Portable Capacitance Meter using Charge/Discharge Circuit

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***Abstract*— This study aims to develop a portable capacitance meter utilizing a charge/discharge capacitance measuring circuit. The context arises from the recognized need for efficient capacitance measurement tools in various industries such as electronics, telecommunications, and research laboratories, where portability and ease of use are essential. Market analysis highlights a demand for versatile and user-friendly instruments, amidst competition predominantly offering complex and expensive solutions. The proposed design seeks to address this gap by providing a compact, cost-effective solution with simplified operation, catering to hobbyists and technicians. Implementation entails integrating efficient charge/discharge circuits with intuitive interface elements to ensure accurate and convenient capacitance measurement across diverse settings, thereby meeting the identified customer need and addressing prevalent market factors and competition.**

***Keywords*—** *Capacitance Measurement, Charge/Discharge Circuit.*

I. Introduction

The idea revolves around creating a portable capacitance meter that utilises a charge/discharge capacitance measuring circuit, catering to the needs of electronic enthusiasts, technicians, and professionals. The capacitance meter offers a wide measurement range and high sensitivity. This is achieved by using a Charge/Discharge circuit with a variable frequency drive. The motivation behind this concept stems from the increasing demand for compact, accurate, and versatile measurement devices in the electronics industry. Identified customers include hobbyists, students, electronic repair technicians, and engineers who require a reliable tool for measuring capacitance values in various electronic components and circuits.

In the market, there are existing capacitance meters and multi-meters, but our product aims to differentiate itself by focusing on portability, ease of use, and accurate charge/discharge measurements. Cheap capacitance meters are often limited to 100 pF with limited sensitivity. Expensive capacitance meters are also unable to reliably measure capacitance below 100 pF, however, they do have a higher upper limit. But in most practical situations encountered by the target consumers, the proposed product provides a suitable range. Further, the proposed product does not require any batteries to operate, making it more sustainable. The proposed device can send its recordings directly to a computer or a mobile device, via wired and wireless communication channels a feature only found in very high-end devices, and very seldom in portable devices. Important specifications include a wide capacitance measurement range, high accuracy and a user-friendly interface. The target market price is set to be competitive, offering value for money compared to similar products while maintaining quality and functionality.

II. Literature Review

Capacitors are an essential electronic component used in almost every circuit, moreover, many components have unintended capacitive effects that need quantification. Various capacitive measurement techniques exist to measure low capacitance values, measuring different capacitive effects to get the capacitance. [1] classifies capacitance measurement circuit architectures, specifically for low capacitance values, into 5 categories, which are Capacitance to voltage methods, Resonance methods, capacitance to oscillations methods, capacitance to phase methods and capacitance to digital methods. Electrical capacitance tomography systems need very precise and sensitive capacitance-measuring hardware. Charge/Discharge circuit uses trans-impedance amplifiers, to build a current sensing amplifier [2]. The Charge/Discharge circuit is primarily used in ECT systems however, the circuit can be easily utilised in portable systems. The product demonstrated in this paper uses the Charge/Discharge circuit in a portable operation. Providing accuracy and sensitivity in a compact handheld device. [3] Presents a novel switchless charge-discharge circuit architecture for use in electrical capacitance tomography. This switchless method addresses the charge injection problem caused by analogue switches and eliminates the need for a digital control signal for the switches. However, this adds complexities and makes the system more difficult to implement. [4] passes a sine-wave excitation signal through the measurand and uses a demodulator to get the capacitance value. This can be seen as a modification of the charge/discharge circuit.

III. Product Design and Implementation

A. Charge/Discharge Circuit

The charge/discharge circuit used in this capacitance meter was originally developed for ECT systems, as presented in [2]. The charge/discharge capacitance measuring circuit in a differential configuration is shown in Fig. 3. The charge/discharge capacitance measuring circuit operates in two phases: charge and discharge. During the charge phase, current flows from the voltage source through the measured capacitance and is converted to voltage by op-amp 1. The discharge phase involves the discharge of the measured capacitance, with op-amp 2 converting the current into voltage. Given the charge frequency (f), voltage source (Vc), op-amp resistance feedback (R_f), measured capacitance (Cx) and charge injection capacitance (C_q), the output voltage of the circuit is given by Eqn. 1 as derived in [2] and [5].

$$V3 = 2fV_cR_f(C_x + C_q) \quad (1)$$

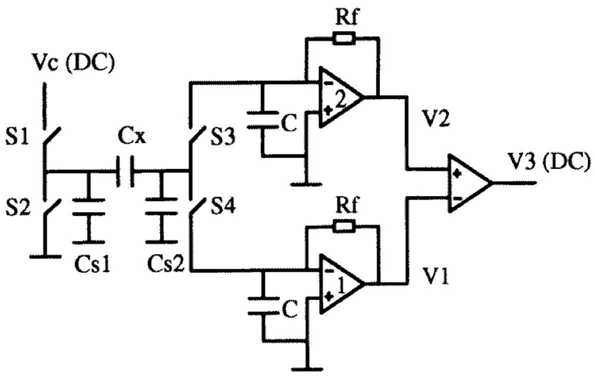

Fig. 1. Charge/Discharge circuit [2].

