DESIGN AND CONSTRUCTION OF AN ELECTRIC CHARGE METER

BY

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A FINAL YEAR PROJECT

ON

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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING DECREE (B.ENG) IN ELECTRICAL AND COMPUTER ENGINEERING.

SEPTEMBER, 2003.

CERTIFICATION

This is to certify that this project **ELECTRIC CHARGE METER** was designed and constructed by BOLARIN NIHINLOLAWA YETUNDE and OROSOKAN DAPO for the partial fulfilment for the Award of Bachelor's Degree in Electrical and Computer Engineering (B.ENG).in Federal University Of Technology, Minna.

....

ENGR. P.O.ATTAH **DATE**
Project Supervisor

....

ENGR. M.N.NWOHU **DATE**
Ag. Head of Department of Electrical
And Computer Engineering.

....

EXTERNAL EXAMINER **DATE**

DECLARATION

I Bolarin Nihinlolawa Yatunde hereby declare that this project has never been presented before either wholly or partially for any degree else where, was totally designed, and constructed by me under my supervisor, Engr. P.O. Attah.

Information obtained from published and unpublished works of others have been acknowledged accordingly.

21/10/2003
97/5976EE

DEDICATION

This project is dedicated to God Almighty my creator, my protector, who for his Grace.

Goodness and Mercy, I am still alive today despite all the storms.

ACKNOWLEDGEMENT

My humble and honest gratitude goes to Almighty God, His son Jesus Christ for His divine provisions, watchful eyes and guidance throughout the course of my study.

Special thanks go to my Family: My Dad Chief S.S. Bolarin, My Mum Mrs J.B. Bolarin, My sisters; Adeola and Eniola, and My brothers; Olamide and Gbolahan. Words are not enough to say thanks for their constant love, care and understanding throughout my academic career.

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My appreciation also goes to every member of staff of my department and the school entirely for their efforts and encouragement to me during the course of training.

I am indeed indebted to all my friends and course mates, for their care, love, and interest in my welfare and support throughout my academic career.

I wish my deep love and appreciation to Alhaji Adeniran and Family for their care and understanding and advice given to me. Thanks for always being there for me.

I cannot afford to forget my only family in school; Fellowship of Christian Students (His dwelling place), My school siblings, my heartthrobs, infact, I am short of words to qualify them; the members of drama unit, for their interest in the growth of my faith in God. My education and Well-being.

ABSTRACT

The charge meter uses a comparator as its measuring element. The charge on the meter is transferred to the capacitor, it amplifies it and the output of the amplification stage is connected to the metering network and comparator. The metering network measures the magnitude of the charge while comparator indicates the polarity of the charge. It does this by comparing its input to the reference voltage.

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CHAPTER ONE

:RAL INTRODUCTION

INTRODUCTION

ɔstatic discharge in workshop or laboratory can lead to a great deal of damage.

The phenomenon is becoming an increase important concern with today`s integrated circuit ɛchnology. The basic phenomenon is the building up of static charge on a person's body with juent discharge to the product when such a person touches the product.

Even the electrostatic charge on a human body can give rise to voltage up to 25KV in tude. When discharge occurs, large currents momentarily course through the product. This t may not only interfere with the correct operation of the equipment but can lead to irreparable e to certain components, for example it can cause IC memories to be cleared, certain machines eset and so on.

Research has shown that, human body may be considered as a capacitor with value of 100- . During an electrostatic discharge (ESD), a person can have an internal resistance of 150- . The electrostatic charge appears to be concentrated in some parts of the body, such as hands.

The phenomenon depends strongly on the humidity in the atmosphere. Static electricity is more noticed in raining season than in dry season because the air is much drier in raining than in dry season. Dry air is a relatively good electrical insulator. So if something is charged arge tends to stay. In more humid conditions, such as you find on typical dry day, water ıles, which are polarized, can quickly remove charge from a charged object.

The discharge is obviously preceded by the forming of an electrostatic charge, which is lly caused when a conductive and a non-conductive material are rubbed together. The area of aterial rubbed plays an important role in determining the type of charge acquired by the al.

Because of all these and the speed of the discharge pulses, electrostatic discharge can rapidly e semiconductors when they are touched by hands. Consumers do not view these events as normal operation of a well-designed product. Consequently manufacturers test their product to rolled ESD event that represents a typical field scenario and determines whether the product es successfully.

LITERATURE REVIEW

l methods have been used to measure the electric charges. Among them are:

ar foil leaf/ leaf electroscopes: This deals with electrostatic potentials in the range of many eds or thousands Volts. This is an insulated conductor, when any charged body is brought it indicates the extent of the charge by showing deflection on the meter. The accuracy and the of value that can be read by this method are very limited because of the wide range of ion. The device cannot actually read the amount of the charge, the polarity cannot be ined. This only detects potentials with very high voltage.

Ridiculously sensitive charge detector: This device can detect very small voltage like 1 s sensitivity is ridiculously high. Since "static electricity" in our environment is actually a of high voltage, the device can sense those high voltage objects at a great distance of imately 20 metres. If a metal object is lifted up on a non-conductive support and touched to isor wire, the sensor can detect whether that object supports an electrostatic potential of as s one volt. It has two major disadvantages, namely: (a) it can only detect the charge but cannot e the actual amount of the electric charge present. (b) It doesn't work when the humidity is

Electrometer: It determines the fraction of the charge on an outer sphere the remaining will still be inside an inner one. The calibration is in terms of the fraction left. When it senses irges, it deflects but the deflection is not accurate, it is about 300 times the least detectable

Torsion Balance: This device compares the effects of different amount of charge. The man vented this device worked on his phenomenon that says, "If a charged metal sphere touches an ged metal sphere of the same size, the second sphere becomes charged also. Some of the from the first one is conducted to the second and the charges become equal, and are both o the original charge". This device always finds the magnitude of the electric force to be tional to the product of the charges. It can compare the amount of charges but cannot state the amount of the charge, cannot sense the very low potentials and humidity does not have effect This cannot be used in the laboratory while working on semiconductors because it will just the charge have been transferred to the semiconductor.

