

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,  
 $\mu$  is the mean of the data,  
 $N$  is the total number of data points.

Therefore, Normalized Cross correlation formula for the two signals:

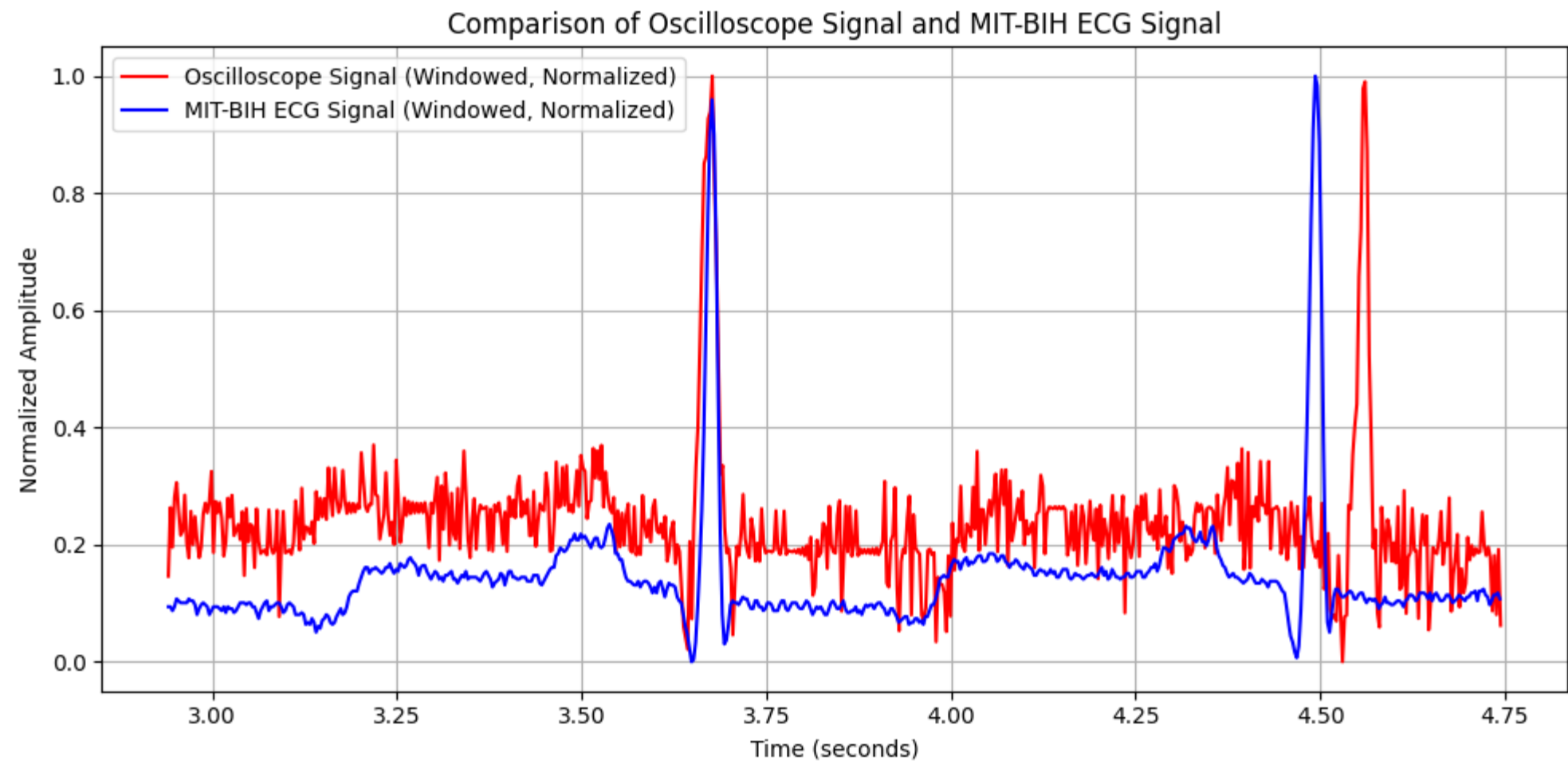
$$NCC = \cos \theta = \frac{\sum_{i=0}^N (x_i - \mu) \cdot (y_i - \mu)}{\sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} \sqrt{\frac{1}{N} \sum_{i=1}^N (y_i - \mu)^2}} * \frac{1}{N}$$

