Spread Spectrum Technology for Auditory Evoked Potentials

[Spread Spectrum Technologie für auditorisch evozierte Potentiale]

Andre Lodwig

PATH medical GmbH, Germering

Schlüsselwörter: ABR, ASSR, Spread Spectrum, electrical interference

Introduction

Auditory evoked potentials (AEP) are weak components in the overall EEG that cannot be measured directly but require at least averaging to be detected. This means the acoustic stimulus has to be repeated several hundred or even thousands of times and the response recorded and added synchronously. Additionally, artifact management is crucial for recordings in real clinical settings.

The periodic repetition of stimuli and the synchronized recording introduces a general risk of recording external electrical signals with frequencies that are related to the stimulus rate. This may lead to false detection of AEP. Therefore, typical interferer frequencies such as the 50Hz and 60Hz mains grid frequencies would never be used as the stimulus rate. None of the interferer overtone should hit a multiple of the stimulus rate, or false responses may also be detected.

However, there are more possible interferer frequencies, such as the 16⅔ Hz that European electric railway typically uses or refresh rates of computer monitors that can be anywhere from 50 to 100Hz. In addition to this, mains frequency is not very constant and may vary by ±0.2 Hz or more, dependent on country.

The abovementioned selection of possible interfering frequencies, along with their overtones and variations, considerably limits the remaining “whitespace” in the electrical spectrum that remains available for selecting stimulus rates.

A common technology in radio technology, which faces similar issues, is called “Spread Spectrum”. The technology “spreads” the transmitted and received power over a frequency range instead of using a fixed carrier frequency. Virtually every modern radio standard makes use of Spread Spectrum, such as Wifi, mobile phone or satellite communication.

The carrier frequency in radio engineering translates to the stimulus rate in AEP recording, since this is the signal that is actually received as the AEP response.

While it is relatively trivial to introduce a non-constant stimulus rate to time-domain ABR recording by inserting random extra pauses, things are more complicated in ASSR. However, ASSR usually involves testing at up to 8 stimulus rates simultaneously (4 per ear), with each of those recording channels also analyzing overtones. This can results in as many as 64 frequencies that are recorded. Moreover, ASSR responses are typically lower in amplitude than ABR responses. This results in ASSR to be much more vulnerable by external electrical interference.

Spread Spectrum ASSR

The term ASSR refers to “auditory steady state responses” which suggest the auditory system is in a “steady state” of responding to a periodic stimulus of a constant repetition (or modulation-) rate. However, the ASSR response is nowadays looked at as a superposition of responses to single stimuli (Bohórquez 2008), and therefore a mild variation in stimulus rate still evokes just the same response. The difficulty in recording ASSR at a varying stimulus rate is mainly of a technical nature.

The traditional way of recording ASSR involves fourier transformations of the EEG signal and some type of statistical evaluation of the spectra (Mühler et al. 2005) The goal is to find ASSR reponse components at the stimulus rate and overtones. The FFT is usually applied to frames of the EEG signal, which need to be long enough to result in a frequency resolution that allows a clear separation of the target frequencies. Often, adjacent lines in the spectrum are used to estimate the noise floor. For example, a frame size of 1s result in 1 Hz frequency resolution of the calculated spectrum. As a side effect, this also means that artifact management needs to discard (or weight down) a full second of test data if noise events are detected in the frame. Varying stimulus rates is not easily possible with this setup.

Communications engineering knows a concept called Quadrature Amplitude Modulation (QAM), where the receiving side basically performs an ongoing fourier transform at a single carrier frequency. Applying this method to the recording of ASSR allows varying the stimulus rate while recording, as well as using shorter frames of data. Statistical evaluation of the signal can still be done by applying a noise estimator to the received signal and comparing the received signal amplitude to this noise level. The method is implemented in the PATH medical Sentiero Advanced ASSR module. The main goal of this study is to evaluate the effectiveness of the spread spectrum concept in adding robustness against external electrical interference.

