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Multicriteria optimization of a meander line with broad-side coupling by genetic algorithms

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Abstract. Multicriteria quality functions for the dungerous pulse splitting into a sequence of pulses of smaller amplitude were formulated. The optimization was performed by simple genetic algorithm using these functions. As a result, 3 sets of optimal parameters providing the given criteria were obtained. Comparison of the results of the heuristic search and genetic algorithm showed their similarity. As a result of the genetic algorithm optimization in accordance with the formulated criteria, the attenuation (times) achieved 2.5 for the set of parameters one, 3.3 – for set two, and 3.42 – for set three.

1. Introduction

Today, electronic equipment (EE) is actively used in almost all fields of science and technology: military, nuclear, transport, space, etc. Uninterrupted operation of EE is very important. EE is developing rapidly: the size of components on printed circuit boards (PCBs) decreases and density of their packaging in EE increases, the operating voltages decrease and the operating signal frequencies increase. This leads to an increase in the sensitivity of EE components to natural (unintentional) and artificial (intentional) electromagnetic interferences. A particular danger for EE is created by ultrashort pulses (hereafter, a dangerous pulse (DP)), which can penetrate the EE through slots in the enclosure or shield and lead to malfunctions or complete failure of elements and devices [1, 2]. The most common means for protecting EE against such DPs are noise suppressors, electromagnetic shields, various filters, decoupling and gas-discharge devices. However, each of these devices has its own disadvantages [3, 4]: low power, low speed, and parasitic parameters. This makes it difficult to ensure the reliability and uninterrupted operation of the EE. Thus, it is necessary to find new ways of effective protection.

Various stripline devices for DP protection and signal filtering are noteworthy [5–10]. Modal filters (MF) [11] based on modal splitting technology [12] have been proposed, which are devoid of the noted disadvantages and also have a number of advantages (absence of semiconductor components, radiation resistance, long operation life, operation at high voltages and low cost). Another approach is splitting a DP into a sequence of lower amplitude pulses in a meander line turn with broad-side coupling (MLBSC) [13]. Conditions that ensure the splitting into four pulses (cross-talk, even mode (EM), additional pulse and odd mode (OM)) have been formulated:

$$2\tau_e l \geq t_\Sigma, \tag{1}$$

$$l(\tau_o - \tau_e) \geq t_\Sigma, \tag{2}$$

$$\tau_{max} = 3\tau_{min} \tag{3}$$

where τ_o and τ_e are the per-unit-length delays (PULD) of the OM and EM of the line respectively, t_Σ is the total DP duration, *l* is the length of a meander half-turn, τ_{min} and τ_{max} are the minimum and maximum of the PULD of the EM and OM of the line, respectively. Condition (1) ensures the arrival of an EM pulse after of the cross-talk pulse, (2) – splitting of the main signal into pulses of EM and OM, and (3) – the arrival of all pulses with equal time intervals between each other. As a result of the study [13], the maximum DP attenuation by 3.3 times relative to half of the e.m.f. was shown. However, the parameters providing conditions (1)–(3) and such DP attenuation were obtained using a heuristic search, which did not take into account the matching of the line in a tract, and the real geometric parameters. In order to consider these criteria, one can use more efficient methods of global optimization, for example, genetic algorithms (GAs), which are provided by the TALGAT software available to the authors [14]. The aim of this paper is to perform multicriteria GA optimization of an MLBSC by the criteria of complete DP splitting and minimization of its amplitude. For this, it is first necessary to formulate the criteria that provide DP splitting and minimize its amplitude at the end of the line, and then to perform the optimization.

2. Initial data for simulation

The cross-section of the line under investigation is shown in figure 1*a*, and has the following parameters: conductor A is active, conductor G is reference ground, *w* and *t* are the width and thickness of the conductors respectively, *s* is the space between conductors, *h* is the thickness of the dielectric substrate, ε_r is the relative permittivity of the substrate, *d* is the distance from the edge of the structure to the conductor (d=3w). The equivalent circuit of the line is shown in figure 1*b*, where $R1=R2=(Z_eZ_o)^{0.5}$. As an excitation, we selected a trapezoid pulse with the parameters: e.m.f. – 1 V, the duration of the flat top – 100 ps, the rise and fall times – 50 ps each.

