Z Source Inverter

A Project report submitted in partial fulfilment
of the requirements for the degree of B. Tech in Electrical Engineering

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DECLARATION

“We Do hereby declare that this submission is our own work conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute and that, to thebest of our knowledge and belief, it contains no material previously written by neither another person nor material (data, theoretical analysis, figures, and text) which has beenaccepted for the award of any other degree or diploma of the university or other instituteof higher learning, except where due acknowledgment has been made in the text.”

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CERTIFICATE

To whom it may concern

This is to certify that the project work entitled **Z Source Inverter** is the bona fide work carried out by **GHANSHYAM YADAV(11701618045), CHANDAN MAL (11701618052), AAMID FAROOQ(11701619048)**, a student of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2021-22, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and this project has not submitted previously for the award of any other degree, diploma and fellowship.

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ACKNOWLEDGEMENT

It is my great fortune that I have got opportunity to carry out this project work under the supervision of **Asst. Prof. Mr. Sarbojit Mukherjee** in the Department of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India. I express my sincere thanks and deepest sense of gratitude to my guide for his constant support, unparalleled guidance and limitless encouragement.

I wish to convey my gratitude to **Prof. (Dr.) Debasish Mondal**, HOD, Department of Electrical Engineering, RCCIIT and to the authority of RCCIIT for providing all kinds of infrastructural facility towards the research work.

I would also like to convey my gratitude to all the faculty members and staffs of the Department of Electrical Engineering, RCCIIT for their whole hearted cooperation to make this work turns into reality.

Thanks to the fellow members of our group for working as a team.

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: Table of Contents:

• List of Acronyms

AC - Alternate Current

DC – Direct Current

UPS – Uninterruptible Power Supply

ZSI – Z Source Inverter

VSI – Voltage Source Inverter

CSI – Current Source Inverter

SL ZSL – Switch Inductor Z Source Inverter

MOSFET – Metal Oxide Semiconductor Field Effect Transistor

ST – Shoot Through

PWM – Pulse Width Modulation

SBC – Simple Boost Control

Chapter - 1

(Introduction)

INTRODUCTION

1.1. Definition

Inverters are static power converters that produce an AC output waveform from a DC power supply. They are applied in adjustable AC speed drives, Uninterruptible Power Supplies (UPS), and shunt active power filters. Growing demand of renewable application results various type of inverter topology along with MPPT control [1], [2].

1.2. Types of inverter according to the phase –

1) Single-phase Inverter
2) Three-Phase Inverter

1.2.1. Single Phase Inverter

These are the inverter that converts the DC power generated and then convert into the single phase of AC power that you can use.

- **There are two types of Single-Phase Inverters**

1) Half Bridge Inverter
2) Full Bridge Inverter

- **Half-Bridge Inverter**

This type of inverter is the basic building block of a full-bridge inverter. It contains two switches and each of its capacitors has a voltage output equal to $\frac{V_{dc}}{2}$. In addition, the switches complement each other, that is, if one is switched ON the other one goes OFF.

- **Full Bridge Inverter**

This inverter circuit converts DC to AC. It achieves this by closing and opening the switches in the right sequence. It has four different operating states which are based on which switches are closed.

1.2.2. Three Phase Inverter

A three-phase inverter converts a DC input into a three-phase AC output. Its three arms are normally delayed by an angle of 120° so as to generate a three-phase AC supply. The inverter switches each have a ratio of 50% and switching occurs after every T/6 of the time T 60°angleinterval**.**

It has also two mode of conductions – 180° mode of conduction and 120° mode of conduction.

180° mode of conduction –

In the 180° mode of conduction, every device is in conduction state for 180° where they are switched ON at 60° intervals. These output terminals of the bridge connected to the three-phase delta or star connection of the load.

120° mode of conduction -

In this mode of conduction, each electronic device is in a conduction state for 120°. It is most suitable for a delta connection in a load because it results in a six-step type of waveform across any of its phases. Therefore, at any instant, only two devices are conducting because each device conducts at only 120°.

1.3. Types of Inverters

According to the source inverter. There are classified into two categories –

1. VSI (Voltage Source Inverter)
2. CSI (Current Source Inverter)
3. ZSI (Z Source Inverter)

1.3.1. Voltage Source Inverter

A voltage source inverter or VSI is a device that converts a unidirectional voltage waveform into a bidirectional voltage waveform, in other words, it is a converter that converts its voltage from DC form to AC form. An ideal voltage source inverter keeps the voltage constant throughout the process. VSI based different multilevel inverter is also available[3], [4].

- **Construction**

A VSI usually consists of a DC voltage source, voltage source, a transistor for switching purposes, and one large DC link capacitor. A DC voltage source can be a battery or a dynamo, or a solar cell, a transistor used maybe an IGBT, BJT, MOSFET, or GTO.

VSI can be represented in 2 topologies, a single-phase and a 3-phase inverter.

- **Each phase can be classified into two categories-**

1. Half-bridge inverter [5]
2. Full-bridge inverter [6]

- **Single Phase Half Bridge Voltage Source Inverter**

It consists of 1 DC voltage source, 4 transistors S1, S2, S3, S4, and 4 anti-parallel diodes D1, D2, D3, and D4 for switching purposes and one large DC link capacitor “C” as shown in circuit diagram –

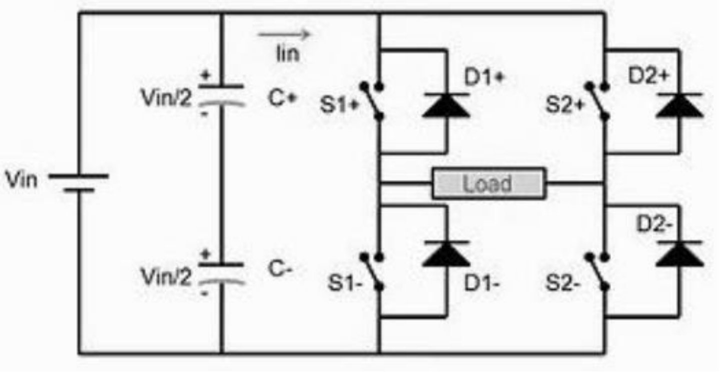

Fig 1 – Circuit Diagram of Single - Phase Half Bridge VSI

- **Three Phase Full Bridge Voltage Source Inverter**

It [7]consists of 6 transistors with T1, T2, T3, T4, T5, T6, 6 anti-parallel diodes like D1, D2, D3, D4, D5, D6, 3 load terminals, one DC source, and one large DC linked capacitor, and a thyristor is connected along with commutation circuit. The three outputs like "ABC", where "A" is connected to T1 & T4, "B" is connected to T3 and T6, and "C" is connected to T5 and T2. These ABCs are in turn connected to a 3 - phase balanced load.

A balanced load consists of 2 main components a source and a load, where a balanced source implies phase and magnitude are equal and are phase-shifted by 120 degrees. According to the KCL principle, the balanced load implies all the load impedances in all the 3 phases are equal in magnitude and phase. The thyristors T1, T3, and T5 supply current to the load or act as forwarding paths, whereas thyristors T6, T4, and T2 carry the current back to the source and act like return paths, as shown in figure – 2.

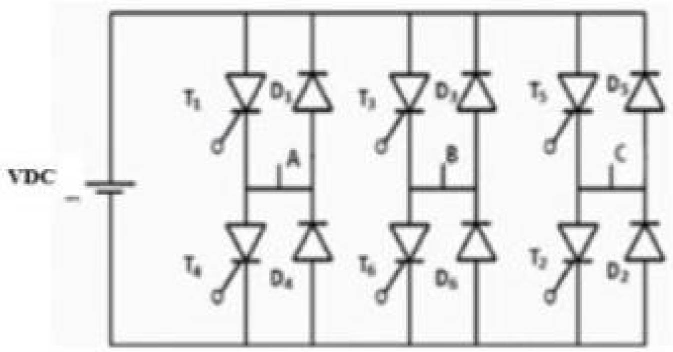

Figure 2 - Three Phase Full Bridge VSI

1.3.2. Current Source Inverter

The current source inverter [8]is also known as current fed inverter which converts the input dc into ac and its output can be three-phase or single phase. According to the definition of the current source, an ideal current source is the kind of source in which current is constant and it is independent of voltage.

- **Construction**

The voltage source is connected in series with a large value of inductance (L_d) and this named the circuit as the current source. The circuit diagram of the current source inverter fed induction motor drive is shown in the figure.

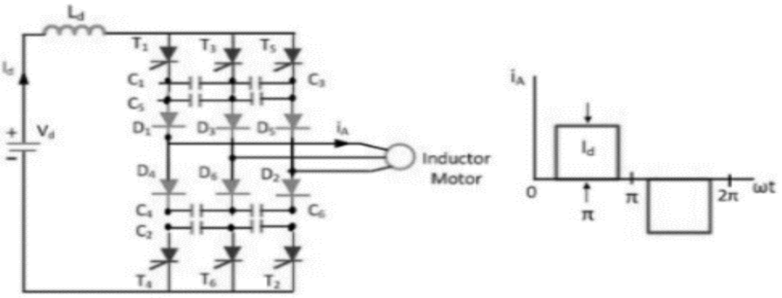

Fig 3 – Current Source Inverter

The circuit consists of six diodes (D_1, D_2, D_3, D_4, D_5, D_6), six capacitors (C_1, C_2, C_3, C_4, C_5, C_6), six thyristors (T_1, T_2, T_3, T_4, T_5, T_6) which are fixed with a phase difference of 60^0. The inverter output is connected to the induction motor. For a given speed, torque is controlled by varying the dc-link current I_d and this current can be varied by varying the V_d. The conduction of two switches in the same lag doesn't lead to a sudden rise of current due to the presence of a large value of inductance L_d.

1.3.3. Z Source Inverter

A Z-source inverter (ZSI) [9]–[11] is a type of power inverter, a circuit that converts direct current to alternating current. It functions as a buck-boost inverter without making use of a DC-DC converter bridge due to its unique circuit topology. Impedance (Z-) Source networks provide an efficient means of power conversion between source and load in a wide range of electric power conversion applications (dc-dc, dc–ac, ac–dc, ac– ac). Z-source-related research has grown rapidly.

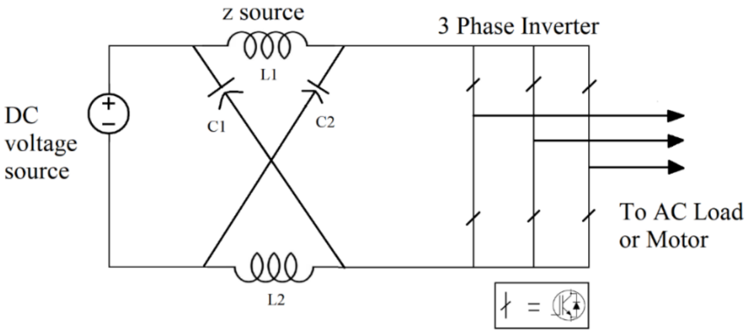

Fig 4 - Circuit Diagram of Z Source Inverter

Chapter - 2

(Literature Review)

The work on this paper[12] is focusing on Quasi-Switch- inductor z-source Inverter. This work on traditional Z-source Inverter but has unique feature of capacitor H-bridge circuit, simplified structure of QSLZSI. Reduce component count, simple control strategies, and higher boost factor. In this paper describe how QSLZSI better and overcome drawback in ZSI, QZSI. In this paper describe the operating principle of the QSL performative analysis and comparison with traditional ZSI, summary of stress. It is also discuss in simulation, an experimental result section on simulation and experimental verification. The conclusion of this paper is given as comparsion with traditional ZSI are QSLZSI has simplified topology structure simplifies control strategies proposed topology is suitable in applicational where input voltage varies in a wide range like fuel cell and photovoltaic power conditioning system.

The work on this paper[13] is focusing on L-Z-Source Inverter. In this ZSI , it contain inductors and diodes. This uses a unique diode network and inductor for boosting its output voltage with the common ground as for dc source and inverter and keeping in mind to avoid disadvantage by a capacitor which is mainly use in ZSI, SL- ZSI. In this paper desribed the operation principles, extenion of the Z-Source Impedance Network. With the feature comparison with other ZSI like Boost Ability and Stress Comparison, Inrush current and Voltage Overshoot analysis, efficiency analysis and comparison, Simulation and experimental result. The conclusion of this paper is given as the unique inductor and network diode are low voltage source to main circuit invertor without hampering classical ZSI and SL-ZSI.

The work on this paper [14]is focusing on very high boost required on dc-dc boost converters. For high boost, their would be lose of efficiency required more sensesfor controlling.This is a signal buck-boost as presence of x shape impedance network. It is explain extended-boost ZSI topologies where it diode-assisted extended-boost ZSI topologies, Capacitor-Assisted Extended-Boost qZSI Topologies, Hybrid Extended-Boost qZSI Topologies, Parasitic Effects on the Voltage Gain. In simulation section, the input voltage is 100 V, three phase load is 130 ohm, dc side capacitor are 1000 micro Farad, Inductor is 6.3mh,ac side second order filter is 10 uF capacitor, inductor 6.3mH used

Chapter - 3

(Theory)

3.1. Operations of ZSI

The ZSI [12] has a unique impedance network with two split inductors and two capacitors which are anti-parallel to the source and we can see the X-shape made in the circuit diagram. There are six MOSFETs (Metal Oxide Semiconductor Field Effect Diode) that work as a switch. The three-phase ZSI bridge has nine permissible switching states while the traditional Voltage source inverter (VSI) has eight switching states. The ZSI has six active states when the DC voltage is impressed across the three-phase load and two zero states when the load terminals are shorted through either the lower or upper three switching devices, respectively. The ninth state, the ST state occurs when the load terminals are shorted by both the upper and lower switching devices of any phase leg (this state is forbidden in the traditional inverters to avoid ST fault). This ST state sometimes also called the 'third zero state' can be achieved in seven different ways: ST via any phase, combination of any two-phase legs, and all three-phase legs. This added network allows switches from the same phase leg to be turned ON simultaneously without causing damage. Instead, the shoot-through state-created causes the inverter output to be boosted without distortion if it is used properly with the other eight non-shoot - through active and null states. Impedance (Z-) source network is the combination of two linear energy storage elements that is L and C. However, to improve the performance of the circuit, different configurations of network are possible with the addition of non-linear elements such as diodes or switches into the impedance network. Boost factor B of this topology can be defined as

$$B = \frac{v_{dc}}{v_{in}} = \frac{1}{1-2D}, D = \frac{T_0}{T}$$

D is duty ratio and T_0 is interval of shoot-through zero state. Modulation index M of Z-source inverter is

$$M \leq 1 - D$$

where, M is the ratio of amplitude of modulation waveform and carrier waveform. The concept of Z-source can be applied to all power conversions. Furthermore, they can be divided into two level and multilevel topologies or isolated and non-isolated inverters. Z-source inverter has wide variety of voltage range (between 0 and ∞) because of its unique characteristics of buck-boost capability. Circuit diagram of Z-source inverter during shoot through and active states is shown. During shoot through state, output terminals of network are shorted by a switch, which reverse-bias the diode in impedance network. In active stage, stored energy of inductors and capacitors is transmitted to the load. The aim of this is to design simple Z source inverter and through its topology briefly and its applications. Mainly this is used in industries rather than the other. We also see how does it work, its simulations with all graphs across inductors, capacitors, PWM (Pulse Width Modulation) and load. This unique feature also increases the immunity of the inverters to electromagnetic noise, which may cause uncontrolled shoot-through zero (or open circuit) that destroys the conventional VSIs and CSIs, respectively. Meanwhile, in a ZSI, both switches in a leg can be turned on simultaneously to eliminate dead time and to improve the quality of the output waveform. Moreover, others have focused on their modelling and control operating modes, and new Z-network topologies. Despite these advantages, the ZSI has some obvious drawbacks, such as discrete input current, which leads to low utilization and lifetime damage of the dc source, large voltage stress across the switches and capacitors, huge inrush current, and a lower modulation index for high - gain output voltage that leads to poor output voltage waveform quality. The design and control of inverters also play a crucial part in maximizing the power transfer and increasing the operating efficiency and reliability of the total power conversion system. Because of these flexibilities, ZSIs have already been investigated for a number of applications, such as motor drives, electric vehicles, distributed generation, photovoltaic generation, uninterruptible power supply, and fuel-cell converters.

3.2. Equivalent Circuit and Operating States of ZSI

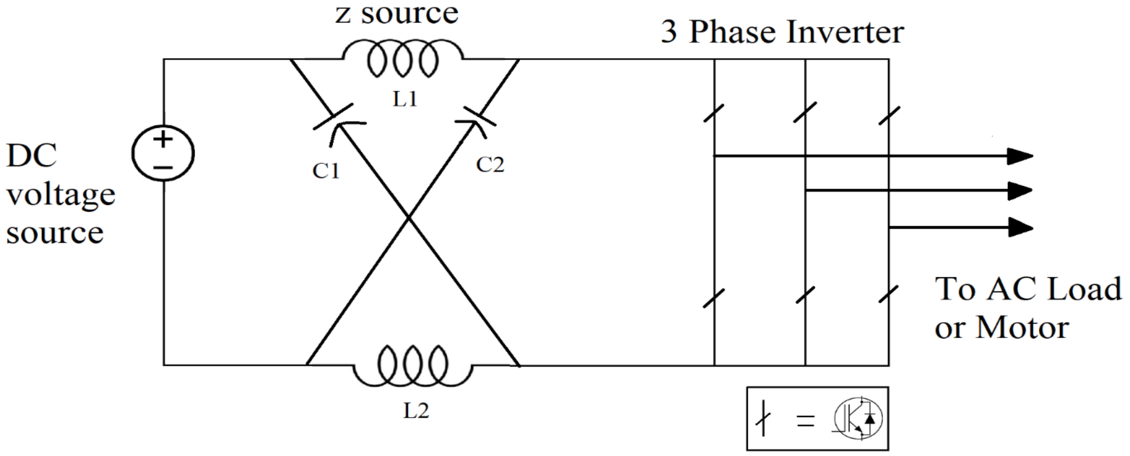

Fig 5 - Circuit Diagram of ZSI

Depending upon the switching states of the inverter bridge, the ZSI can be classified into three operation modes as given below -

1. Active State
2. Zero State or Null State
3. Shoot Through State

3.2.1. Mode 1 – Active state

Inverter bridge is operating in one of the six active states and the bridge can be seen as an equivalent current source. During this mode, the DC source voltage appears across the ‘inductor and the capacitor’. The capacitor is charged (stays charged at a steady-state) and energy flows to the load via the inductor. That energy gets delivered to the inverter. And in this way the inductor discharges in this mode.

Time Interval is T_{active}. Therefore, the switching time period T_s is given by $T_s = T_{shoot} + T_{active}$.

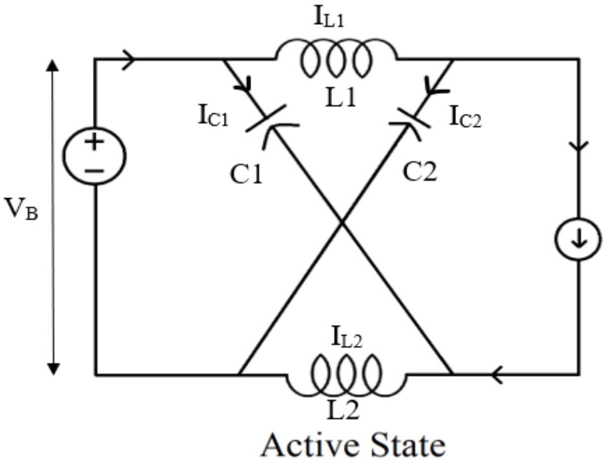

Fig 6 - Active State

3.2.2. Mode 2 – Zero state

Inverter bridge is operating in one of the two zero states as the bridge ‘short circuits’ the load through either the upper or lower three switching devices. During this mode, the bridge can be viewed as an ‘open-circuit’ (current source with zero current flowing). The voltage of the DC source appears across the ‘inductor and the capacitor’, except that no current flows to the load, from the DC source.

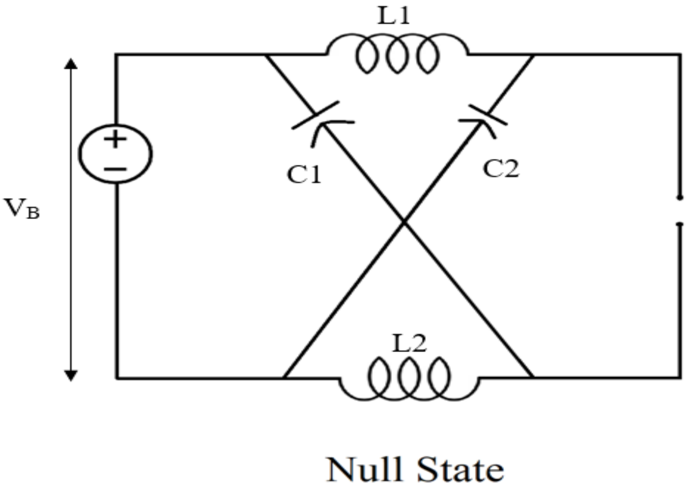

Fig 7 – Zero State or Null State

3.2.3. Mode 3 – Shoot Through State

Inverter bridge is operating in one of the seven different ways of ST. The bridge is viewed as a ‘short circuit’ from the DC link of the inverter. During this mode, no voltage appears across the load like in the zero-state operation, the DC voltage of the capacitor is boosted to the required value according to the ST duty ratio. This ST interval (T_0) is inserted into the zero states to boost the voltage whenever the PV panel is unable to provide the required voltage or during any voltage dips because of the changing insolation (irradiance) and temperature. Although in this mode the DC source (PV) is separated from the inverter bridge by the diode (V_d. V_{PV}, V_d ¼ 2VC) and the voltage across the capacitors appears across inductors, hence charges the inductor.

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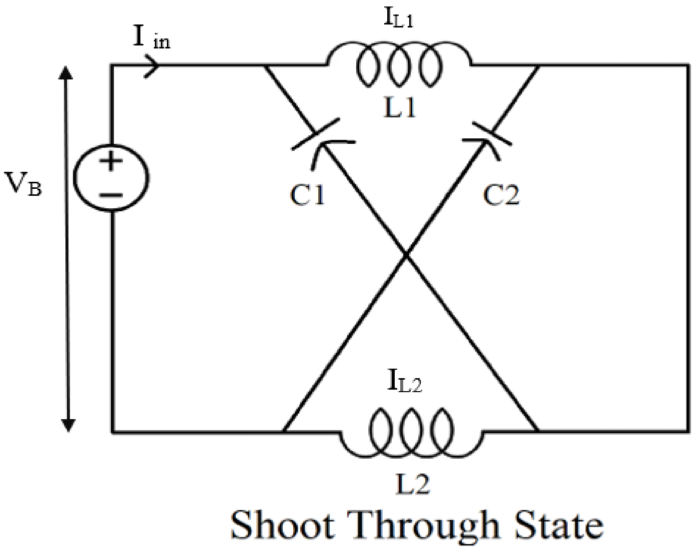


Fig 8 – Shoot Through State

The ZSI is working in a shoot-through state during the time interval $T_{shoot.}$ Therefore, the sum of the two voltage capacitors ($V_{C1} + V_{C2}$) is greater than the input battery voltage ($V_{C1} + V_{C2} > V_B$)

It is noted that the diode conducts in both modes 1 and 2 [non-shoot-through (non-ST)] whereas it is reversed biased during mode 3 (ST).

