FLORIDA INTERNATIONAL UNIVERSITY

College of Electrical and Computer Engineering

Power Analysis of Alpha and Beta Waves in EEG Signals to Determine the most likely state of a subject

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OBJECTIVE

A person EEG's signals were recorded using 3 electrodes. The purpose of this project is to determine the most likely states of this person based on the relative power content of the alpha and beta waves.

SIGNALS AND ELECTRODES

The 3 electrodes used are Pz, Cz and Fz. The EEG signals were recorded for two different states of the patient. These 6 signals contain 500 samples each one, sampled at 250 Hz for a total of 2 seconds.

Figure 1 shows the location of the 3 electrodes used in the experiment.

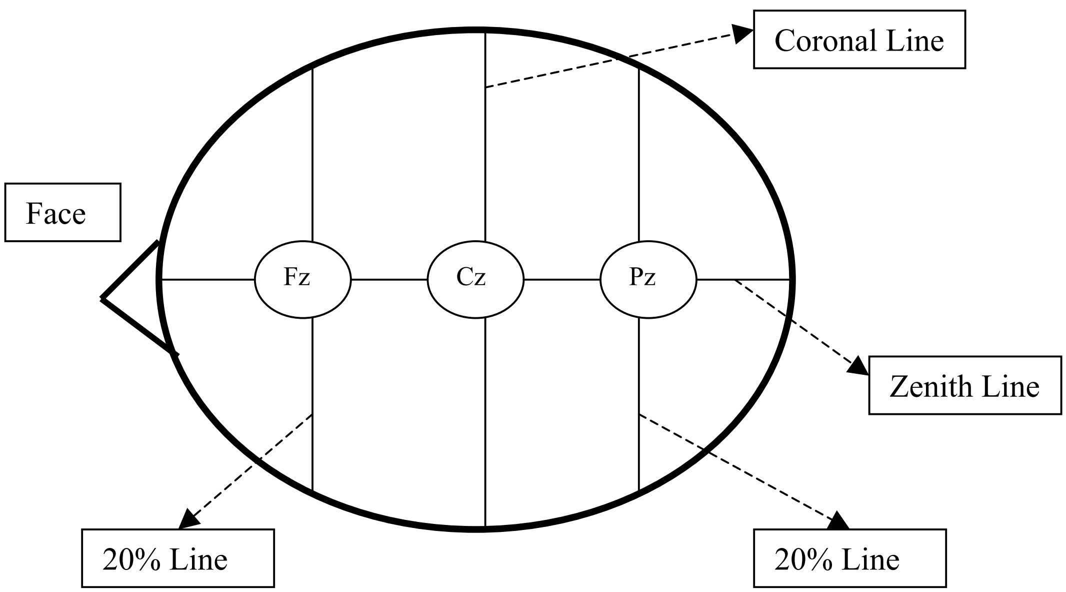


Figure 1. Location of the Electrodes. Top View.

The original signals contain a DC offset that was removed prior to further processing. Appendix A has figures showing the 6 EEG signals with the DC offset removed.

EEG BAND POWER ASSESSMENT

Two digital filters are required to separate the alpha and beta waves present in the EEG signals.

The characteristics of these filters are as follows:

1) Filter A.

To isolate the **Alpha and Beta I** bands (8 - 17 Hz). The attenuation in the stop band must be at least 20dB.

An IIR Chebyshev Type I Filter was designed with the following characteristics:

- Passband = 8-17 Hz
- Stopband Cutoff Frequencies=7 and 18Hz.
- Ripple in the passband=1.5dB
- Bandstop attenuation=20dB
- N=7 (filter order)

The actual passband and stopband used were [7-17Hz] and [6-18Hz]. This was required to account for the smearing effect on the lower passband frequency.

2) Filter B.

To isolate the **Beta II Band** (18 – 40 Hz). The attenuation in the stop band must be at least 20 dB.

An IIR Chebyshev Type I Filter was designed with the following characteristics:

- Passband = 18-40 Hz
- Stopband Cutoff Frequencies=17 and 41Hz.
- Ripple in the passband=0.5dB
- Bandstop attenuation=20dB
- N=11 (filter order)

The actual passband and stopband matched the ideal requirements.

