Laboratory of Biomedical Signal and Image Processing

REPORT OF LAB2

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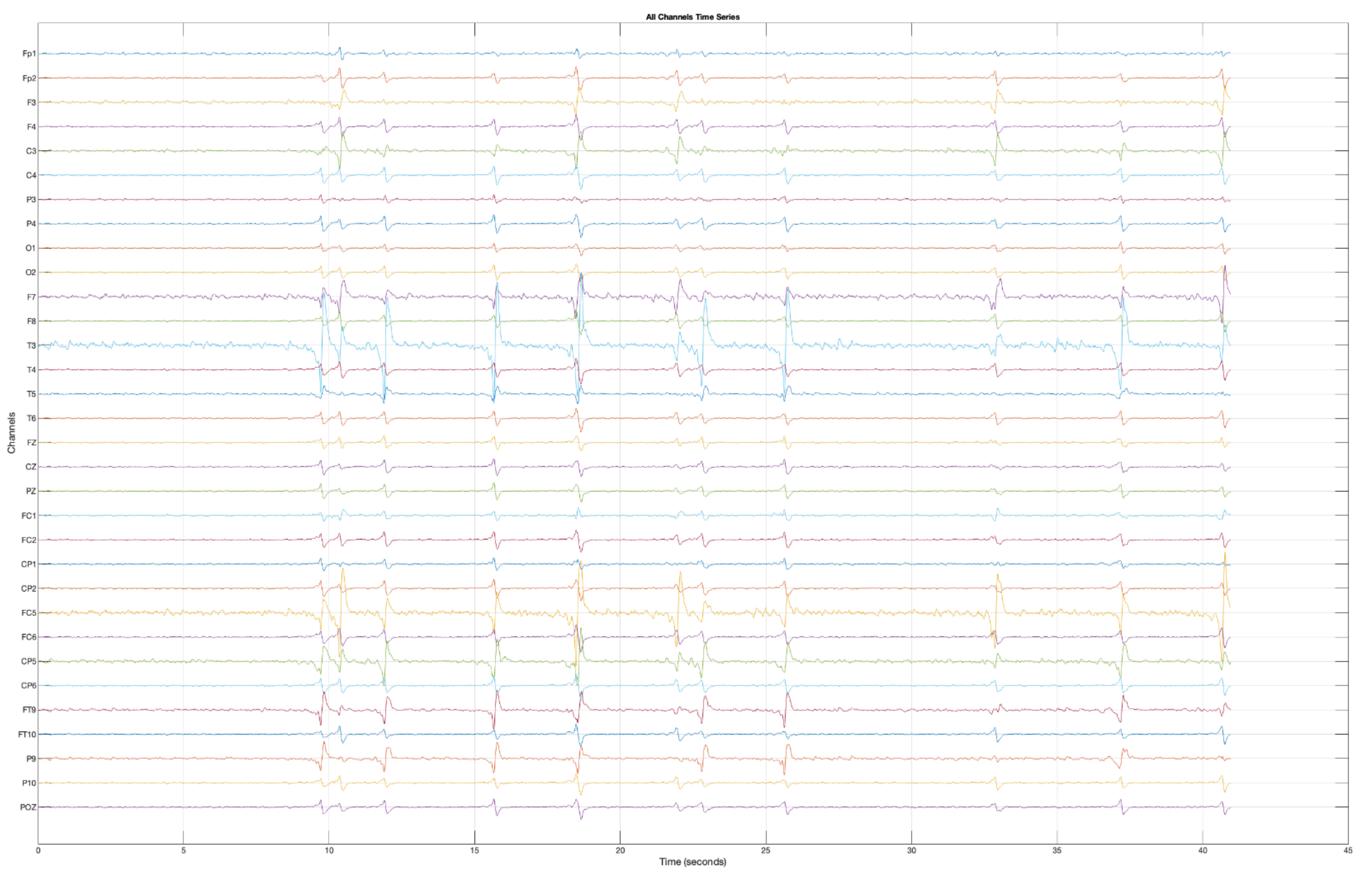
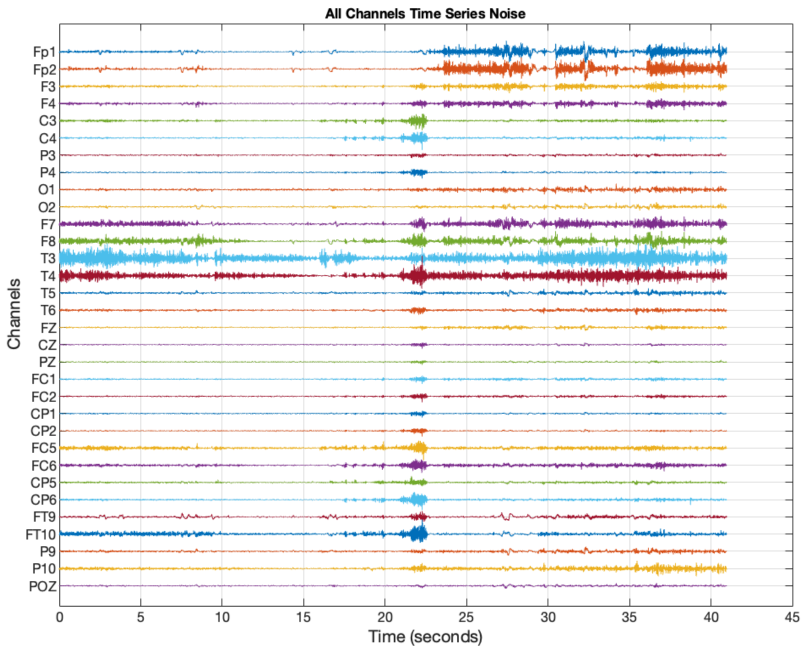
۱- سیگنال بدون نویز X_org را رسم کنید. برچسب کانال‌ها و زمان را مشخص کنید. می‌توانید از فایل plotEEG.m و تابع disp_eeg.m استفاده کنید. برای نمایش بهتر می‌توانید متغیر offset (فاصله بین سیگنال نمایش داده شده از دو کانال) را تنظیم کنید.



In the figure above we can see the channels' plot together in one figure. The offset is considered equal to: *offset = max(max(abs(X_org)))/3 ;*

۲- نویز X_noise را رسم کنید. برچسب کانال‌ها و زمان را مشخص کنید.

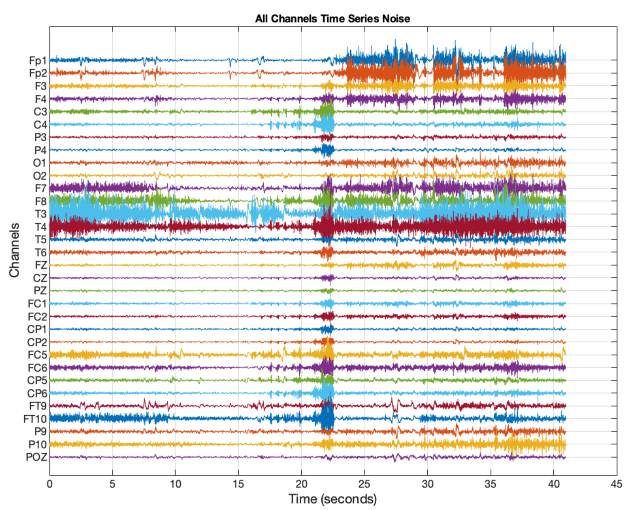
In the same way, as in the previous section, we plot X_noise as the figure below:



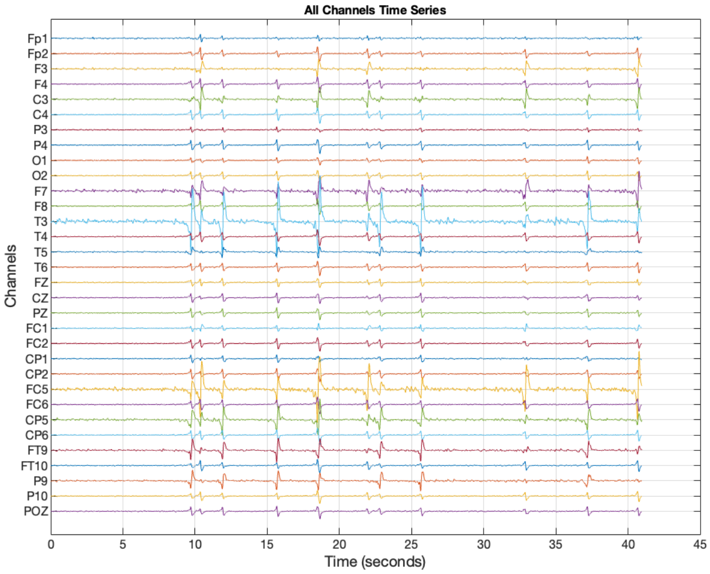
۳- نویز را با SNRهای مختلف ($-5dB$ و $-15dB$) با سیگنال اصلی جمع کنید و سیگنال مشاهدات را بسازید. سیگنال نویزی را به‌ازای $SNR = -15dB$ رسم کرده و با سیگنال بدون نویز مقایسه کنید.

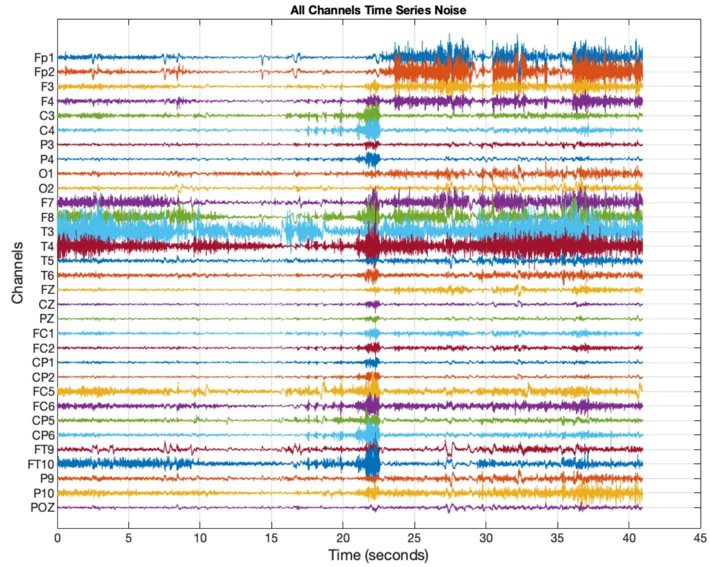
With this piece of code, we can build the noisy signal based on the desired SNR values. The -15 db noisy signal can be seen in the figure below:

```
% Compute the power of the original signal
P_signal = sum(sum(X_org.^2));
P_noise= sum(sum(X_noise.^2));

% SNR values (in dB)
SNR_values = [-15,-5];

for i = 1:length(SNR_values)
    SNR_dB = SNR_values(i);

    sigma = sqrt((P_signal/P_noise)*(10^(-SNR_dB/10)));

    % Add the noise to the original signal
    X_noisy(i,:,:) = X_org + sigma.*X_noise;

    fprintf('Added noise with SNR = %d dB\n', SNR_dB);

end
```



We can compare the original signal and the noisy signal to see how distracted the original one has become:





۴- با استفاده از یک روش ICA دلخواه منابع را استخراج کنید. می‌توانید از تابع COM2R.m (الگوریتم Com2) استفاده کنید.

