The detection of magnetic field component of Schumann eigenmodes using search coil sensors at Modra observatory

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Abstract. *At Modra observatory, more than three years of the regular monitoring of electric field component of Schumann eigenmodes have been performed. Attempts to detect their magnetic field component have been made by means of big search coils. In this article, we describe the experimental equipment and principal results obtained.*

Keywords: magnetic field, search coils, Schumann resonances, spectral analysis

1. Introduction

Schumann resonances (SchR) are the electromagnetic eigenmodes in the almost concentric spherical cavity formed by the Earth's surface and the lower ionosphere layers (at an altitude of approx. 50-60 km). The corresponding eigenfrequencies lie in the ELF range (the first one about 7.8 Hz, then approx. 14, 20, 26 Hz and higher). Due to relatively poor conductivity of the Earth's surface (crust) and complex conductivity of the ionosphere, the Q-factor of SchR eigenmodes is low, about 5-10.

The prevailing field components are the vertical electric component and horizontal magnetic ones (N-S and E-W). The principal source of excitation energy is the global thunderstorm activity. In exceptional cases, the flux of charged particles emitted by Sun can change (for a relatively short time) the overall picture of the SchR. But majority of such variations may be attributed to processes of Earth origin. Therefore, the long-term monitoring of principal parameters of the SchR – the central frequency, amplitude and quality factor (halfwidth) of the first several eigenmodes – gives an important base for geophysics. Numerous literature is devoted to SchR themselves and their geophysical aspects. As an example, we quote here an excellent and exhausting monograph [1].

2. Subject and Methods

The energy density of SchR eigenmodes is very small. The total energy generated and dissipated in global lightning activity is not very high and is (in average) smeared inside the huge volume of Earth – ionosphere resonator. The corresponding amplitude is about 10^{-7} V/m in electric field and 10^{-13} T in magnetic one (several tenths of pT). The sensors of "search-coil" type are common for this purpose. At Modra observatory, the experiments started with a sensor shown in Fig. 1a (the inside view) and Fig. 1b (the working configuration). The coil itself has a total of 150,000 turns of 0.14 mm diameter wire, mechanically divided into 6 separate formers (the corresponding windings are connected in series). Over the principal windings there are two layers of shielding and (at the two central formers) separate calibration coils (2,000 turns each). The core of dimensions 75 × 75 × 950 mm is made from 0.5 mm thick stripes of TRAFOKER alloy, with small-signal relative permeability about 5000 (at 25 Hz). The hysteresis curves and loss factors for various frequencies (in 10–50 Hz range) were measured by Dr. Elemír Ušiak from Faculty of Electrical Engineering and Informatics, Slovak Technical University. The estimate of core demagnetization factor (in ellipsoidal approximation) is 0.023 – that gives the effective permeability about 40 –50. Therefore, it is not worth of using very high permeability materials, which are very expensive, to build a core. It was possible to determine the self-inductances of subcoils only without the core, likely due to high ohmic resistance. The values were about 17 H, the resonant frequencies lay in the interval 560 –730 Hz. As mentioned above, all subcoils are connected in series, with central point for the symmetric amplifier input. The whole coil assembly is mechanically tightly fixed and located (together with the amplifier) inside a 2.25 mm diameter 1200 mm long cylinder from hard polyethylene. The tube is covered by a double electrostatic shielding from 0.8 mm thick metallic sheets (shaped not to form a short-circuit body). Fig.1a shows the sensor inside; in Fig.1b there is an overall view (with the amplifier).

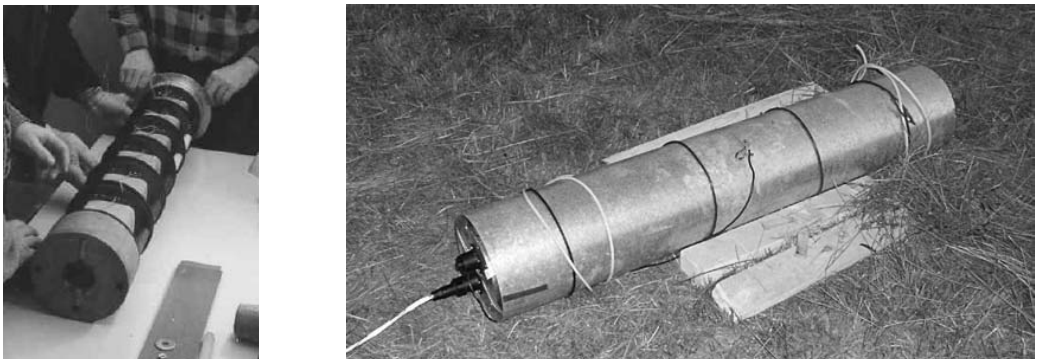
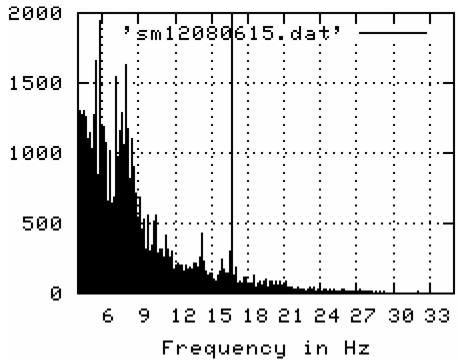