This electric charge meter will detect the presence of unwanted charge and read out the t of charge so that protective measures can be taken.

shows the block diagram of the electric charge meter:

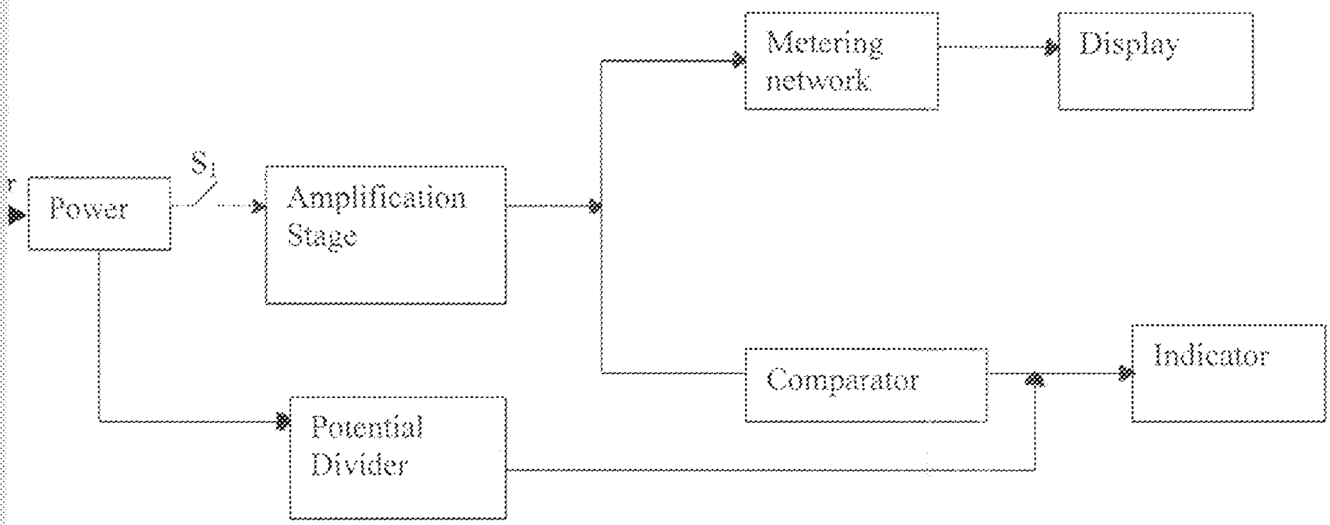


Fig 1.1: The Block Diagram Of Electric Charge Meter.

PROJECT OBJECTIVE / MOTIVATION

Although work on circuits containing semiconductors and integrated circuits should always rried out with an earthed soldering iron and an earthed wrist strap, it is still good practice to tain whether anti-electrostatic discharge are necessary. Putting into considerations that itors in particular, are essential in nearly every circuit application. With this meter, presence of ostatic charges can be detected so that protective measures can be taken. The objective of this ct is to produce a prototype of electric charge meter that will measure the value of electric e and be technologically compliant.

PROJECT LAYOUT

In this report, the first chapter introduces the various existing methods of detecting electric ...es, outlining some merits and demerits. The most important ones are discussed at length. The ...d adopted uses the two-path signal; one to the metering network and the other to the ...arator.

Chapter two deals with the design of individual modules

Chapter three discusses the construction, testing and discussion of the result.

In chapter four, conclusion was reached and recommendations were made.

CHAPTER TWO

EM DESIGN AND ANALYSIS

INTRODUCTION

The design made here was done using the principle of an electric charge, i.e. Q=CV C is the

itors and V is the voltages.

The project was designed to meet the following requirements:

) Detect the presence of electrostatic charges

) Measure the value of electric charges

) Detect whether the charge is positive or negative

) It should be technologically current

) Be easy to use

Having considered the above specification, a decision was attained that the electric charge can be designed after putting into consideration the principle of electric charge.

Therefore it is not wrong to say the principle used is called "PRINCIPLE OF ELECTRIC RGE METER".

WHAT IS AN ELECTRIC CHARGE?

There are different answers to this. Some defines charge as stuff that flows during an electric nt, another version said it appears on a balloon when you rub it on your hair. Some says it is the hat connects all the flux-lines of electrostatic fields of protons and electrons, the medium that y flows through, that causes electrical attraction and holds everyday objects together. That its ured in units called Coulombs and that, the scientist once called "quantities of electricity", cles of electricity" and lots more.

As a matter of fact, the definition of electric charge cannot be said without linking up thing together, therefore definition of the word "electric charge" becomes a serious problem. ric charge is a component of atom, in other words after we have broken an object into cules, broken molecules into atoms, when we break atoms apart we discover particles of electric ge.

CHARGE

"Like charges repel, unlike charges attract."

"Positive charge comes from having more protons than electrons; negative charges come from having more electrons than protons."

"Charge is quantized, meaning that charges comes in integal multiples of the elementary charge e."

Probably most people are familiar with the first two concepts, but what does it mean for ge to be quantized? Charge comes in multiples of an indivisible unit of charge, represented by etter 'e'. In other words, charge comes in multiples of the charge on the proton or electron. on and Electron have the same size charge, but the sign is different. A proton has a charge of while an electron has a charge of –ve. Electrons and protons are not the only things that carry ges. Other particles like positrons also carry charge in multiples of the electronic charge.

"Charge is quantized" can be expressed in terms of equation

$q = ne$ ....1.

Where q is the symbol used to represent charge

n is negative or positive integer

e is the electric charge

$1.60*10^{-19}$ Coulombs

ELECTROSTATIC ENERGY (u)

Electrostatic energy (u) for point charge can be found. It is simply the same thing as work in efinition of voltage. Since the electric potential is defined as the potential energy of charge q d between points a and b and is simply equal to qVab.

In other words; U =QV ……………………………………….2

e U is the Electrostatic energy

Q is the energy charge

V is the potential difference

DISTRIBUTION OF CHARGES

In a conductor, charges moves until all parts of a conductor are at the same potential. If a and a small sphere have the same total charge, the large sphere will have a lower potential.

THE LAW OF CONSERVATION OF CHARGE

The law of conservation of charge states "the net charge of an isolated system remains tant".

If a system starts out with an equal number of positive and negative charges, there's nothing an do to create an excess of one kind of charge in that system unless we bring in charge from de the system or remove some charge from the system. Likewise, if something starts out with a n net charge, it will always have the same net charge unless it is allowed to interact with thing external to it.

