LOW POWER AUTOMATIC VOLTAGE REGULATOR FOR SENSITIVE EQUIPMENTS BY USING AUDIO AMPLIFICATION TECHNIQUE

Vijayasothy Vijayagopal
149366J

Degree of Master of Science in Industrial Automation

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

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Dissertation submitted in partial fulfilment of the requirements for the
Degree Master of Science in Industrial Automation

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DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own investigation and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

………………………………… ……………………..

Signature: Date:

The above candidate has carried out research for the Masters Dissertation under our supervision.

…………………………………. ……………………

Signature of the supervisor: Date

DEDICATION

To my parents for earning an honest living for us and for supporting and encouraging me to believe in myself. I dedicate this thesis to my family for nursing me with affections and love and their dedicated partnership for success in my life.

ACKNOWLEDGEMENT

Thanks are due first to my supervisor, Dr. D.P Chandima, for his great insights, perspectives, guidance and sense of humor. My sincere thanks go to the officers in Post Graduate Office, Faculty of Engineering, University of Moratuwa , Sri Lanka for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

Lastly, I should thank my parents, friends and colleagues who have not been mentioned here personally in making this educational process a success. May be I could not have made it without your supports.

ABSTRACT

In the market there are many choices for Automatic voltages regulators such as auto transformers with relays, servo-mechanism types, Thyristor used types and power inverters type with varying degrees of quality, efficiency, and power output capability. But they cannot be used for low power sensitive applications such as biomedical instruments etc. due to high harmonic content, wave distortions and RFI/EMI issues etc.

The High-Frequency Inverter is mainly used today in uninterruptible power supply systems, AC motor drives, induction heating and renewable energy source systems. The simplest form of an inverter is the bridge-type, where a power bridge is controlled according to the sinusoidal pulse-width modulation (SPWM) principle and the resulting SPWM wave is filtered to produce the alternating output voltage. This can be achieved by using a High-Frequency Inverter that involves an isolated DC-DC stage (Voltage Fed Push-Pull/Full Bridge) and the DC-AC section, which provides the AC output.

My objective to overcome the said problem is to design a simple Low power Automatic Voltage Regulator for sensitive equipment by using audio amplification technique giving an output waveform as similar to the main supply without moving parts (electro-mechanical devices). It would be a linear mode operating electronic amplifier circuit using bipolar junction transistor (BJT) for 50Hz operation of the main supply.

The noise free low signal obtained from the main supply is used as an input signal, having supply frequency (without oscillator) and low voltage. To obtain a controlled noise free standard supply voltage and frequency at the output terminals by the process of power amplification, which could be used for the sensitive equipment in nature such as medical equipment etc.

This is done by passing the main supply through the RFI/ EMI filters (radio frequency and electromagnetic interference) and utilizing the very low voltage “signal” of frequency 50Hz via step down process. The signal as said is filtered using low pass filters and amplified by utilizing audio amplification method. Since 50Hz or 60 Hz frequency is within the audible range, the amplifier is almost the same as audio amplifier which has the push pull output which inverts the noise free DC supply, obtained after the rectification and filtered from the main supply and converts back to AC supply at the same frequency and at the same RMS value.

The sample input signal is calculated (by graphical method) with voltage fluctuation expected and is augmented via preamplifier stage to get a higher amplitude signal. This is done for the various amplitude of input signals to the preamplifier and from its output signals. The fraction of the augmented signal is used for amplification by the stages following the preamplifier. Any variation in the main supply would not interrupt this signal but provide the variation in amplitude by fraction and this is used to control the output voltage. Also the output voltage from the push pull transformer is kept at higher value, expected drop plus normal supply voltage, (by step up winding) and is brought to the supply voltage by electronically. And even supply voltage goes up, it will bring down to the normal supply voltage automatically. As this circuit is operative with the supply frequency, it may be easy to synchronize with the main supply voltage whenever needed. The general effects of voltage regulation on semiconductors and transformers characteristics were also considered with the guidance of IEC 60146-1-1,Semiconductor converters and IEC 60146-1-3 , IEC 60076 converter transformers.

Calculations have been done based on practically obtained data to determine the voltage regulation introduced by the normal loading with the voltage variation between 260V and 180V. The subsidiary Legislation under the Electricity Act defines a maximum voltage variation is ±6% of the nominal voltage (216.2- 243.8V) to the consumer. Our system response approximately±2%

For the future development, high power transistors are used in the driver circuit and for the better response integrated circuits may be used instead of discrete circuit which I have used. There are lots of IC’s available. The circuit also could be used with MOSFET in the output stage. The circuit should be modified when using MOSFET as it is capacitive and voltage control device at the input as compared to BJT, which is current operative device.

Key words

Thyristor, Radio Frequency Interference /Electromagnetic Interference (RFI/EMI) filters, Root Mean Square (RMS), Bipolar Junction Transistor (BJT), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Sinusoidal Pulse-Width Modulation (SPWM), Inverter, signal.

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LIST OF ABBREVIATIONS

Abbreviation	Description
BJT	Bipolar Junction Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MMF	Magnetomotive force
PWM	Pulse width modulation,
RFI/EMI	Radio Frequency Interference /Electromagnetic Interference
SMPS	Switch mode power supply system
SPWM	Sinusoidal Pulse-Width Modulation

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1. INTRODUCTION

1.1 Background

For the purpose of transmission and utility, the electric power supply must have constant electromotive force (EMF) and frequency at the terminals of the equipment. Whatever the load exists (within the limits) constant voltage and frequency have to be maintained at the terminals. But practically it does not happen due to the several factors such as reactive loads, switching loads etc. disturbing the voltage and the frequency of the supply. Therefore the voltage controllers have to be constructed along with the transformers to maintain constant voltage and frequency, free from noise (harmonics, Radio frequency and electromagnetic interference etc.) at the distance away load terminals.

Due to the advanced development of semiconductors, nowadays it is done by electronic circuits and feedback techniques in Automatic Voltage Regulator circuits (AVR).Several researches are still conducted to improve the system. Power quality issues and remedies are relevant research topics and a lot of advanced researches are being carried out. These issues are mainly due to increased use of power electronic devices, nonlinear loads and unbalance in power systems. Dynamic loads cause power quality problems usually by voltage or current variations such as voltage dips, fluctuations, momentary interruptions, oscillatory transients, harmonics, harmonic resonance etc. Various publications define power quality in different aspects. Power quality is defined as concept of powering and grounding sensitive equipment in a manner that is suitable for operation of that equipment.

For example, when choosing a power supply for a medical device, it's important to handle with caution, compared with industrial power supplies and AVR, medical grade power sources are subject to different risks and more rigorous safety standards. After all, when the device will be coming into such close proximity with a patient, it is imperative that the power does not fail or the current exceed certain specifications.

It's crucial to track down a vendor with experience in this field, preferably one that is accustomed to designing medical grade power supplies as opposed to simply adapting a commercial product. The following medical Instruments are required highly sensitive ac power supply with 50Hz without distortion.

- **Mini Centrifuge Z 130 M**

Unlike traditional mini centrifuges, the new Z130M eliminates the need to change rotors when switching between micro tubes and PCR strips. The included, unique COMBI-Rotor is all that is required for running 12 micro tubes and 4 PCR strips simultaneously. With a fixed speed that produces 5500rpm, this centrifuge is perfect for quick spin downs.

Figure 1:1 Mini Centrifuge Z 130M

Table 1.1 Technical Data Z 130M

Max Speed	5500rpm
Max RCF	2000 xg
Max Volume	12×1.5/2.0ml tubes 32×0.2ml PCR tubes 4×PCRstrips (8×0.2ml)
Dimensions(W×H×D)	14cm× 11.2cm× 20cm
Weight	1.3kg
Order numbers	324.00V01-Z 130 M,230V / 50-60Hz/40W, 324.00-Z 130M,120V/50-60Hz/40W

(Source : HERMLE LABOR TECHNIK, Mini Centrifuge Z 130M)

- **SSM5 and SSL5 , Shaker, microtitre,**

These compact rockers are ideal where gentle mixing is required, either on the bench or in incubators. Choice of two models: With the combination of high speed and a tiny orbit the SS:5 range has an ideal action for mixing microtitre plates and micro centrifuge tubes.

Microtitre plates are held to the platform by a highly efficient non slip mat. Micro tubes can be held via the purpose built accessory racks, available separately. The SS:5 range has adjustable speed control between 250 and 1250rpm, the speed is shown via the bright LED display and accurately controlled by an encoder. The versatile timer can be set from 1 second to 9 hours.

Figure 1:2 SSM5 & SSL5

(Source: Stuart^R Catalogue, SSM5 and SSL5 Shaker, microtitre, Page 104)

Key Features

- High speed, small orbiting action – ideal for microtitre plates
- Capacity for four or eight microtitre plates
- Digital selection of speed
- In built digital timer
- Accessories available for mixing micro centrifuge tubes

Table 1.2 Technical Specification of SSM5 and SSL5

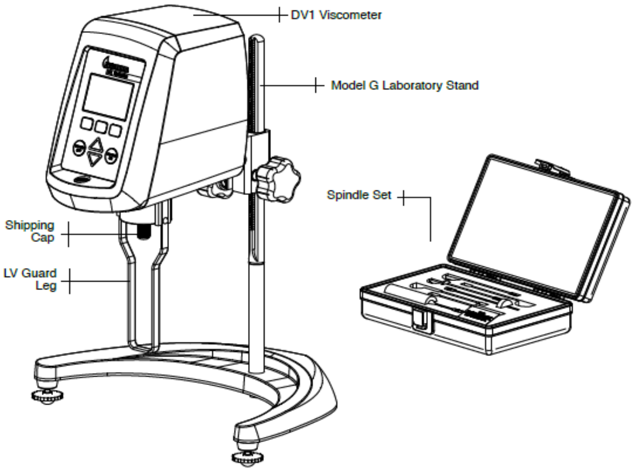
	SSM5	**SSL5**
Platform dimensions, mm(w × l)	220×220	306×306
Number of plate positions	4	8
Speed range , rpm	250 to 1250	250 to 1250
Orbit diameter, mm	1.5	1.5
Maximum Load, kg	1	2
Operational Temperature range	+4 to +40ºC	+4 to +40ºC
Maximum Permissible Humidity	80%	80%
Dimensions, mm (w × d × h)	240×300×160	360×420×160
Net weight, kg	5	10
Electrical supply	230V,50Hz,50W	230V,50Hz,50W
IP Ratings	31	31

(Source: Stuart^R Catalogue ,SSM5 and SSL5 Shaker, microtitre ,Page 104)

- **Digital Viscometer**

The Brookfield DV1 Viscometer measures fluid viscosity which is a measure of a fluid’s resistance to flow. The principle of operation of the DV1 is to drive a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection.

Spring deflection is measured with a rotary transducer. This system provides continuous sensing and display of the measurement during the entire test. The measurement range of a DV1 (in centipoise or milli Pascal-seconds) is determined by the rotational speed of the spindle, the size and shape of the spindle, the container the spindle is rotating in, and the full-scale torque of the calibrated spring.



Input Voltage: 115V AC or 230 VAC
Input Frequency: 50/60 Hz
Power Consumption: 50 VA

Figure 1:3 Digital Viscometer

(Source: BROOKFIELD DV1, Digital Viscometer Operating Instructions Manual No. M14-023)

- **The Cleaver Scientific SAFE SERIES**

Developed to address the needs of researchers looking to work with safer alternatives to UV irradiation and ethidium bromide, both of which are known to have harmful mutagenic effects.

Figure 1:4 The Cleaver Scientific SAFE SERIES

(Source: Cleaver Scientific Ltd ,Experts in Electrophoresis ,PRODUCT Catalogue 2015 , HORIZONTAL GEL SYSTEMS I 29)

Table 1.3 Technical Specification of Cleaver Scientific safe series

runVIEW™ Viewing Dock

Transilluminator Wavelength	470nm	**Timer**	1-999 minutes with Alarm
Voltage/Resolution	25-150V/1V	**Safety Device**	No load detection
Current/Resolution	300mA/1mA	**Operating Temperature**	Ambient to 40ºC
Power	30W	**Dimensions**	293×220×80mm
Operating Mode	Constant Voltage or current	**Rated Voltage**	100-240V,50/60Hz

(Source: Cleaver Scientific Ltd, Experts in Electrophoresis, PRODUCT Catalogue 2015, HORIZONTAL GEL SYSTEMS I 29)

Track DNA without harmful UV: Blue light is safe and has none of the detrimental effects of UV transillumination, including mutagenesis which can compromise cloning efficiency, while runVIEW™'s capacity to provide real-time visualisation of electrophoresis enables DNA to be tracked as it migrates through the gel. This allows the user to judge precisely when the band of interest is ready for extraction.

1.2 Problem Statement

Medical equipment may also have low electrical-noise limits, especially monitoring and diagnostic systems that work by measuring small voltage changes in a patient's body. Portable sensors often make extensive use of analog and RF circuitry, which tends to be sensitive to noise in any case. The problem is exaggerated by the need to make systems small, putting the power supply close to sensitive analog circuitry.

Some of the high power AVR and their advantages and disadvantages are shown in the following table, each version has their own weaknesses, therefore these type of AVR cannot be used for low power control for sensitive equipment such as medical equipment.

.

Table 1.4 Comparison of AC voltage Regulators

Family	Basic Technique used	Advantages	Disadvantages
Motor driven variacs	A servo motor based autotransformer with a voltage feedback loop	-Simple construction -High capacity -Simple electronics -High efficiency	-Bulky -Slow response -Can get stuck at the lowest input voltage and create an over-voltage when the line voltage returns to norm
Transformer tap changers	A transformer with multiple taps and a feedback loop to automatically change the taps	-High efficiency -Easy to design -Simple construction -Low cost	-If input voltage fluctuates frequently “tap dancing” could occur -Arcing in taps can create problems, with inductive loads -Voltage transients may appear at the output during tap changes

Thyristor based	A series secondary winding or an auto transformer is used with a thyristor phase controlled technique to maintain the RMS voltage constant	-Compact -Low cost -Efficient -Fast response	-High harmonic content at the output -Could cause problems with inductive loads -Filtering at output may be necessary for reducing RFI/EMI issues
Solid state types	Either linear amplifier based technique or switching technique. based compensation is used	-Wide input range is possible -Compact design may be possible (with a switching technique for voltage buck or boost)	-Complex circuitry -RFI/EMI problems (in switching technique based ones) -Reliability issues in environments with high common mode transient surges

(Source: Reference no – 04, Page no- 70)

The pure sine wave inverters type of power regulators tend to incorporate with expensive high power digital components. The modified sine wave units can be very efficient, as there is not much processing being performed on the output waveform, but this results in a waveform with a high number of harmonics, which can affect sensitive equipment such as medical monitors. Many of the very cheap devices are output with square wave types, perhaps a slightly modified square wave, with the proper RMS voltage, and close to the right frequency.

Following are some points to bear in mind when selecting the optimal power source for sensitive equipment. Not all medical and sensitive equipment are made alike, and it stands to reason that different equipment will have very different power supply requirements.

- **Switch mode power supplies (SMPSs):** Nowadays most of the portable medical devices are used with switch mode as opposed to the linear power. SMPSs are smaller than conventional transformers and generate less heat while also being relatively inexpensive. While they are widely used in imaging devices, patient monitors, diagnostic equipment and pharmaceutical dispensers, there are some conspicuous drawbacks. Since not all SMPSs were created for use in medical applications, the leakage current may be too high. It may be necessary to add in additional isolation (i.e. electrically separating two parts of a circuit by using electromagnetic field coupling between the two) to ensure optimal patient safety.

- **Electromagnetic interference:** Hospital equipment tends to operate on very low level electronic signals that are highly sensitive to electromagnetic interference. Particularly in devices such as portable ultrasound equipment, electromagnetic compatibility is therefore a key concern.

1.3 Objectives

My objective to overcome above said problem, is to design a simple Low power 230V, 50Hz Automatic voltage regulator for sensitive instruments ,without moving parts (electro-mechanical devices) comprising an linear electronic amplifier circuit using bipolar junction transistor (BJT). An noise free low signal obtain from the main supply as its input signal of having supply frequency (without oscillator), are used to obtain a controlled noise free standard supply voltage and frequency at the output terminals by the process of power amplification. Which could be used for the equipment of sensitive in nature for voltage and frequency without destructive noises, such as medical equipment etc.

This could be achieved by using, the right frequency and the RMS of the main supply voltage without any deviation from the ideal supply. That is the main supply is sent through RFI/ EMI filters and step down to low voltage “signal” having the frequency of the main power supply via step down process. The “signal” as said, is filtered using low pass filters and send to a preamplifier circuit, which initially increase the amplitude of the input signal to higher value.

Fraction of the output voltage of preamplifier is sent through voltage/feedback selector network to power amplifiers which includes voltage/current (V/I) amplifier, Pre-driver and power driver circuits. The basic method used is by utilising audio amplification method. Since 50Hz or 60Hz frequency is within the audible range. Almost the amplifier is same as audio an amplifier which has the push pull output which inverts the DC supply, obtained after the rectification and filtered from the main supply, back to AC supply of the same frequency and RMS.

The sample input signal is calculated (by graphical method) with voltage fluctuation expected and is augmented via preamplifier stage to a higher amplitude signal .This is done for the various amplitude of input signal to preamp and from its output signal. The fraction of the augmented signal is used for amplification by the stages follows the preamplifier. Any variation in the main supply (within the allowable standard range) would not interrupt this signal but provide the variation in amplitude by fraction and this is used to control the output voltage. Also output voltage from push pull transformer is kept in higher value expected drop plus normal supply voltage, (by step up winding) and is brought to supply voltage by electronically and even supply voltage goes up it would bring further down to maintain the standard voltage. The general effects of voltage regulation on semiconductors and transformers characteristics were also considered with the guidance of IEC 60146-1-1, semiconductor converters and IEC 60146-1-3, IEC 60076 converter transformers.

2. LITERATURE REVIEW

2.1. Background

The operation of a voltage generation is based on Faraday’s law of electromagnetic induction. If a coil or winding is linked to a varying magnetic field will produce a electromotive force(voltage) across the terminals and the current direction varies as the field moves to and fro, which we refer as alternating current. Thus generators have two parts, one that creates magnetic field and other where energy is induced.

Now days the magnetic field is created by electromagnets. As we aware that the induced voltage in a rotating coil within the Magnetic poles or rotating magnetic pole within the coil is function of speed, strength of magnetic flux and number of conductors ($E = 4.44kfN\varphi$ where k; winding factor, N ; number of conductors , φ : air gap flux, E;EMF, f; Frequency) and the current is received with the help of slip rings and brushes , (Fig. 2.1) or alternatively rotating the magnetic poles (North and South) within a rectangular coil would result same ,but current could be received from the terminals of the wire without slip rings and brushes.(Example Bicycle dynamos Fig.2.2.)

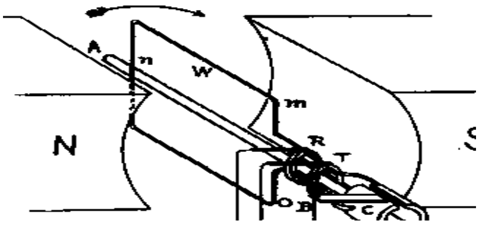


Figure 2:1 Typical coil movement within the poles of magnet

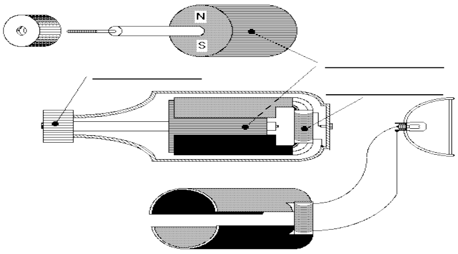


Figure 2:2 Bicycle dynamos

(Source: http://chestofbooks.com/crafts/popular-mechanics/Amateur-Work-6/Elements-Of-Dynamo-Design-III-Equasion-of-the-Dynamo-The.html)

But in a main supply, frequency and the voltage of the supply have to be maintained constant at the terminals of the winding. The frequency of the supply is governed by mechanical speed, f=NP, f; electrical frequency (Hz), N; mechanical speed (RPS), P; number of pole pairs. Therefore for constant electrical frequency, mechanical speed should be constant. The number of conductors always constant in a designed generator. Therefore voltage is directly depend on the field ,and the varying voltage could be maintained constant at defined level by varying the flux and it is generated by varying the current in the windings of the electromagnets.

Alternatively, the generated voltage as we refers as AC voltage when connect to a load, the direction of the current through the load moves in and out (to and fro) and the polarity of the voltage changes at the terminals. If the load is an inductance it would produce magnetic flux with the polarity changes, the direction as same as the frequency of the generated voltage. That is alternating magnetic flux is produced.

This basic idea was used to develop transformers to step up the generated voltage with increasing the number of turns in secondary than the primary turns. Thereby the high voltage transmission was developed for distance transmission to reduce the loss of power. This method also used to maintain a fix voltage at the receiving station with the tapings for different voltage using step down transformers. To overcome the loss of voltage due to the transmission and due to the load at the receiving station, these taps are changed to maintain the supply voltage for the consumers.
These are done by manually or by other means. The tap changers and regulators are very similar. The tap changers may be of two different types, Load tap changers and De-energized tap changers.

2.2. Electro-Mechanical Regulators for voltage maintenance

Electromechanical regulators called voltage stabilizers or tap-changers have also been used to regulate the voltage on AC power distribution lines.

2.2.1. Load tap changers (LTC)

Load tap changers (LTC) are attached to the transformers and moves the taps on the secondary side (usually the voltage side) of the transformer while the transformer in service and under load. They can even be programmed to operate automatically when needed. For example a distribution line fed from a 132kV -13.8kV transformer may experience voltage drop during peak load periods, and LTC can be used to boost voltage back to an acceptable level.

2.2.2. De-Energized tap changers (DETC)

De-energized tap changers (DETC) moves taps on the primary side (usually high voltage side) of the transformer and may only be moved while the transformer is de-energised. For example a distribution line fed fro 132kV-13.8kV transformer may experience voltage drop during peak load periods and the LTC on its highest tap and cannot boost the voltage any more. The engineering group may decide to raise the DETC and provide a better winding turn ratio so that the LTC can compensate for the voltage drop. Once again .DETC can only be operated with transformer de-energised. Voltage regulators (Fig.2.3) can be found both at the substation and out on distribution lines to help maintain a constant voltage level along the entire feeder. They are used especially on extra-long distribution feeders. Their operation is basically the same as that of substation regulators.

They raise or lower the voltage on the distribution line to provide a more or less constant voltage as the amount of load on the line changes.

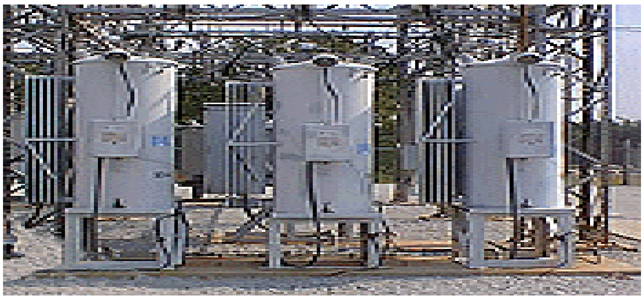


Figure 2:3 Voltage regulators

(Source : http://c03.apogee.net/contentplayer/templates/foe/tdspv2.jpg)

When the load on the line is low, the voltage drop is not very large and the customers near the end of the line have adequate voltage. When the load on the line is high, the voltage drop is also higher and customers near the end of the line may experience low voltage. Voltage regulators automatically adjust to these low and high load situations to assure all customers have proper voltage to run the equipment. The objective is same as an LTC, to regulate distribution voltages.

The voltage regulators can be helpful on long distribution feeders where the last customers experience low voltages .For example if target voltage of the customer is 230V, but the last customer on the line are only getting 200V or 210V, a voltage regulator may provide more acceptable voltage for those at the end of the line

2.2.3. Step-Voltage Regulators in the utility distribution systems

Step-Voltage regulators applied in the utility's distribution systems are generally medium voltage mechanical automatic voltage regulators (AVR) .It should be noted that there are two distinct types of AC automatic voltage regulators; and the Medium voltage (Mechanical) and the low voltage regulators (Mechanical or Electronic).

The difference in their operation and design shows that that their applications are not the same. The latter is intended to protect end-user devices from over voltage and under voltage condition. Nonetheless this will focus on the medium voltage regulators, which is primarily used by the electric utility to compensate for the voltage drop in the feeders or distribution system. In addition, the term step voltage regulator is often used to refer to utility AVR.

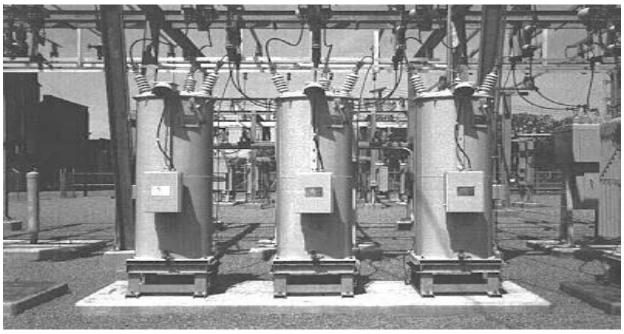


Figure 2:4 Step-Voltage Regulators for utility applications

(Source: http://www.powerqualityworld.com/2011/04/step-voltage-regulator-utility.html **)**

2.2.4. Step-Voltage Regulator basic operation

The step-voltage regulator is basically a transformer that has its high-voltage winding (shunt) and low-voltage winding (series) connected to either aid or oppose their respective voltages. Subsequently, the output voltage could be the sum or difference between the winding voltages.

For example, if the transformer has a turn's ratio of 10:1 with 1000V applied in the primary, then, the secondary voltage will be 100 V. Adding or subtracting by using the connection mentioned above - the output voltage would be 1100V or 900V, respectively. Thus, the transformer becomes an autotransformer with the capability to boost (raise/step-up,Fig2.5) or buck (lower/step-down,Fig2.6) the system voltage by 10% .

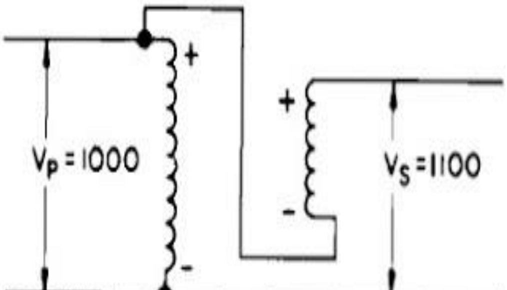


Figure 2:5 Step-up Autotransformer (Boost)

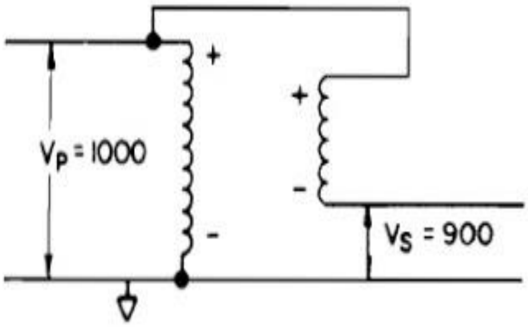


Figure 2:6 Step-down Autotransformer (Buck)

(Source: http://www.powerqualityworld.com/2011/04/step-voltage-regulator-utility.html)

In other words, by switching the location of the physical connection from the shunt to the series winding (reversing switch) and with the turns ratio made variable through automatic tap-changing - the system voltage is adjusted to the required level.

This is made possible since the automatic voltage regulator includes microprocessor-based and/or mechanical controls that tell the unit when and how to change taps. Moreover, modern controllers are equipped with data acquisition and communication capabilities for remote applications.

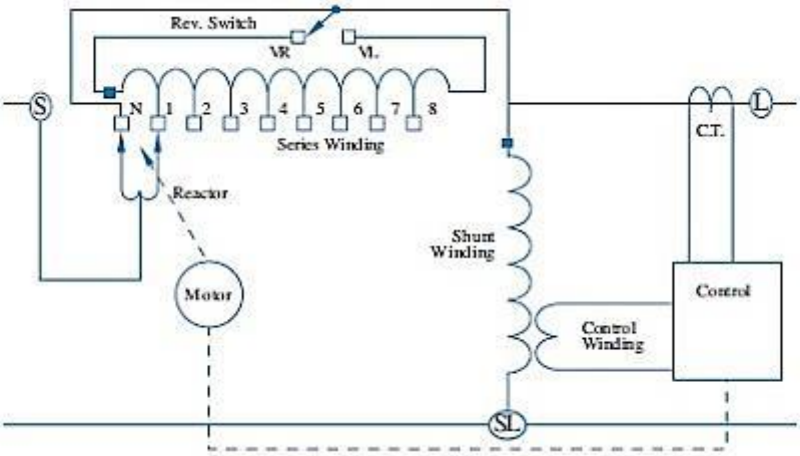


Figure 2:7 Step Voltage Regulator Schematic Diagram

(Source: http://www.powerqualityworld.com/2011/04/step-voltage-regulator-utility.html)

Utility step-voltage regulators usually allow a maximum voltage regulation range of ±10% of the incoming line voltage in 32 steps of 5/8% or 0.625%. That makes 16 steps each for buck and boost – 5/8% x 16 steps = 10%.

