C/F AND L/F CONVERTER

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ABSTRACT

The project concerns analysis, design and construction of C/f and L/f converter based on a resonant method. It was designed for use in a simple laboratory instrument for capacitance and inductance measurement controlled by microcontroller.

1 INTRODUCTION

In practice, we often need to measure capacitance and inductance. There are many methods for measuring these values [1], [2], the most often used are methods based on measuring an impedance of measured element and a Siemens method. One of known methods, but less used, is a resonant method [1]. In this method, we are finding resonant frequency of LC circuit, for which the Thomson equation $f_r = \frac{1}{2\pi\sqrt{LC}}$ is approximately valid. From the resonant frequency and known capacitance C or inductance L the value of the measured element can be determined. An interesting alternative, described in this project, is to design an LC oscillator, which will oscillate (in ideal case) at resonant frequency of the resonant circuit. This allows us to measure simply and quickly, without need of toilsome tuning of additive oscillator and inaccurate resonance finding. Such oscillator we can consider as C/f and L/f converter with square root conversion. This conversion to frequency is very useful, because frequency can be measured very exactly and simply. The output of the oscillator can be connected directly to the input of a microcontroller, which provides measurement of frequency and other processing of measured values.

The advantage of the introduced method is, besides speed and simplicity also the fact, that the elements are measured using harmonic signal with defined amplitude and frequency. A disadvantage of this method is that by low value of resonant circuit quality a drop of resonant frequency against the Thomson equation occurs, which causes inaccurate evaluation of measured value. Also, this method is not very suitable for measuring electrolytic capacitors, but it can be used after a little modification.

2 ANALYSIS OF MEASURING OSCILLATOR

For linear oscillator model in Fig. 1 the condition of stable oscillations is given by Barkhausen criteria $\overline{\beta}(j\omega)\overline{A}(j\omega)=1$ [3], which can be separated to amplitude condition $\left|\overline{\beta}(j\omega)\overline{A}(j\omega)\right|=1$ and phase condition $\arg[\overline{\beta}(j\omega)\overline{A}(j\omega)]=0$.

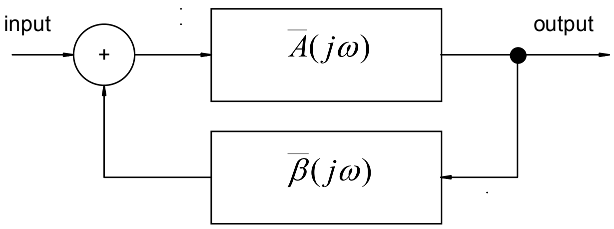

Fig. 1: *Linear feedback system as oscillator*

Oscillation frequency can be approximately derived using simplified model according to Fig. 2., where serial equivalent circuit of inductor is expected.

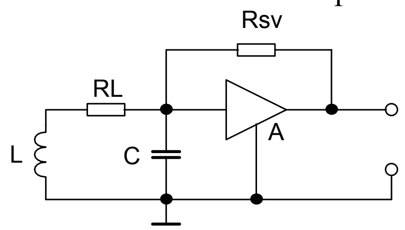

Fig. 2: *Simplified oscillator diagram*

We consider the gain of active part $\overline{A}(j\omega)=A(\omega)e^{j\varphi}$, where φ is the phase shift in active part of the oscillator. From amplitude condition of Barkhausen criteria the necessary condition for stable oscillation $A(\omega)=1+\dfrac{R_{SV}}{Q\omega L}$ can be derived. Oscillation amplitude can be stabilized either by changing of the gain A(ω), or by changing of R_{SV}. This change must be able to cover several orders, because the values Q, ω and L are changing in wide range. If constant voltage level in resonant circuit is required, the change of R_{SV} should be used as major stabilization. Oscillation frequency was derived providing Q >> 1, arg[β(jω)] → 0 from the phase condition of Barkhausen criteria:

$$\omega^2=\frac{1}{LC}\left(1-\frac{1}{Q^2}-\frac{\varphi}{Q}\frac{A(\omega)}{A(\omega)-1}\right).$$

There is a deviation against the Thomson frequency

$$\delta(\omega^2)=-\frac{1}{Q^2}-\frac{\varphi}{Q}\frac{A(\omega)}{A(\omega)-1},$$

of which the magnitude is the same as capacitance or inductance measuring relative error

$$\delta(C,L)=\frac{1}{Q^2}+\frac{\varphi}{Q}\frac{A(\omega)}{A(\omega)-1}.$$

By closer analysis of this equation it could appear that the higher the gain A(ω) is used, the lower is the measuring error. This is true, but in active devices at higher gain is also higher phase shift φ. Supposing 1-pole operation amplifier model and simplifying condition $\varphi \approx A(\omega)$ we can find, that the deviation $\delta(\omega^2)$ is minimal for $A(\omega) = 2$.

