International Symposium on LIGHTNING PHYSICS AND EFFECTS
April 19-20, 2007 – Vienna, Austria

ANALYSIS OF ELECTRIC FIELD SPECTROGRAMS OF LIGHTNING DISCHARGE COMPONENTS

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OUTLINE OF PRESENTATION

1. Introduction
2. Dynamic spectra of non-stationary signals
3. Objectives of analysis of electric field change spectrograms
4. Electric field change measurements
5. Examples of obtained results
6. Conclusion

INTRODUCTION

- Basing on the electric field measurements in the low frequency (LF) range at the earth surface it is possible to distinguish some main and various modes of electric charge transfer to ground in a typical negative lightning flash.
- These modes are known as:
  - stage of stepped/dart/dart-stepped leader,
  - single or multiple return stroke (RS) events,
  - stage of continuing current with or without M-components.

DYNAMIC SPECTRA OF NON-STATIONARY SIGNALS

- Non-stationary signals: a finite duration signal, and in particular a *transient signal* (for which the length is short compared to the observation duration).
- The standard Fourier Transform is not useful for analyzing of such signals.

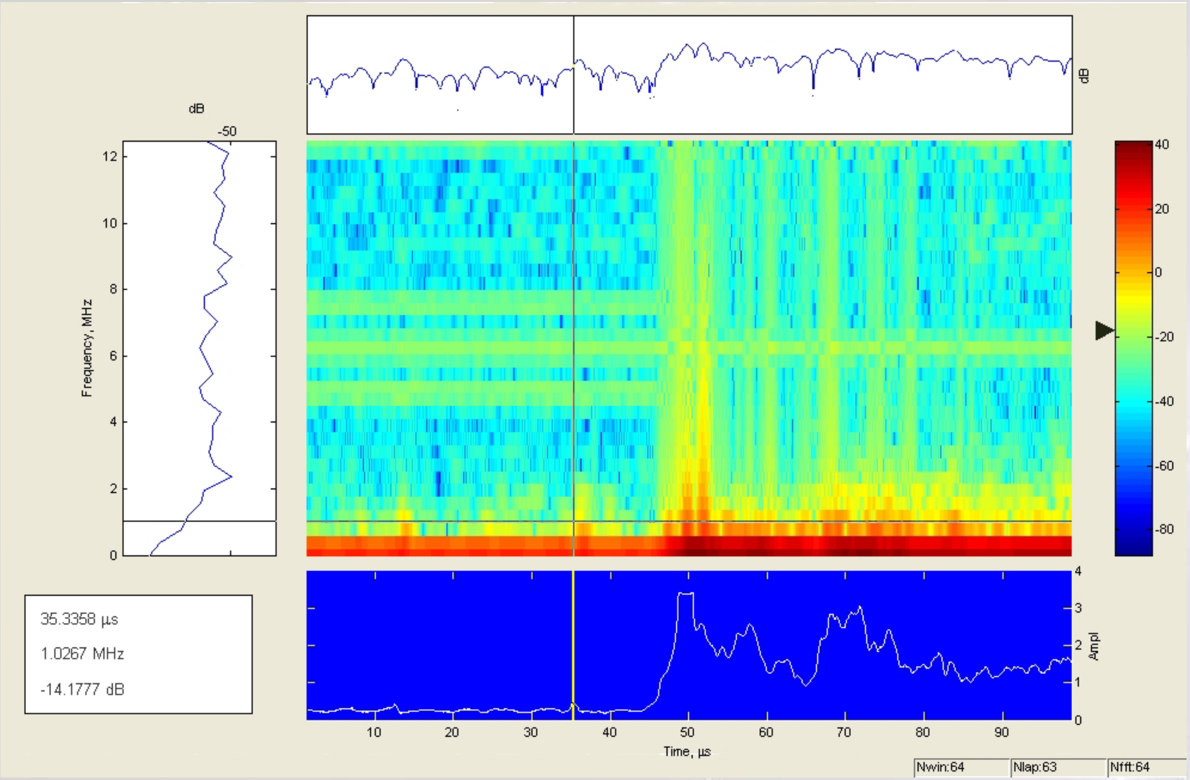
$$\exp(i\omega t) \longleftarrow \boxed{x(t)} \leftrightarrow X(\omega)\exp[i\phi(\omega)] \qquad \omega = 2\pi f$$

- The signal *x*(*t*) is represented by a family of infinite waves, which are completely unlocalized in time, that is, the spectrum tells us which frequencies are contained in the signal, as well as their corresponding amplitudes and phases, but does not tell us at which times these frequencies occur.

