DESIGN CONSTRUCTION AND TESTING OF A DIGITAL CAPACITANCE METER

BY

MUHAMMAD ISA HASSAN

97/6065EE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY

MINNA

NIGER STATE, NIGERIA.

PROJCET SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE BACHELOR OF ENGINEERING (B.ENG) DEGREE IN THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

TABLE OF CONTENTS

Title ....page

Table of contents.. i

Declaration..iv

Certification..v

Dedication..vi

Acknowledgement vii

Abstract..viii

CHAPTER ONE

INTRODUCTION

1.1 Introduction..1

1.2 Historical Background..1

1.3 Motivation..2

1.4 Objectives..2

1.5 Methodology..2

1.6 Organization of the Report..3

CHAPTER TWO

LITERATURE REVIEW..4

CHAPTER THREE

CIRCUIT DESCRIPTION

3.1 Functional block diagram..7

3.2 Circuit Design..7

3.2.1 The Oscillators..8

3.2.2 Design of 100Hz Oscillators...11

3. 2.3 Design of the second Oscillator..12

3.2.4 Decade counter and Latch..13

3 .2.5 The Logic Module...14

3.2.6 Regulated Power Supply Unit...15

CHAPTER FOUR

CONSTRUCTION, TESTING AND RESULT

4.1 Introduction..16

4.2 Component Layout...16

4.3 Construction Strategy...17

4.4 Tools Used..17

4.5 Results..17

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION.......................................18

References...19

APPENDIX I

The complete circuit diagram

APPENDIX II

Power supply circuit diagram

APPENDIX III

Component part list

DECLARATION

I hereby declare that the project work is an original concept completely carried out by me under the supervision of Engineer Musa D. Abdullahi of Department of Electrical and Computer Engineering, Federal University of Technology Minna.

Sign: --

MUHAMMAD ISA HASSAN.

CERTIFICATION

This is to certify that the work titled Design, Construction, and testing of a Digital Capacitance Meter carried out by Muhammad Isa Hassan under the supervision of Engineer Musa D. Abdullahi and submitted to the Department of Electrical and Computer for the award of B.Eng in Electrical and Computer Engineering of Federal University of Technology, Minna.

Engr. M.D Abdullahi

------------------------------------ ------------------------------------

PROJECT SUPERVISOR DATE AND SIGN

Engr. M.N Nwohu

------------------------------------ ------------------------------------

H.O.D ELECTRICAL/COMPUTER DATE AND SIGN

ENGINEERING DEPARTMENT

------------------------------------ ------------------------------------

(EXTERNAL EXAMINER) DATE AND SIGN

DEDICATION

This project is dedicated to Allah (SWT), to the loving family of Alhaji Muhammad S. Lemu.

ACKNOWLEDGEMENT

First and foremost my immeasurable gratitude goes to Almighty Allah, the lord of the world, the grantors of bounties for giving life, good health and strength to undertake this project.

My sincere thanks goes to my family for care, encouragement and moral and financial support without which this work would not have been possible. Worthy of mention here is the encouragement given to me by Engr Ahmed Sadiq, friends and associates in person of Muhammad (Boss), Isa (Jesus), Aliyu (agaie), Abdullahi (Zams), Ndagi, Abdul-Rashid (shido), Salka, Takuma, Abdullahi (Danasabe), Mallam Umar, Mahmud (Ba'afa), Aliyu (aya), Abdul-Hafiz, Habila, Segun and a host of other too numerous to mention.

My special thanks goes to my supervisor Engr M.D Abdullahi for his understanding and indispensable assistance throughout the course of this project.

ABSTRACT

This project presents the design, construction and testing of a digital capacitance meter capable of measuring capacitance ranging from 0.01uFto 9.99uF with two digit accuracy. The circuit contains two oscillators, the first oscillator runs at a constant frequency of 100Hz. The second has the capacitor to be measured as part of its frequency- determining network. The period of the second oscillator is designed to be equal to capacitance multiplied by a factor of 10^6. Therefore, the period (in seconds) of the second is equal to the microfarad value of the oscillator.

The logic block lets the counter counts the pulses from the 100Hz oscillator for just one cycle of the second oscillator. This means that at the end of the counting the value stored in the counter is equal to the one hundred times the microfarad value of the capacitor. This value is stored in a latch and then displayed on the seven-segment display.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter presents a brief historical background on measurement and instrumentation and the motivation, objectives and methodology of this work.

1.2 Historical Background

Charles Augustin de Coulomb (1736-1806), French physicist, is a pioneer in electrical theory. In 1777 he invented the torsion balance for measuring the force of magnetic and electrical attraction. With this invention, Coulomb was able to formulate the principle, now known as Coulomb's law, governing the interaction between electric charges. In 1779 Coulomb published the treatise "Théorie des machines simples" (Theory of Simple Machines), an analysis of friction in machinery. After the French revolution, Coulomb came out of retirement and assisted the new government in devising a metric system of weights and measures. The unit of quantity used to express electrical charge, the coulomb, was named after him.

