

# Low cost capacimeter, metrological analysis

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**Abstract.** Daily, for electronic professionals, a common need is to measure a capacitance from a capacitor. Often this measurement requires expensive equipments, not portables. This paper describes the development of an electronic circuit capable of measuring capacitance within the range of 100 nF up to 1 mF, providing a reliable and affordable system. Measures had been taken and metrological analyzes were performed on the experimental data. Also, the system theoretical model was evaluated in order to compare the behavior of both: practical and modeled system, investigating the availability of further improvements. A functional circuit with uncertainties compatible to those, provided for the theoretical model was developed. The developed system proved to be accurate, inexpensive and suitable for portable measurements. **Keywords:** capacitance measurement, electrical metrology, capacimeter, calibration.

## 1. Introduction

Daily, for electronic professionals, a common need is to measure a capacitance from a capacitor. Many technologies are commercial available.

This paper proposes an easy to make and low aggregated cost capacimeter, able to measure in the range of 100 nF up to 1 mF. Software and hardware implementations were carried out in order to achieve low power consumption, allowing portable power source.

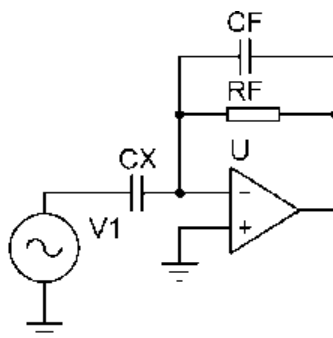
## 2. Measurement Techniques

When it comes to capacitance measurement, there are many techniques applicable. They vary in complexity, in cost and response time.

One widespread measurement technique is called auto balancing bridge [2, 3]. In this circuit there is an operational amplifier (figure 1) whose inverter input is connected to a series association of a sinusoidal source with the element to be measured. Also a negative feedback network with a known value is connected. The positive input is grounded.

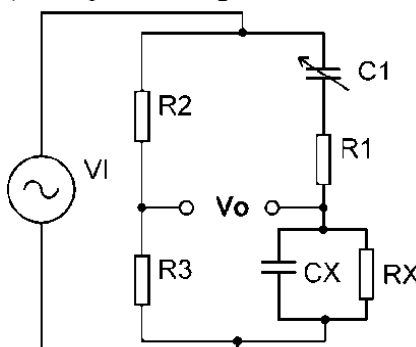
This technique is very accurate and its cost is affordable. Commercial equipment prices using this technology are around dozens of hundreds of dollars.





**Figure 1.** Auto balancing bridge, a common way to measure capacitance.

The Wien Bridge [1] is another procedure with broad use in capacitance measurement. It consists of an electrical bridge in which the left legs are resistors and the right legs are RC associations (series at the top and in parallel at the bottom) as depicted in figure 2.



**Figure 2.** Wien bridge, a precise method to measure capacitance.

The advantage of this kind of circuit is the possibility to choose resistors in the capacitive side ( $R1$  and  $RX$ ) that diminish effects coming from parasitic resistances of the capacitor constructive characteristics.

Wien Bridge is a technique very accurate, requiring thousands of dollars as investment in equipment carrying this technology.

A third technique, the discharge rate measurement, is a simple and low cost technique, in despite of the fact that it is less accurate than the other two.

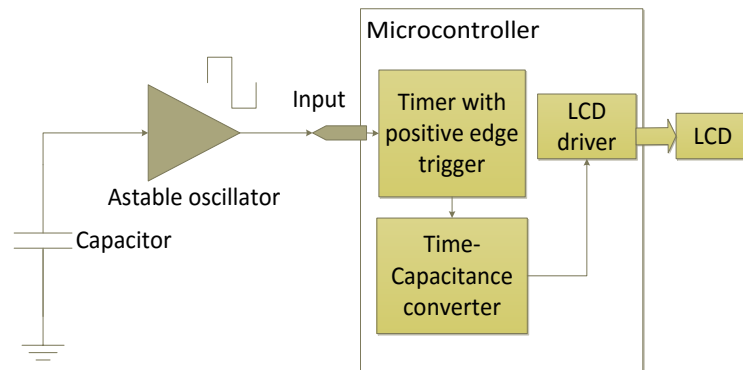
It is based in the time needed to a certain voltage be reached in the element whose capacitance is being measured. Another similar version is the connection of a constant current source with the measurand and then measuring the rate of charge.

