

RANCANG BANGUN SISTEM EEG UNTUK MENGIDENTIFIKASI GERAKAN PADA UPPER LIMB SEGMENT BERDASARKAN MOTOR IMAGERY SEBAGAI PERINTAH KENDALI FES

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Outline

❑ PENDAHULUAN

❑ METODE PENUNJANG

❑ PERANCANGAN SISTEM

- PERANCANGAN PERANGKAT KERAS
- PERANCANGAN PERANGKAT LUNAK

❑ PENGUJIAN DAN ANALISA

- PENGUJIAN PERANGKAT KERAS
- PENGUJIAN PERANGKAT LUNAK
- PENGUJIAN SISTEM KESELURUHAN
- PENGUJIAN AKTIVITAS MOTORIK PADA SISTEM EEG 10-20
- PERBANDINGAN MOTOR IMAGERY – MOTOR EXECUTION

❑ KESIMPULAN

Latar Belakang

- ❑ Angka penderita stroke besar dan terus bertambah[1]
- ❑ Informasi motorik pada pasien pasca stroke tetap ditemukan[2]
- ❑ Proses rehabilitasi pasien pasca stroke dengan FES membantu restorasi fungsi motoric[2]
- ❑ Rehabilitasi fungsi motorik dengan FES yang dikontrol BCI memaksimalkan proses rehabilitasi[4]

Perumusan Masalah

- ❑ Merancang perangkat keras untuk menangkap sinyal EEG
- ❑ Penentuan posisi elektroda pada *scalp* kepala yang merepresentasikan informasi *motor imagery*
- ❑ Penggunaan metode yang tepat untuk pengolahan sinyal EEG agar dapat diperoleh parameter untuk mengidentifikasi gerakan pada *upper limb segment* berdasarkan *motor imagery*

Tujuan

- ❑ Menghasilkan rangkaian instrumentasi berbasis ARM untuk menangkap sinyal EEG dengan baik
- ❑ Mendapatkan titik pada *scalp* kepala yang merepresentasikan informasi *motor imagery*
- ❑ Mendapatkan parameter untuk mengidentifikasi gerakan pada *upper limb segment* berdasarkan *motor imagery*

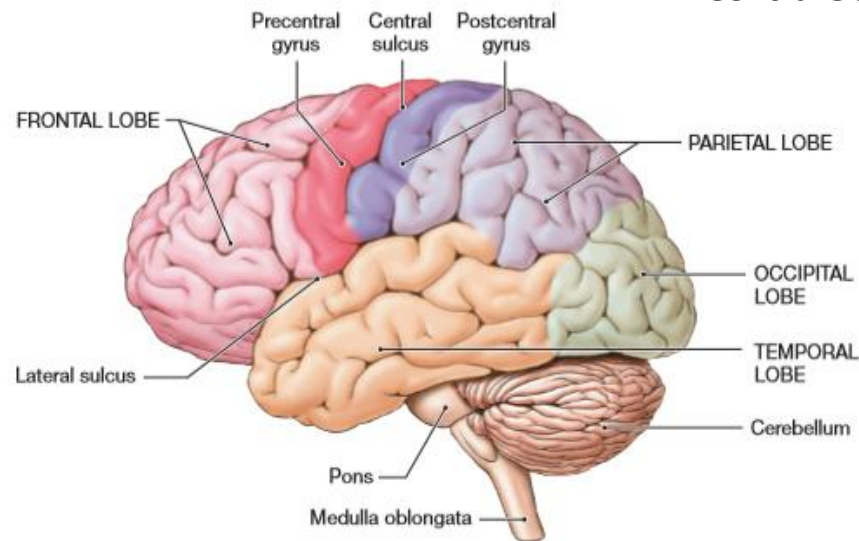
Otak

Komponen penyusunan otak :

- ☐ Cerebrum
- ☐ Cerebellum
- ☐ Diencephalon

Cerebral Cortex

- ☐ Frontal Lobe
- ☐ Parietal Lobe
- ☐ Temporal Lobe
- ☐ Occipital Lobe
- ☐ Central Sulcus

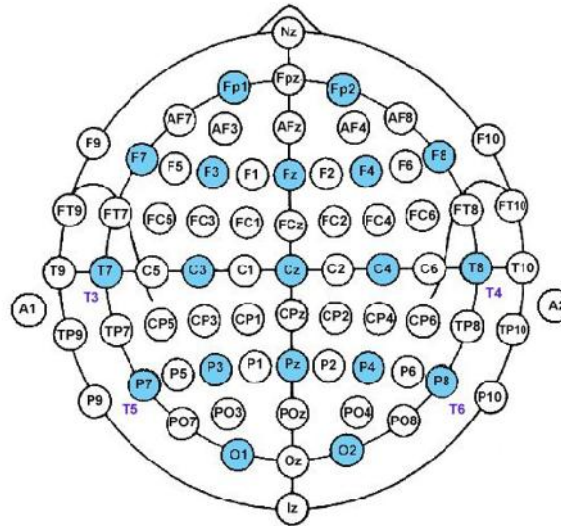


Secara fisiologi, cerebral cortex :

- ☐ Motor Area
 - Primary Motor Cortex
 - Supplementary Motor Area
- ☐ Sensory Area
- ☐ Association Area

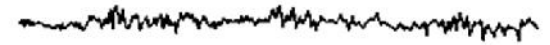
EEG

Penempatan Elektroda

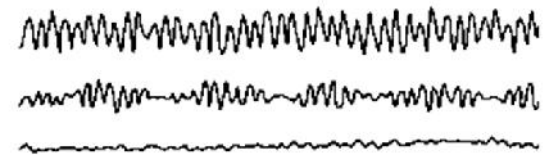


Jenis Gelombang

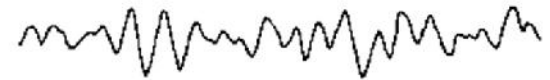
Beta (β) 13-30 Hz
Frontally and
parietally



Alpha (α) 8-13 Hz
Occipitally



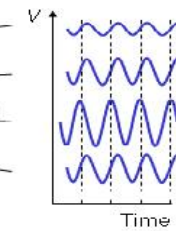
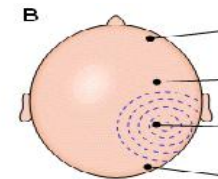
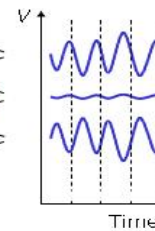
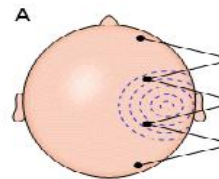
Theta (θ) 4-8 Hz
Children,
sleeping adults



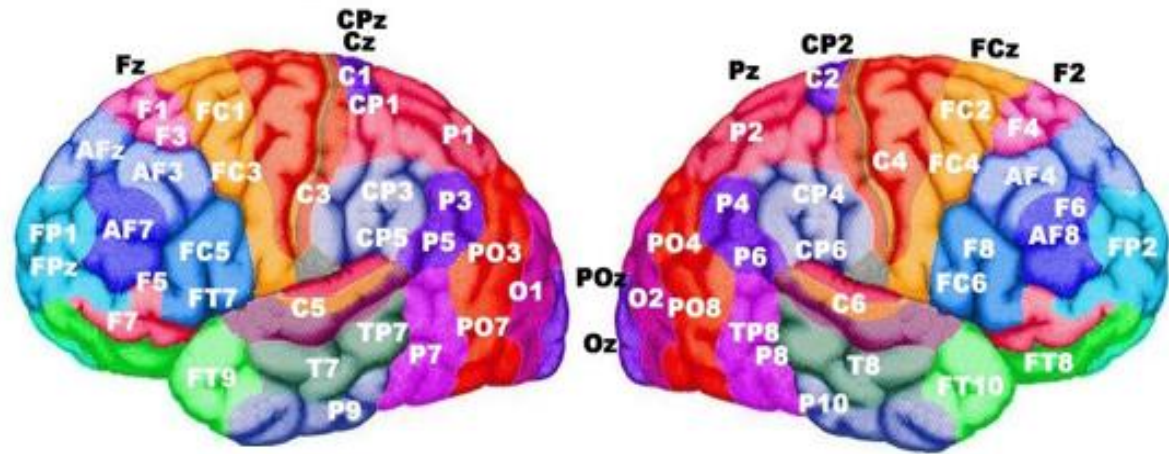
Delta (δ) 0.5-4 Hz
Infants,
sleeping adults



