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SYNOPSIS

This is my M.Sc Project part II. This is the continuation of project part I. In this semester I have focussed on the experimental work. I studied and fabricated electronic circuit which is used in measurement of muon lifetime. I wired up and tested muon lifetime circuit with detector.

The report contains four chapter .Chapter I is introduction which tells us about muon production and reaction that we use to measure muon life time. Chapter II deals with experimental arrangement required to measure muon life time. Chapter III is describing electronic circuit which I have wired up and tested myself.Here I have given details of all the component I used .In last chapter observations are made,data is recorded and finally interpreted using the muon life time circuit.

CHAPTER 1:INTRODUCTION

Muons were first identified in cosmic ray experiments by Anderson and Neddermeyer in 1936. The cosmic radiation, which consists of high energy particles that are mostly protons, enters the earth's upper atmosphere and interacts with the atmospheric nuclei such as nitrogen or oxygen produces secondary particles. Collisions of cosmic rays with atoms in the upper atmosphere produce mostly neutral and charged pions. Each neutral pion decays into a pair of gamma rays . The charged pions each decay , into a charged muon and a muon neutrino. So, the cosmic muons produced by the decay of pions, which are produced high up in the atmosphere . The pion decay, characterized by weak interaction is;

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad \pi^- \rightarrow \mu^- + \bar{\nu}_\mu \qquad \ldots\ldots \quad 1$$

the muons then decay in about 2 microsecond into an electron, a muon neutrino and an electron anti-neutrino.

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \qquad \text{mass of } \mu = 207 m_e = 105.7\ \text{MeV}/c^2 \qquad \ldots\ldots \; 2$$

The particles arriving from space are known as primary cosmic rays whereas the particles created in the collisions are known as secondaries. Many of the new particles are very short lived and do not survive to reach sea level, but positive and negative pions created in the process decay into muons that are detectable at ground level. The total secondary flux at sea level is about 1 cm^{-2} min^{-1}. Roughly 75% of the flux consists of positive and negative muons, 25% of it consists of electrons and positrons.Electrons and Positrons are created when photons produced by neutral pions shower.

If the negative muons stop in matter then they can be captured by atoms whereas the positive ones remain free. The mean lifetime of both positive and negative free muons is about 2.2 microseconds. Captured muons have a shorter lifetime.

Decay of charged pions into muons is as shown in Figure 1. It is primarily these muons that are observed by the detector.

