

Low-Resistance Meter Circuit

Aaryan Gupta¹, Ayush Kale², Ninad Patil³, Shravani Thorat⁴ and Dr. Pallavi Deshpande⁵

¹⁻⁵Department of Electronics and Telecommunication Engineering, Vishwakarma Institute of Information Technology Pune, India

Email: gupta.22311328@viit.ac.in, ayush.22310868@viit.ac.in, ninad.22311488@viit.ac.in, shravani.22311016@viit.ac.in, pallavi.deshpande@viit.ac.in

Abstract— The primary objective of the paper was to design a low-resistance meter that would further increase the accuracy and repeatability involved in the measurement of resistances as low as 0.1Ω .

The project embraced a Wheatstone Bridge with four-wire Kelvin sensing and rather sophisticated noise-reduction techniques in an attempt to minimize errors due to contact resistance, thermal EMF, and lead resistance.

It was compared with standard digital multimeters, and significantly fewer errors in low-resistance measurements were obtained. Calibration and testing have been carried out that confirm higher accuracy and stability for the new meter. For future versions, efforts can go into automation and further noise reduction, focusing especially on industrial applications.

Index Terms— Low-Resistance measurement, Wheatstone Bridge, Milliohm meter, Contact resistance, Precision measurement, Calibration, Four-wire Kelvin sensing, Noise reduction, Electromagnetic interference (EMI).

I. INTRODUCTION

Much industrial and scientific research demands accurate low-resistance measurements, especially in devices that pass current and shunts and low-ohmic resistors.

Due to the nature of such measurements, it is inherently difficult to exact recording because lead resistance, thermal EMF, and even contact resistance may produce gross errors.

To overcome all these issues several high-technology devices like Wheatstone Bridge and four-wire Kelvin sensing are deployed that ensure the accurate measurement of low resistances and eliminate all sources of error. For example, previous research studies, such as Radetić et al. (2013) [1], among others, pointed out the requirement of proper accuracy of low resistances within reliable electrical structures.

They paper describes an integrated design and development of a low-resistance meter using techniques of accuracy to overcome the inherent drawbacks of the measurement.

The comparison with a standard digital multimeter shows enough enhancement in accuracy up to 1Ω . Standard resistors have been used as a calibration of the meter along with controlled variation of test conditions so that reliability and stability can be achieved in testing.

Much more reliable would be the new meter to be in decreasing errors by presenting practical applications with the correct measurement of low resistance.

The papers of Deshpande et al. (2019) [2] and (2019) [3] also shaped the structure and organization of the paper in the sense that such papers provide a clear outline of how to go about structuring their findings and discussions.

II. LITERATURE SURVEY

Some methods have come up to combat the problem faced in the measurement of low resistance. A number of approaches have been designed; among them are the Wheatstone Bridge methods and the modern milliohm meters, for high precision and to limit the cause of errors through lead resistances, contact resistances, and thermal EMF, among others.

The study by Radetić et al. (2013) [1] is aimed at the meaning of the proper low-resistance measurement, especially in the aspect of reliability in electric systems. Contact resistance is one of the factors that highly influence the total measurement inaccuracy, especially in the measurement of low resistance, as indicated in their paper. Similarly, Rietveld et al. (2013) [4] carried out their research to see how low-ohmic resistors behave when they are transported and measured, thus explaining the reasons why the properties of a resistor would change towards achieving accuracy. These studies show that there is a need for accuracy in low-resistance measurements, and most authors point out that lead resistance as well as contact resistance are the main sources of errors. Similarly, many researchers support the cause since there are other external effects which include thermal EMF and lead resistance on low-resistance measurement. According to Rietveld and van der Beek (2011) [5], these factors affect the uncertainty of the measurement, thus underlining the need for proper calibration.

Among the most common techniques used to measure resistance is the Wheatstone Bridge. The use of this bridge has been widely discussed in literature. Studies by Cigoy (2010) [6] argue that a Wheatstone Bridge could measure resistance accurately through the balancing circuits. The major flaw of such a mechanism for measuring accuracy is the susceptibility to interference by noise in the environment and, therefore changes in readings. To counter these challenges, researchers such as Dai DongXue et al. (2020) [7] advise the use of shielding techniques and other noise-reduction methods.

