Lab #4: Design of a Bioinstrumentation Amplifier for EEG

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Name	Student #	Lab Contribution
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Part A: Testing the Circuit

Question A2. ***What resistor values did you choose for a gain of 5 instead of 250?***

Values for the gain resistors of the second amplification stage were calculated according to the equations below.

$\frac{R_2}{R_3} = G - 1 = 5 - 1 = 4$

$R_2 = 5.49k\Omega$

$R_3 = 1.27k\Omega$

Question A5. ***Plot gain vs. frequency for signals between DC and 100Hz.***

The gain values were recorded at different frequency values, shown plotted in Figure 1. A table of the data collected is shown in Appendix 1.

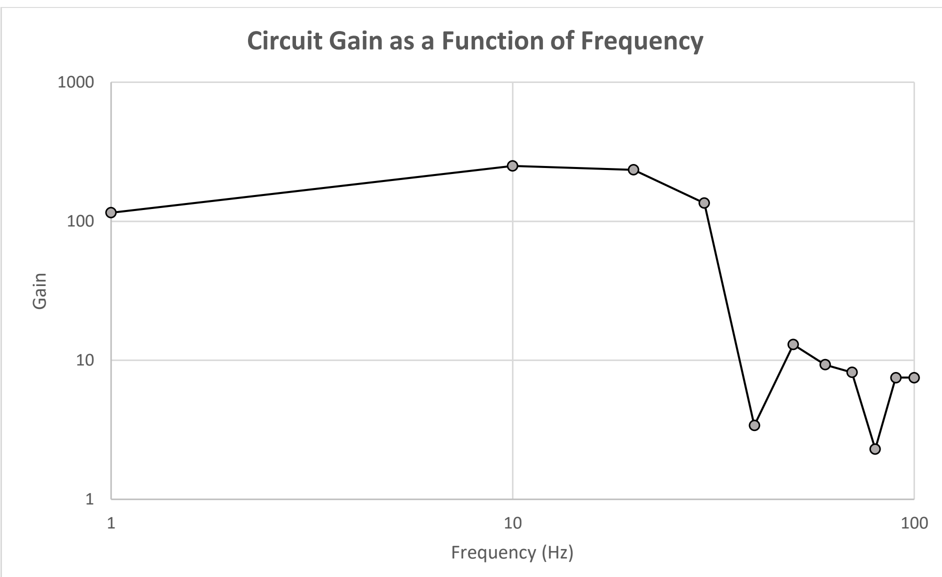

Figure 1. Circuit gain as a function of frequency (semi-log plot).

Part B: Acquiring the EEG Signal

Question B1. ***Readjust the gain of the first and second amplification stages to 40 and 1000. Show your work for getting the second stage to a gain of 1000.***

Values for the gain resistors of the second amplification stage were calculated according to the equations below.

$\frac{R_2}{R_3} = G - 1 = 999$

$R_2 = 475k\Omega$

$R_3 = 0.499k\Omega$

Question B4. ***Spectral analysis of the alert subject (Beta waves)***

i. Plot the frequency spectrum from 0 to 70Hz

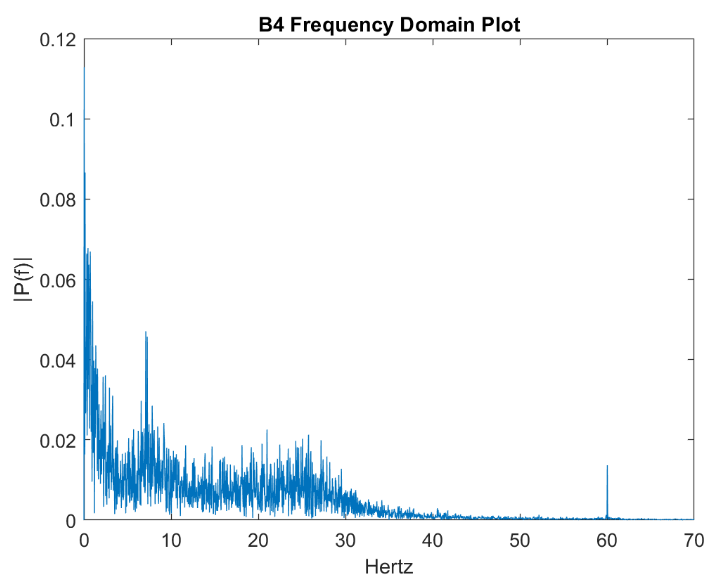

Figure 2. Frequency spectrum from 0 to 70Hz.

