



Microcontroller based ground resistance monitor
by Senthil N Kumar

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Electrical Engineering
Montana State University
© Copyright by Senthil N Kumar (1992)

Abstract:

During ground fault conditions, the flow of current to earth will produce gradients in and around a substation. The magnitude of gradients caused are dependant upon the ground resistance of the substation. Such gradients, if large enough will cause bodily harm to a person in and around the substation.

To determine dangerous situations if any, monitoring of the ground resistance is necessary. An instrument for such monitoring of the ground resistance, the Microcontroller Based Ground Resistance Monitor, has been developed.

The Monitor measures the value of ground resistance after every 24 hours and stores in memory. The voltage used for the measurement and the time of measurement are also recorded. Readings will be recorded automatically for over a period of three years after which readings will be overwritten. The Monitor also calculates the mean and standard deviation squared of the most recent 64 readings of the ground resistance. An LED is switched 'on' if the present value of ground resistance exceeds the preset maximum value. An error analysis and the results of testing the Monitor in a laboratory setting are also outlined.

MICROCONTROLLER BASED GROUND RESISTANCE MONITOR

by

Senthil N. Kumar

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Electrical Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1992

71378

K96

ii

APPROVAL

of a thesis submitted by

Senthil N. Kumar

This thesis has been read by each member of the thesis committee and has been found satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dec 7 1992

Date

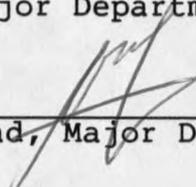


Chairperson, Graduate Committee

Approved for the Major Department

Dec 7 1992

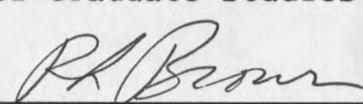
Date


Head, Major Department

Approved for the College of Graduate Studies

12/16/92

Date

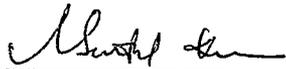

Graduate Dean

STATEMENT OF PERMISSION OF USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholastic purposes, consistent with "fair use" as prescribed in the U.S Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature



Date

12/15/92

TABLE OF CONTENTS

1. INTRODUCTION	1
Grounding in Electric Power Systems	1
Grounding in Substations	2
Resistivity and Ground Resistance	3
Basis of Measurement	4
Thesis Objective	6
Thesis Organization	7
2. DEVELOPMENTAL APPROACH	9
Measurement Setup	9
Experimental Measurements	11
3. HARDWARE	15
Analog Hardware	15
Digital Hardware	25
4. SOFTWARE OVERVIEW	32
Real Time Clock Interrupt	43
Measurement of Resistance	43
User Input and Retrieval	47
5. MEASUREMENTS	53

Lab Measurements Using Ground Resistance Monitor .	53
Noise and Error Analysis	53
Error in the System	55
6. CONCLUSION AND FUTURE WORK	61
REFERENCES	63
APPENDICES	66
APPENDIX A - SOFTWARE	67
APPENDIX B - OPERATION MANUAL	103

LIST OF TABLES

1. Measurement of discrete resistance using ground
resistance monitor.....54

LIST OF FIGURES

Figure		Page
1.	Setup for Measurements.....	5
2.	Experimental Setup at East Gallatin Substation.	10
3.	Equipment Setup for Measurements.....	12
4.	Hardware Block Diagram.....	16
5.	Analog Circuit Diagram.....	17
6.	Filter Response for an Input of 2V.....	23
7.	Digital Circuit Diagram.....	26
8.	Flowchart of Software.....	33
9.	Calculation of Ground Resistance Using Ratio of Voltages	52
10.	Controller Software	68

ABSTRACT

During ground fault conditions, the flow of current to earth will produce gradients in and around a substation. The magnitude of gradients caused are dependant upon the ground resistance of the substation. Such gradients, if large enough will cause bodily harm to a person in and around the substation.

