“DESIGN & DEVELOPMENT OF LOW COST MEDIUM FREQUENCY INVERTER FOR INDUCTION HEATING”

A Major Project Report

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IN
ELECTRICAL ENGINEERING

(POWER APPARATUS & SYSTEMS)

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CERTIFICATE

This is to certify that the Major Project Report (Part-II) entitled “DESIGN & DEVELOPMENT OF LOW MEDIUM FREQUENCY INVERTER FOR INDUCTION HEATING” submitted by Mr. TALSANIYA TUSHARKUMAR HARIBHAI, towards the partial fulfillment of the requirements for the award of degree of Master of Technology (Electrical Engineering) in the field of Power Apparatus & Systems of **Nirma University of Science and Technology** is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date: APRIL 2006

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ABSTRACT

Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. It is also very efficient since the heat is actually generated inside the work piece. This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the work piece. For these reasons induction heating lends itself to some unique application in industry. Another desirable characteristics of induction heating is its ability to heat only a small portion of work piece.

For induction heating, high frequency is used. For this we require an inverter with switching devices which working on high frequency. MOSFET, IGBT, SCR etc. are used as a switching device in the inverter. Also control circuit is required to drive these switching devices. The cost of these switching devices is high. So overall cost of the inverter is increased. Also due to control circuit, overall circuit of inverter becomes very complex.

The main aim of the project is to design a low cost medium frequency inverter for induction heating. Transistors are used as switching device in inverter. As transistors are cheaper than other switching devices, cost of the inverter is reduced. This is a self-oscillating inverter, so no control circuit is required to drive the transistor. Also due to absence of control circuit, complexity, size and cost of inverter is reduced.

LIST OF FIGURE

LIST OF TABLE

Nomenclature

f = Frequency of oscillation**,** Hz**.**

δ = Depth of penetration, mm

ρ= Resistively of material, ohms/meter,

μ_0= absolute permeability,

μr= relative permeability

E = remissibility of the work piece surface

σ =Steppe boatman constant

T1, T2 = work piece and ambient temperature in °K respectively

A = surface area of the work piece.

L= inductance of heating coil, Henry

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Chapter 1: Induction heating & its applications

Chapter 3: Introduction of self-oscillating inverter

Chapter 4: DESIGN & DEVELOPMENT OF LOW COST MIDIUM FREQUENCY INVERTER FOR INDUCTION HEATING

Chapter 5: Selection and design of components

1.1. PRINCIPLE OF INDUCTION HEATING

All induction heating (IH) applied systems is developing using electromagnetic induction, which was first discovered by Michael faraday in 1831. Electromagnetic induction refers to the phenomenon by which,

"ELECTRIC CURRENT IS GENERATED IN A CLOSED CIRCUIT BY THE FLUCTUATION OF CURRENT IN ANOTHER CIRCUIT PLACED NEXT TO IT."

The basic principle of induction heating, which is an applied form of faraday's discovery, is the fact that ac current flowing through a circuit affects the magnetic movement of a secondary circuit located near it. The fluctuation of current inside the primary circuit provided the answer as to how the mysterious current is generated in the neighboring secondary circuit. Faraday's discovery led to the development of electric motors, generators, transformers and wireless communications devices. Its application, however, has not been flawless. Heat loss, which occurs during the induction heating process, was a major headache undermining the overall functionality of a system. Researchers sought of minimize heat loss by laminating the magnetic frames placed inside the motor or transformer. Faraday's low was followed by a series of more advanced discoveries such as Len's low. This law explains the fact that inductive current flows inverse to the direction of changes in induction magnetic movement.

Heat loss occurring in the process of electromagnetic induction could be turned into productive heat energy in an electric heating system by applying this law. Man industries have benefited from this new breakthrough by implementing induction heating for furnishing, quenching and welding.

Positioning a metal body in an alternating magnetic field generates eddy current causing losses, which results in the metal body being heated up. These currents are concentrated in the surface layers because of the “skin effect”. The necessary magnetic field is generated by alternating current flowing through the inductor, which should be matched perfectly to the work piece. Changing the alternating current frequency can influence the heating penetration depth.

Other influencing factors however include power concentration treating duration and work piece material properties such as thermal conductivity. Medium frequency is mostly used for melting, forging, heat treatment and annealing, whereas high or medium frequency is used for hardening and soldering depending on the respective processing requirements. The induction heating process is a non-contact technique, which provides localized heating through custom-designed coils. Because the heat is transferred to the product via electromagnetic waves, there is no product contamination. This process allows the right amount of heat to be applied exactly where it is needed for an exact period of time, ensuring controlled and accurate performance that cab be easily controlled and accurate performance that can be easily repeated.

1.2 CHARACTERISTICS OF INDUCTION HEATING:

1. **Rapid heating**: Since heat is generated within the work piece, there is no heat transfer time as with radiation and convection process.
2. **Accurate temperature control:** The same amount of energy is induced into each part or a given number of parts, providing identical temperature and heat patterns in all parts.
3. **Rapid startup:** As soon as the equipment is started the power is induced within the work piece. There are no warm up or heat wants with other heating methods.
4. **Reduced scaling of the part**: With rapid heating, the work piece is exposed to air for a very short time while at elevated temperatures. This reduced scale formation to less than 0.5% in most cases.

5. **Reduced floor space:** Induction heating equipment is generally unitized construction where installation time and floors space requirements are minimized. Induction systems are ideal for cellular manufacturing operations.
6. **Quality control:** Parts processed individually have the ability to be monitored and recorded for vital data such as; induced energy amounts, cycle time and temperatures. Parts can be marked to achieve individual history retrieval.
7. **Cool, clean working environment:** since heat is created within the work piece rapidly, minimal heat is produced in the operator environment.
8. **Automation:** induction system lend themselves to integration with automatic load and unload mechanisms.

1.3 DEPTH OF PENETRATION

Depth of penetration is given by, $\delta = \sqrt{(\rho/\pi*\mu_0*\mu_r*f)}$

The depth of current penetration depends upon work piece permeability, resistively and the alternating current frequency. Since the first two factors vary comparatively little the greatest variable is frequency. Depth of current penetration decreases as frequency increases. High frequency current is generally used when shallow heating is desired; intermediate and low frequencies are used in application requiring deeper heating.

Most induction surface-hardening application requires comparatively high power densities and short heating cycles in order to restrict hating to the surface area. The principal metallurgical advantages that may be obtained by surface hardening with induction include increased wear resistance and improved fatigue strength.

1.4 POWER REQUIRED DEPENDS UPON FOLLOWING FACTOR.

(a) Power density

(b) Size of section to be heated: in surface hardening, the area heated at one time, multiplied by power density, indicates the total power input (kw). This area is obtained by multiplying the perimeter of the port by length of the inductor.

(c) To calculate the power required for through heating, divide the desired production load by the values for pounds per kilowatt-hour.

(d) Method of heating: when the static method of heating is used, the entire area to be hardened must be heated at one time. When the part is scanned, or progressively hardened, it is necessary to heat only a small segment or band at one time. Thus a smaller converter can be used if parts are progressively hardened.

(e) Production requirements: power density may be adjusted within limits to meet certain production requirements. Beyond this, one or more of the following modification may increase production rate.

- Fix Turing may be improved to reduce handling time
- Work may be quenched outside the inductor to permit immediate reloading
- Two or more inductors may be used if sufficient power is available.

  For hardening by the scanning method, it may be possible to increase the inductor length or to use more than one inductor, depending on available power.

If the production rate, as based on the size of converter, does not meet production requirements, two or more units a of like capacity may be used to harden two, three or four pieces simultaneously in a multiple coil.

1.5 SELECTION OF FREQUENCY

Material	TEM	DIAMETER RANGE (mm)			
	DEG	25Khz	10khz	3khz	1khz
STEEL	1250	7-25	15-50	20-70	30-85
BRASS	750	6-12	10-15	10-20	15-40
COPPER	850	2-4	4-10	4-15	10-20

Table 1

1.6 DETERMINATION OF POWER REQUIREMENT

Ac frequency through its effect on reference depth & efficiency is one of the important design factors in the induction heating. The amount of power that is needed for a given application is also an important consideration. If the work piece is regularly shaped and is to be through heated or melted. The calculation is straightforward. However if it is to be only selectively heated so that the remainder of work piece is a heat sink for the generated heat, calculation of the power needed may be difficult.

For through heating application, the power density should be kept relatively low to allow conduction from the outer layer (which are heated more rapidly by high current densities) to the inner layers. There will always be a temperature gradient but this can be minimized by careful selection of induction heating parameter. Neglecting the temperature gradient the absorbed power depends on the required temperature rise ΔT, the total weight to be heated per unit time w and the specific heat of material c. the power p1 to be supplied to the load is then given by $p1=w*c*\Delta T$. To determine the total input power needed from the power source, which supplied ac current to the induction coil, power lost from the work piece due to radiation & convection and the loss in the coil itself due to joule heating must be added to p1. Heat loss by convection is usually small and is neglected in calculation of power requirements for typical rapid heating application.

Radiation losses are calculated by means of expression $p2= A*e*\sigma*(T2^4-T1^4)$

The radiation power loss can vary greatly during the heating cycle because of surface condition changes dependent on material and temperature. Typical emissivity is 0.1 & 0.2 for aluminum at 200 to 595°c and 0.8 for oxidized steel.

The power lost in the induction coil, $p3=ic^2 *Rc$, depends on frequency, coil design and size of air gap between inductor & work coil. At low frequency Rc is about equal to the dc resistance value and p3 is calculated directly from knowledge of coil current. At high frequency a skin depth is also established in the inductor and must be taken account when estimation p3.

Which above definition total output power required is equal to p1+p2+p3.

Overall efficiency = p1/(p1+p2+p3)

1.7 DIFFERENT TYPES OF INDUCTION HEATING

(a) SURFACE HEATING

The depth of penetration during heating depends upon the choice of frequency, resistivity of material to be heated and relative permeability of material. The penetration depth is inversely proportional to the square root of frequency. In Other words, for application requiring deep case depth hardening low frequency is used.

For surface heating or shallow case depth heating, a high frequency is needed. Depth of heating is also influenced by such variables as the magnetic permeability and conductivity of a part. For the same applied frequency, different metals have different penetration depths. For example, at 1khz, penetration depth in stainless steel is about 6 times deeper than in copper. The induced current flow within the part is most intense on the surface and decays rapidly below the surface. So outside is heated more rapidly than the inside. Nearly 80% of heat produced in the part is in the outer surface or skin. So some times it is known as “skin depth” of the part.

(b) UNIFORM HEATING

Different types of parts require different heating modes. For example, gear, camshafts and axle shafts are typically using a single shot process (where the part is rotated in an inductor for uniform heating followed by the appropriate quenching process). Longer parts such as shafts, ball screws, rolls and bar stock are treated progressively or scanned where a minimal area is heated to achieve proper temperature then either the part or inductor moves over the desired heat treat length.

1.8 APPLICATION OF INDUCTION HEATING

(a) INDUCTION HARDENING & TEMPERING

Electromagnetic induction is one method of generating heat within a part for hardening or tempering a steel or cast iron part. Any electrical conductor can be heated by electro-magnetic induction. As alternating current from the converter flows through the inductor, or work coil, a highly concentrated, rapidly alternating magnetic field is established within the coil. The strength of this field depends primarily on the magnitude of the current flowing in the coil. The magnetic field thus established induces an electric potential in the part to be heated and because the part represents a closed circuit the induced voltage causes the flow of current. The resistance of the part to the flow of the induced current causes heating.

The pattern of heating obtained by induction is determined by the

(a) Shape of the induction coil producing the magnetic field
(b) Number of turns in the coil
(c) Operating frequency
(d) Alternating current power input
(e) Nature of he work piece.

The rate of heating obtained with induction coils depends on the strength of the magnetic field to which the part is exposed. In the work piece, this becomes a function of the induced current and of the resistance to their flow.