3.3. Circuit Analysis of ZSI

i. During Shoot Through State: -

- The voltage across both the capacitors C1 & C2 and the inductors L1 & L2 is given by-

$V_I = V_C$ - (eqn-1)

- The inverter input voltage $V_{in} = 0$
- During the Active State: -
- The inductor voltage V_L is given by,

$V_L = V_B - V_C$ - (eqn-2)

- The Z Source Inverter input voltage is given by

$V_{in} = V_C - V_L = 2V_C - V_B$ - (eqn-3)

- The average voltage of the inductor across L1 or (L2) over one switching period in steady-state operation is zero.
- The inductor voltage V_L is given by: -

$V_L = (V_B - V_C)\, T_{active} + V_C\, T_{shoot}$ -(eqn-4)

3.4. Circuit Analysis of ZSI – Boost Factor

- Capacitor Voltage (V_C) of ZSI is given by: -

$$V_C = \frac{T_{active}}{T_{active} - T_{shoot}} V_B \text{ − (eqn − 5)}$$

- Inverter input voltage (V_{in}) or DC link voltage is given by: -

$$V_{in} = \frac{T_s}{T_{active} - T_{shoot}} V_B = B.V_B \text{ − − − − − − − − − − − − − − − − −(eqn − 6)}$$

$T_S = T_{active} + T_{Shoot}$

- Voltage boost ability of the inverter depends upon the Boost Factor (B) and it is given by:

$$B = \frac{T_s}{T_{active} - T_{shoot}} = \frac{1}{1 - 2\frac{T_{shoot}}{T_s}} = \frac{1}{1 - 2d} \text{− − − − − − − − − − − − −(eqn − 7)}$$

- By adjusting the boost factor, the output voltage of the Z source inverter can be increased or decreased.
- Duty ratio, $d = \frac{T_{Shoot}}{T_S}$

3.5. Output Voltage of Z Source Inverter

- According to the theory, the output peak voltage of ZSI is: -

$$V_{ac} = M\frac{V_{in}}{2} \text{ −(eqn − 8)}$$

$$V_{ac} = M\frac{B\,.V_B}{2} = M.B\,\frac{V_B}{2} \text{− − − − − − − − − − − − − − − − − −(eqn − 9)}$$

- The Voltage Gain (G) of the ZSI is the ratio of inverter output voltage to the inverter input voltage and is given by: -

$$G = \frac{V_{ac}}{V_B/2} = M.B \text{ − − − − − − − − − − − − − − − − − − − (eqn − 10)}$$

Where M = Modulation Index

B = Boost Factor

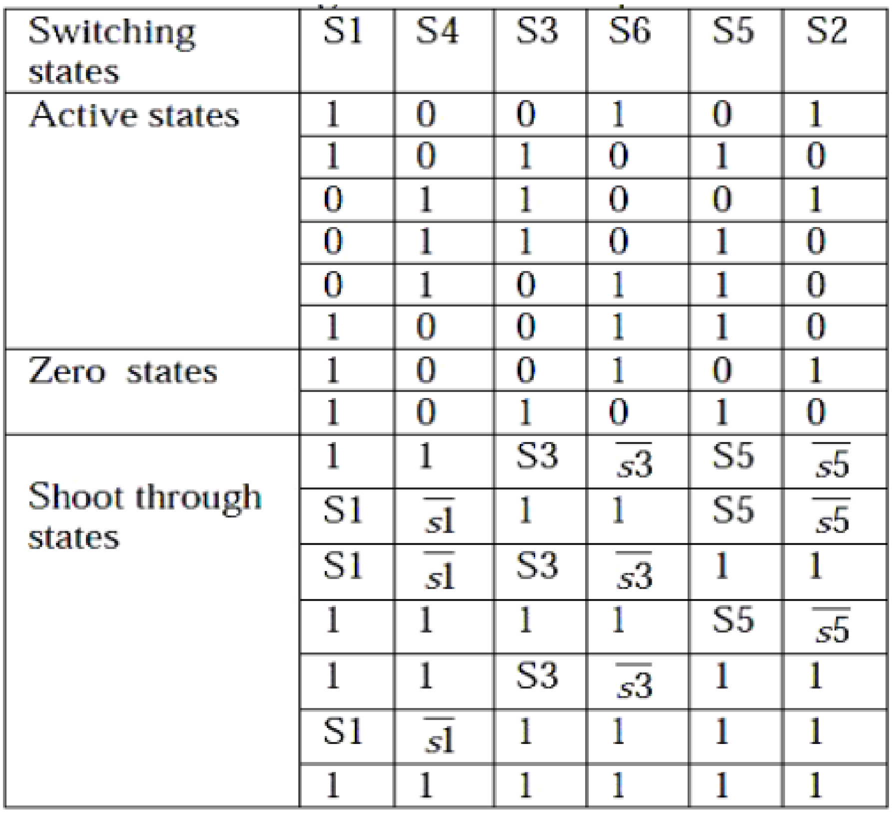
Therefore, any desired output voltage can be obtained by properly selecting the boost factor and modulation index regardless of battery bank voltage.

3.6. Circuit topology and operating states of a three-phase ZSI

The topology of the three-phase Z-source inverter, where the impedance network is placed between the power source and the inverter.

As shown in the table. I, a three-phase Z-source inverter has nine possible switching states: six active states (vectors) when the dc voltage is impressed across the load, two zero states (vectors) when the load terminals are shorted through either the lower or the upper three switches and one shoot through the state (vector) when the load terminals are shorted through both the upper and the lower switches of any one leg or two legs or all three legs. These switching states and their combinations introduce a new PWM method for the Z-source inverter.

Table 1: Switching states of a Three-Phase ZSI



Switching states	S1	S4	S3	S6	S5	S2
Active states	1	0	0	1	0	1
	1	0	1	0	1	0
	0	1	1	0	0	1
	0	1	1	0	1	0
	0	1	0	1	1	0
	1	0	0	1	1	0
Zero states	1	0	0	1	0	1
	1	0	1	0	1	0
Shoot through states	1	1	S3	$\overline{s3}$	S5	$\overline{s5}$
	S1	$\overline{s1}$	1	1	S5	$\overline{s5}$
	S1	$\overline{s1}$	S3	$\overline{s3}$	1	1
	1	1	1	1	S5	$\overline{s5}$
	1	1	S3	$\overline{s3}$	1	1
	S1	$\overline{s1}$	1	1	1	1
	1	1	1	1	1	1

3.7. PWM (Pulse Width Modulation)

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

3.8. PWM Control Methods

Various Sinusoidal Pulse Width Modulation (SPWM) schemes can be applied to the ZSI and their input-output relationship is still hold. Minor modifications in SPWM techniques can provide shoot-through pulses for ZSI.

3.8.1. Different PWM methods used to control ZSI are as follows:

a) Simple Boost Control (SBC) with triangular carrier PWM
b) SBC with sine carrier PWM
c) Maximum boost control and Maximum boost control with third harmonic injection

- **SBC with Triangular Carrier PWM**

In this technique, firing pulses are generated by comparing three sinusoidal reference signals and two constant voltage envelopes with the triangular carrier wave. The sinusoidal reference signals are phase displaced by 120 degrees and the amplitude of two envelopes is equal to the peak amplitude of reference signals. When the magnitude of the triangular carrier wave is greater than or equal to the positive envelope (or) lower than or equal to the negative envelope, shoot-through pulses are generated and they control the shoot-through duty ratio. The reference sinusoidal voltage signals along with the triangular carrier wave and two constant DC voltages are shown in Figure- 9a. The pulses produced using this method are shown in Figure-9b. For a complete switching period T_S, T_0 are the zero state time periods and D0 is the shoot-through duty ratio

$$(D_0) = \frac{T_0}{T_s}$$

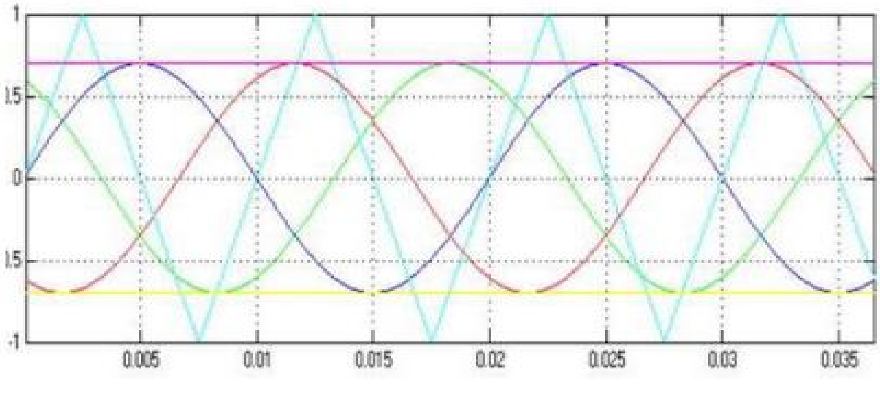


Figure 9(a) - Illustration of SBC with triangular carrier PWM.

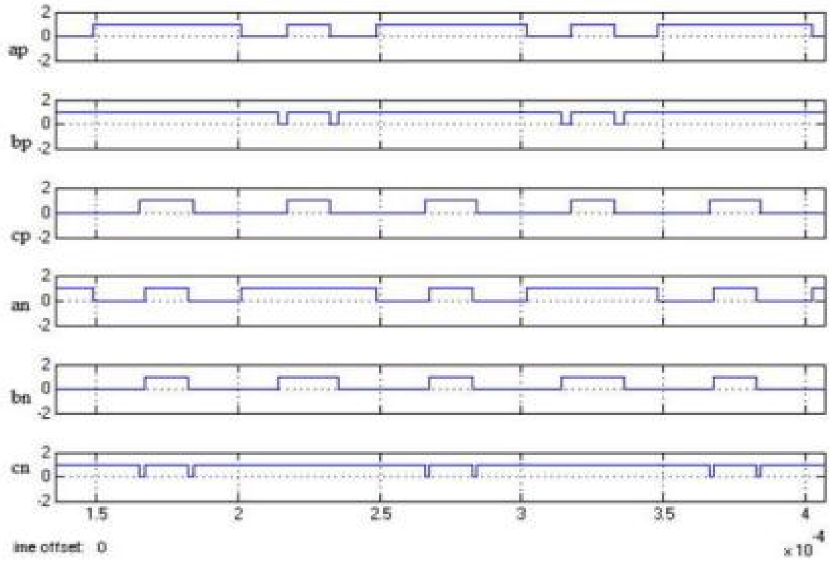


Figure-9(b). The pulse is generated using SBC with a triangular carrier wave.

The shoot through duty ratio (D_0), boost factor (B) and voltage gain (G) with triangular carrier wave are given by,

$$D_0 = 1 - M \quad ----------------------(eqn-11)$$

$$B = \frac{1}{2M-1} ------------------------(eqn-12)$$

$$G = \frac{M}{2M-1} ------------------------(eqn-13)$$

Where, M is the Modulation Index

- **SBC with Sine carrier PWM**

In the conventional method of simple boost control, it is necessary to boost the shoot-through duty ratio to achieve boosted output voltage which is possible with the low value of the modulation index. But the decrement in modulation index leads to high voltage stress on the device. So, it restricts the gain. The simple boost control with a high-frequency sinusoidal carrier wave helps to maximize the output voltage for a given modulation index. For the same modulation index, the sinusoidal carrier PWM can give a higher shoot-through duty ratio compared to the triangular carrier wave and gives a high boost factor and hence high peak output voltage. The reference sinusoidal voltage signals along with the sinusoidal carrier wave and two envelopes are shown in Figure-10a. The pulses produced using this method are shown in Figure-10b.

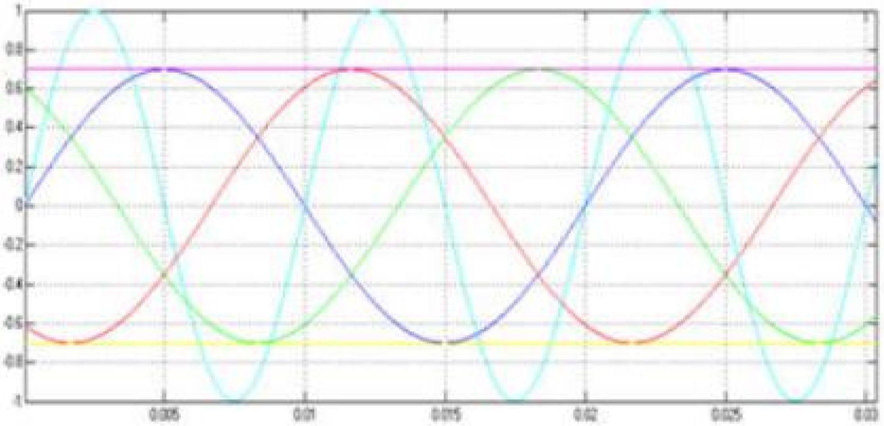


Figure-10(a). Illustration of SBC with sine carrier PWM

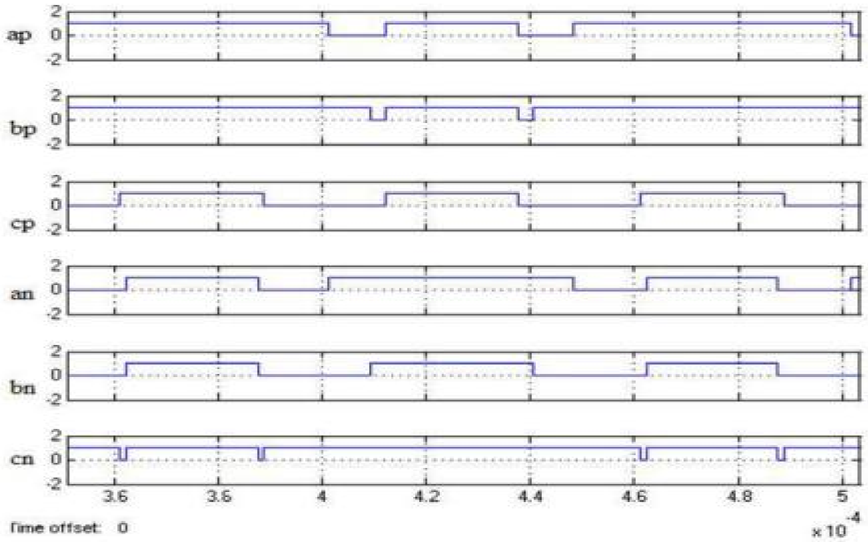


Figure-10(b). The pulse was generated using SBC with sine carrier PWM.

The relations between shoot through duty ratio (d), boost factor (B) and voltage gain (G) with sine carrier wave are as follows

$$d = 1 - \frac{2}{\pi}\sin^{-1} M - (eqn - 14)$$

$$B = \frac{\pi}{4\sin^{-1} M - \pi} - - - - - - - - - - - - - - - - - - (eqn - 15)$$

$$G = \frac{\pi M}{4\sin^{-1} M - \pi} - - - - - - - - - - - - - - - - - - (eqn - 16)$$

- **Maximum Boost Control**

  In this method, all the zero states are turned into shoot through state and hence the voltage stress is minimized. Voltage gain is improved. The circuit is in the shoot-through state when the triangular carrier wave is either higher than the maximum curve of the references (V_a, V_b, and V_c) or lower than the minimum of the references. The shoot-through duty cycle varies with each cycle. The maximum boost control method introduces a low-frequency current ripple associated with the output frequency in the inductor current and the capacitor voltage. This will cause a higher requirement of the inductance and capacitance when the output frequency becomes low. The illustration of maximum boost control is shown in Figure-5a and the pulses obtained are shown in Figure5b.To increase the modulation index range, third harmonic injection is commonly used in a three-phase inverter system. Thus, voltage gain is increased. The illustration of maximum boost control with third harmonic injection is shown in Figure-11a and pulses produced are shown in Figure-11b. In this control, the maximum modulation index $M = \frac{2}{\sqrt{3}}$ can be achieved at 1/6 of third harmonic injection.

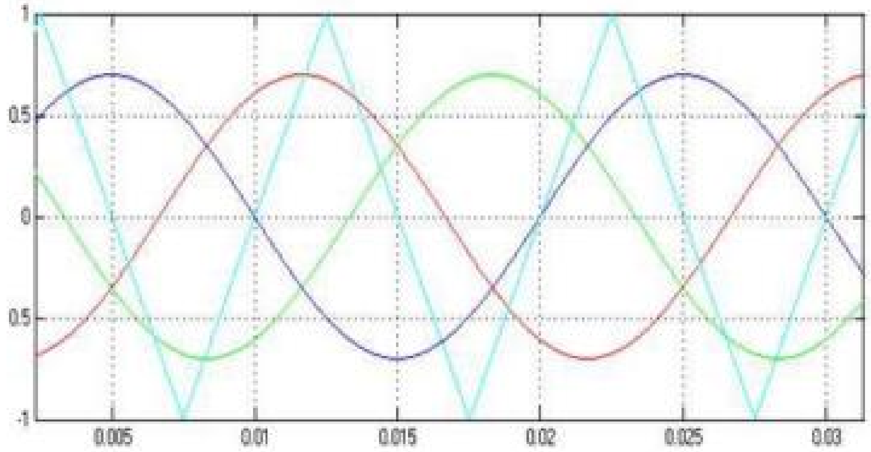


Figure-11(a). Maximum boost control

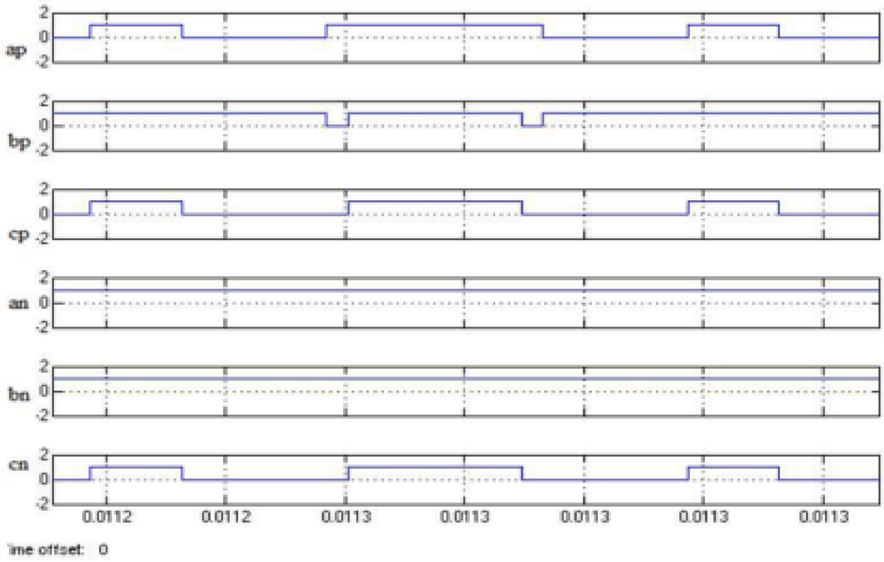


Figure-11(b). The pulse is generated using maximum boost control.

The relations between shoot through duty ratio (d) boost factor (B) and voltage gain (G)for maximum boost control are given as follows: -

The shoot through state appears at the interval of $\left(\frac{\pi}{3}\right)$. Shoot through occurs at the intervals $\left(\frac{\pi}{6}, \frac{\pi}{2}\right)$ can be derived as,

$$\frac{T_0(\theta)}{T} = 2 - \left(M\sin(\theta) - M\sin\left(\theta - \frac{2\pi}{3}\right)\right) - - - - - - - - - - -(\text{eqn - 17})$$

$$\frac{T_0(\theta)}{T} = \int_{\frac{\pi}{2}}^{\frac{\pi}{6}} \frac{T_0(\theta)}{T} = 2 - (M\sin(\theta) - M\sin\left(\theta - \frac{2\pi}{3}\right))d\theta = \frac{2\pi - 3\sqrt{3}M}{2\pi} - -(\text{eqn} - 18)$$

Boost factor B is obtained as

$$B = \frac{\pi}{3\sqrt{3}M - \pi} - - - - - - - - - - - - - - - - -(\text{eqn} - 19)$$

$$G = \frac{\pi M}{3\sqrt{3}M - \pi} - - - - - - - - - - - - - - - - -(\text{eqn} - 20)$$

Maximum modulation index for a given voltage gain G is,

$$M = \frac{\pi G}{3\sqrt{3}G - \pi} - - - - - - - - - - - - - - - - - - (\text{eqn} - 21)$$

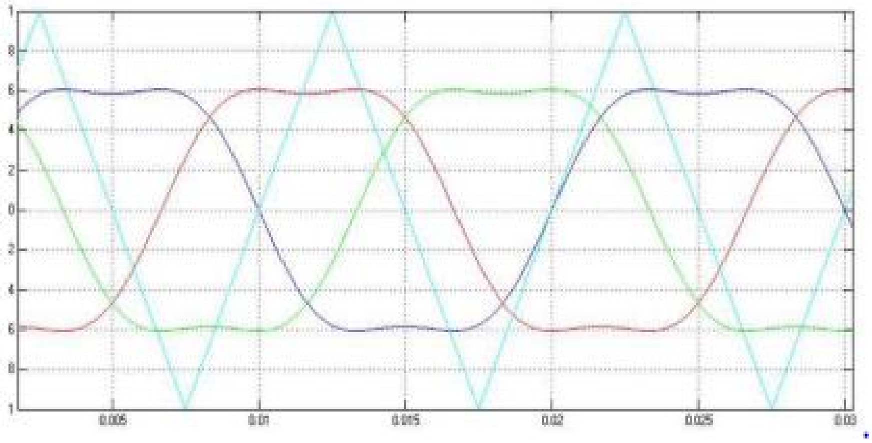


Figure-12(a). Illustration of maximum boost control with third harmonic injection.

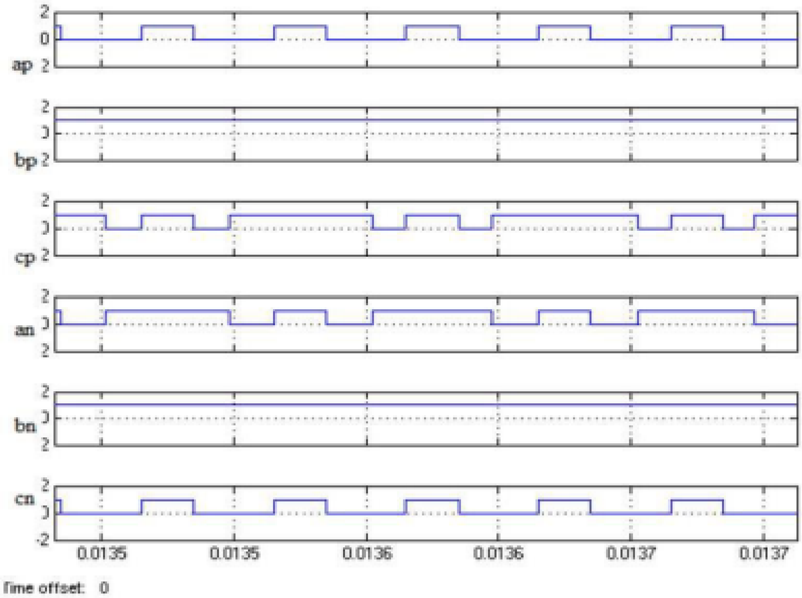


Figure-12(b). Pulse generated using maximum boost control with third injection harmonic

The relations between shoot through duty ratio (d), boost factor (B) and voltage gain (G) for maximum boost control with third harmonic injection are given as follows: -

The shoot through state appears at the interval of every $\left(\frac{\pi}{3}\right)$ in this control also. The expression for the shoot through for the interval $\left(\frac{\pi}{6},\frac{\pi}{2}\right)$ is given below [10],

$$\frac{T_0(\theta)}{T} = \frac{2-\left(MSin(\theta)+\frac{1}{6}MSin(3\theta)-MSin\left(\theta-\frac{2\pi}{3}\right)+\frac{1}{6}MSin(3\theta)\right)}{2} --- (\text{eqn}-22)$$

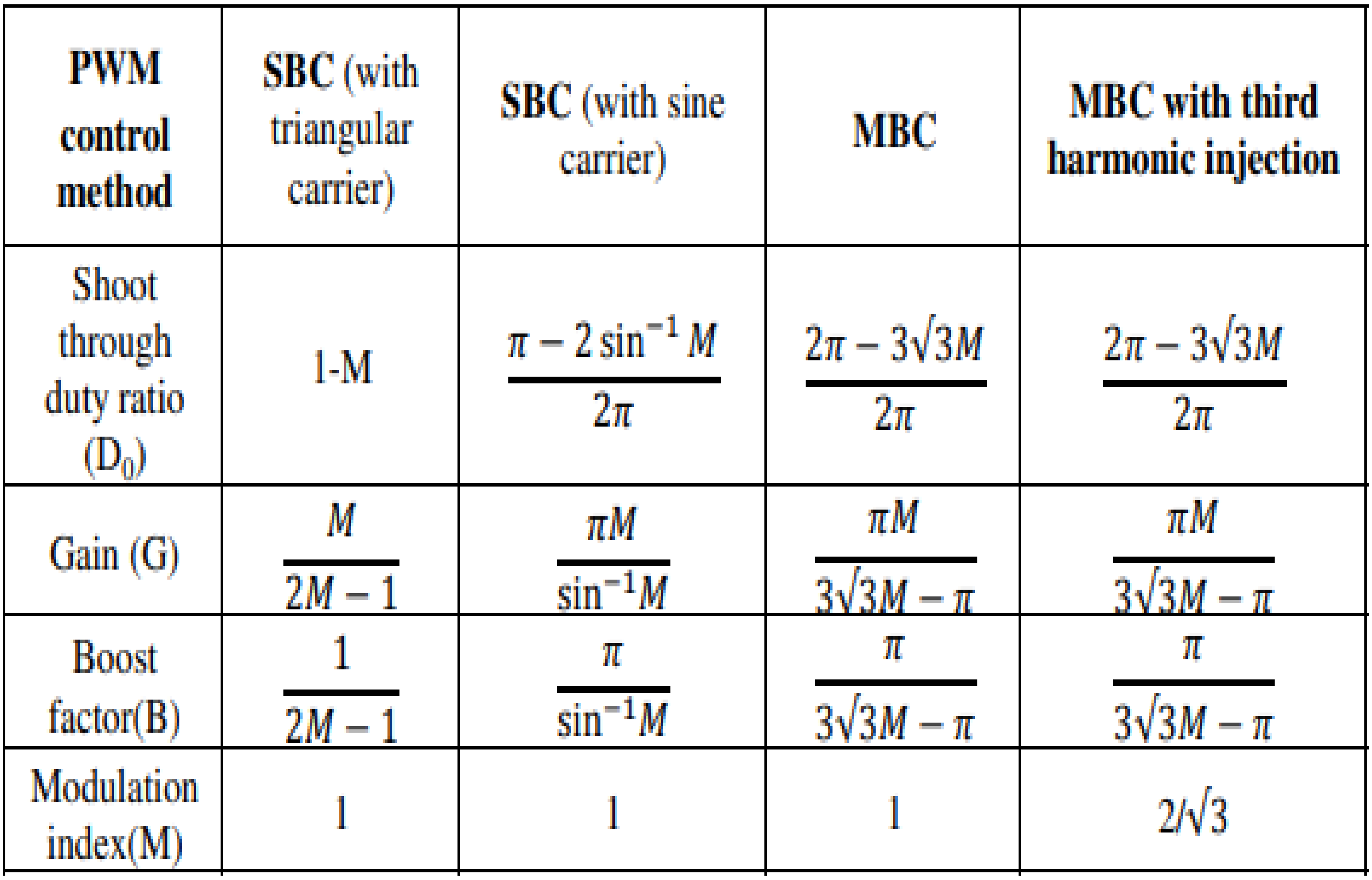
$$\frac{T_0(\theta)}{T} = \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{2-\left(\text{MSin}(\theta)+\frac{1}{6}\text{MSin}(3\theta)-\text{MSin}\left(\theta-\frac{2\pi}{3}\right)+\frac{1}{6}\text{MSin}(3\theta)\right)}{2} d\theta = \frac{2\pi-3\sqrt{3}\text{M}}{2\pi} (eqn\ 23)$$

Boost factor is given as,

$$\text{B} = \frac{\pi}{3\sqrt{3}\text{M}-\pi} -----------------(\text{eqn}-24)$$

Also, maximum modulation index can be obtained as $\frac{2}{\sqrt{3}}$.