Utility AVRs can be installed out on the feeders or at the substation bus. The voltage regulator units could either be single-phase or three-phase. However, on a three-phase feeder, it is more common in utility applications to use single-phase units connected in banks of three (e.g. wye-grounded, closed delta).

This is because utility distribution lines are typically unbalanced in their construction, added with single-phase loads that create significant unbalance in the line currents. Thus, three independently controlled regulators may very well yield better balance between the phase voltages than a single three-phase unit or ganged operation. Also, there are many installations of open-delta regulator banks on lightly loaded three-phase feeders, which require only two regulators and are less costly than a full three-phase bank.

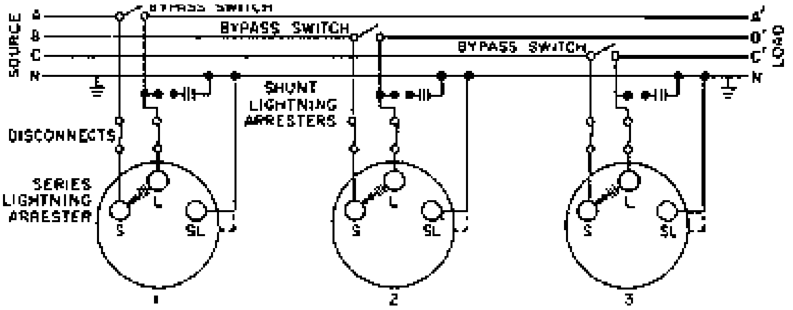


Figure 2:8 Voltage Regulator Grounded Wye Connection

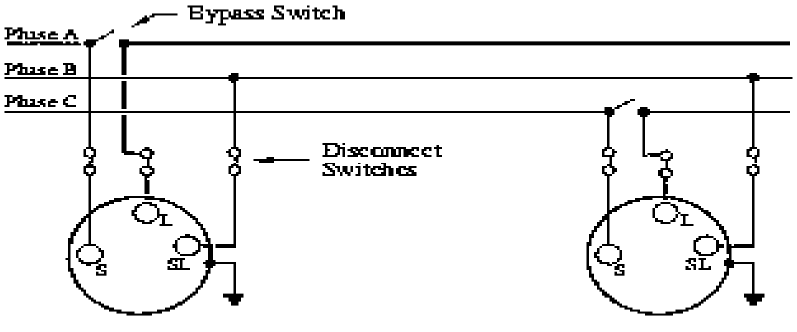


Figure 2:9 Voltage Regulator Open-Delta Connection

(Source: http://www.powerqualityworld.com/2011/04/step-voltage-regulator-utility.html)

Voltage Regulator Applications

Step-voltage regulators are typically installed on the following:

- Existing feeders - before the point where the voltage drop problem starts with heavy load
- Important laterals - To serve a remotely located load

Voltage regulators in the utility distribution systems are relatively slow. These AVRs have a time delay of at least 15 seconds. Therefore, it is not suitable to applications where voltages may vary in cycles or seconds. Utility step-voltage regulators are primarily use for boosting voltage on long feeders where the load is changing slowly over several minutes or hours. The voltage band typically ranges from 1.5 to 3.0V on a 120V base. The control can be set to maintain voltage at some point down the line from the feeder by using the line drop compensator capability. This results in a more level average voltage response and helps prevent over voltages on customers near the regulator.

Figure 2:10 Three-phase bank of voltage regulators

(Source: https://commons.wikimedia.org/wiki/File:Distribution_Voltage_regulators.JPG)

A three-phase bank of voltage regulators used to control the voltage on long AC power distribution lines. This bank is mounted on a wooden pole structure (Fig 2.10). Each regulator weighs about 2600lbs and is rated 576 kVA.

2.3. Servomechanism type Regulators

These regulators operate by using a servomechanism to select the appropriate tap on an autotransformer with multiple taps, or by moving the wiper on a continuously variable auto transformer. If the output voltage is not in the acceptable range, the servomechanism switches the tap, changing the turn's ratio of the transformer, to move the secondary voltage into the acceptable region.

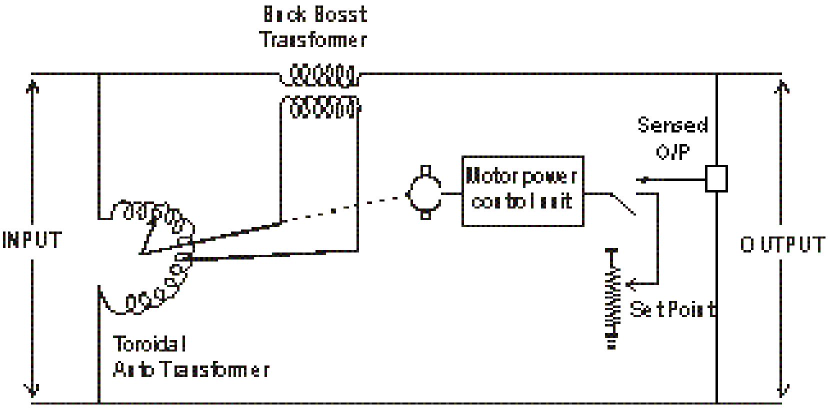


Figure 2:11 Servo stabilizer Circuit diagram

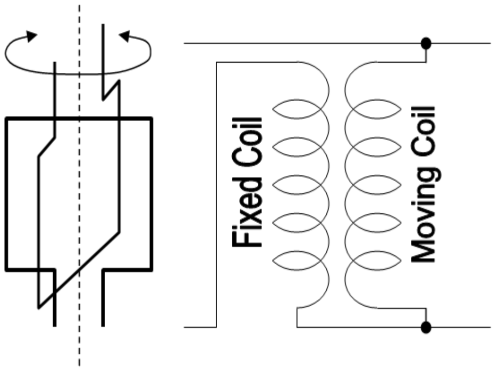


Figure 2:12 Coils rotation AC voltage regulator.

(Source: http://www.stabilizer-regulator.com/voltage-stabilizer/servo-voltage-stabilizer-works)

2.4. Electronic (semiconductors) devices for voltage maintenance

2.4.1. Buck-Boost type voltage Regulators

The Voltage sag is an important power quality problem, which may affect domestic, industrial and commercial customers. Voltage sags may either be decrease or increase in the magnitude of system voltage due to faults or change in loads. Figure (2.13) shows AC Buck- Boost regulator is proposed to maintain constant voltage both for increase or decrease across a medium size domestic or commercial appliance.

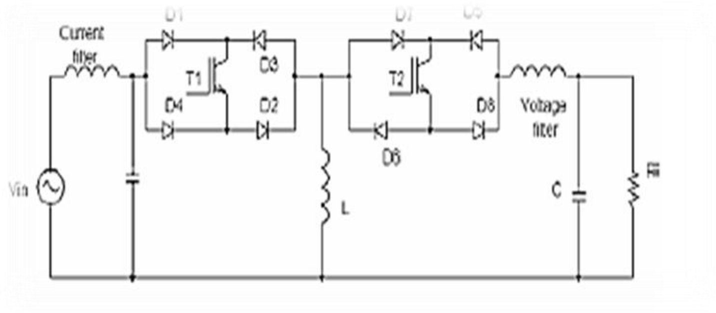


Figure 2:13 Power Circuit of single phase AC switch mode Buck- Boost voltage controller with filters.

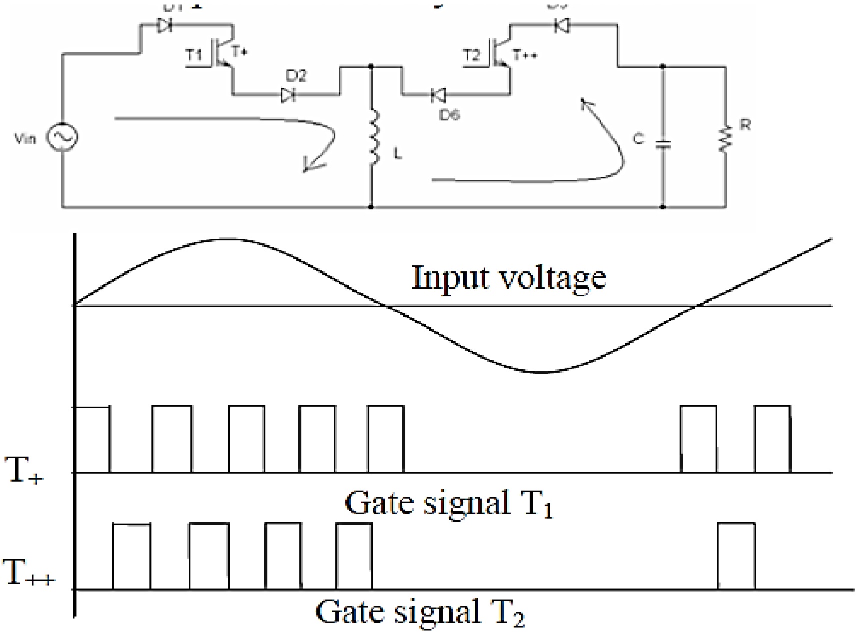


Figure 2:14 Operation for positive half cycles & gate signals

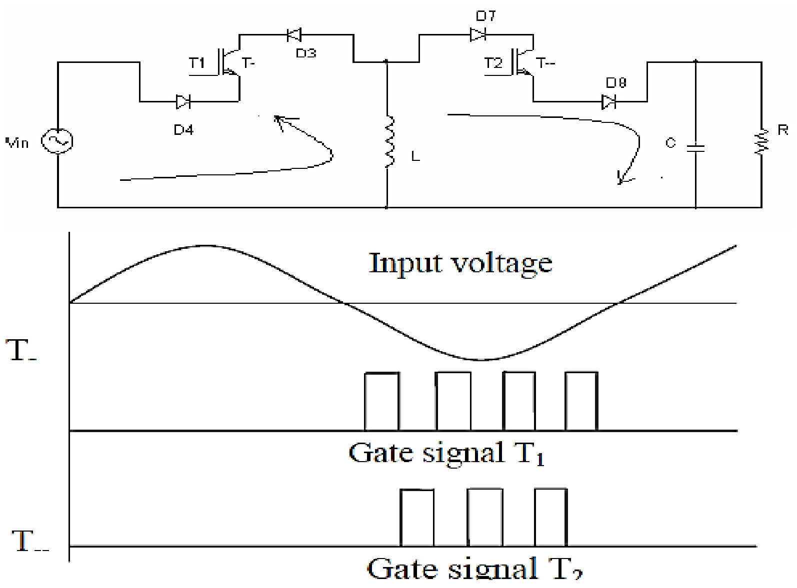


Figure 2:15 Operation for negative half cycles & gate signals

(Source: Reference no- 01, Page no-70)

The Figure (2.16) shows three-arm power converter of the proposed AVR acts as an ac boost converter when the utility voltage is lower than the specified voltage, and it acts as an ac buck converter when the utility voltage is higher than the specified voltage. Hence, the output voltage of the AVR can be maintained at the specified voltage. The salient feature of this AVR is that the power electronic switches of only one arm are switched in high frequency (arm is controlled by a high-frequency pulse width modulation PWM signal), while those of the other arms are switched in low frequency.

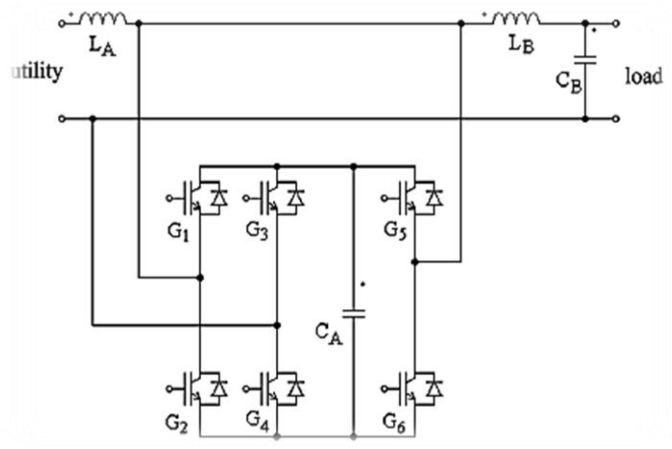


Figure 2:16 Circuit configuration of the three-arm AVR

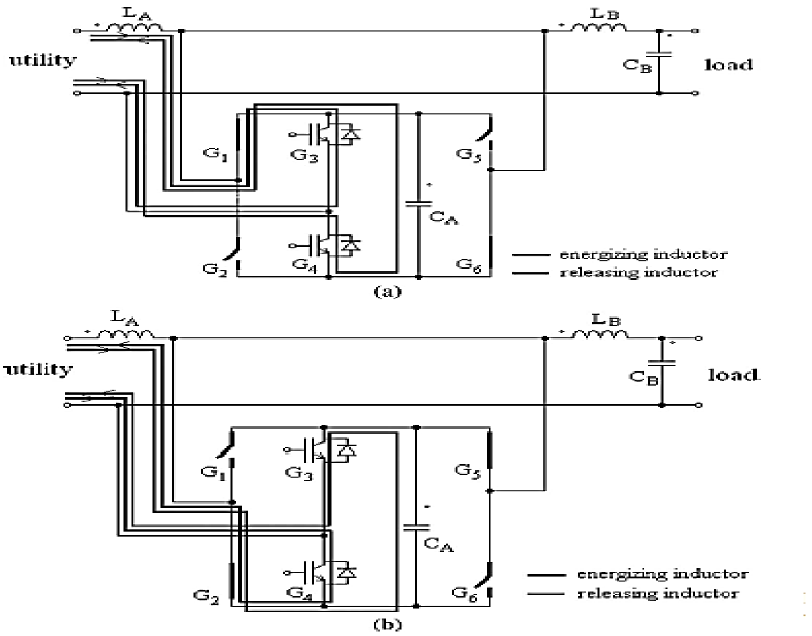


Figure 2:17 Operating circuit of the proposed AVR under the AC boost mode.
(a) Positive half-cycle . (b) Negative half-cycle

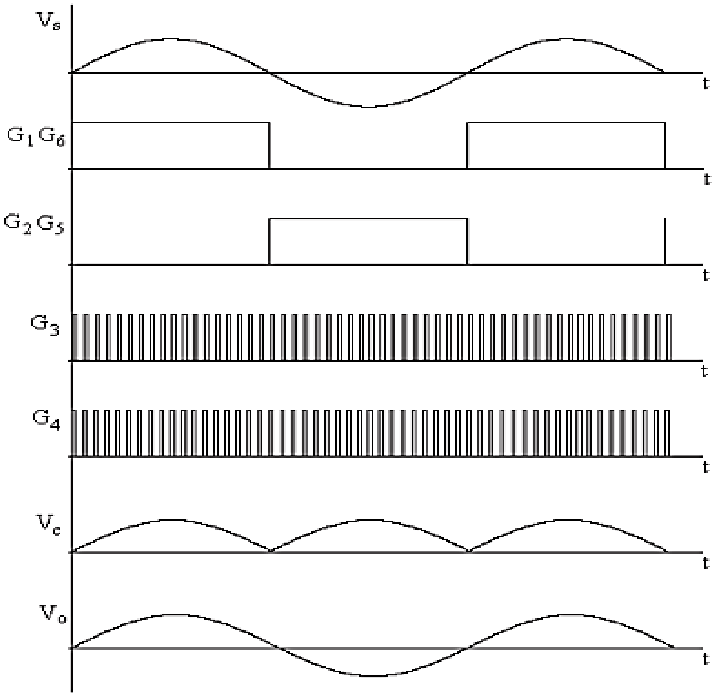


Figure 2:18 Related control signal of the power electronics switches & voltage waveform of the proposed AVR under the boost mode

(Source: Reference no-05, Page no - 70)

2.4.2. High-Frequency Inverter – Block Diagram

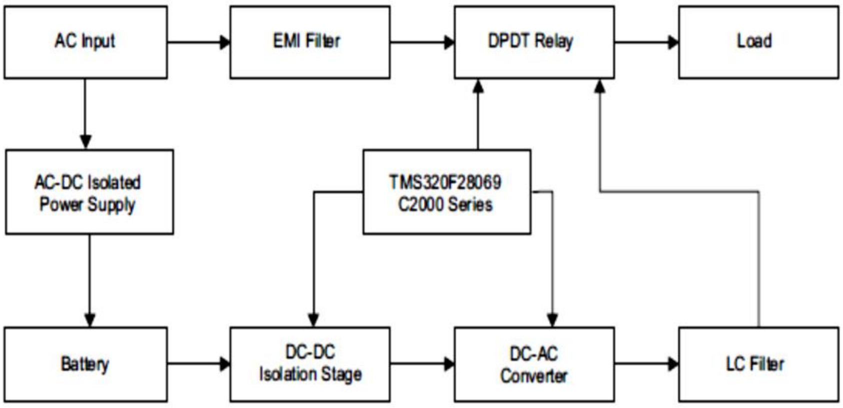


Figure 2:19 High-Frequency Inverter – Block Diagram

(Source: Reference no-18, Page no-71)

The High-Frequency Inverter is mainly used today in uninterruptible power supply systems, AC motor drives, induction heating and renewable energy source systems. The simplest form of an inverter is the bridge-type, where a power bridge is controlled according to the sinusoidal pulse-width modulation (SPWM) principle and the resulting SPWM wave is filtered to produce the alternating output voltage. In many applications, it is important for an inverter to be lightweight and of a relatively small size. This can be achieved by using a High-Frequency Inverter that involves an isolated DC-DC stage (Voltage Fed Push-Pull/Full Bridge) and the DC-AC section, which provides the AC output. This application report documents the implementation of the Voltage Fed Full Bridge isolated DC-DC converter followed by the Full-Bridge DC-AC converter.

The present application report documents the implementation of the DC-DC isolation and DC-AC conversion stage using TMS320F28069. The F2806x Piccolo™ family of microcontrollers provides the power of the C28x core and the Control Law Accelerator (CLA) coupled with highly integrated control peripherals in low-pin count devices. This family is code-compatible with previous C28x-based code, as well as providing a high level of analog integration. An internal voltage regulator allows for single-rail operation. Enhancements have been made to the high-resolution pulse width modulator (HRPWM) module to allow for dual-edge control (frequency modulation).Analog comparators with internal 10-bit references have been added and can be routed directly to control the pulse width modulation (PWM) outputs. The analog-to-digital converter (ADC) converts from 0 to 3.3-V fixed full scale range and supports ratio-metric VREFHI/VREFLO references. The ADC interface has been optimized for low overhead and latency. The above features make the F2806x Piccolo suitable for handling both the stages of the High-Frequency Inverter.

The main blocks of the High-Frequency Inverter include:

- DC-DC isolation stage
- DC-AC converter section

2.4.3. DC-DC Isolation Stage - High-Frequency Inverter

The selection of the DC-DC isolation stage for the High-Frequency Inverter depends on the kVA requirements of the inverter. The power supply topologies suitable for the High-Frequency Inverter includes push-pull, half-bridge and the full-bridge converter as the core operation occurs in both the quadrants, thereby, increasing the power handling capability to twice of that of the converters operating in single quadrant (forward and fly back converter). The push-pull and half-bridge require two switches while the full-bridge requires four switches. Generally, the power capability increases from push-pull to half bridge to full-bridge.

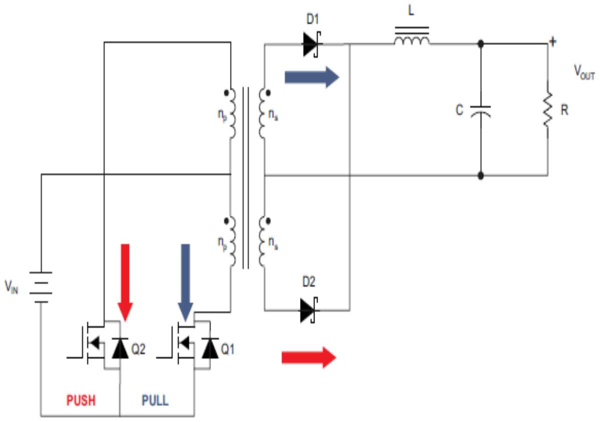


Figure 2:20 Push-Pull Topology

(Source: Reference no-18, Page no-71)

Push-Pull Topology

The Push-Pull topology is basically a forward converter with two primaries. The primary switches alternately power their respective windings. When Q1 is active, current flows through D1. When Q2 is active, current flows through D2. The secondary is arranged in a center tapped configuration as shown in Fig(2.20)

The output filter sees twice the switching frequency of either Q1 or Q2. The transfer function is similar to the forward converter, where "D" is the duty cycle of a given primary switch, which accounts for the "2X" term. When neither Q1 nor Q2 are active, the output inductor current splits between the two output diodes.

A transformer reset winding shown on the forward topology is not necessary, the topology is self-resetting.

$$V_{\text{out}}= V_{\text{in}} \times D\times\frac{Ns}{Np}\times 2\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

2.4.3.1.Half Bridge Converter

The Half Bridge converter is similar to the Push-Pull converter, but a center tapped primary is not required. The reversal of the magnetic field is achieved by reversing the direction of the primary winding current flow. In this case, two capacitors, C1 and C2, are required to form the DC input mid-point. Transistors Q1and Q2 are turned ON alternately to avoid a supply short circuit, in which case the duty cycle *d* must be less than 0.5.

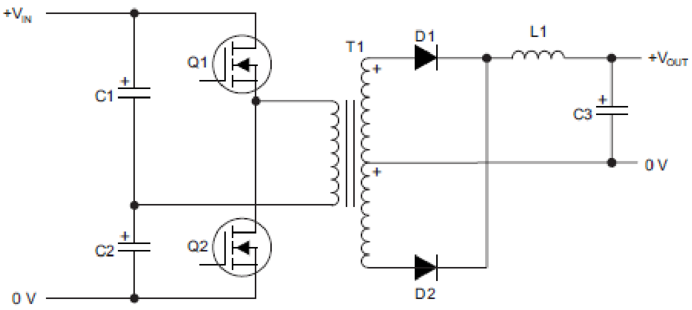


Figure 2:21 Half Bridge Converter

(Source: Reference no-18, Page no-71)

For the Half-Bridge converter, the output voltage V_{OUT} equals:

$$V_{out} = V_{in}\frac{N2}{N1}\times d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where, d is the duty cycle of the transistors and $0 < d < 0.5$.

N2/N1 is the secondary to primary turns ratio of the transformer.

2.4.3.2.Full Bridge Converter

The transformer topology for both the Half Bridge and Full Bridge converter is the same, except that for a given DC link voltage of the Half Bridge transformer sees half the applied voltage as compared with that of the Full Bridge transformer.

The current flows in opposite directions during alternate half cycles. So flux in the core swings from negative to positive, utilizing even the negative portion of the hysteresis loop, thereby, reducing the chances of core saturation. Therefore, the core can be operated at greater Bm value here. The largest power is transferred when the duty cycle is less than 50%. Diagonal pairs of transistors (Q1-Q4 or Q2-Q3) conduct alternately, thus, achieving current reversal in the transformer primary. Output voltage equals:

$$V_{out} = 2\times V_{in}\frac{N2}{N1}\times d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where, d is the duty cycle of the transistors and $0 < d < 0.5$.

N2/N1 is the secondary to primary turns ratio of the transformer

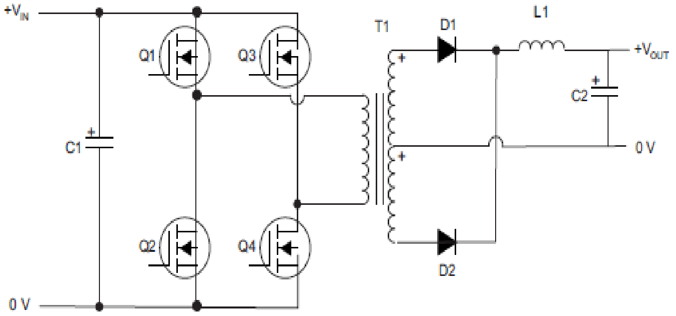


Figure 2:22 Full Bridge Converter

(Source: Reference no-18,Page no-71)

The choice of the DC-DC isolation stage for the High-Frequency Inverter among the three topologies discussed above depends on the VA requirement. For applications targeting 1kVA and above, the Full Bridge converter is the ideal choice pertaining to the points below:

- For a given input voltage, the voltage stress on the transistors is double in case of the push-pull topology than Half Bridge and Full Bridge configuration.
- The center tapped primary in the case of the push-pull converter limits the operation for a higher VA rating for the same core size when compared to the Half Bridge and Full Bridge converter.
- To prevent flux walking in the DC-DC stage, the current in both the halves need to be sensed and the duty cycle needs to be corrected accordingly.

2.5. Problem identification

2.5.1. Flux Walking

Faraday's Law states that the flux through a winding is equal to the integral volt-seconds per turn. This requires that the voltage across any winding of any magnetic device must average zero over a period of time. The smallest DC voltage component in an applied AC waveform will slowly but inevitably "walk" the flux into saturation. In a low frequency mains transformer, the resistance of the primary winding is usually sufficient to control this problem. As a small DC voltage component pushes the flux slowly toward saturation, the magnetizing current becomes asymmetrical. The increasing DC component of the magnetizing current causes an IR drop in the winding, which eventually cancels the DC voltage component of the drive waveform, hopefully well short of saturation.

In a high frequency switch mode power supply, a push-pull driver will theoretically apply equal and opposite volt-seconds to the windings during alternate switching periods, thus, "resetting the core (bringing the flux and the magnetizing current back to its starting point). But there are usually small volt second asymmetries in the driving waveform due to inequalities in MOSFET, RDS on or switching speeds. The resulting small DC component causes the flux to “walk”. low DC resistance, and the high frequency transformer, with relatively few primary turns, has extremely IR drop from the DC magnetizing current component is usually not sufficient to cancel the volt-second asymmetry until the core reaches saturation.

The flux walking problem is a serious concern with any Push-Pull topology (bridge, half-bridge or push-pull CT), when using voltage mode control. One solution is to put a small gap in series with the core. This raises the magnetizing current so that the IR drop in the circuit resistances is able to offset the DC asymmetry in the drive waveform. But the increased magnetizing current represents increased energy in the mutual inductance, which usually ends up in a snubber or clamp, increasing circuit losses. A more elegant solution to the asymmetry problem is an automatic benefit of using the current mode control (peak or average CMC). As the DC flux starts to walk in one direction, due to the volt-second drive asymmetry, the peak magnetizing current becomes progressively asymmetrical in alternate switching periods. However, current mode control senses the current and turns off the switches at the same peak current level in each switching period, so that ON times are alternately lengthened and shortened. The initial volt-second asymmetry is thereby corrected, peak magnetizing currents are approximately equal in both directions, and flux walking is minimized.

However, with the Half Bridge topology this creates a new problem. When current mode control corrects the volt-second inequality by shortening and lengthening alternate pulse widths, an ampere-second (charge) inequality is created in alternate switching periods. This is of no consequence in full bridge or push-pull center-tap circuits, but in the half-bridge, the charge inequality causes the capacitor divider voltage to walk towards the positive or negative rail. As the capacitor divider voltage moves away from the mid-point, the volt-second unbalance is made worse, resulting in further pulse width correction by the current mode control. A runaway situation exists, and the voltage will walk (or run) to one of the rails. Considering the above points, the Full Bridge converter seems to be the ideal choice for the High-Frequency Inverter rated above 1kVA.

3. METHODOLOGY

3.1. Introduction

In my research I have utilized the audio amplification method by using small signal of 50Hz from the main supply, which is within the audible range to deliver regulated 230V at 50Hz . The following flow chart shows the basic method involved in the amplification of noise free 50Hz signal to give regulated voltage.

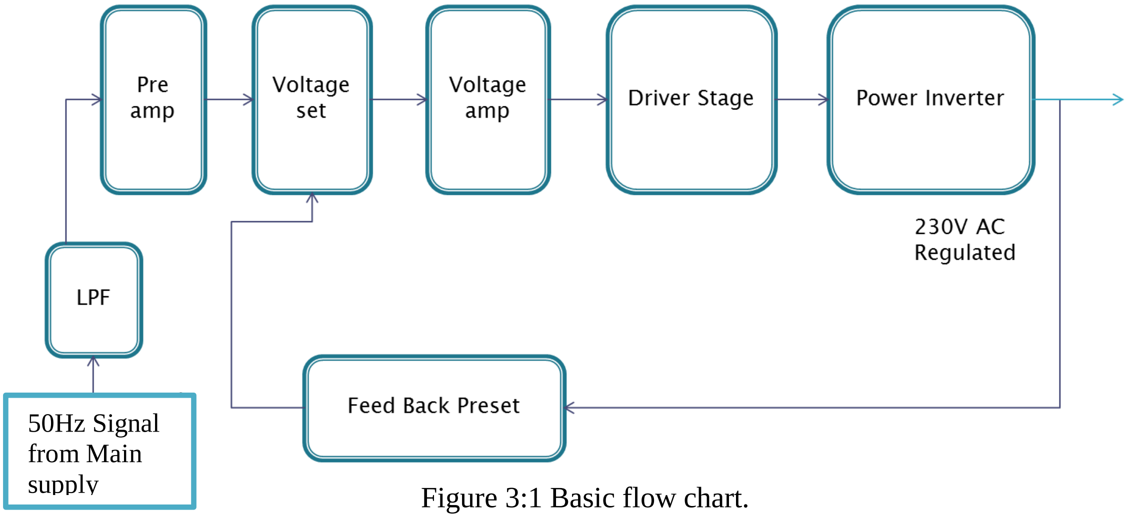


Figure 3:1 Basic flow chart.