ii. Bandpass filter the signal from 1 to 30Hz using a 30th order filter of any choice

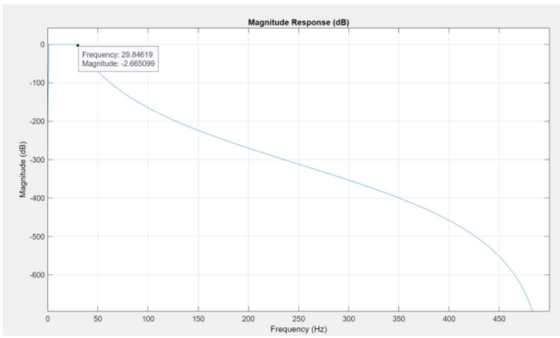

Figure 3. The MATLAB code used to filter the signal from 1 to 30Hz using a 30th order Butterworth filter is found in Appendix 2. The magnitude response of a 30th order Butterworth filter. There is a high rollover frequency past the stopband, but the passband frequencies are only slightly attenuated.

iii. Plot the spectrum of the filtered spectrum of the filtered signal from 0 to 70Hz. Compare to the first plot.

The frequency spectrum of the filtered signal is shown in Figure 3 below. Compared to Figure 2, the DC offset at 0Hz and the 60Hz powerline signal was filtered out. Additionally, it seems that the peak magnitude in Figure 3 was before 1Hz, which was therefore filtered out. This may be the presence of a blinking artifact cause by drowsiness or a lapse in alertness of the subject. Looking at the time domain in Figure 5, there does seem to be an inconsistency at around 10sec with the rest of the signal in the time domain, which was attenuated after the filter. However, the artifact is still present, which may be correlated with the high spike in magnitude in the frequency domain at around 8Hz seen in both Figures 3 and 4.

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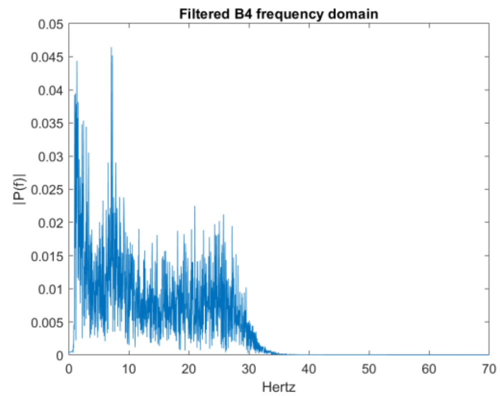

Figure 4. 30^{th} order filtered signal of the alert subject.

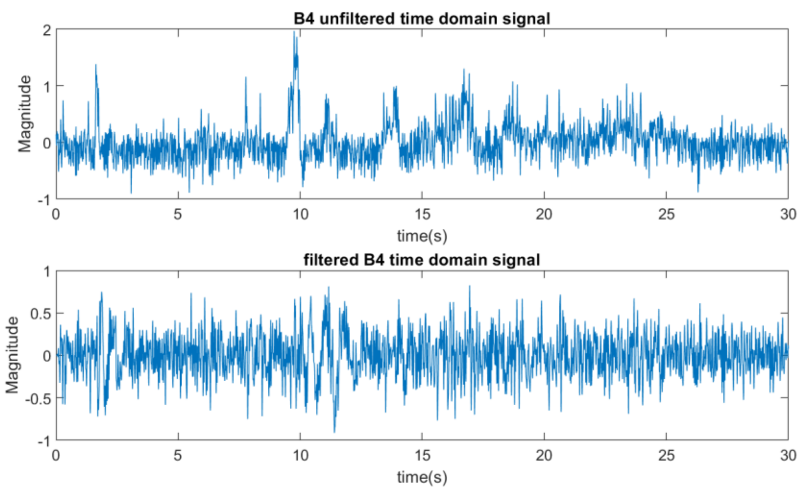

Figure 5: The filtered and unfiltered time domain of an alert subject.