Konfigurasi Elektroda



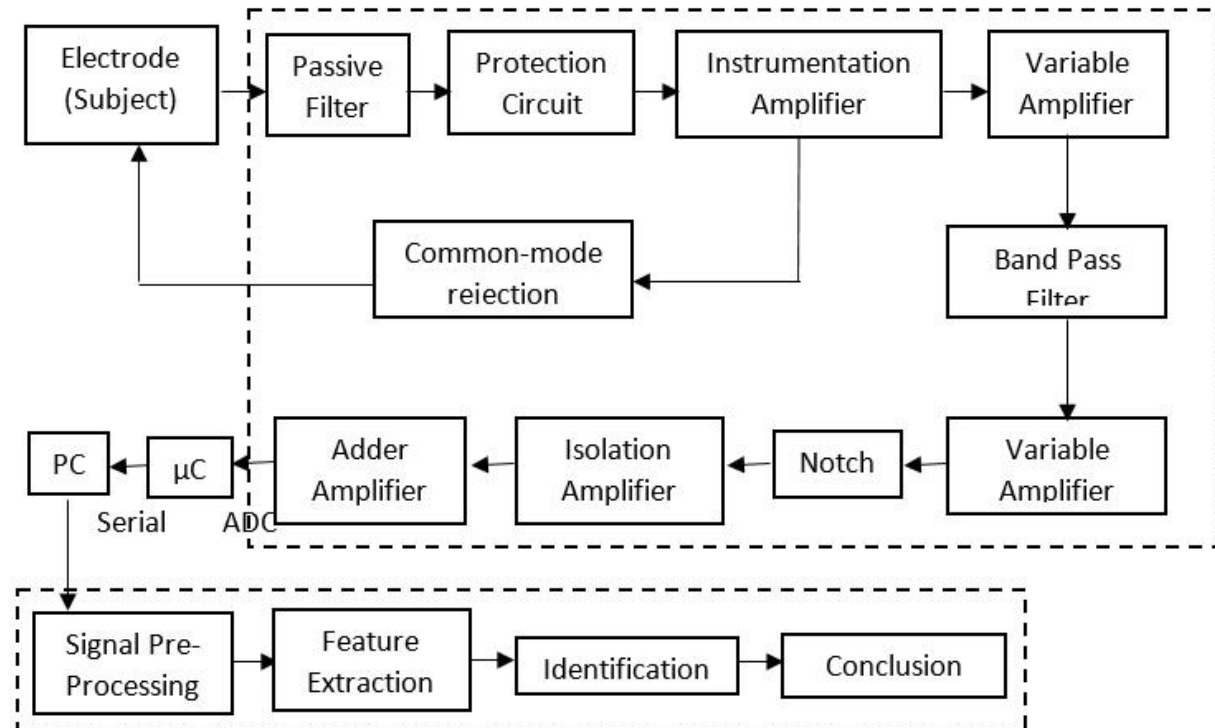
Informasi Motorik



Brodman Area	Left	Right
1, 2, 3, 4	C3	C4
5	C1	CP2
6	FC3	FC4
7	P1	P2
8	F1	F2

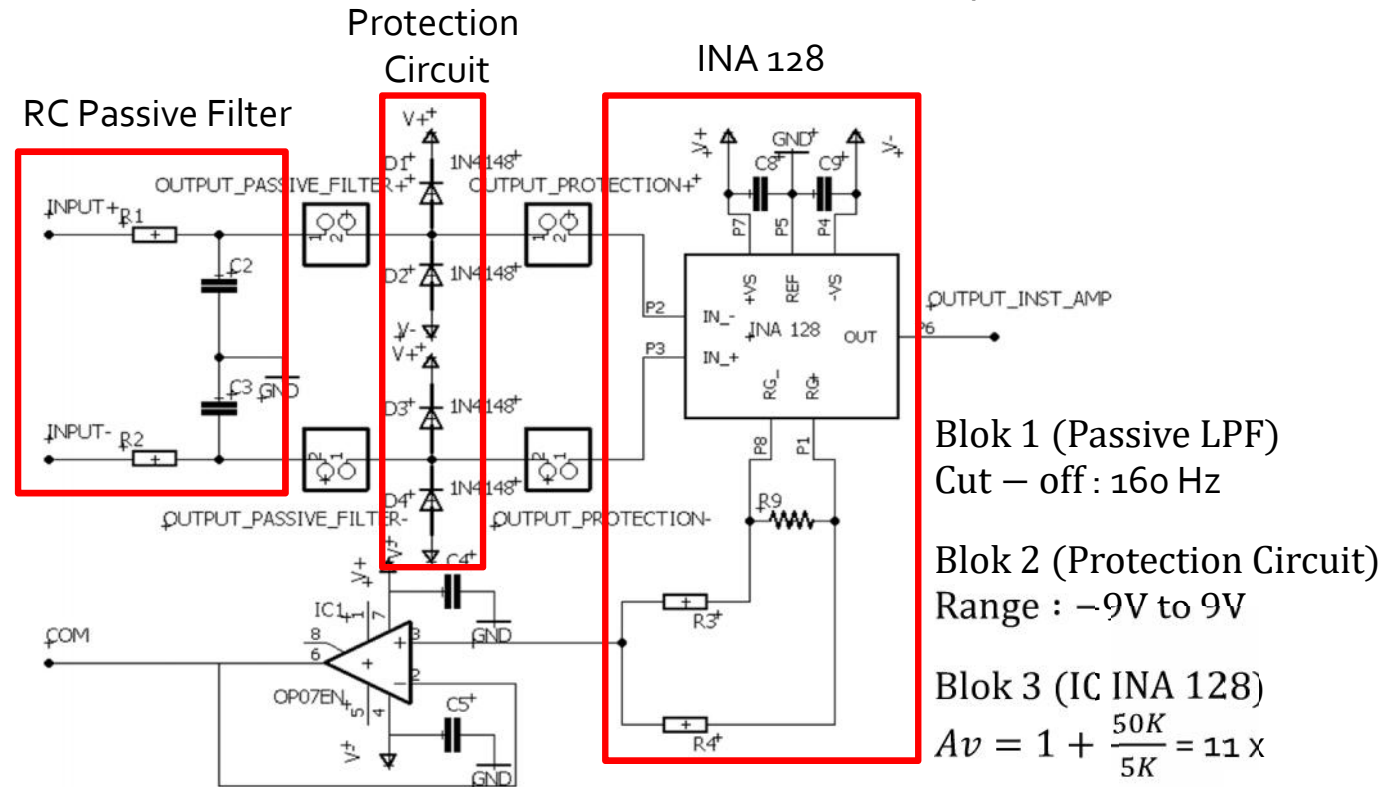
Perancangan Sistem

Diagram Blok Sistem Keseluruhan



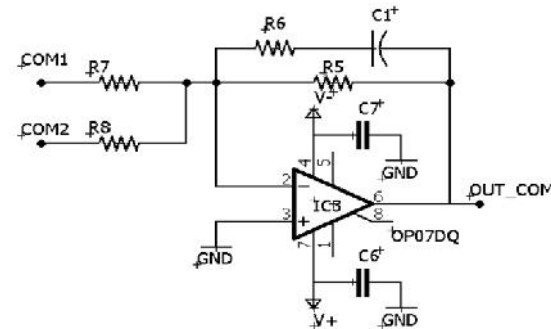
Perancangan Perangkat Keras

Passive Filter, Protection Circuit, Instrumentation Amplifier (INA 128)

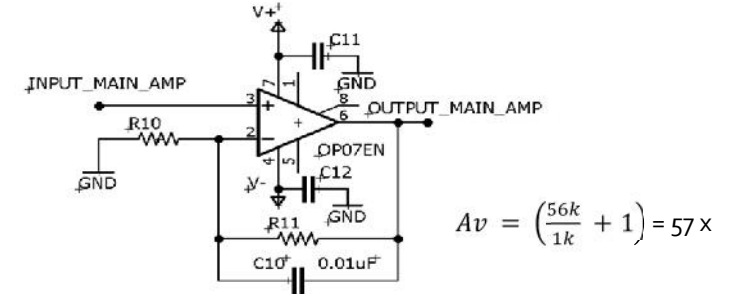


Perancangan Perangkat Keras

Common-Mode Rejection

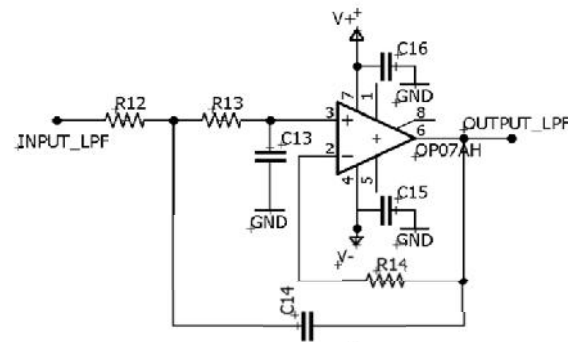


Non-Inverting Main Amplifier



$$A_v = \left(\frac{56k}{1k} + 1 \right) = 57 \times$$

Low Pass Filter -40 dB/dec

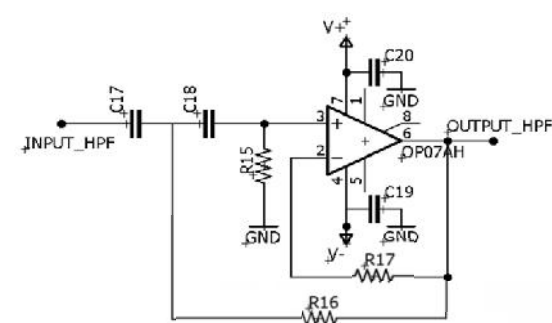


$$f_c = \frac{1}{2\pi\sqrt{C13 \times C14 \times R12 \times R13}}$$

$$70 \text{ Hz} = \frac{1}{2\pi\sqrt{330nF \times 330nF \times R \times R}}$$

$$R12 = R13 = R = 6.8k$$

High Pass Filter -40 dB/dec



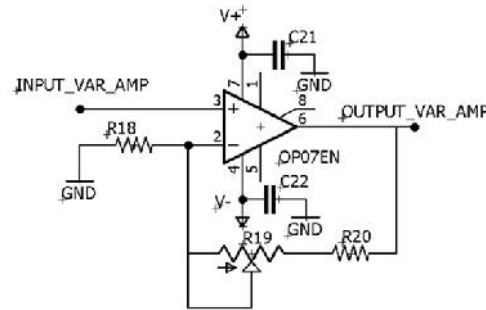
$$f_c = \frac{1}{2\pi\sqrt{C17 \times C18 \times R15 \times R16}}$$

$$0.23 \text{ Hz} = \frac{1}{2\pi\sqrt{100nF \times 100nF \times R \times R}}$$

$$R15 = R16 = R = 6.8M$$

Perancangan Perangkat Keras

Non-Inverting Variable Amplifier



$$V_o = \left(\frac{R19 + R20}{R18} + 1 \right) V_i$$

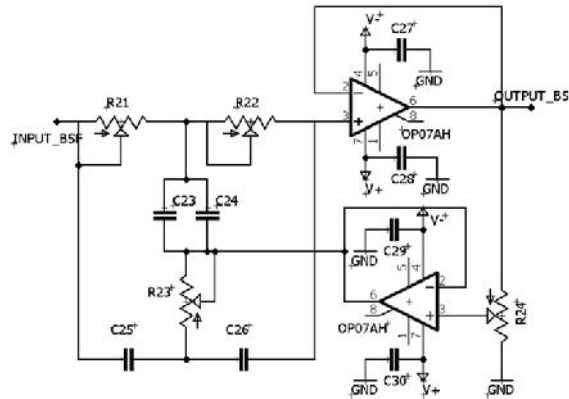
Penguatan dengan resistansi $R_f = R19$ minimum = 1k

$$G_{ai} \text{ minimum} = \left(\frac{1}{1} + 1 \right) = 2 \times$$

Penguatan dengan resistansi $R_f = R19$ minimum = 99k

$$G_{ai} \text{ maximum} = \left(\frac{99}{1} + 1 \right) = 100 \times$$

Notch Filter



$$f_o = \frac{1}{2\pi} \sqrt{\frac{\left(\frac{1}{C25} + \frac{1}{C26} \right)}{C23 \times C24 \times R21 \times R22}}$$

$$50\text{Hz} = \frac{1}{2\pi} \sqrt{\frac{\left(\frac{1}{100\text{nF}} + \frac{1}{100\text{nF}} \right)}{100\text{nF} \times 100\text{nF} \times R \times R}}$$

Sehingga, $R21 = R22 = R = 31.93\text{k}$

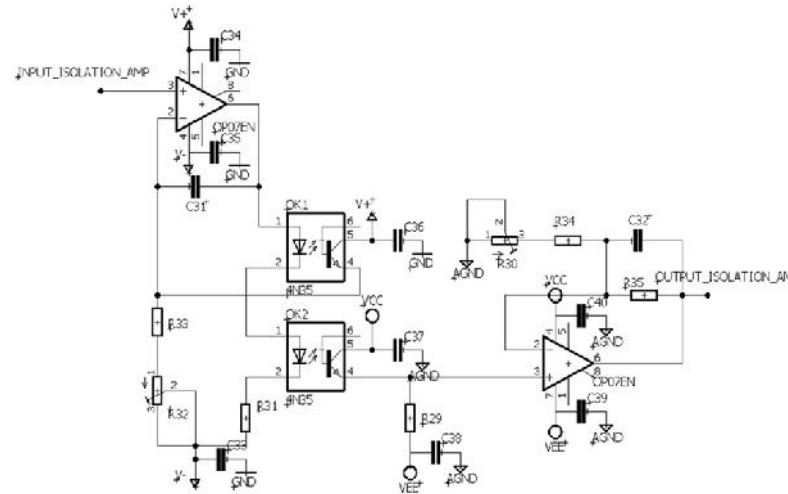
$$f_o = \frac{1}{2\pi} \sqrt{\frac{1}{C25 \times C26 \times R23 \times (R21 + R22)}}$$

$$50 = \frac{1}{2\pi} \sqrt{\frac{1}{100\text{nF} \times 100\text{nF} \times R23 \times (31.93\text{k} + 31.93\text{k})}}$$

Sehingga, $R23 = 15.91\text{k}$

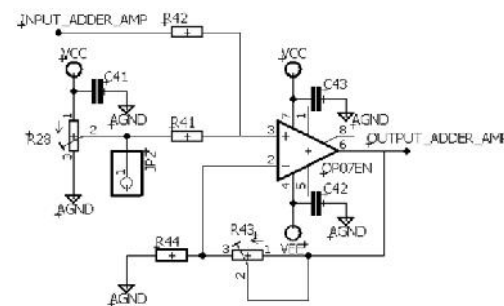
Perancangan Perangkat Keras

Isolation Amplifier



$$V_o = K \cdot \frac{R_{29}}{R_{32} + R_{33}} V_i$$

Non-Inverting Adder Amplifier



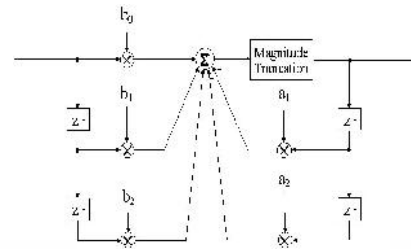
$$V_o = V_i + offset\ Voltage$$

Perancangan Perangkat Lunak

Digital Filter

$$r = 1 - \frac{BW \cdot \pi}{fs}$$

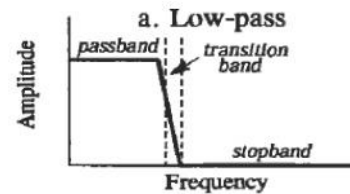
$$\theta = 2\pi \frac{fc}{fs}$$



$$y(n) = \sum_{k=0}^M b_k x(n-k) - \sum_{k=1}^N a_k y(n-k)$$

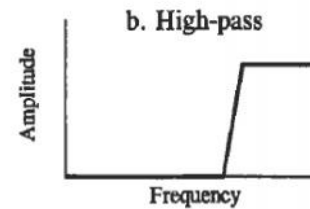
Low Pass Filter

$$H(z) = \frac{1 + 2z^{-1} + z^{-2}}{1 - 2r \cos \theta z^{-1} + r^2 z^{-2}}$$



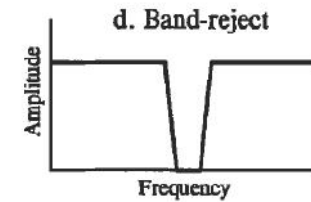
High Pass Filter

$$H(z) = \frac{1 - 2z^{-1} + z^{-2}}{1 - 2r \cos \theta z^{-1} + r^2 z^{-2}}$$



Notch Filter

$$H(z) = \frac{1 - 2 \cos \theta z^{-1} + z^{-2}}{1 + 2r \cos \theta z^{-1} + r^2 z^{-2}}$$