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

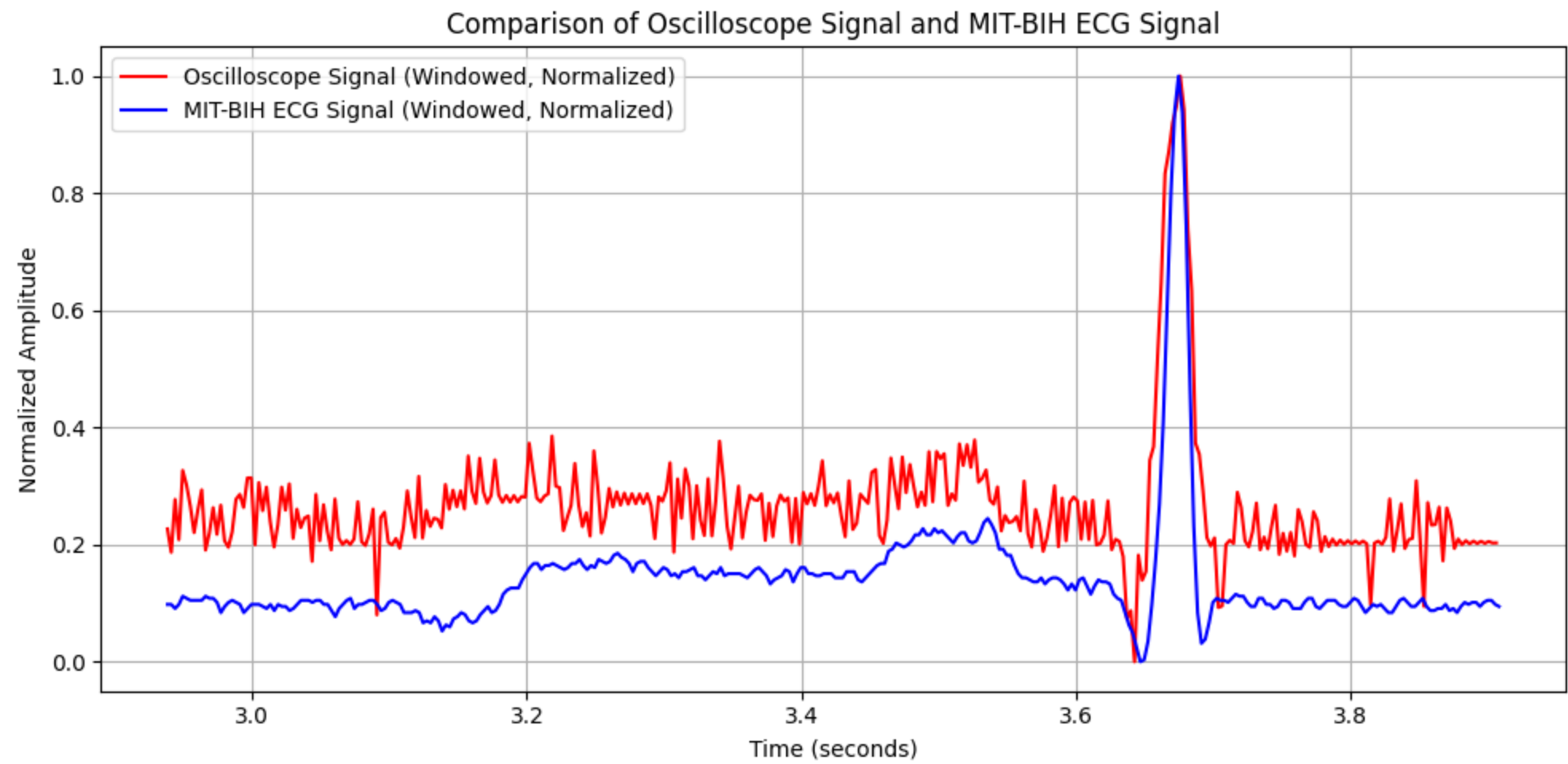
Ideally,  $NCC = 1$

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

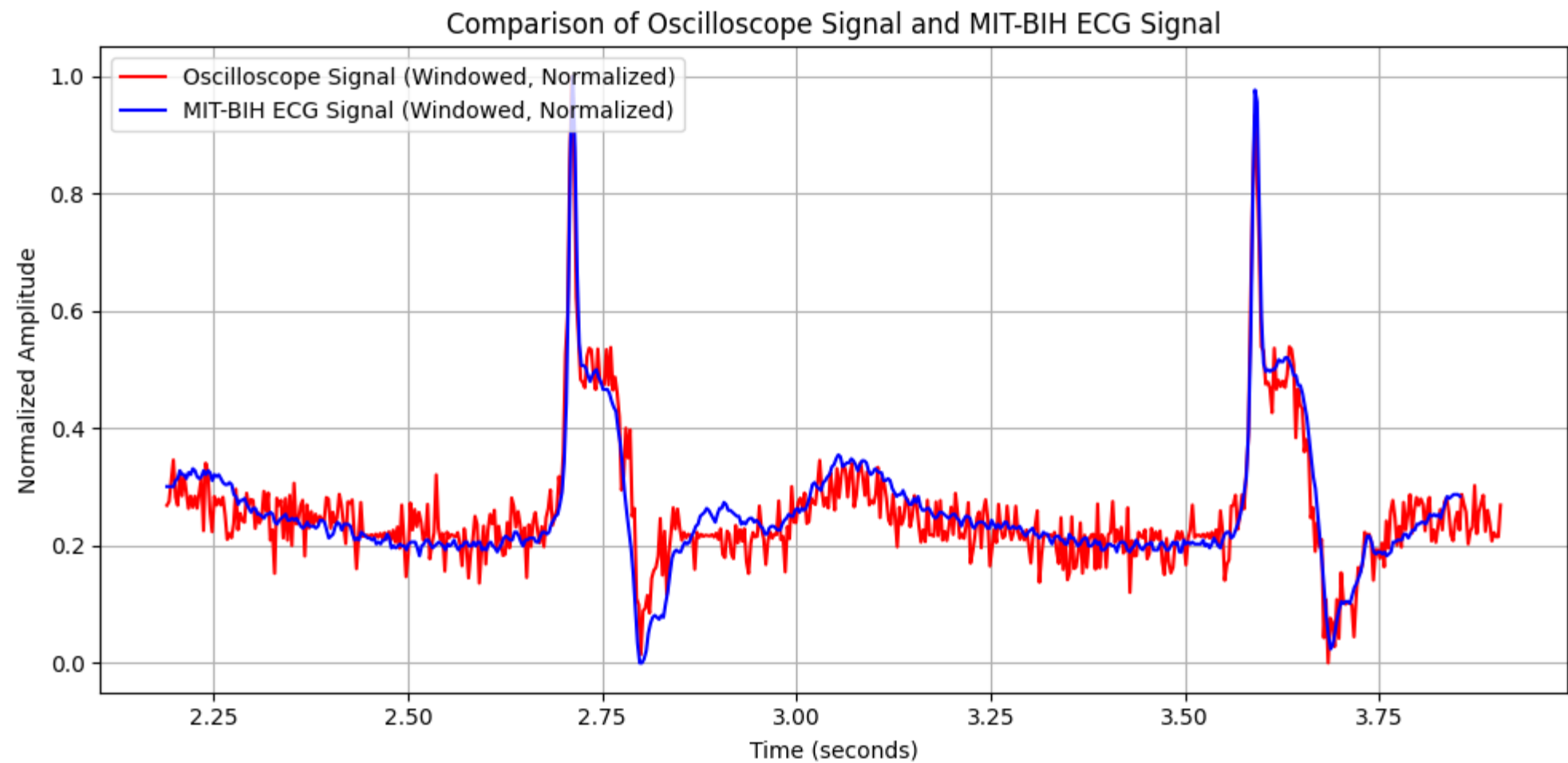
Patient 100 – Without Filter Normalized cross-correlation value: 0.482490



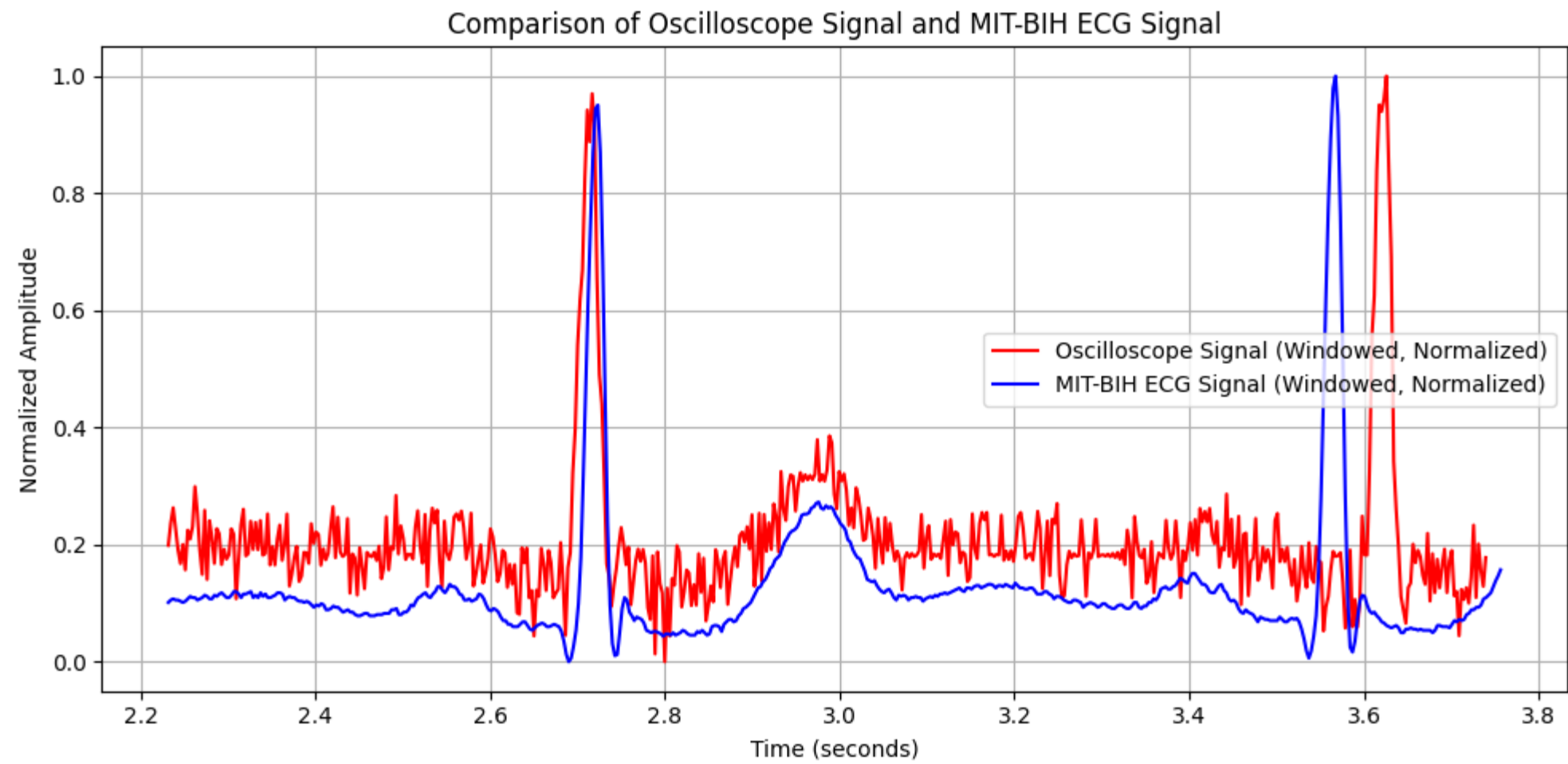
Patient 100 – Without Filter Normalized cross-  
correlation value: 0.865190



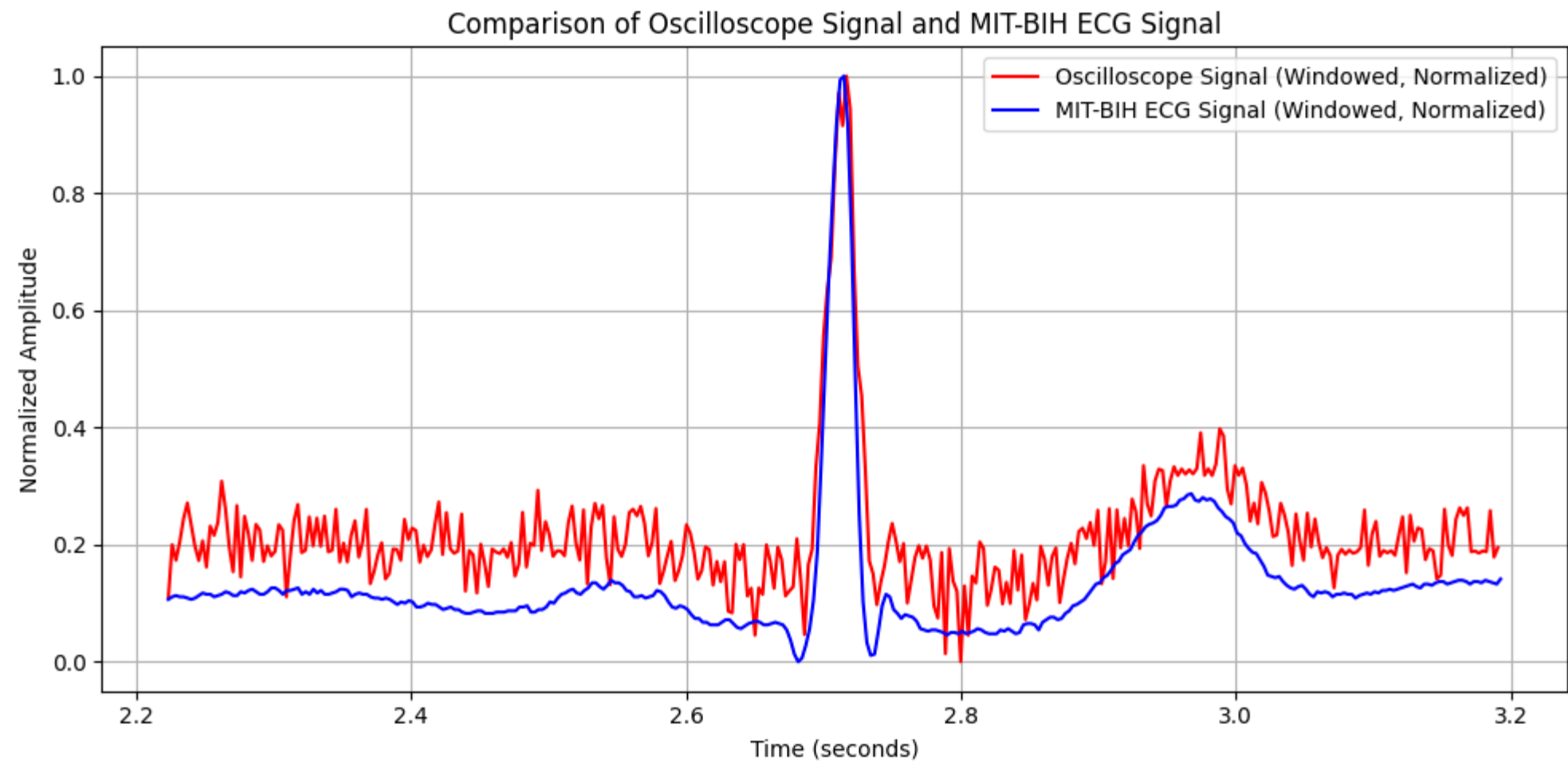
Patient 102 – Without Filter Normalized cross-  
correlation value: 0.907207



