Normalized Cross Correlation:

$$NCC = \cos\theta = \frac{ab}{|a||b|} = \frac{\sum_{i=0}^{N} a_i \cdot b_i}{\sqrt{\sum_{i=0}^{N} a_i^2}\sqrt{\sum_{i=0}^{N} b_i^2}}$$

$\cos\theta$ = [-1,1]

Link:
https://www.sciencedirect.com/topics/computer-science/normalized-cross-correlation

Standard Deviation:

$$sD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

x_i are the data points,
μ is the mean of the data,
N is the total number of data points.

Therefore, Normalized Cross correlation formula for the two signals:

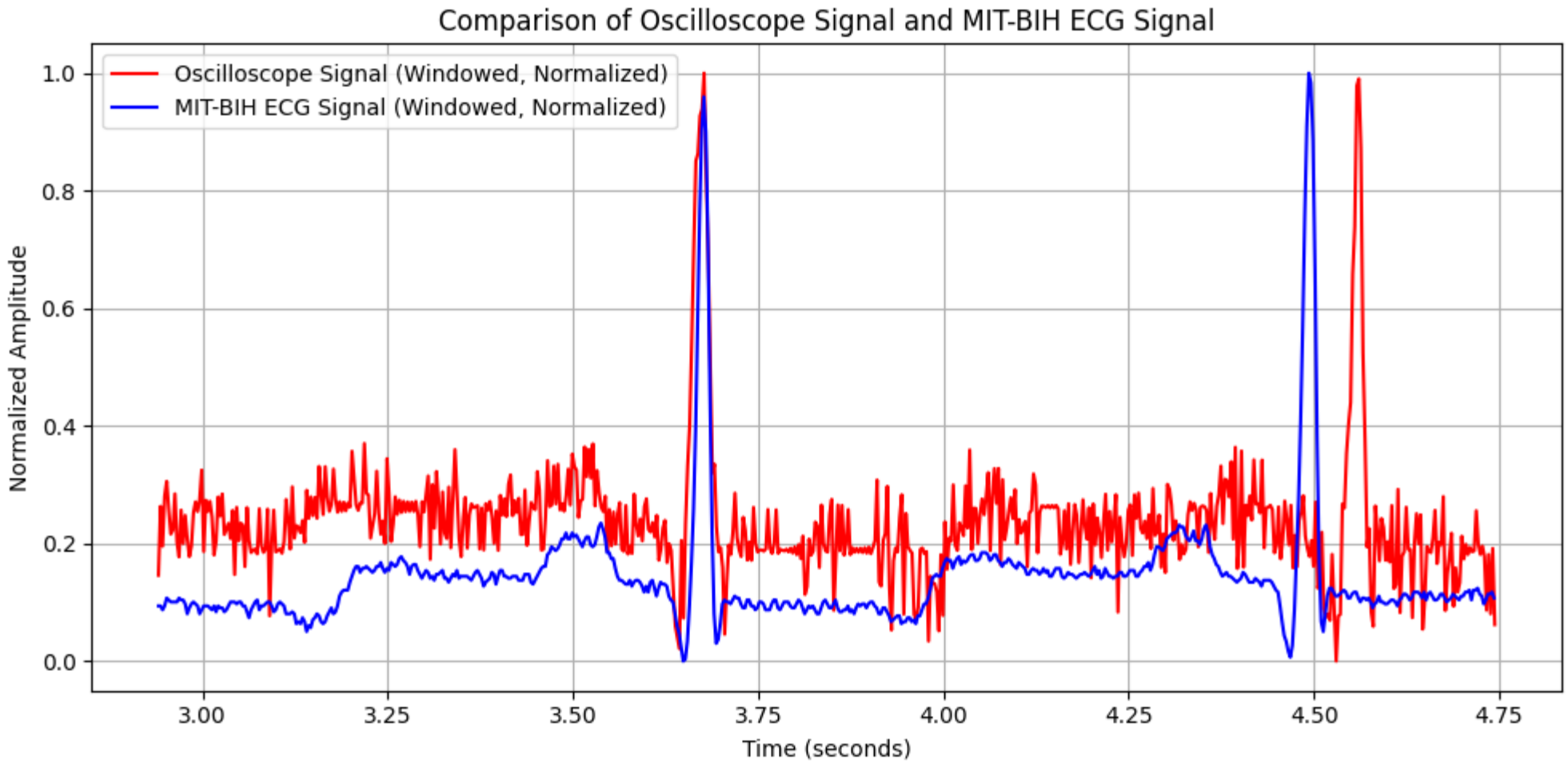
$$NCC = \cos\theta = \frac{\sum_{i=0}^{N}(x_i-\mu)\cdot(y_i-\mu)}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^2}\sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i-\mu)^2}} * \frac{1}{N}$$

x_i are the ECG signal values, y_i are the oscilloscope signal values
μ is the mean of the respective values,
N is the total number of samples in the oscilloscope signal window.

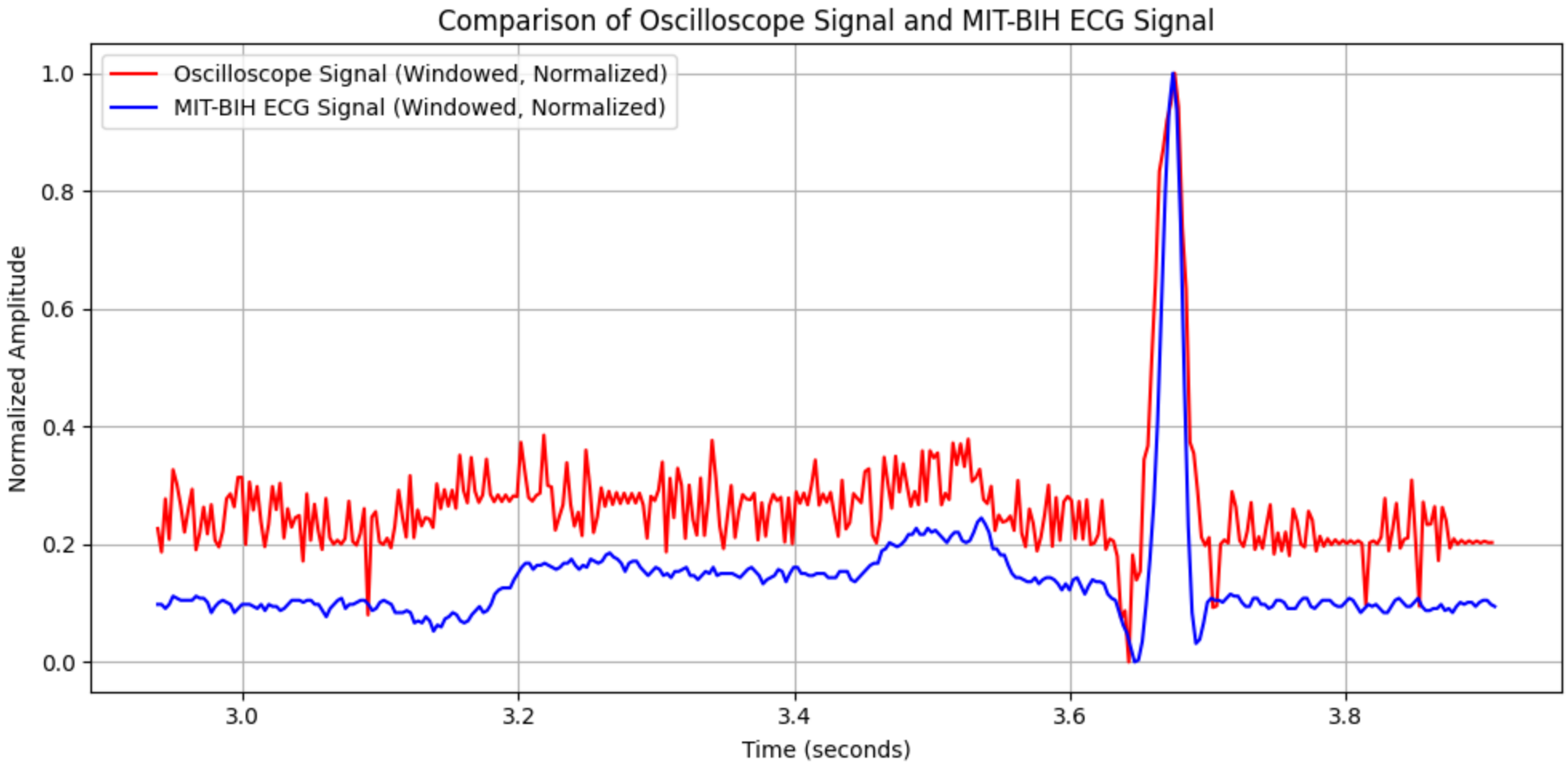
Ideally, $NCC = 1$

$$\% \text{ Error} = \left(1 - \frac{Actual \quad NCC}{Ideal \quad NCC}\right) * 100$$

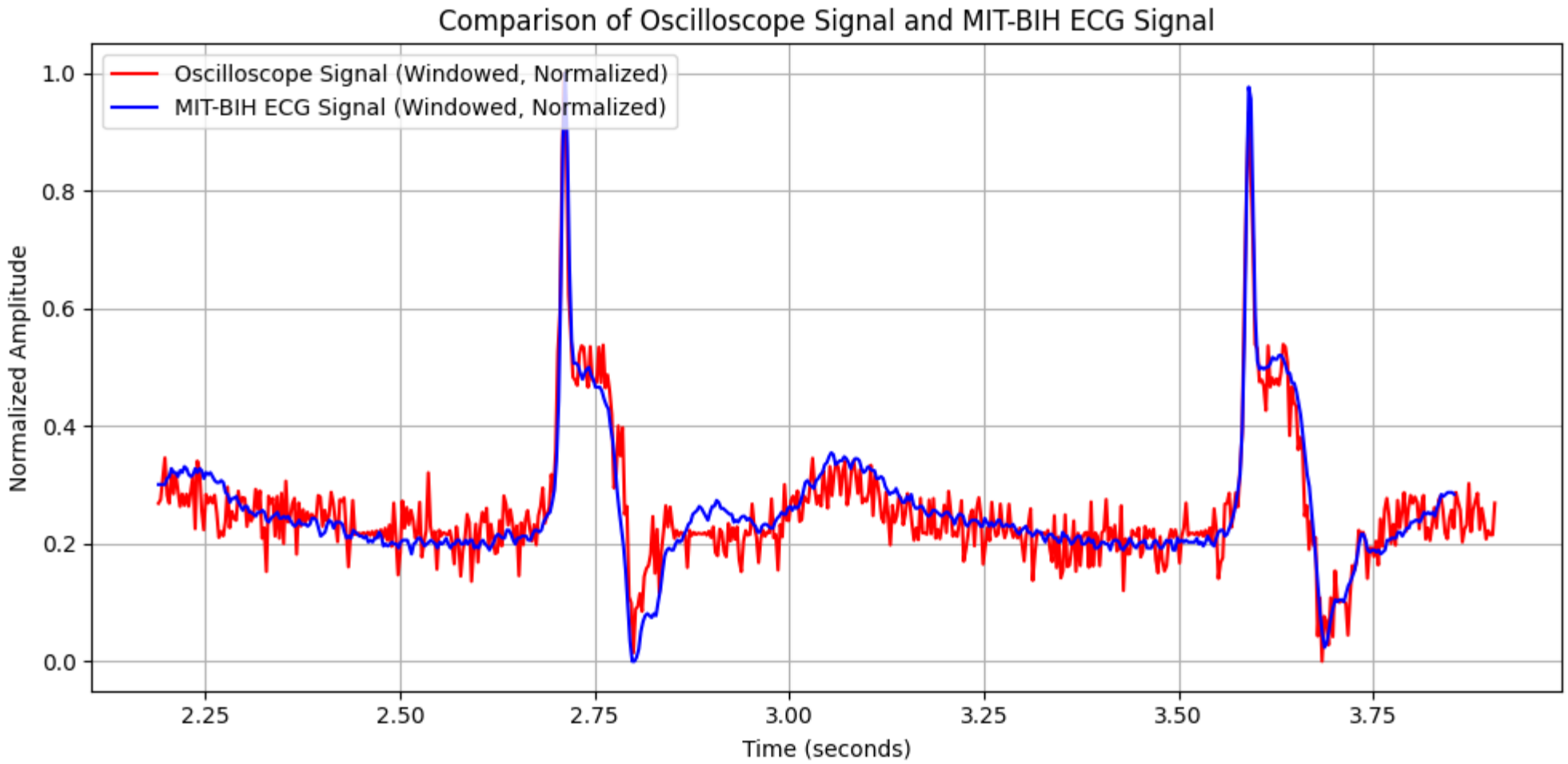
Patient 100 – Without Filter `Normalized cross-correlation value: 0.482490`



