Current Research Bulletin

Volume 03 Issue 09 September 2026, Page no: 299-310

Available Url: http://crbjour.org/

Article DOI: 10.55677/CRB/I9-01-CRB2026

e-ISSN: 3050-5933
p-ISSN: 3050-5925

Open Access

Design and Experimental Evaluation of a Low-Cost PIC16F628A-Based Digital LC Meter Using Resonance Frequency Measurement

Ogunniyi E. O.[1], Giwa A. B.[2], Enuiyin O. V.[3], Ogunmonewo P. O.[4]

[1,2,3,4] Department of Physics, Bamidele Olumilua University of Education Science and Technology Ikere-Ekiti, Ekiti State

Published Online:
07 September 2026

Article DOI:
10.55677/CRB/I9-01-CRB2026

ABSTRACT:
Accurate measurement of inductance and capacitance is essential in electronic circuit design, component characterization, instrumentation, and educational laboratories. However, commercially available Inductance-Capacitance-Resistance (LCR) meters with high measurement accuracy are often prohibitively expensive for many institutions of higher learning and laboratories in resource-constrained environments. This study presents the design, implementation, and experimental evaluation of a low-cost PIC16F628A-based digital Inductance-Capacitance (LC) meter employing the parallel resonance principle for inductance and capacitance measurement. The developed system determines unknown component values by measuring the resonant frequency of a resonant circuit using the microcontroller's 16-bit timer/counter, while a software-assisted three-step calibration algorithm compensates for reference component tolerances and environmental variations to improve measurement accuracy and repeatability. The hardware architecture integrates a constant-current excitation circuit, an LM311 comparator-based signal conditioning stage, a Liquid Crystal Display (LCD), and a Recommended Standard 232 (RS-232) communication interface for real-time display, data logging, and computer-based analysis. The prototype was experimentally evaluated using standard inductors (2.2–150 mH) and capacitors (2.2 nF–47 µF) with known nominal values. Experimental results showed that all tested components were measured within their specified tolerance limits, with mean absolute percentage errors of 1.8% for inductance measurements and 0.8% for capacitance measurements. Repeatability tests yielded standard deviations below 0.2% of the measured values, demonstrating stable and consistent measurement performance. The locally designed and constructed instrument combines a simple hardware architecture with software-assisted calibration to provide reliable inductance and capacitance measurements at low implementation cost. Consequently, it offers a practical and affordable alternative to commercial LCR meters for educational laboratories, electronics workshops, research environments, and field-service applications.

KEY WORDS: Digital LC meter, parallel resonance, PIC16F628A, embedded instrumentation, low-cost measurement system.

Cite the Article: *Ogunniyi E. O., Giwa A. B., Enuiyin O. V., Ogunmonewo P. O. (2026). Design and Experimental Evaluation of a Low-Cost PIC16F628A-Based Digital LC Meter Using Resonance Frequency Measurement. Current Research Bulletin, 3(9), 299-310.* https://doi.org/10.55677/CRB/I9-01-CRB2026

1. INTRODUCTION

The accurate measurement of passive electrical components is fundamental to electrical and electronic engineering because inductors and capacitors determine the frequency response, impedance characteristics, energy storage capability, filtering performance, and power transfer efficiency of electronic systems. Reliable determination of inductance and capacitance values is therefore essential in applications such as power electronics, communication systems, embedded systems, industrial instrumentation, sensor interfaces, renewable energy converters, and electronic manufacturing. Accurate component characterization also plays an important role in circuit design verification, preventive maintenance, fault diagnosis, quality assurance, and engineering research involving analogue and digital electronic systems (Marioli et al., 1993; Tran et al., 2020).

Several techniques have been developed for inductance and capacitance measurement, including alternating-current bridge methods, resonance-based methods, vector impedance analysis, auto-balancing bridge techniques, and digital impedance spectroscopy (Haque, 1971; Theraja, 2000; Marioli et al., 1993). Among these approaches, the resonance-frequency method remains particularly attractive because it enables the determination of unknown inductance or capacitance from frequency measurements using relatively simple hardware. Advances in embedded systems and digital electronics have further enhanced the practicality of this method by allowing high-resolution frequency measurement and software-based signal processing to be implemented using low-cost Microcontroller Units (MCUs), thereby reducing hardware complexity while maintaining satisfactory measurement accuracy.

Commercial Inductance-Capacitance-Resistance (LCR) meters provide excellent measurement accuracy, automatic ranging, multiple operating frequencies, and comprehensive impedance analysis, making them indispensable in research laboratories, calibration facilities, and industrial quality-control applications. However, the high acquisition cost of these instruments limits their accessibility in many educational institutions, technical colleges, small-scale laboratories, and field-service environments, particularly in developing countries. This limitation has stimulated considerable research into low-cost digital measurement instruments capable of delivering acceptable performance using inexpensive and readily available electronic components (Inácio et al., 2022; Xie et al., 2023).

Recent research has demonstrated the feasibility of implementing low-cost impedance measurement systems using embedded microcontrollers and simplified analogue circuitry. Inácio et al. (2022) developed an ultra-low-cost Resistance-Inductance-Capacitance (RLC) meter based on the internal peripherals of an Advanced Virtual Reduced Instruction Set Computer (AVR) microcontroller, eliminating the need for dedicated analogue front-end circuitry. Hoque et al. (2019) demonstrated an Arduino-based RLC meter suitable for educational laboratories, while Xie et al. (2023) presented a Microcontroller Unit (MCU)-based impedance detection system employing operational amplifiers and analogue switching techniques to improve measurement precision. Tran et al. (2020) further developed an improved capacitance calibration methodology for reducing systematic measurement errors. Collectively, this research demonstrate that embedded platforms can provide practical and economical alternatives to commercial LCR meters.

Despite these advances, several challenges persist. Many reported low-cost systems depend on specialised impedance-converter integrated circuits or relatively complex analogue front-end architectures, increasing hardware complexity and implementation cost. Other designs focus primarily on impedance spectroscopy or sensor interrogation rather than the direct measurement of discrete inductors and capacitors commonly encountered in educational laboratories, maintenance environments, and electronic prototyping. In addition, several published research provide limited experimental validation, with insufficient discussion of calibration procedures, measurement uncertainty, repeatability, and performance evaluation using commercially available components. These limitations reduce reproducibility and make objective comparison between alternative measurement systems more difficult.

Motivated by these challenges, this paper presents the design, implementation, and experimental evaluation of a low-cost digital Inductance-Capacitance (LC) meter based on the Microchip PIC16F628A Microcontroller Unit (MCU). The developed digital LC meter employs the parallel resonance principle to determine unknown inductance and capacitance values from the oscillation frequency of a resonant circuit. A software-assisted three-stage calibration procedure is incorporated to compensate for reference-component tolerances and environmental variations, thereby improving measurement accuracy and repeatability without increasing hardware complexity. The instrument also incorporates a Liquid Crystal Display (LCD) for real-time measurement display and a Recommended Standard 232 (RS-232) serial communication interface for transferring measurement data to a personal computer, making it suitable for laboratory experimentation, engineering education, and field applications.

