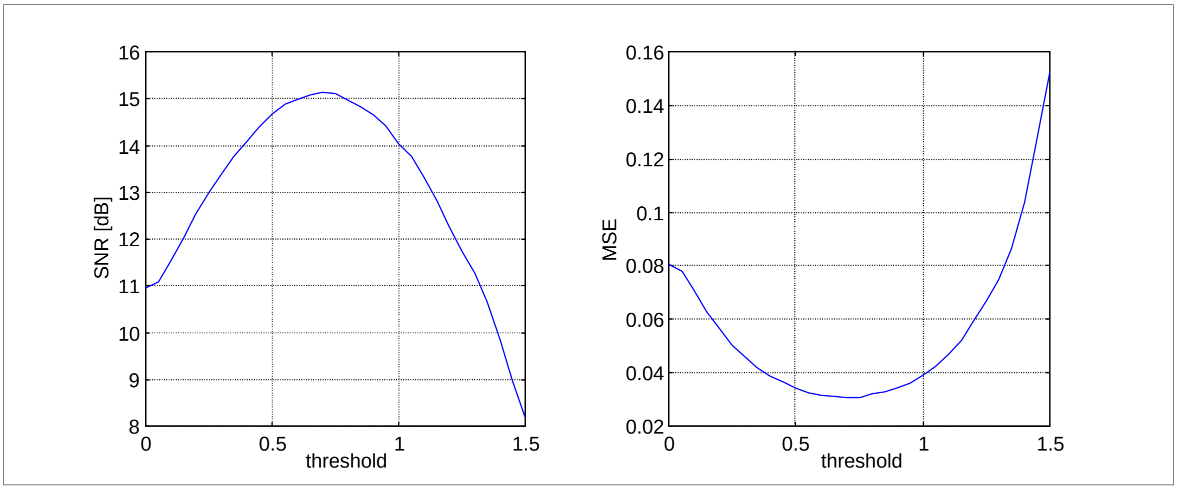

Figure 3. New SNR and MSE versus threshold value.

4.2 Exemplary transmitter measurements

A set of transmitters has been tested in order to investigate capability of transient frequency determination. Figures below contain results obtained for radiotelephone transmitter working in 450 MHz band. Transmitter output signal has been acquired with a vector signal analyser (HP 89441A). Envelope power has been measured with spectrum analyser E4402B, transient frequency with modulation analyser HP53310A.

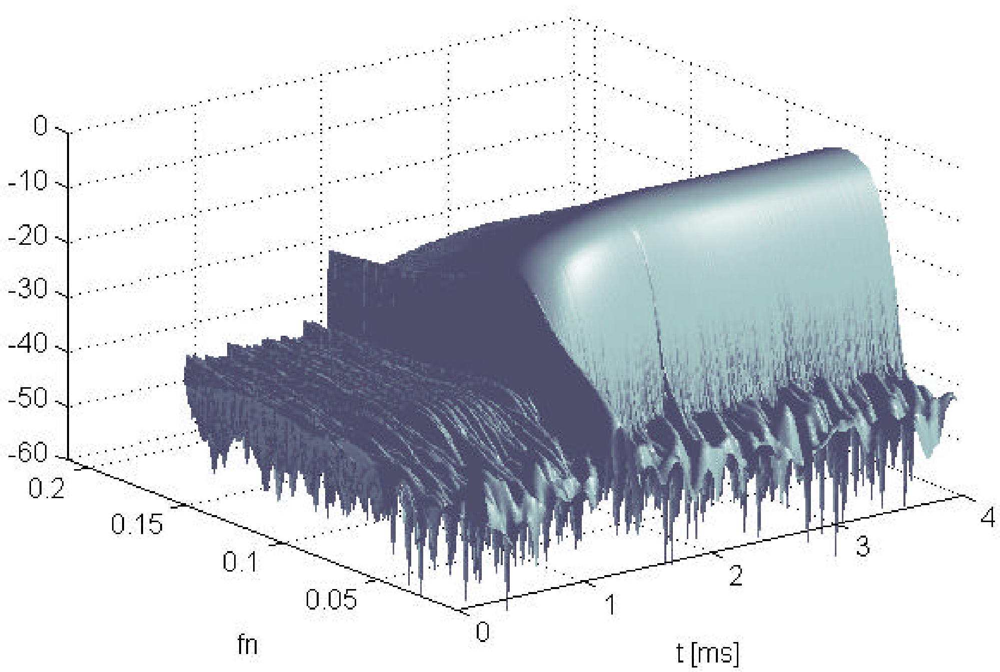

Figure 4. Time-frequency representation of transmitter output signal (fn – normalised transmitter frequency).

