# The Parent of all Sanity Checks

D. Gün, L. Krieger, T. Neugarth, G. Pipa, P. Samimi, M. Vidal

July to November 2020

## Contents

**!Important!**: There is a difference in channel naming between the board and the app, whereas the board starts with channel 0 and the app with channel 1. In this document the App naming is used (Ch-1 to Ch-24).
To increase readability of this document, most Sanity Checks are solely summarised.

# 1 18.07.2020 - First Trial with an old Function Generator

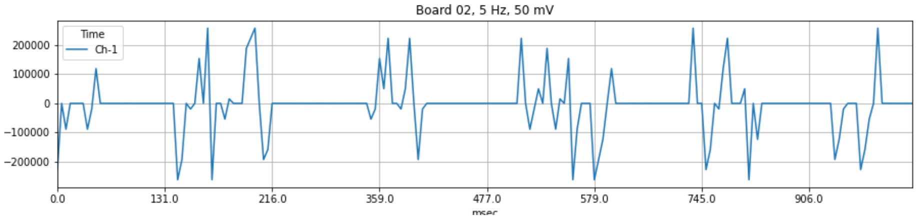
The Traumschreiber board 02 (external reference) and board 03 (internal reference) are tested. Applied were 5 and 50 Hz Sinus with 50 and 100 mV. For board 02 all six channels were tested, for board 03 only channel 1.

## 1.1 Devices and Setup

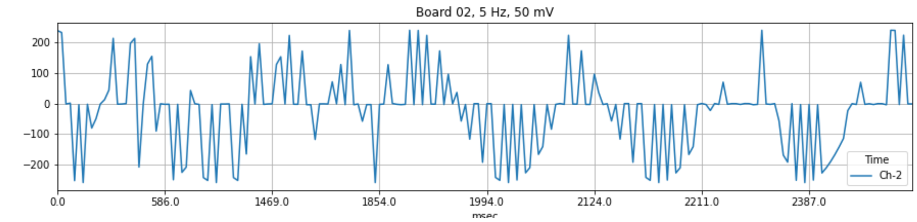
Function Generator: Funktionsgenerator-FG-506 (Voltcraft) (the old one)
Oscilloscope: HMO 1524 (Rhode and Schwarz), used to verify that the function generator works.
Traumschreiber: Board 2 and 3
Bluetooth Receiver : App - current Version (18.07.2020) on a Android mobile phone (Honor 9)
Subject ground and active ground are connected to ground of signal generator. Signal is injected into active channel. The boards were tested with 5 and 50 Hz frequency and 50 mV and 100 mV voltage combinations on the first six channels (board 3 - only first channel).

## 1.2 Results

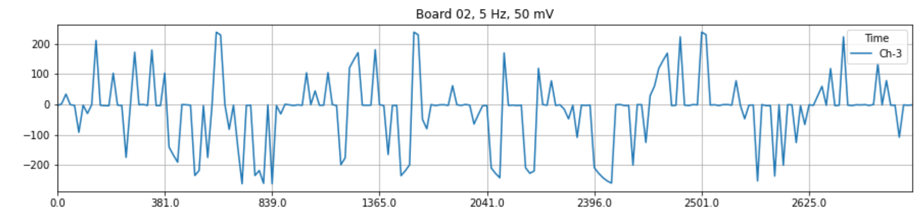
Figure 1 displays exemplary plots. Note that these plots display the first 200 measurements. Therefore the displayed time interval varies strongly between the plots.




(a) Experiment 1, Channel 1




(b) Experiment 2, Channel 2




(c) Experiment 3, Channel 3

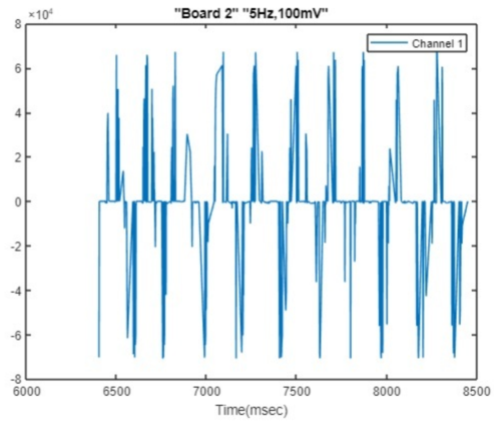
Figure 1: Experiments 1-3: Board 02, 5 Hz Frequency, 50 mV Voltage, Different Channels, Charged via USB

### 1.3 Findings

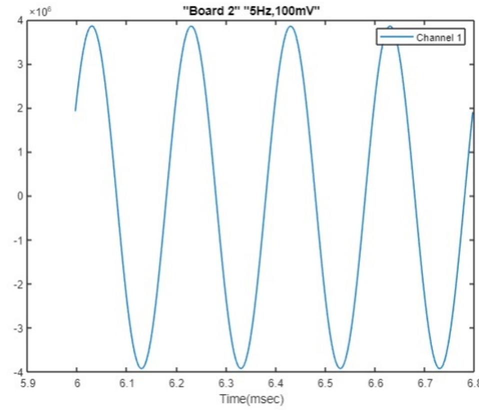
Generally, the signal does not resemble the expected sine. Reason may lay in the old function generator and wrong encoding within the app. The problem with the app was solved to some extend on 22.7.2020. Furthermore, a new function generator was used.
The battery of both devices does not work as expected and cannot be charged once destroyed. This results in a redesign of the battery layout in the next Traumschreiber generation.
One next step is to be to find out why the difference between the measured time spans is so big.

