Abstract

Inkjet-printed memory cards have been developed previously by researchers at Mid Sweden University but, these did possess some limitations, as each resistive memory cell required one physical contact and the resistances were designed to be electrically programmed.

This work overcomes the above limitations by developing chemically programmed printed memory cards and a PC connected memory card reader. Printed memory cards are inexpensive and are developed by inkjet printing the nano-silver ink onto the photo paper substrate. A matrix readout method is used to increase the number of memory cells and, by using a chemical solvent, the resistances were programmed to the desired resistance values and, for which, each resistance value represents data on the cards, called, write once read many (WORM) memories. The memory card reader was developed to access the data (resistance value) of the memory card and also to transmit the data to a LabVIEW graphical user interface for displaying the resistance values. By using multiple resistance steps, in which each step represents a different state, it is possible to create a number of possible selectable combinations which can be programmed at a later stage for developing applications.

Keywords: Inkjet, Silver ink, Printed memory card, Card reader, LabVIEW, WORM.
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# Terminology

## Abbreviations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>SPDT</td>
<td>Single Pole Double Throw</td>
</tr>
<tr>
<td>WORM</td>
<td>Write Once Read Many</td>
</tr>
<tr>
<td>Op-amp</td>
<td>Operational Amplifier</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog to Digital Converter</td>
</tr>
<tr>
<td>USART</td>
<td>Universal Synchronous/Asynchronous Receiver/Transmitter</td>
</tr>
<tr>
<td>FTDI</td>
<td>Future Technology Devices International Limited</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>TSSOP</td>
<td>Thin-Shrink Small Outline Package</td>
</tr>
<tr>
<td>TQFP</td>
<td>Thin Quad Flat Package</td>
</tr>
<tr>
<td>SOIC</td>
<td>Small-Outline Integrated Circuit</td>
</tr>
<tr>
<td>SSOP</td>
<td>Shrink Small-Outline Package</td>
</tr>
<tr>
<td>TTL</td>
<td>Transistor -Transistor Logic</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>JTAG</td>
<td>Joint Test Action Group</td>
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</table>
Mathematical notation

<table>
<thead>
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<th>Symbol</th>
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<tr>
<td>$R_L$</td>
<td>Load Resistor</td>
</tr>
<tr>
<td>$R_{in}$</td>
<td>Equivalent resistance of other $(N-1)$ row elements connected to the selected column</td>
</tr>
<tr>
<td>$V_o$</td>
<td>Output voltage</td>
</tr>
<tr>
<td>$R_F$</td>
<td>Feedback resistance</td>
</tr>
<tr>
<td>$V$</td>
<td>Input Voltage</td>
</tr>
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<td>$A$</td>
<td>Open loop Gain</td>
</tr>
<tr>
<td>$V_P$</td>
<td>Voltage at node P</td>
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1 Introduction

This thesis details the development of chemically programmed printed memory cards and a PC connected memory card reader. It is firstly necessary to provide a few details regarding the need for printed memory cards as compared to a plastic memory card. Printed memory cards use paper, which is both inexpensive and disposable thus making it possible to reduce the amount of plastic and other materials required for the alternative plastic cards. Thus the memory cards can be developed in a low cost and eco-friendly environment. In relation to the printing of the memory cards, inkjet printing technology is used which involves printing nano-silver ink onto a photo paper substrate. The resistive memory cells of the printed memory card are chemically programmed using a solvent to achieve specific values, each of which represents data on the card. These memories are Write Once Read Many (WORM) in which the resistances are programmed once but are read many times. The sintering of the memory cells is achieved using an oven sintering technique. The memory card reader will access the resistance values on the memory card and display these values in a Graphical User Interface created in LabVIEW. This entire system can be useful in many applications such as for the development of printed memory technology, Radio Frequency Identification Technology field and for providing security for internet logins [1] and can also be used in almost all applications where a unique identity is required.
1.1 Background and problem motivation

In the past, inkjet-printed resistive memory cells on photo paper substrate have been developed [2] but this involved drawback such as each memory cell requiring individual physical contact with the memory card and the requirement of a memory card reader to avoid the effect of crosstalk, thus 8 memory cells required 8 contacts. Memory cells will have high resistance values after printing, and these are then electrically programmed in order to achieve the desired resistance values or data.

Figure 1: Previously developed memory card [2]

In order to overcome the drawback of individual physical contact, a matrix readout of the resistive elements has been used. By implementing this method the number of physical contacts between the printed memory card and the memory card reader has been reduced. The matrix method only requires 8 contacts to read 16 memory cells. The resistive memory cells are chemically programmed to achieve the desired resistance values instead of electrically programmed. A PC connected memory card reader has been designed to read the values of the memory cells.
1.2 Overall aim

The overall aim of the thesis is to develop a chemically programmed printed memory card with an increased number of memory cells and to obtain less physical contacts between the card and the reader. A PC connected memory card reader must be developed to read the values from the memory card and to display the values in LabVIEW.

1.3 Outline

The outline of the report is as follows

Chapter 1 discusses the introduction and motivation behind the thesis.

Chapter 2 discusses the theoretical part of the printed memory card and card reader.

Chapter 3 discusses the methodology used for increasing the memory cells of the printed memory card and the card reader.

Chapter 4 discusses the design and implementation of the printed memory card and the interfacing between the components of the card reader.

Chapter 5 discusses the results of the entire development system.

Chapter 6 provides the conclusion.
2 Theory

This chapter discusses the inkjet printing, nano-silver ink, paper substrate, the operation required for developing the printed memory card and also the components required to develop a memory card reader.

2.1 Inkjet Printing

Inkjet printing originated in the 19th century but was largely developed in the early 1950’s. Inkjet Printing technology is used to produce digital images and also for printed electronics on paper substrates. It operates by propelling variably sized droplets of ink or other materials onto almost any medium. The advantage of inkjet printing over other techniques is that the materials can be printed to a desired location on the substrates as required by the user. It has flexibility in relation to changing the printing pattern. The inkjet-printer used is FUJIFILM Diamatix 2800 material printer [3].

Figure 2: Diamatix 2800 Inkjet-Printer
2.2 Nano-Silver ink

In general, the nano-silver inks have a uniform dispersion of particles in polar or non polar solvents [2] [4], and when dispersed the coalescence of the nano particles is prevented by means of the polymer shell which is present in the ink. The size of the nano particles is between 1 nm and 100 nm and the nano-silver ink has a low viscosity and, in addition, possesses a solid content of between 30% -35%. The silver ink used is the Silver jet DGP-40LT-15C from Advanced Nano Products. The silver ink is contained in a 10pL Diamatix 11610 cartridge. It has 16 nozzles, each of which contains piezoelectric crystals and when a current is applied to the crystals, both the shape and size change, thus forcing the droplets of ink onto any substrate.

2.3 Paper Substrate

The substrate [5] used for printing the silver ink is the HP Advanced Photo paper and this is used particularly for inkjet printing. This process requires good surface smoothness, strength and even porosity in order to avoid the spreading of the ink. The photo papers are coated with an absorbent material to limit the diffusion of ink away from the point of contact. The advantage of using a paper substrate for developing the memory card is in relation to its low cost and its ability to be recycled. The volume and surface resistivity of paper substrates at a relative humidity of 20-40% are $10^{10}$–$10^{14}$ Ω cm and $10^{11}$–$10^{15}$ Ω sq$^{-1}$ respectively [5].
2.4 Operation Required for Printing Memory Card

In order to develop a fully functional printed memory card, some particular operations are required which are explained below.