According to Urekar et al. (2019) [8], composite milliohm meters have found applications in industrial environments and have been found to be effective for the reason that they increase the accuracy of low resistances. This is because, in an industrial environment, the price of an error may be very expensive. Field improvement has, in the past, proved to be very key in the introduction of up-to-date technologies such as digital interfaces and adaptive algorithms of error correction to improve the performance of low resistance meters.

There is, however, a general theme running through the literature as far as lead resistance, contact resistance, and environmental noise interference are concerned. A number of attempts have, in fact, been made to overcome such difficulties in improving measurement precision, reducing noise interference, and increasing the reliability of results under both laboratory and industrial conditions.

III. METHODOLOGY

The general design of the low-resistance meter includes various stages that are targeted towards the measurement of resistances in the range of $0.1\ \Omega$ to $10\ \Omega$ with very high accuracy. These include a selection of components, a Wheatstone Bridge circuit constructed, reduction of error sources, and device calibration as shown in Fig. 1. The measurement is done with the current kept constant by measuring across the unknown resistor to determine its value. This is a regulator IC LM317 with a reference voltage of 1.25V. The adjust and output pins have been set up with a $10\ \Omega$ resistor so it can limit current down to 0.125 amperes. The battery used here is 9V. It guarantees a constant current through the unknown resistance. Display control is accomplished by an Arduino Nano with a 4-wire I2C interface that has two power wires and two data wires.

The calculation of Ohm's law that it does is through the division of the measured voltage drop that it receives through its ADC by a fixed current. The accuracy of the measurement highly depends on the accuracy of the $10\ \Omega$ resistors used in the current source. For accuracy, a low-tolerance resistor is used. This error can be reduced with a constant current source. The results were checked through the measurement of three resistors as shown in Table I, by comparing its reading with the reading in DMM with the proposed circuit and percentage error was calculated.

A. Component Selection

High-accuracy components were selected to yield reliable low-resistance measurements. For this purpose, those resistors whose resistance is negligible with changing temperatures have been selected. Such temperature coefficient-caused changes try to minimize measurement errors. The Wheatstone Bridge was selected for the main core of the circuit because of its proven reliability in applications that involve low resistance measurement. Furthermore, the incorporation of accurate resistors and an operational amplifier with low noise was supposed to enhance not only the resolution in measurement but also the stability of the readings.

With this circuit, these components managed to minimize the effects of external factors like noise or changes in temperature to be relatively minimal on the accuracy of the measurement.

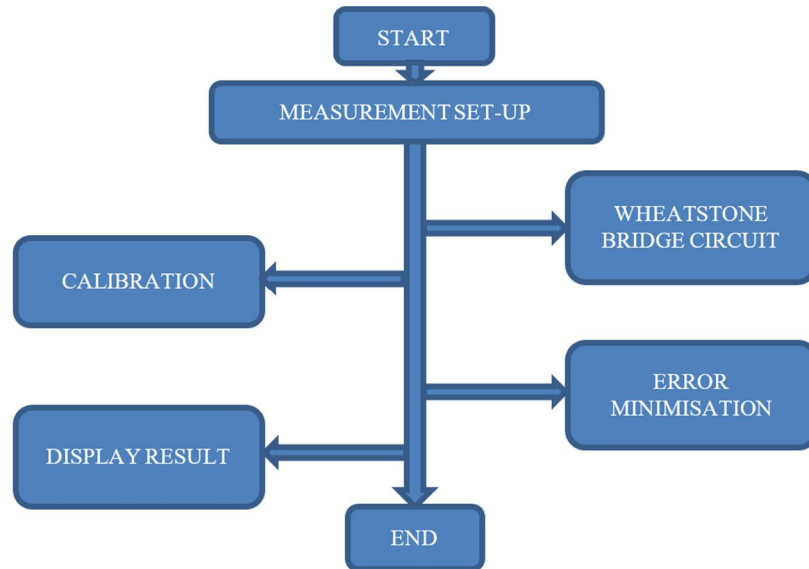


Figure 1. Design process flowchart

Furthermore, the incorporation of accurate resistors and an operational amplifier with low noise was supposed to enhance not only the resolution in measurement but also the stability of the readings. With this circuit, these components managed to minimize the effects of external factors like noise or changes in temperature to be relatively minimal on the accuracy of the measurement.