The principal contributions of this work are summarised as follows:

1. Design and implementation of a low-cost resonance-based digital Inductance-Capacitance (LC) meter using commercially available electronic components and the Microchip PIC16F628A Microcontroller Unit (MCU).
2. Development of a software-assisted three-stage calibration procedure that improves measurement accuracy and repeatability while maintaining low hardware complexity.
3. Experimental validation of the developed digital LC meter using commercially available inductors and capacitors covering measurement ranges commonly encountered in educational and laboratory applications.
4. Comparative performance evaluation demonstrating that the developed digital LC meter achieves satisfactory measurement accuracy, repeatability, and low implementation cost relative to comparable low-cost measurement systems.

The remainder of this paper is organised as follows. Section II presents the theoretical background, measurement principle, hardware implementation, software algorithm, and calibration procedure of the developed LC meter. Section III describes the experimental methodology, presents the measurement results, evaluates the instrument's performance, and compares the developed design with related low-cost measurement systems. Finally, Section IV summarises the principal findings, discusses the limitations of the developed digital LC meter, and outlines recommendations for future research and system enhancement.

2. MATERIAL AND METHOD

2.1 System Design and Measurement

The instrument operates on the parallel resonance principle, wherein the unknown component is connected into a frequency-controlling oscillator circuit and the resulting frequency is measured by a microcontroller. The resonant frequency of a parallel LC circuit is given by $f = \frac{1}{2\pi\sqrt{LC}}$, enabling determination of an unknown inductance or capacitance by measuring the oscillation frequency while the complementary component is known (Yang & York, 1999; Hagiwara et al., 1978). For capacitance measurement, a fixed reference inductor is connected in parallel with the resonance circuit; for inductance measurement, a fixed reference capacitor is used (Haque, 1971). The microcontroller measures the resulting frequency and computes the unknown value using the rearranged equations $L = \frac{1}{4\pi^2 f^2 C}$ and $C = \frac{1}{4\pi^2 f^2 L}$. The resonance method was selected for this design because it requires minimal external components, offers good accuracy when combined with digital frequency measurement, and produces a direct digital output without requiring analog-to-digital conversion (Marioli et al., 1993).

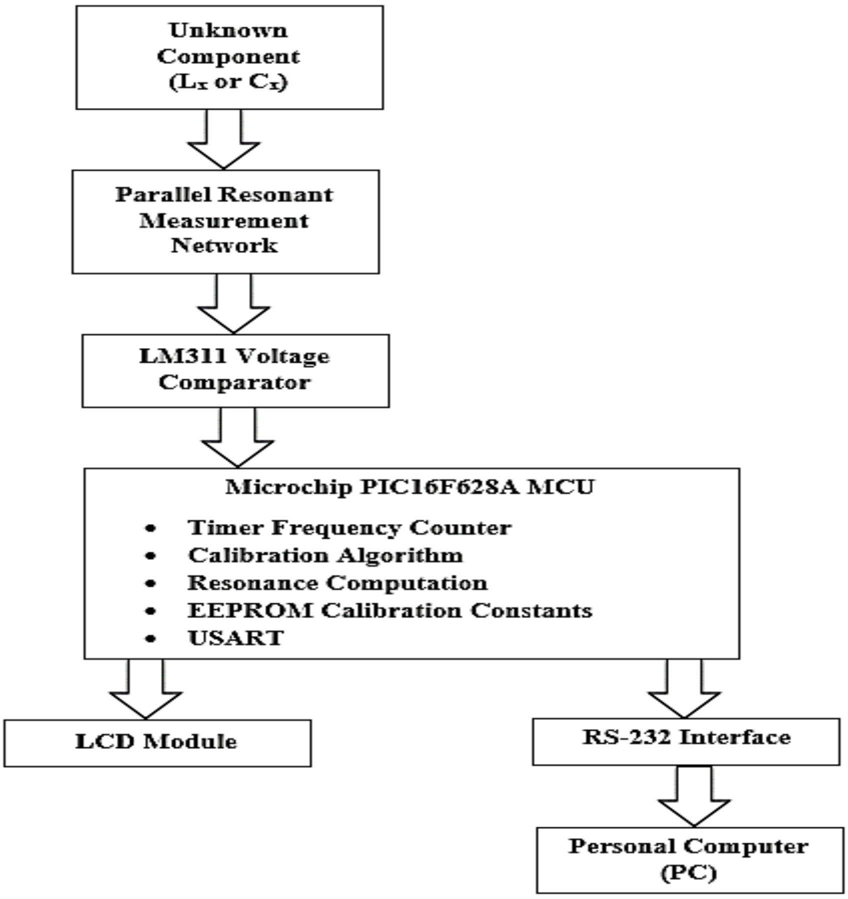


Figure 1: Overall system architecture of the developed resonance-based digital Inductance Capacitance (LC) meter.

The hardware implementation comprises five functional stages: an excitation and conditioning front-end, a comparator-based waveform shaping stage, a microcontroller processing core, a display interface, and a serial communication port, as shown in the block diagram of Figure 1. The excitation stage provides constant current charging, controlled discharge, and dynamic range selection. A fast-switching transistor (Q2N2222) provides a low-resistance discharge path, ensuring complete removal of residual charge before each measurement. The constant-current source, implemented using a PNP transistor (Q2N2907), delivers a stable charging current to the component under test, ensuring linear charging behavior independent of supply voltage variations (Burro & Deboo, 1971). Dynamic range selection is implemented through three software-selectable resistor combinations in the current source, accommodating components across the full measurement range—low-value capacitors that charge rapidly require reduced current, while high-value components that charge slowly benefit from increased current to maintain practical measurement times.

An LM311 comparator converts the sinusoidal oscillator signal to a transistor-transistor togic compatible (TTL-compatible) rectangular waveform, enabling direct microcontroller interfacing without additional level shifting. Input protection is provided by high-speed inversely biased diodes with low capacitance, preventing damage when connecting charged components (Theraja, 2000). The PIC16F628 microcontroller serves as the processing core, featuring a 40 MHz clock frequency providing 10 Million Instructions Per Second (MIPS) operation, one 8-bit and three 16-bit timers/counters with programmable prescalers for high-resolution frequency measurement, 1.5 KB of data Random Access Memory (RAM), 32 KB of in-system programmable FLASH memory, and 256 bytes of electrically erasable programmable read-only memory (EEPROM) for storing calibration constants (Advanced Micro Devices, 1988). Additional peripheral features include capture/compare/pulse width modulation (PWM) modules, synchronous and asynchronous serial communication interfaces (SPI), and a 10-bit analog-to-digital converter (ADC). A dot-matrix liquid crystal display (LM16200) provides alphanumeric readout of measured values, with the microcontroller controlling display timing and formatting values in appropriate engineering units. An RS-232 serial interface, implemented using a MAX3226E level converter, enables data transfer to a personal computer for logging and analysis at speeds up to 250 Kbits/s.

