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DETERMINATION OF OPTIMUM CIRCUIT OF MEASUTRING CAPACITANCE CONNECTION TO FREQUENCY CONVERTER OF THICKNESS

The paper considers the results of research, dealing with the study of value and place of measuring capacitance connection to frequency converter of thickness, based on negative resistance. The technique of transfer function, measurement range and sensitivity obtaining by means of computer-based experiment of described. The choice of optimum variant of connection, based the analysis of the results obtained is substantiated.

Key words: *thickness measurement, frequency generators, negative resistance.*

Introduction

As a result of rapid development of nanotechnologies the problem dealing with determination of metrological parameters of coating becomes very actual in modern engineering. That is why, the necessity to enhance the possibilities of existing facilities of thickness measurement is of great importance. However, it should be noted in conditions of saturated market of such devices, it is not sufficient to create the product, possessing high metrological qualities. Important factors needed for promotion are economic and technological indices of the device, low cost, easy operation and reliability.

Main concept, new thickness measuring devices are based on, was to provide multiple set of characteristics, enabling to improve measurements quality and open the way to commercial applications of such devices.

These characteristics could be classified into three groups: economical efficiency (low cost and easy operation), metrological qualities (sensitivity, noise – proof, small minimum threshold of measurements), practical application (adaptability to manufacture and ability to perform measurements without interruption of technological process).

Proceeding from the analysis performed [1], the most promising, in accordance with the above-mentioned criteria, are frequency converters, based on negative resistance [2], coupled with capacitive primary sensor [3].

We will outline the following advantages of such combinations [4-6]:

C-sensor	**Frequency converter**
• high stability	• high sensitivity and accuracy
• linearity	• wide range of measurements
	• noise-proof of output signal
• *simplicity*	• *simplicity*
• *low cost*	• *low cost*
• *high adaptability to*	• *high adaptability to*
manufacture	• *manufacture*

Measuring system, including frequency converter on negative resistance (Fig. 1) operates in the following manner: variation of measured value (thickness) leads to change of total dielectric constant of measuring gap or geometric dimensions of primary sensor (capacitor), which converts it into analog signal (i. e, in capacitance change), this signal influences internal parameters of frequency converter based on negative resistance (FCNR), as a result, generation frequency of output signal varies.

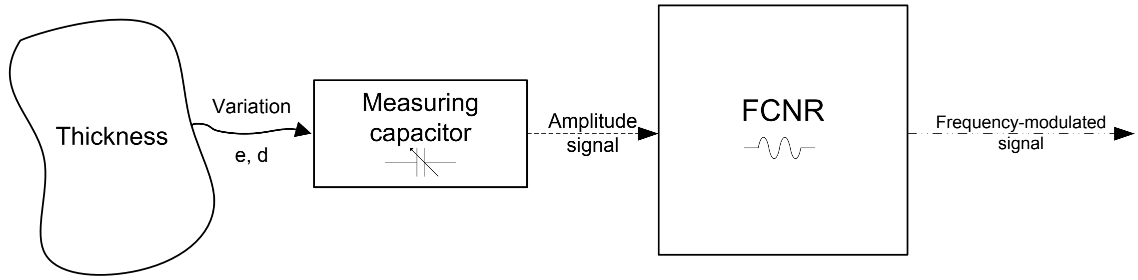


Fig.1. Principle of operation of thickness frequency converter , based negative resistance

The main structural component of FCNR scheme is transistor structure with negative resistance, which performs the function of equivalent capacity in oscillatory resonant LC-circuit. The value of this capacity is controlled by variation of the input signal, as a result, correlation between measuring analog signal and output frequency is achieved.

The main aim of the given research is to determine optimum place primary sensor connection to FCNR on the example of two variation of the converter (Fig. 2).

Schematic diagram of transistor structure comprises 4 blocks (without taking into consideration the connection projective capacitor Cp), that is why 6 possible versions (schemes) of measuring capacitances are possible [7].