(b) THROUGH HARDENING & TEMPERING

Through hardening by induction hating requires low power densities and low frequencies particularly when applied to heavy wall tubing or solid bars. Progressive induction heating and quenching are common in processing long section. Low frequencies provide maximum depth of heating on large cross sections. Dual frequencies may be used to decrease the heating time when power requirements exceed 2000kw. In dual frequency heating, the higher frequency power source may be operated at from 1 to

10 kHz, and the low frequency source at 60 to 180hz. The inductor coil must be proportioned to apply heat at a rate that does not exceed that at which it can be conducted inwardly. Tempering of induction-hardened surfaces may be done in conventional furnace equipment or in an induction coil at lower power densities.

(c) CAP SEALING

Induction sealing of containers helps to preserves food, drugs, and many other perishable items. A conducting seal is placed in the top of a container with the standard cap. The apparatus is then exposed to an electromagnetic field, which induces a current in the seal. The current causes the seal to heat up and melt into shape of container. This process results in airtight seal without unnecessarily heating he container or the product inside.

(d) BONDING

The bonding of various materials to metal is easily accomplished with induction heating. To form the bond, the metal is rapidly heated and compress tightly against the surface of the other material. Provided the metal is a good electrical conductor, a uniform, highly durable bond can be produced in a matter of only a few seconds. Induction heating can also be used in de-bonding.

(e) CRYSTAL GROWING

Highly pure crystals and films can be grown with induction heating due to its capacity to direct high temperature to a particular area. Level produces induction power supplied specifically for crystal growing that allows the operator to precisely control the temperature, pressure and field frequency inside the crystal-growing chamber. By adjusting the frequency, the need to stir the crystals is eliminated, resulting in optimum purity. These crystals are often used in semiconductor and photovoltaic industries

(f) FIBER OPTICS

Induction heating is widely used in the heating of optical fibers. It works better tan other methods because it provided sufficiently high temperatures without requiring a protective furnace which cab damage the fibers. Induction heated fibers are stronger and of better optical quality than those heated in radiant furnaces.

(g) RESEARCH AND TESTING

Induction equipment generally leads to more accurate laboratory results because it can be used to create very high temperatures at various frequencies without producing significant changes to the surrounding environment. In experiments where a controlled environments vital, such as those involving chemical reactions, use f radiant heat ca result in false data due to the heating of the air and introduction of various impurities. Induction heating is also used in the laboratory to provide lighting, reducing error even further.

(h) EPOXY COATING

Epoxy coating is used to prevent the material against the corrosion. For epoxy coating the job must be heated to appropriate temperature. This could be done by using a induction heating. When the job is heated up to some temperature, epoxy is spared on it and so it is coated. Induction heating gives uniform coating on the job. This method is widely used in industry.

1.9 FIGURE SHOWS THE EXAMPLE OF INDUCTION HEATING

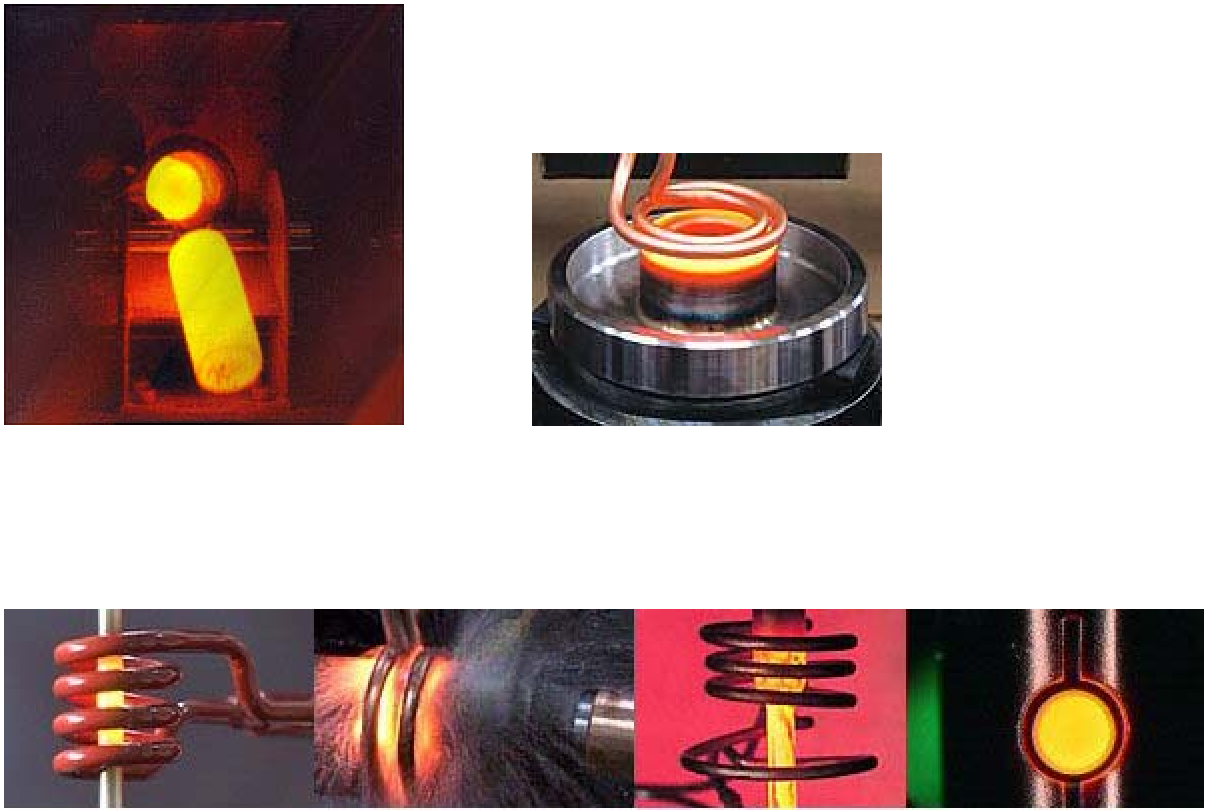


FIG.3 INDUCTION HEATING

CHAPTER 2

LITERATURE REVIEW

There are about 14 basic topologies commonly used to implement a switching power supply. Each topology has unique properties which make it best suited for certain application. Some are best used for AC/DC off line converters at low output power, some at high output power. Some have advantages for higher DC output voltages or in applications where there are more than four or five different outputs is require.

Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. Different types of inverter circuits are used for induction heating like full bridge inverter, half bridge inverter. In this inverter circuits SCR, IGBT, MOSFET etc. are used as switching devices. Also to drive this switching devices control circuits are required. So inverter circuit becomes very complex. The cost of switching devices is high and so cost of inverter is increased.

The main aim of the project is to design a low cost medium frequency inverter for induction heating. Transistor is used as switching device in inverter. As transistor is cheaper than other switching devices, cost of the inverter is reduced. This is a self-oscillating inverter, so no control circuit is required to drive the transistor. Also due to absence of control circuit complexity, size and cost of inverter is reduced.

CHAPTER 3 INTRODUCTION OF SELF-OSCILLATING INVERTER

Self-oscillating inverter is the kind of inverter, which does not require any control circuit to turn on or off the switching devices. There are two well-known families of self-oscillating dc-to-square-wave transistor inverters used in industry. One inverter family employs a saturable magnetic core as the frequency-determining element; the other employs a series LC tuned network as the frequency-determining element.

FAMILY OF SELF-OSCILLATING INVERER

One family of inverter consists of a square-loop-core reactor as the frequency-determining element, and another family employs a series LC-tuned network as the frequency-determining element.

3.1 A Family of saturable Core Inverters

A survey of self-oscillating dc-to-square-wave inverters shows that a large number employs a saturable magnetic device with a square-loop-core material as the principal frequency-determining element. Fig.3.1 (a)-(d) shows four inverters, which are representative of such circuits. Using piecewise-linear models for the transistors, diodes, and storable-core devices, analysis shows that, by proper choice of a frame of reference, each of the four quite differently appearing inverter circuits can be described by the same three-element equivalent circuit shown in Fig.3.1. Thus the four can be considered as members of the same family. The reference-frame voltage is normally chosen to coincide with an appropriate voltage across one of the windings of the saturable transformer or reactor. The locations identified by the voltages in Fig.3.1 (a)-(d) serve as convenient choices for the reference-frame voltages for the four inverters shown. Having chosen the frame of reference, the entire inverter can be simplified either analytically or graphically and reduced to a two-terminal nonlinear resistor in parallel with a nonlinear reactor representing the characteristic of the square-loop magnetic core and a linear capacitor representing the lumped effect of various parasitic capacitance of the circuit such as transformer winding capacitance and semiconductor junction capacitance.

The nonlinear resistor, in essence, is the Therein equivalent circuit looking into the two terminals of the selected reference point assuming that the storable transformer is an ideal transformer.

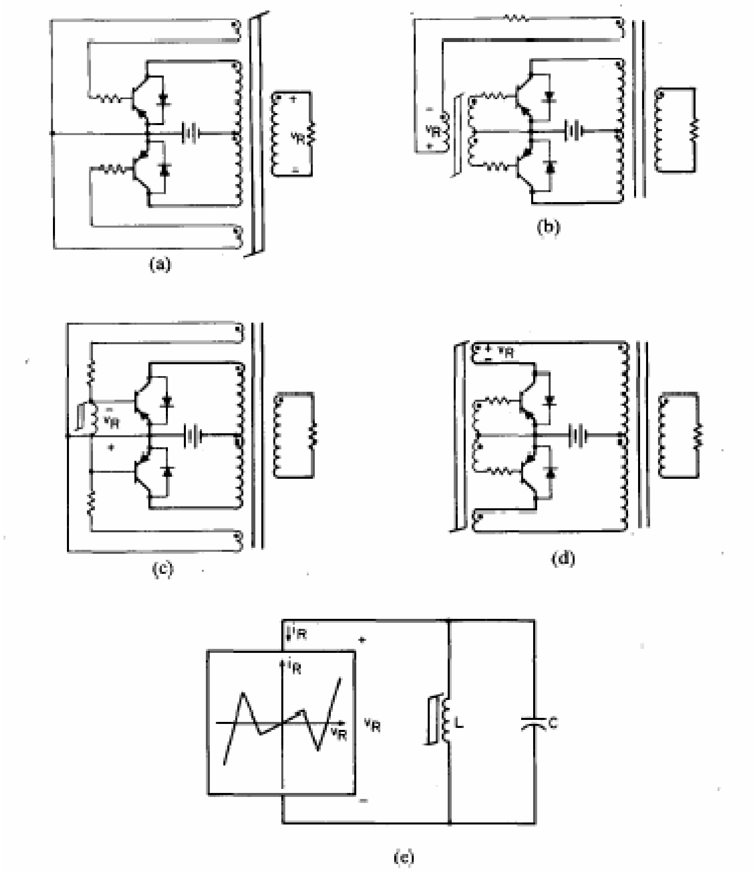


Fig.3.1 (a)-(d) a family of two-transistor saturable-core inverter
(e) The common equivalent circuit

1.2 A Family of LC Tuned Inverters

In power-conditioning applications, there exists another widely used family of self-oscillating dc-to-square-wave inverter, which employs an inductor-capacitor tuned network to determine the frequency of oscillation instead of a saturable magnetic core. Four such inverters are shown in Fig. 3.2. Analysis shows that these four inverters have a common equivalent circuit, Fig. 3.2(e), consisting of three series elements: (1) a five-segment piecewise-linear current- controller resistor, (2) a linear inductor (3) a linear capacitor. The frequency of inverter is depends upon inductor and capacitor of the circuit.

