DESIGN AND CONSTRUCTION OF MICROCONTROLER BASED DIGITAL CAPACITANCE METER

By

HUSSEIN YAHAYA

99/8413EE

DEPARTMENT OF ELECTRICAL/COMPUTER ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY

MINNA, NIGER STATE, NIGERIA

NOVEMBER, 2005

DESIGN AND CONSTRUCTION OF MICROCONTROLER BASED DIGITAL CAPACITANCE METER

By

HUSSEIN YAHAYA

99/8413EE

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF BACHELOR OF ENGINEERING (B.ENG) ELECTRICAL/COMPUTER ENGINEERING

DEPARTMENT OF ELECTRICAL/COMPUTER ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE, NIGERIA

NOVEMBER, 2005

ATTESTATION

This is to certify that this project title MICROCONTROLLER BASED DIGITAL CAPACITANCE METER was designed and constructed by self HUSSEIN YAHAYA for the award of a Bachelor of Engineering (B.ENG.) in the Department of Electrical/Computer Engineering of the Federal University of Technology Minna, Niger State, Nigeria.

.... 2/12/05

MR.M.A.SADDIQ **DATE**

(PROJECT SUPERVISOR)

.... 27/02/06

ENGR. M.D. ABDULLAHI **DATE**

(HEAD OF DEPARTMENT)

....

EXTERNAL SUPERVISOR **DATE**

DECLARATION

I hereby declare that this project was written by my humble self "HUSSEIN YAHAYA 99/8413EE" of the electrical/computer engineering Federal University of Technology Minna, under the supervision of Mr.M A.Saddiq

....
Signature of Student

DEDICATION

This project is dedicated to Almighty Allah, the most gracious most merciful, for whom do I come from and by whom all things made possible.

ACKNOWLEDGEMENT

My acknowledgement goes to those who had in one way or the other contributed towards this huge success in my project. In this regard, I am mostly indebted to my supervisor Mr.M.A.Sadiq under whose understanding advice and constructive criticism, I was able to accomplish the enormous challenge posed by this work.

Many thanks to my parents, Alhaji Yahaya Shehu for his fatherly and financial support, Hajiya Habiba Yahaya (late) who before her death contributed morally and spiritually towards seen me through in my academic carrier. May her soul rest in perfect peace (Amen). I am deeply grateful to my sisters and Brothers Hajiya Hassana Yahaya, Hajiya Amina Yahaya, Aishetu yahaya, Fatima yahaya, Muhammad Awwal Yahaya, Muhammad Sani Yahaya, Muhammad Tukur Yahaya, and others for all the concern, love, effort and moral support shown to me, thanks for everything. Indeed they are my role model. My appreciation also goes to my friends,Usman Nuhu Galadima,Muhammad Sani Yabagi, Muhammad Umar Majigi, Muhammad Sani Muhammad, Muhammad Nurudeen,and all others numerous to mention, thanks for all the contributions made towards this project and my entire schooling. We are together and shall remain together insha`Allahu

Most of all, I give thanks to my guide, stronghold, aspirator, protector, sustainer, my every thing Almighty Allah for all I am, I had achieved and yet to achieve. May His blessing and mercy continue to be with me Amen...

ABSTRACT

This project is designed to measure the charged per unit volt. (Capacitance of capacitor).the project is designed to incorporate two segments that make up the entire circuitry.

The hardware segment interconnects the components. Values are read to the microcontroller on plug to the half cut-in socket and are display through the seven segment, it measures values ranging from micro to Pico farads.

The software was developed using assembler code (language). Assembler is a low-level language. The language was written to read the value of the capacitance using an integrated method of transient response of a RC network. The values read are transmitted through portB of the microcontroller, which than send the read data to the segment display in serial-parallel ports of the shift and store data register.

The design is powered from an unregulated power source of range 24volts-6volts, which gives a significant power protective future of the design.

TABLE OF CONTENTS

CHAPTER FOUR

CHAPTER FIVE

CHAPTER ONE

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 Augustine 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 electrical charges. In 1779 coulomb published the treatise "theorie des machines simple"(theory of simple machines),and 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. This unit of quantity used to express electrical charge, the coulomb was named after him.

In the field of measurement, Edward Weston (1850-1936) develops three important components: the standard cell, the manganin resistor and the electrical indicating instrument.

Lynden jar, one of the earliest and simplest form of electric capacitor, discovered independently about 1745 by the Dutch physicist Pieter van musschenbroek of the university of Lynden and Ewald Geory Von Kleist of pomerania.With the discovery of the fist Lynden jar, it was referred to as a lindens because electricity was thought of as a fluid which could condense. The leyden jar is a glass partially filled with water that as a wire inserted through the top of an insulating stopper (cork).when the wire is charged static electricity, it hold the charge until the wire comes into contact with a conductor which will discharge the glass. The present-day Lynden jar is coated with tinfoil on the inside and outside. Electrical contact is made with a brass of 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 a conductor connects the two coatings with each other. The Lynden jar is still frequently used in our laboratories for demonstration and experimental purposes.

It was roughly one hundred years later when Michael Faraday discovered a variable capacitor. He did this by measuring the varying capacitance of different dielectrics on capacitor.'(4) When the first aluminum capacitor was discovered, some thirty years after Faraday's work, the SI unit used measuring capacitance was named a farad (F) in his honor.

1F = 1 C / V

MEANING: One Farad is equal to one Coulomb per Volt since the farad is a large unit of capacitance; most capacitors have units of Pico farads (pF) or nanofarads (nF). To this day only one type of capacitor has the ability to store enough energy to warrant measurements using a farad as the standard unit, and this is the super capacitor.

A capacitor consists of two conducting surfaces separated by an insulator (dielectric). The value of capacitance depends not only on the geometry of the capacitor, but the dielectric as well.[1]

1.3 MOTIVATION:

Capacitance meter is rare in our labopratories, othough capacitor is becoming absolute but its knowledge is of significance to our electronic world. Most of the available multimeters have no provision for the measurement of capacitance and the few available do not measure capacitance value efficiently with zero error. It is hoped that this project or present work will provide students a simple capacitance meter which can measure capacitance value easy. Likewise elaborate more on the role of capacitor in our modern electronics.

1.4 OBJECTIVES:

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

- Measurement range of 0.01pF to 100uF
- Accuracy of 0.01pF

1.5 METHODOLOGY:

The digital capacitance meter measures the value of the capacitor and digitally displays the values on a seven segment display unit

The capacitance to be measured uses an integrated method that measures transient response of the R-C network. The merit in this system is that the result can be gotten as digital data directly because it uses measurement of time, accurate analog circuit is not required and its calibration is done easily by the use of a microcontroller (ATmega1163L)

When the switch in figure 1a is opened, the capacitor C will be charged through Resistor R and voltage Vc will vary like shown in figure 1b.The relation between past time t and voltage Vc is expressed as:

$$v_C = E\left(1-\varepsilon^{-t\frac{1}{RC}}\right) \text{------------ (1)}$$

Each unit is: t seconds, R ohms, C farad and epsilon is a Napier's number (approx. 2.72). When VC reaches VC1, the time t1 can be expressed in following formulae.

$$t_1 = -RC\cdot ln\left(1-\frac{V_{C1}}{E}\right) \text{------- (2)}$$

This means that the t1 is proportional to C. Thus the capacitance can be calculated from charge time and any other fixed parameters.

Each unit is: t seconds, R ohms, C farad and epsilon is a Napier's number (approx. 2.72). When VC reaches VC1, the time t1 can be expressed in following formulae.

$$t_1 = -RC \cdot ln\left(1 - \frac{V_{C1}}{E}\right) \text{ ----- (2)}$$

This means that the t1 is proportional to C. Thus the capacitance can be calculated from charge time and any other fixed parameters.

