Low Resistance Measurement Based on Time to Digital Converters

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Abstract: A method of measuring low resistance in the range of micro-ohms based on a commercially available time to digital converters is proposed. The method is based on the discharge time of a fixed value capacitor. In contrast to the four probe method, time domain measurement does neither need to pass a large current through the specimen or measure noise prone very low voltages. Due to its ratiometric nature, the measurement results are not affected by variation in the voltage source of the circuit. This has an advantage over the four probe method where a precision current source is required. This greatly reduces the cost of measurement. This method is implemented using the commercially available time to digital converter and an analog circuit. The measurement requires a capacitor of a fixed value that is charged and discharged during the measurements.

I. Introduction

Measurement of low resistance is important in many fields of Science and Technology. Some of the applications are inductive device testing where the resistance of an inductive component is measured, measurement of contact resistance for switching devices, superconductor resistance, resistivity measurement of conductors etc[1].

A common method of measurement for low resistance involves passing a high current through the device under test and measure the potential drop across it. This type of measurements is constrained by the current limitations of the device under test.

The potential drop across the resistance is also very low. For example, 1 amp of current passing through a resistor of one micro-ohm will produce a potential drop of one microvolt. This low voltage drop is prone to noise distortion and become rather difficult to measure. For small voltages, the signal to noise ratio for thermocouple emf, Johnson noise, electromagnetic interference become quite significant[1,2].

The proposed method is based on time domain measurement using a time to digital converter(TDCC). A fixed value capacitor which has been charged to a certain voltage is discharged through the given resistor to be measured. The delay in the discharging of the capacitor can be measured with high resolution and the resistor value can be determined.

This time domain conversion of low resistance measurement has a number of advantages.

This method does not require passing high current through the test material and hence it does not affect its property or cause any damage or heating etc. The four probe method of measuring low resistance requires a highly stable source meter for passing a constant current through the test material, on the other hand, no such sources are required. A small voltage drop across the resistor needs a very specialized nano-voltmeter to measure it which increases the cost of measurement. In time domain method instead of voltage, the time is measured with fewer constraints[3]. The TDC measurement produces a digitised data that can be recorded automatically in a data file[4,5].

II. Circuit description

A. Architecture

The analog part of the measurement unit consists of two comparators that generate START and STOP signals. Referring to figure 1 the test resistor R is connected in parallel to a fixed value capacitor C. The capacitor is charged by a square wave generator G. The connection between the square wave generator and the capacitor is made through a diode for unidirectional flow of current. The square wave is used to charge the capacitor when in the high state. When it goes in the low state the diode gets reverse biased and the capacitor is discharged through the resistor R. Two reference voltages V1= 2V0/3 and V2 = V0/3 are generated using the three resistors R1, R2 and R3 each having the same value of 100K Ohms. The non-inverting inputs of comparator A and B are connected to voltage references V1 and V2 respectively. The inverting input of both the comparators are connected to the charging node of the capacitor C. Thus when the capacitor is being discharged and the voltage on the capacitors crosses the voltage
references V1 and V2, the output of comparators A and B go high respectively at these voltage values. These two outputs generate a START and STOP signal respectively for the TDC-GP2 circuit. The time delay between the START and STOP is counted and digitized by the TDC-GP2 IC and communicated to a processing system, in this case a PC. The time delay is the time capacitor C takes to discharge between the two reference voltages.

![Fig 1: Analog unit (drawn using NI’s Multisim)](image)

**B. Theory of Operation**

The time domain measurement is based on converting the resistance value into a time delay. This time delay is then measured with a high-resolution time to digital converter.

An analog circuit based on the RC time constant is given in fig. 1 is used to generate a time delay[4]. The capacitor is initially charged to a voltage V0 when the square wave in the circuit is high. In this case, the output of the comparators A and B are in the low state. When the square wave goes from high to low voltage state, diode D is reverse biased and the capacitor starts discharging through the resistor R. The exponentially decaying voltage on the capacitor is detected through the comparators A and B which have their inverting inputs connected to the charging node of the capacitor C. When the voltage on the capacitor decreases to V1=2V0/3, output of comparator A goes high. This generates a START signal for the TDC. Similarly, when voltage goes below V2=V0/3 the output of comparator B goes high and generates a STOP signal for the counter to stop counting. Thus the time delay Δt is related to the RC time constant in the following manner.

\[ t = \frac{RC \ln(V0/V)}{V} = \frac{RC \ln(3/2)}{V} \text{ for } V=2V0/3 \]
\[ t1=RC\ln(3/2) \]
\[ t2=RC \ln3 \]
\[ \Delta t = t2-t1 = RC \ln2 \]

**C. TDC – GP2 evaluation kit**

The term time-to-digital converter is used when time interval measurements in the range of 1 nanosecond down to the picosecond range are involved. The modern CMOS-technology makes it possible to integrate fully digital time-to-digital converters into a single chip. The high precision of the time measurement - down to 22 ps - in combination with the large dynamic range (up to 4 ms), the high stability over temperature and supply voltage are some of the advantages of modern CMOS technology.

![Fig 2: TDC GP2 Eva KIt (Taken from Datasheet)](image)

The TDC-GP2 IC has a resolution of 45ps and a range of 2.5 microseconds in double resolution mode. It works on a power supply of 2.5 to 3.6 Volts. More details can be seen in the datasheet.

TDC GP2 -evaluation kit is a complete ready to use hardware and software setup. It has a complete circuit board and a software for configuration and data recording from the hardware. All the measurements can be made from a PC using MS windows OSMore details can be seen from the ACAM website www.acam.de.

**III. Observation and result**

It is obvious that the circuit will show a large offset of the resistor value due to various factors. These may include the resistance of the connection leads, circuit board, the effective series resistance of the
capacitor etc. Thus to estimate this offset value, readings were taken without the resistor and the leads were shorted. The offset may also be caused by the response time of the two comparators. The offset due to the comparators can be nullified by interchanging their connection for start and stop signals. The reading for short-circuited leads was 1886.535 nanoseconds. This corresponds to an effective resistance of 0.0579084 ohms. Now a copper wire was connected to the leads and readings taken. This time the delay time noted in the TDC was 1886.585 nanoseconds. The resistance of the copper wire connected can be calculated as

\[ R = \frac{(t_2 - t_1)}{C \ln 2} \]

\[ R = 1.5 \Omega \]

The summary of the observation is given the table above.

This value was well within the expected resistance value of the copper wire.

**Conclusion**

An analog circuit was designed using comparators to measure low resistance in the time domain. Commercially available time to digital converter GP2 IC was used to measure the time delay of an RC charging and discharging circuit. The delay time was measured with a resolution of 45ps and the low resistance of a copper wire was estimated. This estimation was well within the calculated values using the resistivity of copper. Thus an experimental verification of the proposed method was done.

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**References**