The employed technique on this paper is a variation of the discharge rate technique. Instead of measuring an analogue voltage level, a digital signal is read.

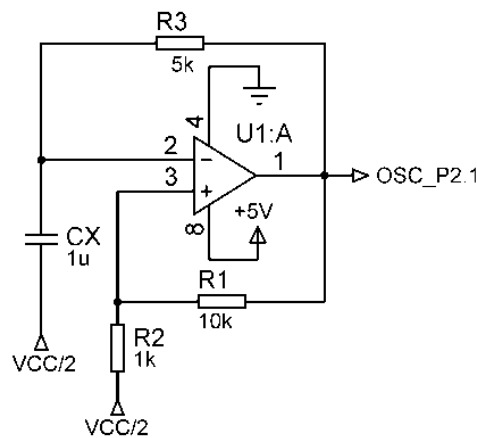
### 3. Circuit Design

The developed system consists of an astable oscillator based on an operational amplifier connected to a low-power microcontroller. The microcontroller measures the time between two edges of the produced signal by the op-amp, calculating the capacitance and then displaying it on a liquid crystal display (LCD). The figure 3 shows the circuit block diagram.

To produce the oscillator (figure 4), it was used the op-amp TL082 since it has low cost and good features as: cutoff frequency, input impedance and slew-rate.



**Figure 3.** Block diagram of the developed system.



**Figure 4.** Astable oscillator that generates a signal whose frequency is measurand based.

The period of the square-wave generated by the oscillator is calculated by equation (1) where:  $T$  stands for the wave period,  $C_x$  is the capacitor to be measured,  $R_1$  and  $R_2$  are Schmitt trigger resistors and  $R_3$  is the negative feedback resistor.

$$T(C) = 2R_3 C_x \ln \left( 1 + 2 \frac{R_1}{R_2} \right) \quad (1)$$

The microcontroller (MSP430G2553) – by Texas Instruments – was chosen due the low cost and low power consumption.

A simple state machine describes the firmware. When the system is turned on, it stays on low consumption state. If a positive edge occurs, the device's timer triggers the count mode waiting for another positive edge that stops the timer counter and allows the microcontroller calculate the signal period.

After that, the processor leaves the low power state to the print state. When the unknown capacitance (measurand) is calculated it is consequently printed in a LCD 16x2. Finishing the printing state, the system enters in low power mode again and remains in the idle state until another event.

## 4. Calibration, Results and Discussion

### 4.1. Experimental Methodology

The produced system (system to be calibrated, calibrate measuring system - CMS) was compared with a Precision LCR Meter E4980A (standard measurement system, SMS) from Agilent Technologies enabling to establish its metrological characteristics.

Three sections of measurements were made, respecting a protocol described as follow: first of all, capacitor's electrical contacts were cleaned and possible residues were removed. The frequency of the SMS was adjusted to a range of 100 Hz to 1 kHz. Admitting RC series model best representing the capacitor, the capacitive reactance is dominant. For most common capacitor used – especially for electrolytic and low quality polyester – this is true.

Secondly, as an instruction manual recommendation, the SMS was measured in open circuit and in short-circuit, in that manner any influence of SMS condition or any parasitic components that it could present would be suppressed. The ambient temperature was maintained at 18° C.

For every section, the capacitance was measured with the SMS. The alligator clips had been put in order to electrical contact was the greatest possible. Thus, the capacitor was discharged and then measured with the CMS. Values were annotated and the process continued until all values were computed.

To measure the stability of the CMS in relation to voltage, every time the voltage was changed, the measurand was removed, the voltage was changed and one more measure was taken.

#### 4.2. Experimental Data

Figures 5, 6 and 7 show the error curves CMS.

