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TIME-FREQUENCY METHODS FOR TRANSMITTER MEASUREMENTS

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Abstract: Digital Signal Processing techniques allow for significant simplification of measurement arrangements and decrease measurement time during tests of radiocommunication transmitters. The paper deals with usage of time-frequency transformations for evaluation of frequency and modulation properties of FM transmitters. The method based on Short-Time Fourier Transform (STFT) has been proposed and discussed taking into account results of simulations and experiments.
Keywords: FM transmitter, time-frequency transformation, frequency deviation

1 INTRODUCTION

ETSI standards (e.g. [1] [2]) specify the set of radiocommunication transmitter parameters to be measured in type-approval procedures. Parameters have been defined so as to describe quality of transmission and spectrum protection aspects. In measurement arrangements defined by standards the use of specialised instrumentation fitted to specific parameters of measured objects is required.

Advances in signal processing methods as well as development of computer equipment and DSP processors are stimuli for development of new measurement methods. The essence of the presented method is the calculation of parameters from the set of transmitter output signal samples using time-frequency transformation. In the paper the application of *Short-Time Fourier Transform* for determination of frequency and modulation parameters of FM transmitters is discussed.

2 STANDARDISED MEASURES AND METHODS

In an ideal case a transmitter should emit only wanted signal whose spectrum is limited to prescribed channel bandwidth.

ETSI standards specify measurements essential for communication quality and electromagnetic spectrum protection. Among others they describe frequency and modulation properties of transmitters. Modulation parameters are checked with modulation signals potentially giving out-of-band emissions.

In the paper measurements of three parameters defined in [1] are considered (as an example transmitter intended for operation in system with 12.5 kHz channel separation is taking into account):

- frequency error (the difference between carrier frequency and its nominal value is measured without modulation using frequency counter);
- maximum permissible frequency deviation (frequency deviation is measured for modulation frequencies ranging from 300 to 2550 Hz with modulation signal 20 dB greater than level giving so-called *normal deviation*);
- a response of the transmitter to modulation frequencies above 2.55 kHz (modulation signal level is set to the value causing normal deviation at 1 kHz and then frequency deviation is measured for modulation frequencies varied between 2550 Hz and the frequency equal to the channel separation).

Exemplary limits are shown in figure1. To fulfil above requirements transmitter modulator should be equipped with limiter (or gain control circuit) and a low-pass filter (to 2.5...3 kHz).

Measurement procedure consists typically of following stages:

1. carrier frequency measurement (without modulation);
2. modulation signal level adjustment to obtain normal deviation at 1kHz (equal to 60% of limit shown in figure 1b for 1 kHz);
3. 20dB increase in modulation signal level;
4. deviation measurements for several modulation frequencies placed between 300 and 2550 Hz;
5. modulation signal level adjustment to the value obtained in second stage;
6. deviation measurements for several modulation frequencies placed between 2550 and 12500 Hz.

Parameters defined in the standard describe modulation properties in the steady-state of modulation. (Deviation is measured after decay of transients caused by changes of modulation signal frequency or level). Changes of modulation signal parameters may cause instantaneous increase of deviation caused by inertial phenomena in limiter and filter in a modulator. It seems that measurements of short-time peaks of deviation should be monitored because they may cause interference in adjacent channels.

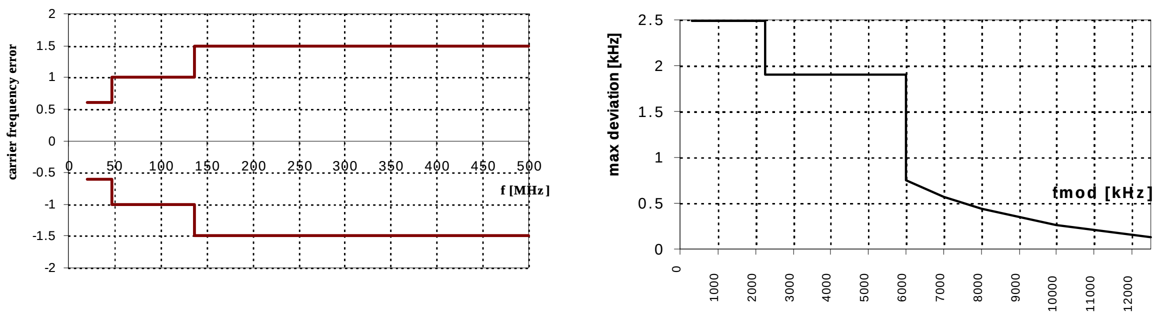

Figure 1. Exemplary limits for FM transmitters with channel separation 12.5 kHz: a) frequency error limits versus nominal frequency, b) maximal permissible deviation limits versus modulation frequency (between 2.55 and 6 kHz limit is determined by deviation measured at 2.55 kHz).