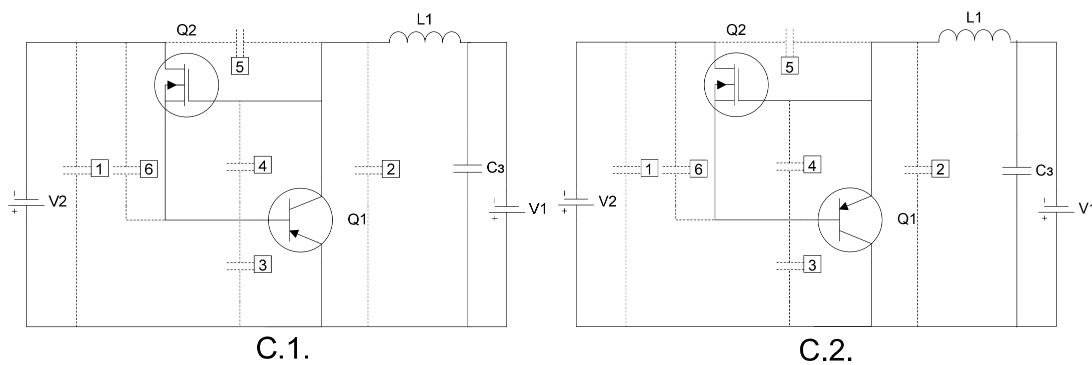
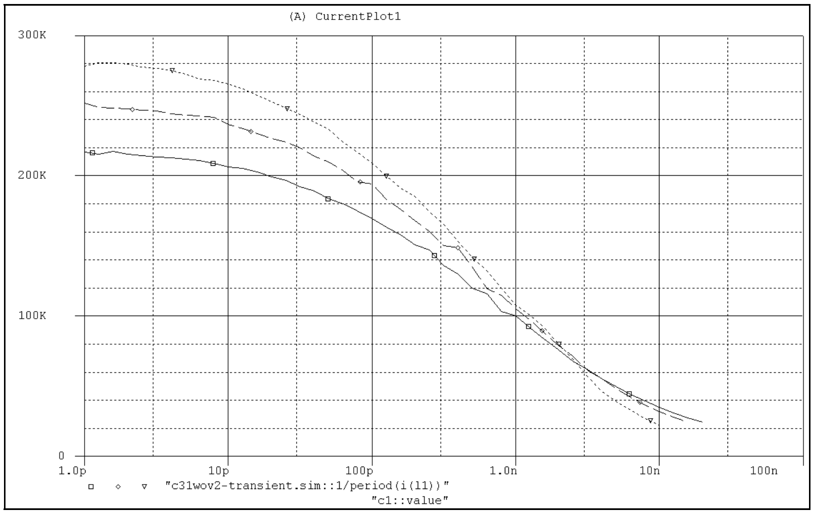


