Development of a Multi-Range Microcontroller Based Lock-In Digital Milliohm Meter

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ORIGINAL RESEARCH

Abstract- Milliohm Meter is an instrument for measuring very small amount of resistance in a conductor, electric motor and transformer windings and in many other current sensing applications that cannot be measured with standard digital ohmmeters. The cost of commercially available milliohm meter is relatively high, making it unaffordable for hobbyists. In this work, a low-cost microcontroller based digital milliohm meter having three measurement sub-ranges was designed, constructed, tested and calibrated. The instrument, based on the PIC16f877A 8-bit microcontroller, used the lock-in detection technique to improve the measurement signal-to-noise ratio without requiring high current for measurement. The milliohm meter's firmware was written with MicroC software by Mikroelektronika® and was simulated using Proteus® software by Labcenter Electronics. After construction and calibration, it was found to have resolutions of 82.9320 counts/mΩ, 9.1394 counts/mΩ, and 0.9221 counts/mΩ for the measurement ranges of 0 – 10mΩ, 0- 100mΩ and 0 – 1000mΩ respectively. Thus, the instrument is capable of measuring resistance value between 0Ω to 1Ω with good resolution values without requiring the computing power and display capabilities of a digital computer.

Keywords- Milliohm, Milliohmeter, Ohmmeter, Multimeter, Resistance measurement

1 Introduction

Measuring instruments play a major role in the theoretical and practical engineering work. They serve as a means of investigating what is happening in an engineering system. To serve this purpose adequately, they must have good accuracy and resolution. Ohm meters are used to measure the resistance of electronic components used in electronic systems. In most instruments, the ohmmeter function is incorporated into a general-purpose multimeter that also measure voltages, currents and other electrical parameters. Such multimeters are usually adequate in measuring resistances with values that are higher than about one 1 ohm. For measurement of smaller resistance values, dedicated instruments known as milliohm meters having the required resolution are needed.

Examples of such measurements are found in the multimeters determination of transformer winding resistances, mechanical switch resistances and car chassis resistance measurement. Using a commercial digital multimeter that does not have the required resolution to measure resistances of the order of milliohms will result in inaccurate measurements.

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
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The design of high accuracy milliohm meter presents an interesting technical challenge. Resistance measurement is usually carried out by passing a fixed current through the unknown resistance and then measuring the resulting voltage that is developed according to Ohms law. If the unknown resistance is very small; it will require passing relatively large current to develop a measurable voltage across the resistance. Passing a large current through the unknown resistance may not be desirable, so the developed voltage may be small, in the microvolts and millivolts range. Such voltages have a magnitude that is comparable to the magnitude of ambient electronic noise like 1/f noise, thermal noise, and shot noise in the system (Libbrecht et.al. 2003). Thus, signal processing techniques may need to be applied to retrieve the signal out of the background electronic noise to achieve a reasonably measurement signal-to-noise ratio.

Lock-in detection techniques offers an attractive way of recovering the signal that is subsumed in a noisy signal. Basically, it is a signal averaging technique that squeezes the measurement bandwidth to a small value by averaging the results of a number of repeated measurements. This technique has been used to recover weak signals that are buried by stronger signals in laser applications (Chighine et al. 2015, Tyagi et al. 2018), in Infrared spectroscopy (Near-infrared non-destructive evaluation of food based on multi-frequency Lock-in detection), paramagnetic resonance detection (Chaudhuri et al. 2020), in brain monitoring application (Giaconia et al.2017), temporal focusing microscopy (Ishikawa et al 2021), and also in photo-acoustic feedback signal detection (Tzang & Piestun 2016). Also, this technique has been used in sub-milliohm resistance measurements and it requires significant computing power and memory storage requirements (Bengtsson 2012).

Retrieving the needed signal from the noise signals requires significant computing power that is not cheaply available in general purpose multimeters. Because of these challenges, commercially available milliohm meters are expensive and their cost is sometimes above the budget of most electronic hobbyists. There is therefore a need to develop an inexpensive milliohm meter circuit that is capable of measuring small resistance values. In this work, a milliohm meter circuit that is able to measure resistance values between 0 and 1 Ohms. The proposed circuit is based on a microcontroller system and it has three ranges namely 0-10mOhm, 0-100 mOhm and 0-1000 mOhm. Based on the resistance value measured, the circuit selects the appropriate measurement range to preserve resistance measurement accuracy.