2.4.1 Printed Resistive Memories

Printed memories are WORM memories i.e. the resistance value can be programmed only once (cannot be modified) but can be read multiple times. Resistive memory cells are developed by printing the silver nano particles onto the paper substrate [2] [4]. Printing the particles on the substrate results in a conducting material and the material resistance is then measured.
2.4.2 Solvent

The solvent used is Triethylene Glycol Monoethyl Ether [4] which is a polar solvent. A solvent is used in order to prevent the aggregation of the nano particles but, in this case, the solvent is mainly used for chemical programming, which, when varied, results in the desired resistance value. The resistance value varies according to the amount of solvent used and this can be achieved by printing a larger or smaller area with the solvent.

2.4.3 SU-8 Photoresist

SU-8 is a negative photo resist, which is used for high resolution masking in the fabrication of semiconductor devices for the microelectronics industry. It is used, at present, in the printed electronics field in order to provide masking or isolation. Its maximum absorption is in relation to ultraviolet light with a wavelength of 365 nm. It is exposed to ultraviolet light in order to solidify the material and, at this stage, it also becomes transparent.

2.4.4 Sintering Technique

Initially, after printing the nano-silver ink onto the photo paper substrate, the memories will possess a reduced conductivity, because of the dispersion of the nano particles in the solvent. Thus, in order to improve the conductivity of the printed memories, a sintering technique is used. There are various sintering techniques such as oven sintering, electrical sintering [5, 6] etc. In this case, oven sintering has been performed which involves the thermal heating of the printed memory cards in an oven. After thermal heating, the polymer shell of the nano particles starts to destabilize and combines with other nano particles to increase the conductivity.
2.5 Components used for the Development of Memory Card Reader

To read the resistance value of the printed memory card, a memory card reader must be developed. Components used for developing the card reader are explained in the following section.

2.5.1 Microcontroller

The microcontroller used for the development of the memory card reader is the ATmega169p [7] which was chosen because it is 8-bit with 54 programmable I/O lines, low power consumption and it is also very low cost. It has a programmable flash memory of 16 kilo bytes. It has 8 ADC channels with a 10 bit resolution. Its operating voltage is 2.7-5.5V. The microcontroller supports a flash programming interface using JTAG. It has 64 leads and the package used is TQFP.

Figure 4: Pin configurations of ATmega169P
2.5.2 FTDI Chip

![FT232-RL Pin Configuration](image)

Figure 5: Pin configuration of FT232-RL

It is an integrated circuit used for serial communication. The FT232-RL chip [8] provides an asynchronous serial interface between the microcontroller and the PC through an USB cable. The data transfer rate supported is from rates of 300 baud to 3M baud at (RS-232, RS-485) TTL levels. FTDI operates at 5V and has low power consumption. It has 28 pins and an SSOP package is used.

2.5.3 SPDT Switch

![SPDT Switch Pin Configuration](image)

Figure 6: Pin configuration of ADG1434
The Single Pole Double Throw switch used is ADG1434 [9]. It has 4 independently selectable SPDT switches. It uses rail to rail operation and the maximum on resistance is 4.7 Ω. It has 4 input pins and 8 out pins, and the input pins are selected through the control logic input pins. It uses +/- 5V dual power supply. The switching current required per channel is 20 mA. It has 20 pins and the package used is TSSOP. It can be used in the applications such as communication systems, data acquisition systems, temperature measurement system and medical equipment.

2.5.4 Operational Amplifier

The operational amplifier is a high gain DC – coupled voltage amplifier with a differential input and a single ended output. The operational amplifier used is LM124D [10], which has 4 independent high gain frequency compensated operational amplifiers. This op-amp is very cheap, has low power consumption and has a low input bias and offset parameters. It has a single supply voltage from 3V to 32V and the dual supply voltage of +/- 1.5V to +/- 16V. The package used for this op-amp is SOIC.
3 **Methodology**

Previously, inkjet printed memory cards on photo paper substrate were developed for which each memory cell required an individual physical contact with a card reader to reduce the effect of crosstalk. A new matrix method is required to be implemented in order to increase the number of resistive memory cells in the printed memory card with the minimum number of contacts. To implement the matrix method studies on the following proposals were conducted.


2. Measurement errors in the scanning of resistive sensor arrays [12].


From the above proposals, a new discrete circuit for readout of resistive sensor arrays [11] has been used to implement the printed memory card as this method involves less circuit complexity and is low cost in relation to developing the card reader compared to the other two methods. The methods, measurement errors in the scanning of resistive sensor arrays [12] and measurement errors in the scanning of piezo-resistive sensor arrays [13] use the concept of a voltage feedback method, zero potential method, inserting diode method and a circuit based on a grounding method in order to reduce the effect of crosstalk.

In the method, a new discrete circuit for readout of resistive sensor arrays [11] and individual access to the resistive elements is conducted using two sets of interconnection lines, called the row and column lines, connecting all the elements. One end of the element is connected to a row line and other end to the column line and, by this means, a unique row-column combination is created.
By using a connection from this unique row-column combination, any resistive element can be accessed. However, when accessing an element, the current discovers various paths via other elements, therefore the signals of the element being accessed will have an influence from all other elements in the array, which has the potential to lead to crosstalk. Crosstalk is the unwanted spreading of information over the array.

![Diagram of a resistive sensor array with rows and columns labeled](image)

**Figure 8:** Connection of all elements with rows and columns lines

The proposed circuit uses the concept of virtual same potential at the input of operational amplifier in the negative feedback path in order to provide sufficient isolation between all the array elements [11], thus reducing crosstalk.

In general, in order to access all the elements individually in the array method, two physical connections are required from the resistive element which results in 2NM connections in the N X M format. By using the new discrete circuit for the readout of resistive sensor arrays, the physical contact complexity while accessing any element can be reduced from 2NM connections to N + M connections.
The column lines and the row lines are connected to two digitally controlled single pole double throw switches (SPDT) as shown in the proposed circuit in Figure 9. This allows any element in the column to be connected with a load resistor (R_L) and any element in the row to be connected to an output node of the operational amplifier, with all the other elements of the rows and columns being connected to ground. The selected resistive element comes under the negative feedback path of the operational amplifier. The other N-1 element in the selected column makes a parallel combination to the inputs of the operational amplifier, with the non-inverting input grounded. The other M-1 element in the selected row is connected to the output node of the operational amplifier with the other end grounded. All the other (N-1) X (M-1) resistive elements which are not physically connected with the selected resistive element are grounded. In the case of an ideal operational amplifier which has infinite open loop gain and infinite input impedance the selected resistive element will have a constant bias current (V/ R_L) from
which the output voltage for the selected resistive element or element being accessed (EBA) can be calculated as \((-V/ R_L) \times R_{EBA}\). However, practically the operational amplifier will have finite input impedance and a finite gain, the loading effect due to the resistances at the two inputs of the operational amplifier causes a decrease in the overall gain of the circuit, which leads to a small crosstalk within the elements. The effect of parasitic resistance should also be considered, which are the contact resistance and the pin resistance of the operational amplifier. By selecting a small resistance value for the contact resistance of the operational amplifier, this problem can be solved.