In the field of measurement, Edward Weston (1850 – 1936) developed three important components: the Standard Cell, the Manganin resistor and the electrical indicating instrument.

Weston was both an inventor and an entrepreneur. As an inventor, he acquired more than 200 patents from the time direct-current generators and arc lamps emerged. He also set up a number of companies, the most successful of which seemed to be the Weston Electrical Instrument Company.

Leyden Jar, one of the earliest and simplest forms of electric capacitor, discovered independently about 1745 by the Dutch physicist Pieter van Musschenbroek of the University of Leyden and Ewald Georg von Kleist of Pomerania. The original Leyden Jar was a stoppered glass jar containing water, with a wire or nail extending through the stopper into the water. The jar was charged by holding it in one hand and bringing the exposed end of the wire into contact with an electrical device. If contact was broken between the wire and the source of electricity, and the wire was touched with the other hand, a discharge took place that was experienced as a violent shock. The present-day Leyden Jar is coated with tinfoil on the inside and outside. Electrical contact is made with a brass rod that punctures the stopper of the jar and is connected to the inside layer of metal by a chain. A complete discharge occurs when the two coatings are connected with each other by a conductor. The Leyden Jar is still frequently used in laboratories for demonstration and experimental purposes.

1.3 Motivation

Capacitance meter is rare in our laboratories. Most of the available multimeters have no provision for the measurement of capacitance. It is hoped that this present work will provide students with an easy tool for capacitance measurement in the lab.

1.4 Objectives

The objective of this work is to design and construct a capacitance meter with the following specifications:

- Measurement range of 0.01μF to 9.99μF
- Accuracy of 0.01μF

1.5 Methodology

The Digital Capacitance meter measures the value of the capacitor and digitally displays the value on a seven-segment display unit.

The capacitor to be measured is made part of the frequency-determining network of an oscillator A. This causes the oscillator to oscillate with a period dependent to the value of the capacitance.

A digital decade counter counts the number of cycles made by another constant 100Hz oscillator B in one period of the other oscillator A above. The count at the end of one period of oscillator A is equal to the capacitance of the capacitor. This value is stored in a latch and then displayed on the seven-segment display.

1.6 Organization of the Report

This report is organized as follows: Chapter two, the literature review is a historical survey of measurements. Chapter three presents the circuit description and detailed design. Chapter four presents construction, testing and results. And chapter five presents the Conclusion and Recommendation.

CHAPTER TWO

LITERATURE REVIEW

Man found the need to measure in order to make things, exchange things, and sell things and latterly to control things. History is strewn with many measures, and there has always been a search for equivalents and standards.

The first measurements were made in Egypt about 3500 BC. The reason was to measure the rise and fall of the Nile in order to effect efficient irrigation and water management. The early Egyptians defined one finger width as a *zebo* and established the relationships:

100 zebos = 1 nent
10 nents = 1khet
10 khets = 1 cable length
10 cable lengths = 1 thousand

This was the advent of the decimal system of counting! And note the use of human dimensions as the first standards.

Over the years these measurements spread. For example, the Phoenicians (Lebanon) in 1200 BC used half sized Egyptian measures. Two design philosophies emerged:

1. "A unit of length would be selected, the cube of which gave a measure for capacity; the weight of cool water contained in it gave the unit for weight."
2. When arithmetic and the art of metrology were in their infancy and their mysteries understood by a few, it was essential: "To be able to express the basic quantities of length, area, volume and weight in their commonly occurring magnitudes without the use of fractions or very large numbers; and to be able to measure these quantities simply and accurately".

In the first centuries AD the Romans brought measures to England, but when they left the Danish feadm or fathom was adopted. This was called the armstretch and was 79.2 inches or 2.01m long. (Big people these Danes: the Egyptian armstretch by contrast was 73.64 inches.) The following relationships were established:

10 finger widths = 1 span

10 spans	= 1 armstretch (ell)
10 armstretches	= 1 chain
10 chains	= 1 furlong
10 furlongs	= 1 thus-hund

Again very simple, reproducible and decimal.

Anyone who has used a measuring stick some 2m long indoors will know it is awkward to handle, so housewives around 850 AD used a wand, which was exactly half an armstretch and to maintain the decimal system used a handwidth (about 3.96 in) as the new unit. From this the container size was a cubic wand (about 1 tonne) and the small measure was a cubic wand (about 1kgm). Half a small measure was called king Alfred's pound or skale weight.

About 1100 AD Henry I measured the distance from his nose to his outstretched thumb and called it a yard. In 1215 AD Magna Carta in clause 35 stated:

"There is to be one measure of wine and ale and corn within the realm namely the London quart and one breadth of cloth and it is to be the same with weights."

Henry III and the Merchants of London took Magna Carta to heart and defined 12 tumb breaths to be one foot (or Great Pous) and 36 thumb breadths to be one yard. A cubic foot of was water was then said to weigh 1000 ounces from the Italian Libra (lb) and onzia (oz). (16 oz equal lib – binary?). This made:

100 skale weight	= 112 lb (or hundredweight)
1 cu. ft	= 62.5 lb (of water)
	= 60 lb (of wine)
1 pint (of London)	= 1/60 of 1 cu. ft.