3.9. Comparison of various PWM control expressions.



PWM control method	**SBC** (with triangular carrier)	**SBC** (with sine carrier)	**MBC**	**MBC with third harmonic injection**
Shoot through duty ratio (D_0)	1-M	$\frac{\pi - 2\sin^{-1} M}{2\pi}$	$\frac{2\pi - 3\sqrt{3}M}{2\pi}$	$\frac{2\pi - 3\sqrt{3}M}{2\pi}$
Gain (G)	$\frac{M}{2M-1}$	$\frac{\pi M}{\sin^{-1}M}$	$\frac{\pi M}{3\sqrt{3}M - \pi}$	$\frac{\pi M}{3\sqrt{3}M - \pi}$
Boost factor(B)	$\frac{1}{2M-1}$	$\frac{\pi}{\sin^{-1}M}$	$\frac{\pi}{3\sqrt{3}M - \pi}$	$\frac{\pi}{3\sqrt{3}M - \pi}$
Modulation index(M)	1	1	1	$2/\sqrt{3}$

Chapter - 4

Circuit Diagram

4.1. Circuit Diagram

4.1.1. MATLAB Simulation

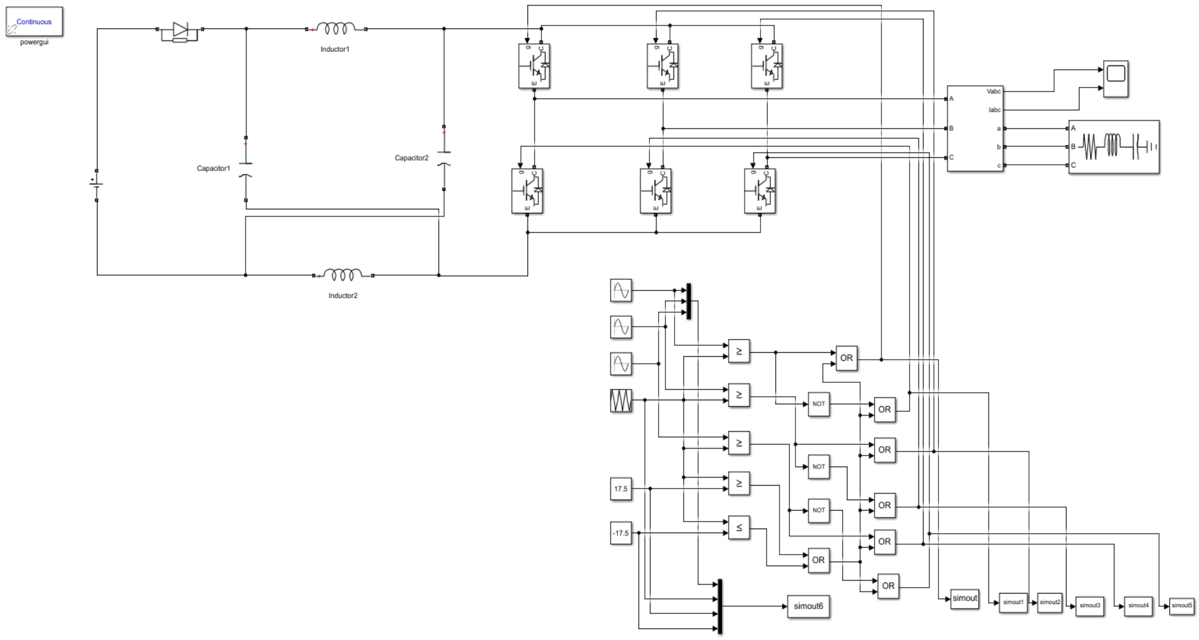


Fig – 13 MATLAB Circuit of ZSI

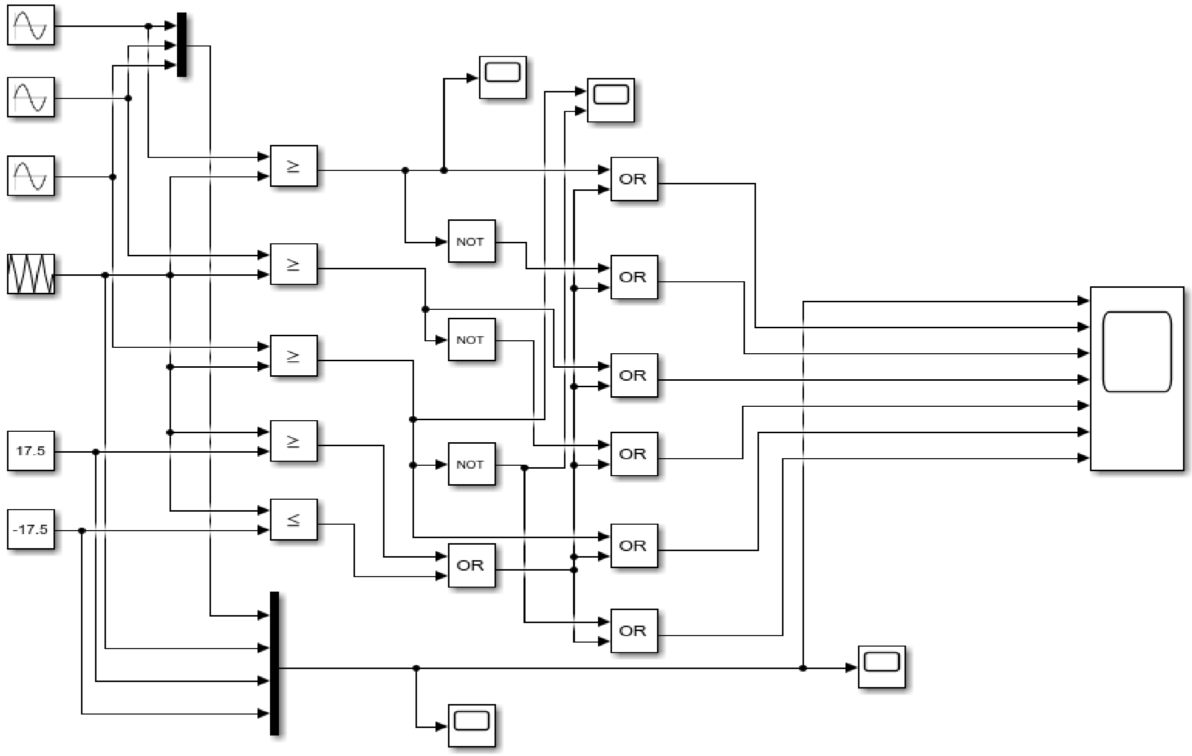


Fig 14 - PWM Circuit Diagram

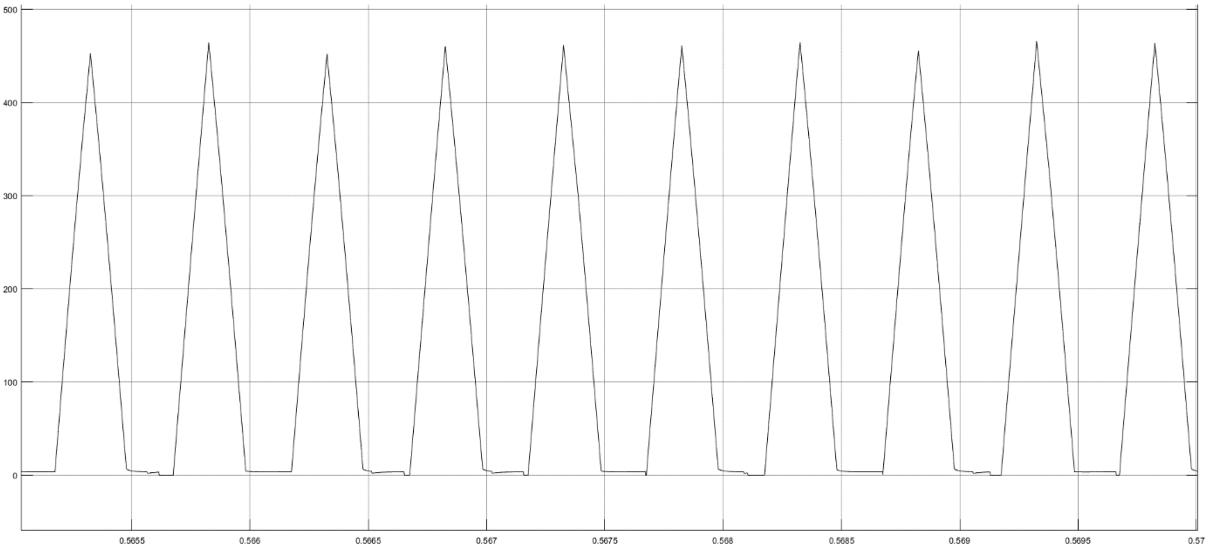


Figure – 15 Graph of Inductor 1

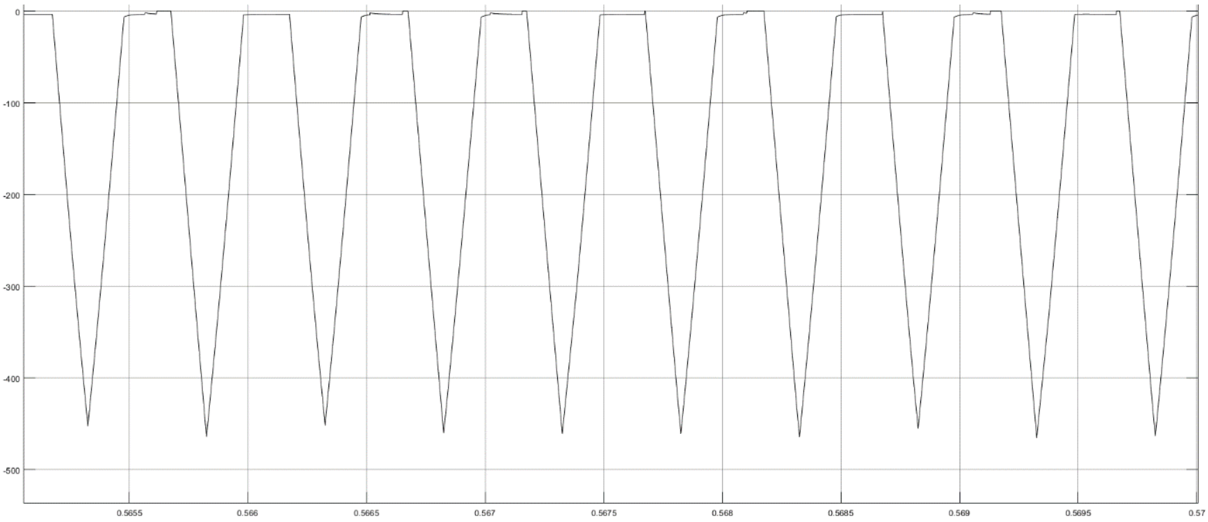


Fig – 16 Graph of Inductor 2

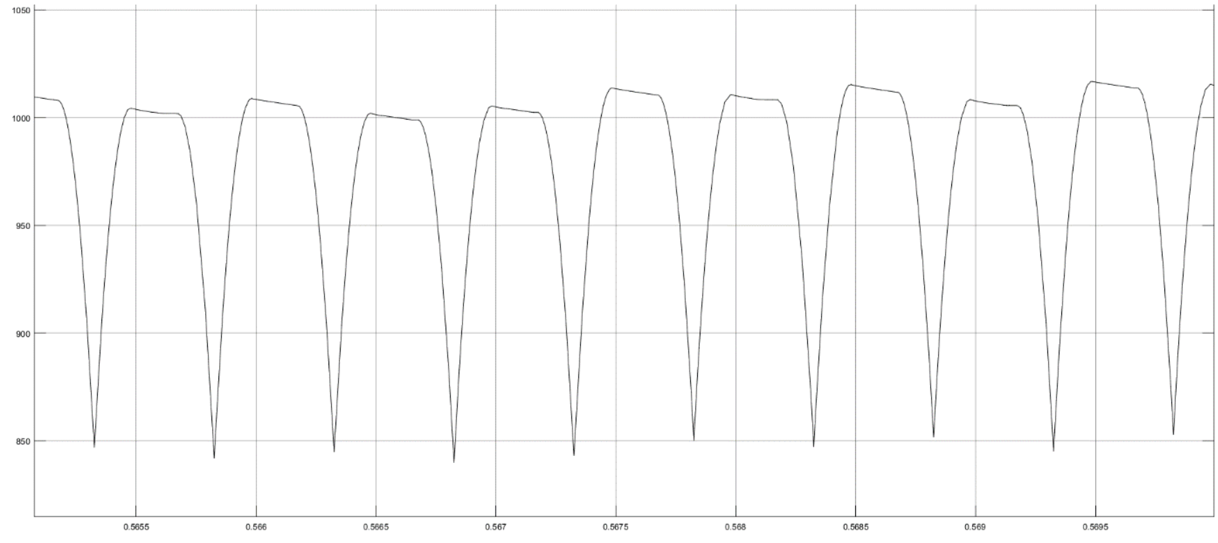


Fig – 17 Graph of Capacitor 1

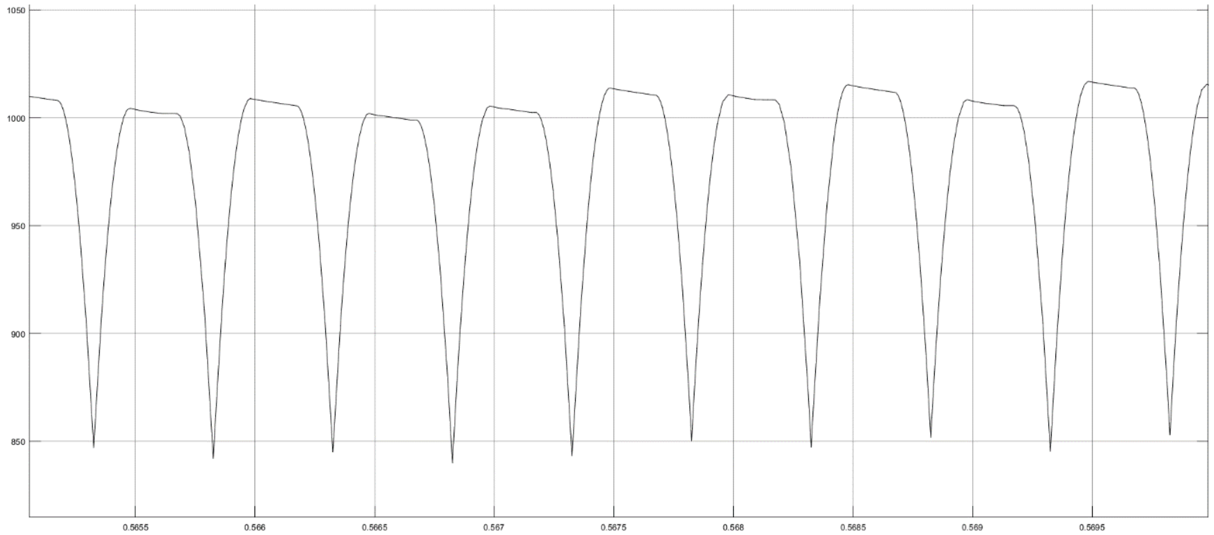


Fig – 18 Graph of Capacitor 2

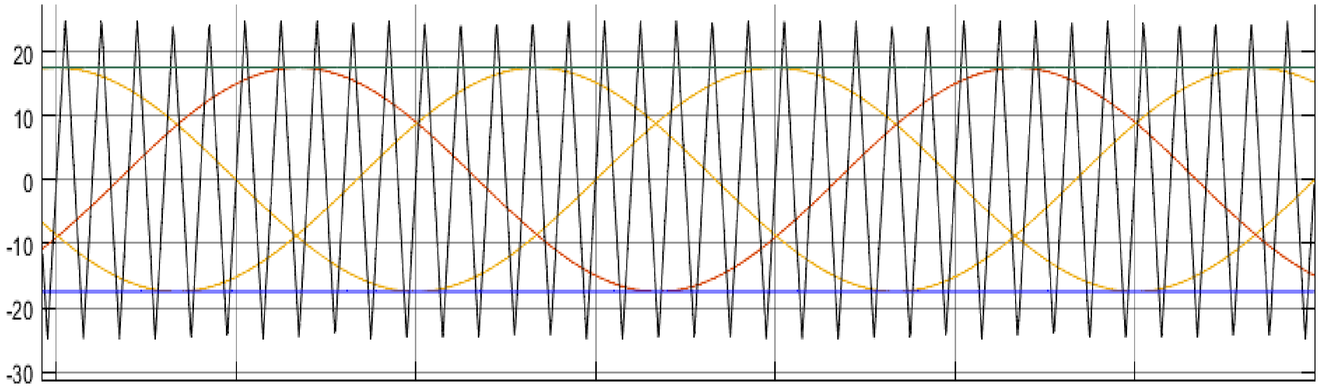


Fig – 19 Graph of Repeating Sequence

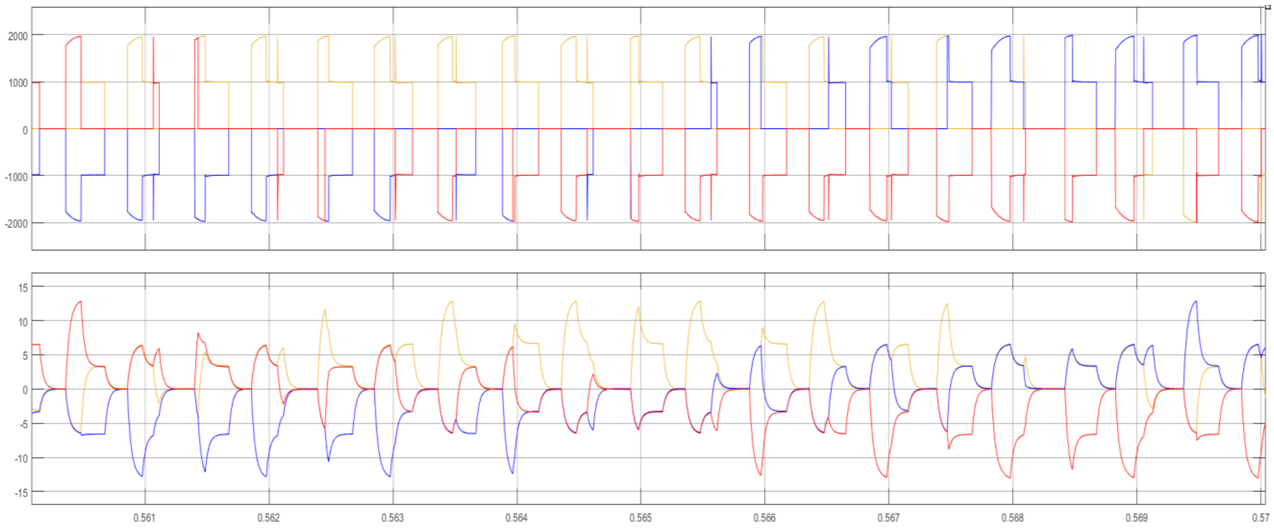


Fig – 20 Graph of Output Voltage & Current

4.2. Hardware Graph

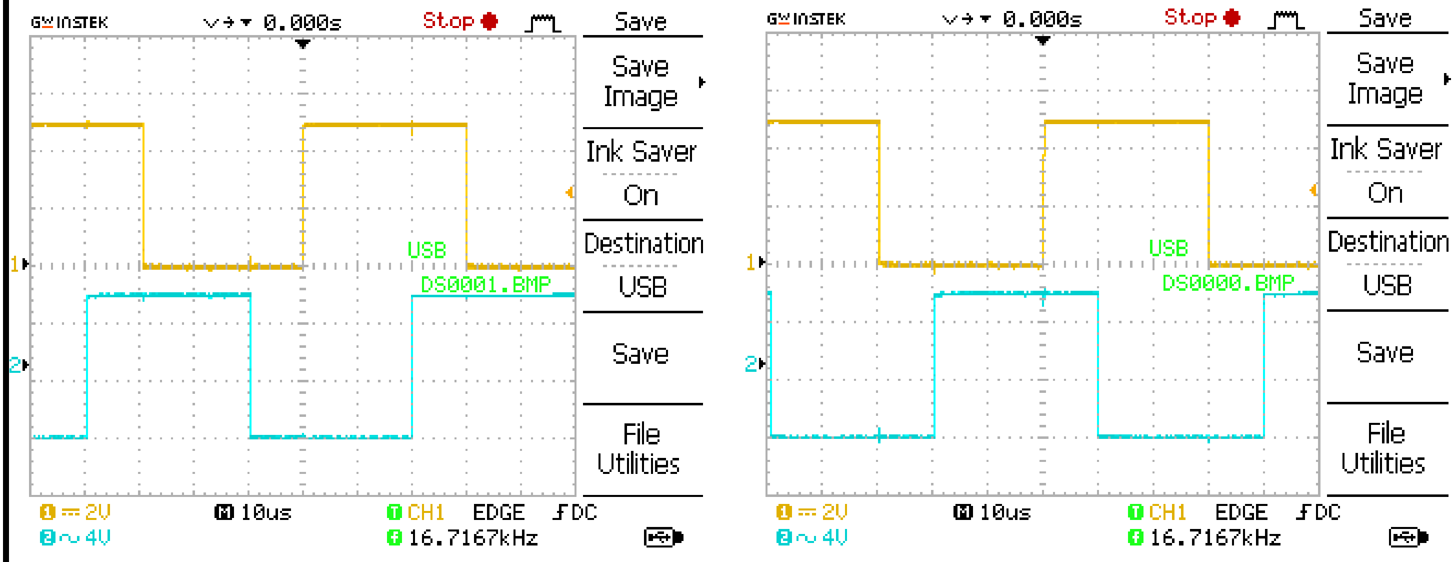


Fig – 21 Output Pulse

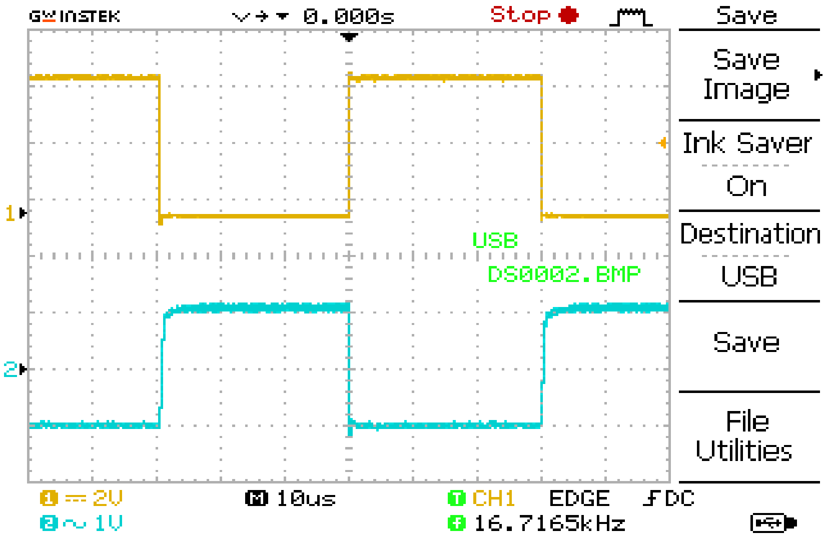


Fig – 22 Output pulse from Arduino

4.3. Hardware Diagram

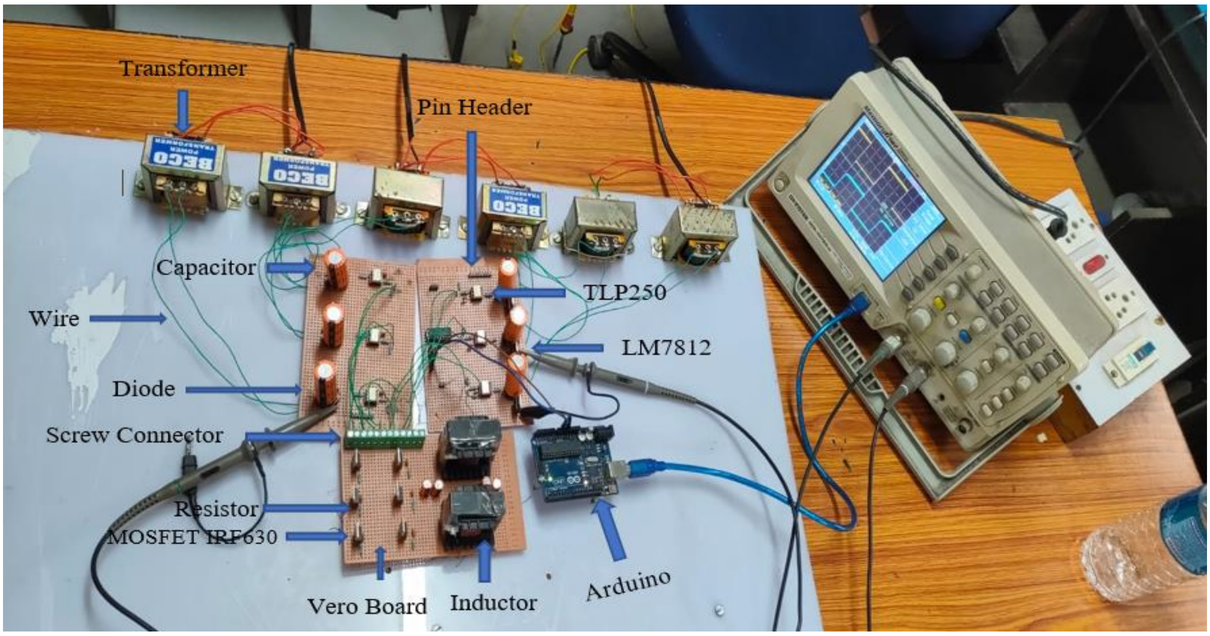
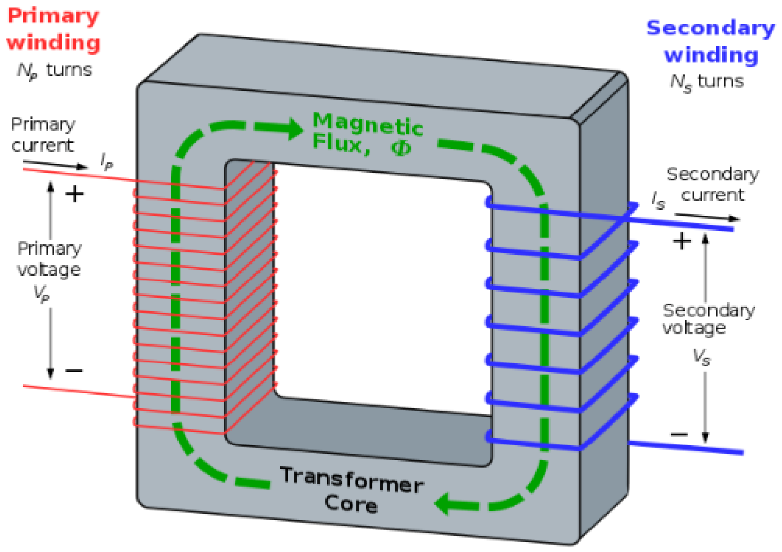