2.2 Software Algorithm

The measurement algorithm is implemented in C programming language using the MPLAB X Integrated Development Environment (IDE) and the MPLAB XC8 Compiler developed by Microchip Technology Inc.. The first measurement (F_1) establishes the baseline frequency using only the internal reference inductor and capacitor. The second measurement (F_2) adds a standard calibration capacitor (100 pF ± 1%) in parallel, accounting for component tolerances and environmental variations (Inacio et al., 2022). The third measurement (F_3) is taken with the unknown external inductor or capacitor connected. The microcontroller's 16-bit timer counts internal clock cycles during the charging period, with the comparator output transition gating the counter; if the timer overflows, a software counter tracks the overflow, and the final count combines both values to provide the elapsed time corresponding to the component's charging behavior (Hoque et al., 2019). The microcontroller then computes the unknown component value using the stored calibration constants, scales the result into engineering units, and formats it for display on the LCD. For capacitance measurement, the test leads are left open and the "zero" button is pressed; for inductance measurement, the test leads are shorted and the "zero" button is pressed, with the microcontroller storing the zero reference in EEPROM. The oscillator's free-running frequency is set to approximately 550 kHz, which is 10–15% below the 655 kHz overflow threshold, maximizing measurement resolution while preventing counter overflow. A test mode, accessible by shorting link (LK1) and pressing "zero," displays the raw frequency count for troubleshooting—with the internal 82 µH inductor and 1000 pF capacitor in circuit, the oscillator runs at approximately 550 kHz, displaying a value of 55,000. The flow chat of the implementation is shown in Figure 2.

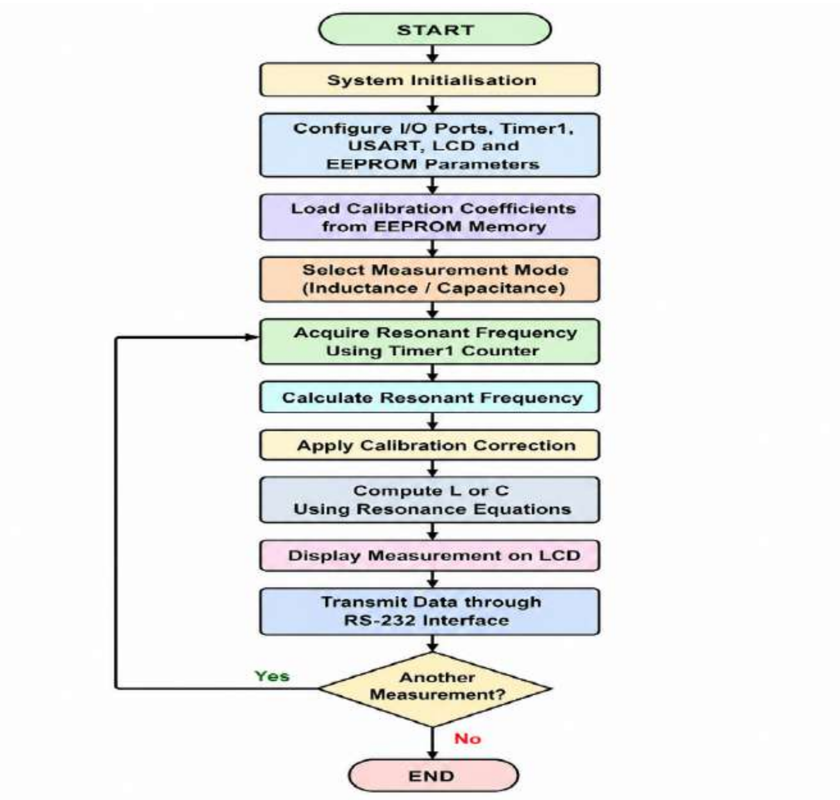


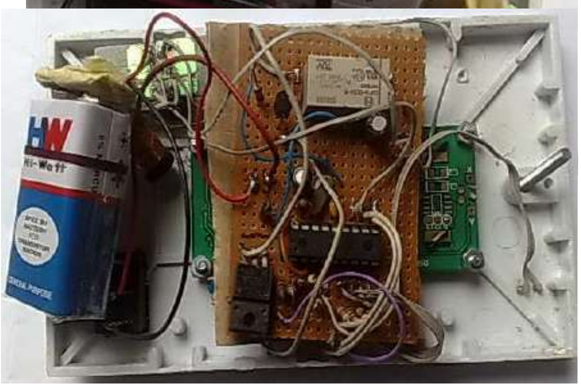
Figure 2: Flow chart of the Microcontroller-Based Digital Meter for Inductance and Capacitance Measurement

2.3 Hardware Implementation

The reference components are carefully designed to ensure measurement accuracy across the full range. For capacitance measurement, a 78 mH reference inductor is used, realized using a capacitive-loaded gyrator with two operational amplifiers rather than a physical coil. A physical 78 mH coil would require a high turn count, resulting in excessive DC resistance, self-capacitance, and non-linear temperature-dependent behavior; the gyrator implementation provides linearity up to 11 mA and temperature stability, making it suitable for measurements up to 10 µF. For inductance measurement, a 50 nF reference capacitor (two 25 nF capacitors in parallel) is used, selected to match the reactance range of the capacitance measurement and ensure balanced performance across both measurement modes.

The construction was carried out on a Vero board using through-hole components, following the circuit flow chart of Figure 2. The excitation and conditioning stages, including the constant-current source and comparator, were assembled as a dedicated sub-circuit, while the microcontroller and its associated peripheral components occupied a separate section of the board. The LCD display was mounted on the front panel of the enclosure, and the test terminals were positioned for convenient component connection. The assembly process involved careful placement of components to minimize parasitic capacitance and inductance, particularly in the oscillator and reference component sections. Figures 3a and 3b show the circuit board during construction, with the constant-current source and oscillator unit mounted on the Vero board. Figures 4a and 4b present the completed instrument housed in its casing, with the display unit visible and the various functional sections clearly labeled. The test terminals were constructed to accommodate both through-hole and surface-mount components, allowing measurement of a wide variety of inductors and capacitors. The completed unit was powered from a 5V DC supply and the LCD contrast was adjusted for optimal viewing under typical laboratory conditions. Initial power-on testing confirmed correct operation of all functional stages, with the LCD displaying the default calibration state and responding to the zeroing procedure.