1.5.1 HARDWARE:

To measure a charge time, only a voltage comparator, a counter and some glue logics are needed. However, a microcontroller (Atmega163L) is used for this project to realize the system easly. In point of fact, I had thought that analog comparator in the AVR is not useful. But I found that the compared output can also be used as a capturing trigger of TC1. This is a nice feature for that use :-)

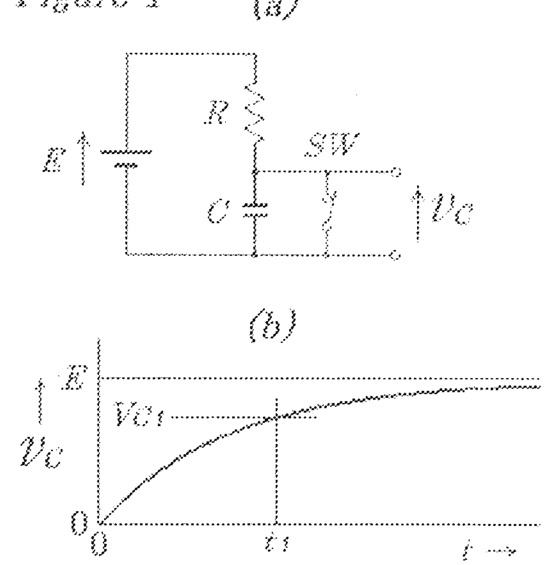
1.5.2 CALIBRATION:

Two reference capacitors of 1nF and 100nF are chosen to calibrate the capacitance meter. This capacitance meter does not have any trimmer pot; it

1.5.3 TRANSIENT:

The transient response and the calibration to give equivalent capacitance reading are executed as programmed in the microcontroller.

Figure 1



1.6 ORGANIZATION OF THE REPORT:

This report is organized as follows: Chapter two, the literature review is a historical survey of measurements and previous work on capacitance meter.

Chapter three

Presents the design and construction including brief analysis on various used components (integrated circuits) that constitute the entire circuit.

Chapter four presents construction, testing and results. Finally Chapter five presents the conclusion and recommendations.

CHAPTER TWO

2.0 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 man measures, and there has always been a search for equivalents and standard.

Going as far back in time as Noah's ark, the lack of a yardstick was not a serious drawback. Most measuring was done by one craftsman completing one job at a time, rather than assembling a number of articles piecemeal to be assembled later, it didn't make much difference how accurate the measuring sticks were or even how long they were. Generally, it doesn't make much difference how long is a mile, yard or inch or how heavy is a pound or ounce. What is really important is that everyone means the same thing when referring to each unit of measurement[1]

The cubit of Noah's time was the length of a man's forearm or the distance from the tip of the elbow to the end of his middle finger. Many times this was useful, because it was readily available, convenient, and couldn't be mislaid. However, it was not a positive fixed dimension or a standard. In techniques for measuring weights, the Babylonians made important improvements upon the invention of the balance. Instead of just comparing the weights of two objects, they compared the weight of each object with a set of stones kept just for that purpose. In the ruins of their cities, archaeologists have found some of these stones finely shaped and polished. It is believed that these were the world's first weight standards.[2]

In 1672, Sir Isaac Newton presented the world with new ideas on the nature of light and color. He had noticed that when two flat pieces of glass were pressed together, he could see circular bands of rainbow-like colors.

These were called Newton's Rings. Actually, Newton had come upon a very precise method of measurement, but he didn't recognize it as such at the time. Later, other scientists were to build on Newton's seminal findings and establish a new branch of science called *interferometry*. Today, this method of using a ray of light as a measuring stick enables man to measure distances within millionths of an inch or a millimetre.

THE METRIC SYSTEM:

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul in Lyons, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the earth. In 1671, Jean Picard, a French astronomer, proposed the length of a pendulum beating seconds as the unit of length. (Such a pendulum would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards.) Other proposals were made, but over a century elapsed before any action was taken.

The issue of designing, constructing or finding a meter that could measure capacitance value came in when difficulties pop as there had always been a problem identifying capacitor due to enormous Varity in size, shape and coding. Most a time it is impossible to identify them by size due to the different forms of construction. The need to have a meter that can measure capacitance value accurately help in eliminating the problem with some circuit not working as desired or even not working as a result of wrong use of capacitor (the required capacitor) such as in RF transmitter which on using wrong value could change the frequency of oscillation by many MHz thereby affecting the oscillation.

From the diagram shown in figure C, measuring from 1p to 10u is a factor of 10million.to cover this, 6 ranges were used. Each range was divided into 100parts, making it possible to read values on a 0-10v scale.

For each range, some components were switch into circuit to create the necessary test frequencies and charge values. This was a function of the rotary switch. An unknown capacitor fit to the test socket and the button pressed which swing on to the value of the capacitor. If on an incorrect range, the needle swing full scale or not move at all, only when it's on, the correct range will deflect the appropriate value. The only other time when the needle will swing full-scale is when the value is equal to full-scale deflection.

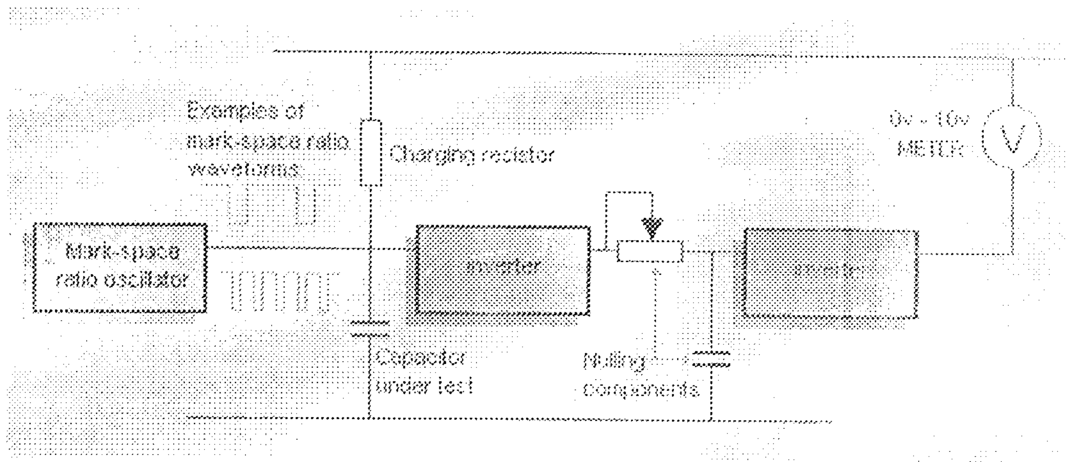
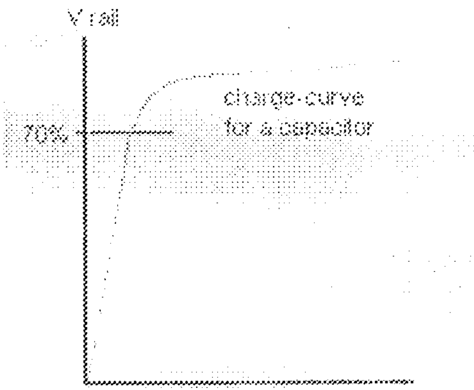


Figure C Block Diagram of the Capacitance Meter

The circuit reads the value of a capacitor and displays it on an analog meter. In this circuit, the only way to read the capacitor is to charge it and measure how long it takes to charge. The charging is a non-linear function, so the circuit was created to by-pass the non-linear problems and works on a linear arrangement. Charging the capacitor to a specified voltage level does this and this level is detected by a gate as shown in figure D below.



The input of the 74c14 detects the voltage on the capacitor at 70% and up to this point the charging is quite linear.

The circuit works on a timing principle. The first oscillator between pin 1 and 2 has a high time of 100 units and a low of 1 unit. The HIGH is created by the 120k resistor and the capacitor selected by the rotary switch and the low is created by the 2k2 and diode. This gives the starting of the circuit charge. The scale is divided into 100 parts.

The next section of the circuit charge, the test capacitor in via a resistor selected by the rotary switch. The requirement is to charge the largest capacitor in exactly 100 units of time, that is100p will take 100 units of time to charge. The 100p capacitor will take 100 units of time of charge and it will not quit get to the point where the gate detects a HIGH before the output of the tuning oscillator goes low and discharge it, ready for the next cycle.

The output pin 4 will not go low so that the 3n3 capacitor will remain fully charge. The third gate invent, the result so that output pin 6 remains low and thus the meter gives a full range reading of 10v which is read as "100" to give a value of 100p. On testing 99pcapacitor, it will charge in 99 units of time and the output pin 4 of the Schmitz gate goes low for one unit of time and discharge the 3n3 capacitor making output pin 6 of the third Schmitt trigger HIGH for one unit of time and thus the meter turn off for one unit of time out of 100.