MATLAB® scripts were used to design and verify the frequency response of the required filters. See Appendix A for details. Figures 2 through 4 show the frequency responses of Filter A, Filter B and combined response, respectively. The combined frequency responses of both filters behave like a notch filter that filters out the 17.5Hz component of the signals. Since this frequency is in theory outside both Alpha and Beta bands, canceling it, has no effect in the overall result.

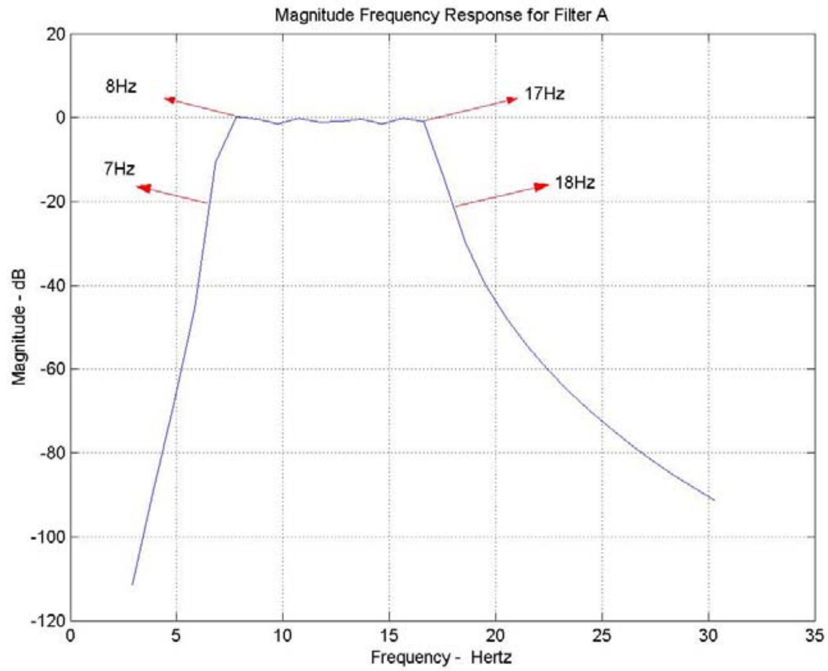


Figure 2. Frequency Response of Filter A.

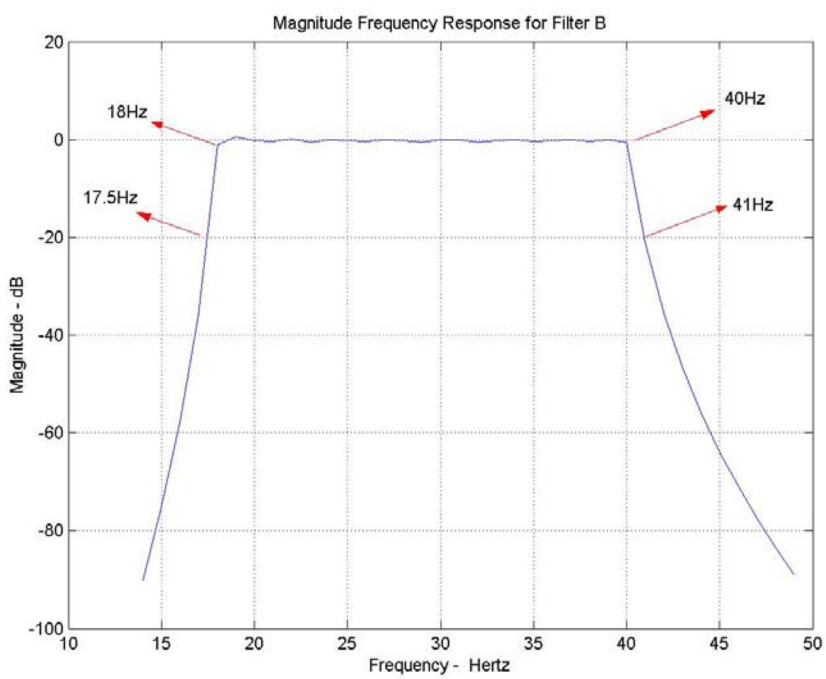


Figure 3. Frequency Response of Filter B.