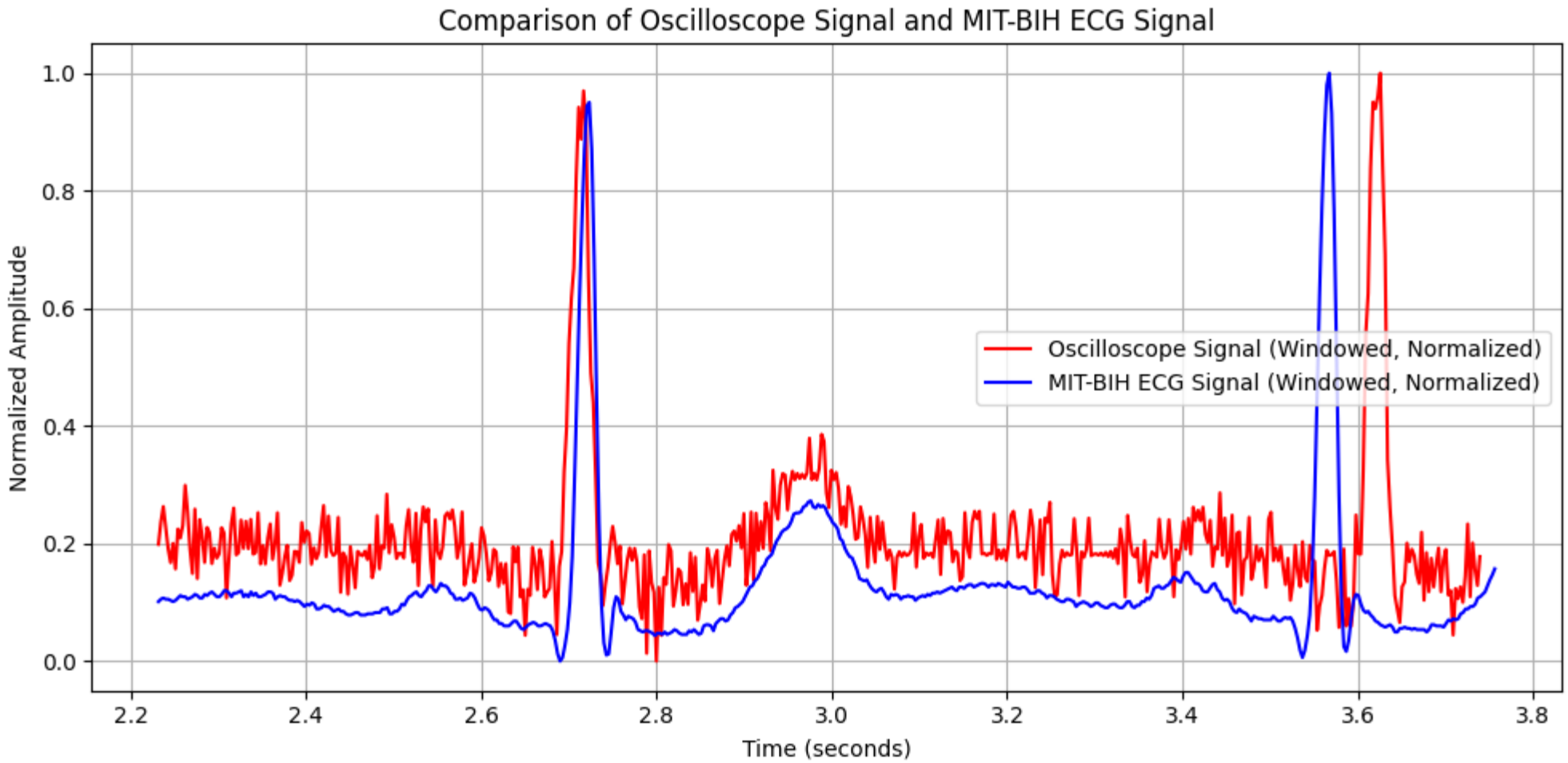
Patient 100 – Without Filter `Normalized cross-correlation value: 0.865190`



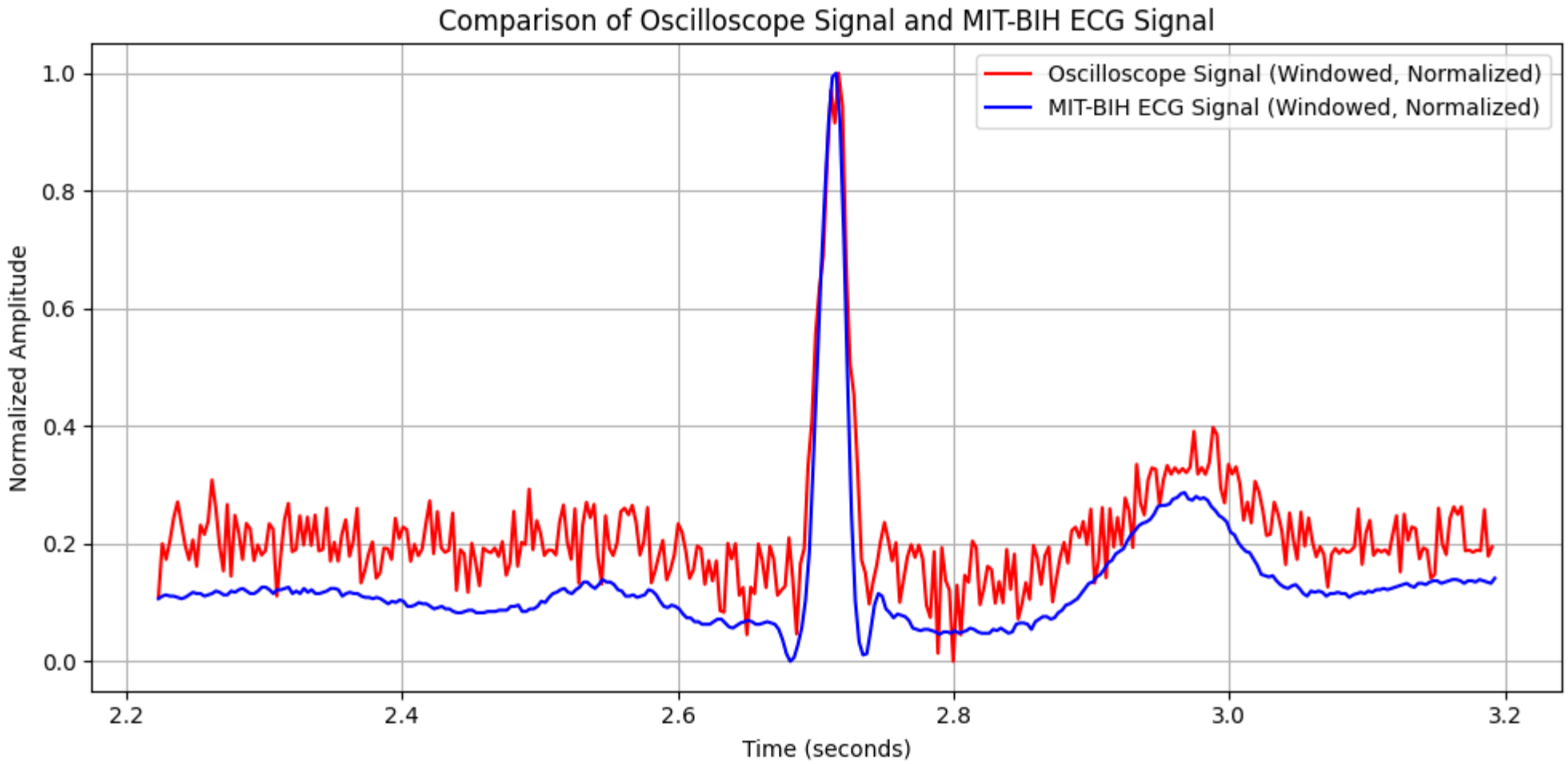
Patient 102 – Without Filter `Normalized cross-correlation value: 0.907207`



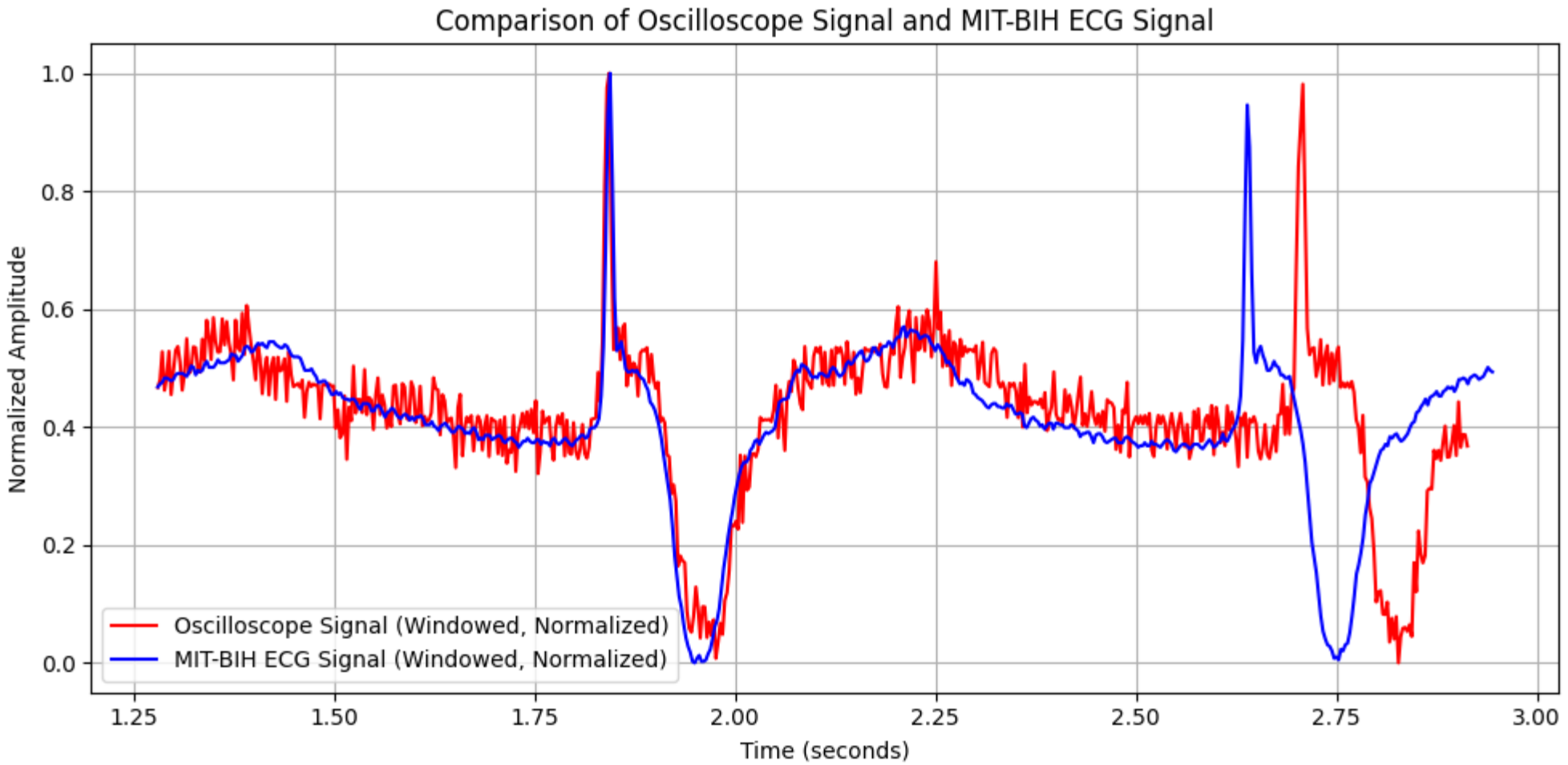
Patient 103 – Without Filter `Normalized cross-correlation value: 0.448286`