The circuit operates at a fairly high frequency, the needle of the meter does not have time to swing back to zero during one unit of time but does drop a small amount and the result is sits on 9.9 or 99 on the scale. If 1p is fitted, the capacitor charge in one unit of time and output pin 4 will go low for 99 units of time. The inverter between pins 5 and 6 produces one a unit pulse to the meter and thus the needle will rise. 1v which reads as "1" or 1p. if no capacitor is fitted to the test terminal, the mark-space ratio oscillator produce, a high for 100 part, and a low for one par of the time which goes directly through the inverter between pin 3 and 4.On absence of no nulling component, output pin 6 is high for 100 parts and low for one part.

Advancement in producing a more accurate, easy reading and simpler meter was made with a migration from analogue techniques to a digital display system.

The capacitor to be measure was made part of the frequency determing network of an oscillator A. This causes the oscillator to oscillate with a period dependant to the value of the capacitor.

A digital counter (decade counter) counts the numbers of cycles made by another constant 100Hz oscillator B in one period of the other oscillator A. The count at the end of one period of oscillator A is equal to the capacitance of capacitor. This value is store in a catch and this display on the seven-segment display.

The block diagram of figure F illustrate it mode of operation. The logic block let the counter the pulses from the 100HZ oscillator for just one cycle of the second oscillator. Meaning 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 se/en-segment display is used to display the value stored on the counter. The most significant digit stands or the units and the other digits stand for two decimal places of the capacitance value inn microfarad. (Three digits seven-segment display).[8

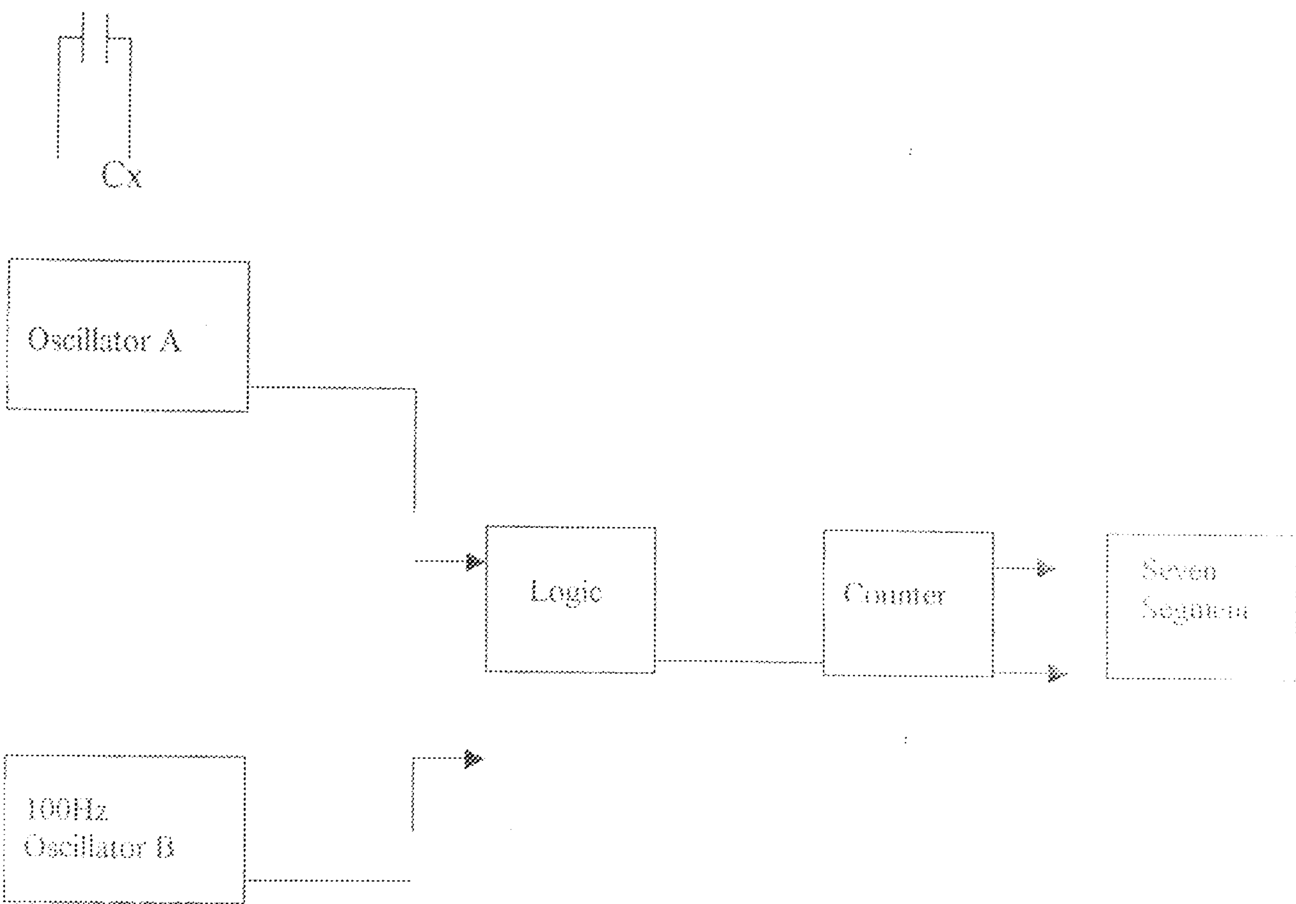


Figure F. block diagram of a capacitance meter

Cx = Capacitor to be measured.

The present work is designed to give a more accurate measurement to capacitance value and it ability to measure a wider-range of capacitance value in a more unified logic manner with high realizability.

Microcontroller are used in devices that requires some amounts of computing power but don't require as much computing power as that provided by complex (an expensive) 486 or Pentium systems which generally requires a large amount of supporting circuitry (large motherboard, hundreds of megabytes of RAM, hard drive, hard drive control, video cards etc).a microwave ovum just don't need that computing power.

Microcontroller based systems are generally smaller, more realizable, and cheaper. They are ideal for the type of application described above was cost and unit size is very important consideration. In such applications, it is almost always desirable to produce circuits that required the smallest number of integrated circuit that requires the smallest amount of physical space, required the least amount of energy, and cost as little as possible.

The program for a microcontroller normally stored on a memory integrated circuit (IC) called an EEPROM, or on the microcontroller chip itself. An EEPROM is a special type of integrated circuit that does nothing more than store program code or other data but which is maintained even when powered off. On developing program on microcontroller (software), it is normally programmed (or burned) into an EEPROM chip and that chip is subsequently physically inserted into the circuitry of the hardware. Or program written directly to the controller itself as done in this project work. This is a recent improvement in the world of microcontrolle

The manner in which the program is transfer from the computer to the microcontroller requires either an EEPROM programmer when using external memory or computer interface when directly burning the program into the microcontroller chip. Programming a microcontroller requires a serial port for down loading. Many of these devices as a "back door".

This project uses the ATmega163L family. I chose to use ATma163L due to it powerful features such as;

- High performance, low-power AVR 8 bit microcontroller
- .130 power instruction-most single clock cycle execution
- 32x8 general purpose working register
- Nonvolatile program and Data memories
- Self-programming in-system programmable flash memory
- 16k Bytes with optional boot block (256-2k bytes) endurance;1000 write/erase cycles.

- Boot section allows reprogramming of program code without external programmer.
- Programming locks for software security.
- Peripheral features.
- Two 8-bit Timer/Counter with separate prescalar and compare mode.
- One 16-bit Timer/Counter with separate prescalar,compare mode and capture mode.
- Real timer clock with separate oscillator and counter mode.
- Watchdog timer with separate on-chip oscillator.
- Analogue comparator
- Special microcontroller features.
- Power-on Reset and programmable brown out detection.
- Internal calibration RC oscillator.
- External and internal interrupt source.
- Four sleep modes; idle, ADC noise reduction, power-save and power-down.
- Power consumption @ 4MHz, 3.0V 25 degrees centigrade.
- Active 5.0mA
- Idle mode 1.9mA

CHAPTER THIRE

DESIGN AND CONSTRUCTION

3.0 INTRODUCTION:

This project constitutes two units, the software unit and the hardware unit (Physical quantity).The physical quantity, which reads the value of capacitor and calculates the correspondent value of capacitance executed by the Microcontroller using the said integrated method that measures transient response of an R-C network.