## 2 29.07.2020 - Comparing the EEGDroid App with the nRF Board as Bluetooth Receiver

The App and nRF board were both tested as bluetooth receiver of board 02 and 03 (with different frequency signals (5 and 50 Hz). Two exemplary recordings are plotted in Figure 2.




(a) 5 Hz signal recorded with the app




(b) 5 Hz Signal recorded with nRF and developer board.

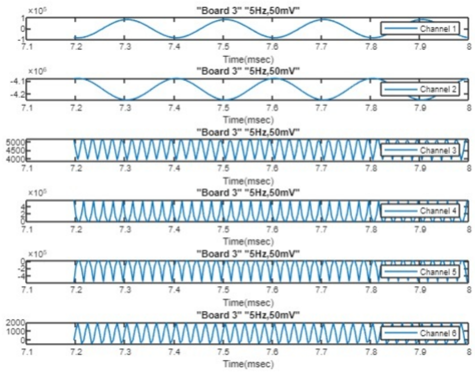
Figure 2: Both recorded on Board 02 with 100mV and 5Hz Signal. The signal recorded with the nRF looks significantly cleaner.

### 2.1 Findings

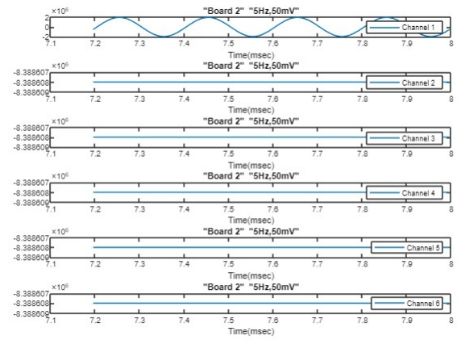
There still exists a problem with the app, resulting in unclear signals. The signal recorded with the nRF board looks fine.

## 3 31.07.2020 - Difference between External and Internal References

To compare Traumschreiber No 2 (external reference) and No 3 (internal reference) a 5 Hz, 50 mV Sine was inserted into Channel 1 of both devices. The nRF board/software are used as receiver. Subject ground and active ground are connected to the ground of the signal generator. Signal is injected to Channel 1. Subject ground and active ground are connected to ground of signal generator. The resulting recordings are displayed in Figure 3.




(a) 5 Hz signal recorded with Traumschreiber No 3 (internal reference)




(b) 5 Hz signal recorded with Traumschreiber No 2 (external reference)

Figure 3: The same signal was recorded with an internal reference and external reference Traumschreiber. The signal recorded with the internal reference leaks to the neighbouring channel whereas the signal of the external one does not.

## 3.1 Findings

Even though the signal of the external does not display signal leakage to neighbouring channel, future board designs will use an internal reference.

# 4 07.08.2020 - Recording ECG with External Reference Board

A first ECG recording was conducted with Board 02 (external reference) and the nRF. The signal displays 50 Hz noise. Applying a 50Hz Butterworth Filter results in a clean ECG Signal, displayed in Figuer 4.

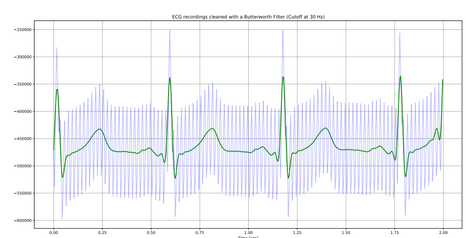


Figure 4: Applyng a Butterwoth Filter to the ECG recording (Board 02) results in a clear Signal.

# 5 17.08.2020 - Recording ECG with Internal Reference Board

Repeating the ECG experiment with Board 03 (internal reference) results in a clean signal without noise. No filtering was necessary. Recording is plotted in Figure 5.

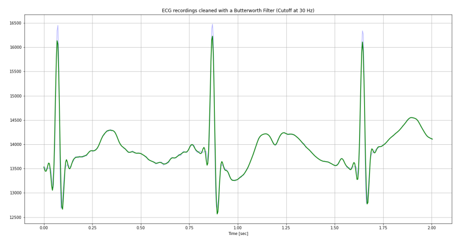



Figure 5: ECG Recording with Board 03 (internal reference, no filtering is needed (opposed to using Board 02)

## 5.1 Findings

Comparing the ECG recordings made with the internal reference board with recordings made with the external reference board, as depicted in Figure 4 and Figure 5, shows an advantage of the internal reference board. No filtering is necessary to achieve a clean signal

# 6 19.08.2020 - Encoding Changes in the App and General Plotting

After investigating how the data is encoded and received via BLE from the new board, the app was changed to accommodate the encoding. Nonetheless, some problems remain, for example displayed in Figure 6. One problem is that the timestamp produced by the app does not coincide with the actual time the data was recorded but rather displays the time it arrived on the device. Since the sampling rate is fixed, the signal can be adapted to match the appropriate timestamps. The comparison is displayed in Figure 7.