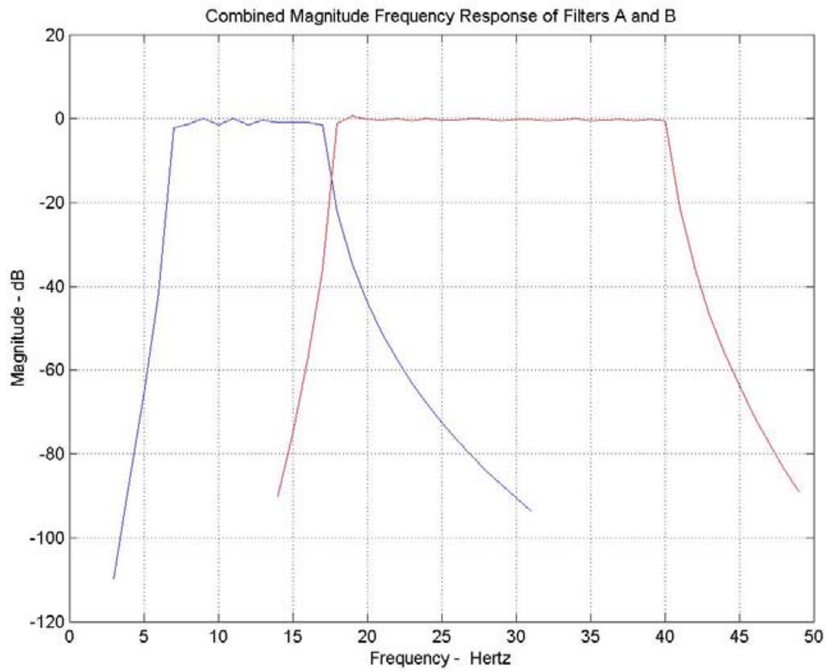
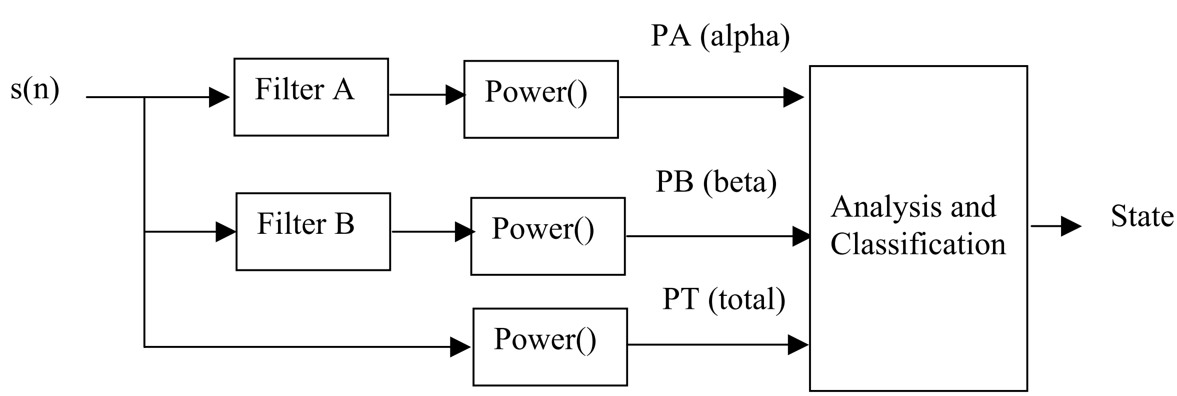


Figure 4. Combined Frequency Responses of Filters A and B.

Power Assessment

The relative power of alpha and beta waves in reference to the total power of the EEG signals will be used to determine the state of the person. The power is obtained as the sum of the squares of the points in the signal. This result is usually divided by the number of points in the signal, but since we are interested in the relative power in reference to the total power of the signal, this division is not necessary.

Graphically, the system looks like this



For each signal we calculate the ratios PA/PT and PB/PT to obtain the relative power of alpha and beta waves in the signal. To be able to analyze and classify the state of the person under analysis, the sum of the power of the alpha waves in the 3 signals is compared to the sum of the power of beta waves in the same 3 signals in the same interval of time. Since Beta II waves are normally 5 times smaller than Alpha waves, the power of beta waves is multiplied by the same factor.

Mathematically, these are the equations used for analysis:

$$\alpha_i = \sum_{k=1}^{N} P\alpha_k \qquad (1.0)$$

where N is the number of signals (in this case 3), $P\alpha_k$ is the power in the alpha band in signal (electrode) k. and α_i is the total power in the alpha band for all N signals at time window i, (i=1,2 in this case).