DYNAMIC SPECTRA OF NON-STATIONARY SIGNALS

- Electric field changes measured during lightning discharges represent non-stationary signals described by the parameters which evolve over time.
- In order to analyze information which is localized in time such as spikes and high frequency bursts one can use the **Short Time Fourier Transform** (STFT) instead of the standard FFT. Time-localization can be achieved by windowing the signal and then taking its Fourier Transform.
- The magnitude of the STFT is called the **spectrogram**. Spectrograms usually show the Power Spectrum Density (PSD).

DYNAMIC SPECTRA OF NON-STATIONARY SIGNALS



The signals have been divided into segments which overlap each other and each segment is windowed with the Hamming window.

OBJECTIVES OF E FIELD ANALYSIS USING STFT

- A non-traditional representation of lightning electric field changes, which combines the time domain with the frequency domain.
- Comparison of the Power Spectra Density of different lightning discharge components.
- Determination of specific features of such components as return strokes, IC pulses, M components, and different short pulses occurring in the lightning channel based on their dynamic spectra.
- Implementation of new detection algorithm procedures to be applied in computer processing and dedicated DSP processors.

ELECTRIC FIELD CHANGE MEASERMENTS

DATA ACQUISITION SYSTEM

- **The first LF/MF antenna (frequency band 300 Hz - 3MHz)**
  a flat-plate antenna – PAD 04 sensor with charge amplifier AD 825
  (the same as used by SAFIR system for CG flash discrimination),
  feedback time constant τ = 6.7 ms;

- **The second LF/MF antenna (frequency band 20 Hz – 1.3 MHz)**
  a flat-plate antenna with charge amplifier AD 711 with feedback time constant τ =5 ms,

- **Two channel AD PC 12-bit card**
  64 MB memory buffer in each channel, triggered by (∂E/∂t) pulse obtained from external Maxwell current antenna with own programme package (LATECH trade mark) for archiving and visualization of collected data

- **The GPS time module unit for time stamping the same as used by SAFIR system**

ELECTRIC FIELD CHANGE MEASERMENTS

a flat-plate antenna –
PAD 04 sensor with
charge amplifier AD 825

(atmospheric electricity
sign convention)

