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Optimization of Three-conductor Microstrip Line Modal Filter by Heuristic Search and Genetic Algorithms

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***Abstract*— The improvement of the protection against ultrashort pulse (USP) through the use of modal filters (MF) is considered. A review of researches dedicated to MFs based on multiconductor microstrip line (MSL) is made. A MF on the basis of a three-conductor MSL is investigated. Optimization of conductors separations in a MF is executed in two ways: heuristic search and genetic algorithm (GA). After optimization by using the GA we obtained an amplitude of USP at the output of MF that is 13% less than the one after heuristic search. It is proposed to use these methods successively.**

***Key words*— multiconductor microstrip line, protection device, modal filtration, optimization, heuristic search, genetic algorithms.**

I. Introduction

Contemporary control and communication systems have wide functional capabilities but at the same time, they are susceptible to electromagnetic interference. Conducted interference is considered to be the most harmful one, as it can penetrate into devices directly through conductors [1]. Modern generators of ultrashort pulses (USP) have very high capabilities [2]. Therefore it is necessary to improve the protection against USP.

A technique of modal filtration [3] was proposed for the protection of electronic equipment against USP. This technique is based on modal decomposition of a pulse signal in multiconductor transmission lines which occurs due to difference between the modal delays. Results of simulation of a microstrip line (MSL) consisting of 2–5 conductors showed decomposition of an input pulse at the end of a conductor into 2–5 pulses with the maximum amplitudes of 3, 3.6 and 4.5 times (correspondingly) less than a signal in the near end of a line [4]. Optimization showed that equalization of differences of delays of the pulses allows increasing duration of a pulse which is going to be completely decomposed in these structures [5]. In addition, the optimization of multiconductor MF is performed by criteria of minimization of the maximum output amplitude and maximization of a difference of time delays between the first and the last decomposition pulses [6]. An experimental confirmation of modal filtering based on multiconductor MSL was performed. So, for two- and three-conductor MSL, attenuation of 11.5 and 13.7 times was obtained [7], and for four- and five-conductor – 12.6 and 15.3 times [8].

Meanwhile, the heuristic search of parameters was used in [5–8] but this method does not guarantee the best results. Therefore, it is better to explore the possibility of using optimization techniques to improve earlier results. The aim of this paper is to perform such research and compare the results with the results of heuristic search.

II. Heuristic Search Optimization

Parameters and forms of a signal were calculated in TALGAT software [9]. It was assumed that a T-wave is propagating along the considered lines. Losses in conductors and dielectrics were considered. A digitized signal of oscilloscope C9-11 was used as an initial pulse, it was measured at 50 Ω load, with an amplitude of 0.657 V. Durations of rise – 27 ps, fall – 29 ps and flat top – 9 ps, so that the overall duration – 65 ps. (Durations were measured by levels of 0.1–0.9).

MF based on a three-conductor MSL was selected as a test structure. Schematic diagram of the MF is shown in Fig. 1, and the cross section in Fig. 2.

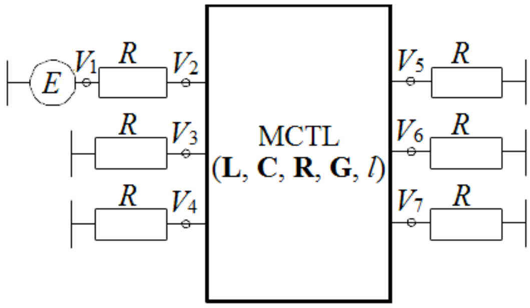

Fig. 1. Schematic diagram for research

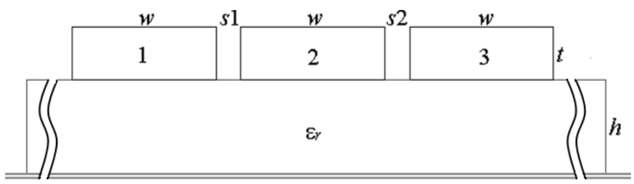

Fig. 2. Cross sections of three-conductor MSL

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MF was optimized for the following parameters: width of conductors is $w = 1000$ µm, thickness of conductors is $t = 18$ µm, thickness of dielectric is $h = 500$ µm, relative permittivity is $\varepsilon_r = 4.5$, length of line is equal to $l = 60$ cm. The value of w was optimized in order to assure 50 Ω characteristic impedance of a single line and it was unchanged, as well as the values of t, h and ε_r. Values of conductors separations were optimized by criterion of minimization of the maximum voltage of a waveform at the output of a MF. As a result of heuristic search, values $s1 = 200$, $s2 = 685$ µm were obtained. The waveforms at the input and output of the three-conductor MF with parameters, resulting in the heuristic search, are presented in Fig. 3. The amplitude of the signal at the output of the line was 0.040925 V.

