Determining the Amplitude Transfer Function of the Permanent Magnetic ELF Measurements of the Széchenyi István Geophysical Observatory

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Abstract

In July 2020, a detailed ELF/VLF noise test was carried out in the Széchenyi István Geophysical Observatory. This test included the temporary installation of a pair of LEMI-type induction coil magnetometers that run from a battery during the test period (9 July 2020) when the power supply of the observatory was gradually shut down. As the temporary coils were installed two days before the test day (7 July) and continued to operate until the 13rd of July, there were several days when both the permanent and temporary systems were in operation. In this study, we use this overlapping period to further investigate electromagnetic noises present in the observatory and to determine the amplitude transfer function of the permanent ELF-band recording system based on the calibrated temporary measurements.

Keywords: extremely low frequency, Schumann resonance, induction coil.

Introduction

Recording of the atmospheric magnetic field in the extremely low frequency (ELF) band (3 Hz–3 kHz) began in November 1996 in the Széchenyi István Geophysical Observatory (NCK) near Nagycenk, Hungary (Sátori et al., 2013; Bór et al., 2020). A pair of locally built induction coil magnetometers were buried about 1 m below the ground in a non-magnetic chamber. These coils record the two horizontal components of the magnetic field in the geographic north–south (NS) and east–west (EW) directions. In November 2016 the original EW coil had to be replaced by a LEMI-120 type magnetic antenna (Bór et al., 2020).

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On the 9th of July, 2020 a detailed noise test was carried out at the NCK, which is described in detail in the paper by Bozóki et al. (2021). The measurements of the observatory, the power supply of buildings and solar panels as well as charging of the batteries were gradually shut down and finally the main power supply of the observatory was interrupted. In order to survey changes in the electromagnetic (EM) noise environment during the test period, a pair of LEMI-type induction coil magnetometers, running on batteries, were installed near the permanent magnetic measurements on the 7th of July and continued to operate until the 13rd of July. This means that there were 7 days when both the permanent and temporary systems were in operation (except the ∼3 hour long period when the noise test took place). This overlapping period is used in this study to further investigate EM noises present in the observatory and to determine the amplitude transfer function of the permanent magnetic measurements based on the calibrated LEMI-type antennas used in the temporary measurement.

Description of the Measurements

At the time of the noise test, permanent ELF-band measurements of the two horizontal magnetic field components were made by two different induction coils. The NS field component has been measured by a locally manufactured induction coil that, before its current utilization, used to serve audio-magnetotelluric measurements. The signal at the output of the antenna is conditioned by a pre-amplifier placed near the coil, and led to the main amplifier which is located in a wooden house about 60 m away from it. The EW component was measured by a LEMI-120 induction coil that substitutes the other locally fabricated magnetic antenna which is broken. The LEMI-120 coil is also buried in the soil about 10 m from the wooden house. It has a built-in pre-amplifier with a balanced signal output. This signal of the antenna is connected to the other (unbalanced) input channel of the main amplifier using a balanced-unbalanced adapter. The main amplifier contains a hardware low pass filter with a cut-off frequency of about 38 Hz and a notch filter centered at 50/3 Hz to suppress the corresponding narrow-band noise from the railway lines running in Austria, relatively close to the observatory. The measured signal at the output of the main amplifier is then sampled at 500 Hz and archived for further processing.

Note that the last time the original recording system was calibrated was in 2008. During the calibration, the induction coil was put in the center line of two calibrating Helmholz coils. Magnetic fields of different amplitudes and frequencies were created by switching different electrical currents onto the calibrating coils. The signal (voltage) at the output of the main amplifier was recorded, so the transfer characteristics of the whole system were determined. Individual parts of the system have not been examined separately. Aging of the electronics in the original pre-amplifier and main amplifier could somewhat modify the transmission characteristics of the system in the time that has passed since the last calibration. Additionally, the response function of the system, as a whole, has become practically unknown in the EW data channel when the original induction coil was replaced by the LEMI-120 antenna. The transfer function of the LEMI-120 antenna is known, so attempts were made to determine the transfer function of the system by measuring the response of the main amplifier alone. However, contradictory results were found when the full transfer function of the system, obtained this way, was applied. The noise test in the observatory with the parallel ELF-band magnetic measurements installed provides a good opportunity to determine the amplitude transfer function of the hybrid-state permanent recording system.