(This latter measure remained until 1824 when the pint was defined as the volume of 1/8 of a gallon of water weighing 10 lb.)

In 1790 Pierre Simon de Laplace, a French astronomer, said "divide a right angle into 100 degrees (instead of 90) and the degree into 100 minutes (instead of 60) and define the distance on the Earth's surface of 1 minute of arc as 1000 fathoms or 1 sea mile". The new fathom was called a meter, i.e. the Earth's circumference became 40,000,000m.

Unfortunately there already existed the nautical mile, which was 1minute of arc (60 minutes equal 1 degree). And when the French measured the earth they measured it as 39.37 in. instead of 39.40 in. However, Laplace started a debate, which still thrives. His initiative and the preceding and succeeding events are indicated below:

1620 Edmund Gunter, England – 100 links of 7.29 in. to a chain, 220 yards

1671 Abbe Mouton of Lyon defined proposal for metric (decimal) system.

1783 James Watt, England, wanted a decimal system.

1790 Laplace, France proposed metric system.

French academy under Tallyrand encouraged decimal system.

Thomas Jefferson, USA proposed decimal system, he was ignored.

1864 Metric system allowed in Britain.

1867 Act of parliament, Britain, for metrication lost by 5 votes.

1897 Metric system legal in Britain.

1954 mks system established.

1960 SI system established.

The metric system spread to all countries under French influence during the Napoleonic periods and Imperial measures stopped developing, except the Therm. Gauss suggested using a few basic units and relating the rest to them. And so the cgs system was developed. Scientists used the decimal system more than engineers, as engineers disliked the smallness of the units (e.g. energy was 1 erg where 10 million ergs equal 1 joule) and the proliferation of names. Eventually in 1954 the mks system was agreed and then in 1960 the SI unit system became accepted. The SI system:

I. Uses the principle of single primary units;
II. Is based on the smallest number of independent defined units;
III. Has no numerical factors except 10;
IV. Can be extended indefinitely.

The metric system meets the ancient requirements of simplicity and accuracy and the engineer's requirement of reasonably sized units. The metric system is not new; the wand was nearly a meter. (1)

CHAPTER THREE

CIRCUIT DESCRIPTION

3.1 Functional block diagram

The block diagram for the system is shown in figure 1 below

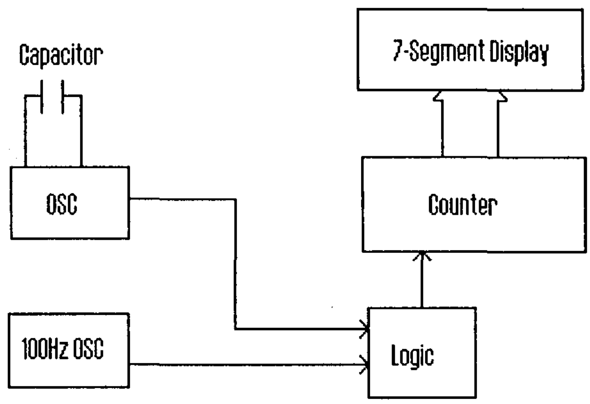


Figure 1 block diagram of the Capacitance meter

The circuit contains two oscillators, the first runs at a constant frequency of 100 Hz. The second has the capacitor to be measured as part of its frequency-determining network. The period of the second oscillator is designed to be equal to Capacitance multiplied by a factor of 10^6.

Therefore the period (in seconds) of the second oscillator is equal to the microfarad value of the Capacitor.

The logic block let the counter count the pulses from the 100Hz oscillator for just one cycle of the second oscillator. This means that at the end of the counting, the value stored in the counter is equal to a hundred times the microfarad value of the capacitor.

The seven-segment display is used to display the value stored on the counter. It consists of three digits. The most significant digit stands for the units and the other two digits stand for two decimal places of the capacitance value in microfarads.

3.2 Circuit Design

The complete circuit diagram is given in Appendix 1.

3.2.1 The Oscillators

The oscillators were implemented using 555 timers.

