Application Note: 17122024-001-ABR

AUDITORY BRAINSTEM RESPONSE (ABR)

The auditory brainstem response (ABR – AEP - BERA) is an action potential generated by the brainstem in response to the presentation of an auditory stimulus. The ABR is made up of a series of peaks, which are generated by neural firing starting at the cochlear, then medulla, then pons and then brainstem (keeps proceeding to the thalamus, radial auditive and to the cortex). According to the Jewett/Williston convention, the five most prominent peaks in the first 10 milliseconds after the stimulus onset are labelled I-II-III-IV-V, see below Figure 1.

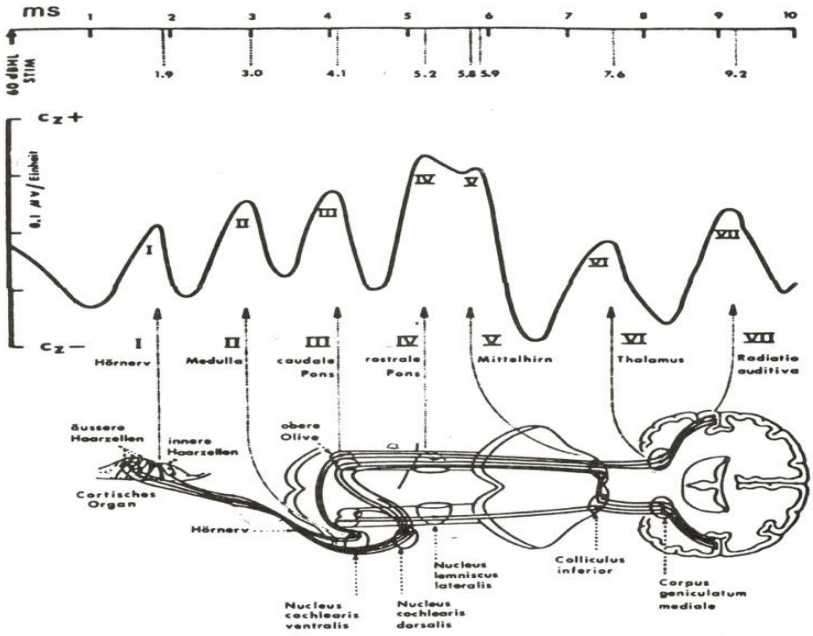


Figure 1 - Typical ABR waveform

The Concept:

The **new ActiveThree** system by BioSemi offers a dedicated sensor setup plus the possibility to insert stimulus triggers (if no dedicated stimulator is available) in sync with the actual stimulus, for measuring Auditory Brainstem Responses (ABR) without delay. These signals differ from typical EEG signals. ABR's are smaller in amplitude (only a few tenths of a microvolt) and have higher frequencies (100 Hz to 1 kHz) than standard EEG signals (tens of microvolts, with frequencies from 0.1 Hz to 100 Hz).

Standard active EEG electrodes, which need to measure down to low frequencies (to DC), are designed to be low power (to save on battery power) and lightweight (2-wire principle to avoid handling problems and EEG caps moving on the head) since many (32–128) are normally used.

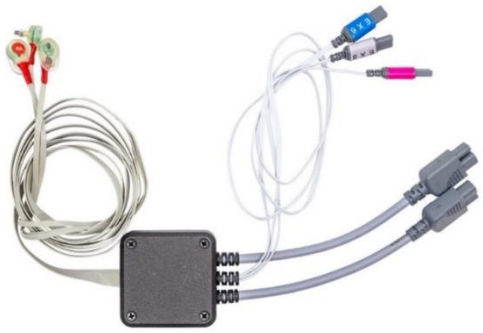
In contrast, with ABR measurements only higher frequencies need to be captured and only three electrodes plus CMS/DRL are used. One electrode is placed on each ear/mastoid and a Reference (usually in the Cz position), CMS and DRL are located on the head in the standard headcap positions.

The ABR signal properties allow for specialized ABR electrodes with 4-wire cables and higher power consumption, enabling active electrodes with a high gain, ultra-low-noise AC amplifier (versus a unity gain DC amplifier in the standard active electrodes).

Application Note: 17122024-001-ABR

The Setup:

The ABR electrode set (Figure 2) uses three active electrodes from which 5 channels are derived (Left – Ref -Right – ABR-L and ABR-R) - Figure 2



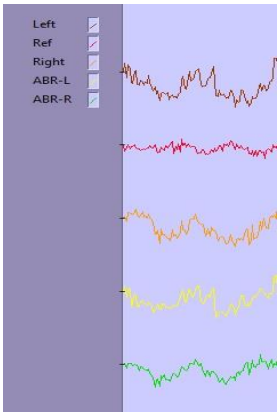


Figure 2 - ABR Electrode Set and derived channel sample (NEUROSPEC, 2024)

The ABR Electrode set consists of **2 AUX** connectors and **3 EX** connectors. They connect to the AD Box as follows and shown in Figure 3a:
AUX Connectors can be connected to any of the AUX receptacles. However, when also using the Audio Optical, AUX 1 is best reserved for the Audio Optical in order to route the resulting triggers to line 9 - see Figure 3b
EX Connectors must be connected to EX6 / EX7 and EX8 on the top of the AD Box

Note: Both the ABR AUX connectors must be connected, or else the ABR Tab will remain greyed out. Connecting the EX6/7/8 plugs is optional.

