LAMPIRAN

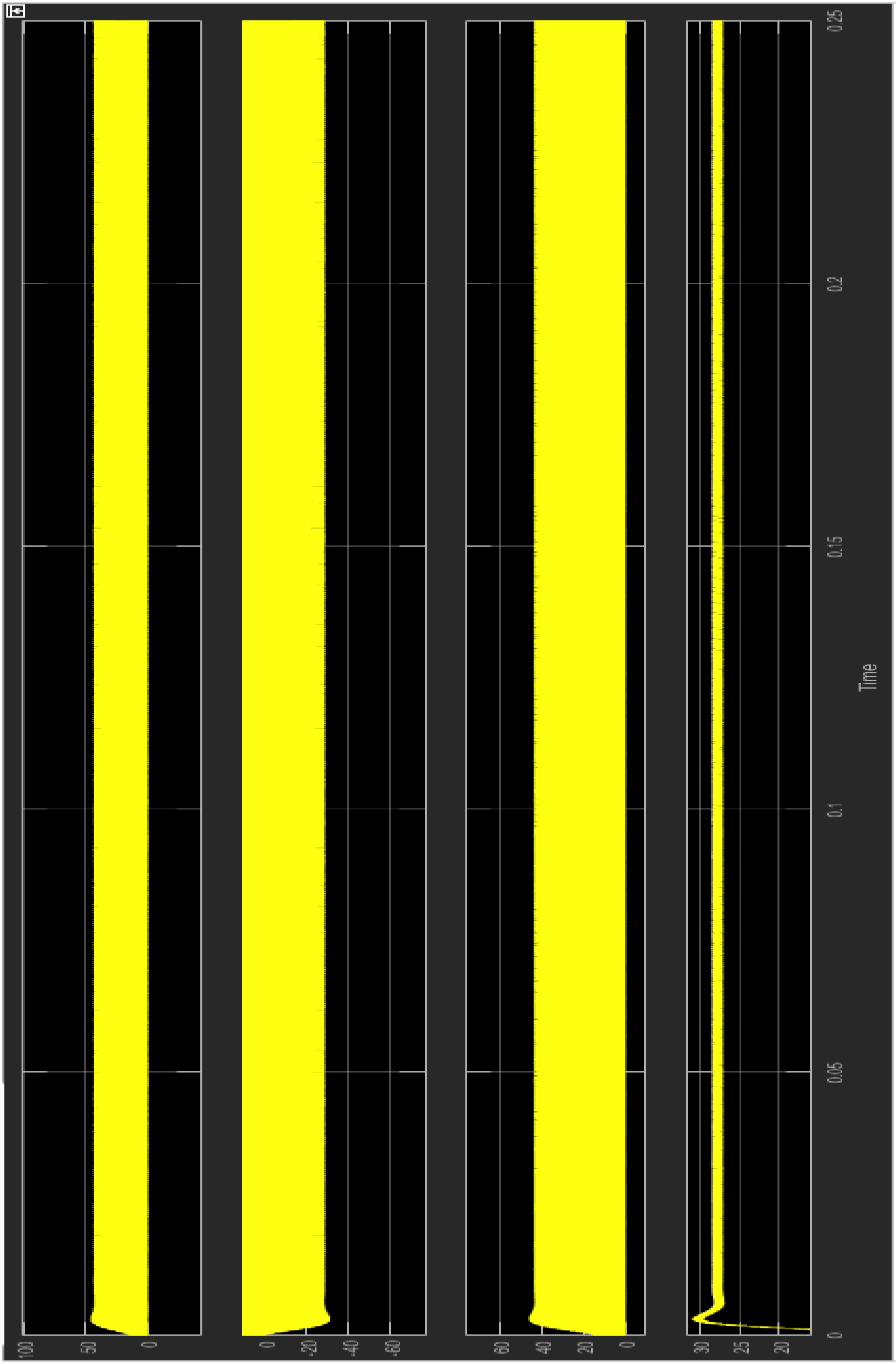
Lampiran 1 *Listing* program

```
//Project            : Regenerative Breaking System
//Date               : 18 Mei 2018
//Author             : Hasan Albinsaid (2014) & Ahmad Yusuf Rizki (2013)
//Microcontroller    : Arduino Uno R3

float setpoinArus =0;
float toleransiArus = 0.05;
float tegangan_max = 17;
float arus_max = 0;
float tegangan_input;
float tegangan_output;
float arus;
bool Enable = 1;

void setup() {
  Serial.begin(9600);
  pinMode(10, OUTPUT);
  TCCR1A = 0x23;
  TCCR1B = 0x19;
  OCR1A = 799;
  OCR1B = 0; //0~65535
  //Rumus frekuensi(mode fast pwm) : nilai_crystal/(OCR1A+1)
  //Rumus dutycycle(mode fast pwm) :(OCR1B)/(OCR1A)
}

void loop() {
  for (int i = 0; i < 25; i++)
  {
    tegangan_input += analogRead(A0) * 0.2007 + 0.3262;
    tegangan_output += (-0.064)*analogRead(A1)+65.3;
    arus += analogRead(A2) * 0.0378-19.209;
  }
  tegangan_input = tegangan_input / 25;
  tegangan_output = tegangan_output / 25;
  arus = arus / 25;
  if (Serial.available())
  {
    setpoinArus = Serial.readStringUntil('\n').toFloat();
    //    Serial.print("Tegangan out sekarang = ");
    //    Serial.print(tegangan_output);
    //    Serial.print("    ");0


    //    Serial.print("Tegangan out diset = ");
    //    Serial.println(setpoinArus);
  }
//Soft Reset
  if (setpoinArus == 9999)
```

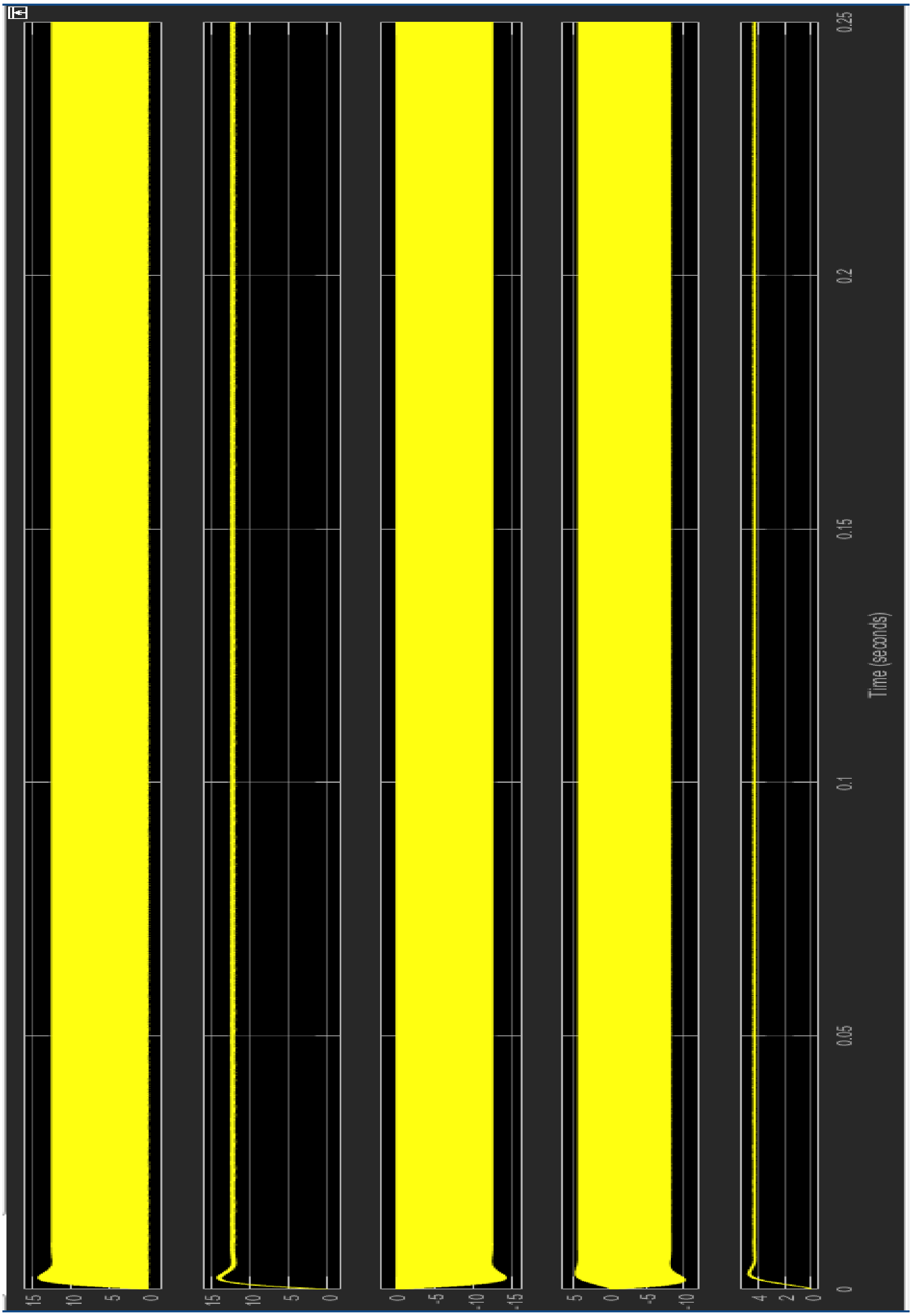
```
{
  setpoinArus=0;
  Enable =1;
}
if (Enable ==1)
{

if (arus < (setpoinArus - toleransiArus))
{
  if ( tegangan_output < tegangan_max)
  {
    if (OCR1B < OCR1A)
    {
      OCR1B+=5;
    }
  }
  else if (tegangan_output > tegangan_max)
  {
    Enable =0;
    OCR1B=0;
  }
}
else if (arus > (setpoinArus + toleransiArus))
{
  if (OCR1B > 0)
  {
    OCR1B-=5;
  }
}
}
delay(1);
Serial.print(tegangan_input);
Serial.print("  ");
Serial.print(arus);
Serial.print("  ");
Serial.println(tegangan_output);
}
```

Lampiran 2 Gelombang tegangan dan arus pada simulasi *buck - boost converter* .

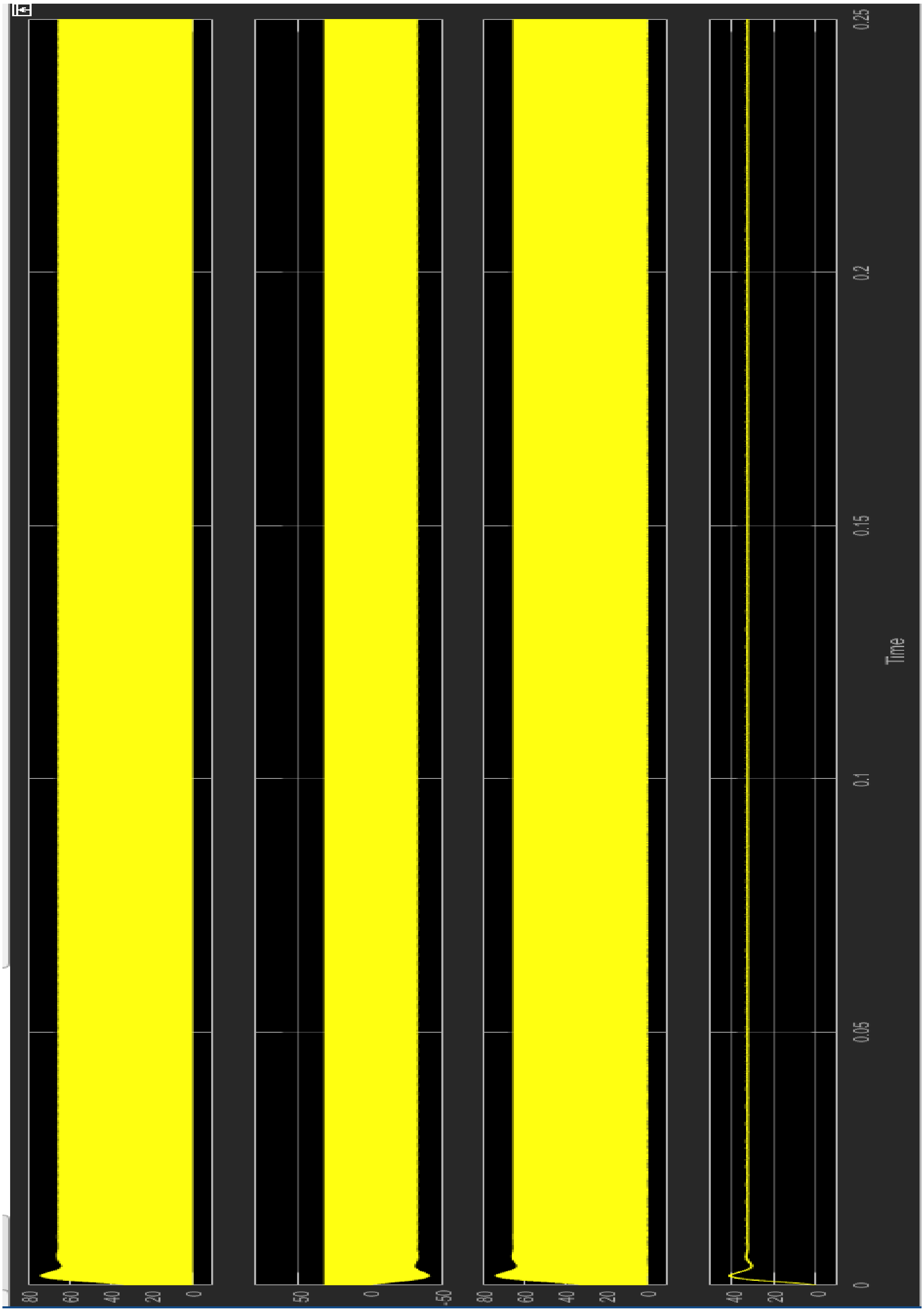
1. V_i = 15 V; D = 65,00 %; R = 6,5 Ω.
2. V_i = 32,4 V; D = 50,00 %; R = 7 Ω.
3. V_i = 60 V; D = 30,00 %; R = 5,7 Ω.
4. V_i = 167 V; D = 3,00 %; R = 0,9 Ω.