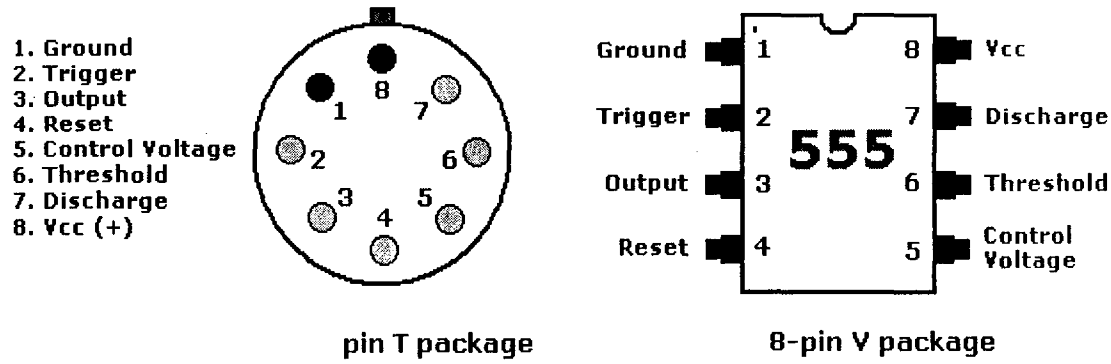


Figure 2 the 555 timers

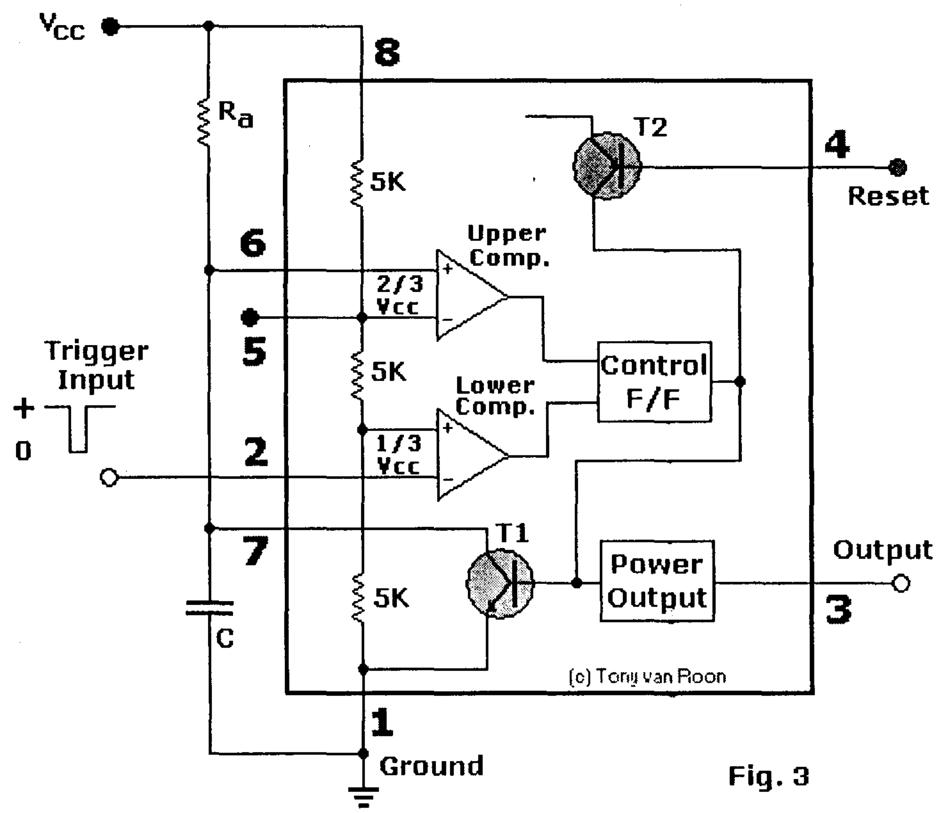


Figure 3 the 555-timer internal block diagram

Inside the 555 timers, at fig. 3, are the equivalent of over 20 transistors, 15 resistors, and 2 diodes, depending on the manufacturer. The equivalent circuit, in block diagram, providing the functions of control, triggering, level sensing or comparison, discharge, and power output. Some of the more attractive features of the 555 timer are: Supply voltage between 4.5 and 18 volt, supply current 3 to 6 mA, and a Rise/Fall time of 100 nSec. It can also withstand quite a bit of abuse.

The Threshold current determine the maximum value of Ra + Rb. For 15 volt operation the maximum total resistance for **R** (Ra +Rb) is 20 Mega-ohm.

Astable operation: Figure 4 shows the 555 connected as an astable multivibrator. Both the trigger and threshold inputs (pins 2 and 6) to the two comparators are connected together and to the external capacitor. The capacitor charges toward the supply voltage through the two resistors, R1 and R2. The discharge pin (7) connected to the internal transistor is connected to the junction of those two resistors.

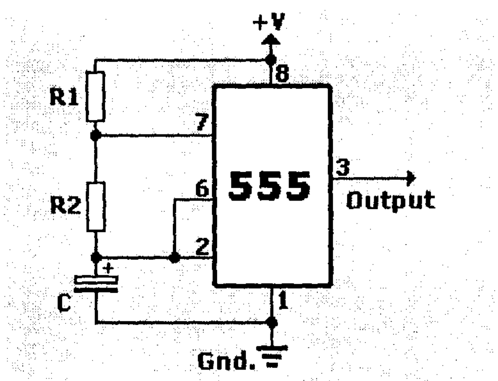


Figure 4 555 timer astable operation

When power is first applied to the circuit, the capacitor will be uncharged; therefore, both the trigger and threshold inputs will be near zero volts (see Fig. 5). The lower comparator sets the control flip-flop causing the output to switch high. That also turns off transistor T1. That allows the capacitor to begin charging through R1 and R2. As soon as the charge on the capacitor reaches 2/3 of the supply voltage, the upper comparator will trigger causing the flip-flop to reset. That causes the output to switch low. Transistor T1 also conducts. The effect of T1 conducting causes resistor R2 to be connected across the external capacitor. Resistor R2 is effectively connected to ground through internal transistor T1. The result of that is that the capacitor now begins to discharge through R2.