LPF 40 Hz

$$y[n] = x[n] + 2x[n-1] + x[n-2] + 0.5209 y[n-1] - 0.7105 y[n-2]$$

HPF 0.5 Hz

$$y[n] = x[n] - 2x[n-1] + x[n-2] - 1.991 y[n-1] - 0.9922 y[n-2]$$

Notch Filter 50 Hz

$$y[n] = x[n] + x[n-2] - 0.9688 y[n-2]$$

Perancangan Perangkat Lunak

Analisa Non-Stasioner

❑ Short Time Fourier Transform

$$STFT\{x(t)\}(\tau, \omega) \equiv X(\tau, \omega) = \int_{-\infty}^{\infty} x(t)w(t - \tau)e^{-j\omega\tau}dt$$

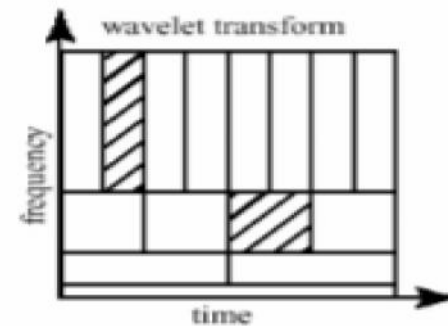
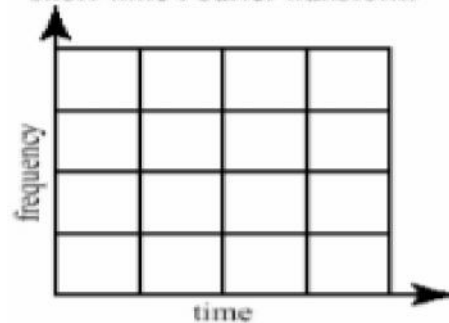
❑ Wavelet Transform

$$CWT_x(t, s) = y_x(t, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t) \cdot y^* \left(\frac{t - t}{s} \right) dt$$

$$y^*(t) = p^{-1/4} \cdot e^{-j\omega_0 t} \cdot e^{-t^2/2}$$

$$f_0 = 0.849$$

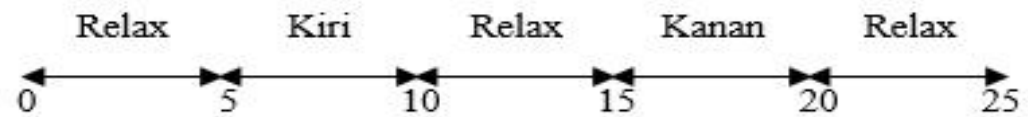
short-time Fourier transform



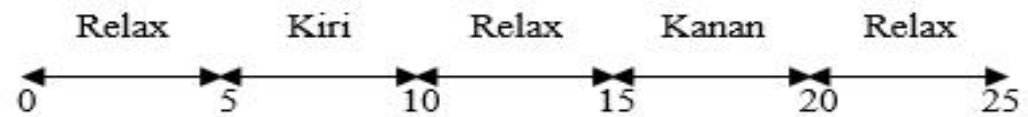
Perancangan Perangkat Lunak

Mode Tasking

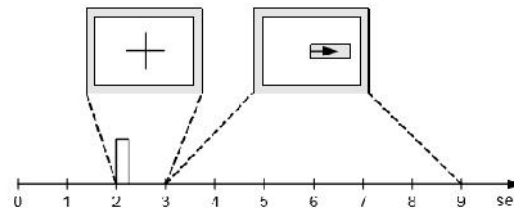
Mode 1 : Motor Execution



Mode 2 : Motor Imagery

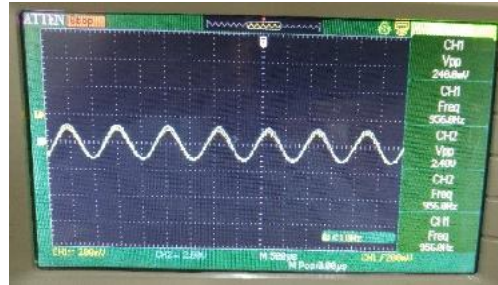


Mode 3 : Motor Imagery → Left-Right



Pengujian Perangkat Keras

- Instrumentation Amplifier

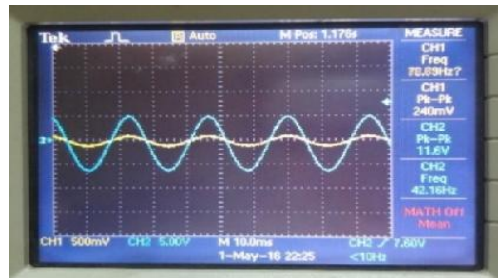


$$A_v = \frac{V_o}{V_i} = \frac{2480}{232} = 10.68966 \quad (\text{pengujian})$$

$$A_v = \frac{50K}{5K} + 1 = 11 \quad (\text{perhitungan})$$

Error : 2.8 %

- Non-Inverting Main Amplifier

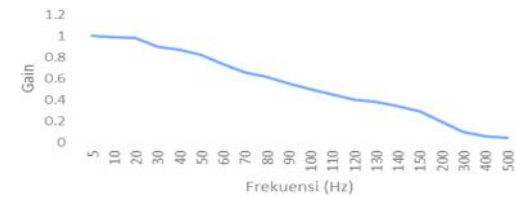


$$A_v = \frac{V_o}{V_i} = \frac{11600}{216} = 53.7037 \quad (\text{pengujian})$$

$$A_v = \frac{56K}{1K} + 1 = 57 \quad (\text{perhitungan})$$

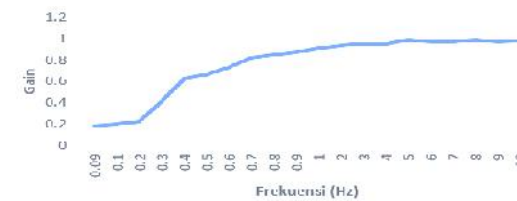
Error : 2.8 %

- Filter Analog



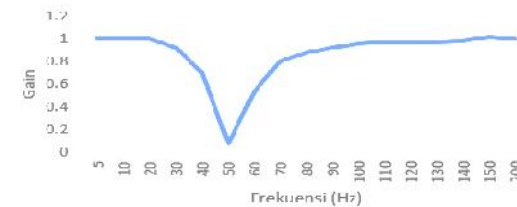
Cut-off Frequency LPF : 68 Hz

Error : 2 Hz



Cut-off Frequency HPF : 0.56 Hz

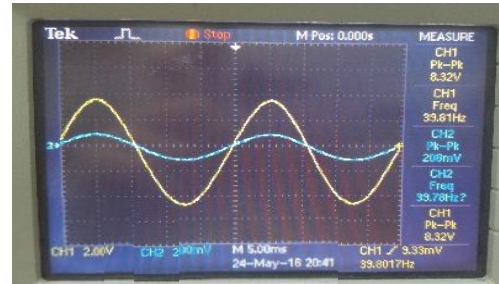
Error : 0.33 Hz



Resonance Frequency Notch Filter : 50 Hz

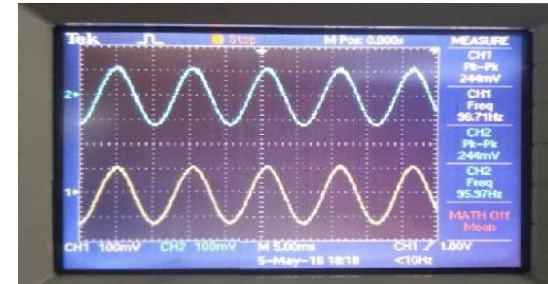
Pengujian Perangkat Keras

- Variable Amplifier



$$A_v = \frac{V_o}{V_i} = \frac{8320}{208} = 40 \quad (\text{pengujian})$$

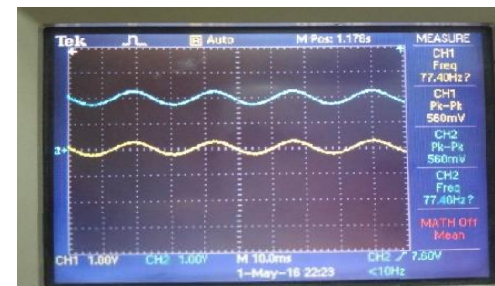
- Isolation Amplifier



$$V_o = V_i$$

$$A_v = 1$$

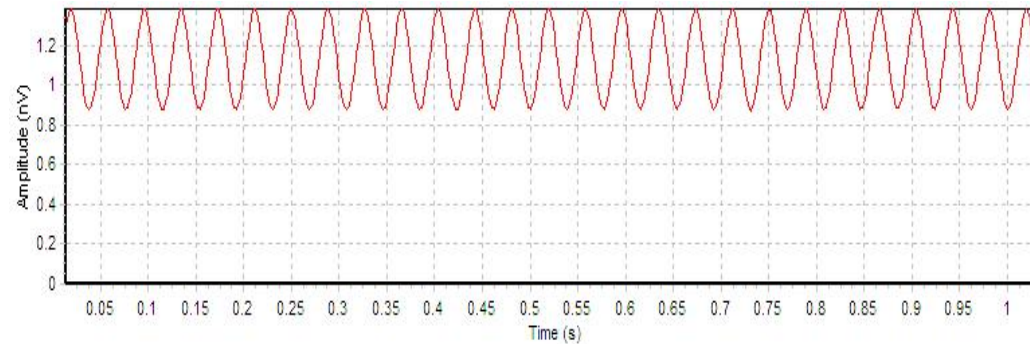
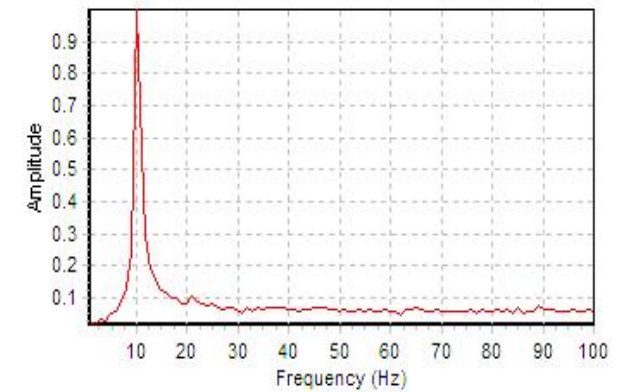
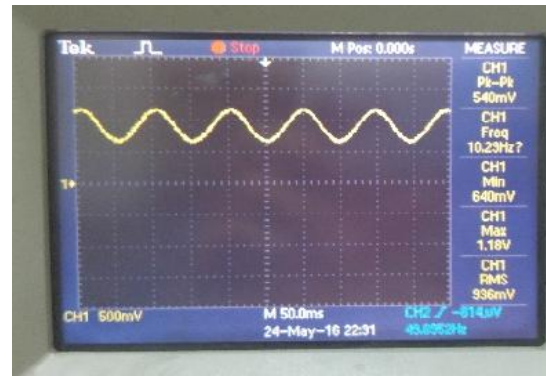
- Non-Inverting Adder Amplifier



