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A NOVEL METHOD FOR MEASUREMENT OF CAPACITANCES AND THEIR LOSS FACTORS

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A novel and simple technique for measurement of capacitances and their losses is presented. The method is based on a partially active-R sinusoidal oscillator. Experimental results are in good agreement with the theoretical analysis.

1. INTRODUCTION

Schemes utilizing operational amplifier-based oscillators for capacitance measurement have been proposed by several authors [1–3]. The circuit proposed in [1] uses two operational amplifiers, three resistors, and two capacitors in addition to the unknown capacitor to be measured. A major disadvantage of this circuit is the need to know the accurate values of the two capacitors. By taking into consideration the operational amplifiers non-idealities, modifications of this circuit to extend its frequency range of operation was proposed in [2]. As noted in [3], both circuits, the original in [1] and the modified in [2], ignored the losses in the capacitors. Therefore in [3], two new oscillator circuits, derived from active-RC filters for measuring the capacitances and their losses, were proposed. Each circuit used two capacitors and two resistors. Although values of the capacitances were not required to be exactly equal, their nominal values must be the same. This is a disadvantage of this method, as in many practical cases the nominal value of an unknown capacitance, to be measured, is not known.

In this paper, a new operational amplifier-based oscillator is presented for the measurement of capacitances and their losses. The circuit uses three resistors and one grounded capacitor; the capacitor to be measured. In the circuit, the finite open-loop gain of the operational amplifier is used to advantage and thus, high frequency ranges of operation can be easily achieved. The circuit assumes that the losses of the capacitor are taken into consideration. Since the circuit uses a single grounded capacitor; the unknown capacitor, the measurement is insensitive to stray capacitances as these stray capacitances can be easily taken into consideration. Measurements of capacitances and their losses using the proposed circuit requires only knowledge of the resistance value and the frequency of oscillation that can be easily measured in any laboratory. Thus, the proposed circuit avoids the disadvantages of the previously proposed circuits.

Proposed Circuit

The proposed circuit is shown in Fig. 1 where the capacitor C and the resistor R represent the unknown capacitance and its losses. It is assumed that the operational amplifier is internally compensated with a frequency-dependent differential-gain represented by the single-pole model of equation (1).

$$G(s) = \frac{G_0\omega_1}{s + \omega_1} \tag{1}$$

where ω_1 is the corner frequency and G_0 is the open-loop gain of the operational amplifier. Assuming that the input resistance of the operational amplifier is infinite and its output resistance is zero, the transfer function of the circuit of Fig. 1, with the feedback loop disconnected at M, is given by

$$T(s) = \frac{y}{x} = \frac{G(s)R}{(R + R_3 + sCRR_3)(kG(s) - 1)} \tag{2}$$

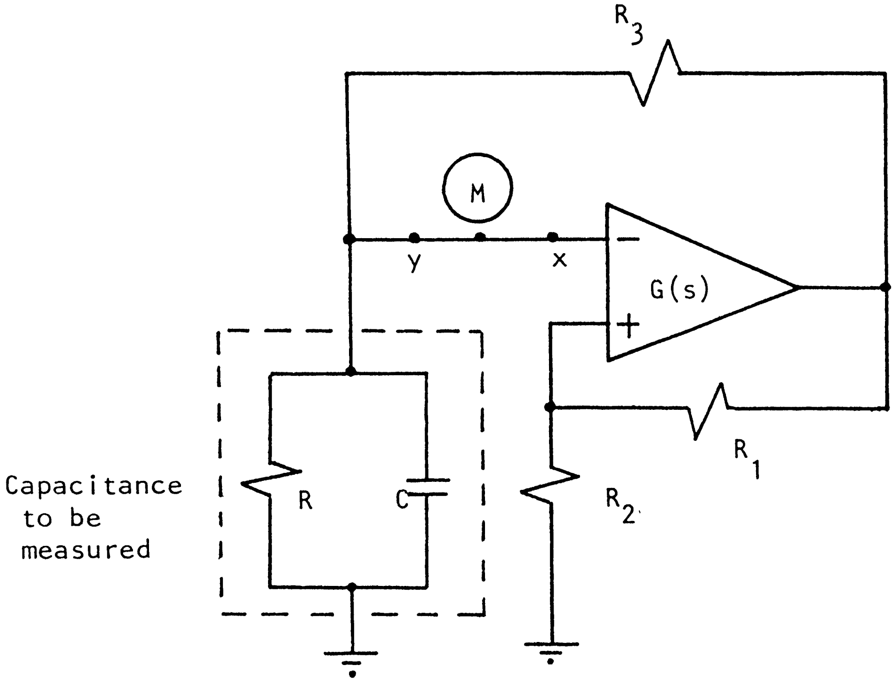

FIGURE 1 Proposed Circuit

where $k = R_2/(R_1 + R_2)$. Now, combining (1) and (2) the transfer function can be expressed as

$$T(s) = \frac{G_0\omega_1 R}{(R + R_3 + sCRR_3)(kG_0\omega_1 - \omega_1 - s)} \tag{3}$$