The fig (3.2) shows the practical methodology applied to operate proposed circuit to give noise free 230V 50Hz supply to the load.

EMI/RFI Filters - It removes the electromagnetic and radio frequency interference which would disturb the power supply and output.

Preset- It is used to set the required input signal to the preamplifier via Low pass filter according to the expected main voltage fluctuation.

LowPassFilter- The low pass filter is used to cut off the frequency above approximately 70Hz.If other frequencies can disturb the output having multiple frequencies.

Preamplifier- This is a high gain amplifier it could amplify very small signal variation, since I’m using low signal variation at the input. This variation is amplified to control the power variation at the output as similar to the audio amplifiers.

Block Diagram of the complete system

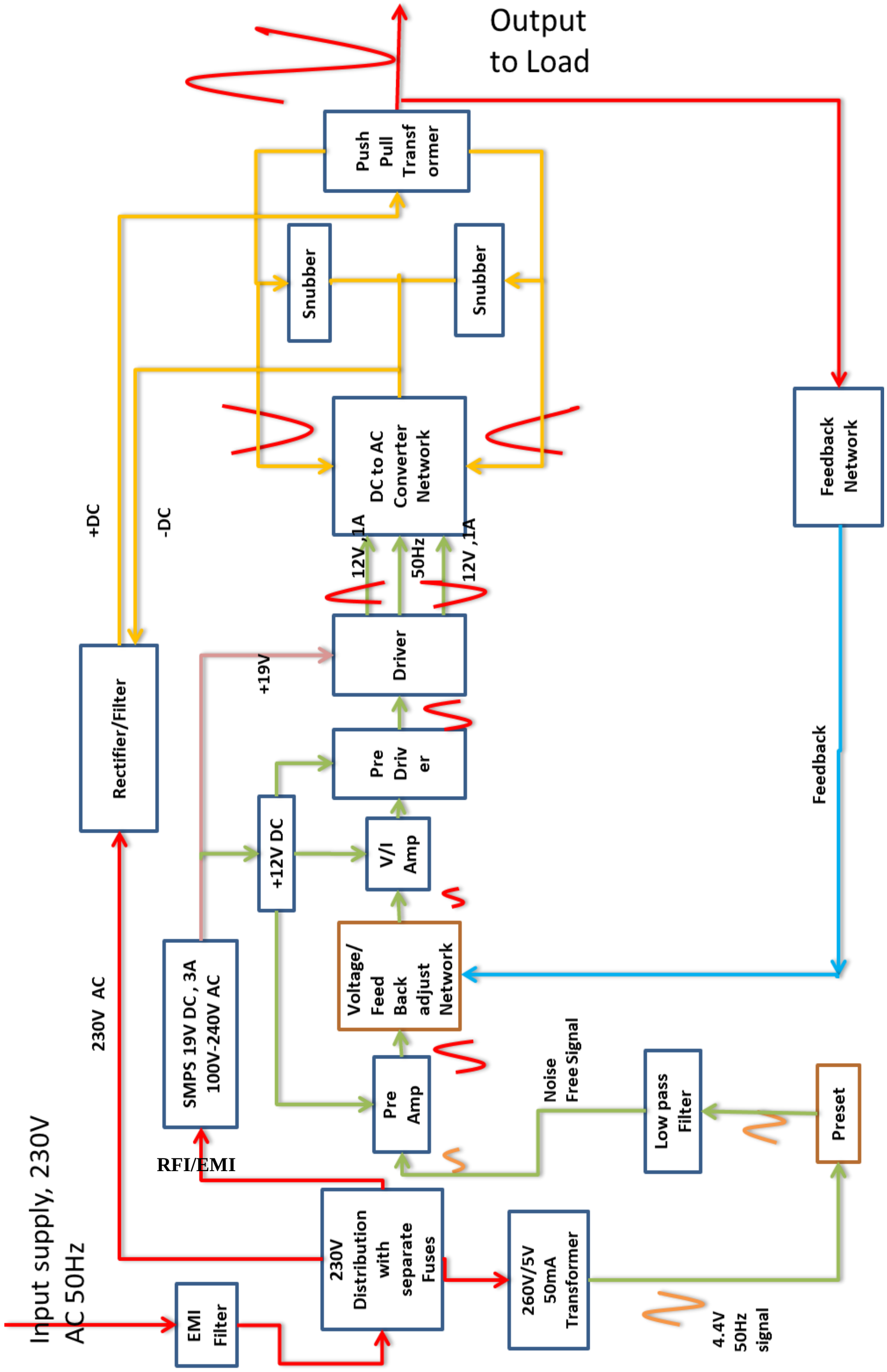


Figure 3:2 Block Diagram of the complete system

Voltage/Feed Back adjust Network- This network is used to maintain the constant output voltage.

V/I Amplifier and Pre-Driver- This V/I amplifier used to amplify voltage and current to trigger the pre-driver .

Driver- The driver stage is used to drive, the output stage comprising pair of darlington transistors connected in push pull mode via secondary center tapped transformer.

DC to AC Converter Network- DC to AC converter network is a push pull output amplifier circuit comprising a pair of high power darlington transistors which are connected to the primary center tapped of power output transformer.

Snubber circuit- This is used to protect the output transistors from surges that could damage the circuitry. In the case of push pull inverter DC to AC, inductive load can cause special problems because an inductor cannot stop instantly, conducting current, it must be dampened or diverted so that the current does not try to flow through open switch. If not dampened the surges can cause trouble to power transistors in the output stage. The high dv/dt, di/dt, V, I associated with this problem can cause the power transistors to malfunction and break.

Push-Pull Transformer- This is the high power push pull transformer connected to the darlington transistor pair. And secondary voltage is the regulated voltage used for utility.

Feedback Network- Feedback network which maintain the constant voltage at the secondary terminals of the push pull power transformer. Which is connected to the voltage /feedback network via feedback network.

The main consumer supply 230V, 50Hz is first sent to RFI/ EMI (Radio frequency interference/Electromagnetic interference) filter. The filtered signal is divided into three supply units in the distribution board and supplied to the respective section via fuses.

1. The first section is a Step down transformer having voltage ratio 260/5V so that it could provide approximately a voltage ratio of 230/4.4V at 230V supply .This arrangement is done for the transformer to stand for rising voltage.
2. The second section is an SMPS power supply unit provides 19V DC and maximum current of 3A, which provides power for electronic circuits.
3. The third section consists of Bridge network and filter which converts 230V AC to smoothed DC supply

From the first section approximately 4.4V AC supply at 50Hz (filtered EMI/RFI)is used as in put signal is applied across a potential divider “Preset”, and suitable voltage is selected for preamp by passing through Low pass filter approximately having cutoff frequency of 70Hz. Any variation about 10% in the main supply (above or the below the nominal supply) would produce fractional variation of voltage at the input of the pre-amplifier after passing via step down transformer, preset ,filter circuit , which would be within the operating area of the preamp to get undisturbed signal.

The noise free signal is applied to the pre-amplifier and output is taken at the output terminal of the pre-amplifier. This output voltage is passed through Voltage/Feedback network. The fraction of the output from the network is passed through V/I amplifier, Pre driver and to a Driver circuit to provide high power output which could be able to trigger power inverter circuit DC to AC. AC output is taken at the secondary terminal of the push-pull transformer. Automatic control of the terminal voltage of the load is done by feedback technique.

Normally number of turns of secondary winding of the push-pull transformer is done to keep the output voltage higher than the normal supply voltage plus expected voltage drop when the output power of the transistors operating in push-pull mode is at 80% (that is normal supply voltage 230V plus expected drop 50V which gives 280V).

This is because the power supply drop would not affect the power inverter section. Now it is brought to the normal voltage by the feedback adjustment which will reduce the driver section output and would drive up or down according to the fluctuation to maintain the system.

Also sample signal is selected from the graphs so that power fluctuation would not affect the input signal but provide information about the percentage of fluctuation and bring the normal supply across the load by V/I amp and driver circuit. SMPS circuit will provide power even voltage fluctuates from 150V to 250V, so that electronic circuit would operate.

4. SYSTEM DESIGN

4.1. Theoretical Development

Traditionally an AC voltage regulator is made with a transformer tap changer or with ac-ac converter based on buck topologies. Recently the developments in ac-ac converters make feasible the implementation of voltage regulator with other topologies. Voltage regulation by electrical methods involves moving spares such as auto transformers with relays, servomotors, tap changing etc. as said above with the noise production. These difficulties are overcome now days by new technique using semiconductors. The implementation of ac-ac converters is more complex operation of semiconductors. This is due to commutation troubles in ac-ac converters. Presently Switch mode power supply (SMPS) system and Pulse width modulation (PWM), sinusoidal pulse width modulation (SPWM) in cooperated with switching technique, using IGBT are used for voltage regulation. Some of the boosters do not have facilities to remove noise such as harmonics, EMI/RFI etc. But inverter based technologies AC to DC (charging batteries) and DC to AC may have facilities to remove above said noise.

To my opinion Power regulators about 1kW could be developed by converting AC to DC with filters and inverting to AC of the same frequency using supply frequency. High power regulators could be developed using capacitors to reduce ripple effect. Small low pass filters could design if the signals at low voltage rather than at high voltage which may require bulky filters and loses are much more due to resistive load. Simple design for low pass filter could be designed using resistance capacitance network. The Low Pass Filter – the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, fc point to pass while blocking those any higher.

4.1.1. Low Pass Filter

Small low pass filters could design if the signals at low voltage rather than at high voltage which may require bulky filters and loses are much more due to resistive load. A simple passive RC Low Pass Filter or LPF, can be easily made with low cost by connecting together in series a single Resistor with a single Capacitor as shown below. In this type of filter arrangement the input signal (V_{in}) is applied to the series combination (both the Resistor and Capacitor together) but the output signal (V_{out}) is taken across the capacitor only. This type of filter is known generally as a “first-order filter” or “one-pole filter”, because it has only “one” reactive component, the capacitor, in the circuit.

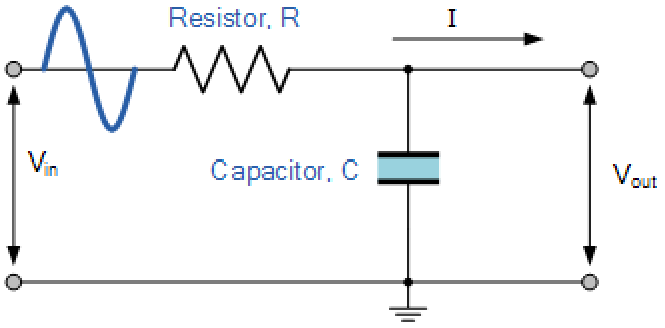


Figure 4:1 RC Low Pass Filter Circuit

(Source: http://www.electronics-tutorials.ws/filter/filter_2.html)

As reactance of a capacitor varies inversely with frequency, while the value of the resistor remains constant as the frequency changes. At low frequencies the capacitive reactance, (X_c) of the capacitor will be very large compared to the resistive value of the resistor, R. This means that the voltage potential, V_c across the capacitor will be much larger than the voltage drop, V_r developed across the resistor. At high frequencies the reverse is true with V_c being small and Vr being large due to the change in the capacitive reactance value.

While the circuit above is that of an RC Low Pass Filter circuit, it can also be classed as a frequency variable potential divider circuit. Capacitive reactance X_c of a capacitor in an AC circuit is given as

$$X_c = {}^{1}/_{2\pi f c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

The circuit impedance is calculated as: $Z = \sqrt{R^2 + Xc^2}$

V_{out} is given by $V_{out} = (X_c/Z)\,V_{in}$ and the cut off frequency is given by

$$f_c = {}^{1}/_{2\pi RC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

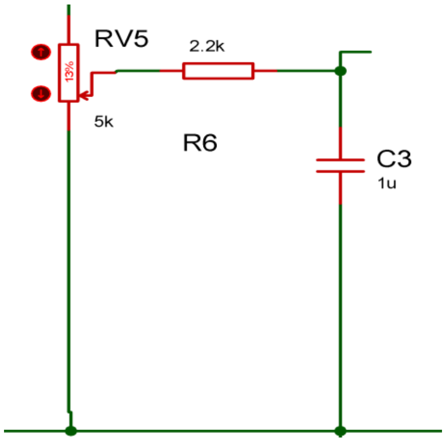


Figure 4:2 RC Filter

From equation (2), $f_c = {}^{1}/_{2\pi RC} = \frac{1}{2\pi \times 2.2k \times 1\mu} \simeq 70Hz$

The Fig (4.2) shows circuit of simple RC filter with R6(2.2kΩ) and C3(1uF) and approximately 70Hz cut off frequency with preset RV5(5kΩ).

4.1.2. Pre-Amplifier

Class A amplifier

For the pre-amplifier, resistive load is used at the collector terminal with high gain transistors instead of transformer. Normally it is done for the voltage gain. A transformer coupled class A operation is given for driver stage using power transistors.

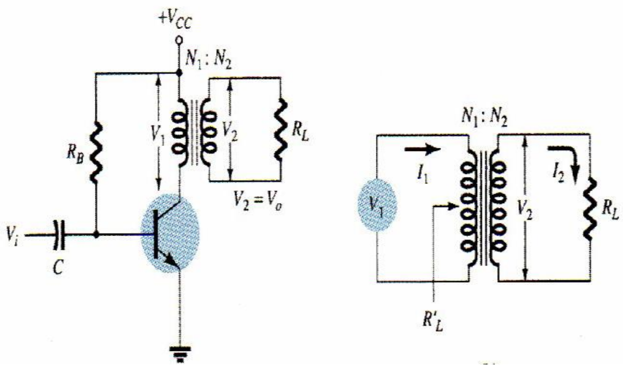


Figure 4:3 Class A amplifier

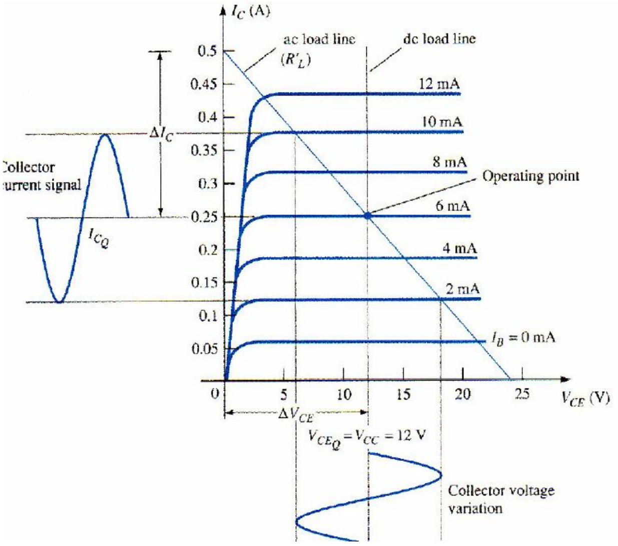


Figure 4:4 Class A amplifier characteristics curves

(Source:https://www.slideshare.net/sarahkrystelle/power-amplifiers-11169136, http://www.electronics-tutorials.ws)

Here the operating point is taken at the midpoint of the load line and V_{cc} at midpoint and variation is on either side of the midpoint. For ideal transformer signal swing and AC power is

$V_{CE(p\text{-}p)} = V_{CE\max} - V_{CE\min}$ ....(4.3)

$I_{C\,(p\text{-}p)} = I_{Cmax} - I_{Cmin}$ ....(4.4)

AC power developed,

from equations (3) & (4) $P_0(\text{ac}) = (V_{CE\max} - V_{CE\min})(I_{Cmax} - I_{Cmin})/8$

$V_2 = V_L = (N_2/N_1) \times V_1$ and power to the load is

$P_L = V_L^2(\text{rms})/R_L$.............................(4.5)

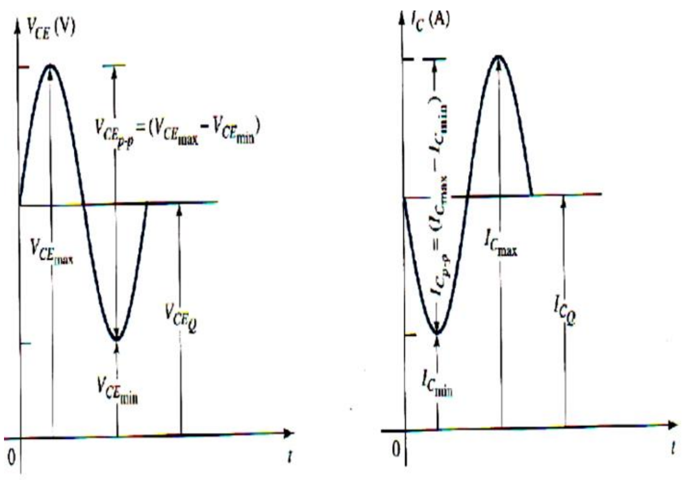


Figure 4:5 Graphical operation of transformer coupled class A amplifier

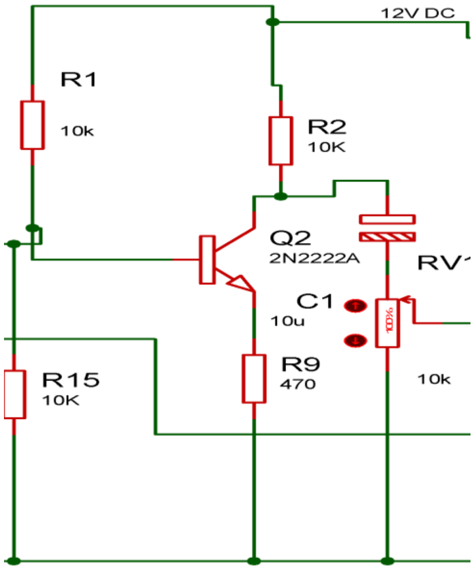


Figure 4:6 Pre-Amplifier

The Fig(4.6) shows the circuit designed pre amp consists of high gain transistor(2N2222A) with collector load of 10kΩ operates in Class A mode coupled to the DC block capacitor C1 with volt adjust RV1 .

The pre-amplifier consists of high gain transistor Q2 (2N2222A) (appendix B,page no-75) with collector load of 10kΩ to provide enough voltage/current (0V to 4V /0 to 50mA) output drive Q6(BD131). The 2N2222A can provide maximum collector current of 800mA and Base current could vary between +15mA to -15mA with h_{fe} =75. This is enough to provide very low input signal after low pass filter for amplification. That is selected items and designed circuit would response for stipulated voltage variation as defined.

4.1.3. V/I Amp with volt control & Current Amplifier using Darlington technique

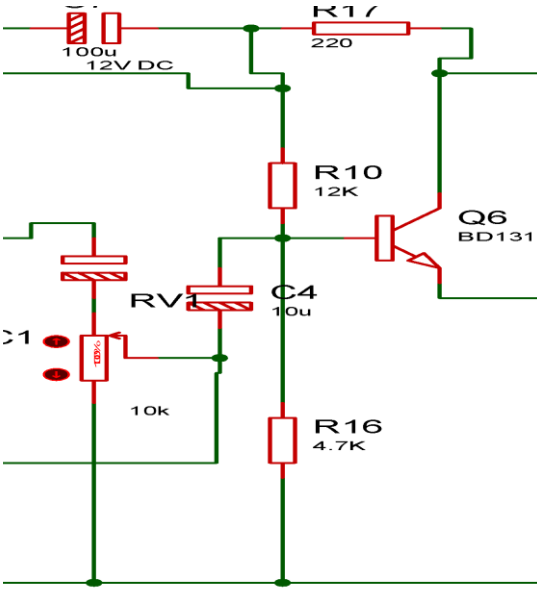


Figure 4:7 V/I Amplifier

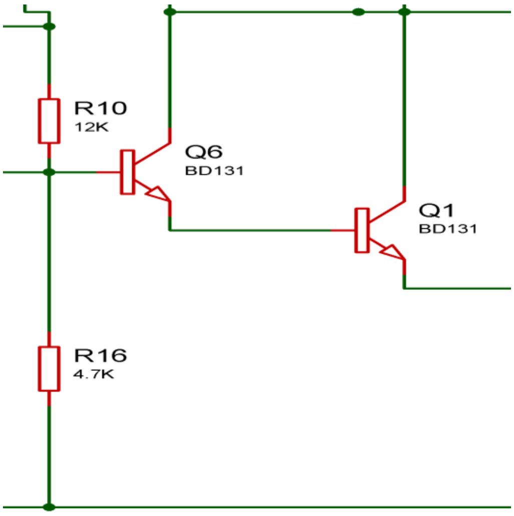


Figure 4:8 Current gain using Darlington pair

The Fig(4.7) shows circuit of simple V/I amplifier using medium power transistor Q6 (BD 131) whose input is controlled by volt adjust RV1 and used as emitter follower coupled to the next stage connecting emitter to the base of Q1 (BD131) for current gain Fig(4.8).

The Fig(4.8) circuit comprises Q6 and Q1 both acts as Darlington pair to obtain current gain and is used to drive driver circuit comprising Power transistors Q4 and Q5 (2N3055) as shown in the Fig(4.9).

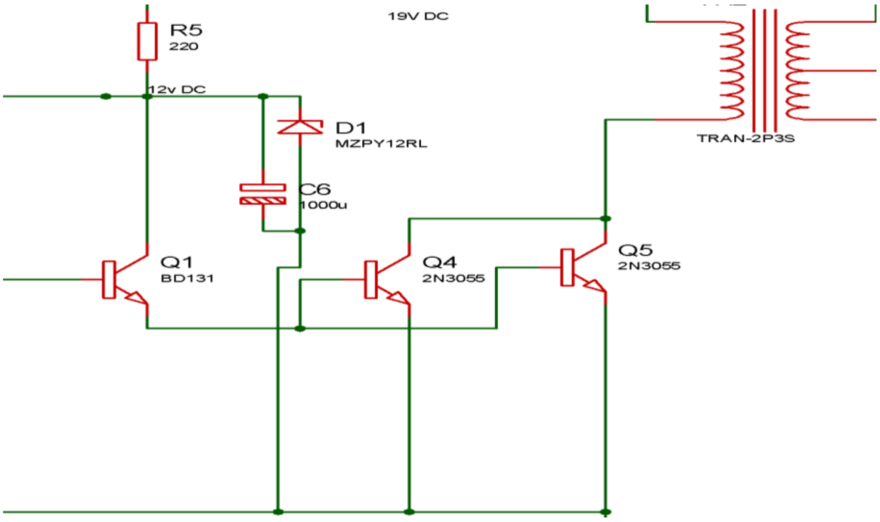


Figure 4:9 Driver circuit with power Transistor

The first Q6 is coupled to the second Q1 as a emitter follower with suitable collector resistance 220Ω to limit the current. The Q1 provides the base current to drive 2N3055 (Q4 and Q5) in Fig (4.9).

It could be noted from appendix- B, BD131 (page no-82) can provide collector current 0.5A to 6A for base current 50mA to 0.5A, and 2N3055 can provide collector current 4A to 10A when base current is 400mA to 3.3A. And therefore these transistors are selected to use for the amplification stages. Enough input voltage/ current could be obtained for base of Q6 (BD131) from the pre amplifier output via voltage controller.

4.1.4. Driver stage

For driver stage class A operation could be used. If high power is required to drive out put transistor, "class B" could be used.

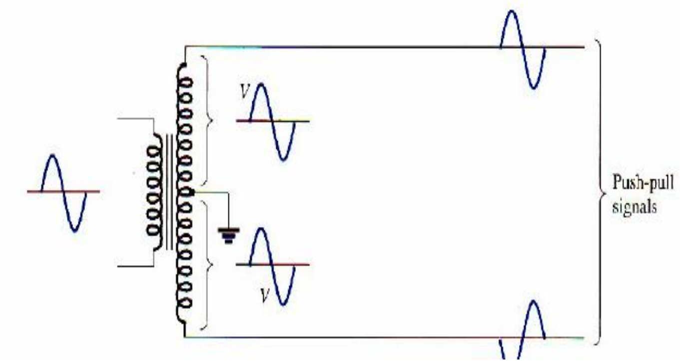


Figure 4:10 Signal output from the center tapped driver transformer

Fig (4:9) shows transistors Q4,Q5 (2N3055) used for class A operation with 19V DC Power supply. Peak voltage would be approximately 9V and required power output maximum would be 6W to drive high power transistors BU808DFI (Power Inverter).

Any Power transistors, "BJT type transistors," which could give collector current 2A with 60V collector emitter, could be used as driver output transistors. **But here,**

considering future development high power transistors, “2N3055,” are used. It can handled nearly 15A collector current at 60V collector emitter voltage and preliminary circuits can provide enough base current to drive these transistors by darlington technique. Therefore these transistors are selected to use for the driver stage.

The output voltage could be controlled by controlling the signal amplitude by using potentiometer at initial suitable stage preferably after pre amplifier. Also automatic output voltage maintenance by using suitable feedback network. Better efficiency can be obtain, using push pull out put for which inputs (signals with 180°phase shift)are taken from the center tapped secondary turns of a transformer which acts as a driver as well as an isolation transformer . This used as isolation transformer to prevent high voltage output stage from the low voltage section. The primary side of the transformer may be connected to class A operation with single windings or class B (push-pull) operation with center tapped winding. Preferably Class A could be selected for simplicity and less cost.

4.1.5. Class B Push-pull Transformer Amplifier Circuit for output

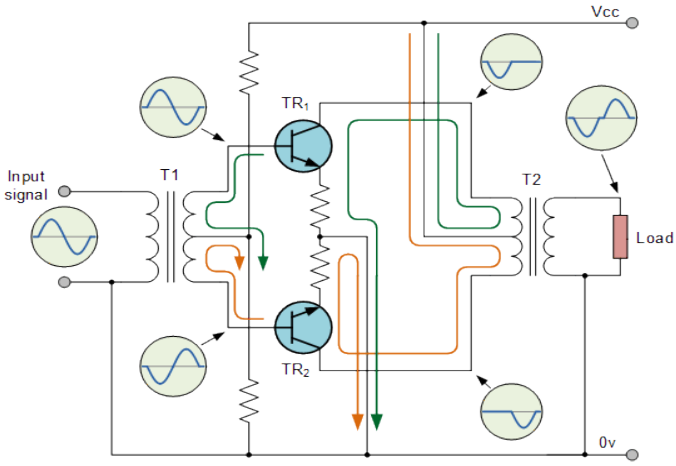


Figure 4:11 Standard Class B Amplifier circuit

(Source: http://www.electronics-tutorials.ws/amplifier/amp_6.html)

The circuit above shows a standard Class B Amplifier circuit that uses a balanced center-tapped input transformer, which splits the incoming waveform signal into two equal halves and which are 180° out of phase with each other. Another center-tapped transformer on the output is used to recombine the two signals providing the increased power to the load. The transistors used for this type of transformer push-pull amplifier circuit are both NPN transistors with their emitter terminals connected together.

Here, the load current is shared between the two power transistor devices as it decreases in one device and increases in the other throughout the signal cycle reducing the output voltage and current to zero. The result is that both halves of the output waveform now swing from zero to twice the quiescent current thereby reducing dissipation. This has the effect of almost doubling the efficiency of the amplifier to around 70%. The Fig (4.12) shows the output characteristics of class B.

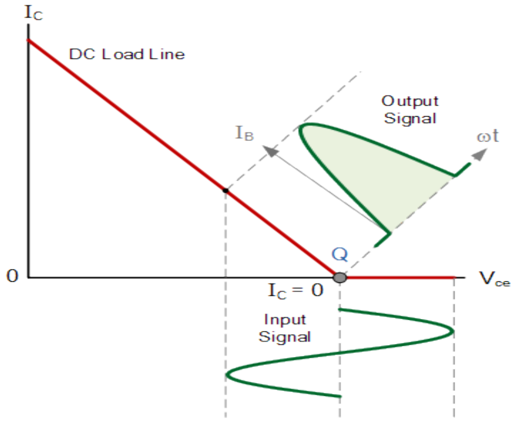


Figure 4:12 Class B Output Characteristics Curves

The Class B Amplifier has the big advantage over their Class A amplifier in that no current flows through the transistors when they are in their quiescent state (i.e. with no input signal), therefore no power is dissipated in the output transistors or transformer when there is no signal present unlike Class A amplifier stages that require significant base bias thereby dissipating lots of heat – even with no input signal present. So the overall conversion efficiency (η) of the amplifier is greater than that of the equivalent Class A, with efficiencies reaching as high as 70% possible resulting in nearly all modern types of push-pull amplifiers operated in this Class B mode.

