Determination of the Optimal Circuit-Engineering Solution of Electronic Circuits

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***Abstract*—The wide range of differences in conditions (temperature, pressure, humidity, vibrations, radiation) for communication equipment leads to hard demands towards the tolerances of the input parameters of the compound electronics circuits. The mentioned demands in case of electronic circuits are maintained with reducing of the tolerances of the functional elements mainly and using of new technical solution, which to give minimum influence of the destabilizing factors. The second method is much more perspective. In such a case this way gives an manual for establishing of an optimum technical decision for designing of communication equipment and an example how to use it.**

Keywords—electronics circuits, optimum technical decision, multivibrator.

I. INTRODUCTION

The dependence of the output parameters $Z_j\left(j=1,.....,m\right)$ of electronic circuits (EC), constituting a particular type of technique is determined by the parameters $q_i\left(i=1,.....,\ n\right)$ of their individual functional elements (FE) and it has the general appearance:

$$Z_j=\varphi_j\left(q_i\right) \tag{1}$$

where: φ_j - a function that depends on the type of EC.

The function $\varphi_j\left(q_i\right)$ depends on the type of EC and satisfies the restrictions:

$$\overline{Z}_{2j}\leq\varphi_j\left(q_i\right)\leq\overline{Z}_{1j} \tag{2}$$

defining the field of EC work capacity.

With deviations set Δq_i and denominations (mean values) $\overline{q}_i>>\Delta q_i$ of the parameters according to (1), we determine the relative deviation of the jth output parameter Y_j [1, 2]:

$$Y_j=\frac{\Delta Z_j}{Z(\overline{q}_i)}\approx\sum_{i=1}^{n}a_{ij}\frac{\Delta q_i}{\overline{q}_i} \tag{3}$$

where:

$$a_{ij}=\frac{\partial\varphi_j(q_1,...,q_n)}{\partial q_i}.\frac{\overline{q}_i}{\varphi(\overline{q}_i,....,\overline{q}_n)}. \tag{4}$$

Derivatives $\partial_{\varphi j}/\partial_{qi}$ are set for points $(\overline{q}_i,....,\overline{q}_n)$. Equation (3) establishes the relationship of the relative deviations of Y_j with the relative deviations $\Delta q_i/\overline{q}_i$ of the EC parameters. In it, the coefficients of influence (4) determine the degree of influence of the deviations of the parameters q_i on the deviations of the output parameters Z_j [3, 4].

Given the numerical characteristics of the laws of distribution of parameters q_i equation (3) allows to determine instabilities Y_j.

According to (3), the reduction of the parameters q_i spread due to the selection of functional elements is practically limited and economically disadvantageous. Of interest are the possibilities of reducing the spread of Y_j at the expense of reducing the coefficients of influence of a_{ij}. The

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mathematical interpretation of the problem of determining the global minimum of Y_j at the expense of minimizing the coefficients a_{ij} is in most practical cases unsuitable because the set of denominations $(\overline{q}_i,....,\overline{q}_n)$ providing such minimization does not satisfy the constraints (2) determining the EC's workability [5].

In this context, it is appropriate to use a partial minimization of the impact coefficients facing the largest variance deviations $\Delta q_i / \overline{q}_i$. The aforementioned minimization should be done on the basis of an EC analysis and ultimately reduced to the introduction of new conditions [6, 7].

$$\mu_K(q_i) \cong \overline{\mu}_{K,}(k = 1,...n) \qquad (5)$$

where: μ_K – parameters q_i ratios;

$\overline{\mu_K}$ – restrictions on μ_K.

The schematic technical implementation of condition (5) depends on the specific EC and is generally implemented by optimizing the parameters ratios, correlating their changes or compensating by introducing compensating FEs (most often in temperature variations) [8].

The essence of the stabilization of the output parameters lies in the introduction of the minimizing conditions (5) into the initial conditions (2).

Since the coefficients of influence (4) depend on the denominations $(\overline{q}_i,....,\overline{q}_n)$, it is appropriate to use the sequential approximation method when selecting the latter, taking into account their random changes [9].