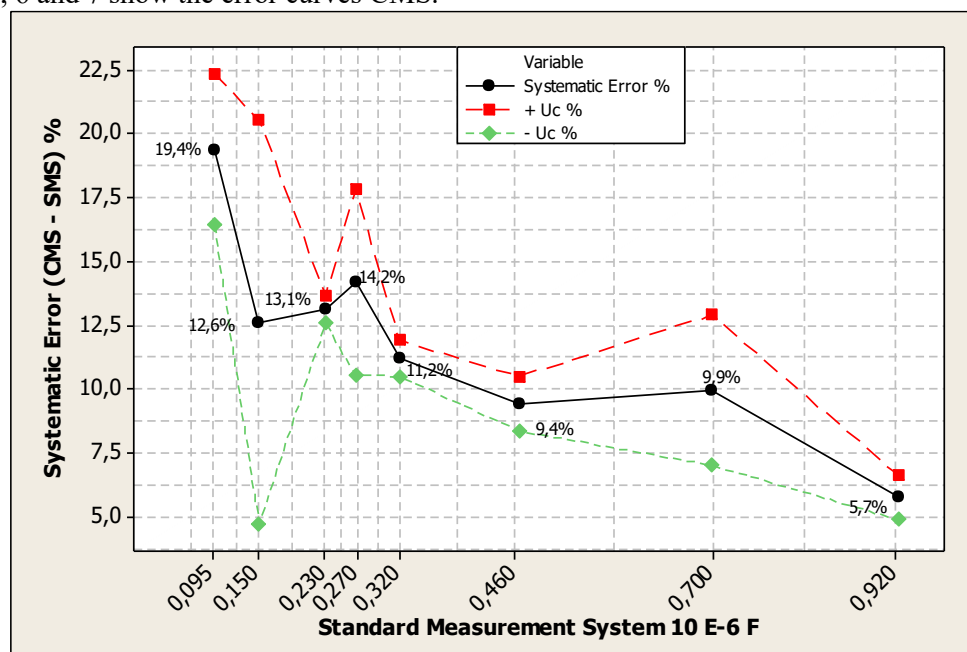


Figure 5. Error Curve 1 CMS.

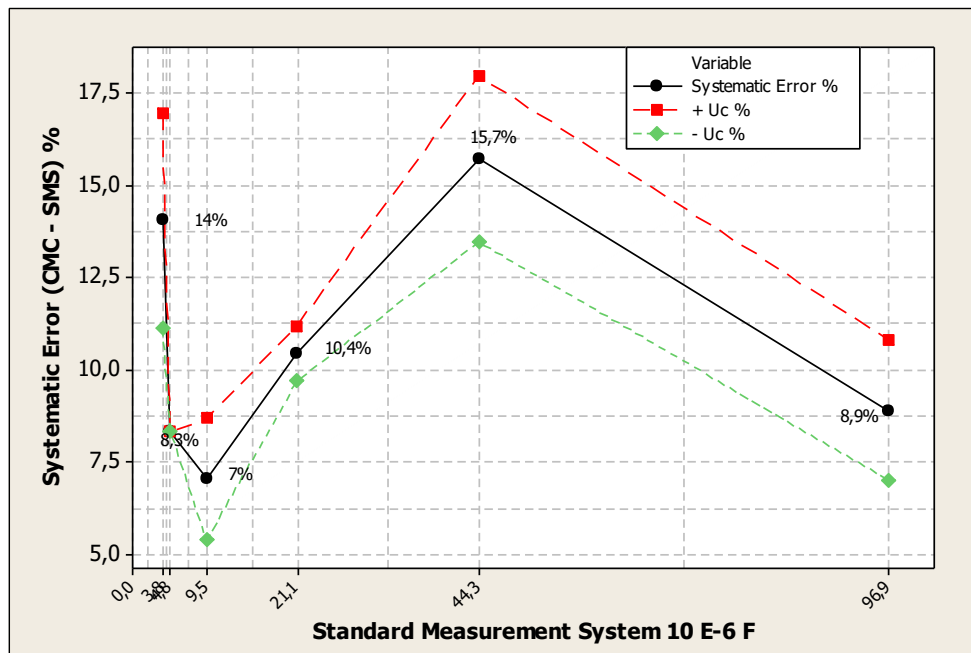


Figure 6. Error Curve 2 CMS.