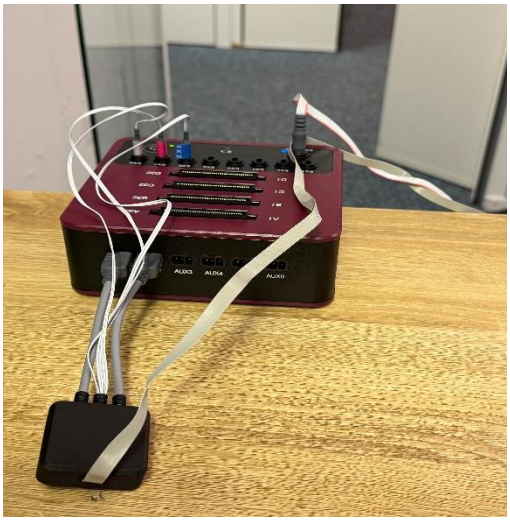


Figure 3a – Cable Setup (NEUROSPEC, 2024) without Audio Optical

Figure 3b – Cable Setup (NEUROSPEC, 2024) with Audio Optical

Now connect the three electrodes plus CMS/DRL to the subject's head as Figures 4a and 4b show:

Figure 4a – CMS, DRL and REF Setup in the cap (NEUROSPEC, 2024)

Figure 4b – RA and LA Setup on the mastoids (NEUROSPEC, 2024)

Launch the latest version of ActiView and from the About/Configure Tab chose the **ABR.cfg** file that sets all the parameters correctly (especially if an Audio Optical is used).
When all the AUX and EX connectors are attached properly, the ActiView software recognizes the ABR setup and automatically enables the ABR tab page as below (Figure 5).

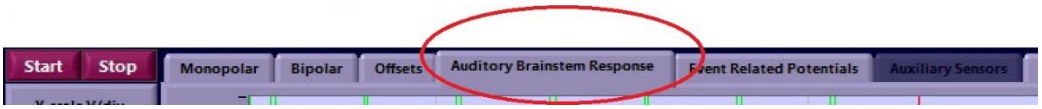


Figure 5 - ABR tab inside ActiView

In the Auditory Brainstem Response Tab, the Channel Select allows switching between Raw, LF and HF, showing the quality of the traces (if there is excessive noise, redo the electrodes setup or change the location) and describes the different settings as follows:

Raw: The **Low Frequency unreferenced channels** (labelled: Left, Ref and Right in reference to CMS)
LF: The **Low Frequency referenced channels** (labelled: Left and Right in reference to Ref) with selectable bandwidth 0 Hz – 5.4 kHz are shown in Figure 6.
HF: The **High Frequency referenced channels** (labelled: ABR-L and ABR-R in reference to Ref) with locked bandwidth 10Hz – 5.4 kHz

The extra LF channels (EX6/EX7/EX8) serve two functions: they measure electrode offset voltages and they allow the ABR electrodes to be used as references for regular EEG channels.

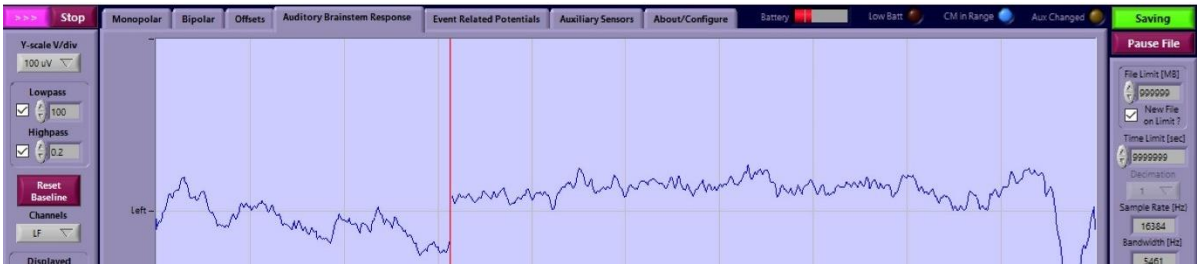


Figure 6 - ABR LF channels inside ActiView

Application Note: 17122024-001-ABR

The Stimulation and Triggers:

In the measurements for this ABR App Note a commercial Click Stimulator was used (from EMS Biomedical Austria) with a standard trigger output which runs in time with the presented clicks.

It may well be, that a dedicated sound /click stimulator is not available. In this case, it is still possible, to measure an ABR with precise time as in Figure 1, but a dedicated *Audio Optical device from Biosemi is required. This device is best connected to the **AUX1** of the AD Box (the ABR AUX connectors are now shifted to AUX2 and AUX3) to allow the stim trigger to come in on line 9 – of course the Audio Optical can also be used on AUX3 or AUX4, however, different trigger lines would be set in the ERP Tab – see more below and in Figure 7.

Figure 7 – Dedicated Audio Optical Setup on AUX1 and the ABR AUX connectors now connected on AUX 2+3 Different Scenarios of using the Audio Optical on AUX2, AUX3 etc. describes the trigger lines above (NEUROSPEC, 2024)

If *Audio Optical is used, use the already setup CONFIG File called **ABR.cfg** available in the ActiView main path (in connection with E-Prime or Presentation or Python etc) then connect the Audio Optical AUX plug into AUX1 and shift the ABR Electrode AUX connectors to AUX2 and AUX3 – this will result in a Trigger 9 during acquisition. When the data is being acquired, toggle to the ERP Tab, then select the Trigger 9, and press the "Start Avg" button to start the averaging process (press again to stop and restart). If the averaging process does not start, check that the proper trigger line is selected.