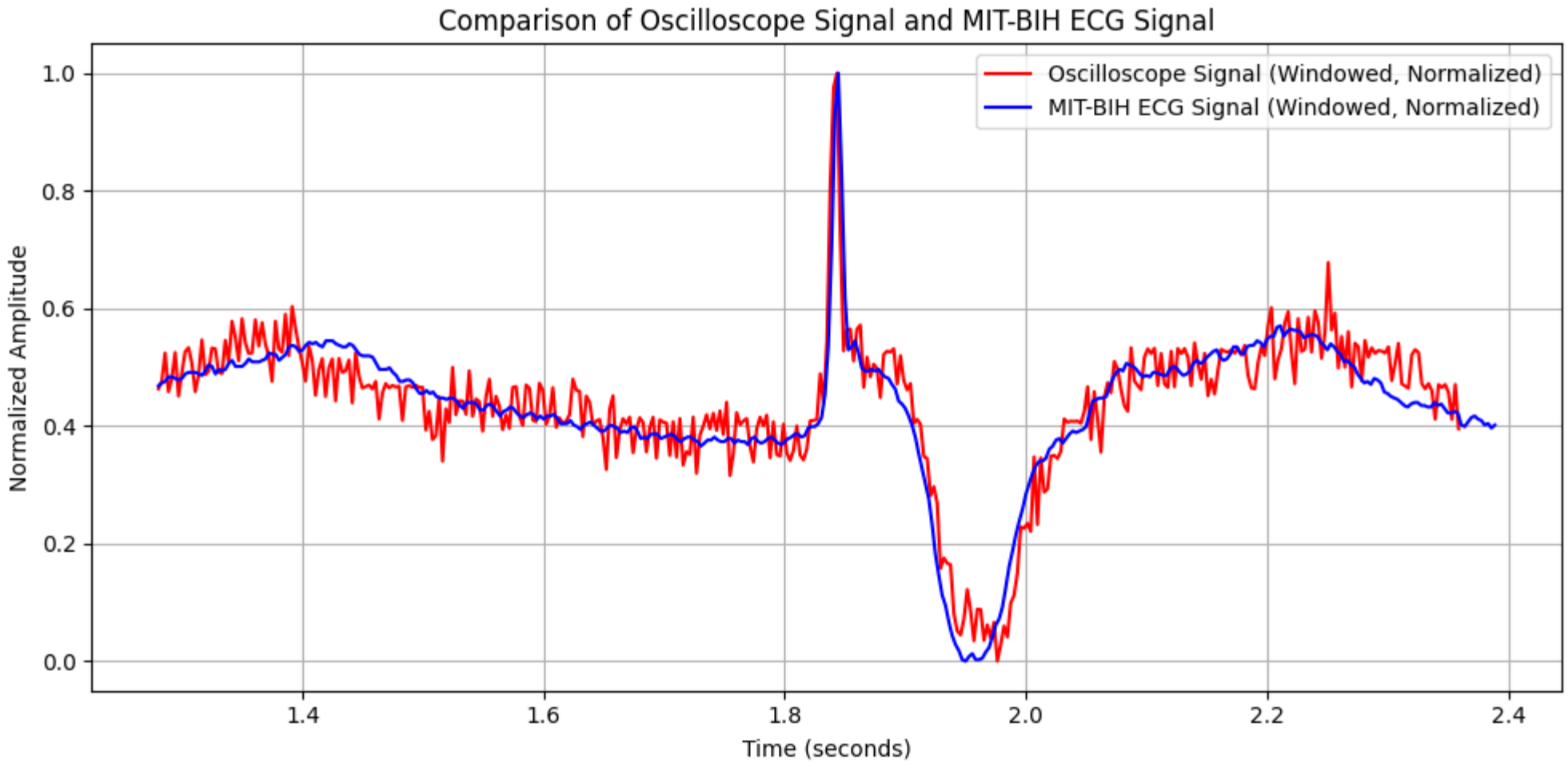
Patient 103 – Without Filter `Normalized cross-correlation value: 0.925462`



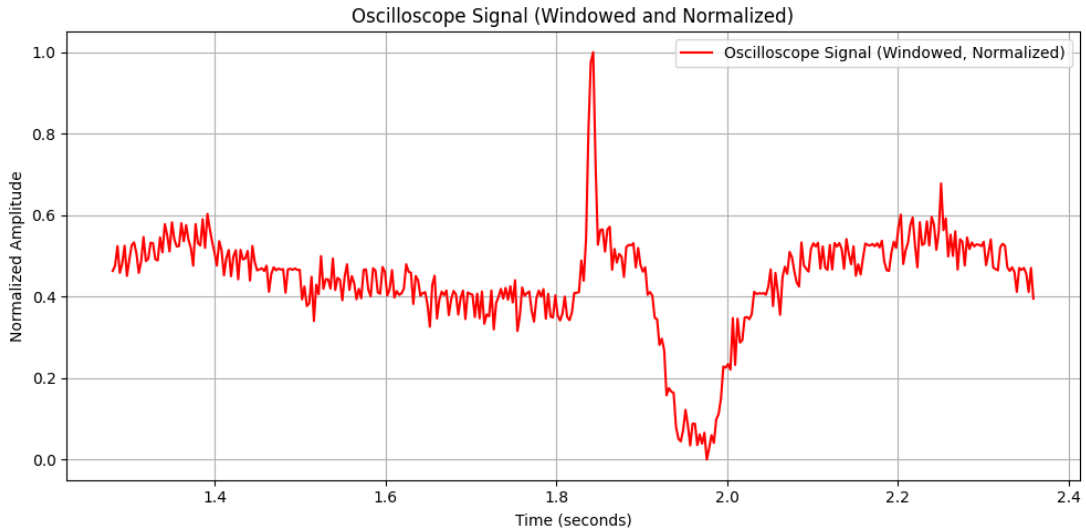
Patient 104 – Without Filter Normalized cross-correlation value: 0.552939



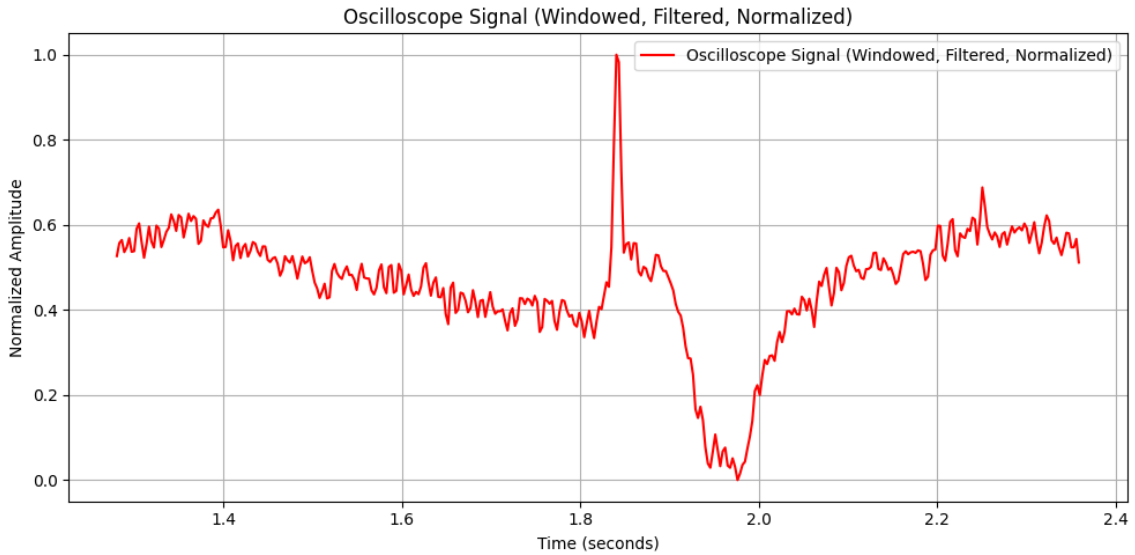
Patient 104 – Without Filter `Normalized cross-correlation value: 0.942190`