The frequency of oscillation is given by,

$$f = 1/(2*\text{pi}*\sqrt{(L*C)})$$

Where L= inductance of inductor

C = capacitance of capacitor

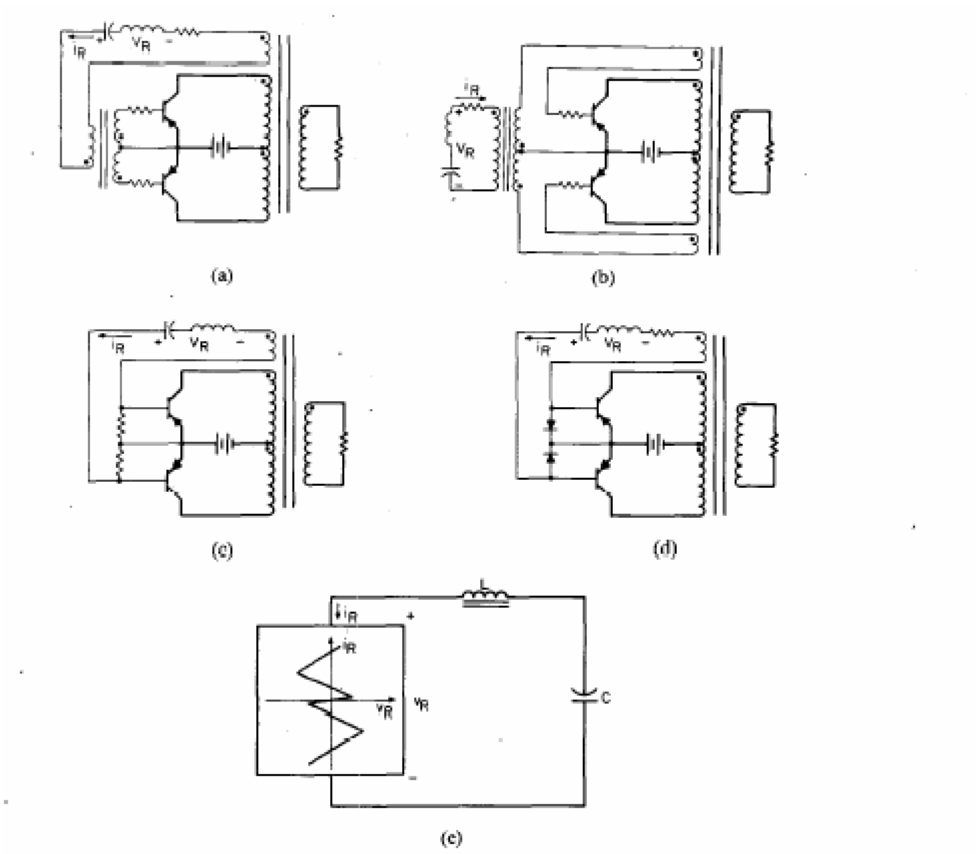


Fig. 3.2. (a)-(d)A family of LC tuned parallel inverters.

(e) The common Equivalent circuit.

CHAPTER 4

DESIGN & DEVELOPMENT OF LOW COST MEDIUM FREQUENCY INVERTER FOR INDUCTION HEATING

4.1 JOB SPECIFICATION

The job to be heated in induction heater has a following specification.

Job material: MILD STEEL

JOB ID: 10 mm

JOB OD: 12 mm

Job length: 1 inch.

Application: SURFACE HEATING

4.2 INTRODUCTION

This is basically a self-oscillating inverter. The basic circuit diagram is shown fig.4.2. The block diagram is shown in fig.4.1. In low power application transistor is used due to low power loss & low cost. so Transistor is used as switching device in this inverter. It is self-oscillating inverter so no control circuit is required to drive the transistors.

4.3 BLOCK DIAGRAM

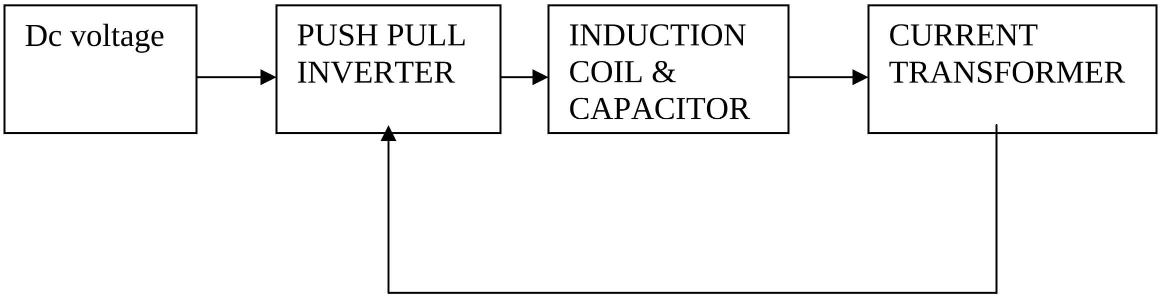


FIG. 4.1 block diagram of self-oscillating transistor inverter

4.4 BASIC CIRCUIT DIAGRAM

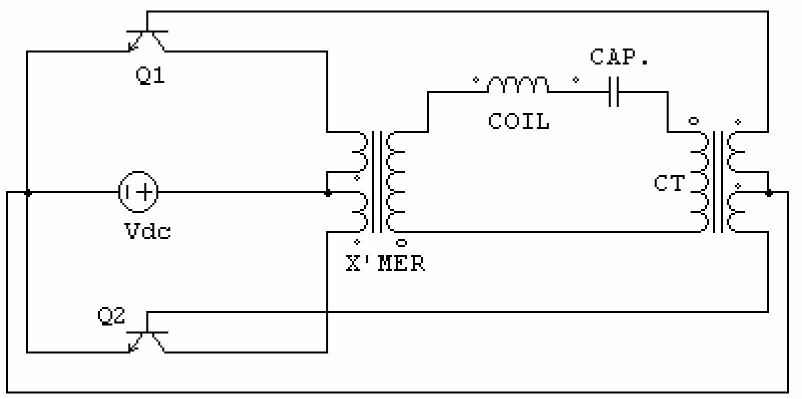


Fig.4.2 basic circuit diagram of self-oscillating inverter

4.5 CIRCUIT DISCRIPTION

This is basically a self-oscillating LC tuned transistor inverter. It does not require any control circuit to drives the transistors. Frequency of the inverter is decided by value of L & C. The frequency of oscillation is given by,

$$f = 1/(2*pi*\sqrt{(L*C)})$$

The basic circuit diagram of self-oscillating transistor inverter is shown in fig.4.2. The circuit function as follows.

When Q1 is on, the supply voltage E is applied to terminal C& D of the transformer. The secondary voltage is constant; the combination of L & C connected in series cause a sine wave of current to flow in secondary side. The transistor Q1 conducts until capacitor C charges. As the current decreases, transistor drive decreases. The action continues until the drive is insufficient to keep Q1 saturated & the transistor begins to switch off. At this instant, the induced voltage in the secondary winding of the transformer begins to drop & Capacitor starts to discharge. The instant capacitor current reverses, Q2 begins to switch on & Q1 is switched off. Q2 continue to conduct until the capacitor is completely charged & then the transistor switch again. During positive half cycle, when capacitor charging, the voltage induced in the secondary of CT makes Q1 is saturation region & Q2 in the cut-off region because the voltage induced in secondary of CT makes base-emitter junction of Q1 in the forward bias & the voltage induced in secondary2 makes base-emitter junction in the reverse bias. During negative half cycle, when capacitor is discharging, the voltage induced in secondary of CT makes Q2 in saturation region and Q1 in cutoff region.

Since for the proper circuit operation the transistor must function as switches, secondary current must be large enough to keep the transistors saturated for all values of secondary current. Saturated switching can be maintained if the ratio N2/N1 is less than the dc current gain of the transistor for maximum value of collector current. In a properly designed circuit the transistors switch only during those portion of a cycle when the load current is low. This switching technique reduces transistor power dissipation and permits switching close to the voltage and current axes.

One feature of this series resonant circuit is that the peak voltage across the load inductor or capacitor is higher than the secondary voltage of the transformer. The amount of this inductor or capacitor voltage will be function of the supply voltage E, the transformer turns ratio and the circuit Quality factor.

In a self-oscillating inverter, base drive for the transistor is fed back from the output. That is why self-oscillating inverter is not a self-starting. To start it we have to drive one of pair of transistor at starting. To drive the transistor at starting, starting circuit is used. So extra circuit is required to start the inverter.

4.6 ADVANTAGE OF SELF-OSCILLATING TRANSISTOR INVERTER

1. Transistors are used as a switching device. As the cost of transistor is less as compared to other switching devices, the cost of inverter is reduced.
2. It is self-oscillating inverter so it does not require any control circuit to drive the transistor.
3. Due to absence of control circuit, complexity of inverter is reduced and so size of the inverter is reduced.

4.7 DISADANTAGE

1. Starting circuit is required to drive the transistor at starting.

CHAPER 5

SELECTION & DESIGN OF COMPONENT

5.1 TRANSISTOR SELECTION

Numerous applications require the transistor to operate efficiently and reliably as a switch. Since a transistor usually takes longer to turn off than to turn on, the condition may exist in the circuit that one of the transistor is still trying to turn off after the opposite device is fully on. When this switch through occurs a surge of current is drawn from the power supply and circuit efficiently is reduced. As frequency is increased to reduce the size and weight of the transformer, the switch through condition may increase power loss. This additional power loss adds to the dissipation in the transistor and raises the operation junction temperature. As the junction temperature increases, the transistor switching response usually degrades causing further power loss. In order to minimize switching losses, which contribute to the junction temperature, the base drive (current and voltage) necessary to switch the transistor efficiently should be determined.

Reactive loads that cause the transistor to operate outside of its maximum dc power rating during the switching interval require special consideration. Keeping the switching locus within the safe operating condition for the device can minimize the possibility of second breakdown failure. The safe operating conditions are dependent on junction temperature, the time the transistor remains at the peak power condition, the collector emitter voltage and current during peak power and the base emitter voltage and current during peak power and the base-emitter voltage level and polarity.

Voltage rating

For the highest reliability, the manufacturer’s open base voltage rating (V CEO) should not be exceeded. It is good practice to stay at least 20 percent below the transistor voltage rating. In choosing the proper transistor voltage classification, it is necessary to consider the highest voltage to which the transistor will be subjected including switching spikes and transient voltages from the dc supply as well as those induced by the load.

Inverter circuits tend to generate voltage spikes, which appear across the transistor collector-to-emitter, and which can results in transistor damage if they exceed the voltage rating. The source of the spikes is the sudden collapse of transformer flux during

Switching. Designing the transformer for low leakage reactance usually can minimize this effect.

Current rating

The inverter circuit current rating of the transistors may be any value up to the manufacturer's absolute maximum limit, which is determined by the current capacity of the various interval leads, the emitter edge length per unit of current or by the saturated collector dissipation. Sufficient base drive current should be provided to keep the transistors in saturation at the maximum load current.

Power rating

For suitable inverter design, careful consideration must be given to minimizing the transistor losses. Using even more base over drive than the indicated 20 percent, thus reducing the saturation resistance, may reduce the loss during transistor conduction. However this procedure cannot be carried too far because the driving circuit losses will increase and transistor turn off time may increase.

It is difficult to recommend general rules for reducing dissipation since each application requires individual consideration. For example, clamping the transistor just outside of saturation may optimize an inverter switching high voltage and low current. This technique is desirable where the switching losses predominate due high operating frequency and saturation losses are not so critical because of the lower collector current.

The conduction and cutoff losses are largely determined by the transistor characteristics and cannot be controlled to a great extent by the circuit designer. However the switching loss is greatly depends upon the circuit design. The maximum allowable case temperature of the transistor should be determined from the peak power dissipation and not just the average.

Silicon power transistors are found useful in a wide rarity of inverter applications, particularly where reliable operation at high operating temperature is required.

Silicon power transistors (2N3055)

The silicon power transistor (2N3055) is NPN diffused transistor. This general-purpose transistor exhibits low saturation voltage, fast switching time and high gain and frequency characteristics. They are particularly useful in industrial and commercial power switching, amplifier and regulator applications. The temperature range to 200°c permits reliable operation in high ambient, and the hermetically sealed T0-3 case insure maximum reliability and long life.

MAXIMUM RATING OF 2N3055 SILICON POWER TRANSISTOR

Voltage rating:

Collector-emitter reverse bias, V_{CEV} = 100volts

Collector-base, V_{CBO} = 100 volts

Emitter-base, V_{EBO} = 7 volts

Current rating:

Collector current, Ic = 15 amp

Base current, Ib=7 amps

5.2 TRANSFORMER

A transformer is essentially a static electromagnetic device consisting of two or more winding which link with a common magnetic field. Ring shape core is used for the transformer. The ring type of construction is a robust construction and has the further advantage of joint-less core. The winding should be close together to reduce the secondary leakage reactance as this increases the ratio error

Design consideration

For any transformer

(Ts/ Tp)=(Ip/Is)=(Es/Ep)=K

Where Ip = primary winding current

Is = secondary winding current

Tp = No. of primary winding turns

Ts = No. of secondary winding turns

K = transformation ratio

Es = secondary voltage

Ep = primary voltage

CORE DESIGN

Considering a load of 30VA.

