VITAL SIGNS MONITORING USING A MICROWAVE RADAR

ANALYSIS OF MEASUREMENTS USING MATLAB

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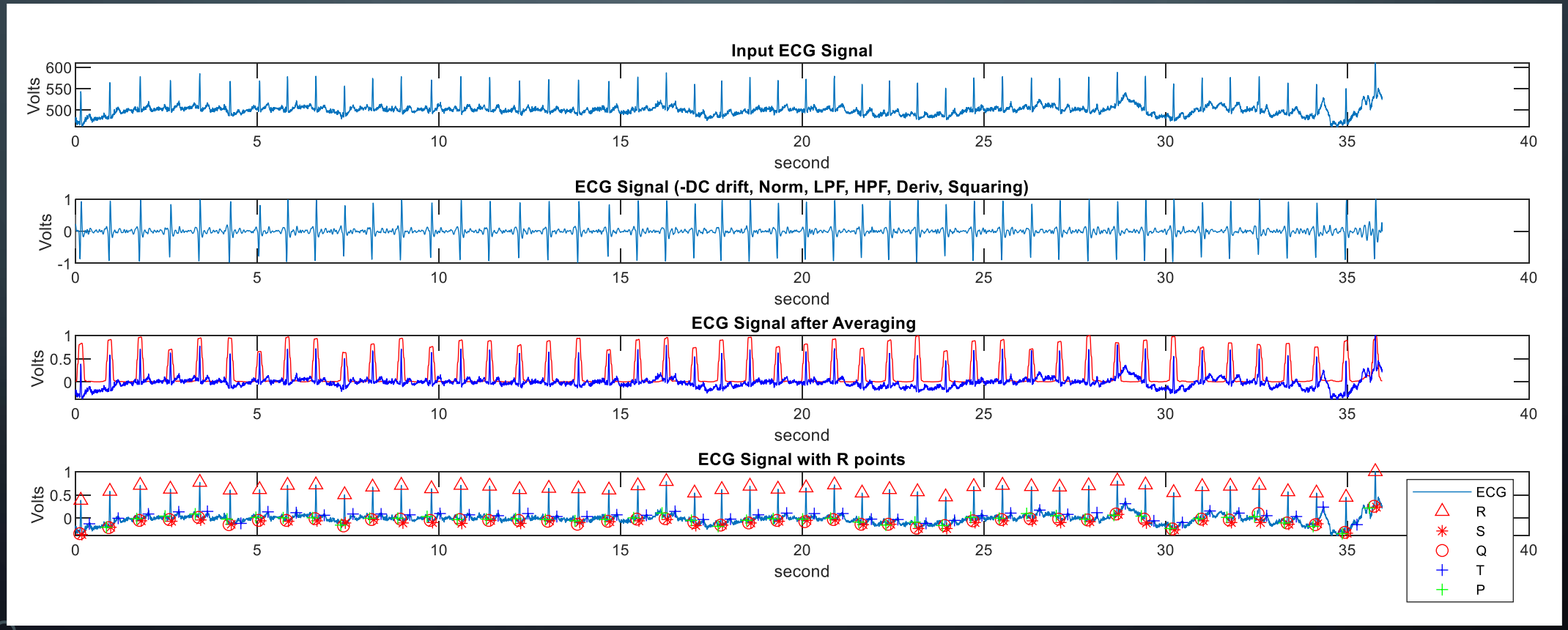
HEART RATE (HR) AND BREATHING RATE (BR) EXTRACTION FROM:

1. ECG signals used as reference signals.
2. Measurements from Microwave Radar.

1. ECG signals used as reference signals.

ECG signals obtained using the Contec CMS-VESD device. Location and Amplitude of R waves in ECG signal were found using the Pan-Tompkins based detection algorithm.



A) HR FROM ECG SIGNAL

Time-domain Analysis (TDA)

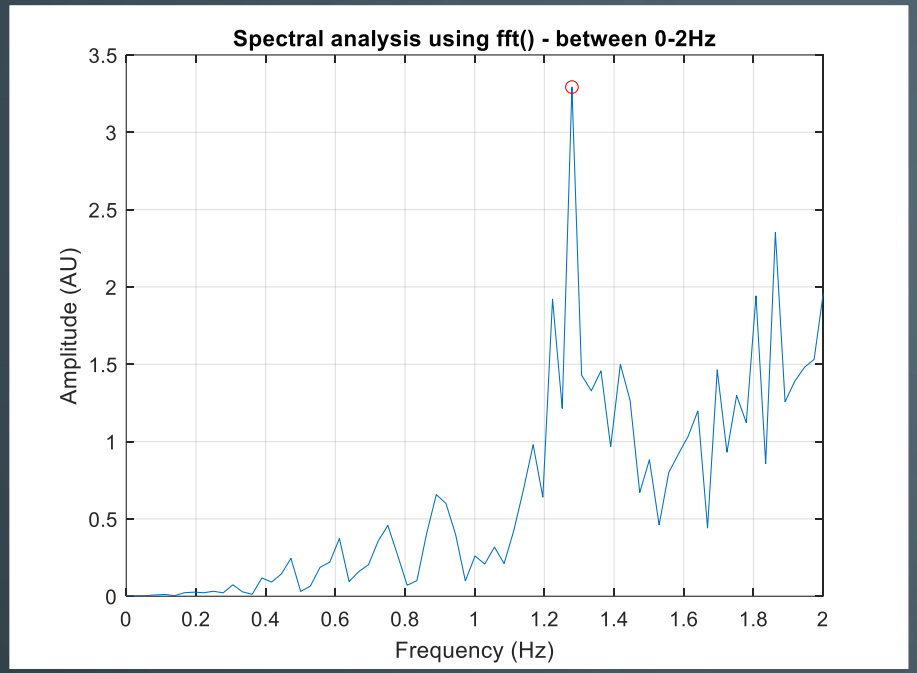
HR obtained by finding the average of the RR intervals.

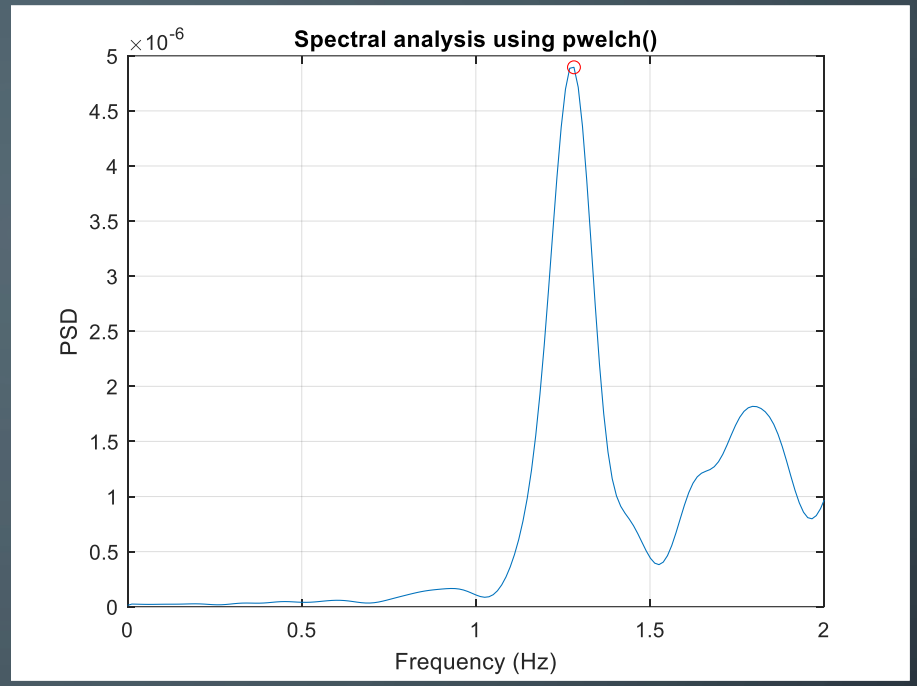
$$\text{HR (in bpm)} = \frac{60}{(mean\ RR\ intervals)}$$

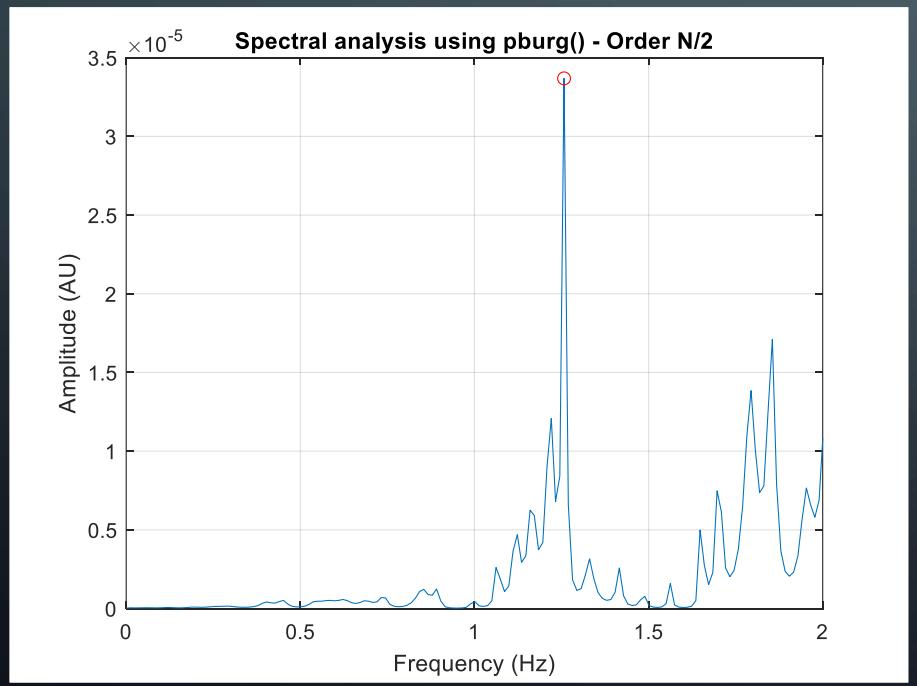
Frequency-domain Analysis

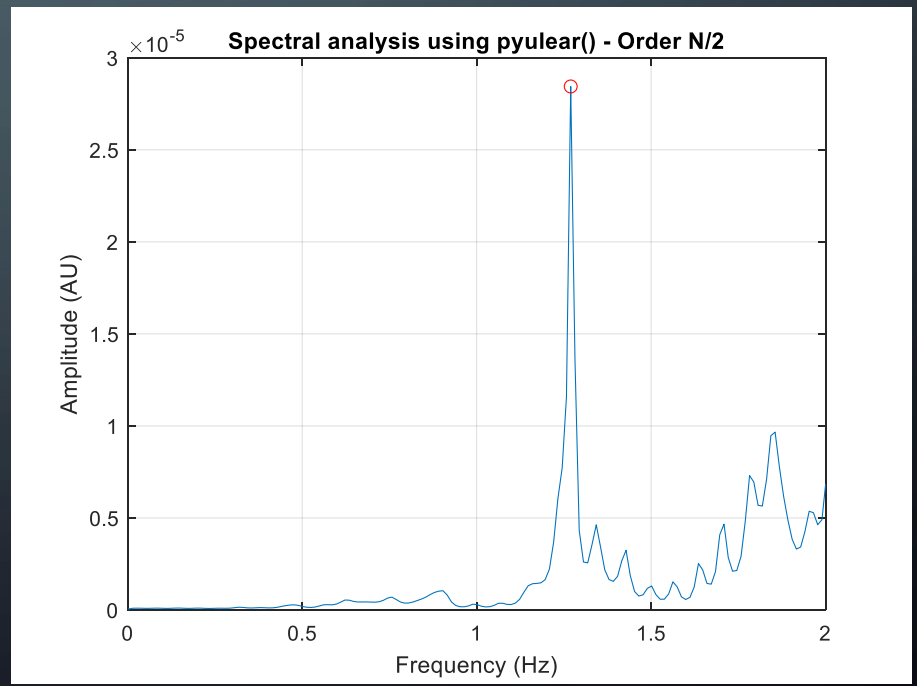
Methods used are:

- FFT
- Welch method – using Hamming window
- Burg Method
- Yule-Walker algorithm


Spectral analysis using fft() - between 0-2Hz
Amplitude (AU)
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8


Spectral analysis using pwelch()
×10^-6
PSD
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Spectral analysis using pburg() - Order N/2
×10^-5
Amplitude (AU)
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5


Spectral analysis using pyulear() - Order N/2
×10^-5
Amplitude (AU)
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3

A) HR FROM ECG SIGNAL

Results:

	TDA	FFT	BURG	WELCH	YW	Average HR	From CMS VESD software
HR (bpm)	75.7895	76.7413	75.4395	76.9043	76.1719	76.2093	76.1250

B) BR FROM ECG SIGNAL

BR was extracted from variations in:

(i) RR intervals – Frequency Modulated (FM) signal, also called Heart Rate variability signal

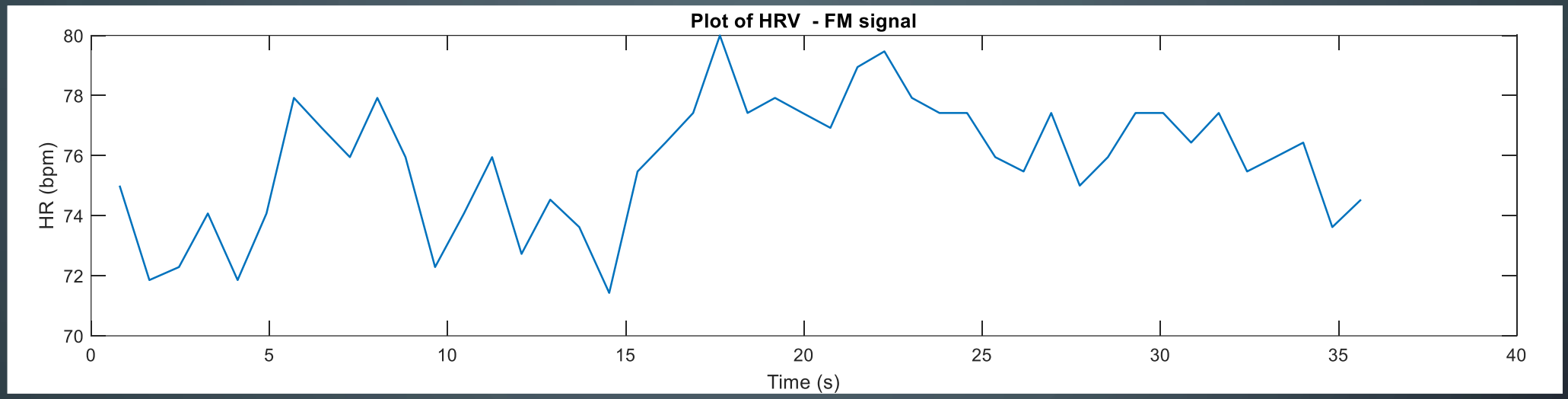
(ii) R values - Amplitude Modulated (AM) signal.