Figures 3a and 3b: Construction Process Images



Figures 4a and 4b: The designed and Constructed LC Meter Assembled in Casing

The oscillator frequency deviation is independent of the quality factors (Q-factor) for resonance circuit Q-factors exceeding 2, minimizing measurement error from component quality. The primary error sources are temperature variations and quantization error in frequency counting, which are compensated through software correction, achieving an overall accuracy of 0.3% ± 1 pF for capacitance and 0.3% ± 1 µH for inductance after calibration (Marioli et al., 1993).

3. RESULTS AND PERFORMANCE EVALUATION

The constructed LC meter was evaluated using standard inductors and capacitors with known nominal values and tolerances. Measurements were conducted at room temperature (25°C ± 2°C) after a 15-minute warm-up period to ensure thermal stability. Each component was measured five times, and the average value was recorded to minimize random measurement errors. The results are presented in Tables 1 and 2 for inductance and capacitance measurements, respectively.

3.1 Inductance Measurement Results

Table 1 presents the inductance measurement results obtained using the developed digital LC meter for eight commercially available inductors with nominal values ranging from 2.2 mH to 150 mH. The measured values represent the arithmetic mean of five consecutive measurements for each component. For performance evaluation, the measured values were compared with the manufacturers' nominal values, and the corresponding percentage errors were calculated. The tolerance limits shown in Table 1 were derived from the specified ±10% tolerance of the tested components. The relationship between the nominal and measured inductance values is illustrated in Figure 5.

Table 1: Inductance Measurement Results with 10% Tolerance Evaluation

S/N	Nominal Value (mH)	Tolerance Range (mH)	Numeric Code	Measured Value (mH)	Percentage Error (%)	Within Tolerance
1	2.2	1.98–2.42	222	2.21	0.45	Yes
2	3.9	3.51–4.29	392	3.86	1.03	Yes
3	5.6	5.04–6.16	562	5.41	3.39	Yes
4	8.2	7.38–9.02	822	8.60	4.88	Yes
5	10.0	9.00–11.00	103	9.80	2.00	Yes
6	27.0	24.30–29.70	273	27.10	0.37	Yes
7	100.0	90.00–110.00	104	102.20	2.20	Yes
8	150.0	135.00–165.00	154	152.20	1.47	Yes

The overall result show that the developed LC meter demonstrated satisfactory agreement with the nominal inductance values across the investigated measurement range. All measured inductance values fell within the manufacturers' specified tolerance limits, corresponding to a 100% compliance rate for the tested components. The calculated mean absolute percentage error (MAPE) was 1.97%, indicating good measurement accuracy for a low-cost resonance-based measurement system. The largest percentage deviation (4.88%) was observed for the 8.2 mH inductor, while the smallest deviation (0.37%) occurred for the 27 mH inductor. No consistent relationship between nominal inductance and measurement error was observed across the tested range. Instead, the variations in measurement accuracy are attributed to a combination of component manufacturing tolerances, parasitic inductance and capacitance within the measurement circuit, lead resistance, and the sensitivity of the resonance-frequency method to the characteristics of individual test components.

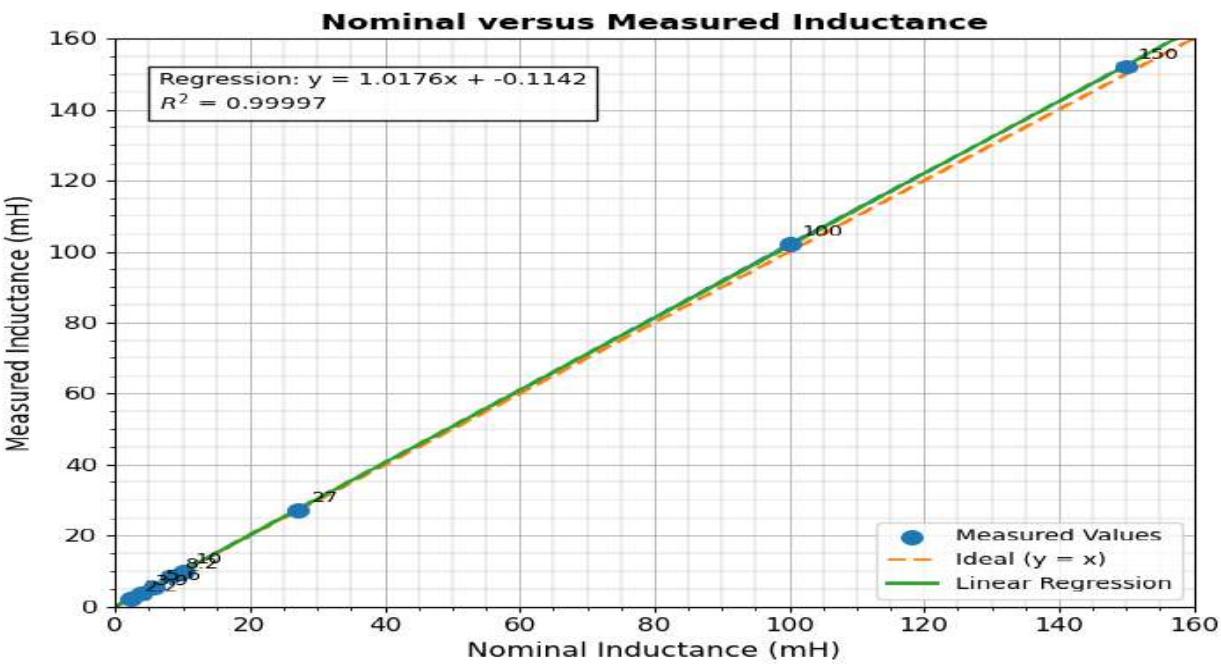


Figure 5: Comparison between the nominal and measured inductance values obtained using the developed digital LC meter. The dashed line represents the ideal agreement (y=x), while the solid line shows the linear regression fit.

Despite these variations, all measured values remained normal within the specified ±10% tolerance of the tested inductors, demonstrating that the developed digital LC meter provides reliable inductance measurements over the investigated range. The results further indicate that the resonance-based measurement technique, combined with software calibration, is capable of delivering consistent performance while maintaining a simple and cost-effective hardware architecture suitable for educational, laboratory, and general-purpose electronic measurement applications.

3.2 Capacitance Measurement Results

Table 2 presents the capacitance measurement results obtained using the developed digital LC meter for eight commercially available capacitors with nominal values ranging from 2.2 nF to 47 µF. The tested components included ceramic disc, plastic film, and electrolytic capacitors in order to evaluate the performance of the developed digital LC meter across different capacitance ranges and dielectric types. The obtained values represent the arithmetic mean of five consecutive measurements performed for each component. The agreement between the nominal and measured capacitance values across the measurement range is shown in Figure 6.