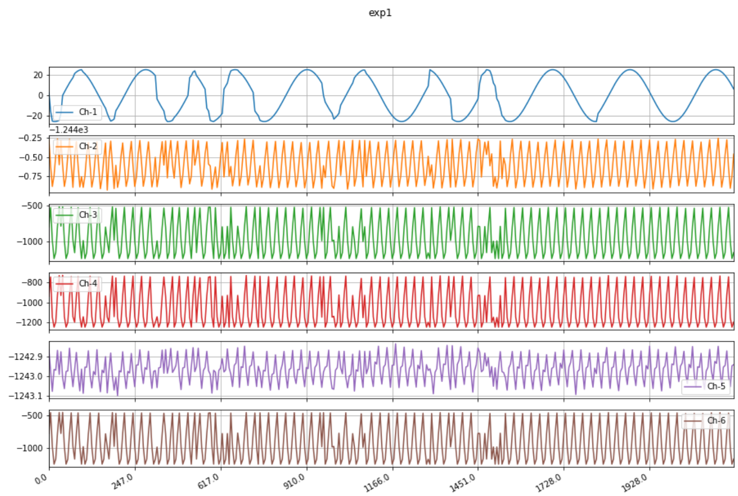
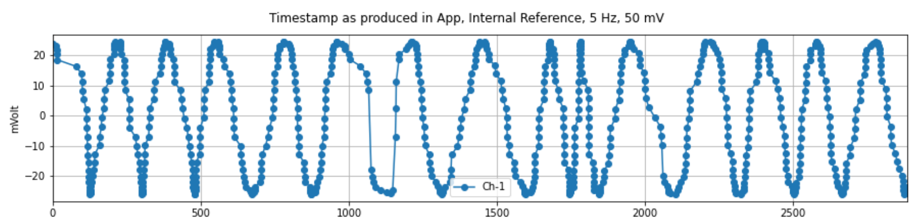
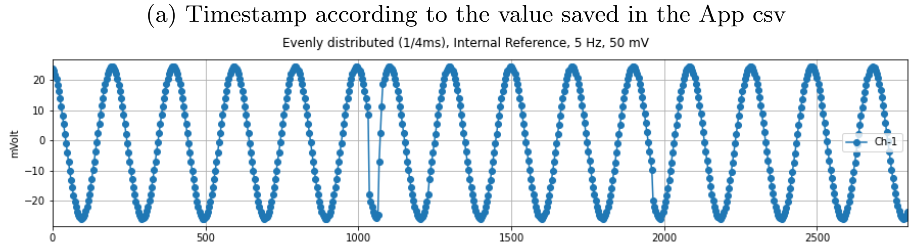



Figure 6: Board with external reference, 5 Hz and 50 mV.Signal recorded with the App. Even after the major updates, the signal is wonky occasionally .




(a) Timestamp according to the value saved in the App csv



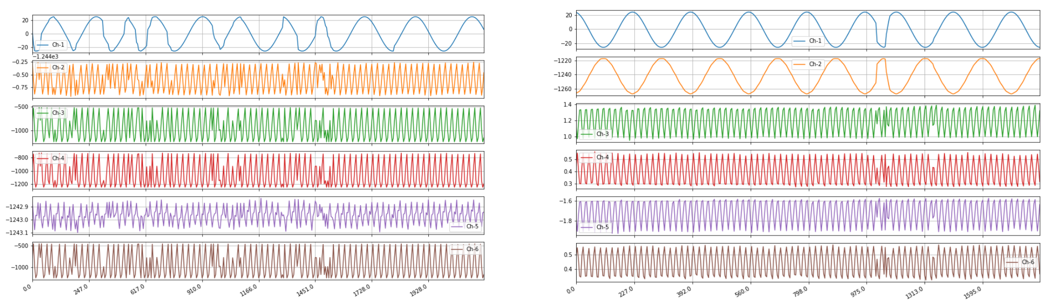

(b) Evenly Spaced Timestamps in accord to the sampling rate

Figure 7: Even though some jumps remain, the signal significantly improves when the timestamp is adapted in accordance to the sampling rate

# 7 August 2020 - Testing VCM settings with Android App

## 7.1 Devices and Setup

Testing board 02 (external reference) and 03 (internal reference) without VCM, switch 3 (ground) is turned on. A variety of 5 and 50 Hz and 50 and 100 mV Sine signals is induced. The boards are charged while recording with a powerbank.