Class B operation is provided when the dc bias leaves the transistor biased just off, the transistor turning on when the ac signal is applied. This is essentially no bias and the transistor conducts current for only one-half of the signal cycle. To obtain output for the full cycle of signal, it is necessary to use two transistors and have each conduct on opposite half-cycles, the combined operation providing a full cycle of output signal. Since one part of the circuit pushes the signal high during one half-cycle and the other part pulls the signal low during the other half-cycle. An input signal is applied to the push-pull circuit with each half operating on alternate half-cycles, the load then receiving a signal for the full ac cycle. The power transistors used in the push-pull circuit are capable of delivering the desired power to the load, and the class B operation of these transistors provides greater efficiency than as possible using a single transistor in class A operation. The Fig (4.13) shows the push-pull operation.

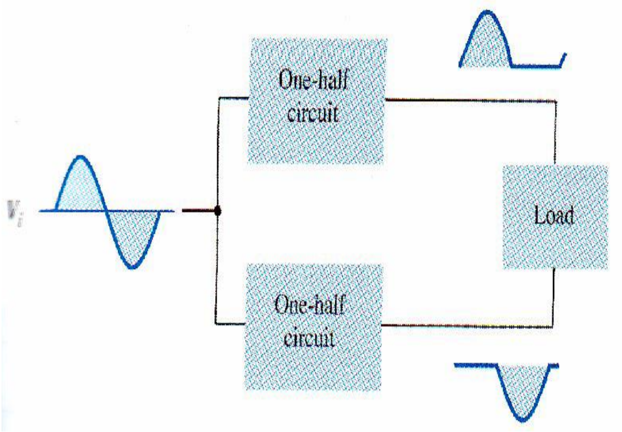


Figure 4:13 Method of Push- pull operation for each half cycle input

i. Input Power

The power supplied to the load by an amplifier is drawn from the power supply that provides the input or dc power. The amount of this input power P_i (dc) can be calculated using,

$P_i(\mathrm{dc}) = V_{cc} I_{dc}$ …………………………(4.6)

Where I_{dc} the average or dc current drawn from the power supplies and V_{cc} is the power supply. In class B operation, the current drawn from a single power supply has the form of a full-wave rectified signal, while that drawn from two power supplies has the form of a half-wave rectified signal from each supply. In either case, the value of the average current drawn can be expressed as

$I_{dc}=\frac{2}{\pi}I_p$ ....(4.7)

Where I_p is the peak value of the output current waveform and V_p voltage across the load on primary side using Eq.(4.6) in the power input equation Eq.(4.7) results in

$P_i(dc)=V_{cc}\frac{2}{\pi}I_p$ ....(4.8)

ii. Output (AC) Power

The power delivered to the load (usually referred to as a resistance, R_L on primary side*)* can be calculated using

$P_o(ac)=V^2_P(rms)/R_L$ ……………………….…(4.9)

In an oscilloscope, the peak, or peak-to-peak, output voltage measured for power is given by:

$P_o(ac)=V^2_P(p\text{-}p)/8R_L=V^2_P(p)/2R_L$………..…(4.10)

V_P(p-p) is peak to peak voltage and V_P(p)peak voltage across the R_L

The larger the rms or peak output voltage, the larger the power delivered to the load

iii. Efficiency

The efficiency of the class B amplifier can be calculated using the basic equation:

$$\begin{aligned}\eta &= \{P_o(ac)/P_i(dc)\}\times 100\% \\ &= \{V^2_P(p)/2R_L\}/\{V_{cc}\tfrac{2}{\pi}I_p\}\times 100\% \\ &= \{\pi/4\}\times 100\% \\ &= 78.5\%\end{aligned}$$

Also power across the load R_S on secondary winding is

$P_L=[\{V_L^2{}_{,rms}\}/\{Rs\}]$…………………………(4.11)

Since, $V_{L,rms}=(1/\sqrt{2})\,V_{L,max}$, then

$P_L=V^2{}_{L,max}/2Rs$………………………………(4.12)

And $V_{L,max}=\sqrt{(2P_LRs)}$ and $\sqrt{2}\,V_{L,rms}/V_{cc}=N_2/N_1$

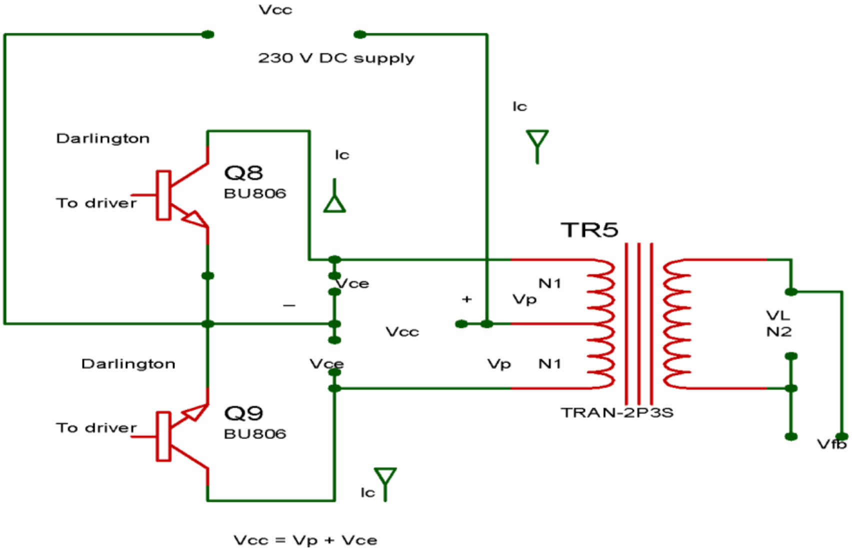


Figure 4:14 Push-pull stage

Turn ratio for the Push pull transformer is given by

If N_1 is the number of turn on one side of center tapped primary winding the total number of primary winding is $2N_1$ and let N_2 is number of turns in the secondary side. If the supply voltage on primary side is V_{cc} then when one transistor is conducting at maximum, the voltage pressing other transistor is$2V_{cc}$, that is peak voltage appears across the terminals of the both primary windings is $2V_{cc}$ ($4V_{cc}$ peak to peak). If V_{Lmax} is the peak voltage across the terminals of the secondary windings

Then :

$V_{L\,max}/2\,V_{cc}=N_2/2N_1$, $\mathrm{V}_{L\,max}=(N_2/N_1)\,V_{cc}$………(4.13)

When one transistor is not conducting at full range and other is in cut-off

$V_{cc} = V_p + V_{ce}$ ……………………………………….(4.14)

where V_{cc} - supply voltage, V_p - voltage across the primary winding of one side
V_{ce} - Collector Emitter voltage across the conducting transistor.

Also it shows now

$V_{L\max} = (N_2 / N_1)\, V_p$ ………………………………...(4.15)

$V_{L\ max}$ could be maintained constant, if V_p is maintained constant. For any V_{cc} variation, if V_{ce} (or in other word collector emitter resistance) is varied accordingly to maintain V_p constant, then $V_{L\ max}$ or RMS value of $V_{L\ max}$ ($V_{L\ rms}$) could be maintained. This is done by making the transistor to conduct accordingly by feedback from $V_{L\ max}$ to the feedback network and to the voltage, Current amplifier(V/I amp) and to the driver stage to control the base current of particular transistor. At full conduction of the transistor, the collector voltage approaches the emitter voltage (negative) and full V_{cc} appears across the primary winding and at no conduction zero voltage appears across it. The same would happen for other transistor of the pair.

For push pull output stage, refer to the appendix B of Darlington power transistor, to be used for push pull operation BU806 (page no-90) and BU808DFI (page no-93) . For BU806 maximum collector emitter voltage is 400V, maximum collector base voltage 400V, maximum collector current 8A ,maximum base current 2A and Maximum base emitter voltage 6V. For BU808DFI maximum collector emitter voltage is 700V maximum collector Base voltage 1400V maximum collector current 15A, maximum base current 3A and maximum base emitter voltage 6V.

It would be better to select BU808DFI for hardware operation. Required Power output and transformer could be calculated using equation (4.9) & (4.13).

Vcc = 210V DC (approximately selected without filter)

V_P (rms) = Voltage across the one side of primary winding

$V_{L,rms}$ = Voltage across the load on secondary side

$P_o(ac) = V^2_P(rms)/R_L$ or $V^2_P(p)/2R_L$

$V_{P(P)}$ peak voltage $= 2V_{cc}$ and R_L is the load of secondary load $R_{S,}$ refer to the primary side.

And on secondary side voltage across the load $V_{L,rms}$, Power across the load Rs on secondary winding is

$P_L = [\{V_L^2,_{rms}\}/\{Rs\}]$……………….(4.11)

and $V_{L\,max} = (N_2/N_1)\,V_{cc}$, $\sqrt{2}\,V_{L,rms}/V_{cc} = N_2/N_1$

Maximum current from driver is chosen 1A at 6V and h_{fe} =10 ,approximately according to the temperature and saturation V_{ce} is 0.5A base current could give 5A collector current. So that we may able get AC power up to 1KW.

Let

Vi = Voltage to the V/I Amp without feedback.

V_{Lrms} = Output Voltage

$V_{I\,(V/I\,Amp)}$ = Input to the V/I Amp with feed back

$Vi(V/I\,Amp) = Vi - \beta V_{Lrms}$

β – Feedback Factor

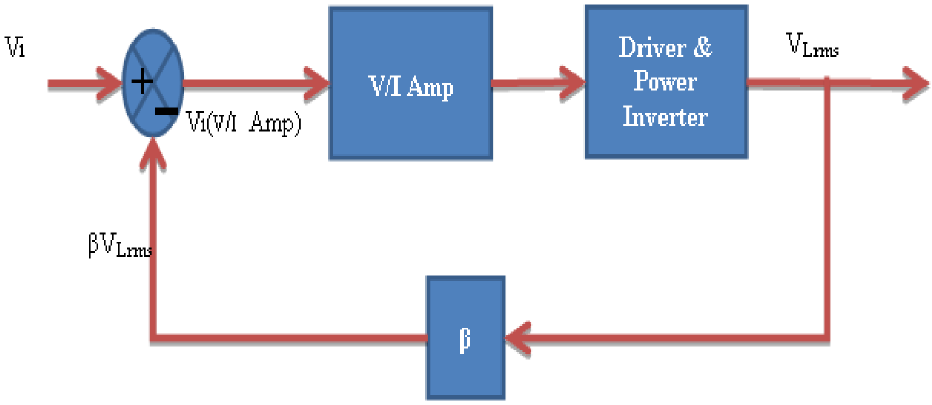


Figure 4:15 Block diagram with feedback for V/I Amp

4.1.6. Push Pull stage with Snubber circuit

One of the major factors in any electronic device is its ability to protect itself from surges that could damage the circuitry. In the case of push pull inverter DC to AC, inductive load can cause special problems because an inductor cannot stop instantly, conducting current, it must be dampened or diverted so that the current does not try to flow through open switch. If not dampened the surges can cause trouble to power transistors in the output stage. The high dv/dt, di/dt, V, I associated with this problem can cause the power transistors to malfunction and break.

To combat this problem snubber circuits can reduce or eliminate any severe voltages and currents. Composed of simply a resistor and capacitor and diode, placed across the collector emitter (common) of BJT or Drain source (common) of MOSFET, would suppress any voltage or current spikes and prevent any damage to the circuit. There are several type of snubber arrangements used in the circuit.

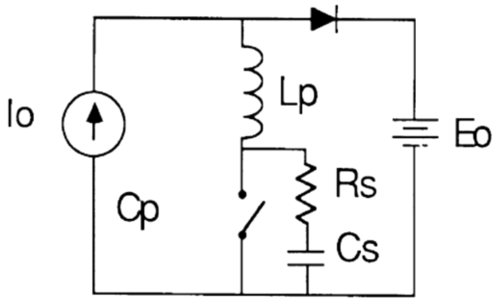


Figure 4:16 RC Snubber

(Source: Rudy Severns "DESIGN OF SNUBBERS FOR POWER CIRCUITS".)

An RC snubber, placed across the switch as shown in Fig (4.16) 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 (Rs and Cs). In those cases where a more optimum design is needed, a somewhat more complex procedure is used. Quick snubber design: To achieve significant damping Cs > C p. A good first choice is to make Cs equal to twice the sum of the output capacitance of the switch and the estimated mounting capacitance.

*R*s is selected so that *R*s =*E*o /*I*o. This means that the initial voltage step due to the current flowing in *R*s is no greater than the clamped output voltage. The power dissipated in *R*s can be estimated from peak energy stored in *C*s:

$U_{p}=(C_{s}E_{0}^{2})/2$…………….(4.16)

This is the amount of energy dissipated in *R*s when *C*s is charged and discharged so that the average power dissipation at a given switching frequency (*f*s) is:

$P_{diss}\approx C_{s}E_{0}^{2}f_{s}$ ……………….(4.17)

Depending on the amount of ringing the actual power dissipation will be slightly higher than this.

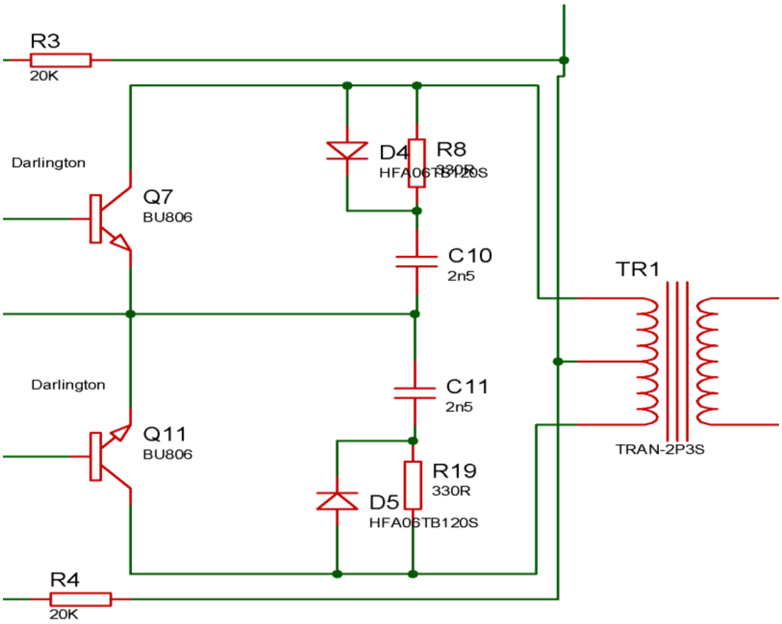


Figure 4:17 Push-pull stage with Snubber circuit

The Fig(4.17) shows snubber circuit connected to across the collectors and emitters of transistor Q7 and Q11 (BU806 ,Darlington pair). D4, R8,C10 are the elements of snubber circuit for the Transistor Q7 and C11, D5, R19 for the Q11 used in push-pull operation.

4.2. Complete Designed Circuit with all elements

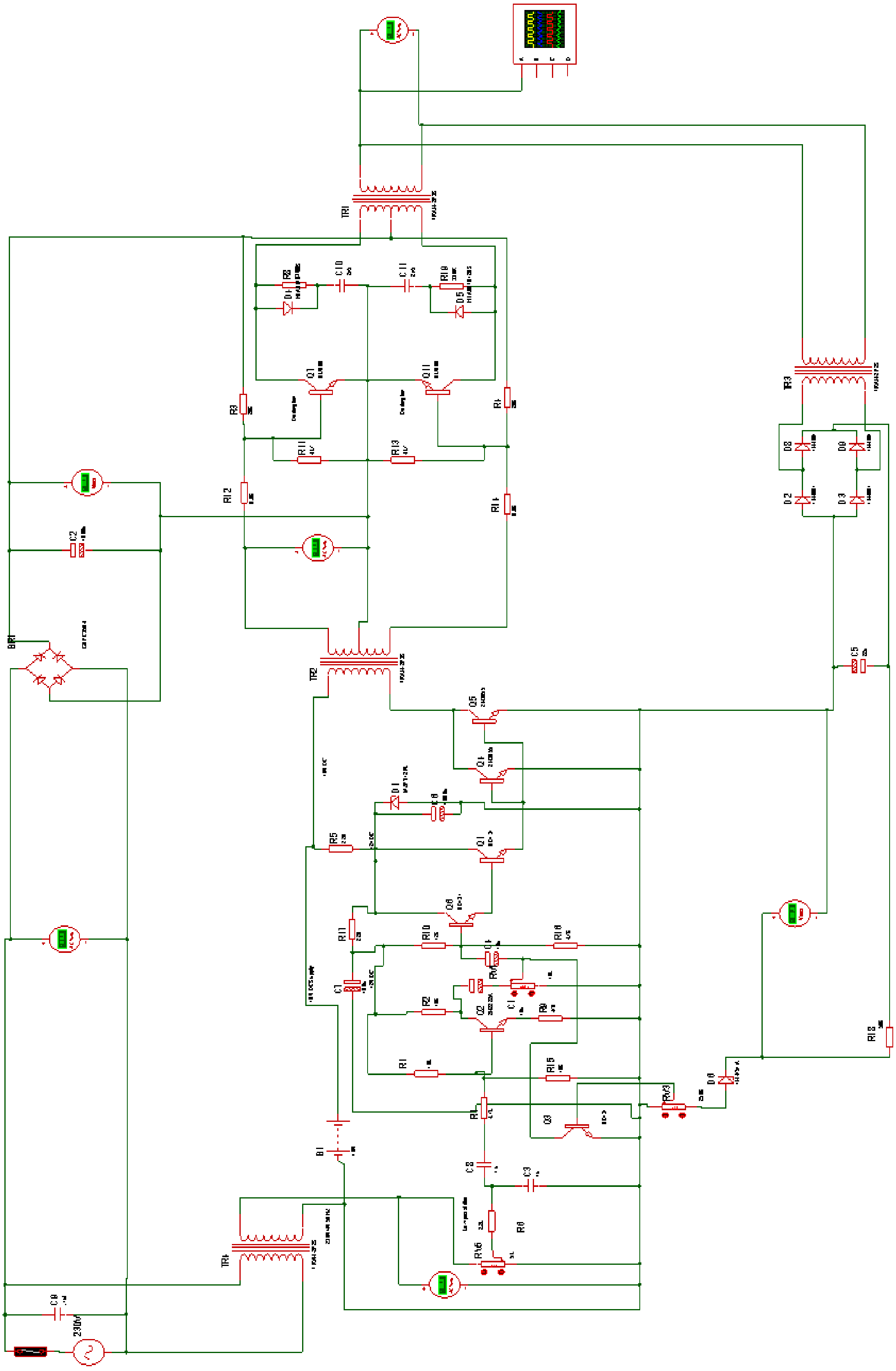


Figure 4:18 Complete Designed Circuit with all elements

4.3. Circuit Protection

Overvoltage &under voltage Protection arrangement if needed. The fig (4.19) shows the circuit protection with tripping device.

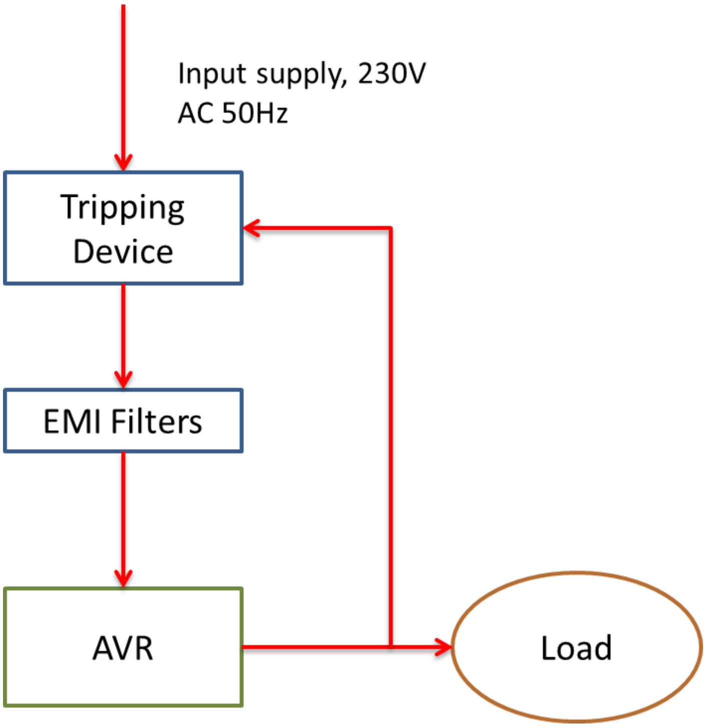


Figure 4:19 Circuit protection with Tripping device

Tripping devices contain over voltage/ under voltage units with timers those are preset to the our requirement to protect the equipment if AVR fails.

5. RESULTS AND ANALYSIS

5.1. Simulation Results of Driver circuit using Proteus-8 professional software

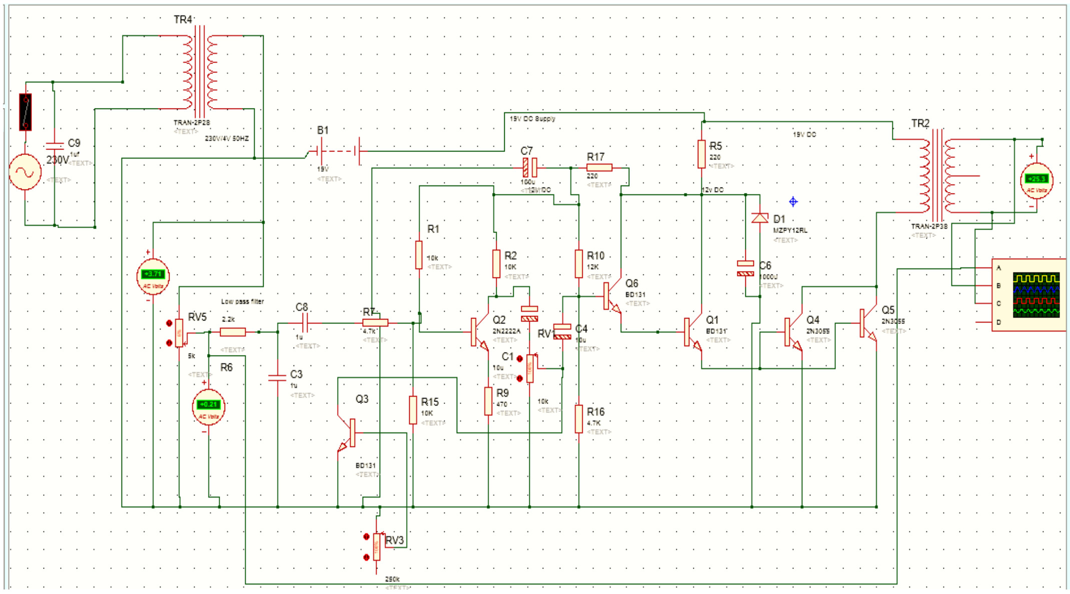


Figure 5:1 Driver circuit

Fig (5.2) shows the simulation of the driver circuit and driver output waveform with the two signals out of phase without loading and applied signal voltage for 230V i/p.

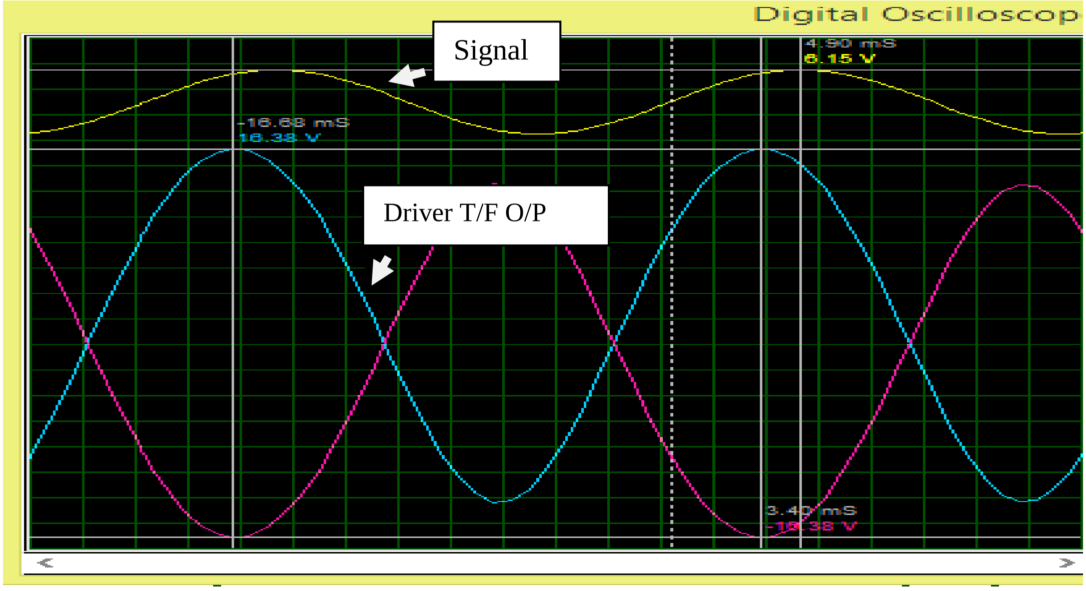


Figure 5:2 Driver Circuit signal & Driver output wave form using Proteus 8 professional without loading

5.2. Simulation Results of complete circuit using Proteus-8 professional software

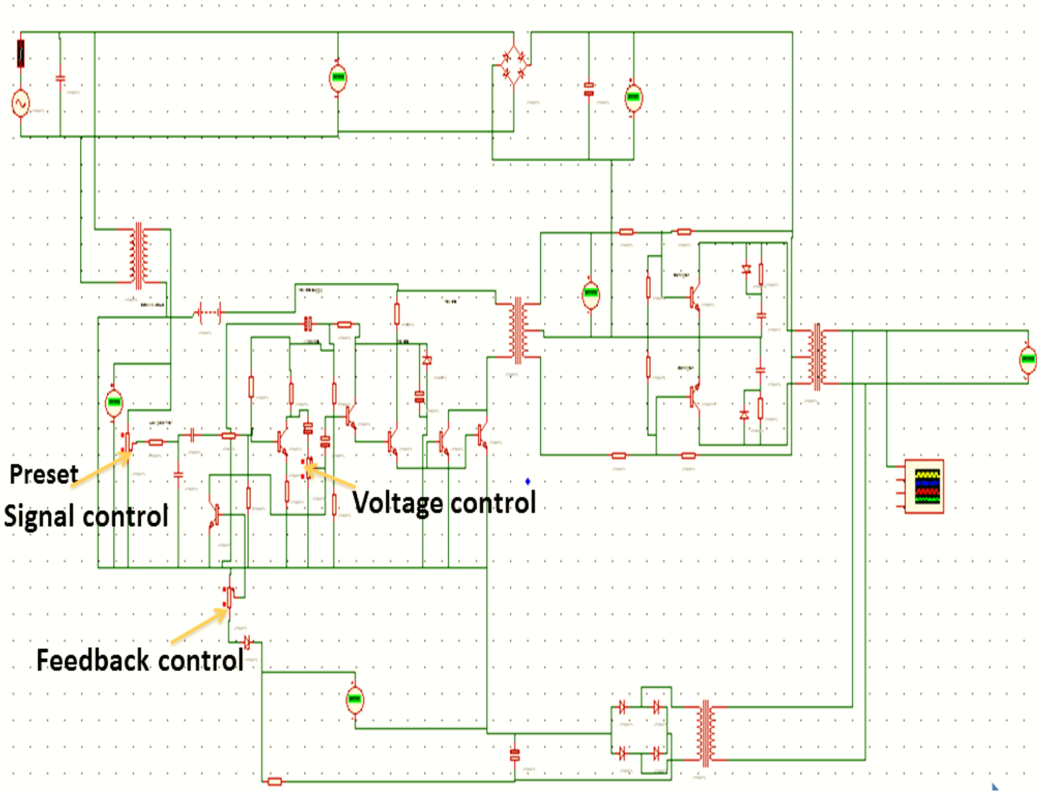


Figure 5:3 Complete electronic circuit using Proteus-8 professional software

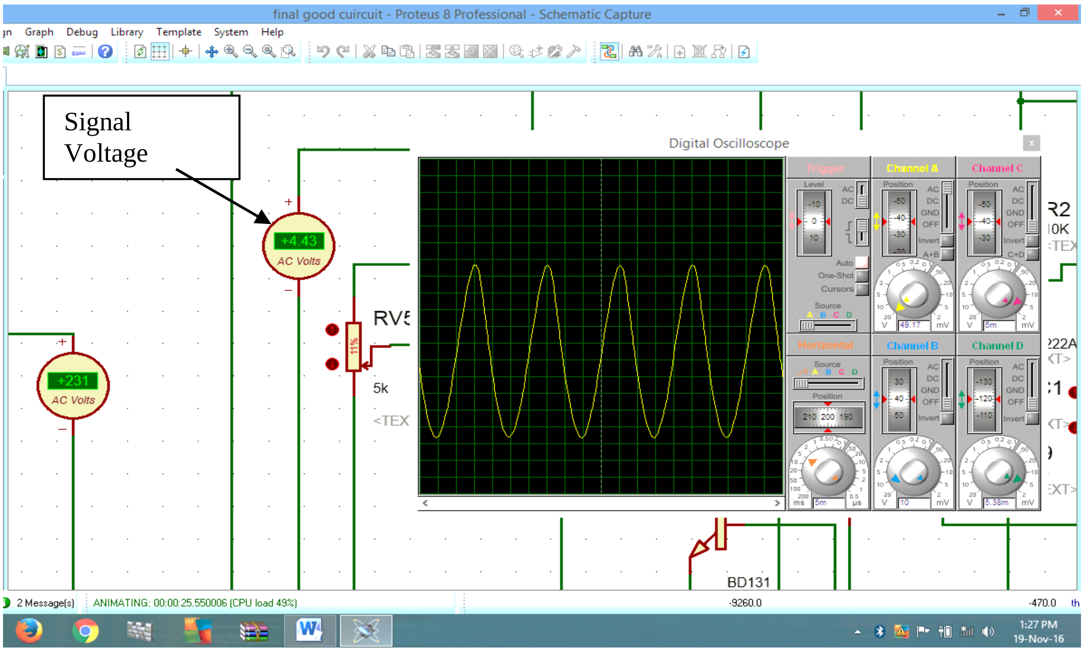


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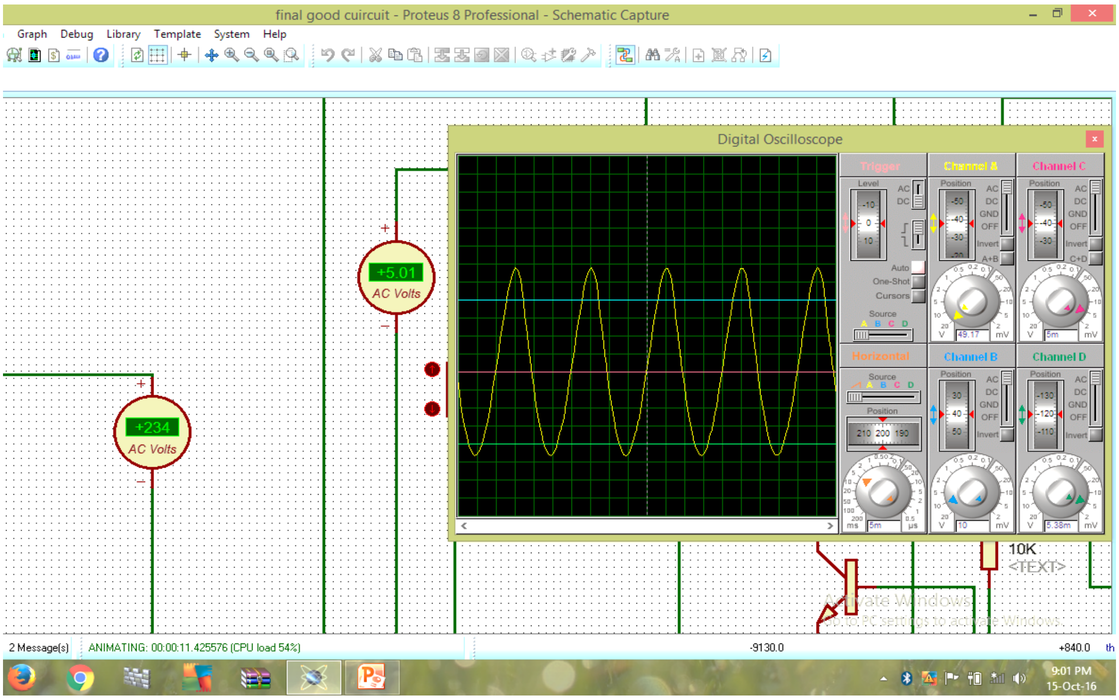
Figure 5:4 Output response when input voltage is 230V (Signal voltage is 4.4V)

