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Negative Impedance Converter Improves Capacitance Converter

Ventseslav D. Draganov[1], Zlatko D. Stanchev[2] and Ilya T. Tanchev[3]

Abstract - **The problem of increasing the frequency output relative sensitivity of the capacitance converter and decreasing the influence of the parasitic capacitances is solved by connecting the Negative Impedance Converter (NIC) into the converter.**

An equation of equivalent NIC's capacitance depending on the value of its circuit elements is worked out in this paper. The results are confirmed from investigation by simulation using software, reading the influence of the parasitic capacitances as well as of the input capacitance of the op amp in NIC's circuit.

Key words - **Negative Impedance Converter**

I. Introduction

When developing the capacitance converters for measuring of non-electrical quantities a necessity to design converter circuits for registering very small capacity with reduced influence of the parasitic capacitance arises.

A converter "*capacitance – DC voltage*" consisting of two converters – *"capacitance – time interval"* and *"time interval – DC voltage"* is developed. It is capable of compensating the parasitic capacitance of the connected primary capacitance converter to certain extent [1]. This solution provides comparatively low sensitivity (a few pF).

It is suggested a new solution enabling the increasing of the output relative sensitivity of *capacitance converter* when it is needed the comparatively large parasitic capacitance (over 10÷20 pF) to be compensated – by connecting Negative Impedance Converter (NIC).

The use of special schemes for improving then sensiti-vity of the capacitance converters by decrease of their actual capacitance C_0 is known. Scheme applications are known which:

- connecting of the NIC into the capacitance converter reduces C_0 of the converter to a final capacitance of C_0 - C_{eq} [2].

- improving a capacitive-sensor circuit with a modulator and an RF transmitter by modifying the modulator portion from adding a "negatron" circuit (a configuration that uses equivalent negative capacitance) [3].

The final result of the both cases is higher frequency output relative sensitivity dF/F_0.

The study of this circuit solution is carried out without reading the influence of the parasitic capacitances as well as of the input capacitance of the used op amp.

The negative impedance converter (NIC) is used to realize negative driving – point impedances. Negative capacitances are applied in gyrator-active C filters [4].

Two floating NIC circuits (FNICs) are now suggested, which can be used to simulate floating negative elements. The dependence of the input impedance of FNIC is defined by the chain matrix. An application of Floating Negative-Impedance Converter (FNIC) for designing of a two directional constant-resistance amplifier is given [5].

II. Exposition

A. Negative Impedance Converter (NIC)

The Negative Impedance Converter (NIC) represents a four-pole (*fig.1*), for which the following dependences are valid [6]:

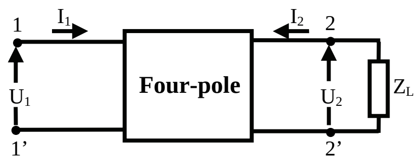

Fig.1. Negative Impedance Converter (NIC)

$$Z_i = \frac{U_1}{I_1} = -k.Z_L \tag{1}$$

$$Z_L = -\frac{U_2}{I_2} \tag{2}$$

$$\frac{U_1}{I_1} = k.\frac{U_2}{I_2} \tag{3}$$

There are two separate boundary cases – the Current Negative Impedance Converter (CNIC) and the Voltage Negative Impedance Converter (VNIC). If the conversion is fulfilled in the respect of the voltages, a VNIC scheme is obtained (*fig.2*).

[1] Ventseslav D. Draganov is from the Faculty of Electronics at the Technical University - 1, Studentska Str., Varna, Bulgaria, e-mail address: draganov_vd@abv.bg

[2] Zlatko D. Stanchev is from the Faculty of Electronics at the Technical University - 1, Studentska Str., Varna, Bulgaria, e-mail address: zlatko_stanchev@abv.bg

[3] Ilya T. Tanchev is from the Faculty of Electronics at the Technical University - 1, Studentska Str., Varna, Bulgaria, e-mail address: itta@ms3.tu-varna.acad.bg