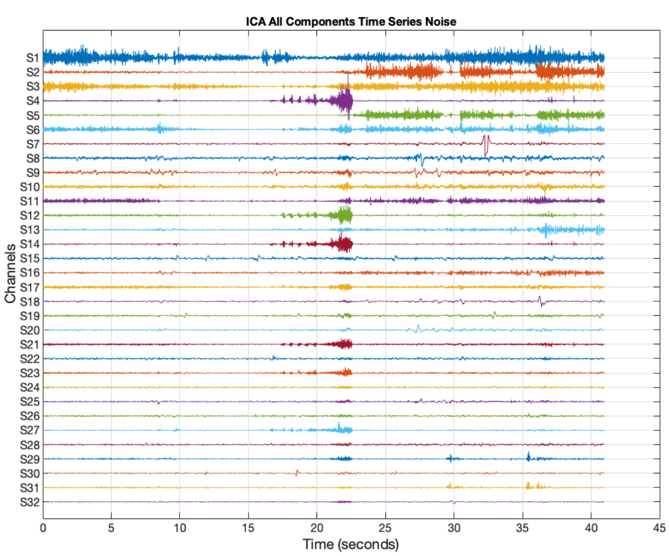
We can Apply COM2 ICA to extract the sources as this code:

```
[F, W, K] = COM2R(X_NoisyDisp, Pest); %Pest=32;
```

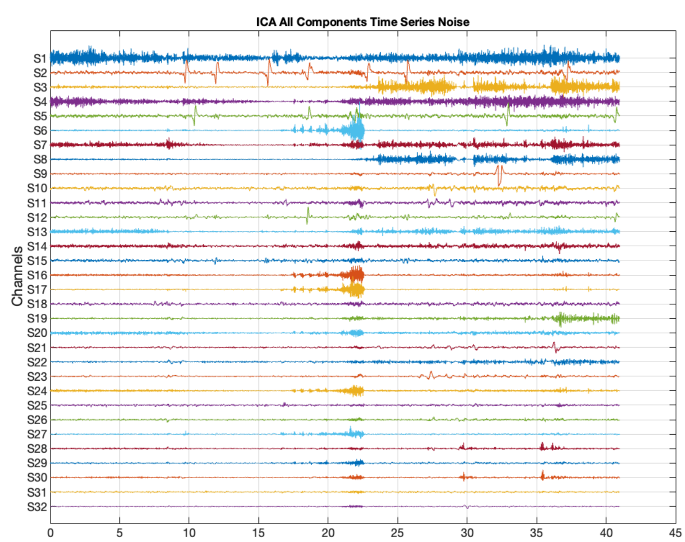
Then we can extract the components as follows:

```
Z_ICA = W * X_NoisyDisp;  % Reconstructed sources
```

For -15 dB Noise:



For -5 dB Noise:



۵- با بررسی همه منابع به دست آمده، منابع مطلوب (منابع اسپایکی) را نگه داشته و بقیه منابع را حذف کنید.

For -5 dB noise, we choose S2, S5, and S12 components where we see more clear spikes than other components: `Spiky_Indices=[2,5,12]; Z_ICA_Spiky=Z_ICA(Spiky_Indices,:);`

For -15 dB noise, we choose S15, S18, S19, and S20 components where we see more clear spikes than other components: `Spiky_Indices=[15,18,19,20];`

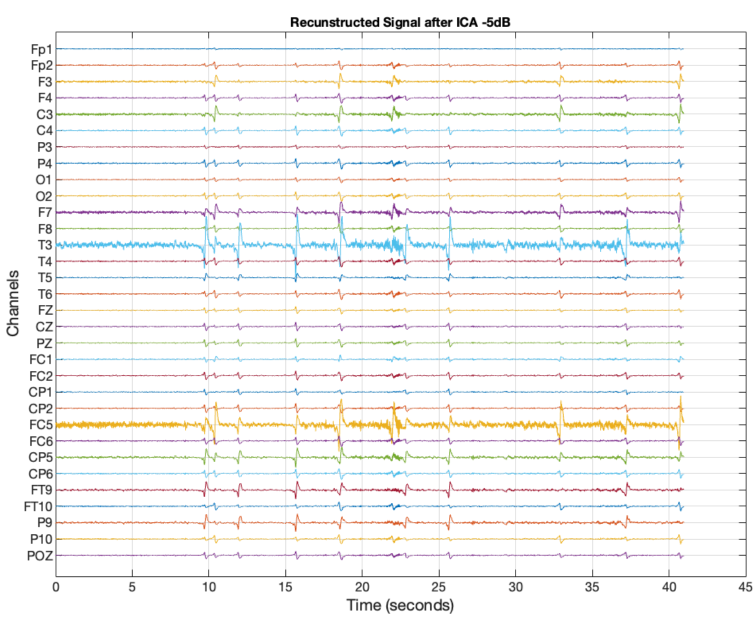
`Z_ICA_Spiky=Z_ICA(Spiky_Indices,:);`

۶- منابع مطلوب را به حوزه سنسور (حوزه مشاهدات) بازگردانید و مشاهدات حذف نویز شده را ایجاد نمایید (X_den).

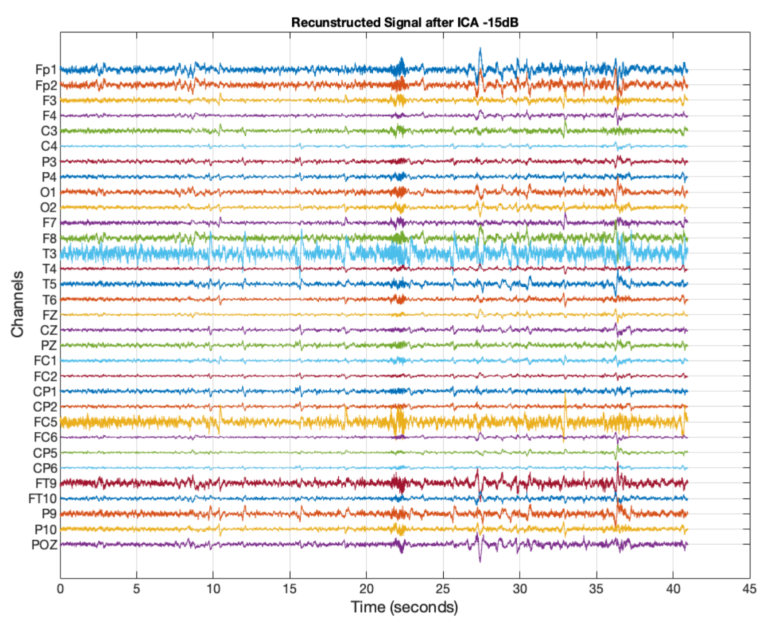
We reconstruct the sensor's original time series (Observation domain) using this code: `% Back to sensor  X_den=F_Spiky*Z_ICA_Spiky;`

Then we plot both noise SNr ratios :

For -5 dB Noise:

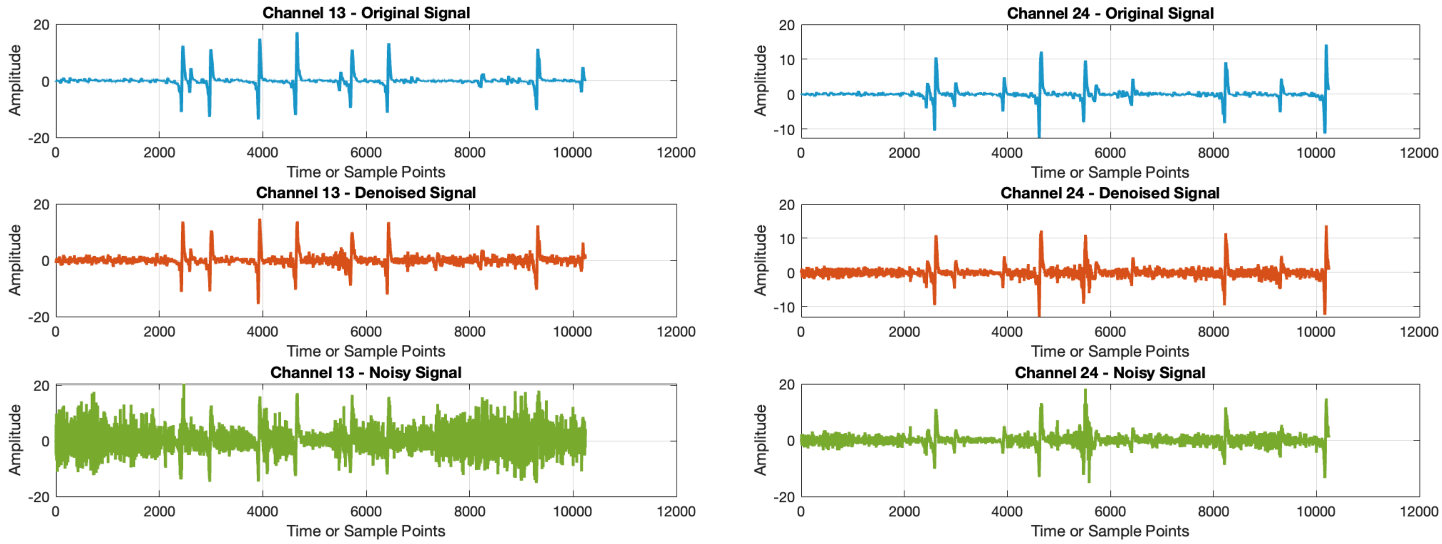


For -15 dB Noise:

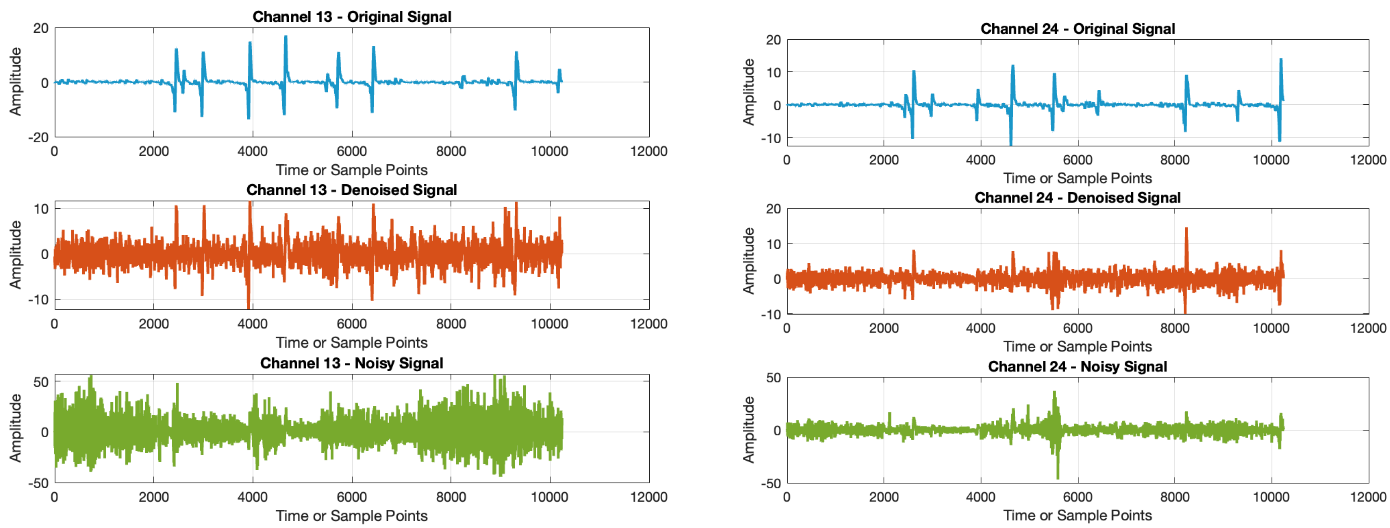


۷- مشاهدات حذف نویز شده را برای کانال‌های ۱۳ و ۲۴ همراه با داده بدون نویز اصلی و داده نویزی رسم نمایید.

For -5 dB:--



For -15 dB: ——--



۸- خطای RRMSE (RMSE نسبی) را برای هر SNR محاسبه نمایید. نتایج به دست‌آمده را تحلیل کنید.

$$RRMSE = \frac{\sqrt{\sum_{n=1}^{32}\sum_{t=1}^{T}\left(x_{org}^{(n)}(t) - x_{den}^{(n)}(t)\right)^2}}{\sqrt{\sum_{n=1}^{32}\sum_{t=1}^{T}\left(x_{org}^{(n)}(t)\right)^2}}$$

The RRMSE of -5 dB between the original and reconstructed signals is: 0.416181

The RRMSE of -15 between the original and reconstructed signals is: 1.369477

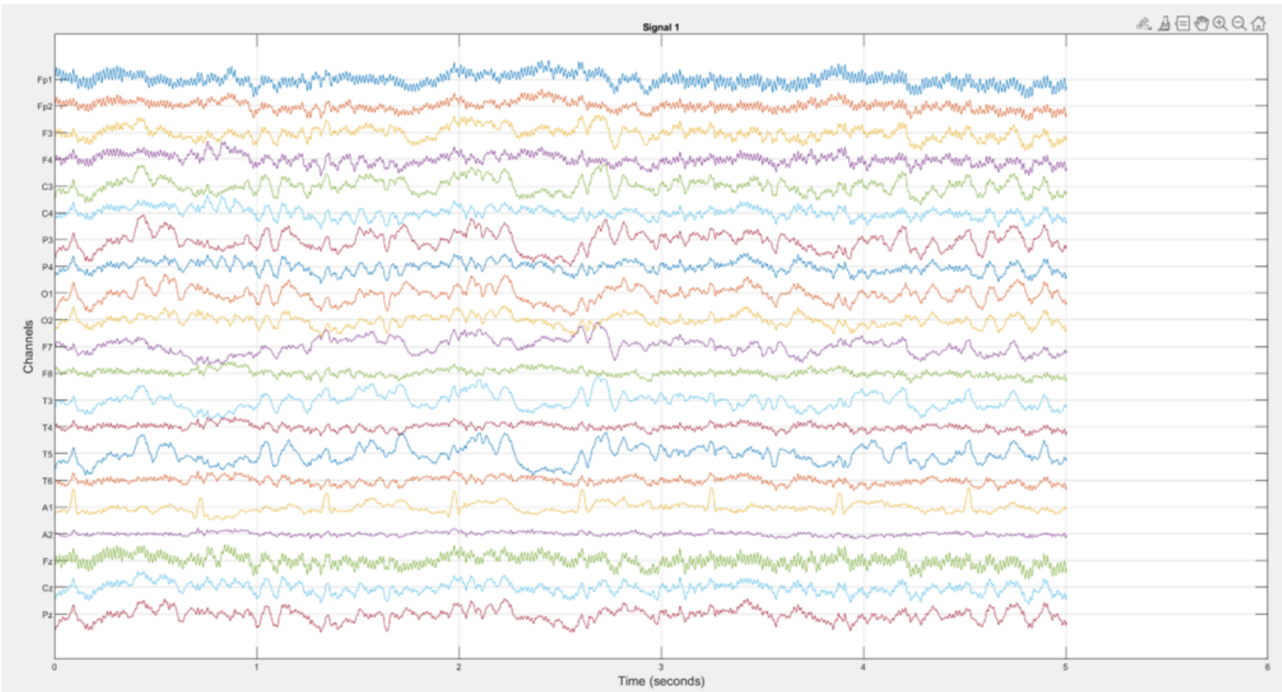
For -5 dB noise: The RRMSE is 0.416, indicating a lower error between the original and reconstructed signals. This suggests that the denoising process was more effective when the noise level was low (-5 dB). The reconstruction is closer to the original signal, with less distortion.

For -15 dB noise: The RRMSE is 1.369, which is significantly higher, indicating that the denoising process has a problem with a higher noise level (-15 dB). The reconstructed signal is so far from the original, reflecting that the added noise at this level was more difficult to remove effectively.

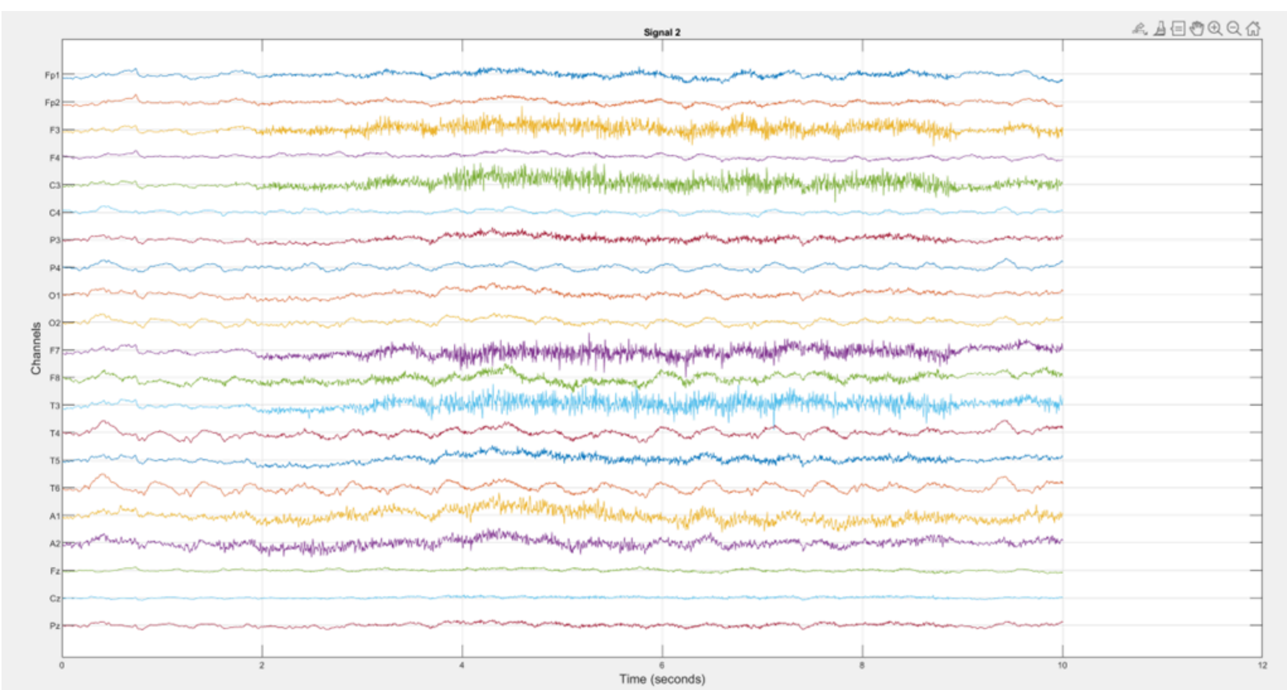
Part 2

۱- سیگنال را در حوزه زمان و با مشخص کردن برچسب همه کانال‌ها رسم نمایید.

