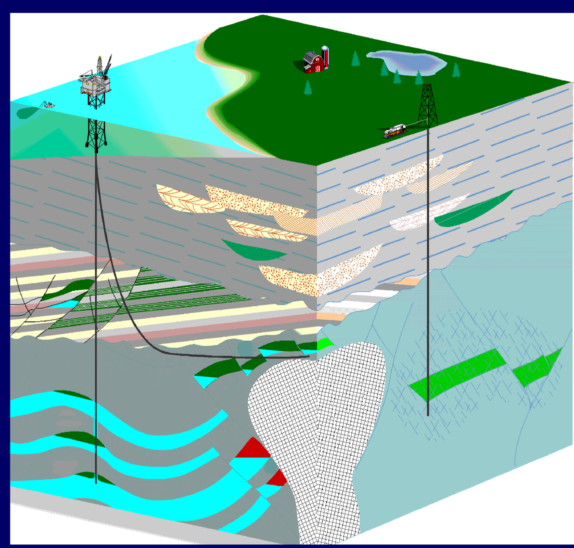

# Integrated induction coil and fluxgate magnetometers

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## Abstract

The concept of a full field array electromagnetic system is an ideal tool to support hydrocarbon and geothermal E & P as well as various engineering monitoring applications. Some of the challenging key questions are defining the reservoir, mapping of the fractures and reservoir depletion monitoring. The new acquisition system KMS-820 designed for general EM applications and microseismic. Here are shown some examples for the sensor performance and MT monitoring with magnetotellurics (MT) at different locations in the world. A 3 component digital fluxgate magnetometer can easily added to the regular MT system and shows good performance for period larger than 20 s. A modification of the transfer function estimation improves the results for shorter periods.

## Acquisition system for EM: solution & architecture

The concept of a full field array system with network capability and controlled by wireless communication is summarized below with an MT example at Hockley Salt Dome near Houston.


Fig. 1: Equipment of one MT station.
3 magnetic sensors for all components which covers the high, low and ultra low frequency range.
Electrodes for the electric field and all needed cables.
PC or tablet to control the unit.

### KMS 820 specification highlights

1. **Low power consumption**
   - Uses between 3 to 5 W (compared to 15-20 W)
   - All channels are switchable
   - 6 analogue channels & unlimited digital
2. **Large dynamic range**
   - 24 Bit analogue channels, 32 bit digital input
3. **High bandwidth**
   - DC, sampling rate 80 kHz
4. **Communication/memory**
   - Wireless & WiFi (switchable), USB
   - Standard SD-card 32 GB with recording schedule
5. **GPS**
   - Switchable, on board timing as option
6. **A general-purpose acquisition system**
   - All EM (MT & CSEM) methods and also microseismics
   - System is broadband and fully firmware controlled