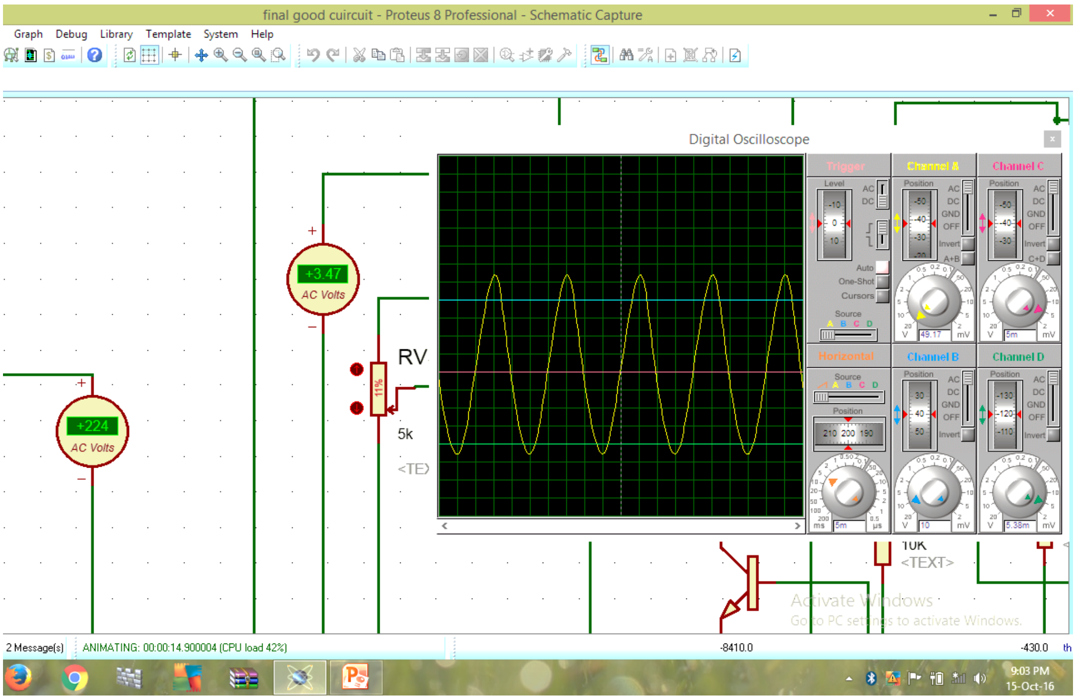
When input voltage goes to 260V(Signal voltage is 5.01V), Output voltage is 234V


final good cuircuit - Proteus 8 Professional - Schematic Capture

2 Message(s) ANIMATING: 00:00:11.425576 (CPU load 54%) -9130.0 +840.0

Figure 5:5 Output response when input voltage goes to 260V

When input voltage goes to 180V(Signal voltage is 3.47V), Output voltage is 224V


final good cuircuit - Proteus 8 Professional - Schematic Capture

2 Message(s) ANIMATING: 00:00:14.900004 (CPU load 42%) -8410.0 -430.0

Figure 5:6 Output response when input voltage goes to 180V

The subsidiary Legislation under the Electricity Act defines a maximum voltage variation is ±6% of the nominal voltage (216.2- 243.8V) to the consumer.

Our system response for 20W load,

- *When input voltage goes to 260V (13%), Output voltage is 234V (1%)*
- *When input voltage goes to 180V (21%), Output voltage is 224V (2%)*

That is the output voltage range lies within the allowable limit even input voltage fluctuate 180V to 260V

5.3. Hardware operation and analysis of Driver Unit

Figure 5:7 Driver unit

5.3.1. Response of preamplifier for input signal ……

Table 5.1Test results for the preamplifier o/p voltage with base voltage

Input Preset Voltage (V)	Base Voltage of Q2 Vb (V)	Output Sample Voltage of Q2 Vc (V)
0.005	0.000	0.018
0.300	0.130	2.150
0.500	0.211	3.263
0.801	0.315	3.833
1.000	0.380	4.000
1.300	0.481	4.153
1.501	0.548	4.218
2.008	0.716	4.319
2.500	0.882	4.372
3.000	1.050	4.403
4.000	1.377	4.437

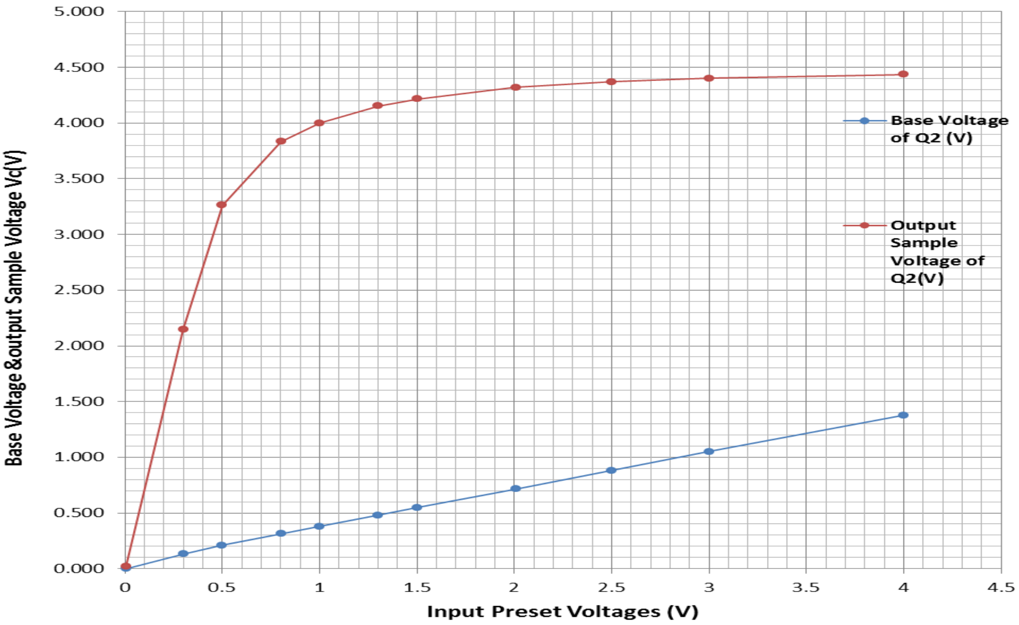


Figure 5:8 Variation of base voltage & sample voltage with i/p preset voltage

5.3.2. Response of Driver output for V/I Amplifier input ……

Table 5.2 Test results for the Driver output with, V/I amplifier i/p signal

Input Signal to V/I AmplifierQ6 (V)	Driver TF Output Voltage (V)	Driver TF Output Voltage 180° phase shift(V)
0.000	0.000	0.000
0.050	0.620	0.620
0.100	0.900	0.900
0.150	1.051	1.051
0.200	1.168	1.100
0.250	1.280	1.163
0.300	1.379	1.255
0.351	1.478	1.323
0.404	1.579	1.423
0.450	1.659	1.500
0.504	1.728	1.563
1.003	2.055	2.053

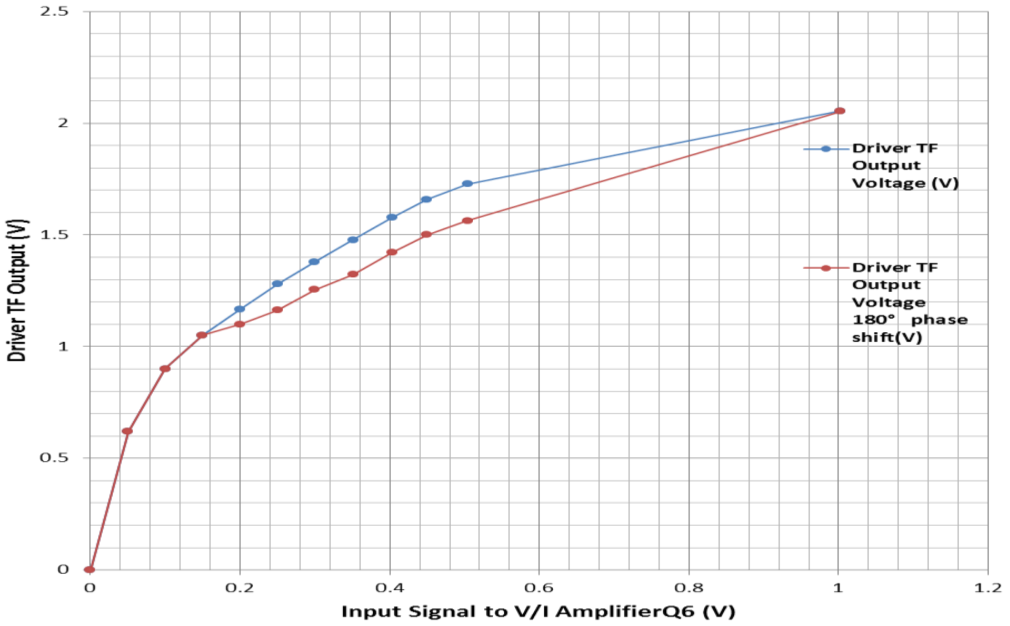


Figure 5:9 Variation of driver t/f output voltage with V/I amplifier input signal

The driver TF output voltage measured at the base of push pull power Transistors Q7,Q11

Linear portion of the collector output of Q2 up to 3.8V, but we take as 2.150V (selected sample) as a linear portion and corresponding preset signal voltage would be 0.3V (Ex: if voltage goes to 260V, 0.3V goes to 0.34V and collector Q2 would be small variation from 2.150V).

But we are selecting maximum of 1.003V from the selected sample(2.150V) for the next stage of V/I amplifier via voltage control it will give maximum driver output open voltage 24V,short circuit current of 1A.

Where it could be noted any variation in the main supply, very little variation could be noted in the input to V/I amplifier (for 1.003V o/p 280V, by FB adjustment 280V would be brought to 230V so that I/P voltage drop below 1.003V which will reduce the driver O/P voltage).

Complete circuit block diagram used for testing

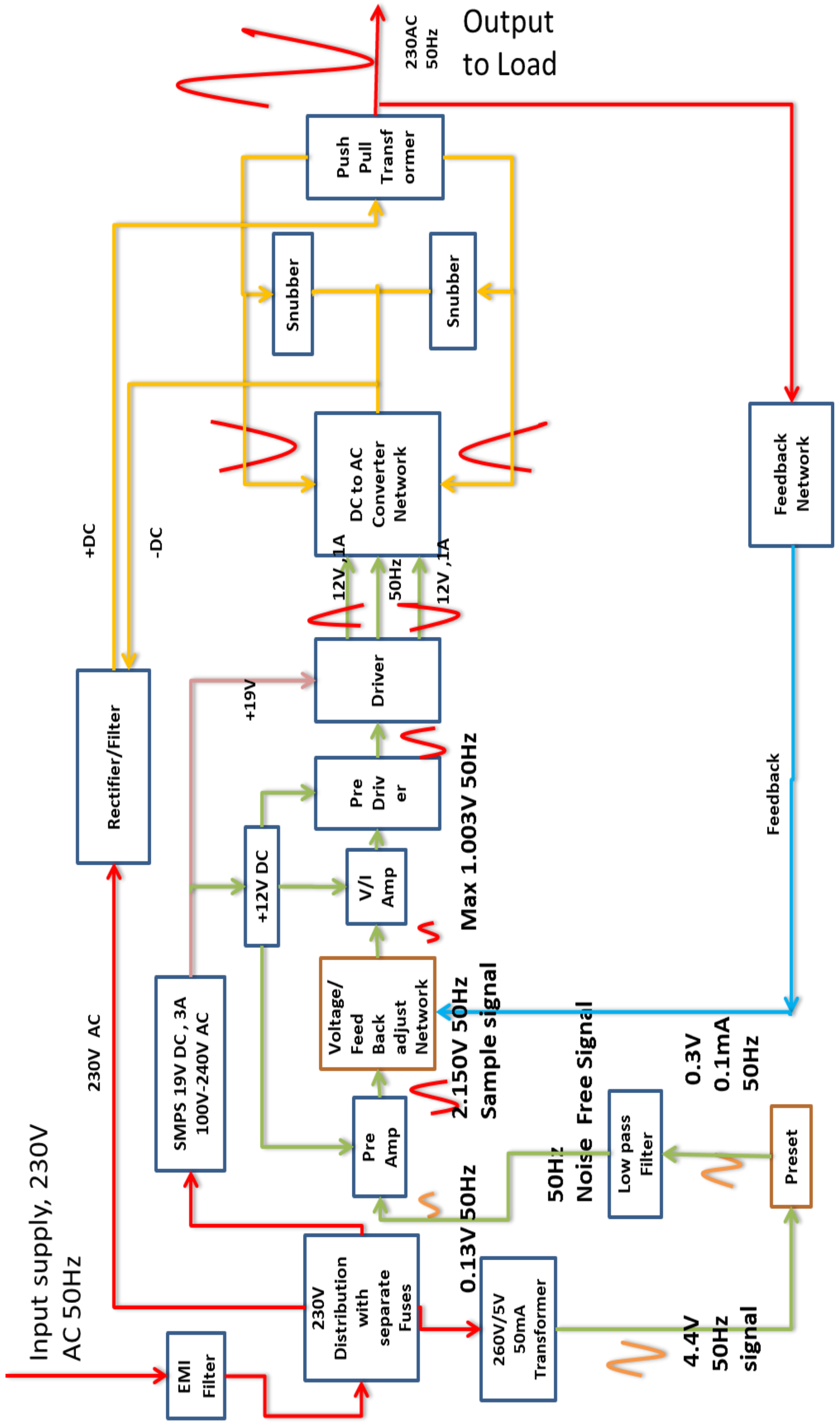


Figure 5:10 Complete circuit block diagram used for testing

5.4. Hardware operation and analysis of complete Unit

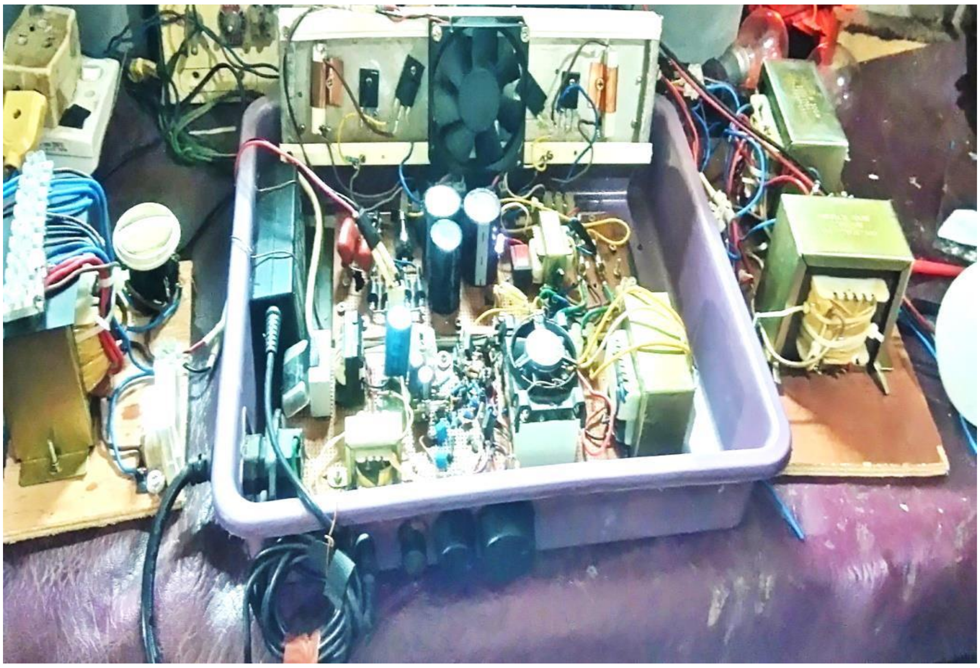


Figure 5:11 Complete Hardware unit

The design of push-pull stage

Pair of Darlington BJT was utilized (BU808 DFI, 1200V /8A type instead of BU 806,400V 5A) for push-pull stage. To overcome the flux walk, transformer was designed for testing purpose of this project. Approximately Four square inch core was selected with primary winding of 2000 turns using enamel wire 36SWG with DC resistance of approximately 200Ω, for each transistor (Total 4000 turn, 400Ω) and secondary turns of 40000 turns with the same wire, to give out put voltage of 350V, when each collector voltage is at 200V swing. This is done to reduce the maximum DC current flow in the primary winding about 1.5A (300V/200Ω). Since rectified voltage would be at peak level with capacitive filters. It is aware that due to the high resistance of the winding, output is less than expected. Testing was done with 20Watts load. To increase the efficiency a large core has to be used with thick winding and heat sinks, cooling fan etc. The Snubber circuits are connected for power transistors to protect from spikes.

5.4.1. Results obtained from Hardware test

To check the response of the Amplifier (V/I amp, Driver & power amp)

Readings of the Input voltage for V/I Amp by adjusting manually FB to get output voltage from 250-50V without load

Table 5.3 Test results of the V/I amplifier i/p voltage and output voltage without load

Input Voltage for V/I Amp with FB(V)	Output Voltage without load(V)
0.044	250.0
0.034	200.0
0.026	150.0
0.021	100.0
0.015	50.0

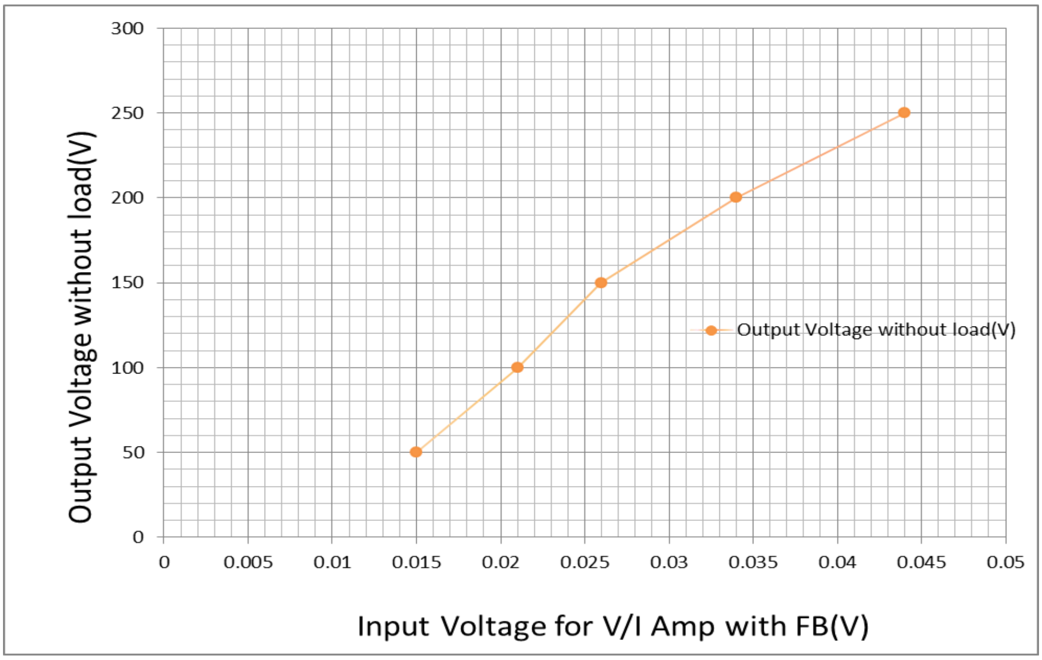


Figure 5:12 Variation of the output voltage with V/I amplifier i/p signal, without load

Readings of the Input voltage for V/I Amp by adjusting manually FB to get output voltage from 250-50V with load

Table 5.4 Test results of the V/I amplifier i/p voltage and output voltage with load

Input Voltage for V/I Amp with FB(V)	Output Voltage with load(V)
0.119	250.0
0.077	230.0
0.051	200.0
0.046	175.0
0.041	150.0
0.03	100.0
0.021	50.0

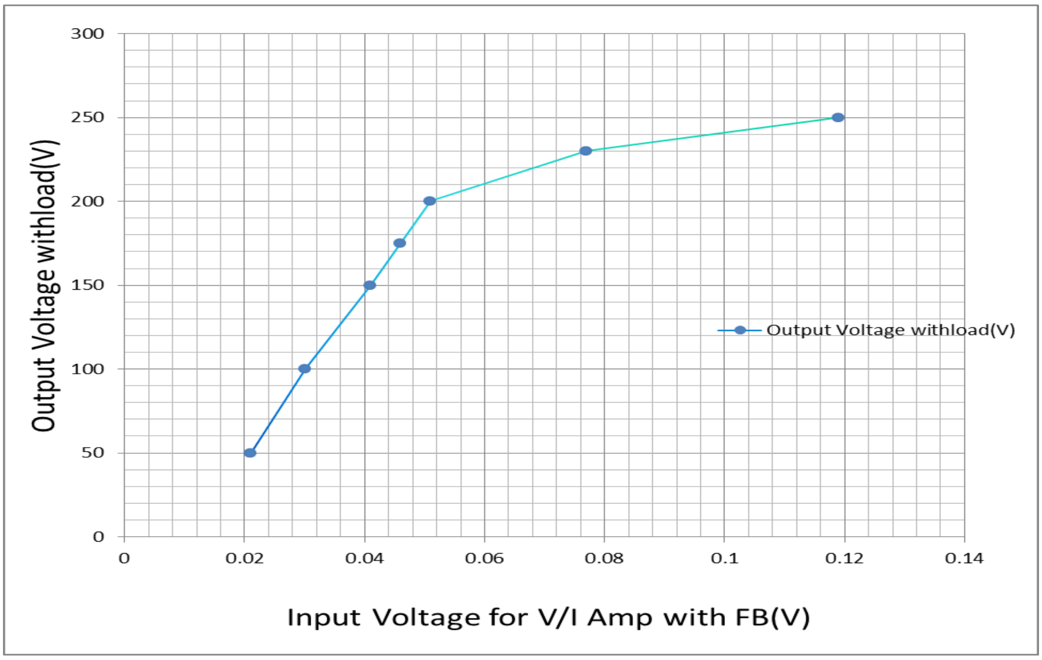


Figure 5:13 Variation of the output voltage with V/I amplifier i/p signal, with load

For testing 20W load has been used to test.