As soon as the voltage across the capacitor reaches 1/3 of the supply voltage, the lower comparator is triggered. That again causes the control flip-flop to set and the output to go high. Transistor T1 cuts off and again the capacitor begins to charge. That cycle continues to repeat with the capacitor alternately charging and discharging, as the comparators cause the flip-flop to be repeatedly set and reset. The resulting output is a continuous stream of rectangular pulses.

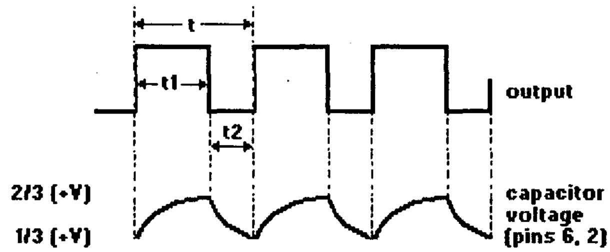


Figure 5 555 timer output waveform

The frequency of operation of the astable circuit is dependent upon the values of R1, R2, and C. The frequency can be calculated with the formula:

$$f = 1/(.693 \times C \times (R1 + 2 \times R2))$$

The Frequency f is in Hz, R1 and R2 are in ohms, and C is in farads.

The time duration between pulses is known as the 'period', and usually designated with a 't'. The pulse is on for t1 seconds, then off for t2 seconds. The total period (t) is t1 + t2 (see fig. 5).

3.2.3 Design of the Second Oscillator

For the second oscillator we want the period T to be given by,

$$T = C \times 10^6$$

but,

$$T = 0.693(R1 + 2R2)C$$

therefore,

$0.693(R1 + 2R2)$ must be equal to

or $$0.693(R1 + 2R2) = 10^6$$

$$R1 + 2R2 = \frac{10^6}{0.693}$$

$$R1 + 2R2 = 1.44 \times 10^6$$

let R1=R2

then, $$3R1 = 1.443 \times 10^6$$

or

$$R1 = 4.81 \times 10^5 = 481 \cdot k\Omega$$

3.2.4 74160 (Decade Counter)

The decade counter chip that was used is shown in fig 6

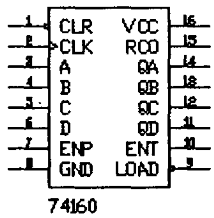


Figure 6 74160-decade counters

Decade Counter truth table:

$\overline{CLR}$	$\overline{LOAD}$	ENP	ENT	CLK	A B D C	QA	QB	QC	QD	RCO
0	X	X	X	X	X X X X	0	0	0	0	0
1	0	0	0	POS	X X X X	A	B	C	D	*1
1	1	1	1	POS	X X X X			Count		*1
1	1	1	X	X	X X X X	QA0	QB0	QC0	QD0	*1
1	1	X	1	X	X X X X	QA0	QB0	QC0	QD0	*1

-*1 - RCO goes HIGH at count 9 to 0.

7475 (Bistable Latch)

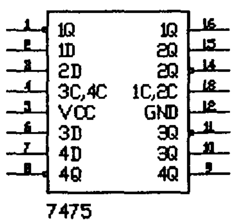


Figure 7 7475

Bistable Latch truth table:

Inputs D	Inputs C	Outputs Q	Outputs $\overline{Q}$
0	1	0	1
1	1	1	0
X	0	Q0	'Q0

3.2.5 The Logic module

This module is the controller for the rest of the circuit. It is responsible for resetting the counter before counting begins and loading the latch at the end of the counting.

The logic of the module is based on two inputs, the output of the second oscillator and the output of the jk flip-flop. And it implements the control logic shown in the table below

Table 1

Osc output	Flip-flop output	Command
1	0	Reset
0	1	Start counting
1	1	Stop counting
0	0	Latch

This module is shown in fig 7.