If Audio Optical is connected to another AUX Port, then make sure to select another trigger and according to the below information:
AUX2 = *Trigger **10***
AUX3 = *Trigger **11***
Etc .....

Note: It is not advisable to use AUX 5 or 6 if the ActiveThree is used in Hyper-Scanning Mode, as these AUX ports are reserved for sync triggers.

Application Note: 17122024-001-ABR

If the Audio Optical is used together with software like Presentation, E-Prime, Python or similar, and the ABR.cfg file has been loaded, the following settings are pre-made to assure triggers to come in on line 9 as described before:

ABR.cfg File:

```
OneShot=11      //0: One-shot triggers disabled 5: Photo coupled 10: Ergo coupled 11: Audio coupled
TrigLength=15   //Trigger length in msec
TrigLevel=120   //Trigger trip level in mV
TrigWindow=1    //0: level triggering, 1: window triggering
TrigPol=1       //0: trig on less than level, 1: trig on more than level
```

Explanation of the Settings:

OneShot = 11 means that the One-shot routine is linked to the Audio Optical (sensor number 11)

TrigLength = 15 defines the length in ms of the trigger pulse generated by the one-shot routine (the trigger length used is around 10msec)

TrigLevel = 120 defines the Voltage Level in mV of the Audio Optical that triggers the one-shot trigger generator (see below that the measured click is around 469mV pp and so the level is set best to around 1/4th to about 120mV)

TrigWindow = 1 sets the one-shot routine whether using level triggering or window triggering.

TrigPol = 1 sets the polarity of the one-shot routine

To check, run the click on the Notebook used, making sure the Headphones and the Audio Optical are connected via a splitter, the loudness of the line output is toggled at least to around 80%, and see if the actual click is seen on the Auxiliary Sensors Tab and the corresponding line 9 with the brown trigger marks as in Figure 8 are detected.

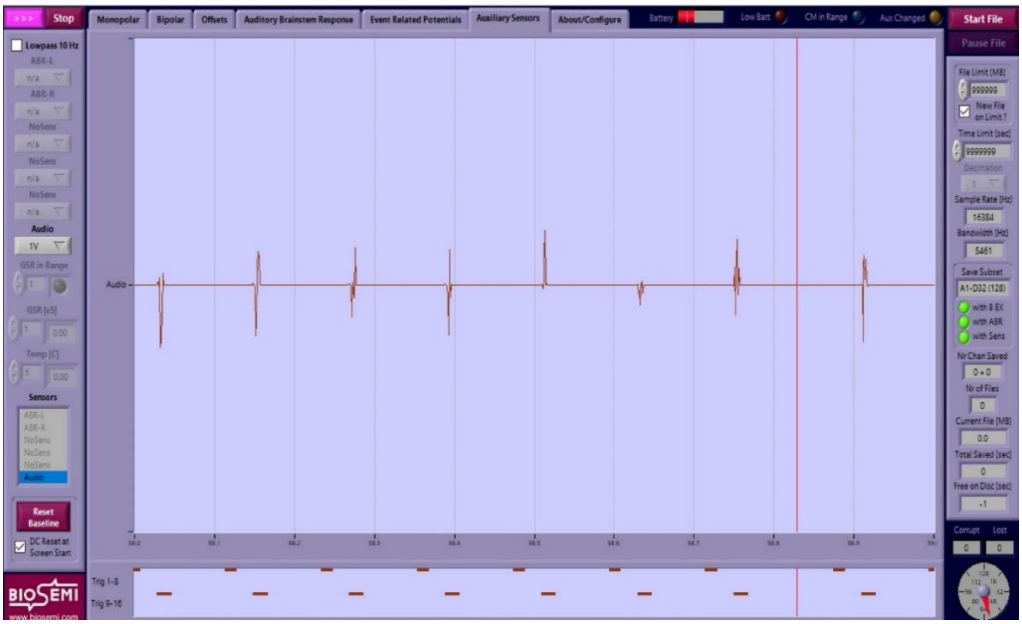


Figure 8 – Trigger test inside ActiView

Application Note: 17122024-001-ABR

If no triggers are detected in ActiView, a tweak is required. When the actual stimulus is seen, but no trigger is visible on line 9 (if Audio Optical is connected to AUX 1 on the AD Box), start a file and save a short test for an audio signal amplitude; analyse the data in **ActiRead** (part of the software delivered with the purchase of an ActiveThree) as shown below. Zoom in on the data with the Zoom Sliders, until you can use the horizontal cursors to measure the actual voltage of the click -as shown in Figure 9. Write down the mV value (in this example it is 469mV).