2 Literature Review

The simplest method of measuring low resistance value consists of a system in which a fixed current is passed through the unknown resistance. The developed voltage, being small in amplitude, is then amplified by an amplifier circuit to give an output voltage that is within the measurable range of a voltmeter. Thus, the voltage reading of the voltmeter is proportional to the unknown resistance. The constant current value is chosen such that the proportionality constant between the measured voltage and the unknown resistance is unity, making the measured voltage a direct reflection of the unknown resistance. This scheme is illustrated in Figure 1.

This method is simple and is easily implemented using a few electronic switches and operational amplifier circuit but the measurement accuracy achievable is limited due to some errors that are introduced into the circuit. Thermal voltages due to Seebeck effect can introduce measurement errors (Bengtsson 2012). The operational amplifier used in the circuit has offset voltages and currents that causes additional voltages in addition to the desired output voltage. These offset parameters are easily removed initially but they can change with time, thus introducing errors that may change with time.

The use of Chopper-stabilized amplifiers provides a way of minimizing errors due to amplifier offset voltages (Radetić et al 2013). Since the measurement is essentially carried out at 0 Hz, low frequency noise is quite significant and if the measurement current is small, the signal is corrupted by noise. Amplifying this voltage also amplifies the noise alongside the wanted voltage (ThinkSRS.com 2020). Variations of this measurement technique are direct comparator method with range extender technique and substitution methods (Galliana & Gasparotto, 2014).

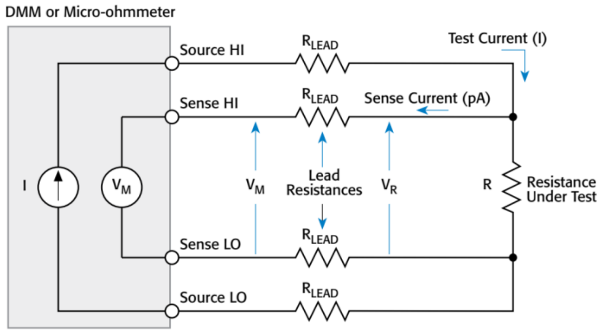

Fig. 1: Low resistance measurement based on Ohm's law (Cigoy, 2010)

Also, accurate resistance measurement can be carried out with the bridge method. In this class of technique typified by the Wheatstone bridge method, the unknown resistance and a standard resistance with a known value are used as constituents of a bridge network. If the instrument used in detecting the point of balance in the circuit is sufficiently accurate, precise resistance measurement can be achieved with this method (Braudaway, 1999). A variation of the bridge method that has attract some attention is the potentiometric bridge measurement principle. In this method, a series combination of an unknown resistance whose resistance is desired to be measured and a standard resistance with accurately known resistance value is excited with a constant current source.

The unknown resistance is proportional to the ratio of the voltages developed across the known and unknown resistances. Reversing the polarity of the applied current makes it possible to eliminate thermal voltage measurement errors (Ali, 2018). However, to achieve a reasonable accuracy of measurement, a high-test current value is required which can result in undesired heating effect in the resistance being measured (Štambuk & Malarić, R. 2015; Urekar, Novaković & Gazivoda 2019).

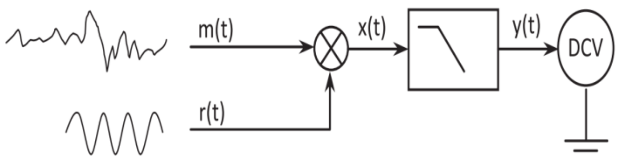

Fig. 2: The lock-in detection technique.

The use of large measurement current to get a good accuracy of measurement can be avoided if lock-in measurement technique is applied. The lock-in detection approach essentially shifts the measurement frequency from DC where measurement errors abound to a higher frequency. In this approach, the measurement experiment is excited at a given frequency f_0 instead of the normal measurement frequency (0 Hz). The exciting signal ($m(t)$) may be a sinusoidal waveform in which the measurement waveform (r(t)) has components only at frequencies around f_0, or rectangular/ square waves where the

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measurement waveform consists of frequencies that are centered around odd harmonics of f_0 (Zhang et al. 2016).

This is shown in Figure 2. The produced measurement signal is multiplied with the same modulating waveform $m(t)$ to produce a signal that has components whose frequencies consists of series of difference and sum signal frequencies.

