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LABORATORY CIRCUIT TO MEASURE SMALL CAPACITY

Keywords: operational amplifier, capacity measurement

This paper presents simple method for small capacity measurement that is based on the operational amplifier oprating as an integrator with the polarization current compensation. Basing on this concept, the laboratory measurement circuit was designed and realized. The developed method accounts also for the circuit self-capacity that in turn allows for measurement error reduction up to 10 % for capacity of several pF. The experiment results were presented, and the measurement results were discussed.

1. INTRODUCTION

The capacity elements play the very important role in case of several electronic circuits. The primary purpose of the capacitor is AC coupling of the circuits, voltage filtration in case of the power supplies or the surge suppression. In case of the circuits with the capacity sensor, the capacity is the indirect quantity when measuring various physical quantities such as distance, displacement, force or even temperature. Sometime, the measurement of capacity at several pF is required; such capacity, within the low and medium frequency range, may be considered as a element with concentrated parameters. There are a lot of measurement methods, developed and applied in many expensive measurement devices. Therefore it is justified to make an attempt in order to design and develop a low-cost laboratory circuit, allowing to measure the capacity under 1 nF with an error lower than 10 %.

2. IDEA AND REALIZATION OF THE MEASUREMENT SYSTEM

The small capacity measurement problem is frequently addressed in available papers [1,2]. Basing on the measurement requirements (resolution, accuracy, operating temperature range, costs etc.), the designer must choose the best system. In this conception the capacities of about 100 pF and less have been especially taking into the account. The circuit to measure such small capacity must feature very high and stable sensitivity, but also must be resistant to transient noise and environmental factors that exist in large extent especially in industry environment. In the design process, the particular care was put on the methods of operational amplifier using, especially in the integrator mode[3,4]. The measured capacity is placed in the amplifier's feedback loop (Fig. 1).

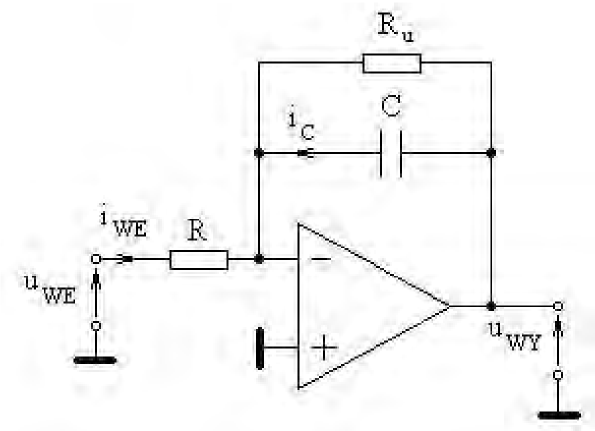

Fig. 1. The operational amplifier in the integrator mode

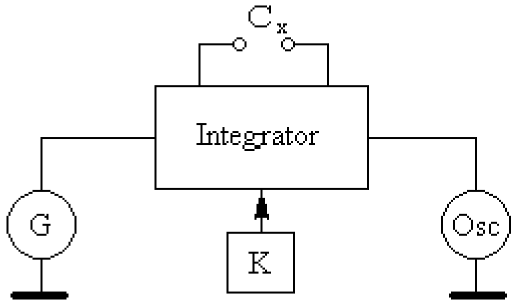

Fig. 2. The measuring circuit diagram:
G – rectangular wave generator,
C_x – measured capacity, Osc – oscilloscope
K – bias current compensation circuit

The basic concept of capacity measurement using this method is presented in Fig. 2. In order to achieve a better accuracy, the circuit design was extended with the amplifier bias current compensation. The rectangular wave from the generator output is fed to the integrator input. The generator should generate the voltage with very short rise times. The output voltage is read out on the high quality oscilloscope, featuring small input capacity and wide bandwidth. The measuring circuit (presented in Fig. 3) was realized using LF411 operational amplifier featuring very high parameters: low polarization current, low bias voltage, low self-capacity and high speed.