Charge can be created and destroyed, but only in positive-negative pairs.

CAPACITORS

Capacitor is a device (sometimes called a condenser) that stores charges in the electric field een its plates. Each plate carries the same amount of charge, one plate being negative and the being positive.

Capacitance: It is proportionality constant, symbol is C and SI unit is Farad F. it is normally ght of as being between two bodies, two parallel plates of area A that are separated a distance d approx $C = E_0 A/d$

$Q = CV$……………………………………………………………3

Where; Q is charge in coulombs

C is capacitance

V is the potential difference.

ELECTROSTATIC CHARGES

Forces between two electrically charged objects can be extremely large. Most things are rically neutral; they have equal amount of positive and negative charges. If this wasn't the case.

orld we live in would have been a stranger place. We also have a lot of control over how things harged. This is because we can choose the appropriate material to use in a given situation.

Electric current is a flow of charge, and when opposite charge are separated, electrostatic omena appears.

Metals are good conductors of electric charge while plastics, woods and rubber are not. They alled insulators. Charge does not flow nearly as easily through insulators as it does through uctors, which is why wires you plug into a wall socket are covered with a protective rubber ng. Charge flows along the wires, but not through the coating to human being.

rials are divided into three categories, depending on how easily they will allow charge (i.e. rons) to flow through them. These are:

Conductors: metal for example. Charge on the surface of a conductor is very mobile, and tends to move about to distribute the charge equally over that surface. Charge separation on the surface of a conductor can be caused by induction, by bringing a charged body near the conductor.

Semiconductors: silicon is a good example.

Insulator: rubber, wood and plastic are good examples. Charged insulators are not in themselves the problem, because the charge on an insulator is not free to move.

ALLOCATION OF NET CHARGE

here are three ways that objects can be given a net charge. These are:

. Charging by friction: This is useful for charging insulators. If you rub one material with another (say a plastic ruler with a piece of paper towel), electrons have a tendency to be transferred from one material to the other. For example, rubbing glass with silk generally leaves the glass with positive charge; rubbing PVC rod with fur generally gives the rod a negative charge.

. Charging by conduction: Useful for charging metals and other conductors. If a charged object touches a conductor, some charge will be transferred between the object and the conductor, charging the conductor with the same sign as the charge on the object.

. Charging by induction: Also useful for charging metals and other conductors. Again, a charged object is used, but this time its only brought close to the conductor, and does not touch it. If the conductor is connected to ground, electron will either flow unto it or away from it. When the ground connection is removed, the conductor will have a charge opposite in sign to that of the charged object. Example of induction is using a negatively charged object and an initially uncharged conductor (i.e. a metal ball on a plastic handle)

THEORY OF SERIES RC CHARGING CIRCUIT

The series arrangement of resistor R and capacitor C and the negative across capacitor C can easured when switch S is closed, current flows from the battery through resistor R to charge the citor, which was initially uncharged; Potential difference across C Vc builds up and eventually nes reference voltage Vb. Figure below:

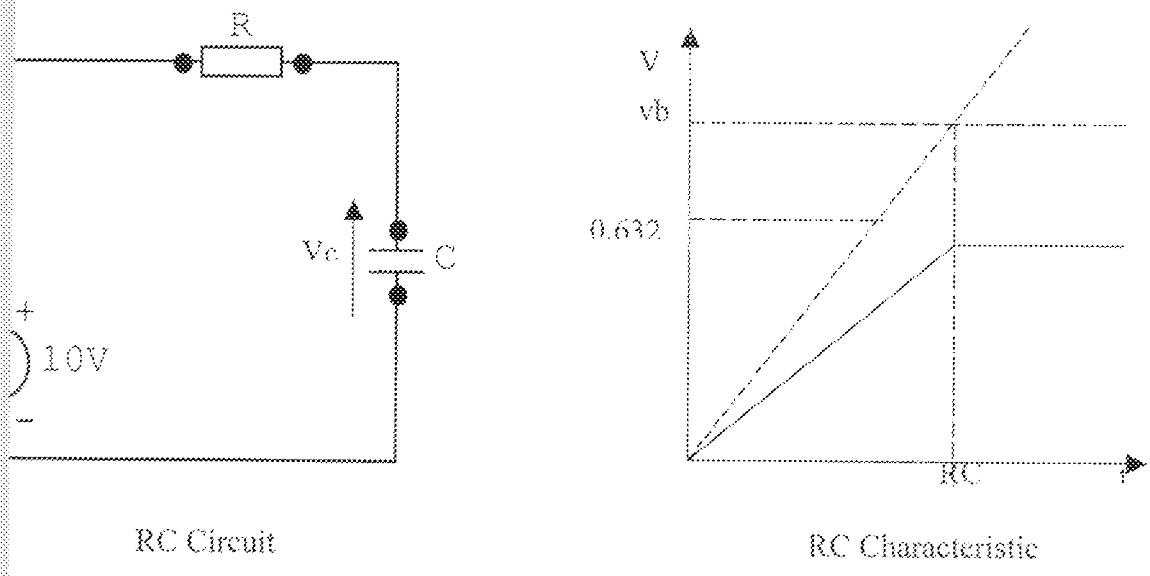


Fig 2.1: RC Charging Circuit

P.d across C,

harging current

Charge on a capacitor plates.

iR + Vc 4.1

q/dt = d(CVc)/dt

Vc/dt 4.2

Vc + RCdVc(t) 4.3

Vc(t) = RC dVc(t)/dt

b – Vc(t))dt = RcdVc(t)

RC = dVc(t)/Vb-Vc(t) 4.4

tegrating both sides;

lVc(t)/Vb-Vc(t) = ∫dt/RC 4.5

n (Vb-Vc(t)) = t/RC + k

ı (Vb-Vc(t)) = -t/RC + k 4.6

Vhere k is a constant of integration whose value can be found from initial known condition and

ecalling that when t = 0, Vc = 0, then the equation (2.4) becomes;

n (Vb-0) =0 + k

n (Vb) = k

Hence k = ln Vb 4.7

From equation (2.4), substituting k in it

n (Vb-Vc(t)) = -t/RC + inVb

ln (Vb-Vc) –ln Vb = t/RC

ln (Vb-Vc)/Vb = -t/RC 4.8

Taking exponential of both sides;