For a sinusoidal modulating frequency

$$m(t) = A\cos 2\pi f_0 t \quad (1)$$

In the frequency domain,

$$M(f) = \frac{A}{2}\{\delta(f - f_0) + \delta(f + f_0)\} \quad (2)$$

When the experiment is done at f_0, the 'carrier' amplitude is modified such that the measurement waveform

$$r(t) = kA\cos 2\pi f_0 t \quad (3)$$

where k represents the waveform amplitude if the measurement was carried out at 0 Hz. In the frequency domain,

$$R(f) = k\frac{A}{2}\{\delta(f - f_0) + \delta(f + f_0)\} \quad (4)$$

The output signal is derived by multiplying the measurement waveform with the modulating waveform to produce an output signal $p(t)$ such that

$$p(t) = m(t) * r(t) = k\,(A\cos 2\pi f_0 t)^2 \quad (5)$$

In the frequency domain,

$$P(f) = k\frac{A^2}{2}\left\{1 + \frac{1}{2}[\delta(f - 2f_0) + \delta(f + 2f_0)]\right\} \quad (6)$$

The low frequency component is extracted from the composite signal $p(t)$with a low pass filter. The low pass filter's bandwidth determines the equivalent measurement bandwidth which can be chosen to be as narrow as possible to reject effects such as dc offsets, 1/f noise etc. Similar results can be obtained if the modulating waveform is a square wave. In this case, the modulating signal consists of odd multiples of the fundamental frequency. The additional frequency components are suppressed by the low pass filter, so accurate results can be obtained with this method with simplified hardware design if careful attention is paid to the design of the low pass filter (Zhang et al., 2016).

This technique has been used for low resistance value measurement. Bengtsson (2012) designed a microcontroller-based milliohm meter circuit that is able to measure resistance with a quoted resolution of 55.6 μΩ/count. This design is particularly remarkable because the system was designed with a cheap 8-bit microcontroller unit with a 10-bit analogue-to-digital converter unit. In this design, the results of measurements are sent to a digital computer for display purposes through a serial RS232 data link. With a fixed resolution and instrumentation amplifier gain, the measurement range of this design is fixed.

A similar design was published by Maya et. al. (2019) in which a system that is able to measure resistance and capacitance was discussed. In this work, the lock-in amplifier system was implemented in hardware using 0.18μm CMOS technology. The CMOS design is quite remarkable because it achieved a very low power consumption (less than 834 μW) and also permits the operating frequency and amplifier gain to be user programmable. The measurement system is controlled with an Arduino® board which also provides an interface to a computer where the result is displayed. The CMOS design has quite respectable sensitivity figures for resistance and capacitance measurements (16.3 μV/Ω and 37 kV/F respectively).

Most of these designs have a fixed range of resistance measurement with a fixed resistance measurement resolution. Better resolution can be obtained by breaking the overall measurement range into smaller sub-ranges. This work seeks to build a microcontroller-based milliohm meter system that have a maximum measurement range of 0 - 1Ω, with sub ranges 0 -10mΩ and 0-100 mΩ.

3 Methodology

3.1 Hardware Design

The hardware system design is shown in Figure 3. The hardware design generally follows the pattern of the design used by Bengtsson 2012. The circuit uses four-wire resistance measurement technique (Cigoy 2010 and Janesch 2013) to minimise errors due to contact resistances. The circuit is designed around a PIC16F877A 8-bit microcontroller unit. The instrumentation amplifier (INA 128) amplifies the voltage drop across the unknown resistance when the microcontroller toggles the output pins connected to resistors $R_1$and R_{31}. Operational amplifiers $U_6$and U_7 provides further voltage gain for measurement ranges 0 -10 mΩ and 0-100 mΩ respectively. The outputs terminals of the amplifiers are connected to the analogue inputs of the microcontroller through a resistive network that adds dc bias to the respective amplifier voltages.

This is required because the internal Analogue-to-Digital Converter (ADC) of the microcontroller can only measure unipolar voltages whereas the output voltages of the amplifiers can assume negative or positive values. The microcontroller samples the analogue channels, runs the lock-in detection algorithm, filters the processed samples and then converts the results to resistance values that are on the 4 * 16 Liquid crystal display (LCD) unit.