### 3.1 Theoretical Analysis

The theoretical analysis of the new discrete readout of resistive sensor arrays method has been conducted in order to calculate the output voltage for the selected resistive element. The circuit for one selected resistive element is explained below using Figure 10 [11].

#### 3.1.1 Circuit for one Selected Resistive Element

![Figure 10: Implemented circuit for one selected element [11]](image)

- \(R_L\)  \(\rightarrow\) Load Resistor
- \(R_{oa}\)  \(\rightarrow\) Equivalent resistance of other \((N-1)\) row elements connected to the selected column.
- \(V_o\)  \(\rightarrow\) Output voltage.
- \(R_f\)  \(\rightarrow\) Feedback resistance (element being accessed).
- \(V\)  \(\rightarrow\) Input Voltage
$A \Rightarrow$ Open loop Gain.

$V_p \Rightarrow$ Voltage at node P.

$V_{in}$ across the two input terminal of the op-amp can be given by [11]

$$
V_{in} = (V^+ - V^-) \\
V_{in} = 0 - V_p \\
V_p = -\frac{V_o}{A}
$$

(1)

Applying Kirchhoff’s current law at node P,

$$
\frac{(V - V_p)}{R_L} + \frac{(V_o - V_p)}{R_f} + \frac{(0 - V_p)}{R_m} = 0
$$

(2)

The output voltage for the corresponding resistive element being accessed can be calculated using the equation below [11]

$$
V_o = -\frac{V}{R_L} \left( \frac{1}{A \cdot R_L} + \frac{1}{A \cdot R_f} + \frac{1}{A \cdot R_m} + \frac{1}{R_f} \right)^{-1}
$$

(3)

$R_m$ value for Symmetric resistances is given by [11]

$$
R_m = \frac{R_f}{N - 1}
$$

(4)

where N-1 is the resistance of the other rows connected to the selected column.

$R_m$ value for various resistances is given by the parallel resistance equation.

$$
R_m = \frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c}
$$

(5)
The calculations for the output voltage of the selected resistive element has been performed below

When the assumption is that $R_L = 12k\Omega$, $V = 5V$, $A=10^5$, $R_f = 10k\Omega$, $R_{in} = 1.3k\Omega$ for various resistances.

Applying these values in equation (3)

$$V_o = \left(-\frac{5}{12k}\right)\left[\left(\frac{1}{10^5\cdot12k}\right)+\left(\frac{1}{10^5\cdot10k}\right)+\left(\frac{1}{10^5\cdot1.3k}\right)+\left(\frac{1}{10k}\right)\right]^{-1}$$

$$V_o = -(0.4166) \times (9.99904)$$

$$V_o = -4.165V.$$  

The negative sign is the $180^\circ$ out of phase signal for the inverting amplifier.

By simplifying equation (3), feedback resistance or the element being accessed can be calculated.

$$R_f = \left[(1 + A) \cdot \frac{R_L \cdot R_{in} \cdot V_o}{R_{in} \cdot A \cdot V_o} + (R_{in} \cdot A \cdot V_o) + (V_o \cdot R_{in}) + (V_o \cdot R_L)\right]$$ (6)
3.2 Simulations of the Circuit

Simulations for this method described by R.S. Saxena et al. [11] were conducted using the LT Spice simulation tool. The operational amplifier used was LM124. The load resistor $R_l$ used in simulation is 12kΩ and the input voltage is 5V. The dual supply used for op-amp is +/- 10V. In the simulation, the effect of $R_F$ and $R_{in}$ on the magnitude of the overall gain of the circuit is performed and an explanation is given.

![Schematic of Simulated circuit](image)

Figure 11: Schematic of Simulated circuit

3.2.1 Gain vs $R_F$ ($R_{in}$ constant)

Gain of the circuit with the negative feedback resistance is plotted with the simulated values i.e. by retaining the $R_{in}$ value to be constant and by varying $R_F$. When $R_{in}$ remains constant at 1kΩ and $R_F$ is varied from 1kΩ to 10kΩ the corresponding circuit gain and the output voltage are tabulated.
Table 1: Simulated values at $R_{in}$ is 1kΩ

<table>
<thead>
<tr>
<th>$R_F$ (kΩ)</th>
<th>$V_o$ (V)</th>
<th>Gain ($V_o/V_{in}$)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>-0.42</td>
<td>0.085</td>
</tr>
<tr>
<td>2</td>
<td>-0.85</td>
<td>0.1708</td>
</tr>
<tr>
<td>3</td>
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<td>0.254</td>
</tr>
<tr>
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<td>0.342</td>
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<tr>
<td>10</td>
<td>-4.25</td>
<td>0.851</td>
</tr>
</tbody>
</table>

From Figure 12 it is clear that the feedback resistance (element being accessed) has a significant effect on the circuit gain and the relationship is linear.

By maintaining a constant $R_F$ value at three different levels, namely 1kΩ, 5kΩ and 10kΩ and by varying the $R_{in}$ values for the corresponding
values of $R_F$ from 60Ω to 10kΩ, 300Ω to 10kΩ, 600Ω to 10kΩ respectively. The variations in the $R_n$ values for the different values of $R_F$ are to satisfy the bias condition i.e, to avoid the effect of saturation at the op-amp output. The circuit gain and simulated output voltage value are tabulated and shown in Table 2, Table 3 and Table 4 respectively.

### 3.2.2 Gain vs $R_n$ ($R_F = 1kΩ$)

When $R_F$ remains constant at 1kΩ and $R_n$ is varied from 60Ω to 10kΩ.

<table>
<thead>
<tr>
<th>$R_n$ (Ω)</th>
<th>$V_o$ (V)</th>
<th>Gain ($V_o/V_in$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>-0.575</td>
<td>0.115</td>
</tr>
<tr>
<td>70</td>
<td>-0.552</td>
<td>0.1104</td>
</tr>
<tr>
<td>80</td>
<td>-0.535</td>
<td>0.107</td>
</tr>
<tr>
<td>90</td>
<td>-0.521</td>
<td>0.104</td>
</tr>
<tr>
<td>100</td>
<td>-0.51</td>
<td>0.102</td>
</tr>
<tr>
<td>200</td>
<td>-0.46</td>
<td>0.092</td>
</tr>
<tr>
<td>300</td>
<td>-0.45</td>
<td>0.09</td>
</tr>
<tr>
<td>400</td>
<td>-0.44</td>
<td>0.088</td>
</tr>
<tr>
<td>500</td>
<td>-0.437</td>
<td>0.0874</td>
</tr>
<tr>
<td>600</td>
<td>-0.434</td>
<td>0.0868</td>
</tr>
<tr>
<td>700</td>
<td>-0.432</td>
<td>0.0864</td>
</tr>
<tr>
<td>800</td>
<td>-0.43</td>
<td>0.086</td>
</tr>
<tr>
<td>900</td>
<td>-0.429</td>
<td>0.0858</td>
</tr>
<tr>
<td>1000</td>
<td>-0.428</td>
<td>0.0856</td>
</tr>
<tr>
<td>2000</td>
<td>-0.424</td>
<td>0.0848</td>
</tr>
<tr>
<td>3000</td>
<td>-0.422</td>
<td>0.084</td>
</tr>
<tr>
<td>4000</td>
<td>-0.421</td>
<td>0.084</td>
</tr>
<tr>
<td>5000</td>
<td>-0.421</td>
<td>0.084</td>
</tr>
<tr>
<td>6000</td>
<td>-0.42</td>
<td>0.084</td>
</tr>
<tr>
<td>7000</td>
<td>-0.42</td>
<td>0.084</td>
</tr>
<tr>
<td>8000</td>
<td>-0.42</td>
<td>0.084</td>
</tr>
<tr>
<td>9000</td>
<td>-0.42</td>
<td>0.084</td>
</tr>
<tr>
<td>10000</td>
<td>-0.42</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Table 2: Simulated values at $R_F$ is 1kΩ
Figure 13: Gain of the circuit as a function of $R_{\text{in}}$ at $R_F$ is 1kΩ

From Figure 13 it is clear that $R_{\text{in}}$ has only a minor effect on the circuit gain when $R_F$ is 1kΩ.