It should be noted that when designing the EC by means of appropriate software, conditions (5) are fulfilled automatically, but in the given case, their introduction into the initial conditions (2) results in a significant reduction of the operations from the computational process and saves time.

II. TECHNICAL SOLUTION – TEORETICAL AND PRACTICAL CONSIDERATIONS

To illustrate the proposed methodology for determining the optimal circuit-engineering solution, we will consider an example of the stabilization of the output pulses of a multivibrator with additional symmetry (Fig. 1) [10, 11, 12].

In [12] for the scheme indicated in Figure 1, the following relationships between its parameters are proposed:

$$R_{C1} > R_p;\ R_3 >> R_{C1}, R_E;\ R_p >> r_{bN1}, r_{bN2};$$
$$E_C = E_E >> \left(|U_{bN1}| + |U_{bN2}|\right); \qquad (6)$$
$$\theta = R_p.C >> \tau_{N1}, \tau_{N2};\ R_{C1} = (3 \div 5)R_E;$$

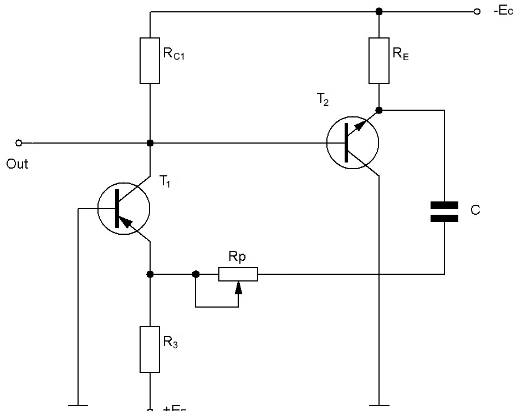

Fig. 1. Multivibrator with additional symmetry.

where: r_{bN1}, r_{bN2} – volumetric resistances at saturated transistor T_1 and T_2 bases;

U_{bE1}, U_{bE2} – emitter-base voltages of T_1 and T_2;

τ_{N1}, τ_{N2} – lifetimes of the non-majority carriers in their bases.

When performing the above ratios for the duration of the output pulses, the formula was obtained [12]:

$$t_p \approx \theta.\ln\frac{R_{C1}}{R_p} \qquad (7)$$

The analysis performed in [1] takes into account the simultaneous exit of the two transistors from saturation at the stage of output pulse formation. Subject to condition (6) for t_p, we obtain:

$$t_p \approx \theta.\ln\frac{R_{C1}/R_p}{1 + 2R_{C1}/(B_2.R_E)}, \qquad (8)$$

where: B_2 – current amplification factor of T_2 in the common emitter circuit.

Using formulas (3) and (9), we represent the relative instability of t_p in the form:

$$\frac{\Delta t_p}{\bar{t}_p} = a_1 \frac{\Delta B_2}{\overline{B}_2} + a_2 \frac{\Delta R_E}{\overline{R}_E} + a_3 \frac{\Delta R_{C1}}{\overline{R}_{C1}} + a_4 \frac{\Delta R_P}{\overline{R}_P} + a_5 \frac{\Delta C}{\overline{C}} \qquad (9)$$

where:

$$a_1 = \frac{\partial t_p}{\partial B_2} . \frac{\overline{B}_2}{\bar{t}_p}; \quad a_2 = \frac{\partial t_p}{\partial R_E} . \frac{\overline{R}_E}{\bar{t}_p} = \frac{\bar{\theta}}{\bar{t}_p} . \frac{\overline{R}_{C1} / \left(\overline{B}_2 \overline{R}_E\right)}{1 + 2\overline{R}_{C1} / (\overline{B}_2 . \overline{R}_E)};$$

$$a_3 = \frac{\partial t_p}{\partial R_{C1}} . \frac{\overline{R}_{C1}}{\bar{t}_p} = \frac{\bar{\theta}}{\bar{t}_p} . \left[1 - \frac{2\overline{R}_{C1} / \left(\overline{B}_2 \overline{R}_E\right)}{1 + 2\overline{R}_{C1} / (\overline{B}_2 . \overline{R}_E)} \right]; \qquad (10)$$

$$a_4 = \frac{\partial t_p}{\partial R_P} . \frac{\overline{R}_P}{\bar{t}_p} .1 - \frac{\bar{\theta}}{\bar{t}_p}; \quad a_5 = 1.$$