A microcontroller (often abbreviated MCU) is a single computer chip (integrated circuit) that execute a user programmed, normally for the purpose of controlling some devices, hence the name microcontroller. The program normally included either in a second chip, called an EEPROM or within the same chip as the microcontroller itself. a microcontroller is normally found in devices such as microwaves, ovum, automobiles, keyboards, CD layers, cell phones, VCRs, security systems, me and attendance clock etc.

Microcontroller are used in devices that requires some amounts of computing power but don't require as much computing power as that

- Power down mode< 1uA
- Input/Output packages
- 32 programmable i/o lines
- 40-pin PDIP and 44-pin TQFP
- Operating voltage
- 2.7-5.5V(for atmega163L)
- Speed grade.
- 0-4MHz (for atmega163L)

The project is subjected to two principle aspects namely hardware and software. The hardware is the designed circuit.

3.1 SOFTWARE DESIGN:

While the purpose of the software aspect is to execute and process the input data. Subjected into modules as shown in program command.

The software was developed using assembler code (language).Assembler is a low-level language which does not know any C-like commands like for {;;} or while {} Assembler instructions are small, for example out PortD, r15 writes the contents of register 15 (which in an AVR can hold one byte) to PortD (which is 8 I/O lines handled as one I/O register).Other assembler instructions only work on the register rather than on registers AND I/O registers or SRAM. "inc r15" is one of them. It increments the value register 15 holds by one. This is useful for loops (like for{;;}).Almost every instruction leaves certain bits in the Status Register set or cleared based on the instruction's result. These bits can be used by branch instructions or arithmetic instructions in order to perform correctly (branch/don't branch, increment result etc).Branch instructions jump to a specific code address (or code line) if the microcontroller is in a specific state or just go on with the next code line if this state is not present. If the counting variable in a loop has not reached the desired value, they can let the micro processing unit repeat the loop.

Thus, adopting a producer approach to programming, each module was designed from knowledge of its purpose and linked to the other, related module by appropriate call and jumps.[5,6]

Complete source code listings is shown in appendix A.

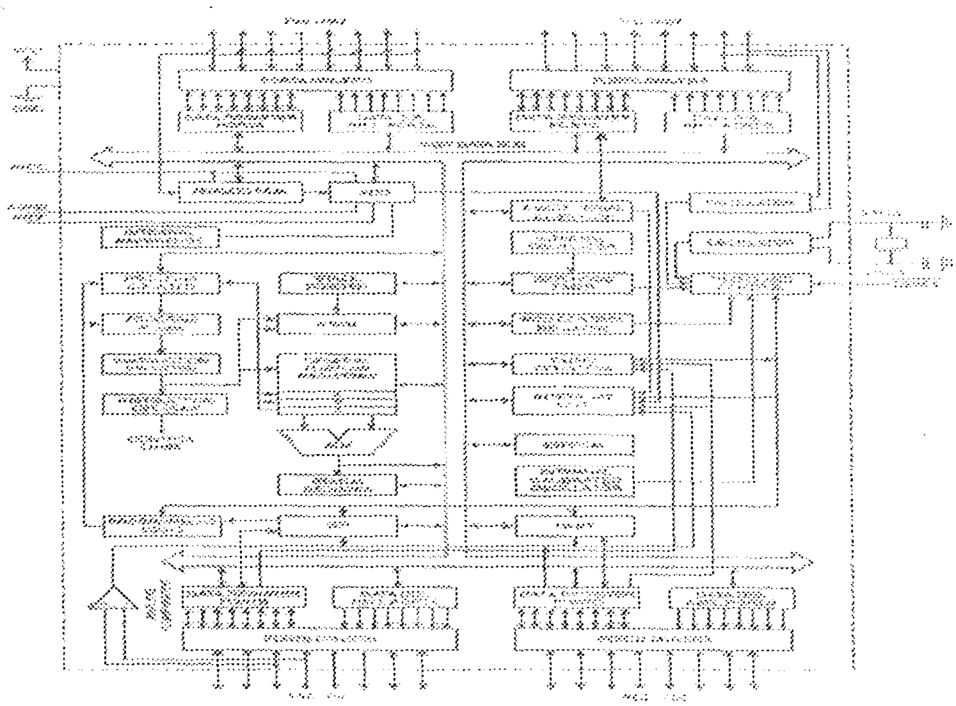
3.2.0 CHOICE OF COMPONENT:

The components used in designing this project are discussed as follows. They were chosen based on their suitability, efficiency and personal knowledge on their role in the electronic world.

3.2.1 MICROCONTROLLAR (ATmega163L)

FUNCTIONAL BLOCK DIAGRAM (ATMEGA163L):

The block diagram and description of the components that constitute the entire system are shown and described below. (Description based on the required parts of this project.)



The ATmegal 163L is a low –power Cmos 8 bit microcontroller base on the AVR architecture. By executing powerful instructions in a single clock cycle. The ATmegal 163 achieves throughputs approaching 1MPS per MHZ allowing the system designer to optimize power consumption versus processing speed.

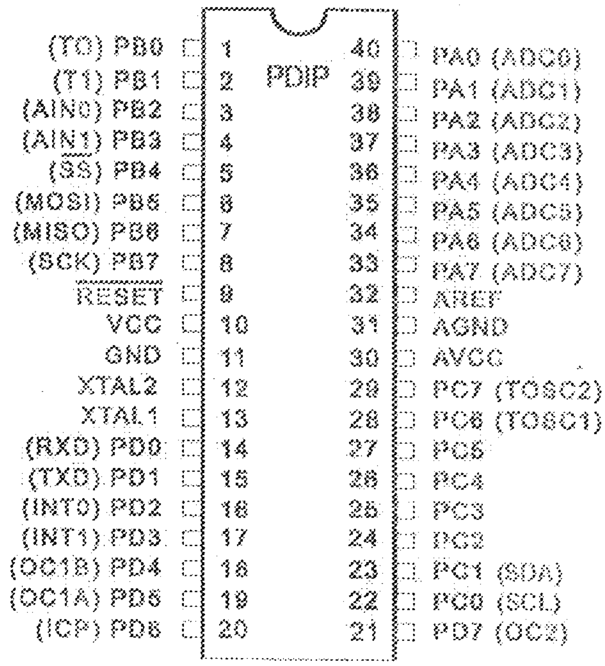
The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega163 provides the following features: 16K bytes of In-System Self-Program-marble Flash, 512 bytes EEPROM, 1024 bytes SRAM, 32 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, a byte oriented 2-wire Serial Interface, an 8-channel, 10bit ADC, a programmable Watchdog Timer with internal oscillator, a programmable serial UART, an SPI serial port, and four software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM; timer/counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the oscillator, disabling all other chip functions until the next interrupt or hardware reset.

In Power-save mode, the asynchronous timer oscillator continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction Mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions.

The On-chip ISP Flash can be programmed through an SPI serial interface or a conventional programmer. By installing a self-programming boot loader, the microcontroller can be updated within the application without any external components. The boot program can use any interface to download the application program in the Application Flash memory. By combining an 8-bit CPU with In-System self-programmable Flash on a monolithic chip, the Atmel ATmega163 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control

PIN CONFIGURATIONS:



PORT A (PA7...PA0): Port A serves as the analog inputs to the A/D Converter.

Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers can sink 20mA and can drive LED displays directly. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tristated when a reset condition becomes active, even if the clock is not running.

PORT B (PB7...PB0): Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit).The Port B output buffers can sink 20mA. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. Port B also serves the functions of various special features of the ATmega83/163 as listed on page 113. The Port B pins are tristated when a reset condition becomes active, even if the clock is not running.

PORT C (PC7...PC0): Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers can sink 20mA. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tristated when a reset condition becomes active, even if the clock is not running.

PORT D (PD7...PD0): Port D is an 8-bit bidirectional I/O port with internal pull-up resistor. (selected for each bit).the port D output buffer can sink 20mA.As inputs, port D pins that are externally pulled low will source current if the pull-up resistors are activated. Port D also serves the functions of various special features of the ATmega1163.Port D pins are tristated when a reset condition becomes activate even if the clock is not running.