Question B5. ***Spectral analysis of the relaxed subject***

The relaxed subject shows no significant increase in signal magnitude in the alpha or beta wave frequency range. The alpha wave slightly dominates over the beta waves (maximum ~0.025 vs. 0.020), which is consistent with the relaxed behaviour of the subject. Additionally, looking at Figure 7 of the time domain of the signals filtered by alpha and beta waves, beta waves show a clear higher frequency than alpha waves, at an increased magnitude.

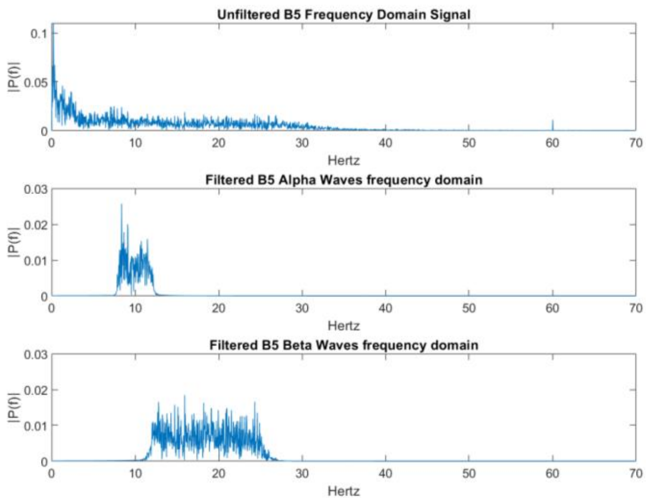

Figure 6. The unfiltered and filtered Alpha and Beta waves in the frequency domain of the relaxed subject.

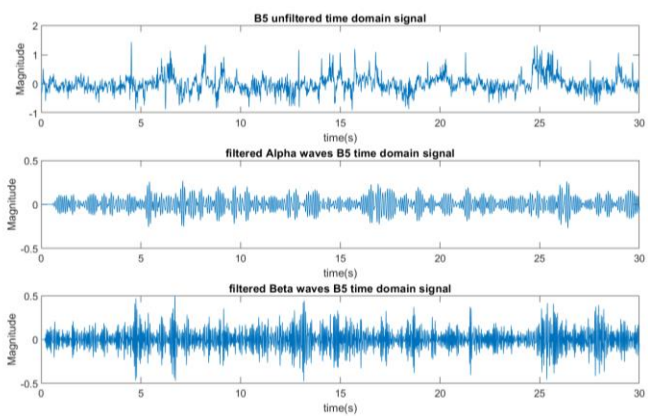

Figure 7: The unfiltered and filtered Alpha and Beta waves in the time domain of the relaxed subject.

Question B7. *Visually inspect the recorded signal (non-blinking + blinking), then perform spectral analysis of the first 10 seconds. Perform separate spectral analysis for the second 10 seconds. Compare the results. Can you suggest a way of getting rid of the blink artifact?*

By first visualizing the non-blinking and blinking signals in the time domain, it is not super apparent the differences between the signals. In the blinking signal (Figure 8), there seems to be a local minima about every second, which does not appear in the non-blinking signal (Figure 10). The differences between the two signals become more obvious when performing spectral analysis.

Figure 11 shows the first ten seconds (non-blinking), where the signal seems to be mostly low frequency, with the alpha wave frequency dominating over the beta in magnitude (0.04 vs. 0.03). Looking at the last ten seconds (blinking), there is a large spike in the beta frequency range, with a magnitude of ~0.15 (Figure 8). Although blinking is usually associated with drowsiness and should be found in the alpha band, since the blinking was done rapidly and intentionally, the artifact may have originated from facial muscle movement, and therefore was prominent in the beta signal.

To get rid of the blinking artifact, you could separate the alpha waves and beta waves through filtering. By filtering out signals in the beta range frequncy (12-30Hz) using a bandwidth filter, you can isolate the alpha waves and remove the effects of blinking on the signal. This is seen in Figures 8 and 10, where the filtered alpha waves are similar between the two signals, whereas the beta waves have a much higher amplitude in the blinking signal vs. the non-blinking signal (peak-to-peak of ~2V vs. 1V).