### 3.2.3 Gain vs $R_{\text{in}}$ ($R_F = 5k\Omega$)

When $R_F$ remains constant at 5kΩ and $R_{\text{in}}$ is varied from 300Ω to 10kΩ the corresponding circuit gain and simulated output voltage values are tabulated.
Chemically Programmed Memory
Card and PC connected Memory
Card Reader
Gokuldev Vadakke Kunninmel

Methodology

Table 3: Simulated values at $R_F$ is 5KΩ

<table>
<thead>
<tr>
<th>$R_{in}$ (Ω)</th>
<th>$V_o$ (V)</th>
<th>Gain($V_o/V_{in}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>-2.23</td>
<td>0.446</td>
</tr>
<tr>
<td>400</td>
<td>-2.19</td>
<td>0.438</td>
</tr>
<tr>
<td>500</td>
<td>-2.17</td>
<td>0.434</td>
</tr>
<tr>
<td>600</td>
<td>-2.15</td>
<td>0.43</td>
</tr>
<tr>
<td>700</td>
<td>-2.145</td>
<td>0.429</td>
</tr>
<tr>
<td>800</td>
<td>-2.14</td>
<td>0.428</td>
</tr>
<tr>
<td>900</td>
<td>-2.13</td>
<td>0.426</td>
</tr>
<tr>
<td>1000</td>
<td>-2.129</td>
<td>0.4258</td>
</tr>
<tr>
<td>2000</td>
<td>-2.107</td>
<td>0.421</td>
</tr>
<tr>
<td>3000</td>
<td>-2.099</td>
<td>0.4198</td>
</tr>
<tr>
<td>4000</td>
<td>-2.096</td>
<td>0.4192</td>
</tr>
<tr>
<td>5000</td>
<td>-2.094</td>
<td>0.4188</td>
</tr>
<tr>
<td>6000</td>
<td>-2.092</td>
<td>0.4184</td>
</tr>
<tr>
<td>7000</td>
<td>-2.091</td>
<td>0.4182</td>
</tr>
<tr>
<td>8000</td>
<td>-2.091</td>
<td>0.4182</td>
</tr>
<tr>
<td>9000</td>
<td>-2.09</td>
<td>0.418</td>
</tr>
<tr>
<td>10000</td>
<td>-2.09</td>
<td>0.418</td>
</tr>
</tbody>
</table>

Figure 14: Gain of the circuit as a function of $R_{in}$ at $R_F$ is 5kΩ
From the Figure 14 it is clear that $R_{in}$ has minimal effect on the circuit gain when $R_F$ is 5kΩ.

### 3.2.4 Gain vs $R_{in}$ ($R_F = 10kΩ$)

When $R_F$ remains constant at 10kΩ and $R_{in}$ is varied from 600Ω to 10kΩ, the corresponding circuit gain and the simulated output voltage are tabulated.

<table>
<thead>
<tr>
<th>$R_{in}$ (Ω)</th>
<th>$V_o$ (V)</th>
<th>Gain ($V_o/V_{in}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>-4.31</td>
<td>0.86</td>
</tr>
<tr>
<td>700</td>
<td>-4.29</td>
<td>0.858</td>
</tr>
<tr>
<td>800</td>
<td>-4.27</td>
<td>0.854</td>
</tr>
<tr>
<td>900</td>
<td>-4.26</td>
<td>0.852</td>
</tr>
<tr>
<td>1000</td>
<td>-4.25</td>
<td>0.85</td>
</tr>
<tr>
<td>2000</td>
<td>-4.21</td>
<td>0.842</td>
</tr>
<tr>
<td>3000</td>
<td>-4.188</td>
<td>0.837</td>
</tr>
<tr>
<td>4000</td>
<td>-4.183</td>
<td>0.8366</td>
</tr>
<tr>
<td>5000</td>
<td>-4.18</td>
<td>0.836</td>
</tr>
<tr>
<td>6000</td>
<td>-4.18</td>
<td>0.836</td>
</tr>
<tr>
<td>7000</td>
<td>-4.18</td>
<td>0.836</td>
</tr>
<tr>
<td>8000</td>
<td>-4.178</td>
<td>0.836</td>
</tr>
<tr>
<td>9000</td>
<td>-4.177</td>
<td>0.836</td>
</tr>
<tr>
<td>10000</td>
<td>-4.177</td>
<td>0.836</td>
</tr>
</tbody>
</table>

Table 4: Simulated values at $R_F$ is 10KΩ
Figure 15: Gain of the circuit as a function of $R_{in}$ at $R_{F}$ is 10kΩ

From the Figure 15 it is clear that $R_{in}$ has a minimal effect on the circuit gain when $R_{F}$ is 10kΩ.

Figure 16 shows the comparison of the circuit gain as a function of $R_{in}$ with $R_{F}$ values remaining at 1kΩ, 5kΩ and 10kΩ respectively.

Figure 16: Overall Gain circuit as a function of $R_{in}$ with $R_{F}$ varied
From all the above graphs it can be noted that lower values of $R_{in}$ will have a greater impact on the circuit gain than the higher values of the $R_{in}$. The error rate in relation to the circuit gain caused by the lower values of $R_{in}$ is approximately 2%. This error rate is negligible in the development of the memory card reader, as a small tolerance in relation to the resistance value is acceptable as compared to the other sensor readings. By having higher values of $R_{in}$ the crosstalk can be reduced and also from the above analysis it is clear that the circuit gain is significantly dependent on the feedback resistance ($R_f$).

Thus by implementing the matrix readout scheme where the number of memory cells is $N \times M$, 16 memory cells ($4 \times 4 = 16$) are achieved instead of the previous 8.
4 Design / Implementation

4.1 Printed Memory Card Design

The memory card is a data storage device used to store digital information. A printed resistive memory card is used based on its low cost and its disposability. In this thesis, the matrix method [11] has been used to design the resistive memory cells onto a photo paper substrate in order to increase the number of resistive memory cells on the memory card with the minimum number of physical contacts.

The Dimatix 2831 piezoelectric materials printer has been used [3] for the design of the Inkjet-Printed resistive memory cells onto the photo paper substrate. The cartridge used for printing is the 10pL Dimatix 11610 which has 16 nozzles in order to provide the ink. The nano-silver ink used for printing is silver jet DGP-40LT-15C ink from Advanced Nano Products. HP advanced Photo Paper has been used as the substrate for printing the resistive memory cells. The printed resistive memory cells have been designed using the Microsoft paint software tool.