Fig. 2. Variants of switching-circuits of capacitor sensitive element

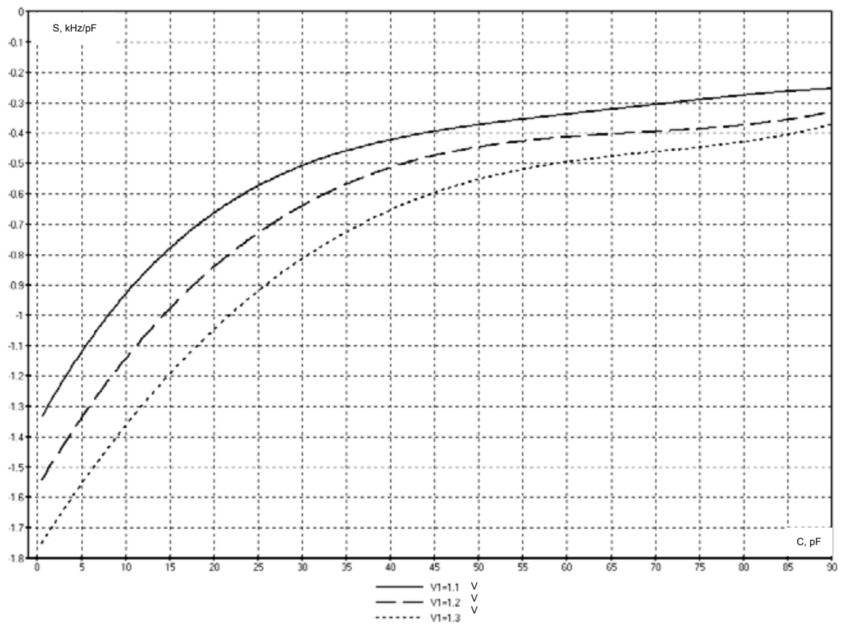
Research tools

As the basic software application used for modelling of developed circuits-hypotheses, software package OrCAD, based on the language of description and modeling of electronic circuits PSpice A/D 16.0 was chosen [8, 9]. Mode of parametric modelling in the given package allows to perform computer experiment in circuit operator mode, varying the capacity of measuring capacitor. For each measurement corresponding change of output frequency generation at different values of supply voltage is found. This enables to determine measurement range, construct dependence of generation frequency in graphic form (by points) and sensitivity (as derivative of transformation function) on capacity and we can make a conclusion regarding further possibility of using converter in this or that measuring range.

For the sake of example we will show the results of analysis of the circuit C.1.4 (fourth switching in circuit 1) (Fig. 3). Three branches of the family on each of presented dependences occur because modeling was performed with three different voltages of the source V1 = 1.1-1.3 V (for determination of V1 change influence on circuit operation).



a)



b)

Fig. 3. a) dependence of generation frequency of circuit C.1.4 on the capacitance of measuring capacitor;
b) sensitivity of circuit C.1.4 transformation in the range of 1 pF - 90 pF

Influence of change of measuring capacity C1, which is connected by the circuit 1.4:

- in the range of 1 pF - 35 nF there exists corresponding change of generation, which is of stable character and can be used for measuring purpose;
- in the range 35 nF generation is missing.

Analysis and processing of the results obtained

The results obtained by the method, described above are shown in generalized Table 1. It should be noted that some of presented circuits are either almost insensitive to capacity change or do not posses certain regularity or such change, that is why, the data, of such circuit are not shown in the table. We should also note that the sensitivity is given without taking onto account its sign (positive or negative), since the sign indicates only the direction of generation frequency variation (increase or decrease).

Table 1.

Capacity influence on FCNR operation

	Number of the circuit					
	C.1.2	**C.1.4**	**C.1.5**	**C.2.2**	**C.2.4**	**C.2.5**
Max. measuring range	1 pF 300 μF	1 pF 55 nF	1 pF 30 μF	1 pF 1 μF	1 pF 1 nF	1 pF 1 μF
Max. sensitivity., kHz/pF	0.6	2	0.4	250	365	197
Tuning range, kHz	280 – 2	280 – 20	280 – 20	4500 – 20	5000 – 40	5000 – 20
Maximum sensitivity at circuit values of C, kHz/pF						
1 pF	-	2	-	251	365	197
10 pF	0.5	1.3	0.4	67	76	70
100 pF	0.205	0.41	0.25	8	8.2	8
1 nF	58E-03	167E-03	80E-03	451E-03	362E-03	422E-03
10 nF	11E-03	25E-03	14E-03	18E-03	-	17E-03
100 nF	1.90E-03	-	2.25E-03	0.629E-03	-	0.604E-03
1 μF	260E-06	-	-	18E-06	-	18E-06
10 μF	28E-06	-	-	-	-	-
100 μF	2.80E-06	-	-	-	-	-

