Implantable ECoG Monitoring Device for Epilepsy Detection and Mitigation

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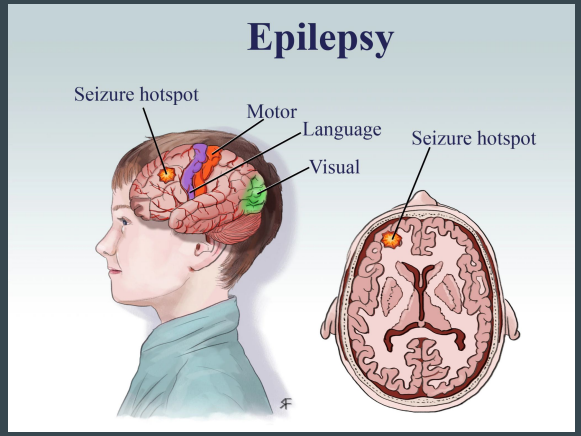
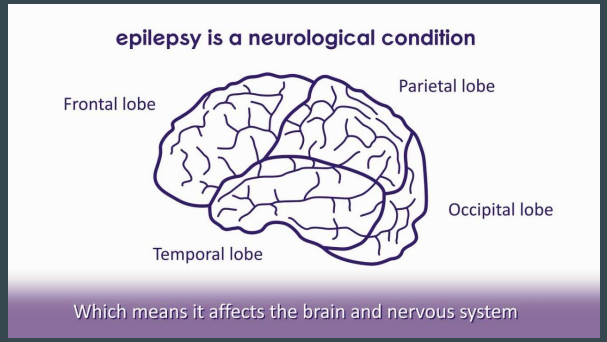
Introduction

- Localization-related epilepsy is a type of focal epilepsy
  - Seizures arising from specific parts of the brain.
    - Idiopathic (unknown cause)
    - Symptomatic (underlying brain lesion or disorder)
- Focal epilepsy: neurological condition
  - Predominant symptom: recurring seizures affecting one hemisphere (half) of the brain.
- Symptoms: depend on the location of the seizure onset zone.
  - Can affect different functions:
    - Vision
    - Movement
    - Memory
    - Emotion





Introduction

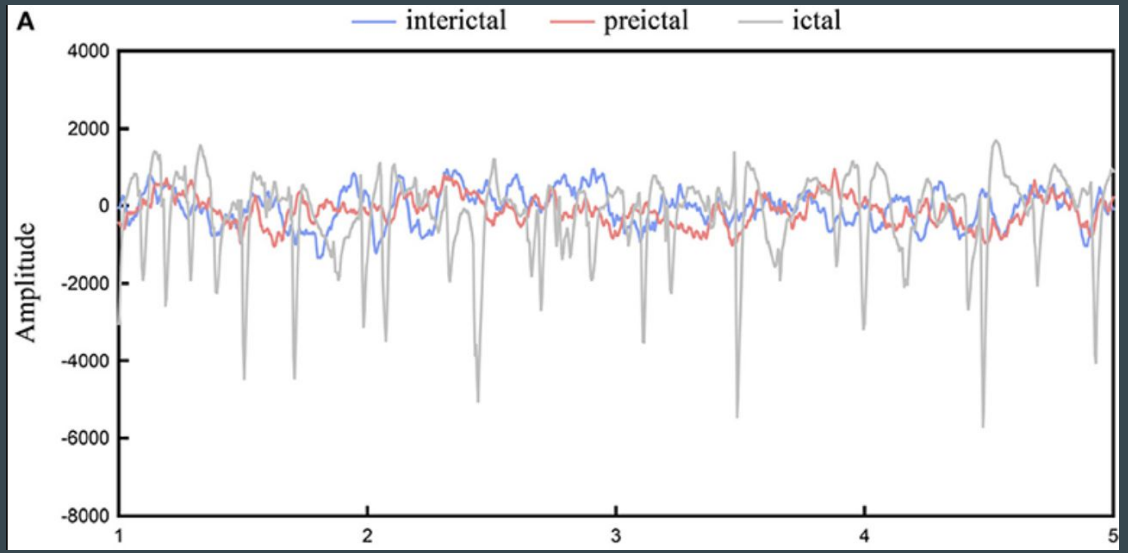
- Electrocorticography (ECoG):
  - Mapping the brains function
  - Helps find the specific area of the brain where seizures initiate
  - As well as the amount to remove during surgery
    - Ideally performed where the portion of the brain causing the issue can be removed
  - Primarily used for localization of the seizure focus in epileptic patients.