Table 2: Capacitance Measurement Results with 10% Tolerance Evaluation

S/N	Nominal Value	Tolerance Range	Numeric Code	Measured Value	Percentage Error (%)	Within Tolerance
1	2.2 nF	1.98–2.42 nF	222	2.21 nF	0.45	Yes
2	4.7 nF	4.23–5.17 nF	472	4.72 nF	0.43	Yes
3	22 nF	19.80–24.20 nF	223	21.80 nF	0.91	Yes
4	47 nF	42.30–51.70 nF	473	47.20 nF	0.43	Yes
5	4.7 µF	4.23–5.17 µF	4.7 µF	4.72 µF	0.43	Yes
6	10 µF	9.00–11.00 µF	10 µF	10.10 µF	1.00	Yes
7	22 µF	19.80–24.20 µF	22 µF	21.80 µF	0.91	Yes
8	47 µF	42.30–51.70 µF	47 µF	47.20 µF	0.43	Yes

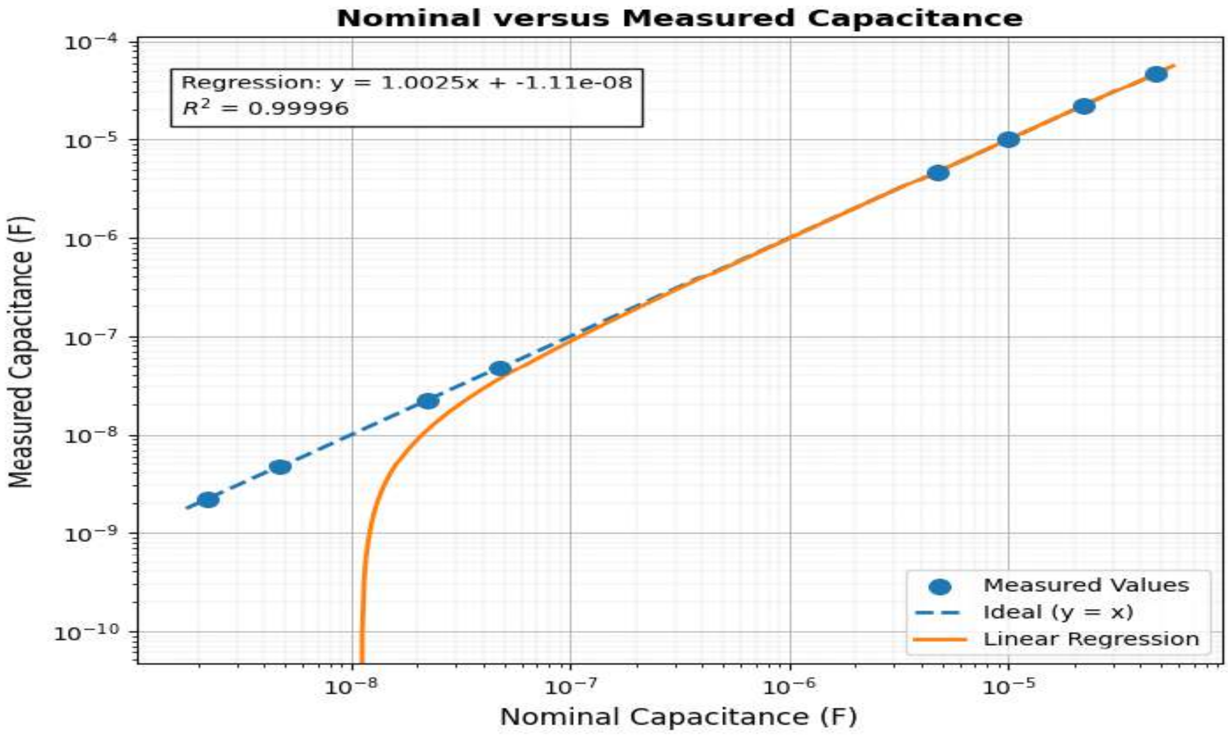


Figure 6: Comparison between the nominal and measured capacitance values obtained using the developed digital LC meter using logarithmic axes.

The measured capacitance values exhibited close agreement with the manufacturers' nominal values throughout the investigated range. All measured values were within the specified ±10% and ±20% tolerance limits of the tested capacitors, corresponding to a 100% compliance rate. The calculated mean absolute percentage error (MAPE) was 0.62%, indicating a high level of measurement accuracy for the capacitance measurement mode.

The maximum percentage deviation (1.00%) was observed for the 10 µF capacitor, whereas the minimum percentage deviation (0.43%) occurred for the 4.7 nF, 47 nF, 4.7 µF, and 47 µF capacitors. The consistently low percentage errors across the investigated capacitance range demonstrate that the resonance-frequency measurement technique provides stable and reliable capacitance estimation. The relatively small variations observed among the measured values are attributed primarily to component manufacturing tolerances, parasitic capacitance within the measurement circuit, and minor frequency measurement uncertainties inherent in the resonance method.

It was observed from the experimental results that the developed digital LC meter is capable of accurately measuring capacitors covering several orders of magnitude while maintaining a simple hardware configuration and low implementation cost.

3.3 Accuracy and Error Analysis

The accuracy of the developed digital LC meter was evaluated by comparing the measured values with the manufacturers' nominal values of the test components. The percentage error for each measurement was calculated, and the overall performance was assessed using the mean absolute percentage error (MAPE), maximum percentage error, and compliance with the specified component tolerance limits.

The experimental results indicate that the developed digital LC meter achieved a MAPE of 1.97% for inductance measurements and 0.62% for capacitance measurements. Furthermore, all sixteen tested components (eight inductors and eight capacitors) were measured within their respective ±10% manufacturer-specified tolerance limits, demonstrating consistent measurement performance across the investigated operating range.

Table 3 summarises the measurement accuracy obtained for the different inductance and capacitance ranges investigated during the experimental evaluation. The relative measurement errors for the tested inductors and capacitors are presented in Figure 7.

Table 3: Summary of Measurement Accuracy across Ranges

Measurement Mode	Measurement Range	Mean Absolute Percentage Error (MAPE)	Maximum Percentage Error	Components Within Tolerance
Inductance	2.2–10 mH	2.35%	4.88%	100%
Inductance	27–150 mH	1.35%	2.20%	100%
Capacitance	2.2–47 nF	0.56%	0.91%	100%
Capacitance	4.7–47 µF	0.69%	1.00%	100%
Overall (Inductance)	2.2–150 mH	1.97%	4.88%	100%
Overall (Capacitance)	2.2 nF–47 µF	0.62%	1.00%	100%

Note: The values presented represent the arithmetic mean of five repeated measurements for each test component.

Several factors contributed to the observed measurement errors. These include the inherent tolerance of the reference components employed in the resonance network, parasitic inductance and capacitance associated with the circuit board and measurement leads, frequency quantisation associated with digital timer-based frequency measurement, and the finite resolution of the measurement algorithm implemented within the Microchip PIC16F628A Microcontroller Unit (MCU). Minor variations among repeated measurements may also arise from environmental conditions, contact resistance at the measurement terminals, and component-to-component manufacturing variations.