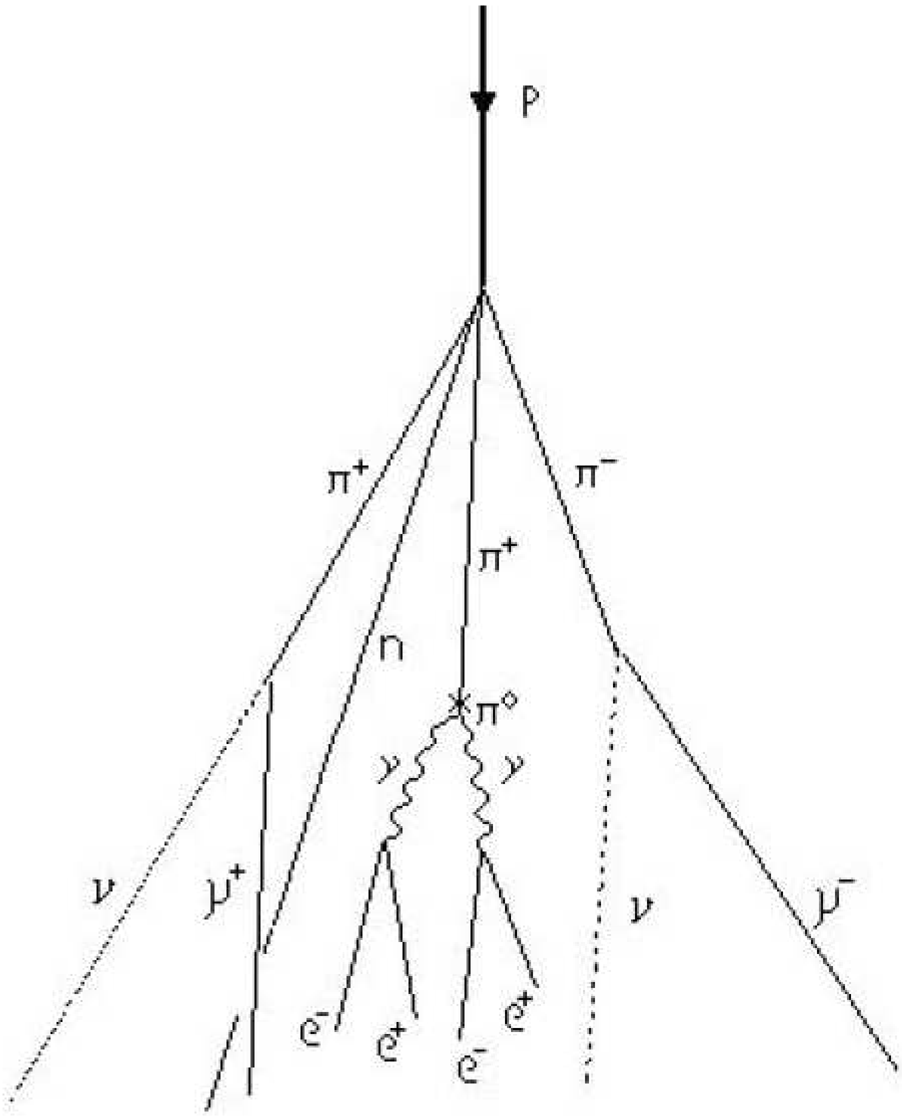


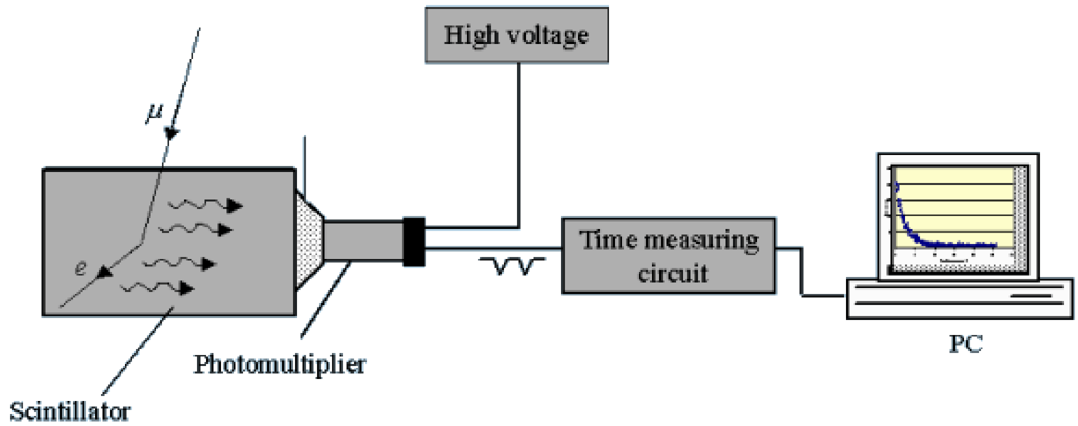
Figure 1. A typical interaction between a cosmic ray proton and an atmospheric nucleus.

According to Newtonian physics, if the mean lifetime of the free muons is about 2.2microseconds then they should only travel a few hundred metres when travelling at the speed of light after being created in the upper atmosphere and many fewer than that indicated above would be expected to reach the ground. The only way to explain the high number of muons detected at sea level is through relativistic time dilation.

CHAPTER 2:EXPERIMENTAL ARRANGEMENT

2.1)experimental setup:

The apparatus consists of a block of plastic scintillator wrapped with black paper and a photomultiplier tube (PMT). Purpose of black paper is to prevent signals from interaction of visible light with scintillator material. Light produced when cosmic rays pass through the scintillator is detected by the photomultiplier. phototubes ars used to guide the scintillator signal from scintillator to photomultiplier tube. Photomultiplier tube is operating at high voltage near about1.5KV. Occasionally a cosmic ray muon stops in the scintillator resulting in two signals first from the incoming muon and the second from the decay electron. The time delay between the two signals is measured and passed to a PC. This work is done by time measuring circuit.I was involved in wrapping the black paper around the plastic scintillator and



also in gluing the PMT to the detector.

figure2:block diagram indicating experimental arrangement of muon life time measurement

Time measuring circuit is explained in detail in next section.Software supplied on a CDROM produces a histogram for display and can analyse the data to give the mean lifetime of the muon.

Scintillator and Photomultiplier tube is discused in details as follows

SCINTILLATOR

PHOTOMULTIPLIER TUBE

2.2)SCINTILLATOR DETECTOR AND PMT

Scintillator Detector principles: Scintillation material gives of light when charged particles passes through it.

A)Scintillation mechanism in organics two eletctronic energy levels of organic molecular

Series of singlet states (spin 0) are labeled as S_O, S_1, S_2 . A similar set of triplet (Spin 1) electronic energy levels are shown in fig. Each level is again divided in to many vibrational states of molecule.At room temperature nearly all molecules are in s_{oo} ground state.Principle scintillation light (Prompt Fluorescence) is emitted in transitions between

this S_{10} state and one of vibrational state of ground electronic state.

$I = I_0\, e^{-t/T}$

I = prompt fluorescence intensity at a time t following excitation.

T = Fluorescence decay time for S_{10} level.

In most organic scintillator T is few nanoseconds.Lifetime of first triplet state T_1 is much longer than that of S_1. Through intersystem crossing some excited singlet state changes to Triplet states.Lifetime of T_1 may be = 10^{-3} seconds and radiation emitted in a deexcitation from T, to S_o is a delayed light emission characterised as phosphorecence.