$Es*Is = 30$ VA

$Es = 30/5 = 6$ volts

Basic emf equation is given by,

$E = 4.44*\phi m*f*Ts$

Flux, $\phi m = 6/(4.44*10000*5)$

$= 3.37*1e\text{-}5$ wb

Assuming the flux density, $Bm = 0.05$ wb/m²

Area of core is given by,

$Ai = 3.37*1e\text{-}5 / .05)$

$= 6.67*1e\text{-}4$ mm²
$= 6.67$ cm²
Gross area of core is given by,

$Ag = 6.67/0.8 = 8.44$ cm²

So ring shape core having a area of 9 cm² is used for this transformer.

WINDING DESIGN

It is a center tap current transformer having one primary and two secondary winding.

Considering a current density of 1.2 A/ mm²

Primary winding

The current in primary winding of transformer is approximately 30A.

The area of primary winding conductor is given by,

$Ap = (30/1.2) = 25$ mm²

Diameter of conductor, $dp = 2.82$ mm

So 3 mm copper rod is used for the primary winding of transformer.

No. of turns: 1

Conductor diameter: 3 mm

The current in secondary winding is approximately 5A.

Considering a current density of 1.2 A/mm²

Area of secondary winding is given by, As = 2.68 mm²

Diameter of secondary winding conductor, ds = 0.9 mm

Secondary winding

No. of turns: 5

Conductor diameter: 0.9 mm

5.3 PUSH PULL TRANSFORMER

Push pull transformer is generally used for medium and high frequency application. The push pull circuit is efficient because it makes bi-directional use of a transformer core, providing an output with low ripple. However, circuitry is more complex, and the transformer core saturation can cause transistor failure if power transistor has unequal switching characteristics. Ferrite is an ideal core material for transformers, inverters and inductors in the frequency range of 20KHz to 3MHz due to low core losses. Ferrite is excellent material for the frequency range above 20 KHz and above. But the cost the ferrite core is very high. Now, the operating frequency of this inverter is 8KHz so we can use a CRGO core in place of ferrite to reduce the cost of the inverter.

It a center tap transformer with two primary and one secondary winding.

Primary winding

No of turns = 20

Diameter of conductor = 1.5 mm

Secondary winding

No. of turns =2

Diameter of conductor = 3 mm

5.4 BASIC DESIGN OF COIL

In sense, coil design for induction heating is built upon a large store of empirical data whose development springs from several simple inductor geometries such as the solenoid coil. Because of this, coil design is generally based on experience.

Heating-pattern uniformity requirements and work piece length are the two main considerations with regard to the selection of a multiturn vs. a single turn induction coil. A fine-pitch, multiturn coil closely coupled to the work piece develops a very uniform heating pattern. Similar uniformity can be modified to suit the application by controlling the dimensions of the liner. When a liner is used, the current path from the power supply passes through the connecting tubing. Between the two connections, the tubing is used solely for conduction cooling of the liner. In fabricating coils with liners, it is exceed twice its diameter be achieved by opening up the coupling between the part and the coil so that the magnetic flux pattern intersecting the heated area is more uniform. However, this also decreases energy transfer. Where low heating rates are required, as in through heating for forging, this is acceptable. When high heating rates are needed, however, it is sometimes necessary to maintain close coupling. The pitch of the coil must be opened to prevent overloading of the generator.

DESIGN OF COIL

The job for which this inverter is design is having a OD of 12 mm. So coil ID must be more than the 12 mm. Also application is for surface heating. So heating must be same though out the length of job. That is why multi turn coil is used. Now the length of job is 1 inch. So for through heating, coil length must be same as the job. So coil length is 1 inch. Also the shape of coil is depends upon the shape of job to be heated. The job having a round hollow conductor having a OD of 12mm. So shape of coil is also round having a OD of 14mm.

COIL SPECIFICATION

1. COIL ID: 14mm
2. Coil length: 1 inch.
3. Coil conductor diameter: 3mm
4. No. of turns: 5

INDUCTANCE CALCULATION

The Induction Coil, whose inductance is measured, is connected with a dimmer. Low voltage is applied to the coil such that 5A current flow in the coil. Than voltage across inductance coil is measured. Suppose this voltage is V1.

Now voltage across coil is given by, V1 = I*XL

=I*2*pi*f*L

=5*2*pi*50*L

Inductance of coil is given by, L = V1/(5*2*pi*50)

So when low voltage is applied to the coil, voltage across the coil is 3.37mvolts.

So inductance of coil is L = 3.37*1e-3/(5*2*pi*50)

= 2.15µH.

5.4 TUNNING CAPACITORS

Capacitor is a very important component of electronics circuits. It is used in filtering, commutation and sunbber circuits. Non-polarized capacitors are used in ac circuits and electrolytic capacitor is used in dc circuits. Electrolytic capacitor s have very high capacitance/volume ratio, but these cannot be used in ac circuits. However non-polarized type electrolytic capacitors are available which are used in ac circuits.

A metal foil of 0.03 to 6µm thickness is wound to form a cylindrical body. Paper is used as dielectric medium between layers. The capacitor is bulky, which is the main drawback. In another type, a metalized paper is used. A metallic layer is coated on the surface of paper. The MP foil is wound to form a cylindrical body. This capacitor will have air pockets. Which may cause flash over. In order to increase the dielectric strength of weak points, air is replaced by oil. The paper is impregnated by vacuum impregnation. Oil impregnated capacitor is durable. Paper capacitor cannot be used at high frequency due to considerable dielectric loss in the paper. Plastic dielectric has much lower dielectric loss; so metalized plastic foils are used to fabricate the capacitor. In such capacitors, slightly porous plastic is used to absorb the oil. These capacitors are used at high frequency due to low dielectric loss. The frequency of oscillation is given by,

$$f = 1/\,(2*pi*\sqrt{(L*C)})$$

The inductance of secondary circuit is 3.7µH and operating frequency of inverter is 8khz. By putting the value of frequency and Inductance, capacitance of capacitor is 106.9µF. now standard capacitor available in market is 36µF. so we use a 3 capacitor of 36µF in parallel. So total capacitance is 108µF.

5.5 TRANSISTOR BIASING CIRCUIT DESIGN

For different types of circuits, different types of bias are required at the emitter-base junction of the transistor. If a transistor is used for signal amplification, its operation should take place in active region. If the device is used as switch, then its operation has to shift between cutoff and saturation regions. Thus for different application the bias required is of different types.

The maximum base-emitter voltage of transistor is 7 volts. So base emitter voltage should not increase more than 7 volts. Otherwise transistor becomes damaged. To provide the protection against voltage spikes resistors are connected in series with base of the transistor.

Rb = (Vbb – Vbe)/Ib = (5-0.7)/5 =0.86 Ω

Base resistor, RB = 1Ω/ 2W

The maximum rating of 2N3055 SILICON POWER TRANSITOR is given in following TABLE.2.

MAXIMUM RATING OF 2N3055 SILICON

Rating	Symbol	Value	Unit
Collector-emitter voltage	V_{CEO}	60	Vdc
Collector-base	V_{CB}	100	Vdc
Base emitter voltage	V_{EB}	7	Vdc
Collector current	I_C	15	Adc
Base current	I_b	7	Adc

TABLE 2

5.6 STARTING CIRCUIT OF SELF-OSCILLATING INVERTER

NECESSITY OF STARTING CIRCUIT

In a self-oscillating inverter, base drive for the transistor is fed back from the output. That is why self-oscillating inverter is not a self-starting. To start it we have to drive one of pair of inverter at starting. To drive the transistor at starting, starting circuit is used.

The commonly used starting circuit of inverter is shown in the fig.5.1. In this method R1 and R2 form a voltage divider to bias the transistors to conduction before oscillation starts. The starting bias developed across R1 should be approximately 0.5 volts for silicon transistors.

This bias voltage

$$Vb = R1*Vdc/(R1+R2)$$

The feedback voltage across winding N3 must be sufficient to maintain base drive current with the additional resistance of R1. This starting circuit is economical since only resistor components are added to the inverter. The disadvantage is high power dissipation in the starting resistor.

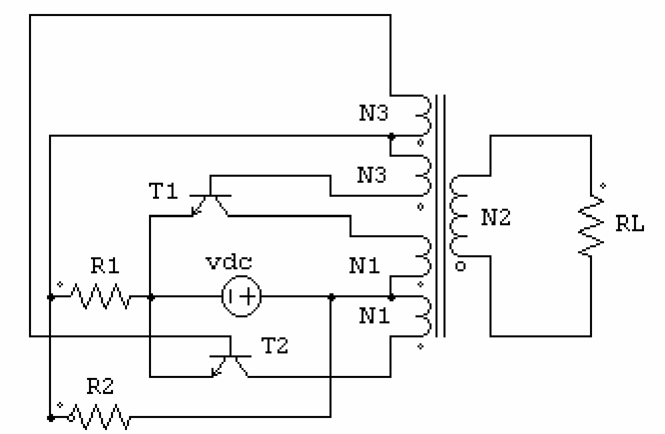


Fig. 5.1

Inverter starting circuit

To overcome disadvantage of this starting circuit, another circuit is used which is shown in fig.6. In that inverter the starting circuit is provided in current transformer. The voltage of 1.5 volt is applied to starting circuit at starting though battery.

To drive the silicon power transistor minimum 0.5 volt is required at the base emitter junction of the transistor. So I used 1.5 volt battery because due to base resistor there may be a some voltage drop.

As we know that for current transformer,

Transformation ratio is given by,

(N2/N1)=(V2/V1);

Where N2 = no. of secondary winding turns

N1 = no. of primary winding turns

V2= secondary voltage

V1= primary voltage, 1.5volts

Calculation for turns ratio: 5

So N2 = 5

V1 = 1.5 volts

V2 = 0.9 Volts

N1 = (N2*V1)/V2

= (5*1.5)/0.9

=13

The circuit diagram of self-oscillating inverter with the starting circuit is shown in the fig.6. In a starting circuit push button switch is used. This push button is normally opened. When we push the green button, battery voltage is applied to the starting circuit. So voltage will be induced in the secondary of the Transformer. This voltage is applied to the base emitter junction of transistor. The advantage of this circuit is that starting circuit come in picture at the time of starting only. Than after it is open circuited. So full load losses in this starting circuit will be reduced as compared to other starting circuits.

ADVANTAGES OF THIS STARTING CIRCUIT

1. Full load losses are reduced in starting circuit because it is working in the circuit at the starting only.
2. We can turn off the inverter by simply short-circuiting the secondary of Transformer.

DISADVANTAGE

1. We can turn off the inverter by simply short-circuiting the starting winding of transformer.

6.2 CIRCUIT DISCRIPTION

The self-oscillating inverter with starting circuit is shown fig.6. The job to be heated is placed in induction coil. The circuit operates as follows.

When the supply voltage is applied to inverter, it will not start oscillating directly because initially base current of transistor is zero as output is zero. So initially one of the pair of transistor must be on to start the inverter. When push button switch s1 is closed, battery voltage is applied to starting winding of transformer. So voltage induced in secondary winding of transformers, which turn on, the upper pair of transistors of the inverter. Ones the one of the pair of push pull inverter is on, the inverter start oscillating. The frequency of oscillation is depends upon the induction coil and tuning capacitor. To turn off the inverter push button switch s2 is closed. So oscillation is die out in the inverter & inverter become turn off.