The temporary magnetic measurements were carried out with LEMI-120 type magnetic antennas that were run from a battery and were placed at a distance of about 50 m from the permanent measurements. The sampling frequency of the system was set to 500 Hz. These coils were oriented towards the geomagnetic NS and EW directions. Transforming the recorded data to components corresponding to the geographic NS and EW directions was done by applying digital rotation with the actual declination value (4.6°) in July 2020 determined by the absolute magnetic field measurements of the observatory (Lemperger et al., 2021). The temporary measurements were corrected for the transfer function of the coils (provided by the LEMI company) and are regarded as the absolutely calibrated reference data in this study.

Results

Figures 1-6 show dynamic spectra corresponding to the permanent and temporary magnetic measurements in the 7–13 July period (except the test day). Both measurements show that the magnetic field is highly contaminated by different noises at NCK and that this noise contamination is stronger in the H_{NS} field component. The first three modes of Schumann resonances at around 8, 14 and 20 Hz can only be identified in certain calm periods (like the afternoon hours on 12 July) primarily in the EW field component. It can be clearly seen in these figures that the permanent measurements include a notch filter at $\sim$16.6 (= 50/3) Hz which aims to suppress the characteristic narrowband noise from Austrian railway lines (Bór et al., 2020) and that there is a low pass filter above $\sim$38 Hz in the permanent measurements which is not present in the temporary measurements. A number of narrowband noises can be identified in the figures, some of which are continuous, some of which are transient but appear regularly, and some of which are of changing frequency. Low frequency ($<$ 5 Hz) wideband noises appear as well which sometimes reach the lowest Schumann resonance mode at $\sim$8 Hz. It is to be noted that narrowband noises with changing frequencies were detected in the H_{EW} component by the permanent system which are usually not observed by the corresponding coil of the test measurements. The reason for this observation needs to be clarified in the future.

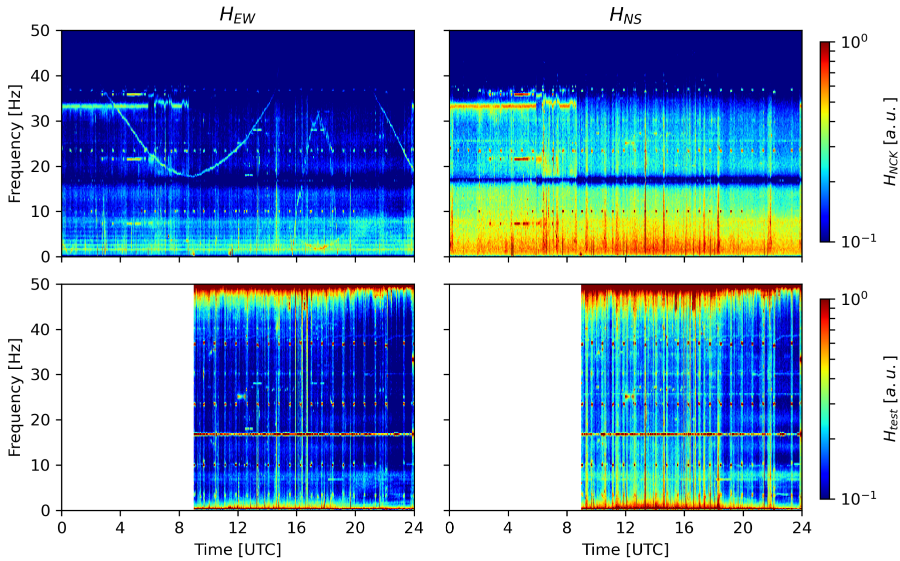

Fig. 1. Dynamic spectra corresponding to the H_{EW} (left column) and H_{NS} (right column) field components from the 7th of July, 2020 measured by the permanent (upper row) and the temporary (bottom row) magnetic measurements.