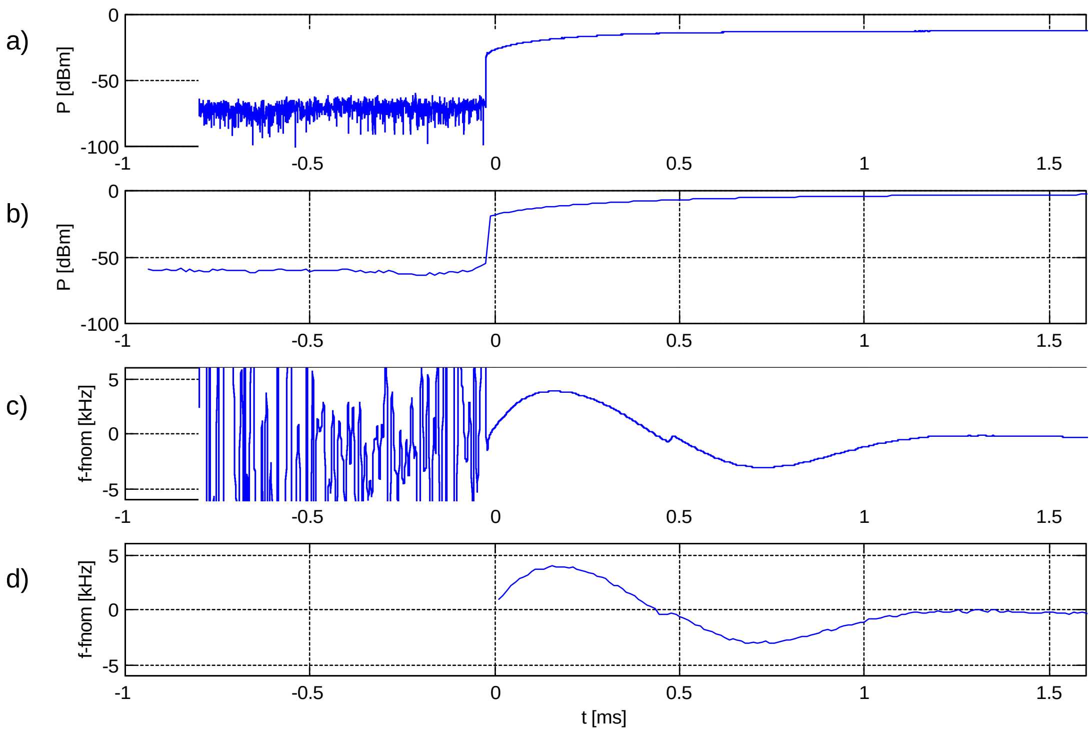

Figure 5. Instantaneous power and frequency plots a) obtained from spectrum analyser b),c) calculated d) measured with modulation analyser.

5 CONCLUSIONS

The method seems to be a good solution for evaluation of radiocommunication transmitter transient behaviour. Scalogram provides a general view on transient power and frequency behaviour what helps detecting potential problems with transmitter operation.

Proposed measurement arrangement is significantly simplified in comparison with test arrangements and thus less expensive. Signal acquisition can be made by off the shelf measurement instruments (e.g. oscilloscopes). Moreover software for calculation of parameters can be run on a standard PC.

REFERENCES

[1] I. Daubechies, *Ten Lectures on Wavelets*, SIAM, 1992.
[2] S. Mallat, *A Wavelet Tour of Signal Processing*, Academic Press, 1998.
[3] N. Delprat, B. Escudie, P. Guillemain, R. Kronland-Martinet, P. Tchamitchian, B. Torresani, Asymptotic wavelet and Gabor analysis: extraction of instantaneous frequencies, *IEEE Transactions on Information Theory* (1992), Vol. 38, pp 644 664.
[4] B. Boashash, Estimating and Interpreting The Instantaneous Frequency of a Signal, *Proceedings of the IEEE,* (1992), Vol. 80, pp 520-568.
[5] ETS 300113; Technical characteristics and test conditions for radio equipment intended for the transmission of data (and speech) and having an antenna connector; ETSI, June 1996.
[6] ETS 300 086, Technical characteristics and test conditions for radio equipment with an internal or external RF connector intended primarily for analogue speech, ETSI, 1991.

AUTHOR: Jerzy KOLAKOWSKI, Institute of Radioelectronics, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland, Phone: +48 22 6607635, Fax: +48 22 8253759
E-mail: j.kolakowski@ire.pw.edu.pl