Bogdan BLAGITKO, Volodymyr BRYGILEVYCH, Vasyl RABYK

Ivan Franko National University of L'viv, Ukraine

Hardware and software for electronic circuit diagnostics

***Abstract**. Theoretical and practical aspects of diagnostics of the electronic circuits in the DC and in the frequency domain, and required for this purposes hardware and software were considered. The embedded microprocessor system for the node potentials measurement, software and examples of diagnostics of the electronic circuits in the DC and in the frequency domain were described.*

***Streszczenie.** W pracy przedstawiono teoretyczne i praktyczne aspekty diagnostyki układów elektronicznych przy prądzie stałym i w dziedzinie częstotliwości oraz niezbędne dla tego oprogramowanie i sprzęt pomiarowy. Przedstawiono opis wbudowanego systemu mikroprocesorowego dla pomiaru potencjałów węzłowych, oprogramowanie oraz przykłady diagnostyki układów elektrycznych przy prądzie stałym i w dziedzinie częstotliwości (**Sprzęt i oprogramowanie systemu diagnostyki układów elektronicznych**).*

Keywords: measurement, testing, circuit diagnostics, nodal potentials
Słowa kluczowe: pomiar, testowanie, wykrywanie uszkodzeń w układach elektronicznych, potencjały węzłowe

1. Introduction

Diagnostics of the electronic circuit includes two stages: experimental and computational. During the experimental stage the investigator works with the real circuits (measures the circuit response to different input signals). The goal of the computational stage (when the investigator works with the model of the circuit) is to find the parameters of the diagnosed circuit elements using the results obtained during the experimental stage

To determine the parameters of faulty elements with a limited number of measurements, the multi-test method of diagnostic of the circuit by the DC and in the frequency domain is used. It consists in measuring the nodal potentials [1, 2]. The main problems that arise by this approach are associated with the choice of measurable quantities, test sources and its internal impedance, test elements and its parameters and spot frequencies. The choice of instrumentation depends on the influence of the fault of the nodal potentials measurements on the diagnostic results of electronic circuits [3].

Number of elements, parameters of which can be diagnosed in an electronic circuit, depends on the number of measurements in it and is determined by the testing capability of this circuit. For the determination of the testing capability the sensitivity matrix of nodal potentials with respect to the parameters of the circuit [4] is used. In [4] it is suggested to determine the value of the testing capability of the circuit as:

(1) $$\mu = n_x - \rho ,$$

where n_x - the number of parameters of the circuit elements, ρ - rank of the sensitivity matrix of the nodal potentials, depending on the parameters of elements X and a complex number *s*. If $\mu = 0$, then all the parameters of the circuit may be defined. Otherwise, identification of all parameters of elements of the circuit is impossible.

This paper reviews the main stages of the practical DC and the frequency domain diagnostic of electronic circuits (hardware and software tools for the diagnostics of electronic circuits). The software includes a multi-test method for diagnostic of circuits and its algorithmization. The hardware includes the method of measuring the nodal potentials in accessible and partially accessible nodes [1] of the circuit and its implementation in the microprocessor system.

The diagnostic of electronic circuits is proceeded with the choice of available and partly available nodes based on topological conditions for diagnosed elements, spot frequencies for test sources and test elements. Testing capability is defined by determining the rank of the matrix of nodal potentials sensitivity (by column).

2. The algorithmization of diagnostics method of electronics circuits

Modified method of nodes potentials is used for describing electronic circuits in the frequency domain. Let the scheme consists of $n_X=n_R+n_C+n_L$ elements and has n_A accessible, n_P partly accessible and n_I internal nodes [1]. Classically, during the diagnostics the test sources are connected ordinarily to each from n_A accessible nodes, and for each test, the nodes potentials in $n_A+ n_P$ accessible and partly accessible nodes are measured. Total quantity of independent nodes potentials for n_A tests is defined by expression:

(2) $$Q = n_A(n_A + n_P + n_I)/2 .$$

Testing by different frequencies allows increasing the amount of diagnosing equations in the frequency domain. Necessary condition of the solution existence of the diagnostic problem is as follows:

(3) $$n_X \le q \cdot Q$$

if only amplitude is measured and

(4) $$n_X \le 2q \cdot Q$$

if amplitude and phases of nodes potentials are measured, where *q* – number of spot frequencies by which testing is performed [2].

