Electronic Communications Committee (ECC)
within the Conference of Postal and Telecommunications Administrations (CEPT)

ECC RECOMMENDATION (07)01

FREQUENCY MEASUREMENTS USING FAST FOURIER TRANSFORM (FFT) TECHNIQUES

Recommendation adopted by the Working Group "Frequency Management" (WGFM)

INTRODUCTION

This Recommendation harmonises the relevant parameters for frequency measurements using FFT techniques in order to achieve mutual acceptance of the measurement results.

"The Conference of Postal and Telecommunications Administrations,

considering

a)   that the frequency is an important parameter to characterize RF signals

b)   that there is an increasing number of different signal types that have to be measured by radio monitoring services

c)   that FFT techniques facilitate accurate measurements of the frequency for nearly all types of signals

d)   that the number of low cost digital signal analyzers using FFT techniques and capable of performing accurate frequency measurements is increasing

e)   that the frequency measurement method using FFT techniques offers advantages over conventional methods in terms of frequency accuracy, speed, digital storage of spectrum data, reproducibility of results, discrimination of closely spaced carriers and noisy environments

f)   that FFT techniques better measure time varying (gated, pulsed or transient) signals and complex modulated dynamic signals by processing all frequencies of the measured spectrum simultaneously.

recommends

1)   that when performing frequency measurements using FFT techniques, the method, set-up and specifications described in the Annex are used.

Note:
Please check the Office web site (http//:www.ero.dk) for the up to date position on the implementation of this and other ECC Recommendations

ANNEX

General

The frequency definitions used in ITU-R Recommendation SM.328 are:

- **The Assigned Frequency :**

    This is the centre of the frequency band assigned to a station.

- **The Characteristic Frequency :**

    This is a frequency which can easily be identified and measured in a given emission. A carrier frequency may, for example, be designated as the characteristic frequency.

- **The Reference Frequency :**

    This is a frequency having a fixed and specified position with respect to the assigned frequency. The displacement of this frequency with respect to the assigned frequency has the same absolute value and sign as the displacement of the characteristic frequency has to the centre of the frequency band occupied by the emission.

FFT techniques can be used to measure the Characteristic Frequency as defined above.

Compared with swept spectrum analyzers, FFT offers advantages in terms of speed and accuracy. For example, if a signal is to be analysed with a 10 kHz span and a 10 Hz resolution, a swept spectrum analyzer will take over a minute, whereas the FFT analyser can present a result in less than one second.

The spectral components of a modulated signal continuously change over time. Because a swept spectrum analyzer needs time to perform a sweep, the right end of the resulting spectrum shape will show a signal a signal stored later than the left end. FFT techniques, however, is able to capture all spectral components simultaneously and gives the possibility to average the successive momentary frequency values over time records.

Principle of measurement using FFT techniques

Basic system set-up

An FFT frequency measurement system consists of the following principal components:
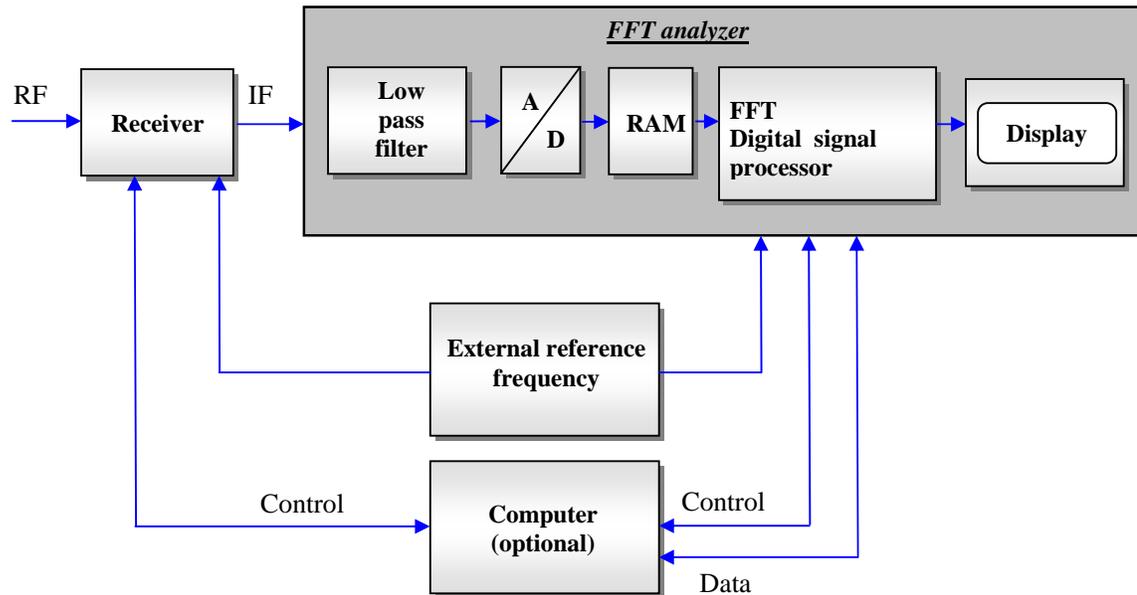
The majority of FFT analyzers apply a zoom-FFT to magnify the frequency range of interest in cases, when a small frequency band of the spectrum is needed to be analysed.