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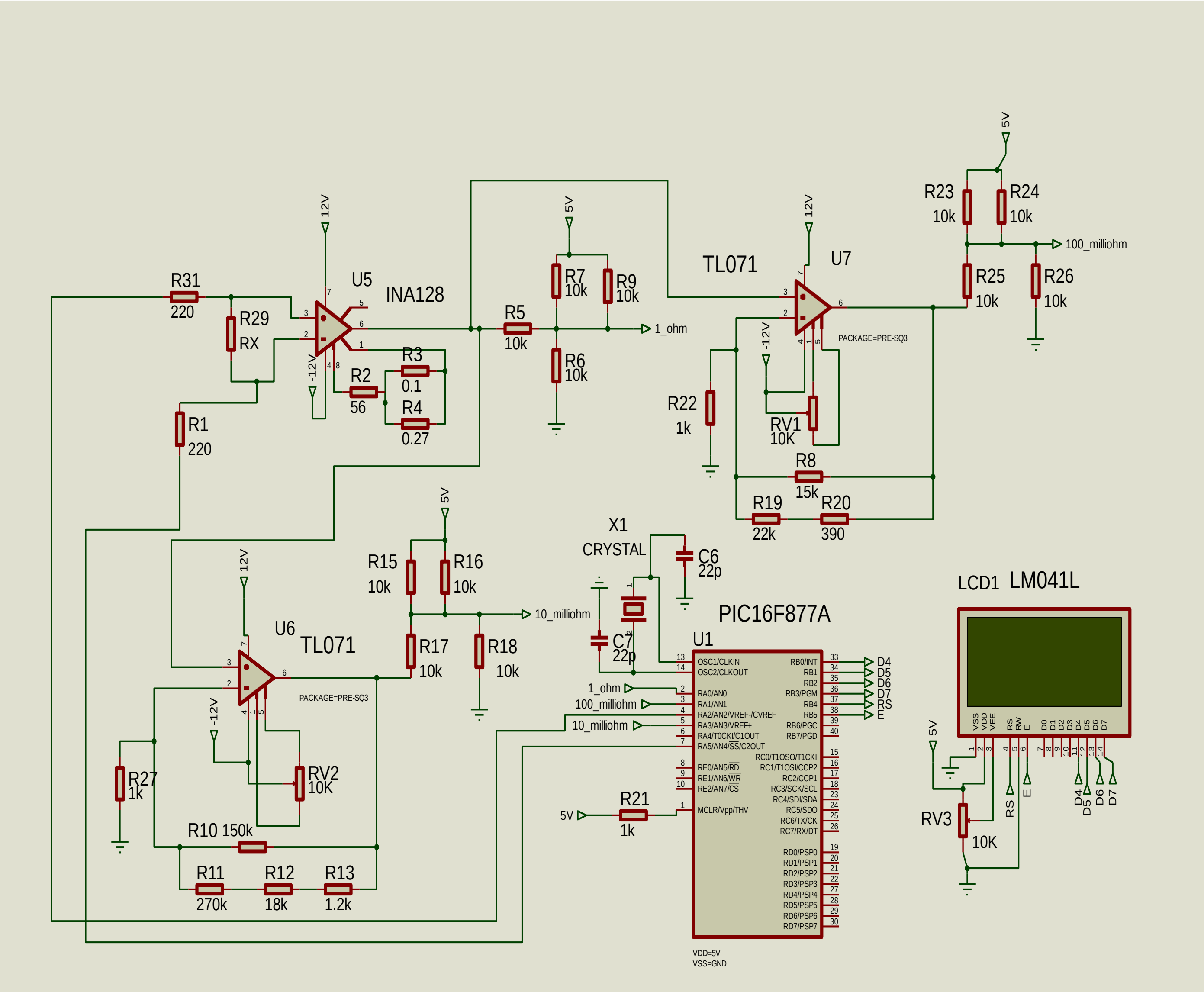

Fig. 3: Hardware design of the milliohm meter system

3.2 Firmware Design

The pseudocode of the measurement system is presented in Figure 4. The system needs to carry out measurements periodically, so an 8-bit timer0 unit was used to create periodic interrupts occurring at the measurement frequency. The firmware initializes all variables and sets up timer0 interrupt. Once an interrupt occurs, samples are obtained from the three analogue channels, and after this, the digital output pins are toggled in preparation for the next set of measurement that will be done when another interrupt occurs. Thus, the time between successive interrupts gives the associated amplifiers enough time to settle to the correct voltage levels.

At the next interrupt, another set of measurement is done. For each resistance measurement range, the current measurement is the subtracted from the previous measurement to obtain the correct measurement value for each cycle of measurement. This was done to cancel out additive thermal voltages that are developed at the interface between the measurement probes and the measurand due to dissimilar metallic contacts.

The measurement is repeatedly carried out for 2^13 cycles, and in every cycle of measurement, the obtained counts is accumulated for each measurement range. The obtained accumulated count is then divided by the number of measurement cycle (in this case 2^13) to obtain the averaged resistance count value. This was done for the count values obtained by sampling each of the three analogue channels that corresponds to the three ranges of resistance measurement.

