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# DEVELOPMENT OF INSTRUMENT FOR AUTOMATION OF IRRIGATION SCHEDULING AND GROUND WATER RECHARGE MONITORING USING SOIL MOISTURE MEASUREMENT

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# ABSTRACT

Proper characterization of soil water status in the root zone can lead to better predictions of when to irrigate a crop and how much water to apply to a field. This will result in better water conservation practices and prevention of chemical leaching. But, soil moisture in the unsaturated zone is in a dynamic state. Under influence of precipitation, evapotranspiration, etc. the moisture content in a soil profile continuously varies with time.

Effective study and management of the soil-plant-atmosphere continuum will require knowledge bases combining appropriate mathematical models and expert systems, utilizing data from an effective sensor netwrok. However, development of expert systems and complex integrative models for irrigtaion scheduling, etc. has been limited because of extensive data collection requirements in the field. Numerous sensors need to be monitored on a periodic basis appropriate to the scale associated with water movement in the field. For such applications, rapidly responsive sensor networks would replace labour intensive hand measurements, which are often unreliable, in the field.

The report presents development of a sensor system capable of automated measurement of soil water status, using the four-electrode resistivity (VES) method, in a soil profile. In this method, by changing the separation between two electrodes (metallic rods) placed at the ground surface (without digging any holes), the variation in moisture content in the subsurface soil profile can be monitored. The analysis of the apparent resistivity variations at different electrode spacings make it possible to draw conclusions about the sub surface conditions (e.g. variations in the amount of moisture content in formation). The state-of-art microcontroller based design, with on-board software, makes the instrument suitable for near real-time analysis of the measured data. The data obtained from this instrument can be directly used in various simulation models.

## 1.0 INTRODUCTION

Data associated with soil, plant and atmospheric conditions are variable in space and time and, as such, numerous sensors in the field must be monitored in a periodic fashion appropriate to the scale associated with water movement in the field. Moreover, research programmes considering variability of soil properties and their impact on crop production and water quality would benefit substantially from development of smart sensors, and their networks, capable of quickly sampling temporal and spatial variability of these properties (Grismer, 1992). Rapidly responsive instruments would replace labour intensive hand measurements in the field. Also, extensive monitoring enables partial incorporation of important stochastic elements in the field into subsequent analyses.

One of the most important parameters affecting hydrologic research is the moisture stored in the soil profile, and its movement. Soil moisture also affects thermal properties of the soil, infiltration and runoff production, and serves as the reservoir for the evapotranspiration process. Inadequate knowledge of the spatial and temporal variability of soil moisture conditions in a natural environment is an important aspect of our difficulty in understanding and modelling the processes closely linked to soil moisture.

## 2.0 OBJECTIVES

One of the main emphasis in the ongoing programmes of soil conservation has been on the improvement of soil moisture regime and enhancement of infiltration in the watersheds. Also, the data on soil moisture content, and its variation with depth and time, is very important for effective irrigation management.

For effective implementation of these schemes, regular monitoring and periodic appraisal of the data from the watersheds is crucial. This requires a soil moisture instrument which (1) has quick response to the soil moisture variation in the subsurface, (2) is able to monitor the data regularly and, at the same time, is least destructive to the site, (3) is easy to install and operate and, (4) is not very expensive.

The objective of the study is to develop such an instrument for regular measurement of soil moisture, and its variation with depth upto water table and time, using resistivity technique. This technique does not require any digging of holes, etc. for measurements and, therefore, is non-destructive as well as cost effective.

Using soil moisture variation with depth, as obtained from the resistivity data using the instrument, the in-situ ground water recharge can be estimated and irrigation scheduling can be performed. Also, the soil moisture status in a soil profile can be fed to a specially designed circuitary to control the valves, etc. thereby automatizing the irrigation scheduling process. Another potential application of the proposed instrument would be to obtain in-situ information on total dissolved solids (TDS) in the soil profile, which is an indicator of the fertility of the soil.