To determine dangerous situations if any, monitoring of the ground resistance is necessary. An instrument for such monitoring of the ground resistance, the Microcontroller Based Ground Resistance Monitor, has been developed.

The Monitor measures the value of ground resistance after every 24 hours and stores in memory. The voltage used for the measurement and the time of measurement are also recorded. Readings will be recorded automatically for over a period of three years after which readings will be overwritten. The Monitor also calculates the mean and standard deviation squared of the most recent 64 readings of the ground resistance. An LED is switched 'on' if the present value of ground resistance exceeds the preset maximum value. An error analysis and the results of testing the Monitor in a laboratory setting are also outlined.

CHAPTER 1

INTRODUCTION

This thesis discusses the design and construction of the microcontroller-based ground resistance monitor. An introduction of ground resistance and the need to monitor it are provided in this chapter.

Grounding in Electric Power Systems

Important aspects of grounding in electric power systems are:

- (a) System (neutral) grounding- for proper operation and protection of the system.
- (b) Equipment grounding- for safety.
- (c) Lightning protection grounding- for protection against lightning.

Grounding electrodes such as wires, rods, pipes, strips, plates are used to achieve adequate grounding. When current is injected in a grounding electrode and collected at a point very far away from the electrode, the soil attains a potential gradient which depends on the current density in the soil and

the resistivity of the soil. This produces a potential on the electrode with respect to a faraway point on the soil assumed to be at zero potential. The voltage of the electrode per unit current injected into the soil is defined as the ground resistance of the electrode. It is a function of the size and shape of the electrode and the resistivity of the soil. Most of this ground resistance is offered by the soil in the vicinity of the electrode as the current density in the soil becomes negligible at large distances.

Grounding in Substations

When a line to ground fault occurs, currents of thousands of amperes may be injected into the soil through the grounding electrodes and produce a high potential gradient on the surface of the earth.[1]. In order to keep this potential gradient within safe limits, the grounding system used in the substations is in the form of a horizontal grid buried at a depth of about 2 feet and spread over the entire area of the substation.

A substation grounding system is designed to keep the step and the touch voltage within safe limits. These voltages are defined in the following paragraphs.

Step Voltage: The difference in surface potential experienced by a person bridging a distance of 1m with his feet without contacting any other grounded object.

Touch Voltage: The potential difference between the grounding system potential and the surface potential at the point where a person is standing is known as the touch voltage. The maximum touch voltage to be found within a mesh of a grounding grid is the mesh voltage.

Resistivity and Ground Resistance

The step voltage, the mesh voltage and the ground resistance are all proportional to the resistivity of the soil in the vicinity of the substation. Resistivity of the soil depends on the following factors[1]:

- (i) Type of soil (sand, gravel, clay etc.);
- (ii) Chemical composition of soil;
- (iii) Concentration of salts dissolved in contained water;
- (iv) Moisture content of soil;
- (v) Temperature;
- (vi) Closeness of packing.

As the temperature and precipitation vary, the resistivity of the soil will change. As the resistivity of the soil changes, so does the step voltage, mesh voltage and ground resistance of the grid.

For a particular substation and its grounding system, step voltage and mesh voltage are known functions of the substation ground resistance. With small currents used for measurements, it is easier to measure the ground resistance

than the step and mesh voltages. In order to ensure that the station is safe for personnel in all climatic conditions, it is proposed to monitor the ground resistance of the substation grounding system.