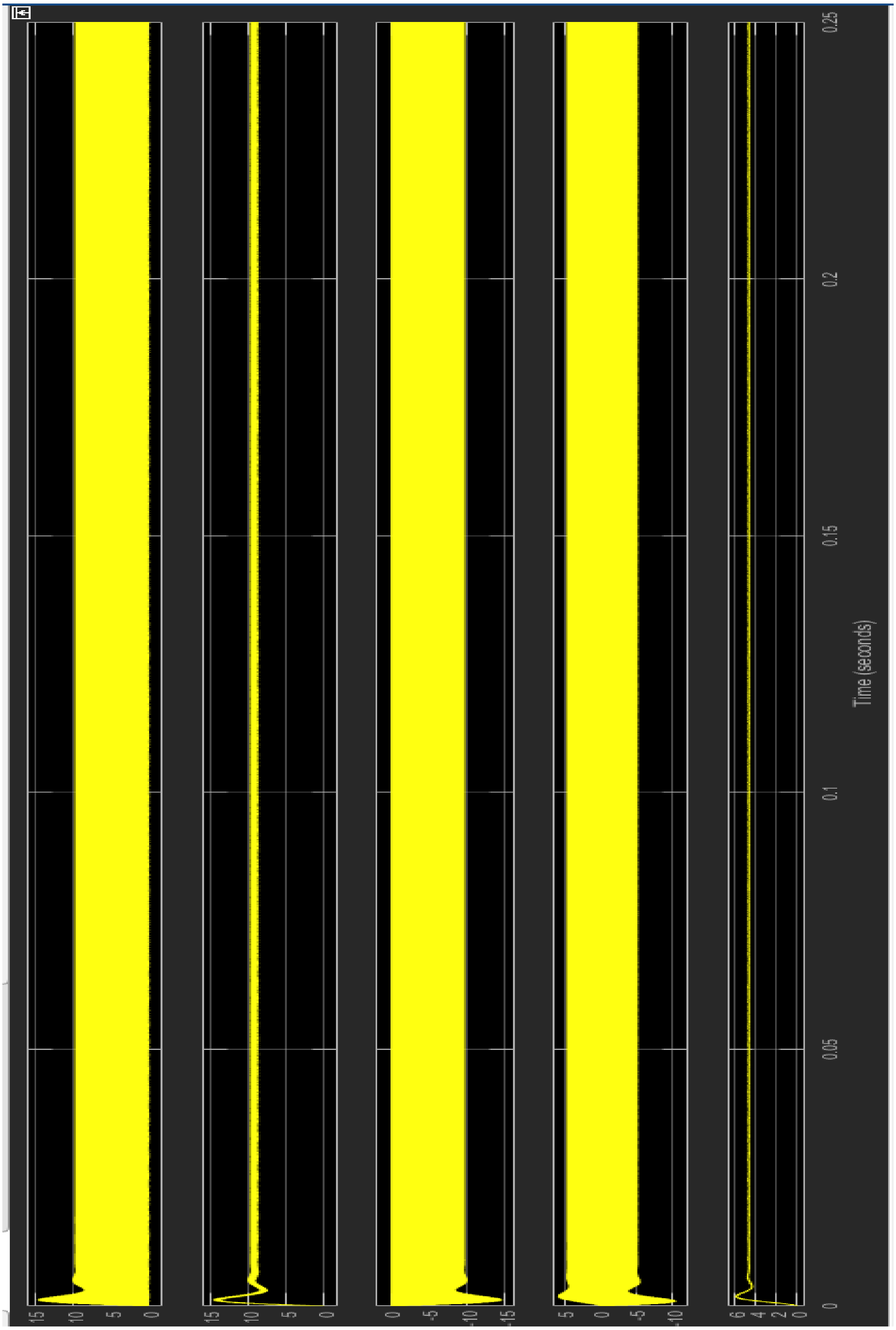
Gambar L2.1 Gelombang tegangan (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor dan beban (Vi = 15 V; D = 65,00 %; R = 6,5 Ω)



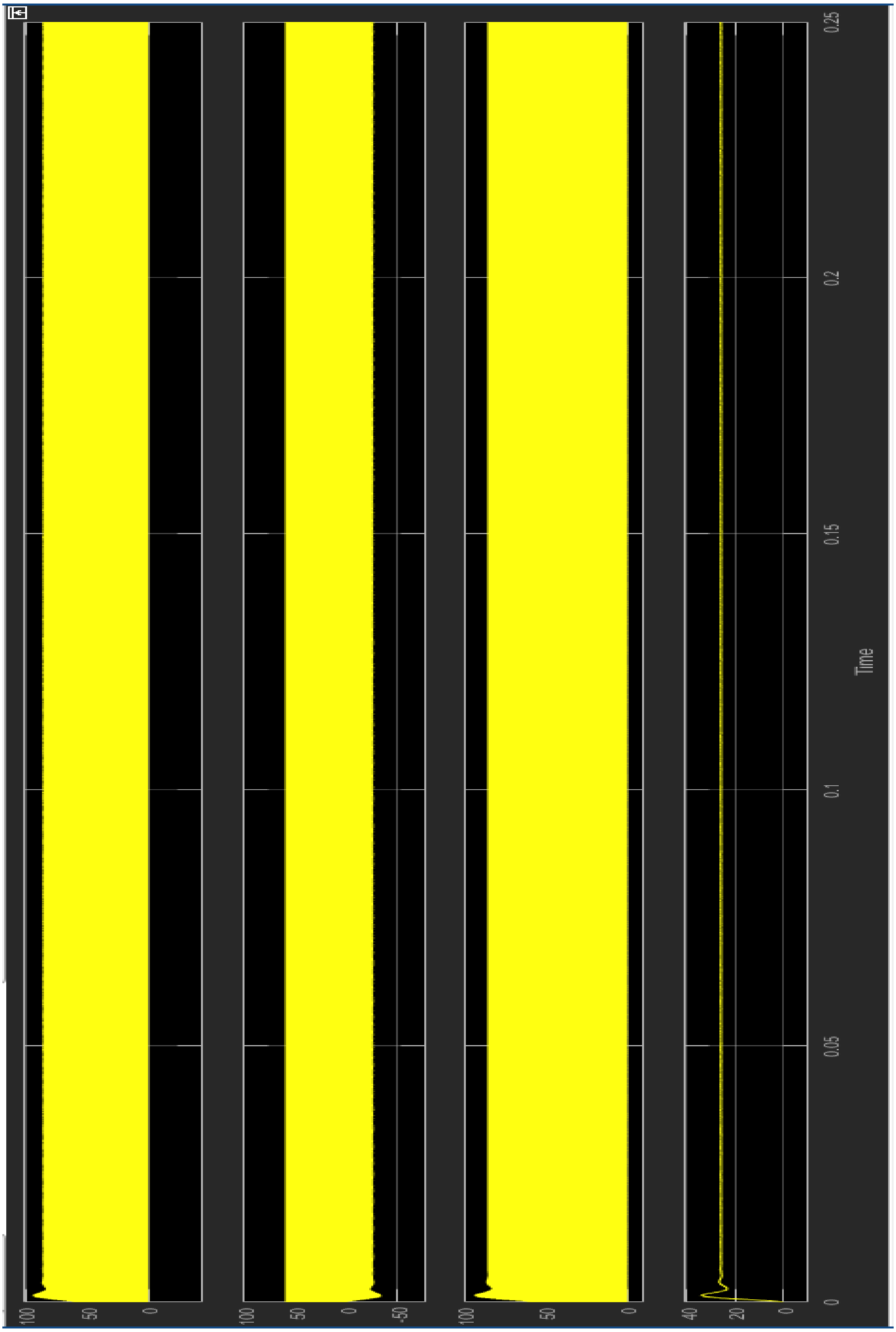
Gambar L2.1 Gelombang arus (a) IGBT/MOSFET (b) induktor (c) dioda
(d) kapasitor (e) beban (Vi = 15 V; D = 65,00 %; R = 6,5 Ω)



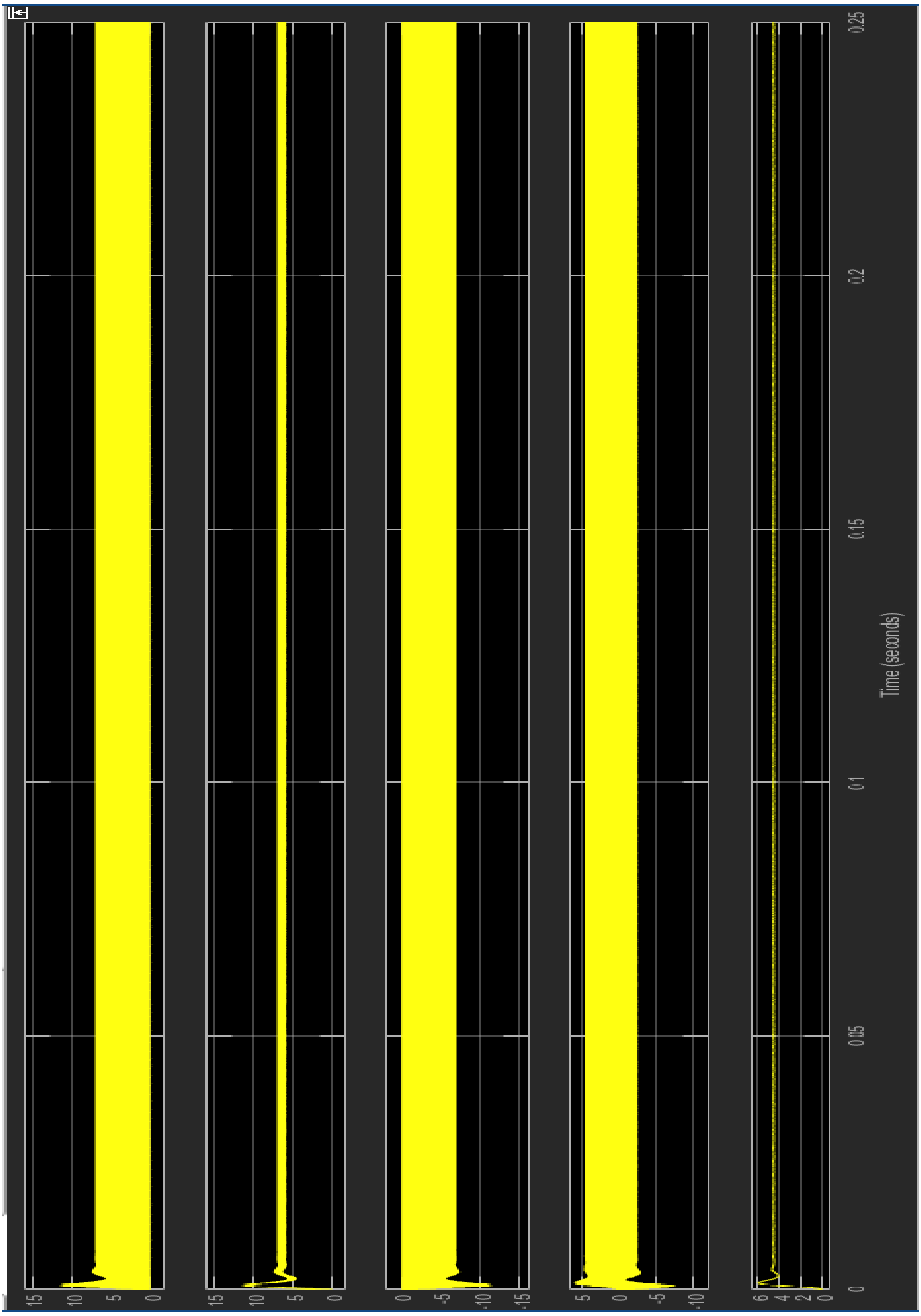
Gambar L2.2 Gelombang tegangan (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor dan beban (Vi = 32,4 V; D = 50,00 %; R = 7 Ω)