## 3.0 PRESENT STATUS/TECHNOLOGY

Few workers have demonstrated the development/use of automated sensors for soil moisture measurement. Grismer (1992) reported a conceptual model for an integrated soil-plant-atmosphere sensor network, and the development of automated system for sampling of soil water properties in a remote field. Amer et al. (1994) tested the reliability and accuracy of fibre-glass soil moisture electrical resistance sensors as compared to gravemetric sampling and TDR. Long and Huck (1980) used a system with tensiometers, a pressure sensor and fluid switch wafers for automated measurement of soil water potential in a soil profile.

From electrical resistivity sounding measurements, Curtis and Kelly (1990) determined the variation of electrical resistivity with depth in the soil-vadose zone. The soil resistivity data was combined with estimates of hydraulic conductivity to demonstrate relationship between recharge potential and resistivity. With their experiments, they could designate a range of resistivities as representing highly permeable, moderately permeable, or slowly permeable for recharge purposes.

The use of electrical resistivity measurements in soil moisture studies has been demonstrated by Goyal et al. (1986), Goyal (1990), Goyal (1993), and Goyal et al. (1996). Although resistivity technique has been routinely used in ground water exploration, its use in soil moisture measurement was very limited due to non-availability of the appropriate instrument. Also, effective utilization of the resistivity technique in soil moisture monitoring requires a dedicated computer software for interpretation of the apparent resistivity data as measured in the field.

The analysis of apparent resistivity data, measured from the resistivity meter, in terms of subsurface moisture contents needs a sophisticated computer software. This task was, for the first time in India, carried out by the author as part of his Ph.D. thesis in 1993 (Goyal, 1993). The software developed under the Ph.D. thesis would be placed on-board the proposed instrument for near real-time analysis of the measured data.

## 4.0 FEATURES AND SPECIFICATIONS OF THE INSTRUMENT

The instrument consists of (1) a micro-controller based micro-ohm meter, (2) relays card, (3) power supply and converter card, (4) computer interface, and (5) multi-core cable with take-outs at selected intervals for connection of various electrodes (Figure 1). Using a simple panel operation, the instrument would carry out the measurements and the data processing to provide the final soil moisture depth profile upto the water table (upto 10m approx.). The instrument design is based on a state-of-art microcontroller (Intel 80C31).