In each measurement session, three count values are obtained, one count for each resistance measurement. In each measurement session, three count values are obtained, one count for each resistance measurement range. Thus, it is required to select the best count value with the highest resolution as the final count that will be converted to the measured resistance value. The count corresponding to the resistance range of 0-10 mΩ is first considered. If the count value is less than a set maximum count value, it is selected as the final count value. If it is

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equal to, or greater than the set maximum value, the count of the 0-100 mΩ range is considered, and if the value is less than the set maximum value, it is selected as the final count value. If the count is equal to, or greater than the set maximum value, the count corresponding to the 0-1000 mΩ range is considered. This selection procedure is illustrated in the flow chart in Figure 4. In all the ranges of measurement, the highest count obtainable is 1023 (2^10 -1) because the internal ADC unit of the microcontroller has a resolution of 10 bits. The set maximum count value (the threshold value) is chosen as 950 which represented 92.9% of the available maximum count.

```
Set up Timer Interrupt
Declare Variables: SUM_1Ω = 0, SUM_10mΩ = 0;
SUM_100mΩ = 0;
                                        Index = 0; count = 0;
Do

If (interrupt event)
                          //Read the analogue channels
S_1Ω[index]  = ADC_READ();
S_10mΩ[index] = ADC_READ();
S_100mΩ[index] = ADC_READ();
Increment index;

End

If (index==2)
Index = 0;
//update the count
SUM_1Ω = SUM_1Ω + (S_1Ω[0]- S_1Ω[1]  );
SUM_10mΩ = SUM_10mΩ + (S_10mΩ[0] S_10mΩ[1] );
SUM_100mΩ = SUM_100mΩ + ( S_100mΩ[0]-S_100mΩ[1]);
Increment count
End

If (count = = 2^13 )
//Scale the accumulated counts
RES_1Ω = SUM_1Ω /2^13;
RES_10mΩ = SUM_10mΩ /2^13 ;
RES_100mΩ = SUM_100mΩ /2^13 ;
End

While(1)

Select appropriate resistance range
Convert results to resistance
Display on LCD unit
End
```

Fig. 4: Pseudocode of the milliohm meter

The time interval between consecutive interrupt was chosen to be higher than the settling time of the instrumentation and operational amplifiers within range. Thus, it is necessary to select the best count value with the highest resolution as the final count that will be converted to the measured resistance value. The count corresponding to the resistance range of 0-10 mΩ is first considered. If the count value is less than a set maximum count value, it is selected as the final count value. If it is equal to, or greater than the set maximum value, the count of the 0-100 mΩ range is considered, and if the value is less than the set maximum value, it is selected as the final count value. If the count is equal to, or greater than the set maximum value, the count corresponding to the 0-1000 mΩ range is considered, and if its value is less than the set maximum count value, it is selected, otherwise an over range condition is specified.

In all the ranges of measurement, the highest count obtainable is 1023 (2^10 -1) because the internal ADC unit of the microcontroller has a resolution of 10 bits. The set maximum count value (the threshold value) is chosen as 950 which represented 92.9% of the available maximum count. The time interval between consecutive interrupt was chosen to be more than the settling time of the instrumentation and operational amplifiers. With settling times of 20µs for a 10V change and about 0.3µs for INA 128 and TL071 amplifiers respectively, the time between successive interrupt was chosen as 500µs which is sufficient for all the amplifiers to settle to the required values. This gives a measurement frequency of 1 kHz since two interrupt events are required for one measurement cycle. The pseudocode shown in Figure 4 was converted to a C program for PIC microcontrollers using MicroC compiler by MikroElectronika®.

3.3 Hardware Design Details

3.3.1 Measurement Current

It is good to make the value of the output current of the microcontroller reasonably high to obtain a significant voltage drop across the unknown resistance. According to Microchip PIC16F87X datasheet, the microcontroller's output current is limited to about 25 mA. With $R_1 = R_{31} = 220\Omega$, and a supply voltage of 5V, the maximum current sourced and sinked by the microcontroller pins (pins 4 and 7; see Figure 3) is 11.36 mA which is lower than the 25mA maximum allowable microcontroller output current.