The diagnostic equation for the i-th test and the f_j spot frequency is of the following form:

(5) $$F^{(i)}\left(X, f_j\right) = V_m^{(i)}\left(f_j\right) - V^{(i)}\left(X, f_j\right) = 0 ,$$

where $i=1,\ldots,n_A$; $j=1,\ldots,q$; $V_m^{(i)}(f_j)$ - vector of measured nodes potentials in accessible and partly accessible nodes for the i-th test; $V^{(i)}(X, f_j)$ - vector of nodes potentials, received by modeling of the scheme for the i-th test; X – vector of elements parameters that are diagnosed.

If the amplitude and phase is measured actual equation system which is received from [2], is of the following form:

(6) $$\begin{cases} \mathrm{Re}[F\left(X, f_j\right)] = 0 \\ \mathrm{Im}[F\left(X, f_j\right)] = 0, \quad j = 1,\ldots q \end{cases} .$$

The following diagnostics equation system is received if only amplitude of nodes potentials is measured.

(7) $$F\left(X, f_j\right) = \left|V_M\left(f_j\right)\right| - \left|V\left(X, f_j\right)\right| , \quad i = 1, \ldots, q$$

Equation systems (5) and (6) are nonlinear and are solved using the Newton's method. Its modification is executed with introduction of the positive parameter α to improve convergence of the Newton's method. Modified nonlinear equation systems (5) or (6) is as follow:

(8) $$F(X) = 0,$$

where X – vector of elements parameters that are diagnosed. The parameter α in the k-th iteration is found by means of minimization of misalignment vector:

(9) $$\min F\left(X^k - \alpha_k \Delta X^k\right),$$

where $$\Delta X^k = \left[dF(X^k) \big/ dX \right]^{-1} F(X^k).$$

The Jacobean matrix of the diagnostics equation is bad conditioned for most of the electrical circuits. For solving such linear equation systems parametric regularizing method in each iteration of the Newton's method, is used. In this method solving of bad conditioned linear equation systems leads to minimization of functional:

(10) $$M^\alpha(X^\alpha, b) = |AX - b|^2 + \alpha |X|^2, \quad \alpha > 0$$

on the parameter α, which is determined by misalignment.

3. Example of electronic circuit diagnostics

Let us consider the diagnostics of electronic circuits in the frequency domain by the multi-test method on the example of high-pass filter schematic diagram of which is shown in fig. 1.

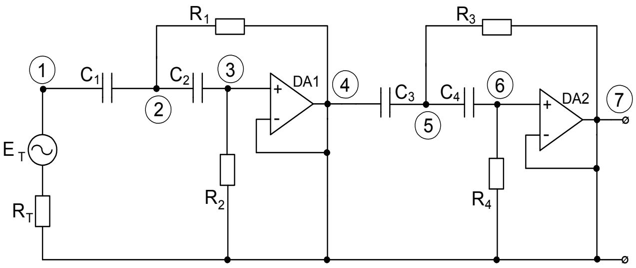

Fig. 1. Schematic diagram of the two-cascade high-pass filter

The filter consists of two cascades, each of which is implemented using operational amplifiers. For this circuit node 1 is accessible and nodes 2, 4 and 7 - partially accessible. Node 1 is connected to the test source $E_T = 5$ V with the test resistor $R_T = 10$ kΩ. Expressions (2) and (3) yield: $n_A = 1$, $n_P = 3$, $n_I = 3$, $n_X = 8$, $Q = 4$. Amplitude and phase of the nodal potentials in accessible and partially accessible nodes were determined using the simulation of electronic circuits behavior in the frequency domain. Number of diagnostic equations that are obtained for a single frequency point is $Q_I = 2Q = 8$. To determine the $n_X = 8$ parameters of diagnosed elements one spot frequency is enough.