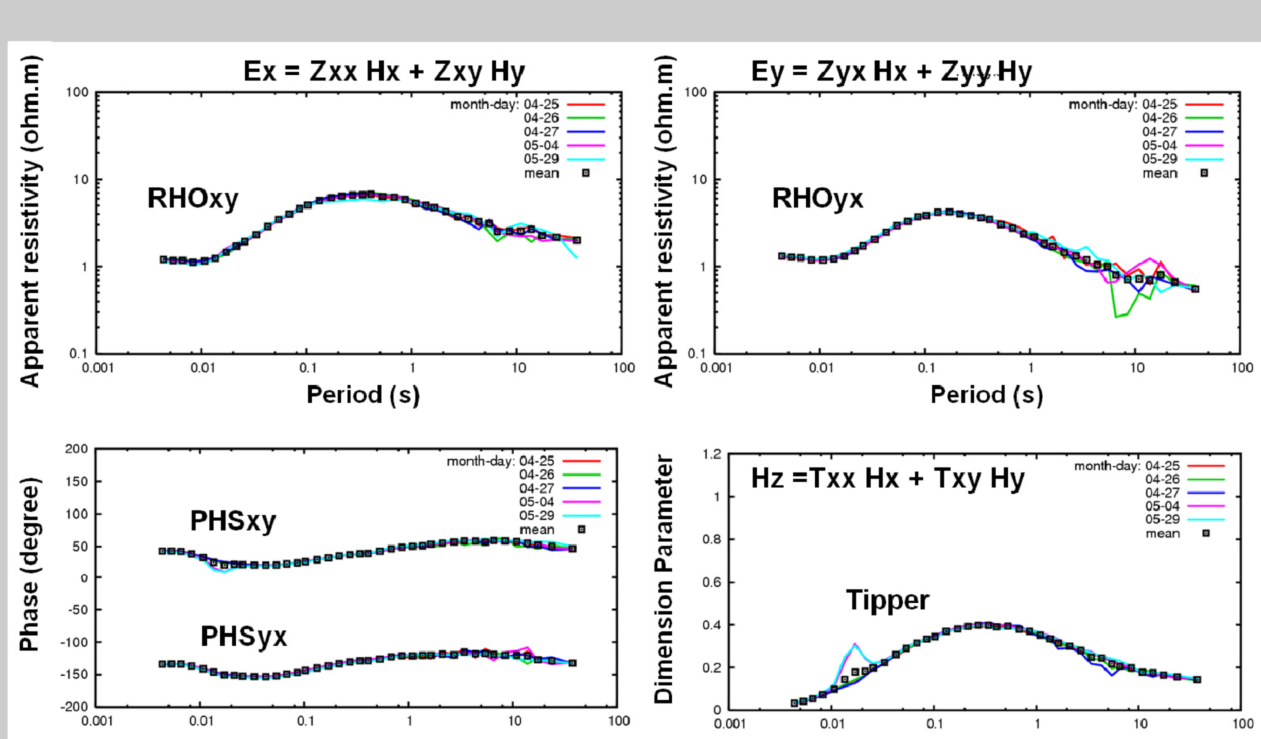


**Fig. 2:** MT response cures for 5 separated overnight recordings over a month at Hockley field test site near Houston.

## Sensor parallel test

The magnetic fields are recorded with induction coils which are optimized and limited in different frequency bands for MT 0.1 mHz to 1 kHz and for AMT 20 Hz to 40 kHz.

Many sensor performance tests have been under-taken with different coils Lemi and EMI coils under different conditions.

The difference between coils is calculated in the complex frequency domain and the system response function has been considered. To achieve the specification of manufacturer a proper set up is mandatory, that means coils have to be buried totally.