3.3.2 Amplifier Gain Determination

Let V_{OH} = Microcontroller high output voltage
V_{OL} = Microcontroller low output voltage
V_x = voltage drop across unknown resistance
V_1 = output voltage of the instrumentation amplifier
V_2 = output voltage of U7 (100mΩ range)
V_3 = output voltage of U6 (10 mΩ range)
$V_{1\Omega}$ = input voltage to analogue channel 0
K_1 = voltage gain of the instrumentation amplifier
K_2 = Voltage gain of U7
K_3 = Voltage gain of U6
R_{OH} = output resistance of the microcontroller with logic high output voltage
R_{OL} = output resistance of the microcontroller with logic low output voltage

When pin 4 is set to logic 1 and pin 7 of the microcontroller is set to logic zero, From Figure 3,

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$$V_{x10} = \frac{R_x \times (V_{OH} - V_{OL})}{R_{OH} + R_{OL} + R_{31} + R_1 + R_x} \quad (7)$$

When the digital pins are toggled, i.e., pin 4 is set to logic 0 and pin 7 is set to logic one, V_x becomes

$$V_{x01} = \frac{R_x \times (V_{OL} - V_{OH})}{R_{OH} + R_{OL} + R_{31} + R_1 + R_x} \quad (8)$$

The network formed by R_5, R_6, R_7 and R_9 adds a constant bias voltage to V_1 at the expense of an attenuation factor of 4. Thus,

$$V_{1\Omega} = {}^{V_{CC}}/_{2} + {}^{V_1}/_{4} = {}^{5}/_{2} + {}^{V_1}/_{4} = 2.5 + {}^{V_1}/_{4} \quad (9)$$

$$V_{1\Omega} = 2.5 + \frac{1}{4}(K_1 \times V_x) \quad (10)$$

The internal ADC samples$V_{1\Omega}$to produce an integer X according to the relationship

$$X = \text{round}\left(\frac{V_{1\Omega}}{V_{ref}} \times (2^n - 1)\right) \quad (11)$$

Where V_{ref} is the ADC reference voltage and has a value of 5V in our case, and n is the number of bits used to represent the sampled result, which in this case, is 10 bits. Thus, in one measurement cycle, the count value obtained is given as

$$X = \text{round}\left(\frac{\left[\left(2.5 + \frac{1}{4}(K_1 \times V_{x10})\right) - \left(2.5 + \frac{1}{4}(K_1 \times V_{x01})\right)\right]}{5} \times 2^{10} - 1\right) \quad (12)$$

$$X = \text{round}\left(\frac{\frac{K_1}{4} \times (V_{x10} - V_{x01})}{5} \times (2^{10} - 1)\right)$$

$$X = \text{round}\left(\frac{K_1 \times (V_{x10} - V_{x01})}{5} \times \frac{(2^{10} - 1)}{4}\right)$$

$$X = \text{round}\left(\frac{K_1}{20} \times (V_{x10} - V_{x01}) \times (2^{10} - 1)\right)$$

$$X = \text{round}\left(\frac{K_1}{10} \times \left(\frac{R_x \times (V_{OH} - V_{OL})}{R_{OH} + R_{OL} + R_{31} + R_1 + R_x}\right) \times (2^{10} - 1)\right) \quad (13)$$

If R_{OH} and R_{OL} are small compared to $R_{31} + R_1 + R_x$, then

$$X \approx \text{round}\left(\frac{K_1}{10} \times \left(\frac{R_x \times (V_{OH} - V_{OL})}{R_{31} + R_1 + R_x}\right) \times (2^{10} - 1)\right) = \text{round}\left(\frac{K_1}{10} \times \left(\frac{R_x \times (V_{OH} - V_{OL})}{2R_1 + R_x}\right) \times (2^{10} - 1)\right) \quad (14)$$

The microcontroller unit gives a maximum count of 1023 when the unknown resistance has a value of 1Ω which corresponds to the highest resistance that is measurable in that range. With $R_x = 1\Omega$ and $X = 1023$, eq. (14) gives $K_1 = 882$.

Similarly, if X_{100} represents the ADC count for the 0-100 mΩ range, then

$$X_{100} \approx \text{round}\left(\frac{K_2 K_1}{10} \times \left(\frac{R_x \times (V_{OH} - V_{OL})}{R_{31} + R_1 + R_x}\right) \times (2^{10} - 1)\right) \quad (15)$$

With $X_{100} = 1023$ and $R_x = 100$ mΩ,$K_2 K_1 = 8802$. Thus, $K_2 = {}^{8802}/_{882}$.

Similarly, if X_{10} is the ADC count for the 0-10 mΩ range, then

$$X_{10} \approx \text{round}\left(\frac{K_3 K_1}{10} \times \left(\frac{R_x \times (V_{OH} - V_{OL})}{R_{31} + R_1 + R_x}\right) \times (2^{10} - 1)\right) \quad (16)$$

With $X_{10} = 1023$ and $R_x = 10$ mΩ, $K_3 K_1 = 88002$. Thus, $K_3 = \frac{88002}{882}$

The instrumentation amplifier, operational amplifiers U7 and U6 circuits are configured to have voltage gains of K_1, K_2 and K_3 respectively.