CHAPTER 7

EXPERIMENTAL SET UP OF SELF-OSCILLATING INVERTER

7.1 EXPERIMENTAL SETUP

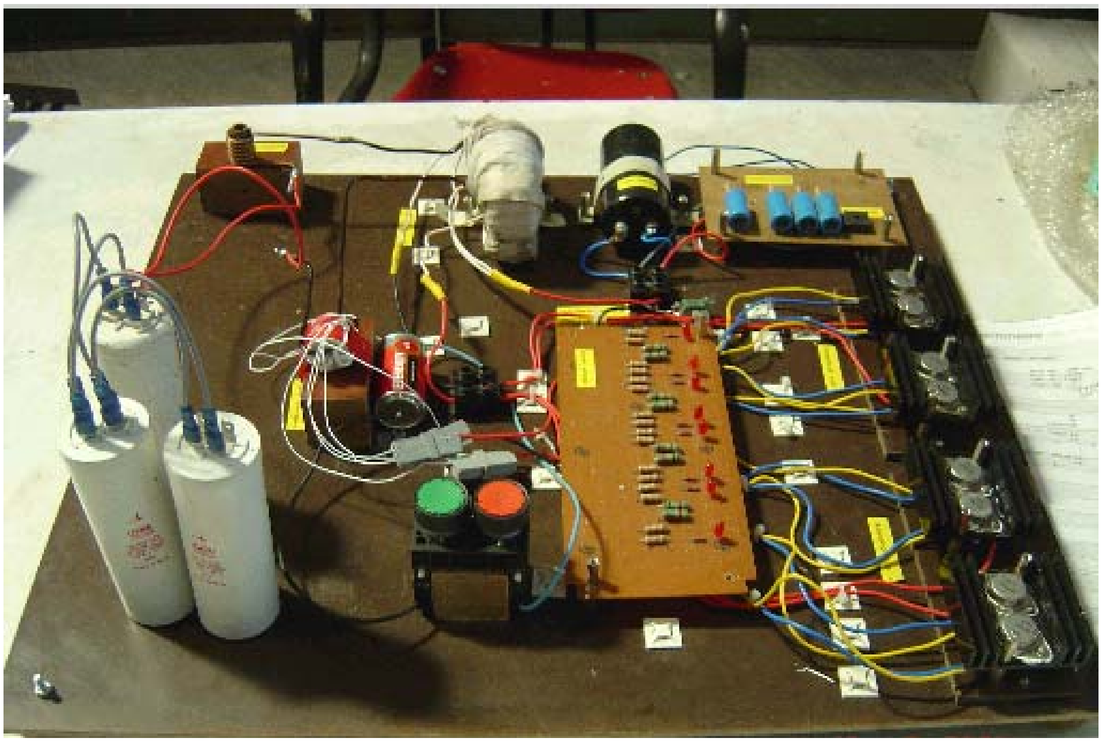


Fig.7.1

7.2 SILICON POWER TRANSISTOR 2N3055

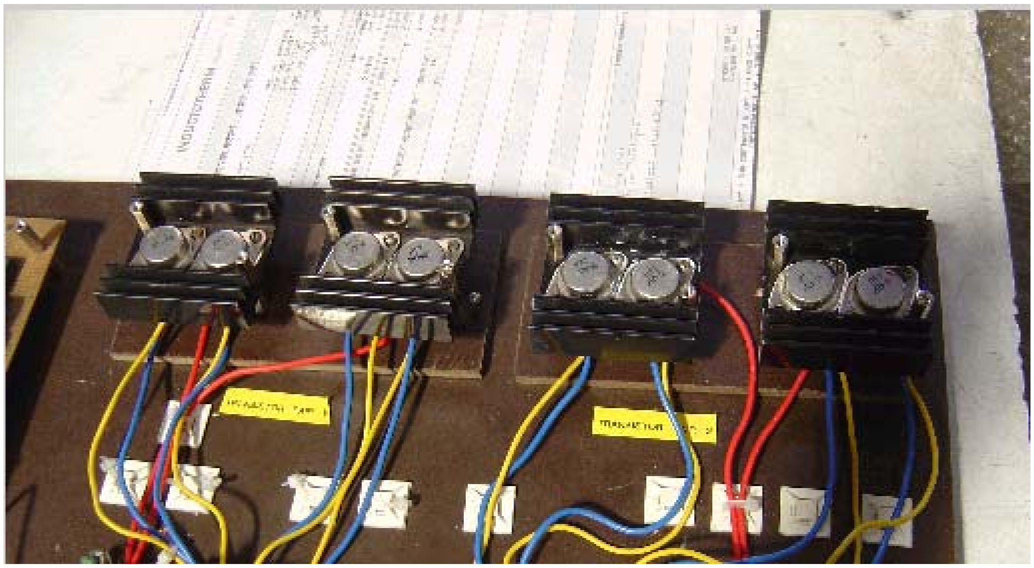


Fig. 7.2

7.3 PUSH PULL TRANSFORMER

Fig. 7.3

7.4 BIASING NETWORK

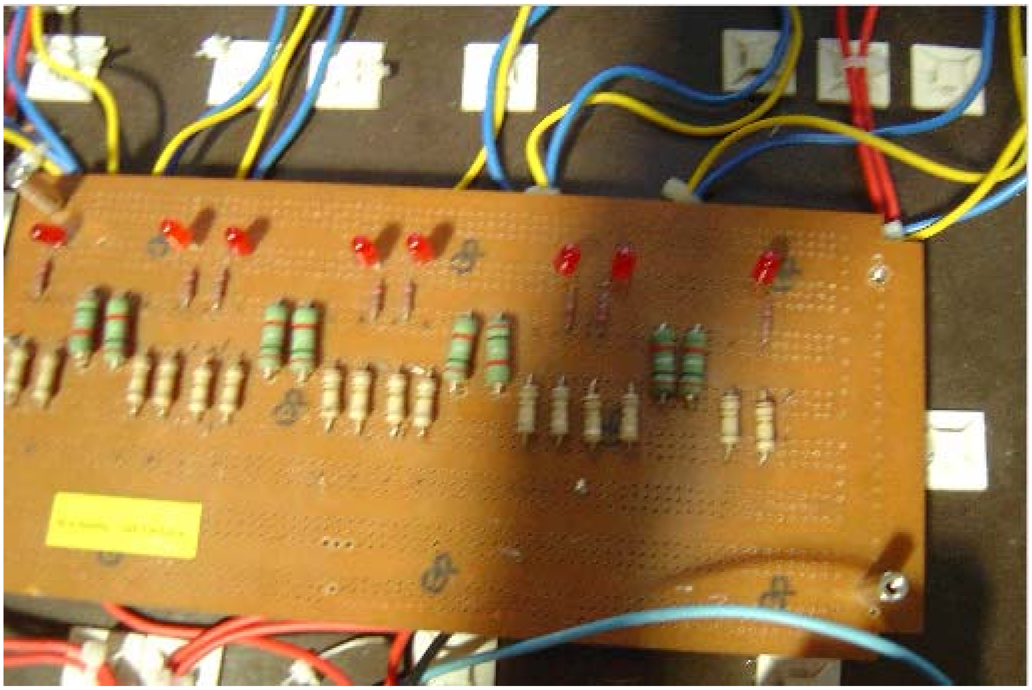


Fig. 7.4

7.5 TRANSFORMER

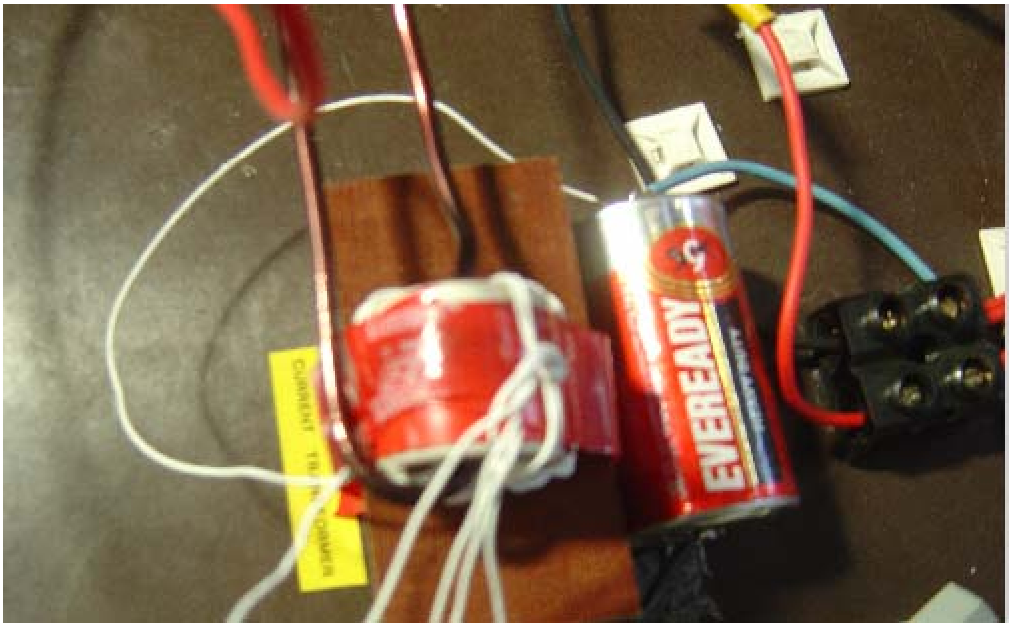


Fig. 7.5

7.6 TUNNING CAPACITOR

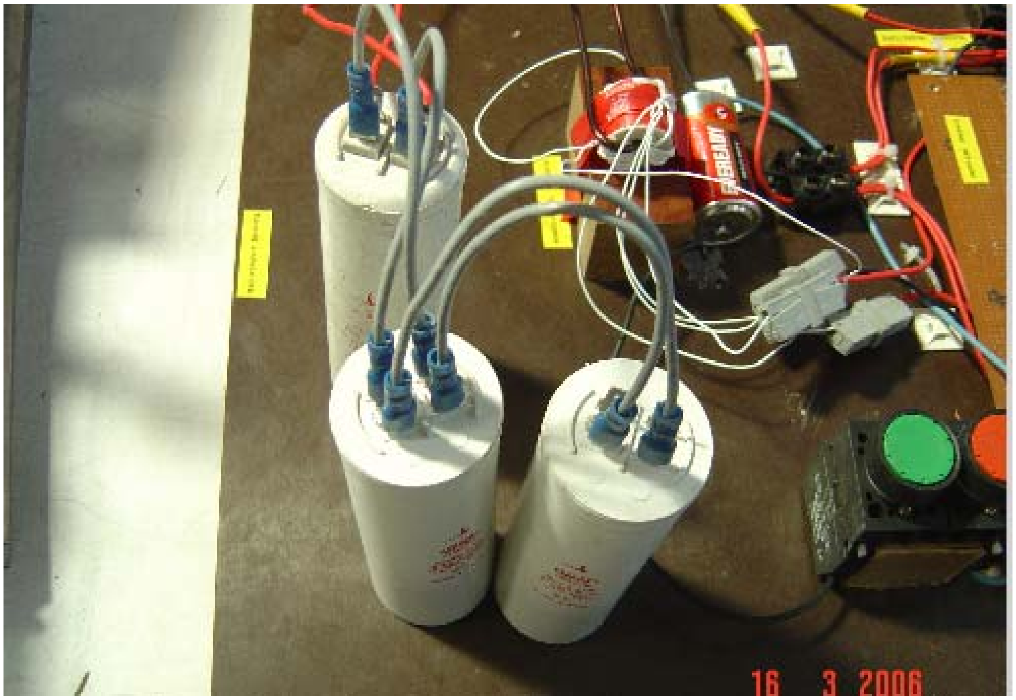
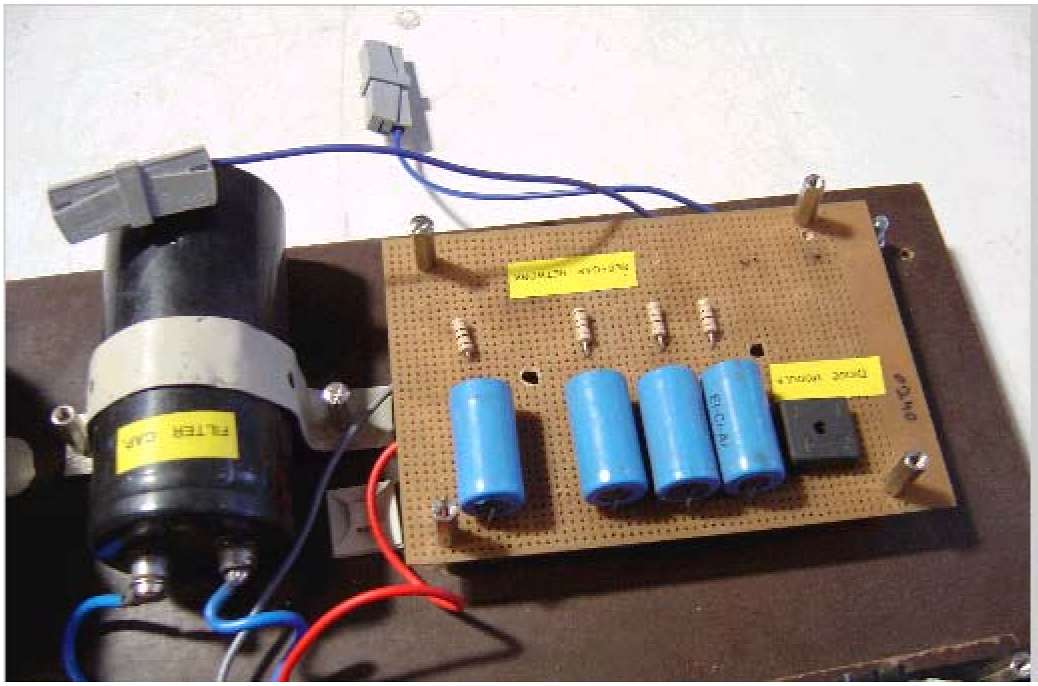