The choice of the spot frequency for the testing was performed empirically using amplitude – frequency characteristic (AFC) (fig. 2) of nominal and faulty circuits and the sensitivity of the diagnosed elements by different spot frequency [5].

Results of simulations of normal and faulty circuits for the single spot frequency are presented in Table 1. Results of the diagnostic for the circuit are presented in Table 2.

The accuracy of the solution of the system of nonlinear equations for the diagnostic (8) of the circuit (Fig. 1) was $\varepsilon \le 0,1$ *mV*. From Table 2 we see that elements of the first cascade are diagnosed more accurately than the elements of the second cascade.

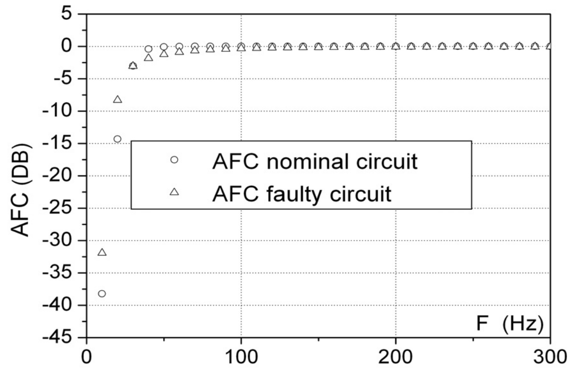

Fig.2. Magnitude of nominal and faulty circuits

Table 1. Results of modeling for nominal and faulty circuits (fig. 2)

F [Hz]		$\dot{V}_1$ [B]	$\dot{V}_2$ [B]	$\dot{V}_4$ [B]	$\dot{V}_7$ [B]	Remark
30	Re	3,017	2,018	0,510	-2,131	Nominal circuit
	Im	-0,941	1,163	1,634	0,649	
	Re	2,773	1,845	0,459	-0,981	Fault circuit
	Im	-1,004	1,001	1,442	1,799	

Table 2. Results of diagnostic of high-pass filter (fig. 2)

Element	Nominal value	Actual value	Result of diagnostic	Error of diagnostic, [%]
C_1(nF)	100,0	120,0	120,1	0,07
C_2(nF)	100,0	120,0	120,1	0,07
R_1(kOm)	49,00	39,20	39,21	0,028
R_2(kOm)	57,53	46,03	46,031	0,002
C_3(nF)	100,0	120,0	119,62	0,31
C_4 (nF)	100,0	120,0	119,67	0,28
R_3(kOm)	20,25	24,05	24,123	0,30
R_4(kOm)	138,5	166,2	166,68	0,27

When measuring only the amplitude of the nodal potentials the number of diagnostic equations that are obtained for one spot frequency is $Q_1 = Q = 4$. To determine $n_X = 8$ of the diagnosed elements two spot frequency are enough. Results of the simulations of normal and faulty circuits for two frequencies are presented in Table 3, and the results of the diagnostics in this case are presented in Table 4.

Table 3. Results modeling for nominal and faulty circuits (fig. 1)

F [Hz]	$\dot{V}_1$ [B]	$\dot{V}_2$ [B]	$\dot{V}_4$ [B]	$\dot{V}_7$ [B]	Remark
30	3,160	2,329	1,711	2,228	Nominal circuit
	2,911	2,099	1,513	2,050	Fault circuit
50	2,838	2,536	2,218	2,817	Nominal circuit
	2,569	2,273	1,969	2,228	Fault circuit

Table 4. Results diagnostic high-pass filter (fig. 1)