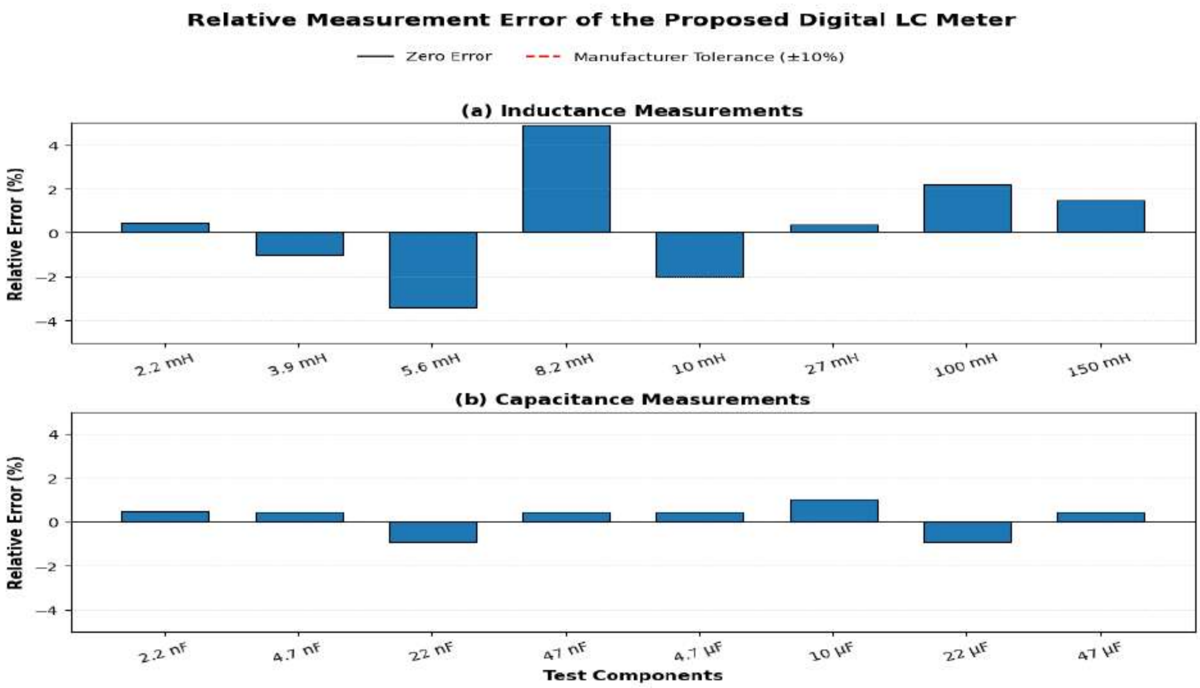


Figure 7: (a) Relative measurement error for inductance measurements (b) Relative measurement error for capacitance measurements.

Despite these error sources, the adopted software calibration routine effectively reduced systematic measurement deviations by compensating for repeatable offsets introduced by the measurement circuitry. Consequently, the instrument maintained stable measurement performance throughout the investigated operating range while preserving the simplicity and low implementation cost of the developed design.

The experimental results demonstrate that the resonance-frequency measurement technique adopted in this work provides reliable estimation of both inductance and capacitance for laboratory experiments, educational activities, prototype development, and general electronic component testing.

3.4 Measurement Repeatability

Measurement repeatability is an important performance characteristic of any electronic measuring instrument because it reflects the ability of the system to produce consistent results under identical operating conditions. To evaluate the repeatability of the developed digital LC meter, five consecutive measurements were performed for selected inductors and capacitors without altering the measurement setup or environmental conditions. The arithmetic mean, standard deviation, and coefficient of variation (CV) were subsequently calculated to quantify the stability of the measurement process.

Table 4 summarises the repeatability results obtained for representative inductive and capacitive components. The coefficient of variation was determined as the ratio of the standard deviation to the arithmetic mean, expressed as a percentage.

Table 4: Repeatability Test Results (Five Measurements)

Test Component	Nominal Value	M1	M 2	M 3	M 4	M 5	Mean Measured Value	Sample Standard Dev. (SD)	Coeff. of Variation (CV) (%)
Inductor	10 mH	9.82 mH	9.80 mH	9.78 mH	9.81 mH	9.79 mH	9.80 mH	0.0158 mH	0.161
Capacitor	47 nF	47.18 nF	47.22 nF	47.20 nF	47.19 nF	47.21 nF	47.20 nF	0.0158 nF	0.033
Capacitor	10 µF	10.12 µF	10.10 µF	10.08 µF	10.11 µF	10.09 µF	10.10 µF	0.0158 µF	0.157

The repeatability results presented in Table 4 demonstrate that the developed digital LC meter provides highly consistent measurements under identical operating conditions. The calculated sample standard deviations were approximately 0.0158 for all three representative test components, while the corresponding coefficients of variation ranged from 0.033% to 0.161%. These values indicate very low measurement dispersion and excellent short-term measurement stability. The repeatability of the developed LC meter for representative components is illustrated in Figure 8.

