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# A MICROPROCESSOR BASED LOW RESISTANCE MEASUREMENT SETUP USING FOUR PROBE METHOD

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This paper describes a method of measuring very low resistances for highly conducting media using current interruption technique. In this experimental setup, four probe technique for measurement of resistance is implemented to eliminate the contact resistances between the junctions. Power saving has been achieved in this system due to the current interrupt technique. The details of both hardware and software are given. A few typical results obtained using this measurement setup are tabulated.

**Key words: Low resistance, current interrupt technique, four probe method**

## INTRODUCTION

Measurement generally involves using an instrument as a physical means of determining a quantity or variable. Microprocessor based systems are suitable for dedicated applications in industries, instrumentation etc. and being very small and compact can form the part of the equipment to be controlled. All resistances of the order of 1 ohm and under may be classified as low resistances. It is usually essential, with low resistances, that the two points between which the resistance is to be measured shall be very precisely defined. Thus the methods which are specially adopted to low resistance measurement employ potential connections, i.e. connecting leads which form no part of the circuit whose resistance is to be measured. These two points are spoken of as the potential terminals, and serve to fix a definite length of the circuit under test. The potentiometer methods and bridge methods which are applicable for the measurement of low resistances may have the highest accuracy, but since they are null methods, two or more ratios are brought to equality and the measurement has to be done with accurately known standards. The four-probe method which has been employed in this paper avoids the foregoing requirements.

As one of the versatile instruments in both laboratory as well as in industry, an attempt has been made to facilitate fast and accurate measurement of low resistances of highly conducting media. The resistance value of the sample is displayed digitally by means of a microprocessor(8085). The scheme employs 4 terminal method to eliminate lead and contact resistance effects, while making the measurement. Further, due to application of current interrupt technique, overheating of the specimen under test is prevented. Continuous passage of current in such media may result in heating and introduce temperature effects. The floating potential across the potential terminals ($V^+$ and $V^-$) which is corresponding to the resistance, which is to be measured is read by a microprocessor and the resistance value is given as direct read-out by it.

The measurement set-up developed here can be used as a standard one for measuring resistances from 1μΩ to 1KΩ . It can be used to measure resistance of various wires, windings, coils, contact resistance of connectors, switches, relays etc. The easiness of operation and convenient digital display makes it especially suitable for repetitive type of operations resulting in time savings of production lines, laboratories and incoming inspection departments.

The overall accuracy of the unit is within 1.1%. The accuracy of the instrument set-up can be improved with the help of proper earthing, compact arrangements of components using thick leads and by making use of proper "four probes". In view of these accuracies and inbuilt facilities in this unit, it can be used with much advantage in different types of measurements. All these measurements can be made with the help of a band switch arrangement.

Technical Specifications:

| | | |
|---|---|---|
| Range | : 100μΩ | |
| | : 100 mΩ | Selected by band switch |
| | : 100 Ω | |
| | : 1k Ω | |
| Resolution | : 1μΩ in 100μΩ range | |
| | : 1mΩ in 100m Ω range | |
| | : 1Ω in 100 Ω range | |
| | : 10 Ω in 1kΩ range | |
| Method of measurement | : 4 probe method | |
| Test current | : 1A (in 100μΩ range) | |
| | : 100mA (in 100m Ω range) | |
| | : 1mA (in 100Ω & 1kΩ range) | |

### Principle of operation

The basic procedure for measuring the unknown resistance of a sample is to find out the ratio of voltage (V) across the sample to the current(I) passed through the same. The same procedure is adopted for measuring the very low resistances which is described here.

In this paper, the method used is linear four-point probe method which consists of placing four probes that make contact along a line on the surface of the material. Current is passed through the outer pair of probes and the floating potential is measured across

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the inner pair. The method described here overcomes the difficulties of lead and contact resistances and also offers several other advantages.