Zoom-FTT is a process where the input signal is frequency down converted, decimated and sampled prior to passing it into the standard FFT unit. Zoom-FFT operation makes it possible to reduce the frequency span while maintaining a constant centre frequency and focus the measurement anywhere within the analyzer frequency range.

Principal elements

Component functions

Receiver

The RF signal is first fed into a receiver that converts the frequency band to be analysed into an IF frequency range that the following A/D converter samples. The IF from the receiver must be in the operating band of the FFT analyzer.

Low pass filter

For digitalizing the IF signal, it must be sampled at regular time intervals. During this process, mixed frequencies that are generated from the input signal and the sampling frequency can fall into the input frequency range of the FFT analyzer, making the measurement result unreliable (aliasing effect).

Therefore the filter has to be designed such that:

- the IF signal can pass

- the signal components higher than half the sampling rate of the following A/D converter are suppressed.

A/D converter

The A/D converter converts amplitudes of the signal in the time domain into a digital data stream. Complete reconstruction of a waveform for accurate representation of the incoming signal is only possible with sample frequencies taken at a rate greater than twice the highest frequency component, in practice this is found to be 2.56 times.

RAM

The sampled data has to be temporarily stored in memory (as a 'time record') before the actual FFT process can be performed.

FFT Digital Signal Processor

This component performs the actual FFT processing which converts the complete blocks of time records into amplitude versus frequency signals. The resulting spectrum is then mathematically analysed in the frequency domain to calculate the characteristic frequency.

Display

In order to achieve valid results, several conditions have to be met in terms of signal-to-noise ratio and interference including multiple signals.

Therefore, automatic frequency measurements showing only a figure as a result are not recommended. It is necessary to have a display showing the spectrum of the measured signals in the frequency domain. This display has to include marker(s) indicating the characteristic frequency.

External reference frequency

The receiver and the FFT analyzer must be locked to a common reference frequency. To achieve the most accurate results, an external reference is required.

Computer

An optional computer can be used to store the measurement data and to control the receiver and/or the FFT analyzer.

There are two different stages in which signal data could be stored:

- The frequency domain data are stored after the FFT process (i.e. in the frequency domain). This method takes up only little storage space, but later measurements can only be repeated with the same FFT settings.

- The time domain samples of the signal are stored before the FFT process. This method allows later measurements with different FFT settings (acquisition time, resolution), but takes up a very large amount of storage capacity.

Storing the data allows measurements at a later time ('off-line'), making it unnecessary for the operator to wait for temporary emissions to come up, and ease frequency measurements of very short (pulsed) emissions.

Specifications

RF input of the receiver	At least 60 dB Dynamic Range
IF output of the receiver	At least 60 dB Dynamic Range
	Bandwidth approximately 150% of the expected occupied bandwidth of the signal to analyse
Low pass filter	Cut-off frequency :
	Just less than 50% of A/D converter sampling frequency
A/D converter	Dynamic range just greater than the amplitude of the IF signal
	Sampling rate at least equal to 2.56 x 150% = 384% of the expected occupied bandwidth of the signal to analyze
	Resolution at least equal to 14 bit
RAM	Minimum size : N1 x N2 x 14 bit
	N1= number of time records for results averaging
	N2=number of samples in each time record

FFT Digital Signal processing

a)   Signal detection function

In FFT systems, the signal detection function is implemented through software in the frequency domain. The following detection functions have to be used:

A1x, A2x, F1x, F7x	Clear Write (momentary signal)
Continuous signal with digital modulation (x-PSK, x-QAM, MSK, OFDM)	
F3E, A3E, J3E, H3E, R3E	
Pulsed signals with digital modulations (TDMA)	Clear Write (gated measurement)

b)   Windowing

Since the FFT process looks at a signal only for a limited time (the acquisition time), it assumes the signal to be non-existent or at least periodic outside the calculation 'window'.

This, however, results in certain errors when in fact the amplitude of the signal is not zero at the beginning and on the end of each time record. To reduce these errors, a filter (so-called window function) has to be applied to the signal.