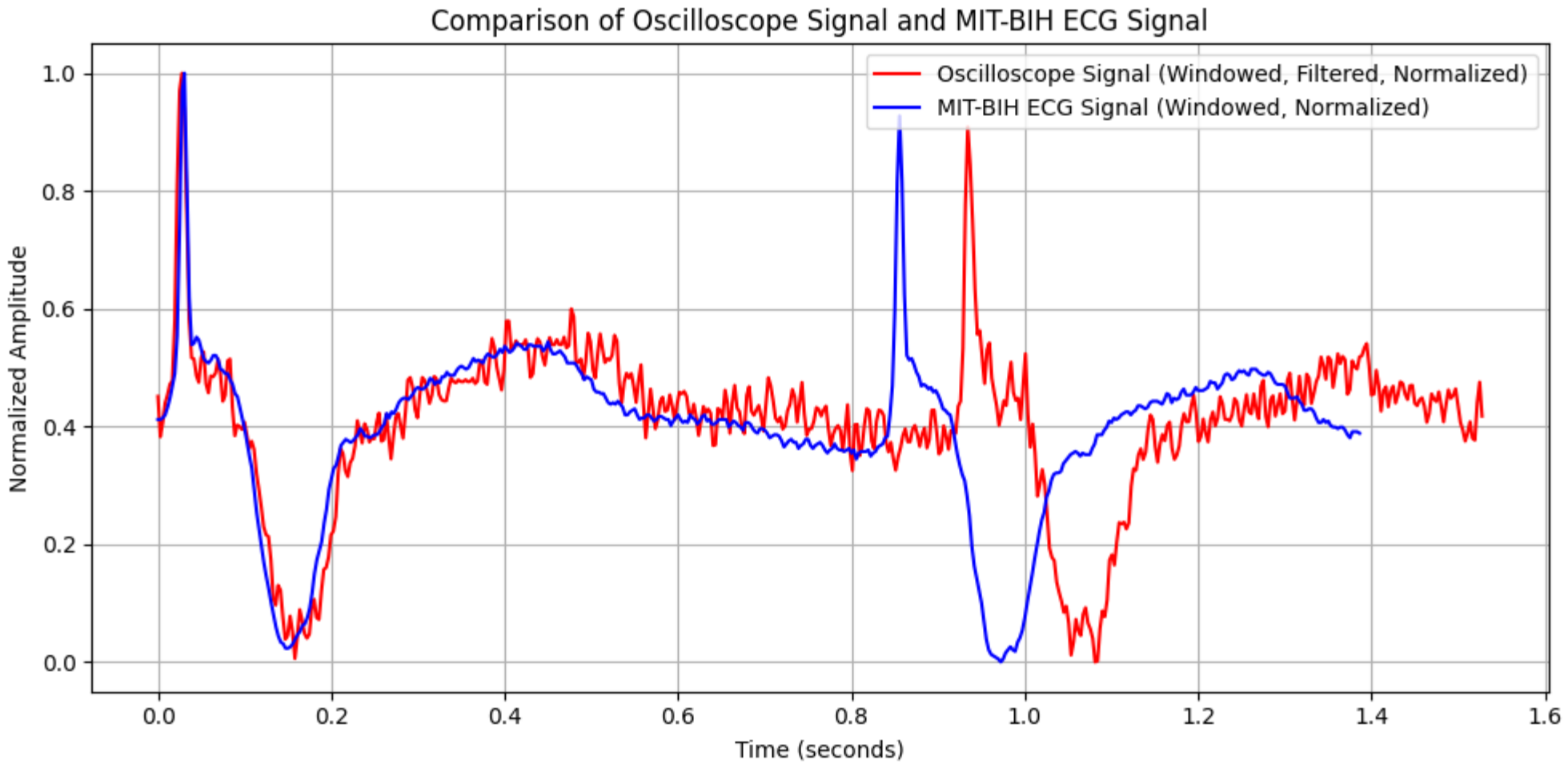
Before the filter:



After the filter:



Patient 104 – With Filter `Normalized cross-correlation value: 0.474590`

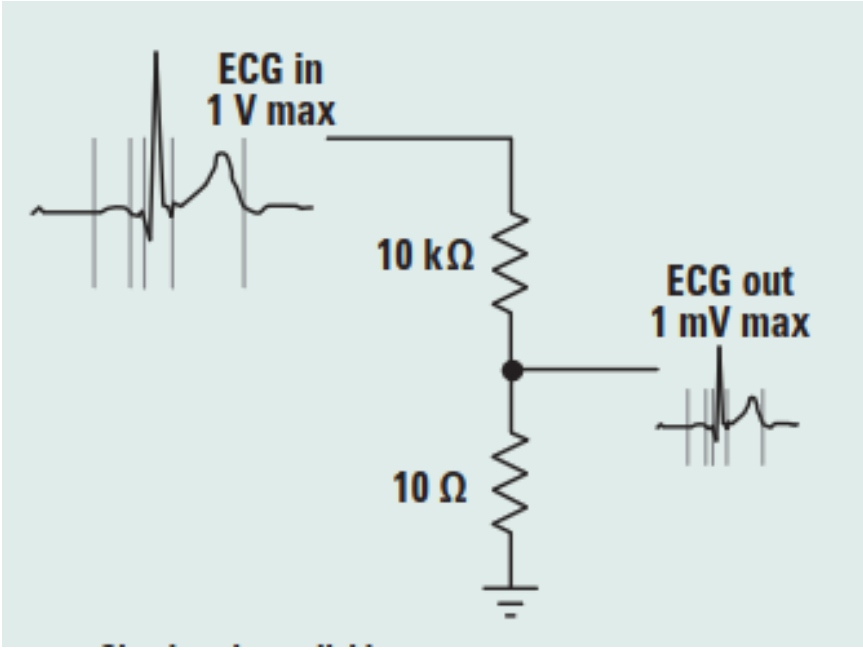


This shows that there is not much change in correlation value after apply the bandpass filter of 0.5 Hz to 125 Hz.

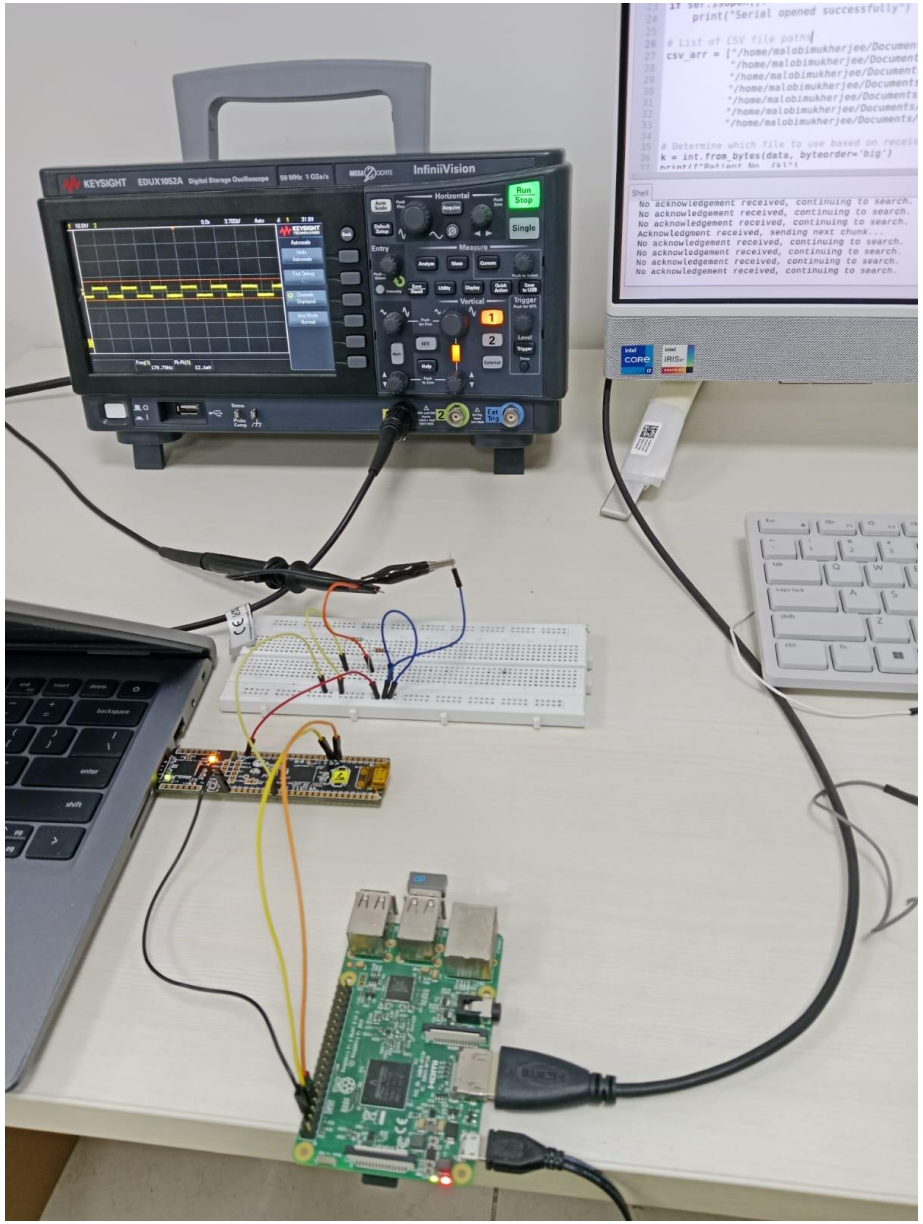
Code Link: https://colab.research.google.com/drive/1RalvVolny4_K-AQ28NRhkKvd7SW1uQvb?usp=sharing

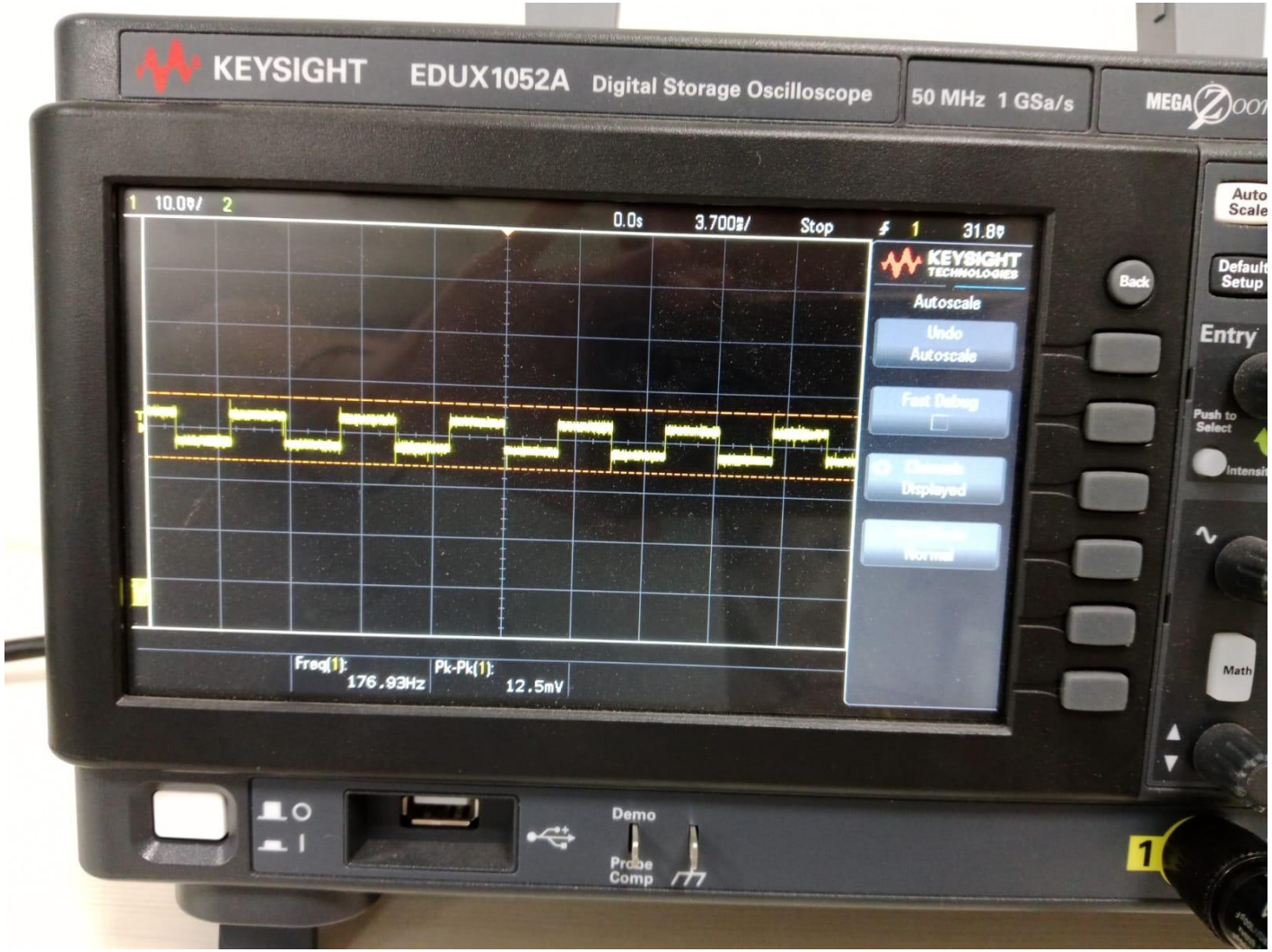
Patient Number	Cross - correlation for single peak without filter	Percentage of error
100	0.865	13.5%
102	0.907	9.3%
103	0.925	7.5%
104	0.942	5.8%