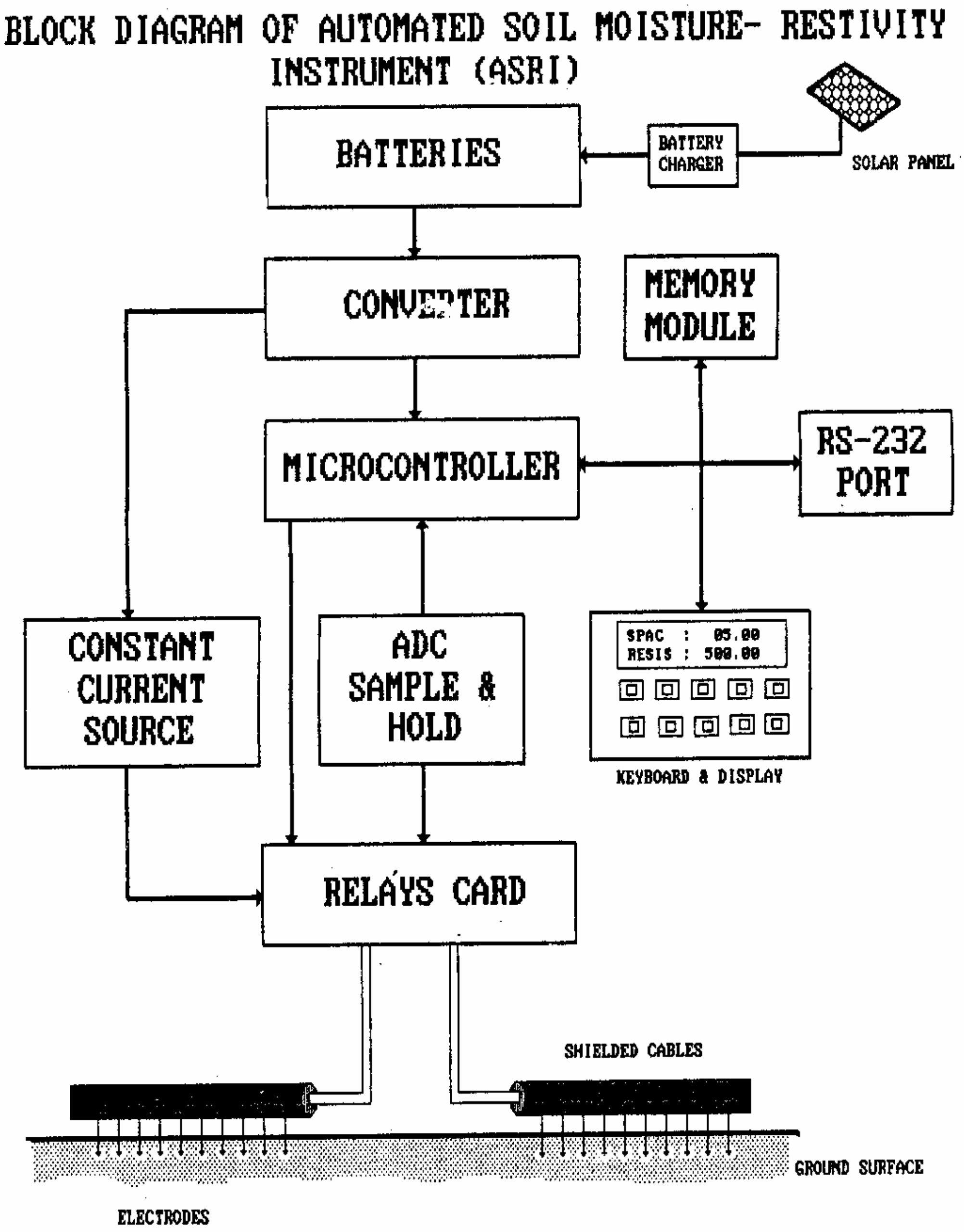


**Figure 1. Block diagram of Automated Soil Moisture-Resistivity Instrument (ASRI)**

## 5.0 METHODOLOGY

The four-electrode resistivity (VES) method utilizes four electrodes which are hammered in a line at the ground surface about 2" deep. A known amount of current (I) is passed through the two outer electrodes (the current electrodes). As a result of this current, a voltage develops in the subsurface, and the resulting voltage difference ($\Delta V$) between the other two electrodes (the potential electrodes) is measured using a suitable electronic circuitary. By increasing the separation between the two current electrodes, the injected current passes deeper, and we get information about the deeper formations (Figure 2).

The 'resistivity meter' is the instrument used for measurement of soil resistance (R), which is obtained by dividing $\Delta V$ by I. By multiplying $\Delta V/I$ value by a geometric factor that depends on electrodes configuration, the apparent resistivity (r) is obtained. The analysis of the apparent resistivity variations at different electrode spacings make it possible to draw conclusions about the sub surface conditions (e.g. variations in the amount of moisture content in formation). This means that by changing the separation between two electrodes placed at the ground surface (i.e. without digging any holes), the variation in moisture content in the subsurface soil profile can be monitored.

If $\Delta V$ is measured in millivolts and I in milliaperes, the resistance (R) can be expressed directly in ohms by dividing $\Delta V$ by I, minding only numbers and ignoring the units of measurement. Different measurement (R) ranges can be assigned for different current settings.