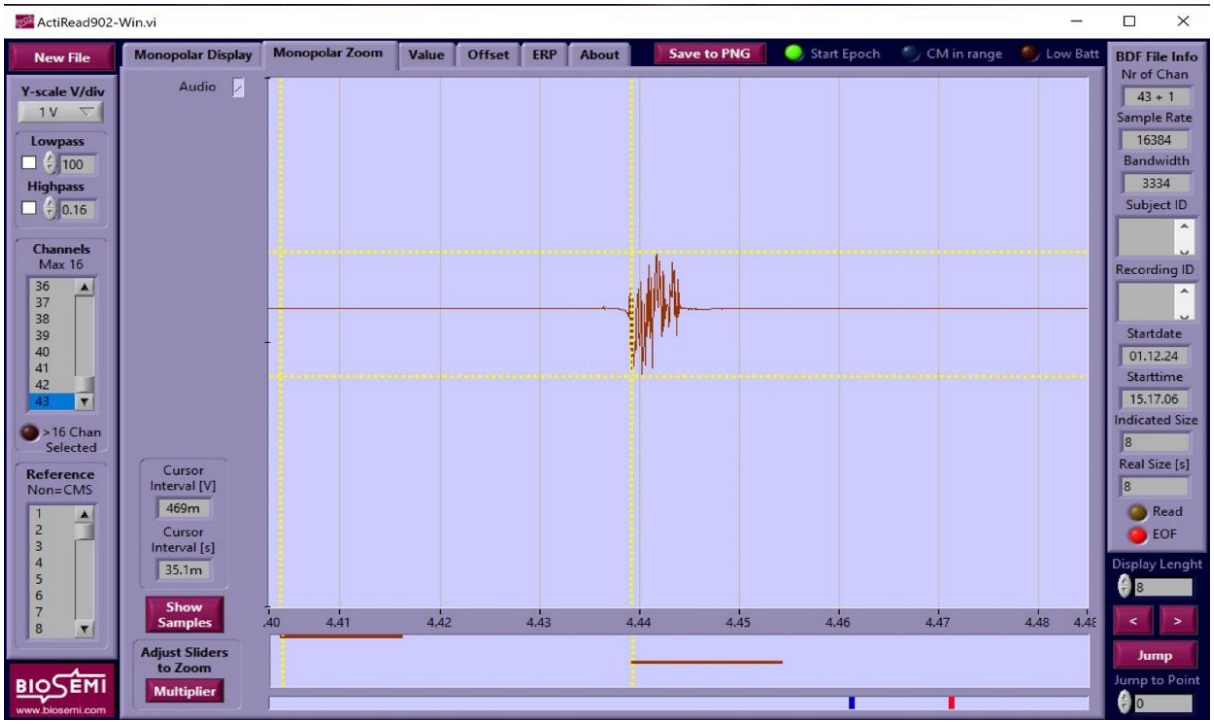


Figure 9 – ActiRead Monopolar Zoom Tab and chose the last channel to see the click

After the trigger setup has been performed, the two triggers (line 1 from the USB Receiver and line 9 from the Audio Optical Facility) appear.

All is now set to start the measurement.

Application Note: 17122024-001-ABR

The Acquisition:

The ABR Electrode setup provides the following electrodes: FLAT // PIN // FLAT – the PIN Type Electrode is specifically made to fit into the regular headcaps and as seen in Figures 4a and 4b.

Also available on request – please enquire: TIPTRODE // PIN // TIPTRODE.

A note about using Tiptrodes from Etymotic Research:

When using Gold Tiptrodes – Figure10, there will be a high negative offset on the Left (EX6) and Right (EX8) channels. The offset is caused by the potential difference between the gold foil Tiptrodes and the Ag/AgCl electrode material on the CMS (and other) electrode. The EX6 and EX8 channels will generally saturate (< -200 mV offset) and cannot be used as references for the headcap electrodes. However, the ABR channels themselves (ABR-L and ABR-R) have a much higher DC input range (+/- 0.7 V) and will not saturate. So, when using Tiptrodes, just ignore the offsets on the EX6 and EX 8 channels.

Figure 10 - Gold Tiptrodes (NEUROSPEC, 2022)

As soon as the headphones are placed on the subject's head, all electrodes are still in place, and the subject is comfortable, start ActiView again, and unless already chosen, go to the About/Configure Tab and choose the file **ABR.cfg**. Then just hit Start and check that the Offsets are in order – the screen should look like in Figure 11a, 11b – start the stimulus and check for the incoming triggers on line 9. Trigger 9 being the exact trigger created by the stimulus and supplied by the Audio Optical. Trigger 1 in Figure 11a is sent from the stimulus computer to the USB Receiver and can be ignored, since Figure 9 shows that this trigger is not properly timed with reference to the click (due to delays and jitter introduced by Windows, which is not a real-time operating system).

