

SELF CALIBRATION CAPACITANCE METER

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Abstract

This paper describes a self calibration method for capacitance measurement on the base of MCU. The method uses a software calibration technique for first order errors elimination as: offset and gain error, error caused by supply voltage variations, uncertainty error of comparator's threshold voltage and its temperature drift as well as uncertainty and temperature drift of resistance. The method do not removes absolute measurement error of capacitance of the reference capacitor. Remaining sources of errors can be leakage currents of I/O pins of MCU, nonlinearity of applied passive components and discrete quantization error of ± 1 instruction cycle. The measurement resolution is 16 bits.

Keywords: MCU, capacitance, instruction cycle, timer, comparator, interrupt, DMM.

INTRODUCTION

Recent digital methods for capacitance measurement are based mainly on the well known principles of A/D conversion with time or frequency quantization. Electronic circuits of this kind are in principle simple, mainly based on the relaxation oscillators and digital counters [1, 6]. However, serious disadvantage of such solutions is degradation of the measurement quantity because of multiple conversions. Namely, the total conversion error is result of capacitance to time interval conversion error and quantization error of time interval. Influence of parasitic effects even at the moderate operating oscillator frequencies, instability of comparator's thresholds voltage as well as uncertainty of passive components parameters are main causers of conversion error of capacitance to time interval. Converter resolution has dominant influence to the quantization error.

With the advent and development of microcontrollers, made possible the realization of capacitance meter as intelligent devices [3].

In addition to managing the work of devices and complex processing measurement results, using the microcontroller can be achieved and a qualitatively new feature, connect the meter

to a computer. Suitable design of the measuring algorithm can than eliminate the influence of parasitic capacitance attaching lines as well as some of the above mentioned errors.

This paper describes software measurement procedure that uses a modified principle of capacitance to time interval conversion and quantization of the time [2]. Thanks to the microcontroller, the proposed method automatically compensates first-order errors that are result of temperature's and long-term instability of the component's parameters like uncertainty in determining the thresholds of comparison, power supply voltage and values of passive components. Taking into account 16-bits measurement resolution, the dominant influence on the total measurement error has the uncertainty of determining the capacitance of reference capacitor. By selecting a stable reference capacitor with high quality dielectric, whose exact value of capacitance is software stores, the total measurement error can be kept within the desirable limits.

Improved accuracy of measuring capacitance using software calibration technique, a small number of required external components, the relatively low consumption and low

cost of implementation are main effective features of the proposed solution.

MEASUREMENT ALGORITHM

The proposed measurement algorithm is based on the successive charging of reference and measured capacitance [2], i. e. successive conversions of both capacitances to time intervals T_{ref} and T_m , respectively, see Fig. 1.

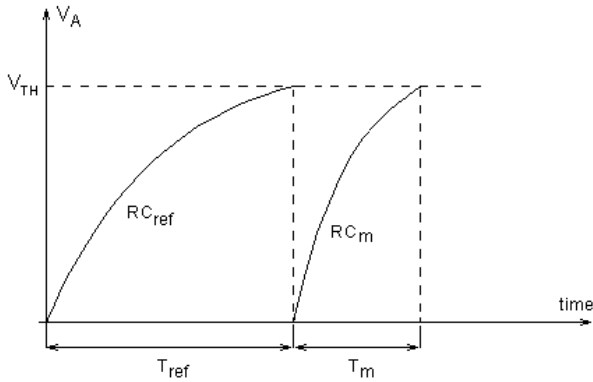


Fig. 1. Successive capacitance C_{ref} and C_m to time intervals conversions.

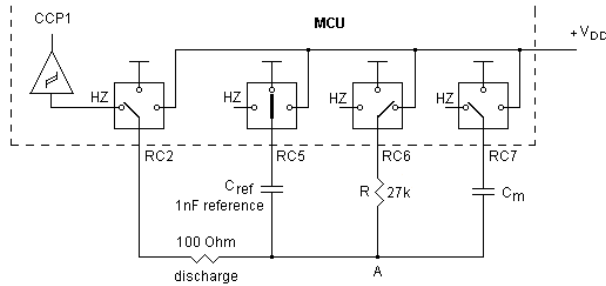


Fig. 2. Symmetrical network of capacitors charging/discharging.

If the network of capacitors charging is symmetrical as in Fig. 2. then the time intervals T_{ref} and T_m can be expressed by following equations

$$T_m = RC_m \ln((V_{DD} - V_0)/(V_{DD} - V_{TH})) = kC_m \quad (1)$$

$$T_{ref} = RC_{ref} \ln((V_{DD} - V_0)/(V_{DD} - V_{TH})) = kC_{ref} \quad (2)$$

where V_{TH} is the threshold voltage and V_0 is the initial voltage value of capacitors. Division the last two equations give

$$C_m = \left(\frac{T_m}{T_{ref}} \right) C_{ref} \quad (3)$$

The last expression shows that proposed measurement procedure automatically compensates the most of causes of the measurement error. The main influence on the total error has absolute measurement error of reference capacitance.