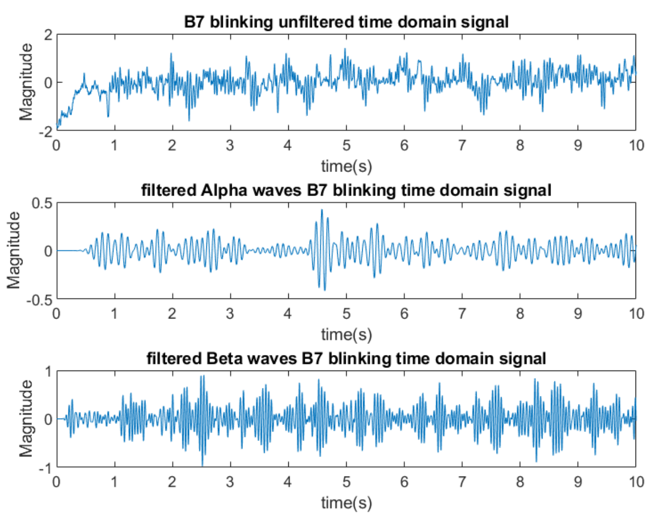

Figure 8: The unfiltered and filtered Alpha and Beta waves in the time domain of the blinking subject.

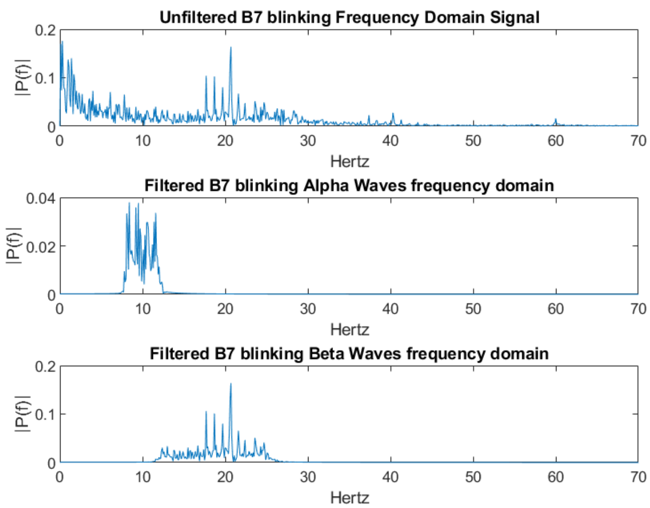

Figure 9: The unfiltered and filtered Alpha and Beta waves in the frequency domain of the blinking subject.

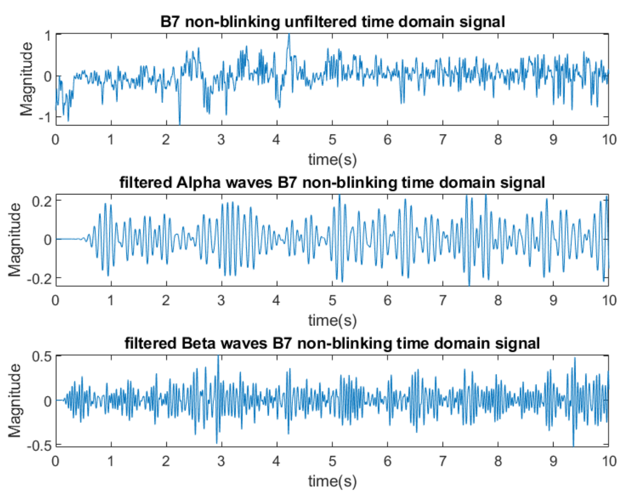

Figure 10: The unfiltered and filtered Alpha and Beta waves in the time domain of the non-blinking subject.

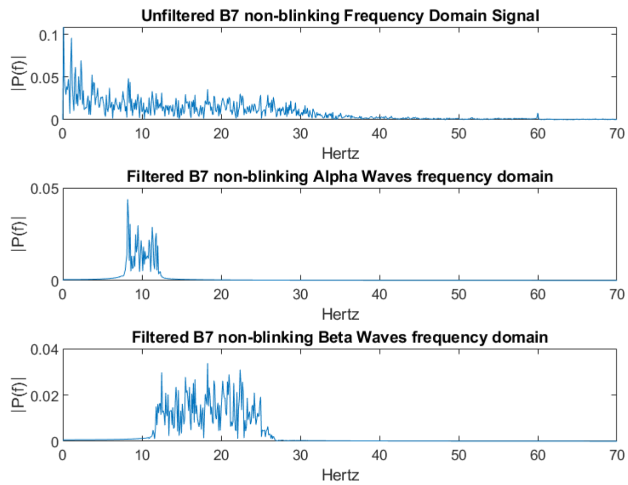

Figure 11: The unfiltered and filtered Alpha and Beta waves in the frequency domain of the non-blinking subject.

