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Protection against charged capacitors for capacitance measurement devices

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***Abstract*—In this paper, the implementation of protection against charged capacitors is presented, which can be applied to capacitance measurement devices. The protection is divided into two parts: the first part is designed for discharging the capacitor and the second part is used to connect the discharged capacitor to the appropriate instrument for capacitance measurement. The electrical schematics are designed using the KiCAD software.**

***Keywords*— microcontrollers, capacitance, capacitor, protection against charged capacitors, NE555**

I. Introduction

Capacitors are passive components that are used almost as often as resistors. Unlike resistors, capacitors have reactance, which is different from resistance. It depends not only on the capacitance of the capacitor, but also on the contribution of the voltage applied to the ends of the capacitor [1]. When it comes to electronic components, capacitors are a bit more intricate than resistors. Unlike resistors, the current that flows through a capacitor does not have a direct correlation with the voltage. Instead, it is dependent on the rate of change in voltage over time.

$$Xc = \frac{1}{2\pi f C} \tag{1}$$

$$I = C\frac{dV}{dt} \tag{2}$$

Basically, the capacitor represents two metal plates (area *A*), which are closely placed (at a distance *d* that is dimensionally smaller than the dimensions of the plates themselves) between which there is some kind of dielectric. Here ε represents the dielectric constant [2].

$$C = 8{,}85 \times 10^{-14}\,\frac{\varepsilon A}{d} \tag{3}$$

A. Capacitance measurement

There are several methods that can be used to measure capacitance accurately. These methods include using alternating measuring bridges such as RC and LC bridges or active self-balancing bridges, measuring resonant frequency, and charging and discharging capacitors with constant current. Each of these methods has its advantages and disadvantages, and the choice of which method to use will depend on the specific application and requirements of the measurement [3]. The measurement method to which this protection could be applied is the constant current charging and discharging time method.

The method of measuring the charging and discharging time of the capacitor implies that the capacitor is charged for a certain time τ = 5RC with a constant current through the resistance R. By knowing these values, we can determine the capacitance of the capacitor in a very simple way [4].

The simplest implementation of this method is via the NE555 timer, which is implemented in astable mode.

B. Astable mode of the NE555 timer

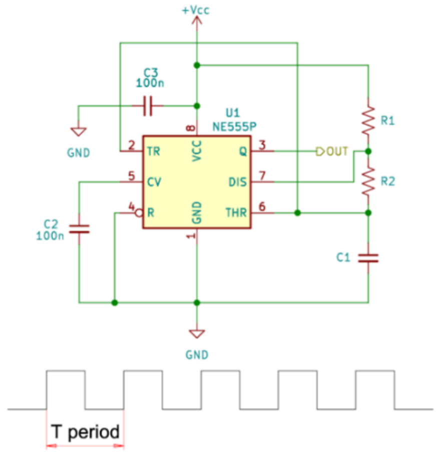

Fig. 1. Timer NE555 in astable mode

This operational mode is distinguished by the generation of periodic square waves at the output of the NE555 timer. The duration of both the HIGH and LOW states in the output signal is determined by the choice of resistors and capacitors, consequently influencing the frequency of the output signal [5].

With these realizations, if the values of resistors R_1 and R_2 are set to be fixed, and the value of capacitor C_1 is changed, the signal period will vary for different capacitance values. In this way, we can precisely determine the capacitance of the capacitor

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whose value we are measuring. The signal period can be calculated as follows (4).

$$T = 0{,}7(R_1 + 2R_2)C_1 \tag{4}$$

- T period of signal at the output of NE555 timer
- R_1 resistance value of R_1
- R_2 resistance value of R_2
- C_1 is the capacitance to be measured

C. Problems

Moreover, the act of measuring its capacitance not only determines its value but also serves as a means to verify the capacitor's integrity, identifying any deviations from its factory default value.

With devices such as UPS (uninterruptible power supply), as well as with various power circuits, such as a computer power supply, it often happens that the failure is precisely on the capacitors themselves [6].

Failures that can occur on the capacitors themselves are: breakdown of the dielectric, open capacitor and failures caused by the influence of the environment.

Dielectric breakdown, a potential failure, can occur over time, accelerated by high temperatures that degrade the dielectric. Since no dielectric is flawless, applying a sufficiently high voltage to the capacitor may lead to the formation of a spark arc, causing current to pass through the dielectric [7].

An open capacitor occurs due to a disconnection between the terminals of the capacitor and the plates inside it. This happens when the capacitor is overloaded, and it happens when the capacitor intended for DC currents is running on high AC currents, which leads to the heating of the terminals and the disconnection between the terminals and the plates of the capacitor [8][9].

The main characteristic of capacitors is that they can remain charged even after the device is turned off. This residual charge can persist for hours, days, months, or even years. Apart from the potential risk of damaging the device, the voltage remaining in such capacitors also poses a safety hazard to the operator during measurements [10].

For these reasons, the protection that will be described in the following chapters solves these two main problems.

II. Description of the Circuit

The protective mechanism can be divided into two primary functions: one for discharging the capacitor and another for establishing the connection between the discharged capacitor and the rest of the circuit.

A. Discharging capacitor

Before measuring the capacitance of a capacitor, it is crucial to discharge it. Many multimeters or capacity meters are burnt out due to negligence or lack of thought when the capacitor is not previously discharged. To avoid this problem, it is recommended to simply short the leads.

However, the discharge process itself can be dangerous for the person who wants to perform the measurement. It is important to note that certain capacitors have the ability to withstand high voltage levels, ranging from several tens to even thousands of volts while in use. Therefore, it is crucial to exercise caution when handling these components. In the event that a capacitor is removed from a plate that was previously connected to a power source, accidental contact with the terminals during measurement can lead to potential injury.