Unlike the discussed model, the real oscillator is non-linear system. The non-linearity is useful in terms of amplitude stabilizing, but on the other side it causes unwanted signal distortion. If we consider output signal distortion k_n only with the n^{th} harmonic frequency, providing $Q >> 1$, $n^2 >> 1$, the approximate equation for voltage distortion at resonant circuit is $k_n' = k_n \dfrac{A(\omega)}{nQ[A(\omega)-1]}$. From this equation we can see that if Q is high enough, the distortion is practically not transferred to resonant circuit, so a small output signal distortion is not critical.

3 CIRCUIT SOLUTION OF MEASURING OSCILLATOR

There are the following requirements given to the measuring oscillator:

- Measured capacitance/inductance in the range from pF/μH to μF/H
- Stable oscillations with all measured components
- Possibly the most accurate dependence of the frequency on the values of L and C (Thomson equation)
- Reasonable values of voltages, currents and frequency in resonant circuit
- Time and temperature stability
- Resonant circuit grounded by one pole (important in term of EMC)

There are serious requirements laid on the measuring oscillator. Measured capacitance and inductance is changing in 6-order range and values Q and tgδ have also large dispersion when real components are used. Circuit diagram of such oscillator we designed is in Fig. 3. As we can see from previous analysis, the maximum quality factor Q and minimum phase shift φ is required for accurate measurement. Because reference devices must not show non-linearity or frequency dependence and their parasitic values must be negligible, manufacturing of such reference coil is difficult. As a solution we use synthetic inductor; good results gives circuit with two operational amplifiers by [4].

Oscillator core consists of circuit with fast operational amplifier OZ1. This must have adequate transition frequency not to burden the measurement with systematic error (Chapter 3). The gain is set by resistors R1, R2 and R3 to the value of about 2 to 3, diodes D1 and D2 implement some non-linearity, which supports the amplitude stabilization (regeneration factor G = 1,2). Resonant circuit consists of Lx + L1 a C1, resp. Cx + C2 and synthetic inductor with OZ2 and OZ3. Switching between these circuits is realized by dry reed relay Re1 and is needed for choosing between capacitance and inductance measuring. Components L1 and C2 are auxiliary and provide reliable oscillation also at zero measured capacitance or inductance. Diodes D3 to D8 with resistors R6, R7, R12 and R13 form protective circuit, that limits voltage level at operation amplifiers inputs in case of connecting charged capacitor.

Amplitude stabilization in small range is provided by oscillator amplifier non-linearity. In regard to range of measured values, very efficient stabilization is needed. It is realized by system gain control with feedback resistance. We used photoresistor (R4) controlled by LED

(D12). That allows us to change resistance in range from about 100Ω to 10MΩ with very good resistance linearity. Photoresistor illumination is controlled by proportional-integrating filter with OZ4, which stabilizes output signal amplitude in all frequency range to 2V, what responds to 1V amplitude in resonant circuit.

Shaper with comparator K1 adjusts output signal voltage level, so the oscillator can be connected directly to microcontroller input. Active edge (H→L transition) occurs at input level 0V, noise immunity is ensured by hysteresis approximately 0,6V.