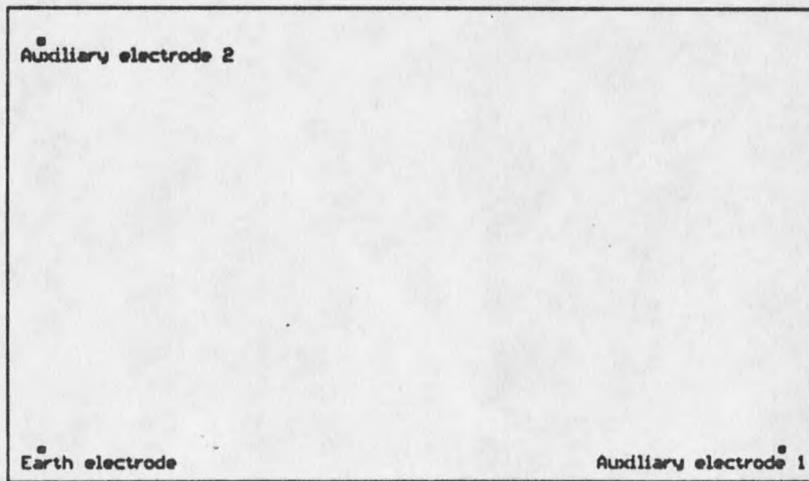
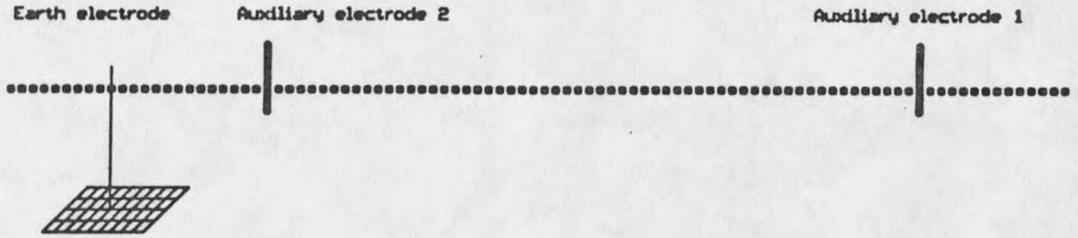
Ground resistance also affects the proper operation of the protective equipment. Monitoring of the ground resistance will help detecting the periods, if any, during which the protective equipment may not provide the required protection against ground faults or lightning.

Basis of Measurement

Measurement of ground resistance is made using the three terminal method.[2]. The earth electrode (grid) is used as one terminal into which the test current is injected. The current is collected at a remote point using an auxiliary electrode, which constitutes the second terminal. Another auxiliary electrode (third terminal) is used to sense the voltage at a distant point.

Consider the setup of the earth electrode and the auxiliary electrodes as shown in figure 1. A known current is passed between the earth electrode and auxiliary electrode 1. The potential difference is measured between the earth electrode and auxiliary electrode 2. Both the auxiliary electrodes 1 and 2 are placed at a large distance from the earth electrode and from each other. The measured voltage

Figure 1: Setup for Measurements



divided by the known current will give the ground resistance. Auxiliary electrode 2 is considered to be at zero potential point. This method is used to eliminate the ground resistance of the auxiliary electrode 1 from the measurements.

Thesis Objective

The objective of this thesis is to document a system that has been developed to monitor the ground resistance. This instrument has been primarily necessitated by the fact that no instrument available in the market provides continuous monitoring of ground resistance. The system developed stores in memory the ground resistance measurements made at regular intervals of time. The voltage, current and time of measurement are also recorded with every reading. The features of the instrument developed are summarized below:

- (i) Measurement of ground resistance after every 24 hours.
- (ii) A range of 0-25.5 Ohms with a resolution of 0.1 Ohms.
- (iii) Recording of potential of the grounding system, the ground resistance and the time of measurement.
- (iv) Switching of alarm or some visual indication whenever the ground resistance exceeds a preset value.

- (v) Error not more than 5%. Ground resistance measurements do not require a high level of accuracy and an error of less than 5% is adequate.
- (v) Automated operation.

Thesis Organization

Chapter 1 introduces and defines the problem. Chapter 2 details the experiments leading to the development of the instrument and the setup used at the substation for the initial testing.

Chapter 3 gives details of the analog and digital part of the hardware involved in the design of the instrument. Detailed block schematics of the analog part are provided and discussion is centered on the use of specific blocks in the schematic. A hardware circuit diagram of both the analog and the digital part is also provided.