From the FFT theory it can be proven that there exists no ideal filter which results in an exact reproduction of the signal in the frequency domain. All used windows are optimized for either good amplitude accuracy or good frequency resolution.

The Gaussian window is recommended due to its high frequency accuracy. However, the most common window function for good frequency accuracy is the Hanning (sometimes also referred to as 'Han') window.

c)   **Frequency resolution**

To achieve good accuracy, the spectral resolution of the FFT process should be at least 200 lines although modern FFT analyzers normally provide 512 lines or more. The required frequency resolution is often determined through the setting of the resolution bandwidth. For a maximum of accuracy, if the FFT resolution is 512 lines, the optimum resolution bandwidth is about 1/500 of the frequency span that is analysed. Higher values for the resolution bandwidth would waste FFT resolution capability, smaller resolution bandwidths would only result in slower performance.

d)   **Time record (acquisition time)**

The duration of each time record has to be at least as long as the period of the lowest modulating frequency of the signal to be analysed. However, it also depends on the required frequency resolution and on the frequency span. The higher the required frequency resolution and span, the longer is the minimum acquisition time. In practical FFT analyzers, the acquisition time is automatically adjusted to the lowest possible value depending on the user's setting of the other parameters.

$T = N \times \Delta t$ where
T = Time record length
N = Number of samples
Δt = sample time (time between 2 samples) = $1/f_s$
f_s = sampling frequency

e)   **Real-time Bandwidth**

This value is the performance indicator of the analyzer. Real-time bandwidth is the frequency span at which the FFT processing time is equals the 'time record' length. There is no break between the end of a time record and the start of the next.

f)   **FFT specifications summary**

Window setting	Best: Gaussian or Hanning window
Frequency resolution	At least 1/500 of the frequency span
Real-time Bandwidth	Is achieved when FFT processing time is equal to the time record length

Process of frequency measurements

The resulting characteristic frequency is determined from the displayed spectral lines. Markers indicate the precise result.

Specific cases

Noisy signals

The spectrum including the noisy signal is sampled some thousand times and the FFT results are averaged. This way, the signal peaks of all noise components that have a Gaussian distribution shape cancel each other. In a second measurement run, the same spectrum part is again sampled and averaged in the same way but without the hidden signal. Both averaged curves are subtracted which cancels all noise components that have been present during both measurements. What is left is the hidden signal with an improved signal to noise ratio.

Short time signals

For good frequency resolution, the time record has to be long. In case of very short emissions like bursts of digital TDMA systems, the maximum capture time can be the burst time. When transmitter and FFT analyzer are not synchronized, randomly taken time records are only valid if the signal was present during the whole time (in the example below on the left it is only sample 3).
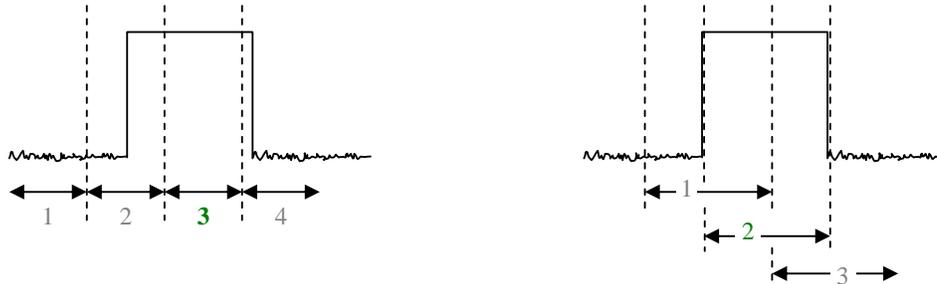
To get valid time records with reasonable probability, the time record length has to be significantly shorter than the burst length. Shorter time record lengths, however, result in less frequency accuracy. To overcome this problem, the FFT could be applied on relatively long time records (the maximum time record length is equal to the burst length) that overlap (e. g. 50% overlap) each others. This technique requires an FFT analyzer with two physical process 'chains' that is capable to capture and calculate the FFT at the same time.

Wide band signals

In case of wideband signals (e. g. F3E, F8E etc.), the resulting spectrum can be wider than the capability of the A/D converter. To overcome this problem, the IF signal of the receiver could be passed through a frequency divider. A division ratio of 200 results in a significantly reduced modulation index. The wideband signals are in this way converted into narrow-band signals that can be captured and analyzed with FFT. The division ratio must be taken into account in calculating the carrier frequency. In the example above, the displayed frequency result of the FFT has to be multiplied with 200 to give the original RF frequency.