In formula (8), the parameter B_2 is the most volatile. For the typical case $B_2(20°C) = 50$; $B_2(60°C) = 150$; and $B_2(-60°C) = 10$. Under $R_{C1} / R_E = (3 \div 5)$ and $R_{C1} / R_p = (2 \div 10)$ according to we get for:

$$a_1[B_2(20^\circ C)] = \frac{\Delta B_2}{B_2(20^\circ C)},$$

$(5 \div 18)\%$ and $-(20 \div 80)\%$ respectively at temperature changes of $(20 \div 60)°C$ and $(20 \div -60)°C$. Given the technological dispersion of B, these instabilities are increasing. Therefore, according to (10), it is appropriate to introduce a minimizing condition in (6):

$$a_1 = \frac{\bar{\theta}}{\bar{t}_p} . \frac{\overline{R}_{C1} / \left(\overline{B}_{2\min} . \overline{R}_E\right)}{1 + 2\overline{R}_{C1} / (\overline{B}_{2\min} . \overline{R}_E)} << 1 \qquad (11)$$

Moreover, as can be seen from the example considered, condition (11) ignores (7) when operating over a wide temperature range.

Taking into account (11), the relative instability $\Delta t_p / \bar{t}_p$ is determined by:

$$\frac{\Delta t_p}{\bar{t}_p} \approx \frac{\bar{\theta}}{\bar{t}_p} . \frac{\Delta R_{C1}}{\overline{R}_{C1}} + \left(1 - \frac{\theta}{\bar{t}_p} \right) \frac{\Delta R_P}{\overline{R}_P} + \frac{\Delta C}{\overline{C}}, \qquad (12)$$

and practically does not depend on the parameters of the transistors used.

It follows from (12) that the temperature instability $\Delta t_p / \bar{t}_p$ can be further minimized by correlation of changes $\frac{\Delta R_{C1}}{\overline{R}_{C1}}$ and $\frac{\Delta R_P}{\overline{R}_P}$ (this is done by inserting resistors R_{C1} and R_p with the same temperature coefficients into the multivibrator circuit). This ensures that the condition is met:

$$\frac{\Delta R_{C1}}{\overline{R}_{C1}} = \frac{\Delta R_P}{\overline{R}_P} \qquad (13)$$

From condition (13) it follows:

$$\frac{\Delta t_p}{\bar{t}_p} \approx \frac{\Delta R_P}{\overline{R}_P} + \frac{\Delta C}{\overline{C}}. \qquad (14)$$

Further minimization of $\Delta t_p / \bar{t}_p$ can be achieved by reducing $\Delta R_P / \overline{R}_P$ and $\Delta C / \overline{C}$, using the introduction of thermocompensating elements (resistor and capacitor with inverse negative temperature coefficients) in the forming circuit R_p, C.

The experimental verification of the obtained ratios $(11) \div (14)$ was carried out in the temperature range $(20 \div 60)°C$ on a multivibrator implemented by transistors with parameters: $E_C = E_E = 10V$, $R_{C1} = 910\Omega$, $R_p = 9510\Omega$, $R_3 = 51k\Omega$, $C = 0{,}01\mu F$ and different resistance values of the resistor R_E. For uncorrelated resistors R_{C1} and R_E and $R_{C1} / R_E = 6{,}1$ is obtained accordingly $\Delta t_p / \bar{t}_p \approx 20\%$. At $R_{C1} / R_E = 0{,}45$ is obtained $\Delta t_p / \bar{t}_p \approx 3{,}5\%$. By introducing resistors R_{C1} and Rp with corrected temperature coefficients and $R_{C1} / R_E = 0{,}45$ there is a decrease in $\Delta t_p / \bar{t}_p$ up to $2{,}6\%$.

III. CONCLUSIONS

The optimization of circuit-engineering solutions of specific electronic circuits is proposed to be implemented through:

1. Optimization of parameters ratios of functional elements.

2. Optimizing the correlation of their changes.

3. Introduction of compensating functional elements.

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