Fig. 7.6

7.7 INDUCTION COIL

Fig. 7.7

7.8 POWER SUPPLY



CHAPTER 8

EXPERIMENTALWAVEFORMS & OBSERVATION TABLE

8.1 PUSH PULL TRANSFORMER OUTPUT VOLTAGE

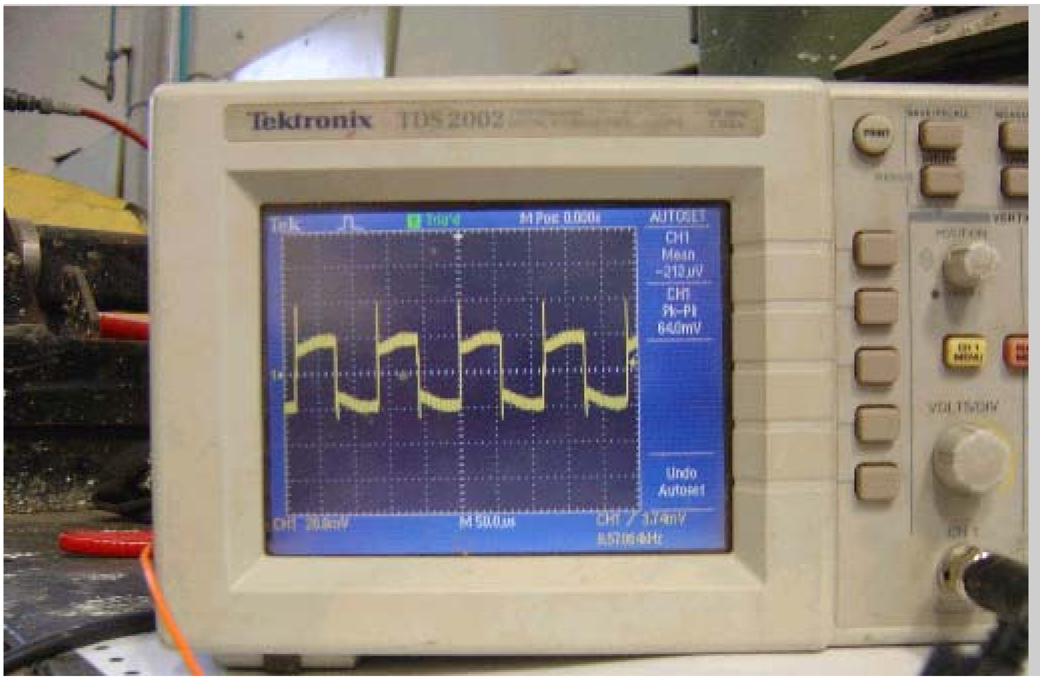


Fig. 8.1

8.2 VOLTAGE ACROSS COIL

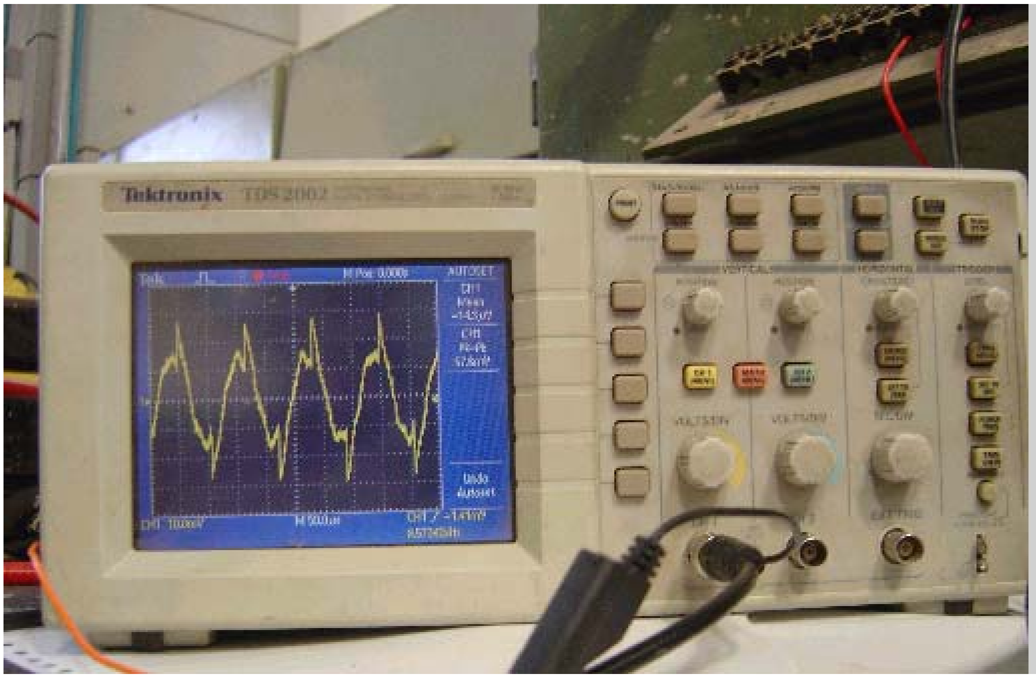


Fig. 8.2

8.3 BASE-EMITTER VOLTAGE OF TRANSISTOR

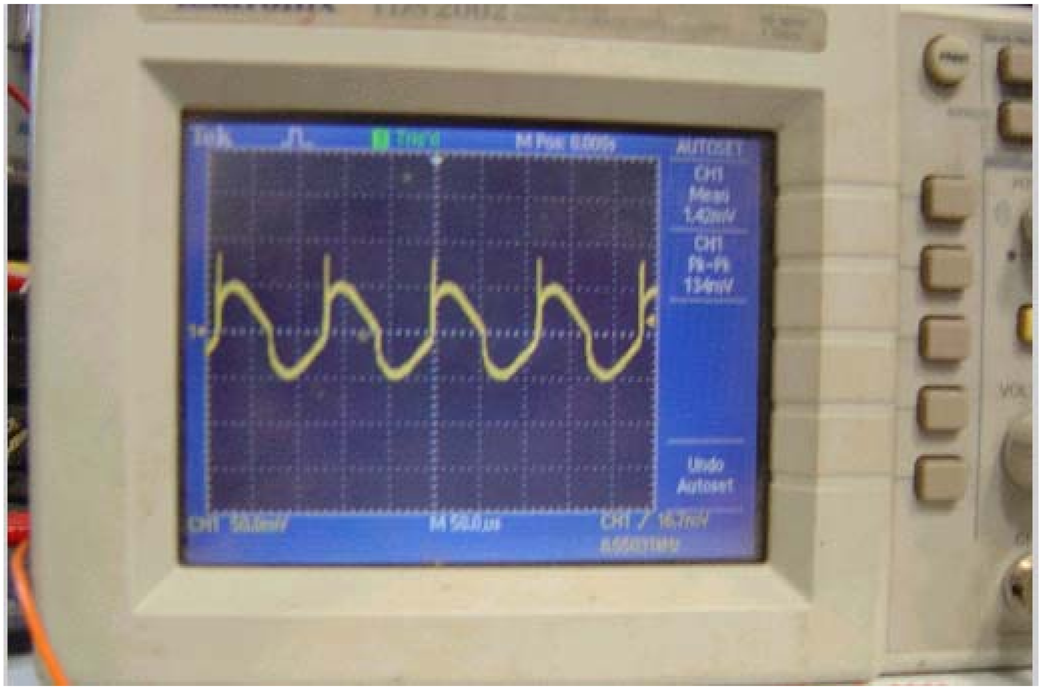


Fig. 8.3

8.4 VOLTAGE ACROSS CAPACITOR

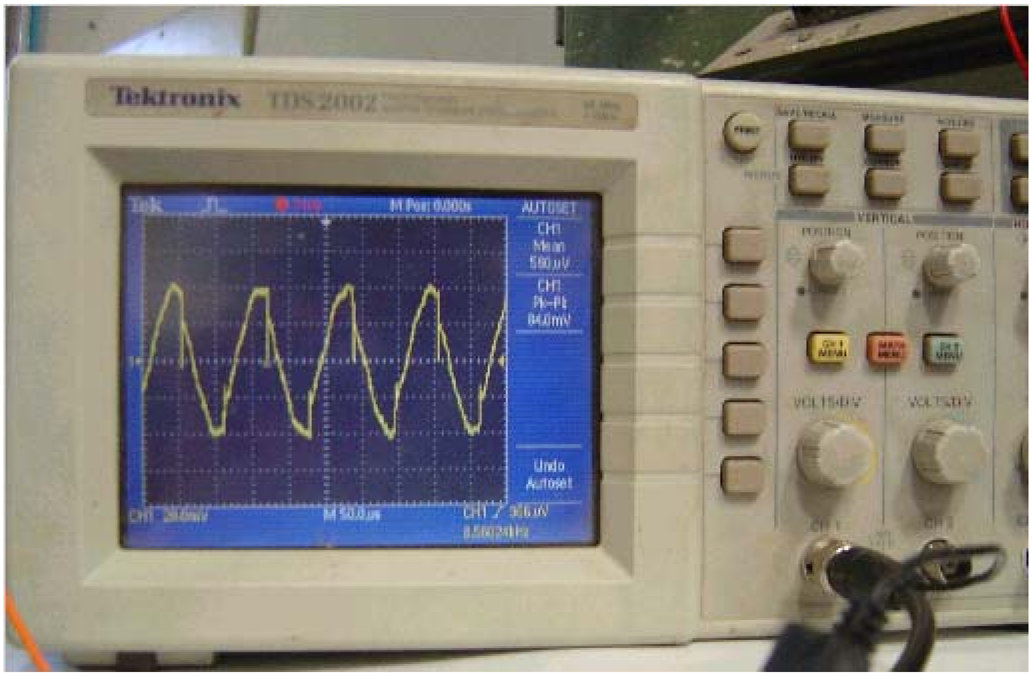


fig. 8.4

8.5 BASE CURRENT OF TRANSISTOR

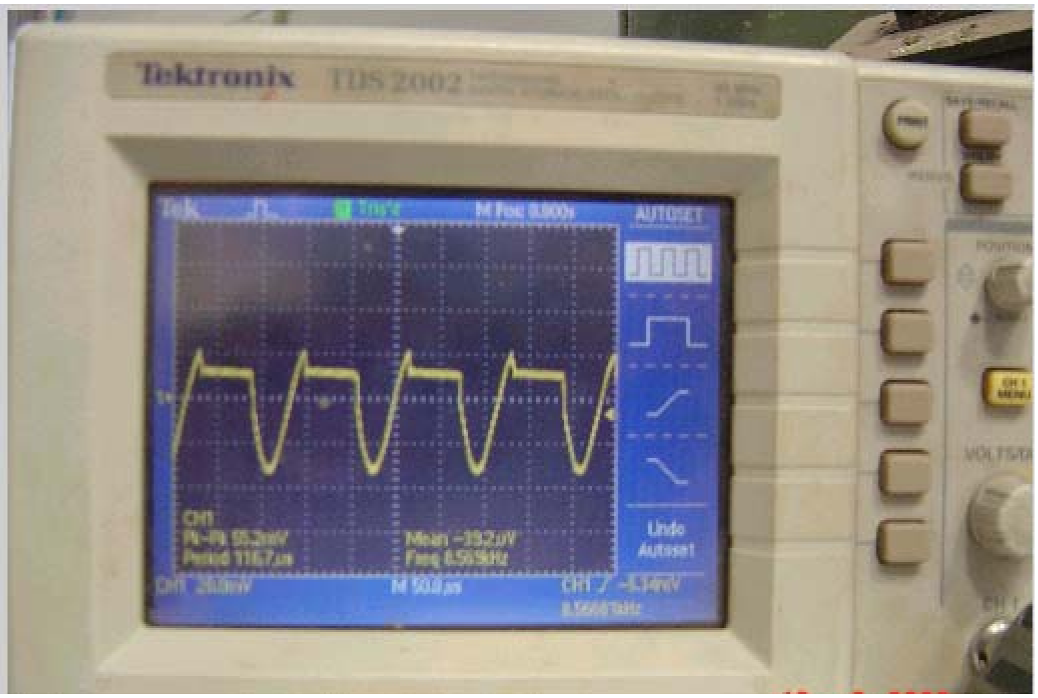


fig. 8.5

8.6 COLLECTOR CURRENT OF TRANSISTOR

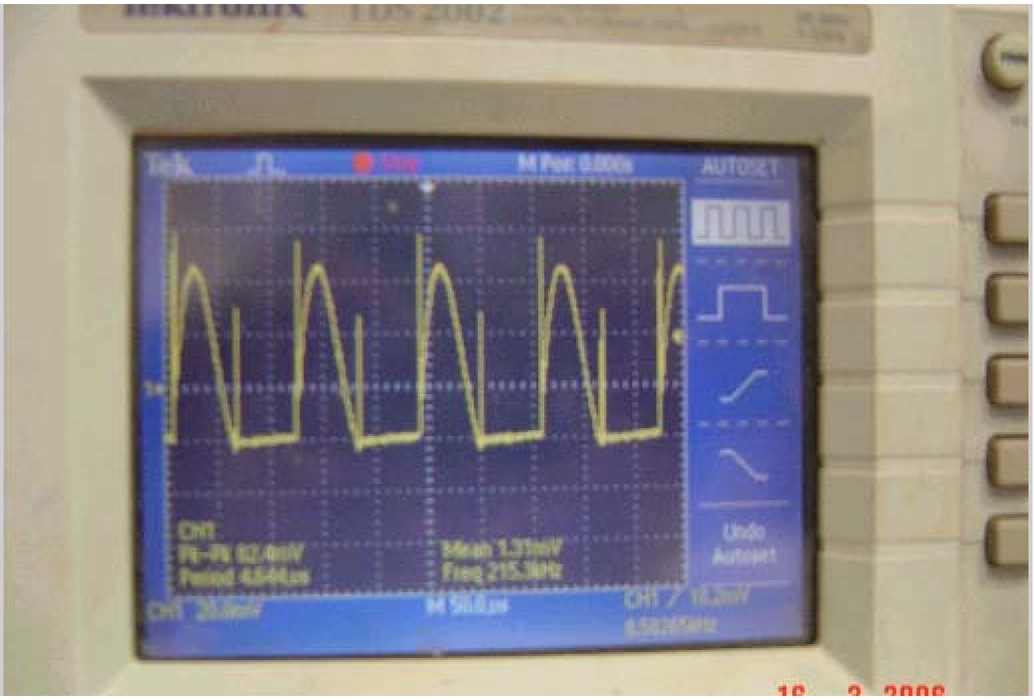


Fig. 8.6

8.7 EMITTER CURRENT OF TRANSISTOR

Fig. 8.7

8.8 SECONDARY CURRENT OF PUSH PULL TRANSFORMER

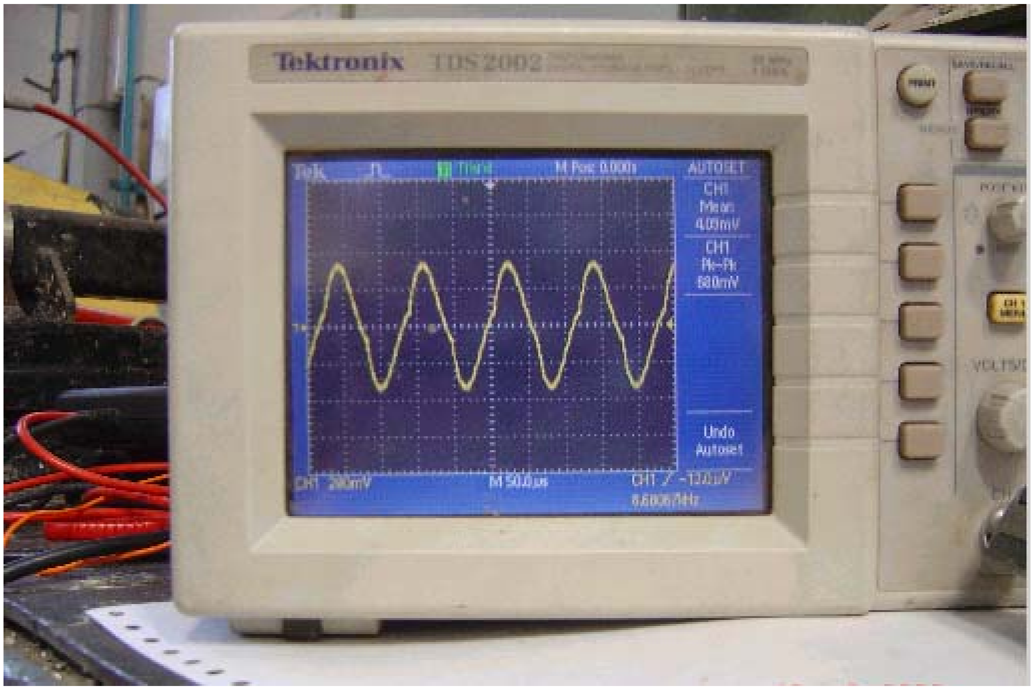


fig. 8.8

OBSERVATION TABLE

OBSERVATION TABLE

TRANSFORMATION RATIO: 5

CAPACITOR: 108 µF

1	V_{DC}	50 volts
2	I	4.82 amps
3	V_{OUT}	3.9 volts
4	V_{BE}	3.93 volts
5	f	7.92 kHz

TABLE 3

Sr.no.	Name of component	No. Of comp.	Cost per comp.	Total cost
1	2N3055 silicon power transistor	8	5	40
2	Base resistors - 1Ω/2w	12	1	12
3	Heat sink	4	35	140
4	Led	8	1	8
5	Diode bridge (10a / 600v)	1	25	25
6	Filter capacitor (10000mfd / 100v)	1	650	650
7	Push pull transformer	1	250	250
8	Induction coil	1	50	50
9	Tuning capacitor	3	150	450
10	transformer	1	50	50
11	Push button switch	2	50	100
12	Battery	1	10	10
13	PCB	1	30	30
			Total cost in Rs	1815

TABLE 4

CHAPTER 10 CONCLUSION

From the observation table shown in 8.9, we conclude that when 50 volts dc is applied to the inverter, it will take 4.82A of current. The frequency of oscillation is 7.92khz, which is requiring for the surface heating of the job. The maximum base emitter voltage of 2N3055 Silicon power transistor is 7 volts. From the observation table we see that base emitter voltage of transistor is 3.93 volts, which is below the maximum limit.

The experimental waveforms of the inverter are shown in chapter 8. As we know that push pull inverter is a dc to square wave inverter. The secondary voltage of push pull transformer is square wave in nature, which is shown in fig. 8.1. This voltage is applied to heating coil and capacitor connected in series. Though the secondary voltage is constant, the combination of inductance & capacitance connected in series causes a sine wave of current to flow which shown in fig. 8.8.

From the cost analysis we can say that cost of control circuit is eliminated from the overall cost of inverter. So cost of inverter is reduced. Also transistor is used as a switching device, which is cheaper than the other switching devices. So cost of switching devices is reduced. So due absence of control circuit overall cost, size & complexity of the inverter is reduced.