The measurement set-up is described in the block schematic of Fig.1. The first block labelled as current pulse generator,

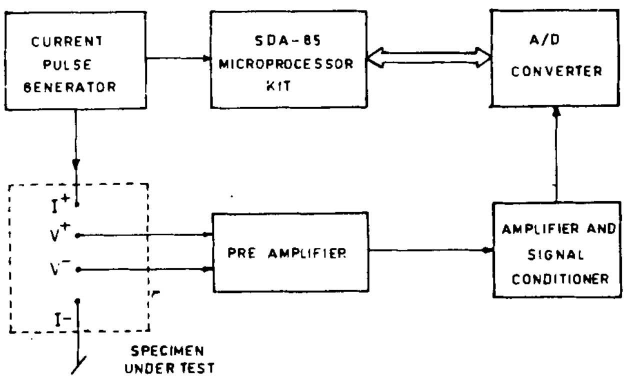


*Fig.1: Block diagram of low resistance measurement set-up*

produces free running current pulses which are having the "on" period of 1 sec. and "off" period of 9 sec. During "on" period only a current will flow through the sample under test i.e. the current is interrupted after 1 sec. and is again made to flow only after 9 secs. The current is entering at I+ and leaves at I−. In between, across V+ and V- the floating potential is measured.

The blocks named as preamplifier and signal conditioner are used to amplify the floating potential across V+ and V- which will be equal to the product of the current passed through the sample and the resistance which is to be measured. The output of the signal conditioner is connected to the input of an 8 bit Analog to Digital converter (A/D).

The A/D converter used here will give 8 bit of digital information. This output is given to one of the ports of a peripheral interface accessory (8255). The control signals for starting and ending the A/D conversion is given through the microprocessor itself.

The microprocessor kit used here is SDA-UNI-01 which is a universal microprocessor/trainer prototyping system with personality cards for different processors. The basic system is designed as an 8085 system with a keyboard (28 keys), eight digit display (four for address and four for data), ROM (upto 16k), RAM (upto 16k), 48 programmable I/O lines, three 16- bit counter-timers, a USART based serial I/O link, cassette recorder interface, EPROM programmer for standard EPROM's like 2716, 2732, 2732A, 2764 27128 and 27256 and bus buffers for interfacing to the 64 pin euroconnector interconnection bus.

The system components are mounted on a double sided glass epoxy PCB, which is solder-masked and screen printed. The keyboard consisting of 28 keys provides access to the system monitor enabling program entry, verification, execution and debugging. The definition of the keys is dependent on the processor in use.

**Circuit description**

Fig.2 gives a detailed schematic circuit diagram of the low resistance measurement setup developed here. IC1 (NE 555) is connected in

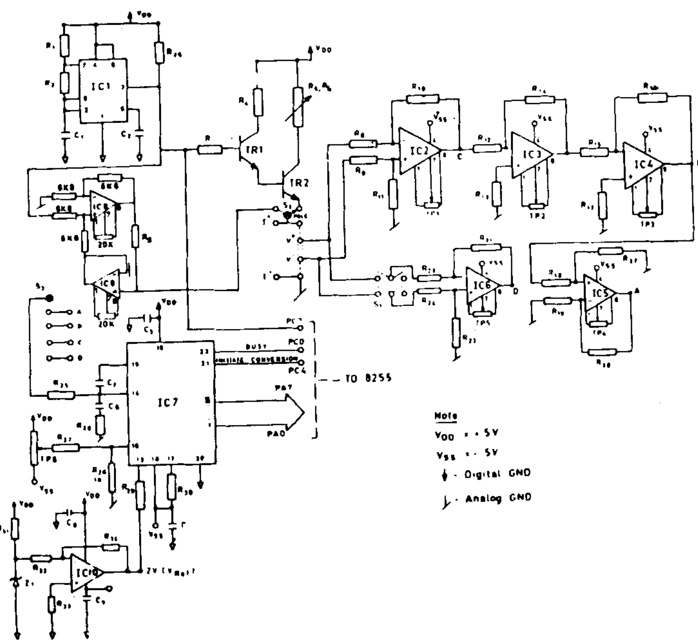


*Fig.2: Schematic diagram of microprocessor based low resistance measurement set-up using four probe method*