(a) Test with External Reference, no VCM, AC=1 (b) Test with Internal Reference, no VCM, AC=1

Figure 8: Testing the different switches/no VCM of both boards in San. Check 6

## 7.2 Results

Signal of external reference board is not clean, the one of the internal reference looks mostly fine. The recording on the active channel is mostly good but there is leakage to neighbouring channels. The VCM will be removed from future board design as it only worked for one ADC but three ADCs are required for recording 24 channels.

# 8 11.09.2020 - Testing the Board Filtering

The board is now advanced with 50 Hz filtering to accommodate potential 50Hz noise from electric devices. Tested by inserting 5, 50 and 80 Hz to different channels of Board 03 and 07. Performance of filtering 50 Hz is depicted in Figure 9. It seems to work.

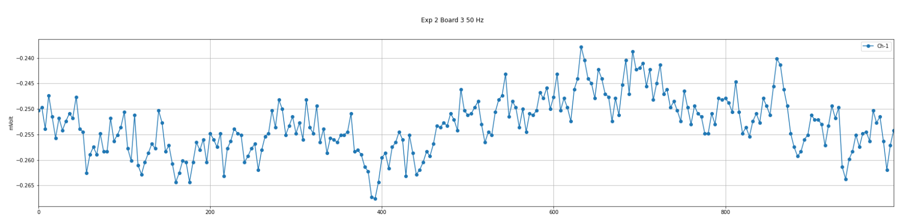


Figure 9: 50 Hz with Filtering (Board 03)

# 9 11.09.2020 - First EOG

To see whether the device is sensible enough to record EOG signals, a superficial recording was conducted.

## 9.1 Setup

The following describes the setup on the participant: Subject Ground to ear lobe
Active Reference to forehead
Channel 0 to temple
Channel 1 under the eye
See Figure 10 for signal example and setup.

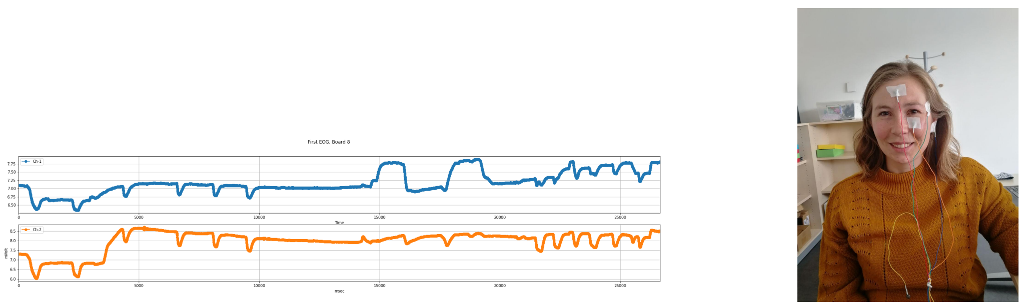



Figure 10: Results and Setup of the First EOG Experiment. Participant was asked to look left, right, up, down and close their eyes.

# 10 16.09.2020 - Different Devices/CPU Load

To test whether the phone's Bluetooth chip and the CPU load (plotting vs not plotting during recording) influences the amount of dropped packages, several devices where tested and the amount of dropped packages evaluated. The phones in questions are:

1. Lab Phone: Motorola Moto G5S Plus (XT1805), CPU: 2Ghz Octa-Core ARM Cortex-A53, RAM: 3GB LPDDR3, Bluetooth: 4.1 + A2DP Link to Phone
2. Lab Tablet - Infrmation still missing
3. Phone III: Honor 9 (STF-L09), CPU: 4x2.36 GHz ARM Cortex-A73, 4x1.84 GHz ARM Cortex-A53, Cores: 8, RAM: 4.0 GB, Bluetooth: 4.2, A2DP, LE. More info in this link
4. Phone IV: Xiaomi Mi A3

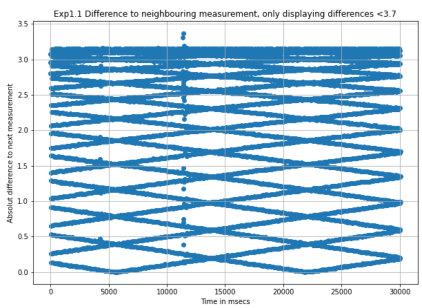
## 10.1 Experiments

Without plotting while recording. Each for 30 seconds.
Test 5 Hz, 50 mV, Board 03 with different one phone as receiver:
Exp 1: Lab Phone - 1.1 without plotting, 1.2 with plotting
Exp 2: Lab Tablet - 2.1 without plotting, 2.2 with plotting
Exp 3: Phone III - 3.1 without plotting, 3.2 with plotting
Exp 4: Phone IV - 4.1 without plotting, 4.2 with plotting

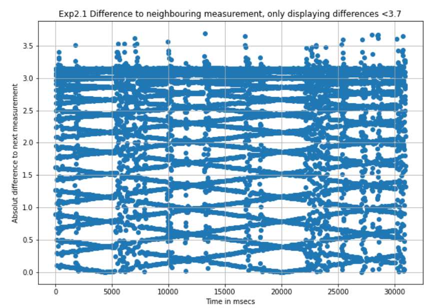
## 10.2 Results

There is no difference between plotting and no plotting with the individual devices. But there is a big difference of the recorded signal quality between different devices as depicted in Figure 11.