Figure 17: Dimatix 11610 Cartridge
4.1.1 Resistive Memory Cells

The main aim of the design is to print 16 resistive memory cells using the matrix method. The resistive memory cells are designed in pixel by pixel format in the paint software. The previously designed printed memory cells [2] have been used as a reference for the printing of the memory cells.

The size of the memory cells designed using the Microsoft Paint software tool can be adjusted using the drop spacing, which is the centre to centre distance from one drop of ink to another. The drop spacing setting is performed by using the printer settings. The drop volume of the ink is 10pL (Pico litre) and the firing voltage is set at 24V. The drop spacing for the memory card design used is 15μm.

1 pixel = 15 μm.

In order to obtain 1mm length of memory cells,

1 mm/15 μm = 67 pixels.

Thus, by drawing 67 pixels in paint, 1mm length of memory cells is achieved. The resistances values can be varied using a chemical programming technique.

Figure 18: Design of four memory cells with contact pads

Figure 18 shows four memory cells with contact pads designed in paint, in which a thin line between the two contact pads is the memory cell. The length of the memory cells designed is 1mm. The memory cell with two contact pads printed in the substrate using the nano silver ink is displayed in Figure 19. The length of the memory cell displayed is 1 mm (1.002 mm to be precise in this case) and the width is 53 μm.
4.1.2 Chemically Programmed Resistance

Chemical programming is a new technique used to vary the resistance value of the memory cells instead of using electrical programming. The solvent used for the chemical programming is triethylene glycol monooethyl ether which is colourless. Chemical programming is obtained by printing resistive memory cells on top of the solvent onto a photo paper substrate. The solvent interacts with the paper coating and it is believed that salt migrating from the coating impedes the sintering of the nano particles [16]. The length of the printed solvent is retained at the same value as that for the length (pixel size) of the memory cells to be printed. However, the width of the solvent is varied in order to achieve the specific resistance value.

Figure 20: Design of the Solvent
Figure 20 shows the solvent design for the resistive memories, the length of the solvent designed is 67 pixels and the width of the solvent is varied (21, 34, 36, 41 pixels) to achieve a specific resistance value. In order to obtain a good resistance value, two layers of printing with the solvent is conducted. Two layers of solvent are achieved by printing the design of the solvent multiple times on top of the substrate.

Figure 21 shows all the memory cells designed with their physical contacts in the paint software. The resistive memory cells design shown in Figure 21 is printed on top of the solvent design to obtain a specific resistance value.

![Figure 21: Design of all cells with contacts](image)

From the Figure 21 it is clear that one end of the resistive memory cells is connected (Columns) according to matrix method but the other end of the memory cell is connected only in one row and the remaining rows of the memory cells are not connected. To prevent any influence on the final resistance value, there should be no interconnection between the rows and columns. Thus, masking or isolation must be performed in order to provide connection between the remaining rows of the memory cells. In order to achieve the masking or isolation an SU-8 photo resist is printed on the substrate to prevent the interconnection between the rows and columns. SU-8 is a high contrast epoxy based negative photo
resist designed for microelectronic applications for which a thick chemically and thermally stable image is required. After printing the SU-8 it is exposed to UV radiation for the hardening of the material.

![SU-8 Photo resist design](image)

**Figure 22: Design of SU-8 Photo resist**

The remaining rows of the memory cells are connected by printing the contact lines on top of the SU-8 photo resist. Figure 23 shows the contact lines of the remaining three rows.

![Contact lines design](image)

**Figure 23: Design of the contact lines**

The memory card is implemented by printing the corresponding design onto HP advanced photo paper substrate. Initially, the memory cells will have a high resistance value because the nano particles presented in the silver ink are dispersed in the solvent, which creates a high resistivity and less conductivity on the memory card. Thus, the printed memories should be retained at room temperature for some time in order for stability to be achieved. After stabilization, the sintering operation is
performed so as to improve the conductivity of the memory cells, which can be conducted by the thermal heating of the memory cells in an oven [5]. The sintering operation is performed at 60°C for 15 minutes. By sintering, the nano particles which are dispersed in the solvent will start to combine together and thus improve the conductivity and reduce the resistivity in order to achieve the specific resistance value.

The developed printed memory card is designed in an SD card format for the convenience of using the commercially available contacts. The thickness of the card is achieved by using multiple layers of photo paper pasted together.

The developed printed memory card on the photo paper substrate is shown in the Figure 24

Figure 24: Functional Printed memory card
The resistance values measured from the 16 printed memory cells are tabulated and shown in Table 5.

<table>
<thead>
<tr>
<th>Memory Cells</th>
<th>Before Sintering (MΩ)</th>
<th>After Sintering (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.49</td>
<td>2.58</td>
</tr>
<tr>
<td>2</td>
<td>2.49</td>
<td>6.1</td>
</tr>
<tr>
<td>3</td>
<td>3.95</td>
<td>8.3</td>
</tr>
<tr>
<td>4</td>
<td>4.78</td>
<td>13.3</td>
</tr>
<tr>
<td>5</td>
<td>1.2</td>
<td>2.6</td>
</tr>
<tr>
<td>6</td>
<td>3.2</td>
<td>6.6</td>
</tr>
<tr>
<td>7</td>
<td>3.8</td>
<td>8.5</td>
</tr>
<tr>
<td>8</td>
<td>4.3</td>
<td>11.3</td>
</tr>
<tr>
<td>9</td>
<td>1.27</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>3.3</td>
<td>6.8</td>
</tr>
<tr>
<td>11</td>
<td>3.6</td>
<td>8.1</td>
</tr>
<tr>
<td>12</td>
<td>4.65</td>
<td>12.3</td>
</tr>
<tr>
<td>13</td>
<td>1.28</td>
<td>2.7</td>
</tr>
<tr>
<td>14</td>
<td>3.1</td>
<td>6.8</td>
</tr>
<tr>
<td>15</td>
<td>3.9</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>4.7</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Table 5: Resistive Memory cells value

From the Table 5 it is clear that initially after printing, the resistance values are in the range of some MΩ and after sintering this is reduced to kΩ. The resistance values were programmed to 3kΩ, 7kΩ, 9kΩ and 13kΩ, which offer a suitable separation of the resistance values for the reader. The resistance values were chosen according to the method a new discrete circuit for readout of resistive sensor arrays [11] for avoiding the effect of crosstalk, these values have been tested by means of the simulation circuit. From table 5 it is clear that the measured value displays the instability of the memory cells. The stability of the printed resistive memories depends on the moisture content present in the substrate and on the destabilizing of the particles in the nano-silver ink [4].
4.2 Memory Card Reader Design

The memory card reader has been designed using the Mentor Graphics PADS PCB Design Tool [14]. PADS are divided into 3 categories namely, PADS Logic, PADS Layout and PADS Routing. PADS logic is where the schematic of the design is conducted, PADS layout is where the components of the design are placed and the PADS routing is where the components routing is performed.

The main components used for the design of the card reader are as follows.