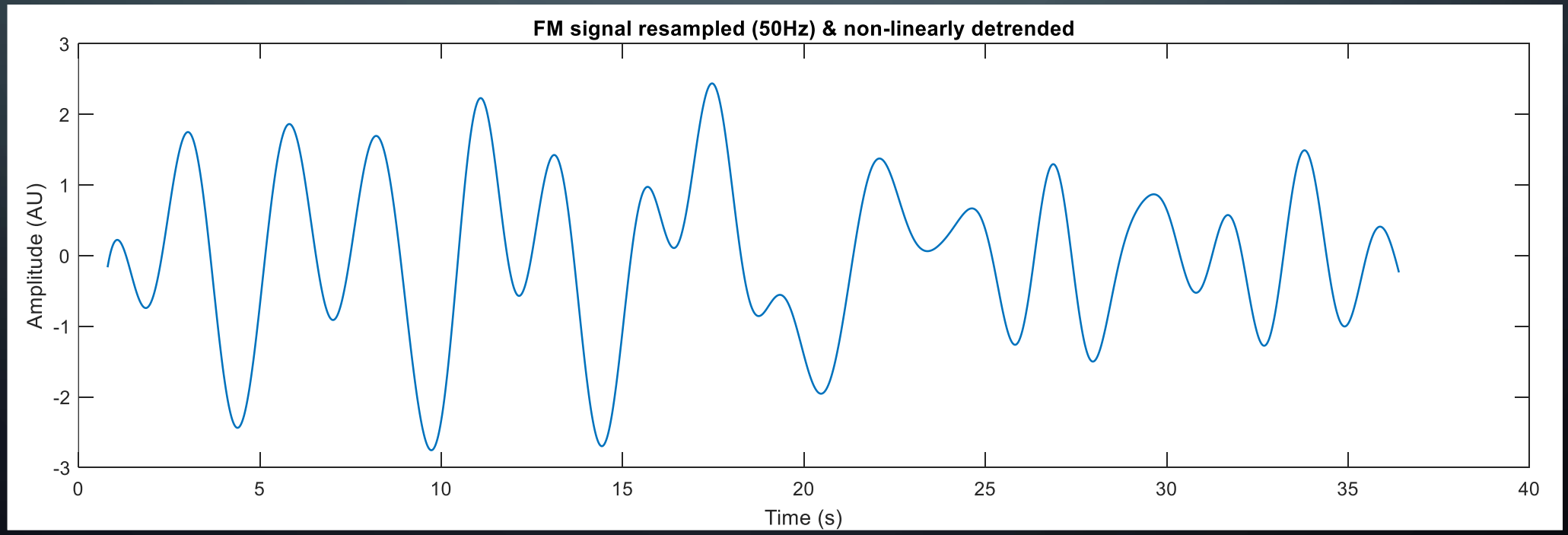
Methods used for both FM and AM signals are:

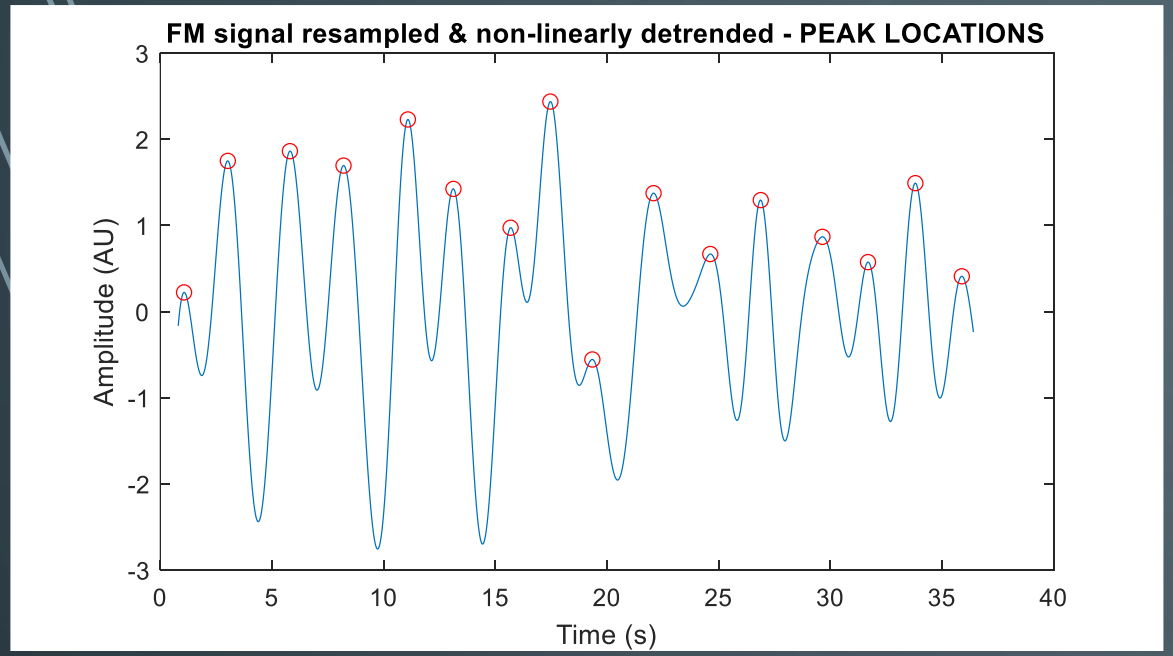
- Time-domain analysis (TDA) – Peak detection
- Frequency/Spectral analysis
  a. FFT
  b. Burg Method
  c. Yule-walker algorithm
  d. Welch method
  e. Lomb-Scargle Periodogram

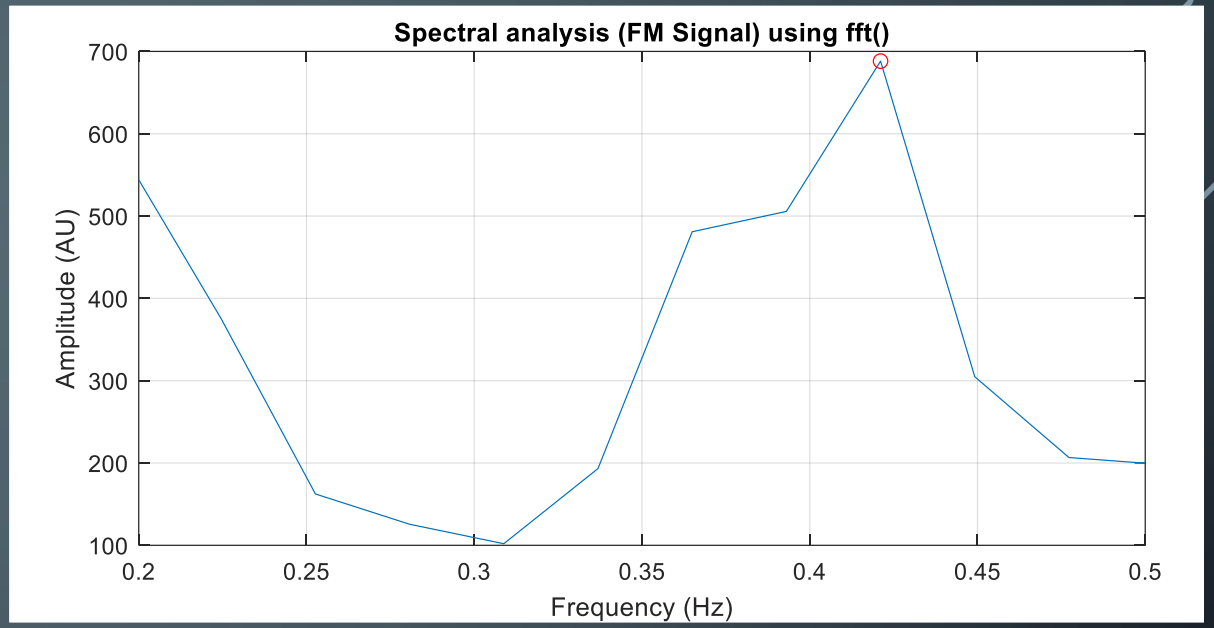
Issue with these signals is that they are non-uniformly sampled signals, since there is one reading per beat. All methods apart from Lomb-Scargle Periodogram require cubic spline or linear interpolation, to resample the signal at a constant known sampling rate.