Some molecules in T_1 state may be excited back to S_1 state and subsequently decay through normal fluorescence called delayed fluorescence.

B) TYPES OF ORGANIC SCINTILLATOR

1)Pure Organic Crystals:

Two materials are used in this category named Anthracene and stilbene. Anthrancene having highest efficiency light output per incident energy. Stilbene has

lower scintillation efficiency.

2)Liquid Organic Solutions:

These are produced by dissolving an organic scintillate in an appropriate sol--vent.

3)Plastic Scintillator:

Organic Scintillater is dissolved in solvent which can be polymerized. Solvent consisting of styrene monomer in which an appropriate organic scintillater is dis-solved. Styrene is then polymerized to form solid plastic.

C) Response of organic scintillators.

1) Light Output

Small fraction of KE lost by charged partical is converted into fluorescent energy response of organic scintillator to charged particle is almost linear

Response of organic scintillator is more to electron as compared to proton or alpha particles. At higher energy discrepancy is less but proten response is always below the electron
response

dL/dx = fluorescent energy emitted *I* unit path length.

dE/dx = specific energy loss for charged particles

dL/dx proportional to *dE*/dx in the absence of quenching

$dL/dx = S\ (dE/dx)$

S = normal scintillation efficiency when we consider quenching then

$dL/ dx = S\ (dE\ I\ dx)\ I\ (1 + KB\ dE/dx)$.. *3*

for fast electrons dE/dx is small $(dL/dx)_e = S\ dE/dx$

$(dL/dE)_e = S$

$dL=S\ dE_e$

$L= SE$

L is linearly related to initial particle energy. For second particle *dE/dx* is large$(dL/dx)_á = S/KB$
$KB = S\ (dL/dx)_á$
$KB = (dL/dE)e/(dL/dx)_á$
In order to match experimental data more closely, other formulas for dL/dx are pro-posed by number of authors. Graun & smith studied large number of organic scitillators and found out formula for dL/dx which is extended version of birks formula

$dL/dx = S\ (dE/dx)\ /\ [1 + KB\ (dEl\ dx) + C\ (dE/dx)^2]$..................................4
C is again empirically fitted parameter.

2) Time Response
If luminescent states in molecules (organic) are formed instantaneously and only prompt fluorescence is observed then intensity is $I = I_0$ e-t/T
It gives light pulse of very fast leading edge followed by exponential decay

To understand nature of pulse we must consider following two effects

1) Finite time to populate the luminiscent states.
2) delayed fluorescence & phosphorescence.
3) in organic scintillator approximately it takes about few ns to populate the levels which gives prompt fluorescence light.

Overall shape of light pulse is given by

$$I = I_0 e\text{-}t/T - I_0 \, e\text{-}t/T_1$$

$$I = I_0 \ (e\text{-}t/T - I_0 \, e\text{-}t/T_1)$$

2.3) PMT:

Scintillator counting in radiation detection and spectroscopy would be impossible without availability of devices converting extremely weak light output of scintillation pulse into a corresponding electrical signal. PMT does this job which converts very small output of scintillator to large electrical signal.

Electron multiplication ;

Secondary electron emission. Electron from photocathode are accelerated and caused to strike the surface of electrode called dynode. If material of more than one electron secondary electron emission is similar to that of photo-emission.

Basic element of PMT

In PMT there are Photocathode, Dynode, Anode. Dynode does the job of multiplying the signals. Dynodes are coupled to get large output proportional to scintillator output. It multiplies electrons and get are collected at anode. PMT'S are available in variety of sizes and properties.

,Photocathode

First element of PMT which converts incident light photon into electrons. Photoenission occurs in 3 steps 1). Absorption of incident photon & transfer of energy to an electron within photonissive material. 2) Migration of electron to surface 3.) Escape of electron from surface of photocathode.

Spontaneous electron emission

Normal conduction electron have some thermal kinetic energy which at RT will average about 0.025 ev. Some electron may have energy that exceeds the potential barrier.

If electron is energy that exceeds the potential barries thermal induced signals.
In metals thermal emission rate is few because of high potential barrier.
Quantum efficiency of photocathode

$$QE = \frac{\text{no of photoelectrons emitted}}{\text{no of incident photons}}$$

Quantum efficiency of any photocathode will be a strong function of wavelength or quantum energy of incident light. It also depends material used for photocathode. Higher the quantum energy, higher the quantum efficiency.
a = overall multiplication factor

$$a = \frac{\text{number of secondary electrons emitted}}{\text{primary incident electron}}$$

CHAPTER 3:TIME MEASUREMENT CIRCUIT

3.1) PMT PULSE:

This circuit is the heart of the muon life time measurement experiment.When muon passes through scintillator it produces signals in the form of light .This light is fed to photomultiplier tube which gives negative output.PMT gives pair of pulses as a output shown below.