*Components list*
*IC1 - 555*
*IC2 - IC6; IC8 - IC9 - OP - O7*
*IC7 - 8702*
*IC10* - μA 741
TR1 - SL 100
TR2 - TIP31
T1-T6 - Trim Pot - 20k ohms
Z1 - Zener diode (6.2V)
R3 - 4k ohms
R4 - 300 ohms
R8,R9,R12, R15-R18, R21-R24, R28 & R31 - 1k ohms
R10, R11 & R32 = 10k ohms
R14,R20,R25,R30 = 100k ohms
R26 = 100 ohms
R33 = 2.4k ohms
R34 = 3.3k ohms
C3 -C6 = 0.1μF
C7 = 67PF
C8 = 220 PF

a stable mode of operation and produces square pulses with 1 sec. 'on' time and 9 sec. 'off' time. The pulse generated by IC1 is converted as current pulse by means of a current generator which consists of a darlington pair (TR1 & TR2) and two operational amplifiers (IC8 & IC9), capable of producing the various current outputs, ranging from 1mA to 1A. By including the resistances R5, R6 in the collector circuit of TR2 1A and 100 mA can be generated respectively. TR2 is an NPN silicon power transistor which can be used for power amplification and high speed switching applications. Since it requires a minimum base bias current of 30 mA, Tr1 is added as driver transistor. To draw 1 mA current, the darlington pair cannot be used. Instead, IC8 and IC9 serve the purpose. IC8 acts as a voltage to current converter. The 1mA current is obtained such that

Output from IC1 in volts/$R_S$ ohms = 1mA

By measuring the output voltage of IC1, $R_S$ is fixed.

Only during 'on' time of the current pulse, the current will flow through the sample under test and the potential drop across the voltage terminals ($V^+$ & $V^-$) is sensed which is the product of the current flowing through the sample and the value of resistance of the sample.

The various current ranges are selected by means of a band switch(S2). The floating potential is sensed and amplified by the signal conditioner which consists of five amplifier stages (IC2-IC6). IC2 and IC6 are differential amplifiers and are having a gain of 10 and unity respectively. IC3 is having a gain of 10 and IC4 is used as an inverter. IC6 is having a gain of 100. The maximum input to the A/D converter is 1V. The analog input to the A/D converter from the signal conditioner is given through the band switch(S2), which is a 4-pole-4-ways switch. At the first position, 1A will pass through the sample and the output of IC6 (with the overall gain of $10^4$) will be connected as A/D converter input. In the 2nd position, 100mA will pass through the sample and the output of IC6 (gain = $10^2$) is connected to the A/D converter input. At the 3rd position, 1mA will pass through the sample and the output of IC2 (gain = $10^1$) is connected to the A/D converter input. At the 4th position 1mA will flow through the sample and the output of IC6 (gain = $10^0$) is connected to the A/D converter input.

The differential inputs of IC6 are connected to $V^+$ and $V^-$ through the switch S1, i.e. only for 1 kΩ range selection S1 should be closed such that $V^+$ and $V^-$ are connected to the inputs of IC6. For the other three ranges, the switch should be opened. The maximum input given to the A/D converter is limited to 1V.

In the A/D converter (IC7) used here, conversion is performed by an incremental charge balancing technique, which has inherently high accuracy, linearity and noise immunity. An amplifier integrates the sum of the unknown analog current and pulses of a reference current, and the number of pulses (charge increments) needed to maintain the amplifier summing junction near zero is counted. At the end of conversion, the total count is latched into the digital output as an eight bit binary word.

With reference to the timing diagram (Fig. 3), applying a logic '1' to the initiate conversion pin initiates the A/D conversion cycle. Once conversion has been initiated, the cycle cannot be interrupted and the initiate conversion pin is disabled until conversion is complete. Two modes of opertation are permitted, clocked or free-running. For clocked operation, the initiate conversion input is held at logic '0' for standby and taken to logic '1' when a conversion is desired. For free-running operation, the initiate conversion pin is connected to $V_{DD}$ or similar permanent logic '1' voltage.

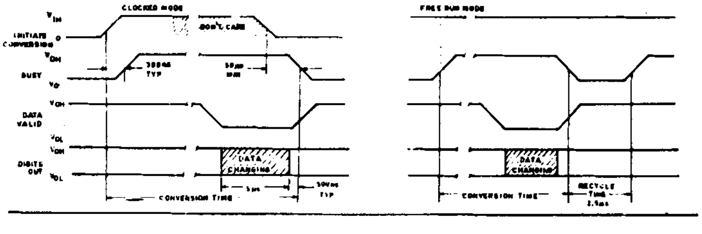

*Fig.3: Timing diagrams (rise, fall times = 200 ns typ., $C_L$ = $50_pF$)*

A logic '1' output on the Busy pin indicates that a conversion cycle is in process. A logic '1' to logic '0' transition indicates that conversion is complete and the result has been latched at the Digits out pins. A logic '0' to logic '1'transition indicates that a new conversion cycle has been initiated. If the device is operating in the free-running mode, the Busy output will remain low for approximately 2.5μs, marking the completion and initiation of consecutive conversion cycle.