By closing the loop, the characteristic equation of the circuit, $T(s) - 1 = 0$, can be expressed as

$$\begin{aligned} s^2CRR_3 - s(CRR_3(kG_0 - 1)\omega_1 - R + R_3) \\ + G_0\omega_1 R - (R + R_3)(kG_0 - 1)\omega_1 = 0 \end{aligned} \tag{4}$$

Therefore, by equating the real and imaginary parts of (4) to zero, i.e., using the Barkhausen criterion, the frequency and the condition of oscillation of the circuit of Fig. 1 can be expressed as

$$\omega_0^2 = \frac{((G_0(1 - k) + 1)R + (1 - kG_0)R_3)\omega_1}{CRR_3} \tag{5}$$

and

$$CR_3R(kG_0 - 1)\omega_1 = R + R_3 \tag{6}$$

Equation (6) shows that, for any value of the capacitance C and the ratio of resistances k, the circuit of Fig. 1 can generate sinusoidal oscillations if the value of the resistance R_3 is properly adjusted. From (5), it is obvious that the expected frequency of oscillation is much greater than ω_1. By solving equations (5) and (6) for the unknown capacitance C and its losses R, one obtains

$$C = G_0\omega_1/(R_3(\omega_0^2 + \omega_1^2(kG_0 - 1)^2) \tag{7}$$

and

$$R = R_3 \frac{\omega_0^2 + \omega_1^2(kG_0 - 1)^2}{\omega_1^2(kG_0 - 1)(G_0(1 - k) + 1) - \omega_0^2} \tag{8}$$

Equations (7) and (8) form the basis for the proposed technique for measuring capacitances and their losses. The proposed technique can be summarized as follows:

a. Assume the values of the resistors R_1 and R_2 are fixed; that is, the ratio k is fixed.
b. Then the value the resistance R_3 is changed carefully until the point where the circuit just starts oscillation is reached.
c. Find the value of the resistance R_3 at which the oscillation just starts.

d. Measure the frequency of oscillation.
e. Then using equations (7) and (8), the value of the unknown capacitance C and its associated losses R can be calculated.

EXPERIMENTAL RESULTS

The circuit shown in Fig. 1 was built using a 741 operational amplifier with G_0 = 221018 and $\omega_1 = 14\pi$rad/sec. The proposed technique was used to measure capacitances and their losses for a number of capacitors. The results are shown in Table I, and show that the accuracy obtainable in measuring the capacitance is good. It must be mentioned, however, that the accuracy of measuring the capacitances and their losses will depend on the accuracy of measuring the resistors R_1, R_2, and R_3. Also, the accuracy will depend on the accuracy of measuring the parameters G_0 and ω_1 of the operational amplifier.

CONCLUSION

In this paper, a new simple oscillator circuit for measuring the capacitances and their losses has been presented. The circuit uses one internally-compensated operational amplifier, three resistors, and requires only one capacitor; the unknown capacitor, to oscillate. The proposed oscillator exploits, to advantage, the frequency dependence of the open-loop gain of the operational amplifier. Thus, the measurements of capacitances and their losses will be performed at relatively high frequencies. Experimental results show that measurements with moderate accuracies can be easily obtained using readily available circuit components; for example, the 741 operational amplifier. However, since the operation of the circuit depends on the parameters G_0 and ω_1 of the operational amplifier, it is recommended to use temperature-compensated operational amplifiers, such as the LM324. Also,

TABLE 1
Measured and calculated capacitances. R_1 = 100.6K, R_2 = 99.6Ω.

C (capacitor meter) (nF)	C (from circuit) (nF)	Frequency (f) (khz)	Resistance (R) (kohm)
30.83	29.696	54.05	2.81
99.6	101.517	50.25	0.951
215.5	219.353	39.76	0.703
293.9	297.266	39.41	0.528
394.7	399.638	34.25	0.520
494.2	499.254	31.25	0.500
610.1	611.242	29.87	0.447
688.5	700.360	29.28	0.406
788.1	814.87	30.72	0.317
904.1	908.3	38.13	0.186

regulated dc power supplies are recommended to avoid the variation of the parameters G_0 and ω_1 with the dc supply voltage.

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