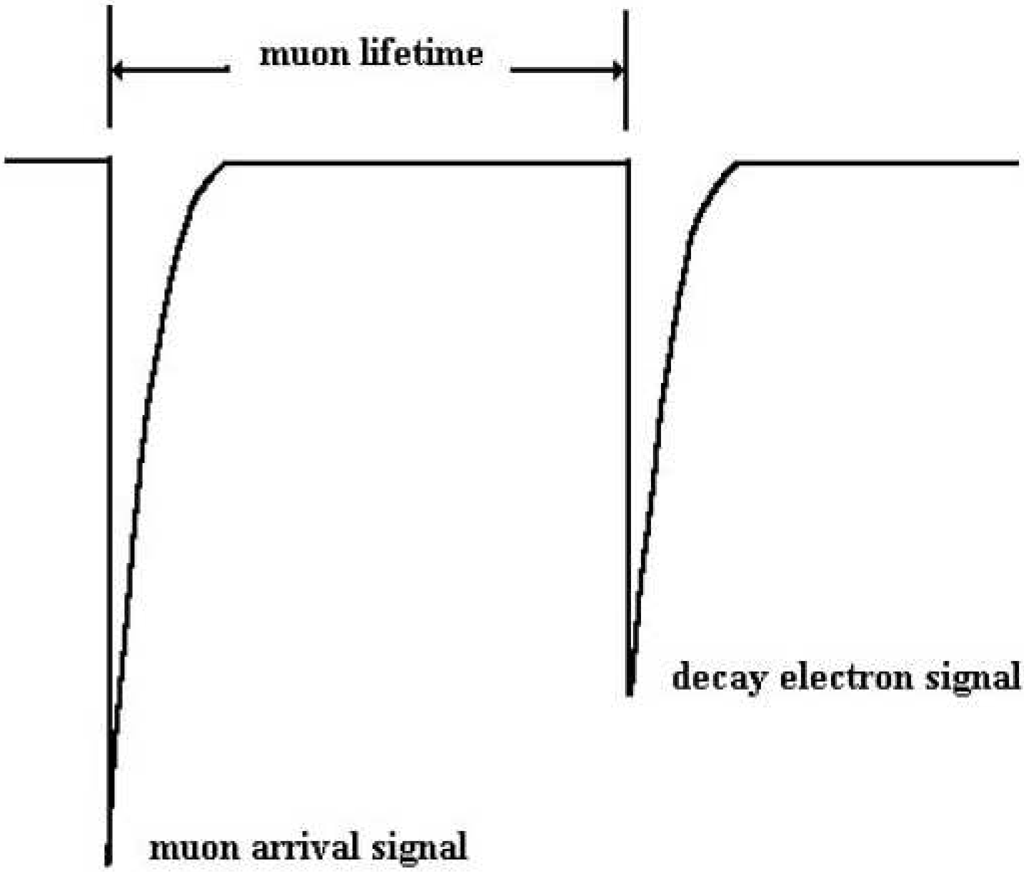


Figure3: output of photomultiplier tube

When a muon stops in the scintillator a short pulse of light is produced which is detected and amplified by the photomultiplier tube. The output from the PMT is passed to a comparator, which has the effect of filtering out noise and only allowing larger, genuine signals through. If a signal has passed through the comparator, it starts a counter, counting at a rate of 10MHz, giving a resolution of 0.1μs. If a second pulse (from the muon decaying) arrives soon after the first, the counter is stopped and the PC signalled to indicate that the counter has stopped and is ready to be read. The PC reads the data and resets the electronics ready for more decays.

If a second pulse does not arrive, the counter continues until a count of 25.5 microseconds is reached. The circuit will reset itself (and not signal the PC) and wait for the next decay.

3.2)IC USED

1)LM 360

This is used in discriminator part which takes PMT signal as a input gives suitable output. Connection diagram is shown in metal can package and Dual In Line package.It is eight pin configuration IC.