Obtaining emulator output in mV

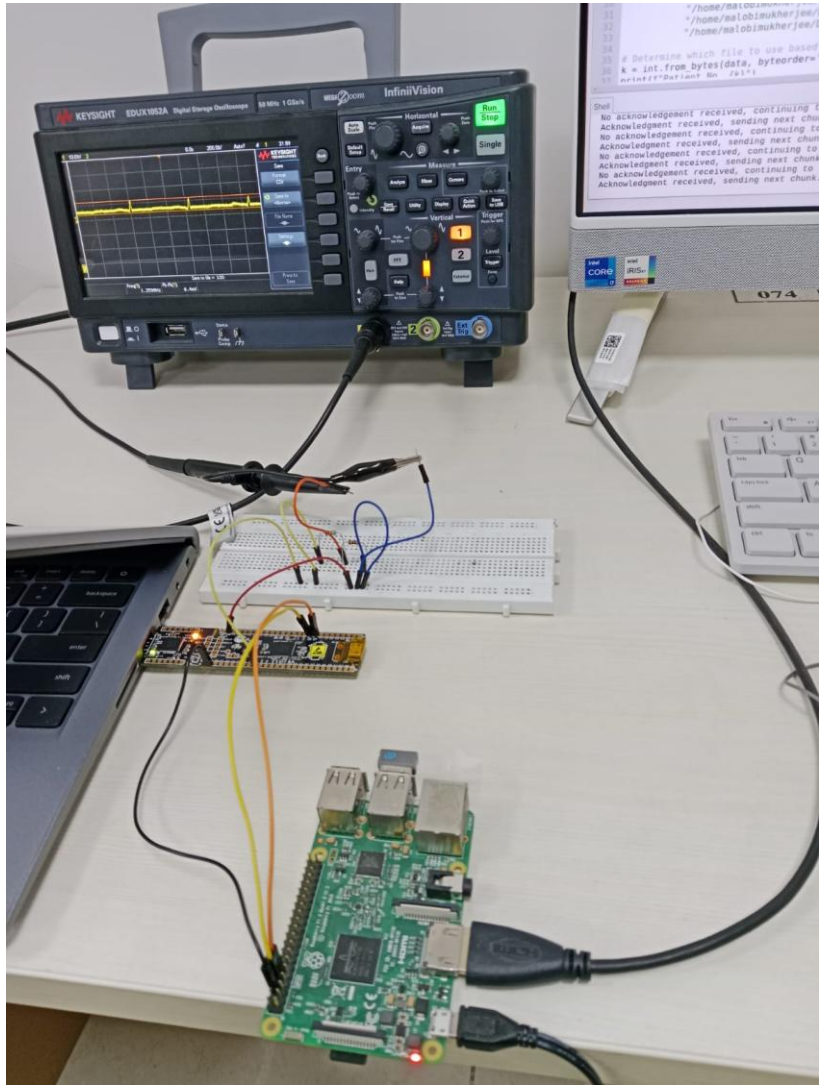


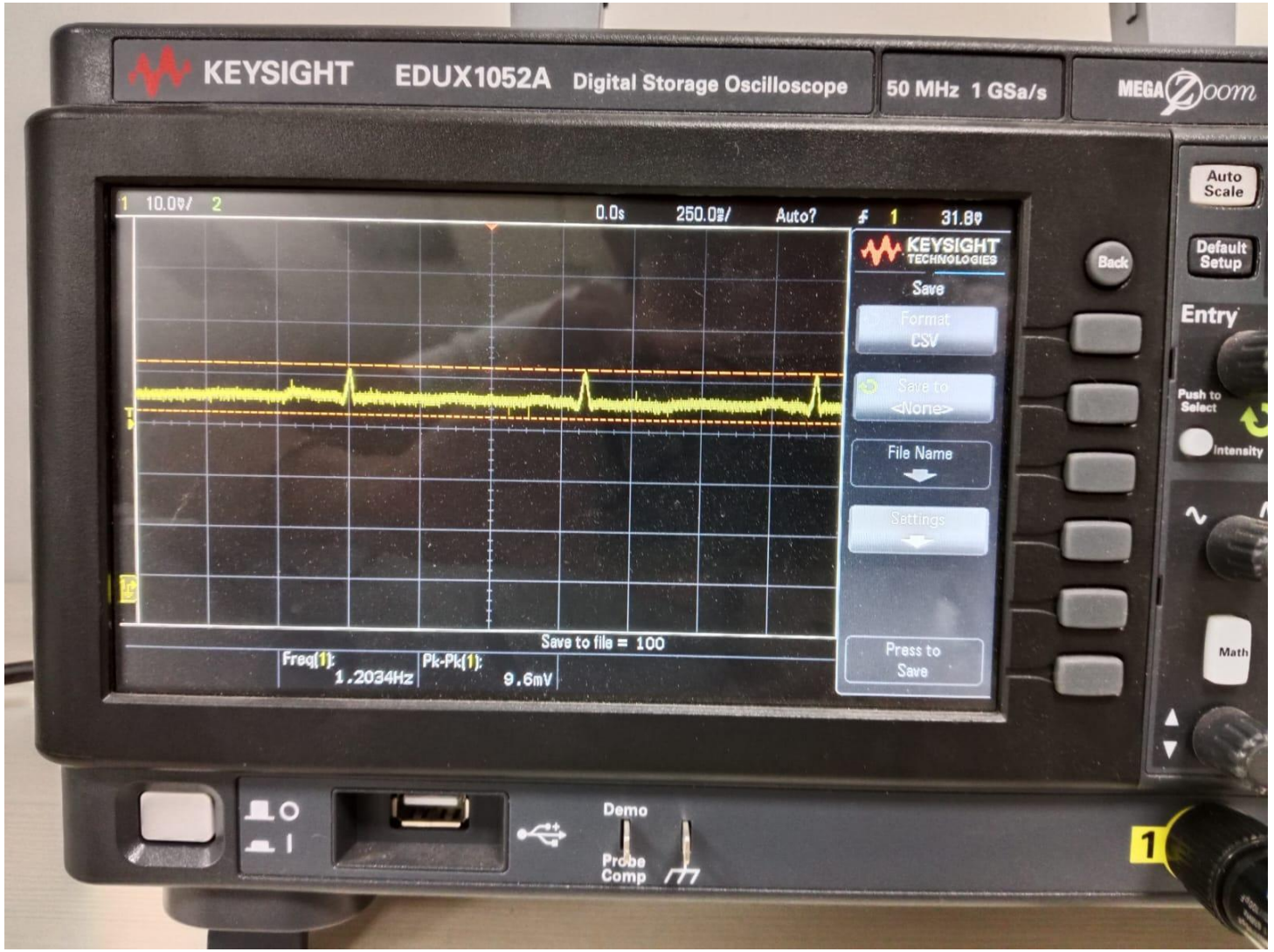
Obtaining emulator output in mV – Square output