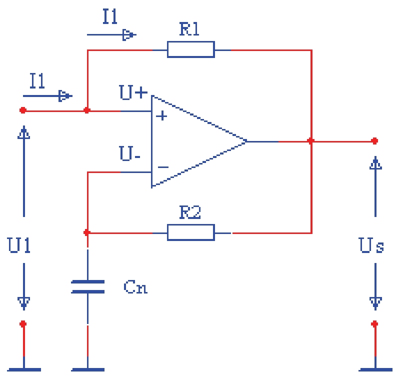

Fig.2. Voltage Negative Impedance Converter (VNIC)

When using *ideal elements* the dependence is valid:

$$Z_{Cn} = X_{Cn} = \frac{1}{\omega.C_n} \tag{4}$$

$$Z_{Ci} = X_{Ci} = \frac{1}{\omega.C_i} \tag{5}$$

$$U_1 = U_- = U_+ = U_S.\frac{X_{Cn}}{X_{Cn} + R_2} \tag{6}$$

$$U_S = U_1 - R_1.I_1 \tag{7}$$

From (6) it follows:

$$U_S = \frac{U_1.(X_{Cn} + R_2)}{X_{Cn}} \tag{8}$$

After substituting of (8) in (7), it is obtained:

$$\frac{U_1(X_{Cn} + R_2)}{X_{Cn}} = U_1 - R_1.I_1. \tag{9}$$

After transforming of (9) it is obtained:

$$U_1 = -\frac{R_1.I_1.X_{Cn}}{R_2} \tag{10}$$

whence it is determined:

$$Z_i = \frac{U_1}{I_1} = -R_1.\frac{X_{Cn}}{R_2} \tag{11}$$

From (5) and (11) the input capacity of VNIC is defined:

$$C_i = -\frac{R_2}{R_1}.C_n. \tag{12}$$

The Voltage Negative Impedance Converter (VNIC) enables schemes of negative capacitance to be synthesized, taking into consideration the stability since the negative capacitance cannot exist in natural mode, only connected to other elements.

The choice of the element values in the negative impedance realization is usually based on the following general design consideration:

$$R_0 << (R_1, R_2, X_C) << R_{id} \tag{13}$$

where R_0 is output resistance, R_{id} is input differential resistance of the used operational amplifier [2].

The maximum useful frequency can be increased by making $R_1 = R_2$ [2].

B. Capacitance converter with VNIC, connected into the measured capacitance

For decreasing the influence of the initial capacitance on *the primary capacitance converter* and of the parasitic capacitances of its connecting conductors with goal - increasing the frequency output relative sensitivity of the capacitance converter, using relaxing generator, to the litter *VNIC* is connected – *fig.3*.

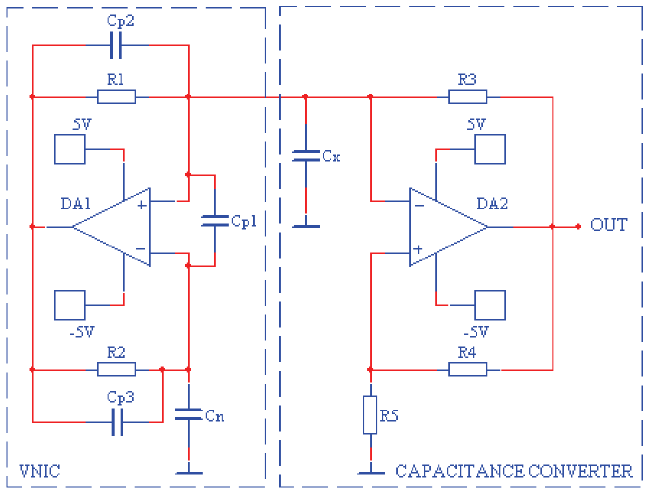

Fig.3. Capacitance converter with VNIC, connected into the measured capacitance

The capacitance converter consists of relaxing generator, which, is realized by the operational amplifier *DA2*, the resistors R_3, R_4, R_5 and the capacitor C_x on the primary capacitance converter. Parallel to the primary capacitance converter is connected VNIC, which is realized by the operational amplifier *DA1*, the C_n capacitor and the resistors R_1 and R_2.