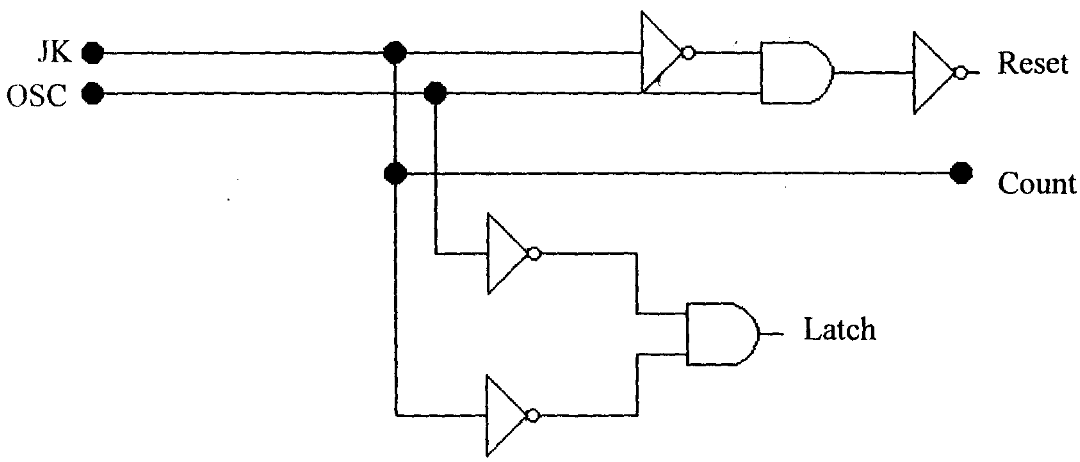


Figure 8 the logic module

3.2.2 Design of the 100Hz Oscillator

Let C=1μF

$$F = \frac{1}{0.693 \cdot (R1 + 2 \cdot R2) \cdot C}$$

$$100 = \frac{1}{0.693 \cdot (R1 + 2 \cdot R2) \cdot 1 \cdot 10^{-6}}$$

therefore,

$$R1 + 2R2 = \frac{1}{100 \cdot 0.693 \cdot 1 \cdot 10^{-6}}$$

or,

$$R1 + 2 \cdot R2 = 1.443 \times 10^{4}$$

Let R1=150Ω, then:-

$$2R2 = 1.443 \times 10^{4} - 150$$

or,

$$2R2 = 1.428 \times 10^{4}$$

$$R2 = \frac{1.428 \times 10^{4}}{2}$$

$$R2 = 7.14 \times 10^{3} \cdot \Omega$$

therefore,

$$R1 = 150 \cdot \Omega$$

$$R2 = 7.2 \cdot k\Omega$$

The timing diagram for this circuit is shown in fig 8

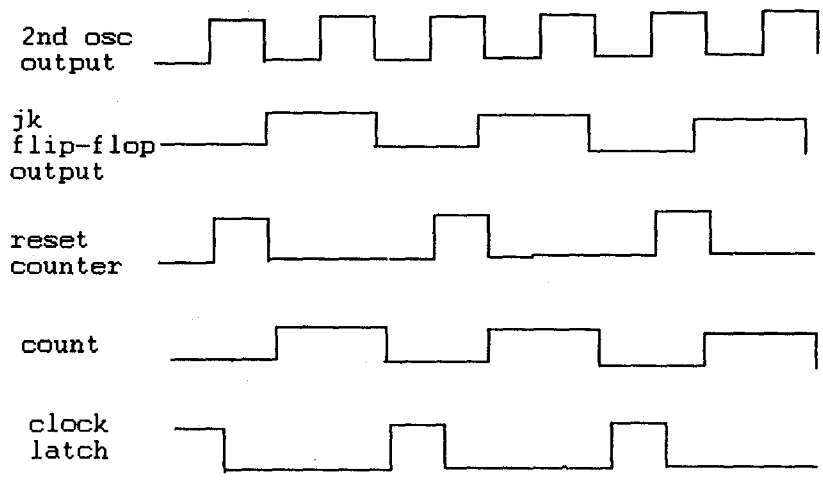


Figure 9 timing diagram for the logic module

3.2.6 Regulated Power Supply Unit

The regulating circuit enables the power supply unit to supply constant output voltage under varying input voltage or varying load current condition. An IC voltage regulator was employed to provide the regulated power supply. Table output of 5v was obtained with permissible load current of 500mA.

The complete regulated power supply circuit diagram is giving in Appendix II.

CHAPTER FOUR

CONSTRUCTION, TESTING AND RESULTS

4.1 Introduction

Design and construction is surely not a trial and error process. But designs, especially logic design, more often than not needs to pass through many circles of implementation, testing, redesign implementation, etc. Before it finally gives the desired result.

Because of this, a very systematic approach was taken in the construction and testing of the workpiece.

4.2 Component Layout

The circuit was implemented on a Vero board. Vero boards are hard plastic boards with holes to hold components and long strips of copper sheet running the whole length of the board. The copper sheet help holds the components tightly to the board after soldering. They also serve as interconnecting wires from one point to another. Where continuity is not desirable, the copper strip can be cut using a sharp razor blade.

IC sockets were used on the Vero board so that the ICs themselves don't have to be soldered to the board. This makes it easier to remove and replace any faulty IC without the trouble of desoldering.

The components were laid such that those with a lot of mutual interconnection were place close to one another to reduce unnecessary routing of wires. The components were placed on the opposite side of the copper strips. The interconnecting wires were laid on the same side as the components while all soldering was done on the opposite side. For a neater job, wire guides were used to hold the interconnecting wires firmly in place and to keep them from scattering.

The wire used was gauge 32. Thicker wires will make the wiring too clumsy because of the great number of interconnections used. Thinner wires will lead to excessive voltage drop and possible overheating—both very undesirable.

To make things easier, the work was implemented in modules. Jacks and sockets with ribbon cables were used to interconnect modules together. Using ribbon cables makes the interconnection easier and neater.