Element	Nominal value	Actual value	Result of diagnostic	Error of diagnostic, [%]
C_1(nF)	100,0	120,0	120,2	0,16
C_2(nF)	100,0	120,0	120,2	0,16
R_1(kOm)	49,00	39,20	39,21	0,025
R_2(kOm)	57,53	46,03	45,94	-0,15
C_3(nF)	100,0	120,0	120,3	0,25
C_4 (nF)	100,0	120,0	120,3	0,25
R_3(kOm)	20,25	24,05	24,28	0,96
R_4(kOm)	138,5	166,2	166,32	0,072

4. Microprocessor system for measuring real and imaginary parts of the nodal potentials.

When testing and diagnostic electronic circuits in the frequency domain the problem of measuring amplitude and phase or real and imaginary parts of the nodal potentials arise.

One of the methods for finding the amplitude and phase of signals is synchronous detection method. In [6] the description of the method of amplitude and phase measurements for sinusoidal signals is described. The method is based on four quadrature samples of the same frequency, each of which is shifted with respect to previous one for 90 degrees. In [7] the realization of this method in a microprocessor system is described for the diagnosis of electronic circuits.

Let's consider the implementation of microprocessor systems for amplitude the magnitudes and phases of nodes using synchronous detection method [6,7]. This system allows measuring the DC nodal potentials, real and imaginary parts of the nodal potentials in the frequency domain and recording the amplitude response and phase response of electronic circuits.

Let us assume the circuit with input test harmonic signals of known amplitude U_{IN} and frequency ω:

(11) $$u_{IN}(t) = U_{IN}\sin(\omega t) .$$

Complex voltage of the i - th node can be expressed as:

(12) $$\dot{V}_i = x_i + jy_i ,$$

where x_i, y_i are real and imaginary part of nodal potential $\dot{V}_i$, respectively. Amplitude and phase of this node are determined by expressions:

(13) $$U_i = \sqrt{x_i^2 + y_i^2} ; \qquad \varphi_i = \arctan\left({y_i}/{x_i} \right).$$

Using measured voltages $u_{IN}(t_1)$, $u_{IN}(t_2)$ of the input test signal $u_{IN}(t)$ and $u_i(t_1)$, $u_i(t_2)$ of the node number i, the real and imaginary parts of potential of the i-th node in the frequency domain are determined. These signals are measured three times at the instant of time t_1, t_2, t_3 with the time interval $T/4$, where T is the period of the test signal. The time instant of measuring in each node is shifted by one period. This enables one to measure the test signal and the voltage of the i-th node at the same instant with respect to the beginning of the measurements. Measuring each of the signals at time point t_3 is used to compensate the voltage offset. The first and the second measurements are used to calculate the real and imaginary parts of the potential of the i -th node.

Measured voltage $u_{IN}(t_1)$, $u_{IN}(t_2)$ and $u_i(t_1)$, $u_i(t_2)$ are adjusted by the value of obtained voltage offset. The first measurement starts at a random time point t_1 in relation to the test signal $u_{IN}(t)$.

Voltage at the i- th node at the instants of time t_1 and t_2 is described by the following equations:

(14) $$\begin{cases} u_i(t_1) = U_i\sin(\omega t_1 + \varphi_i) = U_i\sin(\beta + \varphi_i) \\ u_i(t_2) = U_i\sin(\omega t_2 + \varphi_i) = U_i\sin(\beta + \varphi_i + \pi/2) \end{cases},$$

where $\omega t_1 = \beta$; $\omega t_2 = \omega(t_1 + T/4) = \beta + \pi/2$.

Real and imaginary part of the nodal potentials is defined with the system of equations below:

(15) $$\begin{cases} x_i = u_i(t_1)\cdot\sin\beta + u_i(t_2)\cdot\cos\beta \\ y_i = u_i(t_1)\cdot\cos\beta - u_i(t_2)\cdot\sin\beta \end{cases}.$$

Structurally, microprocessor system is designed as the PCB to which the investigated circuit is connected. The board includes liquid crystal display (LCD), keyboard, sine wave generator, filter and amplifier. The core of this microcontroller board is C8051FX352 processor, which is responsible for the system functionality, the generation of harmonic signals and for the measurement of signals.