The frequency of generated oscillations is defined by the expression [7]:

$$f = \frac{1}{T} = \frac{1}{N.R_3.C_{eq}} \tag{13}$$

where:

$$C_{eq} = C_x + C_i \tag{14}$$

the coefficient N is defined by values of the resistors R_4 and R_5 as well as of the supply voltage.

After replacing (12) and (14) in (13) following relationship is defined:

$$T = N.R_3.\left(C_x - \frac{R_2}{R_1}.C_n\right) \tag{15}$$

The period of the generated signal is decreased proportionally to the values of the capacitance C_n and the resistor R_2 and conversely proportionally - to the value of the resistor R_1 in the circuitry of VNIC.

EXPERIMENTAL RESEARCH

The capacitance converter, with *VNIC* connected into the measured capacitance, is studied by simulation with the program product *Electronics Workbench 5.12*. The influence of the value variations of the elements of VNIC, connected to the converter on the period of the generated signal *T*, is studied by reading the influence of the input capacitance of the op amp in NIC's circuit as well as of the parasitic capacitances.

1. The dependence of the period of generated oscillations from the capacitance of the C_n capacitor in VNIC's circuit.

The dependence is defined by reading also the influence of input capacitance C_{in} on op amp *DA1* in VNIC's circuit. For this purpose, parasitic capacitance C_{p1} is connected to input terminal on *DA1* in parallel, which is a real parasitic capacitance with values from 0 to 5pF; when C_{p1} = 0pF only the input capacitance C_n exercises influence on the op amp, which is smaller than the capacity C_x.

The experimental results are shown graphically in *fig.4*, where value of the resistors $R_1 = R_2 = 15$ kΩ and the *primary capacitance converter* C_x = 5 pF.

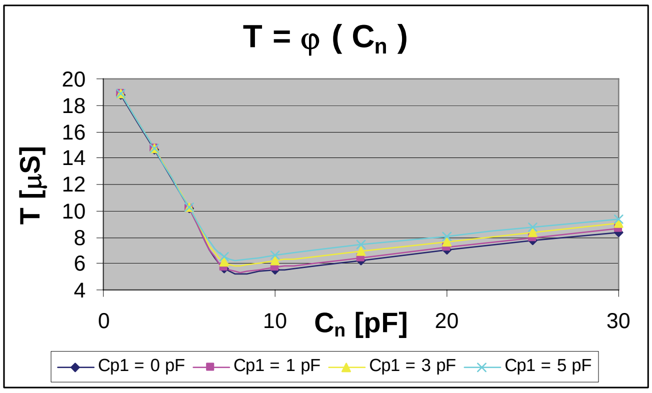

Fig.4. Dependency T = φ (C_n), with C_p = 0 ÷ 5 pF

Conclusion: The dependence $T = \varphi\ (C_n)$ corresponds to this formula from (15) to a considerable degree when the value of the capacitance $C_n < C_x$.

In order to receive an explanation for the radical change of the character of this dependence when the values $C_n > C_x$ the dependence of the current through the parasitic capacitance C_{p1} (*fig.5*) and the voltage between the input terminals of *DA1* (*fig.6*) on the capacitance C_n variation. When $C_n > C_x$ the current through the input capacitance increases, the voltage between the input terminals of *DA1* also increases and the circuitry with *DA1* becomes unstable (it does not correspond to VNIC) – the capacitances C_{in} and C_{p1} are connected to C_x in parallel which on its behalf leads to increasing of the total capacitance defining the generator frequency.

