COMPARISON OF EXPERIMENTAL AND MODEL Q-BURSTS IN TIME DOMAIN

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Abstract. We compare natural extremely low frequency pulses (Q-bursts) with computations of analytical time domain solution. The wide band receiver was used in experiment with the upper cut-off frequency about 11 kHz. The ball antenna allowed for ELF-VLF records of vertical electric field in the fair weather conditions with a unique resolution of 22 kHz sampling frequency. We use the uniform Earth–ionosphere cavity model, the linear frequency dependence of propagation constant, and we find an excellent agreement between the observation and modeling.

Introduction and experimental setup

Term ‘Q-burst’ is related to discrete natural ELF radio pulses detected worldwide and lasting for 0.3 – 1.5 seconds. These signals originate from powerful lightning strokes whose pulsed amplitude exceeds the continuous Schumann resonance (SR) background by a factor ten or greater. Some Q-bursts were related to the ‘red sprites’. In the present study we compare the precise electric field measurements in the ELF-VLF band with the time domain solution for the uniform Earth–ionosphere cavity [see Nickolaenko, Hayakawa, Ogawa, and Komatsu, 2008 for detail].

Fig. 1. Frequency response of ELF – VLF receiver. The wide band receiver detects the ELF – VLF pulses, and the narrow band filtering corresponds to typical response of a receiver for the global electromagnetic (Schumann) resonance studies.

A ball antenna was installed at Tochi station (33.3° N, 133.4° E) a few kilometers away from the center of Kochi City, Japan. Electric fields were observed in the fair weather afternoons covering the four seasons since November 2003. The ‘narrow band’ and ‘wide band’ frequency responses of our receiver are
shown in Fig.1. We discuss the wide band data acquired with the 22 kHz sampling rate [Ogawa and Komatsu, 2007].

**Waveforms observed**

Typical waveforms are shown in Fig. 2, which usually corresponded to the source–observer distances \( D \) close to 20 Mm. These pulses contain the direct and antipodal waves that merge into a W type Q-burst. Two kinds (the wide – and narrow–band) of waveforms were acquired, and we use below the wide band records for a comparison with model computations.

![Waveforms observed](image)

**Fig.2. A Q-burst of W type in the wide and narrow frequency bands.**

One may conclude by comparing the upper and lower panels in Fig.2 that wide– and narrow band waveforms are different. The wide band signal contains the resolved leading and rear parts. The first one contains the direct (initial pulse) and antipodal (second pulse) waves forming the W pattern. The secondary or rear pulse is a combination of merged round–the–world waves, and it is delayed from the first pulse by \( \sim 0.16 \) s. The delay allows for estimating the signal velocity in the Earth – ionosphere cavity being about 250 thousands kilometers per second [Ogawa and Komatsu, 2007]. The fine details of the record are absent in the narrow band channel: individual atmospherics become invisible. We know [Nickolaenko, Hayakawa, 2002] that for large source – observer distances cavity losses concentrate the pulse spectrum below 100 Hz. Therefore, the waveform modifications although being present in the narrow band do not recognizably change the waveform. One can identify the W pattern at the beginning. The dispersion pertinent to the narrow band filtering provides a greater impact on the delayed ELF waveform by turning it into a kind of attenuating sinusoid.
Model

We compute waveforms directly in the time domain for the uniform Earth–ionosphere cavity model. The ‘linear’ propagation constant is used \( \nu(f) = (f - 2)/6 - if/100 \) that was found from the Schumann resonance cross-spectra measured at large longitudinal separation of two observatories [Nickolaenko and Hayakawa, 2002]. Computations were performed with the algorithm accelerating the convergence of time series.

![Figure 3](image.png)

Fig.3. Evolution of E – and H – pulses with the source distance. Signal focusing is obvious around the source antipode.

A flat infinite frequency response of the receiver was assumed. Figure 3 depicts a series of pulsed waveforms computed for a set of source – observer distances ranging from 2 to 20 Mm. The field increase is clearly seen at the vicinity of antipodal distance of 20 Mm. We used the ‘white’ source current moment of a lightning discharge with \( Ids(f) = 10^8\text{A}^*\text{m} \). The above current moment is related to a stroke with the peak current of 25 kA and the channel length of 4 km. Since we compare experimental and computational waveforms, the particular source amplitude is insignificant. The stroke polarization was positive. Visual comparison of pulse amplitudes indicates that the above current moment underestimates the observed value by a factor of up to five, which is in agreement with regular Q-bursts observations.

Comparison of experimental (black) and model (color) data

Frames below present individual pulses: black lines depict the results observed and the model data are shown by the red dotted lines. The time is shown along the abscissa, and the pulse middle sub-peaks were aligned to facilitate the comparison. The major feature of all data sets was their high reciprocity. Once the
sub-peaks coincide, the rest of the waveforms became synchronized also, provided that a correct source – observer distance was found.

Pulse No.1. Industrial 60 Hz interference is clearly seen.

Pulse No.2. A few discrete pulses and a distinct negative slow tail atmospheric are superimposed on the waveform of the Q – burst. Industrial interference is noticeable.
Pulse No.3. A positive slow tail atmospheric is combined with the Q – burst together with continuous 60 Hz industrial interference signal.

Pulse No.4. A W type Q – burst arrived from antipodal distance. Direct and antipodal waves almost merge. Many ‘short distance’ VLF atmospherics were detected indicating on a high activity of the Asian thunderstorm center.
The left ordinates of each frame show experimental amplitude of vertical electric field in all the frames. The right ordinate shows the computed amplitude corresponding to the red dotted curves. As one may see, the source amplitude used in our computations was underestimated in comparison with measurements by a factor of 2 – 5.

The wide band record in the above frames resolves small ‘regular’ spikes responsible for the Schumann resonance background signal. Different kinds of atmospherics occur during the records including the ‘slow tails’ denoted in the plots. These signals were not processed during this particular study. Our wide band measurements applied an exceptional sampling frequency of 22 kHz, they covered both the slow tail (VLF) and the Schumann resonance (ELF) bands, and very pure records were obtained. The high quality of experimental records is clear. In particular, the industrial interference at 60 Hz frequency (radiation from local power supply lines) is very small.

Conclusion

Data presented in this report allow for the following conclusions:

Experimental and model data are similar: if one aligns the first (arrival) peak, positions of all other peaks practically coincide. The pulses have rather sophisticated waveforms, which do not resemble an attenuating sinusoid.

Results of precise ELF – VLF observations correspond to the radio propagation model within the uniform Earth – ionosphere cavity having the linear frequency dependence of propagation constant. Similarity of model data to observations confirms the accuracy of such a model.

Insignificant deviations between the plots are easily explained by the finite pulse – to – background ratio (~ 10), by an impact of industrial 60 Hz interference, and by the random (hence, unknown) details of the spectrum of a parent lightning stroke.

References