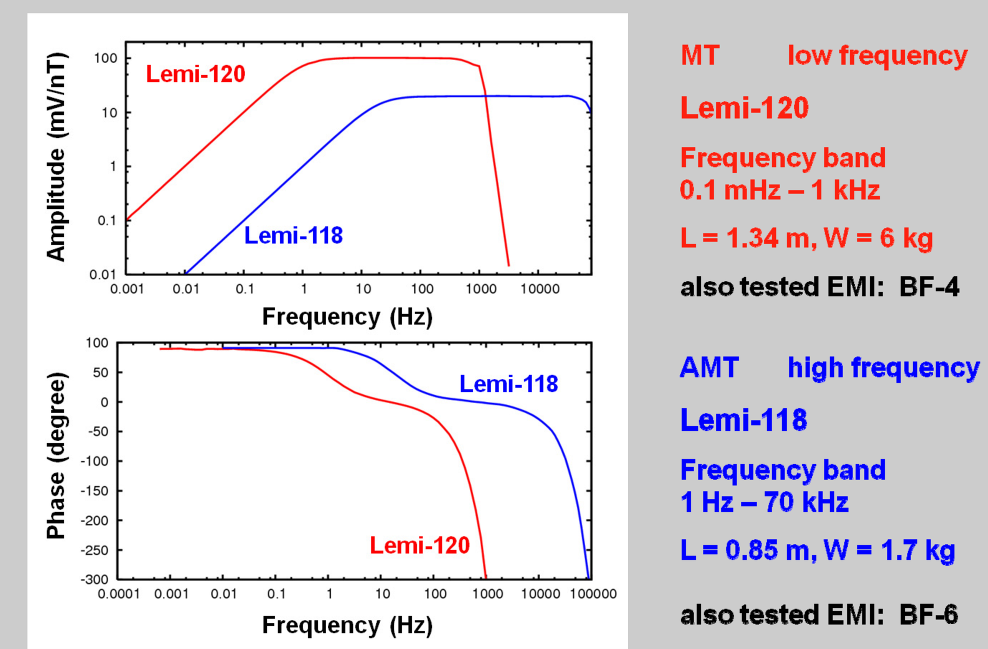


**Fig. 3:** system response for the Lemi-sensors

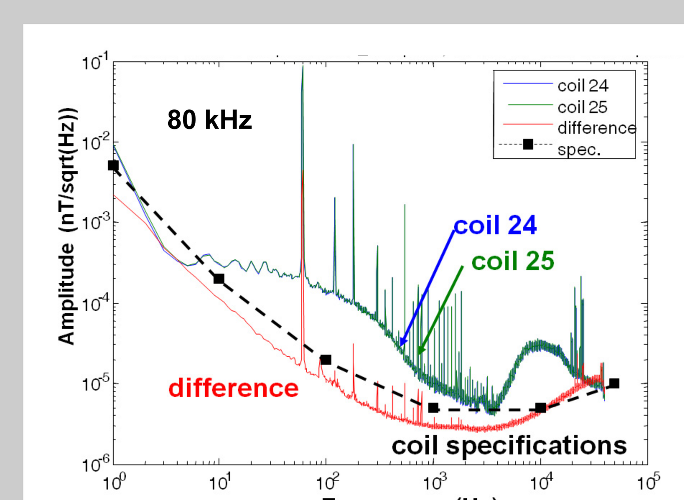


**Fig. 4:** Parallel test with HF coil Lemi-118

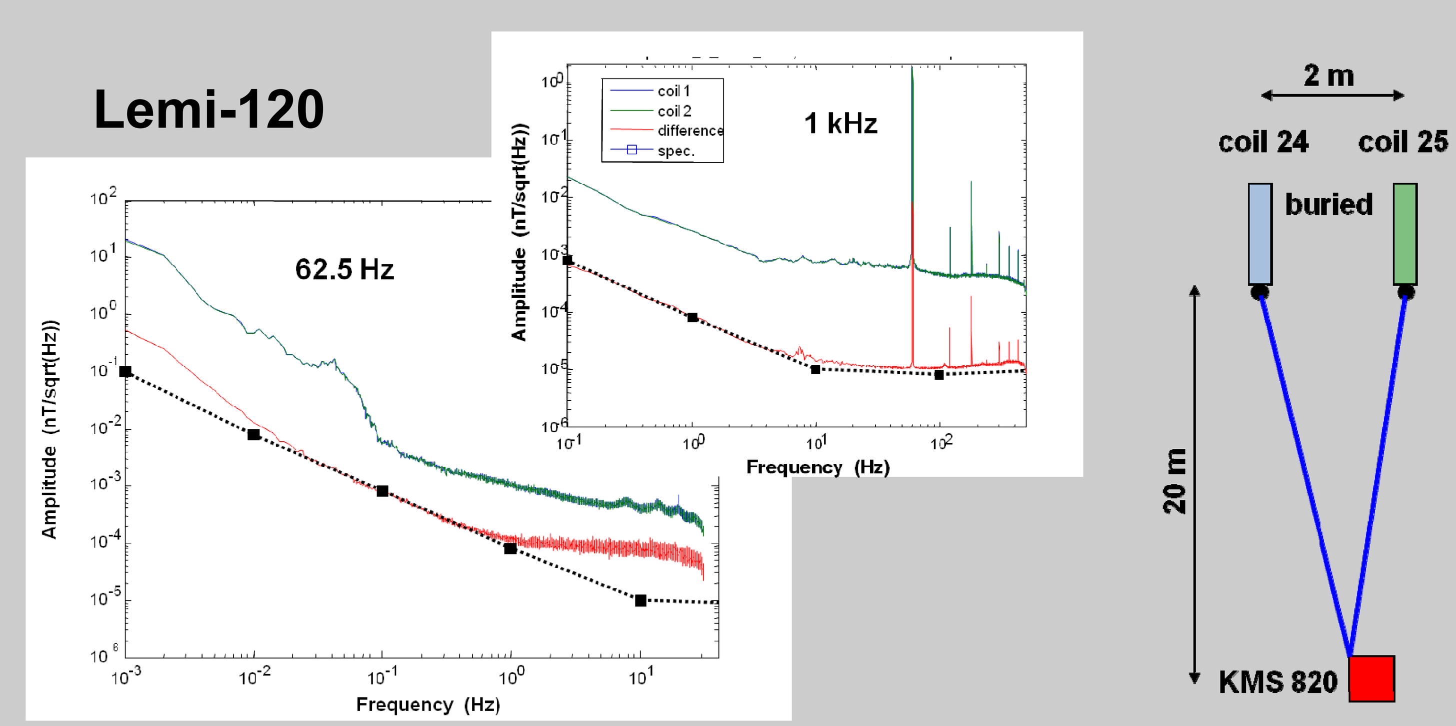


**Fig. 5:** Parallel test with LF coils Lemi-120 for low 62.5 Hz and high 1 kHz sampling rate

The issue to bury the vertical coil is shown below. If the vertical coil is not properly protected against wind, the data are useless.