Resolution: If Eq. 13 is considered under the assumption that $2R_1 \gg R_x$, then the count per ohm $\frac{X}{R_x}$ is

$$\frac{X}{R_x} \approx \left(\frac{K_1}{10} \times \left(\frac{(V_{OH} - V_{OL})}{2R_1 + R_{OH} + R_{OL}}\right) \times (2^{10} - 1)\right) \quad (17)$$

Equation (17) shows that the resolution is directly proportional to the gain of the amplifiers and the number of bits used in data representation. A higher gain figure gives good resolution at the cost of a lower range of resistance measurement. From the datasheet of PIC16F877A microcontroller, R_{OH} and R_{OL} have typical approximate values of 70Ω and 22Ω when VDD and the output currents are 5V and 10mA respectively. With the values of components selected, the approximate figure of the resolution $\frac{X}{R_x}$ is 0.848013 counts/mΩ, 8.4628 counts/mΩ and 84.611 counts/mΩ for the measurement ranges 0 - 1Ω, 0 – 100 mΩ and 0 -10 mΩ respectively.

3.3.3 Calibration

To find the resolution of the constructed circuit for the 0-10mΩ ranges of measurement, a resistance wire was used as the unknown resistance. The resistance wire has a diameter of 0.6mm which approximately corresponds to the diameter of an AWG gauge22 with a specific resistance of 53.99 mΩ/mat 20^{0}C.To facilitate measurement, crocodile clips having a diameter of 2mm was connected to the inputs of the instrumentation amplifier. Resistance measurement was carried out by connecting one of the crocodile clips to one end of the resistance wire and varying the position of the other clip. In each measurement procedure, the count and the range of resistance measurement are read from the LCD screen.

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For other resistance ranges, the measurement procedure is the same except that the resistance wires were replaced with standard resistors of known resistance values.

After the milliohmeter count values have been obtained, the data were then plotted to show a graphical representation of the result. A line of best fit was plotted using the least squares criteria with polyfit® and polyval® functions in MATLAB. The slope of the best fit line was used as a measure of the actual resolution of the milliohmeter for the particular range of measurement.

4 RESULTS

Figure 5 shows the plot of the milliohmeter count versus resistance measurement for the 0-10mΩ range. The line of best fit has a slope of 44.775 which corresponds to a resolution of 44.775 count/cm, or equivalently about 82.93 counts/mΩ. Figure 6 shows a plot of the measured count of the milliohm meter circuit versus resistance for the 0-100mΩ range of measurement. A line of best-fit was inserted in the plot to give an idea of the linearity of the instrument. The slope of graph has a value of 9.1394 which corresponds to a measurement resolution of 9.1394 counts/mΩ. Figure 7 shows the plot of the milliohm meter count versus the resistance for the 0-1000 mΩ measurement range. The line of best-fit has a slope of 0.9221 which corresponds to a resolution of 0.9221 counts/mΩ. Table 1 shows the theoretical and the obtained experimental values of the resolution for each of the three ranges of measurement.

