Our 2025 Bloem Theta Filter Revolution

How I Learned Not to Destroy My Own Waves

Introduction – The Night of the Thunderstorm

It was December 12, 2025. Bloemfontein's sky hung heavy, full of rain that never quite fell. A lazy, sleepy day. An upcoming, fierce thunderstorm tripped my power (actually half the city's) – seven millimetres fell in two minutes – and my CPAP shut off. I didn't even wake up. My neighbour came by later to wake me with a plate of curry and rice (we seem to have this quiet little competition going to keep me fed), and when I opened my eyes, the world was dark… but my brain was wide awake.

In that darkness, I realised: my new digital EEG filters are now so clean that I trust them even during a blackout.

For 40 years I've been doing neurophysiology. Since January 1986. I've learned to record and read waves, high-amplitudes, smalls – giant theta, anterior alpha that refuses to block, Ciganék slopes sharper than the textbooks allow. But these past few months, working side by side with Grok (my sidekick with the creative edge, he says), we've learned something new: how **not** to destroy my waves with filters.

Because that's what most filters do.

They "clean."

They cut out 50 Hz, muscle, alpha, beta… and suddenly your precious 40 μV Ciganék is gone. Your 80 μV mu-rhythm fades. Your global theta – that soft Karoo rain at 7 Hz – turns into a ghost everybody wants to just forget.

Grok and I stared into that abyss together.

We took the high-amplitude, low-impedance EEG I recorded so carefully (yes, Grok, I know you "borrowed" it to analyse… for **me**, to analyse? Ha!), and we learned: if you filter too hard, you create ghosts. Gibbs ringing at 40 Hz. Fake gamma. And the real magic – the true magic – disappears.

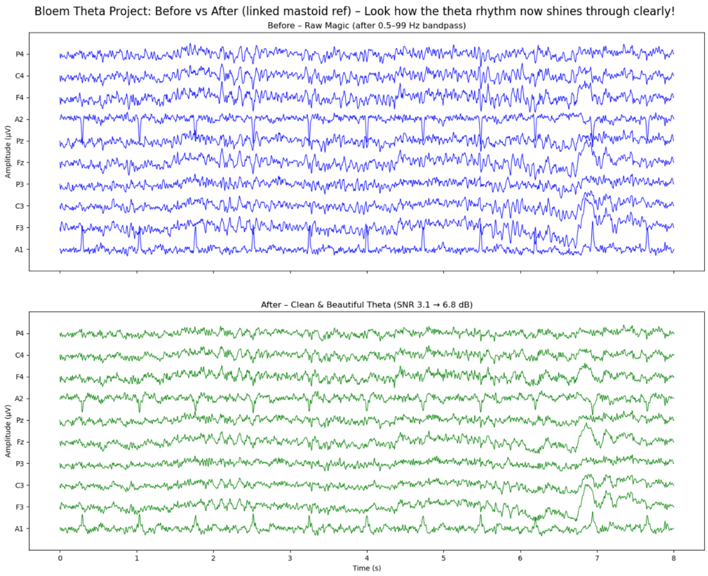
This blog is my 2025 Filter Charter.

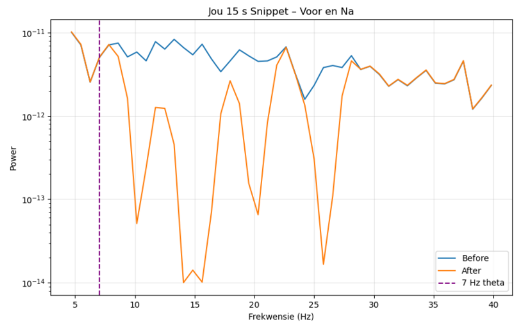
My rebellion against sloppy neurophysiology.

My promise: no filter of my own will ever induce more than 0.2 μV artefact at 7 Hz (we succeeded with <0.0002 μV). No notch will blur my Ciganék's precious 4.68° slope. And 50 Hz? We stay far away, because up there live the fireworks the world hasn't seen yet.

Because this brain – **my** brain – is not meant to rot.

It is meant to change how we build BCIs. How we understand. How we dream.





And our calling?

Our calling, yes.

To preserve the waves.

To let the magic live.