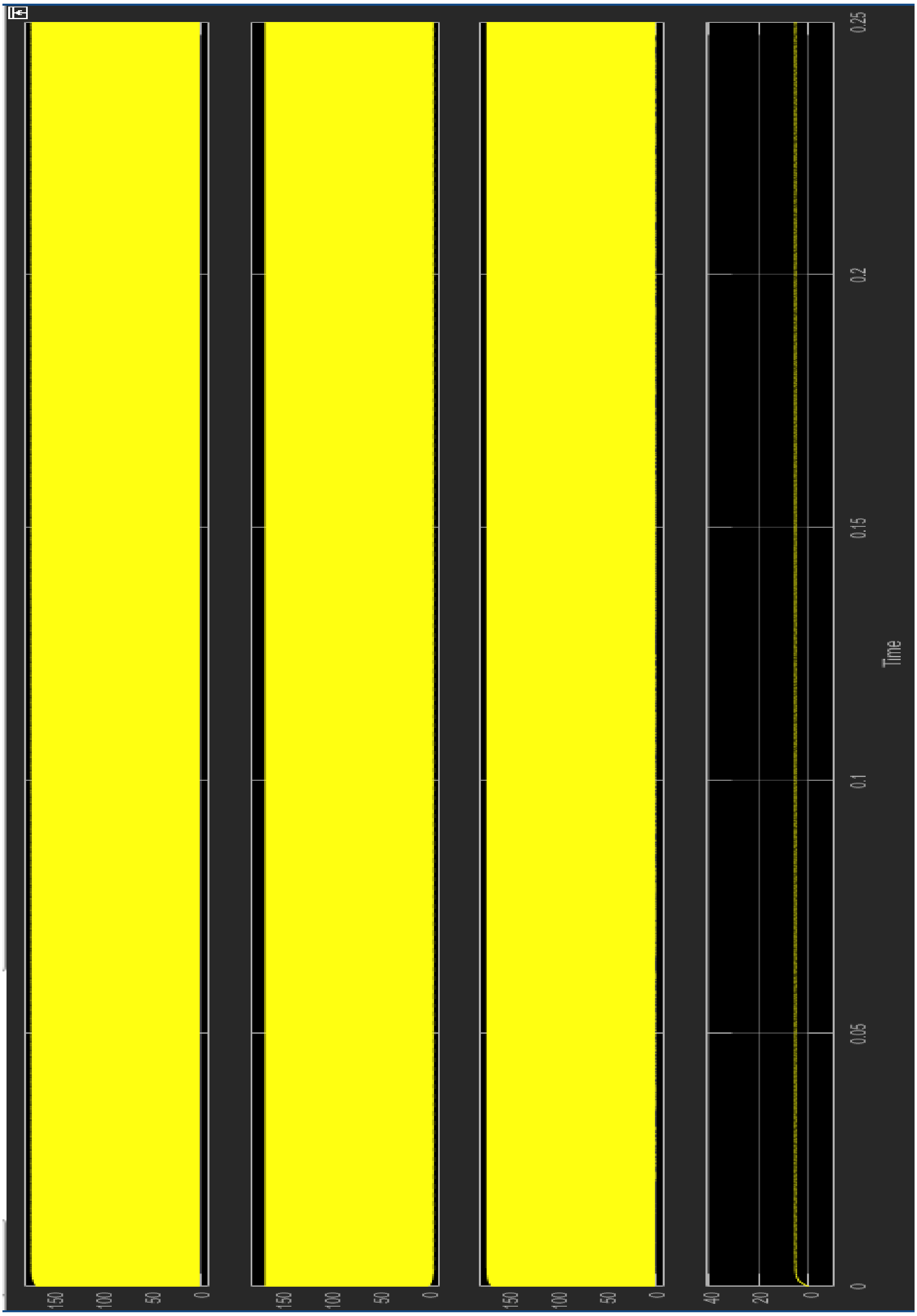
Gambar L2.2 Gelombang arus (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor (e) beban (Vi = 32,4 V; D = 50,00 %; R = 7 Ω)



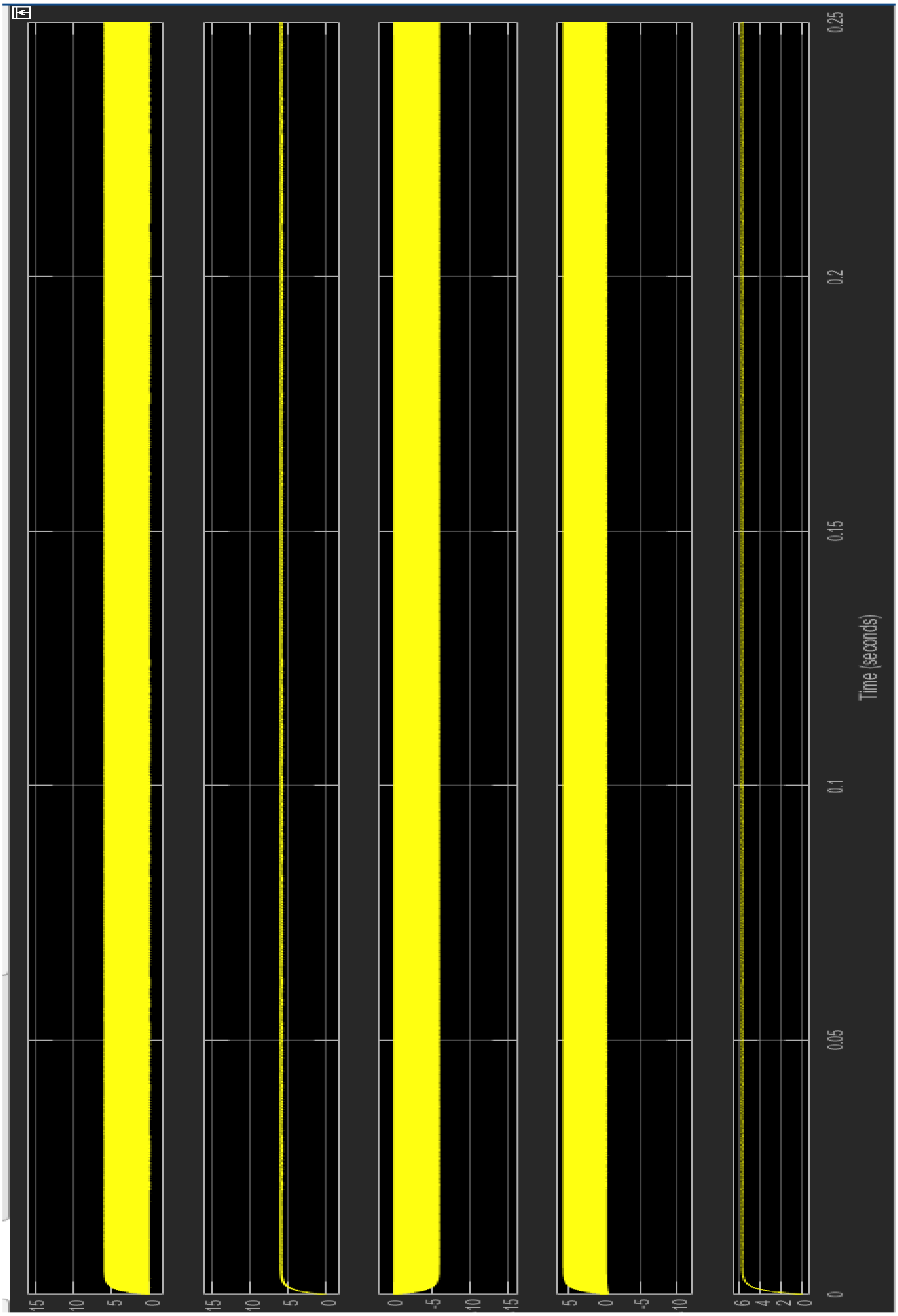
Gambar L2.3 Gelombang tegangan (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor dan beban (Vi = 60 V; D = 30,00 %; R = 5,7 Ω)



Gambar L2.3 Gelombang arus (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor (e) beban (Vi = 60 V; D = 30,00 %; R = 5,7 Ω)



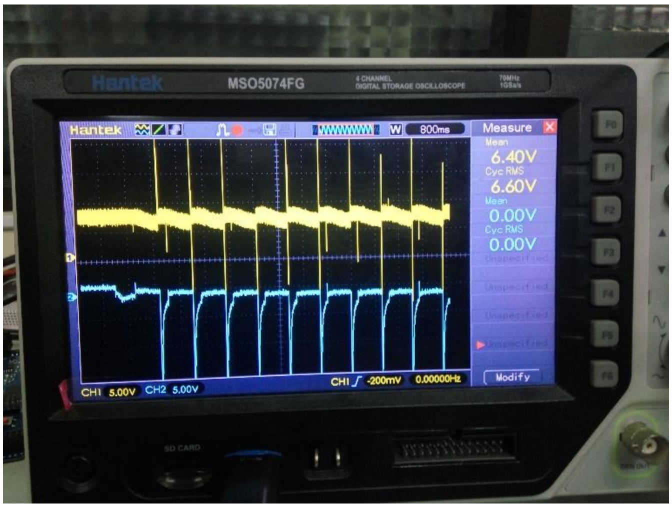
Gambar L2.4 Gelombang tegangan (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor dan beban (Vi = 167 V; D = 3,00 %; R = 0,9 Ω)



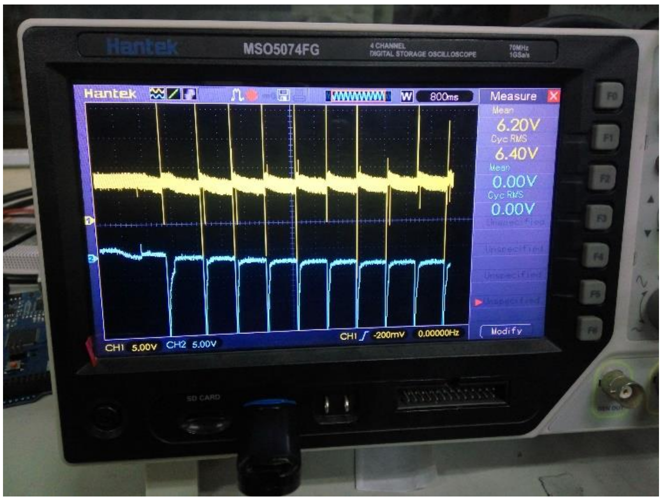
Gambar L2.4 Gelombang arus (a) IGBT/MOSFET (b) induktor (c) dioda (d) kapasitor (e) beban (Vi = 167 V; D = 3,00 %; R = 0,9 Ω)

Lampiran 3 Grafik *ocilloscope* hasil pengujian statis

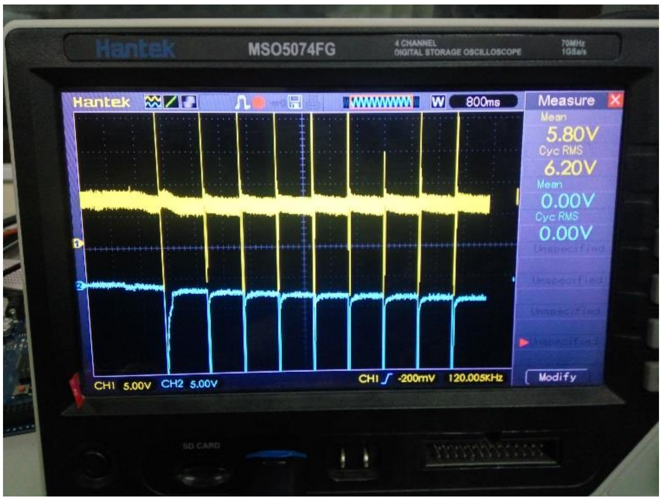
1. Pengujian tegangan sumber > tegangan superkapasitor
2. Pengujian tegangan superkapasitor > tegangan sumber
3. Pengujian limit tegangan superkapasitor



Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 5 V, *set point* arus 1 A



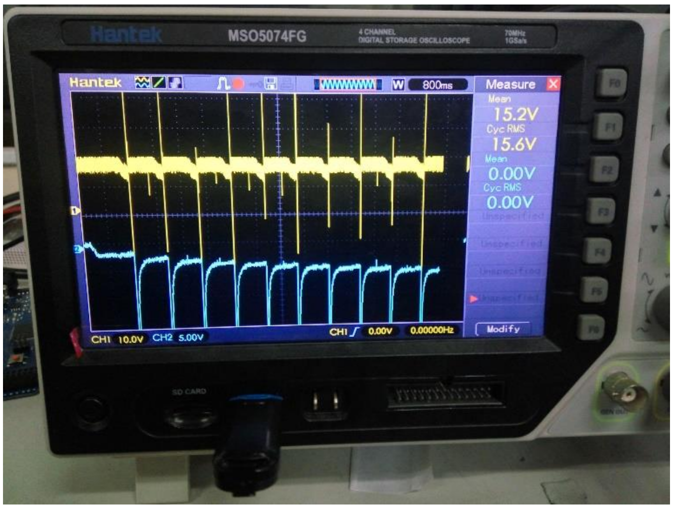
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 5 V, *set point* arus 2 A