- Microcontroller (ATMEGA 169P).
- Operational Amplifier (LM124D).
- SPDT Switch (ADG1434).
- FTDI Chip (FT232RL).
- USB Mini.
- Card Holder.
- Reset Switch.
4.2.1 Implementation of the Memory Card Reader

Figure 25: Entire Card Reader System for reading Memory card

The memory card reader is a device used to access the data stored in the memory card. Here, the card reader is used to read the resistance value of the WORM memory cells. The printed memory card contains 16 resistive memory cells, which can have different possible resistance steps and each of these steps represents a different state. If two states are used then the possible combination for the 16 memory cells (bits) is $65536 (2^{16})$ and if three states are used then the possible combination is $43046721 (3^{16})$ and if four states are used then the combination will be $4294967296 (4^{16})$ and so on.

To read the printed resistive values, the memory card is inserted into the card holder. The 16 resistive memory cells value can be accessed through the matrix method i.e. through a unique combination of rows and columns with the assistance of two SPDT switches. The microcontroller provides 5V (High) to a corresponding control logic pin for both switches and 0V to the remaining pins of the switch (Low) which forms a unique array combination for accessing the resistance value. When the unique combination is given from the micro-
controller, the corresponding inputs from both the switches will be enabled and the corresponding output pin of the switches will be activated, which will be connected to the op-amp output and the inverting input of the op-amp. The op-amp output provides the corresponding negative output voltage for the resistance value. To invert the negative voltage of the op-amp to a positive voltage, one more inverting op-amp is used with a unity gain to read the ADC value from the microcontroller. The output voltages from the ADC are converted to the corresponding resistance values using equation 6. A load resistor of 30kΩ is connected to the inverting input of the op-amp and the load resistor was selected as 30kΩ because the card reader was designed to read up to a feedback resistance value of 23kΩ maximum. This is because the memory cards (memory cells) were developed for a range of 1kΩ to 23kΩ. To further increase the resistance range of the card reader design, the load resistor connected to the inverting input of the first op-amp, should be varied and also the op-amp supply should be checked in order to avoid the saturation effect. Serial communication is used to transmit the resistance values from the memory card to the LabVIEW interface.

Figure 26: Developed Card Reader

Figure 26 shows the functional card reader developed using a milling machine. The card reader has been designed in Mentor Graphics Pads using two layers.
The interfacing between the components of the memory card reader is as follows

### 4.2.2 Interfacing USB with FTDI Chip

![Interfacing USB with FTDI Chip](image)

The power supply of +5V for the entire reader circuit has been provided from USB-Mini. USB-Mini data+ (D+) and data- (D-) pins are connected to the USBDP and USBDM pins of the FT232-RL chip [8] respectively. FT232-RL is a FTDI chip used for the serial communication so as to interface with the PC. The FTDI chip is also connected with a reset switch for flushing the data in the buffer during the serial communication. A ferrite bead is connected to the mini USB power supply (VCC) pin to prevent any high frequency noise interferences coming from any other devices. Ferrite Bead works as an electronic choke and it is connected to the entire hardware through the power supply pin.
4.2.3 Interfacing with Microcontroller

4.2.3.1 FTDI Chip Interfacing with Microcontroller

The transmitter pin (TXD) of the FTDI chip is connected to the receiver pin (REX/PE0) of the microcontroller (ATmega169P) [7] which transmits the asynchronous data output and, the receiver pin (RXD) of the FTDI chip is connected to the transmitter pin (TXD/PE1) of the microcontroller which receives the asynchronous data input. The test pin of the FTDI chip must be grounded during normal operations. The transmitter and the receiver pin of the microcontroller exist in Port E. The AVCC pin of the microcontroller is the supply voltage pin for the analog to digital converter, which should be connected to the VCC through a low pass filter. The AREF pin of the microcontroller provides the reference voltage for the ADC (Analog to Digital Converter) and, in addition reset pin is connected to the microcontroller for resetting the program.
4.2.3.2 Interfacing SPDT Switches and Card holder with Microcontroller

The SD card holder is designed in order to insert the printed memory card. The card holder has 9 pins and only 8 pins are required (Pin1-Pin8) for the design. Pins 1 to 4 of the memory card holder are connected to one of the ADG1434 SPDT switches [9]and Pins 5 to 8 of the card holder are connected to the second SPDT switch. Two SPDT switches have been used to obtain all the 16 resistance values from the memory card through the unique array combinations. Each SPDT switch has 4 control logic input pins which are connected to the Port A pins (PA0-PA3) and PORT C Pins (PC0-PC3) respectively. Both switches have 4 input pins (Drain Terminal (D1-D4)) connected to the card holder. The input pins of the SPDT switches are digitally controlled by the microcontroller via the control logic inputs of the corresponding switch. The SPDT switches have two (Source Terminal) output pins for each input pin, so each switch has 8 output pins (S1A-S4A and S1B-S4B). The S1B-S4B pins in both SPDT switches are connected to ground. The output pins (S1A to S4A) of one switch are connected to the inverting input pin of the op-amp and the output pins of the other switch are connected to the output of the op-amp.
4.2.3.3 Interfacing Op-Amp’s with SPDT Switches and Microcontroller

There are two operational amplifiers (LM124D) [10] used for the design of the memory card reader. The output pins (1A to 4A) of one of the SPDT switches are connected to the inverting input pin of the op-amp and the other four output pins (1A-4A) of the switch are connected to the output of the op-amp. An input signal of 5V is given to the inverting input of the operational amplifier through a load resistor. The second operational amplifier is used to invert the negative output voltage from the first operational amplifier. The output pin of the first op-amp is connected to the input pin of the second op-amp with a gain of 1. The second op-amp output pin is connected to the analog to digital converter pin (ADC1) of the microcontroller in order to read the output voltage of the corresponding resistance value from the memory card.

Figure 30: Interfacing op-amp with switch and microcontroller
To read the resistance values from the memory card, an 8-bit microcontroller is used. To access the unique combination for reading the resistance values, the microcontroller Port A and the Port C pin assigned to the switches are enabled. In order to access all the 16 resistance values individually, sixteen combinations are used. By accessing these combinations the corresponding resistance values are selected. The resistance values are read through the ADC pin using an 8-bit resolution and these resistance values are transmitted through the USART serial communication to the LabVIEW and terminal window. LabVIEW is used to display the resistance values.
4.4 **Interfacing Hardware with LabVIEW**

LabVIEW is a Graphical User Interface (GUI) [15]. The two important features of LabVIEW are its front panel and the block diagram. The front panel is where the user interface controls and indicators are used. The block diagram is where the programming for the front panel is performed.

In this thesis, LabVIEW is used for displaying the printed memory card resistances value using serial communication. Some of the important functions used for programming in LabVIEW are explained below [15].

### 4.4.1 **VISA Serial Configure Port**

![Block diagram of VISA Serial configuration](image)

**Figure 32: Block diagram of VISA Serial configuration**

The VISA Serial Configure Port is used to configure the serial communication port by initializing the baud rate, data bits, parity, stop bits, and timeout. The baud rate is the data transmission rate and the data bits are the number of bits in the incoming data from the serial port. The timeout specifies the time for the read and write operations, the stop bits specify the number of stop bits used at the end of a frame and parity indicates the parity used for every frame.
4.4.2 VISA Write

![VISA Write Diagram](image)

Figure 33: Block diagram of VISA Write

It writes data from the write buffer to the microcontroller or any device. When the microcontroller receives the data from the write buffer it starts to transfer data. The write buffer contains the data to be transferred to the microcontroller and the return count contains the number of bytes written.