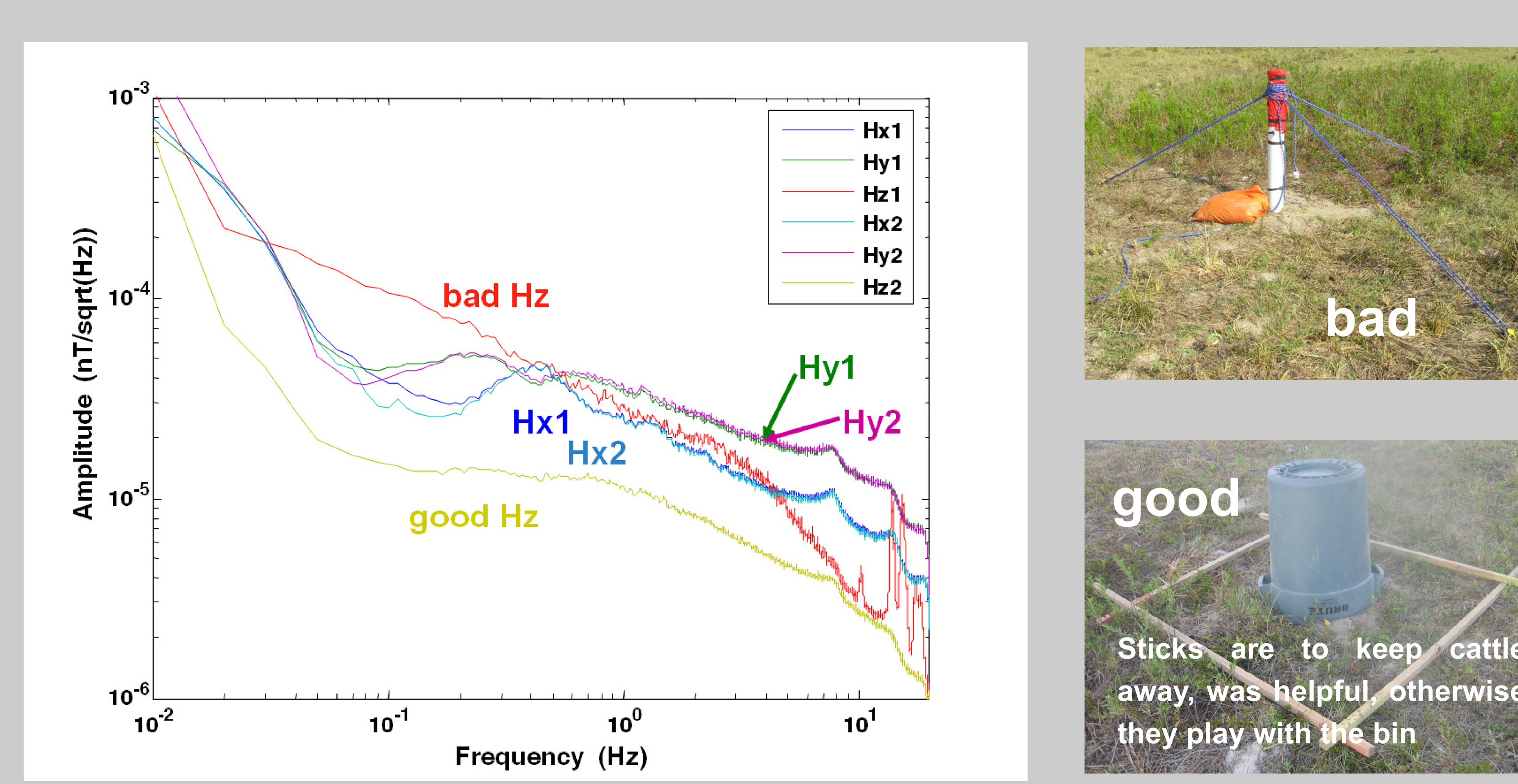


**Fig. 6:** Parallel set up of 2 MT stations, all magnetic fields recorded with 40 Hz sampling are shown. The good Hz is smaller in amplitudes as horizontal components and the bad solution in spite of a tube and trial of fixing it is out of order in the whole frequency range.

# for EM analysis and monitoring

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## Digital fluxgate magnetometer

A 3 component digital fluxgate (FG) magnetometer can additionally be added to the KMS 820. The small sensor can easily be buried and is synchronized to the sampling in the analogue channels.