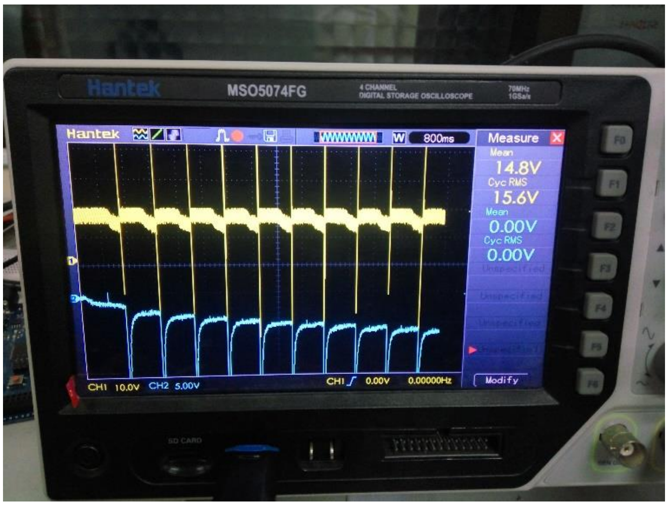
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 5 V, *set point* arus 3 A

Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 10 V, *set point* arus 2 A

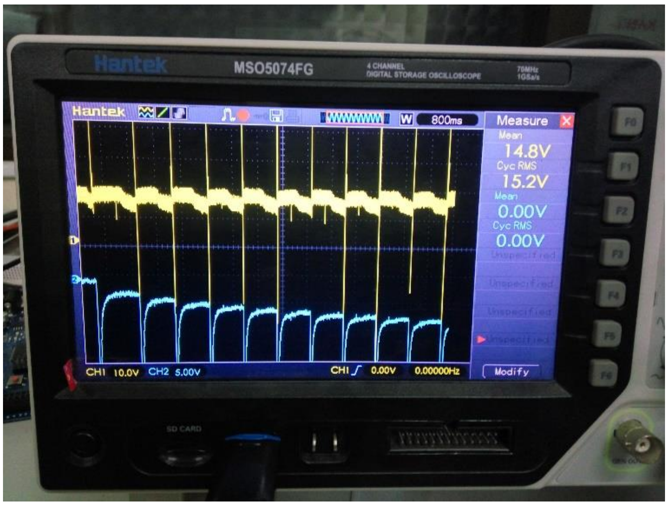
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 10 V, *set point* arus 3 A



Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 15 V, *set point* arus 1 A



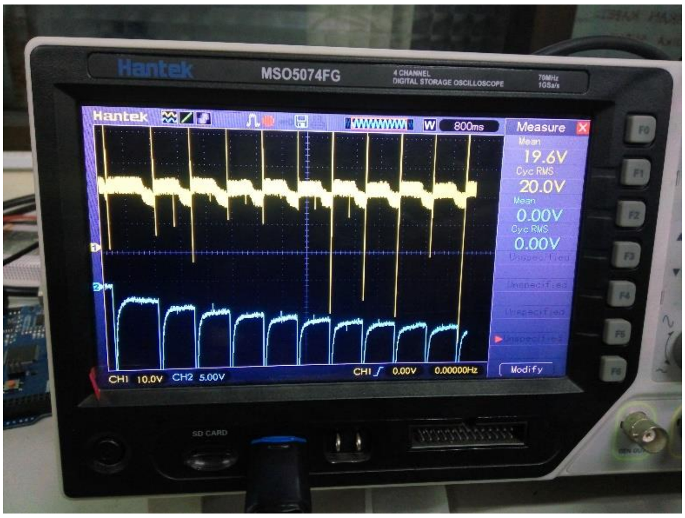
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 15 V, *set point* arus 2 A



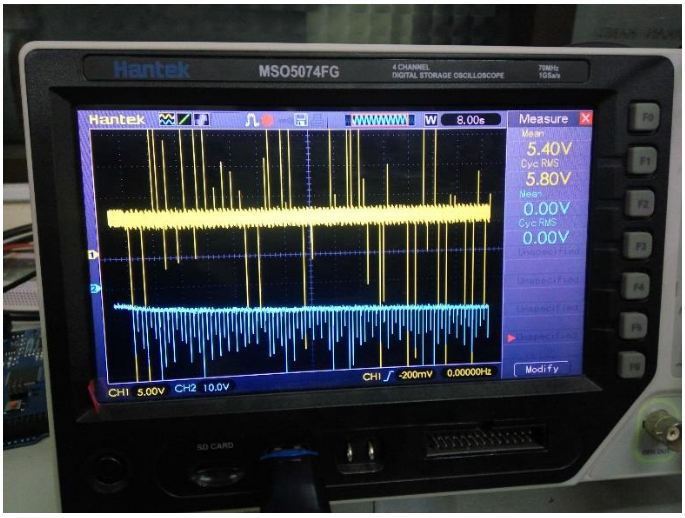
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 15 V, *set point* arus 3 A

Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 20 V, *set point* arus 1 A

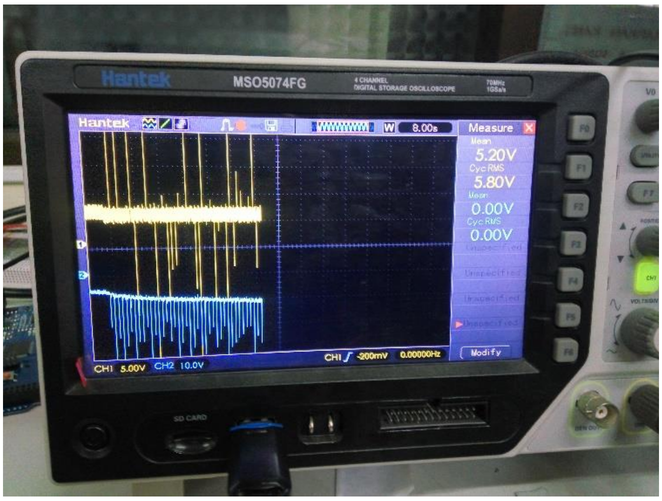
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 20 V, *set point* arus 2 A



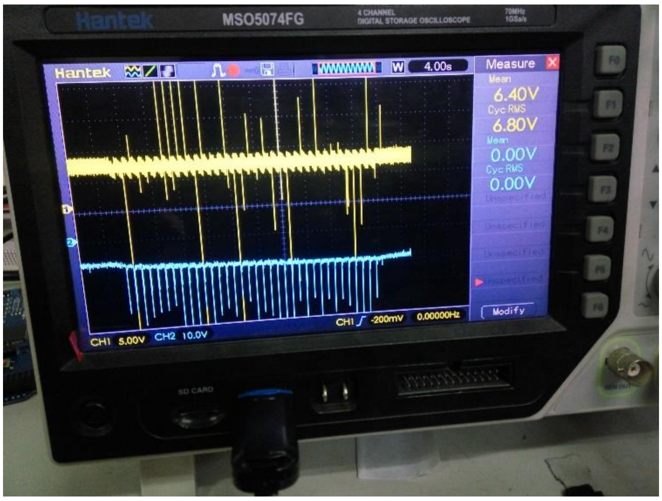
Gambar L3.1 Grafik Pengujian Vs > Vc dengan Vs = 20 V, *set point* arus 3 A



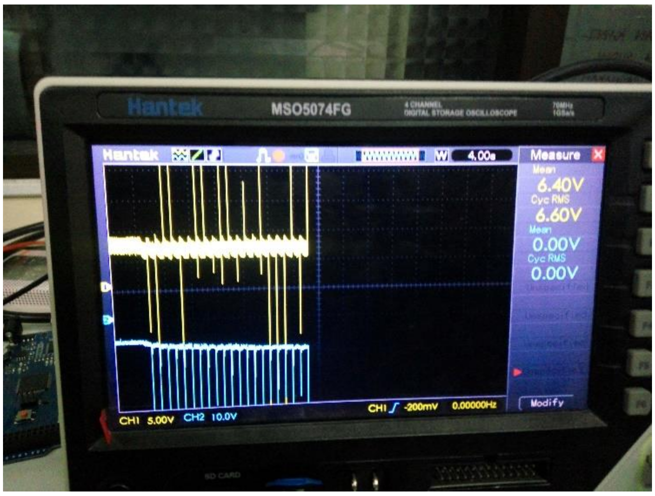
Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 4 V, *set point* arus 1 A



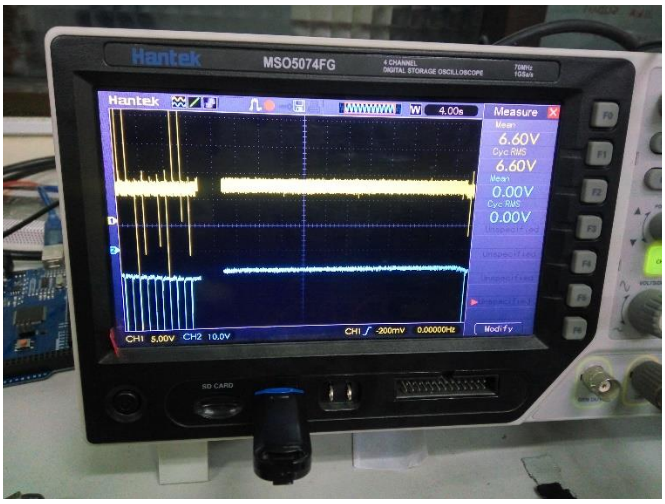
Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 4 V, *set point* arus 2 A



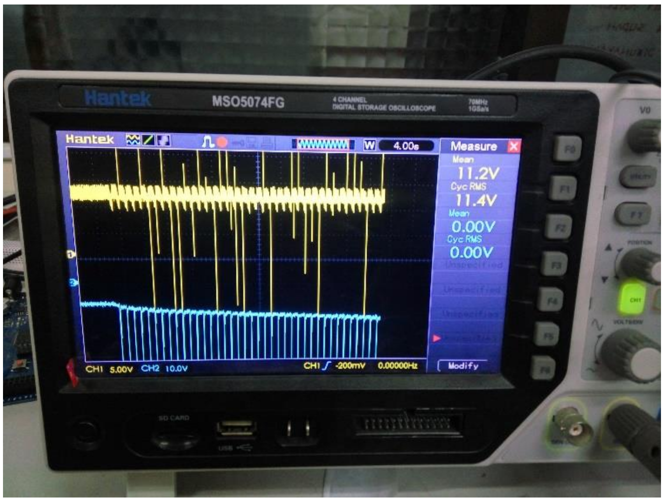
Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 5 V, *set point* arus 1 A



Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 5 V, *set point* arus 2 A

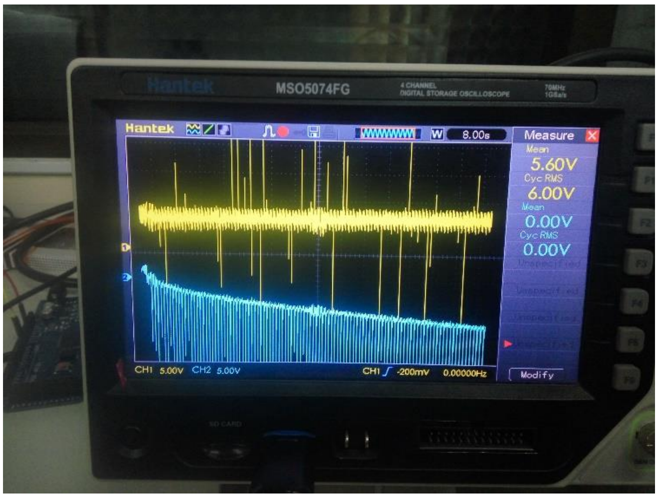


Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 5 V, *set point* arus 3 A

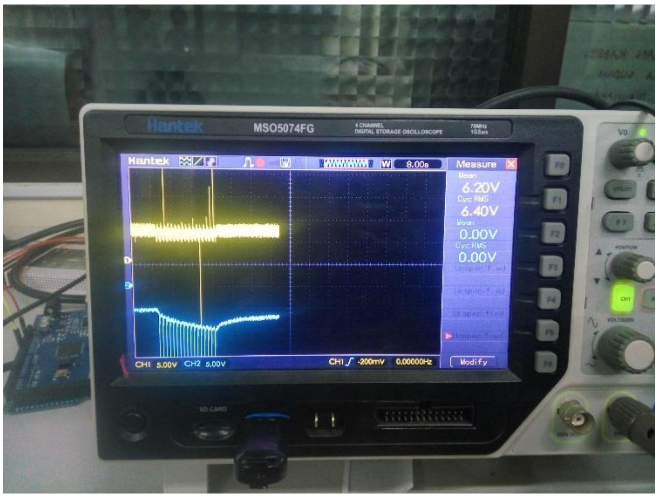


Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 10 V, *set point* arus 1 A

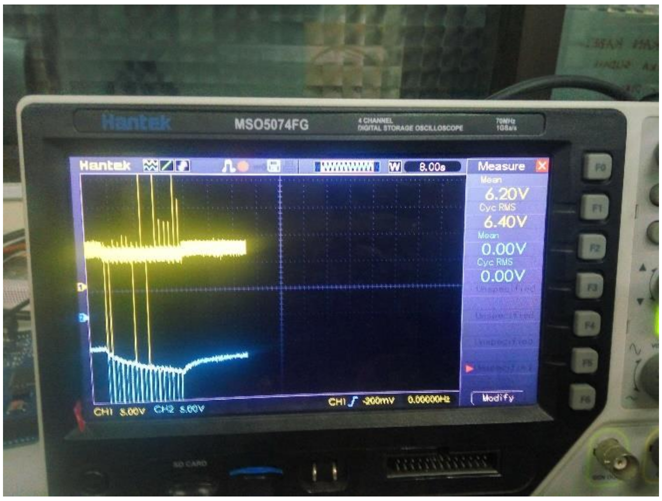
Gambar L3.2 Grafik Pengujian Vc > Vs dengan Vs = 10 V, *set point* arus 2 A



Gambar L3.3 Grafik pengujian limit tegangan kapasitor pada 10 V, dengan Vs = 5 V, *set point* arus 1 A\



Gambar L3.3 Grafik pengujian limit tegangan kapasitor pada 12 V, dengan Vs = 5 V, *set point* arus 2 A



Gambar L3.3 Grafik pengujian limit tegangan kapasitor pada 14 V, dengan Vs = 5 V, *set point* arus 3 A

Gambar L3.3 Grafik pengujian limit tegangan kapasitor pada 17 V, dengan Vs = 10 V, *set point* arus 1 A

Lampiran 4 *Datasheet* komponen yang digunakan

1. Dioda MUR1560G
2. MOSFET IRF640N
3. Arduino Uno R3
4. IC TLP 250
5. IC TLP 521-1

1. Dioda MUR1560G

MUR1510G, MUR1515G, MUR1520G, MUR1540G, MUR1560G, MURF1560G, SUR81520G, SUR81560G

Switch-mode Power Rectifiers

These state−of−the−art devices are a series designed for use in switching power supplies, inverters and as free wheeling diodes.