B. Wheatstone Bridge Circuit Design

The measurement circuit is based on the Wheatstone Bridge, and the bridge, as illustrated in the flowchart Fig. 1, was first adjusted to provide for accurate resistance measurements by attaining circuit balance. To ensure precision, highly accurate resistors were used because the technique relies on comparing unknown resistances to known reference resistors.

C. Error Minimization

The design was reduced error-based and the four-wire Kelvin sensing key improvement was adopted. This isolates the current supply from the voltage measurement hence keeping the lead and contact resistances at bay. It is very beneficial in measurements of resistances below $1\ \Omega$ ensuring that only the resistance of the test object is taken.

Even greater noise and interference attenuation were achieved using shielding techniques. As advised by Clement et al. (2006) [9] the entire circuit was placed in a grounded metal case to shield it against EMI which otherwise would interfere with EMI-richer environments. Such would allow for accurate measurements.

D. Signal Processing and Display

The microcontroller converted the analog outputs from the Wheatstone Bridge into digital values through processing the signals. The microcontroller thereafter showed the values on the LCD screen after converting them. Analog-to-digital conversion provided real-time feedback and thus made it much easier to use the device, for instance, the immediate correction of the value.

More so, the microcontroller helped in flexibility since it permits software-enabled calibration for minor errors. This improves the accuracy of the circuit and thus makes proper choices of circuits under different conditions of resistance or even operating conditions

E. Calibration Process

In order to calibrate the meter, standard resistors with already-known values were used. Calibration with the aid of $0.1\ \Omega$, $0.5\ \Omega$, and $10\ \Omega$ resistors allowed calibration across the entire range of operation of the circuit. With the aid of a comparison of the meter readings with the known values, it was possible to optimize the circuit toward diminished error and increased accuracy.

D. Testing and Performance Evaluation

After the calibration of the circuit, it was then tested with a variety of resistors. Finally, the obtained results were compared with those from a standard DMM to verify if the newly manufactured meter worked appropriately. In the experiment, DC methods were applied for the accuracy in the measurement of low resistance. Though the interest is with DC, techniques involving AC are also valuable in terms of minimizing the drift that occurs due to thermal as well as contact resistances, as explained by Ribeiro et al. (2010) [10]. The developed meter seemed much better compared to the DMM, especially for the measurement of resistances that were less than $1\ \Omega$, thereby indicating that the error minimization techniques used were appropriate

IV. IMPLEMENTATION

The implementation phase was the integration of different pieces, assembling the circuit, and testing it on real-life conditions. As seen in Fig. 2, a logical iterative design process is set for every stage from part selection to testing.

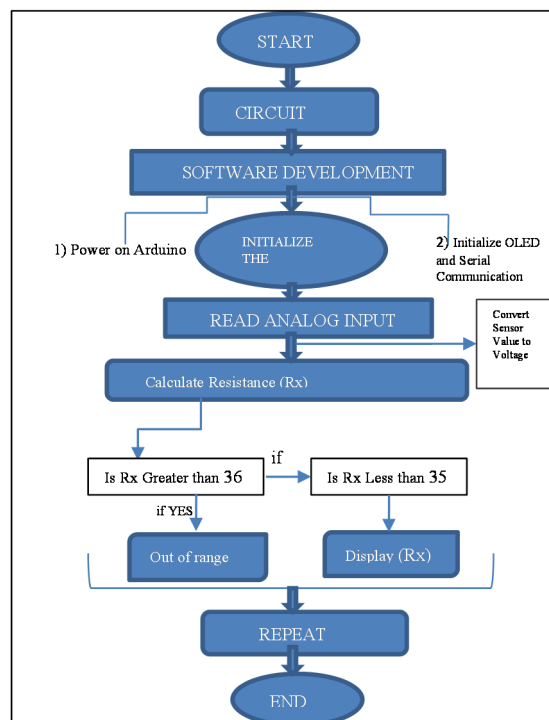


Figure 2. Implementation Flow Chart

A. Component Integration

All the parts chosen, including Wheatstone Bridge, the operational amplifier, the microcontroller, and the display unit, were integrated into a single circuit. Wheatstone Bridge consisted of accurate resistors whose connection entailed a selected microcontroller fitted with its program set to command data processing besides error correction. To guarantee that the circuit does not develop an error during testing, an adequate power supply was added to the circuit.