REALIZATION

The proposed measurement algorithm is implemented by software using the Microchip microcontroller PIC16F870 [4]. The architecture of the some I/O lines of this microcontroller allows the connection with RC network of measurement circuit, Fig. 3. To view the results of measurements was used double row DMM LCD with 16 characters per line [5].

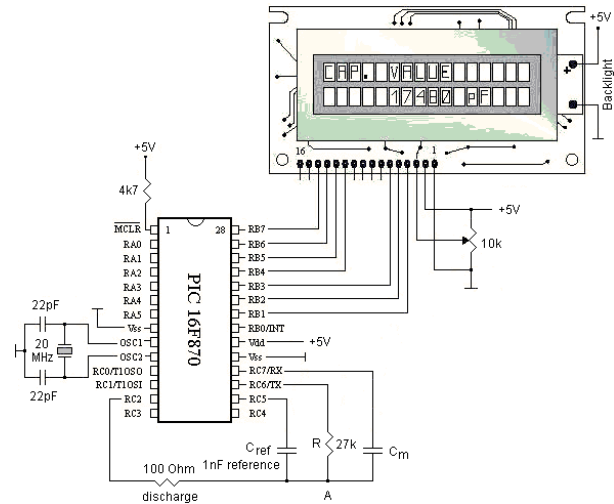


Fig. 3. Functional scheme of capacitance meter.

Microchip microcontroller PIC16F870 is a low-cost, low-power, high-performance, CMOS, fully-static, 8-bit microcontroller using an advanced RISC architecture. The microcontroller addresses 2K x 14 FLASH program memory, 128 x 8 SRAM and 64 x 8 data EEPROM memory. Each program memory is internal. Significant characteristic of this component is the data EEPROM ownership. This readable and writable memory can save some constant parameters useful for the program. Up to 20 MHz clock input determines the operating speed of microcontroller. A total of 35 single word instructions (reduced instruction set) are available. Consequently, all instructions execute in a single cycle (200 ns @ 20 MHz) except for program branches which are two cycle.

PIC16F870 consists of some standard peripherals as a 10-bit five-channels ADC, PWM, USART, three timers and three I/O ports. The device has an eight-level deep hardware stack and multiple internal and external interrupt sources. A watchdog timer with its own on-chip RC oscillator serves for reliable operation of the device.

The PIC16F87X family is supported by a full-featured macro assembler, a software simulator, an in-circuit emulator, a low-cost development programmer and a full-featured programmer.

Input line RC2 of the port C is used as a source of external interruption to detect the moment of exceeding the threshold switching Schmitt's input buffer on this line during the charging one of two capacitors. In this moment the content of the 16-bits timer 1 (TMR1) is transferred and latched into CCP1 (Capture module) capture registers. This content represents quantized time interval and will be read in the interrupt service routine. According to the manufacturer's declaration, the high threshold voltage of the Schmitt's input buffer V_{TH} ranges within $0.8V_{DD} - V_{DD}$, where V_{DD} is microcontroller supply voltage [4].

Line RC2 of the port C is also used to quickly discharge capacitors when configured as output and reset. In order to prevent possible damage to the line driver output, the discharge current is limited by the 100 Ohms serial resistor.

To achieve sufficient accuracy, the maximum permissible clock frequency of 20MHz is adopted. So, instruction cycle is minimized to the value of 200ns. With the timer 1 (TMR1) resolution of 16-bits and with adopted clock frequency of 20MHz full cycle counting of the timer amounts

$$T_{\max} = 2^{16} T_{CY} = 2^{16} 200 \text{ ns} = 13107.2 \mu\text{s} \quad (4)$$

where T_{CY} is the instruction cycle duration.

The value of the resistor R can be calculated from following equation

$$T_{\max} \geq T_{m\max} = RC_{m\max} \ln\left(\frac{V_{DD}}{V_{DD} - V_{TH}}\right) \quad (5)$$

With the adopted values $V_{DD}=5V$, $V_{TH}=4V$ and the measurement range of $300nF$, from equation (5) is obtained the maximal value of resistance $R=27.15k\Omega$.

Special care is devoted to the choice of reference capacitance whose accuracy and stability greatly affects the overall accuracy measurement. A capacitor with dielectric of polypropylene film in the form of foil, suitable for use in pulse applications because of their small losses at high operating frequencies, was selected. A value of $1nF$ capacitance with a tolerance of 2.5% is adopted. So, from equation (2) is approximately calculated the duration of time interval $T_{ref} = 43.5\mu\text{s}$.