$$V_o = V_i + 2 \text{ Volt}$$

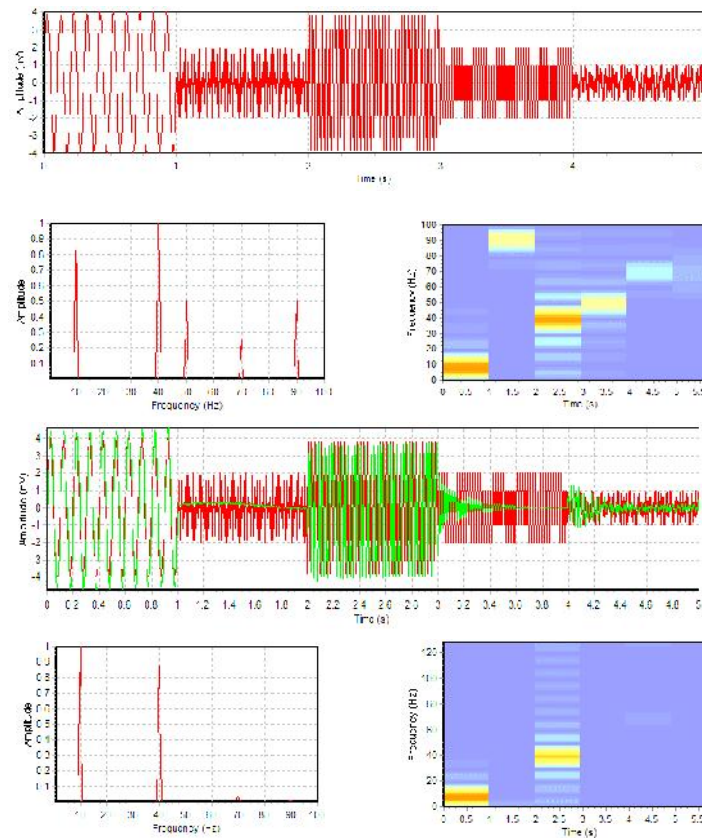
Pengujian Perangkat Lunak

Pengujian ADC + DFT



Pengujian Perangkat Lunak

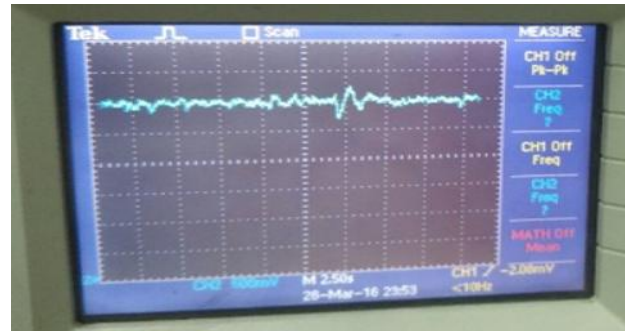
Pengujian Filter Digital + STFT



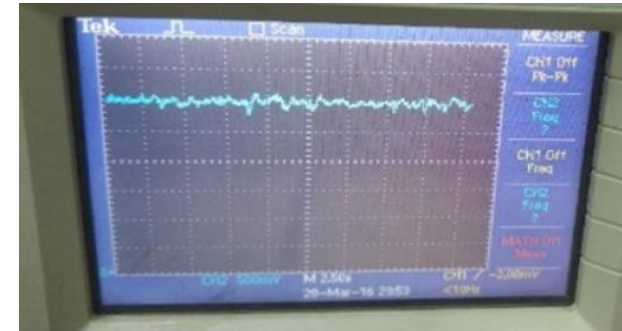
$$f(x) = \begin{cases} 4 * \sin\left(2 * \pi * j * \frac{10}{f_{\text{sampling}}}\right), & x < 200 \\ 2 * \sin\left(2 * \pi * j * \frac{90}{f_{\text{sampling}}}\right), & 200 \leq x < 400 \\ 4 * \sin\left(2 * \pi * j * \frac{40}{f_{\text{sampling}}}\right), & 400 \leq x < 600 \\ 2 * \sin\left(2 * \pi * j * \frac{50}{f_{\text{sampling}}}\right), & 600 \leq x < 800 \\ \sin\left(2 * \pi * j * \frac{70}{f_{\text{sampling}}}\right), & 800 \leq x < 1000 \end{cases}$$

Pengujian Sistem Secara Keseluruhan

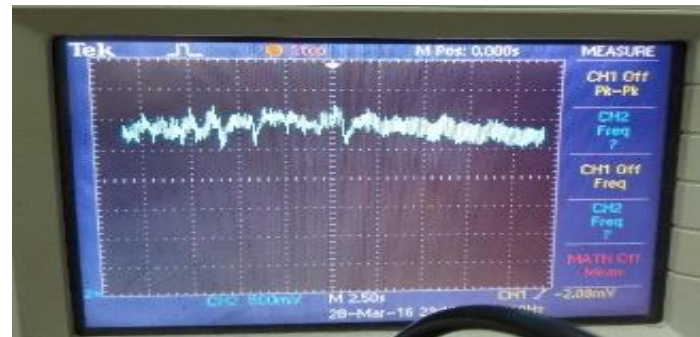
Pengujian Sistem secara keseluruhan pada scalp kepala



Titik C₃



Titik C₄



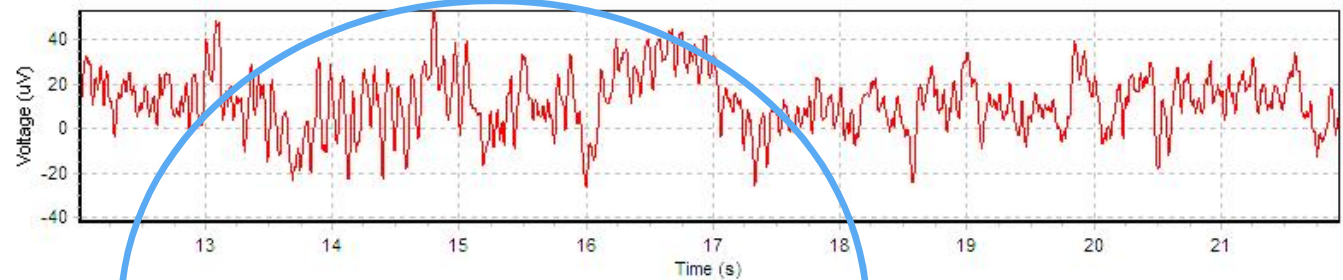
Titik FP₁

Pengujian Sistem Secara Keseluruhan

Pengujian Sistem secara keseluruhan pada scalp kepala

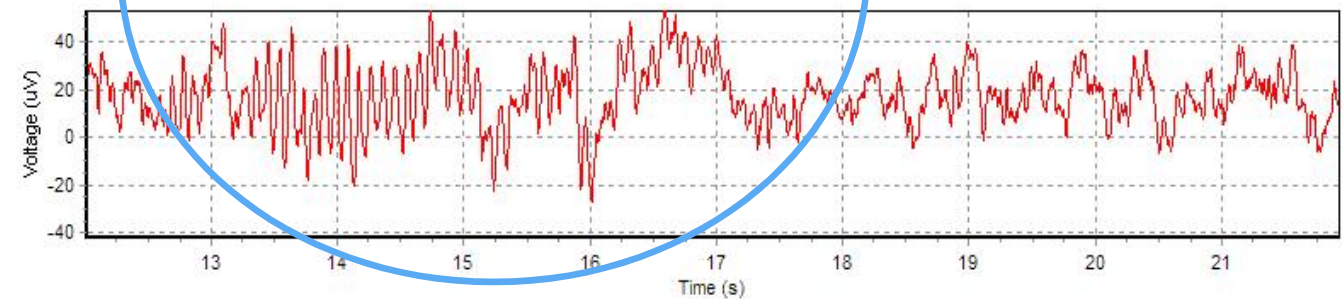
Data Subjek 2

C₃



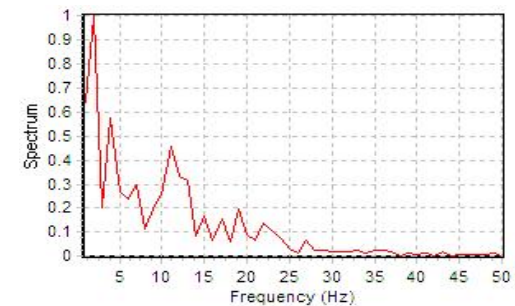
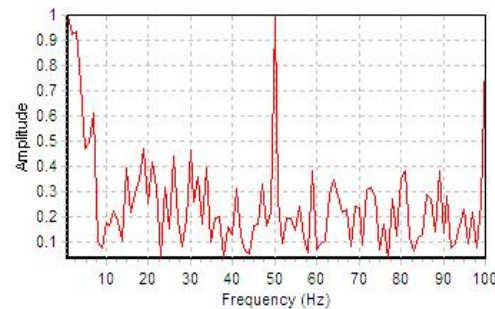
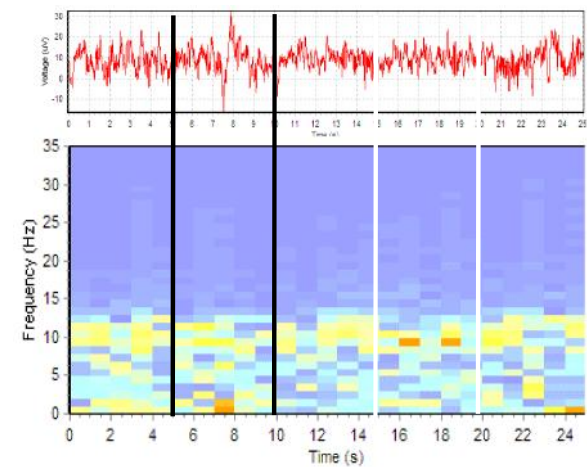
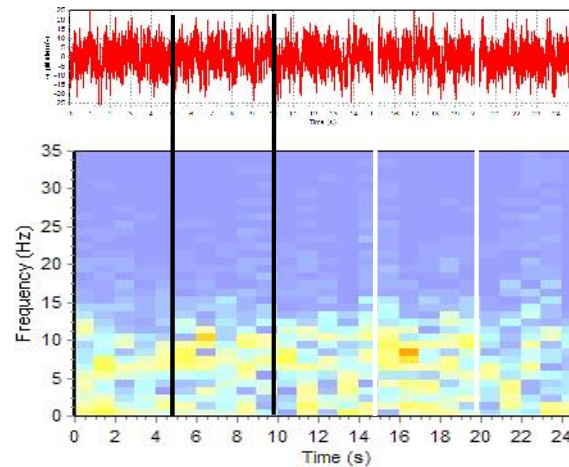
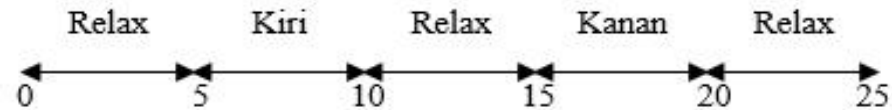
C₄

Menutup Mata



Perbandingan Sistem Rancangan dengan Enobio Neuroelectric 20

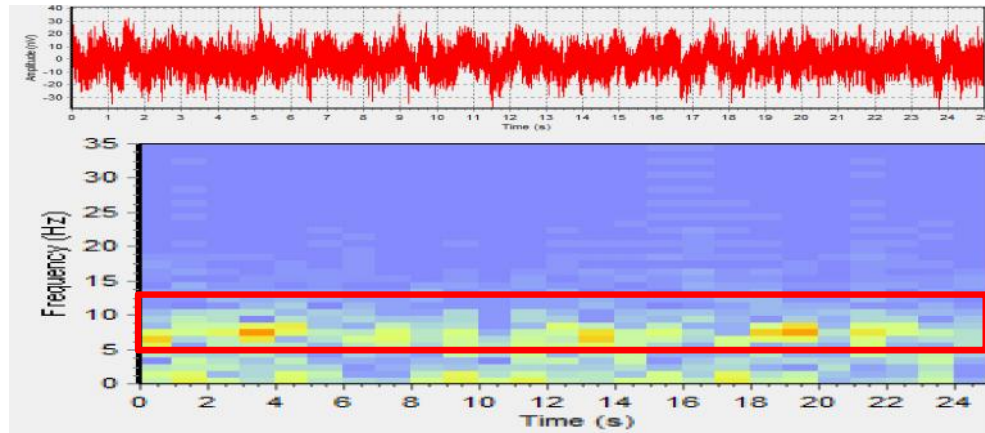
Data 20160505223753_patient_01_01_ima – 20160511_01_02_1