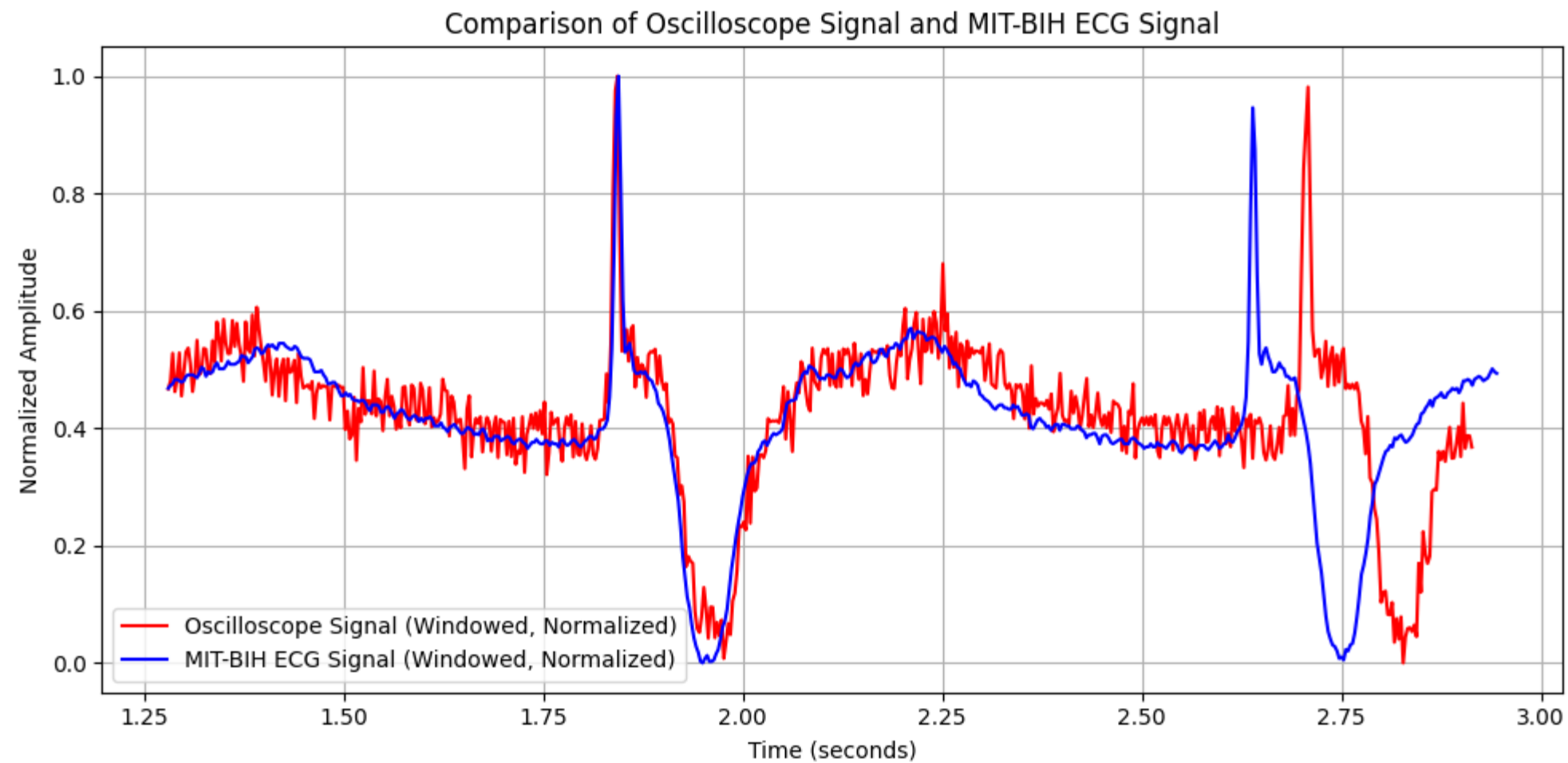
Patient 103 – Without Filter Normalized cross-  
correlation value: 0.448286