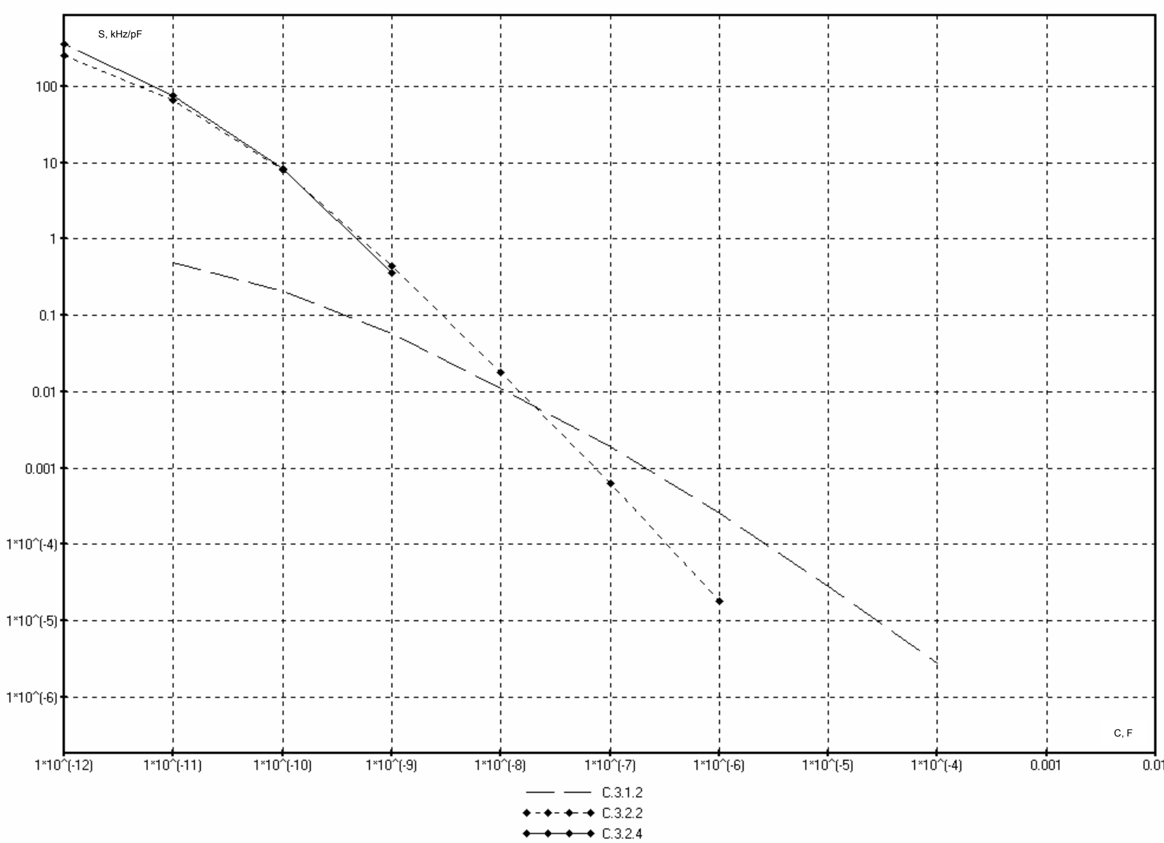


Fig. 4. Diagram “sensitivity – variation range” relation

On the basis of this Table the diagram “sensitivity – variation range” relation is constructed

(Fig. 4). Certain capacity value of measurement range is plotted on the abscissa, corresponding value of sensitivity in the same range is plotted on the ordinate. The given diagram enables to compare circuits of various switchings and define connection circuit of external sensor, optimal for given conditions.

Proceeding from the suggested dependences, we can conclude that connection C.1.4, possesses the highest sensitivity among the circuits of the first group, where as connection - C.1.2 possesses maximum measuring range.

Regarding the circuits of the second group, the comparison of C.2.2 and C.2.4 shows that the second circuit has advantages only in the area of units – hundreds of picofarads. The first circuit has larger range of measurement and sensitivity at all other values. One more advantage of C.2.2 circuit is low dependence of its parameters on variation of V1, and, as an result, minor influence of random voltage deviations of power source. Among the circuit of the second group more universal circuit C.2.2, is recommended to use, and only in case, when it is necessary to obtain higher sensitivity within the range up to 100 pF- C.2.4.