Features

- Ultrafast 35 and 60 Nanosecond Recovery Time
- 175°C Operating Junction Temperature
- High Voltage Capability to 600 V
- ESD Ratings:
  - Machine Model = C
  - Human Body Model = 3B
- Low Forward Drop
- Low Leakage Specified @ 150°C Case Temperature
- Current Derating Specified @ Both Case and Ambient Temperatures
- SUR8 Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q101 Qualified and PPAP Capable
- All Packages are Pb−Free*

Mechanical Characteristics:

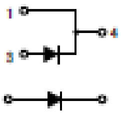
- Case: Epoxy, Molded
- Weight: 1.9 Grams (Approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead Temperature for Soldering Purposes: 260°C Max. for 10 Seconds

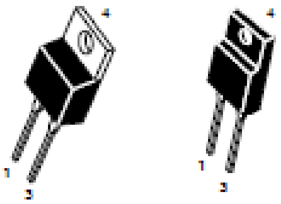
*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

ON Semiconductor®

http://onsemi.com

ULTRAFAST RECTIFIERS
15 AMPERES, 100−600 VOLTS

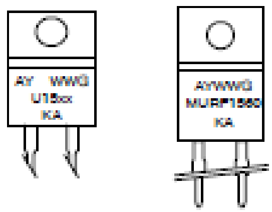




TO−220AC
CASE 221B
STYLE 1

TO−220 FULLPAK
CASE 221AG
STYLE 1

MARKING DIAGRAMS



A = Assembly Location
Y = Year
WW = Work Week
G = Pb−Free Package
U15xx = Device Code
xx = 10, 15, 20, 40 or 60
KA = Diode Polarity

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 7 of this data sheet.

February, 2014 − Rev. 10
1
Publication Order Number:
MUR1520/D

MUR1510G, MUR1515G, MUR1520G, MUR1540G, MUR1560G, MURF1560G, SUR81520G, SUR81560G

MAXIMUM RATINGS

Rating	Symbol	MUR/SUR8					Unit
		1510	1515	1520	1540	1560	
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	150	200	400	600	V
Average Rectified Forward Current (Rated V_R)	$I_{F(AV)}$	15 @ T_C = 150°C				15 @ T_C = 145°C	A
Peak Rectified Forward Current (Rated V_R, Square Wave, 20 kHz)	I_{FRM}	30 @ T_C = 150°C				30 @ T_C = 145°C	A
Nonrepetitive Peak Surge Current (Surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	200			150		A
Operating Junction Temperature and Storage Temperature Range	T_J, T_{stg}	−65 to +175					°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
MUR1510 Series: Thermal Resistance Junction−to−Case Junction−to−Ambient	 $R_{\theta JC}$ $R_{\theta JA}$	 1.5 73	°C/W
MURF1560: Thermal Resistance Junction−to−Case Junction−to−Ambient	 $R_{\theta JC}$ $R_{\theta JA}$	 4.25 75	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	1510	1515	1520	1540	1560	Unit
Maximum Instantaneous Forward Voltage (Note 1) (i_F = 15 A, T_C = 150°C) (i_F = 15 A, T_C = 25°C)	v_F	 0.85 1.05			 1.12 1.25	 1.20 1.50	V
Maximum Instantaneous Reverse Current (Note 1) (Rated DC Voltage, T_C = 150°C) (Rated DC Voltage, T_C = 25°C)	i_R	 500 10			 500 10	 1000 10	μA
Maximum Reverse Recovery Time (I_F = 1.0 A, di/dt = 50 A/μs)	t_{rr}	35			60		ns

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

1. Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%.

2. MOSFET IRF640N

VISHAY. www.vishay.com

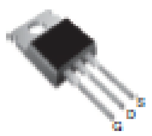
IRF640, SiHF640

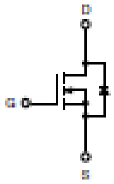
Vishay Siliconix

Power MOSFET

PRODUCT SUMMARY		
V_{DS} (V)	200	
$R_{DS(on)}$ (Ω)	V_{GS} = 10 V	0.18
Q_g (Max.) (nC)	70	
Q_{gs} (nC)	13	
Q_{gd} (nC)	39	
Configuration	Single	

TO-220AB





N-Channel MOSFET

FEATURES

- Dynamic dV/dt rating
- Repetitive avalanche rated
- Fast switching
- Ease of paralleling
- Simple drive requirements
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

RoHS*

Note

* This datasheet provides information about parts that are RoHS-compliant and / or parts that are non-RoHS-compliant. For example, parts with lead (Pb) terminations are not RoHS-compliant. Please see the information / tables in this datasheet for details.

DESCRIPTION

Third generation power MOSFETs from Vishay provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220AB package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 W. The low thermal resistance and low package cost of the TO-220AB contribute to its wide acceptance throughout the industry.

ORDERING INFORMATION	
Package	TO-220AB
Lead (Pb)-free	IRF640PbF
	SiHF640-E3
SnPb	IRF640
	SiHF640

ABSOLUTE MAXIMUM RATINGS (T_C = 25 °C, unless otherwise noted)

PARAMETER			SYMBOL	LIMIT	UNIT
Drain-Source Voltage			V_{DS}	200	V
Gate-Source Voltage			V_{GS}	± 20	
Continuous Drain Current	V_{GS} at 10 V	T_C = 25 °C	I_D	18	A
		T_C = 100 °C		11	
Pulsed Drain Current [a]			I_{DM}	72	
Linear Derating Factor				1.0	W/°C
Single Pulse Avalanche Energy [b]			E_{AS}	580	mJ
Repetitive Avalanche Current [a]			I_{AR}	18	A
Repetitive Avalanche Energy [a]			E_{AR}	13	mJ
Maximum Power Dissipation	T_C = 25 °C		P_D	125	W
Peak Diode Recovery dV/dt [c]			dV/dt	5.0	V/ns
Operating Junction and Storage Temperature Range			T_J, T_{stg}	-55 to +150	°C
Soldering Recommendations (Peak temperature) [d]	for 10 s			300	
Mounting Torque	6-32 or M3 screw			10	lbf · in
				1.1	N · m

Notes

a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).
b. V_{DD} = 50 V, starting T_J = 25 °C, L = 2.7 mH, R_g = 25 Ω, I_{AS} = 18 A (see fig. 12).
c. $I_{SD} \leq$ 18 A, dI/dt $\leq$ 150 A/μs, $V_{DD} \leq V_{DS}$, $T_J \leq$ 150 °C.
d. 1.6 mm from case.

S15-2667-Rev. C, 16-Nov-15 1 Document Number: 91036

For technical questions, contact: hvm@vishay.com

THERMAL RESISTANCE RATINGS				
PARAMETER	SYMBOL	TYP.	MAX.	UNIT
Maximum Junction-to-Ambient	R_{thJA}	-	62	°C/W
Case-to-Sink, Flat, Greased Surface	R_{thCS}	0.50	-	
Maximum Junction-to-Case (Drain)	R_{thJC}	-	1.0	

SPECIFICATIONS (T_J = 25 °C, unless otherwise noted)						
PARAMETER	SYMBOL	TEST CONDITIONS	MIN.	TYP.	MAX.	UNIT
Static						
Drain-Source Breakdown Voltage	V_{DS}	V_{GS} = 0 V, I_D = 250 μA	200	-	-	V
V_{DS} Temperature Coefficient	$\Delta V_{DS}/T_J$	Reference to 25 °C, I_D = 1 mA	-	0.29	-	V/°C
Gate-Source Threshold Voltage	$V_{GS(th)}$	V_{DS} = V_{GS}, I_D = 250 μA	2.0	-	4.0	V
Gate-Source Leakage	I_{GSS}	V_{GS} = ± 20 V	-	-	± 100	nA
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = 200 V, V_{GS} = 0 V	-	-	25	μA
		V_{DS} = 160 V, V_{GS} = 0 V, T_J = 125 °C	-	-	250	
Drain-Source On-State Resistance	$R_{DS(on)}$	V_{GS} = 10 V, I_D = 11 A [b]	-	-	0.18	Ω
Forward Transconductance	g_{fs}	V_{DS} = 50 V, I_D = 11 A [b]	6.7	-	-	S
Dynamic						
Input Capacitance	C_{iss}	V_{GS} = 0 V, V_{DS} = 25 V, f = 1.0 MHz, see fig. 5	-	1300	-	pF
Output Capacitance	C_{oss}		-	430	-	
Reverse Transfer Capacitance	C_{rss}		-	130	-	
Total Gate Charge	Q_g	V_{GS} = 10 V; I_D = 18 A, V_{DS} = 160 V, see fig. 6 and 13 [b]	-	-	70	nC
Gate-Source Charge	Q_{gs}		-	-	13	
Gate-Drain Charge	Q_{gd}		-	-	39	
Turn-On Delay Time	$t_{d(on)}$	V_{DD} = 100 V, I_D = 18 A, R_g = 9.1 Ω, R_D = 5.4 Ω, see fig. 10 [b]	-	14	-	ns
Rise Time	t_r		-	51	-	
Turn-Off Delay Time	$t_{d(off)}$		-	45	-	
Fall Time	t_f		-	36	-	
Internal Drain Inductance	L_D	Between lead, 6 mm (0.25") from package and center of die contact	-	4.5	-	nH
Internal Source Inductance	L_S		-	7.5	-	
Gate Input Resistance	R_g	f = 1 MHz, open drain	0.5	-	3.6	Ω
Drain-Source Body Diode Characteristics						
Continuous Source-Drain Diode Current	I_S	MOSFET symbol showing the integral reverse p - n junction diode	-	-	18	A
Pulsed Diode Forward Current [a]	I_{SM}		-	-	72	
Body Diode Voltage	V_{SD}	T_J = 25 °C, I_S = 18 A, V_{GS} = 0 V [b]	-	-	2.0	V
Body Diode Reverse Recovery Time	t_{rr}	T_J = 25 °C, I_F = 18 A, dI/dt = 100 A/μs [b]	-	300	610	ns
Body Diode Reverse Recovery Charge	Q_{rr}		-	3.4	7.1	μC
Forward Turn-On Time	t_{on}	Intrinsic turn-on time is negligible (turn-on is dominated by L_S and L_D)				

Notes

a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).
b. Pulse width ≤ 300 μs; duty cycle ≤ 2 %.

3. Arduino Uno R3

Arduino Uno

Arduino Uno R3 Front

Arduino Uno R3 Back

Arduino Uno R2 Front

Arduino Uno SMD

Arduino Uno Front

Arduino Uno Back

Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.
The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.
Revision 2 of the Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.
Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V

Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Schematic & Reference Design

EAGLE files: arduino-uno-Rev3-reference-design.zip (NOTE: works with Eagle 6.0 and newer)
Schematic: arduino-uno-Rev3-schematic.pdf
Note: The Arduino reference design can use an Atmega8, 168, or 328, Current models use an ATmega328, but an Atmega8 is shown in the schematic for reference. The pin configuration is identical on all three processors.

Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.
External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.
The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.
The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.**This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.

Atmel

8-bit AVR Microcontrollers

ATmega328/P

DATASHEET COMPLETE

Introduction

The Atmel® picoPower® ATmega328/P is a low-power CMOS 8-bit microcontroller based on the AVR® enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega328/P achieves throughputs close to 1MIPS per MHz. This empowers system designer to optimize the device for power consumption versus processing speed.