Table 5.5 Test results for the V/I amplifier ,output voltage without load

Input Voltage for V/I Amp with FB(V)	Output Voltage without load(V)	β × Output Voltage (V)
0.044	250.0	0.665
0.034	200.0	0.675
0.026	150.0	0.683
0.021	100.0	0.688
0.015	50.0	0.694

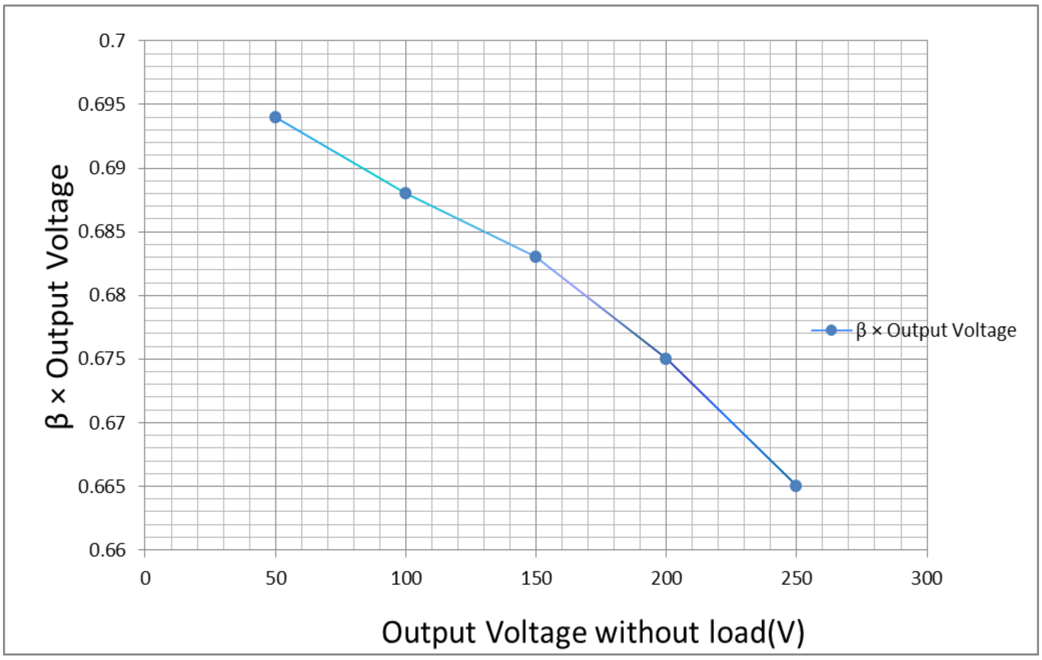


Figure 5:14 Variation of output voltage with feedback, without load

Table 5.6 Test results for the V/I amplifier, output voltage with load

Input Voltage for V/I Amp with FB(V)	Output Voltage with load(V)	β × Output Voltage (V)
0.119	250.0	0.590
0.077	230.0	0.632
0.051	200.0	0.658
0.046	175.0	0.663
0.041	150.0	0.668
0.030	100.0	0.679
0.021	50.0	0.688

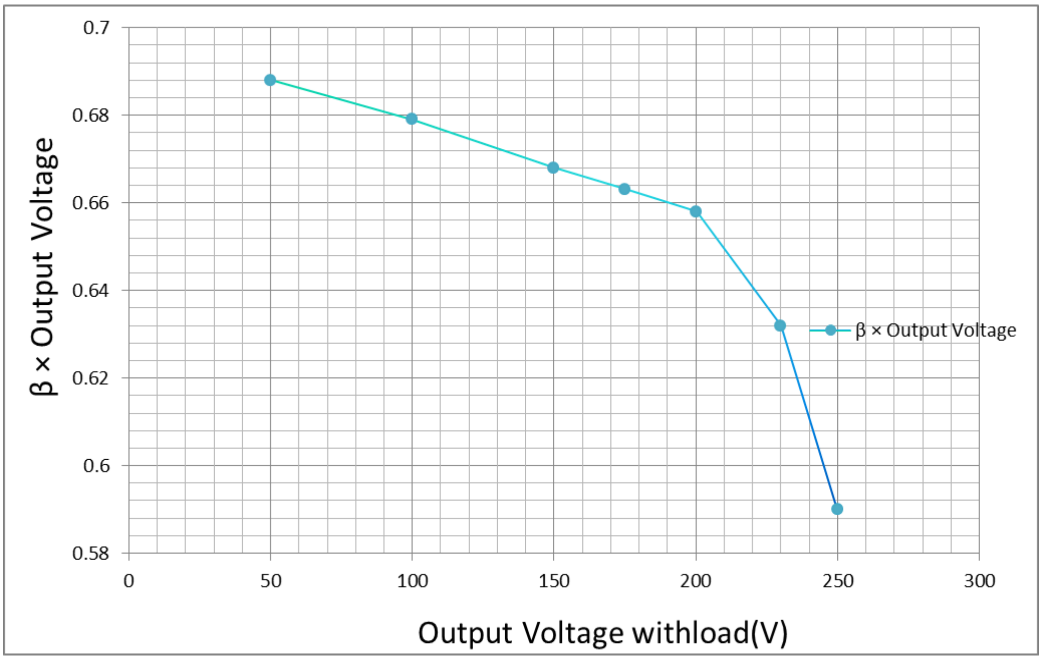


Figure 5:15 Variation of output voltage with feedback, with load

5.4.2. Automatic Response of the complete AVR unit

Automatic Response ofthe set Output voltage according to the input supply voltage changes (180V-260V),

Table 5.7 Test results for the I/P voltage vs. O/P voltage

Input Supply Voltage (V)	Output Voltage with load (V)
277.0	238.0
252.0	231.0
228.6	230.0
203.5	226.0
178.0	220.0

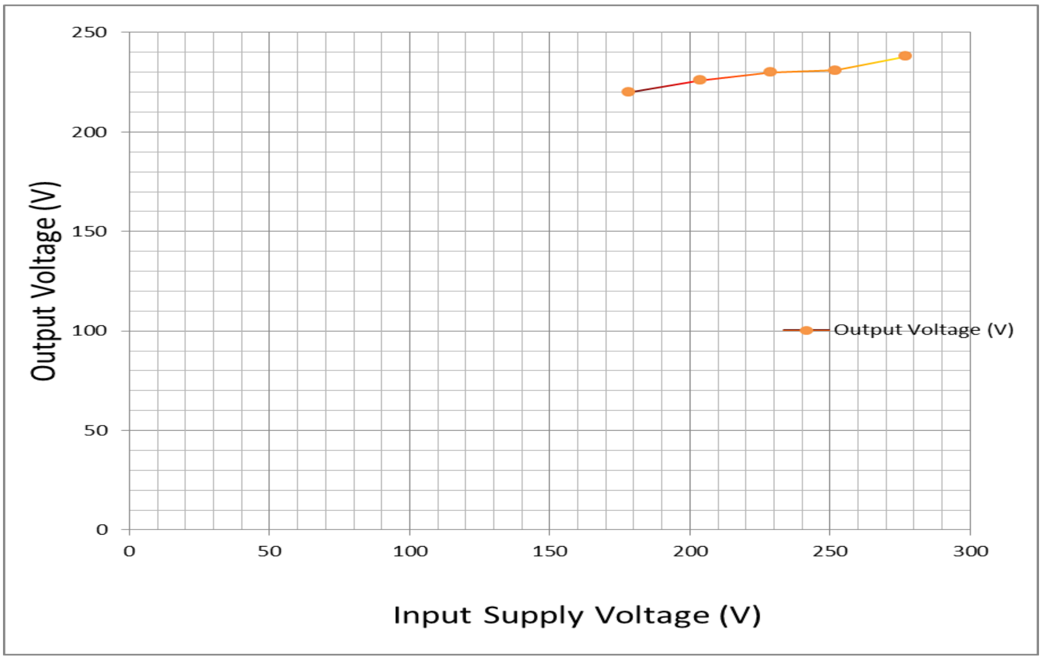


Figure 5:16 Output voltage variation according to the supply voltage fluctuation

Output voltage range within the allowable limit ±6%, even input voltage varies 250V-200V which is above allowable ±6% (216.2- 243.8V) .For testing 20W load has been used.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

My objective is to design a simple low power 230V, 50Hz Automatic voltage regulator, without moving parts (electro-mechanical devices) comprising an linear electronic amplifier circuit using Bipolar junction transistor (BJT) with sinusoidal out-put eliminating noise to use for sensitive equipment (for voltage and frequency variation). The noise free low signal obtain from the main supply as its input signal of having supply frequency (without oscillator), are used to obtain a controlled noise free standard supply voltage and frequency at the output terminals by the process of power amplification. Which could be used for the equipment of sensitive in nature for voltage and frequency without destructive noises, such as medical equipment etc.

There are lot of high power voltage controllers are available in the market. But each has its weaknesses therefore cannot used for low power sensitive equipment such as medical instrument. This project does not have any moving parts or any complicated electronic switching circuits etc. That is extracting a noise free signal (50Hz) from the normal consumer supply and is augmented to the standard supply. The only set back was due to thermal noise and flux walk when inverting DC to AC. These are common problem in electronic circuits .But suitable design would reduce or eliminate the said problems. Further as it is operating with the supply frequency, without oscillators, easy to synchronize with the main supply and no switching problem. Also this could be used for boosting main supply with output transformer modification without frequency disturbances.

Hardware testing and Simulation technique were studied for 20W load. They have shown good results with sinusoidal output. The only set back in hardware testing, was unable to design high power push-pull transformer to get high power above 100W due to the cost and flux walk.

The subsidiary Legislation under the Electricity Act defines a maximum voltage variation is ±6% of the nominal voltage (216.2- 243.8V) to the consumer.
Our system response,

- When input voltage goes to 260V (13%), Output voltage is 234V (1%)
- When input voltage goes to 180V (21%), Output voltage is 224V (2%)

That is the output voltage range lies within the allowable limit even input voltage fluctuate 180V to 260V

Flux walk is the main problem in push pull operation. The weight and cost of the items are mainly depending on the push-pull transformer as compared to the spares in fabricating. For example to get 200W output we may have to pay about Rs.8000 for making push-pull transformer. Whereas cost of the spare parts are within Rs.3000. The unit cost may come down if the production increases. But regulators are available for low cost varying from Rs.5000 to Rs.20,000 for 200W to1000W, but employing different technique using autotransformers with relays, servomechanism types, thyristor used types etc but cannot be used for the low power sensitive equipment. They may have high voltage tolerance, Switching noise, high response time for rapid fluctuation, frequency disturbance etc. These regulators could be used for the equipment having their own internal regulators. My designed circuit is as far as free from the above said defects.

6.2. Recommendations and Further Work

Due to the various reasons and practical difficulties separate power supplies were used in the circuit. But it could be modified into a single power unit and AC signal (50Hz) also could be taken from the same. For better response integrated circuits may be used instead of discrete circuit which I have used. There are lots of IC’s are available in the market. For future improvements, I have used high power driver transistors (2N3055), which could be used with suitable driver transformers and power transistors to get high power output. The circuit also could be used with MOSFET in the out-put stage, as recommended to reduce flux walk. The circuit should be modified when using MOSFET as it is capacitive and voltage control devise at the input as compared to BJT, it is current operative devise. The power supply to the output push-pull stage is given by the direct rectification of the Main supply. But according to the convenience power with less voltage also could be arranged with suitable Push-Pull transformer. To get the high power , suitable output transformer should be designed .

Also full bridge network output could be obtain with single primary winding instead double winding in the push-pull stage ,using four separate output from the driver transformer. Two (S1, S4) of the four out-put should be 180 degree out of phase when compared to the other two (S2, S3). They are connected to the four power output transistors (Fig 6.1) in such a way, one pair operate, sending the current in one direction of the winding and other pair for reversal of the current. This is done according to the frequency of the supply. External timing is not needed.

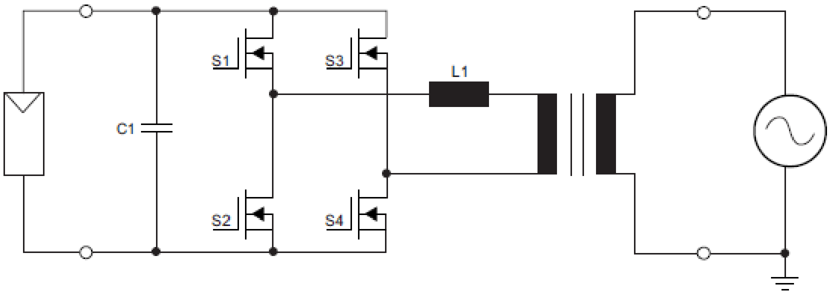


Figure 6:1 Full Bridge network with single primary winding

(Source: Reference no-18,Page no-70)

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Appendix A

Cost of implemented unit

Type	Quantity	Price
Resistors		
2.2kΩ , ¼ W	1	20cts
4.7k Ω , ¼ W	3	60cts
10k Ω , ¼ W	3	60cts
470 Ω , ¼W	1	20cts
12 kΩ , ¼W	1	20cts
220 Ω , 2W	2	Rs.2.00
1kΩ , 5W	2	Rs.20.00
20kΩ , 2W	2	Rs.2.00
4.7kΩ , 1W	2	Rs.1.00
330Ω , 2W	2	Rs.2.00
Capacitors		
1µF , 25V	2	Rs.10.00
470µF , 50V	1	Rs.10.00
1000µF ,50V	1	Rs.20.00
22 µF , 50V	1	Rs.10.00
220µF ,400V	1	Rs.50.00
0.01µF, 600V	2	Rs.20.00
10µF , 25V	2	Rs.10.00
Diodes		
1A , 400V	4	Rs.4.00
8A , 1000V	4	Rs.12.00
Zener Diode		
12V , 2W	2	Rs.4.00
Variable resistor		
5 kΩ	1	Rs.10.00

10 kΩ	1	Rs.10.00
250 kΩ	1	Rs.10.00
Transistors		
2N2222	1	Rs.25.00
BD131	2	Rs.70.00
2N3055	2	Rs.100.00
BU808DFI	2	Rs.150.00
Bu806 (optional)	2	Rs.100.00
Total		**Rs.631.80**

Type	Quantity	Price
Transformer		
260/5V 100mA	1	Rs.100.00
230/12V 100mA	1	Rs.100.00
Driver 9 /12/12 2A	1	Rs.500.00
110V -250V/19V SMPS	1	Rs.1200.00
Others		
Circuit board	2	Rs.100.00
Bolt and nut ,lead etc.		Rs.100.00
Total		**Rs.2100.00**

Total cost excluding push pull transformer, casing, labour etc is **Rs.2731.80**

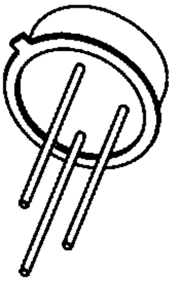
Additional cost involves in making Push-pull transformer and amount of power required. Normally BU808DFI can withstand for 8A at 400V with proper cooling and able to deliver approximately 1kW. The cost of the 1kW Regulator may be around Rs.15000 in the common market having their own weakness such as noise, frequency disturbance, time response for fluctuationetc.

For the information: To overcome the flux walk, transformer was designed for testing purpose of this project. Approximately Four square inch core was selected with primary winding of 2000 turns using enamel wire 36SWG with DC resistance of approximately 200Ω, for each transistor (Total 4000 turn, 400Ω) and secondary turns of 40000 turns with the same wire, to give out put voltage of 350V, when each collector voltage is at 200Vswing. This is done to reduce the maximum DC current flow in the primary winding about 1.5A (300V/200Ω). Since rectified voltage would be at peak level with capacitive filters. It is aware that due to the high resistance of the winding, output is less than expected. To increase the efficiency a large core has to be used with thick winding and heat sinks, cooling fan etc. The cost involved approximately Rs. 2500.

Appendix B

DISCRETE SEMICONDUCTORS

DATA SHEET



2N2222; 2N2222A
NPN switching transistors

Product specification
Supersedes data of September 1994
File under Discrete Semiconductors, SC04

1997 May 29

Philips
Semiconductors

PHILIPS

NPN switching transistors 2N2222; 2N2222A

FEATURES

- High current (max. 800 mA)
- Low voltage (max. 40 V).

APPLICATIONS

- Linear amplification and switching.

DESCRIPTION

NPN switching transistor in a TO-18 metal package.
PNP complement: 2N2907A.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to case

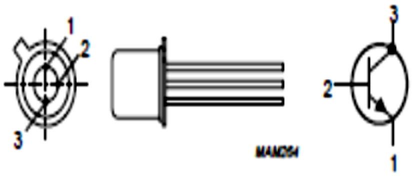
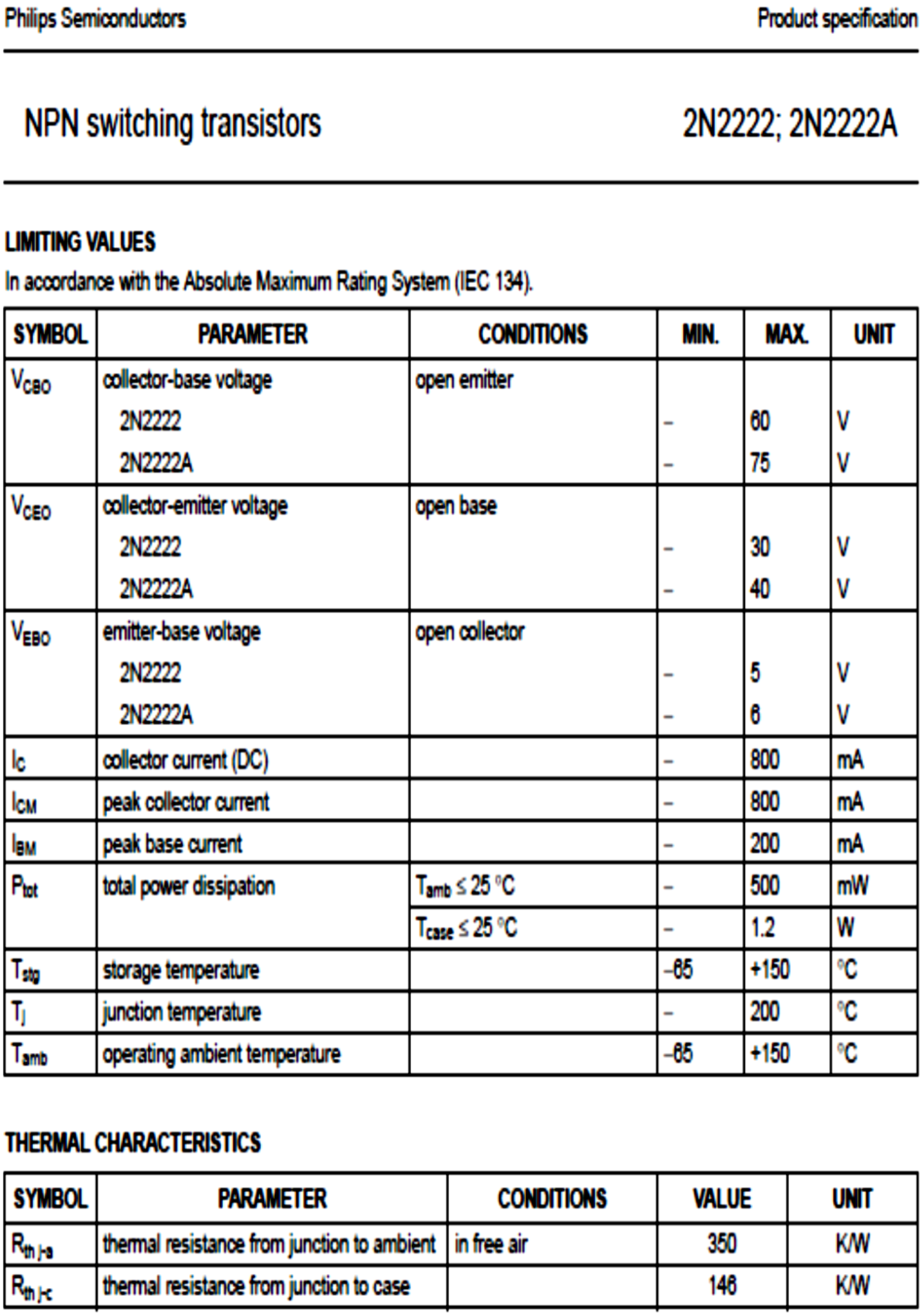


Fig.1 Simplified outline (TO-18) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
I_C	collector current (DC)		–	800	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
h_{FE}	DC current gain	$I_C = 10$ mA; $V_{CE} = 10$ V	75	–	
f_T	transition frequency	$I_C = 20$ mA; $V_{CE} = 20$ V; $f = 100$ MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
t_{off}	turn-off time	$I_{Con} = 150$ mA; $I_{Bon} = 15$ mA; $I_{Boff} = -15$ mA	–	250	ns



Philips Semiconductors | Product specification

NPN switching transistors | 2N2222; 2N2222A

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
V_{EBO}	emitter-base voltage	open collector			
	2N2222		–	5	V
	2N2222A		–	6	V
I_C	collector current (DC)		–	800	mA
I_{CM}	peak collector current		–	800	mA
I_{BM}	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25\ °C$	–	500	mW
		$T_{case} \leq 25\ °C$	–	1.2	W
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	200	°C
T_{amb}	operating ambient temperature		–65	+150	°C

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	in free air	350	K/W
$R_{th\ j\text{-}c}$	thermal resistance from junction to case		146	K/W

CHARACTERISTICS

$T_j = 25$ °C unless otherwise specified.

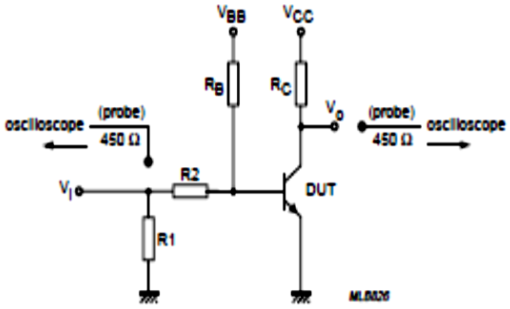
SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current				
	2N2222	$I_E = 0$; $V_{CB} = 50$ V	–	10	nA
		$I_E = 0$; $V_{CB} = 50$ V; $T_{amb} = 150$ °C	–	10	μA
I_{CBO}	collector cut-off current				
	2N2222A	$I_E = 0$; $V_{CB} = 60$ V	–	10	nA
		$I_E = 0$; $V_{CB} = 60$ V; $T_{amb} = 150$ °C	–	10	μA
I_{EBO}	emitter cut-off current	$I_C = 0$; $V_{EB} = 3$ V	–	10	nA
h_{FE}	DC current gain	$I_C = 0.1$ mA; $V_{CE} = 10$ V	35	–	
		$I_C = 1$ mA; $V_{CE} = 10$ V	50	–	
		$I_C = 10$ mA; $V_{CE} = 10$ V	75	–	
		$I_C = 150$ mA; $V_{CE} = 1$ V; note 1	50	–	
		$I_C = 150$ mA; $V_{CE} = 10$ V; note 1	100	300	
h_{FE}	DC current gain	$I_C = 10$ mA; $V_{CE} = 10$ V; $T_{amb} = -55$ °C			
	2N2222A		35	–	
h_{FE}	DC current gain	$I_C = 500$ mA; $V_{CE} = 10$ V; note 1			
	2N2222		30	–	
	2N2222A		40	–	
V_{CEsat}	collector-emitter saturation voltage				
	2N2222	$I_C = 150$ mA; $I_B = 15$ mA; note 1	–	400	mV
		$I_C = 500$ mA; $I_B = 50$ mA; note 1	–	1.6	V
V_{CEsat}	collector-emitter saturation voltage				
	2N2222A	$I_C = 150$ mA; $I_B = 15$ mA; note 1	–	300	mV
		$I_C = 500$ mA; $I_B = 50$ mA; note 1	–	1	V
V_{BEsat}	base-emitter saturation voltage				
	2N2222	$I_C = 150$ mA; $I_B = 15$ mA; note 1	–	1.3	V
		$I_C = 500$ mA; $I_B = 50$ mA; note 1	–	2.6	V
V_{BEsat}	base-emitter saturation voltage				
	2N2222A	$I_C = 150$ mA; $I_B = 15$ mA; note 1	0.6	1.2	V
		$I_C = 500$ mA; $I_B = 50$ mA; note 1	–	2	V
C_c	collector capacitance	$I_E = i_e = 0$; $V_{CB} = 10$ V; f = 1 MHz	–	8	pF
C_e	emitter capacitance	$I_C = i_c = 0$; $V_{EB} = 500$ mV; f = 1 MHz			
	2N2222A		–	25	pF
f_T	transition frequency	$I_C = 20$ mA; $V_{CE} = 20$ V; f = 100 MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
F	noise figure	$I_C = 200$ μA; $V_{CE} = 5$ V; $R_S = 2$ kΩ;			
	2N2222A	f = 1 kHz; B = 200 Hz	–	4	dB

NPN switching transistors 2N2222; 2N2222A

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
Switching times (between 10% and 90% levels); see Fig.2					
t_{on}	turn-on time	I_{Con} = 150 mA; I_{Bon} = 15 mA; I_{Boff} = −15 mA	–	35	ns
t_d	delay time		–	10	ns
t_r	rise time		–	25	ns
t_{off}	turn-off time		–	250	ns
t_s	storage time		–	200	ns
t_f	fall time		–	60	ns

Note

1. Pulse test: $t_p \leq 300$ µs; $\delta \leq 0.02$.

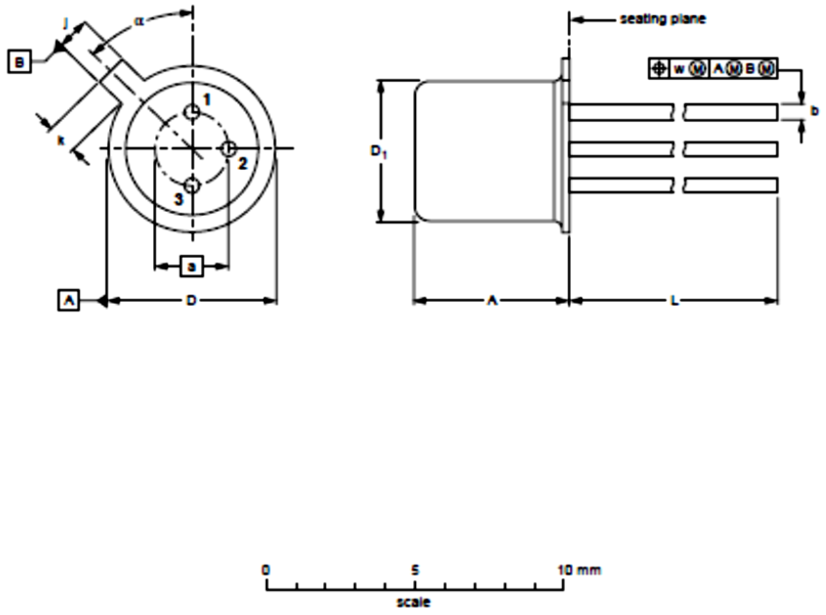


V_i = 9.5 V; T = 500 µs; t_p = 10 µs; $t_r = t_f \leq 3$ ns.
R1 = 68 Ω; R2 = 325 Ω; R_B = 325 Ω; R_C = 160 Ω.
V_{BB} = −3.5 V; V_{CC} = 29.5 V.
Oscilloscope input impedance Z_i = 50 Ω.

Fig.2 Test circuit for switching times.

PACKAGE OUTLINE

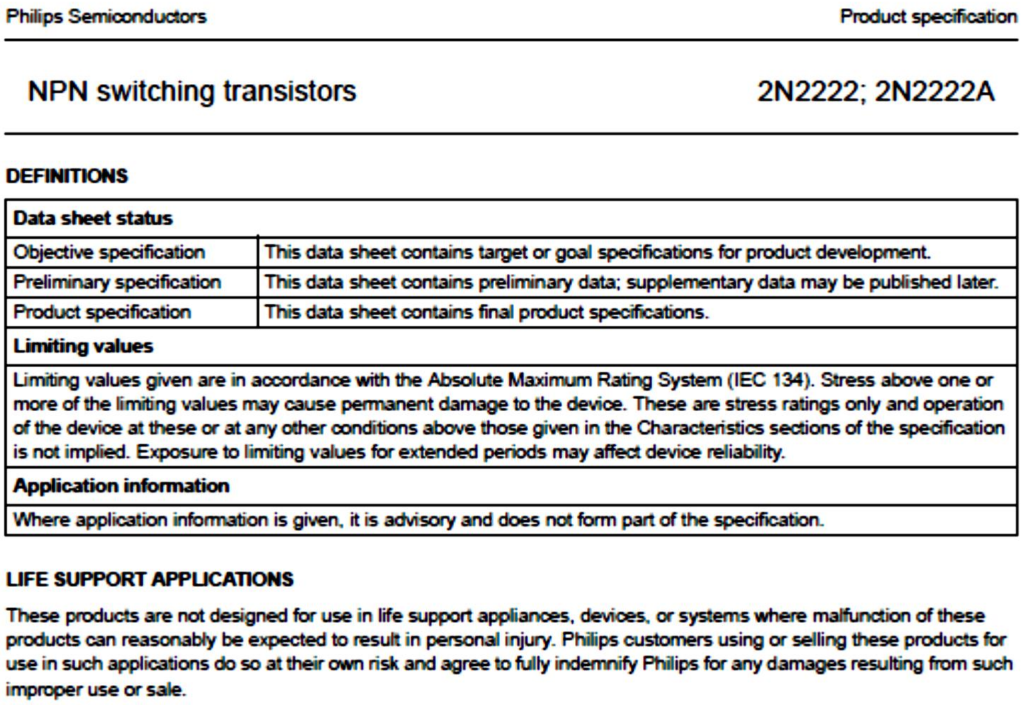
Metal-can cylindrical single-ended package; 3 leads **SOT18/13**



DIMENSIONS (millimetre dimensions are derived from the original inch dimensions)

UNIT	A	a	b	D	D_1	j	k	L	w	α
mm	5.31 4.74	2.54	0.47 0.41	5.45 5.30	4.70 4.55	1.03 0.94	1.1 0.9	15.0 12.7	0.40	45°

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT18/13	B11/C7 type 3	TO-18				97-04-18



Philips Semiconductors

Product specification

NPN switching transistors

2N2222; 2N2222A

DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.

Limiting values

Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

Application information

Where application information is given, it is advisory and does not form part of the specification.

LIFE SUPPORT APPLICATIONS

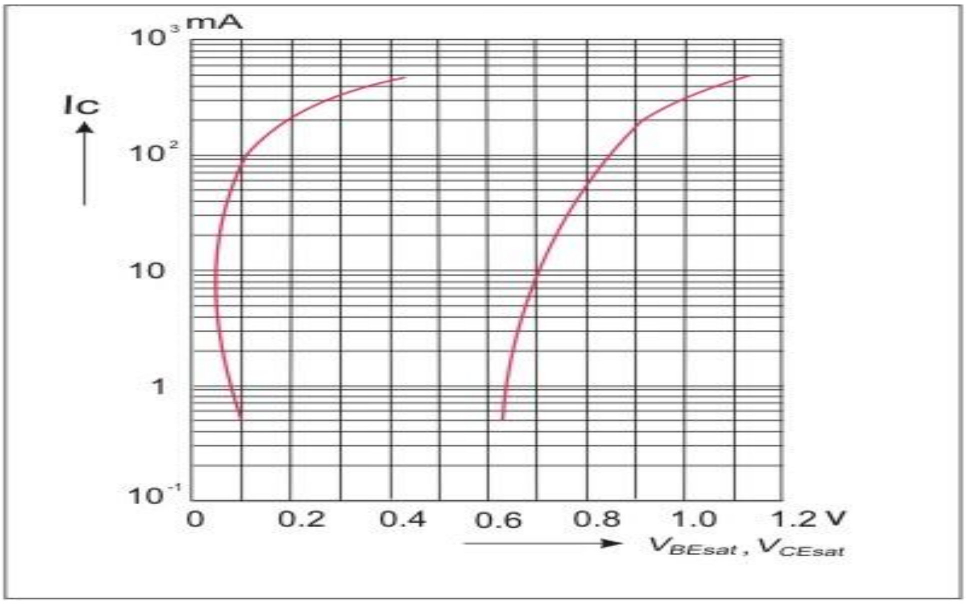
These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such improper use or sale.