Signal 1:



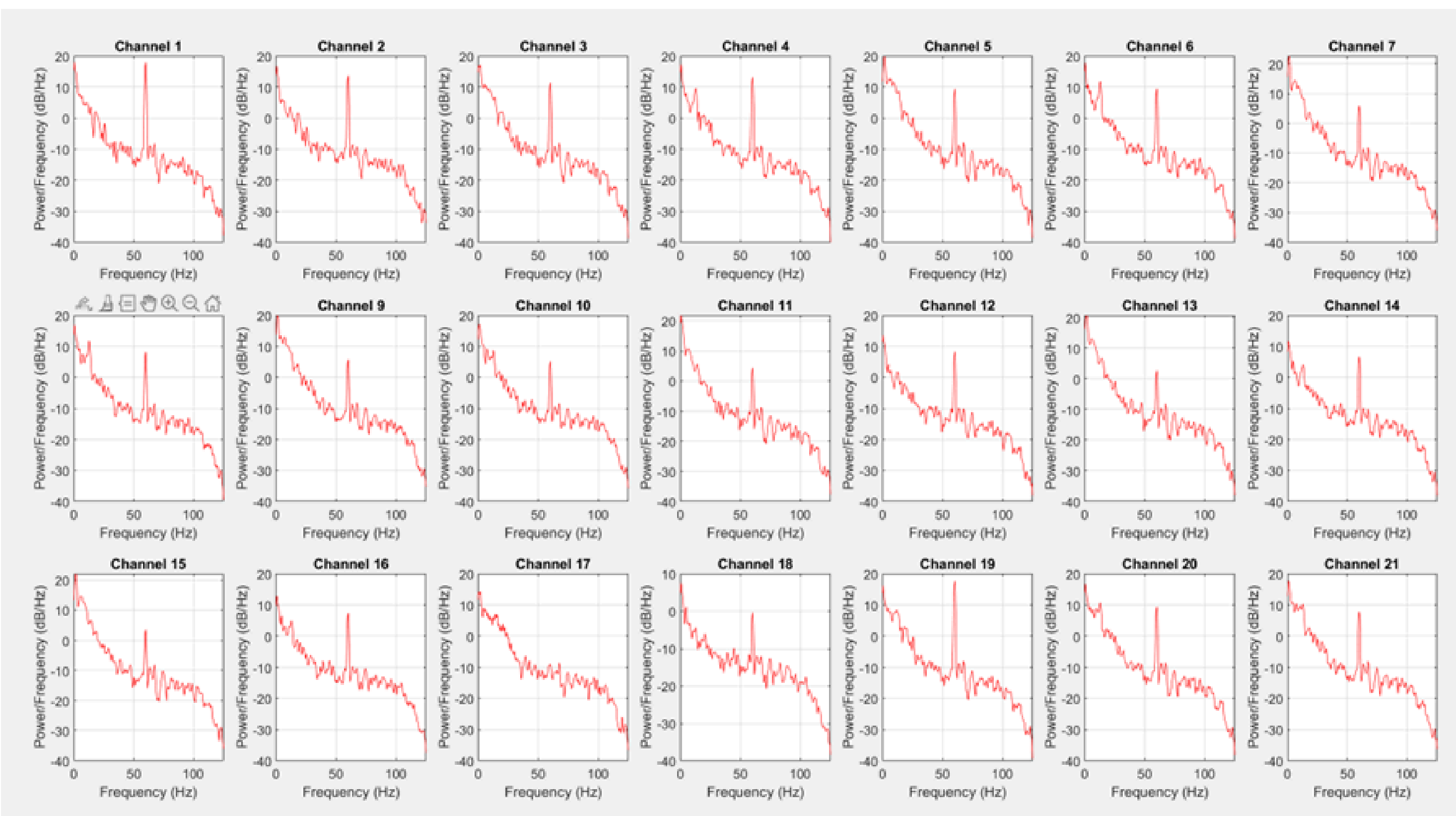
Signal 2:

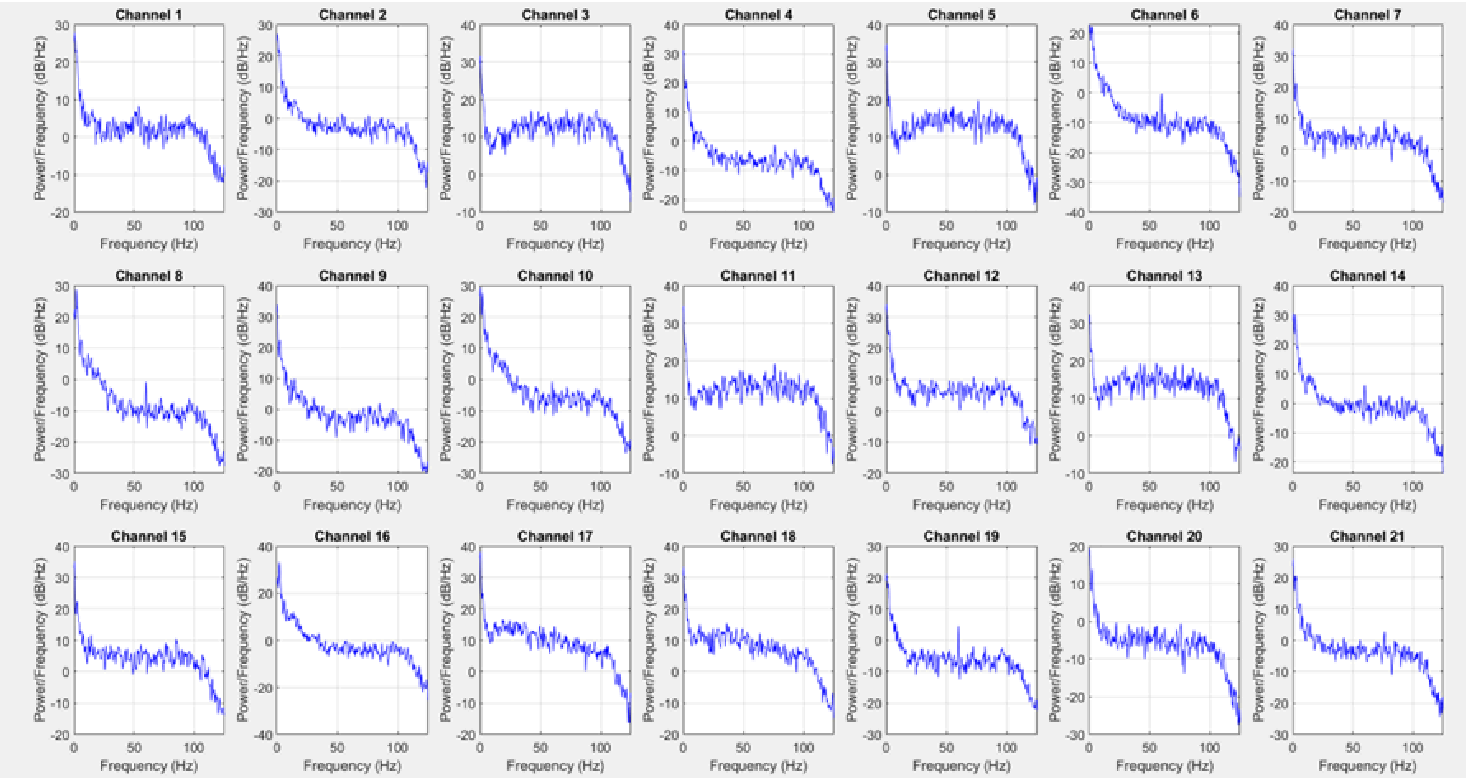


2.2

۲- سیگنال را از نظر نویز و آرتیفکت بررسی کنید. چه نوع آرتیفکتی در سیگنال می‌بینید؟ به نظرتان این آرتیفکت با استفاده از روش ICA قابل حذف شدن است؟

There are various artifacts in these two signals. For example, in signal 1 we have blinking artifacts on almost all channels. In signal 2, we have EMG noise on signal (on channels F3, C3, F7, A1, A2), and sweating artifacts (on Cz, Fz, and Pz). Below, you can see the recorded signals of each 21 channels in frequency domain for both signal 1 and 2 (using 'pwelch.m' function). It can be clearly seen that in 60Hz we have powerline noise:





Yes, they can be removed using ICA. Independent Component Analysis (ICA) is commonly used to remove the following types of artifacts from EEG data: Eye blinks // Eye movements (EOG artifacts) // Muscle activity (EMG artifacts) // Heartbeats (ECG artifacts) // Line noise (60 Hz)// Sweat artifacts // Head/Body movements. ICA separates these artifacts from neural signals, allowing for cleaner EEG data.

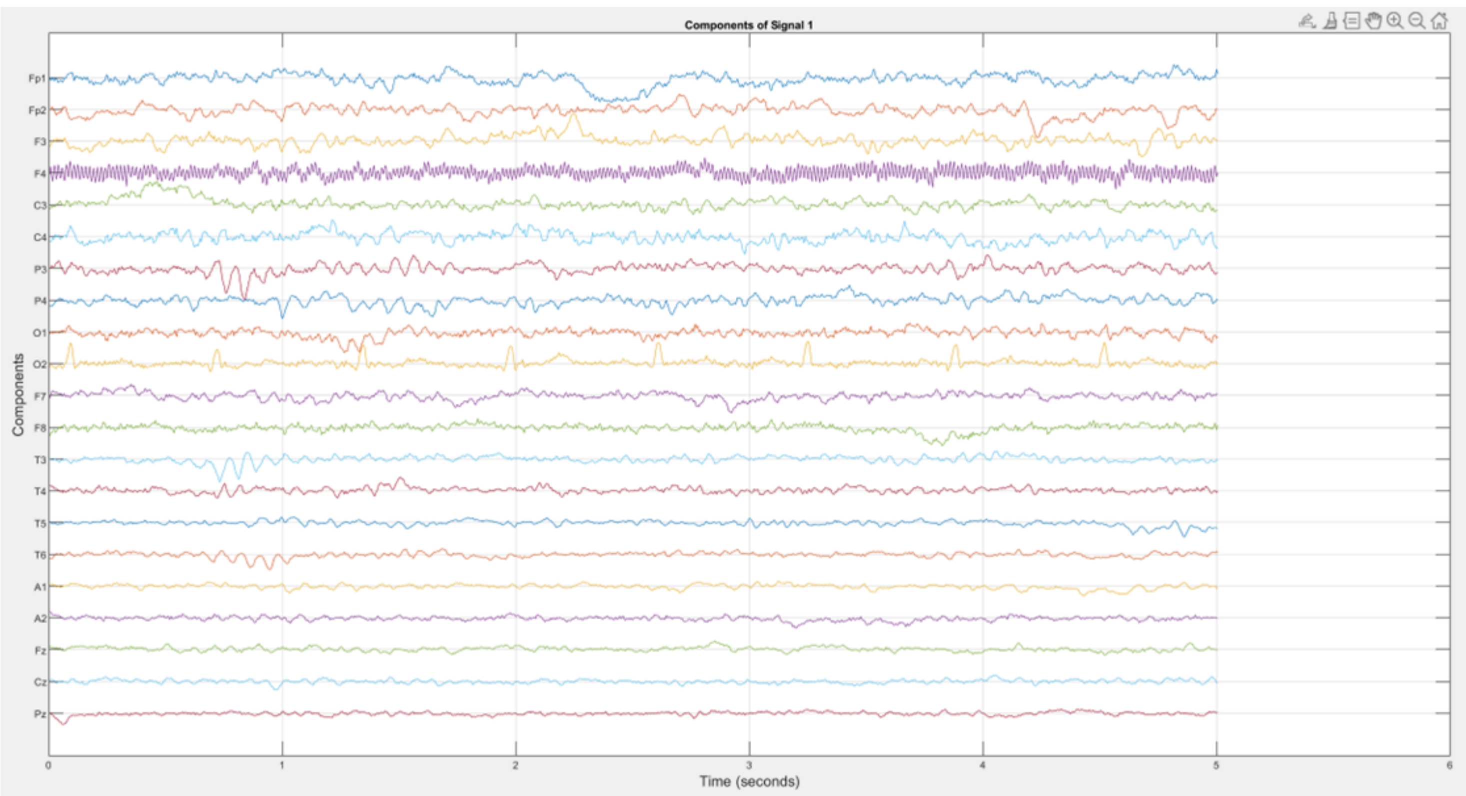
۳- یک الگوریتم ICA بر روی سیگنال اعمال کرده و مولفه‌های مستقل و ماتریس ترکیب را به دست آورید. می‌توانید از تابع COM2R.m (الگوریتم Com2) استفاده کنید.