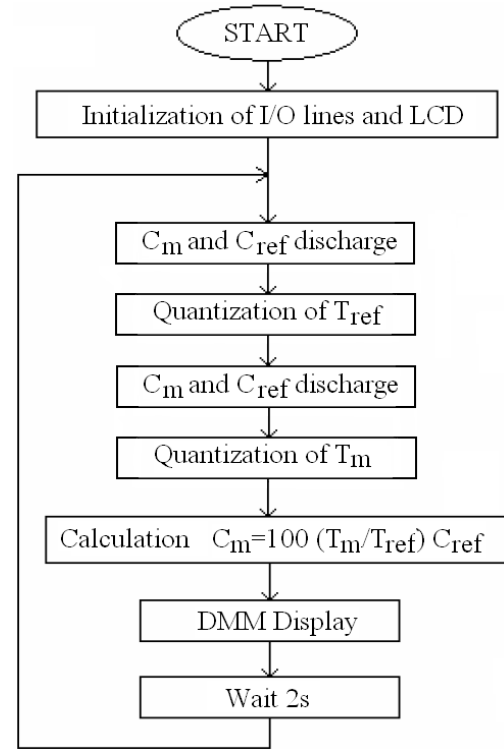


Fig. 4. Flow diagram of measurement procedure.

Flow diagram of the program for the implementation of measurement procedure is shown in Figure 4.

The program starts initialization routine for port C, timer 1 and CCP1 module configuration as well as the DMM LCD module to display the results. Discharge the capacitances in the circuit is done by the reset all I/O lines associated with the RC network when they are configured to be outputs. The duration of capacitors discharge must be long enough to be a transitional regime in the circuit finishes.

In the next measurement phase I/O lines are configured to allow charging of reference capacitor C_{ref} . During this time lines RC2 and RC7 are configured as high impedance inputs. In this way, the components C_m and R_S are excluded from the network. Digital equivalent

of the time interval T_{ref} is obtained by counting instruction cycles using the 16-bits timer/counter TMR1 of the CCP1 module in capture mode. When the voltage V_A , see Fig. 2 and Fig. 3, reaches the threshold voltage V_{TH} the program branches to the beginning of the interrupt service routine-ISR. The ISR then reads the 16-bits register pair of the CCP1 module.

By return from ISR the main program continues with the repetition of previously described procedure of discharging of all capacitors. After completing discharge time, the main program configures the I/O lines to allow charging of measured capacitance C_m by excluding C_{ref} and R_S from the network. At the same time the main program resets timer TMR1 and configures CCP1 module for capture mode. Digital equivalent of the time interval T_m is obtained in the same manner as T_{ref} .

The calculation of the measured capacitance C_m is done by dividing the digital equivalents of time intervals and by multiplying the result of division with value of reference capacitance. In order to obtain resolution of $10pF$ the value of reference capacitance of $1.02nF$ is presented as 102 and stored in the program memory. At the end, calculated result is showed on the two rows LCD dot matrix module with adequate message.

Described measurement procedure is repeated every two seconds.

The complete microcontroller's firmware is written using CCS C compiler IDE ver. 4.057.

The relative measurement error of the capacitance can be calculated from equation (3) and showed in the following form

$$\frac{\partial C_m}{C_m} = \frac{\partial C_{ref}}{C_{ref}} + \frac{\partial N_m}{N_m} - \frac{\partial N_{ref}}{N_{ref}} \quad (6)$$

where dN_m/N_m and dN_{ref}/N_{ref} are relative quantization error of time intervals T_m and T_{ref} respectively.

RESULTS

Accuracy of the measurement algorithm is tested using decade capacitance box, made in TETEX, whose capacitance tolerance is not greater than 2%. The maximal value of the box capacitance is 100nF. During connecting and paralleling of the boxes special care is devoted to the cables length in order that reduce the influence of parasitic capacitances.

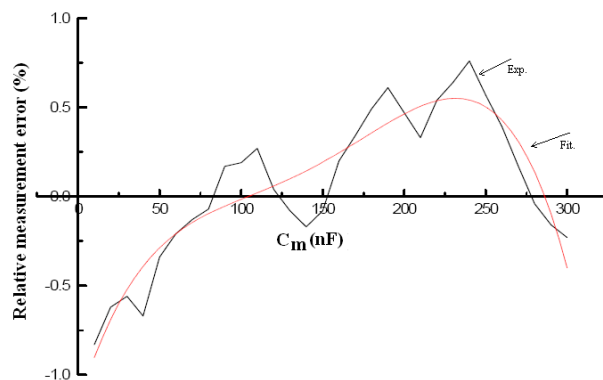


Fig. 5. Experimental and fitted curve of relative measurement error.

Experimentally obtained and fitted curve of the relative measurement error are showed in the Fig. 5. As can be seen the relative measurement error not exceeds the margins of $\pm 0.8\%$. This fact acknowledges our theoretical assumptions.

CONCLUSION

The paper discusses the realization of a digital capacitance meter with improved accuracy on the base of microcontroller. The software implemented measuring algorithm automatically compensates for most of the first-order errors such as uncertainty in determining the value of passive components, threshold voltage drift of comparator and power supply voltage instability. It was shown that the measurement error mainly depends on the accuracy of only one parameter-capacitance of the reference capacitor.

The main attributes of the device are improved measurement accuracy and low cost of implementation.

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