Rating and characteristics curves

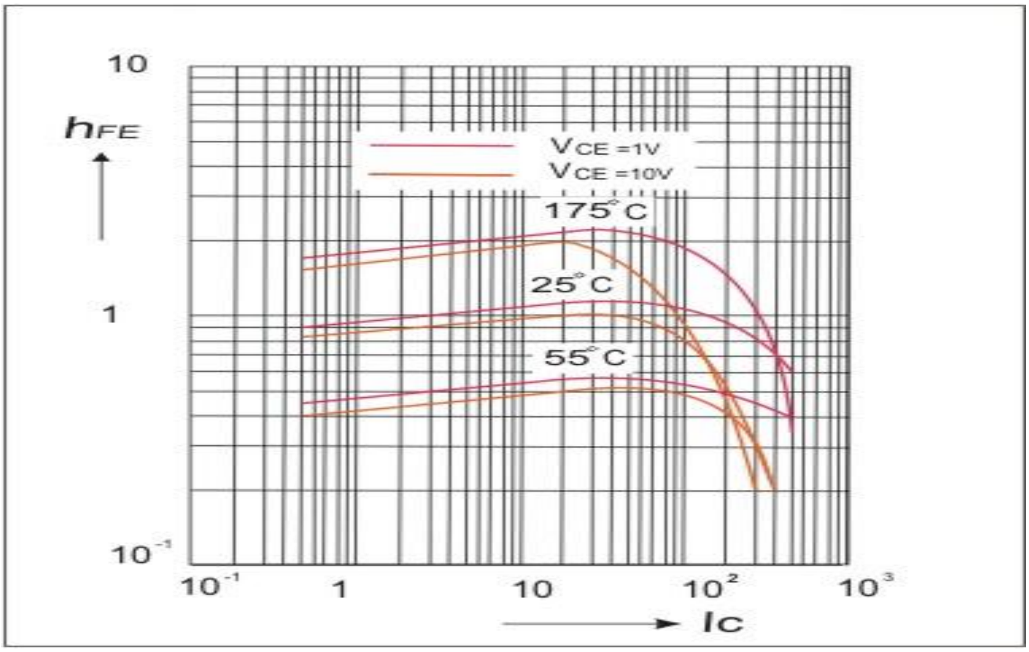
Turn off time= 300ns

Noise fig 4db

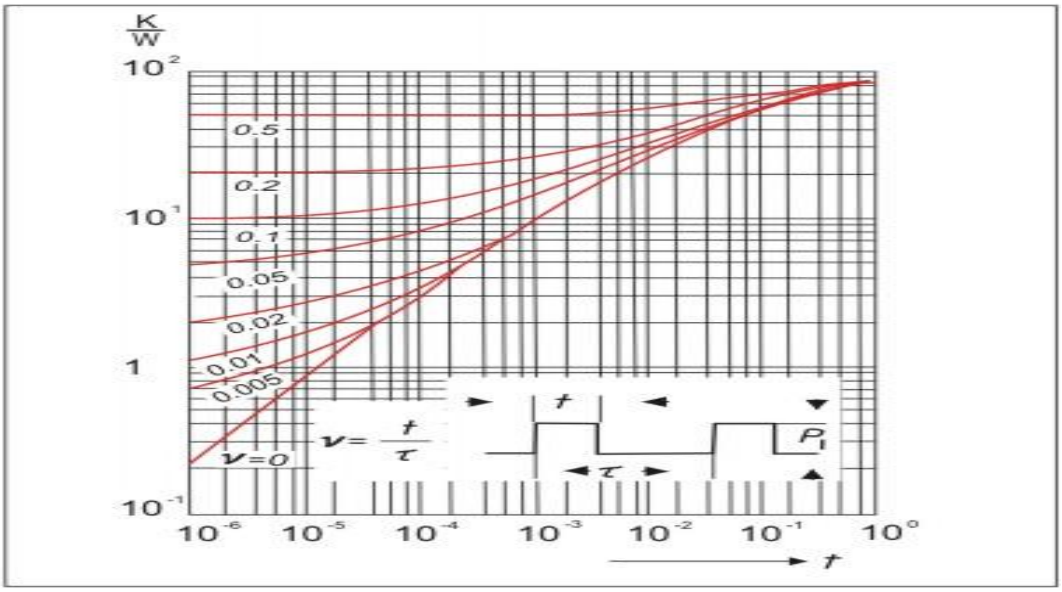
Tamp =25^0 C, h_{fe}=10



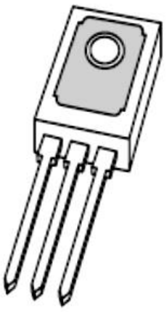
DC current gain



Permissible load



DATA SHEET



BD131
NPN power transistor

Product specification
Supersedes data of 1997 Mar 04

1999 Apr 12

Philips
Semiconductors

PHILIPS

NPN power transistor BD131

FEATURES

- High current (max. 3 A)
- Low voltage (max. 45 V).

APPLICATIONS

- General purpose power applications.

DESCRIPTION

NPN power transistor in a TO-126; SOT32 plastic package. PNP complement: BD132.

PINNING

PIN	DESCRIPTION
1	emitter
2	collector, connected to metal part of mounting surface
3	base

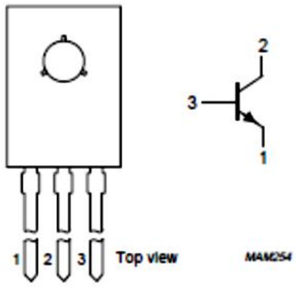
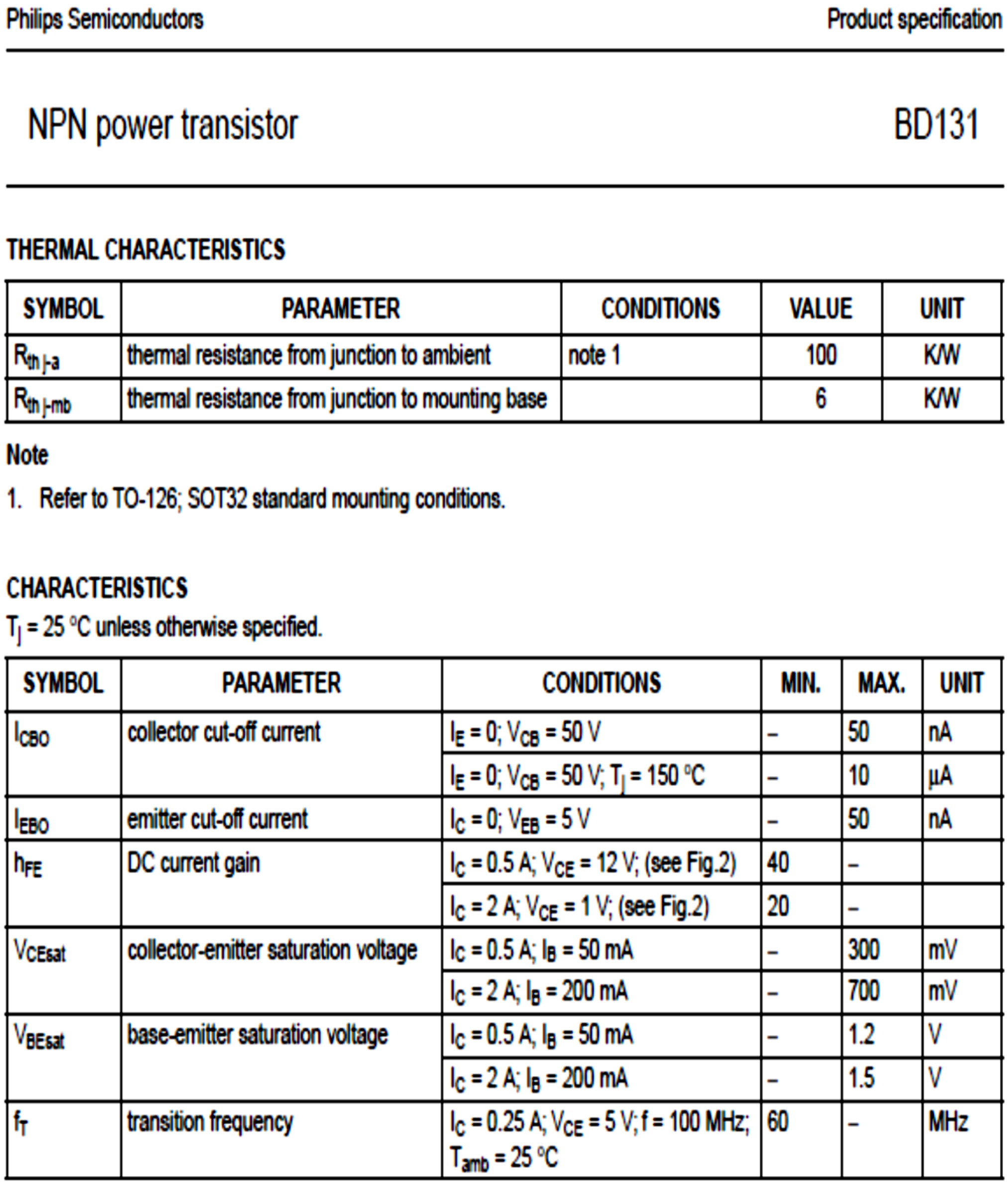


Fig.1 Simplified outline (TO-126; SOT32) and symbol.

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	70	V
V_{CEO}	collector-emitter voltage	open base	–	45	V
V_{EBO}	emitter-base voltage	open collector	–	6	V
I_C	collector current (DC)		–	3	A
I_{CM}	peak collector current		–	6	A
I_{BM}	peak base current		–	0.5	A
P_{tot}	total power dissipation	$T_{mb} \le 60$ °C	–	15	W
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C



Philips Semiconductors Product specification

NPN power transistor BD131

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	100	K/W
$R_{th\ j\text{-}mb}$	thermal resistance from junction to mounting base		6	K/W

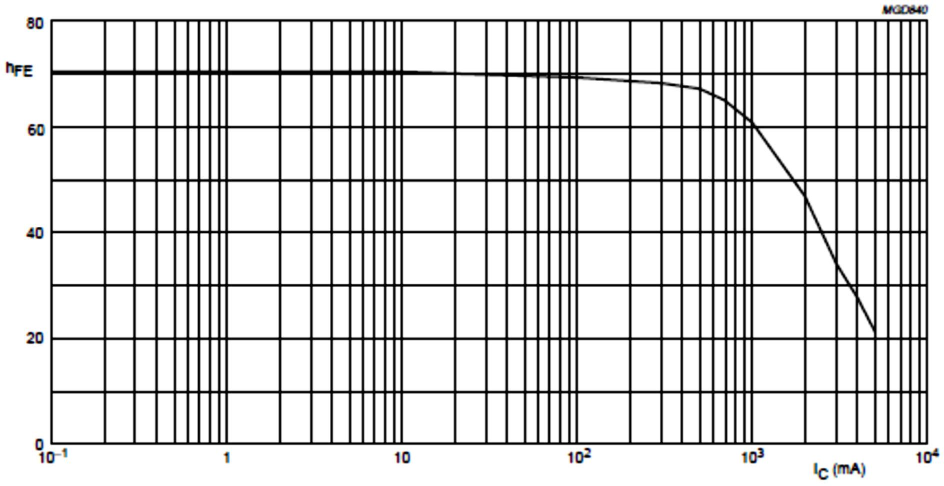
Note

1. Refer to TO-126; SOT32 standard mounting conditions.

CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current	$I_E = 0$; $V_{CB} = 50$ V	–	50	nA
		$I_E = 0$; $V_{CB} = 50$ V; $T_j = 150$ °C	–	10	µA
I_{EBO}	emitter cut-off current	$I_C = 0$; $V_{EB} = 5$ V	–	50	nA
h_{FE}	DC current gain	$I_C = 0.5$ A; $V_{CE} = 12$ V; (see Fig.2)	40	–	
		$I_C = 2$ A; $V_{CE} = 1$ V; (see Fig.2)	20	–	
V_{CEsat}	collector-emitter saturation voltage	$I_C = 0.5$ A; $I_B = 50$ mA	–	300	mV
		$I_C = 2$ A; $I_B = 200$ mA	–	700	mV
V_{BEsat}	base-emitter saturation voltage	$I_C = 0.5$ A; $I_B = 50$ mA	–	1.2	V
		$I_C = 2$ A; $I_B = 200$ mA	–	1.5	V
f_T	transition frequency	$I_C = 0.25$ A; $V_{CE} = 5$ V; f = 100 MHz; $T_{amb} = 25$ °C	60	–	MHz

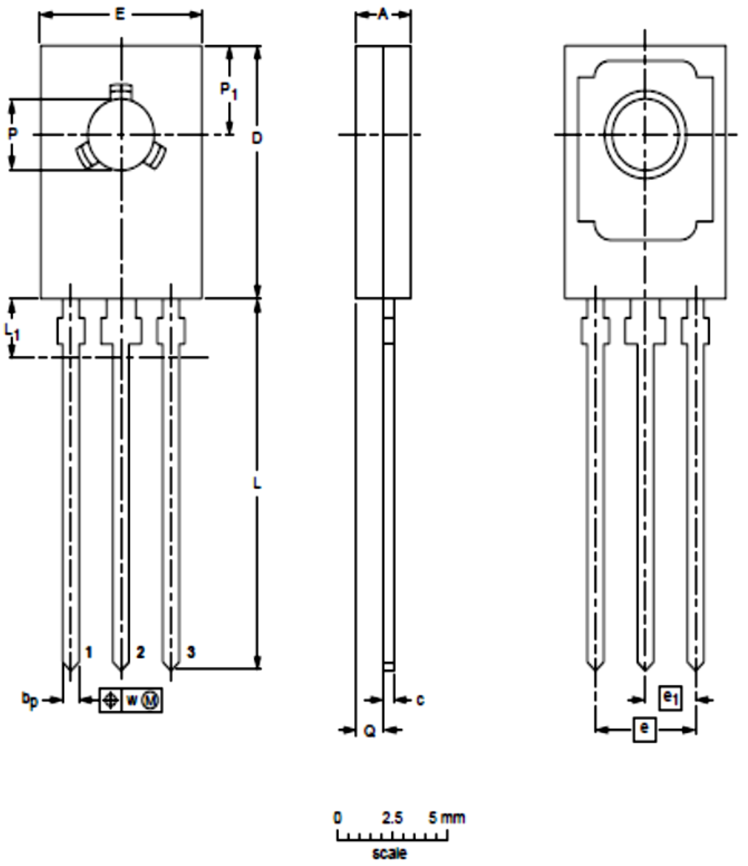


$V_{CE} = 1$ V.

Fig.2 DC current gain; typical values.

PACKAGE OUTLINE

Plastic single-ended leaded (through hole) package; mountable to heatsink, 1 mounting hole; 3 leads SOT32

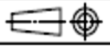


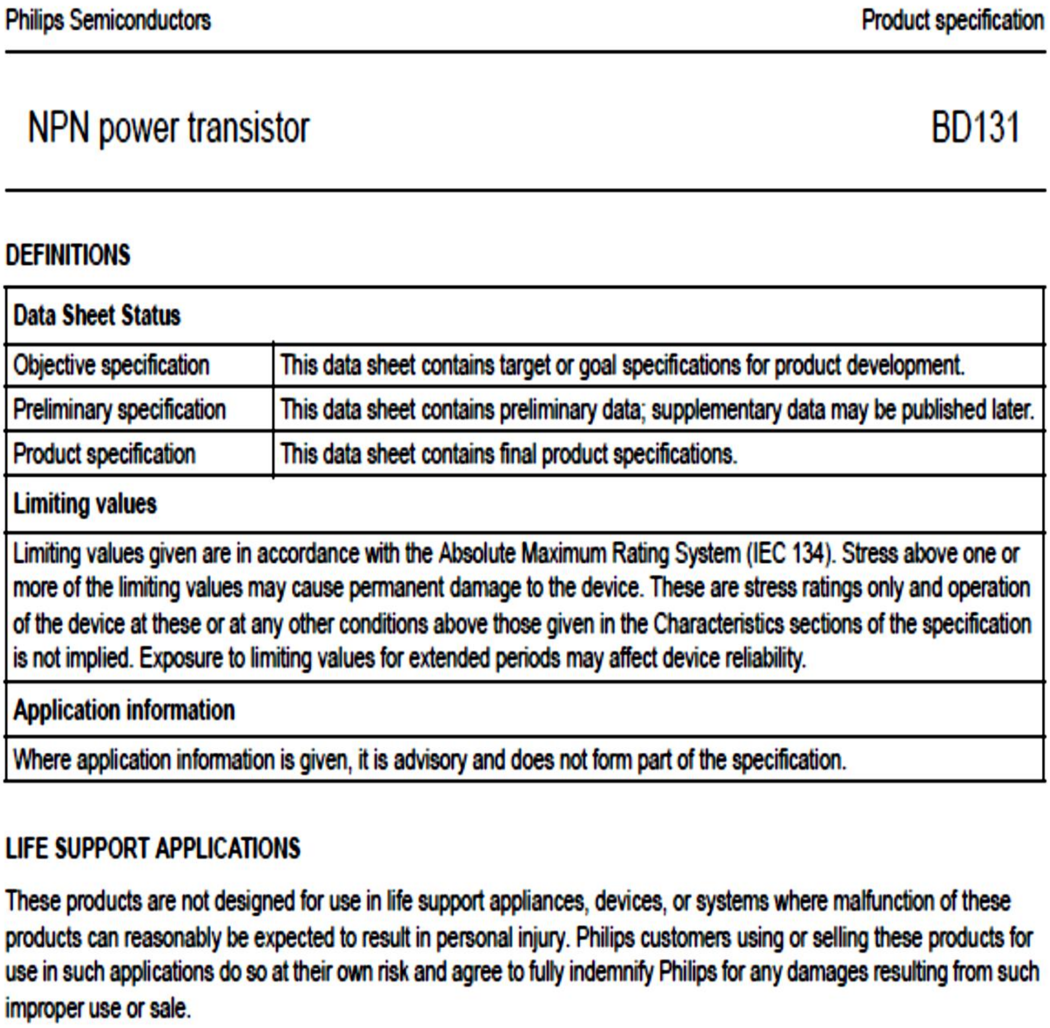
DIMENSIONS (mm are the original dimensions)

UNIT	A	b_p	c	D	E	e	e_1	L	$L_1^{(1)}$ max	Q	P	P_1	w
mm	2.7 2.3	0.88 0.65	0.60 0.45	11.1 10.5	7.8 7.2	4.58	2.29	16.5 15.3	2.54	1.5 0.9	3.2 3.0	3.9 3.6	0.254

Note

1. Terminal dimensions within this zone are uncontrolled to allow for flow of plastic and terminal irregularities.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT32		TO-126				97-03-04



Philips Semiconductors | Product specification

NPN power transistor | BD131

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BU806
BU807

MEDIUM VOLTAGE NPN FAST SWITCHING DARLINGTON TRANSISTORS

- STMicroelectronics PREFERRED SALESTYPES
- NPN DARLINGTONS
- LOW BASE-DRIVE REQUIREMENTS
- INTEGRATED ANTIPARALLEL COLLECTOR-EMITTER DIODE

APPLICATION

- HORIZONTAL DEFLECTION FOR MONOCHROME TVs

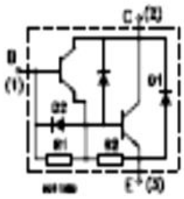
DESCRIPTION

The devices are silicon Epitaxial Planar NPN power transistors in Darlington configuration with integrated base-emitter speed-up diode, mounted in TO-220 plastic package.

They can be used in horizontal output stages of 110 °CRT video displays.

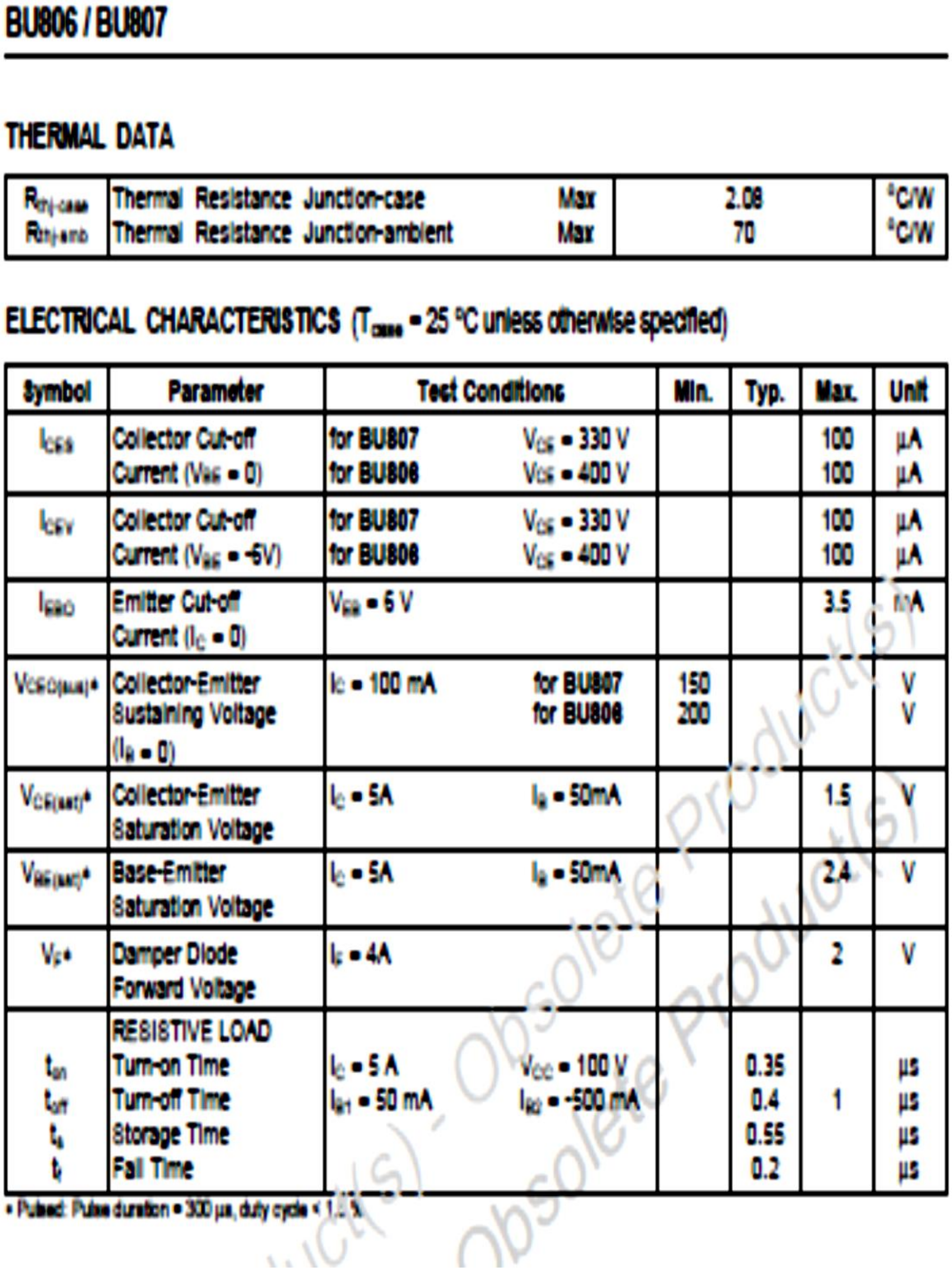
TO-220

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value		Unit
		BU806	BU807	
V_{CBO}	Collector-base Voltage ($I_E = 0$)	400	330	V
V_{CEV}	Collector-emitter Voltage ($V_{BE} = -6V$)	400	330	V
V_{CEO}	Collector-emitter Voltage ($I_B = 0$)	200	150	V
V_{EBO}	Emitter-Base Voltage ($I_C = 0$)	6		V
I_C	Collector Current	8		A
I_{CM}	Collector Peak Current	15		A
I_{DM}	Damper Diode Peak Forward Current	10		A
I_B	Base Current	2		A
P_{tot}	Total Power Dissipation at $T_{case} < 25$ °C	60		W
T_{stg}	Storage Temperature	-65 to 150		°C
T_j	Max Operating Junction Temperature	150		°C



BU806 / BU807

THERMAL DATA

$R_{thj-case}$	Thermal Resistance Junction-case	Max	2.08	°C/W
$R_{thj-amb}$	Thermal Resistance Junction-ambient	Max	70	°C/W

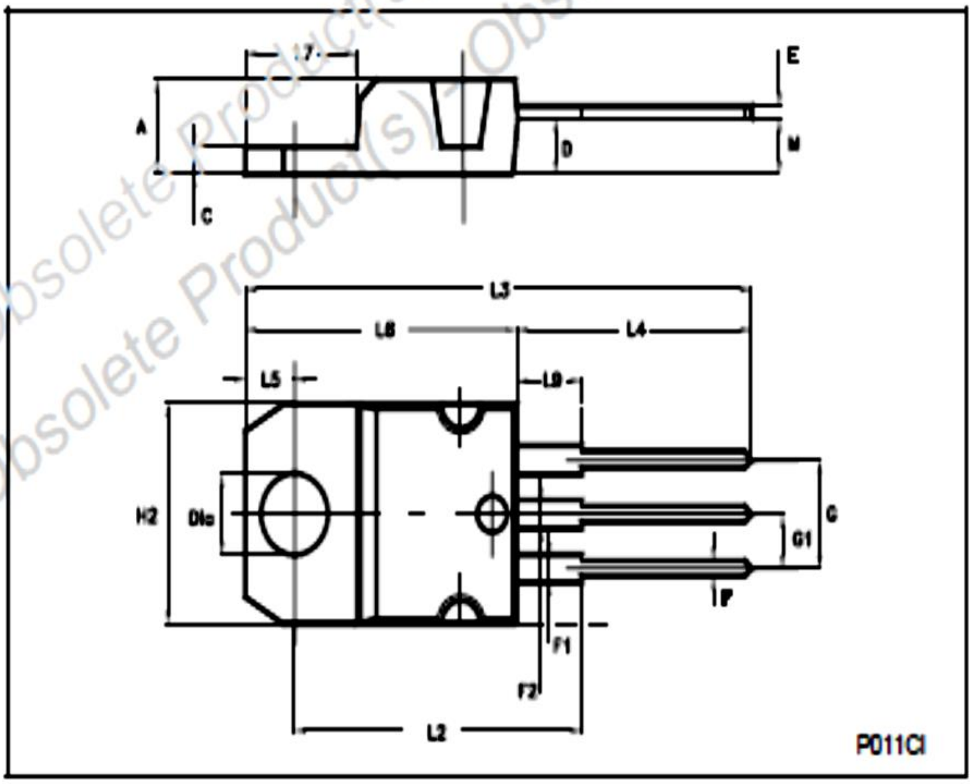
ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CES}	Collector Cut-off Current (V_{BE} = 0)	for BU807 V_{CE} = 330 V for BU806 V_{CE} = 400 V			100 100	µA µA
I_{CEV}	Collector Cut-off Current (V_{BE} = -6V)	for BU807 V_{CE} = 330 V for BU806 V_{CE} = 400 V			100 100	µA µA
I_{EBO}	Emitter Cut-off Current (I_C = 0)	V_{EB} = 6 V			3.5	mA
$V_{CEO(sus)}$*	Collector-Emitter Sustaining Voltage (I_B = 0)	I_C = 100 mA for BU807 for BU806	150 200			V V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 5A I_B = 50mA			1.5	V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 5A I_B = 50mA			2.4	V
V_F*	Damper Diode Forward Voltage	I_F = 4A			2	V
	RESISTIVE LOAD					
t_{on}	Turn-on Time	I_C = 5 A V_{CC} = 100 V		0.35		µs
t_{off}	Turn-off Time	I_{B1} = 50 mA I_{B2} = -500 mA		0.4	1	µs
t_s	Storage Time			0.55		µs
t_f	Fall Time			0.2		µs

* Pulsed: Pulse duration = 300 µs, duty cycle < 1.5 %

TO-220 MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	4.40		4.60	0.173		0.181
C	1.23		1.32	0.048		0.052
D	2.40		2.72	0.094		0.107
E	0.49		0.70	0.019		0.027
F	0.61		0.88	0.024		0.034
F1	1.14		1.70	0.044		0.067
F2	1.14		1.70	0.044		0.067
G	4.95		5.15	0.194		0.202
G1	2.40		2.70	0.094		0.106
H2	10.00		10.40	0.394		0.409
L2		16.40			0.645	
L4	13.00		14.00	0.511		0.551
L5	2.65		2.95	0.104		0.116
L6	15.25		15.75	0.600		0.620
L7	6.20		6.60	0.244		0.260
L9	3.50		3.93	0.137		0.154
M		2.60			0.102	
DIA.	3.75		3.85	0.147		0.151



BU808DFI

HIGH VOLTAGE FAST-SWITCHING NPN POWER DARLINGTON TRANSISTOR

- STMicroelectronics PREFERRED SALESTYPE
- NPN MONOLITHIC DARLINGTON WITH INTEGRATED FREE-WHEELING DIODE
- HIGH VOLTAGE CAPABILITY (> 1400 V)
- HIGH DC CURRENT GAIN (TYP. 150)
- FULLY INSULATED PACKAGE (U.L. COMPLIANT) FOR EASY MOUNTING
- LOW BASE-DRIVE REQUIREMENTS
- DEDICATED APPLICATION NOTE AN1184

ISOWATT218

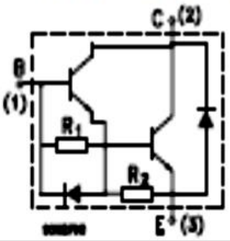
APPLICATIONS

- COST EFFECTIVE SOLUTION FOR HORIZONTAL DEFLECTION IN LOW END TV UP TO 21 INCHES.