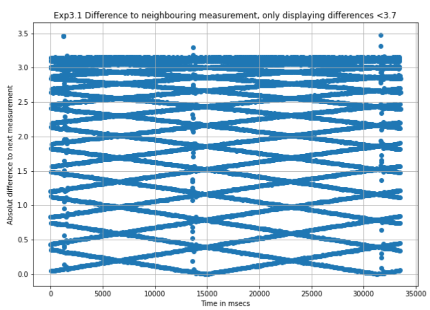
This might be due to general CPU load. A superficial check on the CPU load of the Motorola and Honor Phone reveiled no overload. The Lab's tablet is constantly overloaded.



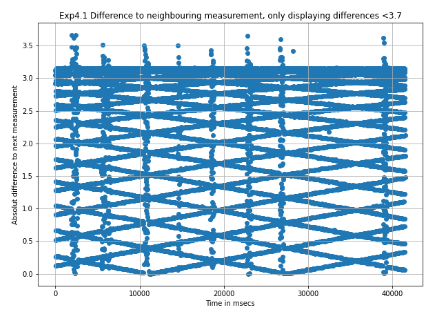

(a) Lab Phone (Motorola Moto G5S Plus)




(b) Lab Tablet




(c) Phone III (Honor 9)




(d) Phone IV (Xiaomi Mi A3

Figure 11: The difference to the subsequent recording is plotted. All devices should measure a clean sine with 5 Hz. But Comparing four different devices as Bluetooth receiver shows abnormalities. Experiment 1 and 3 display less outliers and hence a smoother signal than the other two devices.

# 11 18.09.2020 - Evaluating Filtering

After implementing on-board filtering (50 Hz narrowband) the performance was evaulated. For this frequencies between 40 and 60 Hz were inserted. The results are displayed in Figure 12. The filtering works as expected. Later we will find out that the filtering as it was produces irregularities in the signal.

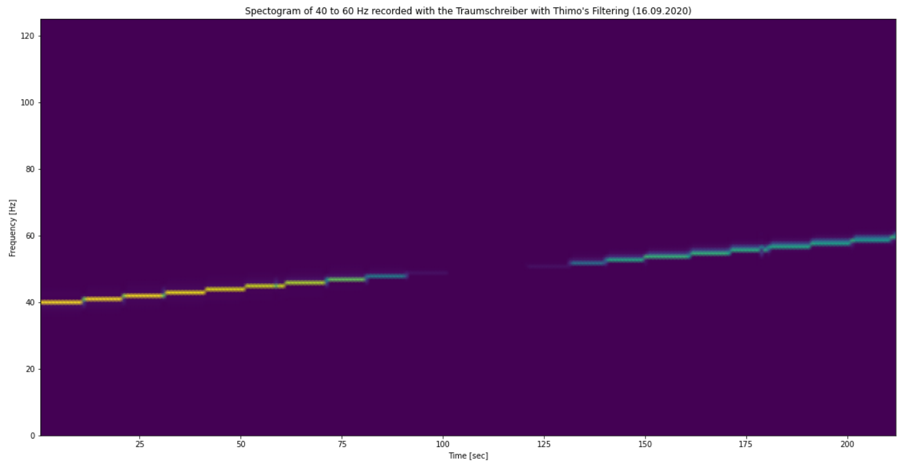



Figure 12: Evaluating the on-board filtering shows that it works as expected.

# 12 21.09.2020 - Signal Quality and Distances

We evaluated the same device with various distances between the Traumschreiber and the receiving device to see whether the abnormalities remain or change.

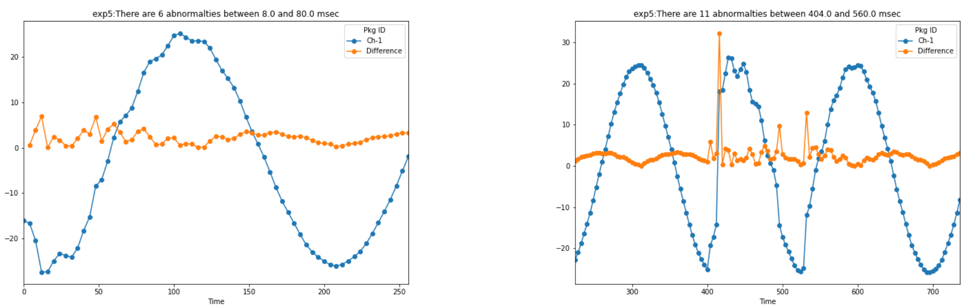
## 12.1 Set-Up

For this experiment the Motorola Lab Phone was used.
Exp1: 5 Hz, 50 mV. Distance 0m
Exp2: 5 Hz, 50 mV. Distance 1.5m
Exp3: 5 Hz, 50 mV. Distance 3m
Exp4: 5 Hz, 50 mV. Distance 5m wall
Exp5: 5 Hz, 50 mV, Distance 8m wall.