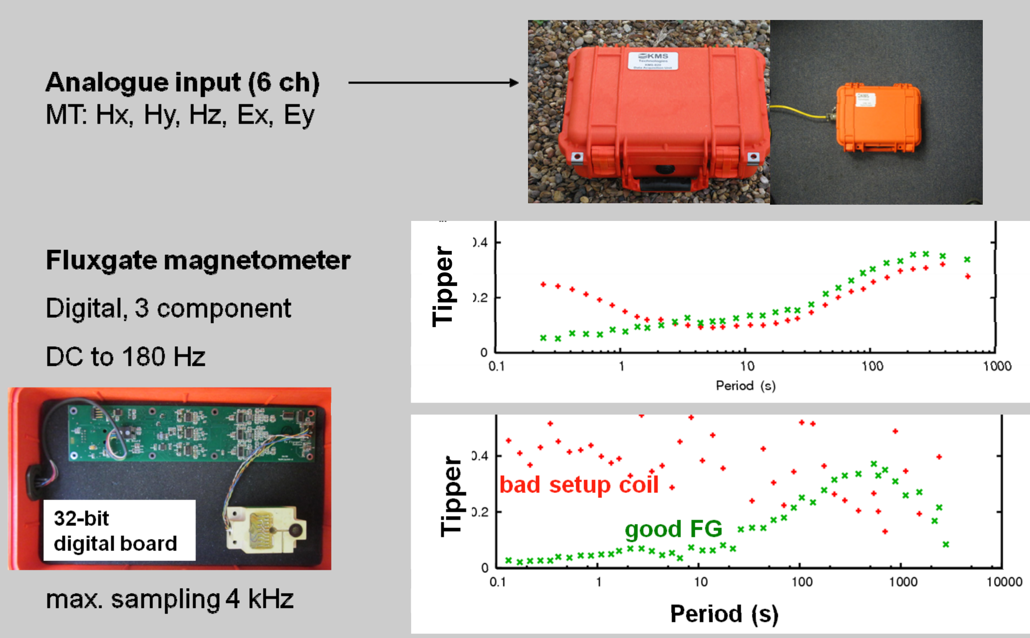
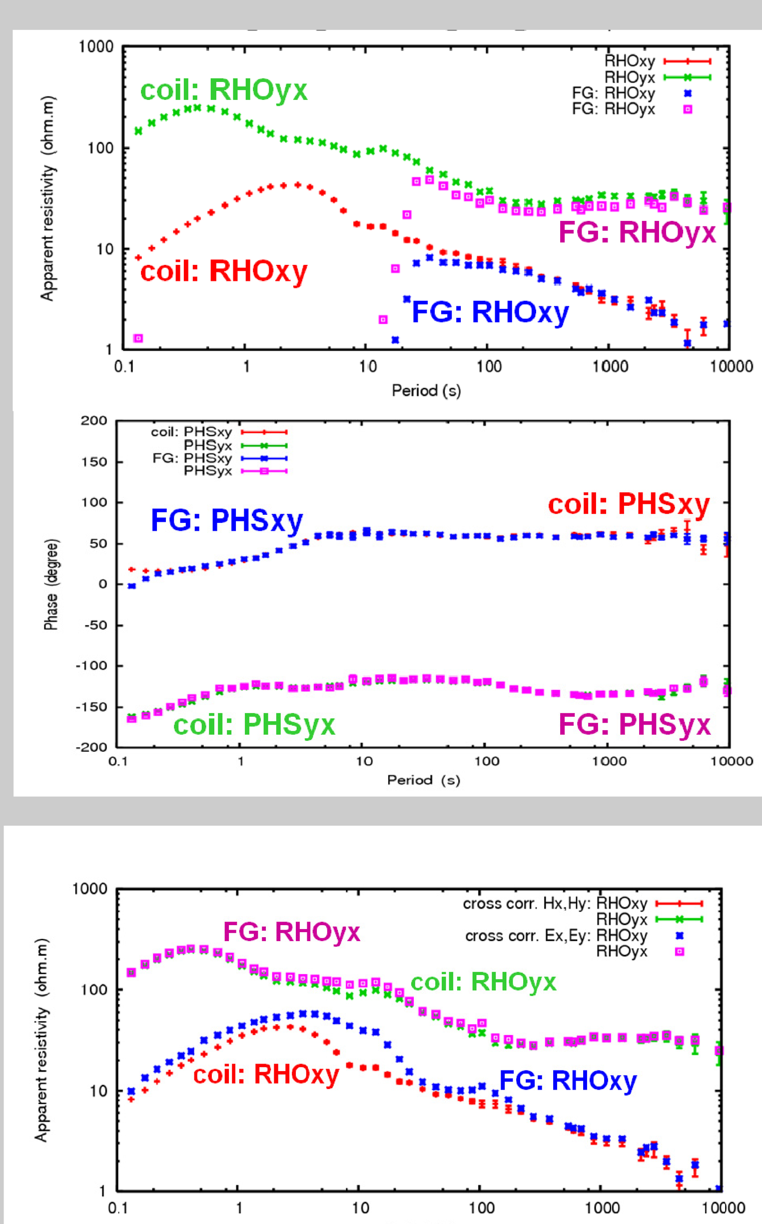



**Fig. 7:** 3C digital fluxgate magnetometer with specifications and 2 examples of tipper recorded in good terrain conditions for the vertical induction coil and for a bad setup.