Therefore, it is necessary to find a solution that will simultaneously discharge the capacitor and protect the device and the operator of the instrument itself. On Fig. 2 shows the circuit that makes it possible.

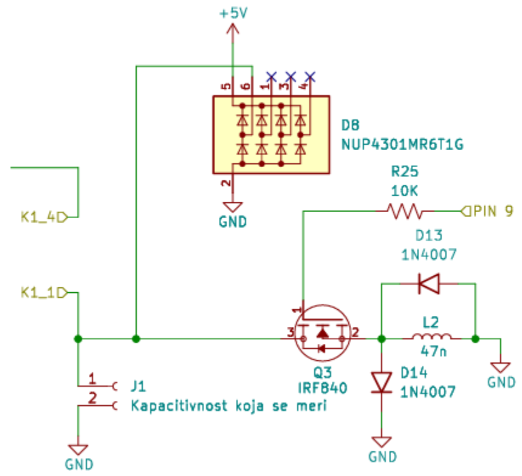

Fig. 2. The first part of the protection intended for discharging the capacitor

The person performing the measurement places the leads of the capacitor into the Pin Socket connector (J1). In this way, the capacitor is brought to the first part of the protection. The first part of the protection can be divided into two parts. Component D8 is responsible for voltages that exceed 70 V, while the other part is intended for voltages that are below 70 V.

Component D8 (NUP4301MR6T1G) is an integrated circuit made up of a series of diodes with low capacitance. The circuit itself is used in practice as an excellent ESD (electrostatic discharge) protection for microcontroller inputs, USB 1.1/2.0 data lines and I^2C Bus lines. This component will discharge the capacitor if it is charged with a voltage higher than 70 V, because the minimum voltage required for this component to react is 70 V (Breakdown voltage) [11].

If the capacitor holds a voltage lower than 70 V, even minor voltages (such as 0.1 V) that may not harm the instrument but can lead to measurement inaccuracies, must be avoided. To address this issue, a MOSFET and its associated passive components have been implemented.

The basic role of the IRF840 (MOSFET) itself is to work as a switch that will short-circuit the leads of the capacitor and thus discharge it completely. Control of its state (open/closed switch) is managed via the gate output, which is connected to a microcontroller's output. The passive components (coil and diodes) in this circuit serve as protection for the MOSFET itself. The function of coil L2 is to prevent rapid discharge that may cause sparking or arcing. Diodes D13 and D14 are used to safeguard the IRF840 during shutdown. After the shutdown, there is a reverse current in the coil that flows in the opposite direction of the discharge current. This reverse current can potentially harm the MOSFET, but the diodes prevent such damage from occurring.

Labels K1_1 and K1_4 represent the second part of the protection that connects the discharged capacitor to the instrument that will measure its capacitance.

B. Connecting capacitor with instrument

After the capacitor has been successfully discharged. The next stage is to connect the discharged capacitor to the instrument that should measure its capacitance. On Fig. 3. the circuit is shown.

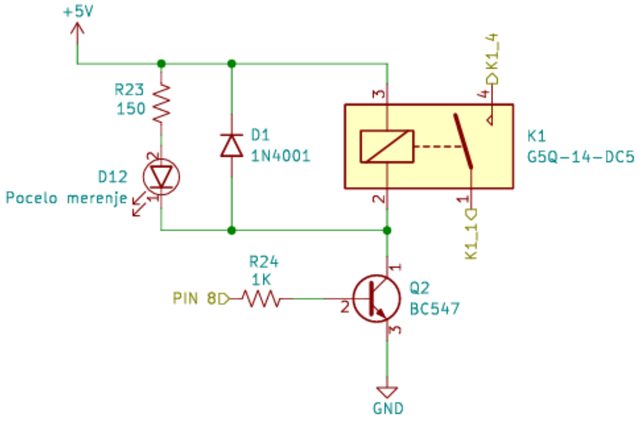

Fig. 3. Second part of the protection that serves to connect the discharged capacitor to the instrument

As already mentioned, the labels K1_1 and K1_4 represent the connection between the first and second parts of the protection. The output pin of the microcontroller is connected to the base of the transistor Q2, which acts as a switch in the circuit design. When a logical one is applied to the output pin of the microcontroller, the transistor Q2 will act as a closed switch. This will activate the relay K1, which in turn will connect the discharged capacitor to the instrument. The instrument will then measure the capacitance of the capacitor. Diode D1 is a flyback diode that protects Q2 when K1 turns off. D12 is an LED indicating the start of measurement.

III. DISCUSSION

By analyzing the circuit, we concluded that this way of discharging the capacitor is very efficient. If we compare the methods available today, such as discharging with a screwdriver (for voltages less than 50 V) or discharging through a high resistance resistor (for high voltages), these methods can be dangerous to the person who performs the measurement. This circuit enables precise discharge of a capacitor over a wide voltage range. The NUP4301MR6T1G component handles high voltages, while the capacitors charged with lower voltages will be discharged through the IRF840 MOSFET.

One issue with this circuit type is its management, which makes the method more complex. It requires programming a microcontroller to handle discharging the capacitor as well as connecting the discharged capacitor to the measuring instrument.

IV. CONCLUSION

Implementing this type of protection, in addition to preventing the instrument from being damaged or destroyed, reduces the risk that the persons performing the measurement will be injured by the voltage remaining in the capacitors after operation. Also, charged capacitors can affect the accuracy of the measurement, so before each measurement, it is necessary to discharge the capacitors.

The idea is to realize and test a circuit like this with capacitors of different capacitances and operating voltages. The plan is to add another layer of protection against capacitors that are charged with a negative voltage.

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