ELECTRIC FIELD CHANGE MEASERMENTS

Maxwell current antenna

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POLAND

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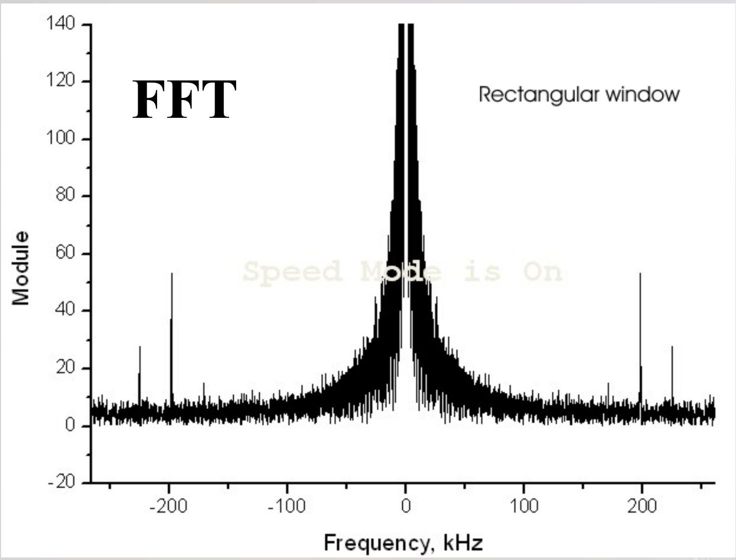
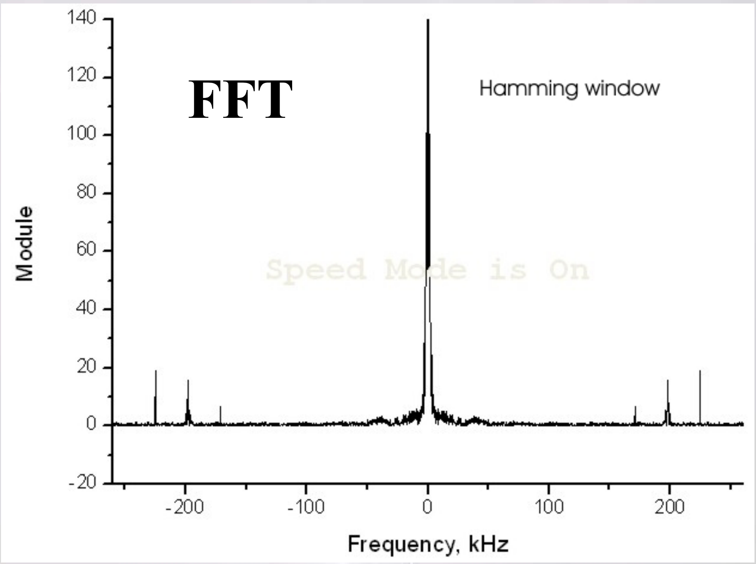
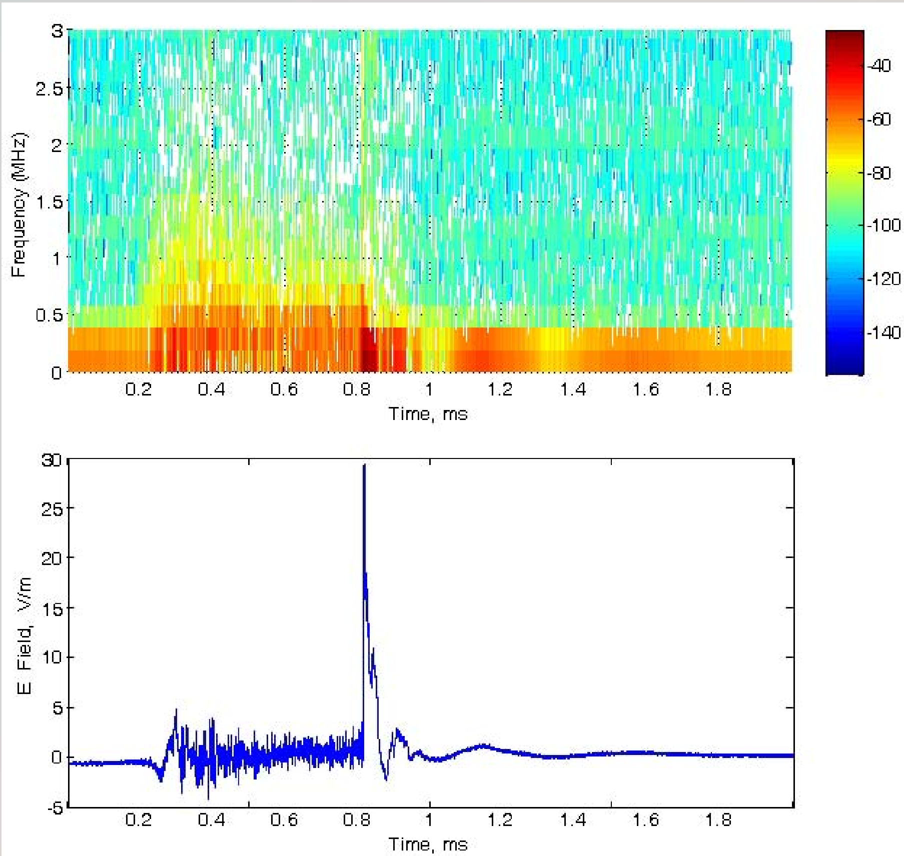
ELECTRIC FIELD CHANGE MEASERMENTS

EMC problems – „disturbances" from radio stations and the power supply. Digital filtering was necessary.