Similarly,

$$\beta_i = 5\sum_{k=1}^{N} P\beta_k \qquad (2.0)$$

Thus, the classification algorithm is as follows,

IF $\alpha_i > \beta_i$ THEN
State *i* is "AWAKE RELAXED"
ELSE
State *i* is "AWAKE ALERT/ATTENTIVE"
END IF

The system was implemented in MATLAB® and the code can be found in Appendix C. The program was run and the results were tabulated as shown in the next section.

RESULTS

The MATLAB script was run and the results, matrices PA and PB, have been tabulated in Table 1.

	State 1			**State 2**		
Electrode	**Signal**	**Alpha Power**	**Beta II Power**	**Signal**	**Alpha Power**	**Beta II Power**
Pz	S1Pz	0.3350	0.0380	S2Pz	0.1963	0.1442
Cz	S1Cz	0.3285	0.0491	S2Cz	0.1034	0.1308
Fz	S1Fz	0.2721	0.0348	S2Fz	0.0726	0.0931
Analysis	**AWAKE RELAXED**			**AWAKE ALERT/ATTENTIVE**		

Table 1. Results of Alpha and Beta Waves Power Analysis.

The results show that the power in the alpha and beta I waves decreased considerably when the subject changed from state 1 to state 2. The high content of alpha and beta I waves in the EEG has been found in individuals who are awake but in a relaxed, quiet state. In state 1 the power of beta II waves is very small, therefore, state 1 has been labeled as “Awake Relaxed”.

In state 2, the amount of power in alpha and beta I waves is a lot smaller than in state 1. On the other hand, the power found in the beta II waves is larger than in state 1 and in signals Cz and FZ is even larger than their corresponding alpha waves power. Since the predominance of power found in state 2 is in the range of the beta II waves, this state has been labeled as “Awake Alert/Attentive”.

This analysis coincides with the results obtained after running the MATLAB script.

CONCLUSIONS

A simple but robust method to determine the state of an individual based on the relative power of alpha and beta waves contained in the EEG signals, has been developed, tested and analyzed satisfactorily.

In awake individuals, the contents of power in alpha and beta waves in the EEG changes so drastically when the person changes from relaxed to alert or vice versa, that these measures lead to conclusive results.

APPENDIX A: EEG SIGNALS

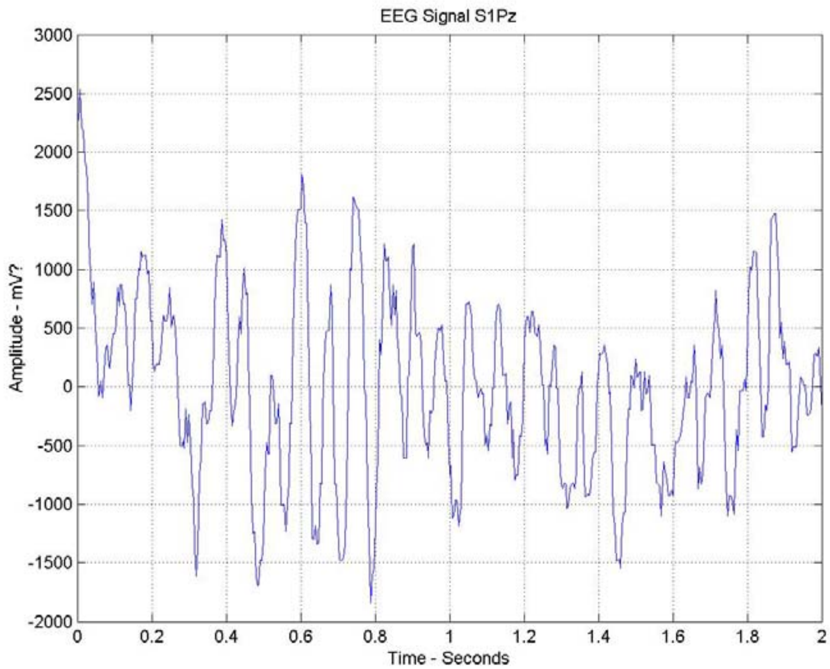


Figure A1. EEG Signal S1Pz.