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9. Cost Effective Soft-Switching PWM High Frequency Inverter with Minimum Circuit Components for Consumer Induction Heater by Tomomasa Nishida, Laknath Gamage, H. Muraoka, E. Hiraki, M. Nakaoka, H. Kifune** and Y. Hatanaka, Hyun-Woo Lee, The Graduate School of Science and Engineering, Yamaguchi University, Yamaguchi, Japan, Tokyo University of Mercantile Marine, Tokyo, Japan, Kyungnam University, Masun, Korea

LIST OF TECHNICAL PAPER PUBLISHED

1. "**DIFFERENT CLASSES OF SELF OSCILLATING INVERTER & ITS APPLICATION IN INDUCTION HEATING"**

Published in **TECHNOYSSIS 2005** held in NIRMA UNIVERSITY, AHMEDABAD.

Appendix

1. Datasheet of silicon power transistor 2N3055

2N3055(NPN), MJ2955(PNP)

Preferred Device

Complementary Silicon Power Transistors

. . . designed for general−purpose switching and amplifier applications.

- DC Current Gain − h_{FE} = 20−70 @ I_C = 4 Adc
- Collector−Emitter Saturation Voltage − $V_{CE(sat)}$ = 1.1 Vdc (Max) @ I_C = 4 Adc
- Excellent Safe Operating Area
- Pb−Free Packages are Available

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−Emitter Voltage	V_{CEO}	60	Vdc
Collector−Emitter Voltage	V_{CER}	70	Vdc
Collector−Base Voltage	V_{CB}	100	Vdc
Emitter−Base Voltage	V_{EB}	7	Vdc
Collector Current − Continuous	I_C	15	Adc
Base Current	I_B	7	Adc
Total Power Dissipation @ T_C = 25°C Derate above 25°C	P_D	115 0.657	W W/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +200	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction−to−Case	$R_{\theta JC}$	1.52	°C/W

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

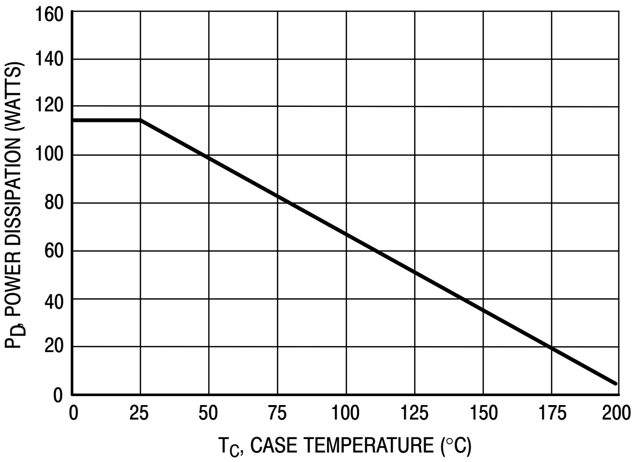
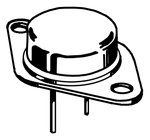


Figure 1. Power Derating

ON Semiconductor®

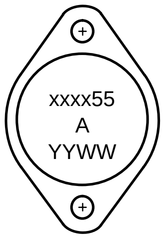
http://onsemi.com

15 A
POWER TRANSISTORS
COMPLEMENTARY SILICON
60 V
115 W



TO−204AA (TO−3)
CASE 1−07

MARKING DIAGRAM



xxxx55 = Device Code
xxxx= 2N3055 or MJ2955
A = Assembly Location
YY = Year
WW = Work Week
x = 1, 2, or 3

ORDERING INFORMATION

Device	Package	Shipping†
2N3055	TO−204AA	100 Units / Tray
2N3055G	TO−204AA (Pb−Free)	100 Units / Tray
MJ2955	TO−204AA	100 Units / Tray
MJ2955G	TO−204AA (Pb−Free)	100 Units / Tray

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

Preferred devices are recommended choices for future use and best overall value.