EXAMPLES OF OBTAINED RESULTS



1RS(-)

$T_p = 40\,\text{ns}$

$f_p = 1/T_p = 25\,\text{MHz}$

$f_{\max} = f_p/2 = 12.5\,\text{MHz}$

$f_{upper} = 3\,\text{MHz}$

$\Delta T_{total} = 2\,\text{ms}$

The Hamming window

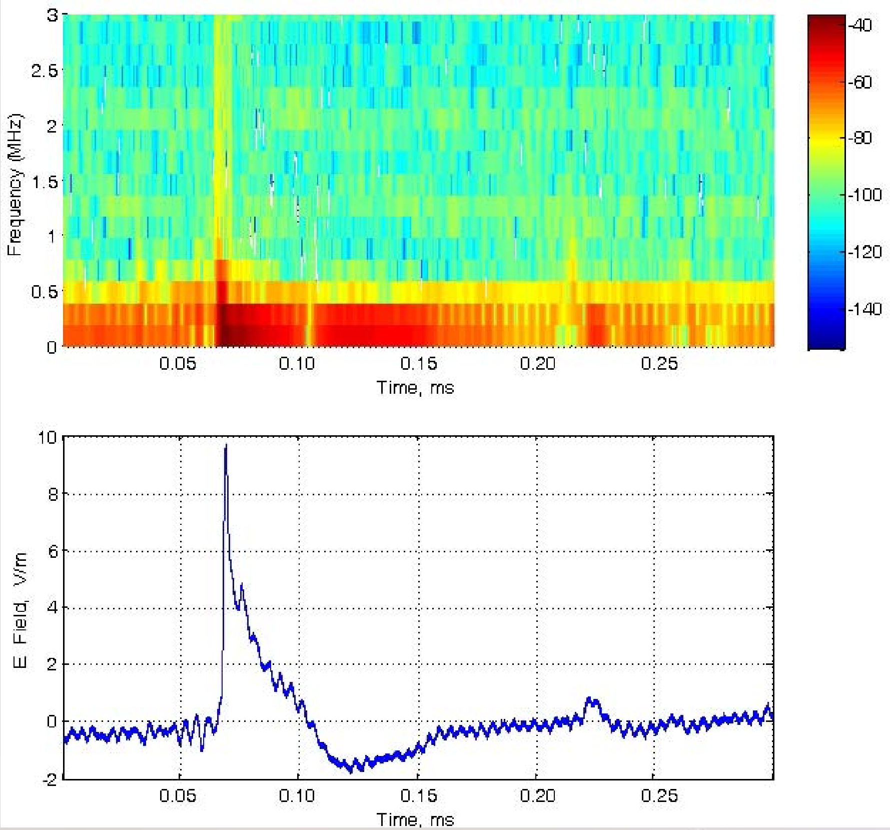
$\Delta T_{window} = 127 \cdot T_p = 5.08\,\mu\text{s}$

$\Delta f = 1/\Delta T_{window} = 196.9\,\text{kHz}$

$5.08\,\mu\text{s} \times 196.9\,\text{kHz}$

a single time - frequency cell

EXAMPLES OF OBTAINED RESULTS



3RS(-)