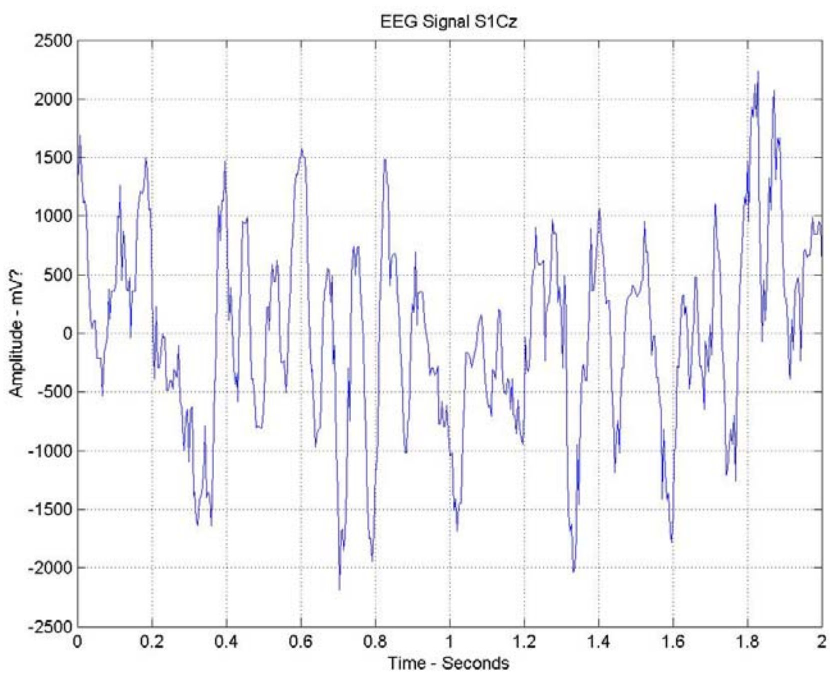


Figure A2. EEG Signal S1Cz.

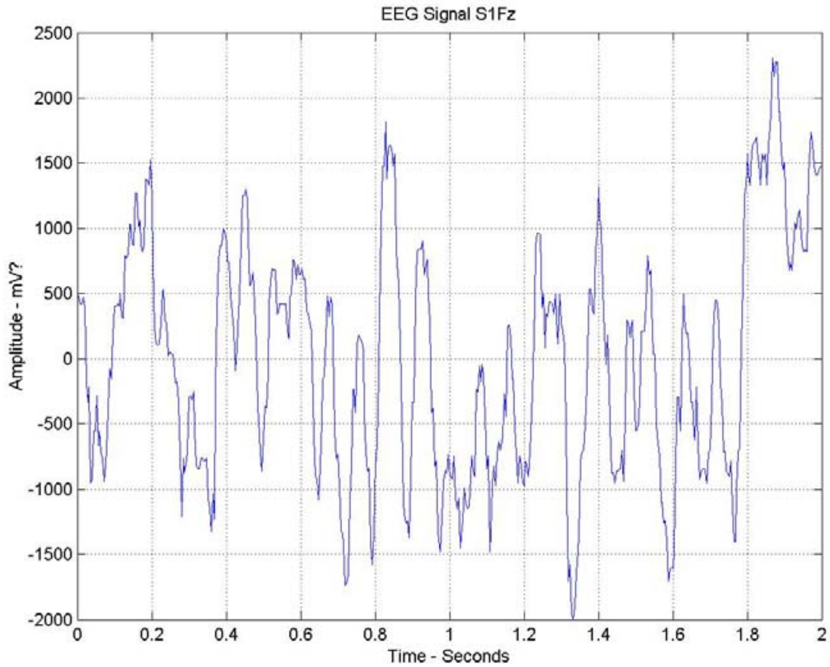


Figure A3. EEG Signal S1Fz.