Fig – 23 Hardware Circuit

4.3.1. Hardware Components: -

- Transformer
- MOSFET (7812)
- Capacitor
- Inductor
- Resistor
- TLP250
- IRF630
- Wire
- Pin Header
- Vero Board
- Screw Connector
- Diode

A. TRANSFORMER



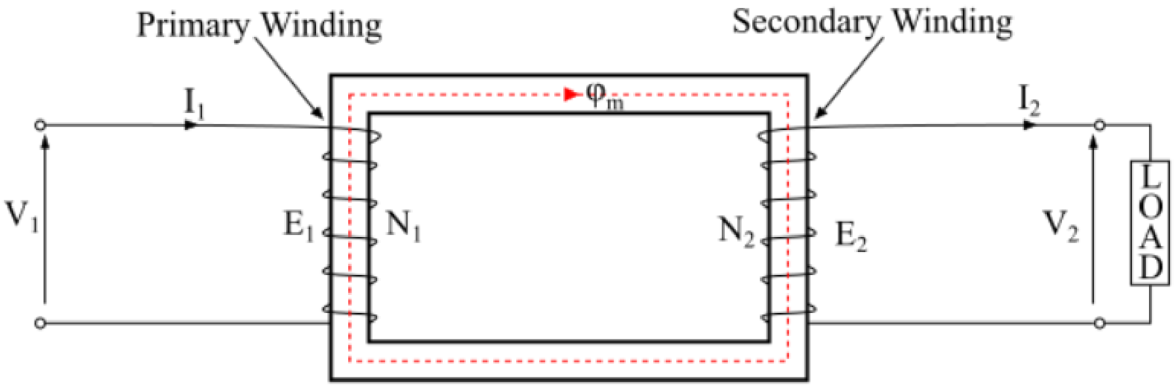
A transformer is a static device. It is a passive component that transfers electrical energy from one electrical circuit to another circuit or multiple circuits. A varying current in any coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force across any other coils wound around the same core. Electrical energy can be transferred between separate coils without a metallic (conductive) connection between the two circuits.

Faraday's law of induction, discovered in 1831, describes the induced voltage effect in any coil due to a changing magnetic flux encircled by the coil.

Transformers are used to change AC voltage levels, such transformers being termed step-up or step-down type to increase or decrease voltage level, respectively. Transformers can also be used to provide galvanic isolation between circuits as well as to couple stages of signal-processing circuits. Since the invention of the first constant-potential transformer in 1885, transformers have become essential for the transmission, distribution, and utilization of alternating current electric power. A wide range of transformer designs is encountered in electronic and electric power applications. Transformers range in size from RF transformers less than a cubic centimetre in volume, to units weighing hundreds of tons used to interconnect the power grid.

- **Working Principle of Transformer**

The working of the transformer is based on the principle of mutual inductance between two coils that are magnetically coupled.



According to the principle of mutual inductance, when an alternating voltage is applied to the primary winding of the transformer, an alternating flux φ_m which is called as the mutual flux is produced in the core. This alternating flux links both the windings magnetically and induces EMFs E_1 in the primary winding and E_2 in the secondary winding of the transformer according to Faraday's law of electromagnetic induction. The EMF (E_1) is called as primary EMF and the EMF (E_2) is known as secondary EMF and being given as,

$$E_1 = -N_1 \frac{d\varphi}{dt} - (eqn - 25)$$

$$E_2 = -N_2 \frac{d\varphi}{dt} - (eqn - 26)$$

Therefore,

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} - (eqn - 27)$$

From the above expression it can be seen that the magnitude of EMFs E_1 and E_2 depend upon the number of turns in the primary and secondary windings of the transformer respectively, i.e., if $N_2 > N_1$, then $E_2 > E_1$, thus the transformer will be a step-up transformer and if $N_2 < N_1$, then $E_2 < E_1$, thus the transformer will be a step-down transformer.

If a load is now connected across the secondary winding, the EMF E_2 will cause a load current I_2 to flow through the load. Therefore, a transformer enables the transfer of power from one electric circuit to another with a change in voltage level.

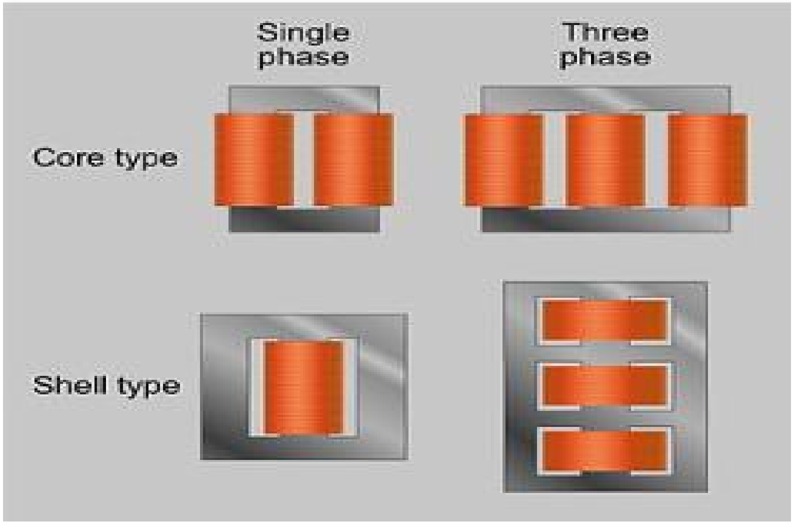
- **Transformer EMF equation**

If the flux in the core is purely sinusoidal, the relationship for either winding between its rms voltage E_{rms} of the winding, and the supply frequency 'f', number of turns N, core cross-sectional area 'A' in m^2 and peak magnetic flux density B_{peak} in Wb/m^2 or T (tesla) is given by the universal EMF equation:

$$E_{rms} = \frac{2\,f\,A\,B_{peak}}{\sqrt{2}} \approx 4.44\,f\,A\,B_{peak} - - - - - - - - - - - - - (eqn - 28)$$

- **Construction**

Closed-core transformers are constructed in 'core form' or 'shell form'. When windings surround the core, the transformer is core form; when windings are surrounded by the core, the transformer is shell form. Shell form design may be more prevalent than core form design for distribution transformer applications due to the relative ease in stacking the core around winding coils. Core form design tends to, as a general rule, be more economical, and therefore more prevalent, than shell form design for high voltage power transformer applications at the lower end of their voltage and power rating ranges (less than or equal to, nominally, 230 kV or 75 MVA). At higher voltage and power ratings, shell form transformers tend to be more prevalent. Shell form design tends to be preferred for extra-high voltage and higher MVA applications because, though more labour-intensive to manufacture, shell form transformers are characterized as having inherently better kVA-to-weight ratio, better short-circuit strength characteristics, and higher immunity to transit damage.



Core Type & Shell Type Transformer

- **Laminated Steel Cores**

Transformers for use at power or audio frequencies typically have cores made of high permeability silicon steel. The steel has a permeability many times that of free space and the core thus serves to greatly reduce the magnetizing current and confine the flux to a path which closely couples the windings. Early transformer developers soon realized that cores constructed from solid iron resulted in prohibitive eddy current losses, and their designs mitigated this effect with cores consisting of bundles of insulated iron wires. Later designs constructed the core by stacking layers of thin steel laminations, a principle that has remained in use. Each lamination is insulated from its neighbours by a thin non-conducting layer of insulation. The transformer universal EMF equation can be used to calculate the core cross-sectional area for a preferred level of magnetic flux.

The effect of laminations is to confine eddy currents to highly elliptical paths that enclose little flux, and so reduce their magnitude. Thinner laminations reduce losses, but are more laborious and expensive to construct. Thin laminations are generally used on high-frequency transformers, with some of very thin steel laminations able to operate up to 10 kHz.

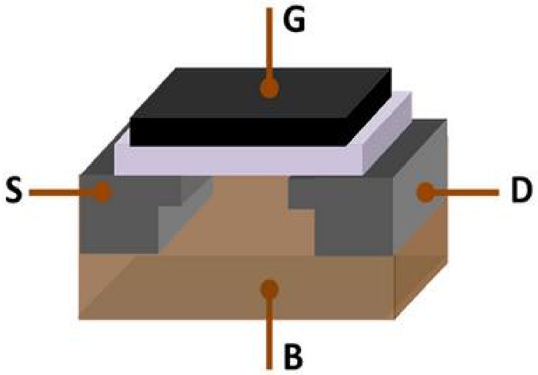
One common design of laminated core is made from interleaved stacks of E-shaped steel sheets capped with I-shaped pieces, leading to its name 'E-I transformer. Such a design tends to exhibit more losses but is very economical to manufacture. The cut-core or C-core type is made by winding a steel strip around a rectangular form and then bonding the layers together. It is then cut in two, forming two C shapes, and the core is assembled by binding the two C halves together with a steel strap.[31] They have the advantage that the flux is always oriented parallel to the metal grains, reducing reluctance.

A steel core's remanence means that it retains a static magnetic field when power is removed. When power is then reapplied, the residual field will cause a high inrush current until the effect of the remaining magnetism is reduced, usually after a few cycles of the applied AC waveform. Overcurrent protection devices such as fuses must be selected to allow this harmless inrush to pass .On transformers connected to long, overhead power transmission lines, induced currents due to geomagnetic disturbances during solar storms can cause saturation of the core and operation of transformer protection devices. Distribution transformers can achieve low no-load losses by using cores made with low-loss high-permeability silicon steel or amorphous (non-crystalline) metal alloy. The higher initial cost of the core material is offset over the life of the transformer by its lower losses at light load.

- **Applications of laminated core type transformer are: -**

These transformers are mainly used for low voltage applications and are very often used in low voltage power circuits as well as in electronic circuits. These transformers are also used to optimize the expenditure of a circuit since these transformers have square or rectangular cross-sectional core which costs less.

B. MOSFET (Metal Oxide Silicon Field Effect Transistor)



Basic Structure of MOSFET shows B(Body), D(Drain), G(Gate), S(Source)

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET), also known as the metal–oxide–silicon transistor (MOS transistor, or MOS), is a type of insulated-gate field-effect transistor that is fabricated by the controlled oxidation of a semiconductor, typically silicon. The voltage of the gate terminal determines the electrical conductivity of the device; this ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals. It consists of four terminals gate, source, body and drain. In general, the body of the MOSFET is in connection with the source terminal thus forming a three-terminal device such as a field-effect transistor. MOSFET is generally considered as a transistor and employed in both the analog and digital circuits. The functionality of MOSFET depends on the electrical variations happening in the channel width along with the flow of carriers (either holes or electrons). The charge carriers enter into the channel through the source terminal and exit via the drain.

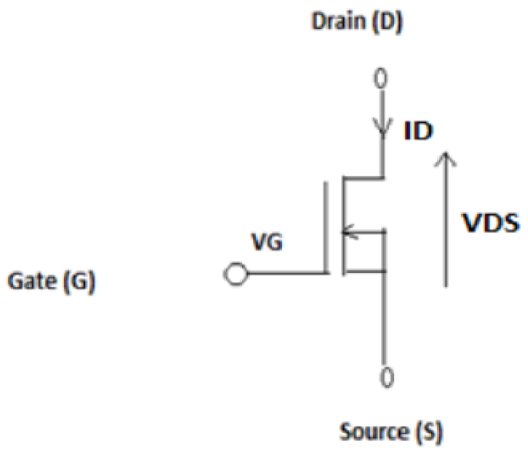
The width of the channel is controlled by the voltage on an electrode which is called the gate and it is located in between the source and the drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity that exists in the device is the crucial section.

- **MOSFET Functions**

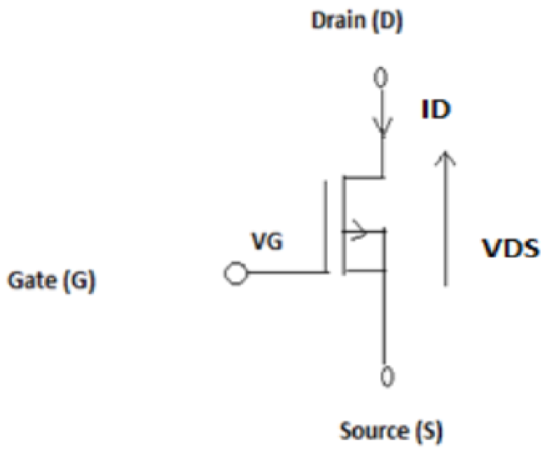
1. Depletion Mode
2. Enhanced Mode

- **Depletion Mode**

When there is no voltage across the gate terminal, the channel shows its maximum conductance. Therefore, when the voltage across the gate terminal is either positive or negative, then the channel conductivity decreases.



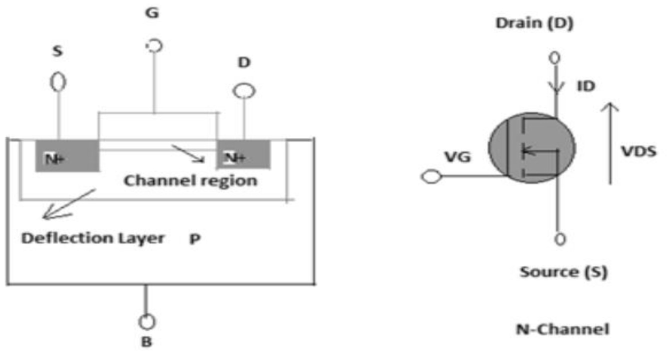
N - Channel



P - Channel

- **Enhancement Mode**

When there is no voltage across the gate terminal, then the device does not conduct. When there is the maximum voltage across the gate terminal, then the device shows enhanced conductivity.



Enhancement Mode

- **Working Principle Of MOSFET**

The main principle of the MOSFET device is to be able to control the voltage and current flow between the source and drain terminals. It works almost like a switch and the functionality of the device is based on the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between the source and drain terminal can be inverted from p-type to n-type by the application of either a positive or negative gate voltage respectively. When we apply a repulsive force for the positive gate voltage, then the holes present beneath the oxide layer are pushed downward with the substrate. The depletion region populated by the bound negative charges which are associated with the acceptor atoms. When electrons are reached, a channel is developed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of the positive voltage, if we apply a negative voltage, a hole channel will be formed under the oxide layer.

In our hardware model we MOSFET (LN7812).

C. Capacitor

A capacitor is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals.

The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed to add capacitance to a circuit. The capacitor was originally known as a condenser or condensator. This name and its cognates are still widely used in many languages, but rarely in English, one notable exception being condenser microphones, also called capacitor microphones.

The physical form and construction of practical capacitors vary widely and many types of capacitors are in common use. Most capacitors contain at least two electrical conductors often in the form of metallic plates or surfaces separated by a dielectric medium. A conductor may be a foil, thin film, sintered bead of metal, or an electrolyte. The nonconducting dielectric acts to increase the capacitor's charge capacity. Materials commonly used as dielectrics include glass, ceramic, plastic film, paper, mica, air, and oxide layers. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlike a resistor, an ideal capacitor does not dissipate energy, although real-life capacitors do dissipate a small amount (see Non-ideal behaviour). When an electric potential difference (a voltage) is applied across the terminals of a capacitor, for example when a capacitor is connected across a battery, an electric field develops across the dielectric, causing a net positive charge to collect on one plate and net negative charge to collect on the other plate. No current actually flows through the dielectric. However, there is a flow of charge through the source circuit. If the condition is maintained sufficiently long, the current through the source circuit ceases. If a time-varying voltage is applied across the leads of the capacitor, the source experiences an ongoing current due to the charging and discharging cycles of the capacitor.

- **Types of Capacitors**

a) Ceramic Capacitors
b) Film Capacitors
c) Power Film Capacitors
d) Electrolytic Capacitors
e) Ceramic capacitors0
f) Film capacitors
g) Paper capacitors
h) Electrolytic capacitors

- **Ceramic Capacitors**

A ceramic capacitor is considered to be one of the most commonly used capacitors. The material used in this capacitor type is dielectric. Also, ceramic capacitors are a non-polar device which means that they could be used in any direction in the circuit.

Depending on the availability of the capacitor, ceramic capacitors are classified into three groups:

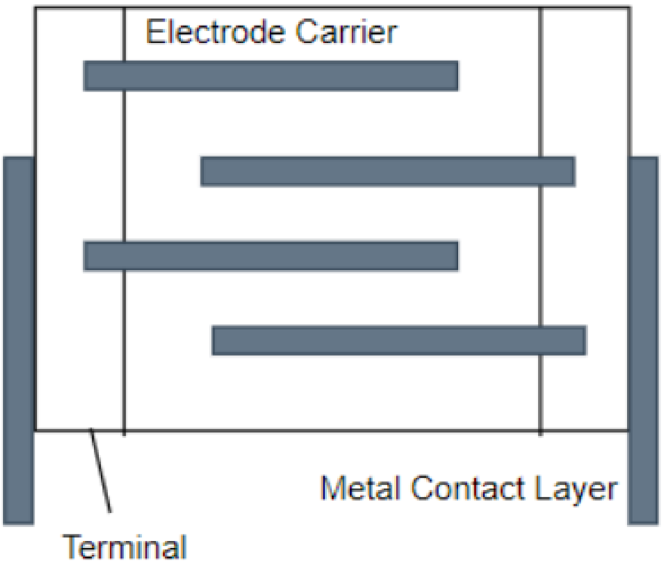
1. Leaded disc ceramic capacitors
2. Surface mount multi-layered ceramic capacitors
3. Microwave bare lead-less disc ceramic capacitors

Depending on the temperature range, temperature drift, and tolerance, ceramic capacitors are classified into the following classes:

- Class 1 ceramic capacitors: These capacitors are considered to be the most stable capacitors with linear characteristics.
- Class 2 ceramic capacitors: These capacitors perform better for volumetric efficiency but their accuracy and stability are at stake. They find applications in coupling and decoupling.
- Class 3 ceramic capacitors: These capacitors have high volumetric efficiency with low accuracy and low dissipation factor. They are used in decoupling.

- **Film Capacitors**

Film capacitors are also known as a polymer film, plastic film, or film dielectric. The advantage of film capacitors is that they are inexpensive and come with limitless shelf life. The film capacitor uses a thin dielectric material with the other side of the capacitor metalized. Depending on the application, the film capacitor is rolled into thin films. The general voltage range of these capacitors is from 50 V to 2 kV.



- **Types of Film Capacitors**

Depending on the dielectric material used and applications, the following is the classification of the film capacitor:

1. Heavy-duty snubber capacitors
2. SMD style capacitors
3. Axial style capacitors
4. Radial style capacitors

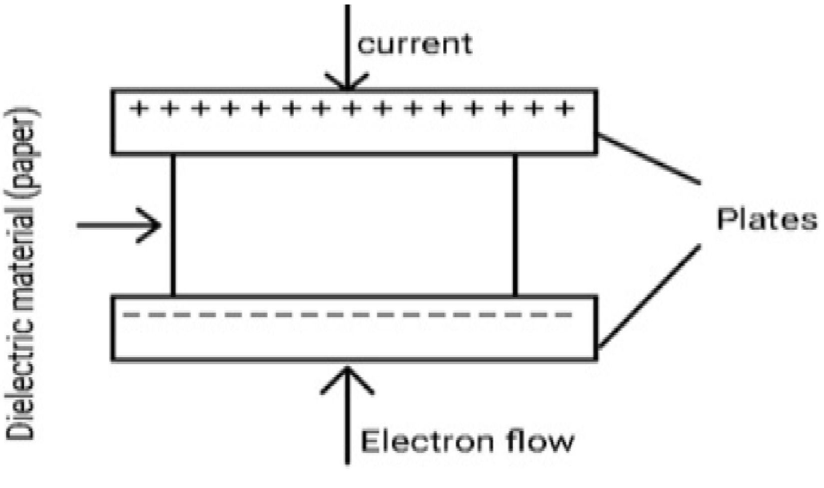
- **Electrolytic Capacitors**

In an electrolytic capacitor metallic anode coated with an oxidized layer used as a dielectric. These capacitors are polarized. Electrolytic capacitors are categorized based on their dielectric.

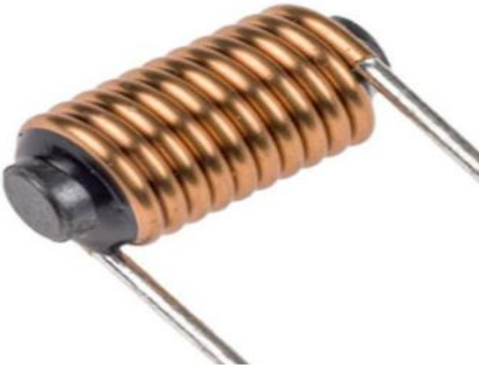
- Aluminium electrolytic capacitors – aluminium oxide (dielectric).
- Tantalum electrolytic capacitors – tantalum pentoxide (dielectric).
- Niobium electrolytic capacitors – niobium pentoxide (dielectric).

- **Paper Capacitor**

Paper capacitor is also known as a fixed capacitor in which paper is used as the dielectric material. The amount of electric charge stored by the paper capacitor is fixed. It consists of two metallic plates and paper which is used as a dielectric material is placed between these plates.



D. Inductor



Inductor, also called a coil, choke, or reactor, is a passive two-terminal electrical component that stores energy in a magnetic field when electric current flows through it. An inductor typically consists of an insulated wire wound into a coil.

When the current flowing through the coil changes, the time-varying magnetic field induces an electromotive force (e.m.f.) (voltage) in the conductor, described by Faraday's law of induction. According to Lenz's law, the induced voltage has a polarity (direction) which opposes the change in current that created it. As a result, inductors oppose any changes in current through them.

An inductor is characterized by its inductance, which is the ratio of the voltage to the rate of change of current. In the International System of Units (SI), the unit of inductance is the henry (H) named for 19th century American scientist Joseph Henry. In the measurement of magnetic circuits, it is equivalent to weber/ampere. Inductors have values that typically range from 1 μH (10^{-6} H) to 20 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. Along with capacitors and resistors, inductors are one of the three passive linear circuit elements that make up electronic circuits. Inductors are widely used in alternating current (AC) electronic equipment, particularly in radio equipment. They are used to block AC while allowing DC to pass; inductors designed for this purpose are called chokes. They are also used in electronic filters to separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers.

- **Working principle of Inductor**

When the current flows through an inductor with conductors wrapped around in the same direction, the magnetic field generated around the wire is bound together and becomes

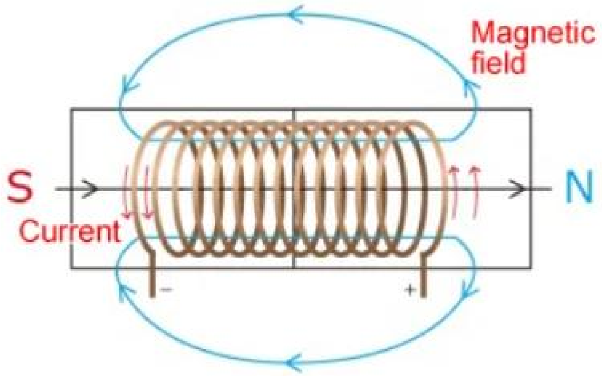
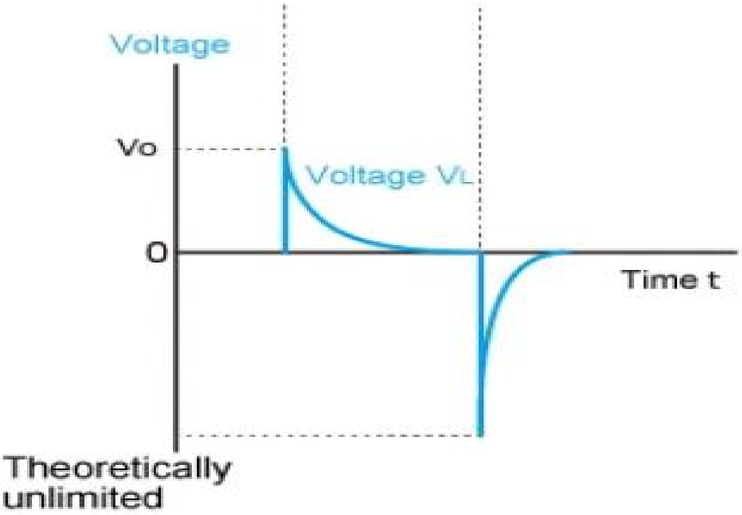


Fig - 24

electromagnetic. Conversely it is also possible to generate an electric current from magnetic force.