Question B9. *Visually inspect the signal (eyes opening and closing every 4 seconds). See if the frequency changes between eyes open vs. eyes closed segments. These periods may be difficult to identify except alpha waves tend to have larger amplitude. Perform spectral analysis for one period when the eyes are open and one period when the eyes are closed.*

The code in Appendix 2 was used to plot the filtered and unfiltered time- and frequency-domain spectra for the trial in which the subject's eyes were opened/closed every 4 seconds as shown in Figures 12 and 13.

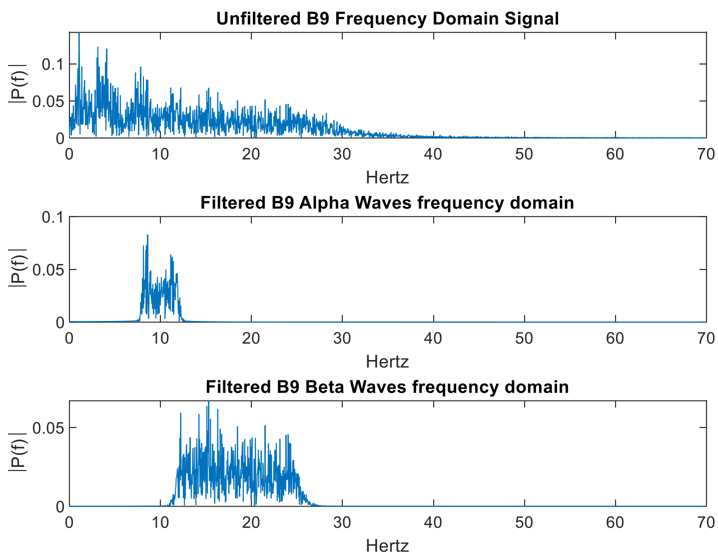

Figure 12. The unfiltered and filtered Alpha and Beta waves of the frequency domain for the entire sample.

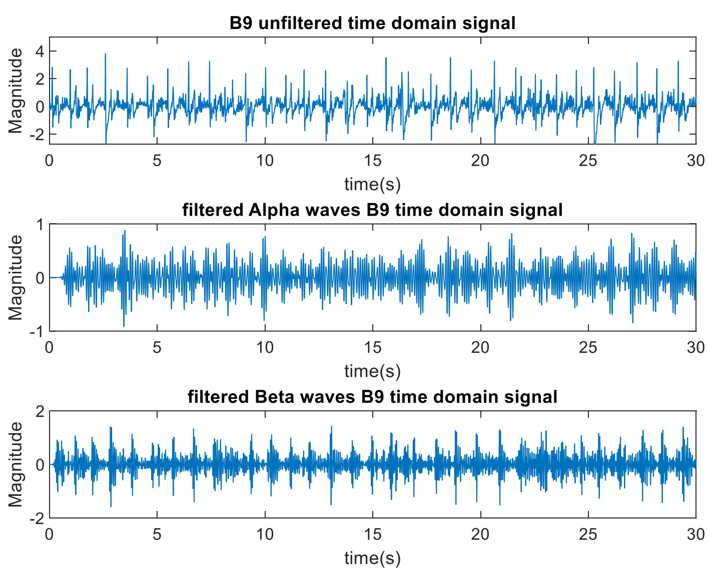

Figure 13. The unfiltered and filtered Alpha and Beta waves of the time domain for the entire sample.

Upon visual inspection, it was slightly difficult to distinguish “open eyes” vs. “closed eyes” data segments, particularly before filtering. However, the filtered time-domain response does indicate a slightly higher alpha-wave magnitude for the segments during which the subject’s eyes were open (e.g., 6-10 seconds eyes were open, and amplitude is noticeably higher than 11-15 seconds when the eyes were closed).

Two segments of the data (6-10 seconds and 11-15 seconds) were isolated, representing “eyes open” and “eyes closed” data respectively. These datasets were then analyzed separately to draw conclusions on their differences. The MATLAB code for this analysis is shown in Appendix 3, utilizing the same process as that described above (Appendix 2).