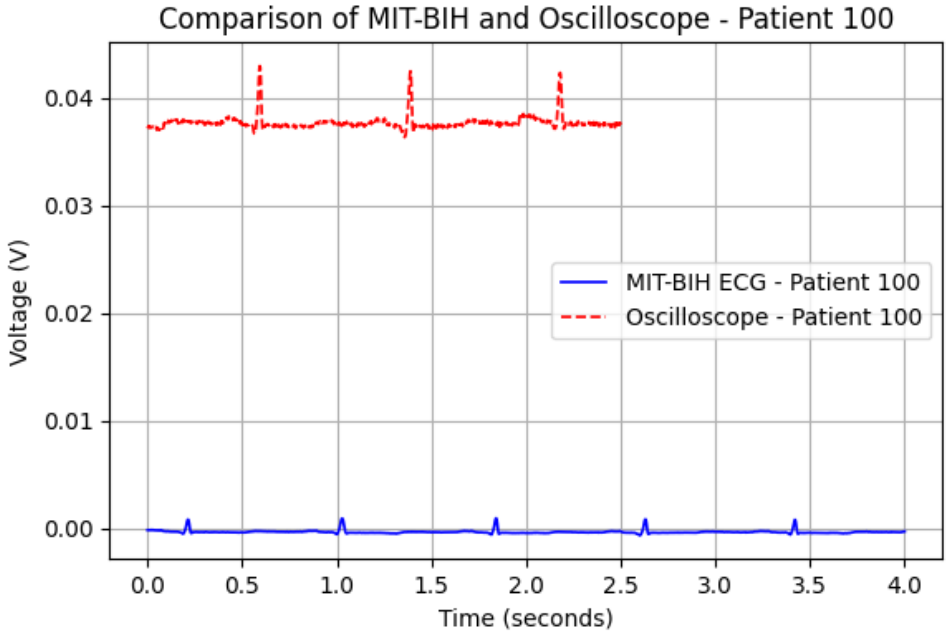


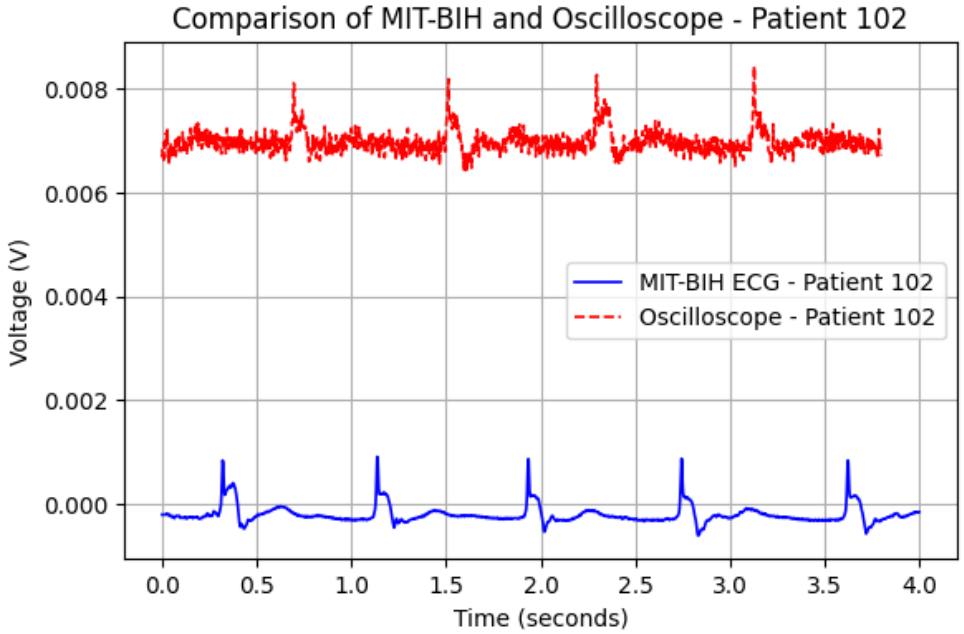


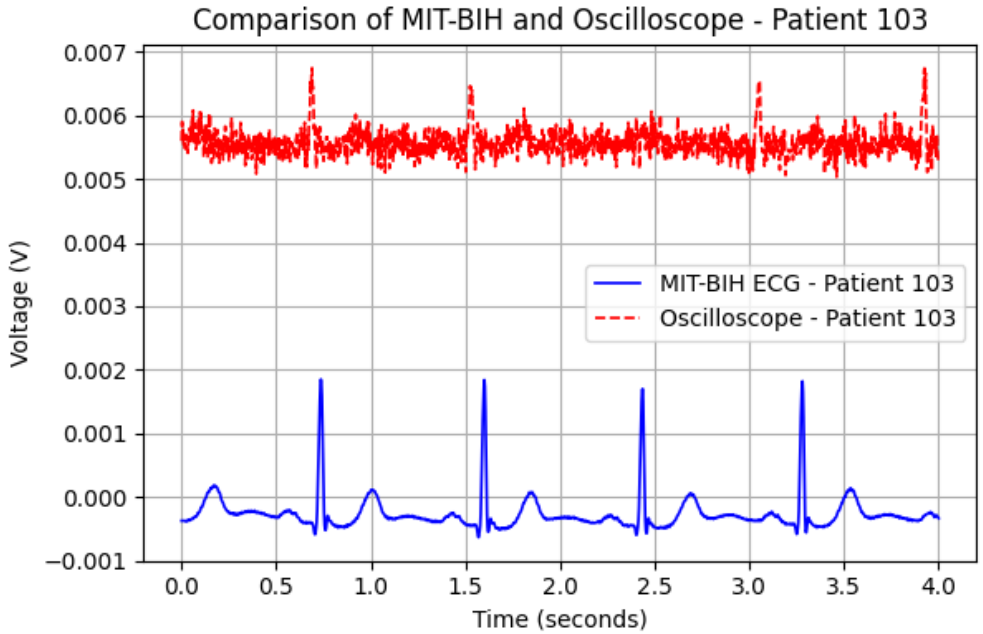
Obtaining emulator output in mV – ECG output

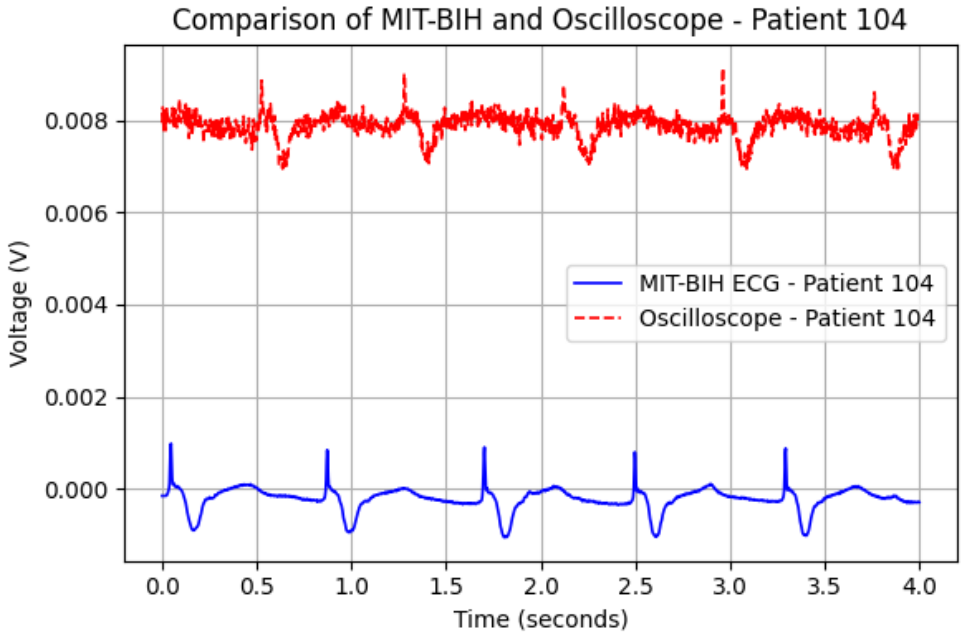




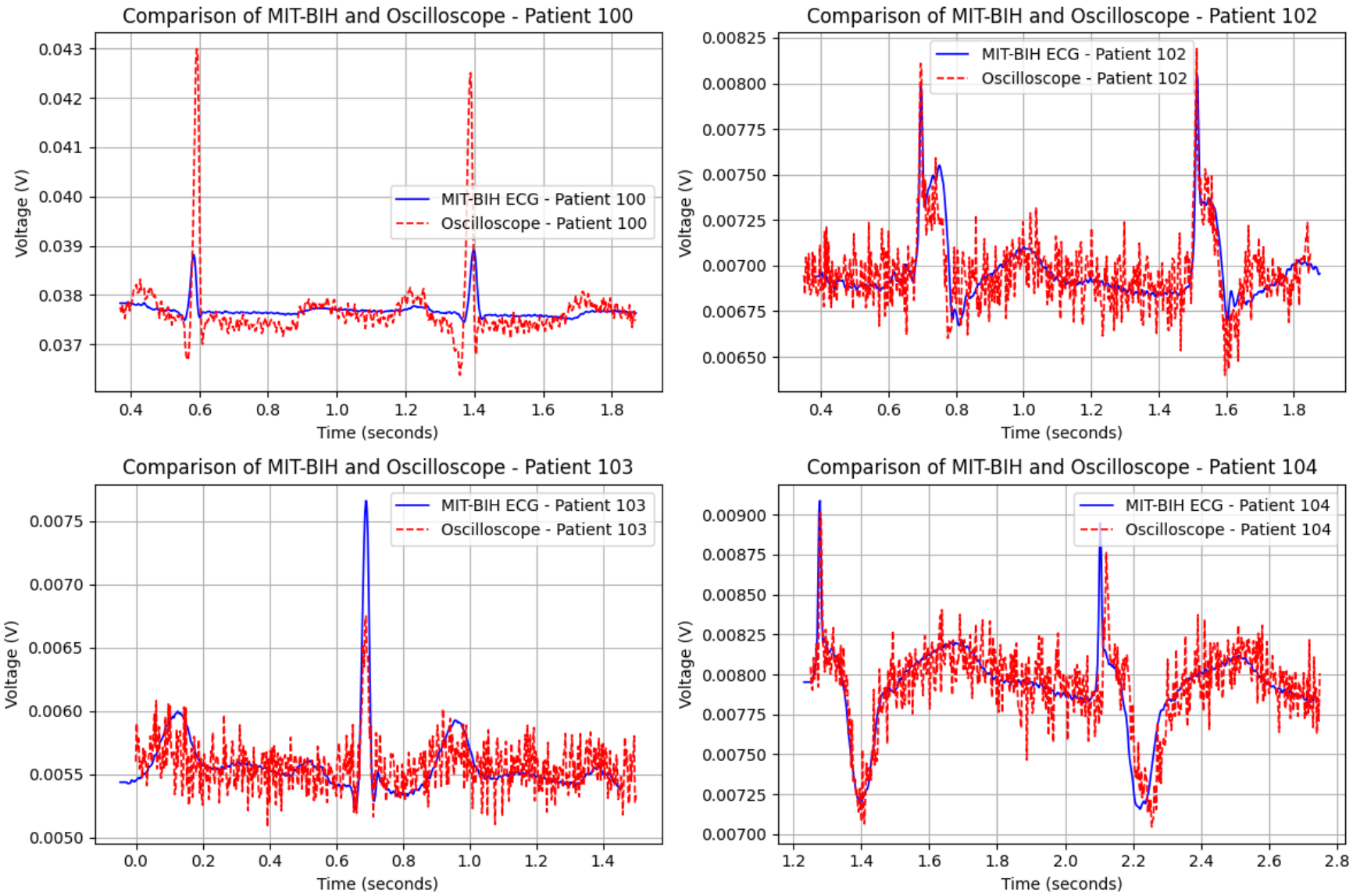

Comparison of MIT-BIH and Oscilloscope - Patient 100
Voltage (V)
Time (seconds)
MIT-BIH ECG - Patient 100
Oscilloscope - Patient 100


Comparison of MIT-BIH and Oscilloscope - Patient 102
Voltage (V)
Time (seconds)
MIT-BIH ECG - Patient 102
Oscilloscope - Patient 102


Comparison of MIT-BIH and Oscilloscope - Patient 103
Voltage (V)
Time (seconds)
MIT-BIH ECG - Patient 103
Oscilloscope - Patient 103


Comparison of MIT-BIH and Oscilloscope - Patient 104
Voltage (V)
Time (seconds)
MIT-BIH ECG - Patient 104
Oscilloscope - Patient 104

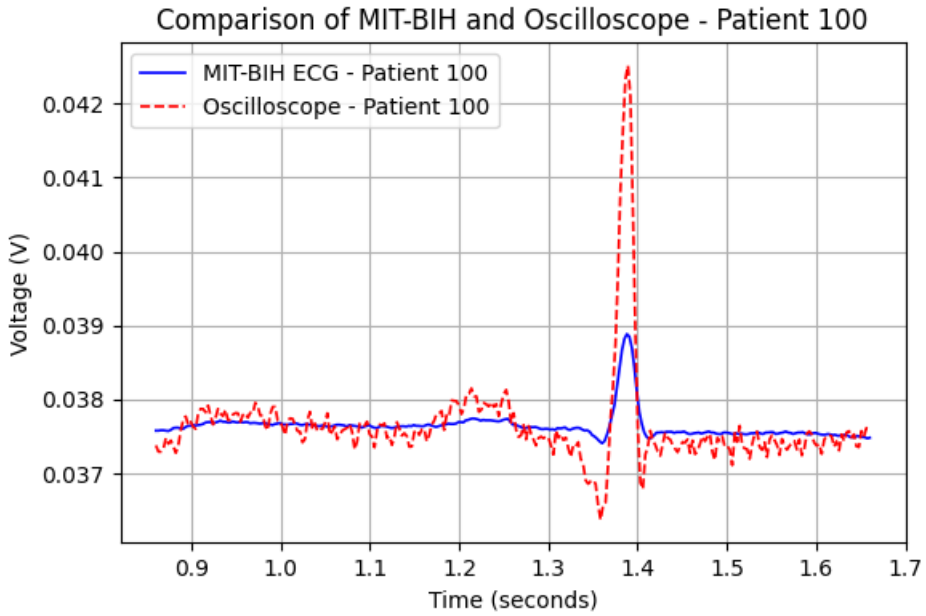
For 2 peaks:

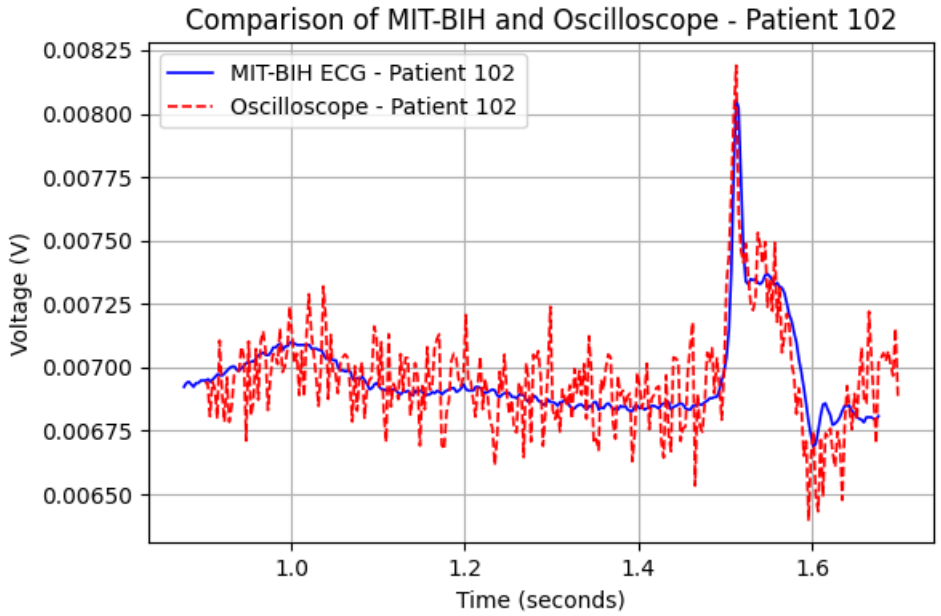

Comparison of MIT-BIH and Oscilloscope - Patient 100
MIT-BIH ECG - Patient 100
Oscilloscope - Patient 100
Voltage (V)
Time (seconds)
Comparison of MIT-BIH and Oscilloscope - Patient 102
MIT-BIH ECG - Patient 102
Oscilloscope - Patient 102
Voltage (V)
Time (seconds)
Comparison of MIT-BIH and Oscilloscope - Patient 103
MIT-BIH ECG - Patient 103
Oscilloscope - Patient 103
Voltage (V)
Time (seconds)
Comparison of MIT-BIH and Oscilloscope - Patient 104
MIT-BIH ECG - Patient 104
Oscilloscope - Patient 104
Voltage (V)
Time (seconds)

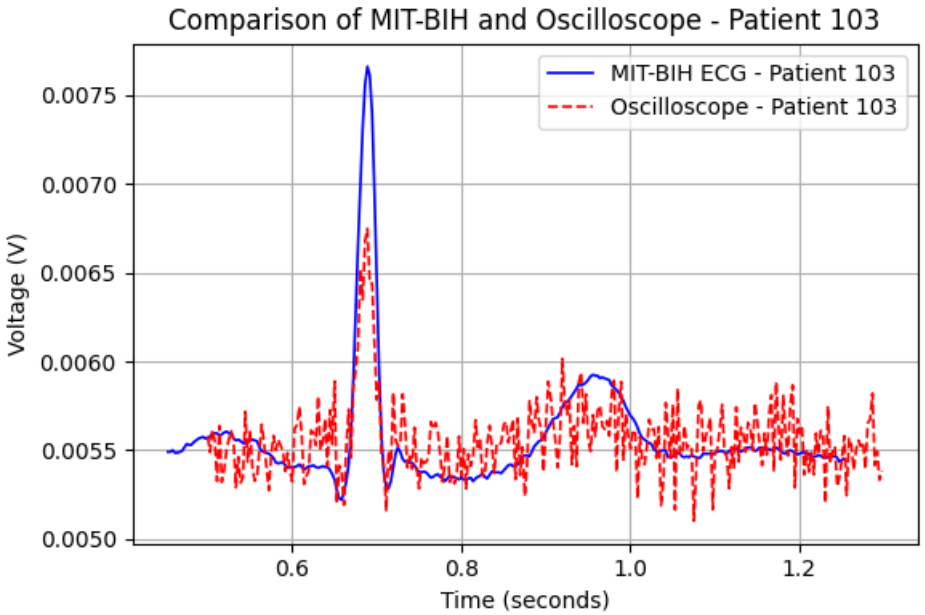
For 2 peaks:

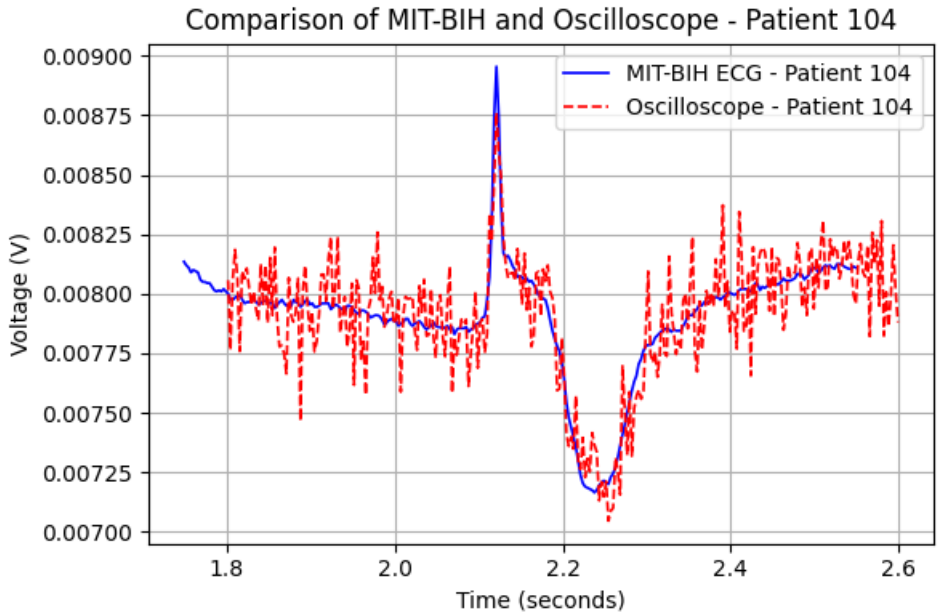
Normalized cross-correlation value for patient 100: 0.527142
Normalized cross-correlation value for patient 102: 0.749451
Normalized cross-correlation value for patient 103: 0.587138
Normalized cross-correlation value for patient 104: 0.802677

For One peaks:







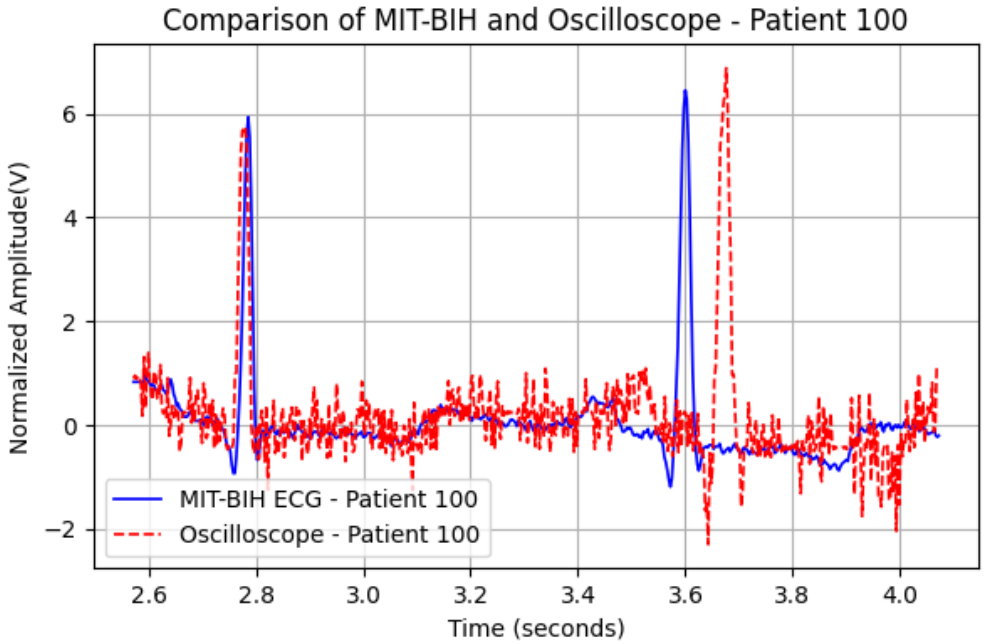


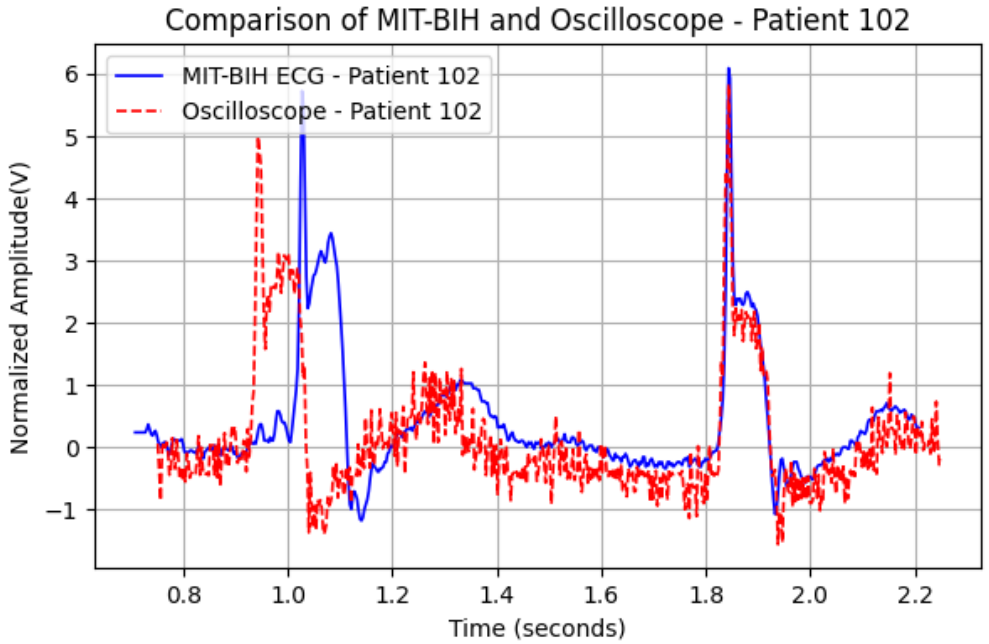
For 1 peaks:

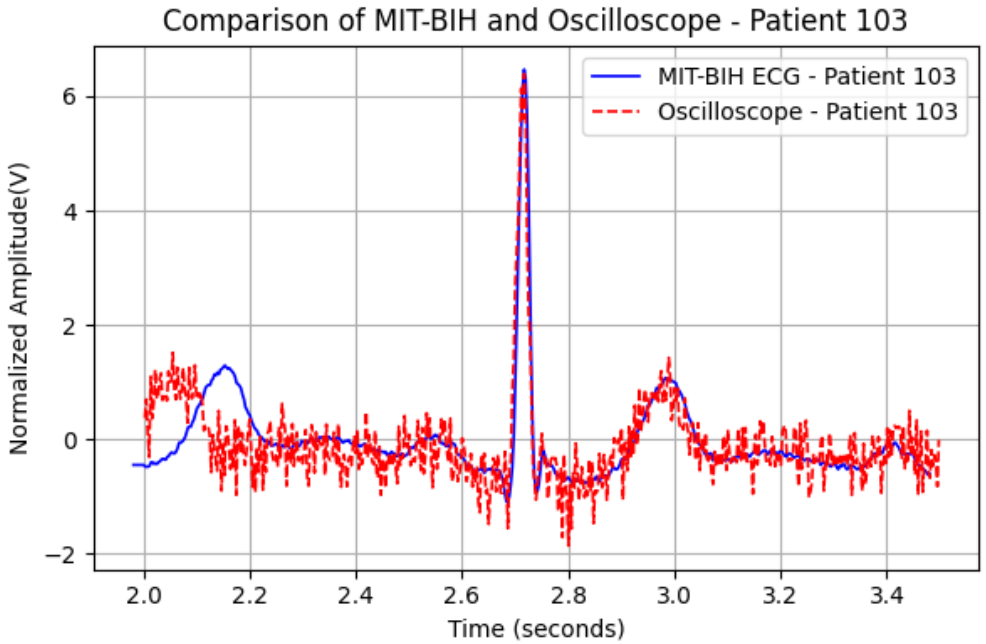
Normalized cross-correlation value for patient 100: 0.951835
Normalized cross-correlation value for patient 102: 0.783558
Normalized cross-correlation value for patient 103: 0.717931
Normalized cross-correlation value for patient 104: 0.830396