Chapter 4 covers the overview of the software used in the data acquisition and data processing system of the instrument. Detailed flow charts of the software are provided. The software assembly code used is included in the appendix. Details of the software used to enhance the accuracy of the calculations are also included.

Chapter 5 tabulates the measurements made both at the substation and in the laboratory using the ground resistance

monitor. An error analysis is included.

The thesis is concluded with a brief summary of the work done, the results obtained, its benefits, and suggestions for further development in chapter 6.

CHAPTER 2

DEVELOPMENTAL APPROACH

Measurement Setup

The measurements for the development and testing of the microcontroller-based ground resistance monitor were made at the East Gallatin substation of the Montana Power Company in Bozeman, Montana. The experimental setup is shown in figure 2. Eight feet long ground rods were used as auxiliary electrodes buried vertically at locations shown in the figure. Insulated underground leads from the auxiliary electrode were run to a point close to the station fence. The three leads (one from the ground electrode and two from the two auxiliary electrodes) were made available for making measurements with the three terminal instrument placed near the fence of the station.

Because of the limited area of the property of the Montana Power Company around the switchyard, the auxiliary electrodes could not be placed at a very large distance. This would result in a lower measured value of the ground resistance by any instrument used on this setup.

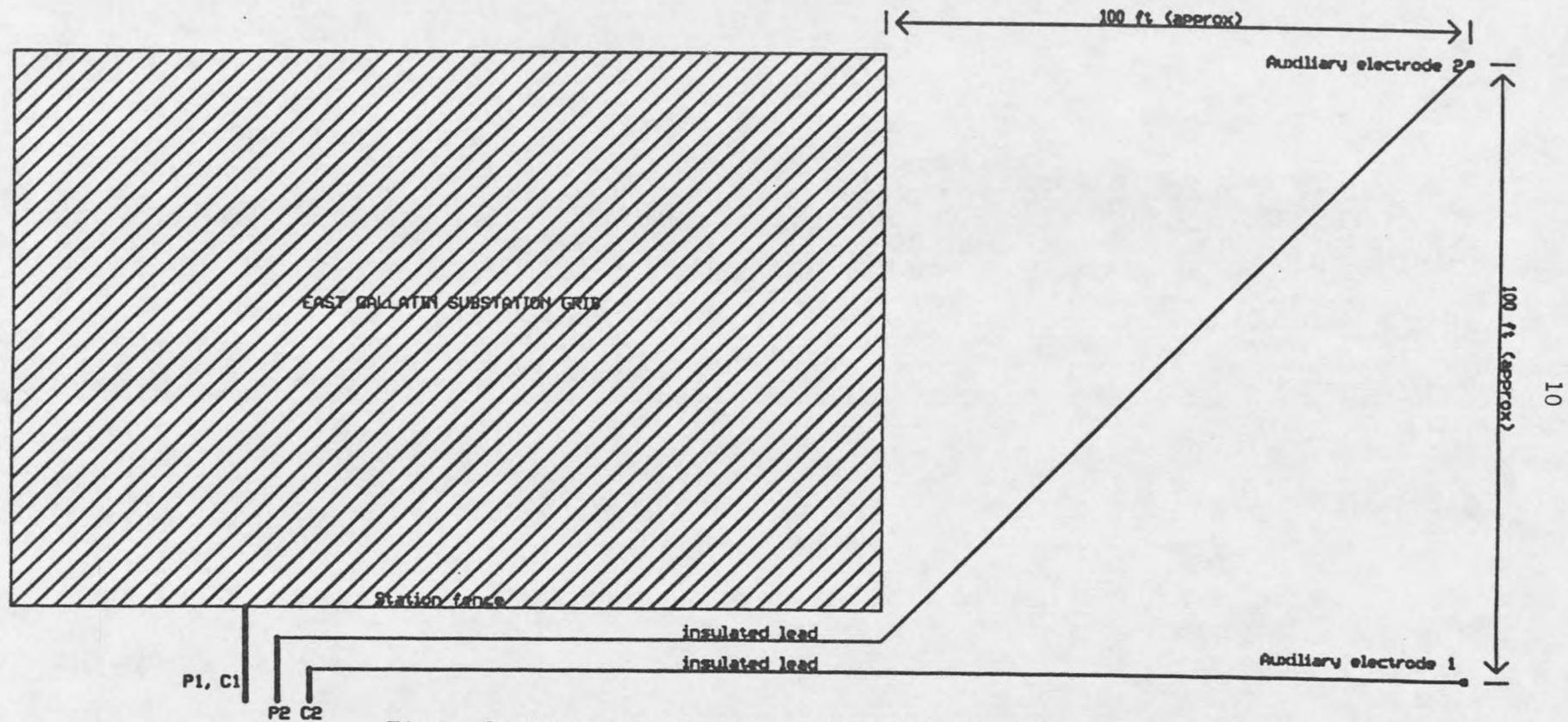


Figure 2: Experimental setup at East Gallatin Substation

Experimental Measurements

Measurements for the development of the instrument were carried out using the setup shown in figure 3. A sine wave generator was connected to the grid through a standard resistor. Auxiliary probe 1 was connected to the sine wave generator ground thus completing the circuit. The voltage drop, V_1 , across the series combination of standard resistance, R_{std} , and ground resistance, R_{gnd} , was measured using an oscilloscope. The voltage drop, V_{gnd} , across the ground resistance, R_{gnd} , was also measured using the oscilloscope. The voltage drop across the standard resistance, V_{std} , was calculated as $V_1 - V_{gnd}$ and the current injected into the grid (I_{gnd}) was calculated by using Ohm's law for the standard resistance. Ground resistance was then calculated using Ohm's law (V_{gnd}/I_{gnd}).

This procedure yielded errors due to the noise generated due to the harmonic currents in the ground. The measurements were made using different frequencies. After a series of trials, it was found that 2 KHz was the minimum frequency for which interference from the ambient voltages was less. It has to be recognized that higher frequencies would bring in errors due to the inductance of the leads connecting the electrodes to the instrument.

A high-Q active band pass filter was used to further decrease the interference because of the stray voltages in the

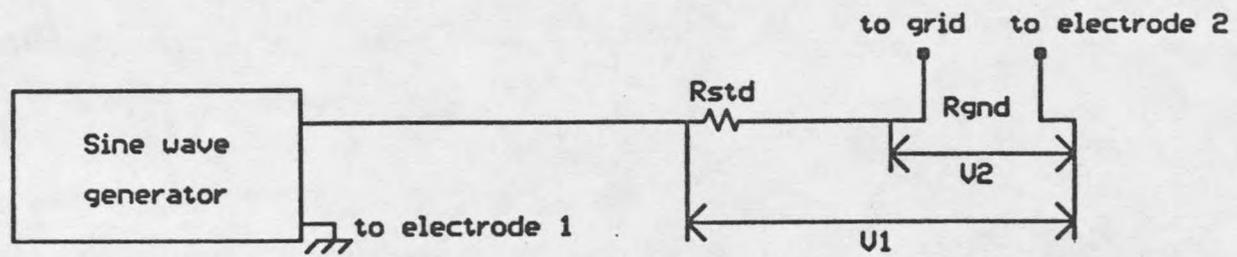


Figure 3: Equipment setup for measurements

ground.