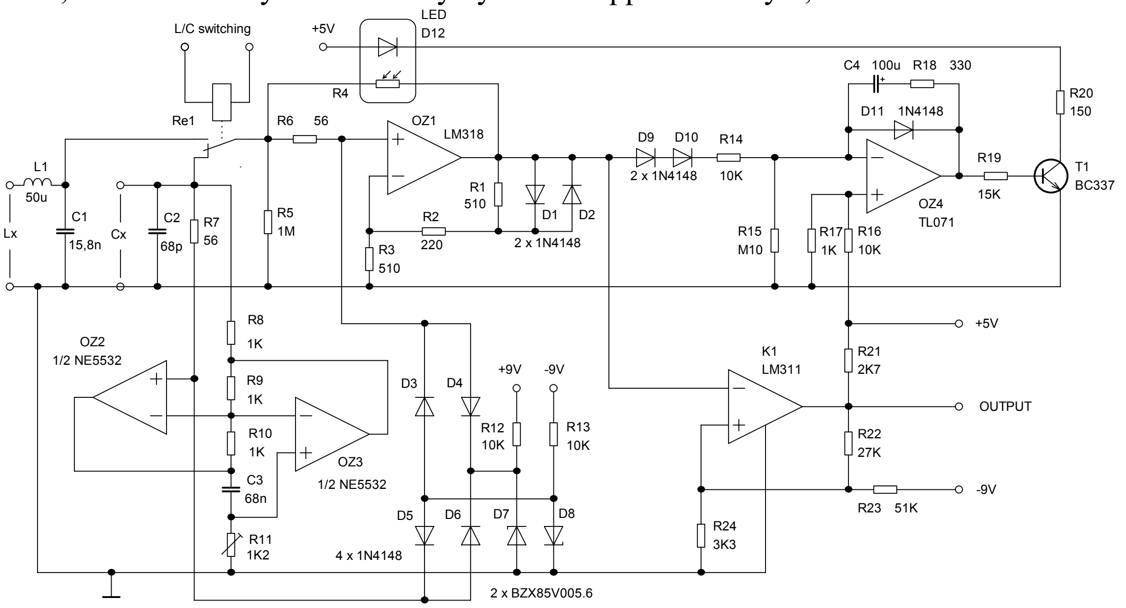

Fig. 3: *Measuring oscillator - circuit diagram*

4 MEASURNG OSCILLATOR FEATURES

Designed oscillator worked well with different capacitors with capacitance up to 4μF and with inductance up to 15H (higher values were not tested). Total parasitic capacitance of resonant circuit, including PCB capacitance and operation amplifier input capacitance was 19pF. The gyrator alone shown d.c. serial resistance 50mΩ and voltage offset 0,5mV.

Measurement accuracy was tested using a set of foil capacitors (Fig. 4a). As a reference value was taken the value measured by bridge capacitance meter P589, which measured at

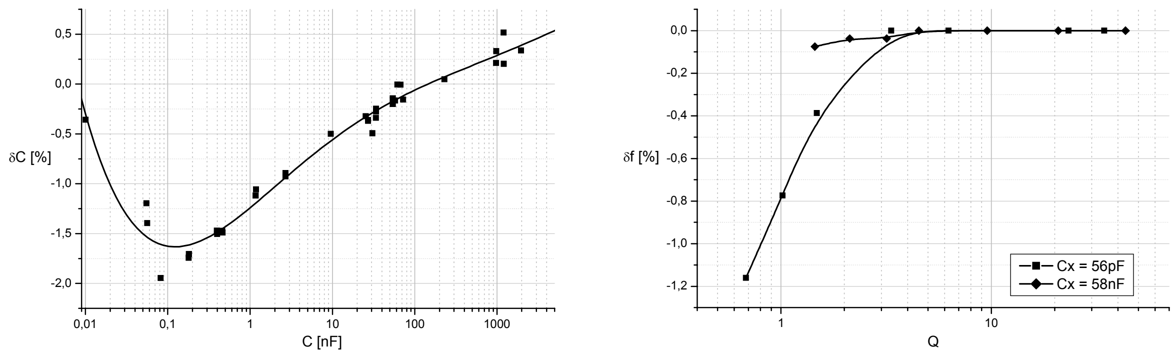

Fig. 4: *Measured characteristics: a) Capacitance measuring error*
b) Effect of resonant circuit load

1kHz. We also obtained interesting results when we investigated the dependence of oscillator frequency on the resonant circuit quality factor (Fig. 4b).

5 CONCLUSION

From measured characteristics mentioned above it is clear that the results are remarkable. Interesting is the interpretation of capacity measuring error (Fig. 4a), that has maximum nearly 2% at about 100pF. It is a systematic error and can be corrected by software. The deviation is caused by frequency drop of capacitance of capacitors, which is caused partly by parasitic inductance of capacitors, partly by physical properties of their dielectrics. For usual capacitors presents this frequency drop about 1% for frequency decade. The question is if this deviation can be considered as error or not; in specific applications may such measured values better correspond to reality then values measured ordinary at 1kHz. Dispersion of measured points round approximation curve is not more than 0,3%, what can be considered as a very good value, particularly when we take into consideration 6-order measured capacitance range.

Frequency dependence on quality factor is very low, acceptable deviations are even with quality factor Q of the order 1. This feature partially allows us to measure elements with resistance in parallel.

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