Feature

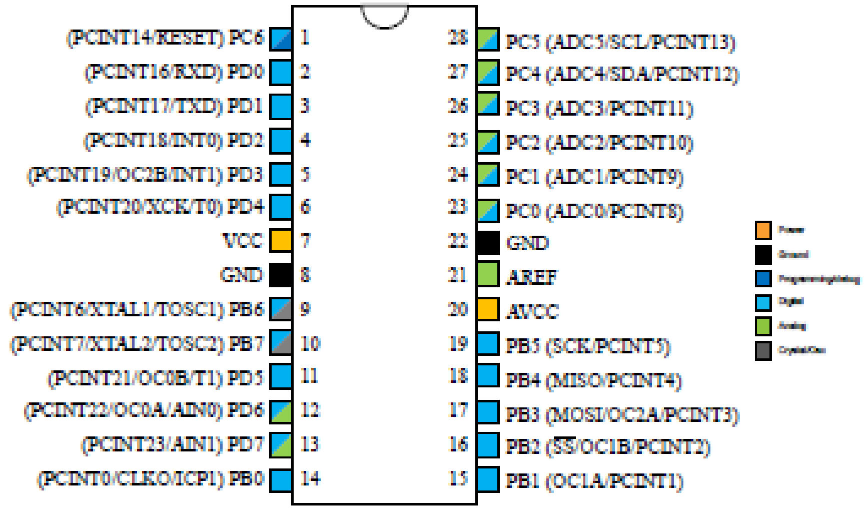
High Performance, Low Power Atmel®AVR® 8-Bit Microcontroller Family

- Advanced RISC Architecture
  - 131 Powerful Instructions
  - Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 32KBytes of In-System Self-Programmable Flash program Memory
  - 1KBytes EEPROM
  - 2KBytes Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data Retention: 20 years at 85°C/100 years at 25°C(1)
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
- Atmel® QTouch® Library Support
  - Capacitive Touch Buttons, Sliders and Wheels
  - QTouch and QMatrix® Acquisition
  - Up to 64 sense channels

5. Pin Configurations

5.1. Pin-out

Figure 5-1. 28-pin PDIP



An interrupt can be generated at each time the counter value reaches the TOP value by either using the OCF1A or ICF1 Flag, depending on the actual CTC mode. If the interrupt is enabled, the interrupt handler routine can be used for updating the TOP value.

Note: Changing TOP to a value close to BOTTOM while the counter is running must be done with care, since the CTC mode does not provide double buffering. If the new value written to OCR1A is lower than the current value of TCNT1, the counter will miss the compare match. The counter will then count to its maximum value (0xFF for a 8-bit counter, 0xFFFF for a 16-bit counter) and wrap around starting at 0x00 before the compare match will occur.
In many cases this feature is not desirable. An alternative will then be to use the Fast PWM mode using OCR1A for defining TOP (WGM1[3:0]=0xF), since the OCR1A then will be double buffered.

For generating a waveform output in CTC mode, the OC1A output can be set to toggle its logical level on each compare match by setting the Compare Output mode bits to toggle mode (COM1A[1:0]=0x1). The OC1A value will not be visible on the port pin unless the data direction for the pin is set to output (DDR_OC1A=1). The waveform generated will have a maximum frequency of $f_{OC1A} = f_{clk\_I/O}/2$ when OCR1A is set to ZERO (0x0000). The waveform frequency is defined by the following equation:

$$f_{OCnA} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot (1 + OCRnA)}$$

Note:

- The "n" indicates the device number (n = 1 for Timer/Counter 1), and the "x" indicates Output Compare unit (A/B).
- *N* represents the prescaler factor (1, 8, 64, 256, or 1024).

As for the Normal mode of operation, the Timer Counter TOV Flag is set in the same timer clock cycle that the counter counts from MAX to 0x0000.

20.12.3. Fast PWM Mode

The Fast Pulse Width Modulation or Fast PWM modes (modes 5, 6, 7, 14,and 15, WGM1[3:0]= 0x5, 0x6, 0x7, 0xE, 0xF) provide a high frequency PWM waveform generation option. The Fast PWM differs from the other PWM options by its single-slope operation. The counter counts from BOTTOM to TOP then restarts from BOTTOM.

In non-inverting Compare Output mode, the Output Compare (OC1x) is cleared on the compare match between TCNT1 and OCR1x, and set at BOTTOM. In inverting Compare Output mode output is set on compare match and cleared at BOTTOM. Due to the single-slope operation, the operating frequency of the Fast PWM mode can be twice as high as the phase correct and phase and frequency correct PWM modes that use dual-slope operation. This high frequency makes the Fast PWM mode well suited for power regulation, rectification, and DAC applications. High frequency allows physically small sized external components (coils, capacitors), hence reduces total system cost.

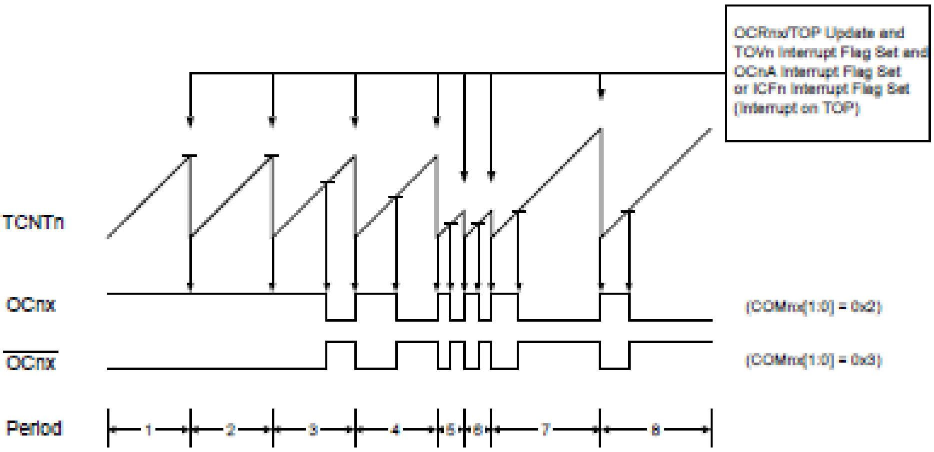
The PWM resolution for Fast PWM can be fixed to 8-, 9-, or 10-bit, or defined by either ICR1 or OCR1A. The minimum resolution allowed is 2-bit (ICR1 or OCR1A register set to 0x0003), and the maximum resolution is 16-bit (ICR1 or OCR1A registers set to MAX). The PWM resolution in bits can be calculated by using the following equation:

$$R_{FPWM} = \frac{\log(TOP+1)}{\log(2)}$$

In Fast PWM mode the counter is incremented until the counter value matches either one of the fixed values 0x00FF, 0x01FF, or 0x03FF (WGM1[3:0] = 0x5, 0x6, or 0x7), the value in ICR1 (WGM1[3:0]=0xE), or the value in OCR1A (WGM1[3:0]=0xF). The counter is then cleared at the following timer clock cycle. The timing diagram for the Fast PWM mode using OCR1A or ICR1 to define TOP is shown below. The

TCNT1 value is in the timing diagram shown as a histogram for illustrating the single-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal lines on the TCNT1 slopes mark compare matches between OCR1x and TCNT1. The OC1x Interrupt Flag will be set when a compare match occurs.

Figure 20-7. Fast PWM Mode, Timing Diagram



Note: The "n" in the register and bit names indicates the device number (n = 1 for Timer/Counter 1), and the "x" indicates Output Compare unit (A/B).

The Timer/Counter Overflow Flag (TOV1) is set each time the counter reaches TOP. In addition, when either OCR1A or ICR1 is used for defining the TOP value, the OC1A or ICF1 Flag is set at the same timer clock cycle TOV1 is set. If one of the interrupts are enabled, the interrupt handler routine can be used for updating the TOP and compare values.

When changing the TOP value the program must ensure that the new TOP value is higher or equal to the value of all of the Compare Registers. If the TOP value is lower than any of the Compare Registers, a compare match will never occur between the TCNT1 and the OCR1x. Note that when using fixed TOP values the unused bits are masked to zero when any of the OCR1x Registers are written.

The procedure for updating ICR1 differs from updating OCR1A when used for defining the TOP value. The ICR1 Register is not double buffered. This means that if ICR1 is changed to a low value when the counter is running with none or a low prescaler value, there is a risk that the new ICR1 value written is lower than the current value of TCNT1. As result, the counter will miss the compare match at the TOP value. The counter will then have to count to the MAX value (0xFFFF) and wrap around starting at 0x0000 before the compare match can occur. The OCR1A Register however, is double buffered. This feature allows the OCR1A I/O location to be written anytime. When the OCR1A I/O location is written the value written will be put into the OCR1A Buffer Register. The OCR1A Compare Register will then be updated with the value in the Buffer Register at the next timer clock cycle the TCNT1 matches TOP. The update is done at the same timer clock cycle as the TCNT1 is cleared and the TOV1 Flag is set.

Using the ICR1 Register for defining TOP works well when using fixed TOP values. By using ICR1, the OCR1A Register is free to be used for generating a PWM output on OC1A. However, if the base PWM frequency is actively changed (by changing the TOP value), using the OCR1A as TOP is clearly a better choice due to its double buffer feature.

4. IC TLP250

TOSHIBA TLP250

TOSHIBA Photocoupler GaAlAs Ired & Photo−IC

TLP250

Transistor Inverter
Inverter For Air Conditionor
IGBT Gate Drive
Power MOS FET Gate Drive

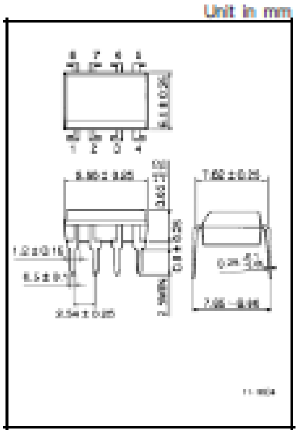
The TOSHIBA TLP250 consists of a GaAlAs light emitting diode and a integrated photodetector.
This unit is 8−lead DIP package.
TLP250 is suitable for gate driving circuit of IGBT or power MOS FET.

- Input threshold current: I_F=5mA(max.)
- Supply current (I_{CC}): 11mA(max.)
- Supply voltage (V_{CC}): 10−35V
- Output current (I_O): ±1.5A (max.)
- Switching time (tpLH/tpHL): 1.5μs(max.)
- Isolation voltage: 2500Vrms(min.)
- UL recognized: UL1577, file No.E67349
- Option (D4) type
  - VDE approved: DIN VDE0884/06.92,certificate No.76823
  - Maximum operating insulation voltage: 630VPK
  - Highest permissible over voltage: 4000VPK

(Note) When a VDE0884 approved type is needed, please designate the "option (D4)"

- Creepage distance: 6.4mm(min.)
  Clearance: 6.4mm(min.)

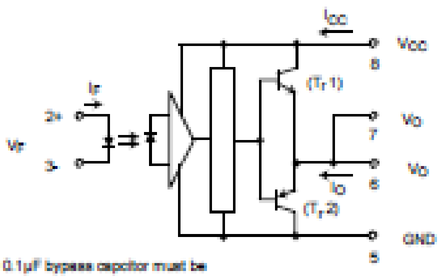
Unit in mm



TOSHIBA 11−10C4

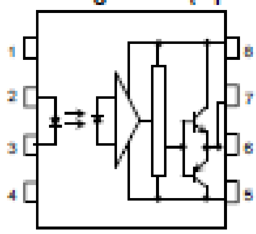
Weight: 0.54 g

Schmatic



A 0.1μF bypass capcitor must be connected between pin 8 and 5 (See Note 5).

Pin Configuration (top view)



1 : N.C.
2 : Anode
3 : Cathode
4 : N.C.
5 : GND
6 : VO (Output)
7 : VO
8 : VCC

Truth Table

		Tr1	Tr2
Input LED	On	On	Off
	Off	Off	On

1 2004-06-25

Absolute Maximum Ratings (Ta = 25°C)

Characteristic			Symbol	Rating	Unit
LED	Forward current		I_F	20	mA
	Forward current derating (Ta ≥ 70°C)		$\Delta I_F / \Delta Ta$	−0.36	mA / °C
	Peak transient forward current (Note 1)		I_{FPT}	1	A
	Reverse voltage		V_R	5	V
	Junction temperature		T_j	125	°C
Detector	"H"peak output current (P_W ≤ 2.5μs, f ≤ 15kHz) (Note 2)		I_{OPH}	−1.5	A
	"L"peak output current (P_W ≤ 2.5μs, f ≤ 15kHz) (Note 2)		I_{OPL}	+1.5	A
	Output voltage	(Ta ≤ 70°C)	V_O	35	V
		(Ta = 85°C)		24	
	Supply voltage	(Ta ≤ 70°C)	V_{CC}	35	V
		(Ta = 85°C)		24	
	Output voltage derating (Ta ≥ 70°C)		$\Delta V_O / \Delta Ta$	−0.73	V / °C
	Supply voltage derating (Ta ≥ 70°C)		$\Delta V_{CC} / \Delta Ta$	−0.73	V / °C
	Junction temperature		T_j	125	°C
Operating frequency (Note 3)			f	25	kHz
Operating temperature range			T_{opr}	−20~85	°C
Storage temperature range			T_{stg}	−55~125	°C
Lead soldering temperature (10 s) (Note 4)			T_{sol}	260	°C
Isolation voltage (AC, 1 min., R.H.≤ 60%) (Note 5)			BV_S	2500	Vrms

Note 1: Pulse width P_W ≤ 1μs, 300pps

Note 2: Exporenential wavefom

Note 3: Exporenential wavefom, I_{OPH} ≤ −1.0A(≤ 2.5μs), I_{OPL} ≤ +1.0A(≤ 2.5μs)

Note 4: It is 2 mm or more from a lead root.