$-Vc/Vb = e^{-t/RC}$ 4.9

$-Vc = Vbe^{-t/RC}$

$c = Vb - Vbe^{-t/RC}$

$c = Vb\,(1 - e^{-t/RC})$ 4.10

ssuming the P.d across R = ½ Vb, C will charge to ½ Vb

herefore vc = ½ Vb 4.11

½ Vb = Vb (1-e^{-t/RC}) 4.12

$\frac{1}{2} = 1-e^{-t/RC}$ 4.13

$/RC = -\ln(\frac{1}{2})$ 4.14

$/RC = 0.693$

$= 0.693RC$ 4.15

2.9 IC DESCRIPTION (TL084)

TL 084 is from a family of TL08x JFET input operational amplifier; it is designed to offer a wider selection than any previously developed operational amplifier family. JFET-input operational amplifier incorporates well-matched high-voltage JFET and bipolar transistors in a monolistic integrated circuit. The device features high slew rates, low input bias and offset currents and low offset voltage temperature coefficient.

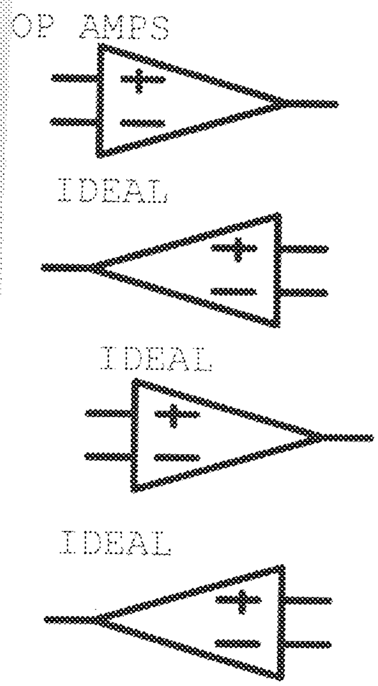
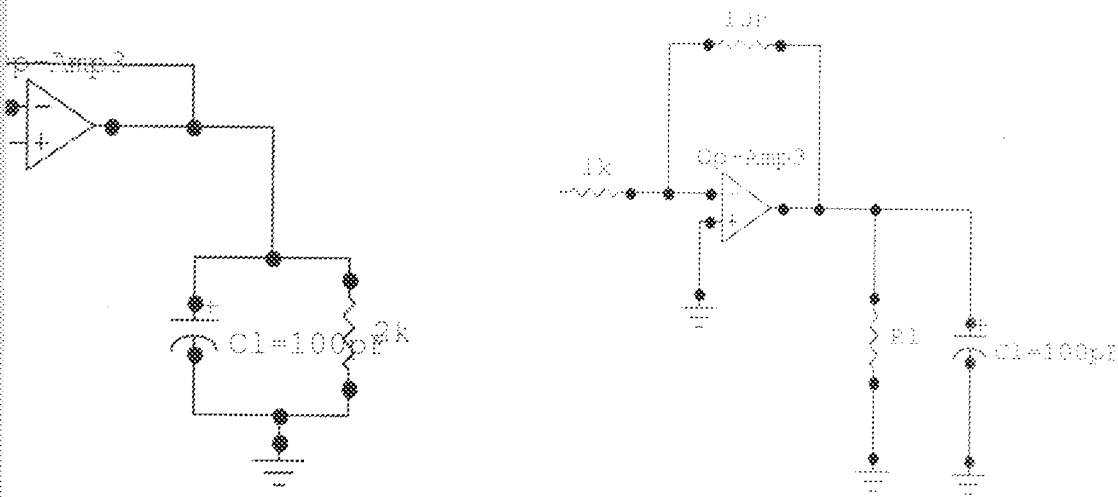


Fig 2.2: Internal Architecture of TL084 Showing Each Amplifier

ote: Pin (11) is internal connected to backside of chips. The bonding pads of the chips are 4*4



g 2.3: Parameter Measurement Information of TL084

).1 APPLICATION INFORMATION OF TL084

.084 can be used in various ways, amongst others is in the audio-distribution amplifier. Below is e circuit diagram showing how the amplifiers are connected to construct audio-distribution nplifier.

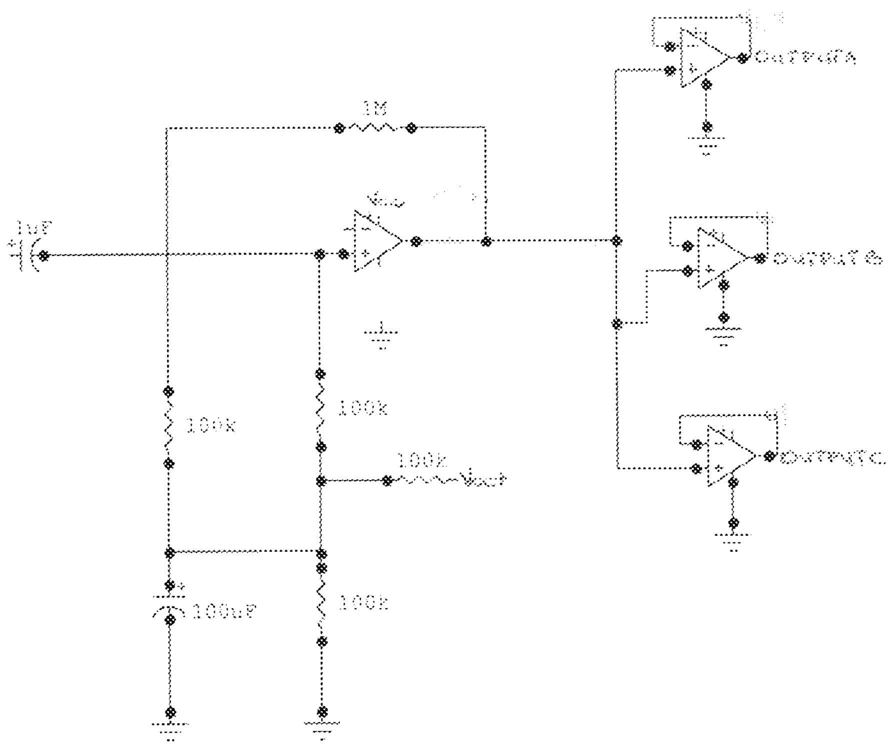


Fig 2.4: Audio-Distribution Amplifiers

0 PRELIMINARY CONSIDERATIONS

The contact potential series propounded demonstrates the contact charging induces the velopment of surface charges that may render the surface either negatively charged due to an cess of electron or positively charged due to a deficit of electrons. With negatively charged irfaces, the excess electrons are held in their deep wells close to the surface by electrostatic fields reated by the molecular environment. As a consequence, negatively charged surfaces tend to remain harged for considerably longer period of time. The positive charge will tend to be more mobile, ince greater probability exists for their neutralization by free electrons.