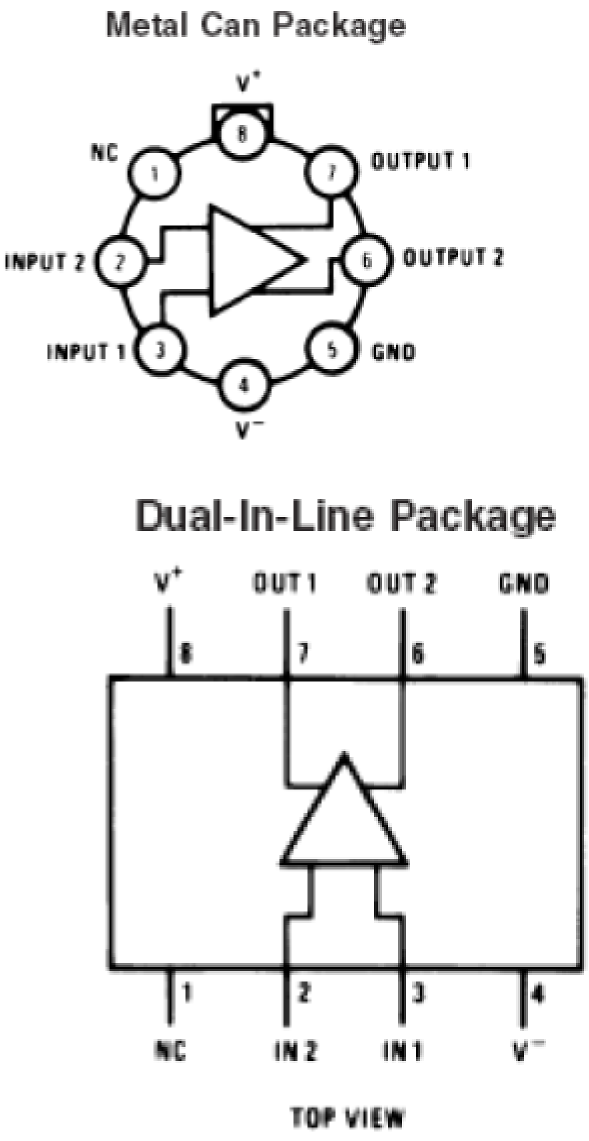


figure4:Lm360

2)74LS74

This is used with 14 pin configuration for a pair of identical D-flip flop

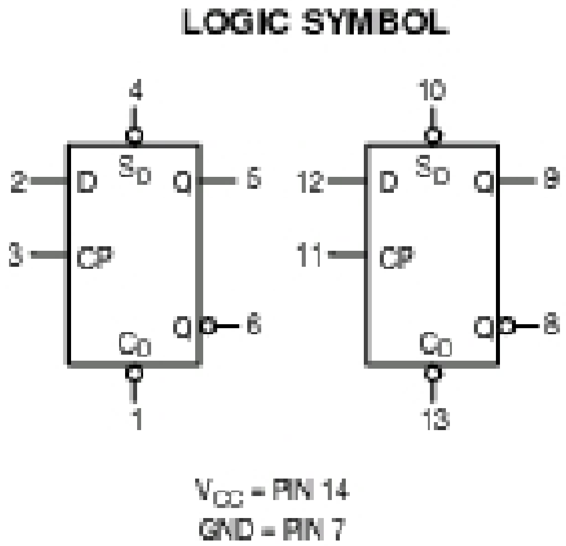


figure5:74LS74

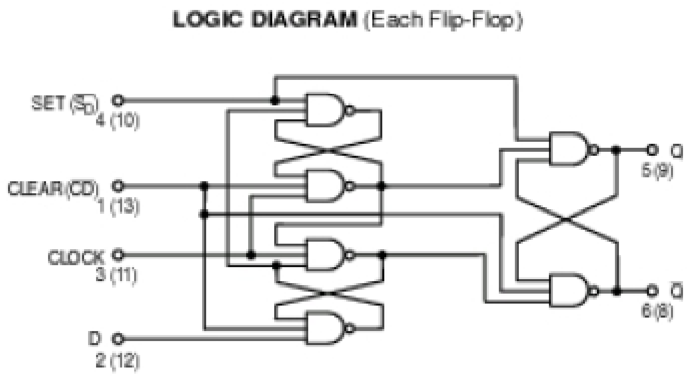


figure6:74LS74(LOGIC DIAGRAM)

<u>3)74LS04</u>

This is IC with 14 pin configuration.It contains six not gates.

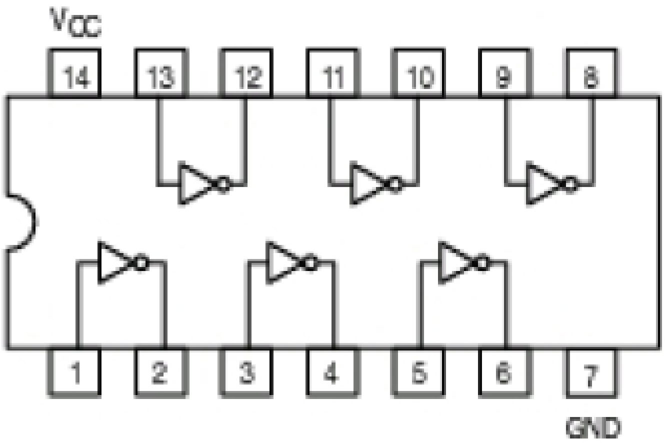


figure7:74LS04(PIN DIAGRAM)

GUARANTEED OPERATING RANGES

Symbol	Parameter	Min	Typ	Max	Unit
V_{CC}	Supply Voltage	4.75	5.0	5.25	V
T_A	Operating Ambient Temperature Range	0	25	70	°C
I_{OH}	Output Current – High			–0.4	mA
I_{OL}	Output Current – Low			8.0	mA

figure8: OPERATING RANGES

4)74LS541

this is 20 pin IC,called as abuffer.It takes 4 bit output from each counter and gives 8 bit output.