Comparing the circuits, belonging to groups 1 and 2, we can notice far greater sensitivity of the circuits, belonging to the second group, at lower capacitance (less than 10 nF), however, in submicrofarad range their sensitivity becomes less. And in case of further increase of capacitance circuits of groups 2 leave autooscillation mode and generation is interrupted.

Thus, making a conclusions we can recommend for usage, depending on operation mode, the following switching circuits:

- for measurements from 1 pF to 10 nF – circuit C.2.2;
- for measurements from 10 nF to 10 μF – circuit C.1.2;
- special high-sensitive version for measurements from 1 to 100 pF – circuit C.2.4;

To make the given dependences more evident, we will introduce the notion of normalized range sensitivity, that taking into account the decrease of sensitivity at the increase of capacitance (df/dc has negative sign) will be written as:

$$Sc = \frac{S \cdot C}{F_b},$$

where S – is sensitivity at the capacitance C, and F_b – normalized frequency 1 mHz.

This nondimensional value numerically equals the sensitivity of the circuit while variation of the capacity of primary converter per unit of corresponding range (MHz/μF, MHz/nF etc). Hence, this value enables to evaluate more accurately the sensitivity of the circuit in any measuring range. It is very convenient to apply Sc for description of circuits , in which possible change of sensitivity values reaches several orders, since it enables to show sensitivity change without application of logarithmic scale on the ordinate and compare more accurately different versions of switching. Graphic dependences of normalized range sensitivity for investigated circuits, shown in Fig 5, confirm the conclusions regarding the application of switching circuits.