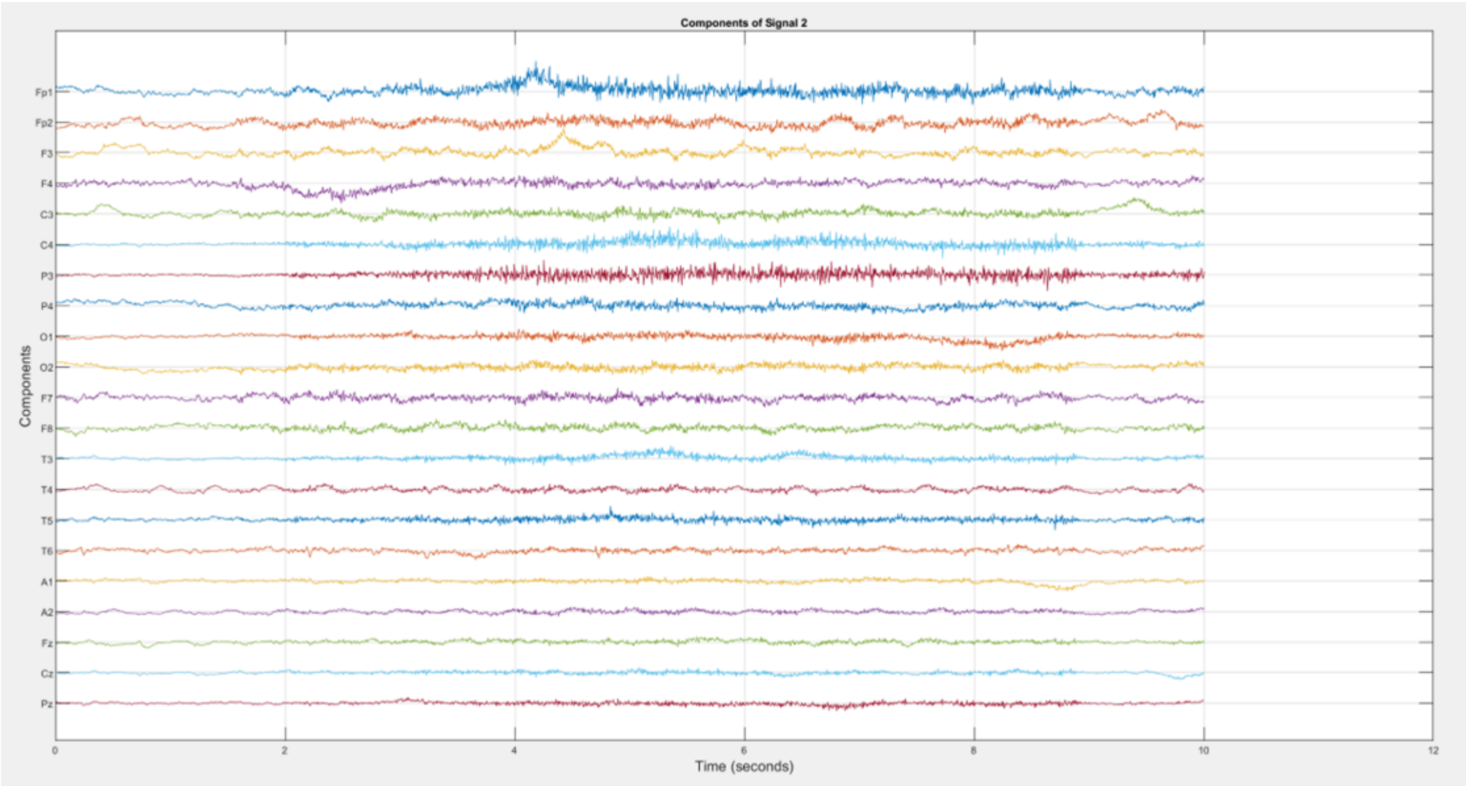
We chose COM2R algorithm to apply for ICA:

```
% W = pinv(F)     [F1,W1,K1] = COM2R(sig1, 21);          sig1_component = W1*sig1;

[F2,W2,K2] = COM2R(sig2, 21);                            sig2_component = W2*sig2;
```

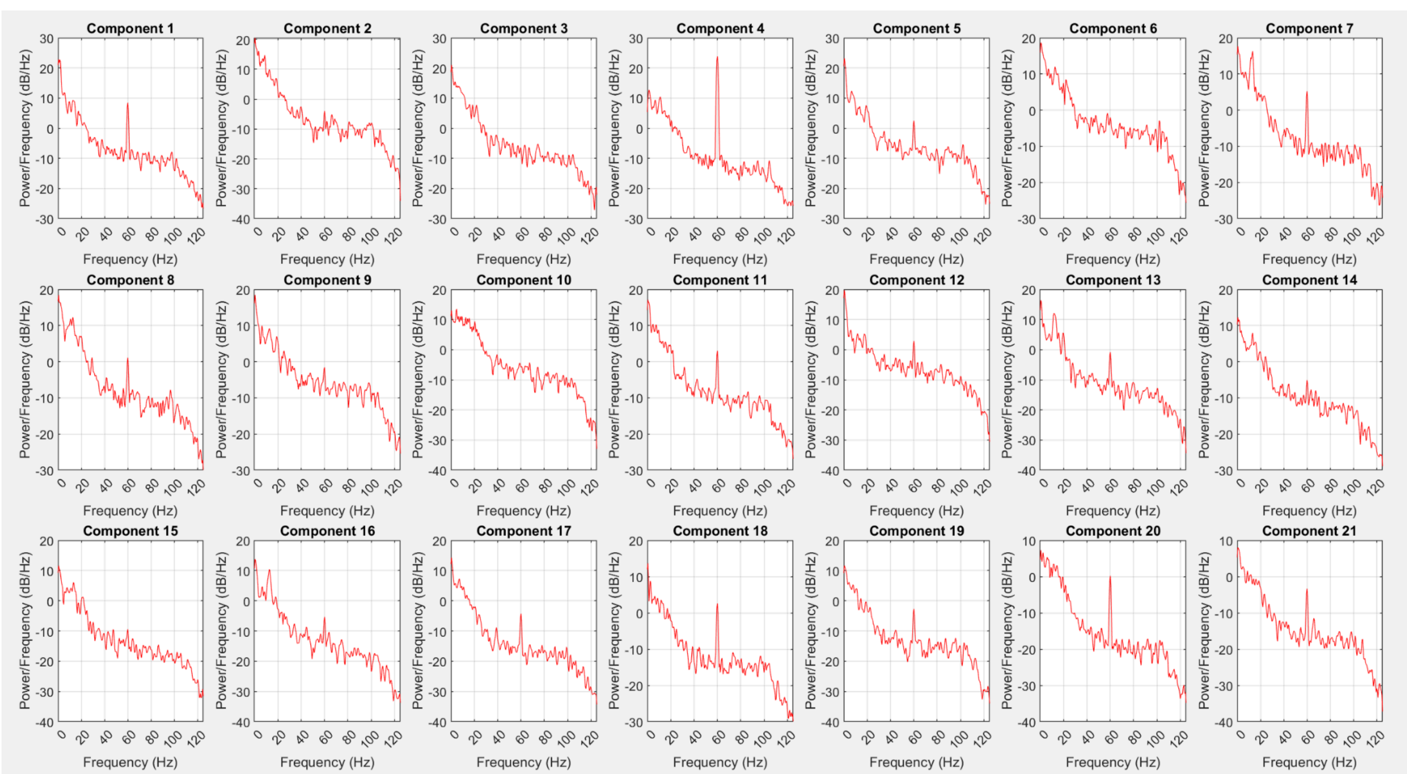
۴- مشخصه زمانی، فرکانسی و فضایی هر مولفه را رسم کرده و در مورد مطلوب یا نامطلوب بودن آن تصمیم‌گیری کنید. برای رسم مشخصه‌های فرکانسی و فضایی می‌توانید به ترتیب از تابع pwelch.m (تابع اصلی متلب) و plottopomap.m استفاده کنید.