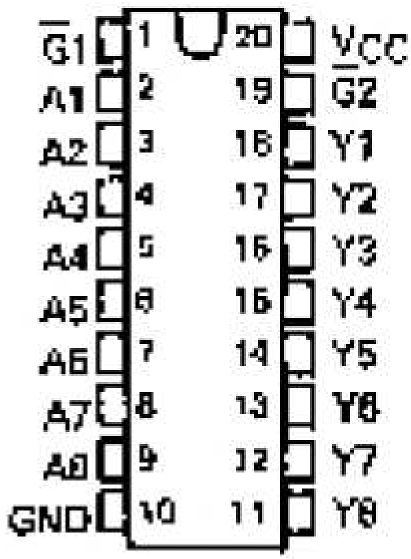


figure9:74LS541

<u>5)74LS1S1</u>

* Synchronous 4-bit counter
* Dual-In-Line Package
* 16 pins

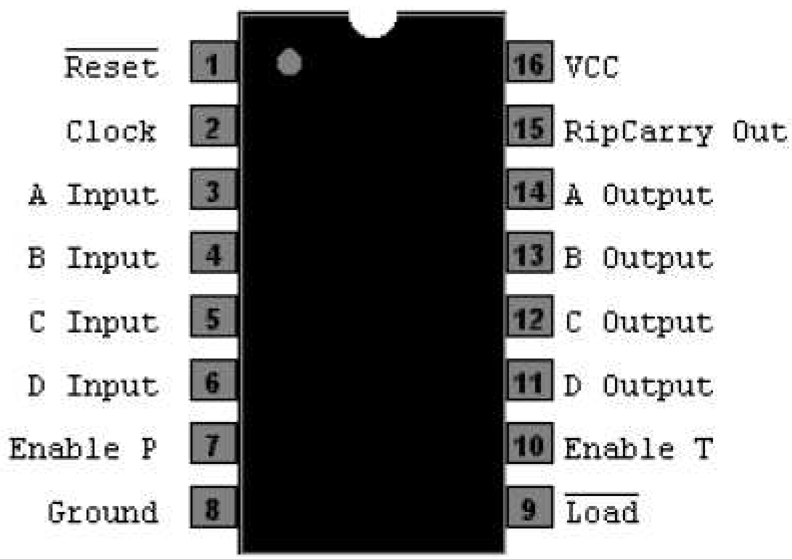


figure10:74LS161

6)74LS11

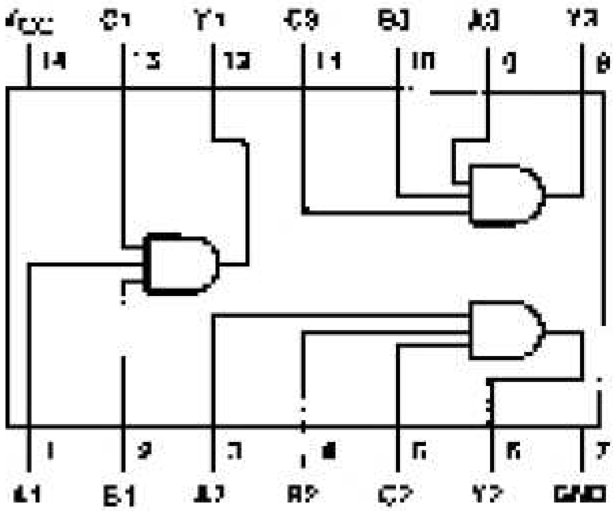


figure11:74LS11(PIN DIAGRAM)

Y = ABC

Inputs			Output
A	B	C	Y
X	X	L	L
X	L	X	L
L	X	X	L
H	H	H	H

H = HIGH Logic Level
L = LOW Logic Level
X = Either LOW or HIGH Logic Level

figure12:TRUTH TABLE FOR 74LS11

3.3)The electronic circuit

The first stage of the circuit is a high-speed comparator, the LM360. The threshold for this comparator is set, using a potential divider.Two D-type flip-flops make up a state machine, using three out of four possible states. The initial state, Waiting, has both F/Fs in a cleared state waiting for a start pulse from the PMT.

When a pulse from the PMT exceeds the threshold voltage, a positive pulse is output to the clock pin of the first F/F. The Q output of this flip-flop goes high (state, Counting) and starts a counter, counting at 10Mhz. The /Q output goes low and this output is taken to the clock input of a second flip-flop. If a second pulse comes from the PMT and passes through the comparator soon after the first, the Q output of the first F/F goes low and the counter is stopped (state, Read data). The /Q output goes high and clocks in a logic high to the second flip-flop. The /Q output of this F/F goes low, is buffered and the signal sent to the BUSY pin of the PC parallel port.