An important difference is illustrated in the comparison of the spectral analyses; the magnitude of the frequencies associated with alpha waves is significantly higher for the “eyes open” portion of the data.

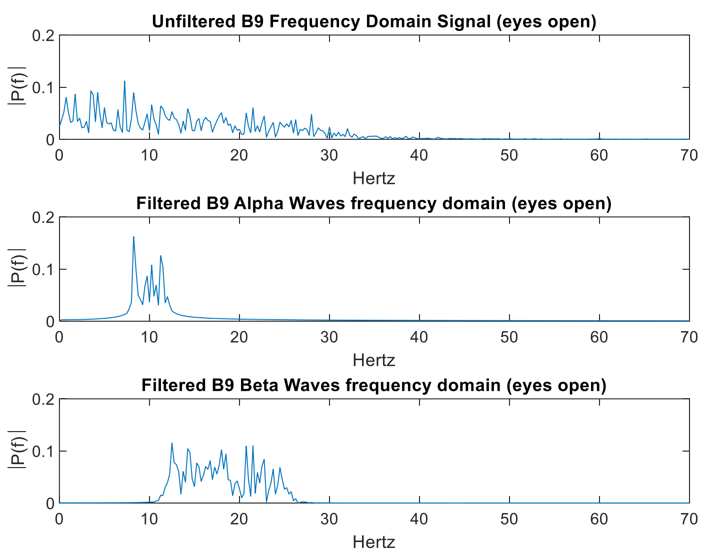

Figure 14. Unfiltered and filtered Alpha and Beta waves of the “eyes open” frequency domain.

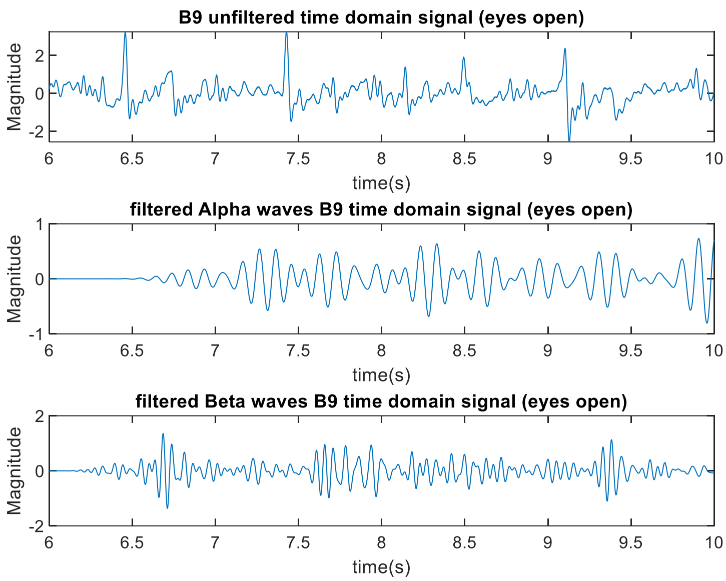

Figure 15. Unfiltered and filtered Alpha and Beta waves of the "eyes open" time domain.

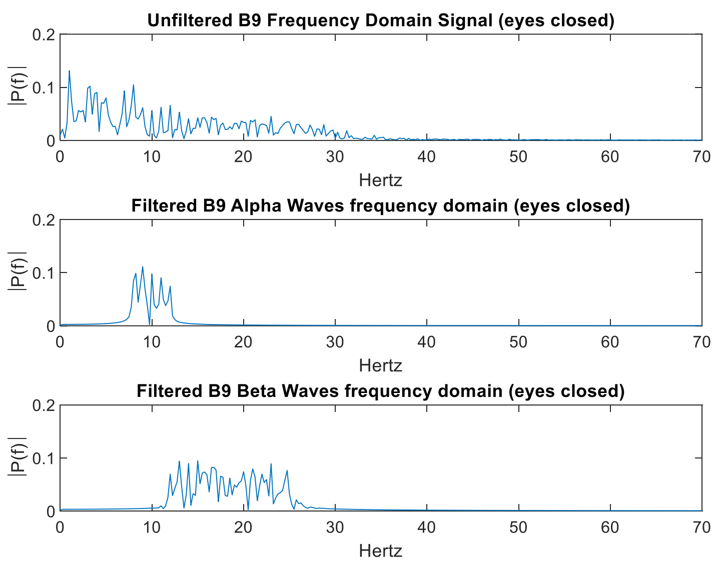

Figure 16. Unfiltered and filtered Alpha and Beta waves of the "eyes closed" frequency domain.