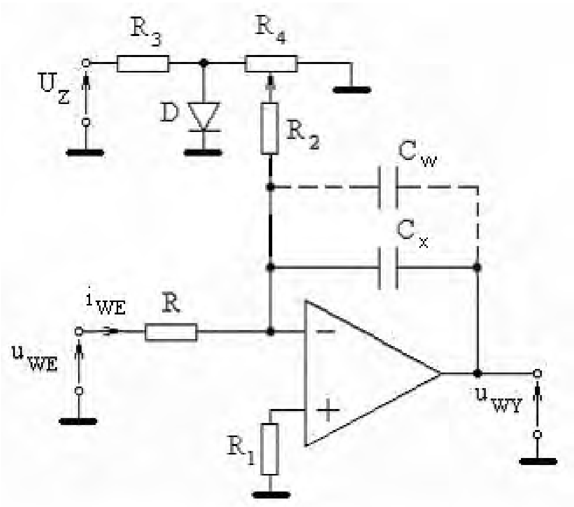

Fig. 3. The integrator with input polarization current compensation

Due to high input resistance of operational amplifier, so the C_x capacitor is charged by input current charges. The output voltage is equal to the capacitor voltage, as the another terminal is connected to the „apparent ground". In order to reduce errors caused by the input polarization currents, the R_1 resistor is connected between the non-inverting input and the ground terminal. The R_1 resistance should be equal to the resistance on the inverting input in order to reduce an error due to input polarization current. The compensation current is fed via the R_2 resistor to the amplifier's input; the current value is trimmed using the R_4 potentiometer and should be equal to the value of input polarization current. The D diode is the thermal compensation element, its thermal coefficient should be equal to the thermal fluctuations coefficient of input polarization current.

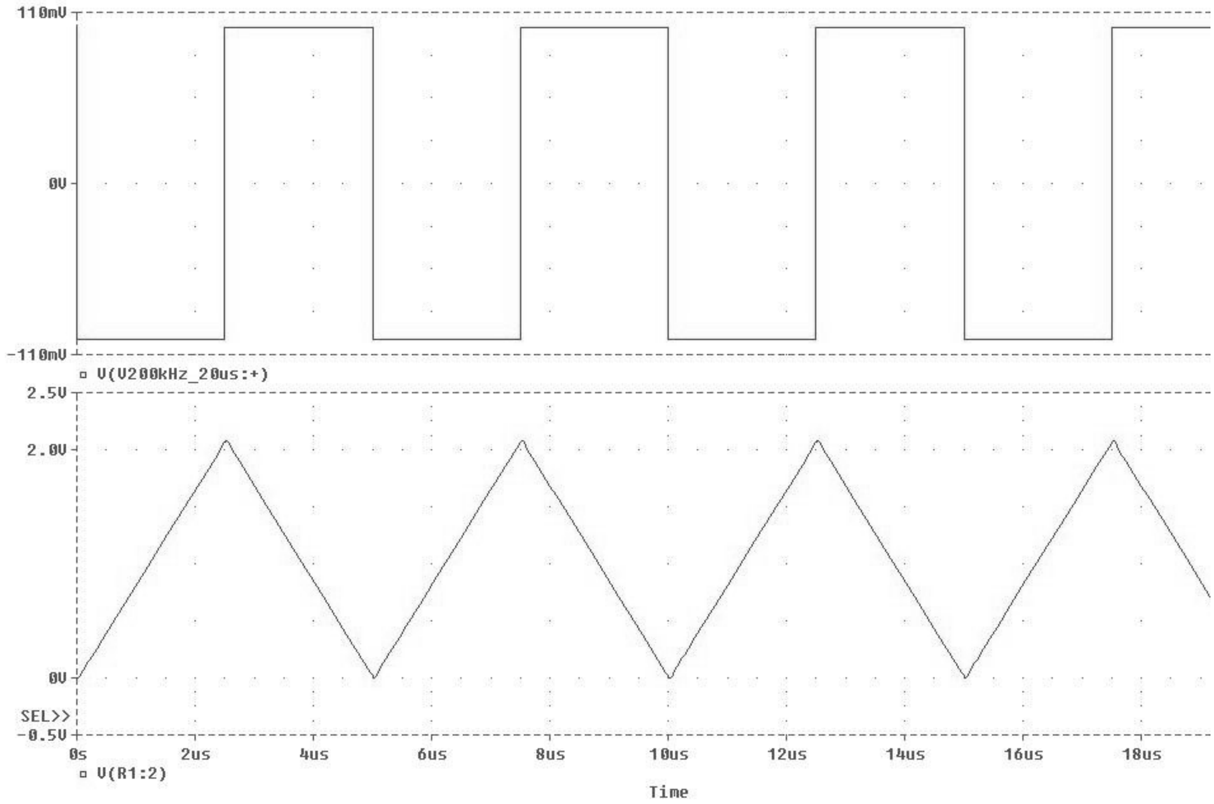

Fig. 4. Example simulation input and output voltage wave

The readout method of measured value is the most important thing during the measurements. For this purpose, the voltage wave displayed on the oscilloscope or generated during the simulation is used (Fig. 4). In the half of the period, the following charge is supplied to the amplifier:

$$Q = i_{WE} \cdot \frac{T}{2}, \tag{1}$$

where i_{we} is the value of the current on the R resistor (Fig. 3) and T means the period of the input voltage. As the almost all of the charge, calculated as referred to above, is gathered within the capacitor with unknown capacity, so the C_x capacity is calculated in accordance to the following formula:

$$C_x = \frac{Q}{\Delta U_{wy}}, \tag{2}$$

where ΔU_{wy} is a change of the output voltage over the time, in which the Q charge was supplied.