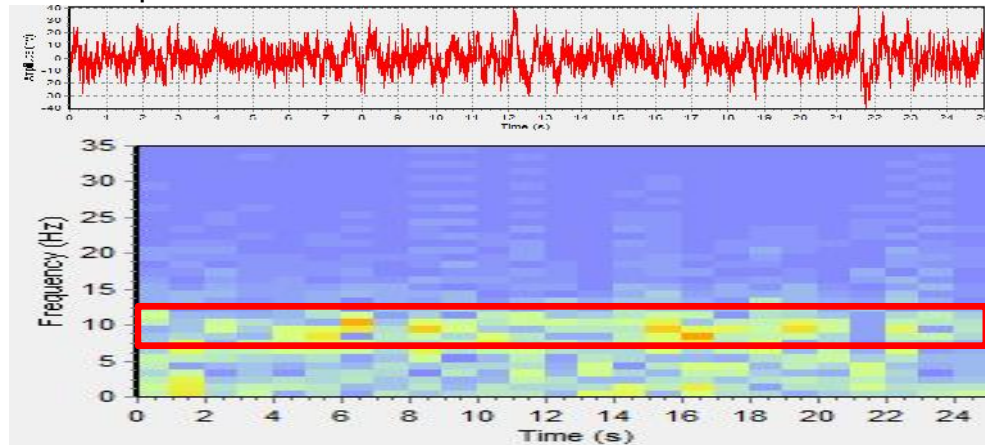
Pengujian Aktivitas Motorik pada Sistem EEG 10-20

Data 20160505223753_patient_01_01_ima

Titik CZ

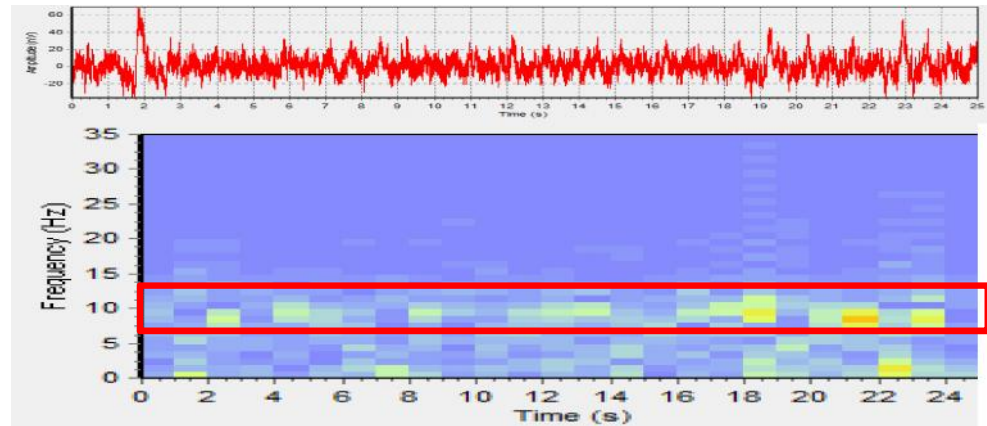


Titik C4

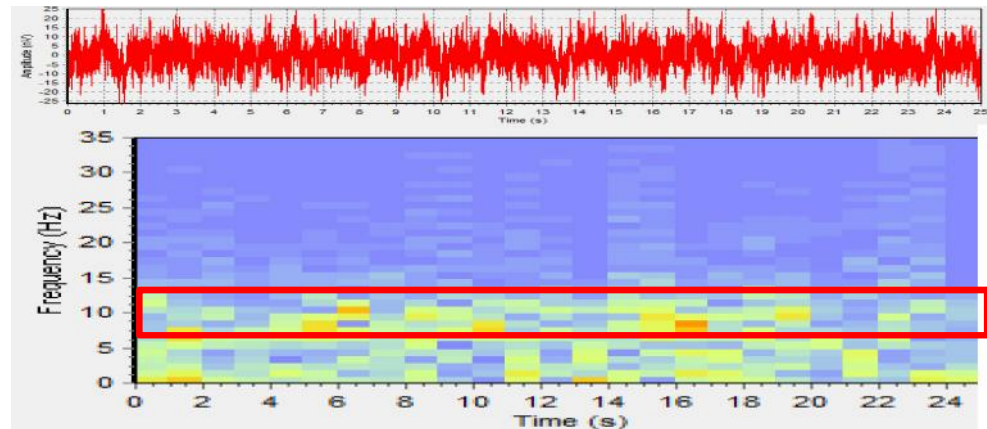


Pengujian Aktivitas Motorik pada Sistem EEG 10-20

Titik F₄

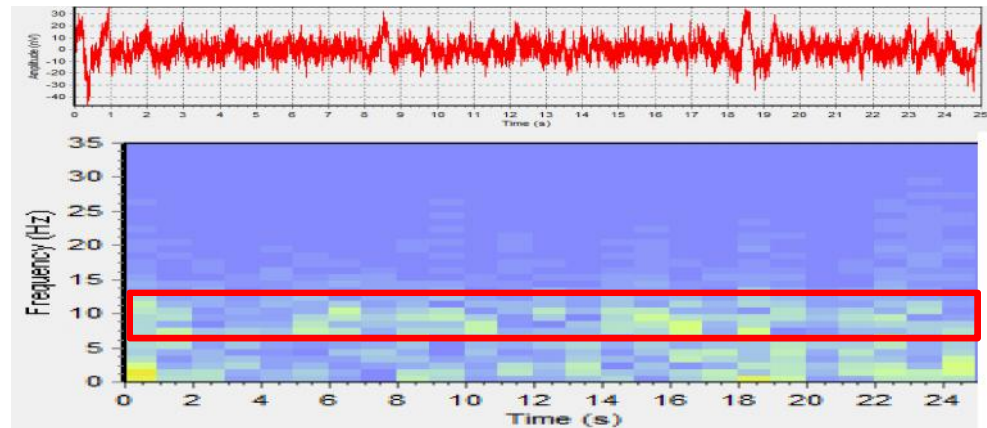


Titik C₃



Pengujian Aktivitas Motorik pada Sistem EEG 10-20

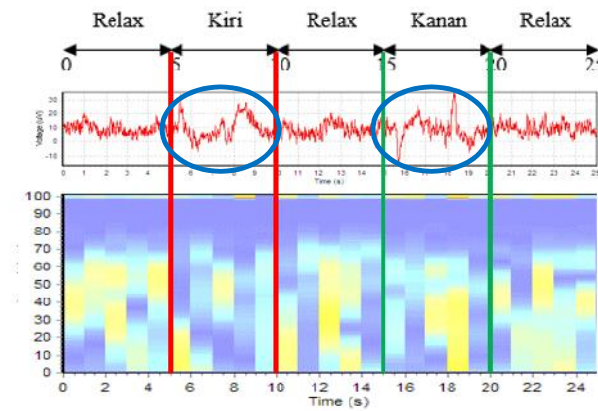
Titik F7



Perbandingan Motor Imagery dengan Motor Execution

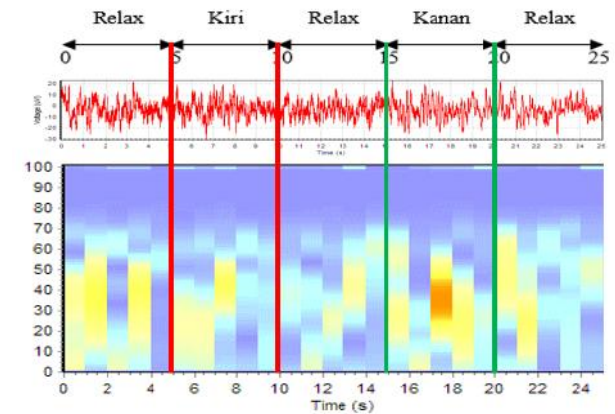
C₃

Motor Execution



Subjek	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-6.01556	19.36798	-12.3885	23.00386	-11.0369	26.92358
2	-54.201	43.39526	-36.8462	52.25306	-38.7858	46.73166
3	7.80016	46.62162	7.80018	50.36654	6.72538	51.1642
4	-6.90762	27.95082	-15.9334	34.39992	-10.2079	32.64914

Motor Imagery



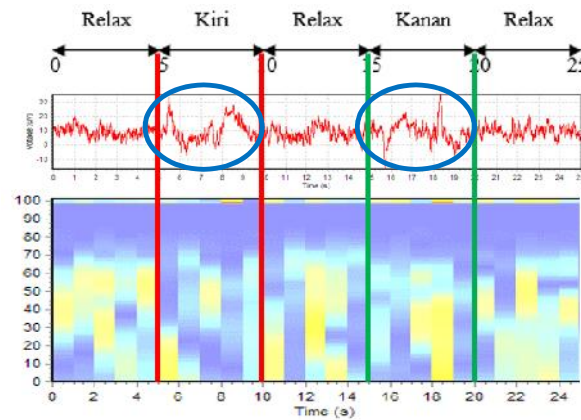
Subjek	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-22.0121	38.13534	-26.9928	37.29056	-30.1894	37.11486
2	-38.0896	39.0476	-17.713	38.0542	-37.778	42.1834
3	-11.188	36.7726	-17.407	35.8059	-13.7297	35.0962
4	-5.1099	28.3833	-6.0493	28.6672	-8.3471	26.2545

Data 20160511_01_02_1 – 20160425_01_01_1

Perbandingan Motor Imagery dengan Motor Execution

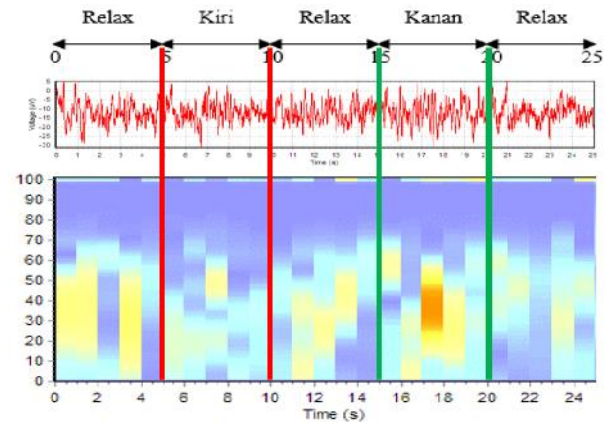
C₄

Motor Execution



Subjek	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-8.82018	12.27872	-10.5435	16.27952	-13.5779	19.8208
2	-43.8476	42.38658	-32.4399	50.5303	-41.1511	44.20688
3	9.6118	47.24352	6.2657	48.676	2.87228	52.87442
4	-13.9901	37.14186	-14.7437	37.74602	-12.0668	37.92177

Motor Imagery



Subjek	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-22.0121	38.13534	-26.9928	37.29056	-30.1894	37.11486
2	-38.0896	39.0476	-17.713	38.0542	-37.778	42.1834
3	-11.188	36.7726	-17.407	35.8059	-13.7297	35.0962
4	-5.1099	28.3833	-6.0493	28.6672	-8.3471	26.2545

Data 20160511_01_02_1 – 20160425_01_01_1

Perbandingan Motor Imagery dengan Motor Execution

MPF - Motor Execution

SUBJEK	C ₃			C ₄		
	Relax	Kiri	Kanan	Relax	Kiri	Kanan
1	10.21156	8.468124	8.63287	10.40595	8.72908	9.222418
2	10.3905	9.625	9.483756	10.8207	9.464238	8.91684
3	11.83598	11.05718	11.97562	11.73652	11.14063	11.13442
4	9.475	8.21608	7.75888	11.43036	11.36092	10.05508
5	10.52128	9.222514	8.74174	10.83578	8.8803	9.3376