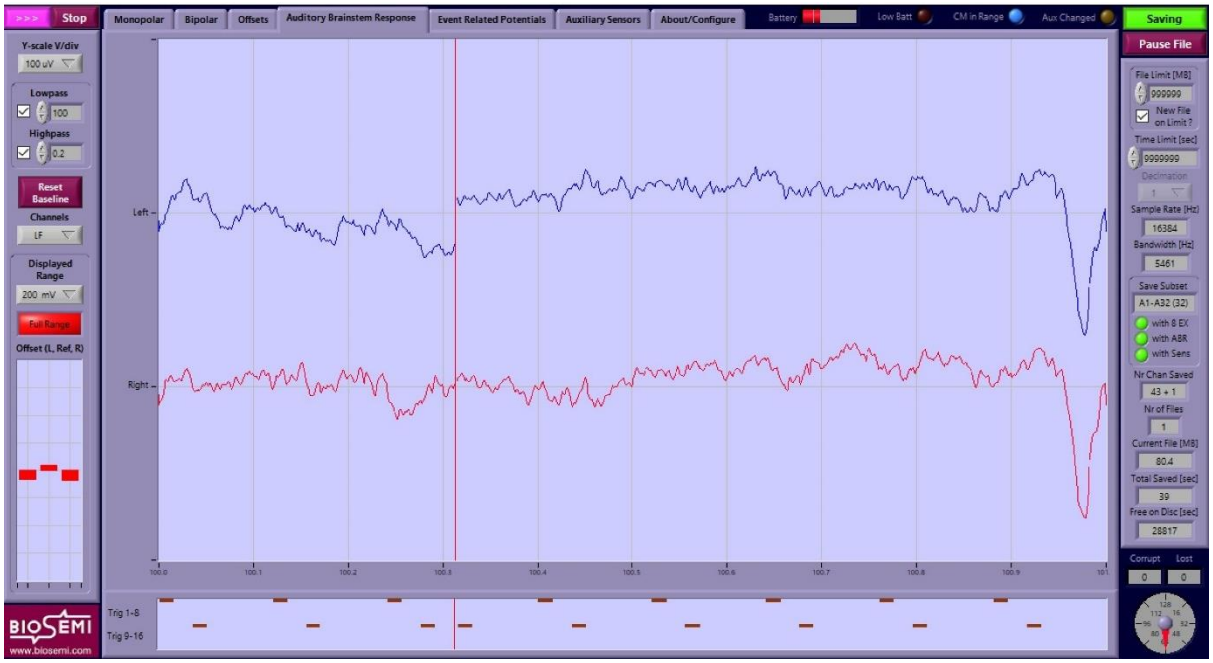


Figure 11a – ActiView Auditory Brainstem Response Tab – LF View

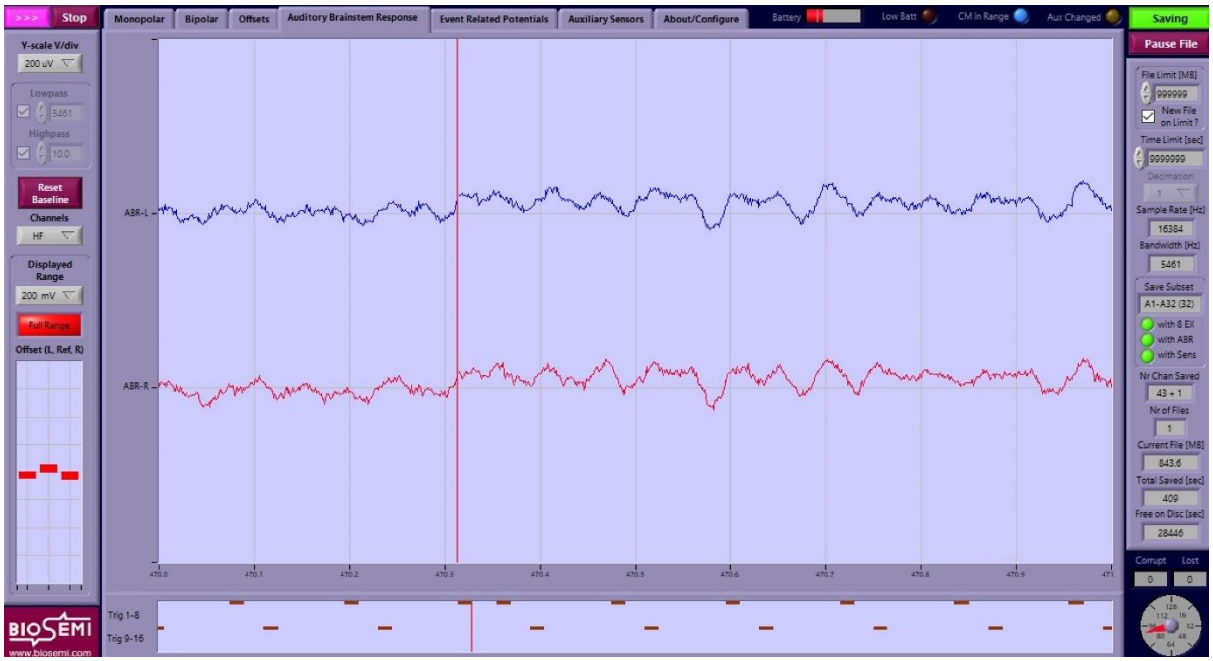


Figure 11b – ActiView Auditory Brainstem Response Tab – HF View

It makes little sense to remain in the Auditory Brainstem Response Tab, as the traces that run by simply show the actual ongoing EEG derived from the three electrodes, and whether there is much noise or not. Therefore, toggle over to the Event Related Potentials Tab and make sure to choose the stimulus trigger (in our example a commercial stimulator was used and Trigger 1 chosen; otherwise choose Trigger 9 if Audio Optical is used) – all other parameters are locked to the correct settings.
See below Figures 12a and 12b:

Figure 12a – ERP Tab – ABR building up – screen shot taken (new in the ERP Tab allows saving of both; either stopped or running acquisition) after 1962 sweeps
(The image shows a grey and two-colored traces – the grey trace shows that there is little noise as it is quite flat)

Application Note: 17122024-001-ABR

Figure 12b – ERP Tab – ABR almost finished – with Negative Up we see the Left and actual stimulated ear built up waveforms I / III and V nicely. The lower trace, the Right Ear shows predominantly the waveform V

As soon the ABR has reached the acceptable levels – in our example we found that 3400 epochs produced the desired results - Stop the acquisition and quit out of ActiView. The recording has now ended, and we can analyse the data in ActiRead or BESA.