Fig. 1. (a) Inside view of disassembled sensor coils. (b) The sensor with amplifier in working configuration.

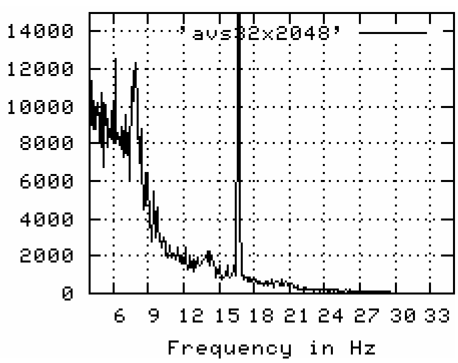
3. The Amplifier and Signal Processing

The main amplifier is located in the immediate neighbourhood of coils, in a cylindrical aluminium housing. The coils are connected by a moisture-proof connector. The amplifier comprises of two parts: the instrumentation-amplifier type stage (three low-noise opamps, separately shielded) with gain about 46 dB, then four active low-pass and 50 Hz notch filters, programmable gain amplifier and output stage (for compensation of induction effect to obtain a flat amplitude response at least in 5–100 Hz range). Except the programmable opamp stage, whole amplifier is DC-coupled. The overall gain is 96.5 dB at 10 Hz. The amplifier is fed from symmetric stabilized source +12 / -12 V (for the minimization of noise, the supply voltage for input stage was +5 / -5 V, derived by internal stabilizer). The source is isolated from ordinary power line through two toroidal transformers 220 V/12 V, connected back-to-back (experi-riments with battery feeding have showed no substantial change in output noise level). The amplifier was thoroughly tested for frequency and phase response, the common-mode rejection ratio and noise properties at various frequencies. The nonlinear behaviour was also checked by “two-tone test”, for input signal given as an voltage input and also for the magnetic field input (the amplifier with sensor as a whole). For detection of magnetic field component, it is very important to suppress the parasitic response to the electric field, due to self-capacitance of windings (which may be in our case relatively high). In the real SchR situation, very quick and simple test of this can be done by observing the output with sensor aligned to vertical axis (the vertical magnetic component is practically negligible). Results of all above mentioned tests are fixed in laboratory and field journals.

The hardware used is described in [2]. In short, the output signal in the range +2.5 V/-2.5 V is digitized by 16-bit ADC (differential input, 200 Hz sampling frequency). To check possible aliasing effects, there was made several measurement cycles with various sampling frequency (in the 180–230 Hz range). No aliasing spectral components were detected. The resulting spectra were obtained by classical DFT, from time series of 65,536 samples (the interval 5 minutes and 28 seconds), then first several (clearly discernible) peaks were fitted by Lorentzian functions and principal parameters for each eigenmode – the central frequency, halfwidth (or Q-factor) and amplitude (in relative units) were stored. These parameters were also determined by Prony algorithm. The methods of signal processing used for the determination of spectra and principal SchR parameters are profoundly elucidated in [3].



(a)



(b)

Fig. 2. (a) The example of magnetic component spectrum (taken at 06:15 UT August 12, 2004) from total time interval 328 s long. The horizontal axis is in Hz, the vertical one in relative units. (b) The same spectrum obtained as an average from four adjacent time subintervals 82 s each.