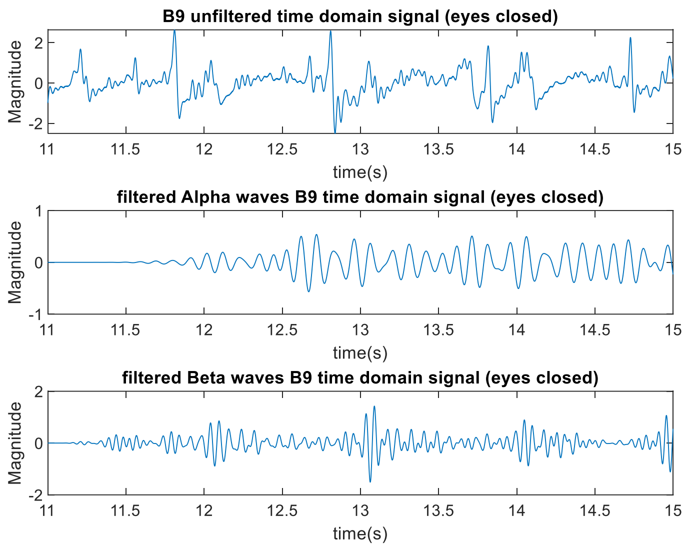

Figure 17. Unfiltered and filtered Alpha and Beta waves of the "eyes closed" time domain.

Appendix 1: Frequency Response of the Circuit

Table 1. Circuit output voltages and gain values calculated for different input frequencies

$Frequency\ (Hz)$	$V_{in}(mV\ p-p)$	$V_{out}(mV\ p-p)$	$G = V_{out}/V_{in}$
1	10	1150	115
10	10	2500	250
20	10	2340	234
30	10	1350	135
40	10	34	3.4
50	10	130	13
60	10	93	9.3
70	10	82	8.2
80	10	23	2.3
90	10	75	7.5
100	10	75	7.5

Appendix 2: MATLAB Code for Spectral Analysis (Time Domain, Frequency Spectrum, Filtering)

```
clc;
clear all;
close all;

%Enter file name you want to open:
load('B7.mat');

Fs = 1000;
T = 1/Fs;

%enter how long the signal was recorded for (in seconds)
StopTime = 10;

t = (0:T:StopTime-T);
L = size(t,2);
x = fft(data);
f = Fs*(0:(L/2))/L;

p2 = abs(x)/L;
p1 = p2(1:L/2+1);
p1(2:end-1)= 2*p1(2:end-1);


flow = 8; %lowest frequency
fhigh = 12; %highest frequency
n = 30;

d = designfilt('bandpassiir', 'FilterOrder',n,'HalfPowerFrequency1',flow, ...
    'HalfPowerFrequency2', fhigh,'SampleRate',Fs);
filtdata = filter(d,data);
%fvtool(d);  %use this to check if the filter is designed correctly
```

```
x1 = fft(filtdata);
p2_1 = abs(x1)/L;
p1_1 = p2_1(1:L/2+1);
p1_1(2:end-1)= 2*p1_1(2:end-1);


flow2 = 12;
fhigh2 = 25;

d2 = designfilt('bandpassiir', 'FilterOrder',n,'HalfPowerFrequency1',flow2,
...
    'HalfPowerFrequency2', fhigh2,'SampleRate',Fs);
%fvtool(d2);

filtdata2 = filter(d2,data);

x2 = fft(filtdata2);
p2_2 = abs(x2)/L;
p1_2 = p2_2(1:L/2+1);
p1_2(2:end-1)= 2*p1_2(2:end-1);

%Change the names of the title

subplot(3,1,1);
plot(t,data);
xlabel('time(s)');
ylabel('Magnitude');
title('B7 non-blinking unfiltered time domain signal');

subplot(3,1,2);
plot(t,filtdata);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Alpha waves B7 non-blinking time domain signal');

subplot(3,1,3);
plot(t,filtdata2);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Beta waves B7 non-blinking time domain signal');

figure;
subplot(3,1,1);
plot(f,p1);
xlabel('Hertz');
ylabel('|P(f)|');
title('Unfiltered B7 non-blinking Frequency Domain Signal');
xlim([0,70]);

subplot(3,1,2);
plot(f,p1_1);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
```

```
title('Filtered B7 non-blinking Alpha Waves frequency domain');

subplot(3,1,3);
plot(f,p1_2);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
title('Filtered B7 non-blinking Beta Waves frequency domain');
```