The Analysis in ActiRead and BESA:

After a successful acquisition of the ABR and according to our explanations above, see the results of our ABR using the ActiveThree below in Figures 13a and 13b:

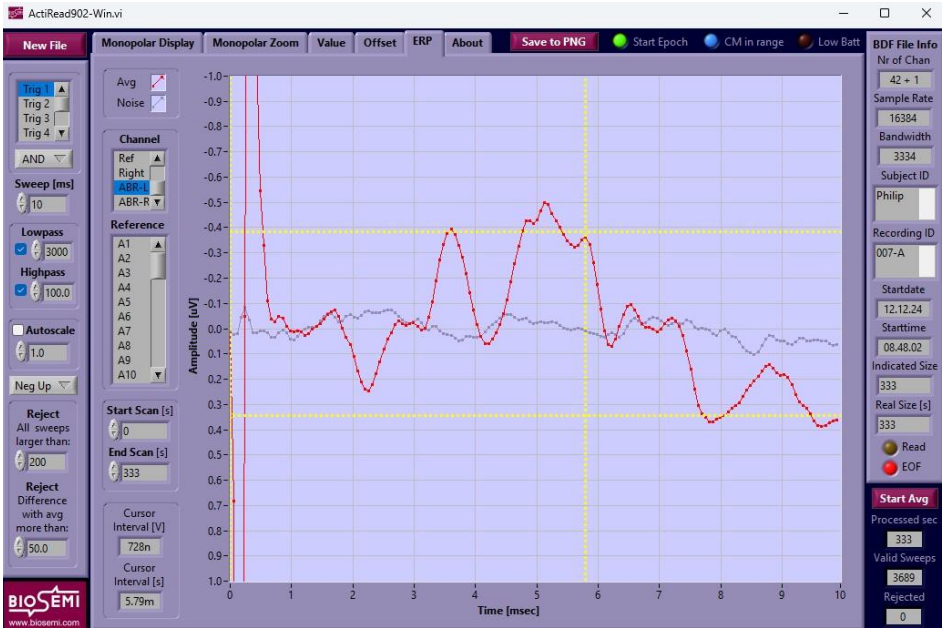


Figure 13a – ABR for the Left stimulated ear – all waveforms I – III – V are very dominantly seen. Distance from Stim Artefact to V is at 5.79msec!

Application Note: 17122024-001-ABR

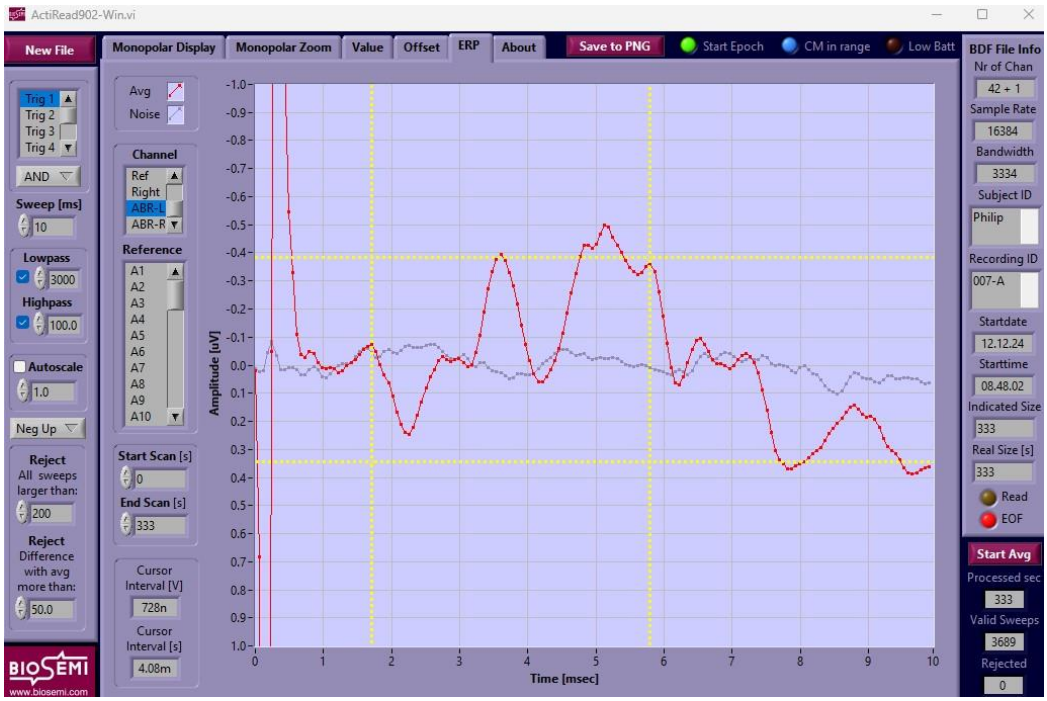


Figure 13b– ABR for the Left stimulated ear – all waveforms I – III – V are very dominantly seen. Distance from waveform I to waveform V is 4.08msec!