When a magnet is moved closer or further away from an inductor that has become an electromagnet, the magnetic field of the inductor changes. This causes an electric current to flow in order to generate a "force against change" that tries to maintain the direction and momentum of the magnetic field. This is called "electromagnetic induction.

As shown in the figure – 24 circuit diagram, when a DC current flows through an inductor , an electromotive force in the direction that interferes with the current is generated at the beginning of the current flow. This property is called the self-inductive effect. However, later on, as the DC current reaches a certain value, the magnetic flux ceases to change and the electromotive force is no longer generated, thus the current is no longer obstructed.



E. Resistor (20Ω, 33Ω, 100Ω - 2W)

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components can be composed of various compounds and forms. Resistors are also implemented within integrated circuits.

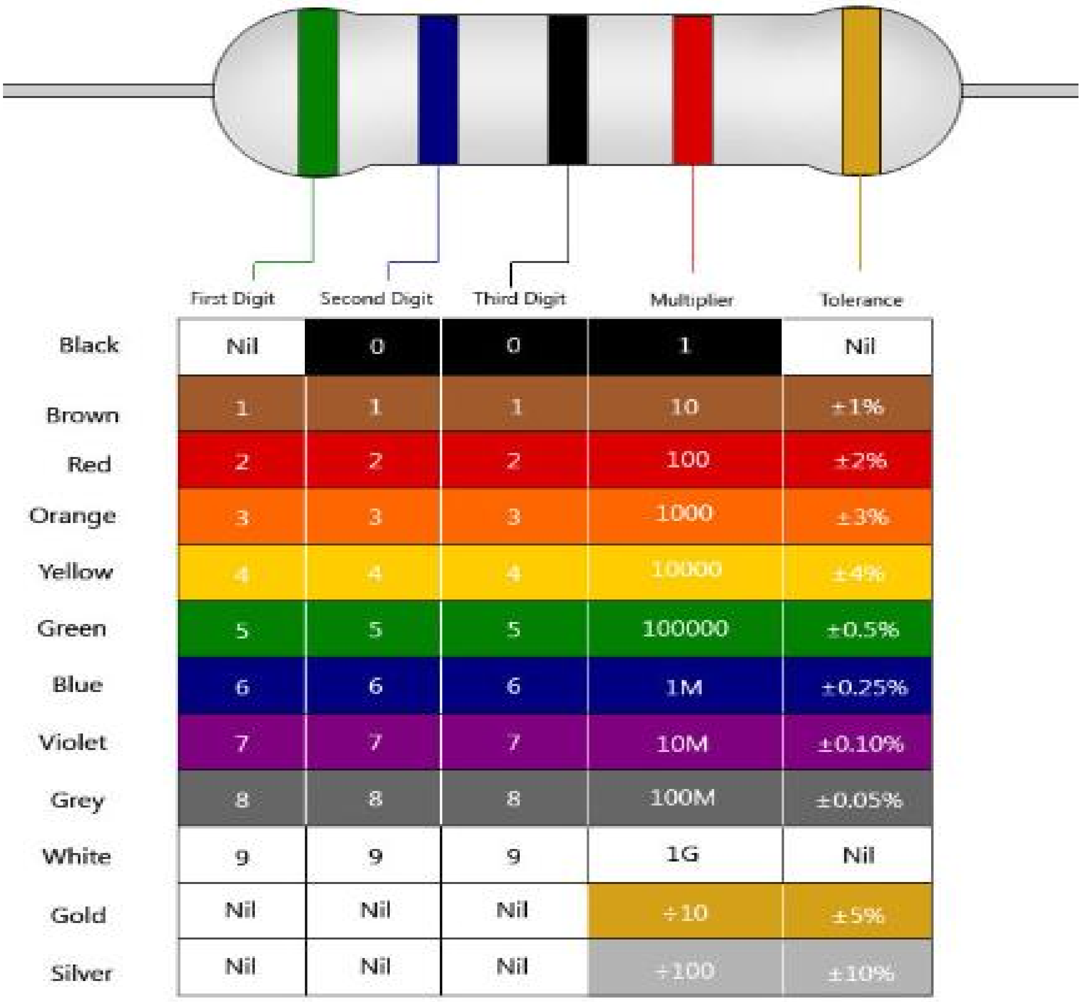
- **Working principle of Resistor**

The resistor absorbs the electrical energy in the process where it acts as a hindrance to the flow of electricity by reducing the voltage, and it is dissipated as heat.

In today's world of electronic circuits, the heat dissipation is typically a fraction of a watt. Ohm's law states that if I is the current flowing through the resistor in amperes, and R is the resistance in ohms, then V is the voltage drop that is imposed by the resistor.

$$V = I * R$$

- **Resistor Colour Coding**

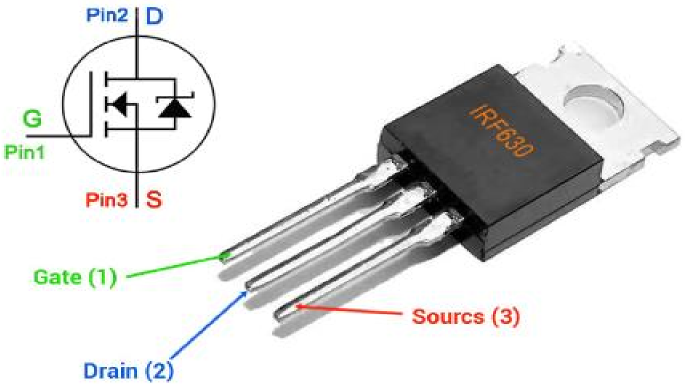


	First Digit	Second Digit	Third Digit	Multiplier	Tolerance
Black	Nil	0	0	1	Nil
Brown	1	1	1	10	±1%
Red	2	2	2	100	±2%
Orange	3	3	3	1000	±3%
Yellow	4	4	4	10000	±4%
Green	5	5	5	100000	±0.5%
Blue	6	6	6	1M	±0.25%
Violet	7	7	7	10M	±0.10%
Grey	8	8	8	100M	±0.05%
White	9	9	9	1G	Nil
Gold	Nil	Nil	Nil	÷10	±5%
Silver	Nil	Nil	Nil	÷100	±10%

F. TLP250

TLP250 is an isolated IGBT/Mosfet driver IC. The input side consists of a GaAlAs light-emitting diode. The output side gets a drive signal through an integrated photodetector. Therefore, the main feature is electrical isolation between low and high-power circuits. It transfers electrical signals optically via light.

G. IRF630 (MOSFET)



IRF630 is a third-generation power MOSFET specially designed for applications which required high-speed switching. This component is a great combination of low on-state resistance, cost-effective, and rugged design.

IRF630 is designed to sustain load voltage up to 200 V and 9 A current. It can drive current up to 36 A in pulse mode for 300 µs with a duty cycle of 2%. This Power MOSFET is specially designed to minimize input capacitance and gate change, and available in package TO-220.

- **IRF630 Pinout Configuration**

Pin Number	Pin Name	Pin Description
1	Gate	Control the biasing of MOSFET
2	Drain	Control flows – in through Drain
3	Source	Control flows – out through source

- **Some of its features are**

1) Extremely high dv/dt capability
2) Fast switching
3) Low intrinsic capacitance
4) Ease of paralleling
5) Gate charge minimized
6) Simple drive requirement

- **IRF630 MOSFET Working**

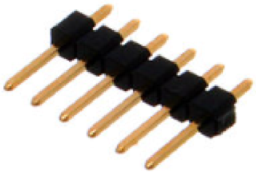
A MOSFET can be turned ON by supplying proper gate voltage between the gate and source terminal. If the gate voltage is not applied properly, the MOSFET will remain turn OFF condition.

H. Wire

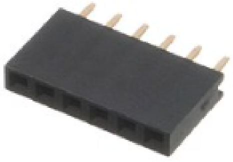
Electrical wiring is an electrical installation of cabling and associated devices such as switches, distribution boards, sockets, and light fittings in a structure.

Wiring is subject to safety standards for design and installation. Allowable wire and cable types and sizes are specified according to the circuit operating voltage and electric current capability, with further restrictions on the environmental conditions, such as ambient temperature range, moisture levels, and exposure to sunlight and chemicals.

I. Pin Header



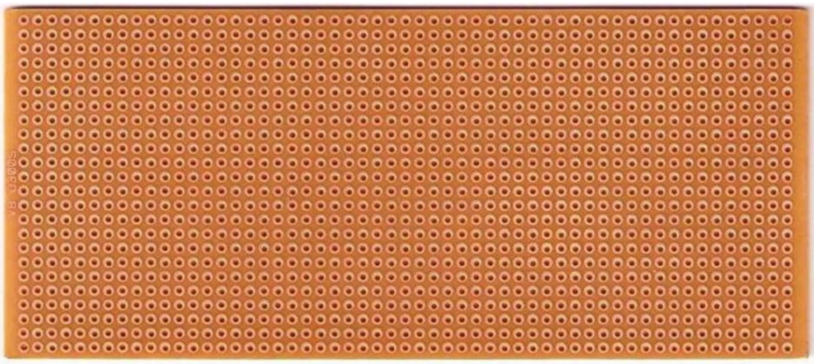
Male Pin Header



Female Pin Header

A pin header (or simply header) is a form of electrical connector. A male pin header consists of one or more rows of metal pins melded into a plastic base, often 2.54 mm (0.1 in) apart, though available in many spacings. Male pin headers are cost-effective due to their simplicity. The female counterparts are sometimes known as female socket headers, though there are numerous naming variations of male and female connectors.

J. Vero Board

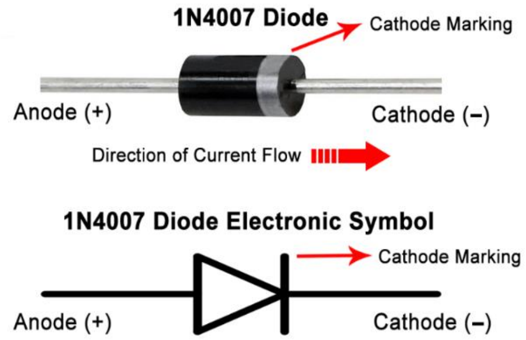


Veroboard is a brand of stripboard, a pre-formed circuit board material of copper strips on an insulating bonded paper board. It is used as a general-purpose material for constructing electronic circuits - differing from purpose-designed printed circuit boards (PCBs) in that a variety of electronic circuits may be constructed using a standard wiring board.

K. Screw Terminal

A screw terminal is a type of electrical connection where a wire is held by the tightening of a screw. The wire may be wrapped directly under the head of a screw, may be held by a metal plate forced against the wire by a screw, or may be held by what is, in effect, a set screw in the side of a metal tube. The wire may be directly stripped of insulation and inserted under the head of a screw or into the terminal. Otherwise, it may be either inserted first into a ferrule, which is then inserted into the terminal, or else attached to a connecting lug, which is then fixed under the screw head.

L. Diode (1N4007)



1N4001 is a member of 1N400x diodes. Diode is a rectifying device which conducts only from anode to cathode. Diode behaves open circuited for the current flow from cathode to anode. 1N4001 is a 1A diode with low forward voltage drop and high surge current capability. It comprises of diffused PN junction and has low reverse leakage current of 5µA. Its DC blocking voltage is 50V. The cathode is identified by a bar on diode case. The other terminal is the anode.

Features:

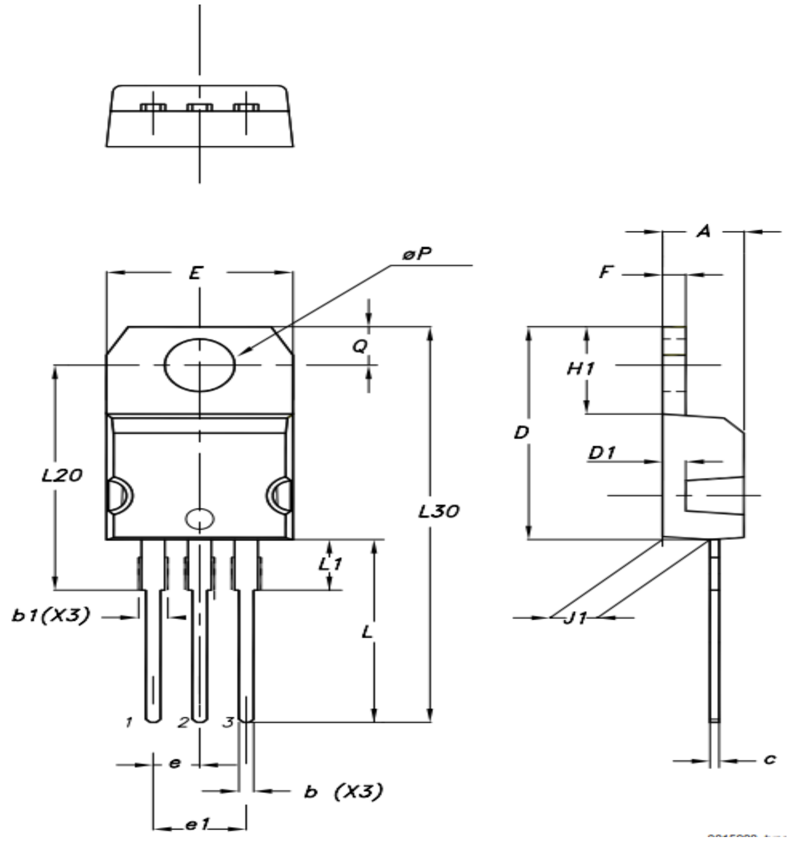
- Low forward voltage drops
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s.

Chapter - 5

Designing of Hardware Component

5.1. Component Design

5.1.1. MOSFET IRF630



During the time of our simulation, we find that our peak-to-peak current $I_{(P\text{-}P)}$ is 2.39 amps, switch voltage is 50 volts. And our switching frequency is 1kHz. Therefore, by taking all the consideration we find that, IRF630 is suitable for our circuit. We can find out all details about IRF630 from appendix.

5.1.2. Inductor Design

The design of an ac inductor is quite similar to that of a transformer. The design of the ac inductor requires the calculation of the volt-amp (VA) capability. In some applications the inductance is specified, and in others, the current is specified. If the inductance is specified, then, the current has to be calculated. If the current is specified, then the inductance has to be calculated.

- **Cores of Inductor**:

An electric current through a wire wound into a coil creates a magnetic field through the center of the coil, due to Ampere's circuital law. Coils are widely used in electronic components such as electromagnets, inductors, transformers, electric motors and generators. A coil without a magnetic core is called an "air core" coil. Adding a piece of ferromagnetic or ferrimagnetic material in the center of the coil can increase the magnetic field by hundreds or thousands of times; this is called a magnetic core. The field of the wire penetrates the core material, magnetizing it, so that the strong magnetic field of the core adds to the field created by the wire. The amount that the magnetic field is increased by the core depends on the magnetic permeability of the core material. Because side effects such as eddy currents and hysteresis can cause frequency-dependent energy losses, different core materials are used for coils used at different frequencies.

The cores can be of different types. Some of them are:

1. Single "I" core

Like a cylindrical rod but square, rarely used on its own. This type of core is most likely to be found in car ignition coils

2. "C" or "U" core

U and C-shaped cores are used with I or another C or U core to make a square closed core, the simplest closed core shape. Windings may be put on one or both legs of the core.

3. "E" core

"E" core E-shaped core are more symmetric solutions to form a closed magnetic system. Most of the time, the electric circuit is wound around the center leg, whose section area is twice that of each individual outer leg. In 3-phase transformer cores, the legs are of equal size, and all three legs are wound.

4. Pair of "E" cores

Again, used for iron cores. Similar to using an "E" and "I" together, a pair of "E" cores will accommodate a larger coil former and can produce a larger inductor or transformer. If an air gap is required, the centre leg of the "E" is shortened so that the air gap sits in the middle of the coil to minimize fringing and reduce electromagnetic interference.

5. Planar core

A planar core consists of two flat pieces of magnetic material, one above and one below the coil. It is typically used with a flat coil that is part of a printed circuit board. This design is excellent for mass production and allows a high power, small volume transformer to be constructed for low cost. It is not as ideal as either a pot core or toroidal core [citation needed] but costs less to produce.

6. Pot Core

Usually, ferrite or similar. This is used for inductors and transformers. The shape of a pot core is round with an internal hollow that almost completely encloses the coil. Usually, a pot core is made in two halves which fit together around a coil former (bobbin). This design of core has a shielding effect, preventing radiation and reducing electromagnetic interference.

7. Ring or bead

The ring is essentially identical in shape and performance to the toroid, except that inductor commonly pass only through the centre of the core, without wrapping around the core multiple times. The ring core may also be composed of two separate C-shaped hemispheres secured together within a plastic shell, permitting it to be placed on finished cables with large connectors already installed, that would prevent threading the cable through the small inner diameter of a solid ring.

8. Toroidal Cores

There are many different types of magnetic material used for fabricating inductors. The purpose of the material is to provide permittivity greater than µO so that the inductors can be made more compactly and with fewer turns of wire. This can reduce skin effect losses in the wire and reduce coupling to other inductive components in the circuit, but the circuit losses then may be limited by the magnetic material itself. There are charts of typical unloaded Q's that can be obtained from various materials.

For this project we have used the EE cores for the designing of inductors. As it is easily available and due to its easy access and easy to turn the coils around it. Hence, pair of EE cores are being used for the designing purpose in our project.

For calculation of inductor design -

$$A_p = \frac{L * I_p * I_{rms}}{B_p * J * K_w} - (\text{eqn} - 29)$$

Where, $L = 1\text{mH}$

$I_{P\text{-}P} = 2.39$ amps

$I_{RMS} = 0.76$ amps

$B_p = 0.3\text{T}$

$J = 280$

$K_W = 0.35$

Therefore, $A_p \approx 42$

After the calculation we choose EE code – 42/15. Further we find out by the appendix.

5.1.3. RC Snubber Design –

An RC snubber, placed across the MOSFET that can be used to reduce the peak voltage at turn-off and to damp the ringing. In most cases a very simple design technique can be used to determine suitable values for the snubber components (R and C). In those cases where a more optimum design is needed, a somewhat more complex procedure is used. The values of resistance R=33 Ω, 1.25 W and capacitance C= 470 nF/200V are used in our snubber circuit.

- **Snubber can do many things: -**

1. Reduce or eliminate voltage or current spikes.
2. Limit dI/dt or dV/dt ·
3. Shape the load line to keep it within the safe operating area (SOA) ·
4. Transfer power dissipation from the switch to a resistor or a useful load ·

5.1.4. Driver Design

MOSFET driver is one of the main component of our circuits. MOSFET drivers are dedicated integrated circuits which are used to drive MOSFET in low side and high side configuration. In our project five number of MOSFETs (S1, S2, S3, S4, and S6) are operated as high side operation and two MOSFETs (S5 & S7) are operated as low side operation. TL250 like other MOSFET drivers have input stage and output stage. The main difference between TLP250 and other MOSFET drivers is that TLP250 MOSFET driver is optically isolated. It means that input and output of TLP250 MOSFET driver is isolated from each other. Its works like an optocoupler. Input stage has a light emitting diode and output stage has a photo diode. Whenever input stage LED light falls on output stage photo detector diode, output becomes high. MOSFET drivers are dedicated integrated circuits which are used to drive MOSFETs in low side and high side configuration. According to our project we need seven TLP250 driver circuits for the seven MOSFETs of our main power circuit. The circuit shown in figure 25

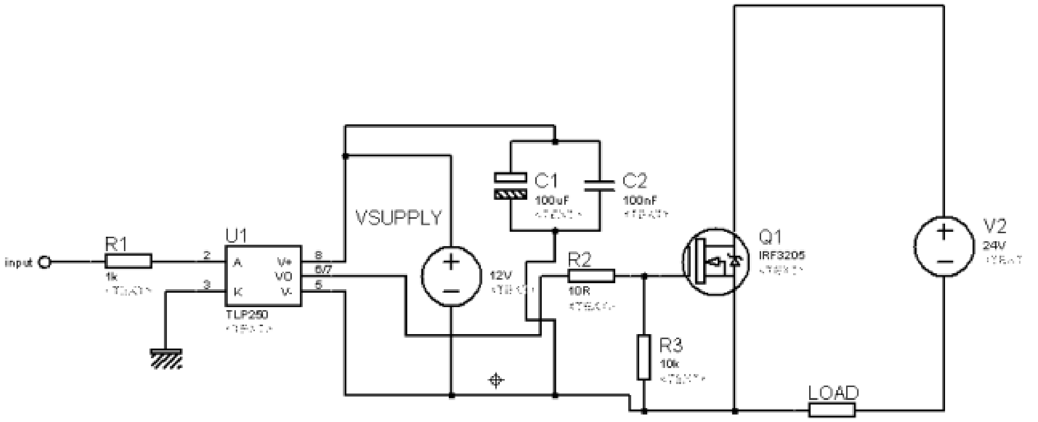


Fig – 25. TLP250 Working Circuit

- **12 V Regulator Power Supply**

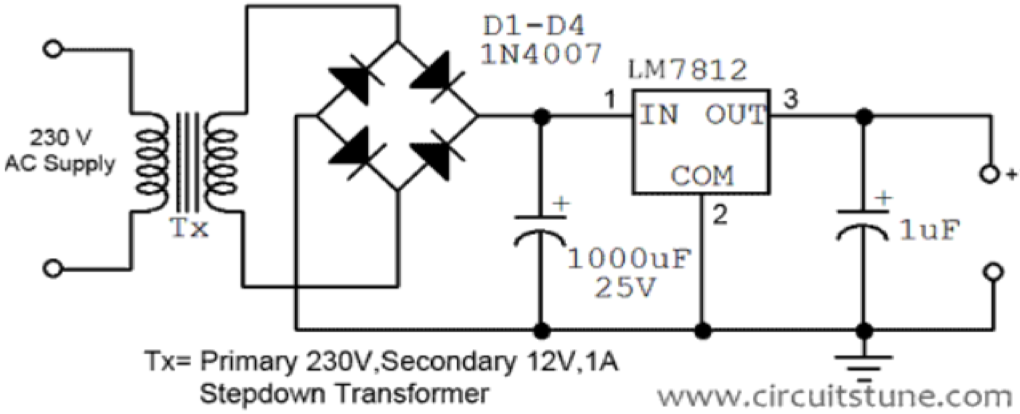


Fig – 26 Circuit diagram of 12V regulated power supply

Here this circuit diagram is for +12V regulated (fixed voltage) DC power supply. This power supply circuit diagram is ideal for an average current requirement of 1Amp. This circuit is based on IC LM7812. It is a 3-terminal (+ve) voltage regulator IC. It has short circuit protection, thermal overload protection. LM7812 IC is from LM78XX series. The LM78XX series IC is positive voltage regulator IC for different voltage requirements. A transformer (Tx=Primary 230 Volt, Secondary 12 Volt , 1Amp step down transformer) is used to covert 230V to 12V from mains. Here used a bridge rectifier made by four 1N4007 or 1N4003 diode to convert AC to DC . The filtering capacitor 1000uF,25V is used to reduce the ripple and get a smooth DC voltage. This circuit is very easy to build. For good performance input voltage should be greater than 12Volt in pin-1 of IC LM7812. Use a heat sink to IC LM7812 for safeguarding it from overheating.