RESET: Reset input. A low level on the pin for more then 500ns will generate a reset, even if clock is not running. Shorter pulses are not guaranteed to generate a reset.

XTAL1: Input to the inverting oscillator amplifiere and input to the internal clock operating circuit.

XTAL2: Output from the inverting oscillator amplifier.

AVCC: This is the supply voltage pin for port A and the A/D converter, it is externally connected to Vcc even if the ADC is not used. if the ADC is not used, it is connected to Vcc through a low pass filter.

AREF: This is the analog reference input pin for the A/D converter for ADC operations a voltage in the range 2.5v to AVcc can be applied to the pin.

AGND: Analog ground. If the board has a separate analog ground plane, this pin is connected to the ground plane or to ground.

The connection of the used ports is shown in the circuit diagram dissipated in the appendix B also shown in the appendix is the Register summary and the instruction set.

Discussion on Atmega63L microcontroller was limited to the required parts that constitute my design.[8]

3.2.2 HEF4094BP (8-BIT SHIFT AND STORE DATA BUS REGISTER)

GENERAL DESCRIPTION:

This HEF4094BP are high-speed Si-gate Cmos device and are pin compatible with the 4094 of the "4000B" series. They are specified in compliance with JEDEC standard number 7A.

The HEF4094BP are 8-bit serial shift register having a storage latch associated with each stage for strobing data from serial input (D) to the parallel buffered 3-stage output(QP0 toQP7).the parallel outputs may be connected directly to a common bus line. Data is shifted on the positive-going clock (cp) transistors. The data in each of the shift register stage is transferred the storage register when the strobe input (STR) is HIGH. Data in the storage register appears at the outputs whenever the output enable input (OE) signal is HIGH.

Two serial output (Qs1 and Qs2) are available for cascading a number of "4094" devices. Data is available at Qs1 on the positive-going clock edge to allow high-speed operation in cascaded systems in which the clock rise time is fast. The save serial information is available at Qs2 on the next negative-going clock edge and is for cascading "4094" devices when the rise time is slow.[8]

APPLICATION:

- Serial to parallel data conversion
- Remote control holding register

QUICK REFERENCE DATA

GND = 0 V; T_{amb} = 25 °C; $t_r = t_f$ = 6 ns

SYMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			HC	HCT	
t_{PHL}/t_{PLH}	propagation delay	C_L = 15 pF; V_{CC} = 5 V			
	CP to QS_1		15	19	ns
	CP to QS_2		13	18	ns
	CP to QP_n		20	21	ns
	STR to QP_n		18	15	ns
f_{max}	maximum clock frequency		95	66	MHz
C_I	input capacitance		3.5	3.5	pF
C_{PD}	power dissipation capacitance per package	notes 1 and 2	83	92	pF

PIN DESCRIPTION

PIN NO.	SYMBOL	NAME AND FUNCTION
1	STR	strobe input
2	D	serial input
3	CP	clock input
4, 5, 6, 7 14, 13, 12, 11	QP_0 to QP_7	parallel outputs
8	GND	ground (0 V)
9, 10	QS_1, QS_2	serial outputs
15	OE	output enable input
16	V_{CC}	positive supply voltage

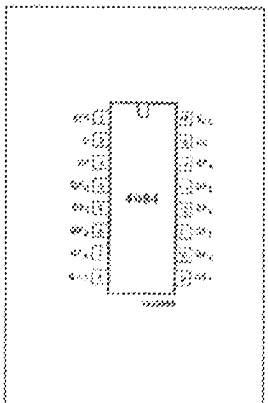


Fig.1 Pin configuration.

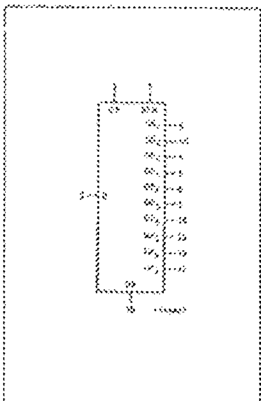


Fig.2 Logic symbol.

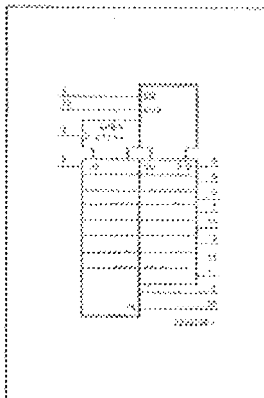


Fig.3 IEC logic symbol.

Notes;

C_{PD} is used to determine the dynamic power dissipation (P_D in μW):

f_i = input frequency in MHz f_o = output frequency in MHz $\sum (C_L \times V_{CC}^2 \times f_o)$ = sum of outputs

C_L = output load capacitance in pF

QUICK REFERENCE DATA

GND = 0 V; T_{amb} = 25 °C; $t_r = t_f$ = 6 ns

SYMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			HC	HCT	
t_{PHL}/ t_{PLH}	propagation delay	C_L = 15 pF; V_{CC} = 5 V			
	CP to QS_1		15	19	ns
	CP to QS_2		13	18	ns
	CP to QP_n		[illegible]	21	ns
	STR to QP_n		16	19	ns
f_{max}	maximum clock frequency		95	88	MHz
C_I	input capacitance		3.5	3.5	pF
C_{PD}	power dissipation capacitance per package	notes 1 and 2	83	91	pF

FUNCTION TABLE

INPUTS				PARALLEL OUTPUTS		SERIAL OUTPUTS	
CP	OE	STR	D	QP_0	QP_n	QS_1	QS_2
↑	L	X	X	Z	Z	Q'6	NC
↓	L	X	X	Z	Z	NC	QP_7
↑	H	L	X	NC	NC	Q'6	NC
↑	H	H	L	L	QP_{n-1}	Q'6	NC
↑	H	H	H	H	QP_{n-1}	Q'6	NC
↓	H	H	H	NC	NC	NC	QP_7

H =HIGH voltage level = LOW voltage level =don't care =high impondence OFF-state

NC = no change, ↑=LOW to HIGH Cp transition, ↓ =HIGH to LOW Cp transition

Q'6 = the information in the seventh register stage is transfer to the eighth register stage and

Qsn output at the positive clock edge.

8-STAGE SHIFT AND STORE BUS REGISTER

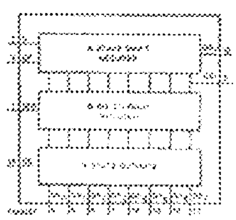


Fig 4. Functional diagram.

3.2.3 SEVEN SEGMENT DISPLAY:

INTRODUCTION:

One common requirement for many different digital devices is a visual numeric display. Individual LEDs can of course display the binary states of a set of latches or flip-flops. However, we're far more used to thinking and dealing with decimal numbers. To this end, we want a display of some kind that can clearly represent decimal numbers without any requirement of translating binary to decimal or any other format.

One possibility is a matrix of 28 LEDs in a 7×4 array. We can then light up selected LEDs in the pattern required for whatever character we want. Indeed, an expanded version of this is used in many ways, for fancy displays. However, if all we want to display is numbers, this becomes a bit expensive. A much better way is to arrange the minimum possible number of LEDs in such a way as to represent only numbers in a simple fashion.

This requires just seven LEDs (plus an eighth one for the decimal point, if that is needed). A common technique is to use a shaped piece of translucent plastic to operate as a specialized optical fiber, to distribute the light from the LED evenly over a fixed bar shape. The seven bars are laid out as a squared-off figure "8". The result is known as a seven-segment LED.

The seven segment display is used in this project to display the resulting output from the microcontroller. The used segment is briefly discussed below.

3.2.4 MAN4640A (COMMON CATHODE VERSION):

MAN4640A is a 4600 series of seven segment displays that provides a superior brightness and high contrast in a choice of color LED displays.[3]

Pin/no	Electrical connections
1	Anode F
2	Anode G
3	No pin
4	Common cathode (Vcc)
5	No pin
6	Anode E
7	Anode D
8	Anode C
9	Anode degree point
10	No pin
11	No connection
12	Common cathode (GND)
13	Anode B
14	Anode A

3.2.4 *BUILDING A 5 VOLT POWER SUPPLY* (POWER SOURCE):

Most digital logic circuits and processors need a 5 volt power supply. Using an unregulated voltage supply from 9volts, 12volts or 24volts to obtain my required 5volt.i used LM7805 regulator IC (Integrated Circuit) The LM7805 is simple to use. I connect the positive lead of my unregulated DC power supply to the Input pin, connect the negative lead to the Ground pin and then i got my 5 volt supply from the Output pin. This 5 volt output serves as my Vcc for this project.