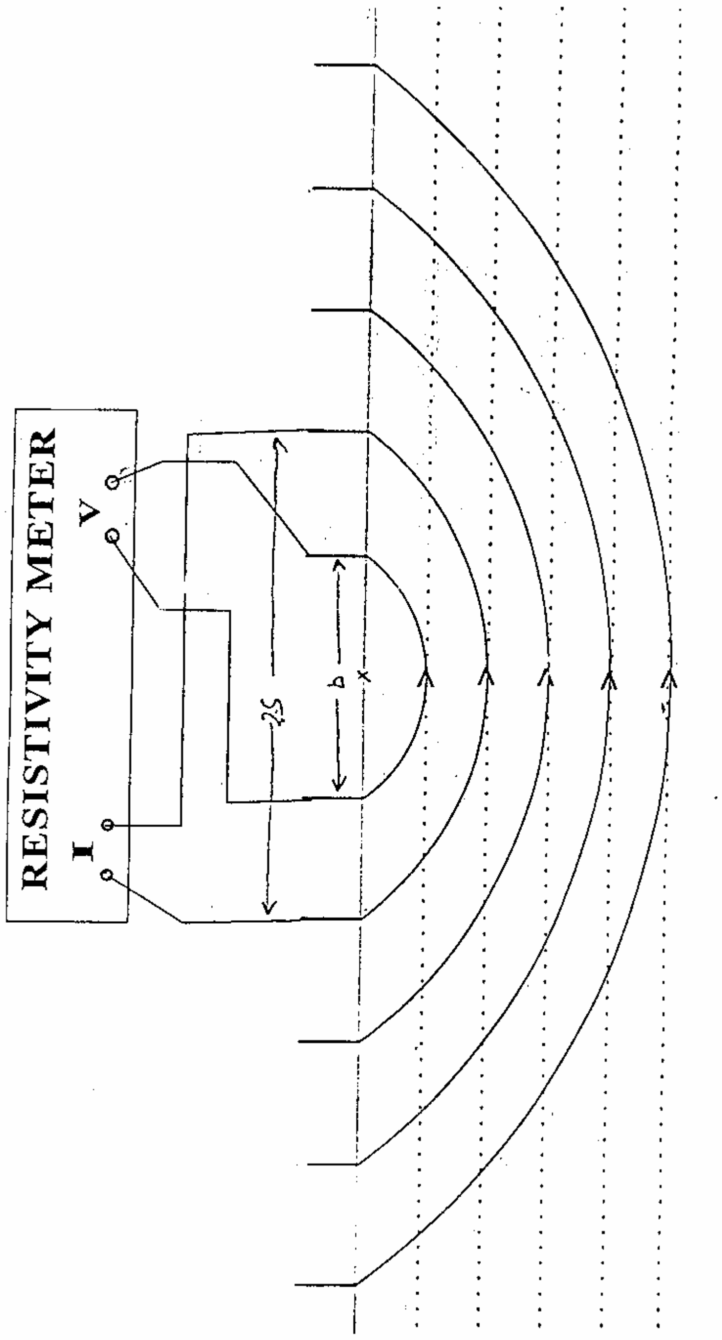


**Figure 2. Schematic showing passage of current in a 4-probe resistivity setup**

## 6.0 DEVELOPMENT OF VARIOUS SUB-SYSTEMS

### 6.1 Relay and Multiplexer Cards

This card is designed to measure the electrical resistance of soils using a number of electrodes (16 nos. at present) inserted in soil at pre-determined distances. All the electrodes are to be connected to a constant current source of 90VDC, 50 mA. Polarity of the mesured potential difference between a set of two electrodes is alternated at a frequency of 3-4 Hz. The block diagram of the card and its mounting arrangement is shown in Figure 3.

The relays are fired by using an arrangement shown in Figure 4. Each card has 4 or 5 inputs depending upon the quadrant it corresponds to. The corresponding addresses of each pin on the card is given below :

| Address | Pin # shorted to common (Quadrant 1 & 2) | Address | Pin # shorted to common (Quadrant 1 & 2) |
|---|---|---|---|
| 0000 | 1 | 1000 | 3 |
| 0001 | 5 | 1001 | 7 |
| 0010 | 12 | 1010 | 10 |
| 0011 | 16 | 1011 | 14 |
| 0100 | 2 | 1100 | 4 |
| 0101 | 6 | 1101 | 8 |
| 0110 | 11 | 1110 | 9 |
| 0111 | 15 | 1111 | 13 |

The address of the Quadrants 3 and 4 are the same but for the input pin number 5 which