A logic '1' output at the Data valid pin indicates that the Digits out pins are latched with the result of the last conversion cycle. The Data valid output goes to logic '0' approximately 5μ s before the completion of conversion cycle. During this 5μ s interval, new data is being transferred to the Digits out pins, and the Digits out are not valid.

Obtaining a high accuracy conversion system depends on the voltage regulation of $V_{REF}$ and the thermal stability of $R_{in}$ and $R_{REF}$. A negative reference voltage must be supplied. This may be obtained from a constant current source circuit or from the negative supply. Here the reference voltage given is — 2V.

The values of $R_{IN}$ (R25) and $R_{REF}$ (R29) are chosen as follows:

$R_{IN}$ = $V_{IN}$ Full Scale/10μ A = 1/10μ A = 100 k ohms

$R_{REF}$ = $V_{REF}$ / — 20μ A = —2/— 20μ A = 100 k ohms

The Digital output from the A/D converter is given to the ports of 8255 of the microprocessor kit. The port connections of 8255 have been indicated clearly in the schematic diagram itself.

Analog to digital conversion has been done as per the following steps.

(i) Set initiate conversion pin to 1 state
(ii) Wait for the Busy pin to reach 1 to 0 transition
(iii) Read the data through 8255
(iv) Repeat for 8 times
(v) Store 8 datas in consecutive memory locations from X to X+7

The eight binary datas at locations X to X+7 are added. The result will be a 16 bit result and is stored at the locations Y and Y+1.