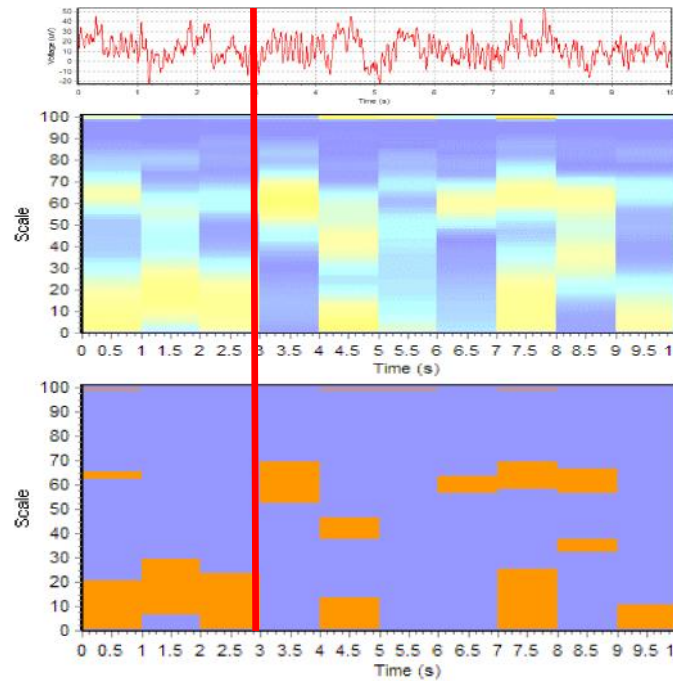
MPF - Motor Imagery

SUBJEK	C ₃			C ₄		
	Relax	Kiri	Kanan	Relax	Kiri	Kanan
1	8.2292	8.33359	8.262108	8.05758	8.72306	8.662992
2	8.86818	9.82048	8.7913032	8.510174	9.32964	8.90684
3	8.361224	8.51762	8.24702	9.43679	8.80332	9.37388
4	8.9414	9.1145	9.1859	11.0561	11.8845	11.1070
5	9.715072	9.792062	9.75642	9.96924	10.03424	10.271928

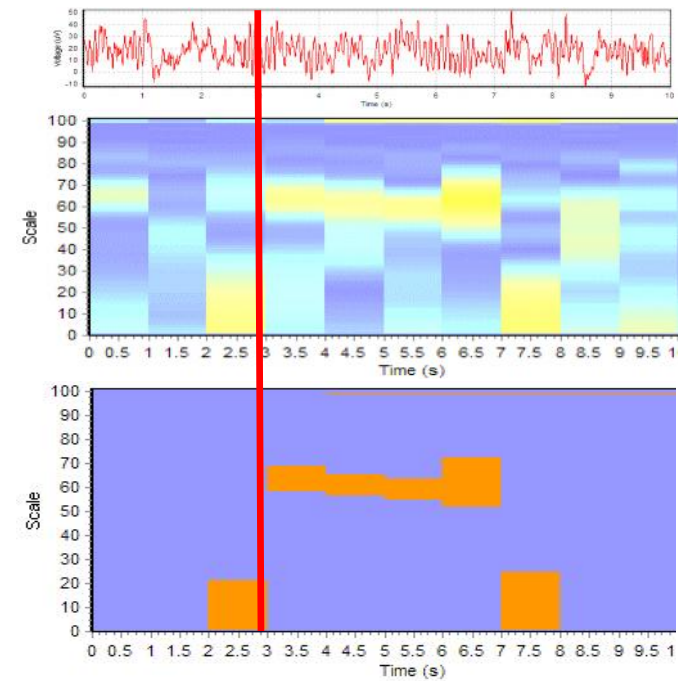
Ekstraksi Parameter Time- Frequency

Subjek 2 – Gerakan Kiri (Motor Imagery)

C₃



C₄

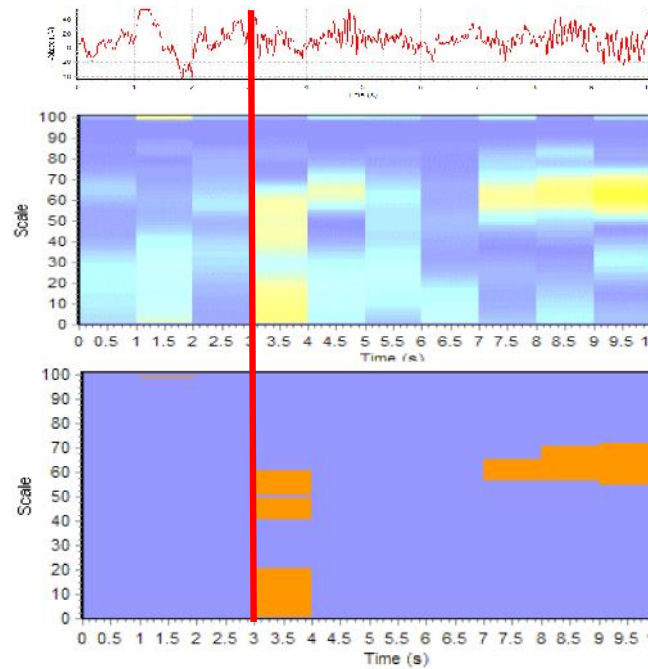


File : 20160604_02_02_02_10

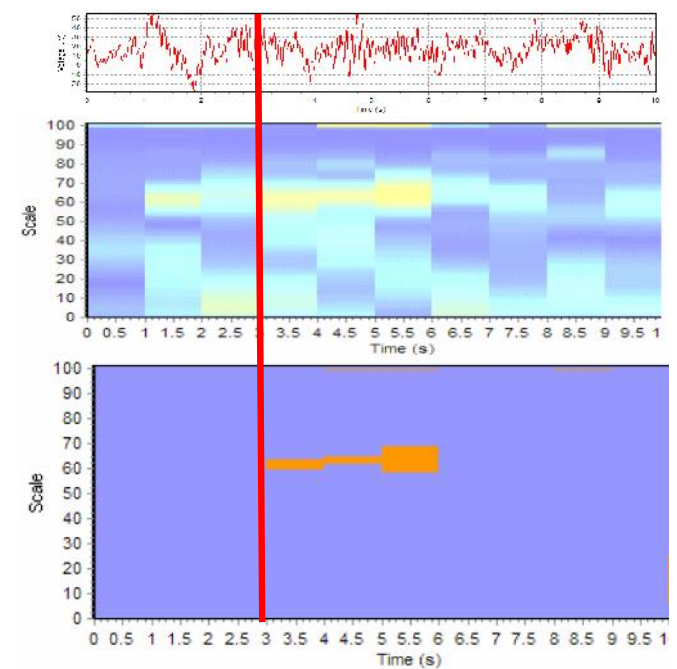
Ekstraksi Parameter Time- Frequency

Subjek 2 – Gerakan Kanan (Motor Imagery)

C₃



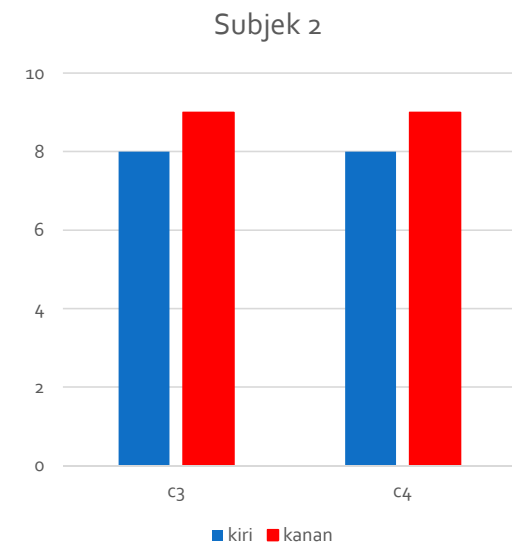
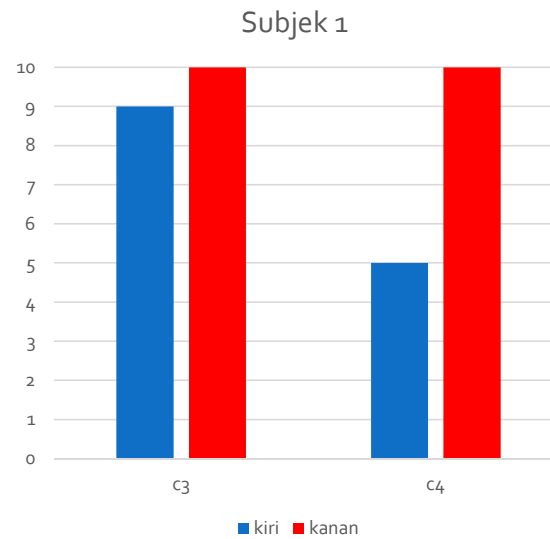
C₄



File : 20160604_02_02_02_10

Ekstraksi Parameter Time- Frequency

Kemunculan *Contour* pada detik ke 4-10



Kesimpulan

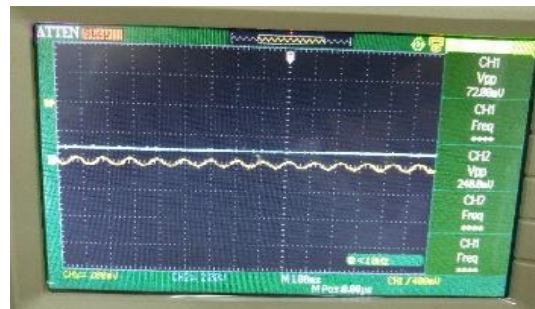
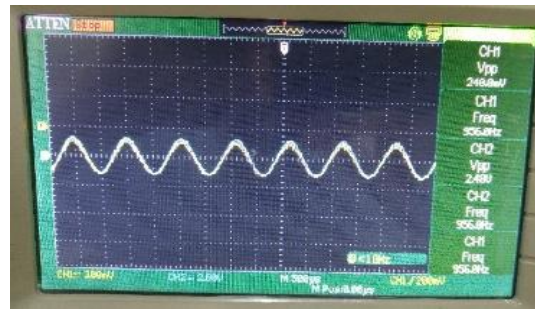
- Penguatan total pada rangkaian instrumenasi EEG sebesar 23842 kali terdiri atas 3 stage amplification, masing-masing 11 kali, 53.7 kali, dan 40 kali
- Frekuensi cut-off HPF 0.56 Hz dan LPF 68 Hz
- Frekuensi resonansi Notch Filter 50 Hz
- Tegangan offset pada non-inverting adder amplifier 2 Volt
- Hasil pengujian pada sistem EEG 10-20, menunjukkan titik-titik yang aktif saat terjadi aktivitas motoric adalah CZ, C3, C4, F4, dan F7

Kesimpulan

- Hasil pengujian *motor execution* pada *upper limb segment* menunjukkan peningkatan amplitude maksimum dan minimum sinyal. MPF pada 5 subjek mengalami penurunan. Power spectrum pada rentang frekuensi alfa (7-13 Hz) menurun
- Hasil pengujian *motor imagery* pada *upper limb segment* tidak menunjukkan perubahan signifikan pada amplitude maksimum dan minimum sinyal. MPF pada 5 subjek mengalami peningkatan. Power spectrum pada rentang frekuensi alfa (7-13 Hz) meningkat
- Hasil ekstraksi parameter *time-frequency* menunjukkan kemunculan *contour* saat terjadi *motor imagery* terjadi di kedua titik C₃ dan C₄