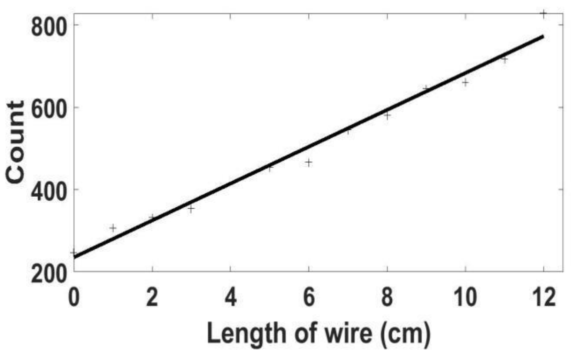

Fig. 5: Plot of wire length vs Count for the 0-10 mΩ range

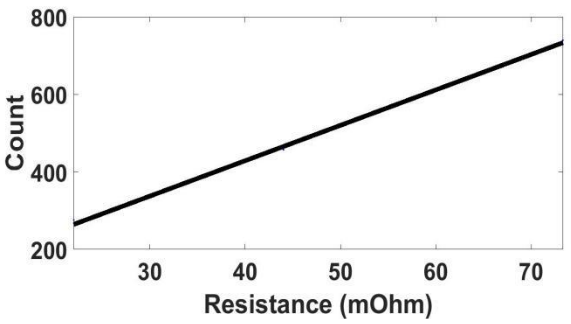

Fig. 6: Resistance vs count of the milliohmeter for 0-100mΩ range of measurement

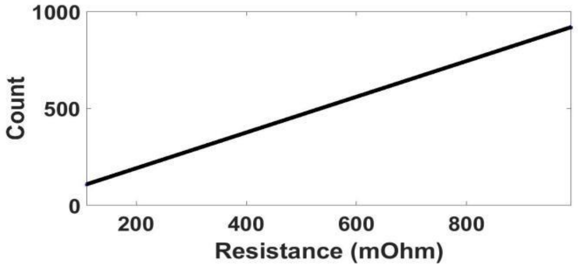

Fig. 7: Plot of resistance vs count for 0-1000 mΩ measurement range

Figure 8 shows the constructed circuit. After the construction was done on a hand-made PCB unit, it was cased with a 3D-printed plastic casing.

(a)

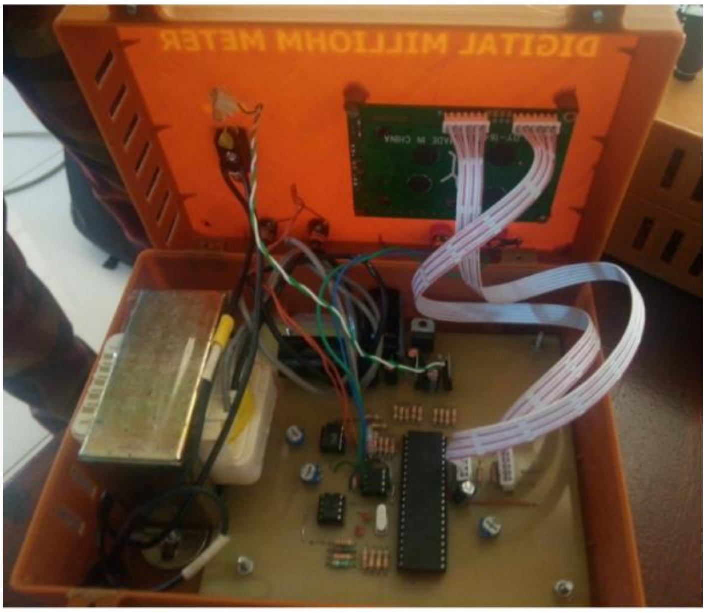
(b)

Fig. 8 (a) Top view of the casing and (b) internal details of the constructed milliohmmeter circuit.

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5 Discussion

For the three resistance measurement ranges, the obtained experimental resolution values differ from the respective theoretical values with an error that is less than 9% as shown in Table 1. The sources of these deviations can be inferred from the Eq. (17).

Table 1. Theoretical and experimental values of the resolution for each measurement range.

Range	Theoretical resolution (count/mΩ)	Experimental resolution (count/mΩ)	Percentage error (%)
0 -10mΩ	84.611	82.9320	1.98
0 – 100mΩ	8.4628	9.1394	7.99
0 - 1000mΩ	0.848013	0.9221	8.74

These deviations are due to tolerances in the components' values used in the circuit, power supply voltage variations and gain errors due to finite values of the open loop gains of the operational amplifiers. Also, the output impedance values of the microcontroller may be significantly different from the 'typical' values specified in the datasheet which will consequently affect the actual resolution values of the milliohm meter. This error can be mitigated by incorporating digital buffers with high output currents into the circuit at the expense of increased cost and circuit complexity.

It should be noted that once the range of measurement is established and the highest resistance that can be measured in that range is fixed, the milliohm meter resolution for that range is already determined.

As seen from Table 1, the theoretically attainable resolution is approximately inversely proportional to the maximum resistance that is measurable in each range. The resolution increases as the measurement range is decreased. Thus, to improve the measurement resolution obtainable from the developed circuit, the number of measurement sub-ranges can be increased to a value that is higher than three subranges used. This will allow better resolution values to be available for measuring very low resistances.

6 Conclusion

It is sometimes required to measure the resistance of devices such as transformers, switches, fuses and contactors having very low resistance values. Such measurements cannot be done with commercially available, general purpose multimeter because of their inadequate resolution. This work has shown how a usable, low cost, microcontroller-based multi-range digital milliohm meter was designed, constructed, tested and calibrated. The instrument uses the principle of lock-in detection to improve the measurement signal-to-noise ratio, eliminated additive voltages generated at the measurement contacts with differential voltage measurement technique and also reduced the effect of contact resistance on the measurement with the use of Kelvin probes.

The developed instrument has significant improvement over earlier designs because it breaks the measurement range into three distinct sub-ranges and does not require a separate computing platform for the display of measurement results.

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