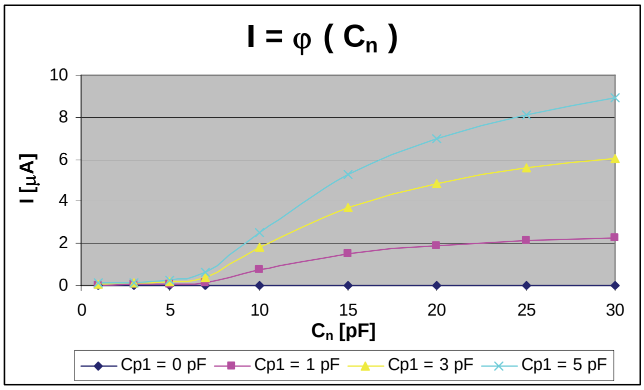

Fig.5. Dependency I = φ (C_n), with C_x = 5 pF and C_p = 0 ÷ 5 pF

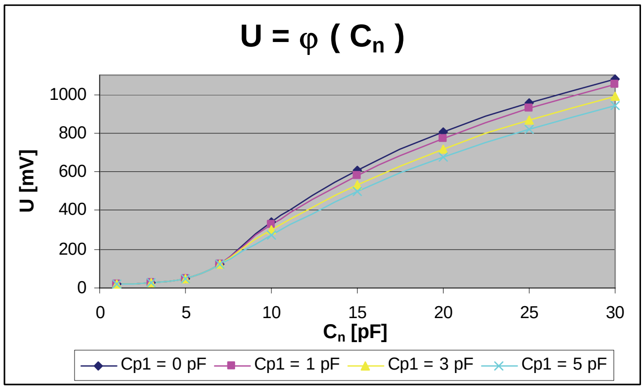

Fig.6. Dependency U = φ (C_n), with C_x = 5 pF and C_p = 0 ÷ 5 pF

The drawn conclusions are also confirmed when the values of C_x = 10 pF (*fig.7*).

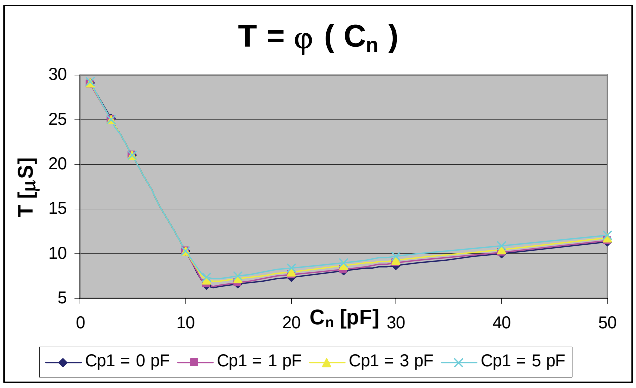

Fig.7. Dependency T = φ (C_n), with C_x = 10 pF and C_p = 0 ÷ 5 pF

2. The dependence of the period of generated oscillations from the resistors R_1 and R_2 in VNIC's circuit

The dependences $T = \varphi\ (R_2 / R_1)$, at change of the relationship $k = \dfrac{R_2}{R_1}$, for R_1 = 15 kΩ, C_x = 5 pF, C_{p1} = 0 pF (only the capacitance C_{in} has an effect), are shown graphically in *fig.8*.

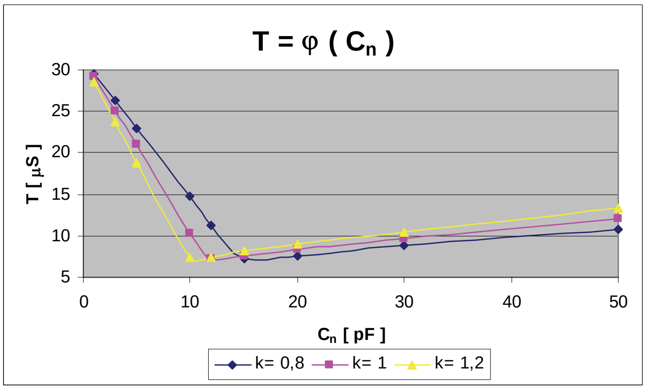

Fig.8. Dependency T = φ (k, C_n)

Conclusion: The results obtained from the tests show the correctness of the dependency $T = \varphi\ (C_n, R_2, R_1)$, expression (15), when the capacitance value $C'_n \leq C_x$.

3. The dependence of the parasitic capacitances C_{p2} and C_{p3}

In a real circuitry and the parasitic capacitances C_{p2} and C_{p3} (*fig.3*) also exists. The experimental results for the dependence of the period of generated signal *T* on the variation of each of them shown graphically in *fig.9* and in *fig.*10.