## 12.2 Results

An abnormal data point has a larger than ordinary difference to the preceding data point. We also evaluated whether the jumps occur clustered in specific parts or if they occur randomly.
For Exp 1 (0 m distance) and its 4759 measured data points, 0 are abnormal. The ratio is 0.0. The jumps occur in 0 parts of the signal.
For exp2 (1.5m distance) and its 5246 measured data points, 13 are abnormal. The ratio is 0.002. The jumps occur in 7 parts of the signal.
For exp3 (3m distance) and its 3906 measured data points, 1 are abnormal. The ratio is 0.0. The jumps occur in 1 parts of the signal.
For exp4 (5m and a wall) and its 3172 measured data points, 9 are abnormal. The ratio is 0.003. The jumps occur in 4 parts of the signal.
For exp5 (8 m and a wall) and its 2614 measured data points, 113 are abnormal. The ratio is

0.043. The jumps occur in 24 parts of the signal.
Some exemplary plots are displayed in Figure 13.




(a) Irregularities in the beginning of a recording

(b) Irregularities after one large jump

Figure 13: There are many irregularities

### 12.3 Conclusion

The further the receiver is away from the Traumschreiber the more abnormal datapoints occur. The irregularities are probably due to filtering. The filtering relies on preceding datapoints and in the case when there are no datapoints, as in the beginning, the performance is suboptimal. Later irregularities are to some extend as well due to the filtering. But we will discuss this later.

## 13 22.09.2020 - Evaluating Package IDs

In order to find the reason for jumps in the signal and other irregularities, two package ID where implemented. The first, from now on referred to "App ID", is a continuous number (0 to 16 and then from the beginning) that is assigned when a package leaves the board and is send to the receiving device. By evaluating this ID we hope to see whether packages get lost on the way between board and receiver. The app version needed to do this analyse is version 1.07.
The other ID, called "Board ID", count on the board how many packages had to be dropped, due to e.g. full buffers, before a packages was sent.

### 13.1 Set-Up: Inducing the same Signal into Two Devices

The general set up is to induce the signal (5Hz, 50mV) into two Traumschreiber at the same time and record with two devices. The devices were either the Motorola phone, the nRF board or the Honor phone. This way we were able to make sure that a disturbed signal is due to problems in transmission (hardware of the phone/app) and not due to random static noise due to trains/construction/the signal generator.

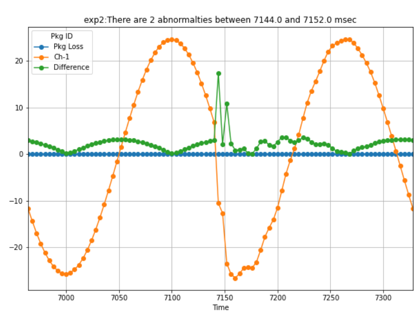
### 13.2 Results

Findings concerning the nRF board as receiver:
The signal was always great, except for some jitter in the beginning ( 150msec). The jitter is due to the on-board filtering. Easy solution for potential problems: Don't record the first second. Can be fixed on board as well.

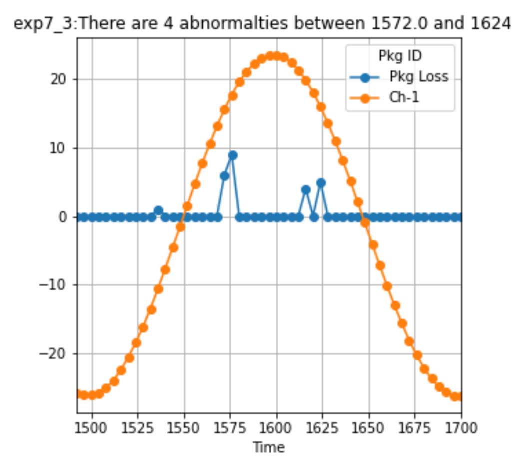
We did not check whether any packages got lost since the information is not available from the nRF board. But the last timestamp in combination with the amount of timestamps and the sampling rate match and the signal looks great as well.

Concerning experiments with a phone as receiver: When the phone is further than 1.5 m away, there are packages lost in transmission. Due to the way the lost package information is encoded/ created it's impossible to say how many packages are actually lost but the following is a rough estimate: 0 m and 1.5m: No Packages lost
3 m: 0.4% are lost
5 m and a wall: 0.5 % are lost
8 m and a wall: 0.6 % are lost
From this we are concluding to stay close to the Traumschreiber with the receiving phone.
Interestingly, comparing two phones, the lab phone and the Honor 9, reveiled that the latter lost 13% of the transmitted packages in this trial.

Another interesting observation was made: when looking at the signal at places a package was reportedly lost, we see that there is not necessarily a jump in the signal. Furthermore, just because the there are no packages lost, the signal does not have to be perfect. So the signal can be good or bad when packages are lost or all there. This is super confusing. Examples in the following Figure 14.