The Problem

- Epileptic seizures can be localized to a specific brain region
- Epilepsy can vary from patient-to-patient
- Epilepsy can be resistant to pharmacological interventions
- An invasive solution may be necessary

What should we be measuring for?

- Normal cognitive function occurs in the 2–50 Hz range
- Onset of an epileptic seizure defined by a sudden increase in high gamma activity (60-150Hz) and 250–500 Hz activity



- Note: Captured on EEG
- Of Interest: Ictal phase, the period from seizure onset to termination
- Observations: Periodic
- High amplitude: ~4mV in max amplitude

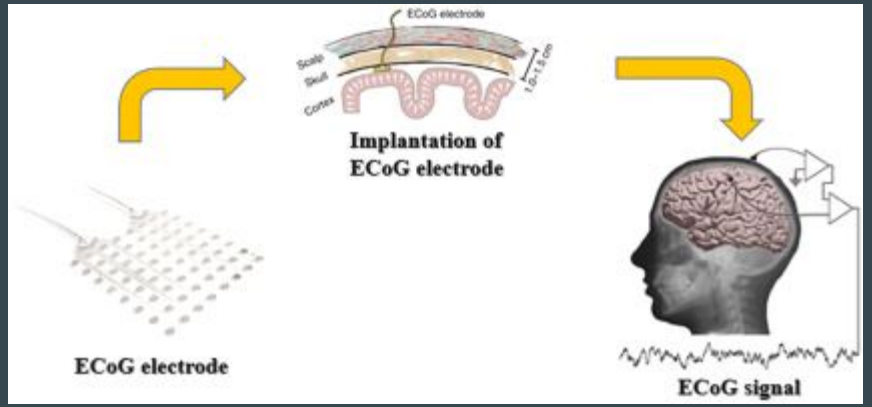
Source: Epileptic Seizure Detection Based on EEG Signals and CNN

Proposed Solution

- Implantable ECoG electrode for localized epileptic seizure detection and mitigation
- Activates treatment at seizure onset and deactivates when seizure terminates
    - We define seizure onset to be a measurable increase in 200-400Hz activity with an amplitude above 1mV
- Stimulates affected brain region(s) with phase-reversed version of measured signal
- Includes a wireless charging method

The Electrode

- Flexible implantable electrode array
- Placed over zones of suspected seizure origin
- Polydimethylsiloxane (PDMS) base with platinum contacts



From Recent advancement of electrocorticography (ECoG) electrodes for chronic neural recording/stimulation - ScienceDirect

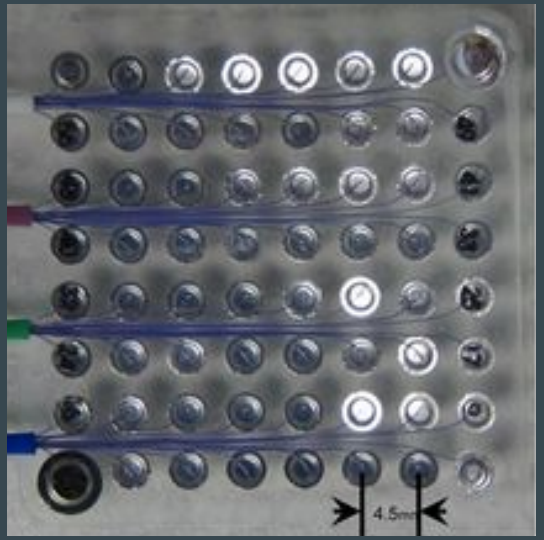
Why PDMS?