$f_{upper} = 3$ MHz

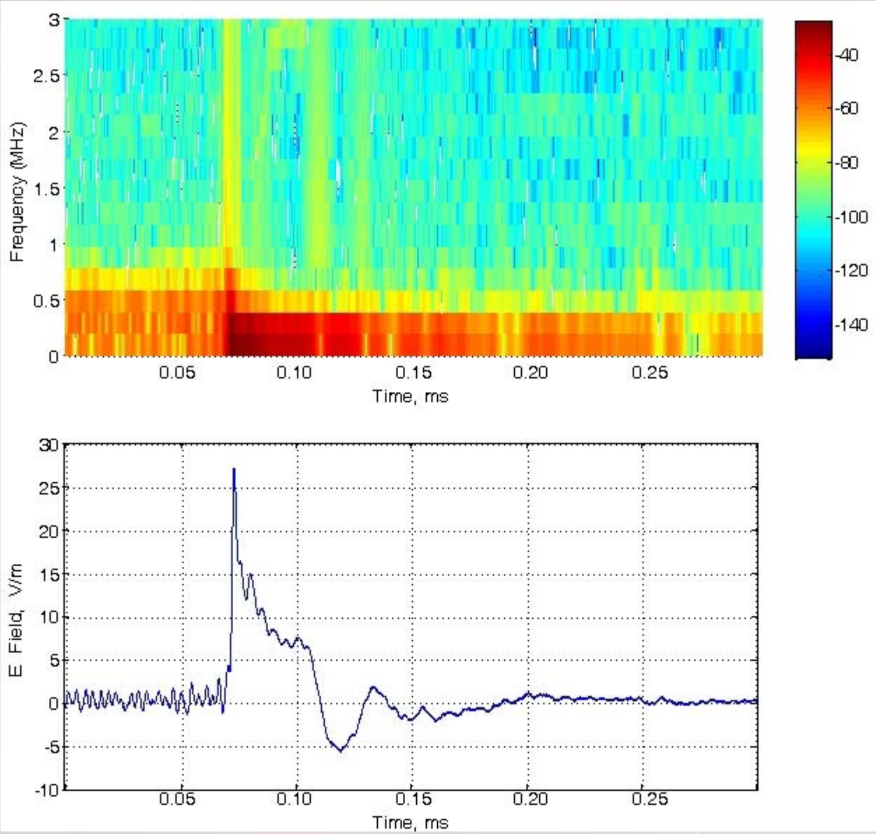
$\Delta T_{total} = 300\ \mu s$

The Hamming window

a single time - frequency cell :

$5.08\ \mu s \times 196.9$ kHz

EXAMPLES OF OBTAINED RESULTS



5RS(-)