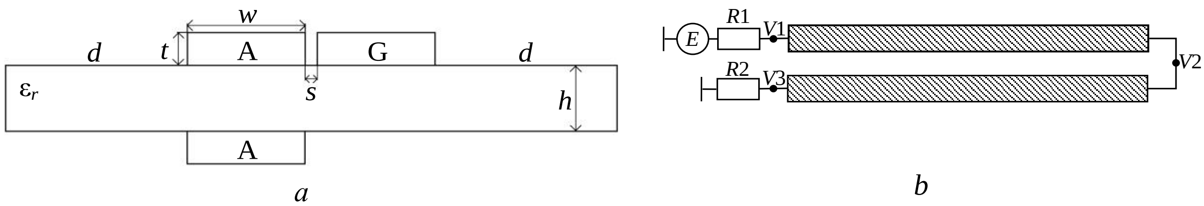

Figure 1. Cross-section (*a*) and equivalent circuit (*b*) of the MLBSC.

Note that in [13], we have found 3 sets of parameters using a heuristic search: sets 1 and 2 provide the conditions (1) and (2) and DP attenuation (times) by 2.5 and 3.3, respectively (relative to *E*/2), and set 3 provides the condition (3) and DP attenuation by 3.4 times (relative to *E*/2). For clarity, Table 1 summarizes the sets of obtained parameters and the corresponding amplitudes at node *V*3 from [13].

Table 1. The sets of parameters and the maximum amplitudes at node *V*3 from [13].

№	w, µm	t, µm	s, µm	ε_r	h, µm	l, mm	U, V
1	1000	18	200	5	540	150	0.202
2	380	18	200	20	940	150	0.151
3	1000	136	5	500	1200	80	0.146

When optimizing the line under investigation, we will use 3 sets of parameters from Table 1, relative to which the ranges were selected: for the first set – 900 µm≤ w≤1100 µm, 10 µm≤t≤26 µm, 150≤s≤250 µm; for the second – 250 µm≤ w≤450 µm, 10 µm≤t≤26 µm, 150≤s≤250 µm; for the third – 900 µm≤ w≤1100 µm, 106 µm≤t≤166 µm, 2≤s≤15 µm.

3. Formulation of a multicriteria quality function

When formulating a multicriteria quality function (F), it is necessary to bring individual criteria to one of the minimization or maximization tasks. We will do this following the paper [11]. For definiteness, we will consider minimization of the sum

$$F = \sum_i F_i \tag{4}$$

where

$$F_i = M_i \frac{f_i}{K_i} \tag{5}$$

where for each i criterion: f_i is the quality function; K_i is the normalization coefficient; M_i is the weighting factor; i=0, 1, 2, ..., N_C, where N_C is the number of optimization criteria. Coefficient K_i is chosen to be equal to the maximum of the possible values of the i-th quality function so that the value f_i/K_i becomes dimensionless and takes values from 0 to 1 in the optimization. Coefficient M_i sets the significance of the i-th criterion. If the criteria are equivalent for the user, then these coefficients are the same and can be set in units or as

$$M_i = \frac{1}{N_C}. \tag{6}$$

We now formulate 2 multicriteria quality functions: F_1 based on (1) and (2) and F_2 based on (3). Sets 1 and 2 will be used when optimizing the line under investigation using F_1, and sets 3 – using F_2.

First, we formulate the criteria based on conditions (1) and (2). Instead of unstrict inequality in the conditions, we consider the case of ordinary equality (the fulfillment of which will also allow us to fully split the DP). Then criterion f_1 providing (1) is

$$f_1 = t_\Sigma - 2l\tau_e \tag{7}$$

and the criterion f_2, which provides (2), is

$$f_2 = t_\Sigma - l(\tau_o - \tau_e). \tag{8}$$

Coefficients K_1 and K_2 are taken to be equal to the maximum values of f_1 and f_2, respectively, which are found from the extreme points of the range of values of the optimized parameters.

The third optimization criterion, f_3, is the criterion for amplitude minimization. To protect against a DP, it is relevant to analyze the signal voltage $U(t)$ at node $V3$. If the danger is created by the maximum level of $U(t)$, then

$$f_3 = \max|U(t)|. \tag{9}$$

Then, the normalization coefficient for f_3 is K_3=max|$E(t)$|, where $E(t)$ is the e.m.f. of the source. Thus, F_1 takes the form

$$F_1 = M_1 \frac{f_1}{K_1} + M_2 \frac{f_2}{K_2} + M_3 \frac{f_3}{K_3} \tag{10}$$

where M_1=M_2=M_3 in the optimization with the first set of parameters of the line, and M_1=M_2=0.2, M_3=0.6 - with the second.