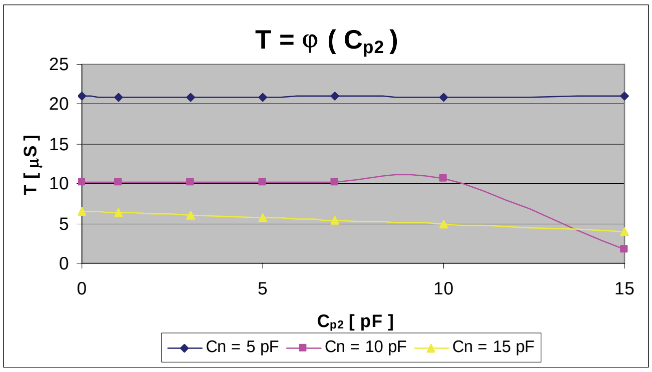

Fig.9. Dependency T = φ (C_{p2})

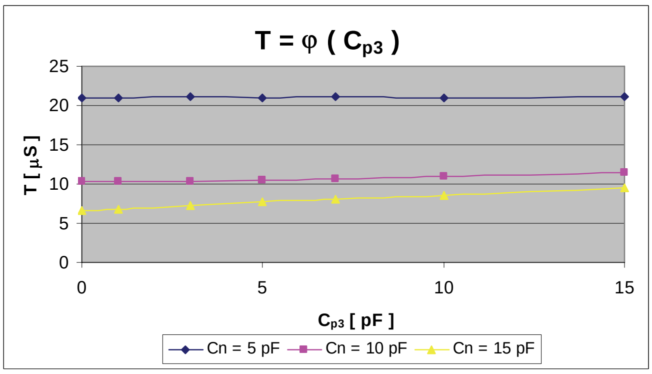

Fig.10. Dependency T = φ (C_{p3})

In *fig.11* the studies of the dependence of the generated signal period *T* on the simultaneous change of the parasitic capacitances C_{p2} and C_{p3} are depicted.

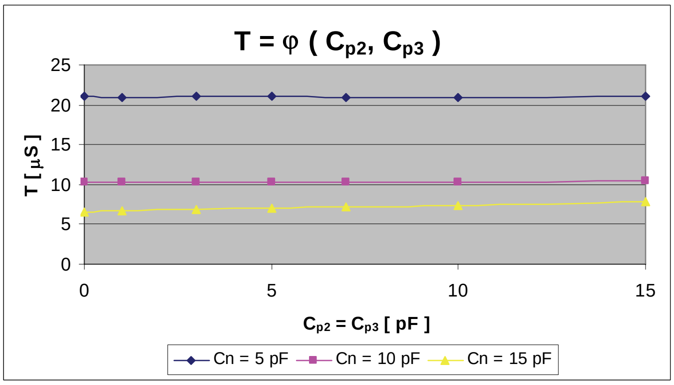

Fig.11. Dependency T = φ (C_{p3}) with C_x = 15 pF

Conclusion: When the capacitance $C_n < C_x$ in the circuitry of VNIC the parasitic capacitances C_{p2} and C_{p3} have noticeable effect only just at values over (5 ÷ 10) pF, which are greater than the real ones.

III. Conclusion

By using the Voltage Negative Impedance Converter (VNIC) the output relative sensitivity of the capacitance converter, constructed on the basis of relaxing generator with connected to it primary capacitance converter is increased. This is due to decreasing of the initial capacitance of the primary capacitance converter as well as to lessening the effect of the parasitic capacitance of the conductors connecting the primary capacitance converter.

The studying the converter carried out through its operating simulation using software confirm the derived theoretical relationships for the effect of the VNIC capacitance variation within a certain range on the frequency of the generated oscillations. The reasons for invalidity of the results outside the range in which the connection of the circuitry of VNIC to the primary capacitance converter decreases its initial capacitance is explained by the results from the studies.

In case of necessity to decrease the effect of the parasitic capacitances in measuring circuits VNIC can be used to increase their sensitivity.

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