$f_{upper} = 3$ MHz

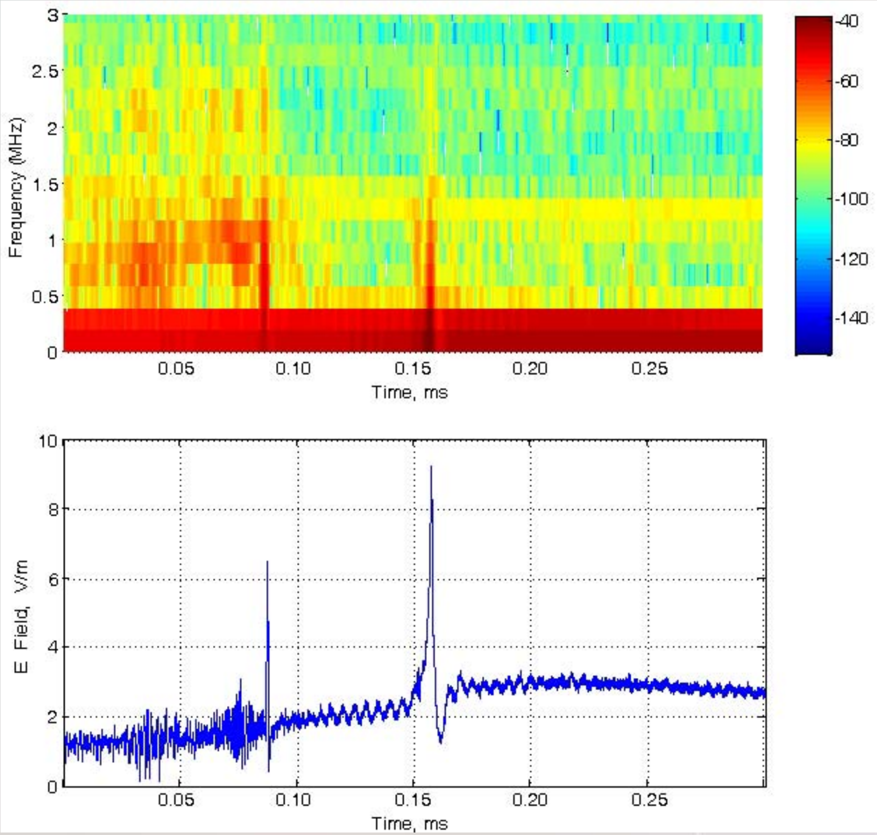
$\Delta T_{total} = 300\ \mu s$

The Hamming window

a single time - frequency cell :

$5.08\ \mu s \times 196.9$ kHz

EXAMPLES OF OBTAINED RESULTS



IC pulses

$f_{upper} = 3$ MHz

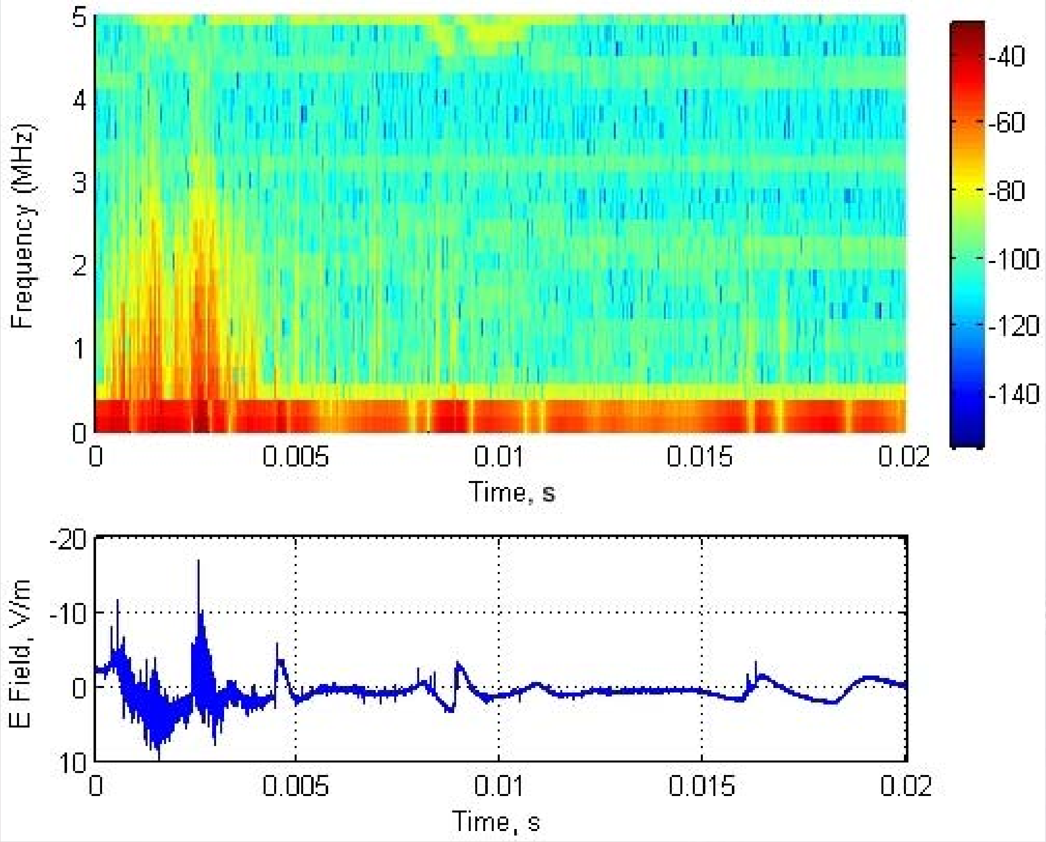
$\Delta T_{total} = 300\ \mu s$

The Hamming window

a single time - frequency cell :