Even with the use of 2 KHz frequency and a high-Q band pass filter, the observations indicated the presence of an offset in the measured voltages. This offset was caused by the leakage currents that flow from the grid into the surrounding earth. These leakage currents may produce potentials of the order of tens of volts. Though the leakage currents change with time, rapid changes in leakage currents are not common. Effect of the leakage currents can be eliminated by the following procedure:

$$R_{gnd} = V_{gnd}/I_{gnd}$$

where R_{gnd} is the ground resistance, V_{gnd} is the voltage across the ground resistance and I_{gnd} is the current through the ground resistance at 2 KHz. Both the standard resistance and the ground resistance are in series. Hence,

$$I_{gnd} = I_{std} = V_{std}/R_{std}$$

where I_{std} is the 2 KHz current through the standard resistance, V_{std} the voltage across the standard resistance and R_{std} is the value of the standard resistance. So,

$$R_{gnd} = V_{gnd} * R_{std} / V_{std}$$

If the leakage currents in the ground produce a stray voltage V_{lkg} , the measured ground voltage is modified and the measured ground resistance is given by:

$$R_{gnd} = (V_{gnd} + V_{lkg}) * R_{std} / V_{std}$$

This offset caused by the leakage currents was eliminated from the calculations by using the aggregate method. The aggregate

method involved the use of two different values of current which produced two different values of voltage across the ground resistance. The difference in voltage and the difference in current was then used to calculate the ground resistance. Assuming that the leakage current and hence V_{lkg} does not change during the time of the two measurements,

$$R_{gnd} = \frac{((V_{gnd2} + V_{lkg}) - (V_{gnd1} + V_{lkg})) * R_{std}}{(V_{std2} - V_{std1})}$$

$$R_{gnd} = (V_{gnd2} - V_{gnd1}) * R_{std} / (V_{std2} - V_{std1})$$

This eliminates the effect of leakage voltages in the calculation for ground resistance. Following the principle of measurement as given above, the microcontroller-based ground resistance monitor was designed and constructed.

CHAPTER 3**HARDWARE**Analog Hardware

In order to measure the resistance of the ground, the procedure used has a standard resistance in series with the ground resistance. A known current is passed through the series combination and the voltage across the standard resistance and the ground resistance are recorded. The data processing system, which consists of the microcontroller and its peripherals, then uses the voltages recorded and the value of standard resistance to calculate the value of the ground resistance. The feeding point for the current is different from the point where the voltage across the ground resistance is measured. The method used was introduced in chapter 1 (basis of measurement).

The block diagram of the circuit is shown in figure 4. The complete circuit diagram is shown in figure 5. The sine wave used is generated by an oscillator (BB4423). The output frequency of the oscillator is adjusted to 2000 Hertz. The frequency used was determined after intensive testing