From the 4 days with complete records in both measurements (8, 10, 11, 12 July) 1-min average amplitude spectra were determined (window type: Hann, window length: 2048, window overlap: 1024) and the ratio of amplitude spectra corresponding to the two systems were calculated for the two field components separately. The most probable values of the ratio spectra were estimated based on the `gaussian_kde` function of the `scipy.stats` python package. These curves were resampled for the 2 Hz–40 Hz frequency range with 0.2 Hz frequency resolution and smoothed by applying a Savitzky–Golay filter (window length: 21, polynomial order: 3). The following frequency bands containing strong, narrowband noise (probably of local origin) were excluded before smoothing: 2.9–4.4 Hz, 6.5–8.8 Hz, 9.5–10.3 Hz, 10.7–11.3 Hz, 22.7–23.7 Hz, 24.4–25.7 Hz, 28.5–29.3 Hz, 29.7–34.7 Hz, 36.1–37.9 Hz. Finally, the ratio values at 8 Hz were selected as the calibration coefficients and all the curves were normalized with these coefficients in order to arrive at the dimensionless amplitude transfer functions. The calibration coefficients are $3.439 \cdot 10^{-5}$ and $3.766 \cdot 10^{-5}$ pT/digital unit for the H_{NS} and H_{EW} field components, respectively.

Figure 7 shows the whole collection of normalized ratio spectra as well their most probable values and the smoothed and resampled curves. If we consider the temporary measurements to be properly calibrated, these curves represent the amplitude transfer functions of the permanent measurements. The ampli-

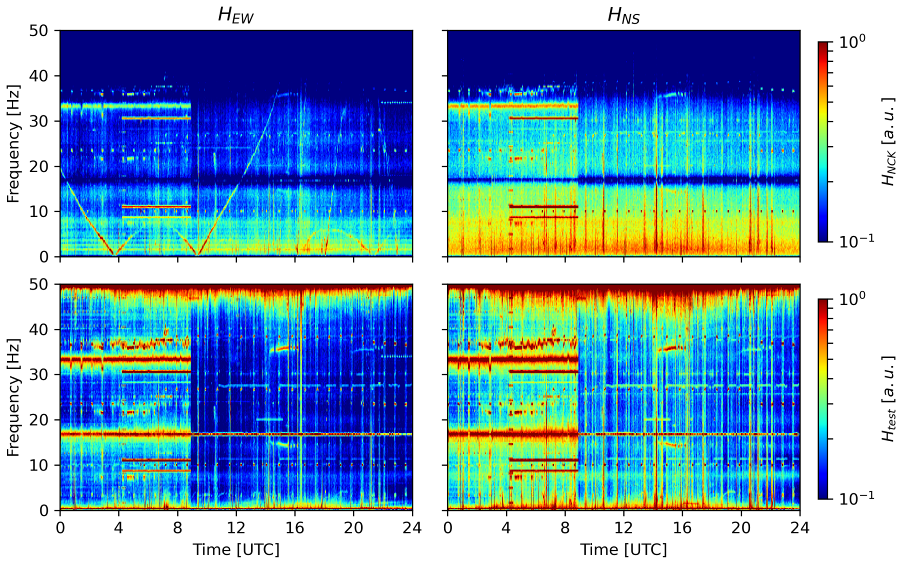

Fig. 2. The same as Fig. 1 but for the 8th of July, 2020.

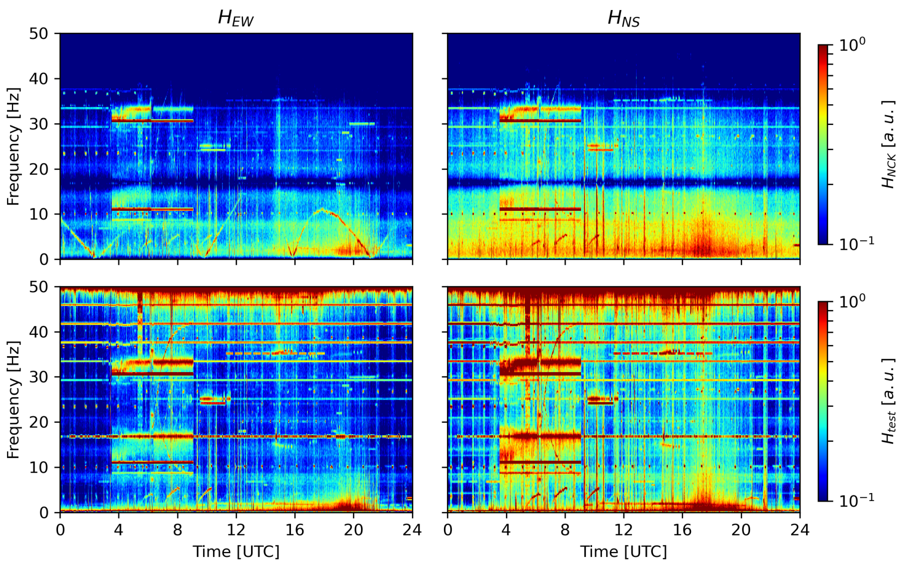

Fig. 3. The same as Fig. 1 but for the 10th of July, 2020.