This is an added advantage as a variety of unregulated power source could be used in powering the device with no cause for damaging.(range from 6volts to 24volts)

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 work piece. I took my time in designing the software which to me is the most delicate and more interesting part of this project. for this it was design and implemented in modulus and simulation to avoid errors and unnecessary repetitions.

4.2 COMPONENT LAYOUT:

This circuit was implemented on a Veroboards are hard plastic boards with holes to hold component 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 disordering. 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. Jack and sockets with ribbon cables were used to interconnect modules together. Using ribbon cables makes the interconnection easier and neater.[3]

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 programme separately. This test was performed on a computer. 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, disordering vacuum tube, razor blade, screwdrivers, pliers. Tools PID/IS programming cable/connector, computer for interfacing, multism2001, breadboard, Vero board, half cut burn in socket. 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

Label value	Meter Reading
1uF	1uF
5uF	4.99uF
1nF	1nF
100nF	99.9nF
1pF	1pF

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS:

The readings of capacitance meter agree with the label value of the capacitors used in the testing. The introduction of microcontroller has brought a huge success in the advancement, simplicity, portability, durability and guarantee with perfect accuracy in the design of electrical circuit.

Microcontroller based projects encourage the knowledge and skill of programming languages such as C++, C language, assembler language which are the basic language employed in industrial electronics. Time was spend on programming as it was not so easy and possible to implement a programmed and worked without debugging most especially for us at the course of learning with less training and exposure on programming languages.

I recommend the introduction of programming courses right at the early phase of studies not at final year as it is now. System programming, micro-computer hard and software technology all are courses scheduled for first and second semester of our final year which was unable to give us required exposure needed to excel in programming languages.

I hope future work will improve more on this project. Based on the fact that more or further research will point out some lapses. This follows the saying that "knowledge that has not come down to us is greater than knowledge at hand"

REFERENCE:

[1] Barney, G.C. Intelligent Instrumentation. Second Edition. Prentice-Hall 1995. pp114-119

[2] Floyd, T.L.Digital Fundamentals. Fourth edition, Merrill Publishing Company 1996, pp74-81

[3]. Fraser, C.j.Microcomputer Application in Measurement System First edition 1990, pp.60-75

[4]. Microsoft Encarta encyclopedia 2004.

[5]. Micro-controller Lecture Manual Mr. Eronu Lecturer ECE522 (2004/2005 session) F.U.T Minna.

[6]. System Programming Lecture Manual. Mr. Rumala lecturer ECE521 (2004/2005 session) Pp.01-13.

[7]. The Art of Electronics; Paul Horowitz (Harvard University) Winfield Hill (Rowland Institute for Sci. Cambridge, Massachusetts) Second edition, pp.673-825.

[8] www.howstuffswork.com(capacitance meter)

[9] www.dig.chip.com(display segment)

Appendix A

```
;--------------------------------------------------------------------------;
; Capacitance Meter Control Program R0.01  oct.2005
;--------------------------------------------------------------------------;

.include "163Ldef.inc"    ;Device definition file included in "AVR Family
Assembler".
.include "avr.inc"

.def   _0      = r15  ;Zero register
.def   _Stm1        = r14  ;System timer (250Hz decrement/zero stopped)
.def   _Stm2        = r13  ;System timer (250Hz decrement/zero stopped)

.def   _Flags       = r25  ;b0:Result is minus
                    ;b1:Capture completed
                    ;b2:Integration time out
                    ;b7:Button pressed
```

```
;-------------------------------------------------------------;
; Data memory area

.dseg
        .org    RAMTOP

DispPtr:.byte      1       ;Display buffer
DispBuf:.byte      4       ;/
KeyScan:.byte      2       ;

Comp1:      .byte  2       ;Range low compensation
Comp2:      .byte  2       ;Range high compensation
Comp3:      .byte  2       ;Zero compensation value

StrBuf:     .byte  10      ;Decimal conversion buffer

;-------------------------------------------------------------;
```

```
; Program code area

.cseg
        rjmp  reset         ;Reset
        rjmp  0             ;Extrenal INT0
        rjmp  0             ;External INT1
        rjmp  tc1_cap              ;TC1 capture
        rjmp  0             ;TC1 compare
        rjmp  tc1_ovf              ;TC1 overflow
        rjmp  tc0_ovf              ;TC0 overflow
;       rjmp  0             ;UART Rx UDR ready
;       rjmp  0             ;UART Tx UDR ready
;       rjmp  0             ;UART Tx sfr empty
;       rjmp  0             ;Analog comparator


;---------------------------------------------------------;
; Initialize
```

```
reset:

        outi    SPL,low(RAMEND)           ;SP
        clr     _0              ;Permanent zero reg.

        ldiw    Z, RAMTOP             ;Clear RAM
        ldi     AL, 128               ;
        st      Z+, _0                ;
        dec     AL              ;
        brne    PC-2            ;/

        outi    PORTD, 0b0111100      ;Port D
        outi    DDRD,  0b1111111      ;/

        outi    PORTB, 0b01111000     ;Port B
        outi    DDRB,  0b10001101     ;/

        outi    TCCR0, 0b100          ;TC0.ck = 39kHz
        outi    TIMSK, 0b00000010     ;Enable TC0.ov
```

```
sbi   ACSR, ACIC              ;Connect ACO to TC1 input capture

clr   _Flags
sei

ldiw  Y, DispBuf  ;Lamp test (500ms)
ldi   AL, -1          ;
std   Y+0, AL         ;
std   Y+1, AL         ;
std   Y+2, AL         ;
std   Y+3, AL         ;
ldi   AL, 125         ;
rcall dly             ;/

rcall load_eep        ;Load gain compensation values
breq  PC+6            ;
ldiw  Z, form3*2      ;
rcall put_formed      ;
ldi   AL, 250         ;
```

```
        rcall  dly              ;/




;------------------------------------------------;
; Command processing loop (main)

main:
        ldi     AL, 25              ;Wait for 100ms and Timer2 erapsed.
        mov     _Stm1, AL  ;
        cbr     _Flags, bit7 ;
        sbrc    _Flags, 7    ;
        rjmp    btn_pressed ;
        tst     _Stm1               ;
        brne    PC-3          ;
        tst     _Stm2               ;
        brne    PC-5          ;/
```

```
	ldi	AL, 125		;Start Timer2 (500ms)
	mov	_Stm2, AL	;/
	rcall	measure		;Measure at low range
	brcc	PC+3		;If time out, retry at high range
	cbi	PORTB, 3	;
	rcall	measure		;/
	rcall	adjust_zero	;Refresh display
	rcall	adjust_gain	;
	rcall	disp_val	;/
	sbi	PORTB, 3	;Set low range


	rjmp	main




btn_pressed:
	ldi	AL, 4		;Delay 16ms
	rcall	dly		;/
	sbis	PINB, 6		;Is ISP 1-3 shorted?
```

```
    rjmp  cal_low           ; yes, calibrate low range
    sbis  PINB, 5           ;Is ISP 4-6 shorted?
    rjmp  cal_high      ; yes, calibrate high range
    rjmp  can_offset    ;else, zero adjustment


cal_high:
    cbi   PORTB, 3   ;Measure capacitance for reference high
    rcall measure            ;
    sbi   PORTB, 3   ;/
    ldiw  C, 0            ;X:D:C = 1000*65536; (100nF reference cap)
    ldiw  D, 1000            ;
    ldiw  X, 0            ;/
    ldiw  Z, Comp2
    rjmp  cal_comp

cal_low:
    rcall measure           ;Measure capacitance for reference low
    rcall adjust_zero  ;/
```

```
    ldiw  C, 0         ;X:D:C = 10000*65536; (1nF reference cap)
    ldiw  D, 10000     ;
    ldiw  X, 0         ;/
    ldiw  Z, Comp1
cal_comp:
    clrw  T0           ;X:D:C /= B:A;
    clrw  T2           ;
    ldi   EL, 48       ;
    lslw  C            ;
    rolw  D            ;
    rolw  X            ;
    rolw  T0           ;
    rolw  T2           ;
    cpw   T0, A        ;
    cpcw  T2, B        ;
    brcs  PC+6         ;
    subw  T0, A        ;
    sbcw  T2, B        ;
    inc   CL           ;
```

```
        dec   EL           ;
        brne  PC-21        ;/
        or    DL, DH            ;Check over flow
        or    DL, XL            ;
        or    DL, XH            ;
        brne  cal_err           ;/
        stdw  Z+0, C
        rcall clr_disp
        rcall save_eep
        rjmp  main

can_offset:
        rcall measure               ;Measure capacitance as zero
        or    BL, BH                ;Check adjustment range
        brne  cal_err               ;
        cpi   BH, high(2000)        ;
        brcc  cal_err               ;/
        stsw  Comp3, A          ;Set the value as zero point
        rcall clr_disp
```

```
        rjmp  main


cal_err:
        ldiw  Z, form4*2
        rcall put_formed
        ldi   AL, 250
        rcall dly
        rjmp  main


dly:
        mov   _Stm1, AL
        tst   _Stm1
        brne  PC-1
        ret


;----------------------------------------------------------------;
; Measure capacitance
```