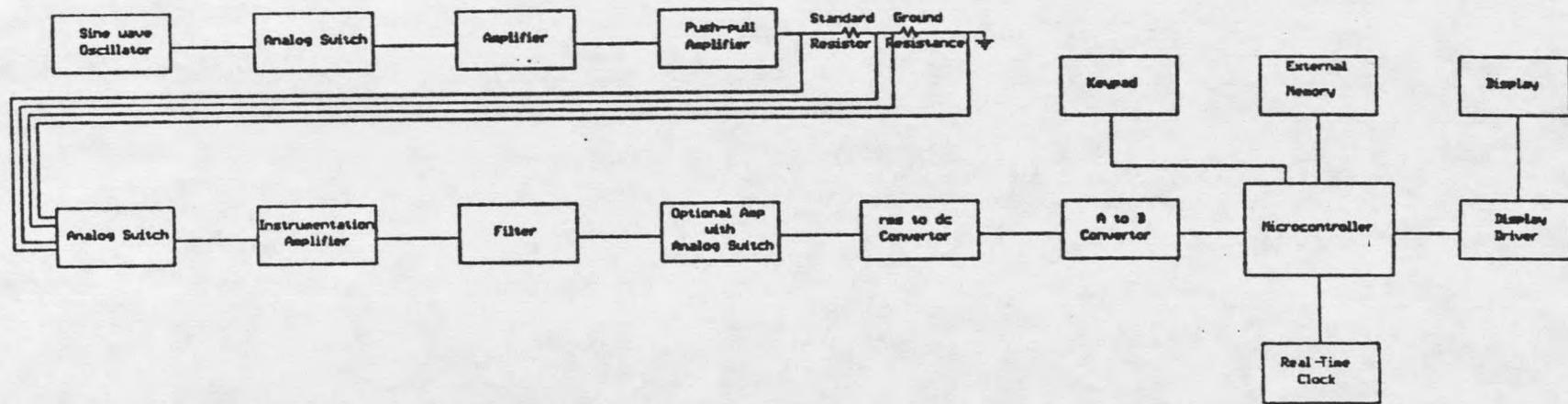


Figure 4: Hardware Block Diagram

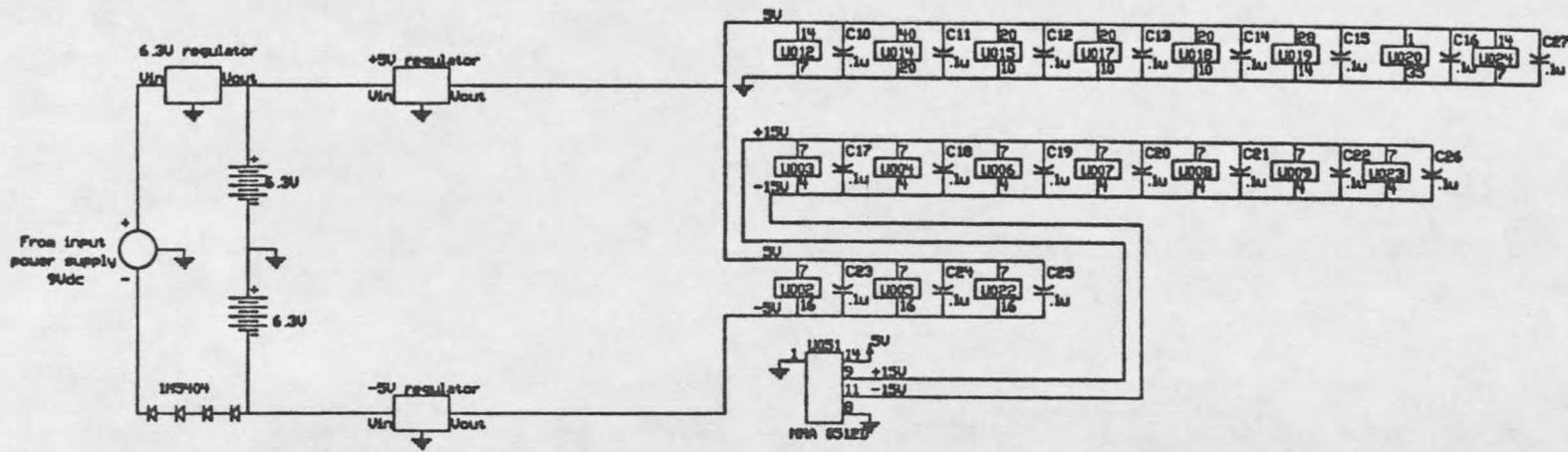
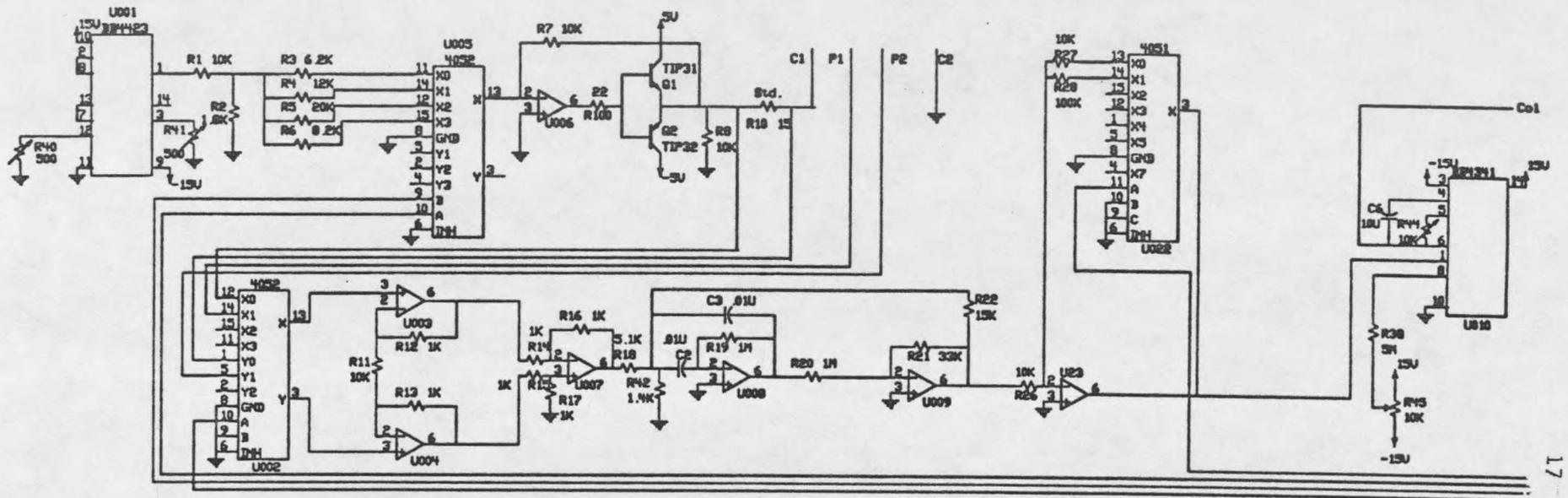