Due to recent development of digital signal processing techniques measurement sets may be simplified and measurements can be performed faster. According to the method transmitter parameters are calculated from the set of transmitter output signal samples using time-frequency transformation. Implementation of modulation signals which swept frequency or level decreases time of measurements and allows modulation transients to be observed.

3 TIME-FREQUENCY METHODS FOR FREQUENCY AND DEVIATION MEASUREMENTS

Time-frequency transformations provide information useful for further calculation of carrier frequency and maximal frequency deviation.

A measurement process begins with an acquisition of the signal. An exemplary test arrangement for RF signal acquisition is presented in figure 2.

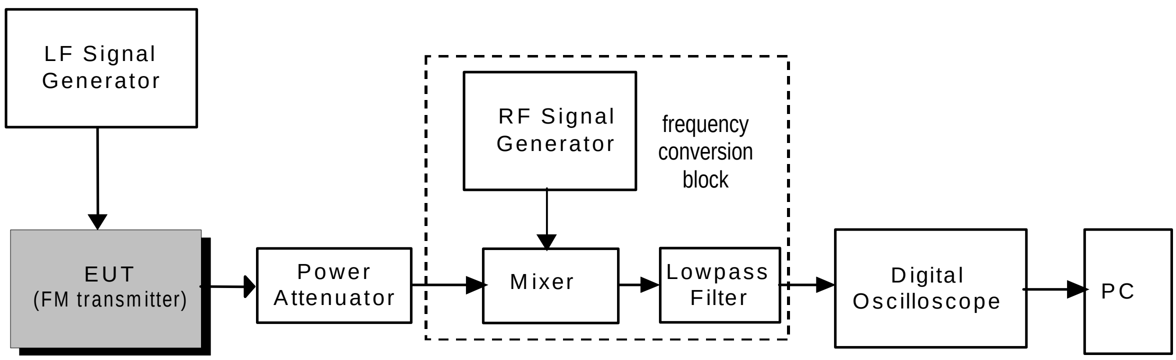

Figure 2. Measurement arrangement for RF signal acquisition

Digitising oscilloscope operates in a single-shot mode and therefore sampling rate and signal frequency should be in accordance with the Nyquist criterion. When above conditions are fulfilled, the test arrangement presented in figure 2 can be significantly reduced - the frequency conversion circuit, drawn in the frame, can be omitted. If the bandwidth of the oscilloscope does not cover signal frequency components or the sampling rate is too low the mixer is necessary.

Then time-frequency transform is calculated and measured parameters are determined. The time-frequency image of the signal provides additional information on deviation behaviour during variation of modulation signal level.

The choice of a type of time-frequency transformation for measurement tasks should be based on quality of results and complexity of calculations. The *Short-Time Fourier Transform* seems to be *a* quite good compromise between above requirements in considered application.

4 APPLICATION OF SHORT-TIME FOURIER TRANSFORM

Short-Time Fourier Transform is defined as a "windowed" version of Fourier transform. It maps one-dimensional function of time into two-dimensional function of time and frequency [3]. For discrete signals it is described as:

$$STFT(n,f)=\sum_{m=-\infty}^{\infty} x(m)w(n-m)\exp(-2jpfm)$$ (*x* – discrete time signal, *w* – analysis window)

STFT can be calculated by application of FFT to the set of samples "seen" through the window sliding along the whole set of samples. Distance between calculated spectrum components in the frequency domain is equal to: $df=f_S/N$ (f_s - sampling rate, *N* - window length measured in samples) and typically limits frequency domain resolution.

Accuracy of frequency determination can be significantly increased by zero padding (extending N-sample set of signal by appending zeros to obtain set length N_z) [4]. Then distance between calculated spectrum components is equal to: $df=f_S/N_z$, so large numbers N_z and small value of intermediate frequency should be preferred. On the other hand, good reconstruction of fast variations of instantaneous frequency is obtained with relatively small numbers of samples *N*. The choice of f_s, *N* and N_z should be based on compromise between requirements for good frequency and time resolutions and complexity of calculations.