A differential amplifier combines these signals to produce a DC measurement signal proportional to the capacitance, with the sensitivity dependent on the charge/discharge frequency. The circuit is designed to be stray-immune, with stray capacitances Cs1 and Cs2 not affecting the measurement.

While the circuit offers advantages, such as cancelling op-amp offsets and high-frequency operation, it does face challenges like the charge injection problem. This problem is partially mitigated by the differential configuration, bringing down the equivalent charge injection capacitance to about 0.2 pF [2]. As the Intended range for this meter is 10 pF to 1.5 µF, this can be ignored, which helps reduce the overall cost and complexity.

B. *Full System Design*

The Complete system is represented in the Fig. 2.

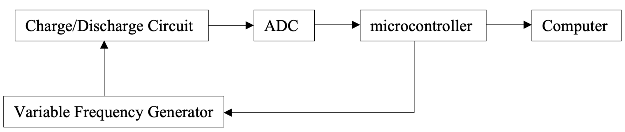

Figure 2 Block Diagram of the system.

The output of the capacitance measurement circuit is directly fed into a 24-bit ADC (CS1237-SOP8), which is then read by a microcontroller using a serial interface. The microcontroller then adjusts the output frequency of the variable frequency Generator(LTC6903) to bring the output of the measuring circuit below 3V. The output of the circuit as seen in Eqn. 1 is directly proportional to the frequency, hence for higher capacitance values the frequency needs to be reduced to keep the output from saturating. This offers two advantages. Firstly this allows for the measurement of higher capacitance values up to 1 µF. Second, it removes the need for a DC amplifier stage for smaller capacitance values. To be able to achieve high frequencies, wideband CMOS switches (ADG901) are used. ADG901 have a bandwidth of 4.5 GHz. This configuration allows the device a very high range, from 1.5 µF at 1 KHz to 10 pF at 50 MHz, while offering a sensitivity of 40 mV/pF when operating at 20 MHz. As resolution is directly proportional to the operating frequency, even higher sensitivity is achieved for lower capacitance values. [6] uses a similar charge discharge circuit and shows that a resolution of 0.3 fF is achievable. Given a 24 bit ADC is used this characteristic is continued in the proposed device. Algorithm 1 presents the simplest pseudocode for the microcontroller. Since the microcontroller can be flashed very easily, new updates to the firmware can be made available post-purchase. Different algorithms can be available for the customer to download to meet their needs.

Algorithm 1

```
Initialise communication with PC.
Configure ADC (CS1237-SOP8)
Configure LTC6903
If command_received = start_measurement
    Set LTC6903 frequency to 50 MHz
    Read ADC
    while ADC saturated:
            Read ADC
            If frequency = 1 KHz
                    PC_print("Capacitance too high")
                    Break
            Reduce LTC6903 frequency by 100 KHz
            If frequency < 1 KHz
                    Frequency = 1 KHz
            Wait 0.1 s

    Get Capacitance_value using Eqn. 1
    If Capacitance_value < 20 pF:
            PC_print("warning Charge injection error
                            Significant")
    PC_print(Capacitance_value)
```

The ESP8266 is an ideal microcontroller for this product as it offers both wireless and wired communication. This allows for the capacitance meter to be used with a mobile phone increasing portability. Further wireless operation means the device can be deployed on remote sites for continuous measurement. The users can use any open-source serial monitor to get the results. All the ICs are then assembled onto a single PCB. The PCB is powered via USB-C. A boost converter is used to power the OP-AMPS and PGAs at 12 V. Using USB-C allows the board to be powered by the PC, hence fewer connections are needed. If wireless communication is needed then the board can be powered via a portable power bank. A component and price estimation is presented in Table 1. Although the cheapest capacitance meter available in the market is around £30, the proposed product outperforms it in terms of resolution and accuracy. Further added features such as inherent stray immunity and the ability to read measurements on a PC places the product in a niche position in the market.

Table 1. Component list with an estimated price

Sub-group	Component	Price(£)
Charge/Discharge Circuit	Analogue Devices ADA4511-2 x 2	1.5
	ADG901 switches x 4	5
	Differential Amplifier AD8479	3

	Square-wave source LTC6903	6
ADC	CS1237-SOP8 (24-bit ADC)	0.3
Microcontroller	ESP8266 microcontroller	5
Power Delivery	USB-C adapter (USB4115-03-C)	1.2
	Boost converter (MAX662ACPA+)	6
Miscellaneous	Probes and adapters	15
	Passive components	5
PCB	2 layer PCB Fabrication (80 mm x 50 mm)	2
TOTAL		50

C. Construction and Packaging

Since the PCB is manufactured from third-party manufacturers, the only assembly required is to solder the components and package them. Given the small form factor of the device, the device can be sold with any plastic casing. A shrink wrap can provide moisture protection while keeping costs down. The meter can then be put in a cardboard box with foam padding. All components are ordered in bulk keeping lead times low. However, a custom PCB takes 1-2 weeks to be manufactured and delivered

IV. References

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