3. EXPERIMENTAL RESULTS

The capacitors, with the capacity from a several pF to dozens nF, were the subject of the experiment. Their accurate capacities (treated as reference values) were measured using the high quality capacity meter. Note that each measurement circuit features its C_w self-capacity that is measured together with the unknown capacity. Therefore, first the known circuit capacities were measured in order to evaluate circuit self-capacity. Then the series of unknown capacity (the bases of interference) measurements were performed (including the measurement devices and power supplies) until the measurements completion. In case of the small capacity measurement, the very important thing is also using of the high quality function generator that allows for achievement of nearly ideal rectangular wave. It should be characterized by the very short rise and fall time.

The performed measurements indicate that proposed input current bias circuit significantly improved the accuracy of measurements. The acceptable relative error lower than 10% was achieved for the capacity from 47 pF and higher. The measurements were made using the high quality function generator and digital oscilloscope. The frequency range, used during the measurements, had no significant influence to the results. In case of capacity of pF, the frequency within the 50 kHz - 1 MHz range infers no output voltage distortions and allows for correct voltage readout. The Figures 5 and 6 show that the measurement accuracy for one series, within the frequency range as referred to above, falls into acceptable several percent range.

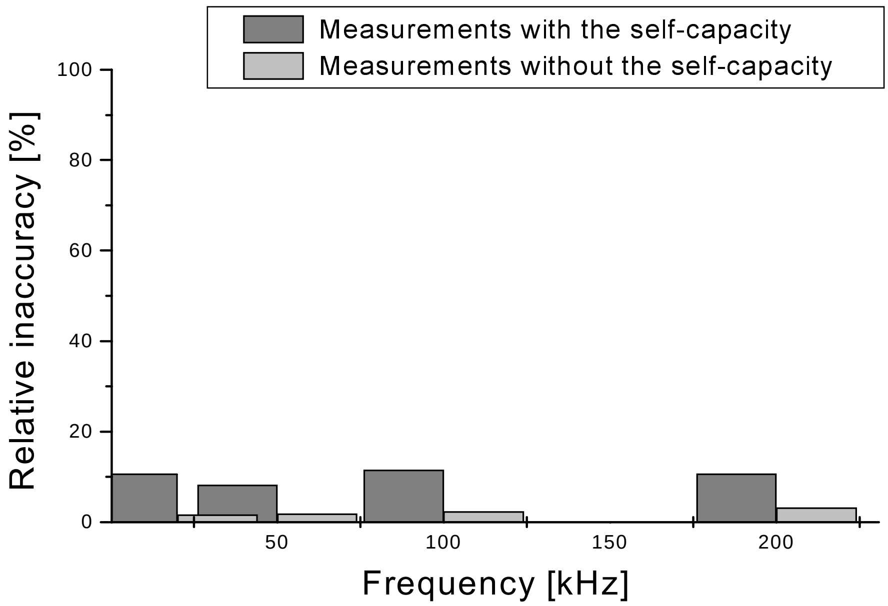

Fig. 5. The effect of the frequency on the 47,4 pF capacity measurement before and after circuit self-capacity elimination

In case of capacity measurement under 50 pF, circuit of self-capacity C_w plays a significant role; such a capacity may reach even a several pF. The value of this capacity was derived basing on the capacity measurements without the C_x capacitor and with the integrator feedback loop. In such a mode, the input voltage is integrated only by the C_w self-capacity. The C_w value was calculated (once the output voltage change is read) basing on the formulas (1) and (2).

If we assume that the measurement circuit self-capacity is parallel connected with the measured capacity (Fig. 3), so after subtraction the self-capacity value from the measured capacity value, the measurement accuracy is much more higher (Fig. 7).