5 EXPERIMENTAL RESULTS

Investigations of proposed method are based on computer simulations and experiments with radiocommunication transmitters.

Three variants of transmitter deviation measurements were performed:

- static measurements (deviation was observed for constant modulation frequency after transient decays),
- dynamic measurements (deviation observed from the beginning of modulation with narrow-band variations of modulation frequency),
- swept measurements (deviation observed from the beginning of modulation with modulation frequency swept in wide range).

In the paper exemplary measurements of FM transmitter working in the 450 MHz band with channel separation equal to 12.5 kHz are discussed. Vector signal analyser was used as a frequency conversion unit, DAC and recorder. Transmitter signals were converted to the band centred at intermediate frequency (30 kHz), and stored as sequences of samples. Similar results have been obtained with mixer driven from external signal generator and digitising oscilloscope.

5.1 Reference measurements

Reference measurements were performed using radiocommunication tester HP8924E, which is able to measure (with small uncertainty) carrier frequency, power and deviation of transmitter output signal. Deviation measurements have been carried out with two values of modulation signal levels: one - corresponding to normal deviation (4mV) and second - 20dB greater (40mV). Modulation frequency has been varied from 0.3 to 12.5 kHz. Selected results are shown in figure 3.

Additionally - the instantaneous deviation versus time was measured with vector signal analyser HP89441A working in the demodulation mode.

5.2 Static measurements

Static measurements were performed for modulation frequencies between 1 and 8 kHz and at two signal levels (4 and 40 mV). Transmitter output signal was down-converted to the band centred at 30 kHz and sampled with 100 kHz rate. Calculations were made for N=8 and N_z=1024. For these parameters deviation resolution is less than 98 Hz, and the number of samples for one period of modulation signal is greater than 12 which provide good reproduction of deviation peaks.

In figure 3 exemplary calculated results of static measurements are shown by markers (lines correspond to results of reference measurements).

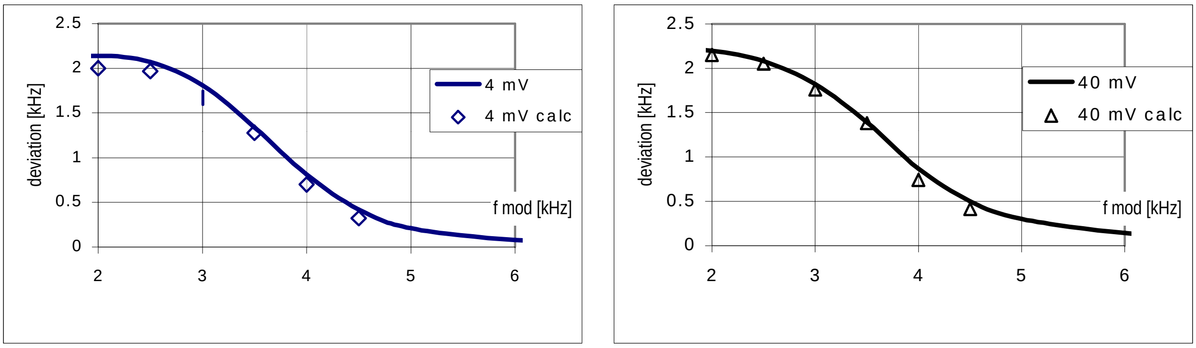

Figure 3. Exemplary results of measurements of deviation versus modulation signal. frequency (lines - reference measurements, markers - calculated results in static measurements).

Generally errors of maximal deviation measurements have not exceeded 100 Hz, better results have been obtained for grater signal (in this case deviation hardly depends on modulation signal level).

Carrier frequency was calculated as a mean value of instantaneous frequency during integer number of deviation periods. Errors of carrier frequency determination did not exceed 50 Hz.

As an example the plots of instantaneous frequency of the transmitter overdriven by 1 kHz modulation signal are shown in figure 4b. This form of results is useful for the determination of further signal parameters, e.g. measure of modulation distortions.