4.3 Construction Strategy

First a simple makeshift probe was constructed. This was to serve as the main test equipment throughout the work.

The second thing was to test the oscillators and the counter separately. This test was performed on a breadboard.

Next the various modules were assembled and tested together.

4.4 Tools Used

A number of tools were used. The construction tools used were: soldering iron, desoldering vacuum tube, razor blade, screwdrivers, and pliers.

Few test equipment were used. A Digital multimeter and a make shifty probe were the most used test instrument.

4.5 Results

The work piece was used to measure the capacitance of a number of standard capacitors and the readings are recorded in the following table.

Table 2

Label value	Meter Reading
1μF	0.99μF
5μF	4.99μF

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The readings of the capacitance meter agree with the label value of the capacitors used in the testing. This implementation, however has the following drawbacks:

1. It is slow and measurement time increases with increasing capacitor value.
2. The range is limited to 0.01μF to 9.99μF.
3. The accuracy is limited to 2 decimal places.

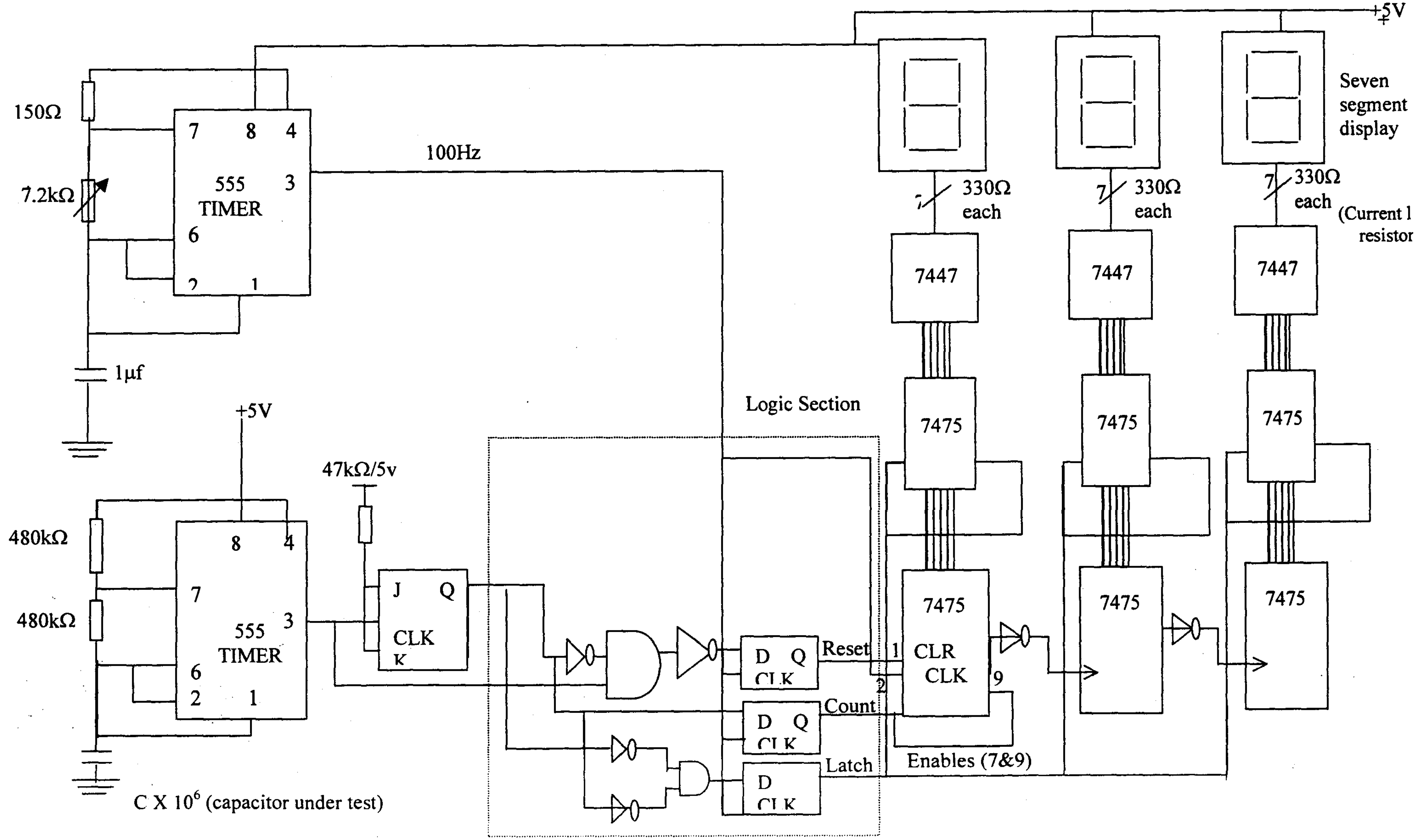
It is hoped that future implementations will take care of some of these issues.