Chapter - 6

Controller Design

6.1. Controller Design

6.1.1. Arduino Uno

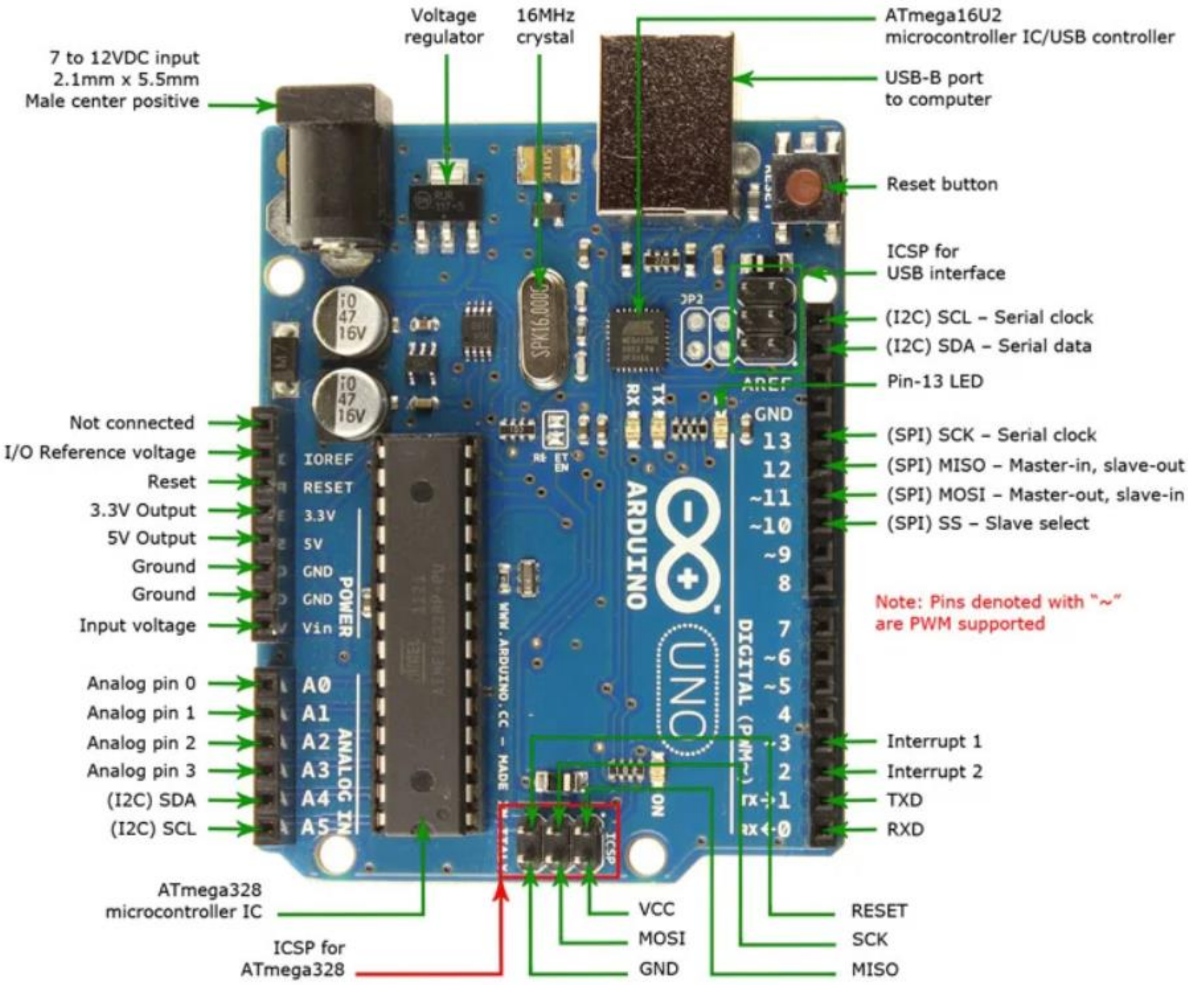


Fig – 27 Arduino Circuit

6.2. Arduino Coding

```
void setup() {
// initialize digital pin 13,12&8 as an output.
pinMode(13, OUTPUT);
pinMode(12,OUTPUT);
pinMode(8,OUTPUT);
}
void loop() {
int var=0;
digitalWrite(13, HIGH);
digitalWrite(8,LOW);
digitalWrite(12,LOW);
delay(6.67);
```

```
digitalWrite(12,HIGH);
while(var==0){
delay(.5);
digitalWrite(13,LOW);
delay(.5);
digitalWrite(8,HIGH);
delay(.5);
digitalWrite(12,LOW);
delay(.5);
digitalWrite(13,HIGH);
delay(.5);
digitalWrite(8,LOW);
delay(.5);
digitalWrite(12,HIGH);
}
}
```

Chapter - 7

Conclusion And Future Scope

7.1. Conclusion

The Z-source converter uses an impedance source network to replace the limitations of traditional voltage source and current source inverters while working with the light load. Z source inverter is used for buck and boost operation so that it increases the efficiency with low cost and less power loss. This paper has provided comparison of traditional inverters against Z-source technology in terms of topology, performance advantages. The ZSI operation, circuit equations, inductor design and choosing of switches IRF630 and LM7812 are clearly explained. Three main ST control methods are described briefly and comparatively evaluated. The circuit analysis is also explained, proving the condition. A detailed design example is carried out using all the equations and calculations, for the three-phase PV ZSI. Simulation results using Simulink are shown to match the theoretical results. All results are very close to the calculated results proving proper analysis of a ZSI has been carried out. Finally, some calculations are shown which would help in choosing devices and components that make up the rest of the inverter. The ZSI with its unique impedance network and features makes it well suited in order to be used for PV applications. In this project we use low type of load on the the ouput side. This paper has provided a comprehensive tutorial on the ZSI performance, different control schemes and design guide lines. At the last we do this thing well in MATLAB simulation but not properly in hardware due to the insufficient of the system.

7.2. Future Scope

In this project we have completed the buck – boost inverter which can easily be used to get the output as required for the load to run the machine. As we use lower input voltage that do buck and boost but in lower quantity. PV behaves as a voltage source towards the right side of the MPP and the current oscillations influence the power. An inverter system is then necessary to feed this DC power into a grid or to an AC load. So, we can use ZSI rather than the VSI.

Chapter - 8

Reference

Reference

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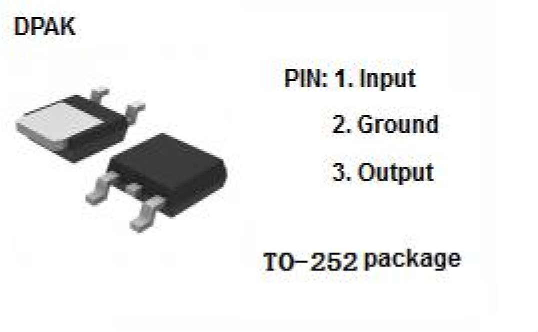
(Appendix A)
Coding

Arduino Coding

```
void setup() {
// initialize digital pin 13,12&8 as an output.
pinMode(13, OUTPUT);
pinMode(12,OUTPUT);
pinMode(8,OUTPUT);
}
void loop() {
int var=0;
digitalWrite(13, HIGH);
digitalWrite(8,LOW);
digitalWrite(12,LOW);
delay(6.67);
digitalWrite(12,HIGH);
while(var==0){
delay(.5);
digitalWrite(13,LOW);
delay(.5);
digitalWrite(8,HIGH);
delay(.5);
digitalWrite(12,LOW);
delay(.5);
digitalWrite(13,HIGH);
delay(.5);
digitalWrite(8,LOW);
delay(.5);
digitalWrite(12,HIGH);
}
}
```

Appendix – B
Data Sheet

isc Three Terminal Positive Voltage Regulator LM7812

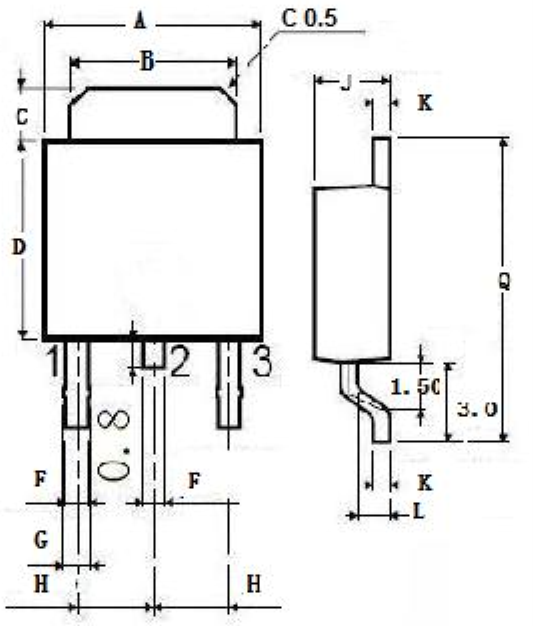


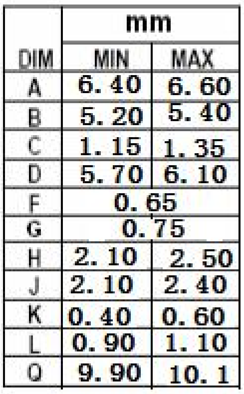
FEATURES

- Output current in excess of 1 A
- Output voltage of 12V
- Internal thermal overload protection
- Output transition Safe-Area compensation
- 100% tested
- Minimum Lot-to-Lot variations for robust device performance and reliable operation

ABSOLUTE MAXIMUM RATINGS(T_a=25℃)

SYMBOL	PARAMETER	RATING	UNIT
V_i	DC input voltage	35	V
I_o	Output current	internally limited	
P_{tot}	Power dissipation	internally limited	
T_{OP}	Operating junction temperature	-40~125	℃
T_{stg}	Storage temperature	-55~150	℃





DIM	mm	
	MIN	MAX
A	6.40	6.60
B	5.20	5.40
C	1.15	1.35
D	5.70	6.10
F	0.65	
G	0.75	
H	2.10	2.50
J	2.10	2.40
K	0.40	0.60
L	0.90	1.10
Q	9.90	10.1

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	MAX	UNIT
$R_{th\ j-c}$	Thermal Resistance, Junction to Case	3	℃/W
$R_{th\ j-a}$	Thermal Resistance,Junction to Ambient	62.5	℃/W

• ELECTRICAL CHARACTERISTICS

T_j=25℃ (V_i= 19V, I_O=0.5A, C_i= 0.33μF, C_O= 0.1μF unless otherwise specified)

SYMBOL	PARAMETER	CONDITIONS	MIN	MAX	UNIT
V_O	Output Voltage	V_{in}=19V; I_O=500mA	11.5	12.5	V
V_O	Output Voltage	I_O=5 mA to 1A;Po≤15W; V_{in}=14.5 to 27V;	11.4	12.6	V
$\triangle V_V$	Line Regulation	$14.5V \leqslant V_{in} \leqslant 30V$ $16V \leqslant V_{in} \leqslant 22V$		240 120	mV
$\triangle V_i$	Load Regulation	$5.0mA \leqslant I_O \leqslant 1.0 A$ $250mA \leqslant I_O \leqslant 750mA$		240 120	mV
I_b	Quiescent Current	V_{in}=19V; I_O=0.5A		8.0	mA
$\triangle_{b1}$	Quiescent Current Change	$5.0mA \leqslant I_O \leqslant 1.0A$		0.5	mA
$\triangle_{b2}$	Quiescent Current Change	$14.5V \leq V_{in} \leq 30V$		1.0	mA

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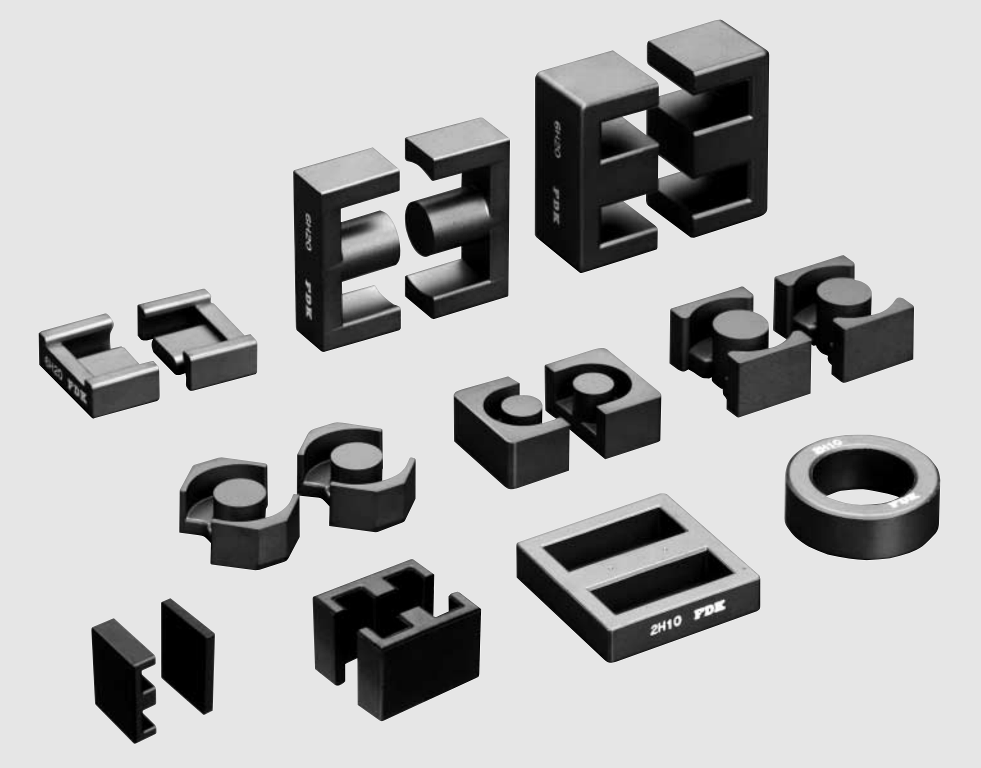
FE21001-1301-010

FDK

FERRITE CORES

FOR TRANSFORMER & CHOKE COIL



FDK CORPORATION

An introduction to FDK's ferrite cores

As a total manufacturer of ferrite products, FDK has developed diverse types of ferrite material and core, which satisfy the latest demands from electronics market. This catalogue presents a comprehensive list of FDK's ferrite cores for various application such as transformer & choke coils for switching power supply, common mode noise suppression coils, pulse transformer for telecommunication equipments etc.
In this Year 2000 Edition catalogue, following materials (including new materials) are introduced:

① 6H series material : for transformer & choke coils for switching power supply
② 7H series material : for transformer & choke coils for high-frequency(over 500 kHz) switching power supply
③ 2H series material : for common mode noise suppression coils and pulse transformers for telecommunications

Contents

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Conventional type

Conventional type EE CORES

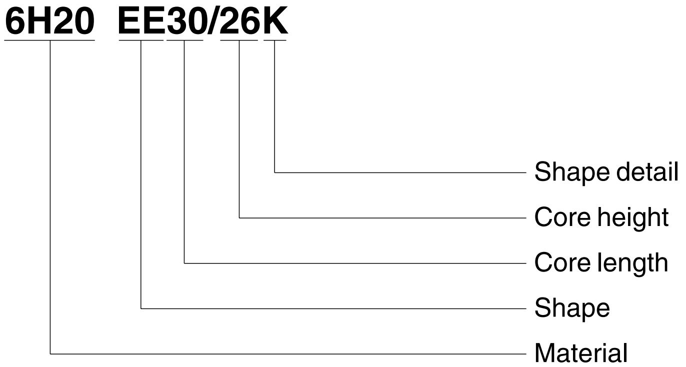
Features

①Customers are invited to select the most suitable products from a wide selection of shapes.

Applications

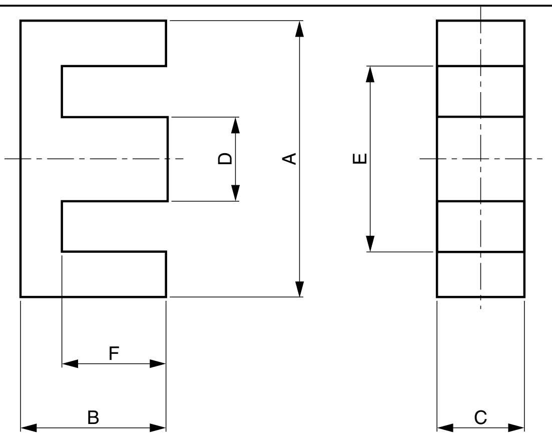
Switching regulators, choke coils, transformers for strobo use, pulse transformers, etc.

Designation



Conventional type EE CORES

Summary

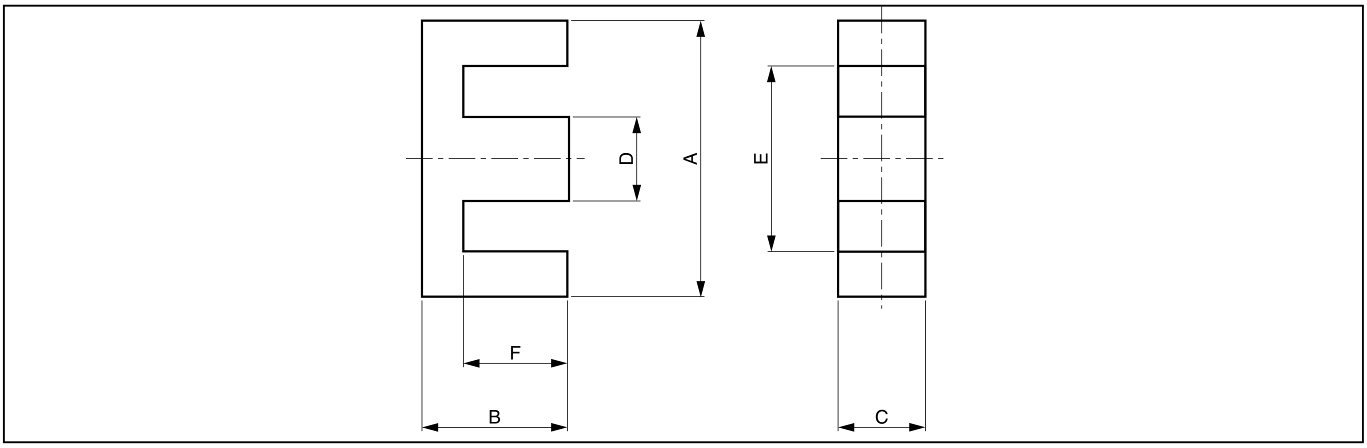


Product code	General standard		Dimensions (mm)					
	IEC	JIS	A	B	C	D	E	F
EE10/11		FEE10.2	10.2±0.2	5.5±0.1	4.75±0.15	2.45±0.15	7.8—0	$4.3^{+0.15}_{-0.075}$
EE12.5/15		FEE12.5	12.5±0.3	$7.6^{+0}_{-0.4}$	5.0±0.2	$2.6^{+0}_{-0.4}$	9.0—0	$4.9^{+0.4}_{-0}$
EE12.6/13	E13/4	FEE12.7A	$12.6^{+0.5}_{-0.4}$	$6.5^{+0}_{-0.2}$	$3.7^{+0}_{-0.3}$	$3.7^{+0}_{-0.3}$	$8.9^{+0.6}_{-0}$	$4.5^{+0.3}_{-0}$
EE13/11			13.0±0.3	$5.6^{+0.3}_{-0}$	6.5±0.2	3.8±0.15	9.8±0.3	$4.1^{+0.3}_{-0}$
EE13/12C			13.0±0.2	6.0±0.15	6.15±0.15	2.75±0.15	10.2±0.2	4.6±0.1
EE16/11			$16.0^{+0.7}_{-0.5}$	5.65±0.2	$7.4^{+0}_{-0.5}$	$4.7^{+0}_{-0.3}$	$11.3^{+0.8}_{-0}$	3.6±0.15
EE16/14K			16.0±0.3	$7.1^{+0.2}_{-0}$	$5.0^{+0}_{-0.4}$	$4.0^{+0}_{-0.4}$	12.0±0.3	$5.1^{+0.25}_{-0}$
EE16/14C		FEE16A	16.0±0.3	7.2±0.3	$5.0^{+0}_{-0.4}$	4.0±0.2	11.7—0	5.2±0.2
EE16/16			$16.0^{+0.7}_{-0.5}$	$8.2^{+0}_{-0.3}$	$4.7^{+0}_{-0.4}$	$4.7^{+0}_{-0.3}$	$11.3^{+0.6}_{-0}$	$5.7^{+0.4}_{-0}$
EE16/24		FEE16B	16.0±0.3	$12.0^{+0.4}_{-0}$	$5.0^{+0}_{-0.4}$	4.0±0.2	11.8—0	$10.0^{+0.4}_{-0}$
EE16/21			16.1±0.25	$10.5^{+0.4}_{-0}$	4.2±0.2	$4.4^{+0}_{-0.3}$	11.6—0	$8.0^{+0.4}_{-0}$
EE19/27		FEE19B	$19.0^{+0.4}_{-0.3}$	13.4±0.3	5.0±0.2	4.5±0.2	14.2—0	11.0±0.3
EE19/15			19.05±0.38	7.59±0.13	4.75±0.13	4.75±0.13	14.33±0.31	5.23±0.13
EE19/16K		FEE19A	19.1±0.3	$7.8^{+0.3}_{-0}$	$5.2^{+0}_{-0.4}$	$4.7^{+0}_{-0.3}$	14.2—0	$5.5^{+0.4}_{-0}$
EE20/20A	E20/6	FEE20.1	20.0±0.4	9.9±0.2	5.65±0.25	5.7±0.2	14.1—0	7.2±0.2
EE22/19		FEE22A	$22.0^{+0}_{-0.6}$	9.55±0.25	$6.0^{+0}_{-0.5}$	$6.0^{+0}_{-0.5}$	15.5—0	$5.3^{+0.4}_{-0}$
EE22/24C			$22.0^{+0}_{-0.6}$	11.9±0.25	$6.0^{+0}_{-0.5}$	$6.0^{+0}_{-0.5}$	15.5—0	$7.9^{+0.4}_{-0}$
EE22/29		FEE22B	22.0±0.5	$14.5^{+0.5}_{-0}$	$6.0^{+0}_{-0.5}$	$6.0^{+0}_{-0.5}$	16.0±0.5	$10.5^{+0.5}_{-0}$
EE24/31A			$24.5^{+0.4}_{-0.3}$	15.3±0.3	9.4±0.15	7.8±0.15	16.7—0	11.4±0.25
EE25/20			25.0±0.3	$10.0^{+0.3}_{-0}$	6.4±0.3	6.4±0.3	18.2—0	$6.5^{+0.3}_{-0}$
EE25/33			25.0±0.3	$16.3^{+0.5}_{-0}$	6.5±0.25	6.5±0.25	18.15—0	$13.0^{+0.4}_{-0}$
EE25/25B	E25/7	FEE25.1	25.05±0.75	12.55±0.25	7.2±0.3	7.25±0.25	17.5—0	8.95±0.25
EE25/19D			25.3±0.4	9.6±0.2	7.0±0.2	6.5±0.25	18.5—0	6.6±0.2
EE25/20B			25.3±0.4	9.95±0.2	6.6±0.25	6.4±0.2	19.0—0	6.75±0.15
EE25/23B			25.3±0.4	11.5±0.2	6.6±0.25	6.4±0.2	19.0—0	8.3±0.15
EE25/19Z		FEE25.4A	25.4±0.38	9.53±0.25	6.35±0.25	6.35±0.25	18.7—0	6.38±0.17
EE25/32Z		FEE25.4B	25.4±0.4	16.0±0.3	6.35±0.3	6.35±0.3	18.67—0	12.83±0.3
EE26/29A			26.0±0.3	$14.35^{+0.4}_{-0}$	8.0±0.15	7.3±0.2	18.6—0	10.7±0.15
EE26/33A			26.0±0.3	$16.35^{+0.4}_{-0}$	8.0±0.15	7.3±0.2	18.6—0	12.7±0.15
EE28/18			27.3±0.5	8.9±0.2	9.7±0.2	8.5±0.3	18.5—0	4.9±0.15
EE28/20			28.0±0.4	$10.0^{+0.25}_{-0}$	$11.0^{+0}_{-0.6}$	$7.5^{+0}_{-0.5}$	18.6—0	$6.0^{+0.25}_{-0}$
EE28/20B			28.0±0.5	$10.7^{+0.15}_{-0.1}$	12.0±0.3	7.2±0.3	18.6—0	$6.2^{+0.15}_{-0.1}$
EE28/25A			28.0±0.3	$12.5^{+0.35}_{-0.15}$	8.0±0.3	$8.0^{+0.1}_{-0.3}$	19.6—0	$8.5^{+0.25}_{-0.05}$

Conventional type EE CORES

Product code	Magnetic parameter								AL (nH)	
	C_1 (mm^{-1})	Le (mm)	Ae (mm^2)	Ve (mm^3)	Ac (mm^2)	Amin. (mm^2)	Aw (mm^2)	W ($\times 10^{-3}$ kg)	6H20	2H10
EE10/11	2.16	26.1	12.1	315	11.6	10.5L	24.0	1.4	850(±25%)	—
EE12.5/15	2.10	31.4	14.9	469	12.0	12.0C	35.2	2.3	900(±25%)	—
EE12.6/13	2.41	29.7	12.4	369	12.6	12.2L	26.3	1.9	800(±25%)	3500(±25%)
EE13/11	1.33	27.9	21.0	586	24.7	19.5B	25.5	3.1	1400(±25%)	—
EE13/12C	1.77	30.2	17.1	517	16.9	16.9C	34.3	2.5	1100(±25%)	—
EE16/11	0.848	28.0	33.0	924	32.5	29.3B	25.7	4.5	2200(±25%)	—
EE16/14K	1.87	35.2	18.9	663	18.2	18.2C	42.6	3.2	1100(±25%)	—
EE16/14C	1.83	35.1	19.2	674	19.2	19.2LBC	41.6	3.4	1100(±25%)	—
EE16/16	1.87	37.6	20.1	756	20.5	19.4B	41.6	3.6	1100(±25%)	—
EE16/24	2.87	55.1	19.2	1060	19.2	19.2LBC	81.6	5.3	800(±25%)	—
EE16/21	2.66	47.1	17.7	834	17.6	17.6LC	63.1	4.5	1500(±25%)	—
EE19/27	2.69	61.3	22.8	1400	22.5	22.5LC	110	7.0	850(±25%)	—
EE19/15	1.66	37.3	22.5	837	22.5	22.5LBC	50.1	4.2	1200(±25%)	—
EE19/16K	1.72	39.6	23.1	915	22.8	22.8C	55.7	4.6	1200(±25%)	—
EE20/20A	1.45	46.0	32.0	1490	32.2	31.6B	62.6	7.5	1550(±25%)	—
EE22/19	1.15	42.5	37.0	1570	33.1	33.1C	54.7	8.3	1850(±25%)	—
EE22/24C	1.46	52.4	35.9	1880	33.1	33.1C	80.6	9.7	1500(±25%)	—
EE22/29	1.73	63.4	36.0	2280	33.0	33.0C	108	11.6	1200(±25%)	—
EE24/31A	0.909	66.6	73.3	4880	73.3	70.5L	105	24.5	2550(±25%)	—
EE25/20	1.16	49.3	42.0	2070	40.8	40.8C	80.5	10.5	1600(±25%)	—
EE25/33	1.79	75.2	42.0	3160	42.2	41.6L	160	15.8	1300(±25%)	—
EE25/25B	1.11	57.7	51.7	2990	52.2	51.0L	95.8	15.0	2000(±25%)	—
EE25/19D	1.20	51.6	43.0	2232	45.5	42.0LB	84.5	10.6	1800(±25%)	—
EE25/20B	1.21	49.8	41.3	2060	42.2	39.6L	87.1	10.3	1800(±25%)	—
EE25/23B	1.37	56.0	41.0	2300	42.2	39.6L	107	11.5	1650(±25%)	—
EE25/19Z	1.20	48.1	40.2	1940	40.3	40.0B	81.0	10.3	1800(±25%)	9000($^{+35\%}_{-25\%}$)
EE25/32Z	1.84	74.0	40.3	2970	40.3	40.3LBC	163	14.8	1350(±25%)	—
EE26/29A	1.33	76.0	57.0	4330	58.4	56.0L	203	19.1	1800(±25%)	—
EE26/33A	1.48	84.0	56.9	4780	58.4	56.0L	241	21.3	1650(±25%)	—
EE28/18	0.535	42.9	80.2	3440	82.5	77.6B	51.0	17.2	4000(±25%)	—
EE28/20	0.559	48.2	86.2	4160	77.6	77.6C	72.0	23.0	4000(±25%)	—
EE28/20B	0.508	49.9	98.2	4910	86.4	86.4C	73.2	25.6	4500(±25%)	—
EE28/25A	0.931	59.0	63.4	3740	63.2	63.2C	104	19.1	2400(±25%)	—