III. Genetic Algorithm Optimization

GA is an evolutionary algorithm based on combination (hybridization). The algorithm is divided into three main stages: crossing (the formation of the population), selection and formation of the new generation. The steps are repeated as long as the result is acceptable or a number of generations (cycles) reach a predetermined value. In general, the use of GA eliminates the task of exhaustive search. Therefore, GA is widely used in solving a wide variety of tasks.

In this paper, GA parameters were chosen as follows: the number of individuals – 3, 10; number of generations – 10, 30, 100; mutation coefficient of 0.1; crossover coefficient of 0.5. Optimization of $s1$ and $s2$ was performed in a range of ±200 µm from the values obtained with the heuristic search.

Paper [4] implies that the lowest possible level of amplitude in three-conductor MF can be achieved by equalizing the amplitudes of the expansion pulses. Meanwhile, Fig. 3 shows the ability to further minimize the pulse amplitudes by their alignment. According to the above stated, at first, GA was used for optimization of $s1$ value only, because the heuristic search revealed that the value of parameter $s1$ at the strongly influences the output waveform. The results for 5 optimizations are presented in Table. I, and the graphics for $s1$ in Fig. 4.

TABLE I. Results of the GA Optimization of Conductor Separation s1 (µm) by Criterion of Minimization of the Amplitude of the Signal at the Output of the MF max(U) (V)

N	Number of individuals, number of generations							
	3, 10		10, 10		10, 30		10, 100	
	s1	max(U)	s1	max(U)	s1	max(U)	s1	max(U)
1	366	0.0373535	333	0.0364478	323	0.0366652	329	0.0364521
2	264	0.0387915	332	0.0364339	325	0.0365686	330	0.0364266
3	273	0.0384555	328	0.0364779	327	0.0364996	329	0.0364521
4	345	0.0364985	325	0.0365686	327	0.0364996	330	0.0364266
5	319	0.0368421	326	0.0365231	324	0.0366183	330	0.0364266

When the number of individuals and generations is 3 and 10 (30 calculations), the difference between the extreme values of $s1$ was 38.6%. However, at number of individuals and generations 10 and 10 (100 computations), this difference is 2.5%, at 10 and 30 (300 calculations) – 1.23%, at 10 and 100 (1000 calculations) – 0.3%. As a result, when $s1 = 330$ µm, the minimum amplitude of 0.03642 V (Table I) is obtained, which is 12.4% less than for the heuristic search. The waveforms at the input and output of the three-conductor MF with parameters after optimization are presented in Fig. 6. It is seen that the amplitudes of the first and second pulses nearly aligned and the third amplitude is smaller. This could mean the possibility of further reducing the amplitude of the output signal by means of simultaneous optimization of separations $s1$ and $s2$. The results of the optimization are given in Table 2, and graphics for $s1$ and $s2$ are shown in Fig. 5.

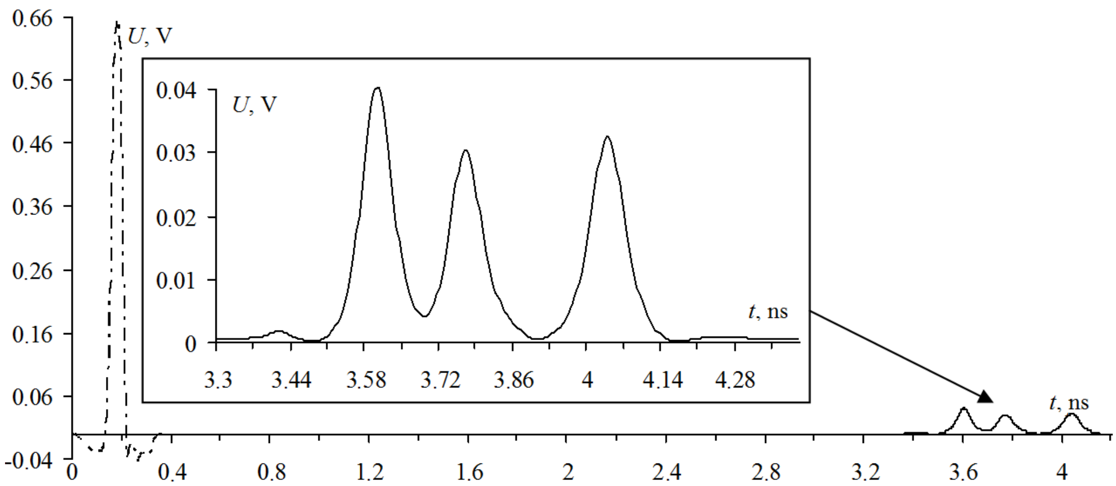

Fig. 3. Waveforms at the input (–·–·–) and output (——) (with enlarged fragment of the signal at the output) of three-conductor microstrip line MF with the parameters obtained as a result of heuristic search