When the PC receives a BUSY signal, the DATA_STROBE line is pulled low to enable the data buffer. The data buffer passes the result from the counter to the PC. After the PC has read the data, DATA_STROBE is taken high and the RESET line pulled low for a microsecond. This RESET signal clears the flip-flops (back to state Waiting) and counter ready for the next signal from the PMT.

If the counter reaches 255 (25.5µs) and a pulse is not received, the RCO pin of the counter will go high. This is inverted to clear the counter and flip-flops, to state Waiting, in readiness for the next signal from the PMT.

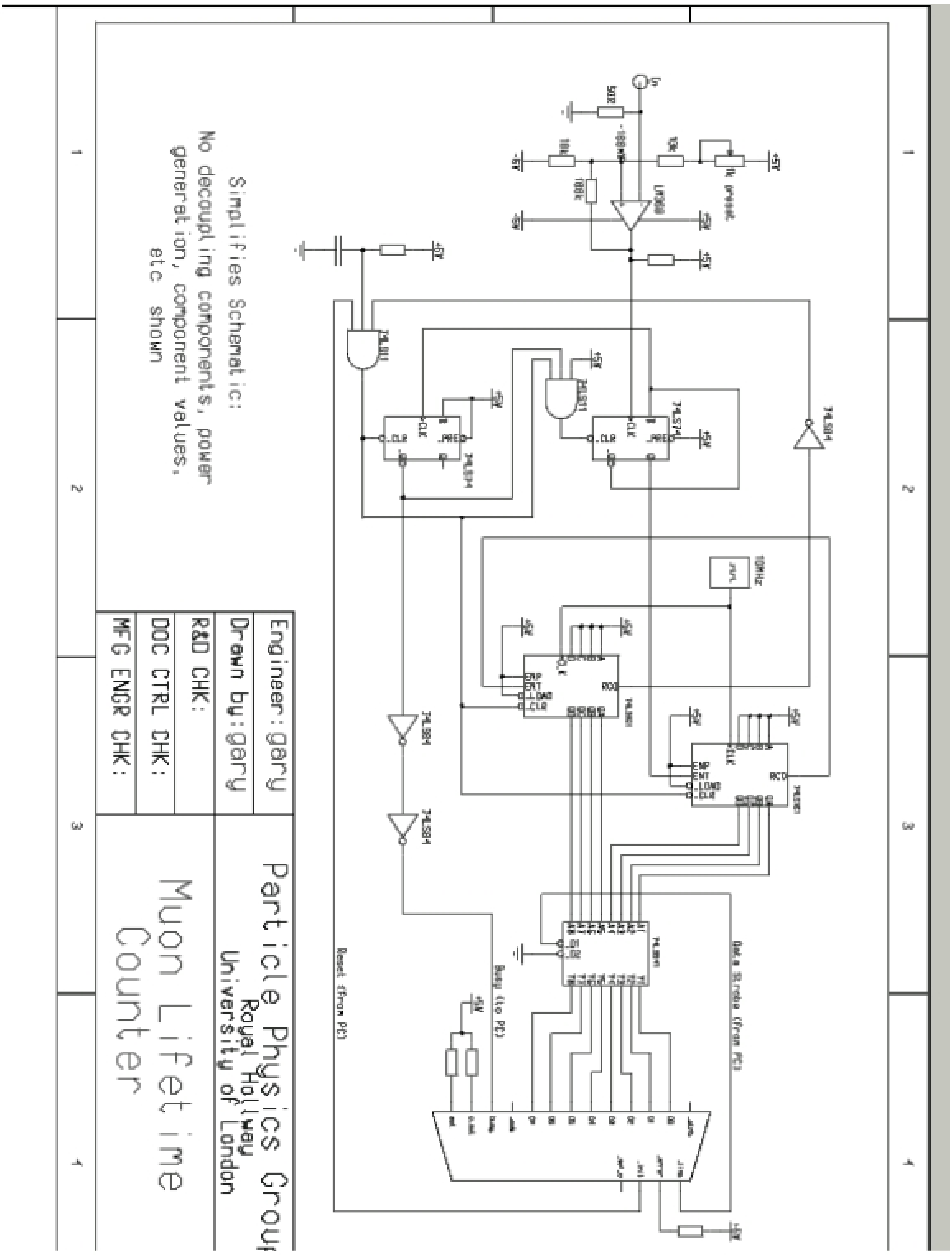


figure13:muon lifetime ircuit

CHAPTER4:DATA INTERPRETATION

when we passes th output of muon lifetime measurement circuit to the pc through user port ,this signals are used by a program which is already designed and available in pc.Available software calculates lifetime of each incident muon further which decays in to electron,neutrino,antineutrino.And result is passed to display on screen.

In following figure we plotted time difference between muon pulse and electron pulse.Curve is clearly exponential in nature which resembles radioactive decay curve.