Although the noise performance of FG is excellent (6 pT at 1 Hz, Fig. XX), for periods less than 20 s the induction coils are superior. The amplitudes are biased, but not the phase. For larger periods FG is consistent with coils. Modification of the least square estimation improves the results.




**E = Z H**

Estimation of transfer function Z

Input Hx & Hy

assumed to be noise free

If not → bias to

Output: Ex & Ey

**Phase is not biased**

**H = Z⁻¹ E**

Estimation admittance

Input Ex & Ey

assumed to be noise free

Less noise than FG

Output: Hx & Hy

**Fig. 8:** MT results: apparent resistivity & phase parallel recording with Lemi-120 induction coil and digital fluxgate magnetometer. On bottom the apparent resistivity with the robust estimation of the transfer function by using E-fields as input data.

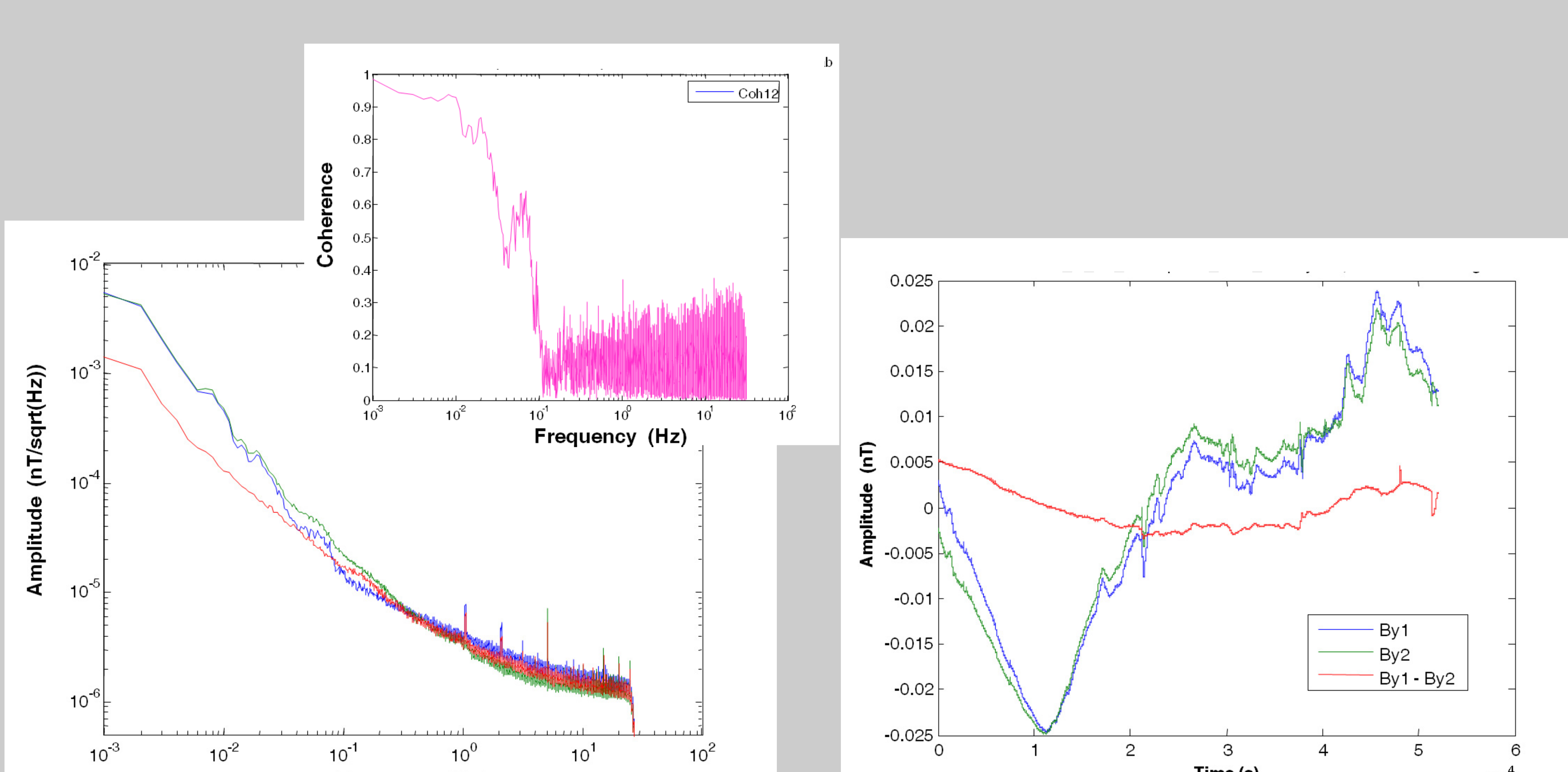



**Fig. 9:** Parallel sensor test with the digital fluxgate magnetometer at Hockley near Houston, left spectra, center coherence and on right time series with 14 hours recording.