B. Circuit Assembly

The circuitry was designed as a four-wire Kelvin connection of the Wheatstone Bridge, which would reduce lead and contact resistance effects. In Fig. 3, reference resistors of high accuracy were used in configuring the bridge. The output then passes to an operational amplifier, which amplifies the small voltage differences produced by the imbalance of the resistances.

The amplified signal obtained is processed further within the microcontroller, which converts it to a value of resistance by an in-built algorithm. Such a value of resistance is subsequently displayed on the LCD screen. The circuit is further protected from EMI coming from other external sources by being housed within a grounded metal casing, thereby lowering the chances of EMI interfering with the measurements

C. Testing and Calibration

The circuit was fully tested after assembly. Calibration with resistors of known values at 0.1 Ω , 0.5 Ω , and 10 Ω was done to determine the accuracy of the circuit over the operational range. Calibration involves measuring known resistance thus making an adjustment in order to minimize errors.

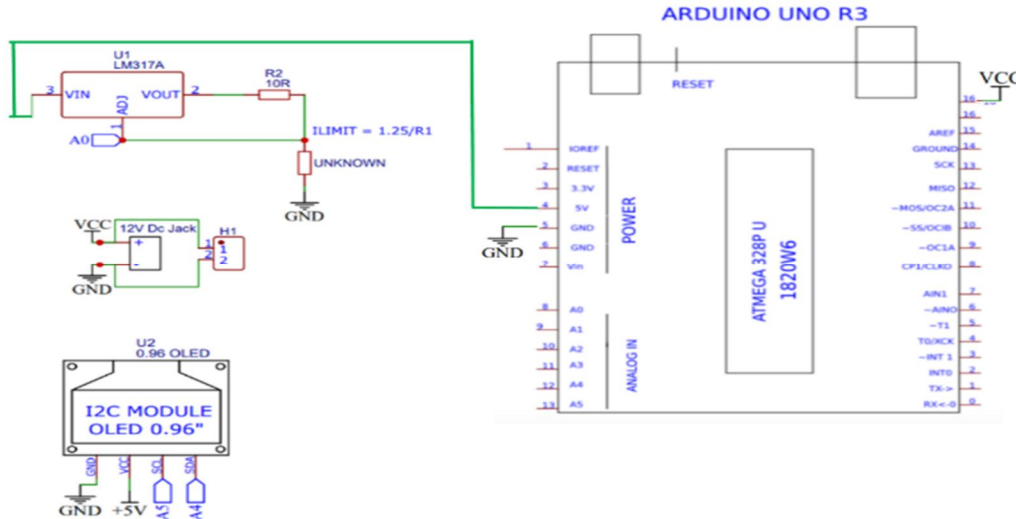


Figure 3. Wheatstone Bridge with four-wire sensing circuit

D. Performance Comparison

After this step, the low-resistance meter was calibrated and tested with a standard DMM. As anticipated the circuit should measure resistances below 1 Ω with an unprecedented precision. The errors of the circuit are significantly smaller than those of the DMM and circuit as can be seen in Tables I in the Results and Discussion section.

It has been found that the low-resistance meter has an error rate, that doesn't disappear for the 0.1 Ω resistor, and 32% for the 0.5 Ω resistor, while the 10 Ω showed an error of 3.5%, all these are noticeably better than that of the DMM at 500%, 120%, and 8%, respectively.

E. Final Assembly and Protection

The final integration of circuit components as shown in Fig. 4, into an enclosure and more shielding to protect the device from environmental influences. Using a grounded enclosure not only protected this circuit from physical damage but restrained the influence of outside electrical interference greatly improving the accuracy of this circuit so that it would work reliably even in the noisiest industrial environments.