The leakage of surface charge may not always take place over the dielectric surface; it may lso be dissipated through the bulk of the dielectric. Consequently, an electric field probe neasurement made at a fixed distance from the metallic surface will indicate constant field strength over the surface, while the same measurement performed over a dielectric surface will exhibit considerable variation in the field strength.

At this point it is appropriate to make a few remarks concerning the mechanism of surface charging by contact. When two materials with work functions $\varnothing_1$ and $\varnothing_2$ respectively contact each other over an area A, an electrostatic charge equal to

$Q = \infty A (\varnothing_1 - \varnothing_2)$ 5

is transferred across the contiguous interface in order to establish thermodynamic equilibrium. Here ∞ represents a constant of proportionality.

In practice however, the neutralization state will not be attained because of the finite time constant, ζ of the semiconductor (or the more insulating material if two electric surfaces are involved) given by $\zeta = \rho\xi$ 6

here p is the volume resistivity and E^1 is the real value of the permittivity of the material. For sulating or dielectric materials, the values of p are relatively very large, while for semiconductors p a strong function of temperature, becoming comparable to that of dielectric materials at absolute ro. The values of p and E' for the usual insulating materials are substituted into equation; the sulting ζ is much larger than the time interval required for breaking the contact. Following the reaking of the contact, a charge equal to

$Q^1 = \beta A (\varnothing_1 - \varnothing_2)$ ……………………………………………………………6

Remains on the surface of one of the materials and an opposite and equal charge of $-Q^1$ on the material. β is a proportionality constant; the dynamic behavior of the two layer system is such that β ≤ ∞. It is precisely this remaining charge on the surface of the two materials that gives rise to the so-called contact potential, since the charges on the two sheet materials yields surface charge densities equal to $q^1 = Q^1/A$ and $q^1 = -Q^1/A$ ……………………………………………………7

respectively, the electric field in the gap separating the two sheets is given by

$E = Q^1/AEo = q^1/E_o$ ………………………………………………………………8

Where E_o is the permittivity within the air gap between the two separate materials

Q^1 is the surface charge of the materials,

q^1 is the surface charge density,

A is the area of the materials

Note that if use had been made of electrostatic units in lieu of SI units then $E_o = 1$, so that the above expression would simplify $E_1 = 4\prod q^1$ ……………………………………………………9

Where E^1 is the electric field

And the electric field contribution due to each sheet is equal to $2\prod q^1$.

1 DESIGN CONSIDERATION

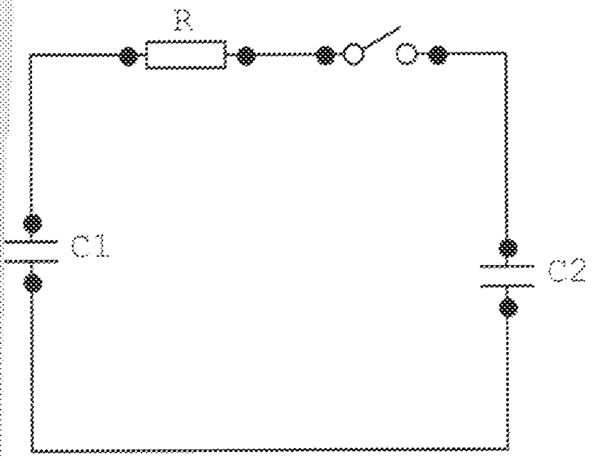


Fig 2.5: Principle of electric charge meter

Consider an object (or person) C_1 with a certain electrostatic charge, which is used to charge a (previously uncharged) capacitor C_2. R is the inevitable transfer resistance provided that the value of C_2 is not less than 10 times that of C_1, the larger part of the charge on C_1 will have moved to C_2 within a relatively short time. The potential across C_2 can then be measured to form a measure of the charge the capacitor has received.

Since the charge is the product of capacitance and potential $Q_1 = C_1U_1$ and $Q_2 = C_2U_2$. When the switch is closed after a theoretically infinite time $U_1 = U_2$, that is. U_2 may be taken as the original potential across C_1 multiplied by the ratio $C:(C_1+C_2)$ using this in the formula for the charge on C_2.

$= U_1 (C_1C_2)/ (C_1+C_2)$ 10

ssume $C_1 << C_2$

$_2 = C_1U_1$ 11

esistance R merely delays the charge transfer but has no effect on the amount of charge ultimately ransferred.

.12 THE POWER SUPPLY UNIT

The DC power supply is a basic electronic system generally consisting of a transformer, a ectifier, a filter and a regulator to convert AC voltages to DC voltages.