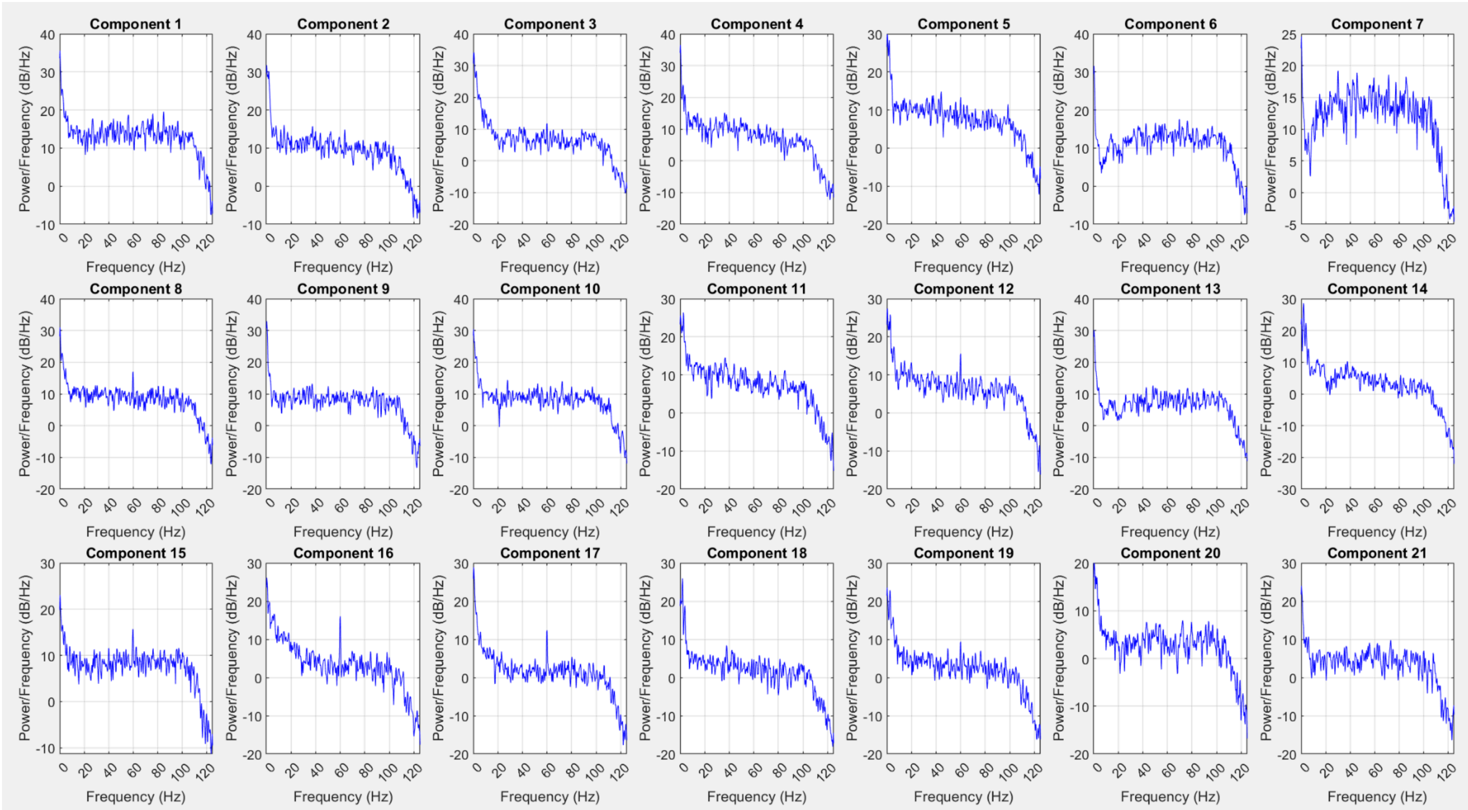
Components in time-domain for signal 1 and 2, respectively:



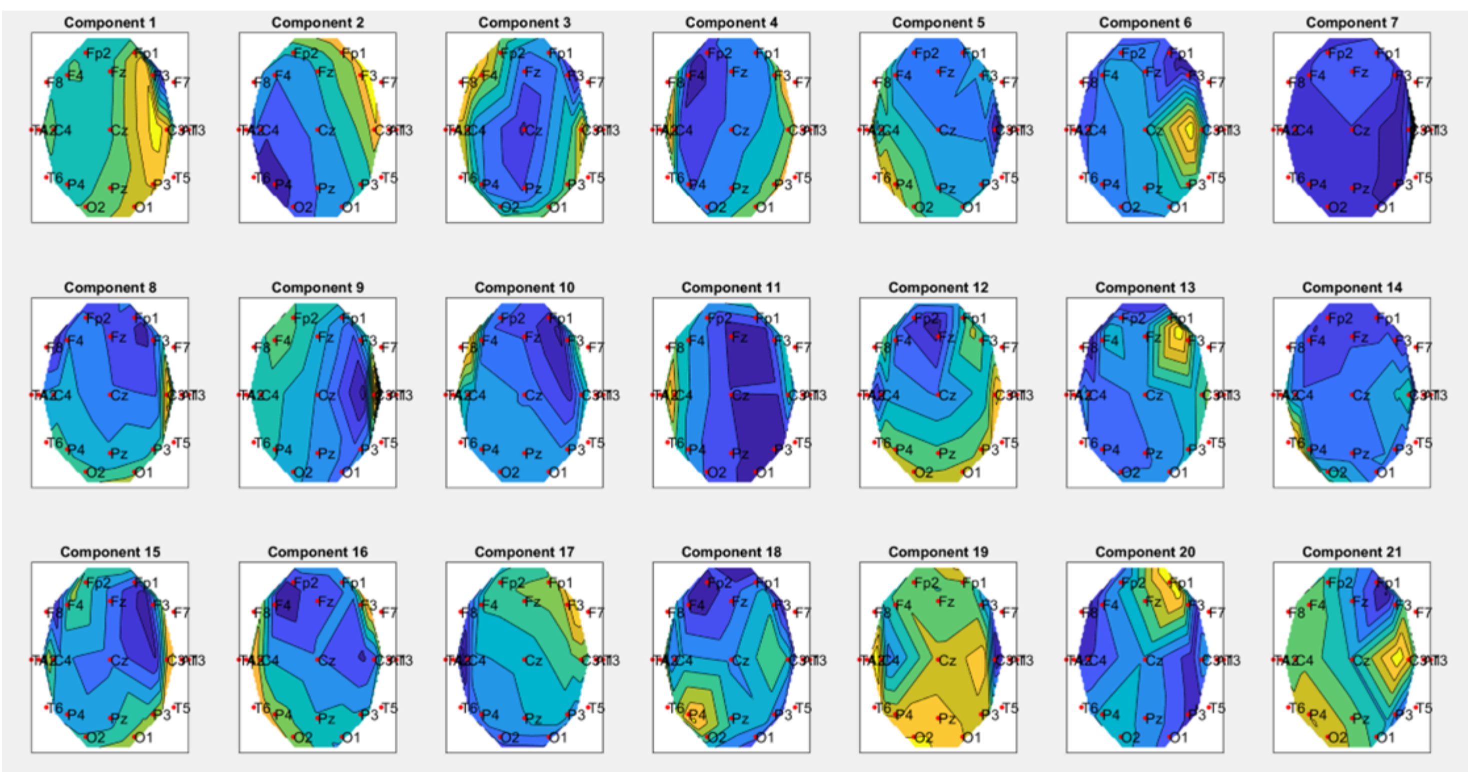


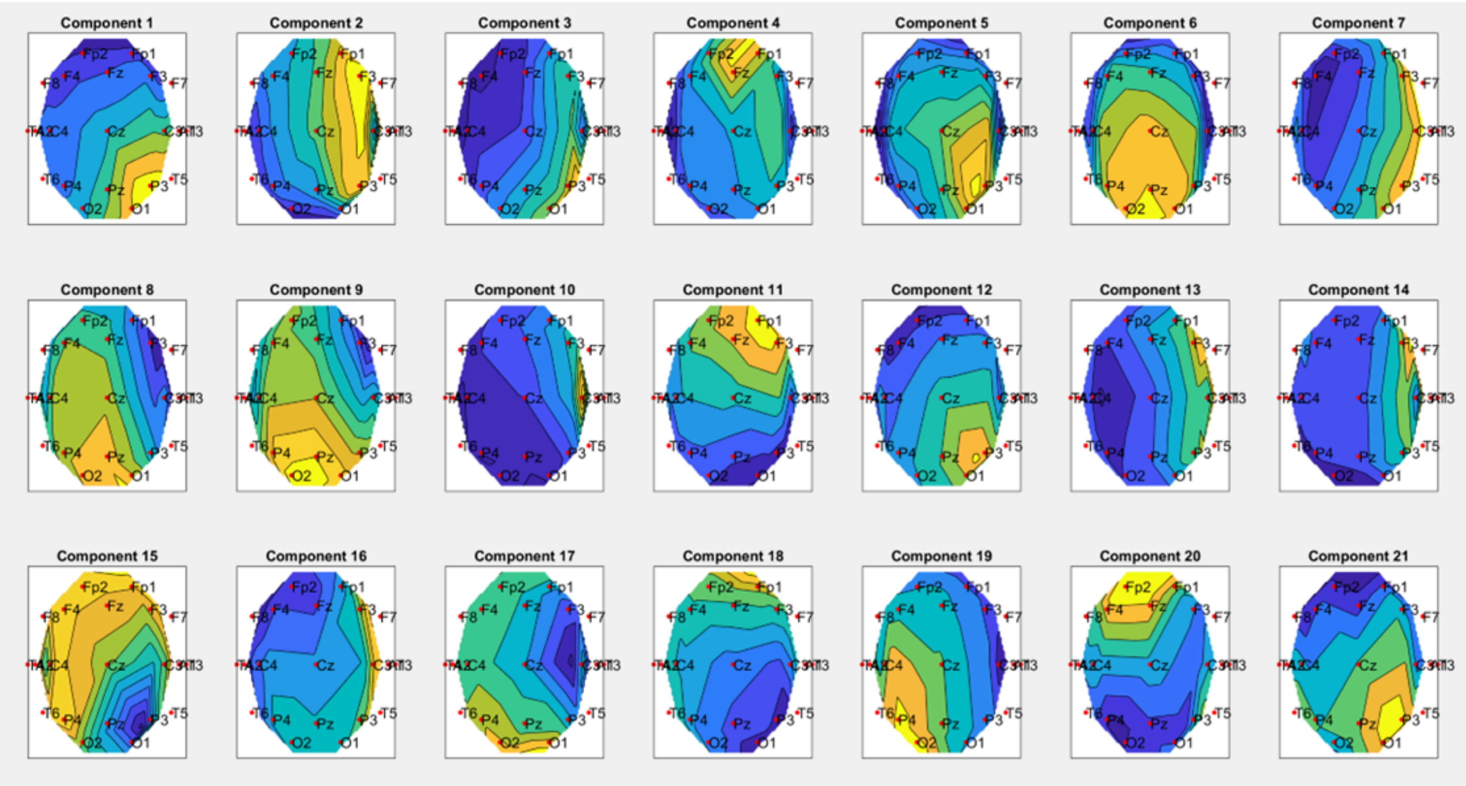
Components in frequency-domain for signal 1 and 2, respectively:





Components in spatial-domain for signal 1 and 2, respectively:




Component 1
Component 2
Component 3
Component 4
Component 5
Component 6
Component 7
Component 8
Component 9
Component 10
Component 11
Component 12
Component 13
Component 14
Component 15
Component 16
Component 17
Component 18
Component 19
Component 20
Component 21

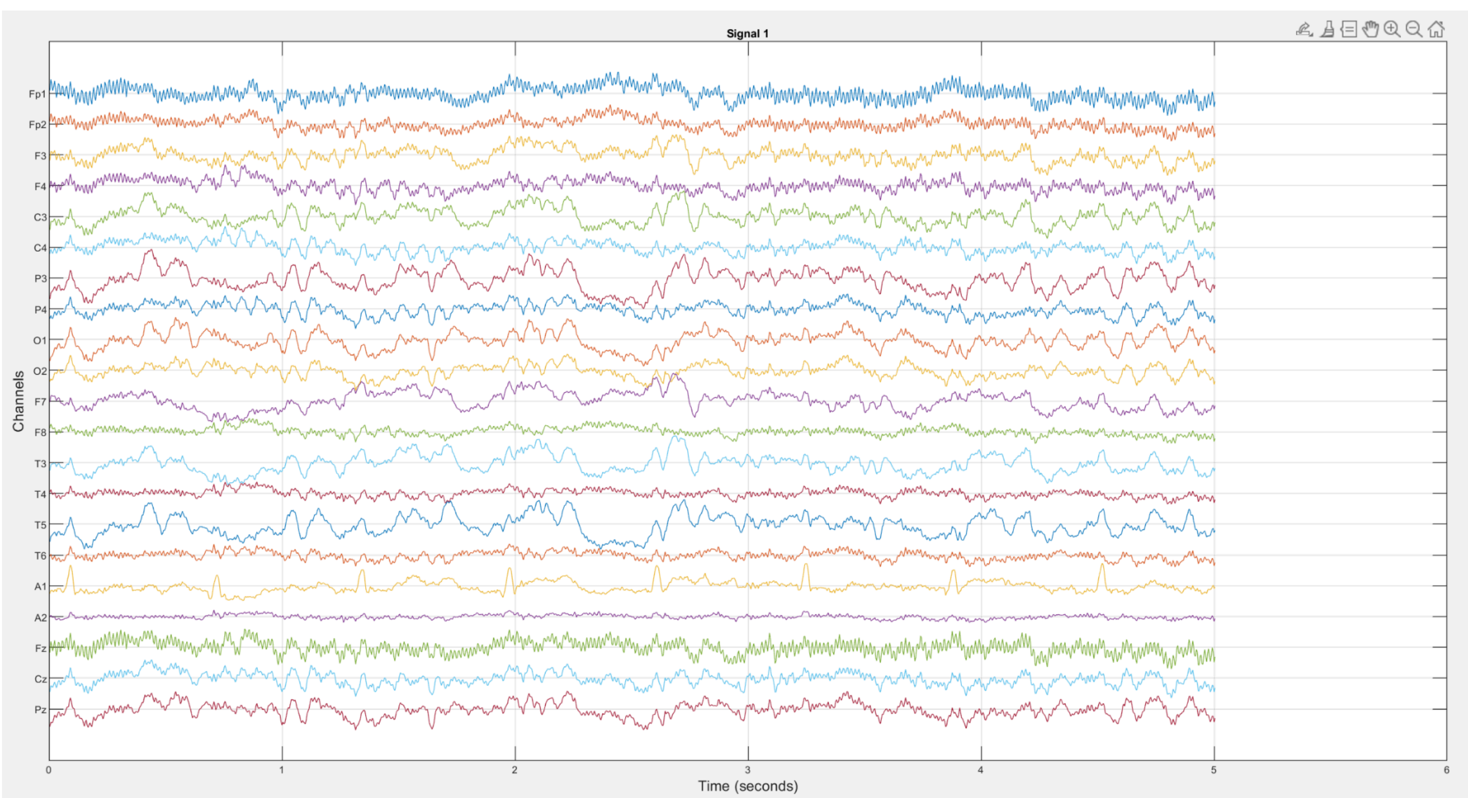
۵- شماره همه منابع مطلوب را در یک بردار SelSources ذخیره کرده و سیگنال حذف نویز شده را بازیابی کنید:

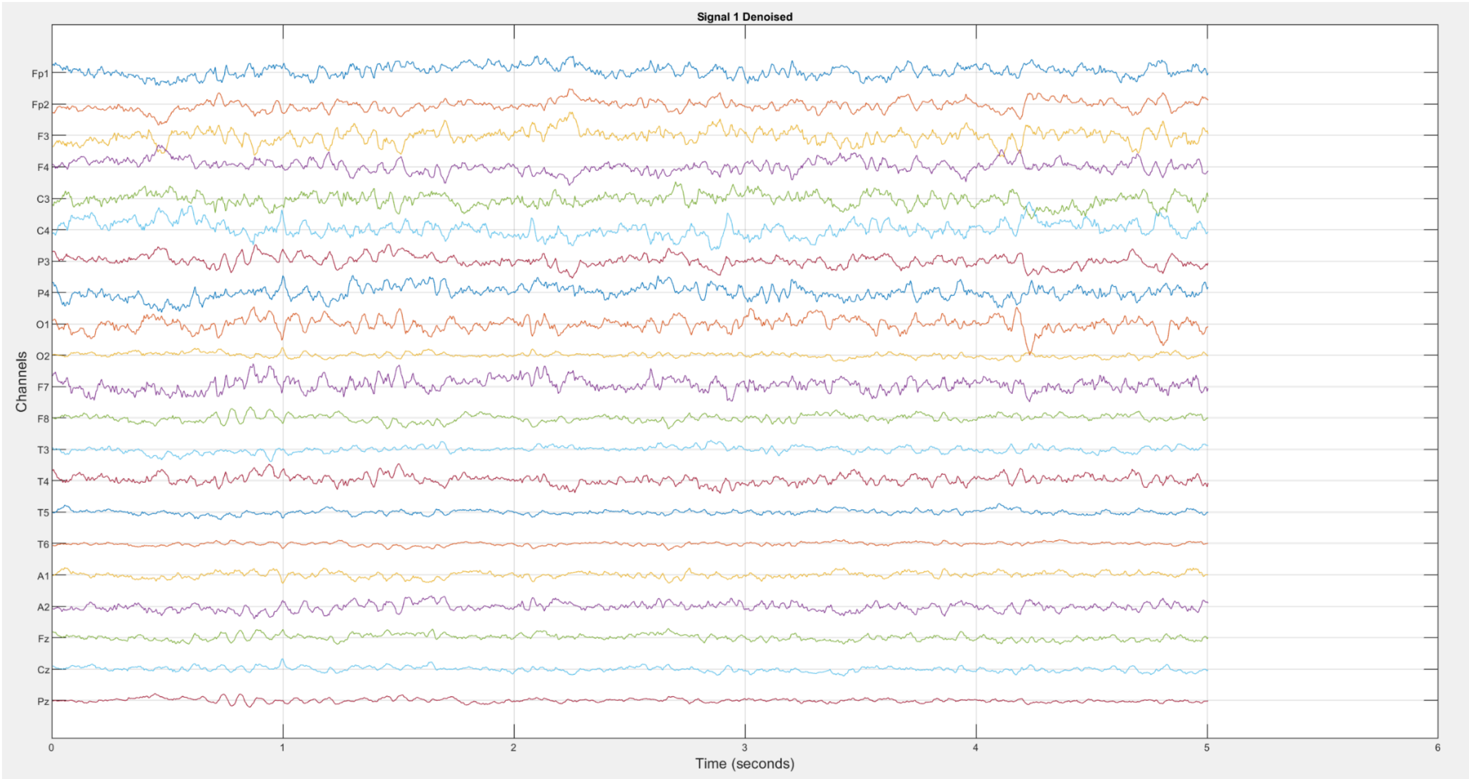
$$X_{denoised} = A(:,SelSources) \times S(SelSources,:)$$

۶- سیگنال حذف نویز شده را رسم کرده و با سیگنال اولیه مقایسه کنید. آیا منابع درستی را انتخاب کرده‌اید؟ آیا حذف نویز به خوبی انجام شده است؟ آیا بایستی مرحله (۵) را دوباره و با دقت بیشتری انجام دهید؟

For Signal 1: If we look at the frequency domain of components, it's obvious that there are sharp peaks at 60hz for these components: 1,4,7,11,18,20. Therefore, there is a high probability that these components are not related to brain activity. (It seems that components 1 and 7 also have eye movement noise if we look at their time domain). Moreover, some components show muscle activity in both time and frequency domains (typically above 30Hz): 6,9,10,12. (10 is probably related to heart activities, because of its periodic nature).

Sig1 before & after denoising:

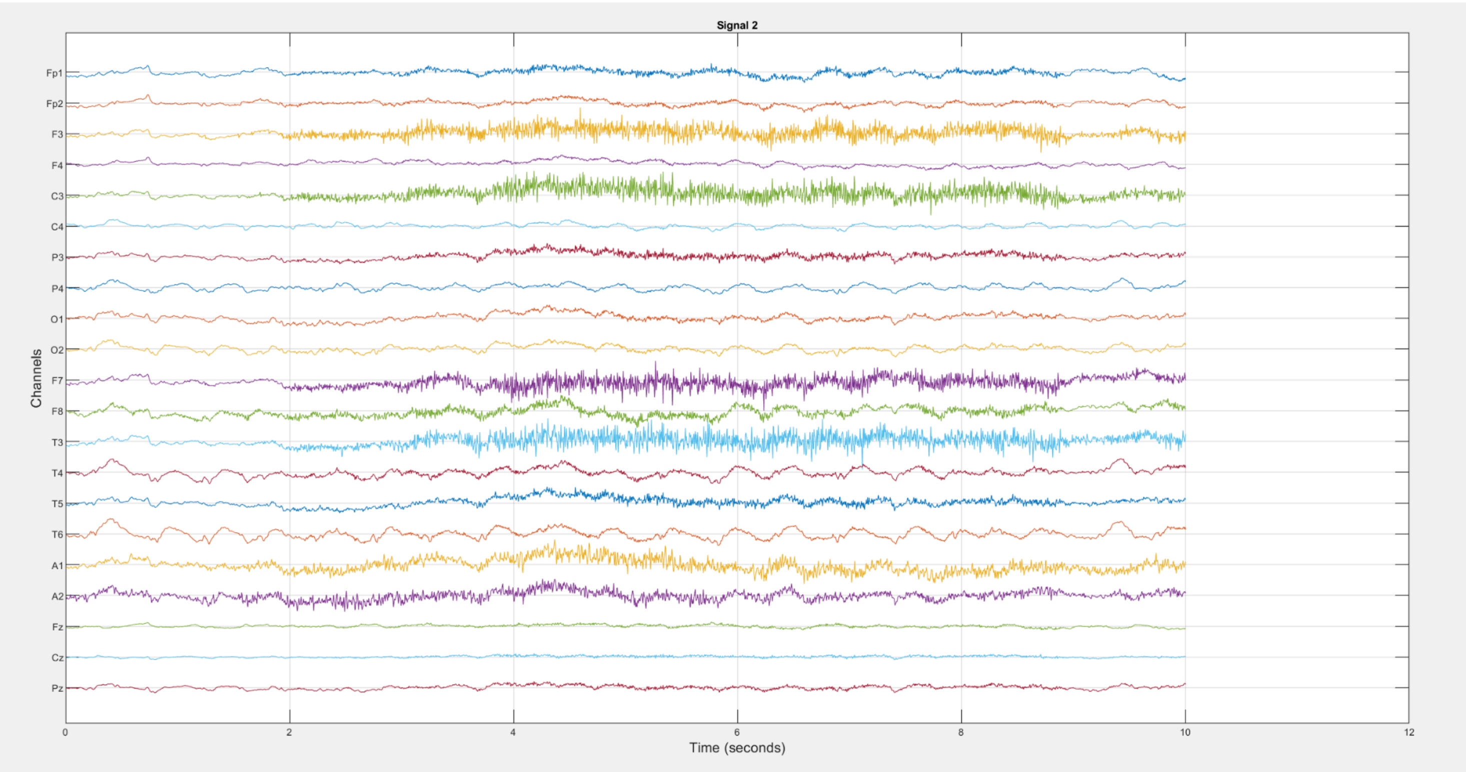


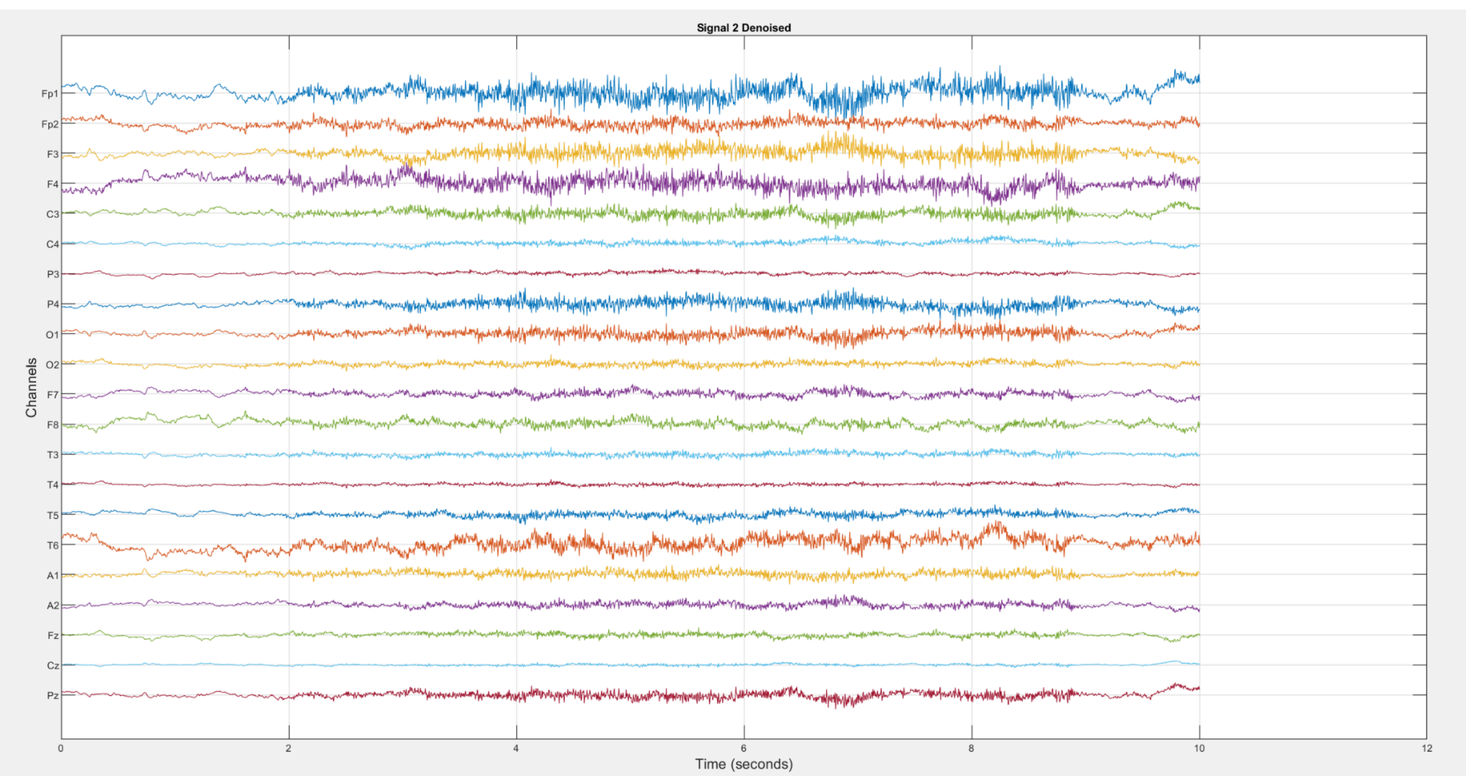


As you can see, the signal has become way cleaner. However, it does not seem to be completely clean, by removing more components and using more sophisticated methods in order to find unwanted components we can still clean the original signal more.

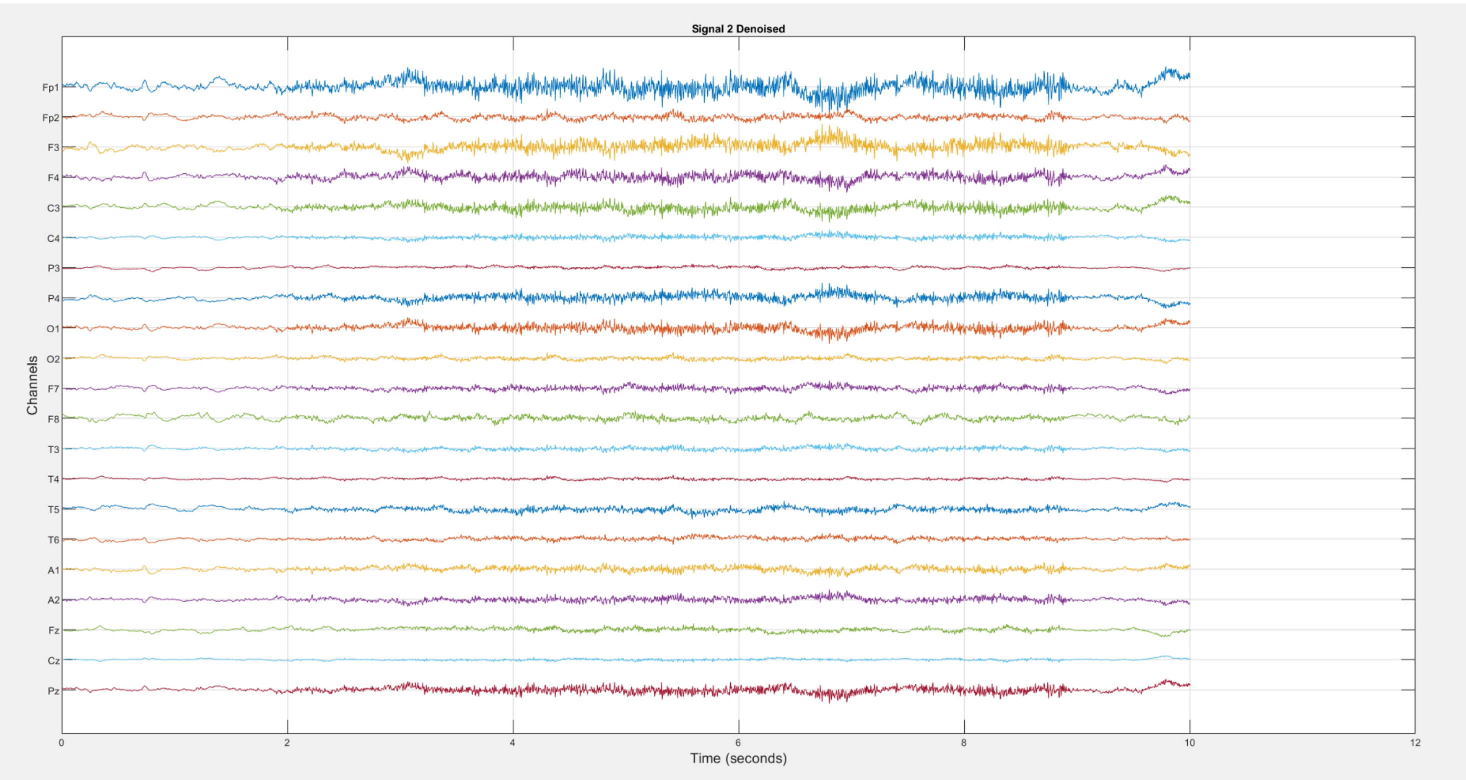
<u>For Signal 2:</u> If we look at the frequency domain of components, it's obvious that there are sharp peaks at 60hz for these components: 8, 12, 15, 16, 17. Therefore, there is a high probability that these components are not related to brain activity. Furthermore, some components show muscle activity in both time and frequency domains (typically above 30Hz): 1 to 7, and 11. (1 to 7 clearly have EMG and eye movement noises).

Sig2 before & after denoising:





As you can see, some channels have been cleaned really well, but some channels seem to still have some noise. I've performed these process one more time with removing more components (components 1 to 13 and 15 to 17):



It can be observed that while some channels have been cleared greatly (from eye movements or periodic activities), some noises have remained in some channels. In this step only 5 components have remained as brain activity which is quite low, therefore it's not wise to remove any components more than this. Thus we can say that this specific signal (signal 2) is way noisier than the first one and we can try other methods which are more complex and can detect noises better.