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

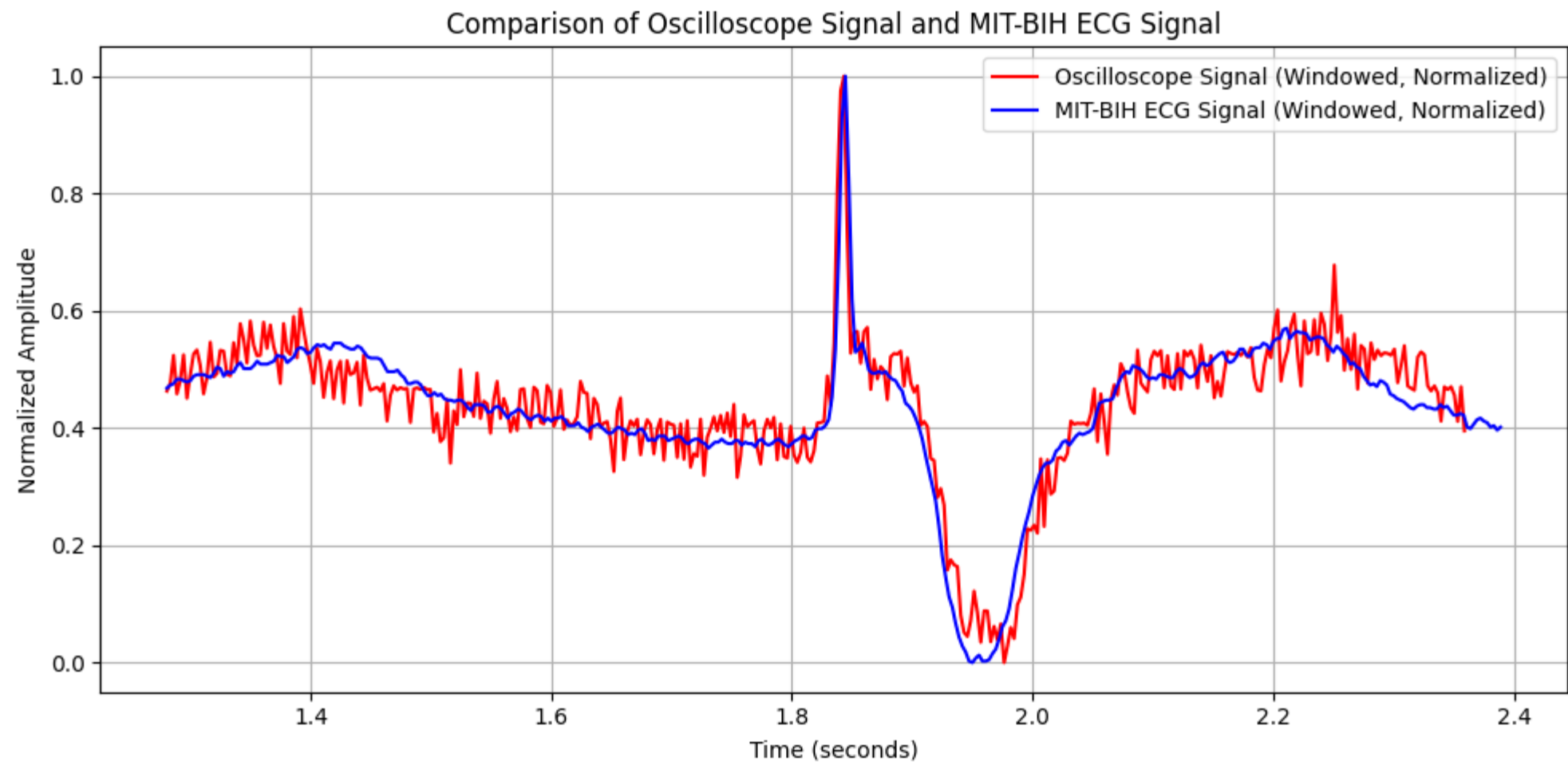


Patient 104 – Without Filter Normalized cross-  
correlation value: 0.552939

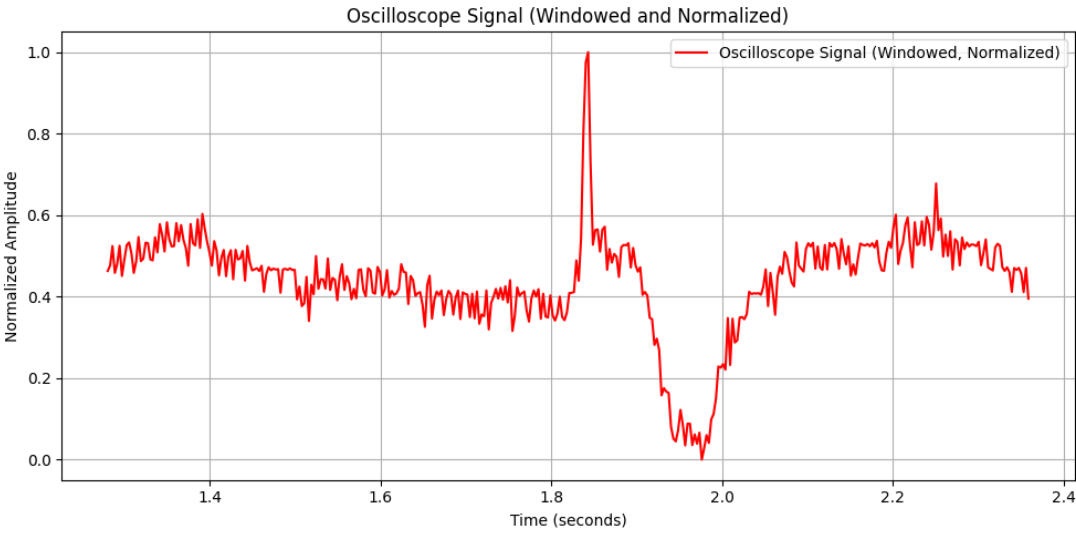




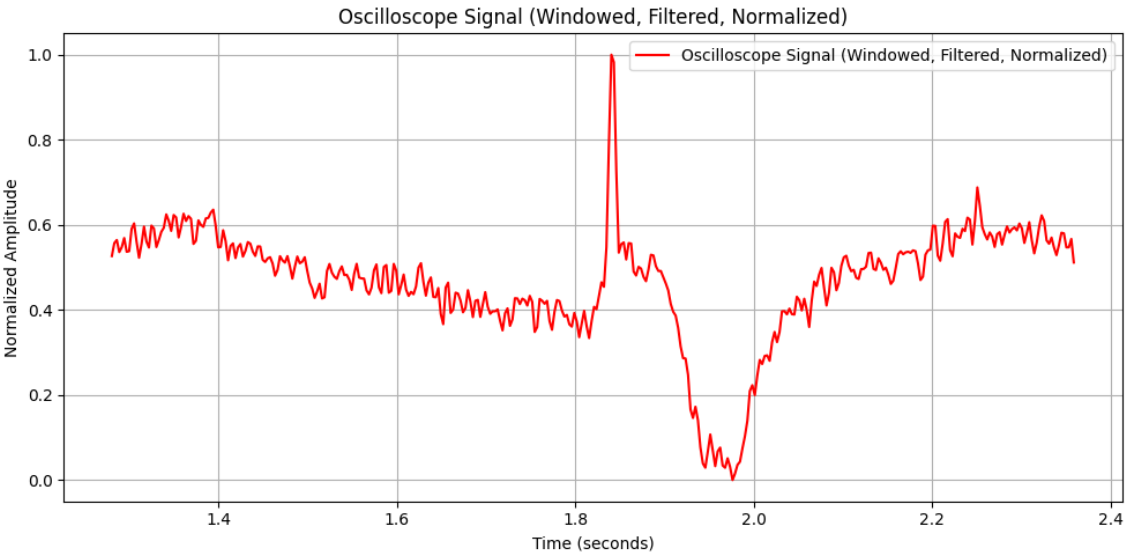
Patient 104 – Without Filter Normalized cross-  
correlation value: 0.942190



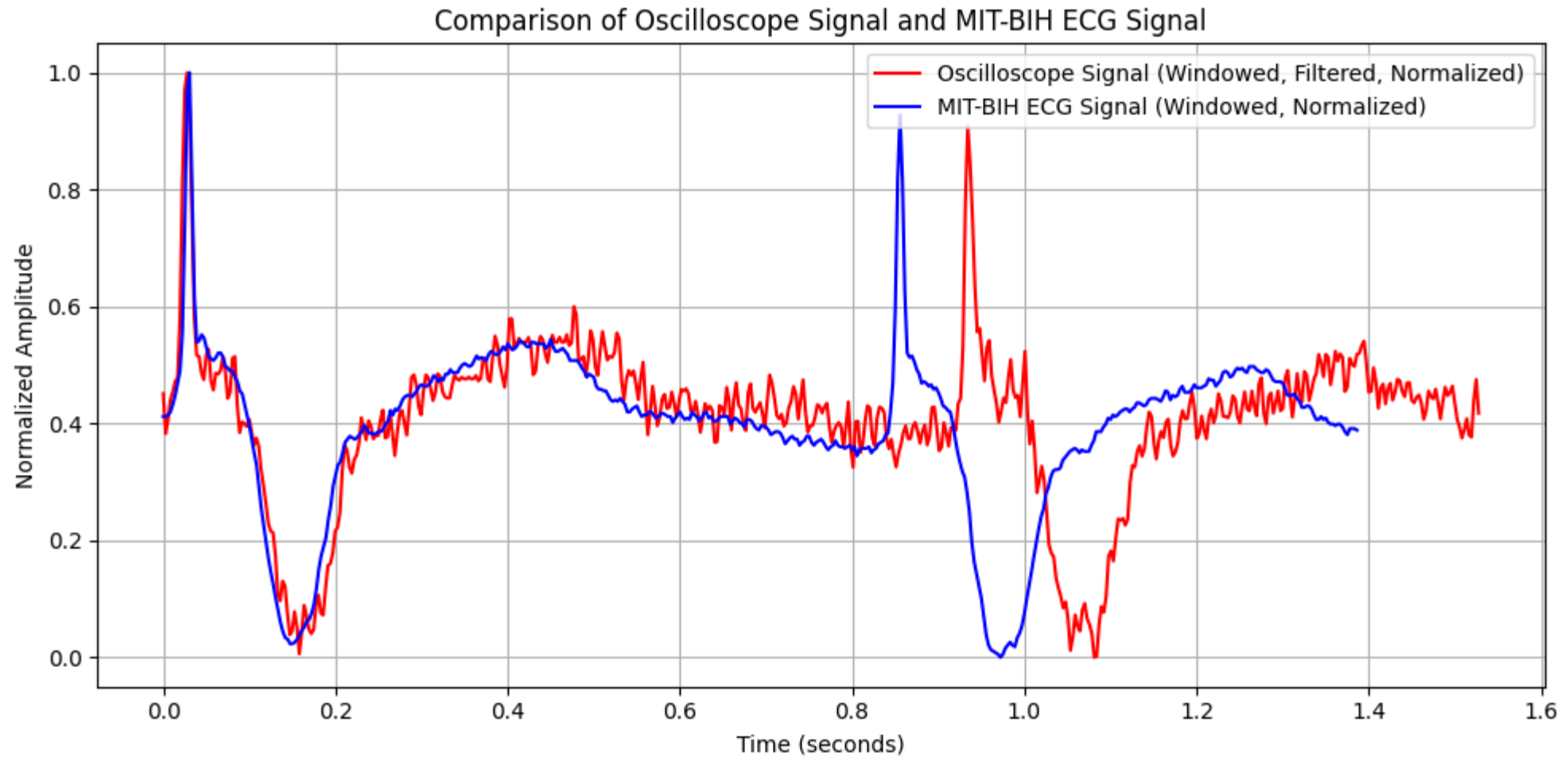
Before the filter:



After the filter:



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

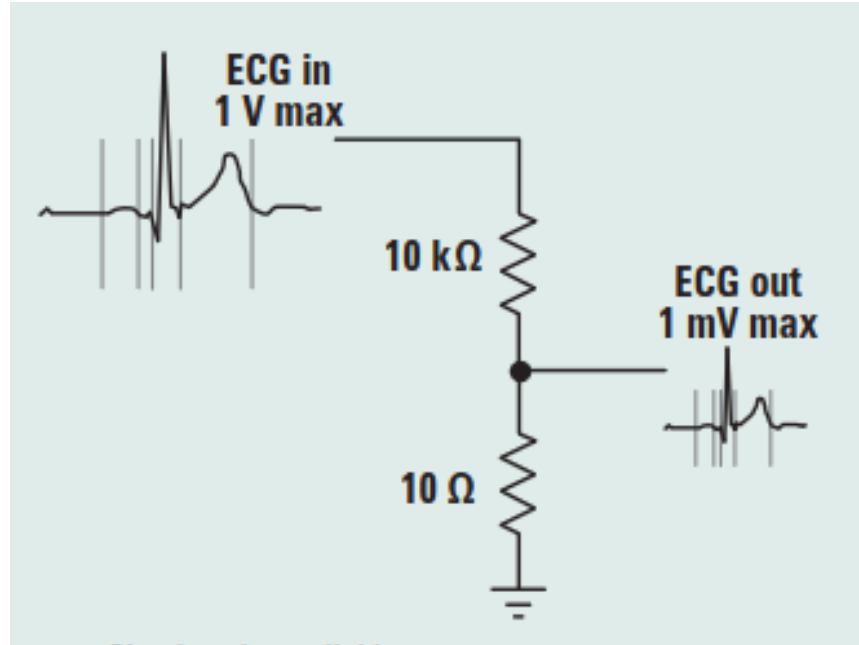


This shows that there is not much change in correlation value after apply the bandpass filter of 0.5 Hz to 125 Hz.