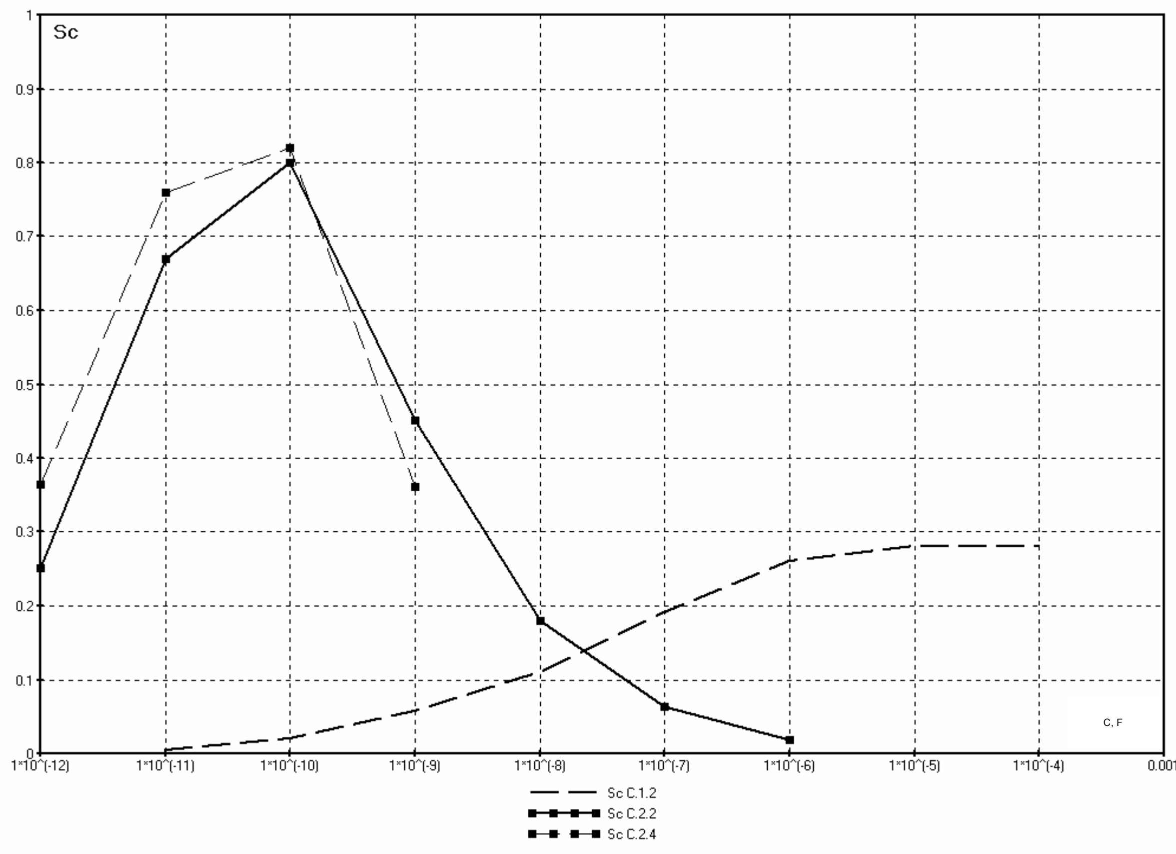


Fig. 5. Normalized range sensitivity

Conclusion

1. The given research contains the results of computer experiment dealing with modeling of capacitive frequency thickness gauge operation, based on negative resistance at different versions of measuring capacitor connection.

2. Technique required for obtaining conversion function, measurement range and sensitivity relatively variation of measuring capacity is elaborated.

3. Optimality criteria for comparison of switchings, based on application of “sensitivity-measurement” relation and normalized range sensitivity diagrams are defined and calculated. The selection of optimal version of measuring capacity connection to frequency converter, based on negative resistance is substantiated.

REFERENCES

1. Осадчук О. В. Проблеми вимірювання товщини нанесеного покриття та методи підвищення його точності / О. В. Осадчук, Р. В. Криночкін // Нові Технології. – 2009. – №1. – С. 102 – 105. – ISSN: 1810-3049
2. Осадчук В. С. Напівпровідникові перетворювачі інформації / В. С. Осадчук, О. В. Осадчук – Вінниця: ВНТУ, 2004 – 208 с.[1]
3. Гриневич Ф. Б. Измерительные компенсационно мостовые устройства с емкостными датчиками / Ф.Б. Гриневич, А. И. Новик.; АН УССР, Ин-т Электродинамики. – Киев: Наукова думка. – 1987. – 112 с. – Билиогр.: с.105-110 (109 назв.).
4. Осадчук В. С. Реактивні властивості транзисторів і транзисторних схем / В. С Осадчук., О. В.Осадчук – Вінниця: УНІВЕРСУМ-Вінниця, 1999. – 275 с. – ISBN 966-7199-67-3.
5. Струнский М. Г. Бесконтактные емкостные микрометры / М. Г. Струнский, М. М. Горбов – Л.: Энергоатомиздат: Ленинградское отд-ние, 1986. – 136 с.: ил.
6. Иоссель Ю. Я. Расчет электрической емкости / Ю. Я. Иоссель, Э. С. Кочанов, М. Г.

Струнский. – 2-е изд. перераб. и доп. – Л.: Энергоатомиздат, Ленинградское отд-ние, 1981. – 288 с.

7. Осадчук О. В. Вплив зовнішньої вимірювальної ємності на ЧПВО / О. В. Осадчук, Р. В. Криночкін // Сучасні проблеми радіоелектроніки, телекомунікацій та приладобудування (СПРТП-2009): матеріали IV міжнародної науково-технічної конференції, Вінниця, 8-10 жовтня 2009 року. – Вінниця, 2009 . – Частина 2. – С.78

8. Болотовский Ю. И. OrCAD. Моделирование. «Поваренная» книга/ Ю. И. Болотовский, Г. И. Таназлы – М.: СОЛОН-Пресс, 2005. — 200 с. — (Серия «Библиотека студента»). - ISBN 5-98003-178-2

9. Хайнеман Р. Моделирование работы электронных схем / Р. Хайнеман. – М.:ДМК-Пресс, 2005. – 327 с.– (Серия «Проектирование»).

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