Material and Method

To demonstrate the effectiveness of Spread Spectrum in ASSR, pre-recorded EEG signals were played back by a laptop computer's sound card, attenuated, and feed into the EEG preamp of a standard PATH medical Sentiero Advanced instrument. The typical recorded length of 5 min EEG was looped so that "test conditions" were very similar among test runs, which were configured to take about one hour. EEG was recorded from an adult, wake subject in a medium relaxed state that would have allowed to record ASSR. This approach offers the advantage that no inter-test variations of the test subject or environment influence the comparison results.

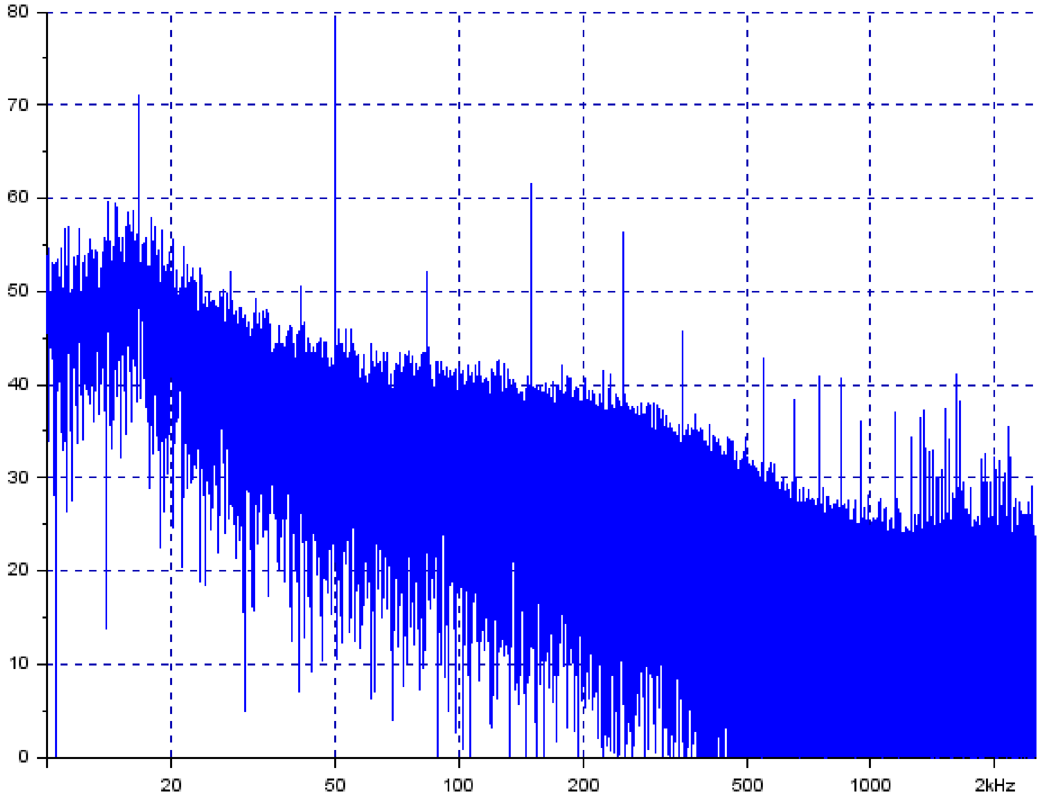

Fig. 1: Spectrum over 100s of the test signal (resulting in a 0.01 Hz bin width). A real recorded EEG signal was contaminated with a square wave of 41.25Hz, selected to hit one of the stimulus rates used by the instrument. The 41.25 Hz fundamental can just be seen in this plot, while overtones are already hidden in EEG activity. The plot also illustrates a component at 16⅔ Hz, resulting from a railway line not far from the EEG recording site, and activity at the 50 Hz mains grid frequency.

The EEG signal was artificially contaminated with a 41.25 Hz square wave about 18 dB below mains interference from the original recording. Fig. 1 demonstrates the resulting spectrum of this test signal. The 41.25 component is visible in this 100 s spectrum (0.01 Hz resolution), while the overtones are already well below overall EEG activity. A number of other artificial signals are also present, such as a 16⅔ Hz component from a railway line close to the recording site, 50 Hz mains interference and their overtones. A number of other signals seem to exist in the 1 kHz to 2 kHz region, probably originating from the office environment where the EEG was recorded.