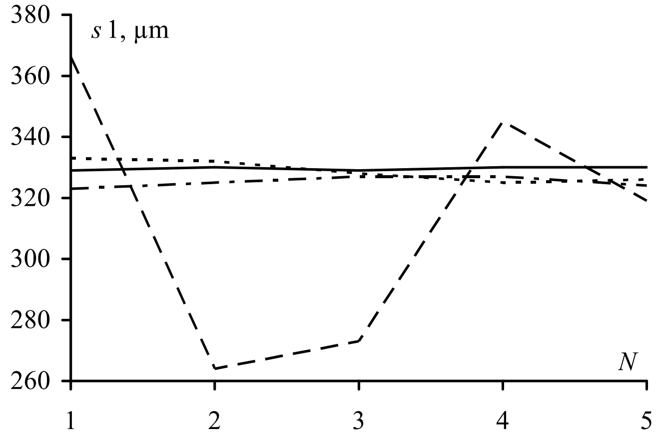

Fig. 4. The results of GA optimization of conductor separation *s*1 for the number of individuals and generations: 3 and 10 (– – –); 10 and 10 (····); 10 and 30 (–·–·–); 10 and 100 (––)

TABLE II. RESULTS OF THE GA OPTIMIZATION OF CONDUCTORS SEPARATIONS S1 AND S2 (µM) BY CRITERION OF MINIMIZATION OF THE AMPLITUDE OF THE SIGNAL AT THE OUTPUT OF THE MF MAX(*U*) (V)

N	Number of individuals, number of generations								
	10, 10			10, 30			10, 100		
	*s*1	*s*2	max(*U*)	*s*1	*s*2	max(*U*)	*s*1	*s*2	max(*U*)
1	389	788	0.037411	350	702	0.036216	330	678	0.036198
2	328	676	0.036188	329	675	0.036196	329	675	0.036196
3	335	680	0.036231	334	679	0.036224	330	675	0.036195
4	359	699	0.036470	339	685	0.036213	331	676	0.036203
5	326	665	0.036367	328	669	0.036318	331	673	0.036311

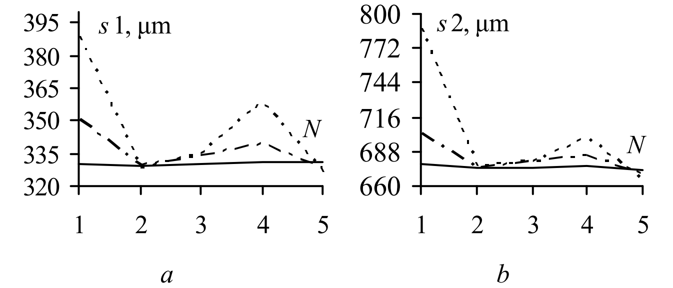

Fig. 5. The results of GA optimization of conductors separations *s*1 (*a*) and *s*2 (*b*) for the number of individuals and generations: 10 and 10 (····); 10 and 30 (–·–·–); 10 and 100 (––)

The difference between the extreme values of the variables at the number of individuals and the number of generations of 10 and 10 was for s1 – 19.3%, s2 – 18.5%, at 10 and 30 for s1 – 6.7%, s2 – 4.9%, at 10 and 100 for s1 – 0.6%, s2 – 0.7%.

As a result, when s1 = 330 µm and s2 = 675 µm, we obtain the maximum possible minimization of the amplitude at the MF output (in this case, the alignment of the first and second pulses) and it is equal to 0.03619 V (Table II). It is worth noting that the optimized parameter s1 has a value that is equal to the previous one (Table 1) and the change in the parameter s2 by 1.5% (from 685 to 675 µm) helped to align the first and second pulses, thus providing the lowest signal amplitude at the MF output. The waveforms at the input and output of a three-conductor MF with the parameters obtained through optimization using GA are shown in Fig. 7.