The graph of lnN(t) vs t is clearly linear in the range 0 - 6us. Beyond 6ms the background events associated with random pairs of pulses becomes dominant. Whilst the slope of the best fit line produced by considering values of lifetime less than 6us gives a value of the mean lifetime of about 2.2us. If values of lifetimes in the dominantly background region of greater than 6us are included

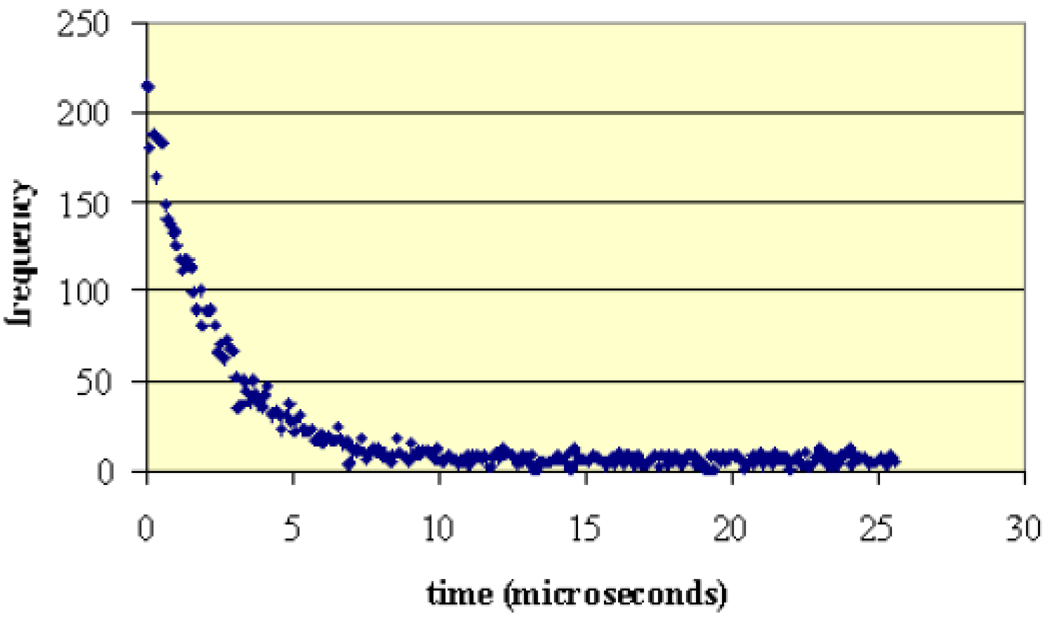


figure14:frequency V time

figure14:frequency V time then the lifetime value rises above 2.2us. From our measurements we can quote the result that the mean muon lifetime = 2.2 ± 0.1us.

We could compensate for the background events by carrying out a least squares fit on lifetime values greater than about 10us to find the corresponding equation of the curve associated with those events.

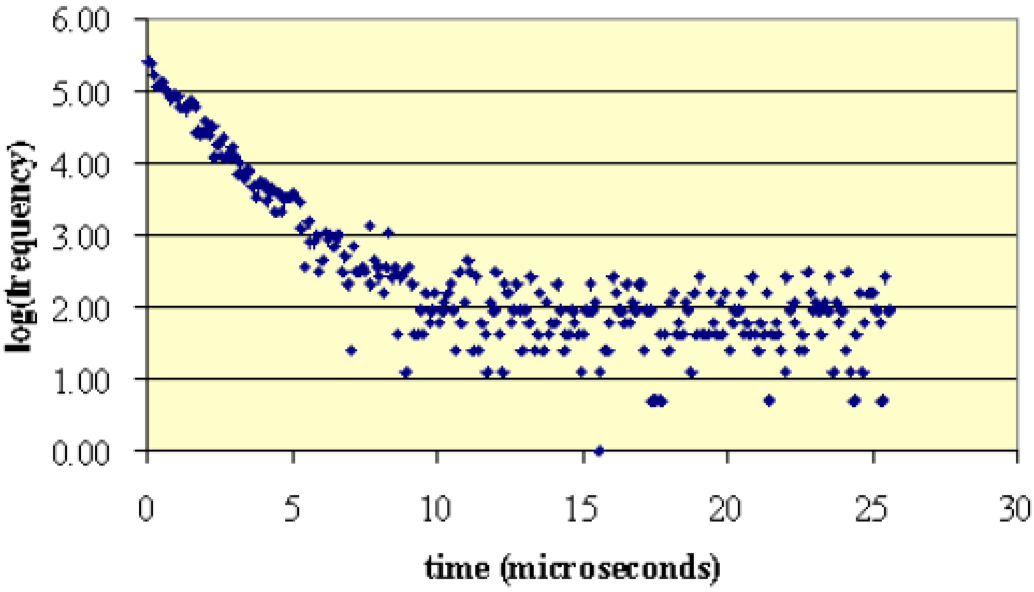


figure14:log(frequency) V time

This would allow us to make corrections to the frequency values at the lower end of the curve and
hence produce a mean lifetime with a 'background' count correction.

LIST OF FIGURES