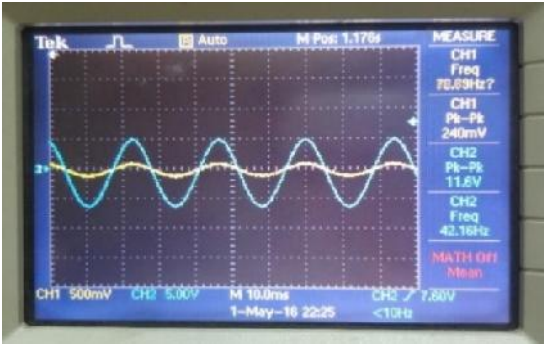
Terima Kasih

Pengujian Instrumentation Amplifier



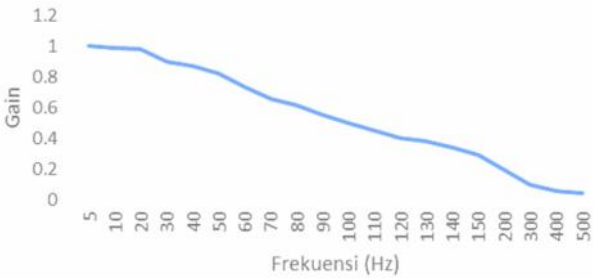
Frekuensi (Hz)	Vin p-p (mV)	VoutD (mV)	VoutC (mV)	Ad	Ac	CMRR
10	232	2480	82	10.68966	0.353448	29.61276
20	232	2480	82	10.68966	0.353448	29.61276
30	232	2480	82	10.68966	0.353448	29.61276
40	232	2480	82	10.68966	0.353448	29.61276
50	232	2480	82	10.68966	0.353448	29.61276
60	232	2480	82	10.68966	0.353448	29.61276
70	232	2480	82	10.68966	0.353448	29.61276
80	232	2480	82	10.68966	0.353448	29.61276
90	232	2480	82	10.68966	0.353448	29.61276
100	232	2480	82	10.68966	0.353448	29.61276
200	232	2480	82	10.68966	0.353448	29.61276
300	232	2480	82	10.68966	0.353448	29.61276
400	232	2480	82	10.68966	0.353448	29.61276
500	232	2480	82	10.68966	0.353448	29.61276
1000	232	2480	82	10.68966	0.353448	29.61276
5000	232	2480	82	10.68966	0.353448	29.61276
10000	232	2480	82	10.68966	0.353448	29.61276
20000	232	2480	82	10.68966	0.353448	29.61276
50000	232	2480	82	10.68966	0.353448	29.61276
100000	232	2480	82	10.68966	0.353448	29.61276

Pengujian Main Amplifier



Frekuensi (Hz)	Vin p-p (mV)	Vout p-p (mV)	RG (k ohm)	Gain (Vout/Vin)	Gain Calculation
1	216	11600	56	53.7037037	57
5	216	11600	56	53.7037037	57
10	216	11600	56	53.7037037	57
20	216	11600	56	53.7037037	57
30	216	11600	56	53.7037037	57
40	216	11600	56	53.7037037	57
50	216	11600	56	53.7037037	57
60	216	11600	56	53.7037037	57
70	216	11600	56	53.7037037	57
80	216	11600	56	53.7037037	57
90	216	11600	56	53.7037037	57
100	216	11600	56	53.7037037	57

Pengujian Low Pass Filter



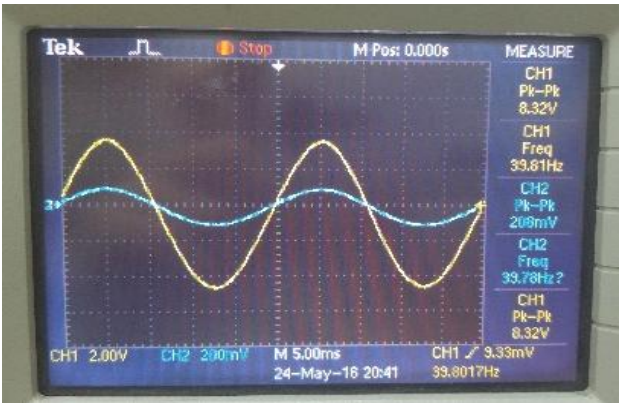
Frekuensi (Hz)	Vin p-p (mV)	Vin rms (mV)	Vout p-p (mV)	Vout rms (mV)	Gain
5	5000	1720	5040	1720	1.008
10	5040	1640	5000	1720	0.992063492
20	4960	1640	4880	1600	0.983870968
30	5040	1710	4560	1580	0.904761905
40	5040	1720	4400	1500	0.873015873
50	4960	1760	4080	1390	0.822580645
60	5120	1780	3760	1260	0.734375
70	5120	1690	3360	1140	0.65625
80	5040	1720	3120	1020	0.619047619
90	5040	1680	2800	930	0.555555556
100	4960	1680	2480	826	0.5
110	4960	1670	2240	726	0.451612903
120	4960	1730	2000	650	0.403225806
130	5040	1660	1920	632	0.380952381
140	4960	1650	1680	552	0.338709677
150	4880	1680	1420	498	0.290983607
200	4960	1680	980	363	0.197580645
300	4960	1670	480	189	0.096774194
400	4880	1660	280	133	0.057377049
500	4880	1660	200	122	0.040983607

Pengujian High Pass Filter



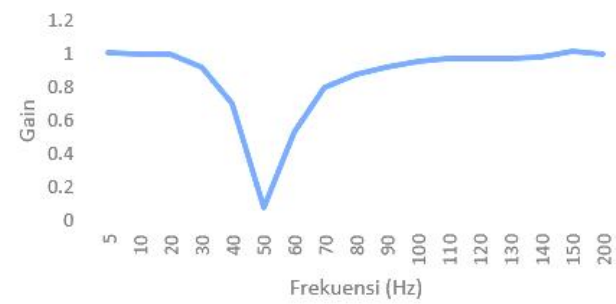
Frekuensi (Hz)	Vin p-p (mV)	Vin rms (mV)	Vout p-p (mV)	Vout rms (mV)	Gain
0.09	4880	1660	880	283	0.180328
0.1	4880	1660	960	320	0.196721
0.2	4960	1670	1120	365	0.225806
0.3	4960	1680	2000	677	0.403226
0.4	4880	1680	3040	1060	0.622951
0.5	4960	1650	3280	1110	0.66129
0.6	5040	1660	3680	1290	0.730159
0.7	4960	1730	4080	1400	0.822581
0.8	4960	1670	4200	1440	0.846774
0.9	4960	1680	4320	1520	0.870968
1	5040	1680	4560	1580	0.904762
2	5040	1720	4720	1620	0.936508
3	5120	1690	4880	1660	0.953125
4	5120	1780	4880	1700	0.953125
5	4960	1760	4880	1700	0.983871
6	5040	1720	4880	1700	0.968254
7	5040	1710	4880	1670	0.968254
8	4960	1640	4880	1660	0.983871
9	5040	1640	4880	1700	0.968254
10	5000	1720	4880	1700	0.976

Pengujian Variable Amplifier



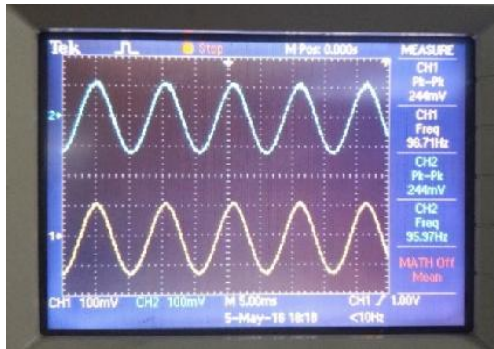
Frekuensi (Hz)	Vin p-p (mV)	Vout p-p (mV)	Gain (Vout/Vin)	Gain Calculation
1	208	8320	40	40
5	208	8320	40	40
10	208	8320	40	40
20	208	8320	40	40
30	208	8320	40	40
40	208	8320	40	40
50	208	8320	40	40
60	208	8320	40	40
70	208	8320	40	40
80	208	8320	40	40
90	208	8320	40	40
100	208	8320	40	40

Pengujian Notch Filter



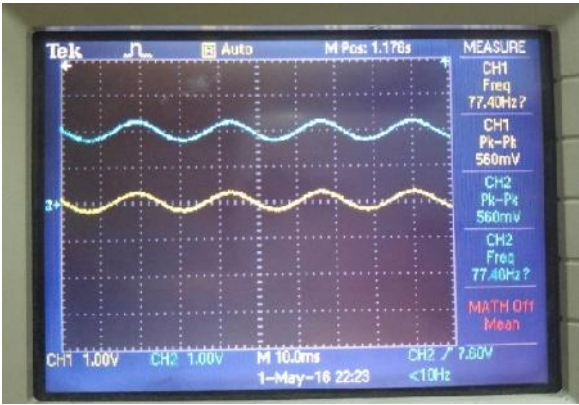
Frekuensi (Hz)	Vin p-p (mV)	Vin rms (mV)	Vout p-p (mV)	Vout rms (mV)	Gain
5	5000	1720	5040	1720	1.008
10	5040	1640	5040	1700	1
20	4960	1640	4960	1660	1
30	5040	1710	4640	1600	0.920634921
40	5040	1720	3520	1170	0.698412698
50	4960	1760	400	100	0.080645161
60	5120	1780	2720	922	0.53125
70	5120	1690	4080	1410	0.796875
80	5040	1720	4400	1510	0.873015873
90	5040	1680	4640	1600	0.920634921
100	4960	1680	4720	1640	0.951612903
110	4960	1670	4800	1660	0.967741935
120	4960	1730	4800	1660	0.967741935
130	5040	1660	4880	1720	0.968253968
140	4960	1650	4880	1720	0.983870968
150	4880	1680	4960	1720	1.016393443
200	4960	1680	4960	1720	1

Pengujian Isolation Amplifier



Vin p-p(mV)	Frekuensi (Hz)	Vout p-p (mV)	Error (mV)	Error (%)
244	1	244	0	0
244	5	244	0	0
244	10	244	0	0
244	20	244	0	0
244	30	240	-4	1.666666667
244	40	244	0	0
244	50	240	-4	1.666666667
244	60	244	0	0
244	70	244	0	0
244	80	244	0	0
244	90	244	0	0
244	100	244	0	0
4080	1	4064	20	0.492125984
4080	5	4080	0	0
4080	10	4080	0	0
4080	20	4080	0	0
4080	30	4080	0	0
4080	40	4080	0	0
4080	50	4060	20	0.492610837
4080	60	4080	0	0
4080	70	4080	0	0
4080	80	4080	0	0
4080	90	4080	0	0
4080	100	4080	0	0

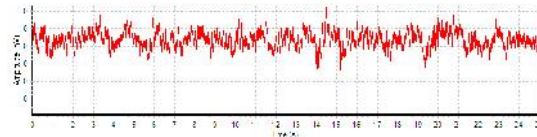
Pengujian Adder Amplifier



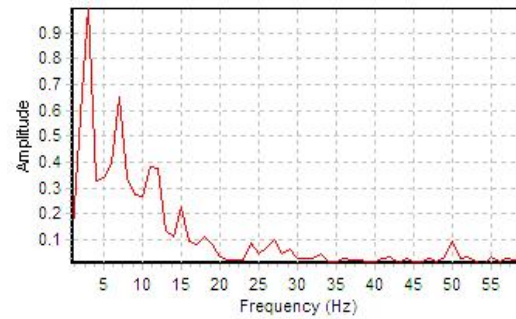
Vin p-p (mV)	Frekuensi (Hz)	Vout p-p (mV)	Error (mV)	Error (%)
560	1	560	0	0
560	5	560	0	0
560	10	560	0	0
560	20	564	4	0.709219858
560	30	560	0	0
560	40	560	0	0
560	50	560	0	0
560	60	560	0	0
560	70	560	0	0
560	80	560	0	0
560	90	560	0	0
560	100	560	0	0
1080	1	1080	0	0
1080	5	1080	0	0
1080	10	1088	8	0.735294118
1080	20	1080	0	0
1080	30	1080	0	0
1080	40	1080	0	0
1080	50	1080	0	0
1080	60	1080	0	0
1080	70	1080	0	0
1080	80	1088	8	0.735294118
1080	90	1080	0	0
1080	100	1080	0	0