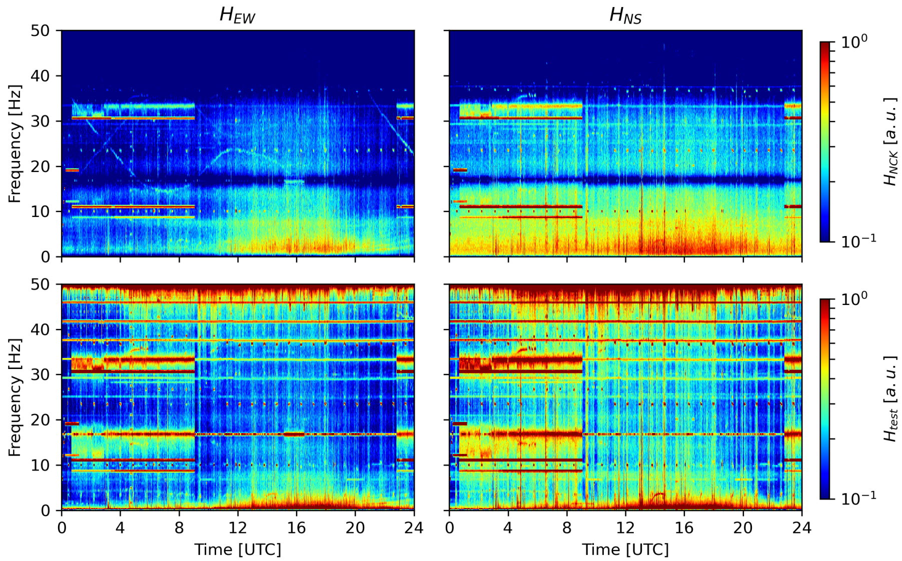

Fig. 4. The same as Fig. 1 but for the 11th of July, 2020.

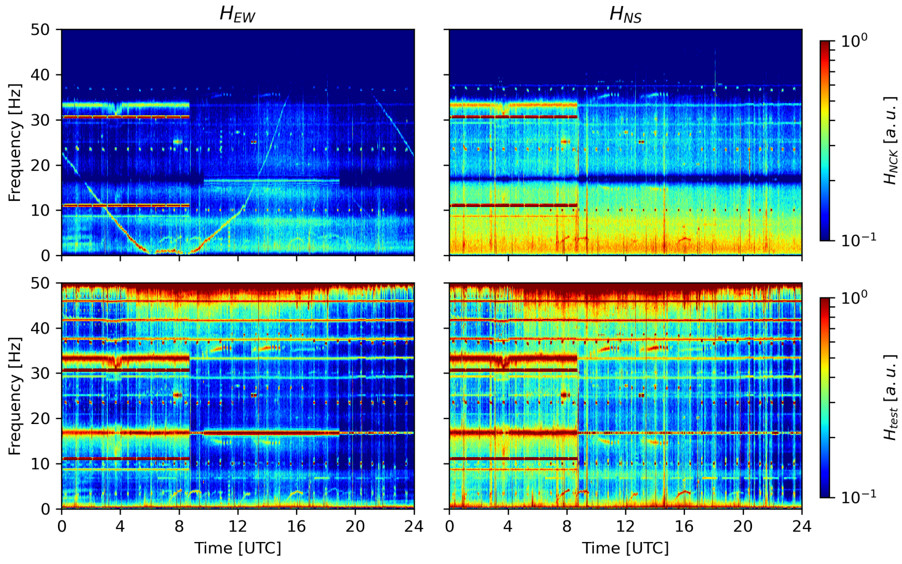

Fig. 5. The same as Fig. 1 but for the 12th of July, 2020.