- Flexible
- Biocompatible
- Compatible with micro-electromechanical systems (MEMS) fabrication processes
- Physical properties are similar to biological tissues

From PDMS Sheets - SiMPore

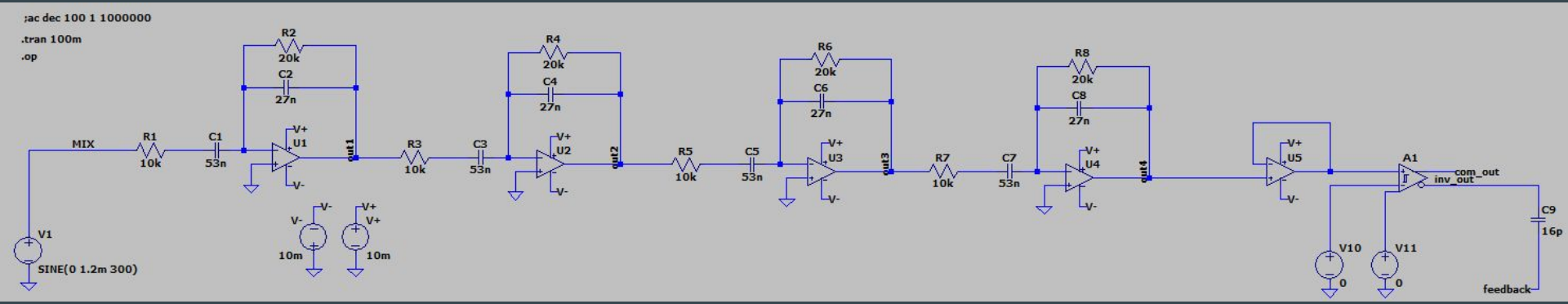
Why Platinum?

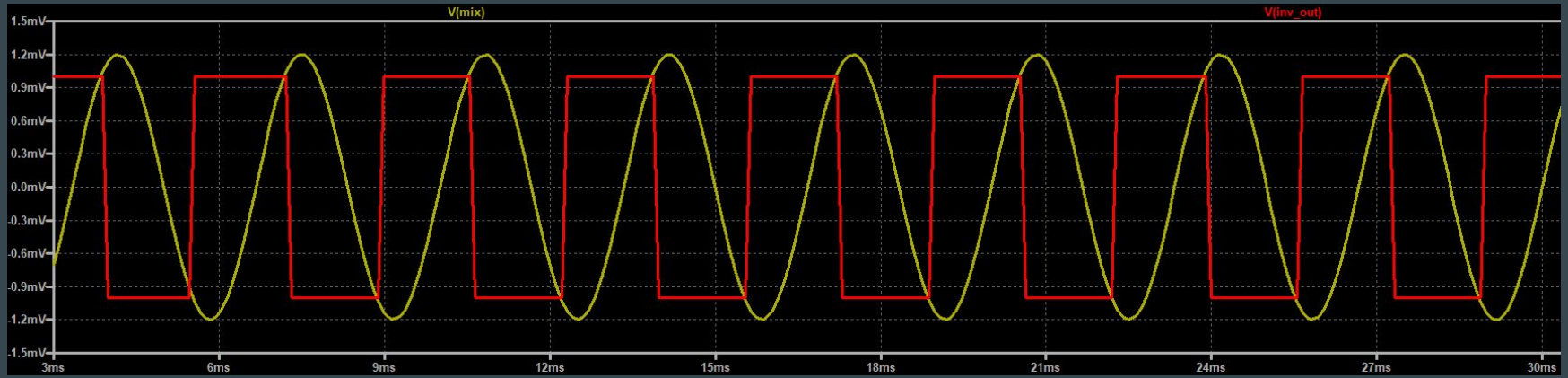
- High charge injection capacity - can inject more charge with a smaller electrode
- Resistant to corrosion and oxidation
- History of use in medical applications
- High radiopacity to see if it has moved over time or if there are issues