LCD indicator displays operating modes of the system and measurement results. The keyboard system consists of 4 keys. Key Mode allows accessing the default mode of the system. Keys ▲, ▼ are used to set the properties of the selected mode and Enter key is used to save it.

Generation of harmonic signals is performed by a digital frequency synthesizer (DDS) AD9832 from Analog Devices. The output of the DDS chip is connected to the LC-filter is in order to filter digital noise. FSYNC input of the DDS accepts clock pulses from an external 24 MHz generator. To ensure the sufficient level of power of generated signals the output filter is connected to the power amplifier with the output cascade on transistors.

Measurements are performed by the 16-bit serial sigma-delta Analogue Digital Converter (ADC) which is a part of the microcontroller. ADC input accepts measured signal from the input multiplexer through the programmable gain amplifier.

5. Conclusion

Two versions of multi-test diagnostics method software were developed – DIAGNDC (the DC mode measurements) and DIAGNFREQ (the frequency domain measurements). Both versions includes the circuit topology description module, the DC analysis module, the frequency domain analysis module, module for the calculations of node potential sensitivity depending on the parameters of elements, the diagnostics equation formation module, module for the solution of the system of equations by the modified Newton method and module for the linear system solution using parametric regularization.

Microprocessor system exploits the capabilities of the C8051FX352 controller and allows measuring nodes potentials both in the DC mode and in the frequency domain. Magnitudes of the node potentials are measured using AC to DC conversion. The frequency range of the measured signals extends up to 40 kHz. For the magnitude and phase measurements of node potentials the frequency range is up to 5 kHz.

REFERENCES

[1] Благитко Б.Я., Рабык В.Г. Основы теории диагностики аналоговых электронных цепей по постоянному току. Теоретическая электротехника, 1988, Вып. 44, С. 121 - 129.

[2] Благитко Б.Я., Рабык В.Г. Методы диагностики аналоговых цепей в частотной области. Теоретическая электротехника, 1987, Вып. 52 , С. 45-55.

[3] Благитко Б.Я., Рабык В.Г. Влияние погрешности измерения узловых потенциалов на результаты диагностики электрических цепей. – Теоретическая электротехника, 1990, Вып. 48, С. 101 – 108.

[4] Бэндлер Дж., Салама А.Э. Диагностика неисправностей в аналоговых цепях , ТИИЭР, 1985, т. 73, №8, С. 35-104.

[5] C. Alippi, M. Catelani, A. Fort, M. Mugnaini. Automated Selection of Test Frequencies for Fault Diagnosis in Analog Electronic Circuits. IEEE Transactions on Instrumentation and Measurement, 2005, Vol. 54, №3, P. 1033 – 1044.

[6] *Wetterlin S. A.* Method of Using Quadrature Sampling to Measure Phase and Magnitude. – 7p. // http://www.wetterlin.org/sam/Quadrature Sampling.pdf

[7] Czaja Z. Fault diagnosis of fully differential circuits in electronic embedded systems / Z. Czaja, W. Toczek. – XIX IMEKO World Congress Fundamental and Applied Metrology. – Lisbon, Portugal, September, 2009. P. 1418–1423.

***Authors**: dr hab. inż. Bogdan Blagitko, Tarnavskego 107, 79017 Lviv, Ukraine, E-mail: blagitko@electronics.wups. lviv.ua; dr hab. inż. Volodymyr Brygilevych, Tarnavskego 107, 79017 Lviv, Ukraine, E-mail: lmgo.icc@gmail.com; dr hab. inż. Vasyl Rabyk, Tarnavskego 107, 79017 Lviv, Ukraine, E-mail: RabykV@ukr.net.*