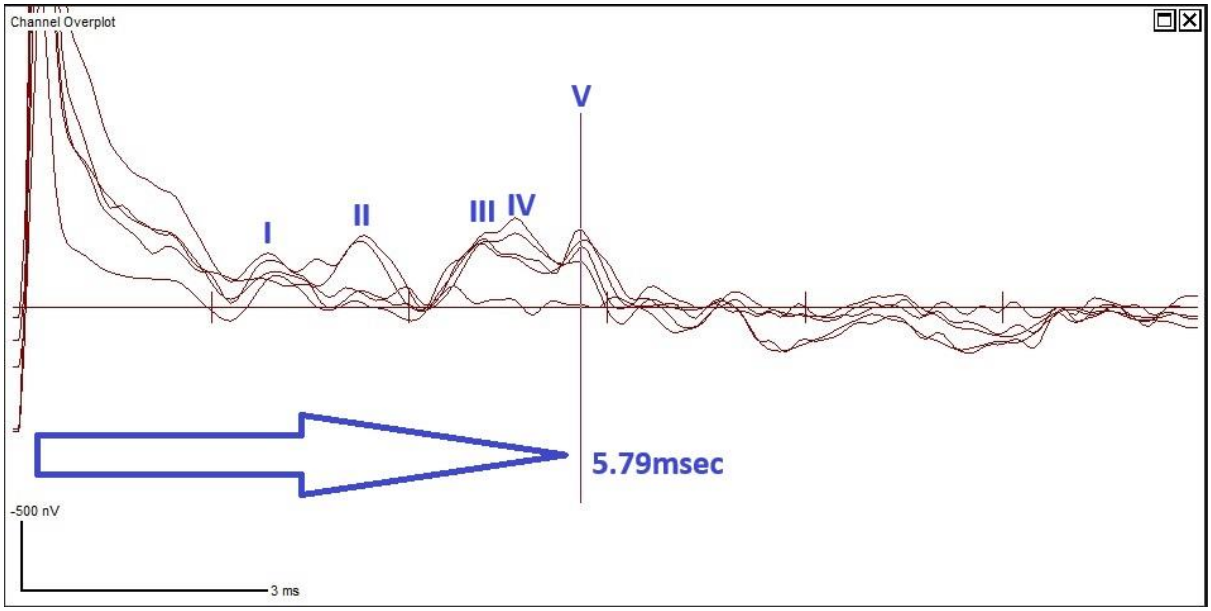


Figure 13c– ABR analyzed in BESA and superimposed all channels to prove it is an ABR

Application Note: 17122024-001-ABR

TECHNICAL SPECIFICATIONS OF THE ABR SETUP AS DESCRIBED BY BIOSEMI BV:

	ABR Channels (ABR-L, ABR-R)	EX Channels (Left, Ref, Right)
Sample rate:	**16,384 Hz**	
Bandwidth (-3 dB):	10 Hz to 5.4 kHz	DC to 5.4 kHz
AC input range:	16 mV peak-to-peak	400 mV peak-to-peak
DC input range:	-700 mV to +700 mV	-200 mV to +200 mV
Noise (full bandwidth):	0.4 uVrms (approx. 2 uVpk-pk)	2.8 uVrms (approx. 15 uVpk-pk)
CMRR @ 50 Hz:	140 dB	100 dB
Resolution:	LSB = 1.95 nV (1/512 uV)	LSB = 31.25 nV (1/32 uV)

The ABR channels use AC amplifiers with a first-order, high-pass response. A plot of the frequency response is shown in Figure 14. The plot was measured with an input signal consisting of white noise with a density of 1 uV/Hz^1/2 (DC to 8 kHz) generated by a Keysight 33500B waveform generator. The passband (-3 dB) is 10 Hz to 5.4 kHz. The plot shows the 6 dB per octave slope below 10 Hz and the sharp roll-off of the anti-alias filter above 5.4 kHz.