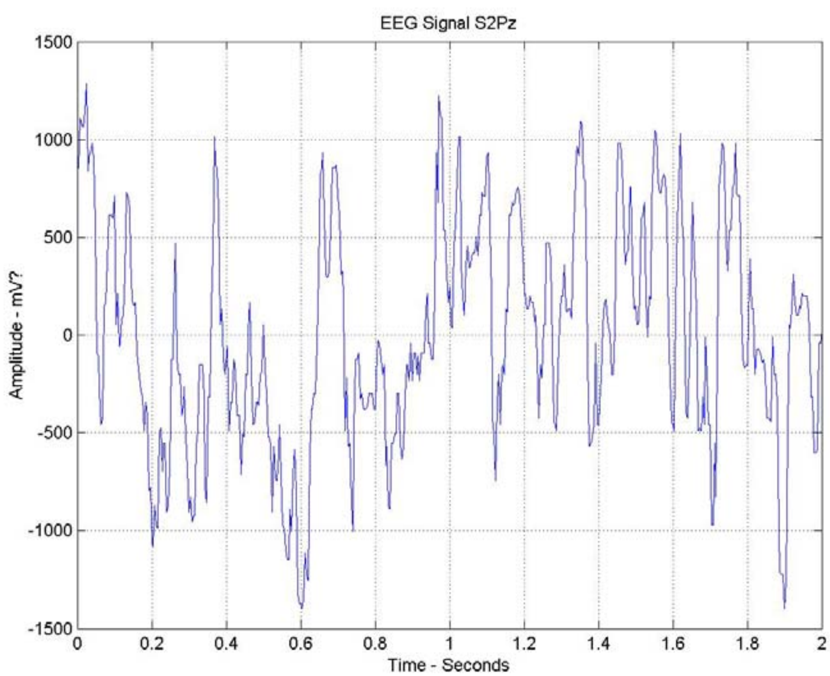


Figure A4. EEG Signal S2Pz.

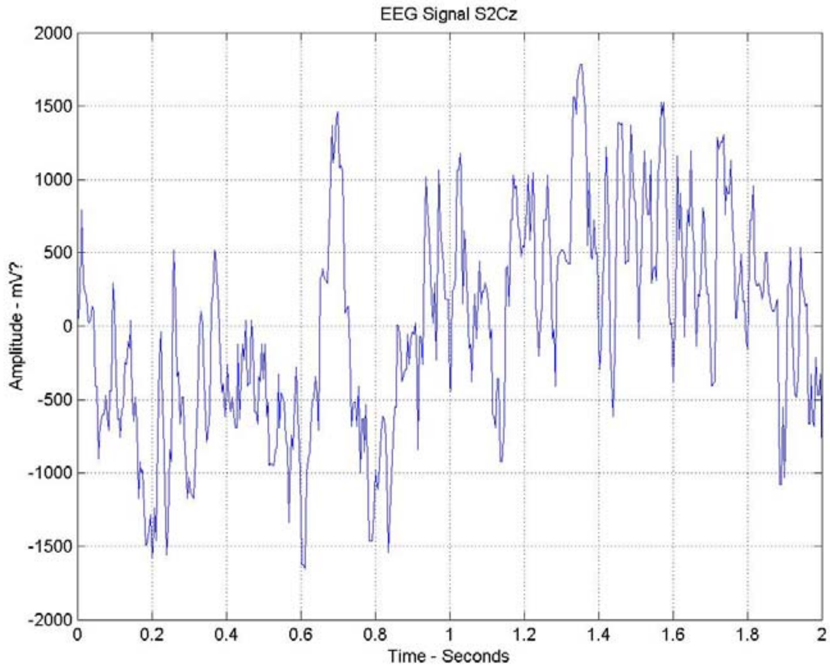


Figure A5. EEG Signal S2Cz.

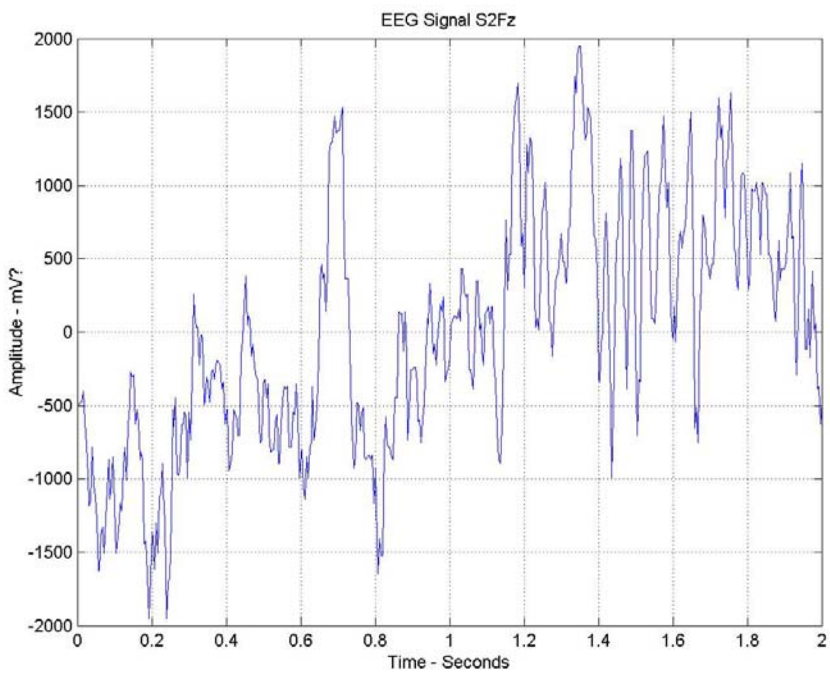


Figure A6. EEG Signal S2Fz.