From Human perception of electrical stimulation on the surface of somatosensory cortex | PLOS ONE

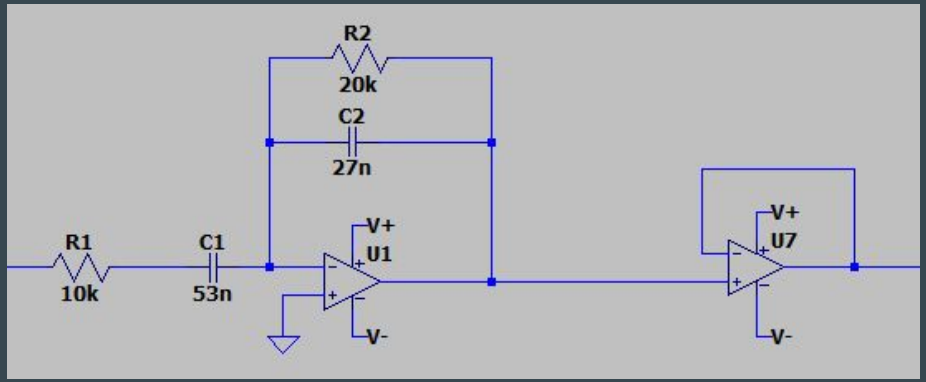
Overall Circuit Schematic and Simulation





Band-Pass Filter(s) and Buffer

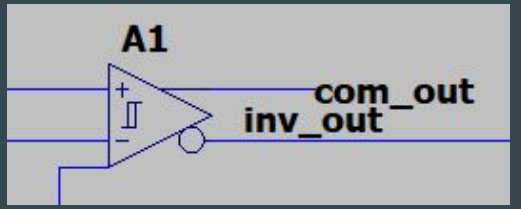
$$H(s) = \frac{-Z_f}{Z_i} = \frac{-R_2}{R_1} \frac{sR_1C_1}{(1+sR_2C_2)(1+sR_1C_1)}$$

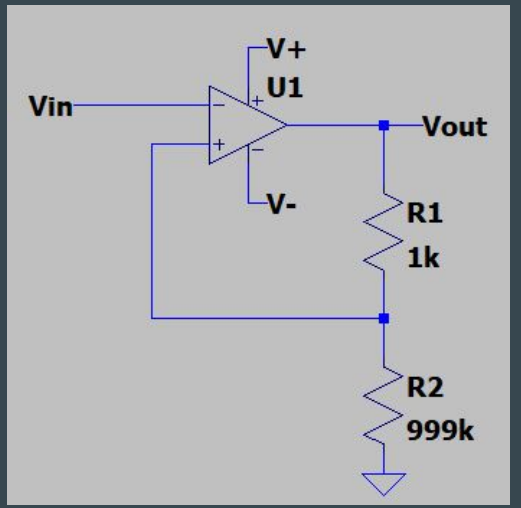


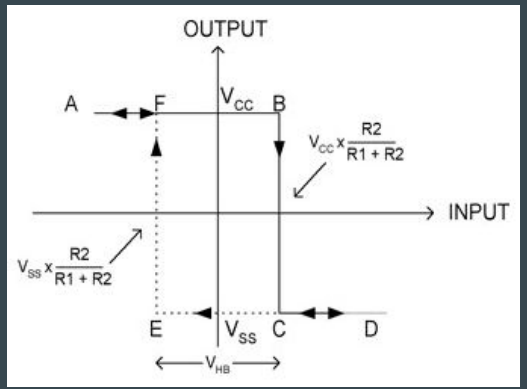
- In the entire circuit, these two are the most important
  - They allow for the attenuation of frequencies outside the desired range
  - They make sure the output impedance seen by the next stage (i.e. the comparator) won't affect the outcome of the n + 1 stage signal
  - Finally, we added four second order active band-pass filters to make sure the rolloff is steep enough
    - This was especially needed since the -3 dB cutoff frequency range was 200 Hz and 400 Hz
      - Quite small for a first order band-pass