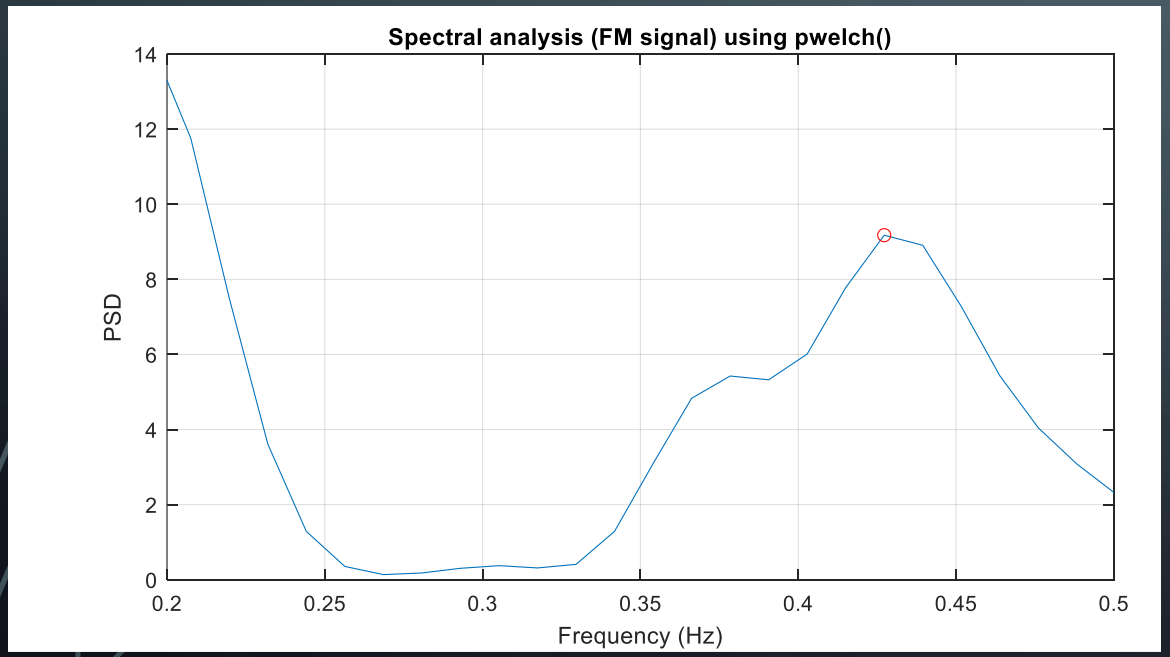
B) BR FROM ECG SIGNAL – FM SIGNAL

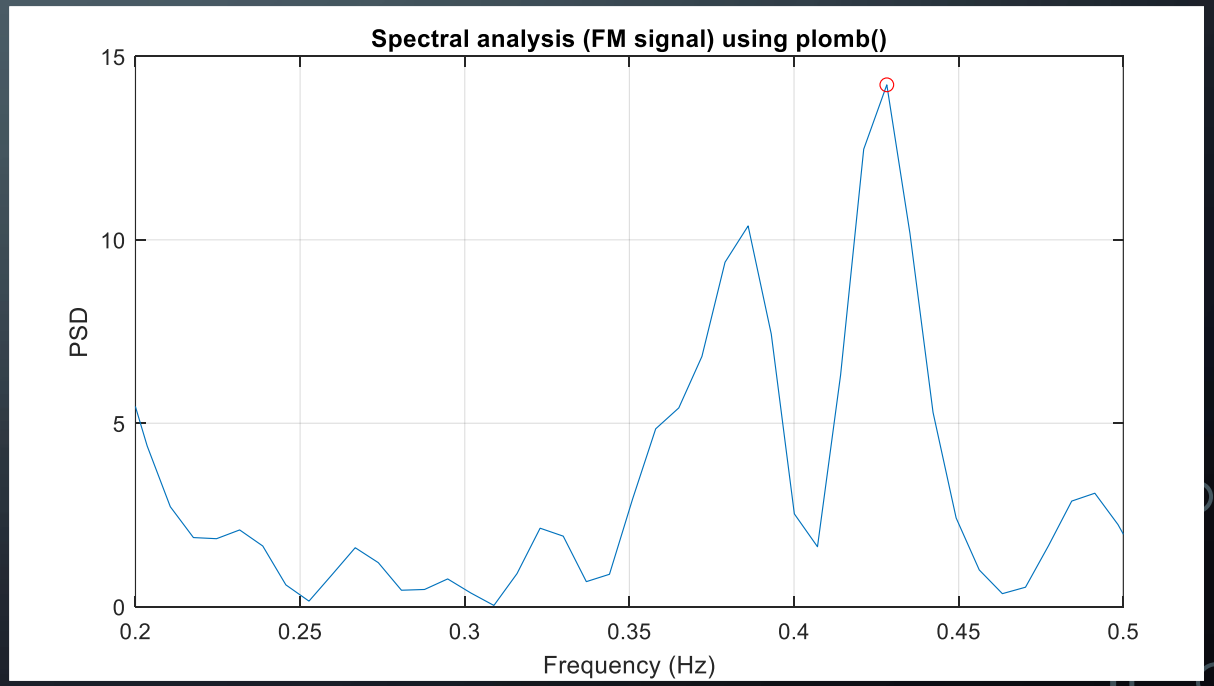


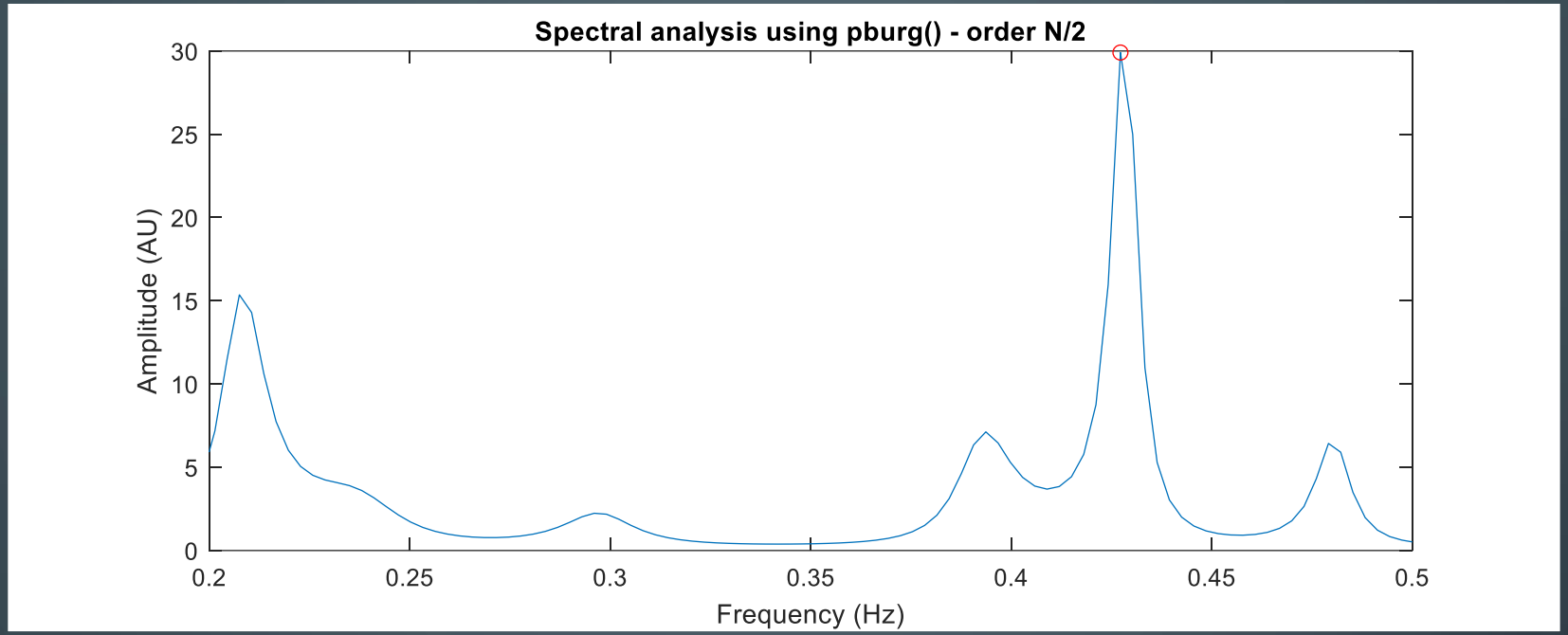


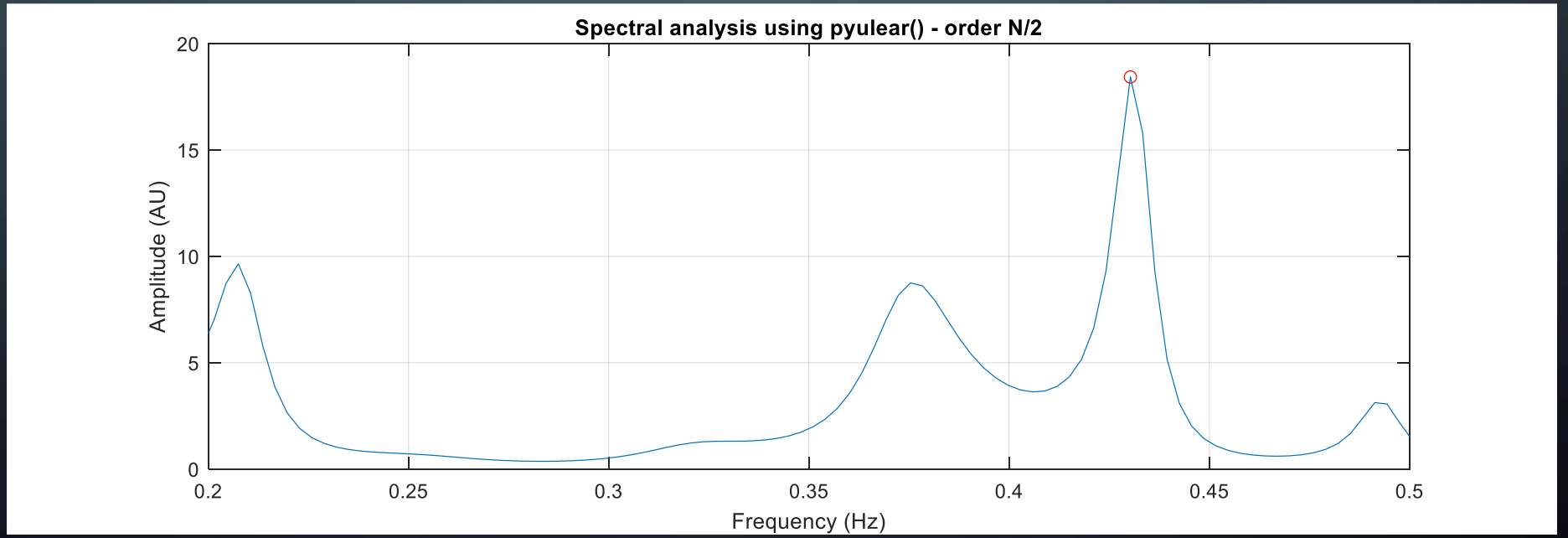

FM signal resampled & non-linearly detrended - PEAK LOCATIONS
Amplitude (AU)
Time (s)
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
35
40


Spectral analysis (FM Signal) using fft()
Amplitude (AU)
Frequency (Hz)
700
600
500
400
300
200
100
0.2
0.25
0.3
0.35
0.4
0.45
0.5

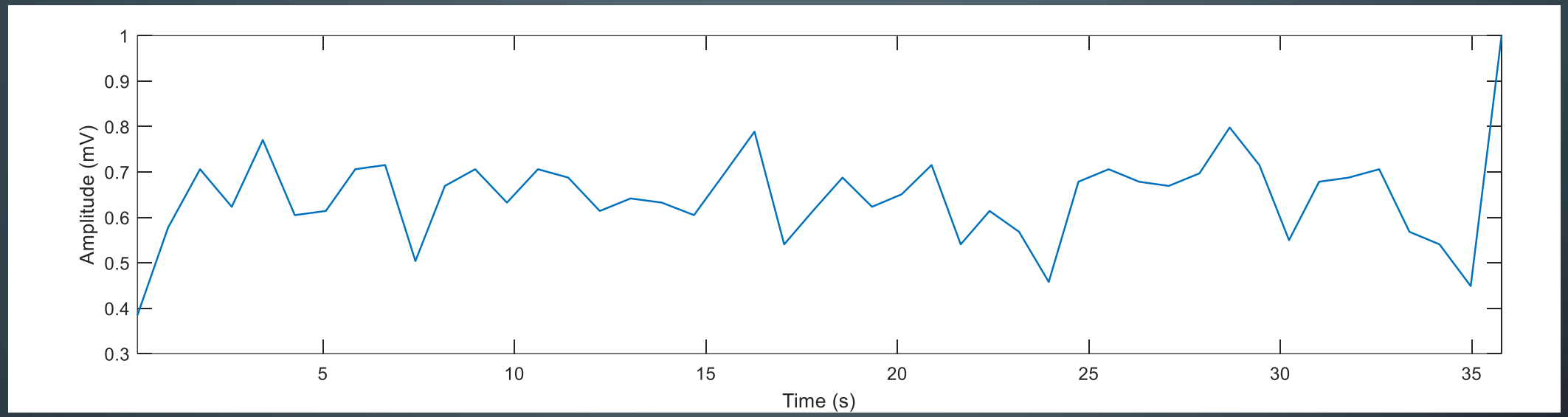

Spectral analysis (FM signal) using pwelch()
PSD
Frequency (Hz)
14
12
10
8
6
4
2
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5

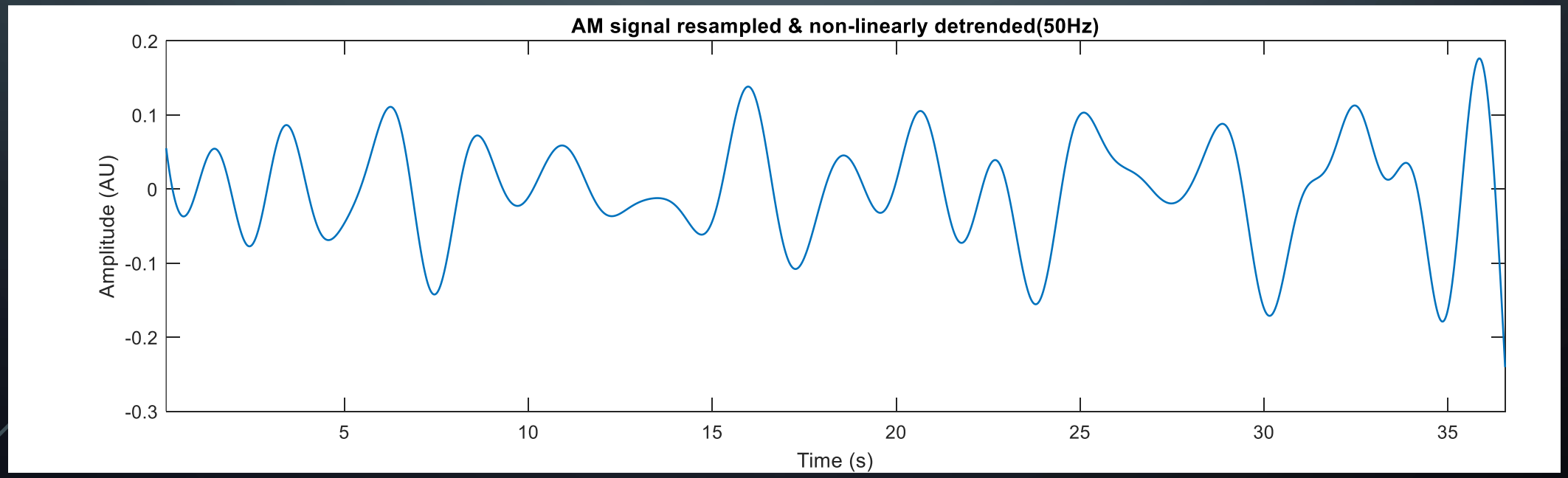

Spectral analysis (FM signal) using plomb()
PSD
Frequency (Hz)
15
10
5
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5

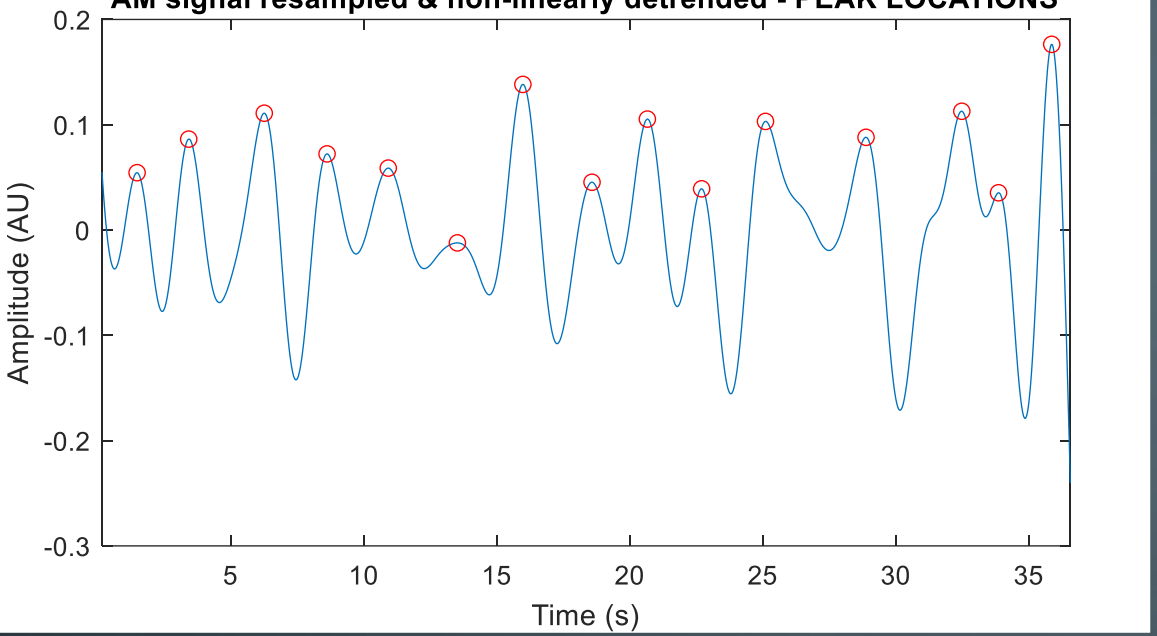

Spectral analysis using pburg() - order N/2
Amplitude (AU)
Frequency (Hz)
0
5
10
15
20
25
30
0.2
0.25
0.3
0.35
0.4
0.45
0.5