DESCRIPTION

The BU808DFI is a NPN transistor in monolithic Darlington configuration. It is manufactured using Multiepitaxial Mesa technology for cost-effective high performance.

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CBO}	Collector-Base Voltage (I_E = 0)	1400	V
V_{CEO}	Collector-Emitter Voltage (I_B = 0)	700	V
V_{EBO}	Emitter-Base Voltage (I_C = 0)	5	V
I_C	Collector Current	8	A
I_{CM}	Collector Peak Current (t_p < 5 ms)	10	A
I_B	Base Current	3	A
I_{BM}	Base Peak Current (t_p < 5 ms)	6	A
P_{tot}	Total Dissipation at T_c = 25 °C	52	W
V_{isol}	Insulation Withstand Voltage (RMS) from All Three Leads to Exernal Heatsink	2500	V
T_{stg}	Storage Temperature	-65 to 150	°C
T_j	Max. Operating Junction Temperature	150	°C

THERMAL DATA

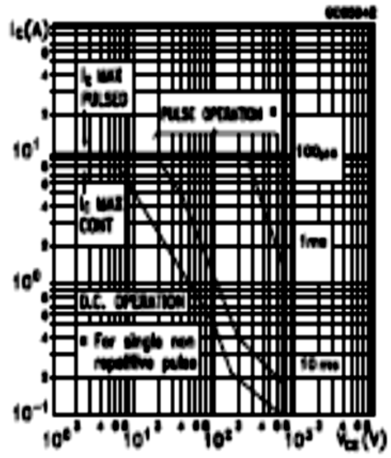
$R_{thj-case}$	Thermal Resistance Junction-case	Max	2.4	°C/W

ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

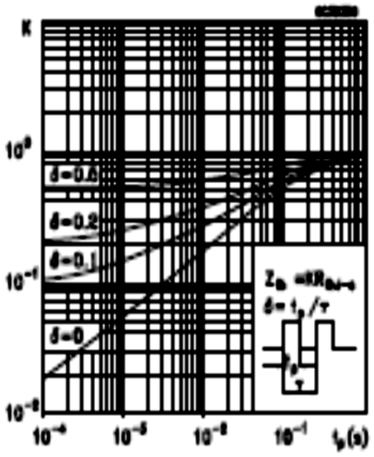
Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CES}	Collector Cut-off Current (V_{BE} = 0)	V_{CE} = 1400 V			400	µA
I_{EBO}	Emitter Cut-off Current (I_C = 0)	V_{EB} = 5 V			100	mA
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 5 A I_B = 0.5 A			1.6	V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 5 A I_B = 0.5 A			2.1	V
h_{FE}*	DC Current Gain	I_C = 5 A V_{CE} = 5 V I_C = 5 A V_{CE} = 5 V T_j = 100 °C	60 20		230	
 t_s t_f	INDUCTIVE LOAD Storage Time Fall Time	V_{CC} = 150 V I_C = 5 A I_{B1} = 0.5 A $V_{BE(off)}$ = -5 V			 3 0.8	 µs µs
 t_s t_f	INDUCTIVE LOAD Storage Time Fall Time	V_{CC} = 150 V I_C = 5 A I_{B1} = 0.5 A $V_{BE(off)}$ = -5 V T_j = 100 °C		 2 0.8		 µs µs
V_F	Diode Forward Voltage	I_F = 5 A			3	V

* Pulsed: Pulse duration = 300 µs, duty cycle 1.5 %

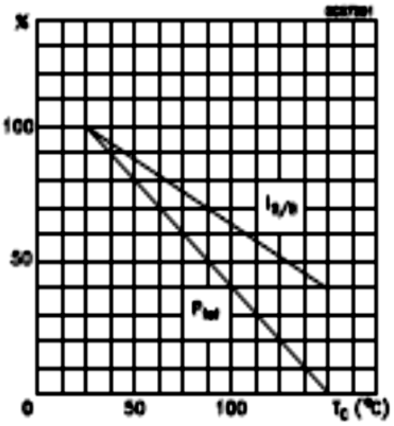
Safe Operating Area



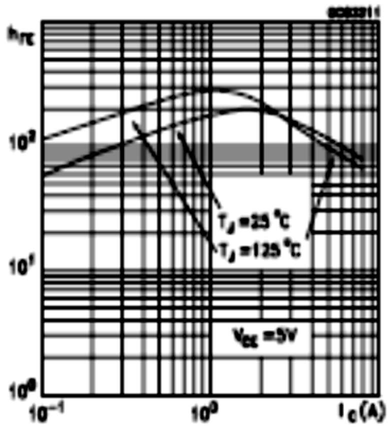
Thermal Impedance



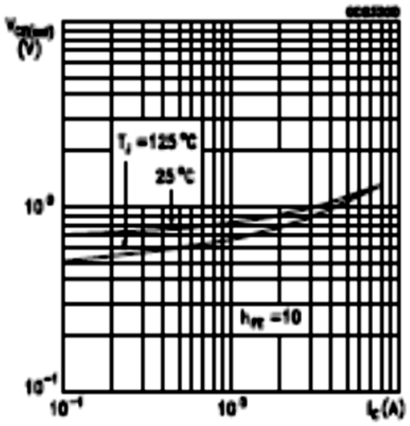
Derating Curve



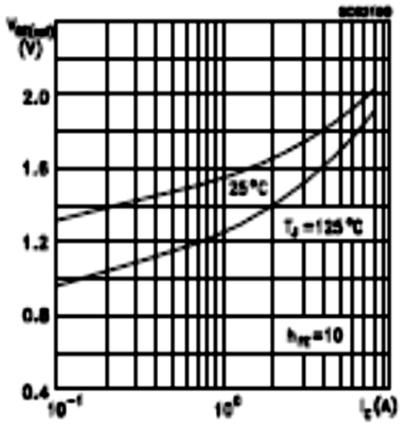
DC Current Gain



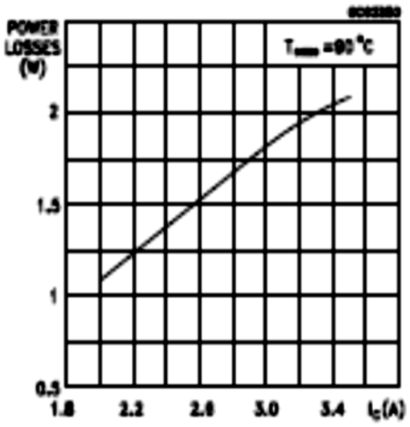
Collector Emitter Saturation Voltage



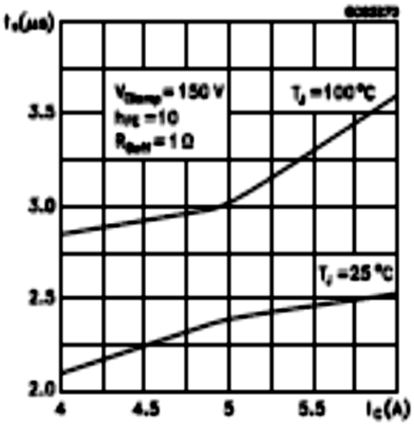
Base Emitter Saturation Voltage



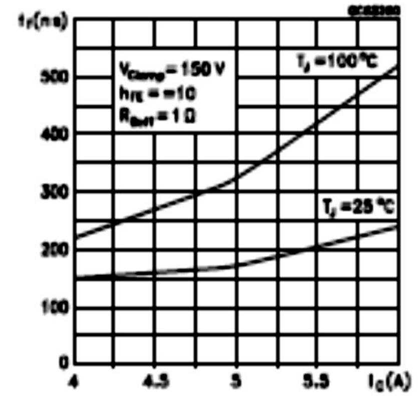
Power Losses at 16 KHz



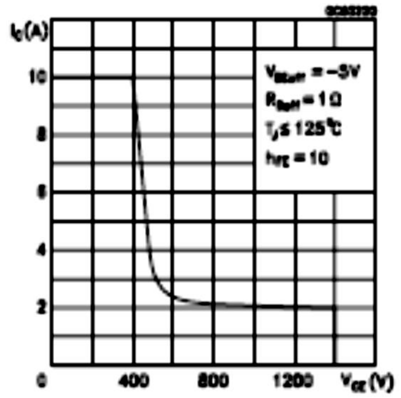
Switching Time Inductive Load at 16KHz



Switching Time Inductive Load at 16KHZ



Reverse Biased SOA



BASE DRIVE INFORMATION

In order to saturate the power switch and reduce conduction losses, adequate direct base current I_{B1} has to be provided for the lowest gain h_{FE} at 100 °C (line scan phase). On the other hand, negative base current I_{B2} must be provided to turn off the power transistor (retrace phase).

Most of the dissipation, in the deflection application, occurs at switch-off. Therefore it is essential to determine the value of I_{B2} which minimizes power losses, fall time t_f and, consequently, T_j. A new set of curves have been defined to give total power losses, t_s and t_f as a function of I_{B2} at both 16 KHz scanning frequencies for choosing the optimum negative drive. The test circuit is illustrated in figure 1.

Inductance L_1 serves to control the slope of the negative base current I_{B2} to recombine the excess carrier in the collector when base current is still present, this would avoid any tailing phenomenon in the collector current.

The values of L and C are calculated from the following equations:

$$\frac{1}{2} L\,(I_C)^2 = \frac{1}{2} C\,(V_{CEfly})^2 \qquad \omega = 2\pi f = \frac{1}{\sqrt{L\,C}}$$

Where I_C = operating collector current, V_{CEfly} = flyback voltage, f = frequency of oscillation during retrace.

Figure 1: Inductive Load Switching Test Circuits.

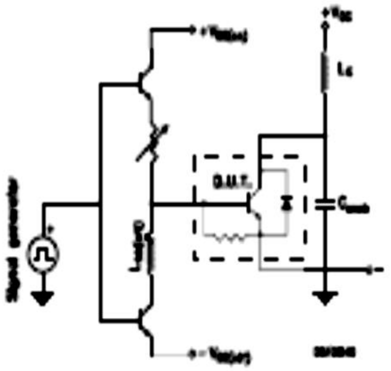
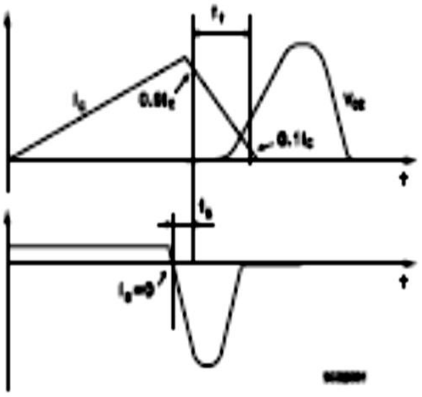
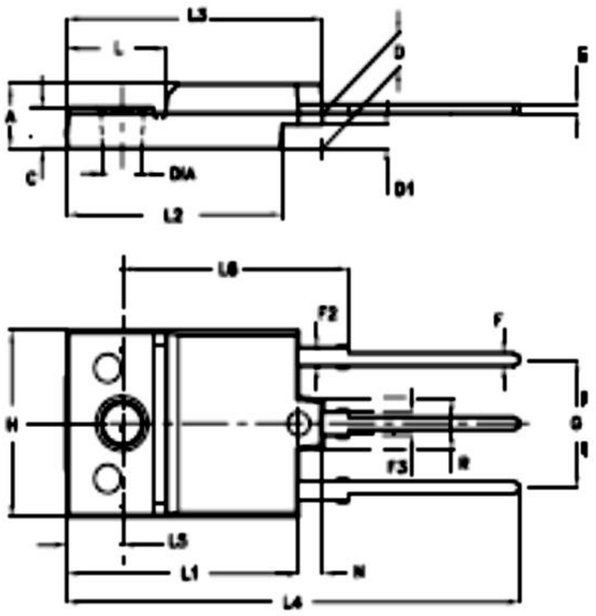


Figure 2: Switching Waveforms in a Deflection Circuit



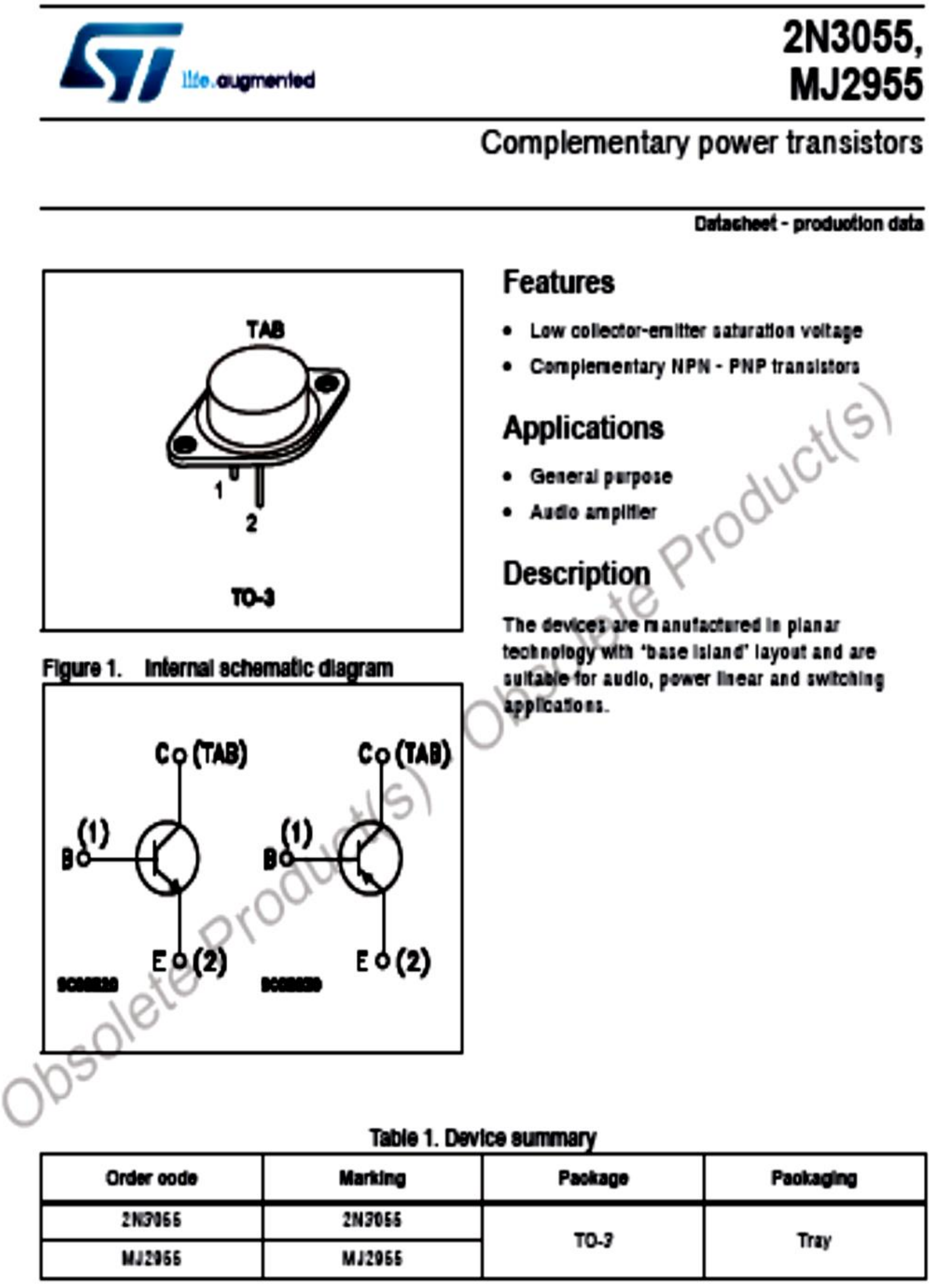
ISOWATT218 MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	5.35		5.65	0.211		0.222
C	3.30		3.80	0.130		0.150
D	2.90		3.10	0.114		0.122
D1	1.88		2.08	0.074		0.082
E	0.75		0.95	0.030		0.037
F	1.05		1.25	0.041		0.049
F2	1.50		1.70	0.059		0.067
F3	1.90		2.10	0.075		0.083
G	10.80		11.20	0.425		0.441
H	15.80		16.20	0.622		0.638
L		9			0.354	
L1	20.80		21.20	0.819		0.835
L2	19.10		19.90	0.752		0.783
L3	22.80		23.60	0.898		0.929
L4	40.50		42.50	1.594		1.673
L5	4.85		5.25	0.191		0.207
L6	20.25		20.75	0.797		0.817
N	2.1		2.3	0.083		0.091
R		4.6			0.181	
DIA	3.5		3.7	0.138		0.146



- Weight : 4.9 g (typ.)
- Maximum Torque (applied to mounting flange) Recommended: 0.8 Nm; Maximum: 1 Nm
- The side of the dissipator must be flat within 80 µm

P025C/A



2N3055, MJ2955

Complementary power transistors

Datasheet - production data

Features

- Low collector-emitter saturation voltage
- Complementary NPN - PNP transistors

Applications

- General purpose
- Audio amplifier

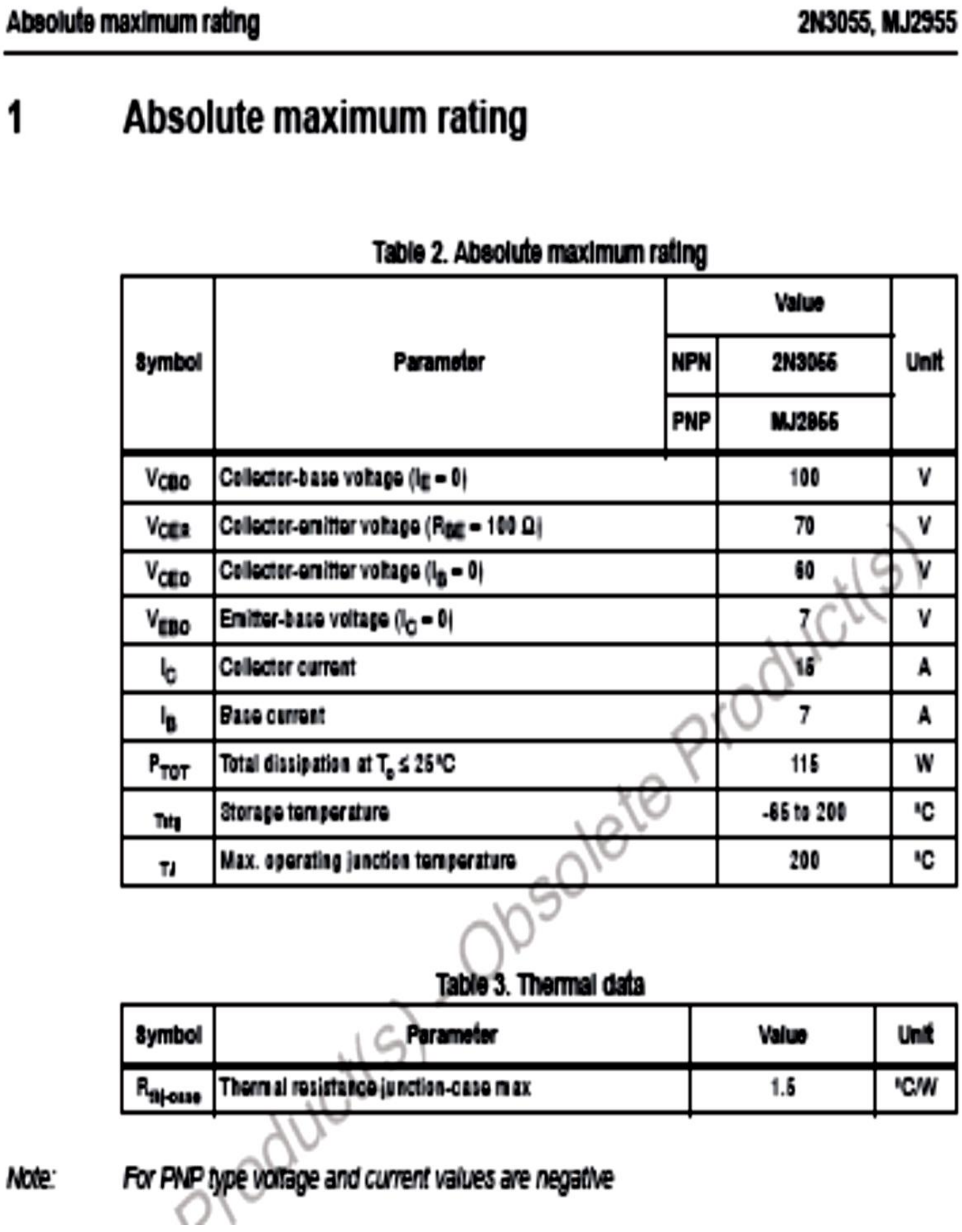
Description

The devices are manufactured in planar technology with 'base island' layout and are suitable for audio, power linear and switching applications.

Figure 1. Internal schematic diagram

Table 1. Device summary

Order code	Marking	Package	Packaging
2N3055	2N3055	TO-3	Tray
MJ2955	MJ2955		



1 Absolute maximum rating

Table 2. Absolute maximum rating

Symbol	Parameter	Value		Unit
		NPN	2N3055	
		PNP	MJ2955	
V_{CBO}	Collector-base voltage ($I_E = 0$)		100	V
V_{CER}	Collector-emitter voltage ($R_{BE} = 100\ \Omega$)		70	V
V_{CEO}	Collector-emitter voltage ($I_B = 0$)		60	V
V_{EBO}	Emitter-base voltage ($I_C = 0$)		7	V
I_C	Collector current		15	A
I_B	Base current		7	A
P_{TOT}	Total dissipation at $T_c \leq 25$ °C		115	W
T_{stg}	Storage temperature		-65 to 200	°C
T_J	Max. operating junction temperature		200	°C

Table 3. Thermal data

Symbol	Parameter	Value	Unit
$R_{thj-case}$	Thermal resistance junction-case max	1.5	°C/W

Note: *For PNP type voltage and current values are negative*

2 Electrical characteristics

(T_{case} = 25°C; unless otherwise specified)

Table 4. Electrical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
I_{CEX}	Collector cut-off current (V_{BE} = -1.5 V)	V_{CE} = 100 V V_{CE} = 100 V T_C = 150 °C			1 5	mA mA
I_{CEO}	Collector cut-off current (I_B = 0)	V_{CE} = 30 V			0.7	mA
I_{EBO}	Emitter cut-off current (I_C = 0)	V_{EB} = 7 V			5	mA
$V_{CEO(sus)}$[1]	Collector-emitter sustaining voltage (I_B = 0)	I_C = 200 mA	60			V
$V_{CER(sus)}$[1]	Collector-emitter sustaining voltage (R_{BE} = 100 Ω)	I_C = 200 mA	70			V
$V_{CE(sat)}$[1]	Collector-emitter saturation voltage	I_C = 4 A I_B = 400 mA I_C = 10 A I_B = 3.3 A			1 3	V V
V_{BE}[1]	Base-emitter voltage	I_C = 4 A V_{CE} = 4 V			1.8	V
h_{FE}[1]	DC current gain	I_C = 4 A V_{CE} = 4 V I_C = 10 A V_{CE} = 4 V	20 5		70	

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

Note: *For PNP type voltage and current values are negative*

2.1 Electrical characteristics (curve)

Figure 2. Safe operating area

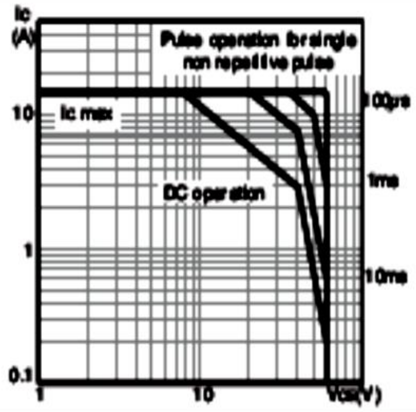
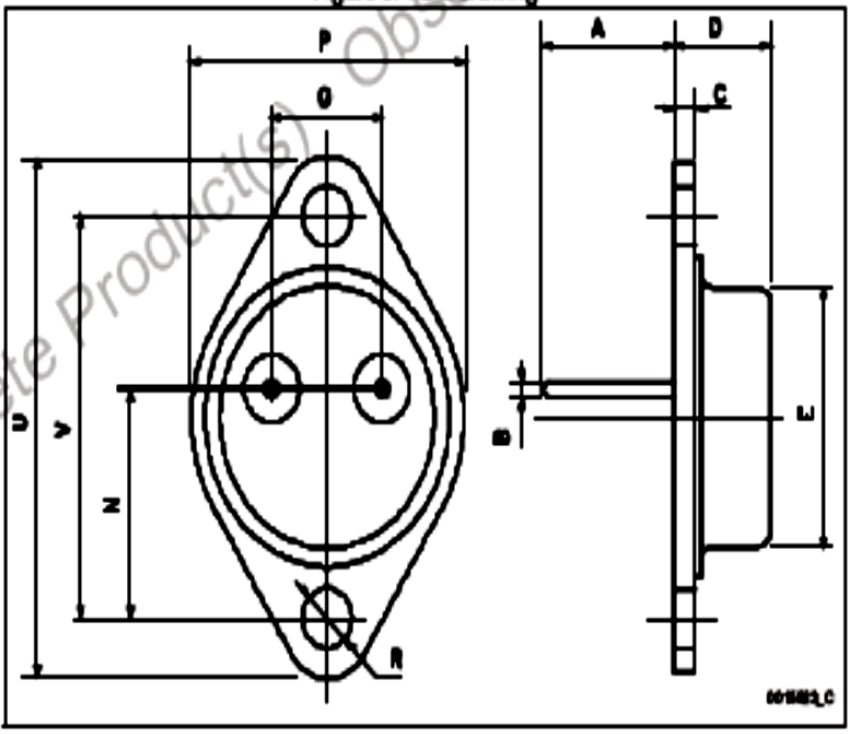
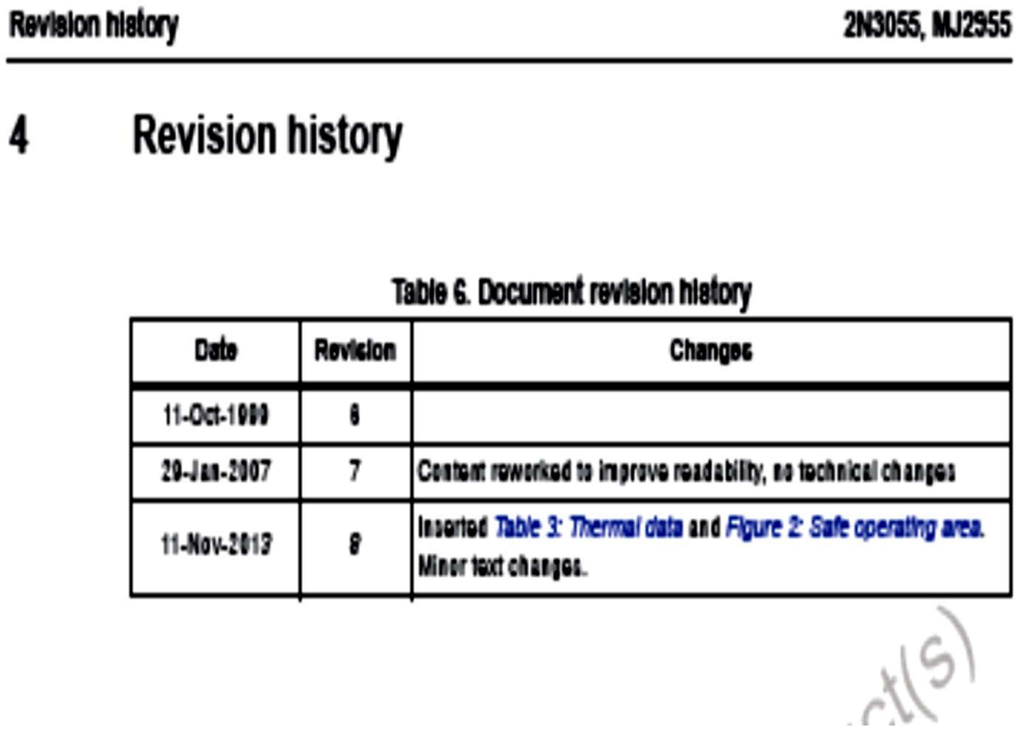


Table 5. TO-3 mechanical data

Dim.	mm		
	Min.	Typ.	Max.
A	11.00		13.10
B	0.97		1.15
C	1.50		1.65
D	8.32		8.92
E	19.00		20.00
G	10.70		11.10
N	16.50		17.20
P	25.00		26.00
R	4.00		4.09
U	38.50		39.30
V	30.00		30.30

Figure 3. TO-3 drawing





4 Revision history

Table 6. Document revision history

Date	Revision	Changes
11-Oct-1999	6	
29-Jan-2007	7	Content reworked to improve readability, no technical changes
11-Nov-2013	8	Inserted *Table 3: Thermal data* and *Figure 2: Safe operating area*. Minor text changes.