The quality function F_2 is formulated similarly but its first criterion f_1 is chosen based on the condition (3). Then f_1 for F_2 takes the form

$$f_1 = 3\tau_{min} - \tau_{max}. \tag{11}$$

Coefficient K_1 is taken to be equal to the maximum value of f_1, which was found from the extreme values of the range of the optimized parameters. We note that f_2 and K_2 for F_2 are the same as f_3 and K_3 for F_1 respectively. Thus, F_2 will take the form

$$F_2 = M_1 \frac{f_1}{K_1} + M_2 \frac{f_2}{K_2} \tag{12}$$

where M_1=M_2.

4. Multicriteria optimization of an MLBSC

Simulation of the line under investigation was performed in the TALGAT software [14]. Table 2 summarizes the results of optimization by simple GA for the line under investigation using F_1 and F_2: 3 sets of optimal line parameters, PULD and the maximum amplitudes at node *V*3. The signal waveforms at node *V*3 for sets of optimal parameters are shown in figure. 2. The optimal number of individuals in the population and the number of generations for which the formulated criteria are fulfilled are the following: 5 and 10 for set 1; 20 and 100 for set 2, 10 and 15 for set 3.

Table 2. Optimization results for the line under investigation using F_1 and F_2.

№	w, µm	t, µm	s, µm	ε_r	h, µm	l, mm	τ_{max}, ns/m	τ_{min}, ns/m	U, V
1	903.507	25.908	155.196	5	540	150	6.54487	5.2058	0.198
2	283.527	10.8679	167.636	20	940	150	11.6206	10.2814	0.151
3	1070.79	161.423	2.00476	500	1200	80	58.3685	19.4275	0.146

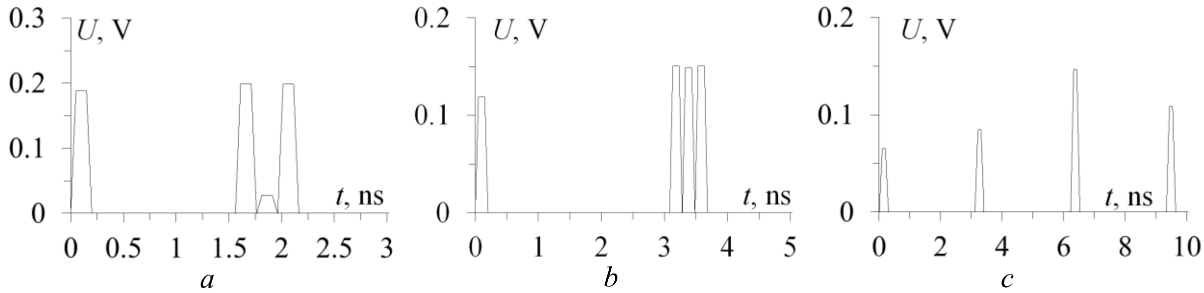

Figure 2. Voltage waveforms at the end of the line under investigation with optimal sets: 1 (*a*), 2 (*b*), 3 (*c*)

The results show that the formulated criteria are satisfied: the DP at node *V*3 with three sets of parameters is represented by a sequence of pulses of smaller amplitude, and conditions (1)–(3) are provided when substituting the corresponding PULD from Table 2. The results of GA optimization and the heuristic search from [13] were found to be similar.

6. Conclusion

Multicriteria quality functions for the DP splitting into a sequence of pulses of smaller amplitude were formulated. The optimization was performed by a simple GA using these functions. As a result, 3 sets of optimal parameters providing the given criteria were obtained. Comparison of the results of the heuristic search and GA showed their similarity. As a result of the GA optimization in accordance with the formulated criteria, the attenuation (times) achieved 2.5 for the set of parameters one, 3.3 – for set two, and 3.42 – for set three. The formulated criteria will be used in the further practical implementation of the device, at the stage of optimizing its real geometric parameters (in accordance with the technological capabilities of PCB manufacturers).

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