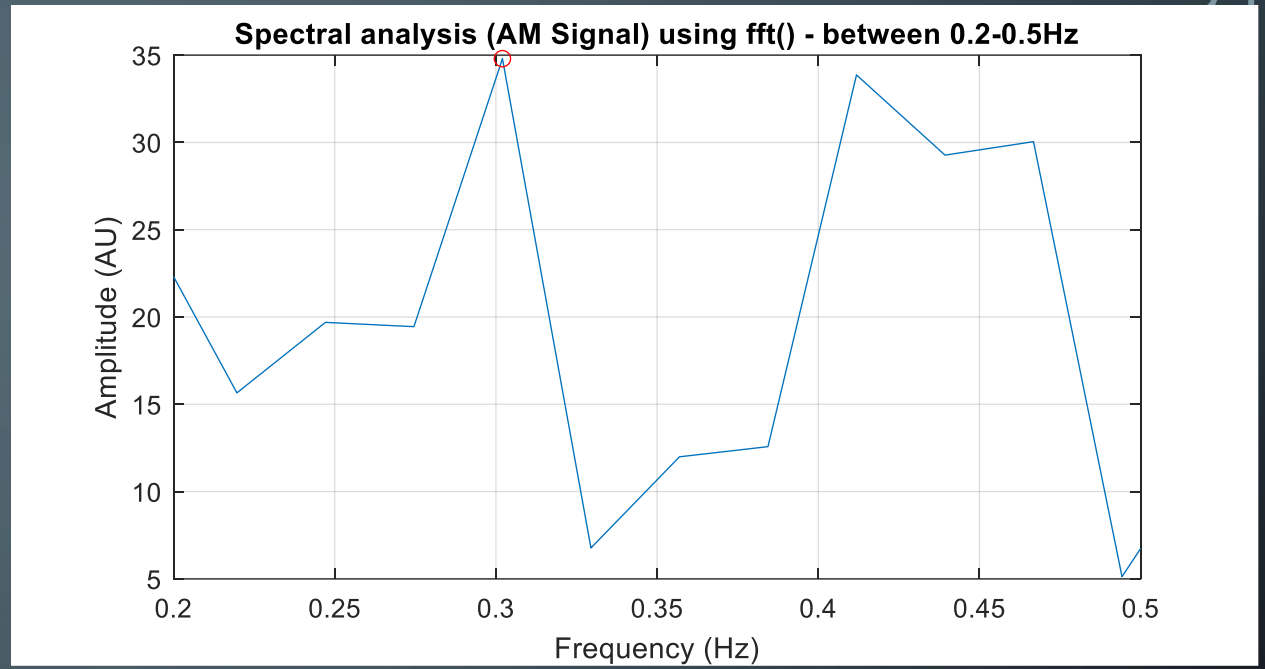

Spectral analysis using pyulear() - order N/2
Amplitude (AU)
Frequency (Hz)
0
5
10
15
20
0.2
0.25
0.3
0.35
0.4
0.45
0.5

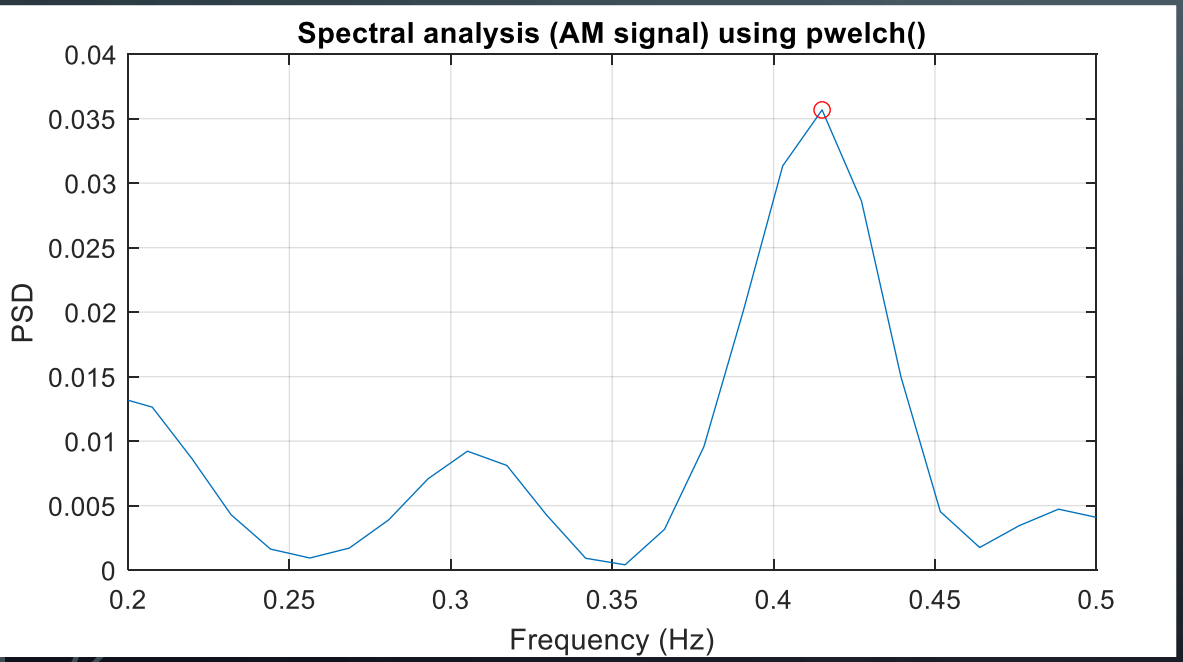
B) BR FROM ECG SIGNAL – AM SIGNAL

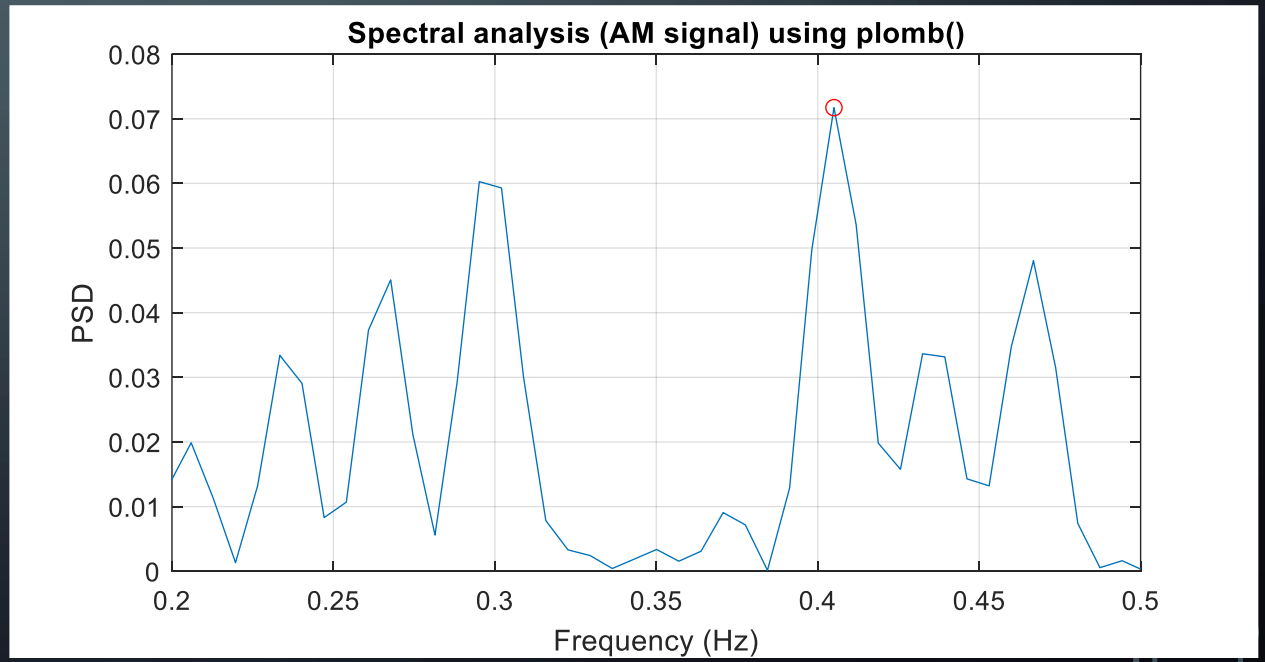


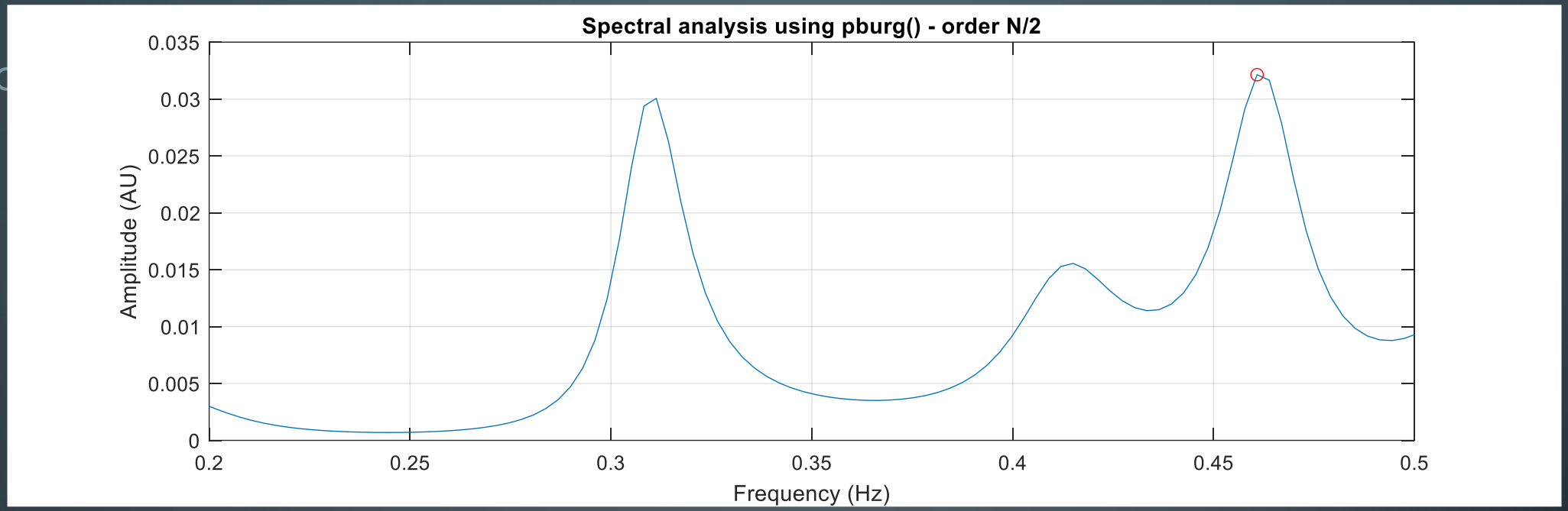


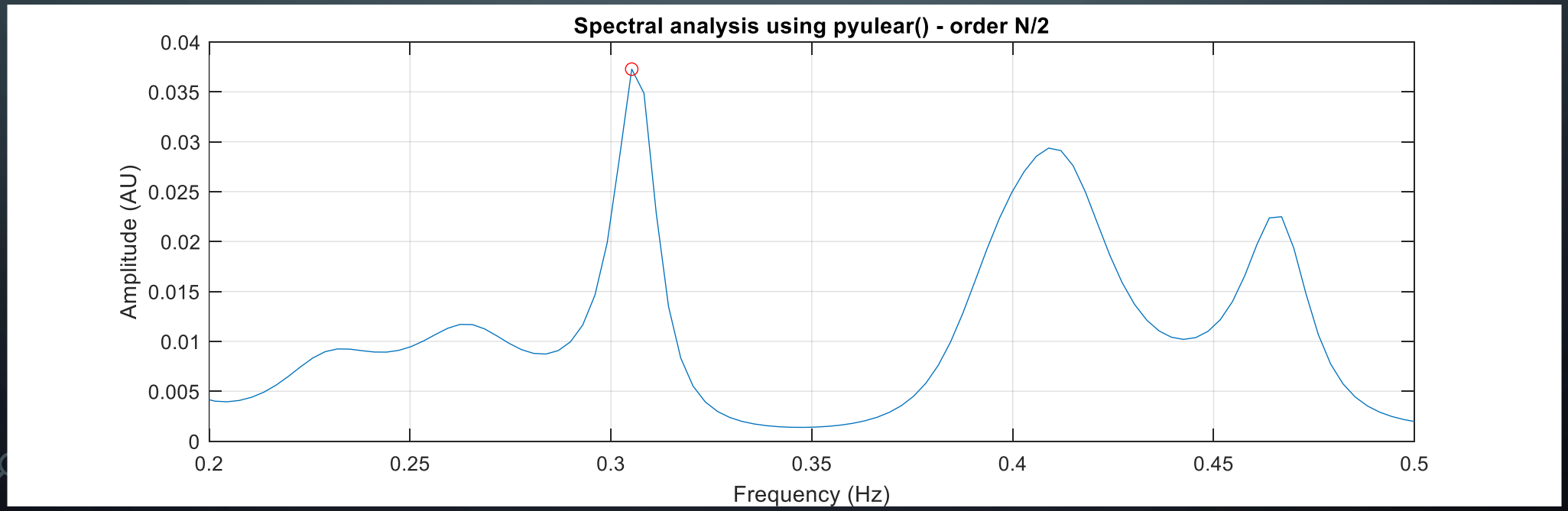

AM signal resampled & non-linearly detrended - PEAK LOCATIONS
Amplitude (AU)
Time (s)
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25
30
35