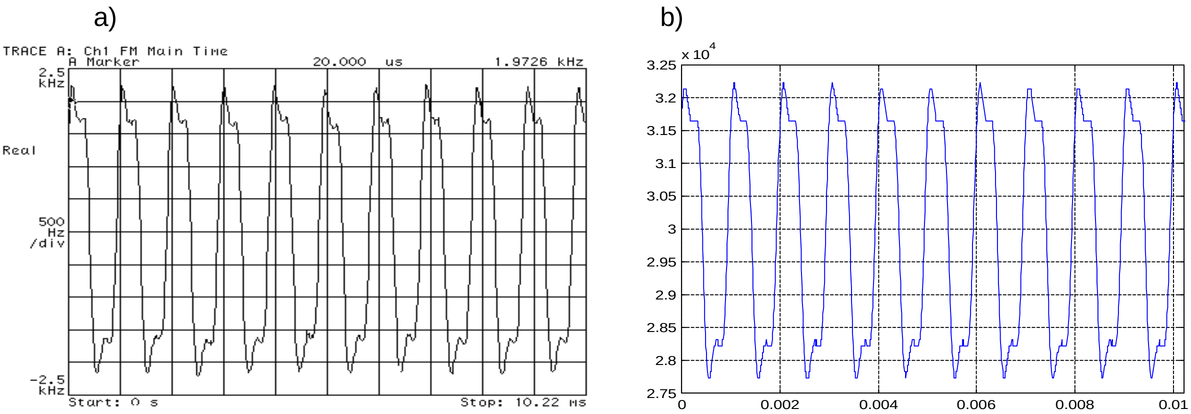

Figure 4. Exemplary plots of instantaneous frequency of the transmitter overdriven by 1 kHz modulation signal (a - measured using vector signal analyser in demodulation mode, b - calculated using STFT).

5.3 Dynamic measurements

If instantaneous frequency is measured starting at the moment of the beginning of transmitter input excitation, the modulation transient-state can be observed.

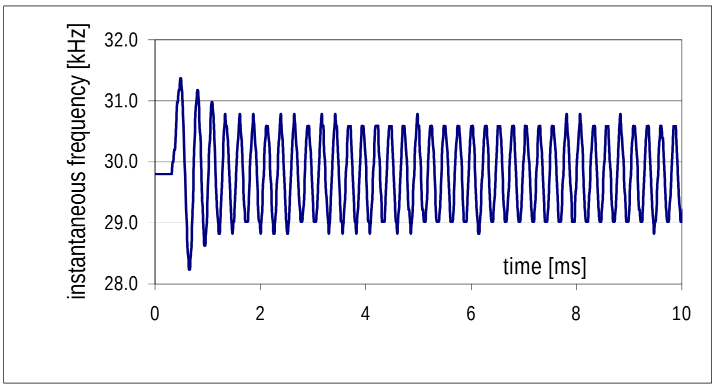

Figure 5. Instantaneous frequency versus time for overdriving modulation signal

An example of calculated instantanous frequency versus time for modulation signal frequency equal to 4 kHz is presented in figure 5. Above example shows that deviation during first some periods of modulation signals may be greater than in the steady-state. An increase is caused by inertial phenomena in modulator and exceeded 75% of the value measured after decay of transients.

These effects cause interference in adjacent channels, it seems that investigations of modulation transients should be performed at many modulation frequencies and results can explain observed interference.

5.4 Swept measurements

In measurements described above modulation frequency was changed slowly - step by step. In order to speed up the measurement the modulation signal with sweeping frequency has been considered. It was assumed that modulation frequency is changing linearly in time between defined values and the velocity of frequency changes is adjusted to record whole necessary information in one sweep.

An exemplary instantaneous frequency versus time plot is shown in figure 6 (modulation frequency was varied from 2 to 5 kHz in 17 ms).

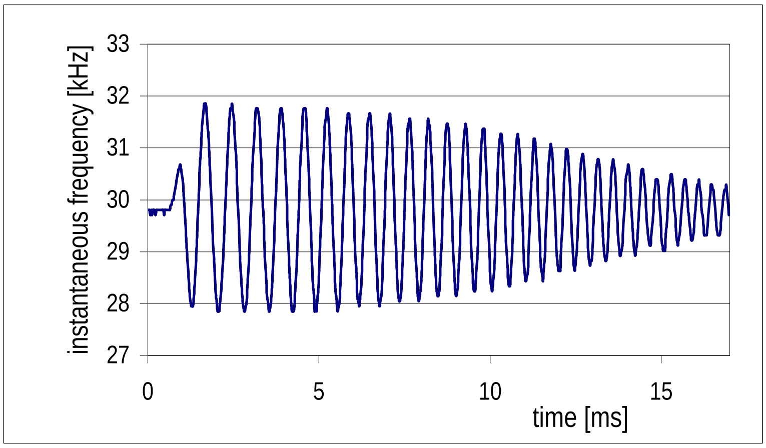

Figure 6. An exemplary instantaneous frequency versus time plot (obtained for sweep of modulation frequency from 2 to 5 kHz in 17 ms.)