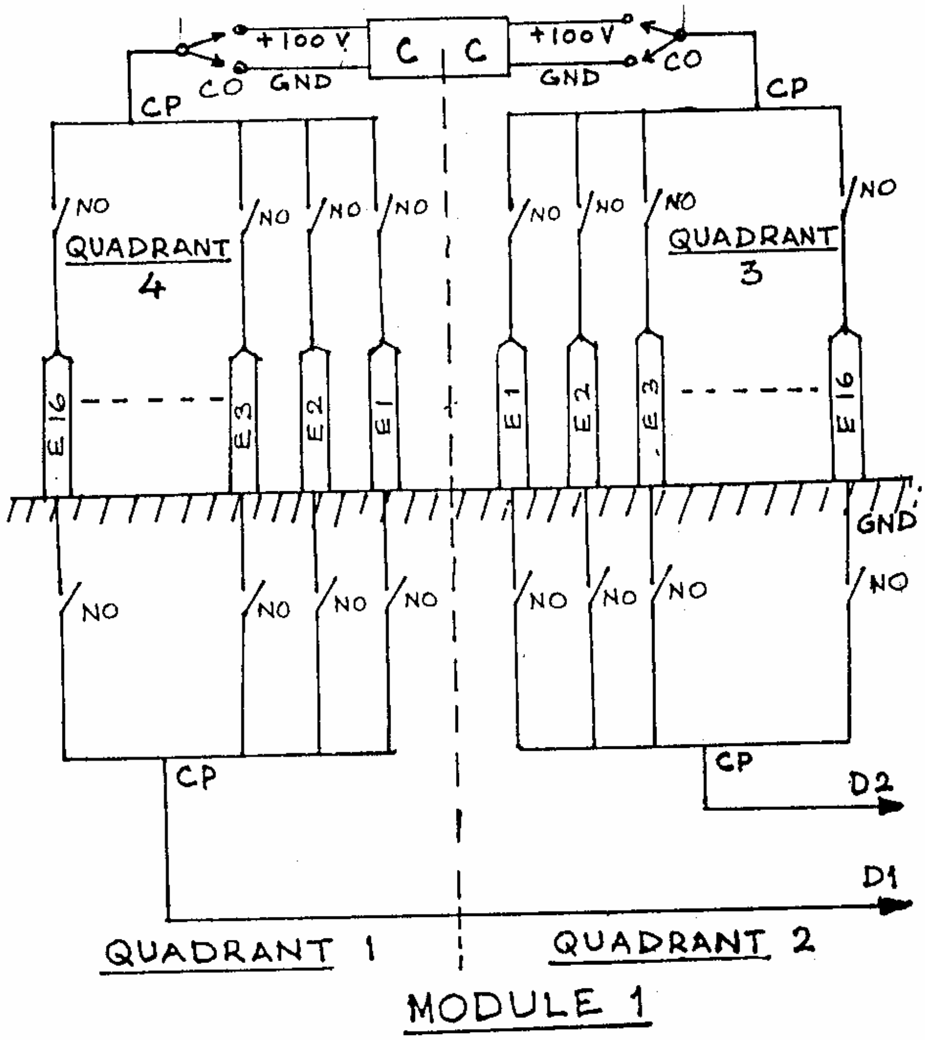


**Figure 3. Arrangement of relay-modules for selection of electrodes**

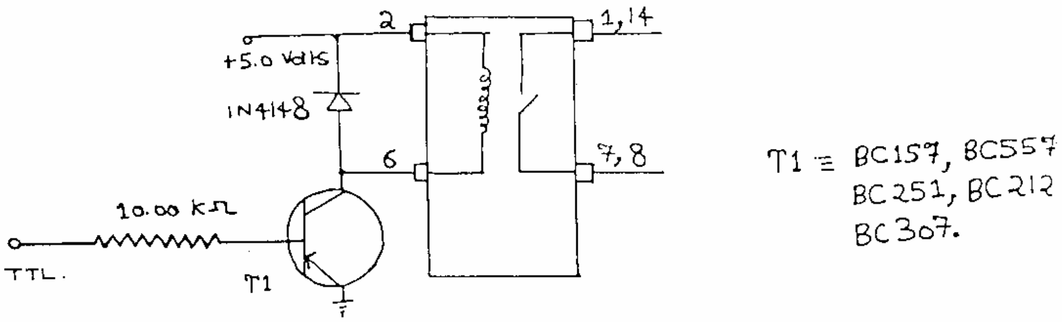


**Figure 4. Arrangement for operation of the relays**

selects how the C/O relay switches the current source. The common points of Quadrants 3 and 4 are connected to the C/O relays whereas the common points of the Quadrants 1 and 2 are to be connected to the differential amplifier of the data logger circuit. Different data lines from the Relay/Mux card are brought to 4 16-pin connectors on a PCB, and the other connections are also brought to two 10-pins and 5-pins connectors each. In order to add further electrodes in the design, the modules can be expanded as shown in Figure 5. The relevant PCB layout for interconnection between various sub-sections is given in Figure 6.

### 6.2 Constant Current Supply

A 90 VDC current supply of 50 mA (with increments of 5 mA) is used to supply a constant current to the set of current electrodes. A simple voltage attenuator circuit is used to condition the output voltage between the two potential electrodes in the range of 5VDC for input to the ADC in the data logger.

### 6.3 Data Logger

A key element of the soil moisture instrument is the microcontroller controlled circuit designed to select a set of four electrodes at a time, to control the excitation of the two current electrodes, to read the voltage difference between the two potential electrodes, to condition the incoming potential data, to perform the division of V by I to obtain the resistance, to store the calculated resistance and the electrode configuration data, and to release the collected data to a 'dedicated hardware' for processing of the resistance in terms of layer resistivity and layer thickness.

The circuit is designed around the Intel 80C31 microcontroller and an 12-bit ADC (ICL 7135). On-board circuitary controls the signal conditioning, analogue multiplexing and serial communication (Figure 7).