Note 5: Device considerd a two terminal device: Pins 1, 2, 3 and 4 shorted together, and pins 5, 6, 7 and 8 shorted together.

Note 6: A ceramic capacitor(0.1μF) should be connected from pin 8 to pin 5 to stabilize the operation of the high gain linear amplifier. Failure to provide the bypassing may impair the switching proparty. The total lead length between capacitor and coupler should not exceed 1cm.

Recommended Operating Conditions

Characteristic	Symbol	Min.	Typ.	Max.		Unit
Input current, on (Note 7)	$I_{F(ON)}$	7	8	10		mA
Input voltage, off	$V_{F(OFF)}$	0	—	0.8		V
Supply voltage	V_{CC}	15	—	30	20	V
Peak output current	I_{OPH}/I_{OPL}	—	—	±0.5		A
Operating temperature	T_{opr}	−20	25	70	85	°C

Note 7: Input signal rise time (fall time) < 0.5 μs.

5. IC TLP521 - 1

TOSHIBA TLP521-1,TLP521-2,TLP521-4

TOSHIBA Photocoupler GaAs Ired & Photo-Transistor

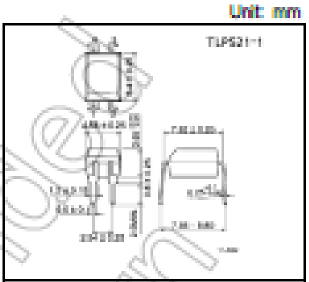
TLP521-1, TLP521-2, TLP521-4

Programmable Controllers
AC/DC-Input Module
Solid State Relay

The TOSHIBA TLP521-1, -2 and -4 consist of a photo-transistor optically coupled to a gallium arsenide infrared emitting diode.
The TLP521-2 offers two isolated channels in an eight lead plastic DIP package, while the TLP521-4 provides four isolated channels in a sixteen plastic DIP package.

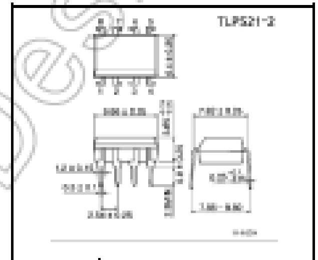
- Collector-emitter voltage: 55 V (min)
- Current transfer ratio: 50% (min)
  Rank GB: 100% (min)
- Isolation voltage: 2500 Vrms (min)
- UL recognized: UL1577, file no. E67349
- c-UL recognized: CSA Component Acceptance Service No. 5A
  File No.E67349

Unit: mm



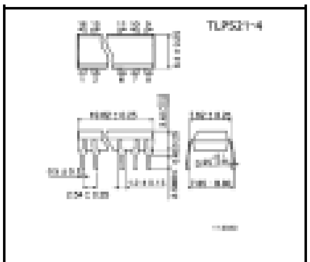
TOSHIBA	11-5B2

Weight: 0.26 g (typ.)



TOSHIBA	11-10C4

Weight: 0.54 g (typ.)

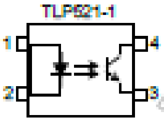


TOSHIBA	11-20A3

Weight: 1.1 g (typ.)

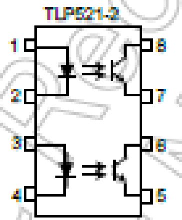
Pin Configurations (top view)

TLP521-1



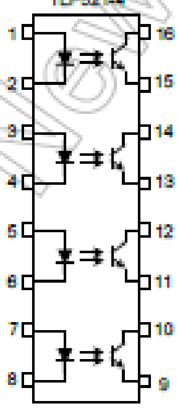
1 : Anode
2 : Cathode
3 : Emitter
4 : Collector

TLP521-2



1, 3 : Anode
2, 4 : Cathode
5, 7 : Emitter
6, 8 : Collector

TLP521-4



1, 3, 5, 7 : Anode
2, 4, 6, 8 : Cathode
9, 11, 13, 15 : Emitter
10, 12, 14, 16: Collector

Start of commercial production
1979-05

Absolute Maximum Ratings (Ta = 25°C)

	Characteristic	Symbol	Rating TLP521-1	Rating TLP521-2 TLP521-4	Unit
LED	Forward current	I_F	70	50	mA
LED	Forward current derating	ΔIF/°C	-0.93 (Ta ≥ 50°C)	-0.5 (Ta ≥ 25°C)	mA/°C
LED	Pulse forward current (100 μs pulse, 100 pps)	I_{FP}	1		A
LED	Reverse voltage	VR	5		V
LED	Diode power dissipation	P_D	150	100	mW
LED	Diode power dissipation derating	ΔPD/°C	-2.0 (Ta ≥ 50°C)	-1.0 (Ta ≥ 25°C)	mW/°C
LED	Junction temperature	T_j	125		°C
Detector	Collector-emitter voltage	VCEO	55		V
Detector	Emitter-collector voltage	V_{ECO}	7		V
Detector	Collector current	I_C	50		mA
Detector	Collector power dissipation (1 circuit)	PC	100		mW
Detector	Collector power dissipation derating (1 circuit) (Ta ≥ 25°C)	$\Delta P_C/°C$	-1.0		mW/°C
Detector	Junction temperature	Tj	125		°C
Storage temperature range		T_{stg}	-55 to 125		°C
Operating temperature range		T_{opr}	-55 to 100		°C
Lead soldering temperature (10 s)		T_{sol}	260		°C
Total package power dissipation (1 circuit)		PT	250	150	mW
Total package power dissipation derating (1 circuit) (Ta ≥ 25°C)		$\Delta P_T/°C$	-2.5	-1.5	mW/°C
Isolation voltage (AC, 60 s, R.H.≤ 60%) (Note 1)		BV_S	2500		Vrms

Note: Using continuously under heavy loads (e.g. the application of high temperature/current/voltage and the significant change in temperature, etc.) may cause this product to decrease in the reliability significantly even if the operating conditions (i.e. operating temperature/current/voltage, etc.) are within the absolute maximum ratings.
Please design the appropriate reliability upon reviewing the Toshiba Semiconductor Reliability Handbook ("Handling Precautions"/"Derating Concept and Methods") and individual reliability data (i.e. reliability test report and estimated failure rate, etc).

Note 1: Device considered a two terminal device: LED side pins shorted together and detector side pins shorted together.

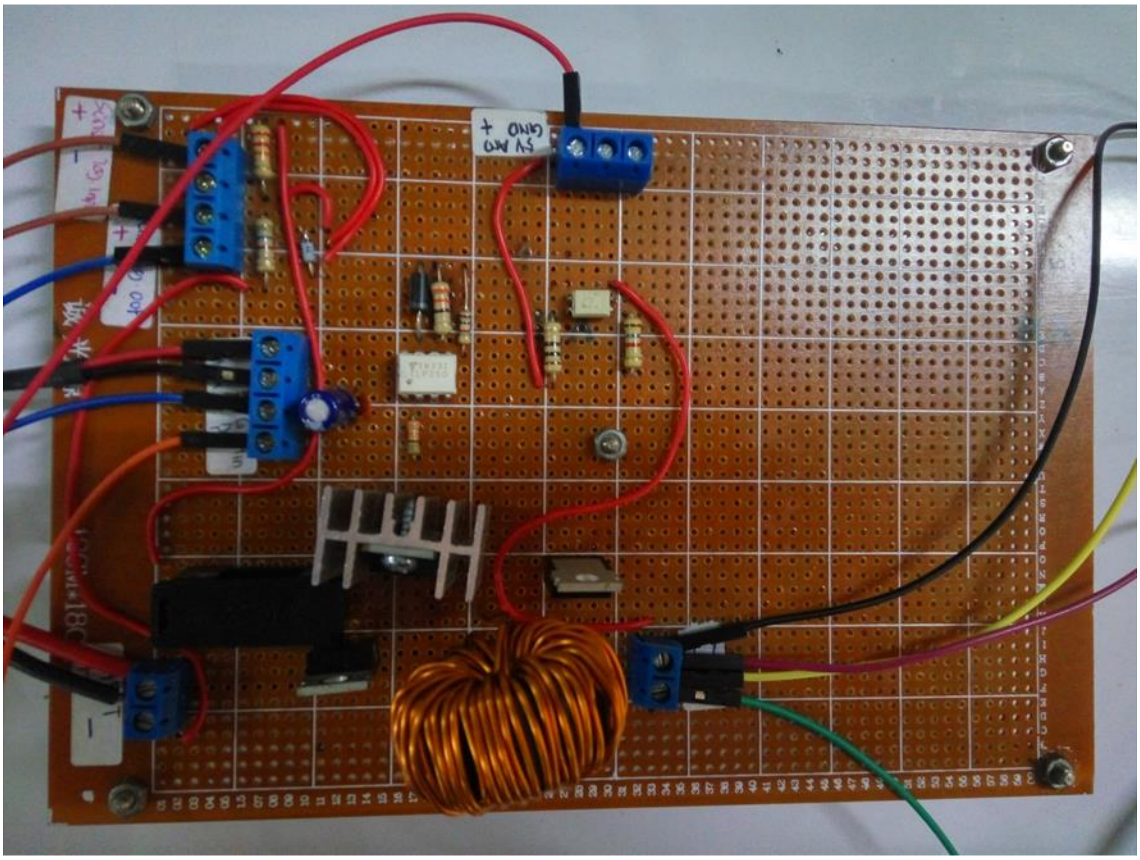
Recommended Operating Conditions

Characteristic	Symbol	Min	Typ.	Max	Unit
Supply voltage	V_{CC}	—	5	24	V
Forward current	I_F	—	16	25	mA
Collector current	IC	—	1	10	mA
Operating temperature	Topr	-25	—	85	°C

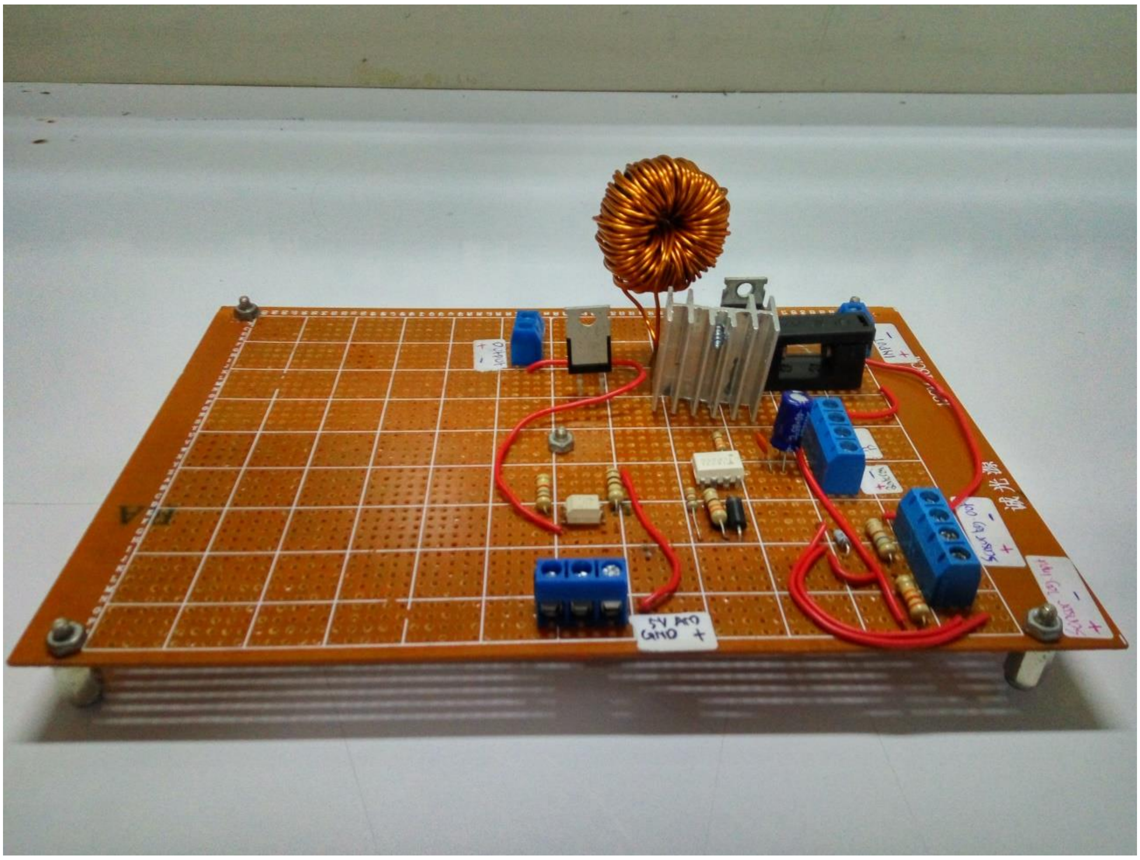
Note: Recommended operating conditions are given as a design guideline to obtain expected performance of the device. Additionally, each item is an independent guideline respectively. In developing designs using this product, please confirm specified characteristics shown in this document.