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May 5, 2005 − Rev. 5

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
***OFF CHARACTERISTICS**				
Collector−Emitter Sustaining Voltage (Note 1) (I_C = 200 mAdc, I_B = 0)	$V_{CEO(sus)}$	60	−	Vdc
Collector−Emitter Sustaining Voltage (Note 1) (I_C = 200 mAdc, R_{BE} = 100 Ω)	$V_{CER(sus)}$	70	−	Vdc
Collector Cutoff Current (V_{CE} = 30 Vdc, I_B = 0)	I_{CEO}	−	0.7	mAdc
Collector Cutoff Current (V_{CE} = 100 Vdc, $V_{BE(off)}$ = 1.5 Vdc) (V_{CE} = 100 Vdc, $V_{BE(off)}$ = 1.5 Vdc, T_C = 150°C)	I_{CEX}	 − −	 1.0 5.0	mAdc
Emitter Cutoff Current (V_{BE} = 7.0 Vdc, I_C = 0)	I_{EBO}	−	5.0	mAdc
***ON CHARACTERISTICS** (Note 1)				
DC Current Gain (I_C = 4.0 Adc, V_{CE} = 4.0 Vdc) (I_C = 10 Adc, V_{CE} = 4.0 Vdc)	h_{FE}	 20 5.0	 70 −	−
Collector−Emitter Saturation Voltage (I_C = 4.0 Adc, I_B = 400 mAdc) (I_C = 10 Adc, I_B = 3.3 Adc)	$V_{CE(sat)}$	 −	 1.1 3.0	Vdc
Base−Emitter On Voltage (I_C = 4.0 Adc, V_{CE} = 4.0 Vdc)	$V_{BE(on)}$	−	1.5	Vdc
SECOND BREAKDOWN				
Second Breakdown Collector Current with Base Forward Biased (V_{CE} = 40 Vdc, t = 1.0 s, Nonrepetitive)	$I_{s/b}$	2.87	−	Adc
DYNAMIC CHARACTERISTICS				
Current Gain − Bandwidth Product (I_C = 0.5 Adc, V_{CE} = 10 Vdc, f = 1.0 MHz)	f_T	2.5	−	MHz
*Small−Signal Current Gain (I_C = 1.0 Adc, V_{CE} = 4.0 Vdc, f = 1.0 kHz)	h_{fe}	15	120	−
*Small−Signal Current Gain Cutoff Frequency (V_{CE} = 4.0 Vdc, I_C = 1.0 Adc, f = 1.0 kHz)	f_{hfe}	10	−	kHz

*Indicates Within JEDEC Registration. (2N3055)

1. Pulse Test: Pulse Width $\leq$ 300 μs, Duty Cycle $\leq$ 2.0%.

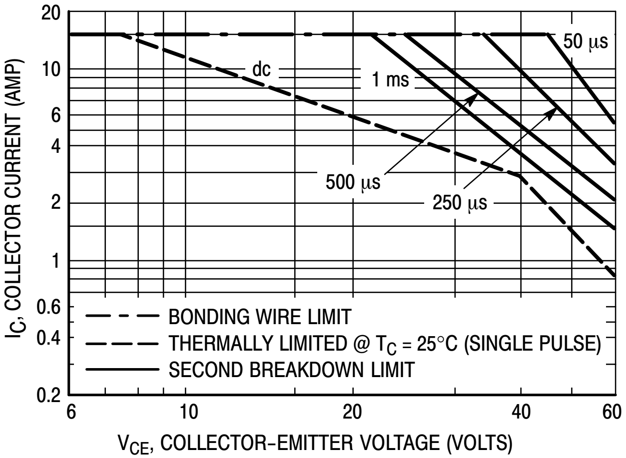


Figure 2. Active Region Safe Operating Area

There are two limitations on the power handling ability of a transistor: average junction temperature and second breakdown. Safe operating area curves indicate $I_C - V_{CE}$ limits of the transistor that must be observed for reliable operation; i.e., the transistor must not be subjected to greater dissipation than the curves indicate.

The data of Figure 2 is based on T_C = 25°C; $T_{J(pk)}$ is variable depending on power level. Second breakdown pulse limits are valid for duty cycles to 10% but must be derated for temperature according to Figure 1.

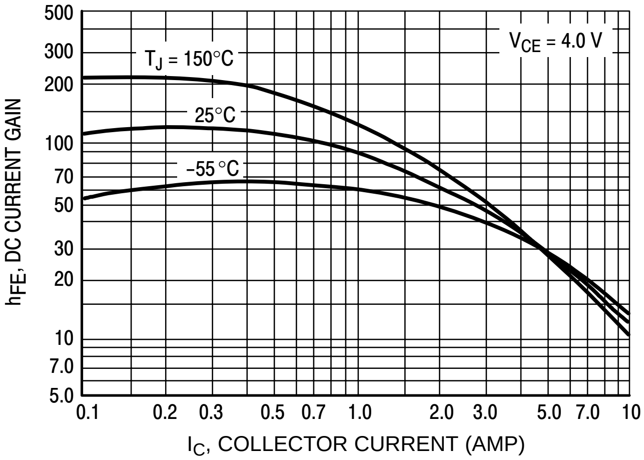


Figure 3. DC Current Gain, 2N3055 (NPN)

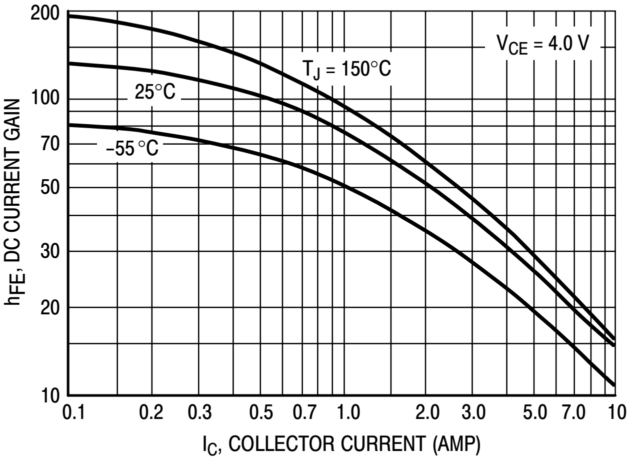


Figure 4. DC Current Gain, MJ2955 (PNP)

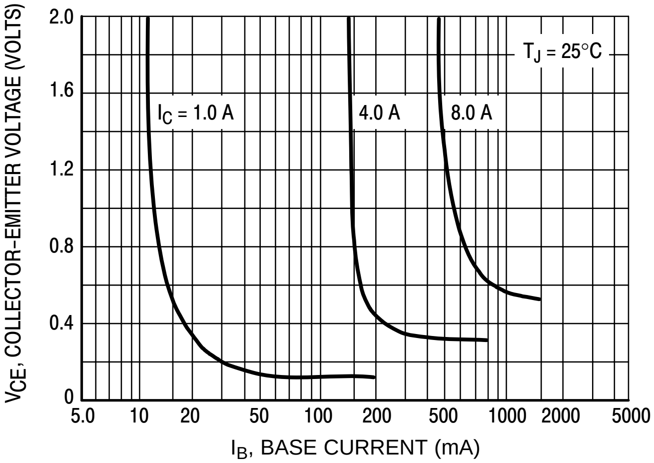


Figure 5. Collector Saturation Region, 2N3055 (NPN)

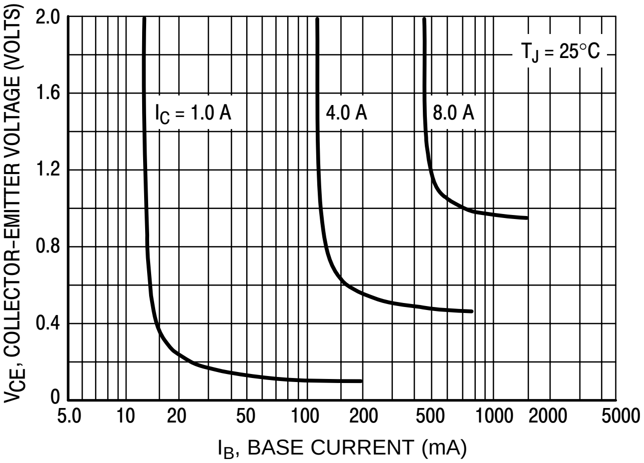


Figure 6. Collector Saturation Region, MJ2955 (PNP)

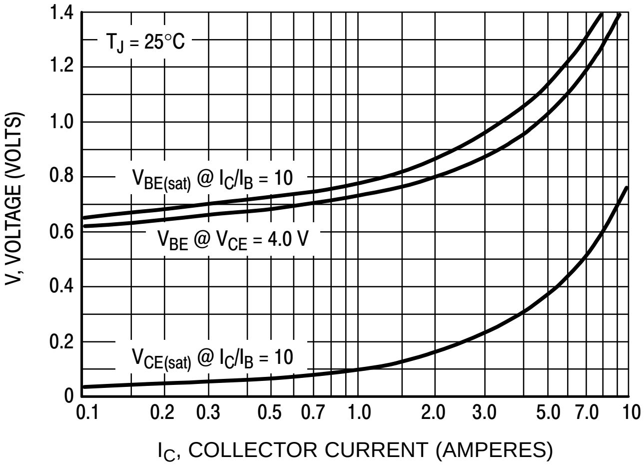


Figure 7. "On" Voltages, 2N3055 (NPN)

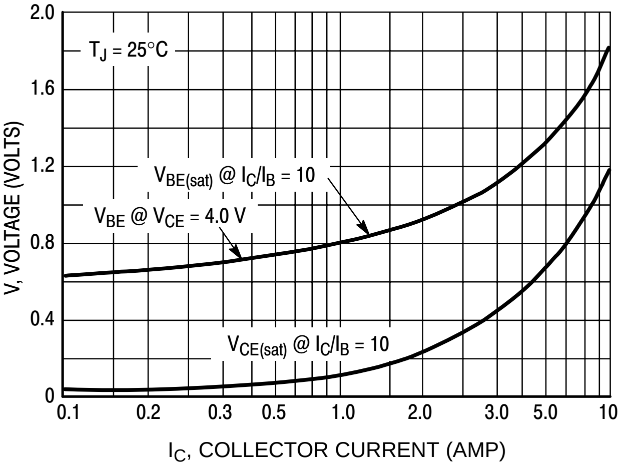
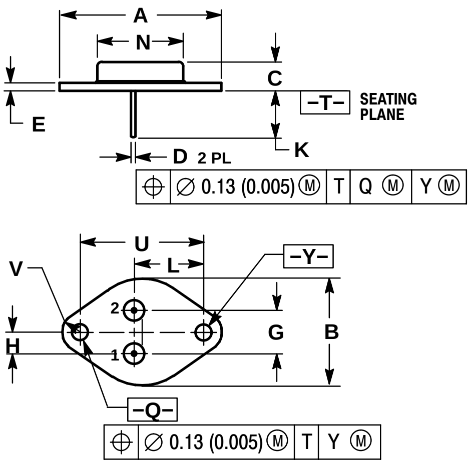


Figure 8. "On" Voltages, MJ2955 (PNP)

PACKAGE DIMENSIONS

TO−204 (TO−3)
CASE 1−07
ISSUE Z



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. ALL RULES AND NOTES ASSOCIATED WITH REFERENCED TO−204AA OUTLINE SHALL APPLY.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.550 REF		39.37 REF	
B	−−−	1.050	−−−	26.67
C	0.250	0.335	6.35	8.51
D	0.038	0.043	0.97	1.09
E	0.055	0.070	1.40	1.77
G	0.430 BSC		10.92 BSC	
H	0.215 BSC		5.46 BSC	
K	0.440	0.480	11.18	12.19
L	0.665 BSC		16.89 BSC	
N	−−−	0.830	−−−	21.08
Q	0.151	0.165	3.84	4.19
U	1.187 BSC		30.15 BSC	
V	0.131	0.188	3.33	4.77

STYLE 1:
PIN 1. BASE
2. EMITTER
CASE: COLLECTOR

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