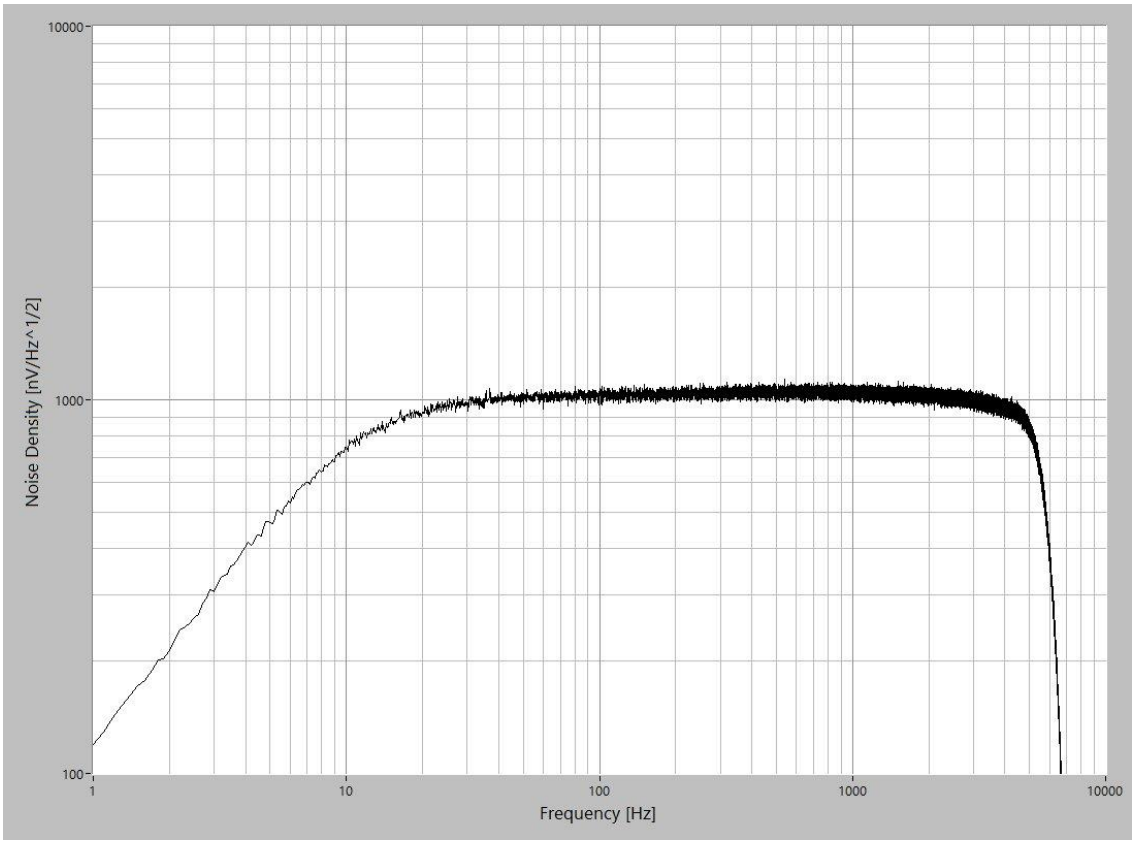


Figure 14 - ABR Frequency Response (BioSemi, 2024)

Application Note: 17122024-001-ABR

The special ABR channels are optimized for low noise between 100 Hz and 1 kHz. The noise density at 1 kHz is a mere 5 nV/Hz^1/2 (lowest in the industry and a factor of 7 lower than the standard channels). Electrode noise at high frequencies is small because the electrode impedance is mainly capacitive at these frequencies, which results in low electrode impedance at high frequencies. The ultra-low noise of the amplifiers in the active ABR electrodes ensures that the noise generated by the skin-gel-electrode interface - and not the noise of the signal acquisition instrumentation - is always the dominating noise source. The noise density of a bipolar ABR channel can be seen in Figure 15. The area under the curve (the total noise) amounts to 0.4 uVrms. Ignore the spikes at 50 Hz and odd harmonics caused by mains supply interference.

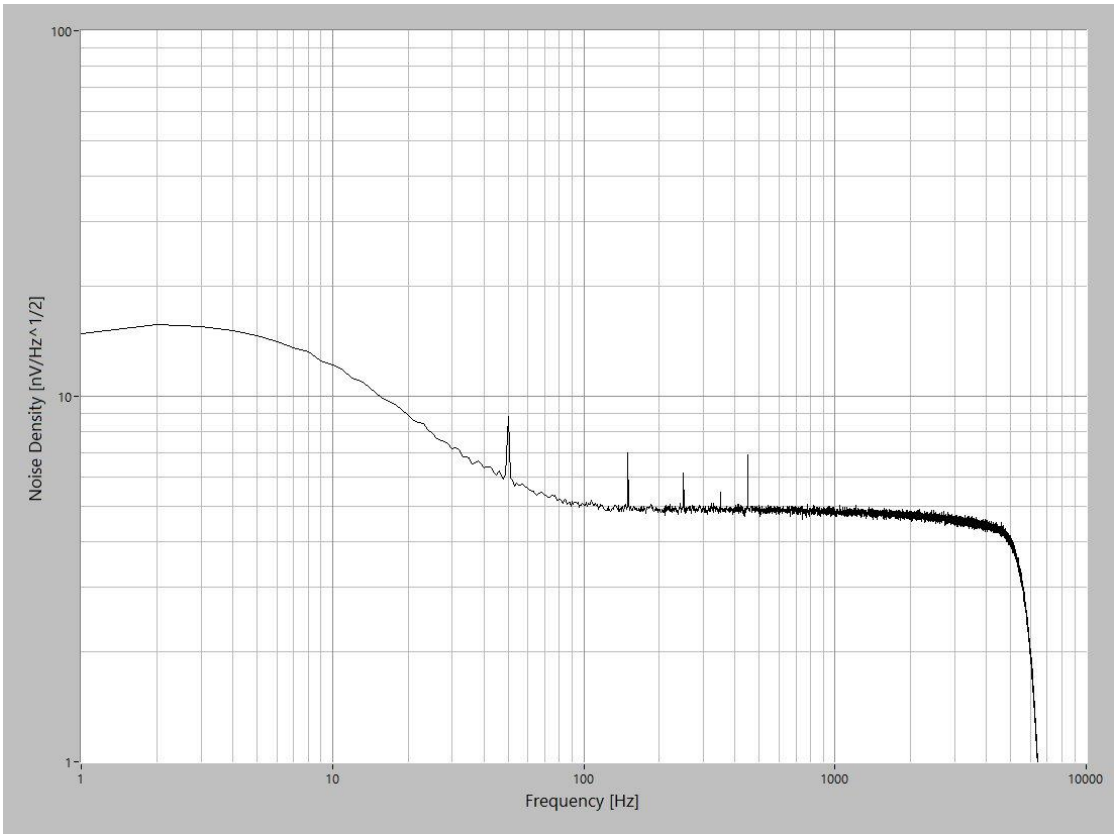


Figure 15 - ABR noise density (BioSemi, 2024)