(a) Irregular Signal despite no package loss




(b) High Signal Quality despite apparent package loss

Figure 14: Apparently, the signal can be good or bad when packages are lost or all there. This was a rather confusing realisation.

## 14 25.09.2020 - Turning off Wifi

The bad results with an ordinary phone (here an Honor 9, one that is used and has a Sim-card) are due to mobile data/wifi/hotspot turned on while recording. After doing a 30 minute long time test , the results show that with mobile data and the like turned on 10% of the data points exhibit a large jump and equally many are lost in transmission. With everything except

Bluetooth turned off both drop to 0.01%. Furthermore, we discovered that some jitter is due to the filtering. Since some packages are dropped before they are sent, these packages are not included in the filtering process either. By changing the order, every recording was used for filtering and only dropped afterwards (if at all). This improved the signal. Unfortunately, the mystery "Good signal with package loss/bad without" remains.

# 15 29.09.2020 - Three Characteristics

In order to prepare for a new encoding scheme that will change the available bits, we decided to send the recording via three Bluetooth characteristics instead of one. This dramatically improved the signal quality. In the experiment we tested the lab phone with a Traumschreiber and recorded 150 000 datapoints (15 minutes). There were no missing packages nor jumps.
In a test with 2 m distance between the phone and Traumschreiber some packages got lost (7 out of 150 000) and some jumps (not correlated with the missing packages) occurred as well (0.04% of the data points are irregular).

# 16 08.10.2020 - With three Characteristics to 24 Channels

With the new encoding we were able to activate all 24 channels opposed to 6 in previous versions. The next step was to ensure that all channels work as expected. For this a 5 Hz sine was injected in all channels.

## 16.1 Results of First Trial

In general the signal looks clean but it is not where expected. This means the active channels where the signal was induced into is not the channel it is in the resulting data file. This occurs with different Traumschreiber, similar but still different pattern of shifts are present. Channel 17 seems to be broken as the signal is most of the time flat at 0 mV. During this first trial, we had to restart the Traumschreiber a couple of times. We assume the problems might be reasoned in that. Some changes in the board implementation were made to correct the tracking of which of the characteristics to send the next package on. This corrected the problem, the signal is where it is supposed to be. Only channel 17 does not look right. The reason was found in the wiring of the board and will be changed in the next version of the board. A depiction of an exemplary active channel is given in Figure 15 .

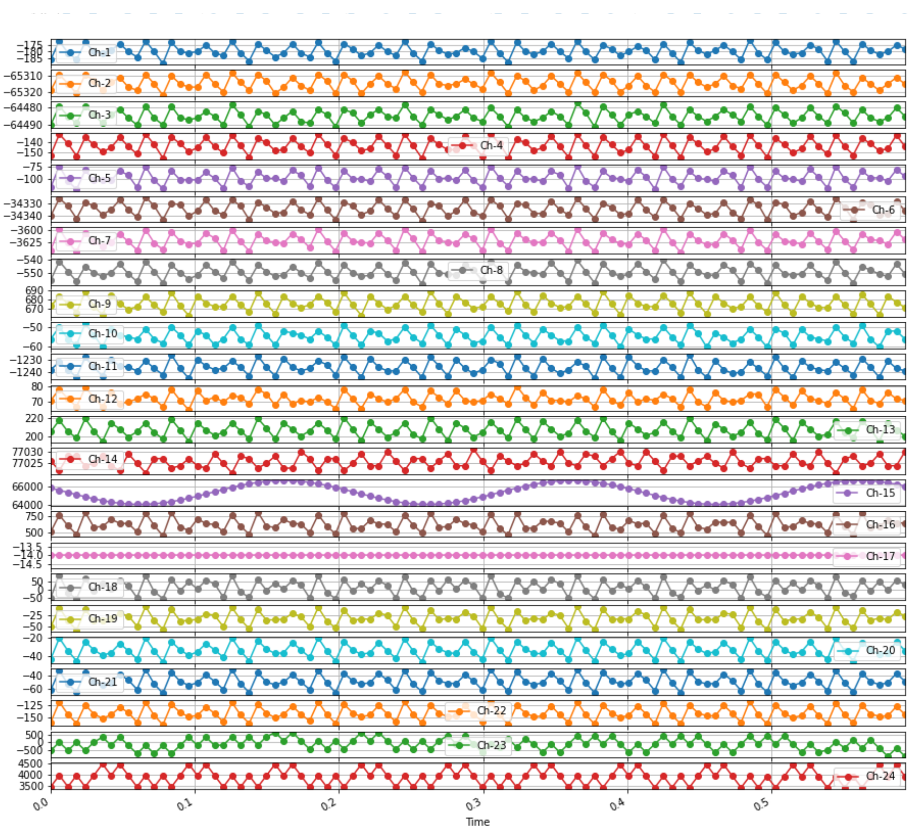


Figure 15: Exemplary active channel when 24 channels are activated. Solely Channel 17 does not work as expected. This will be fixed in the next board version.