Most electronics systems cannot operate successfully and effectively with AC power supply because t always fluctuating. Some electronics system operate from a low voltage DC supply, which derives from an AC source like NEPA, battery is another source of DC supply. Hence the meter is designed o run on a battery of 9V for proper and effective operation. Below is the circuit diagram of power unit

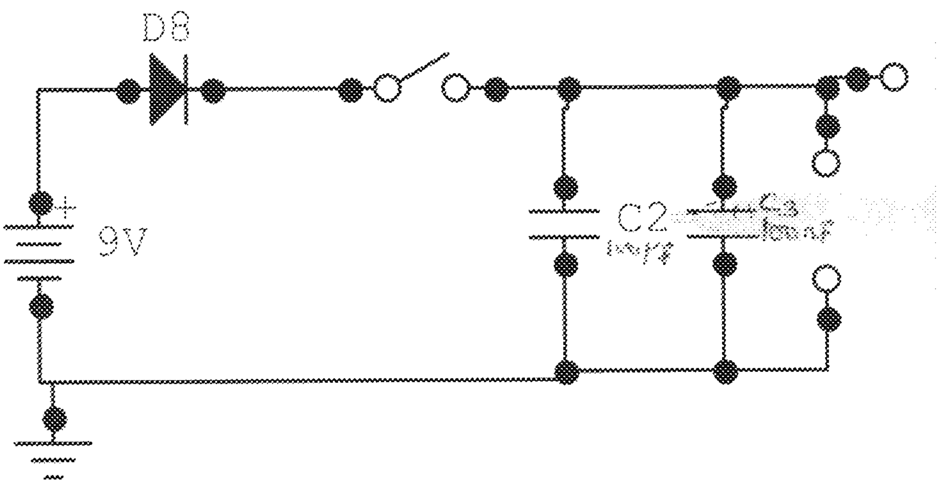


Fig 2.6: Power unit of Electric charge meter.

13 SIGNAL OUTPUT OF THE AMPLIFIER

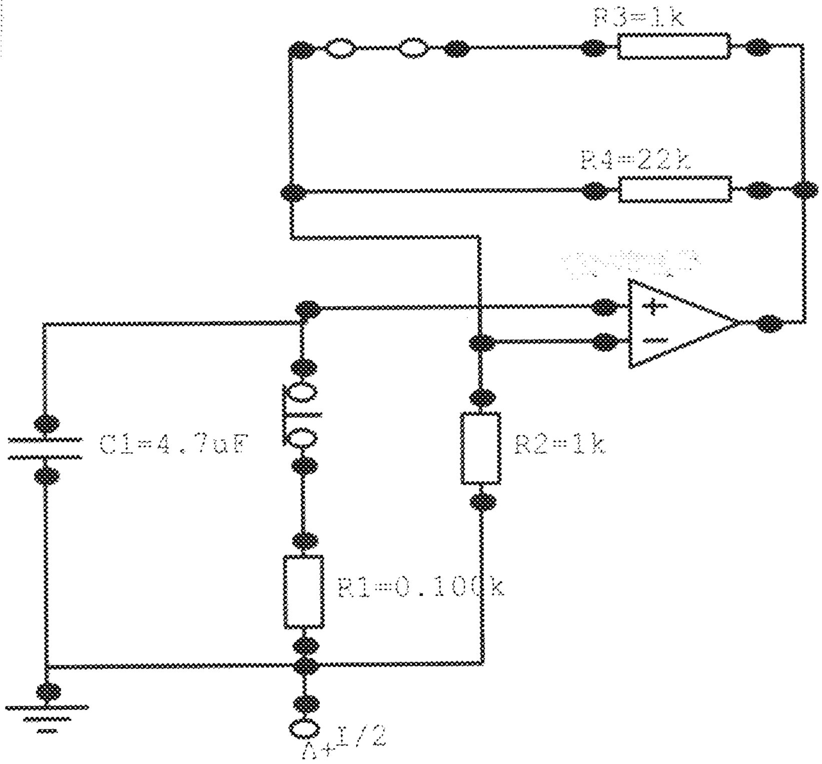


Fig: 2.7: Circuit of Signal Amplifier for Closed S_2

WHEN SWITCH S_2 IS CLOSED

Rt=(R4R3)/(R4+R3)

=(22*1)k/(22+1)k

=0.96k

AV=Rt/R2

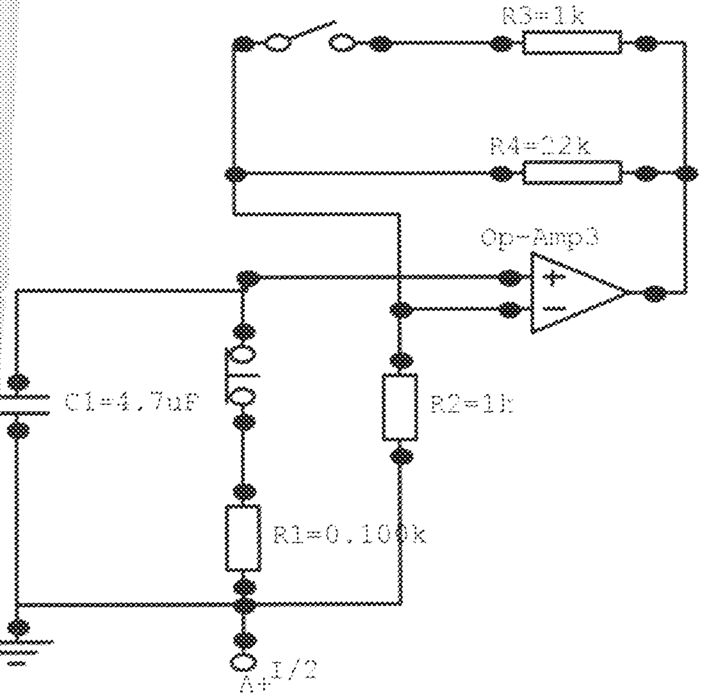
=0.96k/1k

=0.96

Vout=Vin(Rt/R2)