REFERENCES

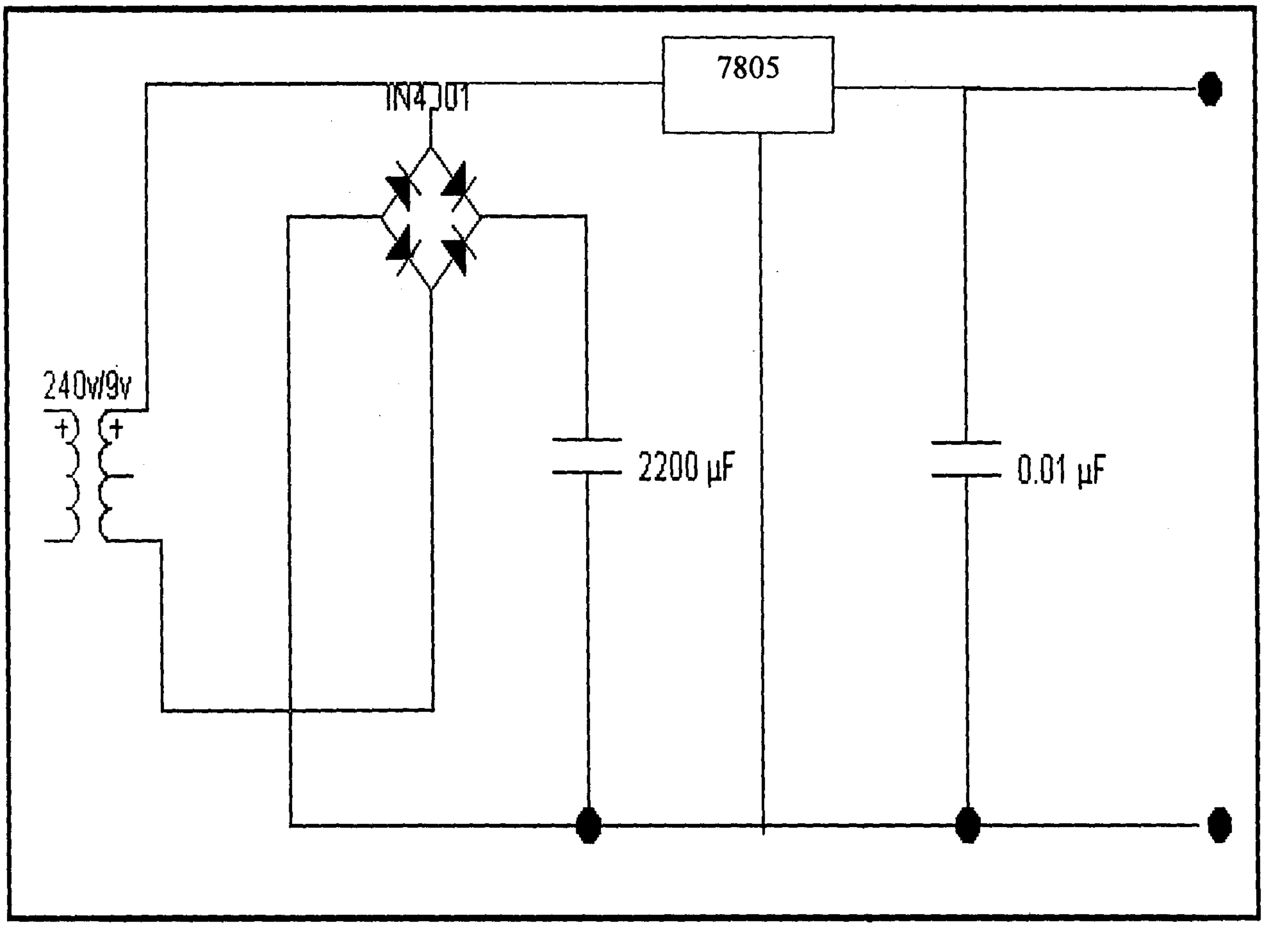
1. Barney, G.C., Intelligent Instrumentation, 1st edn, Prentice-Hall, 1985.
2. Fraser, C.J., Microcomputer Applications in Measurement Systems, 1st edn, Macmillan, 1990
3. Floyd, T.L., Digital Fundamentals, 3rd edn, Merrill Publishing Company, 1986.
4. Microsoft Encarta Encyclopedia 2002

APPENDIX I

CIRCUIT DIAGRAM OF A DIGITAL CAPACITANCE METER



APPENDIX II



Regulated Power Supply Circuit Diagram

APPENDIX III

COMPONENT PART LIST

Oscillating Unit

2 NE 555timers
2 470KΩ
2 10KΩ
1 150Ω
1 10KΩ(Variable resistor)
1 1μF/50V capacitor
2 74LS107
2 Probes
Veroboard
Casing

Counter Unit

3 74LS160
1 74LS00
1 7404

Display Unit
3 7447
3 7475
21 330Ω resistors
3 Single digital seven-segment display (common anode)

Power Supply Unit

1 240V/18V, 500mA transformer
1 7805 regulator
1 2200μF
4 IN4001 diodes
6 47KΩ pull-up resistors
1 1μF capacitor