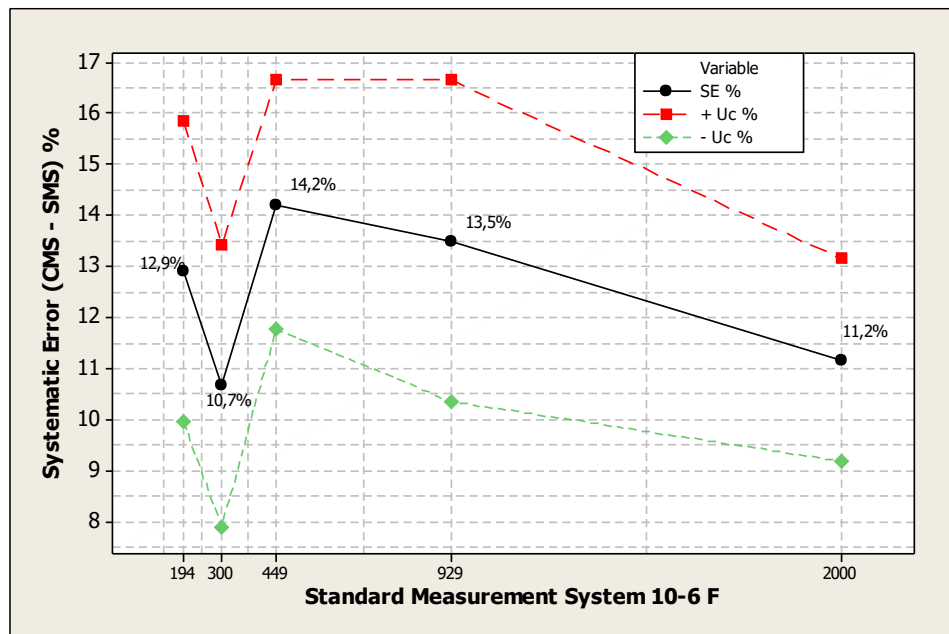


Figure 7. Error Curve 3 CMS.

#### 4.3. Uncertainty analyses of the theoretical model

With the practical combined expanded uncertainty ( $U_p$ ) calculated it was necessary to calculate the theoretical combined expanded uncertainty ( $U_t$ ) in order to compare both of them [4].

$U_t$  was calculated based on microcontroller deviation in frequency by not having a crystal as its timing source reaches the 30,000 ppm. Also, there was the uncertainty due to resistors R1-3 that have a deviation from the nominal value about 10 %. Neither the parasitic capacitance in metallic contacts nor amplifier output capacitance, were taken into account.

Equation (2) defines that the theoretical combined standard uncertainty ( $u_c$ ) squared is equal to the sum of partial derivatives ( $\frac{\partial C}{\partial x_i}$ ) squared multiplied by the uncertainty of that portion ( $u_i$ ).

$$u_c^2 = \sum_{i=1}^n \left( \frac{\partial C}{\partial x_i} u_i \right)^2 \quad (2)$$

In figures 5, 6 and 7 the tendency plus practical expanded combined uncertainty and the tendency minus this uncertainty, as well as the tendency itself are presented. The two envelope curves represent the total uncertainty given by CMS. In most of parts in the error curve, the envelope curves stay below the line that represents the theoretical total uncertainty, correspondent to 18,1 % of deviation in relation to the measure.

As already mentioned, parasitic capacitance in metallic contacts and amplifier output capacitance were not considered when analyzing the theoretical model. Either of them is present parallel to the measurand and explains why in the very first values of capacitance the practical uncertainty line exceeds the equivalent theoretical line.

If the components of the system are changed also does its uncertainty. A microcontroller using a crystal as source of frequency (150 ppm in frequency fluctuation) and precision resistors (1 % of fluctuation) would allow the total practical uncertainty be below 1.36%.

Lastly, each portion of the combined uncertainty impact was evaluated. The portion due to the frequency is represented by  $u_T$  and  $u_{R1-3}$ , that represents the portions due to variations on R1 through R3. The portion that has more impact is the frequency variation.

## 5. Conclusion

An electronic capacimeter was developed and calibrated. It was possible to measure capacitances within 100 nF to 1 mF with empirically raised uncertainties consistent with those from theoretical analyzes. Also, the theoretical model foresees that more accurate components would lead to better uncertainties. A precision LCR bridge was used to obtain values accurate enough to serve as measurements reference. The developed system is cheap and suits well for portable power sources.

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