Appendix 3: MATLAB Code for Eyes Open vs. Eyes Closed Analysis

```
%Separate open and closed segments, and then use similar process to
%previous code to execute spectral analysis

open = data(6001:10000);            %segment of data where eyes were open
closed = data(11001:15000);         %segment of data where eyes were closed

%Spectral analysis of eyes open data

filtopen = filter(d,open);
x3 = fft(filtopen);
x = fft(open);
t = (6:T:10-T);
L = size(t,2);

f = Fs*(0:(L/2))/L;
p2 = abs(x)/L;
p1 = p2(1:L/2+1);

p2_3 = abs(x3)/L;
p1_3 = p2_3(1:L/2+1);
p1_3(2:end-1)= 2*p1_3(2:end-1);

filtopen2 = filter(d2,open);
x4 = fft(filtopen2);
p2_4 = abs(x4)/L;
p1_4 = p2_4(1:L/2+1);
p1_4(2:end-1)= 2*p1_4(2:end-1);

%Plot spectral analysis of eyes open data
figure;
subplot(3,1,1);
plot(t,open);
xlabel('time(s)');
ylabel('Magnitude');
title('B9 unfiltered time domain signal (eyes open)');

subplot(3,1,2);
plot(t,filtopen);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Alpha waves B9 time domain signal (eyes open)');

subplot(3,1,3);
```

```
plot(t,filtopen2);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Beta waves B9 time domain signal (eyes open)');

figure;
subplot(3,1,1);
plot(f,p1);
xlabel('Hertz');
ylabel('|P(f)|');
title('Unfiltered B9 Frequency Domain Signal (eyes open)');
xlim([0,70]);
ylim([0,0.2]);

subplot(3,1,2);
plot(f,p1_3);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
ylim([0,0.2]);
title('Filtered B9 Alpha Waves frequency domain (eyes open)');

subplot(3,1,3);
plot(f,p1_4);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
ylim([0,0.2]);
title('Filtered B9 Beta Waves frequency domain (eyes open)');


%Now repeat for eyes closed data
filtclosed = filter(d,closed);
x3 = fft(filtclosed);
x = fft(closed);
t = (11:T:15-T);
L = size(t,2);

f = Fs*(0:(L/2))/L;
p2 = abs(x)/L;
p1 = p2(1:L/2+1);

p2_4 = abs(x3)/L;
p1_4 = p2_4(1:L/2+1);
p1_4(2:end-1)= 2*p1_4(2:end-1);

filtclosed2 = filter(d2,closed);
x4 = fft(filtclosed2);
p2_5 = abs(x4)/L;
p1_5 = p2_5(1:L/2+1);
p1_5(2:end-1)= 2*p1_5(2:end-1);

%Plot spectral analysis of eyes open data
figure;
subplot(3,1,1);
plot(t,closed);
```

```
xlabel('time(s)');
ylabel('Magnitude');
title('B9 unfiltered time domain signal (eyes closed)');

subplot(3,1,2);
plot(t,filtclosed);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Alpha waves B9 time domain signal (eyes closed)');
ylim([-1,1]);

subplot(3,1,3);
plot(t,filtclosed2);
xlabel('time(s)');
ylabel('Magnitude');
title('filtered Beta waves B9 time domain signal (eyes closed)');

figure;
subplot(3,1,1);
plot(f,p1);
xlabel('Hertz');
ylabel('|P(f)|');
title('Unfiltered B9 Frequency Domain Signal (eyes closed)');
xlim([0,70]);
ylim([0,0.2]);

subplot(3,1,2);
plot(f,p1_4);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
ylim([0,0.2]);
title('Filtered B9 Alpha Waves frequency domain (eyes closed)');

subplot(3,1,3);
plot(f,p1_5);
xlabel('Hertz');
ylabel('|P(f)|');
xlim([0,70]);
ylim([0,0.2]);
title('Filtered B9 Beta Waves frequency domain (eyes closed)');
```