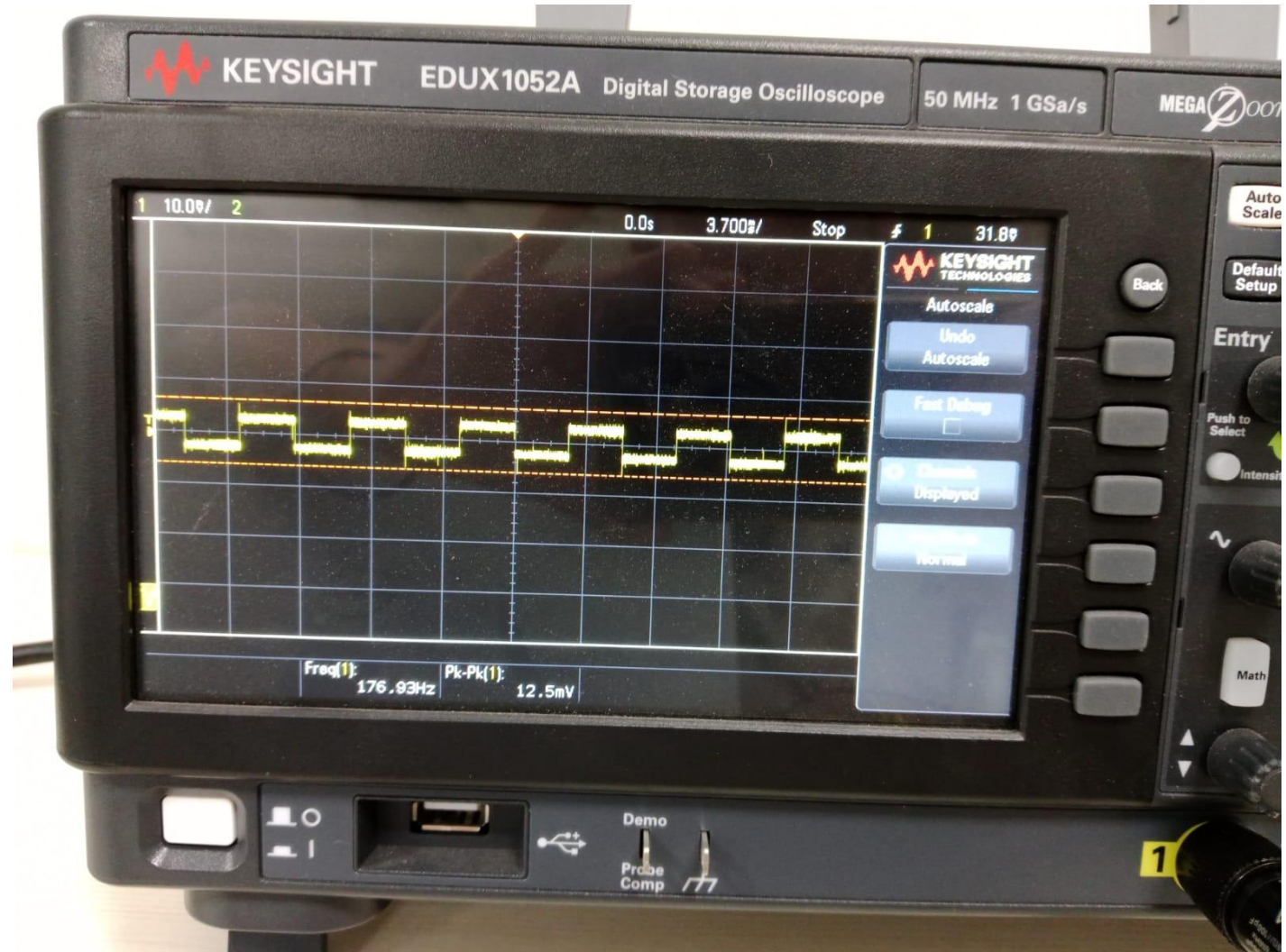
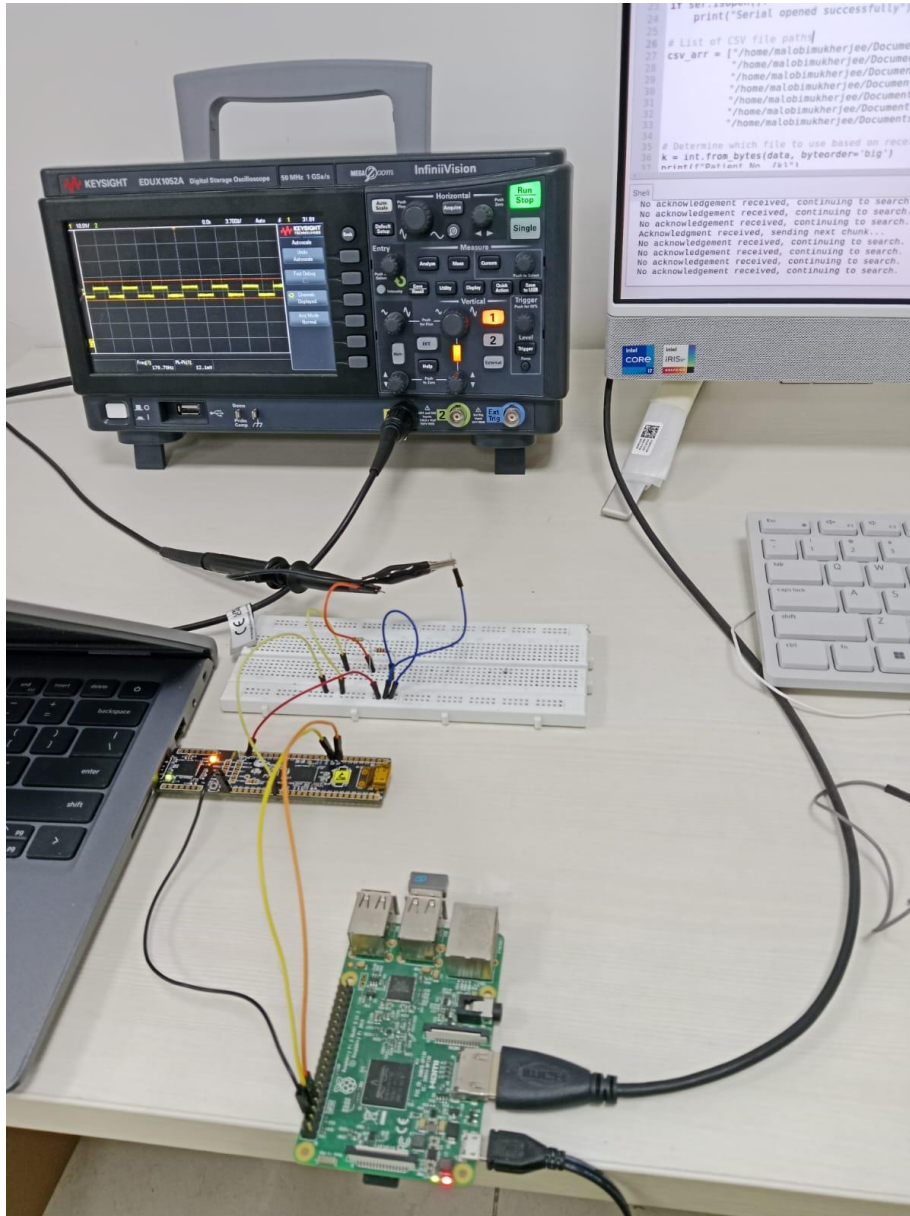
**Code Link:** [https://colab.research.google.com/drive/1RalvVolny4\\_K-AQ28NRhkKvd7SW1uQvb?usp=sharing](https://colab.research.google.com/drive/1RalvVolny4_K-AQ28NRhkKvd7SW1uQvb?usp=sharing)