Conventional type EE CORES



Product code	General standard		Dimensions (mm)					
	IEC	JIS	A	B	C	D	E	F
EE28/33		FEE28	28.0±0.4	$16.5^{+0.5}_{-0}$	$11.0^{+0}_{-0.6}$	$7.5^{+0}_{-0.5}$	18.6—0	$12.0^{+0.5}_{-0}$
EE28/28A			28.2±0.3	$14.0^{+0.4}_{-0}$	8.0±0.15	7.3±0.2	20.8—0	10.35±0.15
EE29/28			29.8±0.3	13.9±0.2	10.7±0.15	8.1±0.15	20.9—0	9.9±0.2
EE29/30MA			29.8±0.3	15.0	7.1±0.2	8.1±0.2	20.5—0	11.0±0.2
EE29/30M			29.8±0.5	15.0±0.2	$10.7^{+0.15}_{-0.3}$	8.1±0.2	20.5—0	11.0±0.2
EE30/26K		FEE30A	30.0±0.5	$13.0^{+0.3}_{-0}$	$11.0^{+0}_{-0.6}$	$11.0^{+0}_{-0.6}$	19.5—0	$8.0^{+0.3}_{-0}$
EE30/30A			30.0±0.5	14.9±0.25	6.9±0.3	6.9±0.2	19.5—0	10.15±0.2
EE30/31			$30.0^{+0.5}_{-0.2}$	15.6±0.2	7.5±0.2	10.5±0.2	20.0—0	10.6±0.15
EE30/42K		FEE30B	30.0±0.4	$21.0^{+0.5}_{-0}$	$11.0^{+0}_{-0.6}$	$11.0^{+0}_{-0.6}$	19.5—0	$16.0^{+0.5}_{-0}$
EE30/26B			30.1±0.3	13.13±0.12	10.69±0.3	10.69±0.27	20.0—0	8.13±0.12
EE31/26			30.5±0.5	13.1±0.15	9.4±0.3	9.4±0.3	21.6—0	$8.6^{+0.3}_{-0.1}$
EE32/32A	E32/9	FEE32.1	$32.0^{+0.9}_{-0.7}$	16.1±0.3	9.15±0.35	9.2±0.3	22.7—0	$11.6^{+0.3}_{-0.1}$
EE33/28A		FEE33A	33.0±0.7	14.1±0.25	12.7±0.3	9.7±0.3	$23.6^{+1.0}_{-0.25}$	9.6±0.25
EE33/33A			33.1±0.4	16.5±0.2	$9.0^{+0}_{-0.4}$	$9.0^{+0}_{-0.4}$	24.2—0	12.2±0.2
EE33/28B			33.2±0.5	14.15±0.15	12.7±0.3	9.8±0.3	23.7—0	9.65±0.15
EE34/28A			34.6±0.45	14.2±0.2	9.27±0.25	9.27±0.25	25.4—0	9.9±0.25
EE35/29A			34.93±0.5	14.43±0.25	9.53±0.25	9.53±0.25	25.04—0	9.68±0.25
EE35/35A			35.0±0.5	17.5±0.25	10.0±0.3	10.0±0.3	24.5—0	12.5±0.25
EE35/37			$35.0^{+0.7}_{-0.5}$	18.3±0.2	10.0±0.3	10.0±0.3	24.5—0	13.3±0.2
EE35/48		FEE35B	35.0±0.5	24.2±0.4	$10.3^{+0}_{-0.5}$	$10.3^{+0}_{-0.5}$	25.0±0.5	18.2±0.3
EE35/48C		FEE35C	$35.0^{+0.7}_{-0.5}$	24.2±0.4	11.7±0.3	10.0±0.3	24.5—0	18.2±0.3
EE40/34B			40.0±0.6	16.75±0.35	$12.0^{+0}_{-0.7}$	$12.0^{+0}_{-0.7}$	26.8—0	$10.55^{+0.2}_{-0}$
EE40/34A			40.0±0.5	$16.7^{+0.6}_{-0}$	$12.0^{+0}_{-0.7}$	$11.0^{+0}_{-0.6}$	27.4—0	$10.0^{+0.5}_{-0}$
EE40/34K		FEE40A	40.0±0.5	$16.7^{+0.6}_{-0}$	$11.0^{+0}_{-0.6}$	$11.0^{+0}_{-0.6}$	27.4—0	$10.0^{+0.5}_{-0}$
EE40/54K		FEE40B	40.0±0.5	$27.0^{+0.5}_{-0}$	$12.0^{+0}_{-0.7}$	$12.0^{+0}_{-0.7}$	26.8—0	$20.0^{+0.5}_{-0}$
EE40/35A			40.8±0.55	16.6±0.25	12.4±0.3	12.5±0.3	28.6—0	10.7±0.28
EE41/33			41.28±0.8	16.76±0.13	12.7±0.25	12.7±0.25	28.01—0	10.54±0.13
EE42/42-15W	E42/15	FEE42.2A	$42.0^{+1.0}_{-0.7}$	$21.2^{+0}_{-0.4}$	$15.2^{+0}_{-0.5}$	$12.2^{+0}_{-0.5}$	$29.5^{+1.2}_{-0}$	$14.8^{+0.7}_{-0}$
EE42/42-20W	E42/20	FEE42.2B	$42.0^{+1.0}_{-0.7}$	$21.2^{+0}_{-0.4}$	$20.0^{+0}_{-0.8}$	$12.2^{+0}_{-0.5}$	$29.5^{+1.2}_{-0}$	$14.8^{+0.7}_{-0}$
EE47/39A			47.1±0.5	19.6±0.25	15.6±0.3	15.6±0.3	31.7—0	12.4±0.3
EE49/48			49.07±0.64	23.77±0.25	15.62±0.43	15.62±0.25	31.37—0	$15.24^{+0.3}_{-0.15}$
EE50/66		FEE50B	50.0±0.7	$33.0^{+0.7}_{-0}$	$15.0^{+0}_{-0.8}$	$15.0^{+0}_{-0.8}$	33.5—0	$24.5^{+0.7}_{-0}$
EE55/55A	E55/21	FEE55.2A	$55.0^{+1.2}_{-0.9}$	$27.8^{+0}_{-0.6}$	$21.0^{+0}_{-0.6}$	$17.2^{+0}_{-0.5}$	$37.5^{+1.2}_{-0}$	$18.5^{+0.8}_{-0}$
EE55/55B	E55/25	FEE55.2B	$55.0^{+1.2}_{-0.9}$	$27.8^{+0}_{-0.6}$	$25.0^{+0}_{-0.8}$	$17.2^{+0}_{-0.5}$	$37.5^{+1.2}_{-0}$	$18.5^{+0.8}_{-0}$
EE56/47A			56.6±0.55	23.6±0.25	18.7±0.3	18.7±0.3	38.1—0	14.8±0.3
EE80/76			80.0±1.0	38.1±0.4	19.8±0.4	19.8±0.4	62.2	28.2±0.3

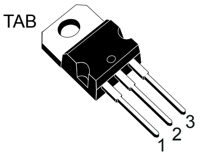
Conventional type EE CORES

Product code	Magnetic parameter								AL (nH)	
	C_1 (mm^{-1})	Le (mm)	Ae (mm^2)	Ve (mm^3)	Ac (mm^2)	Amin. (mm^2)	Aw (mm^2)	W ($\times 10^{-3}$ kg)	6H20	2H10
EE28/33	0.844	73.6	87.2	6420	77.0	77.0C	145	32.1	2800(±25%)	—
EE28/28A	1.48	84.2	56.9	4790	58.4	56.0L	144	19.0	1650(±25%)	—
EE29/28	0.766	65.9	86.0	5670	86.7	85.6LB	136	28.6	2900(±25%)	—
EE29/30MA	1.07	92.1	86.0	7960	86.7	85.6LB	150	30.0	2300(±25%)	—
EE29/30M	1.61	92.1	57.3	5280	57.5	56.8LB	151	26.4	1500(±25%)	—
EE30/26K	0.528	57.9	110	6360	114	107L	75.8	32.2	4200(±25%)	—
EE30/30A	1.15	66.1	57.3	3790	47.6	47.6C	134	20.7	1900(±25%)	—
EE30/31	0.907	68.1	75.1	5110	78.8	72.0L	107	23.7	2600(±25%)	—
EE30/42K	0.823	90.2	110	9920	114	107LB	152	49.8	3000(±25%)	—
EE30/26B	0.621	61.3	97.6	5980	114	107LB	76.4	32.0	4200(±25%)	—
EE31/26	0.723	61.0	84.4	5150	88.4	79.9L	110	25.8	3150(±25%)	—
EE32/32A	0.886	74.8	84.4	6310	84.2	78.7L	167	31.0	2700(±25%)	—
EE33/28A	0.615	67.7	110	7520	123	114B	129	40.0	3800(±25%)	—
EE33/33A	1.02	78.1	76.3	5960	77.4	75.7LB	299	29.5	2600(±25%)	—
EE33/28B	0.561	65.6	117	7680	123	114LB	138	39.0	4150(±25%)	—
EE34/28A	0.852	69.9	82.1	5750	85.9	79.7B	164	29.5	2500(±25%)	—
EE35/29A	0.768	69.6	90.6	6300	90.8	90.5LB	154	32.2	3400(±25%)	—
EE35/35A	0.807	80.7	100	8070	100	100LBC	188	40.6	3000(±25%)	—
EE35/37	0.839	83.9	100	8390	100	100LBC	200	42.5	2600(±25%)	—
EE35/48	1.01	105	104	10800	100	100LC	273	54.0	2500(±25%)	—
EE35/48C	0.863	105	121	12700	117	117LC	273	63.5	2900(±25%)	—
EE40/34B	0.544	77.5	142	11000	137	137C	167	52.0	4200(±25%)	—
EE40/34A	0.557	77.4	139	10800	125	125C	177	56.4	4500(±25%)	—
EE40/34K	0.608	77.4	127	9860	114	114C	178	52.0	3800(±25%)	—
EE40/54K	0.808	117	145	17000	137	137C	323	85.0	3150(±25%)	—
EE40/35A	0.526	78.1	149	11600	155	145L	178	58.8	4250(±25%)	—
EE41/33	0.483	77.3	160	12400	161	158LB	169	63.0	4950(±25%)	—
EE42/42-15W	0.542	97.8	180	17600	180	180BC	276	87.0	4400(±25%)	—
EE42/42-20W	0.415	97.8	236	23000	235	235BC	276	118	5600(±25%)	—
EE47/39A	0.385	89.5	232	20800	243	223B	206	106	6000(±25%)	—
EE49/48	0.428	110	257	28200	245	245C	250	134	5900(±25%)	—
EE50/66	0.649	144	222	32000	213	213C	506	160	4000(±25%)	—
EE55/55A	0.350	124	353	43700	352	352C	400	218	6700(±25%)	—
EE55/55B	0.295	124	420	52000	417	417C	400	260	8650(±25%)	—
EE56/47A	0.316	107	345	36700	352	329B	292	189	6500(±25%)	—
EE80/76	0.491	185	377	69800	392	352L	1480	350	4800(±25%)	—

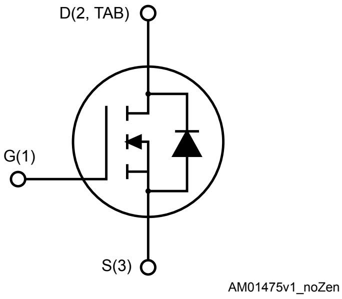
IRF630

Datasheet

N-channel 200 V, 0.29 Ω typ., 9 A, STripFET™ Power MOSFET in a TO-220 package



TO-220



Features

Order code	V_{DS}	$R_{DS(on)}$ max.	I_D
IRF630	200 V	0.40 Ω	9 A

- Extremely high dv/dt capability
- Very low intrinsic capacitance
- Gate charge minimized

Applications

- Switching applications

Description

This Power MOSFET series realized with STMicroelectronics unique STripFET™ process has specifically been designed to minimize input capacitance and gate charge. It is therefore suitable as primary switch in advanced high-efficiency isolated DC-DC converters.

Product status link
IRF630

Product summary	
Order code	IRF630
Marking	IRF630
Package	TO-220
Packing	Tube

1 Electrical ratings

Table 1. **Absolute maximum ratings**

Symbol	Parameter	Value	Unit
V_{DDS}	Drain-source voltage (V_{GS} = 0 V)	200	V
V_{DGR}	Drain-gate voltage (R_{GS} = 20 kΩ)	200	V
V_{GS}	Gate-source voltage	±20	V
I_D	Drain current (continuous) at T_C = 25 °C	9	A
	Drain current (continuous) at T_C = 100 °C	6.5	A
I_{DM}(1)	Drain current (pulsed)	36	A
P_{TOT}	Total power dissipation at T_C = 25 °C	120	W
E_{AS}(2)	Single pulse avalanche energy	110	mJ
dv/dt(3)	Drain-body diode dynamic dv/dt ruggedness	5.8	V/ns
T_{stg}	Storage temperature range	-65 to 175	°C
T_J	Operating junction temperature range		

1. *Pulse width is limited by safe operating area.*
2. *Starting T_J = 25 °C, I_D = 4.5 A*
3. *I_{SD} = 9 A, di/dt = 520 A/µs, V_{DD} = 50 V, $T_J < T_{Jmax}$*

Table 2. **Thermal data**

Symbol	Parameter	Value	Unit
$R_{thj-case}$	Thermal resistance junction-case	1.26	°C/W
$R_{thj-amb}$	Thermal resistance junction-ambient	62.5	°C/W

2 Electrical characteristics

T_{CASE} = 25 °C unless otherwise specified

Table 3. On/off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	V_{GS} = 0 V, I_D = 250 µA	200			V
I_{DSS}	Zero gate voltage drain current	V_{GS} = 0 V, V_{DS} = 200 V			1	µA
		V_{GS} = 0 V, V_{DS} = 200 V, T_C = 125 °C[1]			100	µA
I_{GSS}	Gate body leakage current	V_{DS} = 0 V, V_{GS} = 20 V			±100	nA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	2	3	4	V
$R_{DS(on)}$	Static drain-source on-resistance	V_{GS} = 10 V, I_D = 4.5 A		0.29	0.40	Ω

1. *Defined by design, not subject to production test.*

Table 4. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
C_{iss}	Input capacitance	V_{DS} = 25 V, f = 1 MHz, V_{GS} = 0 V	-	370	-	pF
C_{oss}	Output capacitance		-	77	-	pF
C_{rss}	Reverse transfer capacitance		-	14	-	pF
Q_g	Total gate charge	V_{DD} = 160 V, I_D = 9 A V_{GS} = 0 to 10 V (see Figure 13. Test circuit for gate charge behavior)	-	11.6	-	nC
Q_{gs}	Gate-source charge		-	2.2	-	nC
Q_{gd}	Gate-drain charge		-	5.5	-	nC

Table 5. Switching times

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on delay time	V_{DD} = 100 V, I_D = 4.5 A, R_G = 4.7 Ω, V_{GS} = 10 V (see Figure 12. Test circuit for resistive load switching times and Figure 17. Switching time waveform)	-	5.6	-	ns
t_r	Rise time		-	2.6	-	ns

Table 6. **Source-drain diode**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_{SD}[1]	Forward on voltage	I_{SD} = 9 A, V_{GS} = 0 V	-		1.5	V
t_{rr}	Reverse recovery time	I_{SD} = 9 A, di/dt = 100 A/μs, V_{DD} = 50 V (see Figure 17. Switching time waveform)	-	118.5		ns
Q_{rr}	Reverse recovery charge		-	393		nC
I_{RRM}	Reverse recovery current		-	6.6		A

1. *Pulsed: pulse duration = 300 μs, duty cycle 1.5%*

2.1 Electrical characteristics (curves)

Figure 1. **Safe operating area**

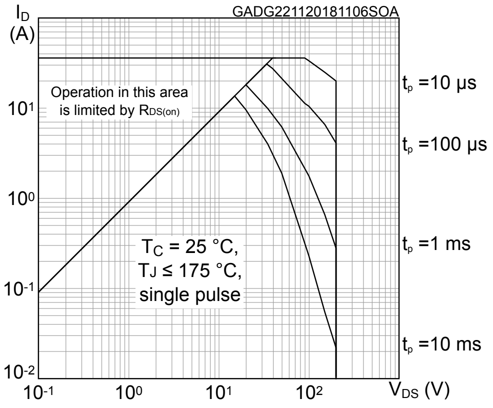


Figure 2. **Thermal impedance**

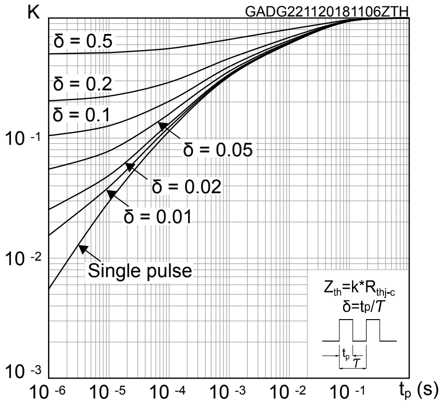


Figure 3. **Output characteristics**

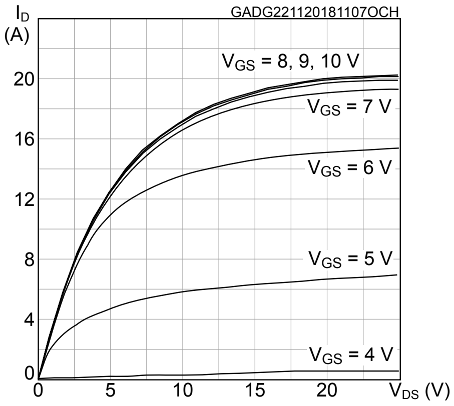


Figure 4. **Transfer characteristics**

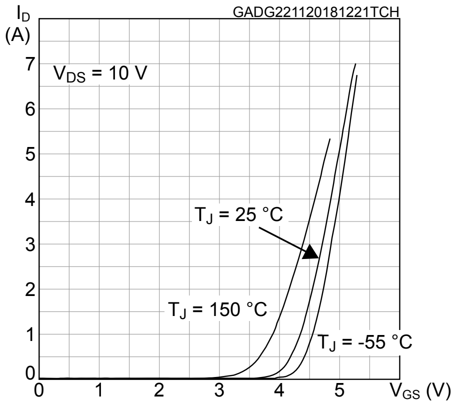


Figure 5. **Gate charge vs gate-source voltage**

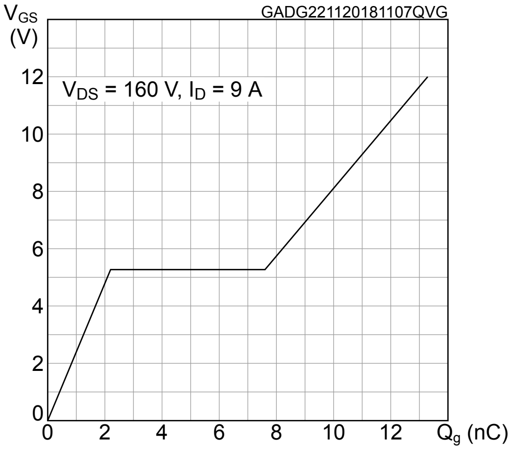


Figure 6. **Static drain-source on-resistance**

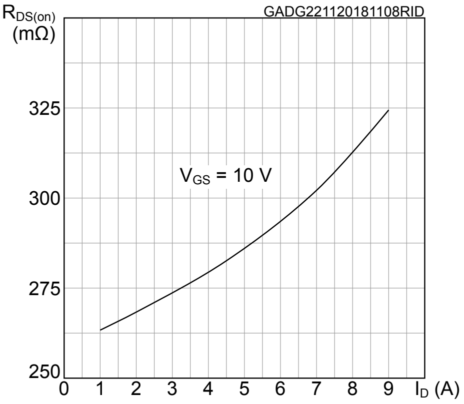


Figure 7. Capacitance variations

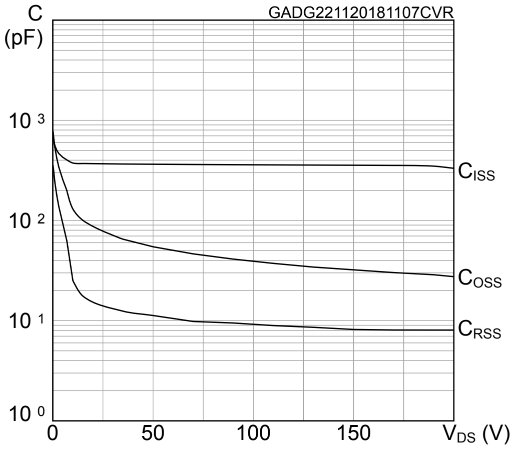


Figure 8. Normalized gate threshold voltage vs temperature

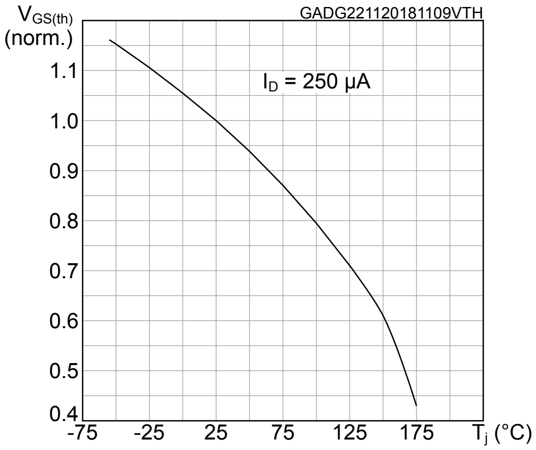


Figure 9. Normalized on-resistance vs temperature

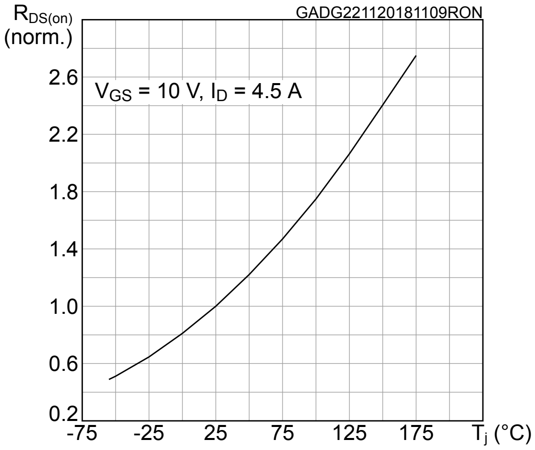


Figure 10. Normalized $V_{(BR)DSS}$ vs temperature

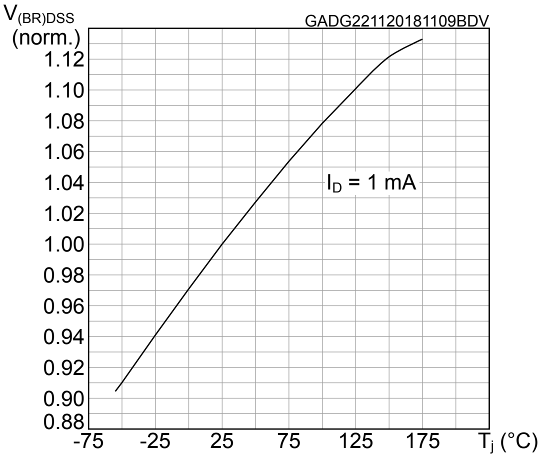
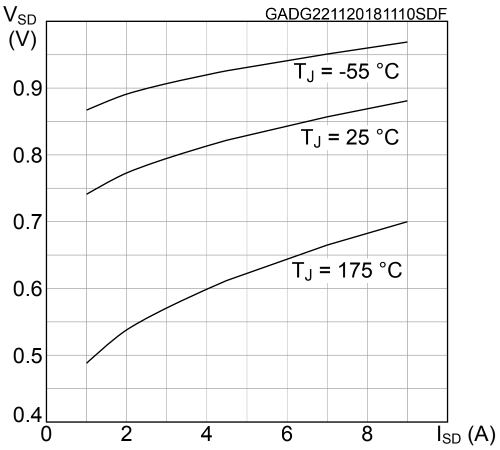