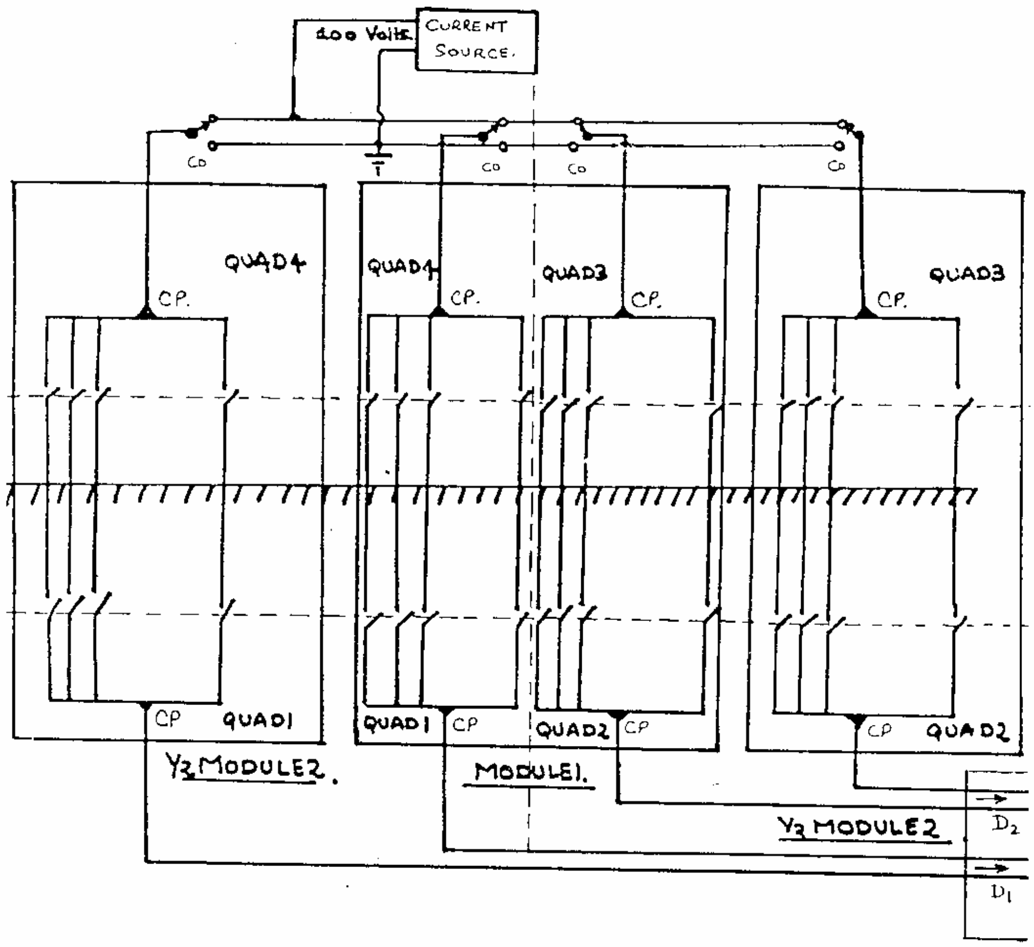


**Figure 5. Schematic of expansion for the relay-modules**

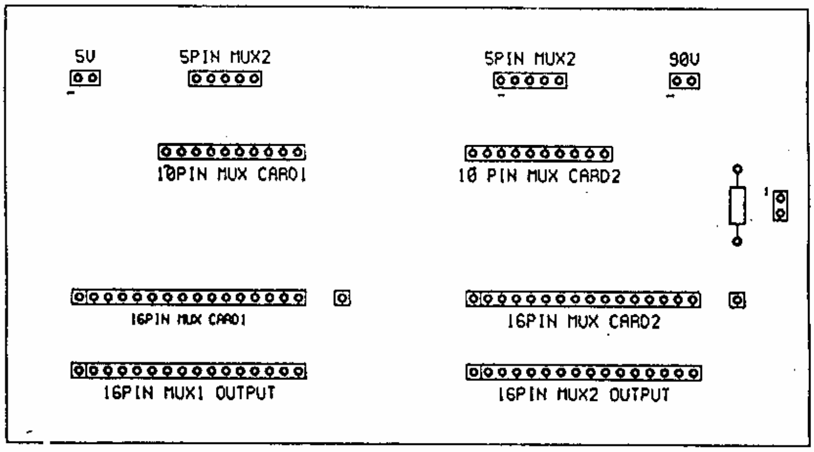


**Figure 5. PCB layout of the relay-modules**

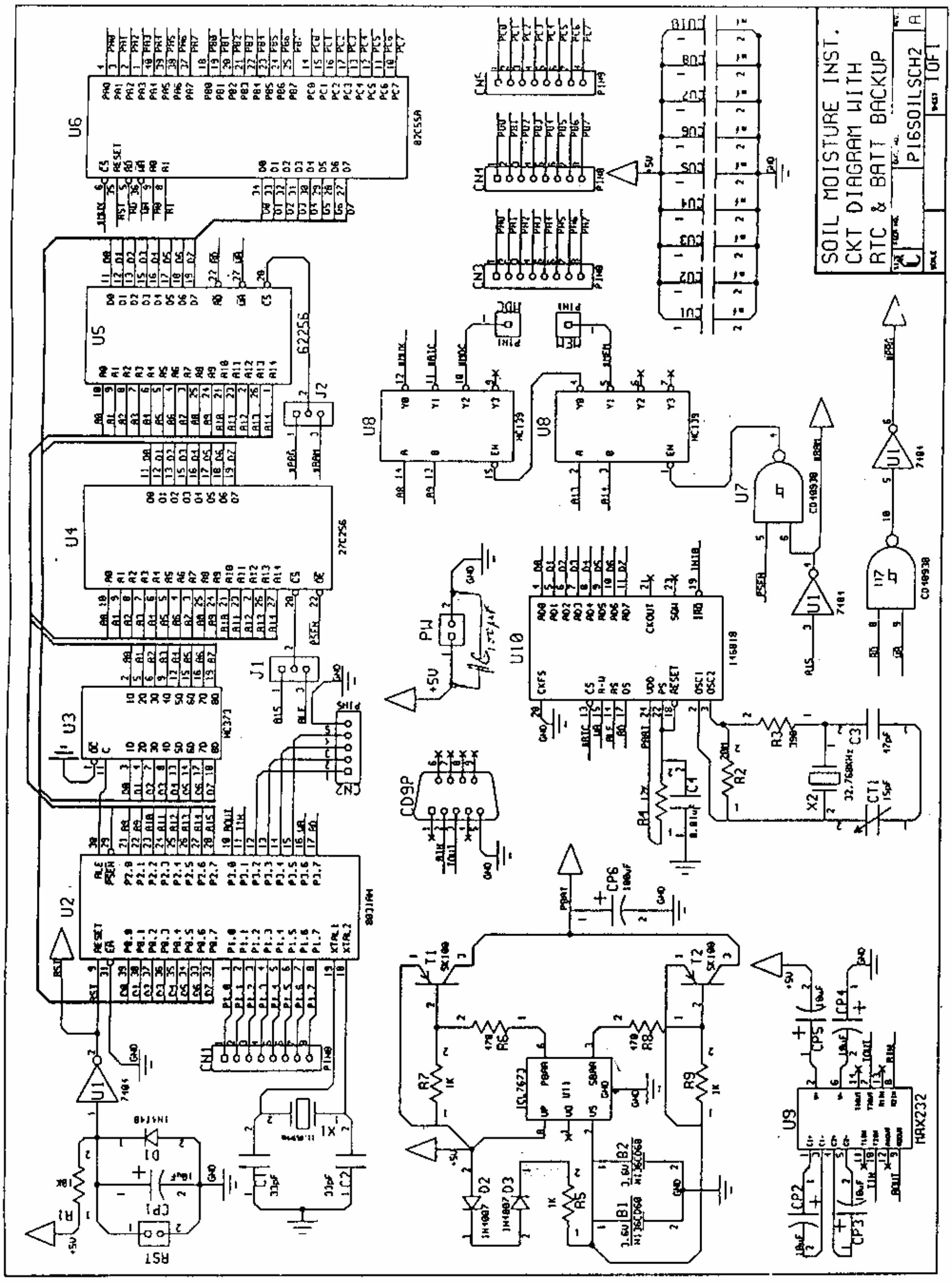


**Figure 7. Circuit diagram of microcontroller based cards**

A program running on the microcontroller sends a signal, through aline driver, to the Analogue-Multiplexer & Relay (AMR) card to select a particular set of four electrodes for the measurement. Once a connection is established through the AMR card, a constant current (e.g. of 10 mA) is applied between the current electrode pair for a preset period, which is under control of the microcontroller. Potential difference between the selected pair of potential electrodes is measured and, after necessary attenuation so as to bring the level to 0-5V input, is sent to the 'sample/hold' in the ADC. Polarity of the excitation voltage is then reversed, and the measured voltage, after attenuation, is added to the previous value in the ADC and stored.

A keyboard and display circuit is also developed for programming the data logger and for displaying the data on a LCD (Fig. 6). The card is based on an intelligent LCD module and a 4x4 tactile keypad matrix.

## 7.0 SUMMARY

An automated instrument for regular measurement of soil moisture, and its variation with depth and time, using resistivity technique has been designed and various sub-systems of the instrument have been developed.

Initially, it was thought that the data-analysis software available in FORTRAN would be converted to the assembly language of Intel 8031's microcontroller. Due to some technical and logistic problems, however, this could not be done, and had to be abandoned. Alternatively, it was thought that the data logging electronics would be built around a PC motherboard so that the FORTRAN software could be used as such in a DOS environment. Due to non-availability of some components to be used (e.g. intelligent LCD display & interface, membrane type keypad) and excessive power requirement of the design, this attempt was also abandoned.

Subsequently, after a lot of discussions with various experts, a combination of embedded microcontroller based data logger and a portable PC is proposed to be used for the soil moisture instrument. A modified circuit is currently being assembled for testing under lab and field conditions.

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