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

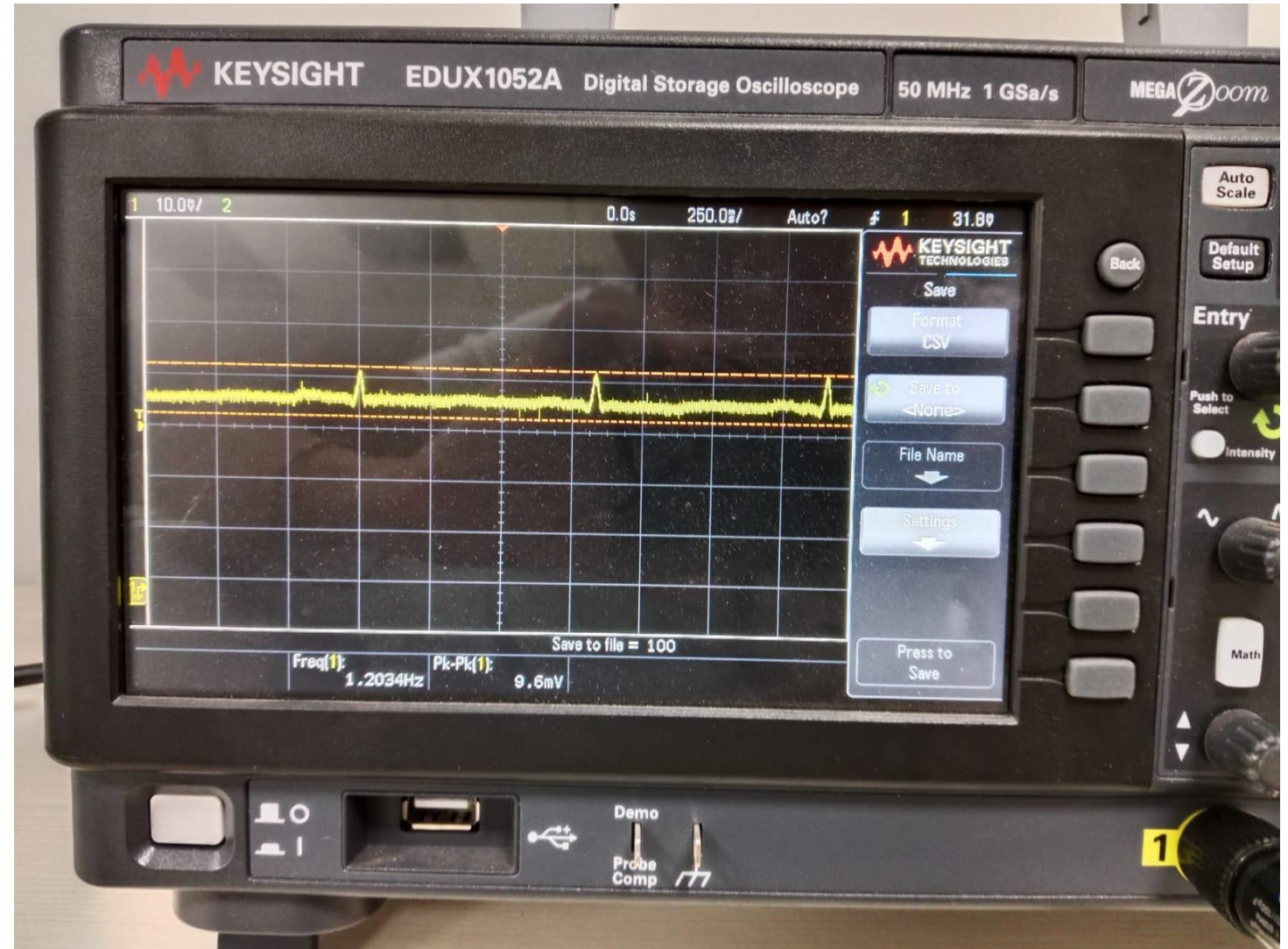
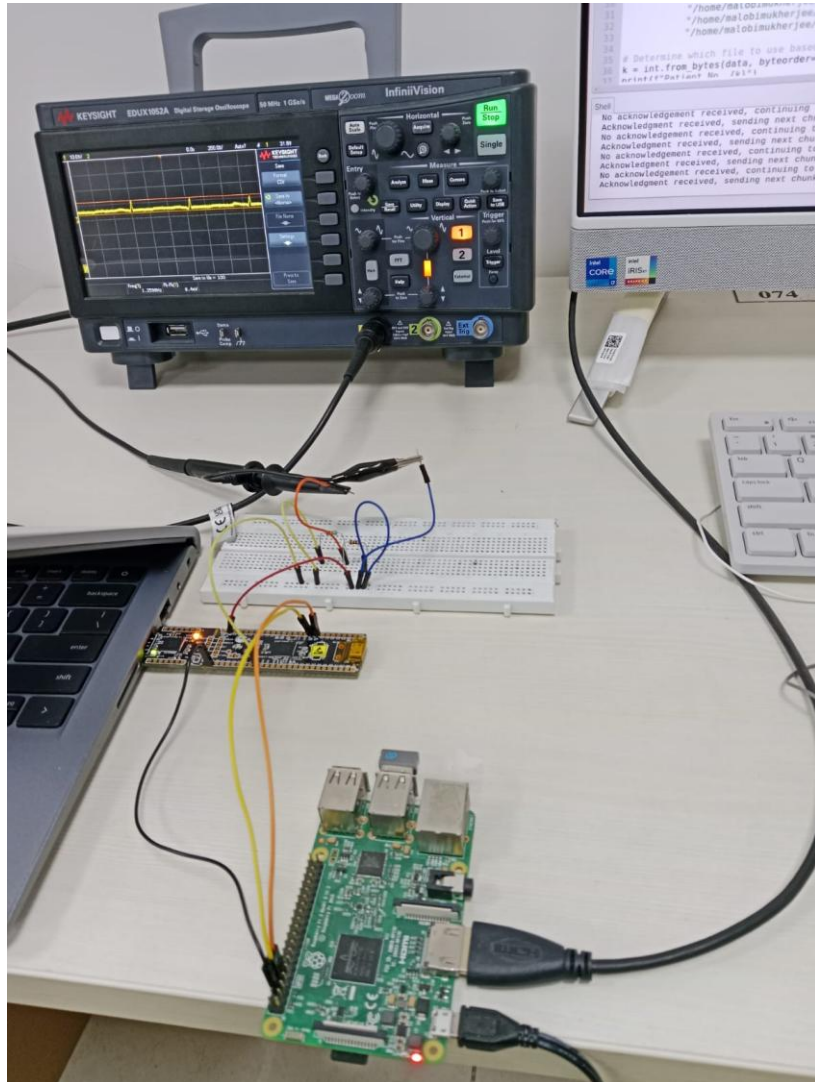


# Obtaining emulator output in mV – Square output

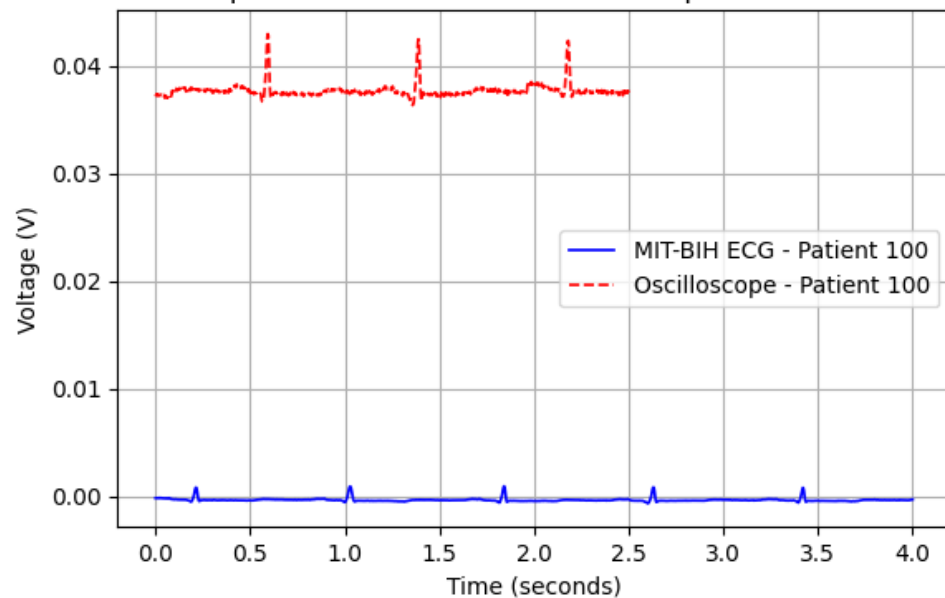




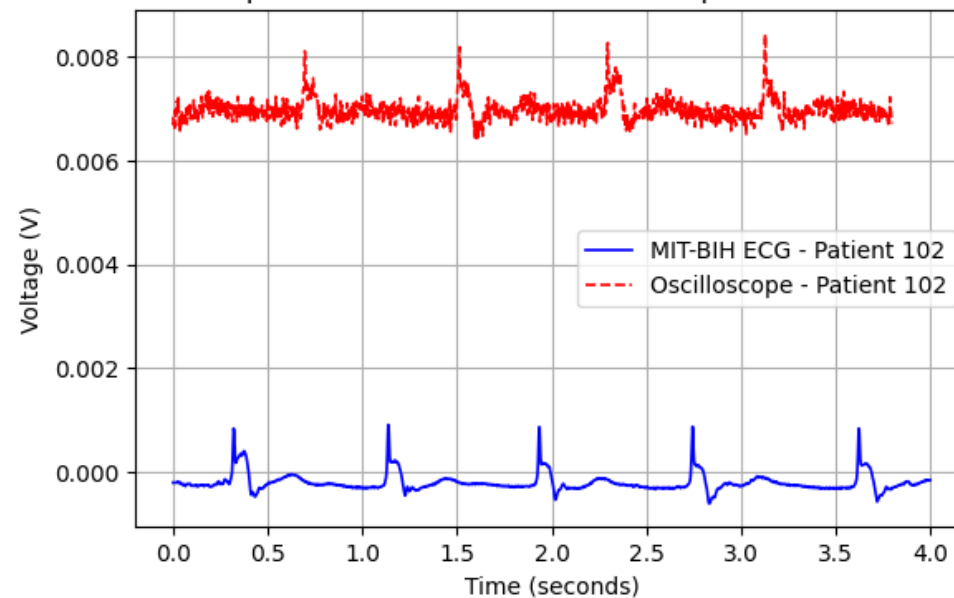
## Obtaining emulator output in mV – ECG output