Figure 11. Source-drain diode forward characteristics



3 Test circuits

Figure 12. Test circuit for resistive load switching times

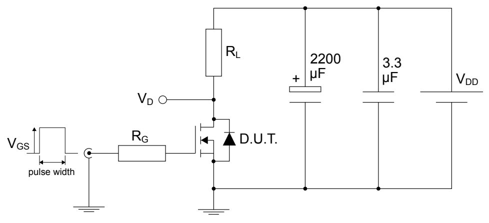


Figure 13. Test circuit for gate charge behavior

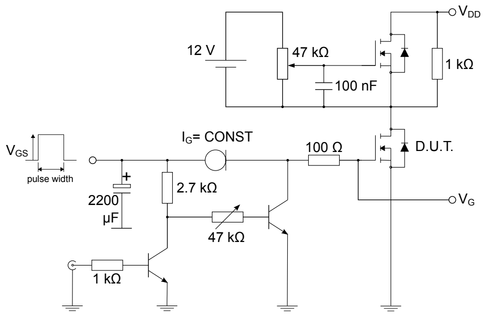


Figure 14. Test circuit for inductive load switching and diode recovery times

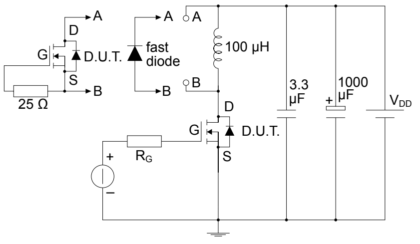


Figure 15. Unclamped inductive load test circuit

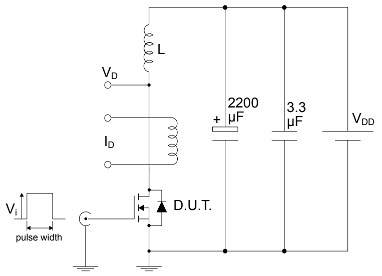


Figure 16. Unclamped inductive waveform

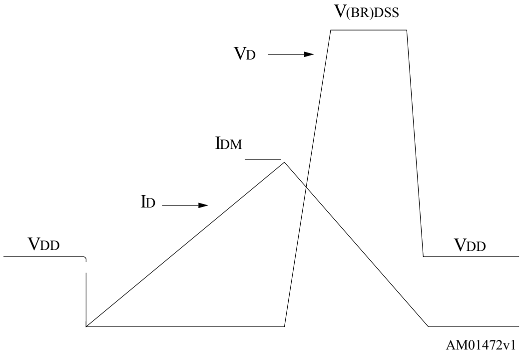
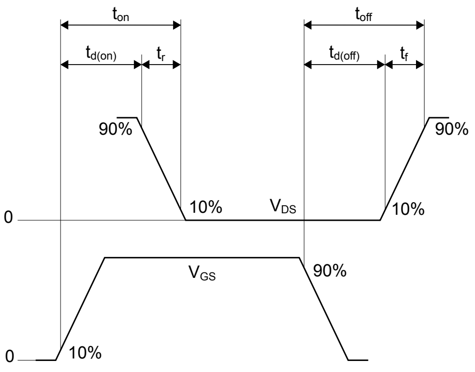


Figure 17. Switching time waveform

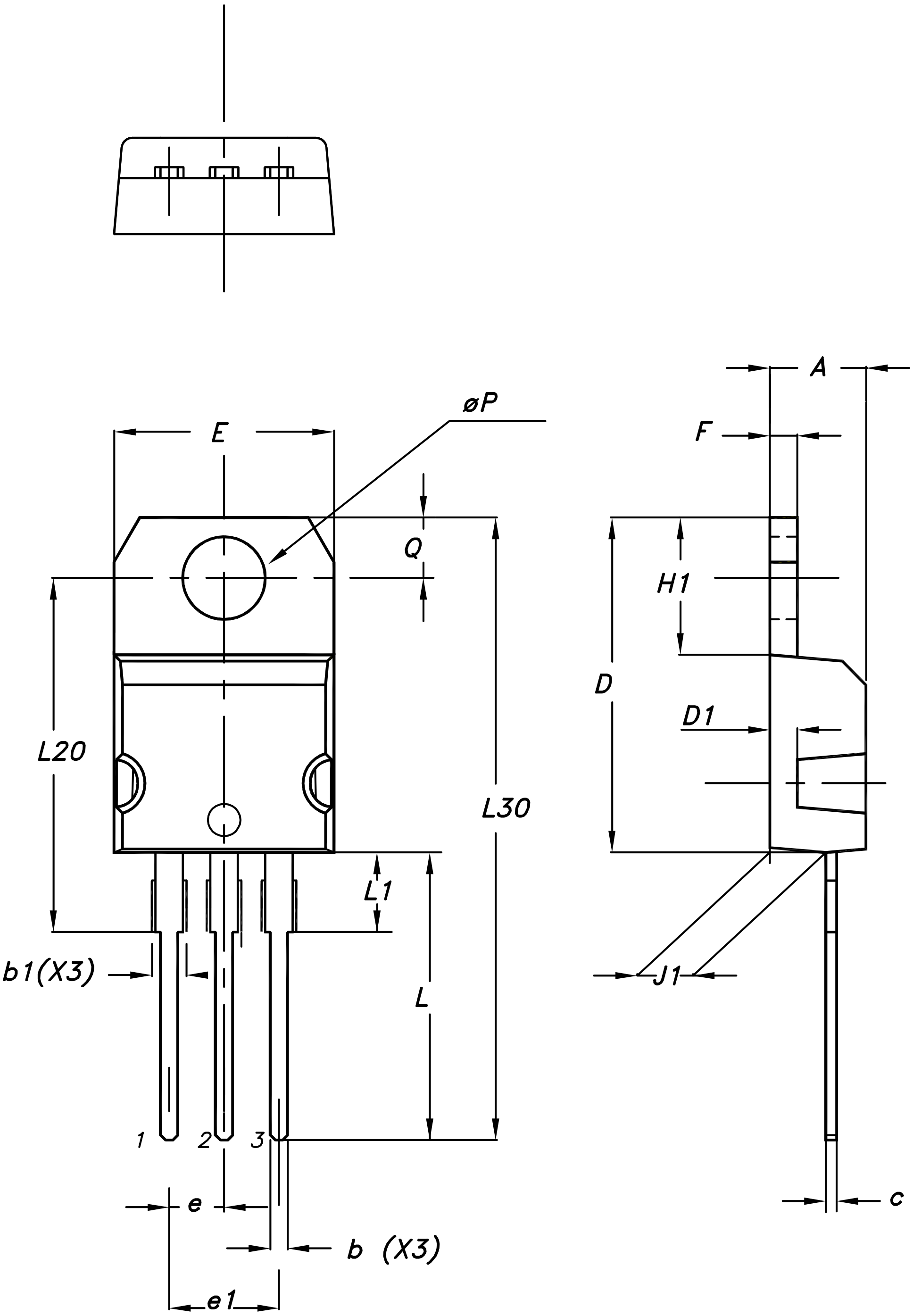


4 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: www.st.com. ECOPACK® is an ST trademark.

4.1 TO-220 type A package information

Figure 18. TO-220 type A package outline



0015988_typeA_Rev_22

Table 7. **TO-220 type A package mechanical data**

Dim.	mm		
	Min.	Typ.	Max.
A	4.40		4.60
b	0.61		0.88
b1	1.14		1.55
c	0.48		0.70
D	15.25		15.75
D1		1.27	
E	10.00		10.40
e	2.40		2.70
e1	4.95		5.15
F	1.23		1.32
H1	6.20		6.60
J1	2.40		2.72
L	13.00		14.00
L1	3.50		3.93
L20		16.40	
L30		28.90	
øP	3.75		3.85
Q	2.65		2.95

Revision history

Table 8. **Document revision history**

Date	Version	Changes
09-Sep-2004	8	Complete version
03-Aug-2006	9	New template, no content change
12-Dec-2018	10	Part number IRF630FP has been moved to a separate datasheet and the document has been updated accordingly. Minor text changes

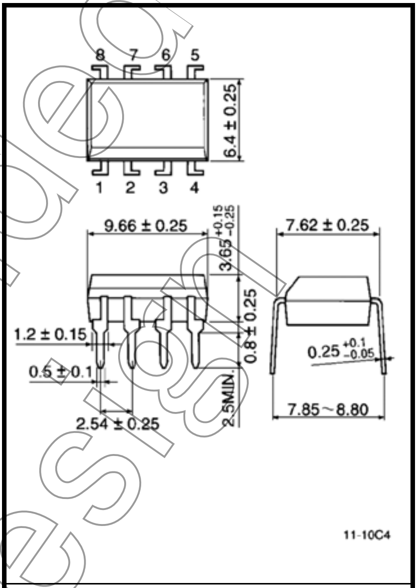
Contents

TOSHIBA Photocoupler GaAℓAs Ired & Photo−IC

TLP250

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

Unit in mm



TOSHIBA 11−10C4

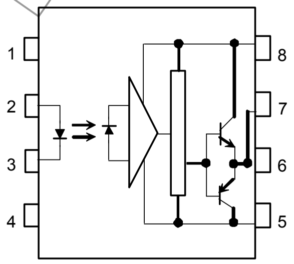
Weight: 0.54 g (typ.)

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 (t_{pLH}/t_{pHL}): 0.5μs(max.)
- Isolation voltage: 2500V_{rms}(min.)
- UL recognized: UL1577, file No.E67349
- Option(D4)
  VDE Approved : DIN EN60747-5-2
  Maximum Operating Insulation Voltage : 890V_{PK}
  Highest Permissible Over Voltage : 4000V_{PK}

**(Note):When a EN60747-5-2 approved type is needed,
Please designate "Option(D4)"**

Pin Configuration (top view)

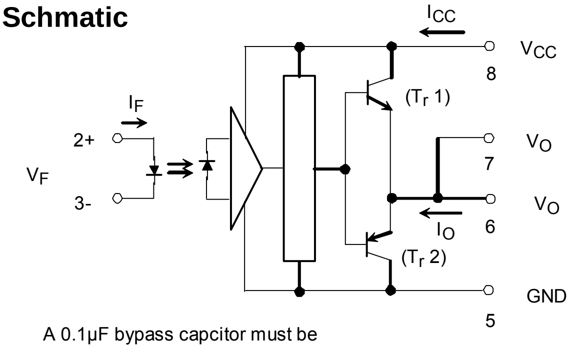


1 : N.C.	5 : GND
2 : Anode	6 : V_O (Output)
3 : Cathode	7 : V_O
4 : N.C.	8 : V_{CC}

Truth Table

		Tr1	Tr2
Input LED	On	On	Off
	Off	Off	On

Schmatic



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

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 curent	(Note 1)		I_{FPT}	1	A
	Reverse voltage			V_R	5	V
	Junction temperature			Tj	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			Tj	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)				T_{sol}	260	°C
Isolation voltage (AC, 1 min., R.H.≤ 60%)		(Note 4)		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: 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: Device considerd a two terminal device: Pins 1, 2, 3 and 4 shorted together, and pins 5, 6, 7 and 8 shorted together.

Note 5: 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	(Note6)	$I_{F(ON)}$	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: 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.

Note 6: Input signal rise time(fall time)<0.5μs.

Electrical Characteristics (Ta = −20~70°C, unless otherwise specified)

Characteristic		Symbol	Test Cir−cuit	Test Condition		Min	Typ.*	Max	Unit
Input forward voltage		V_F	—	I_F = 10 mA , Ta = 25°C		—	1.6	1.8	V
Temperature coefficient of forward voltage		$\Delta V_F / \Delta Ta$	—	I_F = 10 mA		—	−2.0	—	mV / °C
Input reverse current		I_R	—	V_R = 5V, Ta = 25°C		—	—	10	μA
Input capacitance		C_T	—	V = 0 , f = 1MHz , Ta = 25°C		—	45	250	pF
Output current	"H" level	I_{OPH}	1	V_{CC} = 30V (*1)	I_F = 10 mA V_{8-6} = 4V	−0.5	−1.5	—	A
	"L" level	I_{OPL}	2		I_F = 0 V_{6-5} = 2.5V	0.5	2	—	
Output voltage	"H" level	V_{OH}	3	V_{CC1} = +15V, V_{EE1} = −15V R_L = 200Ω, I_F = 5mA		11	12.8	—	V
	"L" level	V_{OL}	4	V_{CC1} = +15V, V_{EE1} = −15V R_L = 200Ω, V_F = 0.8V		—	−14.2	−12.5	
Supply current	"H" level	I_{CCH}	—	V_{CC} = 30V, I_F = 10mA Ta = 25°C		—	7	—	mA
				V_{CC} = 30V, I_F = 10mA		—	—	11	
	"L" level	I_{CCL}	—	V_{CC} = 30V, I_F = 0mA Ta = 25°C		—	7.5	—	
				V_{CC} = 30V, I_F = 0mA		—	—	11	
Threshold input current	"Output L→H"	I_{FLH}	—	V_{CC1} = +15V, V_{EE1} = −15V R_L = 200Ω, V_O > 0V		—	1.2	5	mA
Threshold input voltage	"Output H→L"	V_{FHL}	—	V_{CC1} = +15V, V_{EE1} = −15V R_L = 200Ω, V_O < 0V		0.8	—	—	V
Supply voltage		V_{CC}	—			10	—	35	V
Capacitance (input−output)		C_S	—	V_S = 0 , f = 1MHz Ta = 25°C		—	1.0	2.0	pF
Resistance(input−output)		R_S	—	V_S = 500V , Ta = 25°C R.H.≤ 60%		1×10^{12}	10^{14}	—	Ω

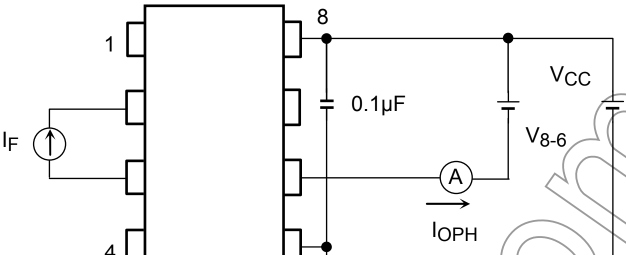
* All typical values are at Ta = 25°C (*1): Duration of I_O time ≤ 50μs

Switching Characteristics (Ta = −20~70°C , unless otherwise specified)

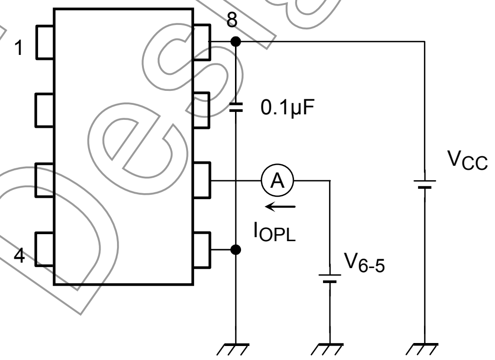
Characteristic		Symbol	Test Cir− cuit	Test Condition	Min	Typ.*	Max	Unit
Propagation delay time	L→H	t_{pLH}	5	I_F = 8mA V_{CC1} = +15V, V_{EE1} = −15V R_L = 200Ω	—	0.15	0.5	μs
	H→L	t_{pHL}			—	0.15	0.5	
Output rise time		t_r			—	—	—	
Output fall time		t_f			—	—	—	
Common mode transient immunity at high level output		C_{MH}	6	V_{CM} = 600V, I_F = 8mA V_{CC} = 30V, Ta = 25°C	−5000	—	—	V / μs
Common mode transient immunity at low level output		C_{ML}		V_{CM} = 600V, I_F = 0mA V_{CC} = 30V, Ta = 25°C	5000	—	—	V / μs

All typical values are at Ta = 25°C

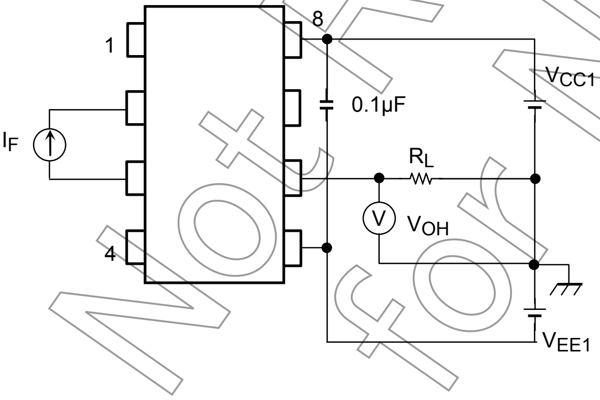
Test Circuit 1 : I_{OPH}



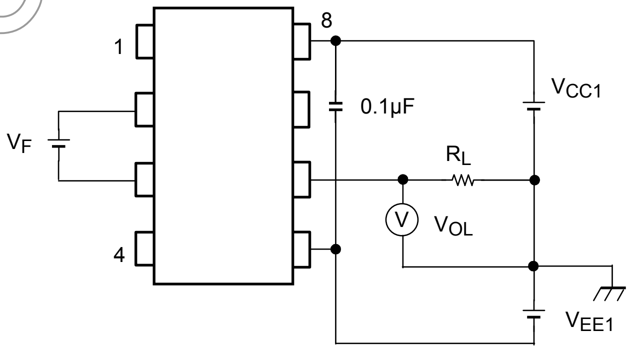
Test Circuit 2 : I_{OPL}



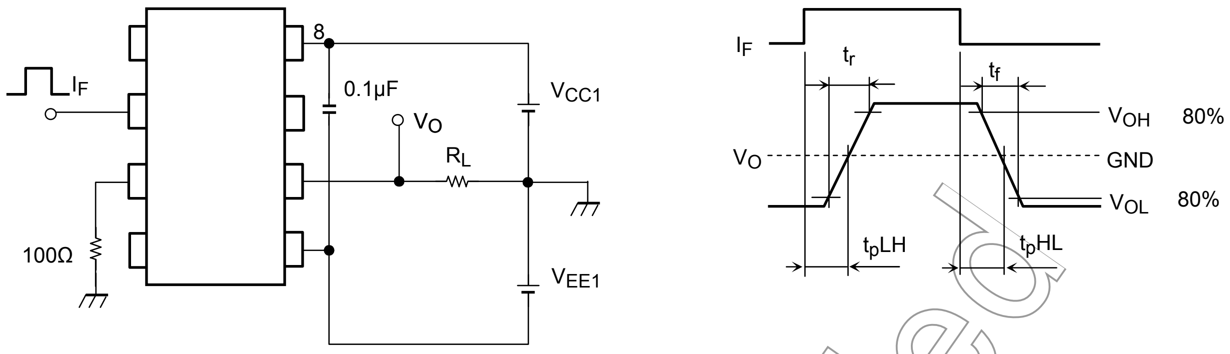
Test Circuit 3 : V_{OH}



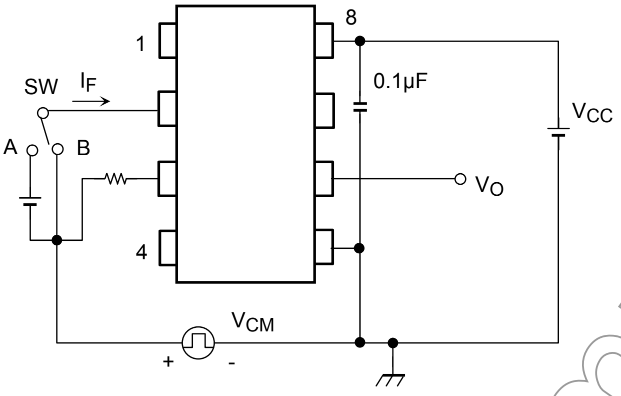
Test Circuit 4 : V_{OL}

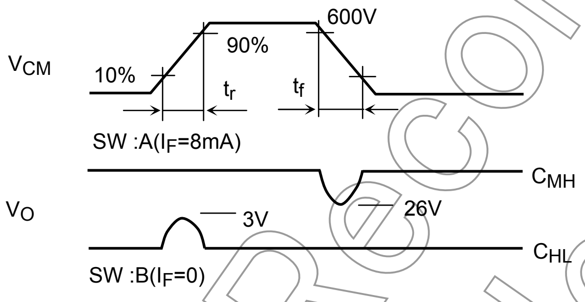


Test Circuit 5: t_{pLH}, t_{pHL}, t_r t_f



Test Circuit 6: C_{MH}, C_{ML}



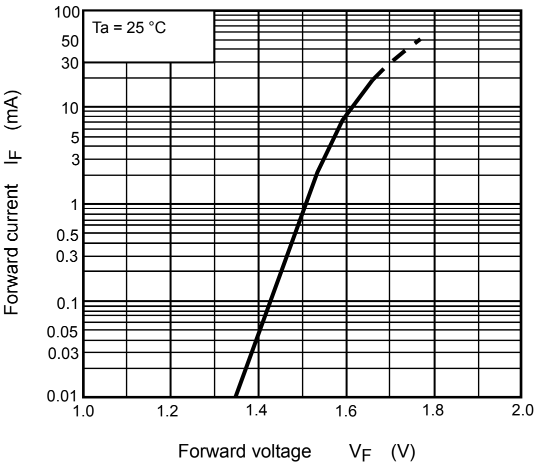


$$C_{ML} = \frac{480\ (V)}{t_{r\ (\mu s)}}$$

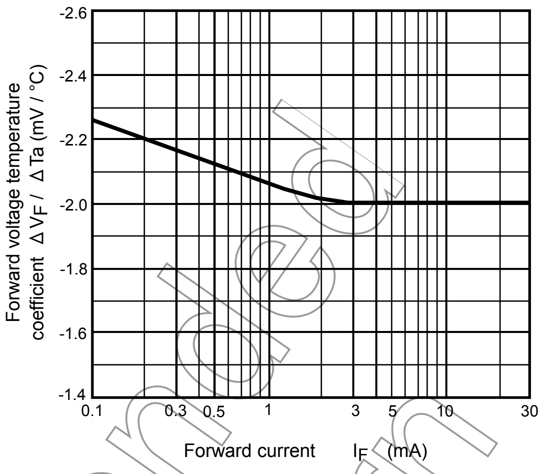
$$C_{MH} = \frac{480\ (V)}{t_{f\ (\mu s)}}$$

C_{ML}(C_{MH}) is the maximum rate of rise (fall) of the common mode voltage that can be sustained with the output voltage in the low (high) state.

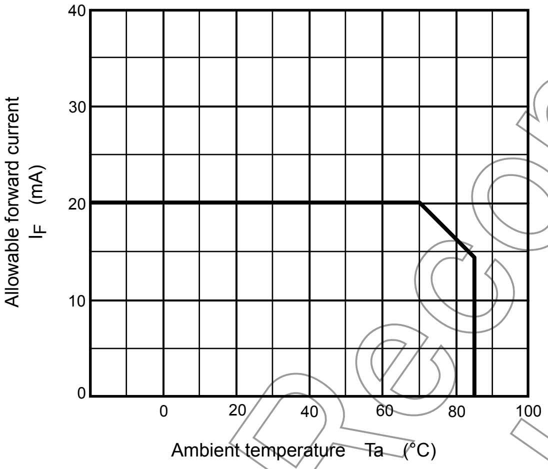
I_F – V_F



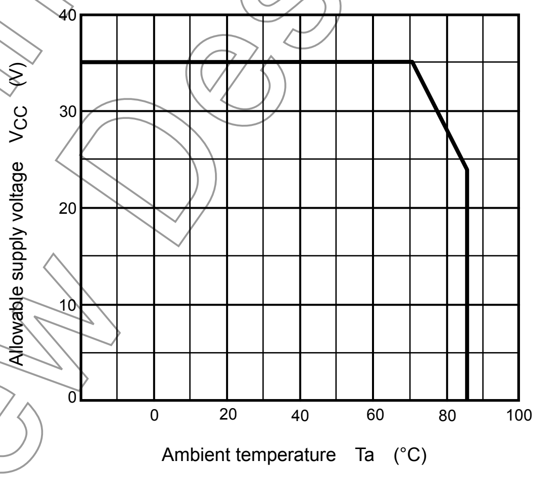
Δ V_F / Δ Ta – I_F



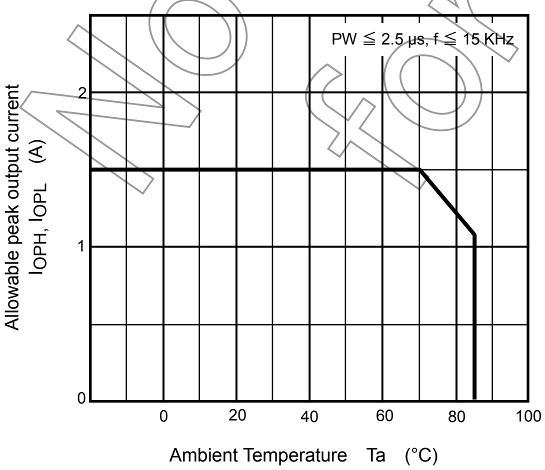
I_F – Ta



V_{CC} – Ta



I_{OPH}, I_{OPL} – Ta



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