APPENDIX B: FILTER DESIGN WITH MATLAB®

```
%-------------------------------------------------------------------------------
Fs=250;        % sampling frequency
%------------------------------------------------------------------------------------------------
% Bandpass Filter 1: Bandpass between 8 and 17Hz. Bandstop below 7 and above 18 Hz.
%------------------------------------------------------------------------------------------------
Fp1=7;
Fp2=17;
Fs1=6;
Fs2=18;
Wp=[Fp1/(Fs/2) Fp2/(Fs/2)];         % normalized bandpass vector
Ws=[Fs1/(Fs/2) Fs2/(Fs/2)];         % normalized bandstop vector
Rs=20;                              % 20db Attenuation in the bandstop

% IIR Chebyshev approach
Rp=1.5;                                    % Max ripple in the bandpass
[N, Wn] = cheb1ord(Wp, Ws, Rp, Rs);        % get the chebyshev order
[B,A] = cheby1(N,Rp,Wn);                   % get chebyshev coefficients
[H1,W1] = FREQZ(B,A,125,250);              % get the frequency response vector
% plot the frequency response
figure;plot(W1(4:32),20*log10(abs(H1(4:32))));
title('Magnitude Frequency Response for Filter A');
xlabel('Frequency -  Hertz');
ylabel('Magnitude - dB');
grid on;

%------------------------------------------------------------------------------------------------
% Bandpass Filter 2: Bandpass between 18 - 40Hz. Bandstop below 17 and above 41 Hz.
%------------------------------------------------------------------------------------------------
Fp1=18;
Fp2=40;
Fs1=17;
Fs2=41;
Wp=[Fp1/(Fs/2) Fp2/(Fs/2)];                % normalized bandpass vector
Ws=[Fs1/(Fs/2) Fs2/(Fs/2)];                % normalized bandstop vector
Rs=20;                                     % 20db Attenuation in the bandstop

% IIR Chebyshev approach:
Rp=0.5;                                    % Max ripple in the bandpass
[N, Wn] = cheb1ord(Wp, Ws, Rp, Rs);        % get the chebyshev order
[B,A] = cheby1(N,Rp,Wn);                   % get chebyshev coefficients
[H2,W2] = FREQZ(B,A,125,250);               % get the frequency response vector
% plot the frequency response
```

```
figure;plot(W2(15:50),20*log10(abs(H2(15:50))));
title('Magnitude Frequency Response for Filter B');
xlabel('Frequency -  Hertz');
ylabel('Magnitude - dB');
grid on;

%-----------------------------------------------------------
% Combined Frequency Response of Filter 1 & 2
%-----------------------------------------------------------
figure;plot(W1(4:32),20*log10(abs(H1(4:32))));
title('Combined Magnitude Frequency Response of Filters A and B');
xlabel('Frequency -  Hertz');
ylabel('Magnitude - dB');
grid on;
hold on;
plot(W2(15:50),20*log10(abs(H2(15:50))),'r');
```

