Broad-band electric field measurements above thunderstorms by the IME-HF instrument prepared for the TARANIS mission

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TARANIS:
(Tool for the Analysis of Radiation from lightNIng and Sprites)

• French space agency CNES, launch in August 2020 (?)
• Scientific team lead by J-L. Pincon, LPC2E Orleans: French institutes and universities, international participation (Czechia, Poland, USA).
• Main focus: **Transient luminous phenomena, Terrestrial gamma ray flashes**
TARANIS

• Sun-synchronous high inclination low-Earth orbit (700 km)
• CNES MYRIDE microsat (the same as DEMETER), 160 kg
• 2-3 years of operations are anticipated
TARANIS

2 microcameras, 4 photometers, 2 detectors of energetic electrons, 3 X-ray detectors, instruments to measure electromagnetic fields in 3 frequency bands, onboard analysis and synchronous triggering
IME-HF instrument

A broad-band (5 kHz – 37 MHz) analyzer intended to study radiation originating in atmospheric lightning discharges and in optical phenomena (Transient Luminous Events) observed between the Earth troposphere and ionosphere.

- Identification of wave signatures associated with transient luminous events and terrestrial gamma-ray flashes
- Characterization of lightning flashes from their HF electromagnetic signatures
- Identification of possible HF electromagnetic or/and electrostatic signatures of precipitated and accelerated particles
- Determination of characteristic frequencies of the medium using natural waves properties
- Global mapping of the natural and artificial waves in the HF frequency range, with an emphasis on the transient events
Trans-ionospheric pulse pairs (TIPPs)

- pairs of short VHF bursts separated by a few tens of microseconds
- the first burst accompanies an IC discharge (Compact Intracloud Discharge)
- the second burst is the ground reflection of the first burst

Jacobson and Light, 2003
(FORTE satellite observation)
IME-HF Analyser
for the TARANIS satellite

• Broadband waveform measurements of the HF electric field between 5 kHz and 37 MHz
• Sampling frequency 80 MHz, processing on a VIRTEX4 FPGA
• Onboard data selection algorithm, generation of alert signal
• 128 Mbits event mode data, 40 kbit/s survey mode data
• Power 3.8W
• Mass 470g
## IME-HF Data structure

### Survey data:
- Regular 80 MHz waveform snapshots (12 bit, 17us every 0.8s);
- Averaged filter bank output (12 channels, no gaps, 7.4ms resolution);
- Automatically selected best 80 MHz waveform snapshots (12 bits, 300us every 15s, enough to capture TIPPS and signals from other lightning processes).

### Event data:
- Up to 416 ms of 80-MHz waveforms of internally or externally triggered events, nominally 3 events of 42 ms per half-orbit
- Full resolution 12 us filter bank data, 12 channels, up to 32 events

### Radio waveforms:
- Programmable down-converted 16 bit waveforms,
- Bandwidths of 5 kHz, 10 kHz, 20 kHz, or 80 kHz
Flexible Detection Algorithm

1. Detection algorithm for transient signals based on filter bank channels
   
   A rank is calculated as a sum of weighted differences between maxima and averages of the RMS values of the twelve bandpass filters.

   We can adjust the weight for each band-pass filter, the number of filter-bank samples over which the maximum amplitude is obtained and the interval over which the average values are calculated.

2. Detection algorithm for transient signals based on waveform

   A simplified rank is calculated as a difference between maximum over a series of waveform samples and its average
Analyzer sensitivity

Analyzer without sensors, from telemetry data, 2kHz - 40MHz:

Gain 4x ... amplitudes from $12 \, \text{uV}_{pp} \, \text{m}^{-1}$ à $49 \, \text{mV}_{pp} \, \text{m}^{-1}$

0 dB corresponds to spectral amplitude $1.9 \, \text{nV} \, \text{m}^{-1} \, \text{Hz}^{-1/2}$ (\(L_{\text{eff}}=1\text{m}\))

-5 dB at 1 MHz -> sensitivity $1.1 \, \text{nV} \, \text{m}^{-1} \, \text{Hz}^{-1/2}$
Filterbank frequency response

Gain=1  Voltage between antennas = 30.4 mVp-p
**Instrument sensitivity**

Sensors + analyzer, from telemetry data, 2kHz - 40MHz:

**Gain 4x** ... amplitudes from **12 $\mu$V$_{pp}$ m$^{-1}$** à **49 mV$_{pp}$ m$^{-1}$**

0 dB corresponds to spectral amplitude **1.9 nV m$^{-1}$ Hz$^{-1/2}$ ($L_{eff}$=1m)**

18 dB at 1 MHz -> sensitivity **15 nV m$^{-1}$ Hz$^{-1/2}$**
Ground-based measurements

IME-HF Analyser for the TARANIS satellite is also used in high-resolution ground-based measurements of electric and magnetic fields (using Shielded Loop Antenna with Versatile Integrated Amplifier)

• Measuring station La Grande Montagne, Plateau d'Albion, in cooperation with LSBB Rustrel, France; 4 antenna interferometer, 3-component VLF measurements;
• Measuring station Corsica in cooperation with the Institute of Aerologie, Toulouse, France; with LMA;
• Measuring station Lomnicky stit observatory, High Tatras, in cooperation with the IEP SAS, Kosice, Slovakia; with cosmic ray detectors
• Measuring site Milesovka meteorological observatory, Czechia;
• Measuring site, Ter Wisch, Netherlands; with LOFAR.
Measurement of inter-stroke pulse sequences


Measurement of short pre-stroke pulse sequences


Daytime Tweek Atmospherics

Santolík, O., I. Kolmašová (2017), Unusual Electromagnetic Signatures of European North Atlantic Winter Thunderstorms, Scientific Reports, 7,1, 13948.
Conclusions

• Broad-band electric field measurements up to 37 MHz have been prepared for the TARANIS spacecraft, waiting for launch;

• Ground based measurements in the same frequency range and at different measurement site in Europe will support the TARANIS mission;

• Examples of recent results of these measurements show a range of subjects from the preliminary breakdown processes, through interstroke pulse sequences, to tweek atmospherics.