Spectral analysis (AM Signal) using fft() - between 0.2-0.5Hz
Amplitude (AU)
Frequency (Hz)
35
30
25
20
15
10
5
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Spectral analysis (AM signal) using pwelch()
PSD
Frequency (Hz)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Spectral analysis (AM signal) using plomb()
PSD
Frequency (Hz)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Spectral analysis using pburg() - order N/2
Amplitude (AU)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency (Hz)


Spectral analysis using pyulear() - order N/2
Amplitude (AU)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency (Hz)

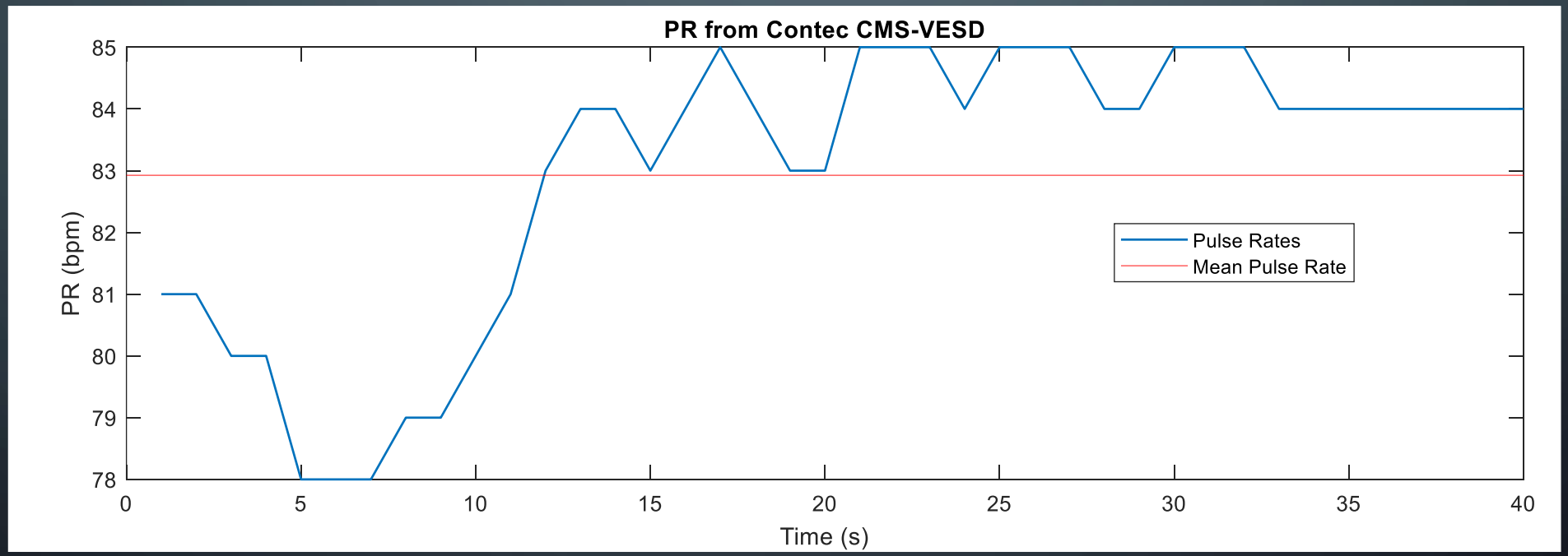
A) BR FROM ECG SIGNAL

Results:

FM SIGNAL							
	TDA	FFT	BURG	WELCH	YW	LOMB-SCARGLE	Average BR
BR (bpm)	25.8472	25.2667	25.6348	25.6348	25.8179	25.6904	**25.6486**
AM SIGNAL							
	TDA	FFT	BURG	WELCH	YW	LOMB-SCARGLE	Average BR
BR (bpm)	24.4328	18.1219	27.6489	24.9023	18.3105	24.3021	22.9531

2. Measurements from Microwave Radar.

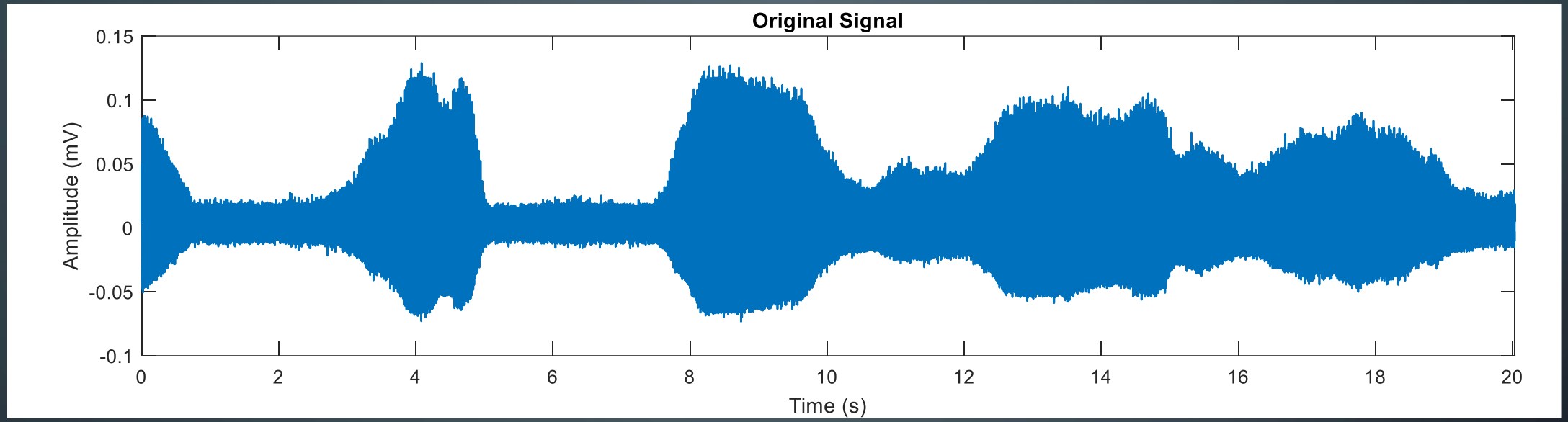
These measurements were made using reference signals from PPG sensor from the Contec CMS-VESD device, and not from ECG sensor. The following data are from “charis.spo” and “measurements_charis.mat” .

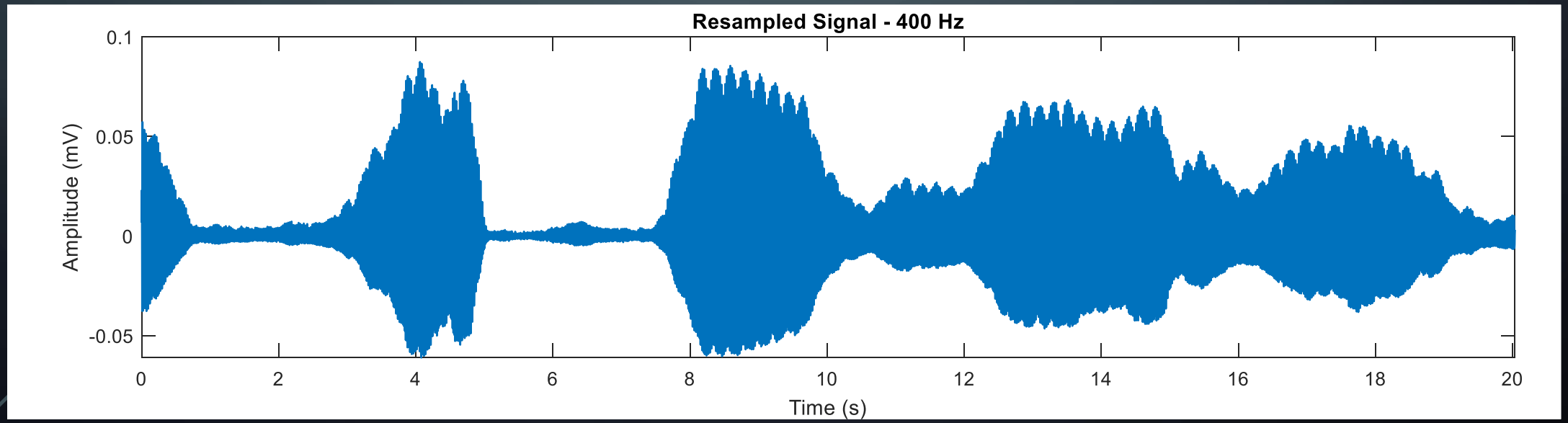


Reference Heart Rate values

MEASUREMENTS FROM MICROWAVE RADAR

For the following processing algorithm, the original data was resampled at 400 Hz.





ANALYSIS OF SIGNALS FROM RADAR

The Heart Signal and Breathing signal were extracted from the original data using filtering techniques and then analysed separately. It should be noted that the order of filters was decided according to filter's stability due to high original sampling rate (100 MHz) and low cutoff frequencies (order of Hz).

In order to increase filter's order, the signal was resampled at a lower frequency.

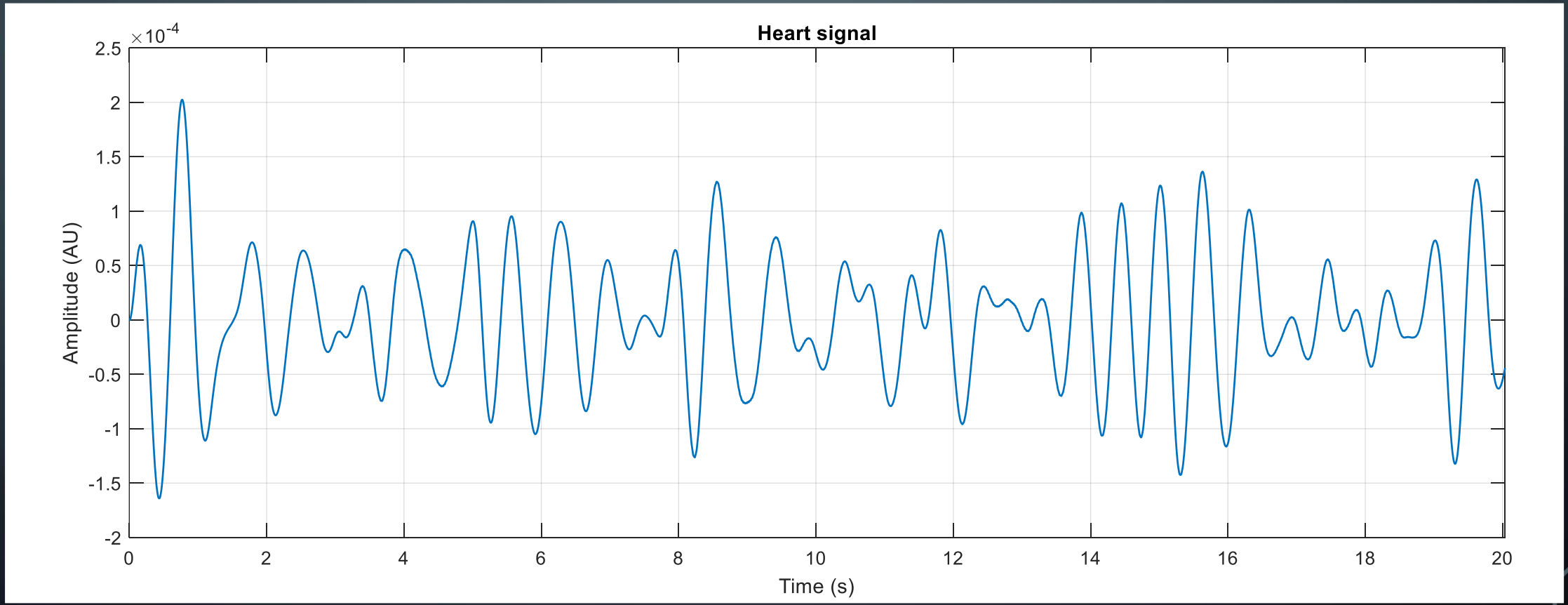
Both signals were then analysed using:

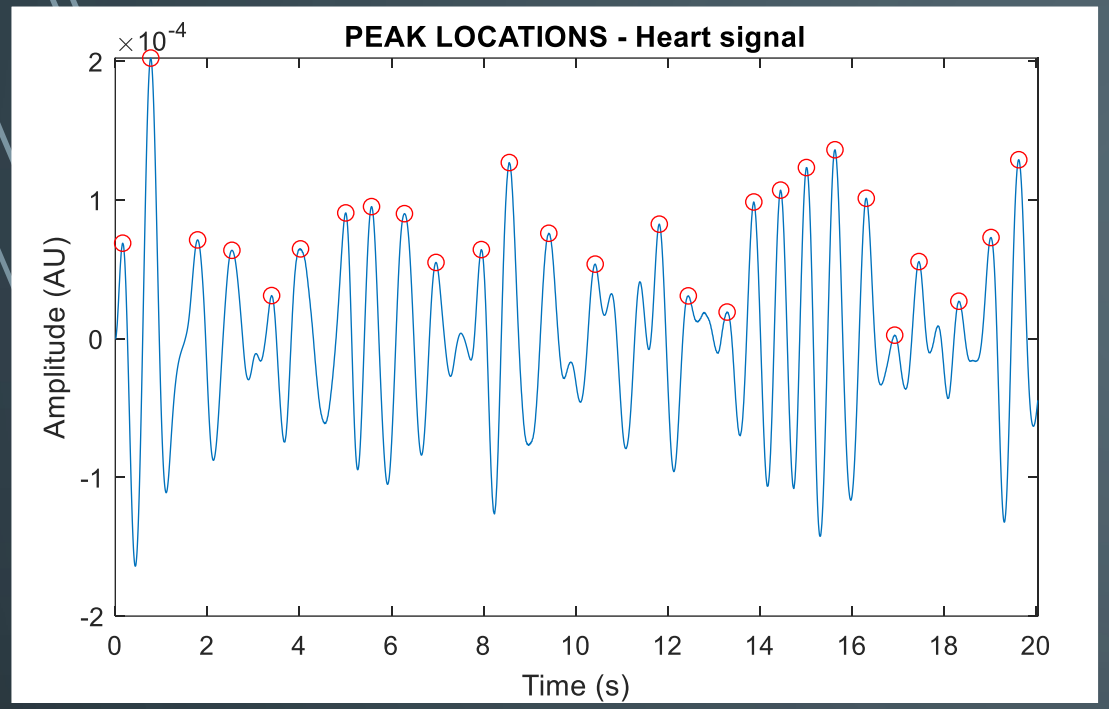
- Time-domain analysis (TDA) – Peak detection
- Frequency/Spectral analysis
    a. FFT
    b. Burg Method
    c. Yule-walker algorithm
    d. Welch method
    e. Periodogram method

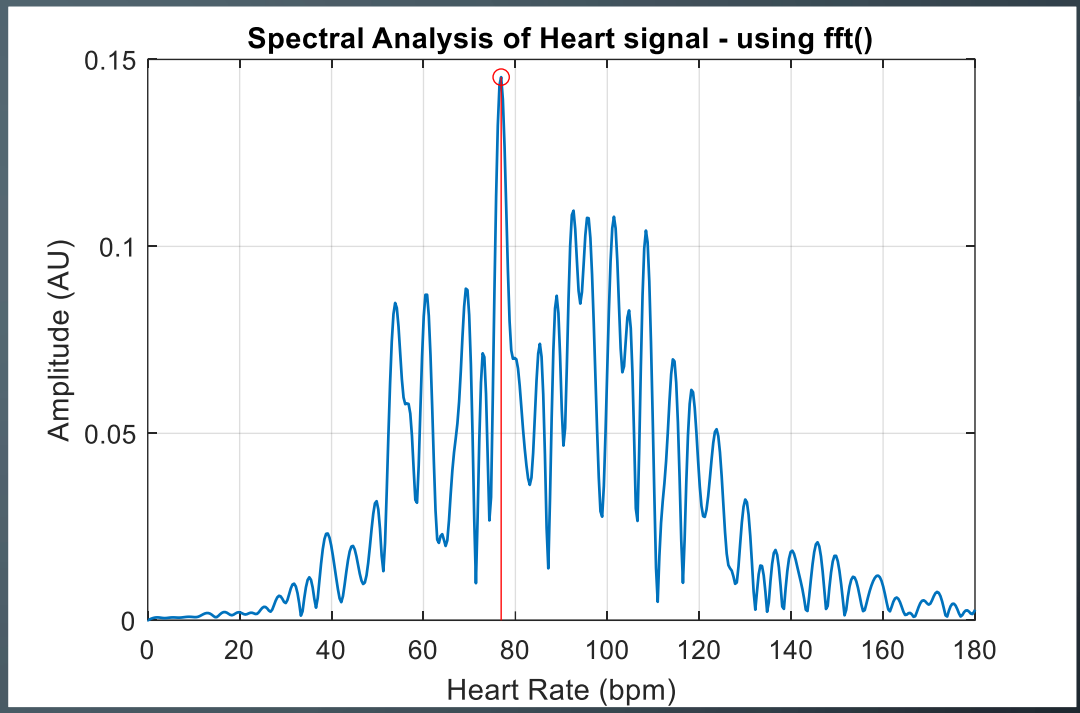
It should be noted that for Welch method, the window length was selected such that at least 5 beats were observed in each segment of HR signal and at least 3 breaths in each segment of BR signal

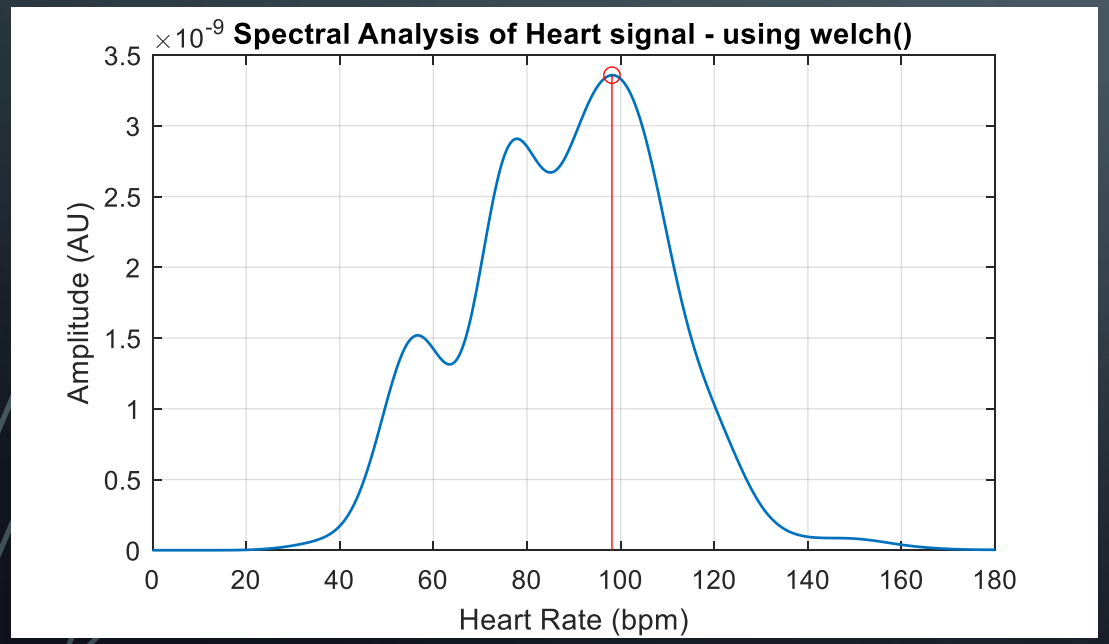
HEART RATE EXTRACTION

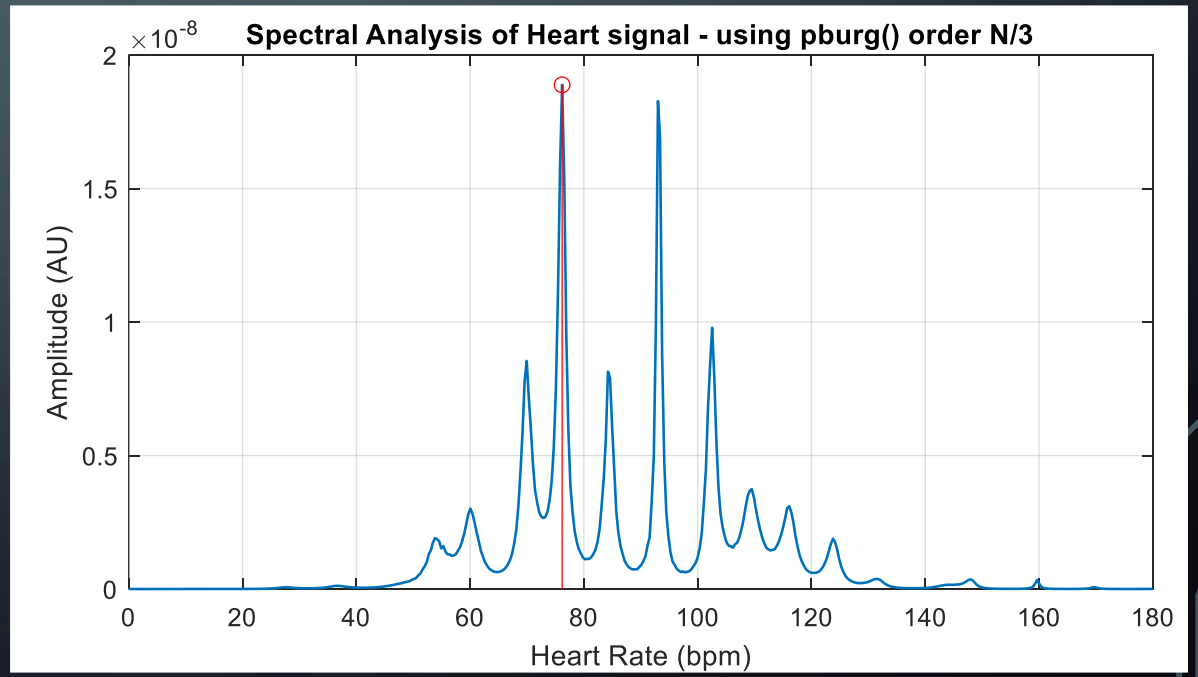
To obtain Heart Signal, the data was filtered using a Butterworth bandpass filter of order 3, with cutoff frequencies of 1 and 2 Hz.