A coupling-attenuator was constructed of 2 resistors of 3.3 kΩ and 2 resistors of 330 kΩ to attenuate the sound card output by about 40dB and feed it into the electrode lines of the instrument. The instrument therefore reports electrode impedances of about 3.2 kΩ.

The Sentiero Advanced unit was alternatively operated with a test firmware with Spread Spectrum disabled, and a firmware that does feature Spread Spectrum. Both variants were modified to use 41.25 Hz as the stimulus rate (average stimulus rate when Spread Spectrum was enabled) for 1 kHz and 1.5 kHz on the right ear. Since these two frequencies are never stimulated simultaneously on one ear, there is no issue in both using the same stimulus rate. The QAM recording technique was used in both variants. The official Sentiero firmware uses more “odd” frequencies in addition to the Spread Spectrum technology.

Test settings were configured to test all 9 available frequencies (250, 500, 1k, 1.5k, 2k, 3k, 4k, 6k, 8k) with half-octave wide stimuli at 4 levels (30, 40, 50, 60 dB), resulting in 36 single tests per ear for a complete test run. An HDA280 headphone was connected.

Test time per single frequency/level pair was configured to be 360 s. The instrument may stop a single recording prematurely if a significant response is detected or if statistics indicate no response can be achieved in remaining time (indicated by a gray triangle in the plots below). Each complete test run (consisting of 36 single tests per ear) took about one hour.

Results

In a first test run, the firmware variant that has Spread Spectrum disabled performed a binaural ASSR test with settings as described above. Quite obviously, just the two frequencies that use 41.25 Hz as their frame rate recorded stable, reproducible false responses, while all other channels, including the ones of the other ear, did not. Fig. 2 gives an impression on the results.

Fig. 2: Test results without Spread Spectrum, recording contaminated EEG test signal. Left panel: ongoing test, with the 1500 Hz 50 dB channel obviously recording a false response. Mid panel: Overall result for right ear (no response was detected on the left ear). Both frequencies that used 41.25 Hz stimulus rate produced false detections. Right panel: Single result (1.5 kHz, 41.25 Hz, 40dB) with a strong false response. A real ASSR response would look quite similar.

All single tests that used the 41.25 Hz rate detected false responses, which were, as expected, independent from stimulus levels. All other tests did not register a response, and no response was detected for the left ear’s channel either, since 41.25 Hz was not used there.

In contrast to this, the firmware with Spread Spectrum enabled performed correctly under the same conditions. Even though the same (average!) rates were used, no false responses were detected. Fig. 3 shows the results.

Fig. 3: Test results with Spread Spectrum enabled, recording contaminated EEG test signal. Left panel: ongoing test, with the 1500 Hz 50 dB channel not detecting any response. Mid panel: Overall result for right ear (no response was detected on the left ear). Both frequencies that used 41.25 Hz average stimulus rate now are free from false responses. Right panel: Single result (1.5 kHz, 41.25 Hz, 40dB) with no statistically significant response.

Real ASSR responses do not drop in amplitude when applying Spread Spectrum, unless the stimulus rate variation was moderate. The results presented here were recorded at +-2% rate variation, while amplitudes do not drop significantly at up to 5%. This means no extra test time is spent when using Spread Spectrum.

Conclusion

In a good, shielded or otherwise electrically "quiet" environment, ASSR can be recorded with fixed stimulus rates without issues. However, rooms like this are not always available; therefore additional robustness against interference is desirable.

The measurements shown above clearly demonstrate that Spread Spectrum is capable of improving robustness of ASSR recordings against periodic electrical interference of any frequency. This makes the method more reliable without any additional test time needed.

Literature

Bohórquez J, Ozdamar O. (2008) Generation of the 40-Hz auditory steady-state response (ASSR) explained using convolution. Clin Neurophysiol. 2008 Nov; 119(11):2598-607

Mühler, R.; Ziese, M. & von Specht, H. (2005) Registrierung von auditory steady-state responses (ASSR) mit Laborsystemen. Z. Audiol., 2005, 44, 20-30.