=(1/2)*9*0.96

=4.32V



g 2.8: Circuit of signal amplifier For Opened S_2

SWITCH S_2 IS
OPENED
AV=R4/R2
=22k/1k
=22
Vout=Vin(R4/R2)
=(1/2)*9*22
=99V

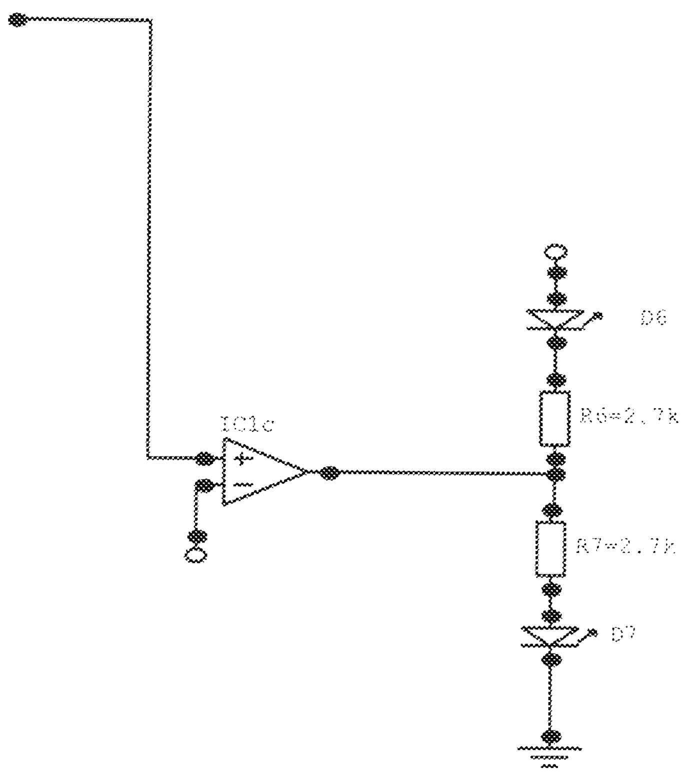
COMPARATOR

A comparator is used to compare the magnitude of two (2) signals.

From the input of IC1a, the signal takes two (2) paths one to the metering network and the
r to comparator IC1c as shown in Fig. The inverting input of IC1c carries half supply voltage as
rence potential. The output of the comparator therefore indicates the polarity of the measured
rge.

Red light comes up when the signal non-inverting side of the comparator is higher than the
rence potential; green light comes up when the signal is lower.

ow is the comparator circuit.



2.8: Comparator Circuit of An Electric Charge Meter

2.15 CIRCUIT DIAGRAM

Circuit diagrams of the electric charge meter are shown in. fig 2.9 and .2.10.

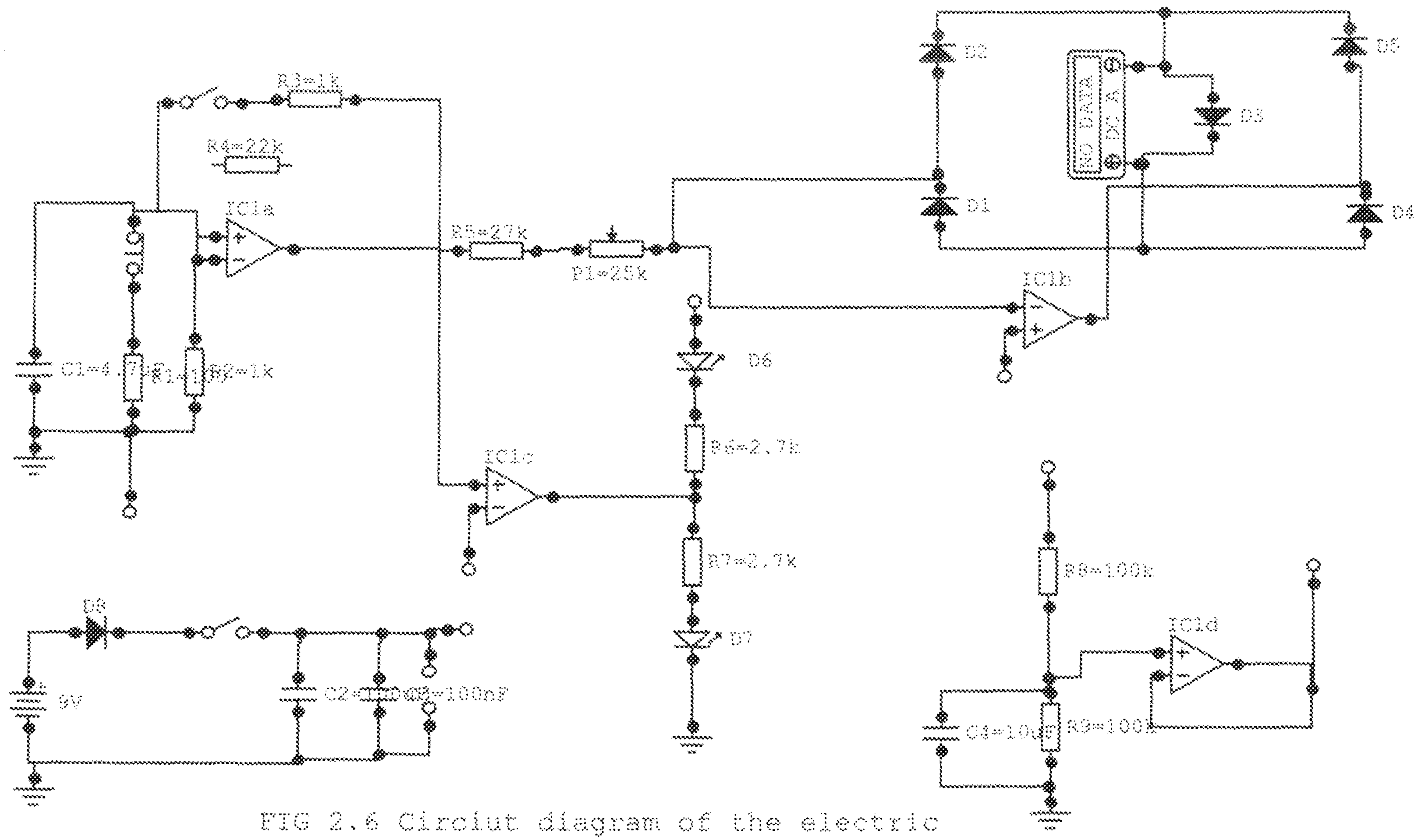


FIG 2.6 Circiut diagram of the electric charge meter.