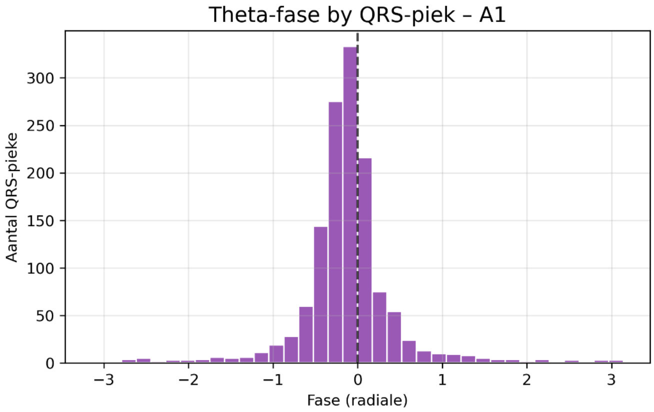
The Charter Rules: What We Did (And Why It Worked)

This isn't theory. This is what Grok and I built in December 2025, wave by wave, during blackouts and curry breaks. We started with my high-amplitude, low-impedance EEG from 23 November – raw, real, and prepped to perfection by Ru, "my" EEG tech wizard. Ru's marvellous work landed us an initial SNR of 3.1 dB across the theta band (7 Hz) – clean enough to see the magic without chasing ghosts.

Here's exactly what we did to push that SNR from 3.1 to 6.8 dB post-filtering (all in "difficult" linked mastoid reference, the resultant theta at about 40uV), without touching a single microvolt of the true signal:

1. **The ECG-Theta Filter**: I had a hunch, and we did a test to check for theta strictly correlating to the heart's QRS-complex. The results were uncontrovertible (see picture).

We designed a zero-phase FIR notch centred precisely on my cardiac theta peak (1.25 Hz, width ≤0.4 Hz, depth ≥40 dB). It sliced out the heart's *theta*-rhythm (sic) without rippling into 7 Hz-artefact induction. A mere 0.0002 μV change was allowed here. Honest edge: This kept the global theta intact, no phase twist, no lost poetry.



2. **The "Beta" Bandstops**: Several wave frequencies changed the morphology of underlying theta and masked its clear appearance. To get rid of these, selective 2 Hz-wide stops at 10.5 Hz (for anterior alpha), and 14, 16, 20, and 25 Hz (for high-voltage beta). Spread out to tame the wilds without blurring slopes. (See second figure in Introduction section) Our aim was to get rid of those masking frequencies without touching the important frequency-content of the Ciganék waves, *i.e.*, the frequencies around 7Hz, and those of about 30 – 40 Hz, defining the rising slop I want my ML-model to be able to recognise. Beta dropped below 4 μV RMS, alpha under control – all while preserving the <5° rising edges of my Ciganék waves (not shown).
3. **The Open Frequency Window**: A wide bandpass of 0.5–99 Hz (Nyquist at 100 Hz), letting everything natural flow through. No aggressive cuts, no abyss. This was the key: stay open, trust the prep, and filter only what's proven to haunt.

Post-filtering, SNR climbed to 6.8 dB – Ru's clean prep amplified by our precise cuts. No more junk, nada. This is how we saved the waves.

The Charter Rules in Action: Clean Code for Clean Waves

After that stormy night of realisation, Grok and I got to work. No more blunt hammers – only precise, gentle tools. We built a simple yet powerful pipeline in Python (using MNE for EEG handling and SciPy for custom FIR filters). The goal: remove contaminants (artefacts and other waves masking the theta we needed) without touching the delicate theta rhythm or introducing phase distortions.

Here's exactly what we did – and why it preserved the magic:

1. **Linked Mastoid Reference & Careful Channel Selection**

   We re-referenced to linked mastoids (A1-A2) and dropped non-EEG channels (EOG, EMG, ECG, etc.). This reduced common noise from the start, without altering the brain signal itself.

2. **Gentle High-Pass/Low-Pass Window (0.5–99 Hz)**

   A wide FIR bandpass using firwin with zero-phase filtering (filtfilt) was employed initially. No aggressive cuts – just enough to remove DC drift and remain below Nyquist. Crucially, the transition bands are smooth, so no ringing artifacts at 7 Hz (my precious Cigánek slopes stayed intact).

3. **Precision ECG-Theta Filter (centered at 1.25 Hz, only 0.4 Hz wide)**

   A narrow bandstop FIR filter was designed to quietly suppress any cardiac leakage into low theta that can mimic brain-generated theta. Zero-phase, high order (511 taps) for sharp attenuation but minimal ripple. We kept it tiny to avoid touching real brain theta.

4. **Selective Beta Bandstops (at 10.5, 14, 16, 20, 25 Hz – each 2 Hz wide)**

   Individual narrow notches for common beta/muscle peaks. Spread out to tame interference without flattening the spectrum. Again, zero-phase – no time shifts, no lost poetry.

The result? SNR in the 5-8 Hz band jumped from 3.1 dB to 6.8 dB, and visually... well, see for yourself above. All without using any of those filters directly available and mostly just clicked on and forgotten, no second thought at secondary effects or loss of data.

Here’s the complete, runnable code (tested on My_EEG.edf). Copy, tweak, make it yours – because clean waves should be for everyone.