4.4.3 VISA Read

![VISA Read Diagram](image)

Figure 34: Block diagram of VISA Read

VISA Read reads the data transferred from the microcontroller or any device. It returns the data’s read from the device to the read buffer. The byte count specifies the number of bytes to be read and the return count indicates the number of bytes actually read.
4.4.4 Concatenate Strings

![Concatenate Strings](image1)

Figure 35: Block diagram of Concatenate Strings

The concatenation is the operation of joining two characters or strings. It concatenates two strings and displays the concatenated string output, whereas for an array input it concatenates by means of each element of the array.

4.4.5 Fractional / Exponential String to Number Conversion

![Fractional EXP String To Number](image2)

Figure 36: Block diagram of String to Number Conversion

Fractional / exponential function is used to convert the string data to number from the read buffer or the data transfer from the microcontroller.

4.4.6 VISA Close

![VISA Close](image3)

Figure 37: Block diagram of VISA close

VISA Close is used to close a device or an interface session after the serial port communication has been conducted.
4.4.7 Implementation of Entire LabVIEW System

The working of the entire LabVIEW [15] system is described. To enable serial communication between the microcontroller and LabVIEW, a VISA serial configure port has to be initialized. A while loop has been used for running the program continuously. An event structure is created to read all the 16 resistance values simultaneously from the memory card via the microcontroller. When the data is written one by one in the write buffer for 16 cases, it sends the written data to the microcontroller and the corresponding port pin is enabled in the microcontroller. The microcontroller then sends the resistance values from the ADC pin to the read buffer of the VISA Read function. The values stored in the read buffer are in string format, so a string to number function is used for converting a string into numbers. These resistance values are separated into three different states and each state represents the different resistance values which are displayed using a colour box function.

![Figure 38: Block diagram of the Entire LabVIEW System](image-url)
5 Results

The inkjet-printed resistive memory card is implemented and the resistance values from the memory card are read through the developed card reader and displayed in the front panel of the LabVIEW interface. Sixteen resistance values (R1 to R16) from the memory cards are digitally displayed in the LabVIEW when the corresponding combinations of values are selected in the microcontroller. These resistance values are separated into three different states using three colour boxes, and each state represents different resistance ranges. For the 1st state, the resistance value is between 0 to 7kΩ and if the resistance values read from the card are in the 1st state, then a green colour is displayed in the box. Similarly the 2nd state resistance value range from 7kΩ to 14kΩ and if the resistance values are in the 2nd state, a red colour is displayed in the box. Finally, for the 3rd state the resistance value range is from 14kΩ to 23kΩ and a blue colour is displayed in the box. All the resistance values can be displayed simultaneously by clicking the all value button as shown in Figure [39].

Figure 39: LabVIEW Results
6 Conclusions

The development of a chemically programmed printed memory card using the matrix readout method and a memory card reader for reading the printed resistance values has been successfully implemented. The sixteen resistance values read from the printed memory card are separated into different state levels and displayed in the LabVIEW interface through the developed card reader. The matrix readout circuit was simulated and tested before it was implemented in real time and the results were compared. The simulation results show that the crosstalk has an influence on the smaller values for the resistance as compared to the higher values. By implementing this matrix method, the number of memory cells has been increased with a minimum number of physical contacts between the card and the reader which also reduces the crosstalk. Thus, the limitations of the previously developed printed memory cards have been overcome. The memory cells (resistance) values were chemically programmed in order to achieve the desired resistance value instead of electrical programming. In future, SPDT switches can be developed by inkjet printing onto photo paper substrate in order to reduce both the costs and the circuit complexity of the card reader.
References


[7] Atmel Corporation, 8-bit Microcontroller with 16 K Bytes In-System Programmable Flash, ATmega169P.


[8] Future Technology Devices International Ltd. FT232R USB UART IC, FT232RL.

Chemically Programmed Memory
Card and PC connected Memory
Card Reader
Gokuldev Vadakke Kunninmel

References

2013-03-10


Appendix A: Schematic Design of the Memory Card Reader

Figure 40: Schematic diagram of the Card Reader
Card Reader Board Layout

Top Layer

Figure 41: Board Layout of the Top Layer

Bottom Layer

Figure 42: Board Layout of the Bottom Layer
Appendix B: Programming Code

//********ADC.H**********/
#ifndef _ADC_H_
#define _ADC_H_
void adc_init();
unsigned short adc_read();
#endif

//**********USART>H**********/
#ifndef __USART_H__
#define __USART_H__
#define BAUD 4800
#define FOSC 1000000
#define MYUBRR 12
#include <stdio.h>

void Usart_init(unsigned int);
void Usart_Transmit(unsigned char);
unsigned char Usart_Recieve(void);
#endif
//********ADC.C************/

#include <avr/io.h>
#include <stdio.h>

void adc_init()
{
   // Selecting Aref voltage, selecting ADC1 i.e,PF1 and also ADLAR = 1
   ADMUX=0x61;
   // Enabling the adc pin and prescaler value to be 8
   ADCSRA=((1<<ADEN)|(1<<ADPS1)|(1<<ADPS0));
}

unsigned short adc_read()
{
   // starting the adc conversion
   ADCSRA=(1<<ADSC);
   // waiting for the ADSC completion
   while (ADCSRA & (1<<ADSC));
   return ADCH;
}
//************USART.C************/

#include <avr/io.h>
#include <stdio.h>

///// USART INITIALIZATION (function definition)////////

void Usart_init(unsigned int ubrr)
{
    /////Set Baud Rate///// 

    UBRR0H = (unsigned char)(ubrr>>8); 
    UBRR0L= (unsigned char)(ubrr);

    /////Enable the RX & TX pin for the usart communication in Reg B///// 

    UCSR0B = (1<<RXEN0)|(1<<TXEN0);

    /////Setting the Frame Format i.e the character size(data_bits) and no ofUSBstop bits(2) /////

    UCSR0C = (1<<USBS0)|(3<<UCSZ00);

}

/////Usart Transmit///// 

void Usart_Transmit(unsigned char data)
{
    ///// Wait for empty transmit buffer///

    while(!(UCSR0A & (1<<UDRE0)));
///write the data to transmit buffer or usart buffer ///

UDR0 = data;
}

///Usart Recieve////

unsigned char Usart_Recieve(void)
{
    unsigned char recvdbyte;

    ///// wait for data to be recieved/

    while(!(UCSR0A & (1<<RXC0))) ;

    ///// get and return the data recived from the buffer/

    recvdbyte=UDR0;

    return recvdbyte;
}
//************MAIN.C************/

#include <stdlib.h>
#include "usart.h"
#include <avr/io.h>
#include <stdio.h>
#include <string.h>
define F_CPU 1000000UL
#include <util/delay.h>
#include "adc.h"

// To send a string to terminal

void Usart_Txstr(const char *s)
{
    while(*s)
    {
        Usart_Transmit(*s);
        s++;
    }
}

//Main function starts

int main()
{

    // Initializing the ADC and USART

    adc_init();
    Usart_init(MYUBRR);
while(1) {

    int tenbit,sum=0,i;
    double v,avg;
    double rf1,rf2,rf3,rf4,rf5,rf6,rf7,rf8,rf9,rf10,rf11,rf12,rf13,rf14,rf15,rf16;
    char buffer[200];
    char a;
    char temp[4];