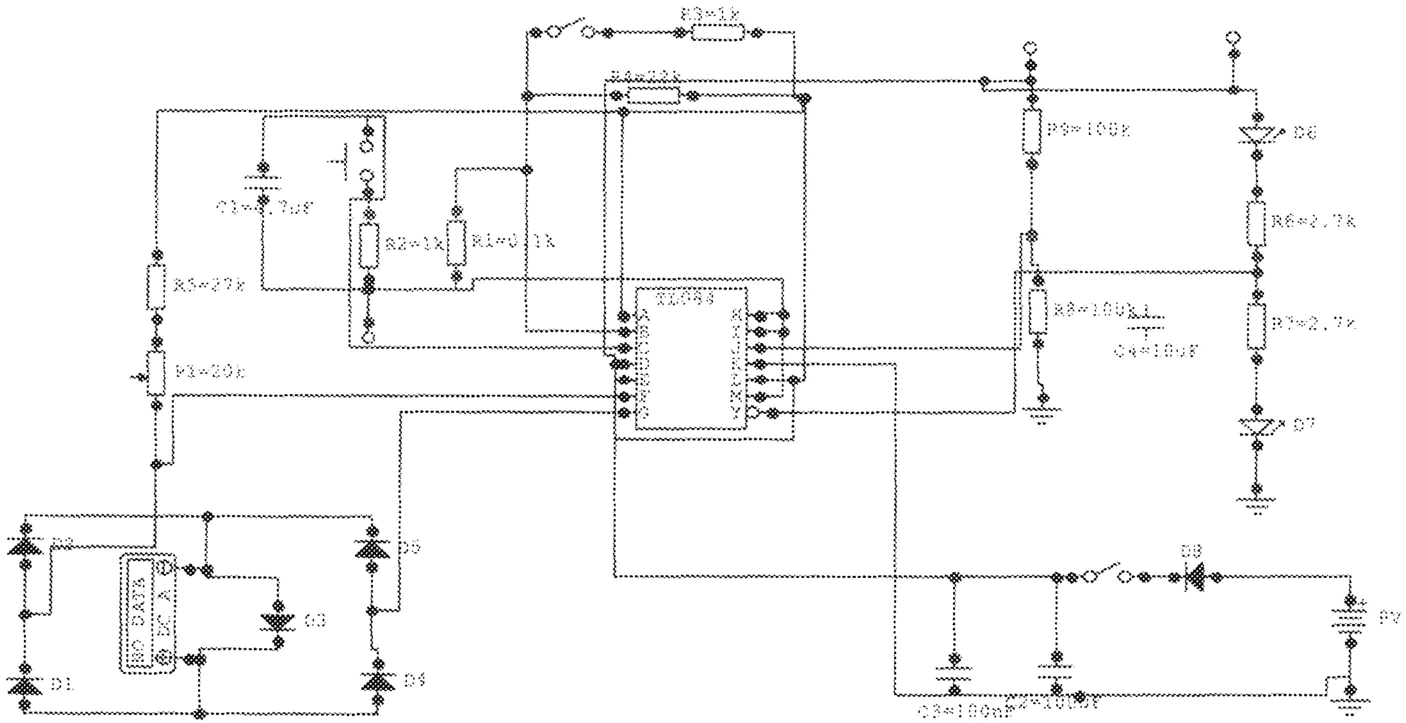


Fig 2.9: Circuit Diagram of An Electric Charge Meter, Showing The Connection of The Pins.

er always deflects in the same direction irrespective of the polarity of the original charge. Diode rotects the meter against too high a potential across it.

Power is derived from a 9V battery that is buffered by capacitor C_2 and decoupled for by citor C_3. Switch S_3 is the on/off switch, while diode D_8 protects the circuit against a wrongly iected battery. The stabilized half supply voltage mentioned on a few earlier occasions is ined from potential divider resistor R_8, resistor R_9 and buffer stage amplifier IC1d. It is essential he correct working of the circuit that the output of IC1d is connected to a good earthling point.

CHAPTER THREE

CONSTRUCTION, TESTING AND RESULT

In constructing this project, most consideration was given to the design specification. The adboard was used in testing each component and module of the design before soldering on to the o board. IC sockets were used to avoid over heating and burning of ICs with the bordering Iron.

CIRCUIT CONSTRUCTION

The charge meter was supposed to be best built on printed circuit board but due to umstances beyond or control, it was neatly soldered on a Vero board.

The circuit was designed to allow either a single 4.7μF or five 1μF in parallel to be used on board but because of neatness in soldering and arrangement with other components a single F was used as the input capacitor.

The power supply section was first connected and then tested on a breadboard; the required ut was finally obtained after series of checking to ensure correct connection of all components.

This was followed by the operational amplifier (op-amp) the metering network, the parator and the stabilized half supply voltage which was connected as specified in the design; it also checked properly before being soldered to the Vero board.

When the construction had been completed, it was mounted into a small casing.

The circuit was properly earthed to the mains earth, knowing the fact that, it is absolutely essential.

The input (touch) terminal used was a non-insulated material.

3.3 TESTING

In testing and calibration of the constructed circuit, a variable power supply was introduced, although initially a 9V battery was used.

When the earth wire had been connected, the power supply was switched on, and the reset knob switch S_1 had been pressed, then the charge meter was ready for use.
It is important for the charge meter to be at zero (0), whenever it is to be used.

With S_2 (slide switch) closed, the meter was set to 5μC range.

The variable power supply was adjusted to give an output of exactly 1.06V.

The output of the variable power supply was connected across capacitor C_1. The potmeter P_1 was adjusted to full scale on meter M_1 then measurement started.

3.4 RESULT

DC 9V battery was used to test the meter and 1.85μC was gotten. When the variable power supply was set at 8V the output was 1.60μC and when the variable power supply was set at 9V there was an output of 1.85μC.

Printed circuit board (PCB) should be made compulsory for students, because it makes the

t neater and of standard measure, even when ordinary soldering solders it.

Replacing non-conducting carpets, clothing or packing may prevent electrostatic charges by

ducting materials.

The use of an earthed wrist strap is strongly advisable when semiconductors are handled

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APPENDIX

PART LIST

RESISTORS	Capacitors
R_1=100Ω	C_1=4.7μF, 100V
R_2=1kΩ	C_2=100μF, 6V
R_3=1kΩ	C_3=100nF
R_4=22kΩ	C_4=10μF, 16V
R_5=27kΩ	**Semi-Conductors**
R_6, R_7=2.7kΩ	D_1-D_5, D_8=1N4001
R_8, R_9=100kΩ	D_6=LED, green, low current.
P_1=20kΩ Preset potmeter	D_7= LED, Red, Low current

Integrated Circuit

IC1=TL084

(Texas instrument)

Misc

S_1= Miniature spring-loaded push-button switch

S_2= Slide switch, 1 make contact PCB model

S_3= Single-Pole, Single-throw switch

M_1=Moving coil mater, 50μA.

9V battery with terminal clip.