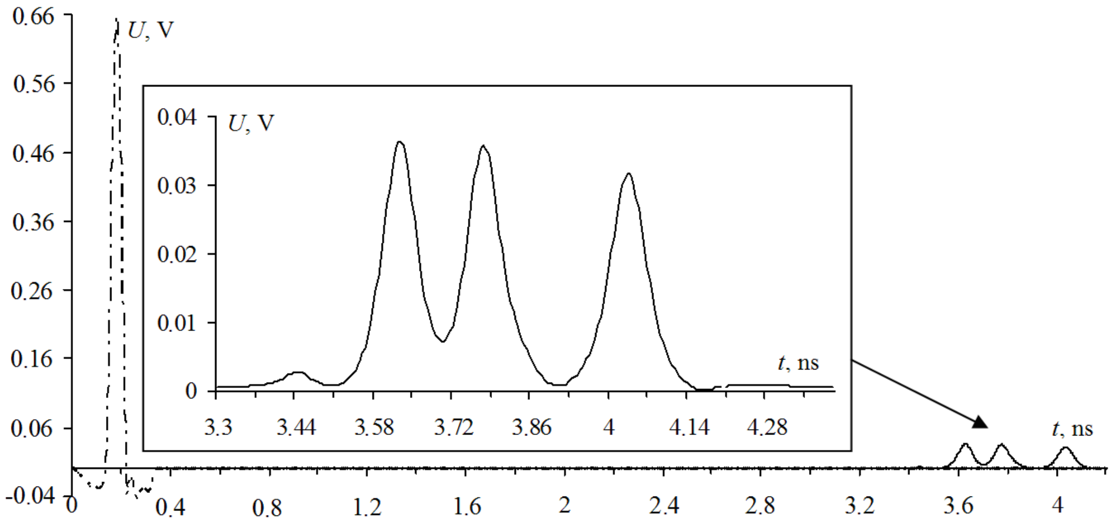

Fig. 6. Waveforms at the input (–·–·–) and output (——) (with enlarged fragment of the signal at the output) of three-conductor microstrip line MF after optimization of parameter *s*1 using GA

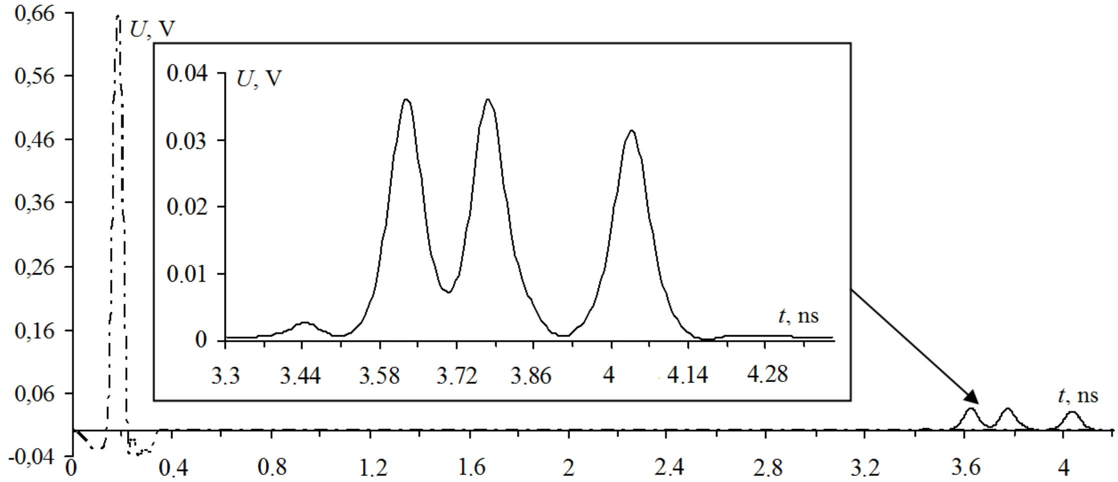

Fig. 7. Waveforms at the input (–·–·–) and output (——) (with enlarged fragment of the signal at the output) of three-conductor microstrip line MF after optimization of parameters *s*1 and *s*2 using GA

IV. Conclusion

The maximum attenuation of the amplitude of the signal at the output was achieved by optimization of two parameters using GA, which amounted to 0.03619 V, which is 0.6% less than the one obtained by optimization of a single parameter and is 13% less than the level obtained as a result of heuristic search. Thus, it is advisable to use a complex optimization, which should include heuristic search and the use of GA. The use of heuristic search to identify specific ranges of parameters to be optimized and for the further optimization by using GA will help to significantly reduce the computational cost of the optimization process.

Further research will be aimed at the optimization, which includes more than one criterion, but several. However, the preparation of the objective function to provide multiple criteria is a challenge.

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