APPENDIX C: IMPLEMENTATION

The following MATLAB Scripts, EEG_*PROJECT.M*, *ALPHA_BETA_POWER.M* and *PWR.M* were written to assess alpha waves power, beta waves power and determine the patient's most likely state.

```
%*********************************************
% EEG_PROJECT.M
%*********************************************
% read 6 eeg signals
load eegsignals;
% remove DC
s1cz=s1cz-mean(s1cz);
s1fz=s1fz-mean(s1fz);
s2pz=s2pz-mean(s2pz);
s2cz=s2cz-mean(s2cz);
s2fz=s2fz-mean(s2fz);
%----------------------------------------------------------
% Plot 6 signals:
%----------------------------------------------------------
Fs=250;                 % sampling frequency
x=1/Fs:1/Fs:2;          % X axis from 0 thru 2 seconds
figure;plot(x,s1pz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S1Pz');
figure;plot(x,s1cz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S1Cz');
figure;plot(x,s1fz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S1Fz');
figure;plot(x,s2pz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S2Pz');
figure;plot(x,s2cz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S2Cz');
figure;plot(x,s2fz);grid on;
xlabel('Time-Seconds');ylabel('Amplitude');title('Signal S2Fz');

%----------------------------------------------------------
% Relative Power of Alpha and Beta Waves
%----------------------------------------------------------
PA=zeros(3,2);   % power alpha (3 signals x 2 states)
PB=zeros(3,2);   % power beta  (3 signals x 2 states)

% obtain the relative power of alpha and beta waves
% in each of the 6 signals
[PA(1,1), PB(1,1)]=alpha_beta_power(s1pz, Fs);
[PA(2,1), PB(2,1)]=alpha_beta_power(s1cz, Fs);
[PA(3,1), PB(3,1)]=alpha_beta_power(s1fz, Fs);
```

```
[PA(1,2), PB(1,2)]=alpha_beta_power(s2pz, Fs);
[PA(2,2), PB(2,2)]=alpha_beta_power(s2cz, Fs);
[PA(3,2), PB(3,2)]=alpha_beta_power(s2fz, Fs);
% compare power:
alpha1 = 0; alpha2 = 0; beta1 = 0; beta2 = 0;
for k=1:3
   alpha1 = alpha1 + PA(k,1);
   alpha2 = alpha2 + PA(k,2);
   beta1  = beta1  + PB(k,1);
   beta2  = beta2  + PB(k,2);
end
beta1 = 5*beta1;
beta2 = 5*beta2;
% Classification:
if alpha1 > beta1
   state='STATE 1 is AWAKE RELAXED'
else
   state='STATE 1 is AWAKE ALERT/ATTENTIVE'
end

if alpha2 > beta2
   state='STATE 2 is AWAKE RELAXED'
else
   state='STATE 2 is AWAKE ALERT/ATTENTIVE'
end

% display detail power results:
PA
PB

%***********************************************
% ALPHA_BETA_POWER.M
%***********************************************
% This function calculates the relative power content of alpha and beta waves in
% the EEG signal passed as input parameter. The power is relative to the total
% power of the EEG signal.
%************************************************************
function [PA, PB]=alpha_beta_power(EEG, Fs)

%---------------------------------------------------------------------------------
% Bandpass Filter 1: Bandpass between 8 and 17Hz. Bandstop below 7 and above 18 Hz.
%---------------------------------------------------------------------------------
Fp1=7;
Fp2=17;
Fs1=6;
Fs2=18;
```

```
Wp=[Fp1/(Fs/2) Fp2/(Fs/2)];          % normalized bandpass vector
Ws=[Fs1/(Fs/2) Fs2/(Fs/2)];          % normalized bandstop vector
Rs=20;                               % 20db Attenuation in the bandstop

% IIR Chebyshev Filter
Rp=1.5;                                     % Max ripple in the bandpass
[N, Wn] = cheb1ord(Wp, Ws, Rp, Rs);         % get the chebyshev order
[B,A]   = cheby1(N,Rp,Wn);                  % get chebyshev coefficients
alpha   = filter(B,A,EEG);                  % get alpha waves only

%-------------------------------------------------------------------------------
% Bandpass Filter 2: Bandpass between 18-40Hz. Bandstop below 17 and above 41 Hz.
%-------------------------------------------------------------------------------
Fp1=18;
Fp2=40;
Fs1=17;
Fs2=41;
Wp=[Fp1/(Fs/2) Fp2/(Fs/2)];          % normalized bandpass vector
Ws=[Fs1/(Fs/2) Fs2/(Fs/2)];          % normalized bandstop vector
Rs=20;                               % 20db Attenuation in the bandstop

% IIR Chebyshev Filter
Rp=0.5;                                     % Max ripple in the bandpass
[N, Wn] = cheb1ord(Wp, Ws, Rp, Rs);         % get the chebyshev order
[B,A]   = cheby1(N,Rp,Wn);                  % get chebyshev coefficients
beta    = filter(B,A,EEG);                  % get beta waves only

PT = pwr(EEG);
PA = pwr(alpha)/PT;
PB = pwr(beta)/PT;
%********************* End ********************
%*********************************
% PWR.M (calculate power)
%*********************************
function pwr = pwr(Y)
pwr=0;
for k=1:length(Y)
   pwr=pwr+Y(k)^2;
end
```