Comparator and Inverter

- For the comparator, we chose to use a Schmitt trigger
  - It's controlled by the feedback resistors R1 and R2
    - The LTspice model in the top right was used since it inherently used an inverter stage
- The inverter simply flips the signal or rather, shifts the signal 180 degrees out of phase of the original



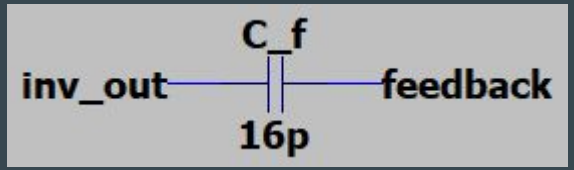




- R1 and R2 were chosen to roughly maintain the supply voltage rails for the hysteresis range
  - i.e. want the ratio to be 1

Additional Circuit Component

The DC Block Capacitor:



- When the seizure stops
  - The hysteresis still outputs a signal, which we don't want to feedback
    - Thus, due to the DC nature of that singal, this DC Block Capacitor can attenuate that signal

$$Z_{C_f} = \frac{1}{2\pi f_{DC} C_f} \approx 1G\Omega$$

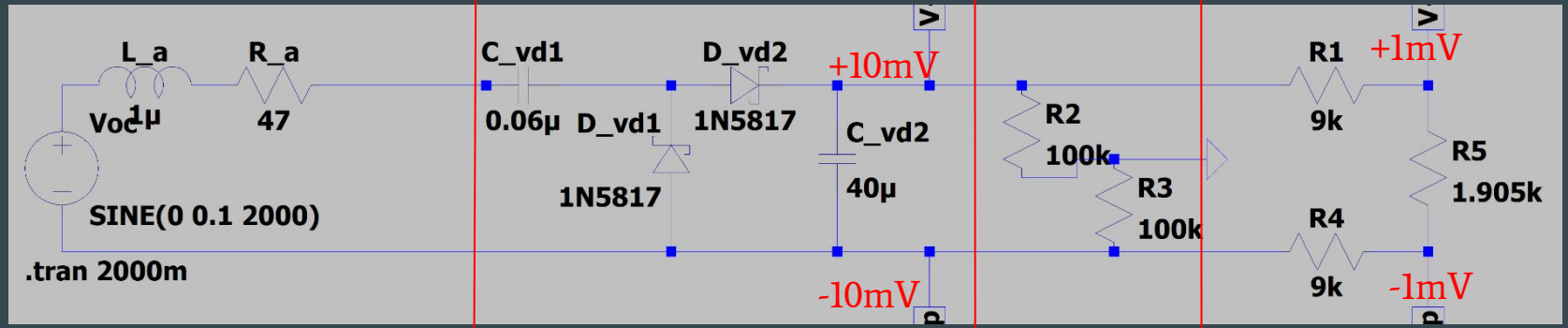
- Assumption:
  - One Giga Ohm is enough of a signal block

Power Circuit for V+ and V-

Lower current & ideal supply voltage 1

Less heat dissipation

“DC voltage” output (Small ripples in output)