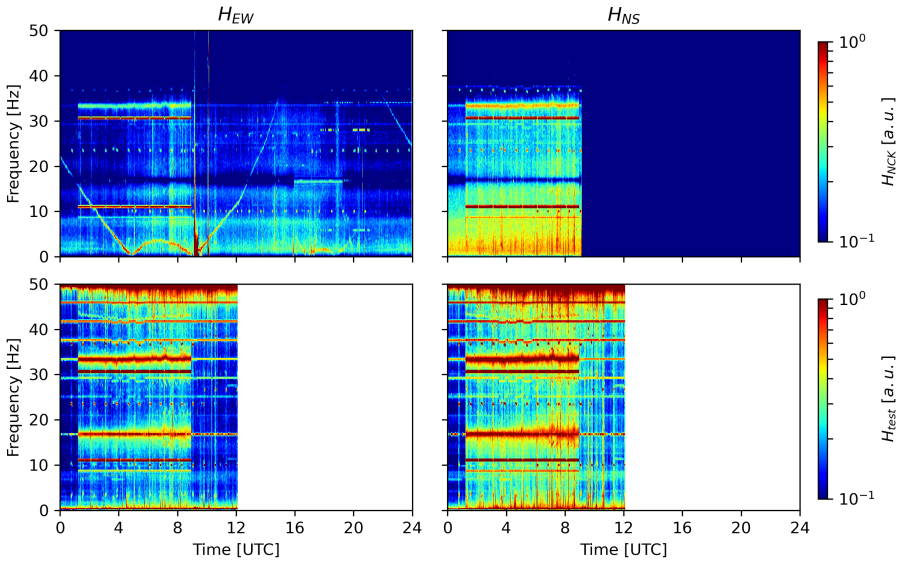

Fig. 6. The same as Fig. 1 but for the 13th of July, 2020.

tude transfer functions show a large notch at around 16.6 Hz and a strongly decreasing trend above 30 Hz, consistent with the differences between the systems (as discussed earlier). It is also noticeable that while the amplitude transfer function corresponding to the H_{EW} field component is practically flat in the 5–30 Hz frequency range, this is not true for the H_{NS} field component. This difference can be explained by the fact that the H_{EW} component is measured by a LEMI-type induction coil in the permanent system while the H_{NS} component by the original, locally manufactured coil.

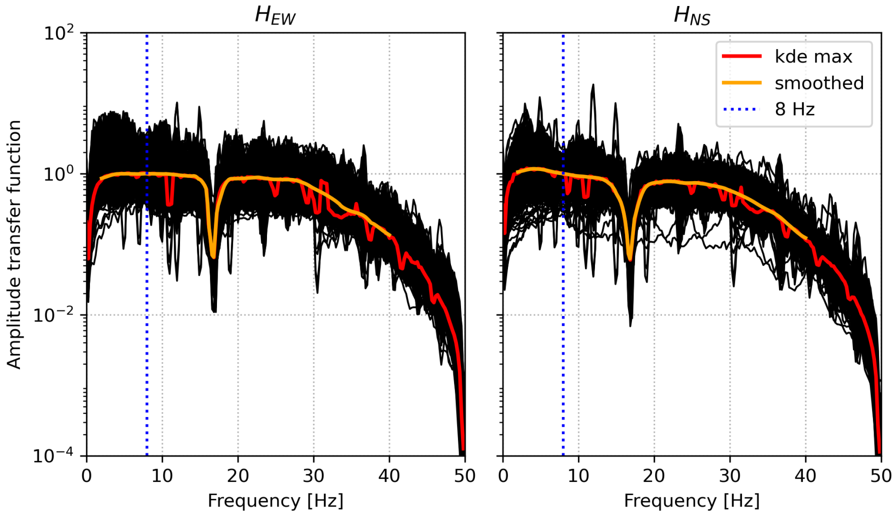

Fig. 7. The normalized ratio of 1-min average amplitude spectra corresponding to the temporary and the permanent measurements (black) and the most probable values of these ratios as provided by kernel density estimation (red). The orange curves represent the smoothed and resampled versions of the red curves and are regarded as the actual amplitude transfer functions. Certain frequency bands containing strong, narrowband noise were excluded before calculating the smoothed amplitude transfer function.

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