## 17 17.11.2020 - Indications

The data is now send with indications instead of notifications - app was adapted to handle it. Encoding: Safe factor is now implemented, the default is 8. At that point it was adjustable via a drop down menu in the app.
Warm-up of 1000 samples was included. During this time the estimation factors are 0.9 and 0.1 (instead of 0.999+0.001). This happens each time a new recording starts (from Traumschreiber perspective).

### 17.1 Safe Factor - What is it?

## 18 24.11.2020 - The Problem with Full Buffer

The device thinks the sending buffer is getting fuller and fuller up to the point were nothing fit in anymore, although the buffer were not actually full. This results in the recording crashing. This might have been due to the interrupt handling was too slow. The solution was to switch back to notifications (instead of indications) and to shorten interrupt handling.
After the changes, the stability is better but the signal still looks unclean (**To Do:** plot $post_notification_fix_10mins.csv).WesuspectabrokenTraumschreiberandFunctionGenerator(becausewiththeoldFGth$
$It'sthecable.Thedamnfreakingcableisbroken,that'swhythesignallooksbadandwelookforerrorsintheimplementationt$

## 19 07.12.2020 - Lab Report

*Anna finishes her Lab Report on Safety Factors, something, something and something. To get the report, contact Laura. The results are summarised in the following:* ***TO DO: Summarise the results***

## 20 08.12.2020 - Function Generator

*We try to get the Function Generator fixed but the communication with the company is rather slow and we do not get a result.*

## 21 08.01.2021 - Reading the Battery Status

*The board can now send the battery status to the app. To get the battery status one has to read out the config-characteristic, when there is no recording running and check the last two Bytes. This contains a 12 Bit value which we still need to figure out, how to interpret. The value is updated each time something connects to the TS and also every time one stops a recording (commit on the 22nd of January).*

## 22 19.01.2021 - Katharina Lüth, the New PhD, and a new Function Generator

*Katharina is working with nightmares (like literally, not us, we're ok, I guess) and contributes to an app tackling them. For her research she is is interested in using the Traumschreiber at some point. We got a new function generator. It's new and beautiful.*

## 23 22.01.2021 - Timeout and Slow Down Issues

*The afore noticed timeout and slowdown issues were pinpointed to a certain commit. One assumption was that it might have something to do with the forth characteristic even if nothing is send over it.*
*The slow down was tackled in the following way: a bugfix on another problem led to the code having only one instance of trying to send out the BLE packages. This instance, however, would*

*not be triggered once the buffers were full and the buffers would never get emptier resulting in a dead lock. With the NRF-boards this never occurred, since they seem to acknowledge the BLE packages more regular, while the Android devices sometimes stack up some backlog until they work it of, eventually the backlog is of the size of the buffers and the dead-lock occurs.*

# 24 03.02.2021 - To Filter or Not To Filter

*To tackle the still suboptimal signal we implement filters and test them. These results are reported in Sanity Check - Filtering or Without Filtering (1.2.21), too.*

## 24.1 Experimental Setup

*Channel 1, 8, and 24 of Traumschreiber 3, 4 (Internal Reference, Pairwise Difference), and 7 (External Reference, Common Reference) are tested. Each Traumschreiber is tested with a 5Hz, 5mV signal. The test are repeated with I) filter-on image and II) filter-off image. To test leakage and frequency neighbouring effect III), a signal is induced into Traumschreiber 4 (with filter-on) and Traumschreiber 7 (filter-off) into Channel 8 and 9 (10 Hz, 5 mV).*

## 24.2 Results

***To Do: Include the images from Sanity Check - Filtering or Without Filtering (1.2.21)***

## 24.3 Conclusion

*Applying a lowpass filter only has a good effect on an original signal (**What do you mean with original signal?**) with cut-off lower than 30Hz. A 50 Hz cut-off lowpass filter has a small effect on the raw signal. In comparison, the filter-on or filter-off image on the Traumschreiber board (**Which board number?**) has no apparent effect on improving our signal. We conclude that the code has to be checked again. In regard to the neighbouring effect, we are not able to make a conclusion. The different performance might be due to one being pairwise-difference set-up (TS4, resulting in a worse performance) and the other a common-difference and not due to their different filter images. Further more conclusive tests have to be performed.*

# 25 04.02.2021 - Filter Coefficients

*For the filtering to work as expected, the sampling rate has to be constant. Furthermore, the filter coefficients have to be appropriate for the sampling rate. This in mind, we make sure the sampling rate is constant. The filter coefficients used are for a sampling rate of 167 Hz (500/3).*

# 26 04.02.2021 - !Important! - Internal and External Reference

*We made a mistake and labelled all internal references as external and vice versa. Please be aware that therefore the naming in all reports prior to this date is incorrect!!!*

# 27 - Yet another frequency analysis

*t9-sweep-40hz-60hz-ch1-4mv-2s-each*