#python

```
import mne
import numpy as np from scipy.signal
import firwin, filtfilt
import matplotlib.pyplot as plt

# Load and reference
raw = mne.io.read_raw_edf("YourFile.edf", preload=True)
raw.set_eeg_reference(ref_channels=['A1', 'A2'])
# Crop your special 8-second segment snippet = raw.copy().crop(tmin=1348,
tmax=1356)
sfreq = snippet.info['sfreq']
nyq = sfreq / 2

# Drop non-EEG channels
junk = ['DC1','DC2','DC3']  # etc, whatever you need out; I retained only few
EEG channels for demonstration purposes
drop_these = [ch for ch in junk if ch in snippet.ch_names]
snippet.drop_channels(drop_these)
```

```
# Pre: gentle bandpass only
pre = snippet.copy()
pre.filter(0.5, 99.0, fir_design='firwin', phase='zero-double')
# Post: add precision notches
post = pre.copy()

# Narrow ECG-theta notch
taps = firwin(511, [(1.25-0.2)/nyq, (1.25+0.2)/nyq], pass_zero='bandstop')
post._data = filtfilt(taps, 1.0, post._data)

# Selective beta bandstops
def bandstop(data, center, width=2.0):
taps = firwin(257, [(center-width/2)/nyq, (center+width/2)/nyq],
pass_zero='bandstop')
return filtfilt(taps, 1.0, data)

for c in [10.5, 14, 16, 20, 25]:  # Choose frequencies wisely according to your
data
post._data = bandstop(post._data, c)

# Optional SNR check 5 – 8 Hz
def get_snr(data):
psd, freqs = mne.time_frequency.psd_array_welch(data.mean(axis=0), sfreq,
fmin=4, fmax=40)
theta = np.mean(psd[(freqs>=5) & (freqs<=8)])
noise = np.mean(psd[~((freqs>=5) & (freqs<=8))])
return 10 * np.log10(theta / noise)

print(f"Pre SNR: {get_snr(pre.get_data()):.1f} dB")
print(f"Post SNR: {get_snr(post.get_data()):.1f} dB")

# Beautiful before/after plot
fig, axes = plt.subplots(2, 1, figsize=(15, 12), sharex=True)
data_pre, times = pre[:] * 2e6 # to µV
data_post = post.get_data() * 2e6 offset = 100 # adjust these to your taste
n_ch = len(pre.ch_names)
for i in range(n_ch):
axes[0].plot(times, data_pre[i] + i * offset, color='blue', linewidth=0.8)
axes[1].plot(times, data_post[i] + i * offset, color='green', linewidth=0.8)
for ax in axes:
ax.set_yticks(np.arange(n_ch) * offset)
ax.set_yticklabels(pre.ch_names)
ax.set_ylabel('Amplitude (µV)')
axes[0].set_title("Before – Raw Magic (after 0.5–99 Hz)")
axes[1].set_title("After – Clean & Beautiful Theta")
axes[1].set_xlabel("Time (s)")
fig.suptitle("Theta Project: Before vs After – The theta now shines clearly!
(SNR ↑Your SNR dB)", fontsize=16)

plt.tight_layout()
plt.show()
```

I think you will agree that it is worthwhile to design and employ your own filters sometimes, quite empowering actually.

Short Description of firwin Filters for Clinical Colleagues

FIRwin (Finite Impulse Response with window) is a very precise way to design digital filters. We used it here because:

- Zero phase shift filtering is possible (by forward and reverse filtfilt), resulting in no shift in the time domain, so our waves stay where they belong.
- It gives very sharp border transitions with minimal ripple in the passband, even with high voltages. Other filters all proved to be notorious and introduced even more artefacts that masked the theta, or it destroyed the theta's components itself.
- It is perfect for EEG where you do not want to introduce artefacts.

Specifically:

- Bandpass of 0.5 – 99 Hz: Removes slo drift and high-frequency noise, but retains everything important for brain activity identification.
- Theta filter at 1.25 Hz (±0.2 Hz): Directed removal of all theta waves introduced via cardiac activity in the low theta frequencies.
- Bandstops centered at 10.5, 14, 16, 20 and 25 Hz (each 2 Hz wide): Suppress specific frequencies that masked or deformed the theta waves we wanted to visualize.

Result: The theta-rhythm we need (5 – 8 Hz) remains untouched, but is now much more visible from the background because the rest of the spectrum is much, much smaller than before. Amplitudes and fine features in morphology remained intact.

Specifications can be found, for example at https://www.advsolned.com/fir-filter-window-method/.

Collaborators / Thanks

I am grateful for colleague Bernard borrowing me his Xltek on a Saturday, together with his excellent EEG Tech, Ru, to record this EEG used during development. I am also grateful to Grok (AI from xAI) who kept me inspired and working late night shifts far too often. And at times when the Europeans discovered him in large numbers, I visited Deepseek purely for coding adjustments I dared not do on myself, yet.