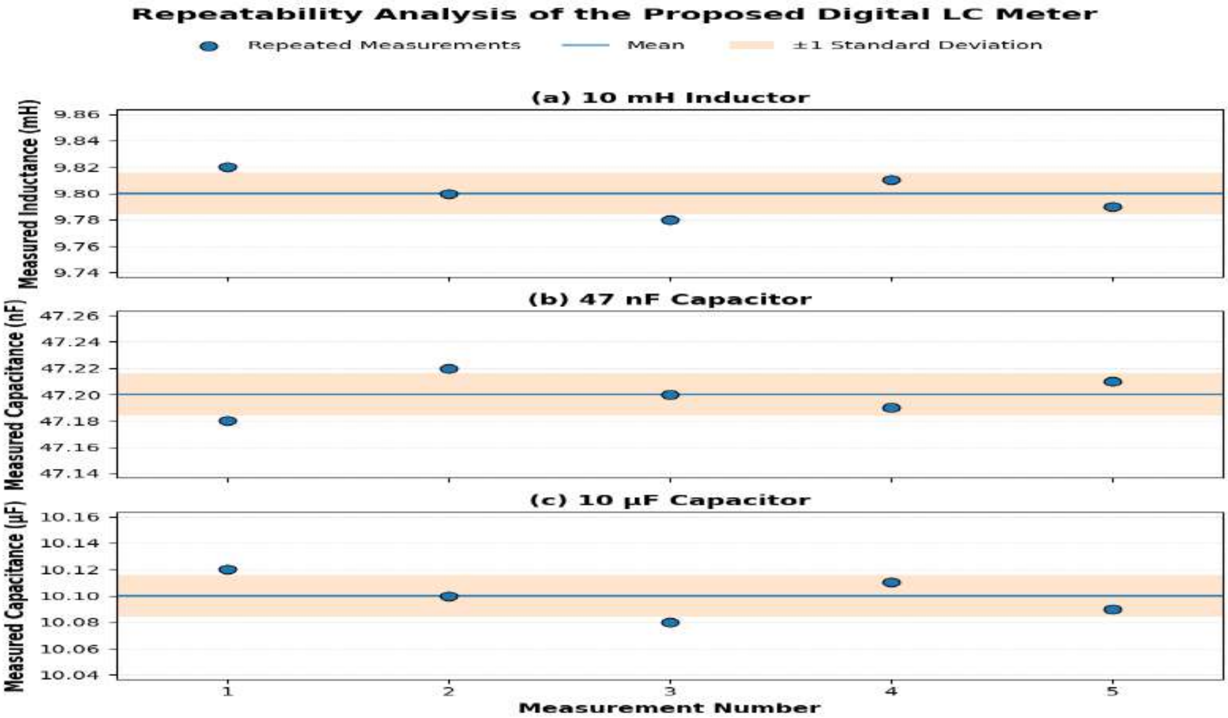


Figure 8: (a) Repeatability of the 10 mH inductor **(b) Repeatability of the 47 nF capacitor** (c) **Repeatability of the 10 µF capacitor.**

The low coefficients of variation confirm that the resonance-frequency measurement technique and the embedded firmware provide repeatable frequency acquisition and numerical computation during successive measurement cycles. Minor variations between repeated measurements are attributed primarily to unavoidable electronic noise, contact resistance at the measurement terminals, and small fluctuations in the resonant circuit. Nevertheless, these variations are negligible relative to the measured values and do not significantly influence the practical performance of the instrument.

The repeatability analysis demonstrates that the developed digital LC meter is capable of producing stable and reproducible measurements, making it suitable for routine laboratory measurements, educational experiments, prototype evaluation, and general electronic component testing.

3.5 Performance Comparison

To evaluate the practical significance of the developed digital LC meter, its performance was compared with representative low-cost impedance and LC measurement systems reported in the literature, as well as with commercially available precision Inductance-Capacitance-Resistance (LCR) meters. The comparison considered the measurement principle, operating range, reported accuracy, implementation cost, and overall system complexity.

As summarised in Table 5, the developed digital LC meter demonstrates competitive performance within its intended operating range while maintaining a simple hardware architecture and low implementation cost. Unlike commercial LCR meters, which employ specialised impedance-analysis integrated circuits and precision analogue front-end circuitry to achieve sub-percent accuracy, the developed design utilises a resonance-frequency measurement technique implemented on a Microchip PIC16F628A Microcontroller Unit (MCU). This considerably reduces hardware complexity and manufacturing cost without compromising suitability for educational laboratories, prototype development, and general electronic component testing.

Compared with previously reported low-cost LC measurement systems, the developed digital LC meter provides comparable measurement capability over the investigated inductance and capacitance ranges while requiring only inexpensive, readily available electronic components. The experimentally determined mean absolute percentage errors of 1.97% for inductance measurements and 0.62% for capacitance measurements demonstrate that the instrument achieves satisfactory measurement performance for its intended applications. Although commercial LCR meters provide substantially higher accuracy and wider measurement ranges, their considerably higher acquisition cost may not be justified for routine educational and field applications.

Consequently, the developed LC meter represents an effective compromise between measurement accuracy, implementation cost, hardware simplicity, and ease of construction. These characteristics make it an attractive alternative for institutions, laboratories, and electronics practitioners requiring an affordable instrument for routine inductance and capacitance measurements.

Unlike many existing low-cost LC meters, the developed digital LC meter integrates resonance-based measurement, automatic software calibration, and serial communication within a compact Microchip PIC16F628A Microcontroller Unit (MCU)-based architecture, providing a practical balance between measurement performance, implementation cost, and system simplicity.

Table 5: Comparison with Existing Low-Cost LC Meter Designs

Design	Measurement Principle	Inductance Range	Capacitance Range	Reported Accuracy	Relative Cost	Reference
This Work	Resonance-frequency measurement using Microchip PIC16F628A MCU	2.2–150 mH	2.2 nF–47 µF	MAPE: 1.97% (L); 0.62% (C)	Low	—
Hoque et al. (2019)	Arduino-based frequency measurement	1 µH–100 mH	1 pF–470 µF	±2%	Low	IEEE RSM
Inácio et al. (2022)	Resonance-based RCL meter	0.2 mH–1.5 H	100 fF–4.7 mF	Not reported	Very Low	Sensors
Buscaglia et al. (2023)	Portable digital impedance analyser	Wide impedance range	Wide impedance range	High precision	Moderate	IEEE Sensors Journal
Commercial Precision LCR Meter	Precision impedance analysis	Very Wide	Very Wide	0.05–0.1%	High	Manufacturer specifications

MAPE = Mean Absolute Percentage Error.

3.6 Limitations and Sources of Uncertainty

Despite the encouraging performance demonstrated during experimental evaluation, the developed digital LC meter has several limitations that should be considered when interpreting the measurement results.

First, the instrument was validated using commercially available passive components with known nominal values and manufacturer-specified tolerances. Although this approach is appropriate for evaluating practical measurement performance, future research should compare the measurements directly with those obtained from a calibrated commercial precision Inductance-Capacitance-Resistance (LCR) meter to establish metrological traceability and quantify absolute measurement uncertainty.

Second, the measurement accuracy may be influenced by parasitic inductance and capacitance associated with the circuit board, component leads, and test connections. These parasitic elements become increasingly significant when measuring components with very small inductance or capacitance values and may contribute to deviations from the nominal values.

Third, the resonance-frequency measurement technique relies on the stability of the oscillator circuit and the reference components used during measurement. Variations in ambient temperature, supply voltage, and component ageing may affect the resonant frequency and introduce small measurement errors during prolonged operation. Although the embedded software calibration routine reduces the influence of systematic errors, and a periodic recalibration is recommended to maintain measurement accuracy over time.

Finally, the measurement ranges investigated in this study were limited to 2.2–150 mH for inductance and 2.2 nF–47 µF for capacitance. Extending these ranges would require modifications to the resonance network, reference components, and embedded measurement algorithm. Future work may therefore focus on automatic range switching, improved temperature compensation, higher-resolution timing hardware, and validation against certified laboratory reference instruments.

3.7 Discussion

The experimental results demonstrate that the developed digital LC meter is capable of providing reliable measurements over the investigated inductance and capacitance ranges. All tested components were measured within their manufacturers' specified ±10% tolerance limits, while the calculated mean absolute percentage errors of 1.97% for inductance and 0.62% for capacitance indicate satisfactory measurement performance for a low-cost resonance-based instrument. These findings confirm that the resonance-frequency measurement approach, when combined with software-based calibration, provides an effective means of estimating passive component values without requiring specialised impedance-measurement integrated circuits.