Pengujian Filter Digital pada Sinyal EEG

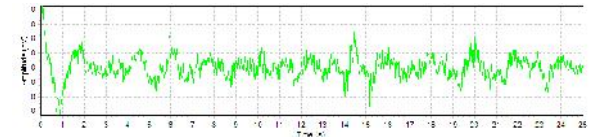
Sinyal Asli



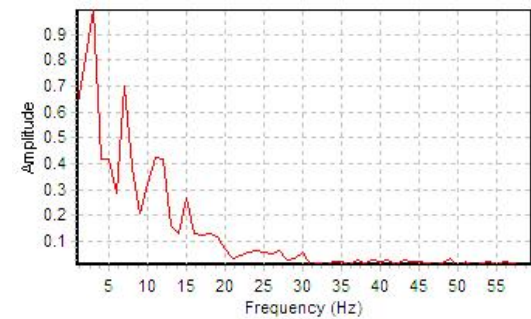
Hasil DFT



Sinyal Terfilter



Hasil DFT



Data Subjek

No	Indeks Subjek	Nama Subjek	Usia	Parameter Ukuran Kepala				
				Nasion-Inion	Telinga-Telinga	10% N-I	10% T-T	CZ-Nasion
1	1	Johan	21	34	34	3.4	3.4	17
2	2	Fathan	20	30	32	3	3.2	15
3	3	Stanley	21	34	34	3.4	3.4	17
4	4	Daniel	22	32	32	3.2	3.2	16
5	5	Ali	22	34	32	3.4	3.2	16

Data Subjek 1 Motor Execution

Sesi	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-4.0016	21.9158	-8.9351	24.5515	-7.7524	31.0393
2	-3.5286	17.8271	-5.3533	21.882	-9.5095	30.8028
3	-4.1368	22.2199	-13.2265	22.2537	-14.7133	25.43
4	-10.3205	17.05	-14.2402	21.5441	-9.9488	23.4026
5	-8.0903	17.8271	-20.1874	24.788	-13.2603	23.9432
Mean	-6.01556	19.36798	-12.3885	23.00386	-11.0369	26.92358

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-9.0364	15.7659	-10.7598	13.8736	-8.3944	15.3942
2	-8.1579	13.6371	-6.2318	14.6846	-12.179	23.5378
3	-4.5761	14.1102	-7.9889	22.7606	-12.821	23.7067
4	-11.368	9.6836	-13.3279	16.4417	-18.8019	14.4481
5	-10.9625	8.1968	-14.4092	13.6371	-15.6932	22.0172
Mean	-8.82018	12.27872	-10.5435	16.27952	-13.5779	19.8208

Data Subjek 1 Motor Imagery

Sesi	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-17.9234	35.3307	-25.9994	30.8028	-44.8883	54.49
2	-20.0184	39.7235	-18.5654	46.4816	-33.7036	39.7235
3	-22.6541	36.9527	-27.1144	28.4374	-23.2623	27.1196
4	-22.7892	33.5736	-26.8779	29.6539	-25.6952	36.4458
5	-26.6752	45.0962	-36.4069	51.0771	-23.3975	27.7954
mean	-22.0121	38.13534	-26.9928	37.29056	-30.1894	37.11486

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-18.2275	29.958	-21.37	28.4712	-24.8843	28.8429
2	-15.3891	25.7342	-17.0786	39.2166	-21.9783	33.1005
3	-18.9709	32.864	-19.2074	26.3762	-18.9709	19.6856
4	-20.6604	32.222	-31.4059	20.5642	-22.1134	30.9041
5	-19.7143	36.6147	-23.0258	28.4712	-18.2275	17.692
mean	-18.5924	31.4785	-22.4174	28.6198	-21.2348	26.045

Data Subjek 2 Motor Execution

Sesi	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-34.5146	40.3993	-33.0954	54.49	-30.6963	40.9737
2	-71.6843	44.9272	-34.2105	48.5428	-26.5062	45.1638
3	-26.9455	37.7298	-38.1302	49.2525	-83.8828	54.49
4	-65.1289	49.49	-27.1482	54.49	-21.539	39.96
5	-72.7318	44.43	-51.6465	54.49	-31.3045	53.0708
Mean	-54.201	43.39526	-36.8462	52.25306	-38.7858	46.73166

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-18.3289	40.2641	-25.5263	52.1585	-41.5431	48.4077
2	-60.5334	37.4595	-38.2992	43.5418	-24.445	44.4542
3	-23.3299	45.7044	-24.1071	54.29	-83.8828	53.49
4	-46.24	44.0149	-25.3911	54.49	-31.1693	32.5261
5	-70.8058	44.49	-48.8756	48.1712	-24.7153	42.1564
Mean	-43.8476	42.38658	-32.4399	50.5303	-41.1511	44.20688

Data Subjek 2 Motor Imagery

Sesi	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-19.275	37.3581	-17.2138	46.7857	-29.2433	41.8523
2	-23.4313	33.5736	-15.7608	38.6084	-26.9455	33.4046
3	-34.6836	34.317	-15.5243	37.2568	-49.0446	49.0835
4	-78.0032	51.3813	-18.0923	31.3096	-42.6244	43.0012
5	-35.0553	38.6084	-21.9783	36.3106	-41.0362	43.5756
mean	-38.0896	39.0476	-17.713	38.0542	-37.778	42.1834

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-16.4366	33.7763	-16.2001	31.4448	-14.8822	30.1945
2	-17.9572	28.3698	-15.6256	35.2293	-18.2275	25.7342
3	-39.448	22.3551	-13.9699	35.4659	-25.5263	28.9781
4	-68.4742	43.4067	-14.9498	25.0921	-35.4945	23.6729
5	-28.3985	27.0858	-16.5718	23.8757	-23.3637	34.2494
mean	-34.1429	30.9987	-15.4634	30.2215	-23.4988	28.5658

Data Subjek 3 Motor Execution

Sesi	C ₃					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	9.0305	39.9227	2.1355	46.4121	8.4897	49.4202
2	6.6307	41.4436	7.2729	43.3702	4.9408	54.5238
3	0.7835	51.9213	11.802	53.7464	10.45	42.8294
4	16.0944	52.0227	9.5712	53.7802	2.7777	54.5238
5	6.4617	47.7978	8.2193	54.5238	6.9687	54.5238
Mean	7.80016	46.62162	7.80018	50.36654	6.72538	51.1642

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	9.605	42.1196	7.5433	45.8375	0.5131	52.8339
2	10.788	39.0777	10.957	39.3481	-7.6324	54.5238
3	8.5573	52.2593	4.907	52.1241	11.7344	47.9668
4	7.4081	51.5495	11.0246	53.138	-0.1291	54.5238
5	11.7006	51.2115	-3.1034	52.9352	9.8754	54.5238
Mean	9.6118	47.24352	6.2657	48.676	2.87228	52.87442

Data Subjek 3 Motor Imagery

Sesi	C3					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	11.5654	48.4738	4.6366	47.764	13.5933	43.3702
2	-15.6428	27.9916	-13.7162	23.4626	-4.2863	27.4847
3	-9.4576	25.7271	-10.9447	22.043	-6.2129	22.6852
4	-24.6333	44.9249	-43.2227	54.5238	-63.2992	54.5238
5	-17.7721	36.7456	-23.7883	31.2363	-8.4436	27.4171
mean	-11.188	36.7726	-17.407	35.8059	-13.7297	35.0962

Sesi	C4					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	12.2414	41.2408	4.1296	44.2489	13.9651	39.9227
2	-5.1651	20.0151	-7.0578	17.9872	-5.9425	17.6492
3	-8.4774	25.8623	-4.5905	22.4486	-11.7559	30.29
4	-13.3782	26.5383	-22.6729	37.5905	-40.7891	50.1637
5	-4.9285	24.8821	-20.307	24.1386	-9.9307	23.6654
mean	-3.9415	27.7077	-10.0997	29.2827	-10.8906	32.3382

Data Subjek 4 Motor Execution

Sesi	C ₃					
	Relax		Relax		Relax	
	Min	Min	Min	Min	Min	Min
1	-1.4335	27.8292	-25.2754	40.05786	-6.95643	33.09528
2	-5.2857	26.0045	-13.6824	31.67573	-6.14526	33.80506
3	-12.0438	27.5926	-17.9749	30.66176	-14.3922	33.53467
4	-11.9762	27.2885	-11.4517	37.96233	-14.1894	32.7573
5	-3.7989	31.0393	-11.2827	31.64193	-9.35615	30.05338
Mean	-6.90762	27.95082	-15.9334	34.39992	-10.2079	32.64914

Sesi	C ₄					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-9.2392	36.4796	-14.2232	38.8749	-12.4657	36.81317
2	-13.0237	32.4923	-11.2151	33.06149	-10.3025	32.82489
3	-9.0702	32.6274	-14.764	34.34584	-11.7559	41.27462
4	-22.1472	42.3929	-19.2254	37.55674	-10.7081	39.78747
5	-16.4704	41.7171	-14.2908	44.89111	-15.102	38.9087
Mean	-13.9901	37.14186	-14.7437	37.74602	-12.0668	37.92177

Data Subjek 4 Motor Imagery

Sesi	C3					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-3.2582	26.2072	-4.5085	32.1206	-9.0702	25.7342
2	-8.5296	27.1534	-5.2181	28.2347	-9.6447	24.2474
3	-3.292	28.336	-4.4409	26.2072	-4.2044	26.9844
4	-7.3131	29.8228	-7.651	27.8968	-15.085	28.336
5	-3.1569	30.3973	-8.4282	28.8767	-3.7313	25.9707
mean	-5.1099	28.3833	-6.0493	28.6672	-8.3471	26.2545

Sesi	C4					
	Relax		Kiri		Kanan	
	Min	Max	Min	Max	Min	Max
1	-16.6731	47.0561	-20.9983	40.0276	-14.274	40.0276
2	-11.199	44.6907	-17.5517	33.7425	-12.7534	35.9727
3	-28.9729	45.4341	-20.7618	46.583	-18.1261	45.5693
4	-26.4386	54.49	-23.7354	48.678	-31.7438	52.5977
5	-30.2232	51.584	-30.8314	49.489	-26.8103	51.4151
mean	-22.7013	48.6509	-22.7757	43.704	-20.7415	45.1164

Data Subjek 5 Motor Execution

Sesi	c3					
	relax		kiri		kanan	
	min	max	min	max	min	max
1	-2.5148	23.6391	-3.6637	30.6676	-2.4811	25.3287
2	-3.0555	26.0045	-9.8136	32.9316	-8.6985	27.1196
3	-2.9203	27.8292	-30.7976	39.1153	-16.5718	36.5472
4	-22.2824	40.5007	-15.8959	37.8988	-23.8705	51.4826
5	-4.103	29.5863	-4.103	34.8576	-13.7671	40.129
mean	-6.9752	29.51196	-12.8548	35.09418	-13.0778	36.12142

Sesi	c4					
	relax		kiri		kanan	
	min	max	min	max	min	max
1	-1.4673	30.4311	-0.9605	32.4923	-6.8738	36.6147
2	-3.292	33.8439	-5.1843	32.7288	-4.6437	37.8312
3	-4.5423	35.8714	-5.7925	54.49	-6.367	45.5017
4	-11.1653	48.2049	-13.9361	52.8343	-22.35	49.0835
5	-3.5624	34.4184	-9.7123	54.49	-19.0723	46.0086
mean	-4.80586	36.55394	-7.11714	45.40708	-11.8614	43.00794

Data Subjek 5 Motor Imagery

subjek 5	c3					
	relax		kiri		kanan	
	min	max	min	max	min	max
1	-2.4473	30.3973	-6.2318	29.0456	-3.5624	30.9379
2	-6.5359	25.599	-0.6901	23.8757	-4.3057	22.051
3	-5.2857	23.6053	-5.4208	24.6866	-0.1495	22.8957
4	-3.0893	24.957	-1.3998	28.6401	-4.5085	25.1597
5	-6.6373	24.6191	-6.6373	28.4712	-4.4747	23.4026
mean	-4.7991	25.83554	-4.07596	26.94384	-3.40016	24.88938
stdev	1.9420744	2.6500535	2.812587	2.4564271	1.8571597	3.5671888

subjek 5	c4					
	relax		kiri		kanan	
	min	max	min	max	min	max
5	0.5263	31.5461	-8.9351	37.696	-3.1907	35.77
6	-0.2847	30.1607	-0.386	28.1671	-2.5148	31.0055
7	-0.8253	29.8566	2.4862	32.2895	-1.9066	32.4585
10	-1.3998	35.9727	0.7966	25.9369	-2.6838	32.3909
11	-4.4409	35.3307	-3.7651	29.958	-2.7514	33.4046
mean	-1.28488	32.57336	-1.96068	30.8095	-2.60946	33.0059
stdev	1.9016845	2.8903033	4.5209351	4.5017731	0.4654262	1.7662589