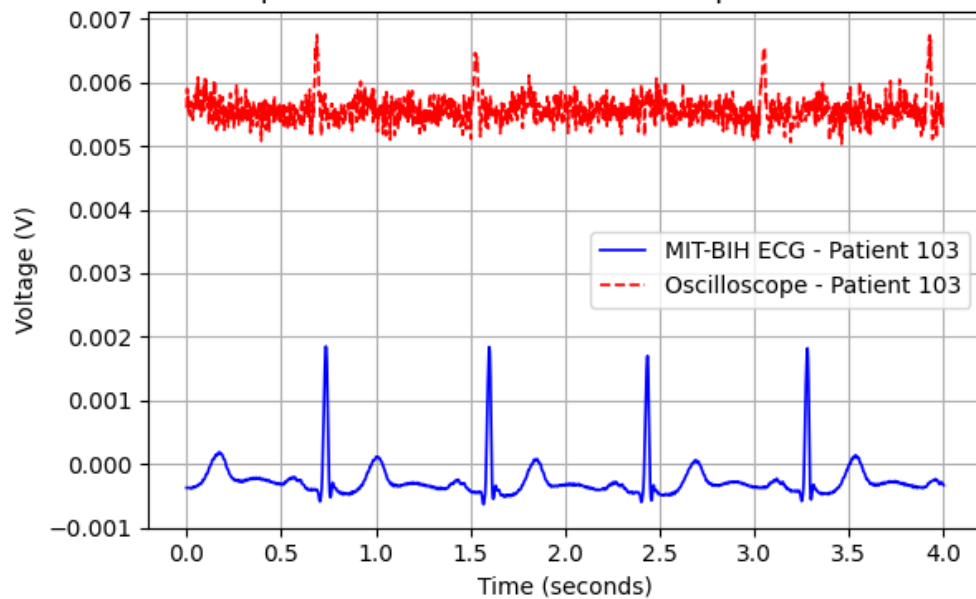
Comparison of MIT-BIH and Oscilloscope - Patient 100



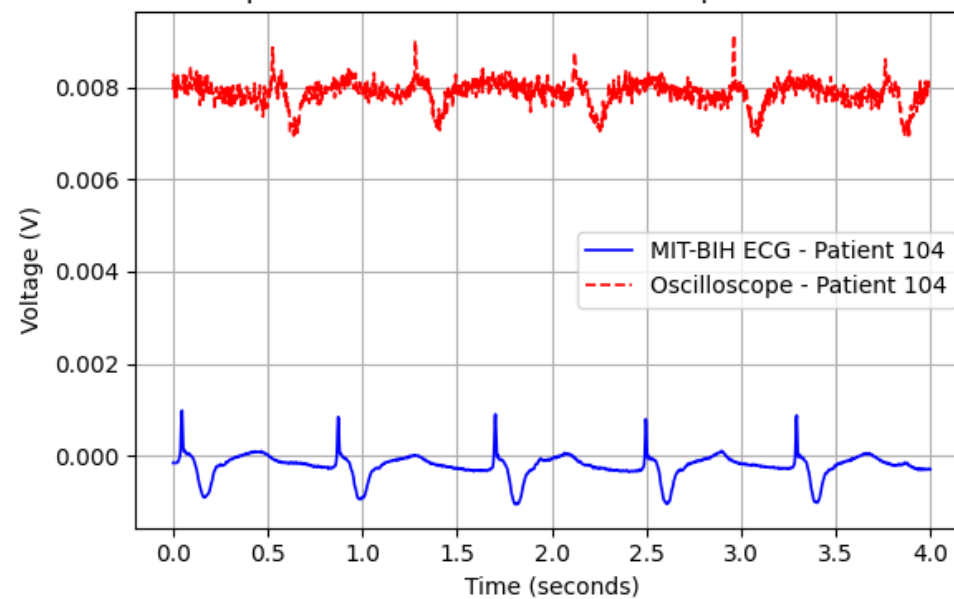
Comparison of MIT-BIH and Oscilloscope - Patient 102



Comparison of MIT-BIH and Oscilloscope - Patient 103

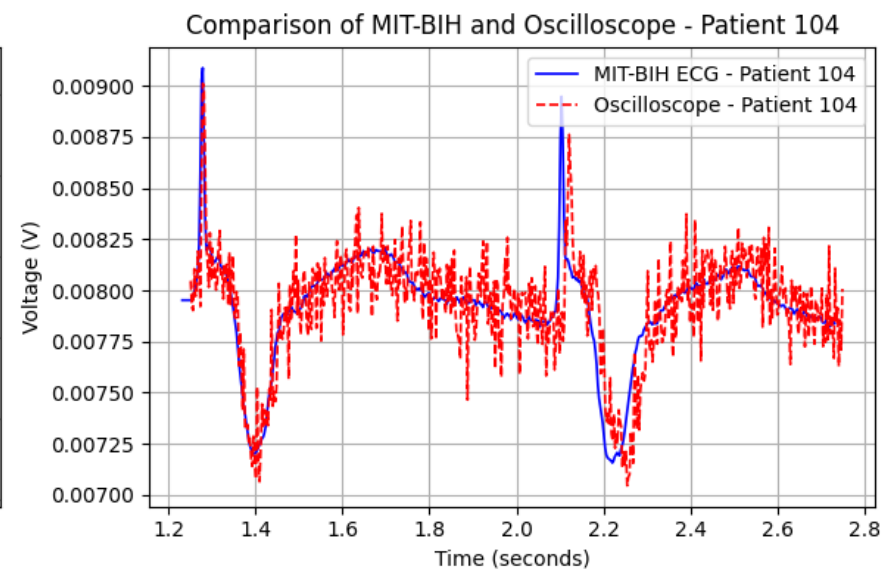
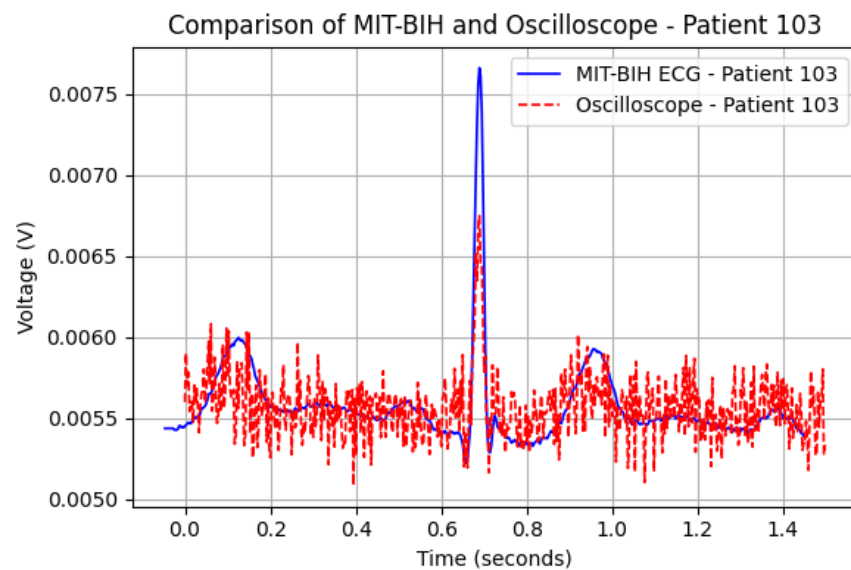
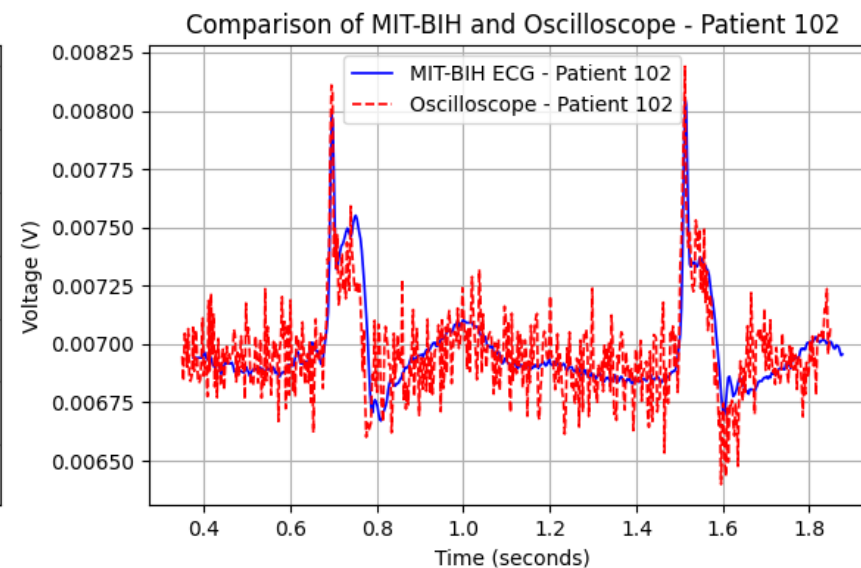
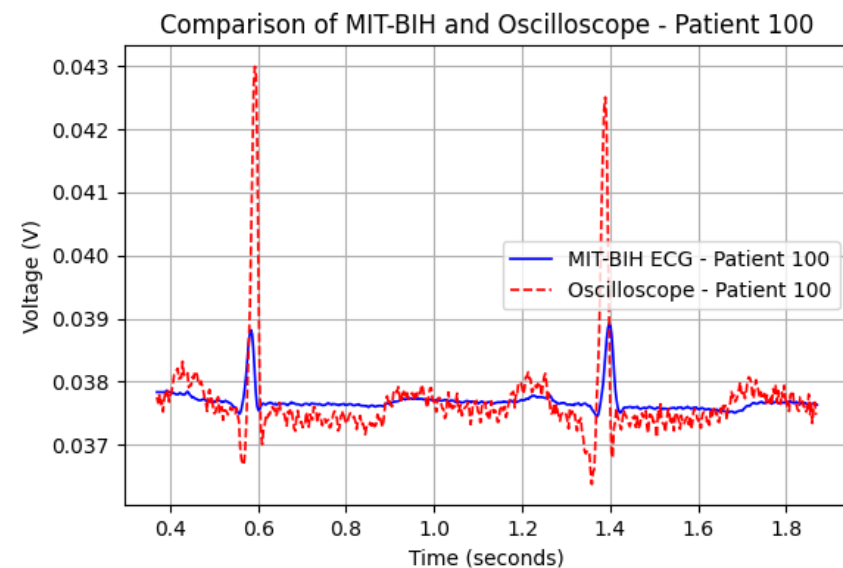