Figure 5: Analog Circuit Diagram

(chapter 2).

The output of the oscillator is a sine wave whose amplitude is 20 V_{p-p}. This wave form is input to a voltage divider that divides the voltage by a factor of six. This stage could however be disposed of and the necessary voltage reduction can be brought about by adjusting the gain of the amplifier in the next stage.

The output from the voltage divider is input to an amplifier stage. The amplifier stage has adjustable voltage gain which can be controlled by the microcontroller using an analog switch and resistors. The analog switch changes the input resistance to the opamp thus changing the gain of the amplifier stage. The analog switch has four inputs and hence the gain can be adjusted to four different levels. Such an adjustment enables the microcontroller to adjust the output voltage by varying the gain. A change in the output voltage would result in a change in the current flowing through the resistors (the serial combination of standard and ground). The microcontroller thus increases the current through the ground resistance whenever it is below a minimum specified level that is usually specified by a keypad input to the microcontroller.

As the microcontroller-based ground resistance monitor will be used in substations where there are tens of volts due to leakage currents flowing from the grid into the surrounding earth, there is a possibility of error being introduced in the

measurements made. To minimize the error, from the leakage currents, two sets of measurements would be made for both the voltage and the current and the difference between the two readings utilized to calculate the ground resistance. This would eliminate the voltage caused by leakage currents flowing from the grid that was common to both the readings. These readings, it may be mentioned, are made for different analog switch settings which in turn means different voltages across each of the resistances. The analog switches are operated by the microcontroller.

The output of this amplifier is fed into a push-pull amplifier. This stage provides up to 100 mA current without distorting the output. The output from the push-pull amplifier is fed into the standard resistor and then into a ground electrode (C1). An auxiliary electrode (C2), buried in the ground at about 100 feet from the ground electrode, is connected to the chassis ground of the ground resistance monitor.

As described in chapter 2, the current probes introduce a high current density area around C1 and C2. To get a fairly accurate value of ground resistance, it is essential that the voltage probe be placed away from this area with high current density. So, the voltage probe (auxiliary electrode P2) is placed at a distance of about 100 feet from either of the other electrodes. This ensures that the voltage probes just pick up the true voltage introduced by the probe C1 and not