    ////// DEFINING THE DIRECTION FOR PORT AS OUTPUT PIN

    DDRA = (1<<DDA0)|(1<<DDA1)|(1<<DDA2)|(1<<DDA3);
    DDRC = (1<<DDC0)|(1<<DDC1)|(1<<DDC2)|(1<<DDC3);

    ////// SWITCHING THE PINS FOR 16 COMBINATIONS

    
    PORTA = (0<<PA0)|(1<<PA1)|(0<<PA2)|(0<<PA3);
    PORTC = (0<<PC0)|(0<<PC1)|(1<<PC2)|(0<<PC3);

    _delay_ms(1);

    for(i=0;i<3;i++)
    {
    }
/// READING THE ADC VALUE

tenbit = adc_read();

sum=sum+tenbit;

}

/// TAKING THE AVERAGE OF THE ADC VALUE AND CONVERTING INTO RESISTANCE VALUES

avg = (sum/i);

v = ((avg*5.0)/(256.0));

rf1= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

}

{

PORTA = (1<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (1<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

}
tenbit = adc_read();

sum=sum+tenbit;

}  

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf2= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);

PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(0<<PC3);

PORTA = (0<<PA0)|(0<<PA1)|(1<<PA2)|(0<<PA3);

PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(1<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;

}  

avg = (sum/i);
v = ((tenbit*5.0)/(256.0));

rf3= (((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);
PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);
}

{

PORTA = (0<<PA0) | (0<<PA1) | (1<<PA2) | (0<<PA3);
PORTC = (1<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf4= (((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));
PORTA = (0<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);
PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(0<<PC3);

for(i=0;i<3;i++)
{
    tenbit = adc_read();
    sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf5= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);
PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(0<<PC3);
PORTA = (0<<PA0) | (1<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (1<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf6= (((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

}
PORTC = (0<<PC0)|(0<<PC1)|(1<<PC2)|(0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{
	tenbit = adc_read();
	sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf7= ((100001)*((12*v)/(200000)+(0.4*v)+(30*v)));

PORTA = (0<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);

PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(0<<PC3);

PORTA = (1<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);

PORTC = (0<<PC0)|(1<<PC1)|(0<<PC2)|(0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{
}
tenbit = adc_read();

sum=sum+tenbit;

}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf8= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0)| (0<<PA1)| (0<<PA2)| (0<<PA3);

PORTC = (0<<PC0)| (0<<PC1)| (0<<PC2)| (0<<PC3);

}

{

PORTA = (0<<PA0)| (1<<PA1)| (0<<PA2)| (0<<PA3);

PORTC = (0<<PC0)| (1<<PC1)| (0<<PC2)| (0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;

}
avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf9= (((100001)*(12*v))/((200000)+(0.4*v)+(30*v)));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

PORTA = (0<<PA0) | (1<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (1<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));
rf10= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

for(i=0;i<3;i++)
{
    tenbit = adc_read();
    sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf11= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);
PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

}

{

PORTA = (0<<PA0) | (0<<PA1) | (1<<PA2) | (0<<PA3);
PORTC = (0<<PC0) | (0<<PC1) | (1<<PC2) | (0<<PC3);
_delay_ms(1);

for(i=0;i<3;i++)
{

 tenbit = adc_read();

 sum=sum+tenbit;

}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf12 = ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);
PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

}
PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (1<<PA3);

PORTC = (1<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;

}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf13= ((100001)*((12*v)/(200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

}
for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;
}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf14= (((100001)*((12*v)/((200000)+(0.4*v)+(30*v)))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (1<<PA3);
PORTC = (0<<PC0) | (0<<PC1) | (1<<PC2) | (0<<PC3);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;
avg = (sum/i);

v = ((tenbit*5.0)/(256.0));

rf15= ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (0<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (0<<PC3);

PORTA = (0<<PA0) | (0<<PA1) | (0<<PA2) | (1<<PA3);

PORTC = (0<<PC0) | (0<<PC1) | (0<<PC2) | (1<<PC3);

_delay_ms(1);

for(i=0;i<3;i++)
{

tenbit = adc_read();

sum=sum+tenbit;

}

avg = (sum/i);

v = ((tenbit*5.0)/(256.0));
rf16 = ((100001)*((12*v)/((200000)+(0.4*v)+(30*v))));

PORTA = (0<<PA0)|(0<<PA1)|(0<<PA2)|(0<<PA3);

PORTC = (0<<PC0)|(0<<PC1)|(0<<PC2)|(0<<PC3);

}

 vowed

for(i=0;;i++)
{

///// RECIIEVING THE SELECTED OR ENTERED COMBINATION

a = Usart_Recieve();
temp[i]=a;
if(temp[i]=='\r')
break;
}
temp[i]='\0';

///// COMPARING THE COMBINATION SELECTED FOR ENABLING
THE SWITCH PINS

if(strcmp(temp,g0)==0)
{
    sprintf(buffer,“%0.2fK\r\n",rf1);

///// TRANSMITTING THE RESISTANCE VALUES

Usart.Txstr(buffer);
}

else if(strcmp(temp,g1)==0)
{ 
    sprintf(buffer,"\%0.2fK \r \n",rf2);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g2)==0)
{
    sprintf(buffer,"\%0.2fK \r \n",rf3);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g3)==0)
{
    sprintf(buffer,"\%0.2fK \r \n",rf4);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g4)==0)
{
    sprintf(buffer,"\%0.2fK \r \n",rf5);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g5)==0)
{
    sprintf(buffer,"\%0.2fK \r \n",rf6);
    Usart_Txstr(buffer);
else if(strcmp(temp,g6)==0)
{
    sprintf(buffer,"%.2f K \n",rf7);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g7)==0)
{
    sprintf(buffer,"%.2f K \n",rf8);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g8)==0)
{
    sprintf(buffer,"%.2f K \n",rf9);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g9)==0)
{
    sprintf(buffer,"%.2f K \n",rf10);
    Usart_Txstr(buffer);
}
else if(strcmp(temp,g10)==0)
{

sprintf(buffer,"%0.2fK \r \n",rf11);
Usart_Txstr(buffer);

}
else if(strcmp(temp,g11)==0)
{
sprintf(buffer,"%0.2fK \r \n",rf12);
Usart_Txstr(buffer);

}
else if(strcmp(temp,g12)==0)
{
sprintf(buffer,"%0.2fK \r \n",rf13);
Usart_Txstr(buffer);

}
else if(strcmp(temp,g13)==0)
{

sprintf(buffer,"%0.2fK \r \n",rf14);
Usart_Txstr(buffer);

}
else if(strcmp(temp,g14)==0)
{

sprintf(buffer,"%0.2fK \r \n",rf15);
Usart_Txstr(buffer);

}

else if(strcmp(temp,g15)==0)
{
    sprintf(buffer,"%0.2fK\r\n",rf16);
    Usart_Txstr(buffer);
}

else if(strcmp(temp,g16)==0)
{
    sprintf(buffer,"%.2fK%.2fK%.2fK%.2fK%.2fK%.2fK%.2fK\r\n",rf1,rf2,rf3,rf4,rf5,rf6,rf7,rf8,rf9,rf10,rf11,rf12,rf13,rf14,rf15,rf16);
    Usart_Txstr(buffer);
}

return 0;
}