## Earthquake in India

During overnight recording in Assam the incidence of an earthquake with magnitude 5 at distance of about 200 km is visible in all field components of the time series. The amplitude is extremely stronger than the MT background activity. The magnitude in the magnetic field components are correlated with the earth magnetic field at this location and time: North Bx 36809 nT, east By –280 nT, vertical downwards Bz 47480 nT. Unexpected is the strong amplitude in the electric field components and more discussion on this is needed.

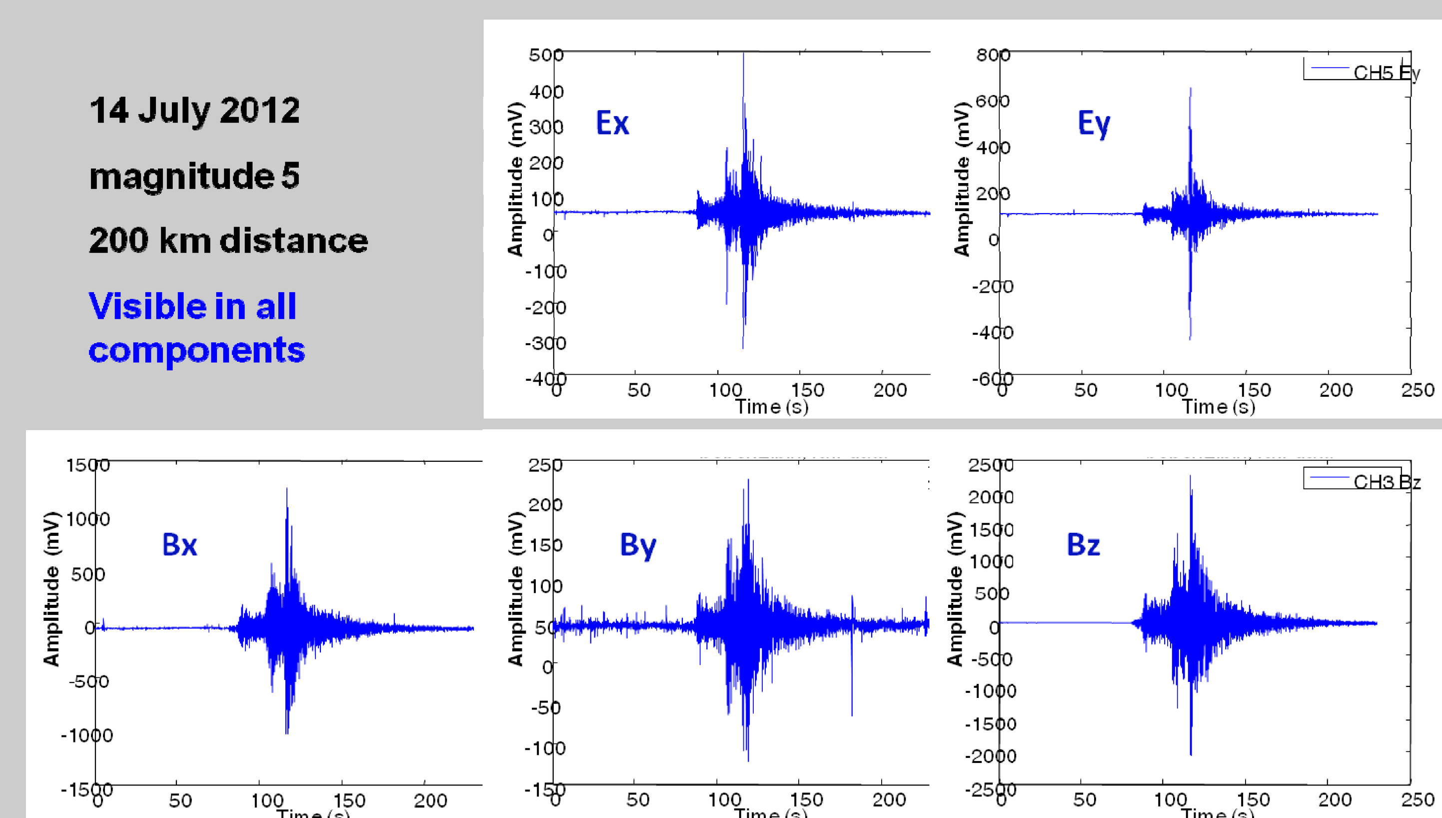



**Fig. 10:** Amplitude of electric an magnetic fields for all 5 components as function of time

## Monitoring in China

The performance of monitoring for seismology with a MT station has been investigated in a 30 day monitoring test. A 24 hour recording schedule with a fixed time table for different sampling rates & recording times and daily data collection & processing have been performed.