measure:

```
        out     TCNT1H, _0              ;Clear TC1 and set time limit
        out     TCNT1L, _0              ;
        clr     T2L             ;
        ldi     AL, 20                  ;
        sbis    PORTB, 3        ;
        ldi     AL, 152                 ;
        mov     T2H, AL                 ;/
        outi    TIFR,   0b10001000      ;Enable TC1.ov, TC1.cap
        outi    TIMSK,  0b10001010      ;
        cbr     _Flags, bit0+bit1+bit2  ;/
        outi    TCCR1B, 0b01000001      ;Start TC1
        cbi     DDRB, 0                 ;Start to charge

        sbrc    _Flags, 2       ;Wait for end of integration
        rjmp    mea_over        ;
        sbrs    _Flags, 1       ;
        rjmp    PC-3            ;/
```

```
        outi    TCCR1B, 0b01000000   ;Stop TC1
        movew       A, T4            ;Get result
        movew       B, T6            ;/
        clc
        ret

mea_over:
        outi    TCCR1B, 0b01000000   ;Stop TC1
        ldi     AL, 4                ;Wait for 16ms
        rcall   dly                  ;
        ldi     BH, -1
        sec
        ret

adjust_zero:
        sbis    PORTB, 3    ;Skip if in high range
        rjmp    PC+19               ;/
```

```
        ldsw  C, Comp3    ;B:A -= Comp3;
        subw  A, C        ;
        sbc   BL, _0           ;
        sbc   BH, _0           ;/
        brcc  PC+10            ;if sign, B:A *= -1; and set sign flag.
        sbr   _Flags, bit0 ;
        comw A            ;
        comw B            ;
        adc   AL, _0           ;
        adc   AH, _0           ;
        adc   BL, _0           ;
        adc   BH, _0           ;/
        ret

adjust_gain:
        ldiw  Y, Comp1
        sbis  PORTB, 3   ;Gain adjustment
        adiw  YL, 2      ;Load compensation value in to D by range
        lddw  D, Y+0          ;/
```

```
subw  C, C          ;B:A = B:A * D / 65536;
ldi   EL, 33              ;
brcc  PC+3          ;
addw  C, D          ;
rorw  C             ;
rorw  B             ;
rorw  A             ;
dec   EL            ;
brne  PC-10         ;
movew       A, B          ;
movew       B, C          ;/
ret

;------------------------------------------------------------;
; Display value of B:A in unit of 0.1pF

disp_val:
```

```
ldiw  X, StrBuf   ;Decimal buffer
clr   DL          ;Number of digits
inc   DL          ;--- Digits++
clr   CL          ; --- /= 10;
ldi   CH,32                ;
lslw  A           ;
rolw  B           ;
rol   CL          ;
cpi   CL,10       ;
brcs  PC+3        ;
subi  CL,10       ;
inc   AL          ;
dec   CH          ;
brne  PC-10        ; /
st    X+, CL                ;
cp    AL, _0                ;
cpc   AH, _0                ;
cpc   BL, _0                ;
cpc   BH, _0                ;
```

```
    brne  PC-19       ;/
    cpi   DL, 2       ;Adjust digits for 0.0pF
    brcc  PC+3        ;
    st    X+, _0      ;
    inc   DL          ;/
    sbis  PORTB, 3    ;Adjust digits if in high range
    addi  DL, 3       ;/

    ldiw  Z, form2*2-4    ;Select form
    sbrs  _Flags, 0   ;
    adiw  ZL, 16      ;
    adiw  ZL, 4       ;
    dec   DL          ;
    cpi   DL, 2       ;
    brcc  PC-3        ;/

put_formed:
    clr   AH
    ldiw  Y, DispBuf
```

```
lpm
adiw  ZL, 1
mov   AL, T0L
clt
cpi   AL, 2
brcc  PC+3
bst   AL, 0
ld    AL, -X
pushw     Z
ldiw  Z, seg7*2
addw  Z, A
lpm
popw  Z
bld   T0L, 0
st    Y+, T0L
cpi   YL, DispBuf+4
brne  PC-20

ret
```

```
clr_disp:
        ldiw  Y, DispBuf
        st    Y+, _0
        cpi   YL, DispBuf+4
        brne  PC-2
        ret


form4:      .db   14, 5, 15, 15 ;E5

form3:      .db   14, 4, 15, 15 ;E4

form2:      .db   10, 1, 0, 13  ;-0.0p
        .db   10, 0, 0, 13  ;-00p
        .db   14, 3, 15, 15 ;E3
        .db   14, 3, 15, 15 ;E3
```

```
form1:      .db   15, 1, 0, 13  ; 0.0p
        .db   0, 1, 0, 13   ;00.0p
        .db   0, 0, 0, 13   ;000p
        .db   1, 0, 0, 12   ;0.00n
        .db   0, 1, 0, 12   ;00.0n
        .db   0, 0, 0, 12   ;000n
        .db   1, 0, 0, 11   ;0.00u
        .db   0, 1, 0, 11   ;00.0u
        .db   0, 0, 0, 11   ;000u
        .db   14, 2, 15,15 ;E2
        .db   14, 2, 15,15 ;E2
        .db   14, 2, 15,15 ;E2



seg7: .db   0xfc,0x60,0xda,0xf2,0x66,0xb6,0xbe,0xe0
      ;      0 , 1 , 2 , 3 , 4 , 5 , 6 , 7
      .db   0xfe,0xf6,0x02,0x4e,0xc4,0xce,0x9e,0x00
      ;      8 , 9 , -  ,u , n , p , E ,
```

```
;---------------------------------------------------------------;
; Load/Save EEPROM

load_eep:
        ldiw   Y, Comp1      ;Load compensation data
        ldiw   C, 0x5501     ;
        rcall  read_eep      ;
        st     Y+, AL              ;
        add    CH, AL              ;
        cpi    YL, Comp1+4         ;
        brne   PC-4          ;/
        rcall  read_eep      ;Check SUM
        cp     AL, CH              ;
        breq   PC+6          ;/
        sti    -Y, -1        ;Set default value if data have been broken.
        st     -Y, AL              ;
        st     -Y, AL              ;
```

```
    st      -Y, AL              ;/
    ret


save_eep:
    ldiw  Y, Comp1    ;Save compensation data
    ldiw  C, 0x5501   ;
    ld    AL, Y+            ;
    add   CH, AL            ;
    rcall write_eep   ;
    cpi   YL, Comp1+4       ;
    brne  PC-4        ;/
    mov   AL, CH            ;Save check SUM

write_eep:
    out   EEAR, CL
    inc   CL
    out   EEDR, AL
    cli
```

```
        sbi     EECR, EEMWE
        sbi     EECR, EEWE
        sei
        sbic    EECR, EEWE
        rjmp    PC-1
        ret

read_eep:
        out     EEAR, CL
        inc     CL
        sbi     EECR, EERE
        in      AL, EEDR
        ret


;-----------------------------------------------------------------;
; TC1 overflow interrupt
;
```