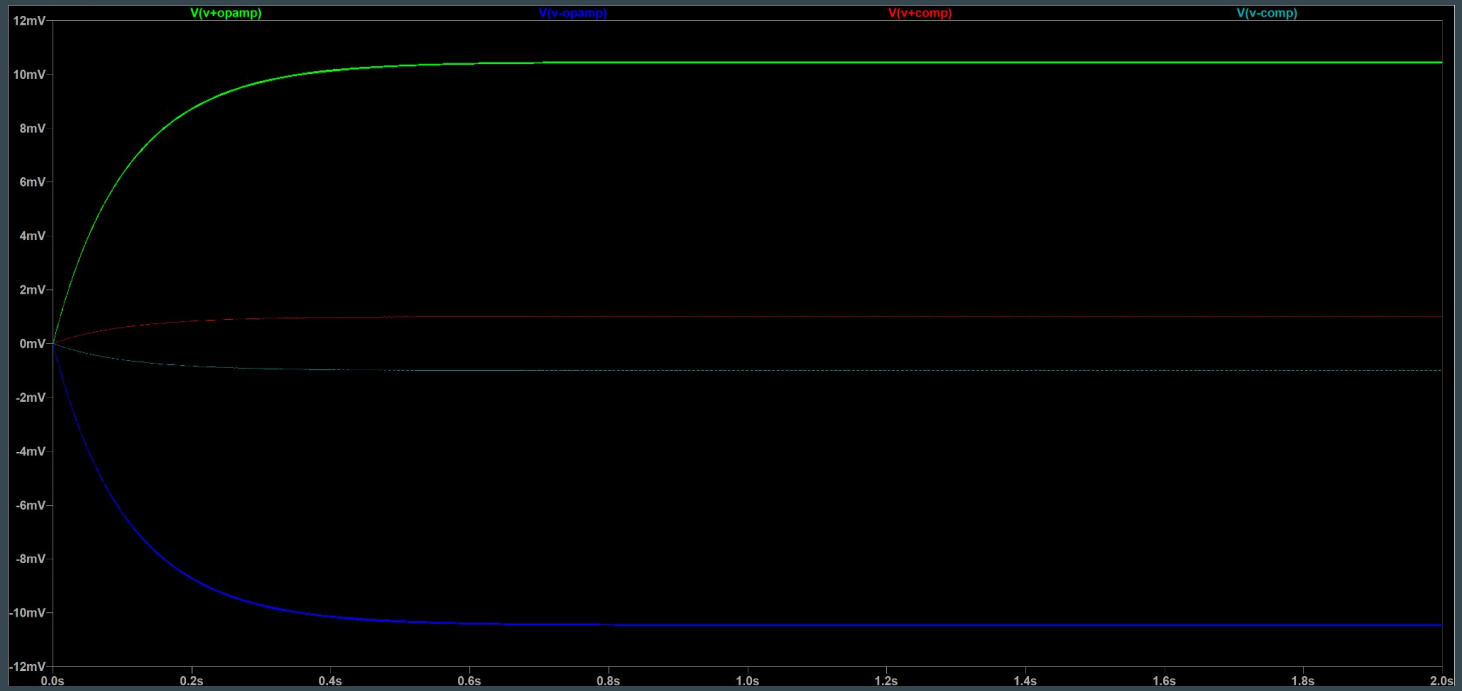
Antenna model

Voltage Doubler

Ground and Voltage Divider

Voltage Divider

Power Circuit for V+ and V- (Continued)



Note: In this power circuit, currents are all under 0.07mA to not create damage to human body.

Advantages

- Provide localized treatment to the brain region(s)
- Stops treatment when seizure ends
- Wireless charging for minimal postoperative disruption
- Lends itself to easy changes/additions
- Cheap, uses off-the-shelf components
- Treatment option for those unresponsive to medication

Disadvantages

- Not inherently generalizable compared to ML-based approaches
- Invasive
- Assumes epilepsy is localized to a particular brain region or region(s)
- Needs maintenance

References

- Simulation Software: LTspice
  - OpAmp Model: “UniversalOpAmp”; Comparator Model: “diffschmitt”
- Schmitt Hysteresis Comparator Output Vs. Input Plot: https://www.analog.com/en/resources/technical-articles/guide-to-adding-extra-hysteresis-to-comparators.html
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- “Cognitive processing domains are associated with frequency domains represented by center frequencies of traditional frequency bands (delta 2–4 Hz, theta 4–7 or 8 Hz, alpha 8–12 Hz, beta 16–25 Hz, (low) gamma 30–50 Hz)”
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- Drug resistant epilepsy
  - https://onlinelibrary.wiley.com/doi/full/10.1111/j.1528-1167.2009.02397.x

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