Lampiran 5 Daftar gambar alat rancang bangun sistem pengereman regeneratif

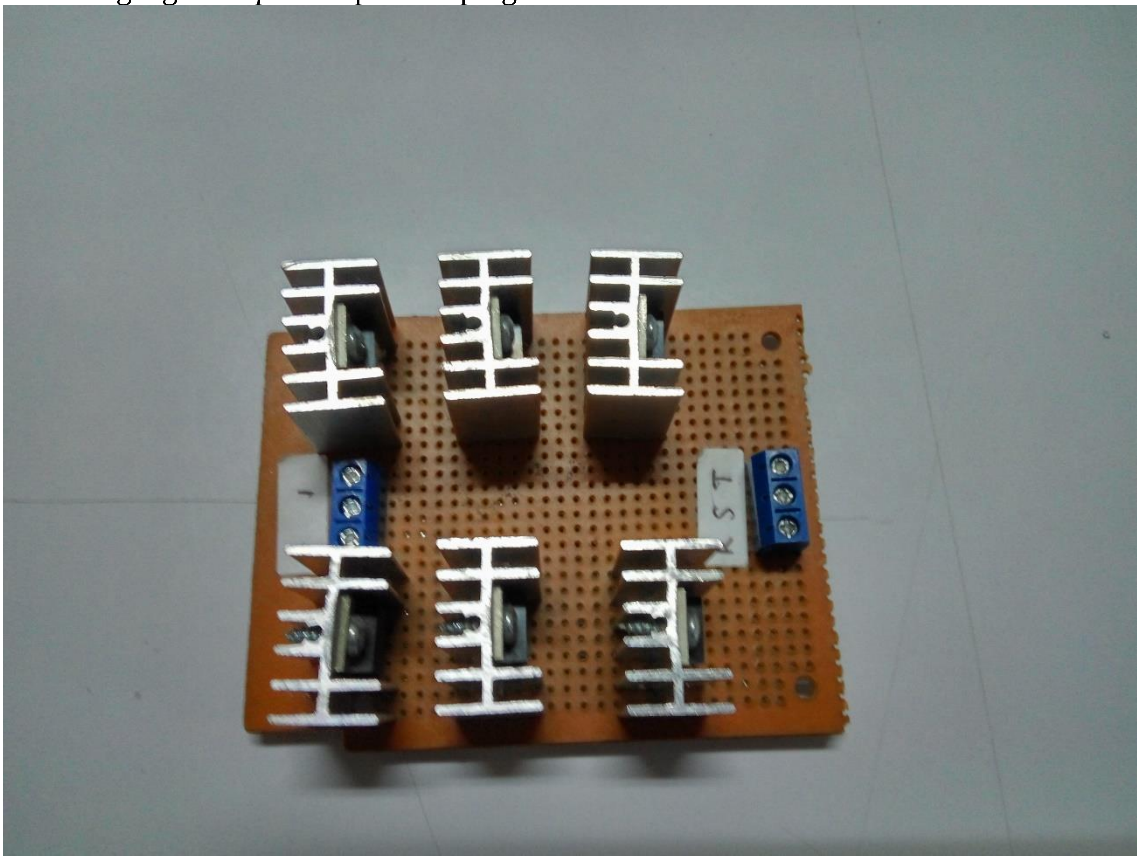
1. *Buck – boost converter*, sensor tegangan *input*, *driver* TLP 250, sensor tegangan *output*
2. Penyearah 3 fasa
3. Kapasitor perata
4. *Supercapacitor* 1 F/22 V
5. Sensor arus ACS712-5A dan *low pass filter*



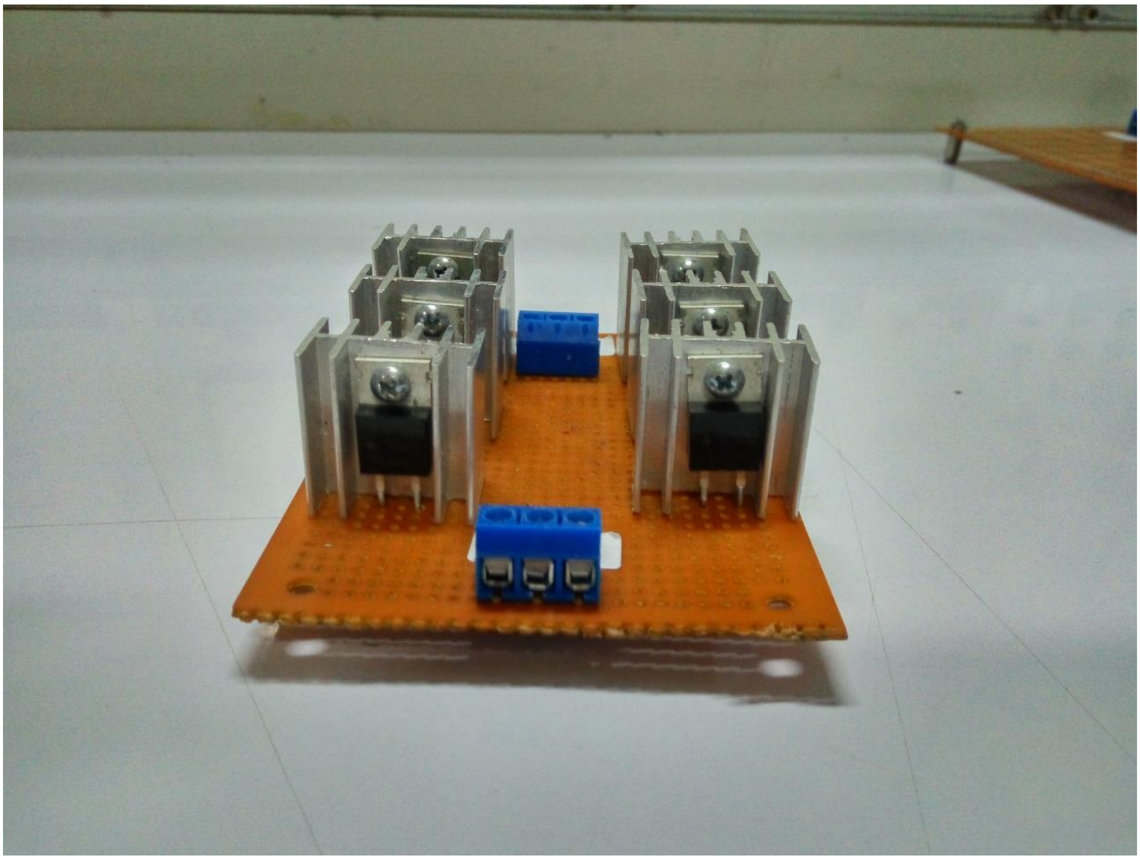
Gambar L5.1 Rangkaian *buck-boost converter*, sensor tegangan *input*, *driver* TLP 250, sensor tegangan *output* tampak atas



Gambar L5.1 Rangkaian *buck-boost converter*, sensor tegangan *input*, *driver* TLP 250, sensor tegangan *output* tampak samping

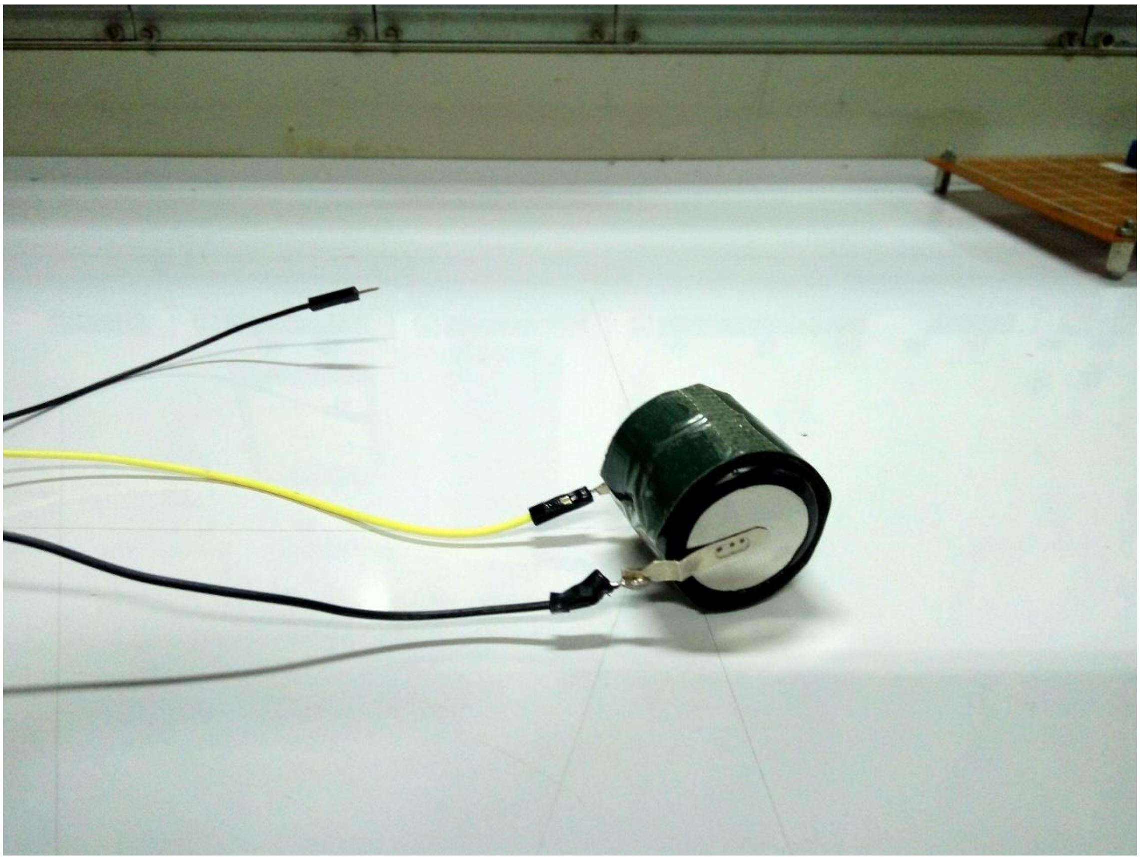


.Gambar L5.2 Rangkaian penyearah 3 fasa tak terkontrol tampak atas

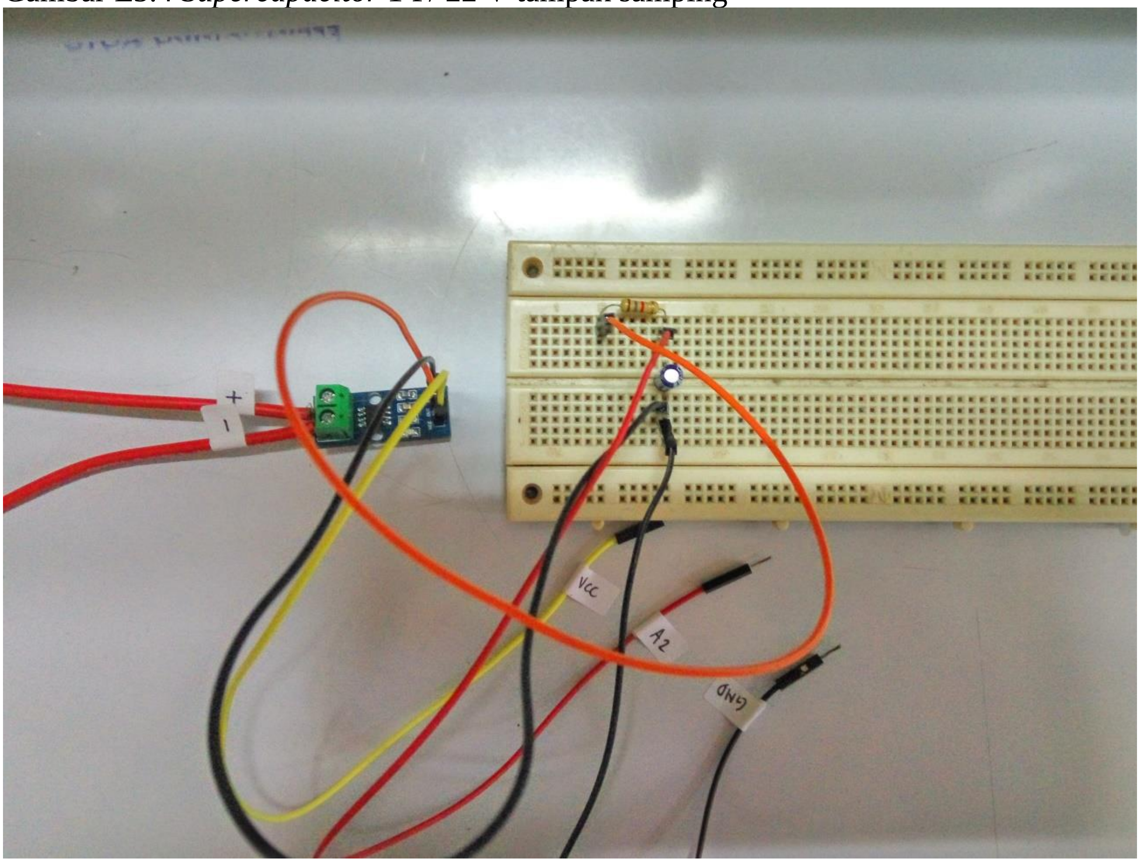


Gambar L5.2 Rangkaian penyearah 3 fasa tak terkontrol tampak depan

Gambar L5.3 Kapasitor perata 14,2 mF/150V tampak depan



Gambar L5.4 *Supercapacitor* 1 F/ 22 V tampak samping



Gambar L5.5 Sensor arus ACS712-5A dan *low pass filter* tampak atas