After STFT calculation the mean value of carrier frequency was determined (time of averaging contained integer number of modulation signal periods). The difference between calculated and nominal value of carrier frequency can be considered as an error of carrier frequency. Consecutively mean value of the frequency was subtracted from each value of calculated instantaneous frequency, this way instantaneous deviations were obtained (with reference to real carrier frequency). Calculation procedure is illustrated in figure 7.

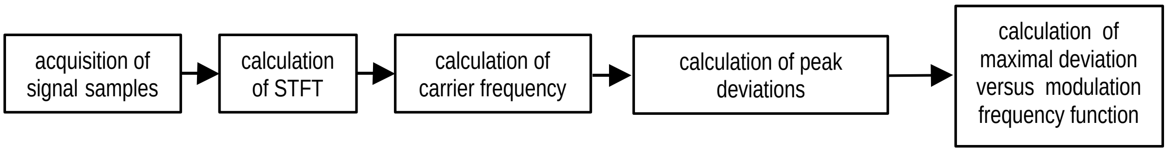

Figure 7. Proposed calculation procedure for swept measurements

Exemplary results for swept measurements are shown in figure 8 (maximal deviation has been calculated as a half of peak-to-peak value). In described case errors of deviation determination does not exceed 200 Hz.

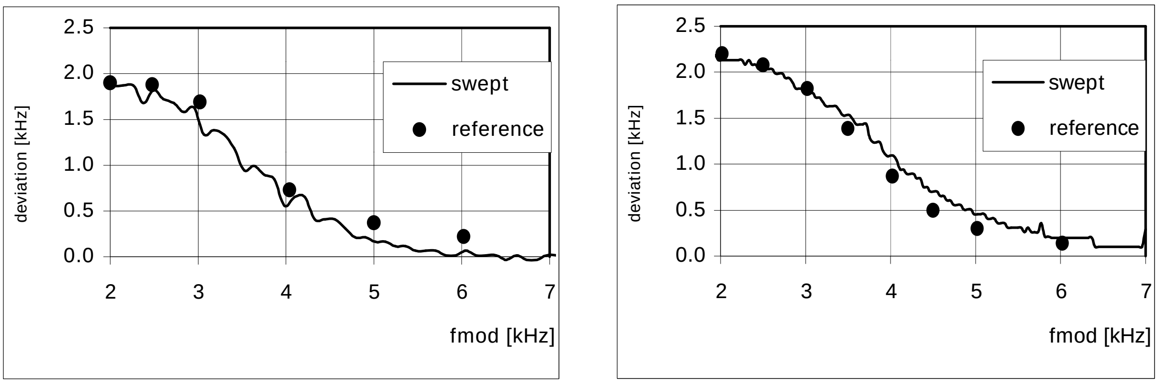

Figure 8. Swept measurement results for modulation signal levels: 4mV (a) and 40mV (b).

6 CONCLUSIONS

The method based on STFT seems to be an effective tool for measurement of parameters describing frequency and modulation properties of transmitters. Proposed measurement arrangement is significantly simplified and thus less expensive than traditional one. Software can be run on a standard PC but time of calculation may be significantly decreased using DSP processors.

In the paper three variants of proposed method have been discussed.

In so-called static measurements (performed after transient-state decay) high conformity with results obtained in reference measurements has been achieved. Errors of carrier frequency and deviation determination are comparable to the distances of SFTF spectrum components. Moreover deviation versus time plot allows modulation distortions to be observed and measured.

Dynamic measurements offer the tool for investigations of transients in modulators, which can be important for determination of adjacent channel interference sources.

Swept measurements allow for fast checking modulation properties of transmitter. Quite good uncertainties are obtained for modulation frequencies lying inside speech frequency range (to 3 kHz). For higher frequencies deviation determination errors grow because of lower values of deviations. Optimal choice of measurement conditions (e.g. the velocity of frequency tuning) depends on modulator properties so adaptive procedures should be proposed. It can be the aim of further investigations.

REFERENCES

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