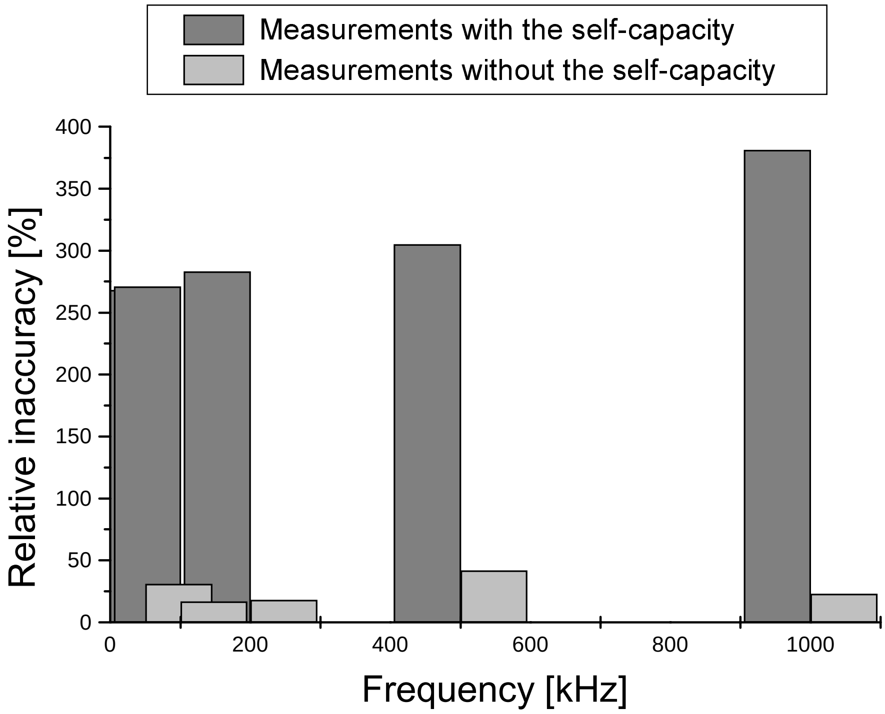

Fig. 6. The effect of the frequency on the 1,6 pF capacity measurement before and after circuit self-capacity elimination

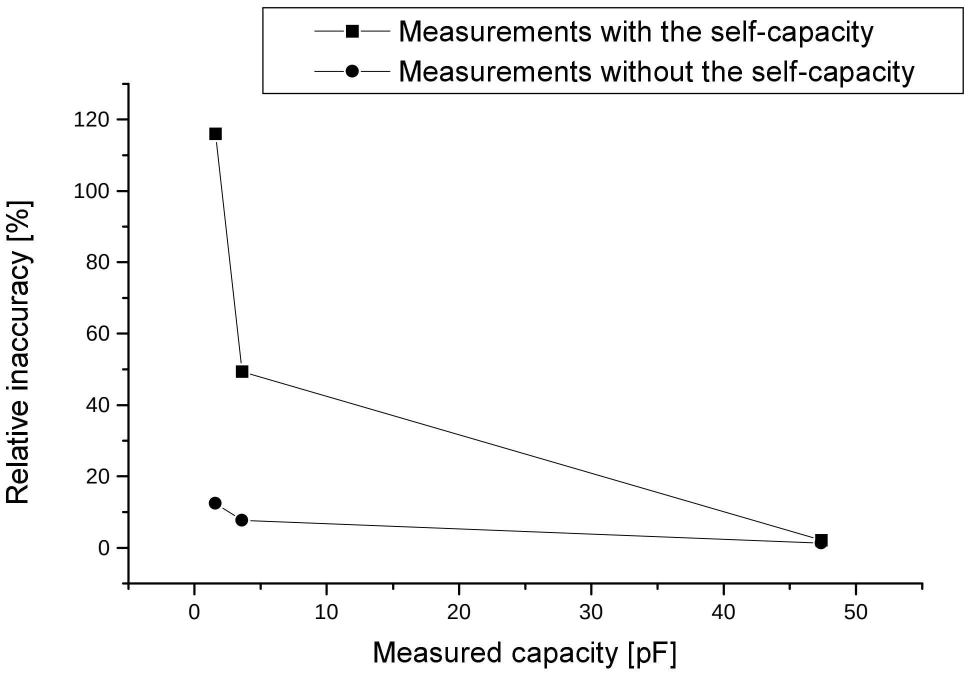

Fig. 7. The comparison of measurement results with and without circuit self-capacity (f=100kHz)

The measurement accuracy is higher when the circuit self-capacity is taken into account. The error lower than 10 % was achieved when measuring the capacities from 3,6 pF and higher. When measuring the capacities lower than 3,6 pF, the rise time of the input voltage plays the significant role. The other problem is that when measuring so small capacity, the electric charge, being gathered on the capacitor plates at frequency of several hundred kHz, is even about several pC. So this charge is very sensitive to noises and very difficult to correctly measuring.

4. CONCLUSIONS

The gained results confirmed the suitability of developed laboratory system for small capacity measurement, with the operational amplifier in the integrator mode and with the polarization current compensation circuit. This measuring circuit features low-cost design and manufacturing. However, measurements require the high quality function generator and the high quality oscilloscope. The experiments showed that satisfactory engineer's accuracy (error <10 %) was achieved, when accounting for the circuit self-capacity, for capacity about 4-5 pF. The even higher measurement accuracy may be achieved when using the suitable shielded cables along with guarding technique [1] that allows for leak current elimination during the measurement.

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