$5.08\ \mu s \times 196.9$ kHz

EXAMPLES OF OBTAINED RESULTS



CC and train pulses

$f_{upper} = 5$ MHz

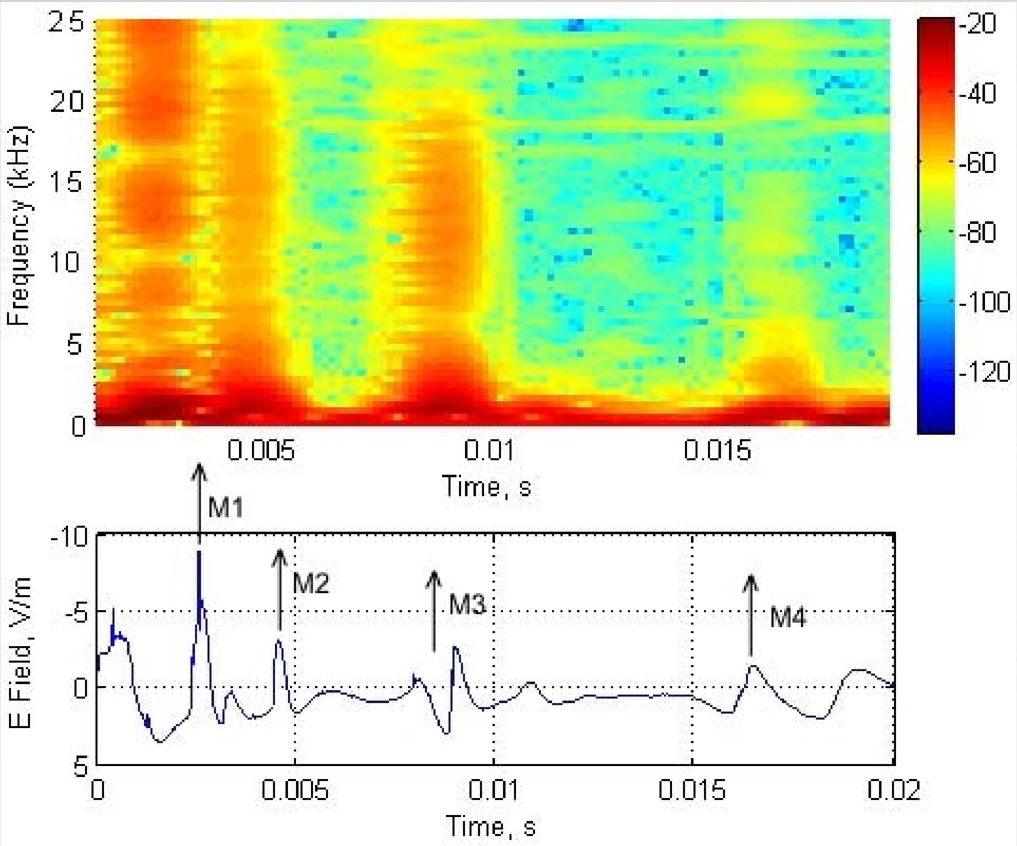
$\Delta T_{total} = 20\,\mathrm{ms}$

The Hamming window

a single time - frequency cell :

$5.08\,\mu s \times 196.9\,\mathrm{kHz}$

EXAMPLES OF OBTAINED RESULTS



CC and train pulses

$f_{upper} = 25$ kHz

$\Delta T_{total} = 20$ ms

The Hamming window

a single time - frequency cell :

$2.54\,\text{ms} \times 394$ Hz

CONCLUSIONS

1. The STFT can be used to analyse the time-frequency features of E Field changes of lightning discharge components.
2. In order to find detection algorithm procedures for RS stages, separated IC pulses and train pulses connected with RS and CC one should determine the PSD up to a few MHz.
3. However, during the analysis, at least two separated spectrograms are needed, that is, for low and heigh fraquency bands due to the Heisenberg-Gabor inequality.
4. It is need to compare in the near future the STFT efficiency with other time-frequency transformations, especcialy with the wavelet transform.