The meter was now completely finished and ready to be field tested as well as potentially for use in academic research as well as industrial applications requiring low-resistance measurements.

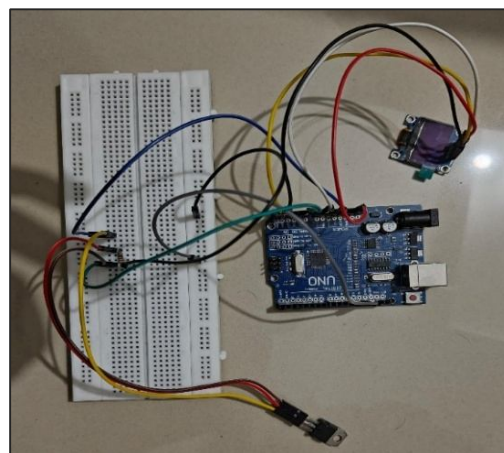


Figure 4. Low Resistance Meter

V. RESULT AND DISCUSSION

TABLE I. DMM AND THE PROPOSED CIRCUIT MEASUREMENT ERRORS AT VARIOUS RESISTANCE VALUES

The original value of the resistor in ohms (Ω)	The Value measured by using DMM in ohms (Ω)	% error in value	The value measured by using the proposed circuit in ohms (Ω)	%error in value
0.1	0.6	500	0.12	20
0.5	1.1	120	0.66	32
10	10.8	8	10.35	3.5

We have checked resistors of 0.1Ω , 0.5Ω , and 10Ω using the low-resistance meter. Percentage errors are calculated based on the circuit reading and that of standard DMM measurements. Percentage errors of both methods are given in Table I. We present here the readings of DMM and the rate of error in the DMM and the circuit together. Thus, as indicated in Table I, the reading from the DMM attached to the 0.1Ω resistor was grossly wrong at 500%. With the proposed circuit, however, we were able to bring the error down to 20%. This, in itself, proves that the circuit is able to increase the accuracy levels in a measurement taken in a very low resistance range where the DMM fails due to its incapability to properly compensate for factors such as contact and lead resistances.

The above circuit would work better due to better calibration and proper choice of components. However, contact resistance and noise could still cause the 20% error, leaving a gap to be filled especially for measurements of very low values.

This resulted in bringing the DMM's error of 120 % to a very low percentage of 32%. Table I. Error bound much increased, a good snapshot of what has been achieved into the higher accuracy circuit as opposed to the DMM of mid-range low resistances. Noise-reduction and shielding mechanisms and concepts have successfully been applied in the design of the circuit and have brought about a corresponding reduction in error; however, thermal EMF, among others is still present. For higher resistance values, that is, 10Ω the output of the DMM was found to have an error of 8%. As outlined in Table I, the proposed circuit delivered a better result with an error of 3.5%. It shows how reliable the circuit is and its great accuracy in measuring the high low-resistance values where noise attenuation and calibration tend to have more effect in the measurement. It shows how great the circuit was with respect to resistance range for such accuracy. It can be clearly understood that the acquired measurements were superior, more so for the values of resistance in the lower range, when the circuit was compared with that of a DMM. Also, the suggested circuit has indicated improved accuracy from reduced measurement errors significantly in field measurements; in addition, it yields a reading better than that produced by standard field measurement equipment. It is consistence with other prior work. For instance, Radetić et al. (2013) [11], called attention to the fact that any measurements of low resistances should be noise-free and appropriately shielded; and Baker (2000) [12], presented a problem with conventional methods when dealing with small resistances. In general, the improved accuracy at very low resistances confirms that the circuit operates well under realistic conditions and promises to be useful for industrial and laboratory applications.