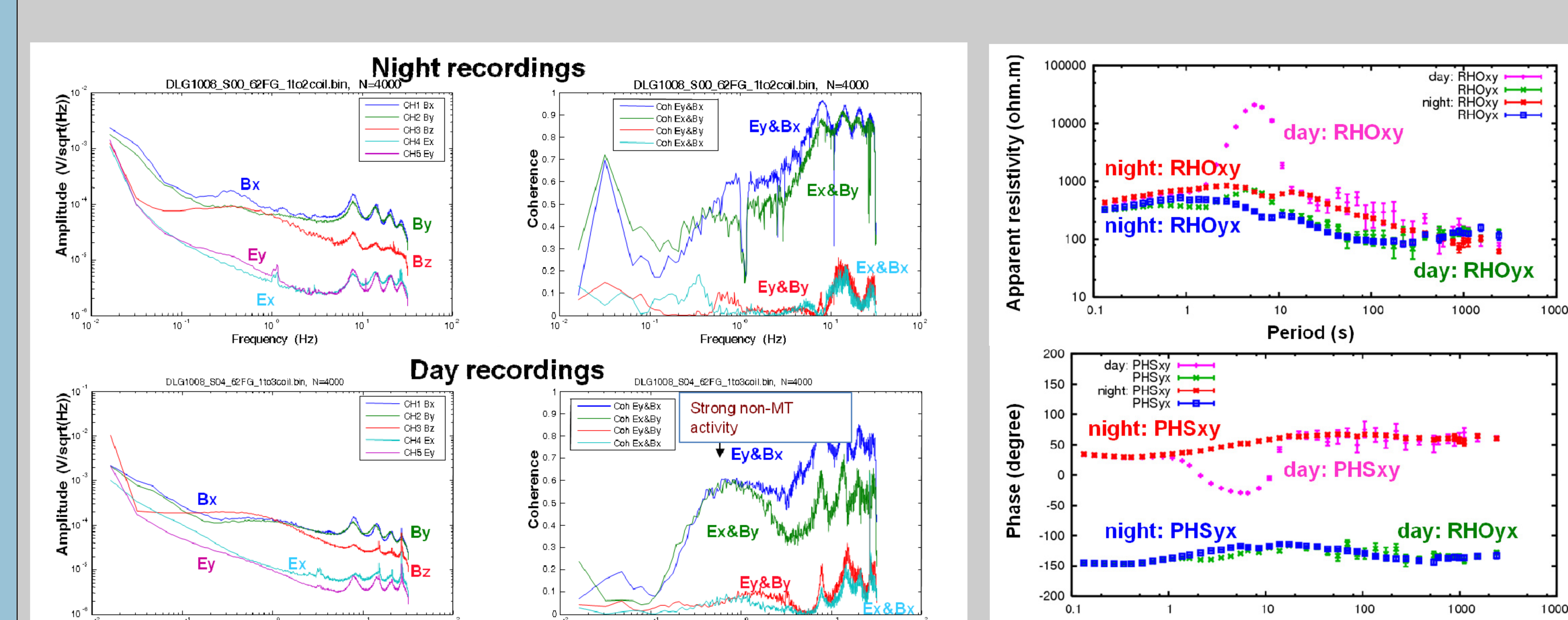



**Fig. 11:** Spectra (left), coherence (middle) and apparent resistivity & phase (right for night (top) and day (bottom) recording.

During nigh (22:00 to 6:00) the MT results are sufficient good, but during day (6:00 to 22:00) the strong coherent cultural noise occurred and distorts apparent resistivity and phase. The cause may be due to construction work in this area. The coherence is high for the orthogonal components and low for the parallel components as expected. The cultural noise activity during day shows far field behavior.

**Acknowledgment:**

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**Reference:**

Egbert, G.D.,1997. Robust multiple-station magnetotelluric data processing, *Geophys. J. Int.*, **130**, 475-496.