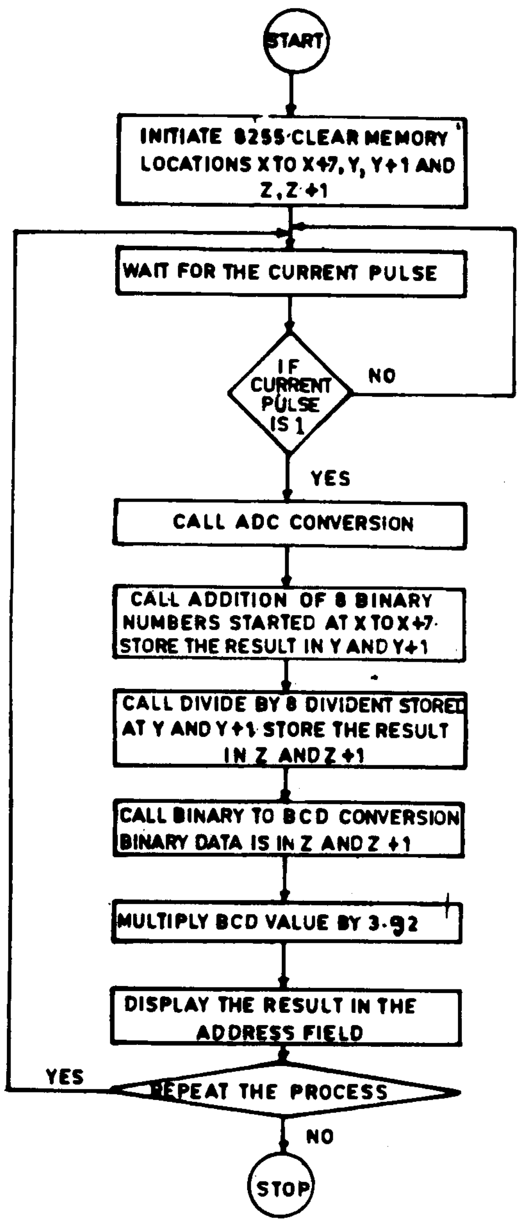


*Fig.4: Flowchart of the entire operation*

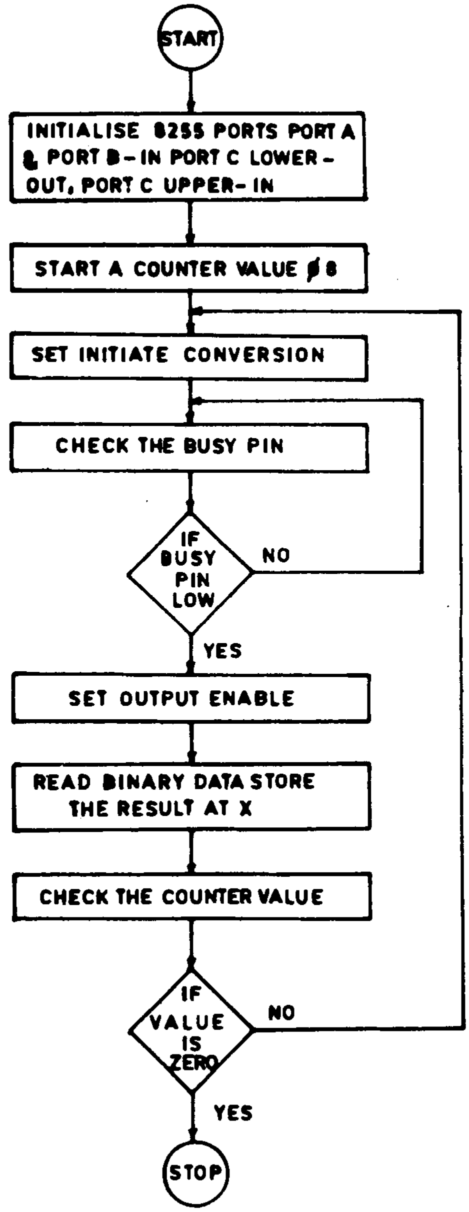


*Fig.5: Analog to digital conversion*

The 16 bit result at the locations Y and Y + 1 is divided by 8 and the result will be an eight bit result. This is a binary data and is to be converted into decimal data. This decimal value should be multiplied by 3.92 because maximum ouput from ADC is 255-decimal (or FF in Hex). As far as the analog input to ADC is concerned, analog signal is 1V. Hence 1V should measure 1000(Result is displayed in Address field), 255 should correspond to 1000.

TABLE-I : Comparison of meters

| Sample | Actual value | Reading in a commercial μΩ meter | Reading in the μ p based low resistance measurement set-up | % of error |
|---|---|---|---|---|
| Resistance of copper rod | 10.45 μΩ | 10.53μΩ | 10.359μΩ | 1.62 |
| Resistance of titanium sheet | -- | 100.10μΩ | 98.67μΩ | 1.4 |
| Contact resistance of PUSH button | 20.00 mΩ initially | 25.45 mΩ | 25.20 mΩ | 0.98 |
| Contact resistance of the 15A, ANCHOR switch | -- | 11.20 mΩ | 11.0 mΩ | 1.78 |
| Contact resistance of band switch | -- | 4.664 mΩ | 4.643 mΩ | 0.43 |
| Contact resistance of DPDT switch minitype | -- | 7.353 mΩ | 7.432 mΩ | 1.07 |
| Metal film resistance | 10.00Ω | 10.90Ω | 10.88 Ω | 0.18 |
| Metal film resistance | 100.00Ω | 100.02 Ω | 100.00Ω | 0.02 |

The BCD data multiplied by 3.92 gives the value of the resistor directly through the reading of the display.

With reference to the flow-charts for entire system operation Fig.4 and A/D conversion Fig.5, the complete software operation can be understood.

## RESULTS AND DISCUSSION

The Low-Resistance measurement setup, which has been developed here had been compared with a commercial model of 4½ Digital Micro Ohm Meter (not microprocessor based) which is also a standard one for low resistance measurement. It also employs four terminal measurement system. The results for various samples have been tabulated.

The micro-ohm meter developed here is found to be better than the commercial micro-ohm meter (cf. Table-I) since it is microprocessor based, more accurate and having more flexibility. The set-up is particularly designed for highly conducting media, which are having very low resistances in the order of micro-ohms.

## CONCLUSION

The measurement setup discussed so far in this paper is useful for measurement of contact resistance, conductor resistance, winding resistance, component resistance, winding temperature rise etc. It displays the value of resistance directly in digits. No need of any balancing and bringing null indicator to zero. The unique design with 4 terminal measurement system provides zero reading when the test leads are shorted together. The readings are true without the effect of the test and lead resistance

It can be efficiently used for highly conducting media which are having very low resistances and since it is microprocessor based, it consists of high speed of operation. Also, since it employs current interrupt technique, material overheating is avoided.

The easiness of operation and convenient digital display makes it suitable for repetitive type of operations resulting in time savings of production lines. research and incoming inspection departments.

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