4. The sensitivity and the results

The sensitivity and frequency response of complete assembly (sensor + amplifier) was checked by improvised Helmholtz coil at a distance of approx. 5 m from sensor coil center. Although the calibration field was clearly non-homogenous (coil diameter 30 cm, 13,000 turns), it was possible to make an estimate of sensitivity with respect to output voltage – about 4 pT/V (at 10 Hz). The frequency response was practically flat between 7.5 and 20 Hz, then it was slightly falling about 3 dB/octave. The average thermal noise of coil resistance (61 kOhm) in 100 Hz passband is about 0.3 microvolt at amplifier input, which corresponds to field amplitude approx. 0.1 pT. The noise contribution of input stage is not possible to measure. From the qualitative point of view, the best result was obtained with opamps OP 27 at input stages, then AD 797 (slightly more noisy), but AD 820 gave a worse result.

During the first field experiments, there was a strong excess noise (of 1/f type). By trial and error method, it was confirmed that the wind vibrations of surrounding trees are transferred to ground and (in the quasistatic Earth's magnetic field) the sensor is acting as an unwanted seismometer. In an open place, this effect was substantially smaller. An example of spectra obtained is given in Fig. 2a and 2b. The first two (and a sign of the third) SchR eigenmodes clearly emerge from spectrum averaged by four adjacent time intervals 82 s each. At this spectra, the strong narrow line at 16.67 Hz (50/3) is an artifact from Austrian electric railways (which is picked up from 55 km distance in WSW direction). We use it as a crude "calibration signal". We regularly observe signals generated by isolated huge lightning discharges at great distances, so called Q-bursts [4]. The part of data sequence showing Q-burst is in Fig. 3.

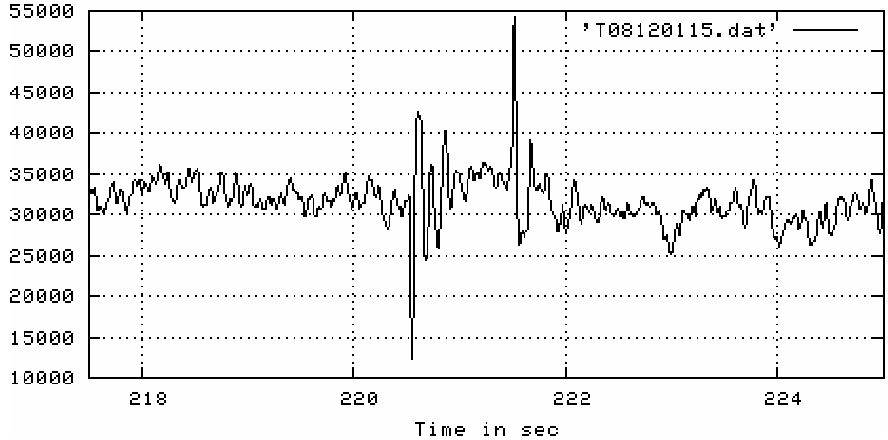


Fig. 3. The part of time series showing the Q-burst waveform (time interval 7.5 s = 1500 signal samples). The horizontal axis is in seconds, the marking of vertical axis corresponds to output voltage (a value of 00000 = -2.5 V, a value of 65536 = +2.5 V).

5. Conclusion

It is possible to detect and analyse magnetic field SchR eigenmodes with the sensor described above. We will use this assembly for regular monitoring, after installation of the special antivibration support (for two orthogonal sensors). The electric field component of SchR eigenmodes has been regularly monitored at Modra observatory for more than 3 years yet (the spectra for each halfhour, as well as daily surveys, can be seen at: *http://147.175.143.11* This opens a possibility to collect and analyse new and very promising sets of geophysical data.

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References

[1] Nickolaenko A.P., Hayakawa M.: Resonances in the Earth-Ionosphere Cavity, Kluwer, Dordrecht, 2002.

[2] Kostecký, P. Ondrášková A. Rosenberg, L. Turňa Ľ.: Experimental setup for the monitoring of Schumann resonance electric and magnetic field variations at the Geophysical Observatory at Modra-Piesok. *Acta astronomica et geophysica Univ. Comeniana*, 2000, XXI-XXII, 71-92.

[3] Rosenberg, L.: Data processing methodology of the electric and magnetic components of the Schumann resonances at Modra Observatory, *Acta astronomica et geophysica Univ. Comeniana*, 2004, XXV, 1-8.

[4] Ševčík S., Kostecký P., Ondrášková A., Kohút I., Turňa Ľ.: Dynamical evolution of Schumann resonamce spectra during a strong Q-burst on July 11, 2004, *Contributions to geophysics and geodesy*, 2005, (in press).