; T2L counts carry outs from TCNT1. When T2L reaches T2H,

; a time-out error flag will be set.

```
tc1_ovf:
        push  AL
        in    AL, SREG
        push  AL

        inc   T2L
        cp    T2L, T2H
        brcs  PC+6
        sbi   DDRB, 2
        sbi   DDRB, 0
        sbr   _Flags, bit2
        outi  TIMSK, 0b00000010

        pop   AL
        out   SREG, AL
        pop   AL
```

```
        reti




;-----------------------------------------------------------------;
; TC1 capture interrupt
;
; When Vc reaches 0.17 Vcc, capture t1 and change reference
; voltage to 0.5Vcc. When Vc reaches 0.5 Vcc, capture t2 and
; terminate the measureing.

tc1_cap:
        push  AL
        in    AL, SREG
        push  AL
        sbis  DDRB, 2                  ;Branch by measureing phase.
        rjmp  tc1c_ed                  ;/

tc1c_st:        ; Vc reaches 0.17 Vcc
```

```
	in	T4L, ICR1L		;Capture t1
	in	T4H, ICR1H		;
	mov	T6L, T2L		;/
	cbi	DDRB, 2			;Change Vth to 0.5 Vcc.
	ldi	AL, 20			;Deley several microseconds and clear
Irq.
	dec	AL			;
	brne	PC-1			;
	outi	TIFR,	0b00001000	;/
	rjmp	tc1c_c

tc1c_ed:	; Vc reaches 0.5 Vcc
	mov	T6H, T4L		;Capture t2-t1
	in	T4L, ICR1L		;
	sub	T4L, T6H		;
	mov	T6H, T4H		;
	in	T4H, ICR1H		;
	sbc	T4H, T6H		;
	mov	T6H, T6L		;
```

```
        mov   T6L, T2L            ;
        sbc   T6L, T6H            ;
        clr   T6H                 ;/
        sbi   DDRB, 2                     ;Set Vth to 0.17 Vcc.
        sbi   DDRB, 0                     ;Discharge capacitor
        outi  TIMSK, 0b00000010           ;Disable Irq.
        sbr   _Flags, bit1        ;End of measureing.

tc1c_e:
        pop   AL
        out   SREG, AL
        pop   AL
        reti


;------------------------------------------------------------;
; TC0 overflow interrupt (1kHz)
;
; - Refresh LED display.
```

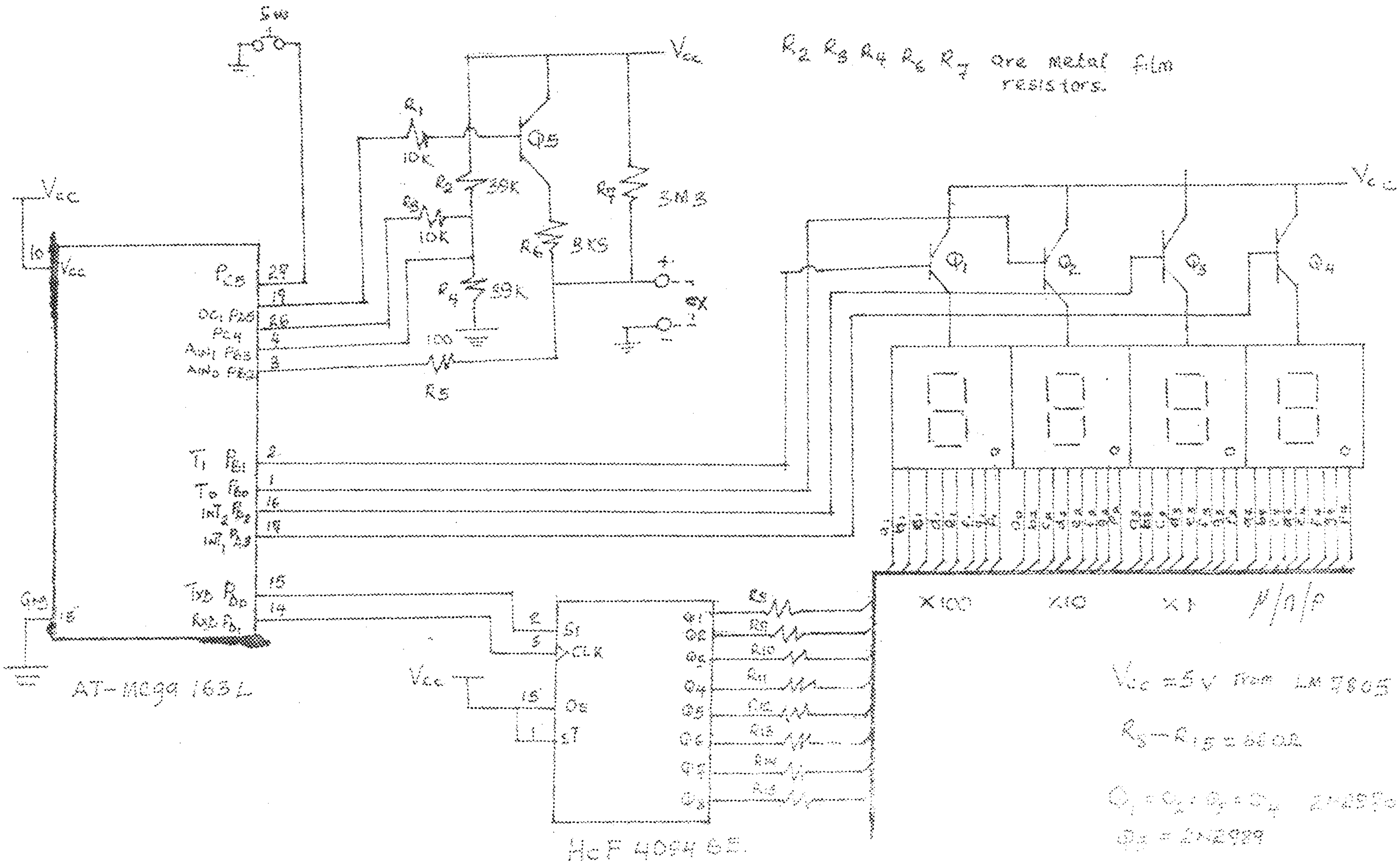
```
; - Scan button inputs.
; - Decrement _Stm1 and _Stm2. (250Hz)

tc0_ovf:
        push  AL
        outi  TCNT0, -39
        sei
        in    AL, SREG
        pushw A
        pushw Z

        ldiw  Z, DispPtr        ;Next display digit
        ld    AH, Z             ;
        inc   AH                ;
        cpi   AH, 4             ;
        brcs  PC+3              ;
        rcall scan_key          ;
        clr   AH                ;
        st    Z+, AH            ;/
```

```
outi  PORTD, 0b0111100      ;Disable row drive
add   ZL, AH                ;Select row bit
ldi   AL, bit6              ;
lsr   AL                    ;
subi  AH, 1                 ;
brcc  PC-2                  ;
com   AL                    ;
andi  AL, 0b0111100         ;/
ld    AH, Z                 ;Load column pattern
ldi   ZL, 8                 ;Set column pattern into sreg
sbrs  AH, 0                 ;
sbi   PORTD, 1              ;
sbrc  AH, 0                 ;
cbi   PORTD, 1              ;
sbi   PORTD, 0              ;
cbi   PORTD, 0              ;
lsr   AH                    ;
dec   ZL                    ;
brne  PC-8                  ;/
```

```
        out     PORTD, AL           ;Enable row drive

t0_exit:
        popw Z
        popw A
        out     SREG, AL
        pop     AL
        reti

scan_key:
        in      AL, PINB    ;Scan button
        com     AL          ;
        andi    AL, bit4    ;
        ldd     AH, Z+6             ;
        std     Z+6, AL             ;
        cp      AL, AH              ;
        brne    PC+7        ;
        ldd     AH, Z+5             ;
        std     Z+5, AL             ;
```

```
eor   AH, AL          ;
and   AH, AL          ;
breq  PC+2      ;
sbr   _Flags, bit7 ;/

tst   _Stm1           ;Decrement Stm with zero stopeed...
breq  PC+2      ;
dec   _Stm1           ;
tst   _Stm2           ;
breq  PC+2      ;
dec   _Stm2           ;/

ret
```

APPENDIX D.



CAPACITANCE METER CIRCUIT