VI. CONCLUSIONS

It could introduce a low-resistance meter that brought about dramatically improved accuracy in measurements compared with the traditional methods and is highly at much lower ohmic resistances. The experiments carried out have yielded some quite impressive decreases in error percentages in all the resistors tested relative to the standard DMM. The error which was indicated to be about 20% was now shown by the new meter at 0.1Ω , instead of the previous figure of 500%, and the accuracy had gone better at 0.5Ω and 10Ω to be 32% and 3.5%, respectively. The improvements were attributed to accurate calibrations together with proper noise-reduction techniques plus the use of high-accuracy components. The designed meter has now become the more reliable tool for making accurate measures in industrial and research applications

ACKNOWLEDGMENT

We wish to thank the Department of Electronics and Telecommunication at Vishwakarma Institute of Information Technology for the constant support and base for resources during the course of this research project. Special thanks are extended to Dr. Pallavi Deshpande for her valuable guidance, motivation, and critical feedback, which proved to be of much value in successfully carrying out this project. We would also like to

thank the laboratory technicians who assisted in practical skills, which were brought to light to apply them to bring the project into a ready-to-use scenario. All experiments could then be conducted very efficiently and effectively. All of them were necessary for this project.

REFERENCES

- [1] R. M. Radetić, M. Pavlov-Kagadejev, D. T. Brodić, and N. D. Milivojević, "An approach to the low-resistance measurement," *Serbian Journal of Electrical Engineering*, vol. 10, no. 2, pp. 293–307, Jun. 2013, doi: 10.2298/SJEE130411005R.
- [2] P. D. Deshpande, P. Mukherji, and A. S. Tavildar, "Accuracy enhancement of biometric recognition using iterative weights optimization algorithm," *EURASIP Journal on Information Security*, vol. 2019, Art. no. 6, May 2019..
- [3] P. D. Deshpande, P. Mukherji, and A. S. Tavildar, "An accurate hand based multimodal biometric recognition system with optimised sum rule for higher security applications," *International Journal of Biometrics*, vol. 11, no. 3, pp. 222–242, 2019, doi: 10.1504/IJBM.2019.100830..
- [4] G. Rietveld, J. H. N. van der Beek, M. Kraft, R. E. Elmquist, A. Mortara, and B. Jeckelmann, "Low-Ohmic Resistance Comparison: Measurement Capabilities and Resistor Travelling Behavior," *IEEE Transactions on Instrumentation and Measurement*, vol. 62, no. 6, pp. 1659–1666, June 2013, doi: 10.1109/TIM.2012.2225917.
- [5] G. Rietveld and J. van der Beek, "Uncertainty in low-ohmic resistance measurements," *IEEE Transactions on Instrumentation and Measurement*, vol. 60, no. 7, pp. 2482–2487, July 2011, doi: 10.1109/TIM.2010.2086770.
- [6] D. Cigoy, "Accurate Low-Resistance Measurements Start with Identifying Sources of Error," Keithley Instruments, Inc., Cleveland, OH, USA, 2010. [Online]. Available: www.keithley.com. [Accessed: Aug. 19, 2024].
- [7] Dai DongXue;Yang Yan;Chen Yan;Wang Wei;. (2020). Measurement for Low-Value Resistors . 2020 7th International Forum on Electrical Engineering and Automation (IFEEA) Measurement for Low-Value Resistors.
- [8] M. Urekar, Đ. Novaković, N. Gazivoda, "COMPOSITE MILLIOHM-METER FOR RESISTANCE MEASUREMENT OF PRECISION CURRENT SHUNTS IN INDUSTRIAL ENVIRONMENT," *Electronics and Energetics*, vol. 32, no. 1, March 2019, pp. 75–89, doi: 10.2298/FUEE1901075U.
- [9] N.Clement, H. Inokawa and Y.Ono., Studies on Metal-Oxide-Semiconductor field effect transistor low frequency noise for electrometer applications. *Jpn.J.Appl.Phys.* 45, 3606–3608 (2006).
- [10] D. C. Ribeiro, J. A. de Carvalho, and P. M. Ramos, "Low resistance measurement using alternating current techniques," *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 5, pp. 1332–1341, May 2010, doi: 10.1109/TIM.2009.2022107
- [11] R. M. Radetić et al., "An Approach to the Low-Resistance Measurement," *Serbian Journal of Electrical Engineering*, 2013.
- [12] R. C. Baker, "Low-resistance measurement techniques," *Measurement Techniques*, vol. 43, no. 5, pp. 479–486, May 2000, doi: 10.1023/A:1004132908704.