Comparison of MIT-BIH and Oscilloscope - Patient 104





For 2 peaks:



For 2 peaks:

Normalized cross-correlation value for patient 100: 0.527142

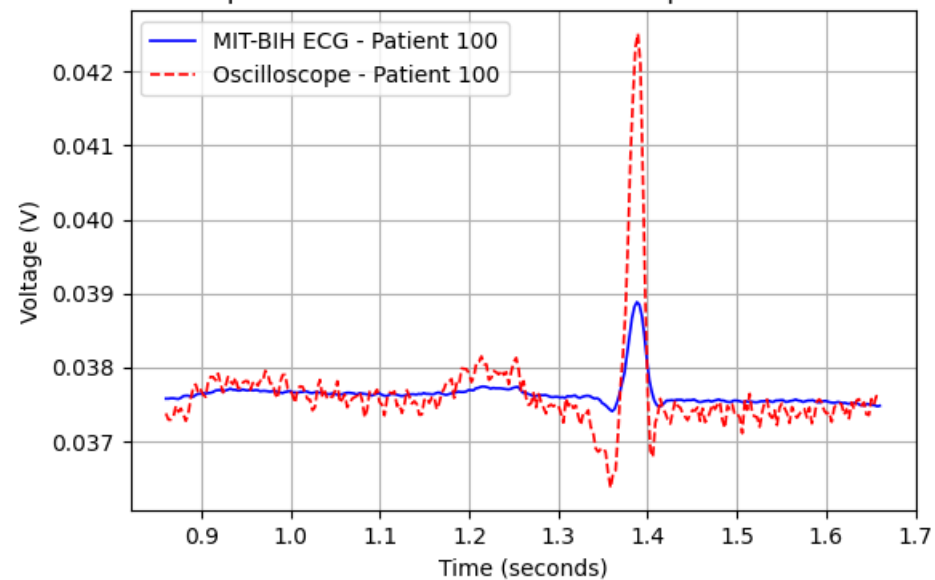
Normalized cross-correlation value for patient 102: 0.749451

Normalized cross-correlation value for patient 103: 0.587138

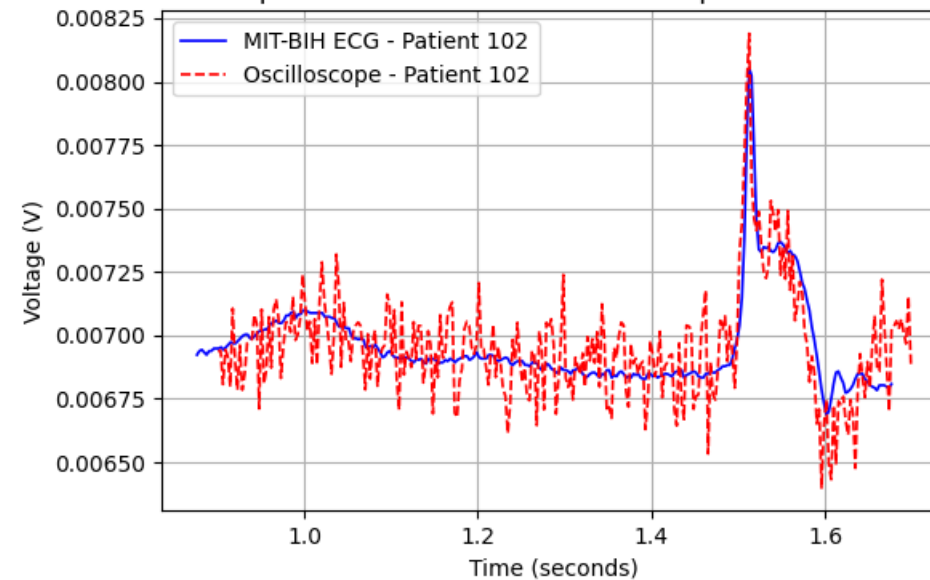
Normalized cross-correlation value for patient 104: 0.802677

For One peaks:

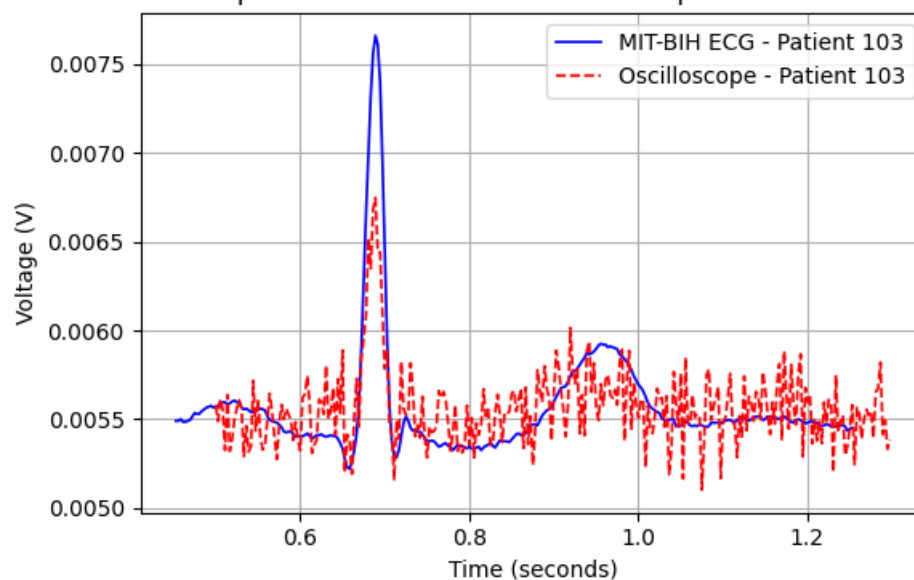
Comparison of MIT-BIH and Oscilloscope - Patient 100



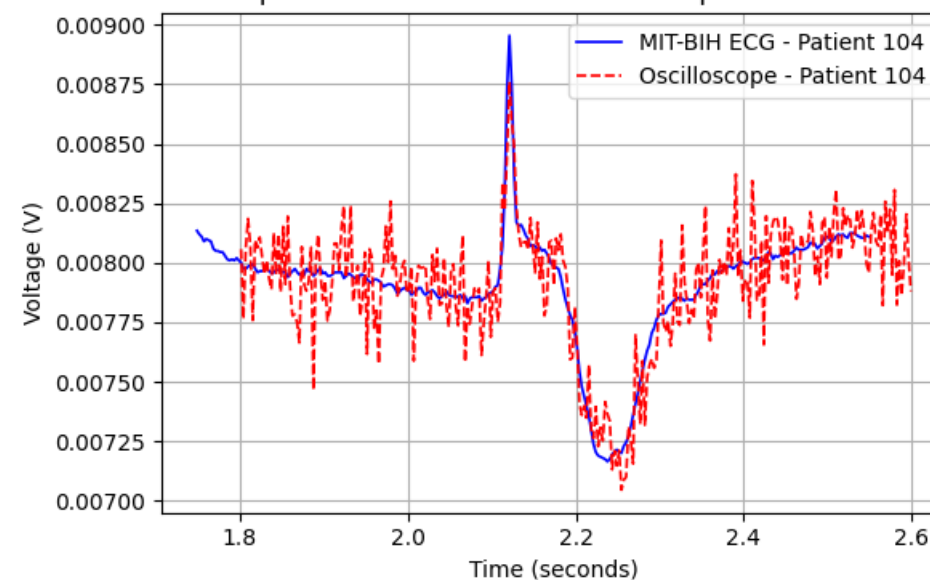
Comparison of MIT-BIH and Oscilloscope - Patient 102



Comparison of MIT-BIH and Oscilloscope - Patient 103



Comparison of MIT-BIH and Oscilloscope - Patient 104



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