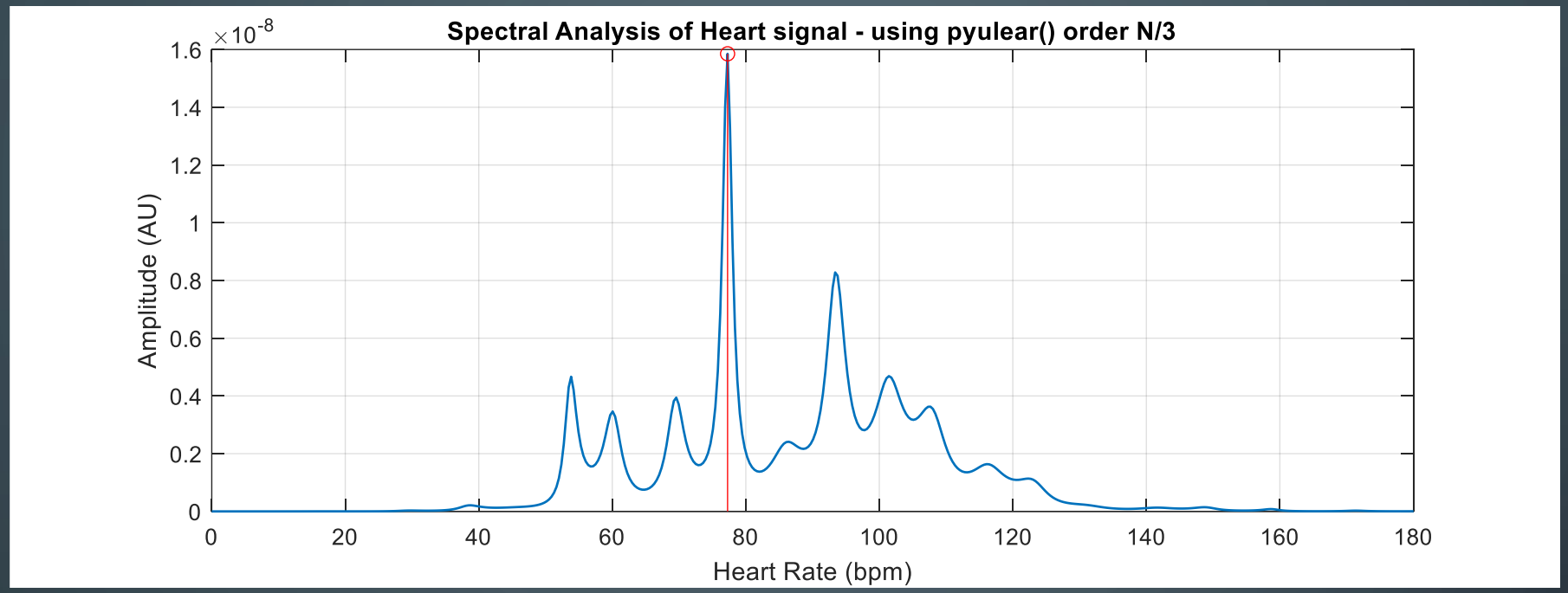


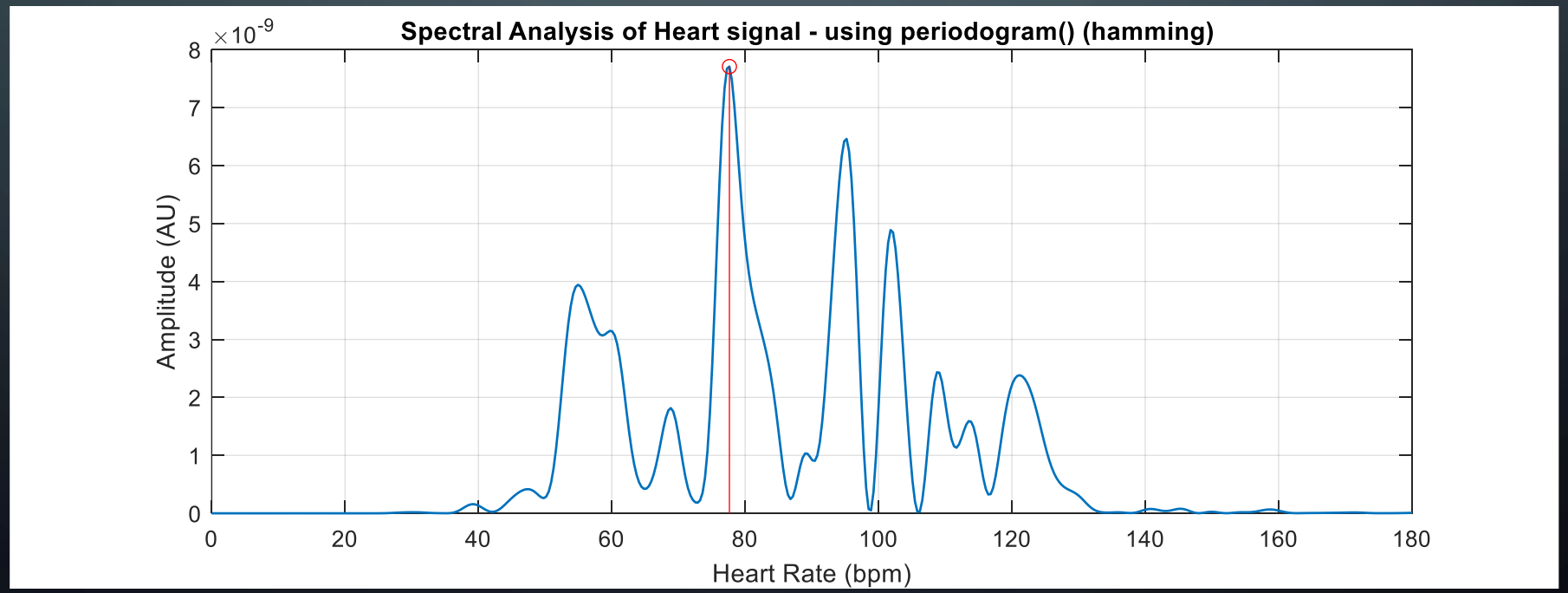

PEAK LOCATIONS - Heart signal
×10^-4
Amplitude (AU)
Time (s)


Spectral Analysis of Heart signal - using fft()
Amplitude (AU)
Heart Rate (bpm)


×10^-9 Spectral Analysis of Heart signal - using welch()
Amplitude (AU)
Heart Rate (bpm)

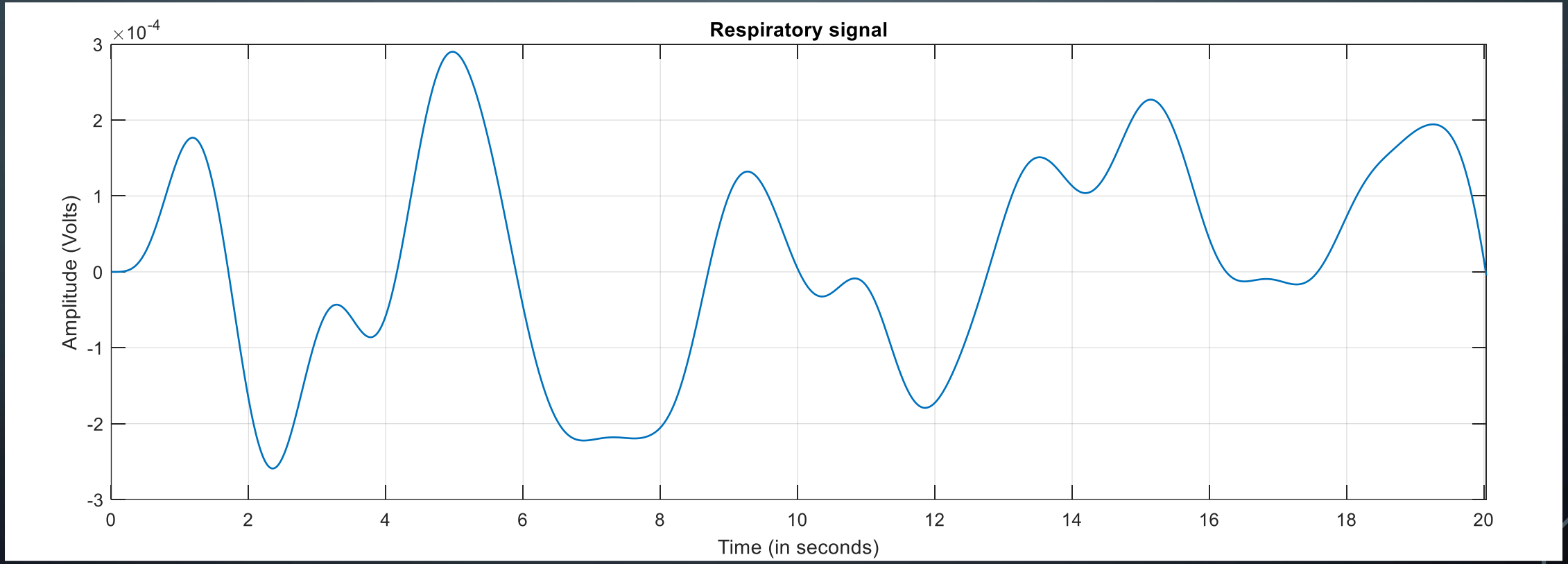

×10^-8 Spectral Analysis of Heart signal - using pburg() order N/3
Amplitude (AU)
Heart Rate (bpm)

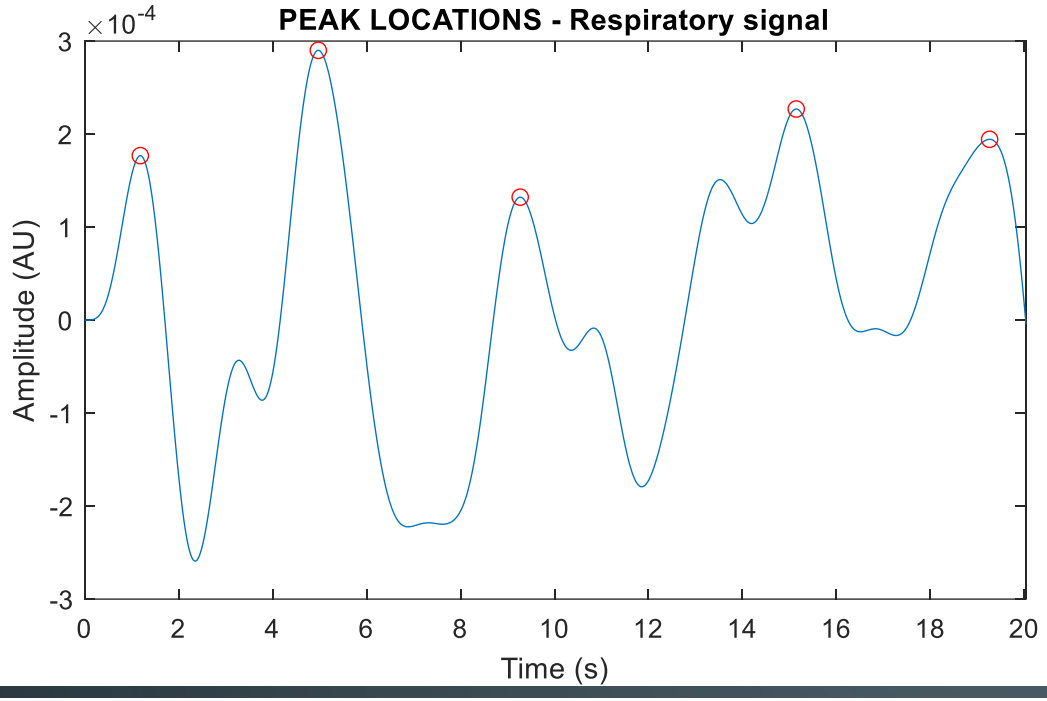

Spectral Analysis of Heart signal - using pyulear() order N/3
×10^-8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Amplitude (AU)
0
20
40
60
80
100
120
140
160
180
Heart Rate (bpm)

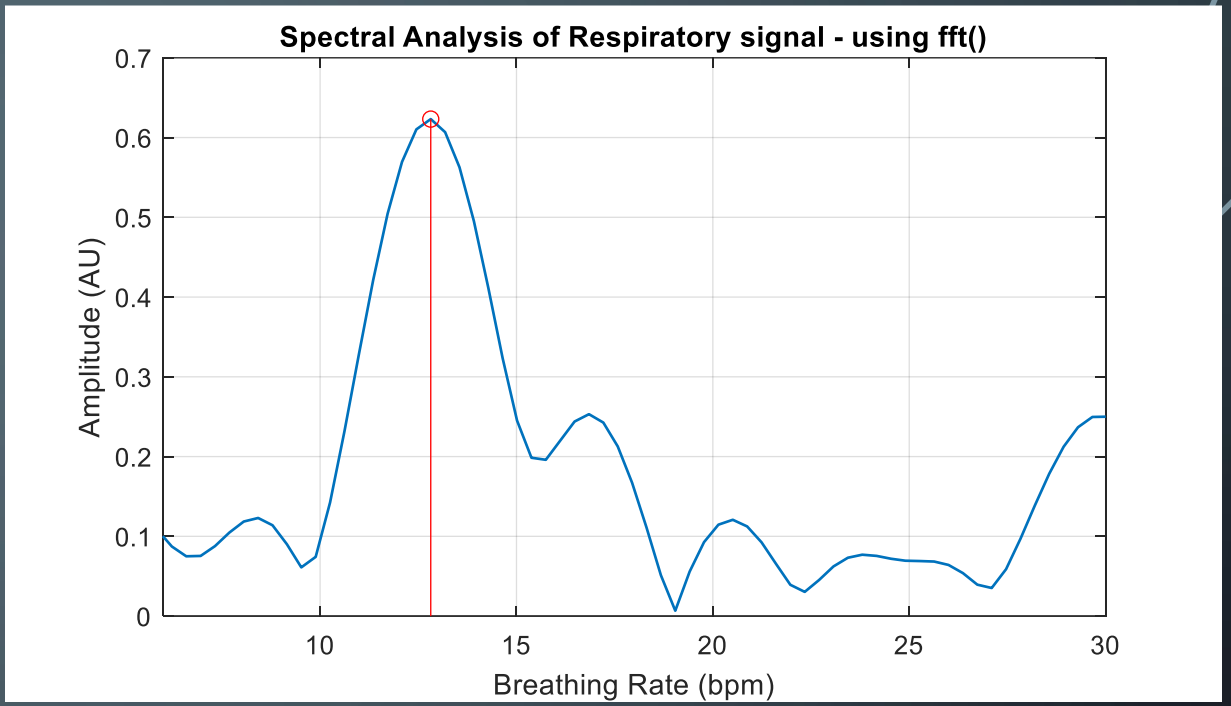

Spectral Analysis of Heart signal - using periodogram() (hamming)
×10^-9
8
7
6
5
4
3
2
1
0
Amplitude (AU)
0
20
40
60
80
100
120
140
160
180
Heart Rate (bpm)