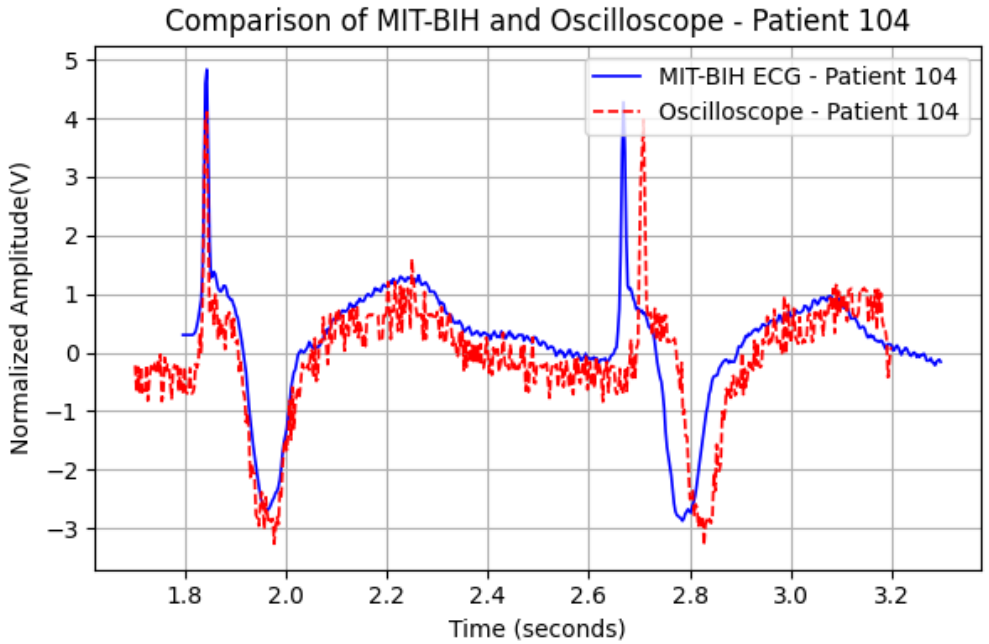
For Volt reading without voltage divider and with normalization

For V reading 2 peaks,





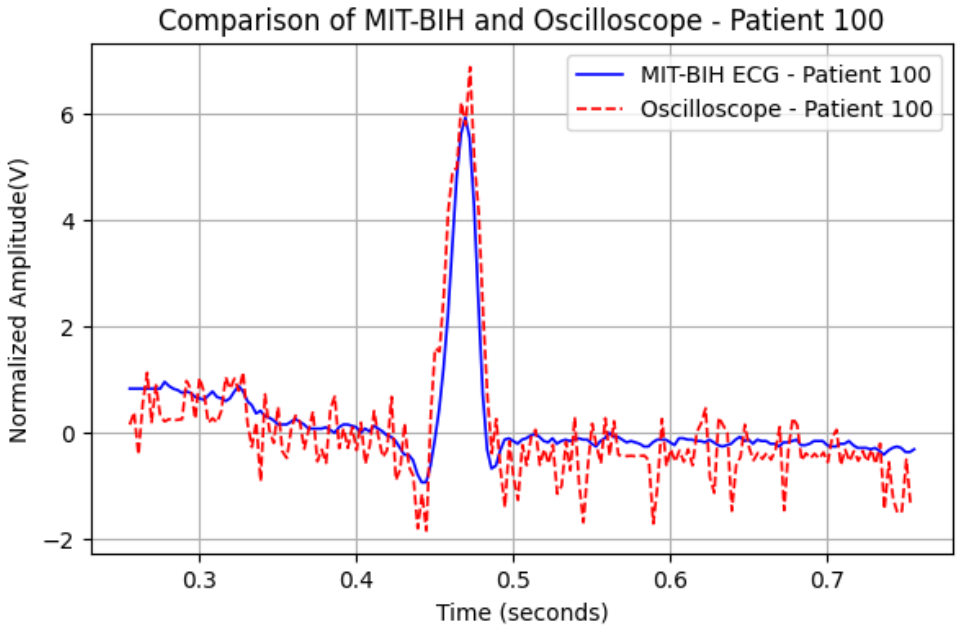


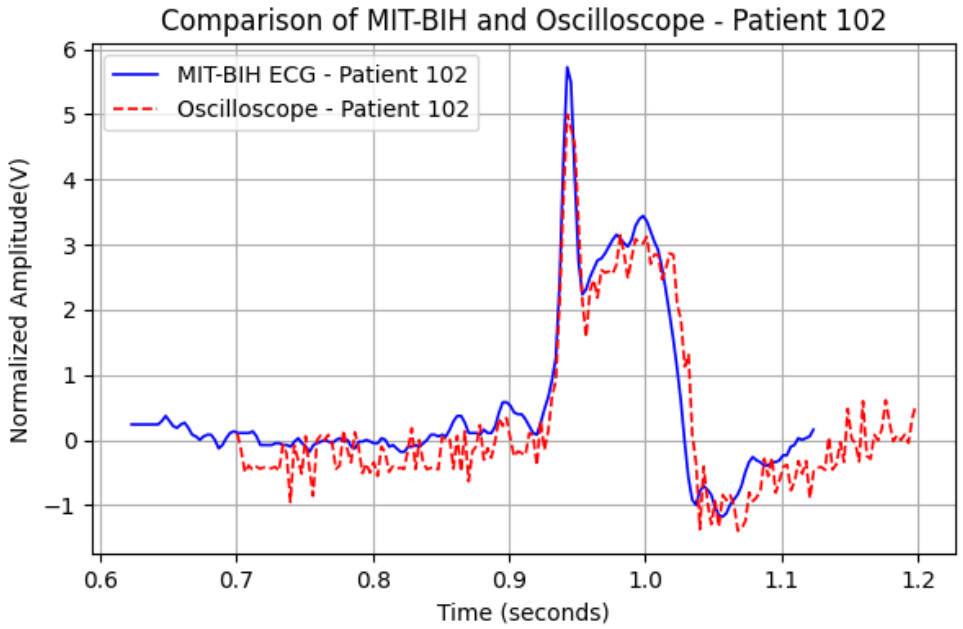


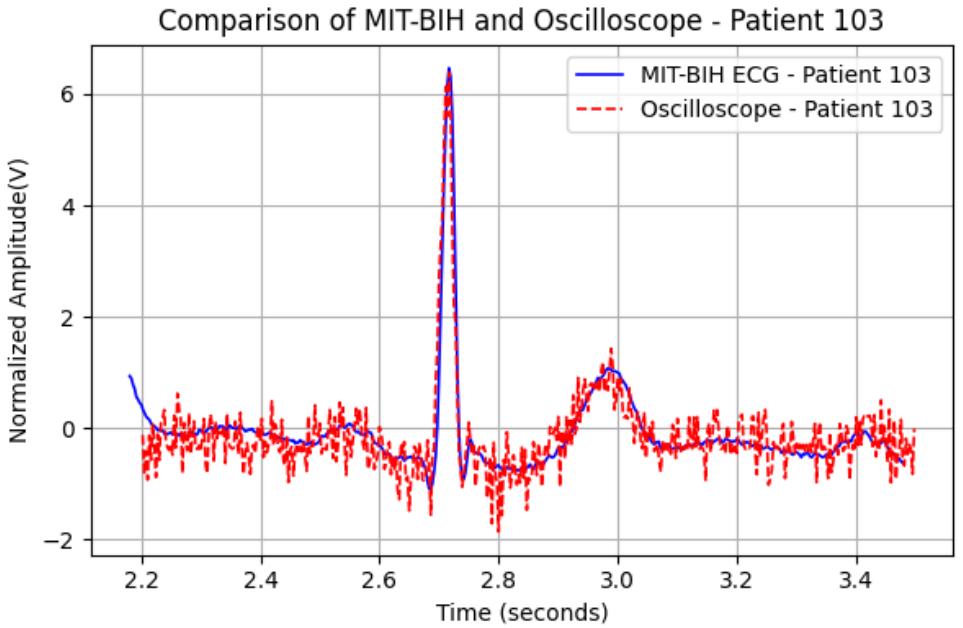
For Volt reading 2 peaks:

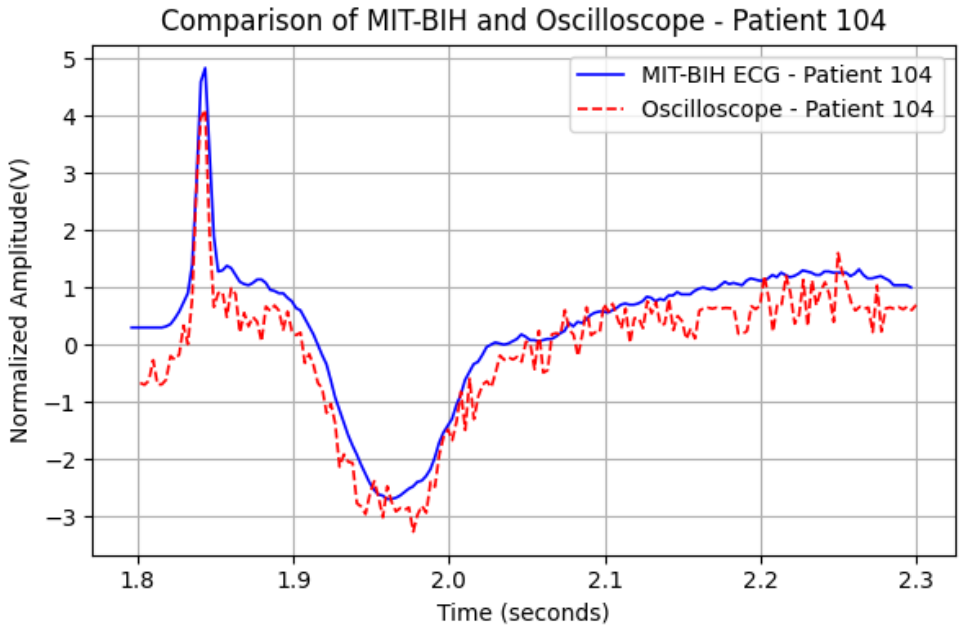
Normalized cross-correlation value for patient 100: 0.558320
Normalized cross-correlation value for patient 102: 0.440430
Normalized cross-correlation value for patient 103: 0.807007
Normalized cross-correlation value for patient 104: 0.737677

For V reading One peaks:









For Volt reading one peaks:

Normalized cross-correlation value for patient 100: 0.905598
Normalized cross-correlation value for patient 102: 0.949064
Normalized cross-correlation value for patient 103: 0.905941
Normalized cross-correlation value for patient 104: 0.970176