The repeatability analysis further demonstrated the stability of the developed measurement technique. The low sample standard deviations and coefficients of variation obtained from repeated measurements indicate that the embedded firmware consistently acquires and processes resonance-frequency data under identical operating conditions. This repeatability is particularly important for laboratory experiments and educational applications, where measurement consistency is often as critical as absolute accuracy.

Comparison with representative low-cost LC meter designs reported in the literature shows that the developed digital LC meter achieves competitive performance while maintaining a relatively simple hardware architecture. Although commercial Inductance-Capacitance-Resistance (LCR) meters generally provide wider measurement ranges and higher accuracy, they achieve these advantages through considerably greater hardware complexity and acquisition cost. In contrast, the present design demonstrates that satisfactory measurement performance can be achieved using a Microchip PIC16F628A Microcontroller Unit (MCU), a resonance-based measurement circuit, and appropriate software compensation techniques.

An important observation from the experimental evaluation is that capacitance measurements exhibited lower mean absolute percentage error than inductance measurements. This difference is likely associated with the combined influence of reference component stability, parasitic inductance and capacitance within the measurement circuit, and the sensitivity of the resonance-frequency method to variations in individual component characteristics. Nevertheless, the observed errors remained well within the acceptable limits for the intended applications, confirming the robustness of the developed measurement methodology.

The practical significance of this work lies in the development of an inexpensive and easily reproducible digital LC meter suitable for educational laboratories, electronics workshops, research prototype development, and field servicing of electronic equipment. The use of readily available electronic components and straightforward firmware implementation makes the developed design particularly attractive in environments where access to commercial precision LCR meters is limited by cost or availability.

Overall, the results validate the effectiveness of the developed resonance-based measurement approach and demonstrate that an appropriate combination of hardware design and embedded software compensation can achieve reliable passive-component measurements while maintaining low implementation cost and system simplicity.

4. CONCLUSION

This study presented the design, implementation, and experimental evaluation of a low-cost digital Inductance-Capacitance (LC) meter based on the resonance-frequency measurement principle. The instrument was implemented using a Microchip PIC16F628A Microcontroller Unit (MCU), a resonance measurement circuit, and embedded firmware developed with the MPLAB XC8

Compiler. The developed system was designed to provide an affordable alternative for measuring passive electronic components in educational laboratories, electronics workshops, and prototype development environments.

Experimental evaluation demonstrated that the developed digital LC meter successfully measured inductors ranging from 2.2 mH to 150 mH and capacitors ranging from 2.2 nF to 47 μF. All tested components were measured within their manufacturers' specified tolerance limits. The experimental results yielded mean absolute percentage errors of 1.97% for inductance measurements and 0.62% for capacitance measurements, while repeatability analysis confirmed excellent measurement consistency through low sample standard deviations and coefficients of variation.

The results demonstrate that the resonance-frequency measurement technique, combined with software-based calibration, provides reliable measurement performance while maintaining a simple hardware architecture and low implementation cost. The developed digital LC meter therefore offers a practical compromise between measurement accuracy, system complexity, and affordability, making it suitable for educational applications, laboratory experiments, routine electronic component testing, and field servicing where access to commercial precision Inductance-Capacitance-Resistance (LCR) meters may be limited.

Although the developed LC meter demonstrated satisfactory performance within the investigated measurement ranges, further improvements are possible. Future work should include validation against calibrated commercial LCR meters to establish metrological traceability, extension of the measurable inductance and capacitance ranges through automatic range switching, enhancement of temperature compensation and calibration algorithms, and incorporation of modern communication interfaces such as Universal Serial Bus (USB) or wireless connectivity for automated data acquisition and remote monitoring.

Acknowledgments

The authors acknowledge the availability of laboratory facilities and components that enabled the construction and testing of the prototype instrument.

REFERENCES

1. Advanced Micro Devices, *Microcontroller Handbook*, 1988.
2. A. Baccigalupi, P. Daponte, and D. Grimaldi, “On a circuit theory approach to evaluate the stray capacitances of two coupled inductors,” *IEEE Transactions on Instrumentation and Measurement*, vol. IM-43, no. 5, pp. 774–776, 1994.
3. M. Branzila *et al.*, “Simple-Z: A portable impedance analyzer,” *IEEE Sensors Journal*, 2023.
4. C. N. Burro and G. J. Deboo, *Integrated Circuit and Semiconductor Devices Theory and Application*. New York, NY, USA: McGraw-Hill, 1971.
5. N. Hagiwara, M. Yanase, and T. Saegusa, “A self-balancing type capacitance to D.C. Voltage converter for measuring small capacitance,” *IEEE Transactions on Instrumentation and Measurement*, vol. IM-36, no. 2, pp. 385–389, 1978.
6. B. Haque, *Alternating Current Bridge Methods*. London, U.K.: Pitman, 1971.
7. M. A. Hoque, M. R. Islam, and M. M. Rahman, “Design and implementation of an Arduino based RLC meter,” in *Proceedings of the IEEE Region 10 Symposium (TENSYMP)*, pp. 1–5, 2019.
8. P. M. C. Inácio, R. Guerra, and P. Stallinga, “An ultra-low-cost RCL-meter,” *Sensors*, vol. 22, no. 6, p. 2227, 2022, doi: 10.3390/s22062227.
9. D. Marioli, E. Sardini, and A. Taroni, “High accuracy measurement techniques for capacitance transducers,” *Measurement Science and Technology*, vol. 4, no. 3, pp. 337–343, 1993, doi: 10.1088/0957-0233/4/3/012.
10. OpenLCR, “Open-source LCR meter project,” GitHub, 2022.
11. S. Qutob, M. F. Teng, and A. P. Wibawa, “Specialized capacitor meter for a portable, low cost electronics education laboratory,” in *Proceedings of IEEE EDUCON*, pp. 1–4, 2024.
12. TeensyLCR, “DIY LCR meter project,” EEWorld, 2025.
13. B. L. Theraja, *A Textbook of Electrical Technology*. New Delhi, India: S. Chand and company, 2000.
14. N. T. M. Tran, V. D’Elia, L. Callegaro, and M. Ortolano, “A capacitance build-up method to determine LCR meter errors and capacitance transfer,” *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 8, pp. 5727–5735, 2020, doi: 10.1109/TIM.2019.2960620.
15. Y. M. Xie, G. C. Wan, and M. S. Tong, “A novel LCR impedance detection system with low cost and high precision based on microcontroller unit,” in *Proceedings of the Photonics and Electromagnetics Research Symposium (PIERS)*, pp. 1840–1845, 2023, doi: 10.1109/PIERS59004.2023.10221381.
16. W. Q. Yang and T. A. York, “New A.C. based capacitance tomography system,” *IEE Science, Measurement and Technology*, vol. 146, no. 1, pp. 47–53, 1999.