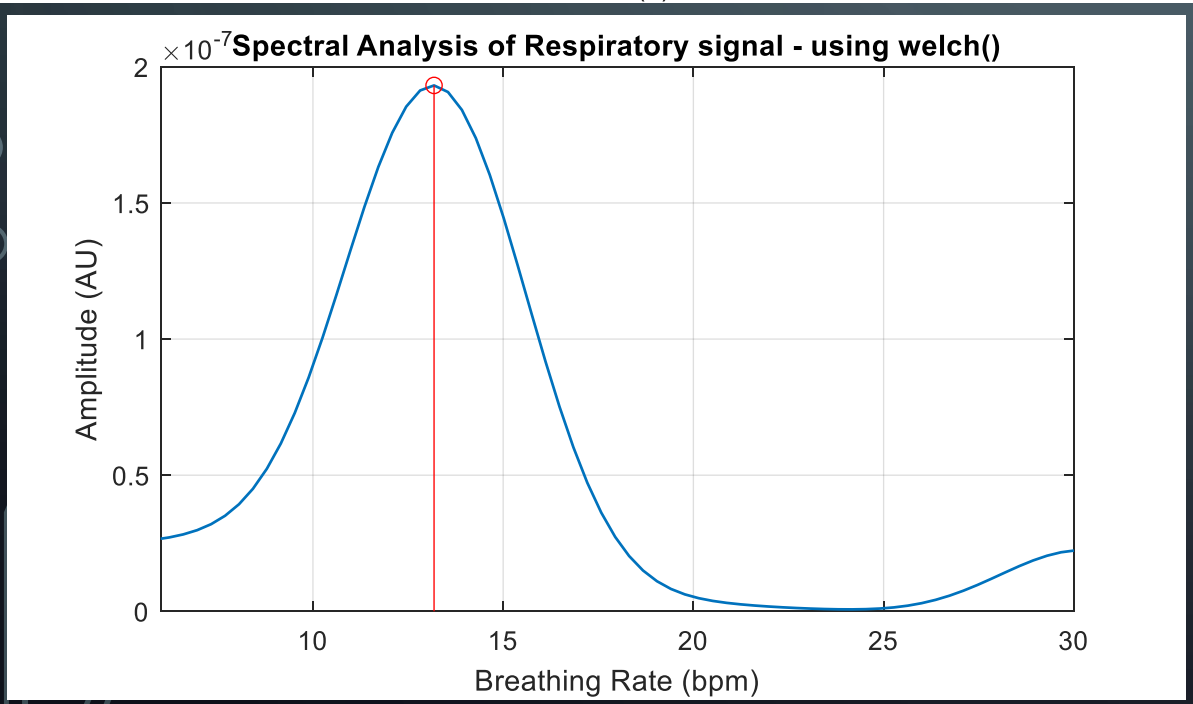
BREATHING RATE EXTRACTION

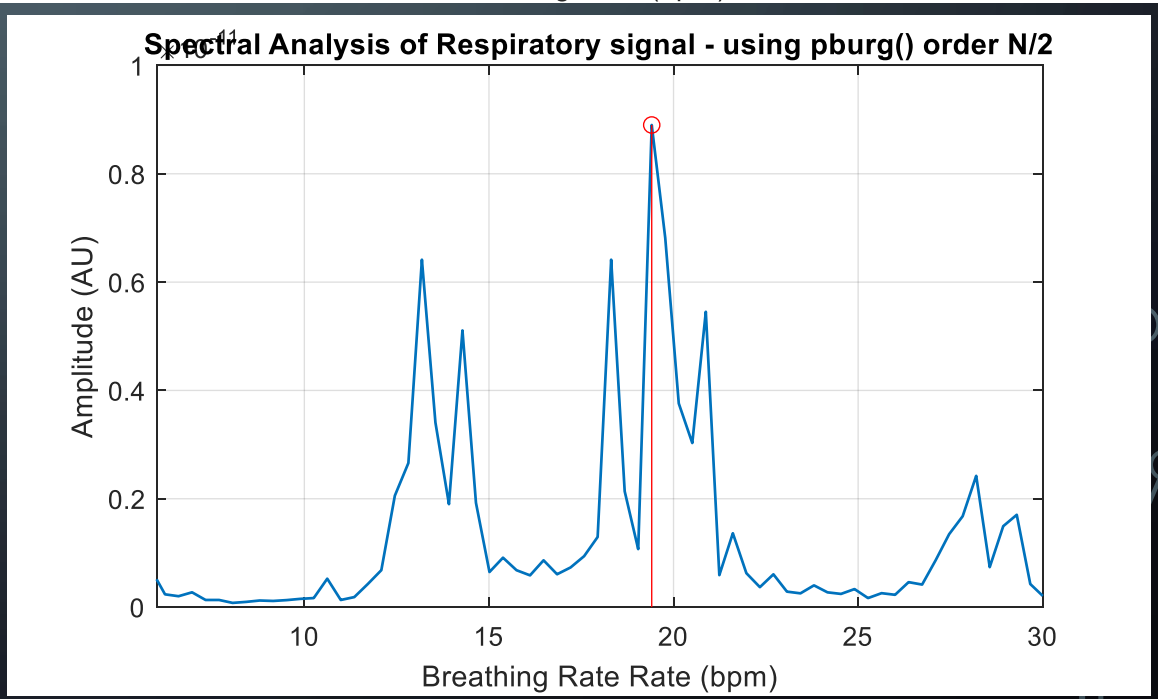
To obtain Breathing Signal, the data was filtered using a Butterworth lowpass filter of order 5, with cutoff frequency of 0.5 Hz.

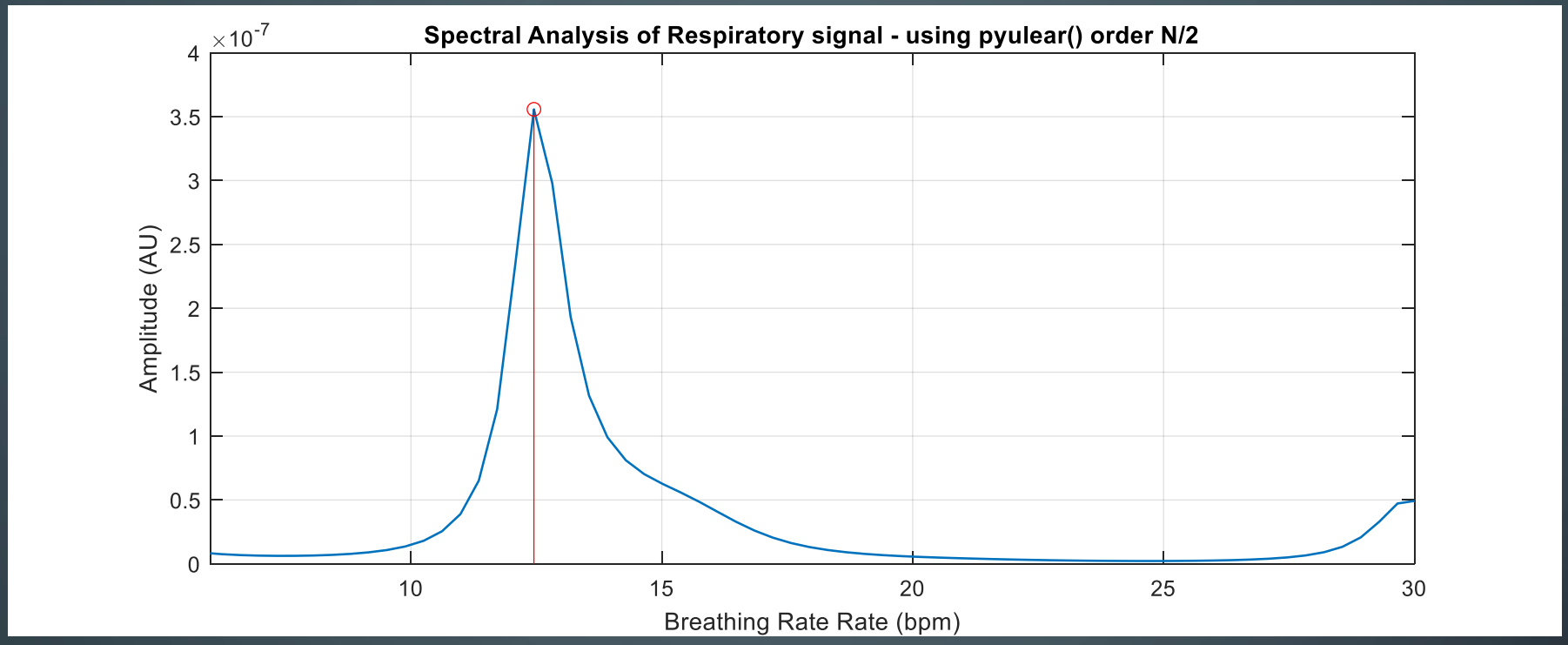


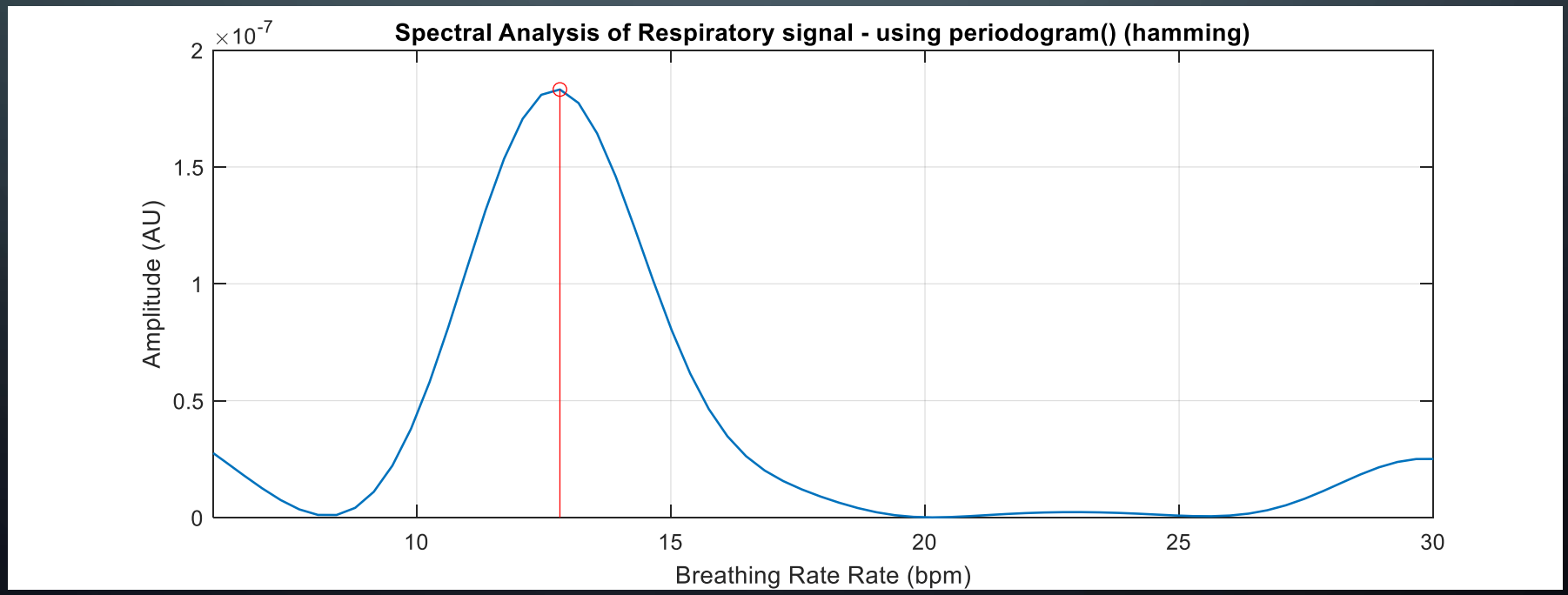

PEAK LOCATIONS - Respiratory signal
×10^-4
Amplitude (AU)
Time (s)


Spectral Analysis of Respiratory signal - using fft()
Amplitude (AU)
Breathing Rate (bpm)


×10^-7Spectral Analysis of Respiratory signal - using welch()
Amplitude (AU)
Breathing Rate (bpm)


Spectral Analysis of Respiratory signal - using pburg() order N/2
×10^-11
Amplitude (AU)
Breathing Rate Rate (bpm)


Spectral Analysis of Respiratory signal - using pyulear() order N/2
×10^-7
4
3.5
3
2.5
2
1.5
1
0.5
0
Amplitude (AU)
10
15
20
25
30
Breathing Rate Rate (bpm)


Spectral Analysis of Respiratory signal - using periodogram() (hamming)
×10^-7
2
1.5
1
0.5
0
Amplitude (AU)
10
15
20
25
30
Breathing Rate Rate (bpm)

The same methods were also replicated for different resampling frequencies, and thus different orders of Butterworth filters due to instability, as well as different spectral resolutions.

It should be noted that:

- For resampling frequency of 200 Hz, there are discontinuities in the spectrum estimated using the Burg method.
- In general, the higher the resampling frequency, the lower the spectral resolution, which can be compensated by increasing nFFT.
- FFT was sometimes off, with respect to other methods, which is due to over-modelling error.

RESULTS:

Using fs=200 Hz, nFFT=2^16, BP order 4, LP order 5									
	TDA	FFT	WELCH	BURG	YW	PERIODOGRAM	AVERAGE	STD	ERROR
HR (bpm)	77.1803	73.7212	100.1587	78.5522	77.0874	77.4536	**81.1922**	**9.3124**	**1.7328**
BR (bpm)	13.2780	12.8174	13.1836	21.0571	12.4512	12.8174	**14.2674**	**3.3394**	
Using fs=400 Hz, nFFT=2^16, BP order 3, LP order 5									
	TDA	FFT	WELCH	BURG	YW	PERIODOGRAM	AVERAGE	STD	ERROR
HR (bpm)	80.1541	76.9043	98.1448	76.1719	77.2705	77.6367	**81.0470**	**8.4846**	**1.8780**
BR (bpm)	13.2780	12.8174	13.1836	19.4092	12.4512	12.8174	**13.9928**	**2.6699**	
Using fs=800 Hz, nFFT=2^16, BP order 3, LP order 5									
	TDA	FFT	WELCH	BURG	YW	PERIODOGRAM	AVERAGE	STD	ERROR
HR (bpm)	84.2158	79.1016	78.3691	98.8770	79.8340	79.1016	**83.2498**	**7.9378**	**4.8573**
BR (bpm)	19.3705	13.1836	19.0430	18.3105	13.1836	18.3105	**16.9003**	**2.9085**	
Using fs=800 Hz, nFFT=2^18, BP order 3, LP order 5									
	TDA	FFT	WELCH	BURG	YW	PERIODOGRAM	AVERAGE	STD	ERROR
HR (bpm)	84.2158	79.1016	78.5522	97.0459	80.2002	78.9185	**83.0057**	**7.1867**	**5.1014**
BR (bpm)	19.3705	13.0005	19.0430	18.3105	17.9443	18.3105	**17.6632**	**2.3442**	
Using fs=1200 Hz, nFFT=2^20, BP order 3, LP order 5									
	TDA	FFT	WELCH	BURG	YW	PERIODOGRAM	AVERAGE	STD	ERROR
HR (bpm)	84.2281	79.0329	81.1615	73.8831	80.2002	78.8269	**79.5554**	**4.4003**	**8.5517**
BR (bpm)	18.8844	13.0463	19.0887	21.2173	12.9089	18.2648	**17.2351**	**3.4449**	

The one used

FINAL REMARKS

For the analysis of signals the data “measurements_charis.mat” was used instead of “measurements_kipria.mat” since this file did not actually correspond to “kipria.spo” file.

The only available .spo files that were matched to radar data are:

- charis.spo
- kyriakos.spo
- abdul.spo

It should be noted that Abdul’s data from radar was in .wfm file form which could not be opened in MATLAB.