Pulse Decomposition in the Turn of Meander Line as a New Concept of Protection against UWB Pulses

Roman Surovtsev, Talgat Gazizov, Alexander Zabolotsky.
Television and Control Department, Tomsk State University of Control Systems and Radioelectronics, 634050, Lenin Ave., 40, Tomsk, Russian Federation
surovtsevr@gmail.com

Abstract—Pulse decomposition in the turn of a meander line with the homogeneous dielectric filling is analyzed in detail. The study shows that the ultrashort pulse in the turn of a line with strong half-turn coupling is decomposed to subsequent pulses, having levels of 60, 60, –40, 20, –10%, when compared with a signal in the beginning of the turn. We obtained the conditions, providing decomposition of an ultrashort pulse into subsequent pulses. The research reveals the optimum value of capacitive coupling coefficient, being equal to 0.9, and providing the minimum level of pulses in the line end.

Keywords—UWB; even and odd modes; meander line; protection

At present, the urgent task is to protect electronic equipment (EE) from nanosecond and subnanosecond pulses that are able to penetrate into the EE bypassing electromagnetic shields of the devices. Filters, decoupling devices, interference restrainers, dischargers are traditional circuit instruments protecting from such ultra-wideband (UWB) pulses, while shields and methods, improving their homogeneity, grounding and techniques, reducing impedances of power-supply circuits are constructive instruments. However, their deficiencies reduce the effectiveness of the protection from UWB pulses.

Modal filters [1] are remarkable for protection from UWB pulses. The physical principle of their operation is based on the phenomenon of UWB pulse decomposition in the coupled line to modes with different propagation delays. Difference between these delays can be longer than the duration of the interference pulse if there is inhomogeneous dielectric filling in the cross section of the coupled line segment. Then, one pulse, applied between active and reference conductors in the segment beginning, will be decomposed into two pulses in the end of the segment. UWB pulse amplitude, depending on a line coupling, can be twice or more times lower than the initial one. For example, the article shows UWB pulse attenuation up to 5 times in the modal filter structure with a strong coupling in the inhomogeneous dielectric filling [2].

It is noteworthy that this protection can be implemented in various ways, including those not even requiring the protection device itself, using intrinsic properties of the existing electrical connections, such as printed circuit boards (PCB) interconnections.

The effectiveness of modal filtering of UWB pulses, unlike traditional protective devices, is growing as UWB pulse shortens. However, it cannot be used in the homogeneous dielectric filling and is more effective if some dielectrics with higher dielectric permittivity are presented, thus, its use is limited. Therefore, the search for new ways of protection against UWB pulse through the use of electrical interconnects of EE PCB is important. Widely spread PCB elements – meander delay lines – are thought to be promising for this aim. They have a wide sphere of implementation in the EE. It is also known how to use the properties of a meander to filter the signal in the frequency band [3]. Besides, it is worth mentioning all-passing properties of the meander line turn, stated in the classical paper [4].

However, there are few researches of meanders implementation for harmful signals suppression, in particular, for the protection from UWB pulse. We consider meander lines’ distortion to be promising for use in these purposes; the degree of distortions is enhanced with the increasing length of the turns and the meander half-turns couplings, even in the homogeneous dielectric filling.

The aim of is paper is to consider the influence of the half-turns length and their couplings on the waveform at the end of a meander turn and to demonstrate the ability to protect from UWB pulse using its decomposition.

I. THE STRUCTURE AND THE CIRCUIT FOR MODELING

A. The structure of the meander line

It is known that the behavior of the signal in the meander line with inhomogeneous dielectric filling is complex due to the existence of cross couplings between half-turns of the line and due to the distortions, caused by these couplings [5].

Meanwhile, homogeneous dielectric filling provides equal delays of even ($\tau_e$) and odd ($\tau_o$) modes of the line, and equal coefficients of capacitive ($K_C$) and inductive ($K_L$) couplings between the conductors of the line, the above compensates some distortions [6]. The number and ratio of distortions also depends on the quantity and density of the meander line conductors [7]. Therefore, we have chosen for the modeling...
A simple meander line structure based on the coupled transmission line in the air dielectric filling, for which the following conditions exist:

$$\tau_o = \tau_{on}, \quad K_C = K_L,$$

(1)

Fig. 1 presents cross section of the examined structure.

![Cross section of the examined structure](image)

The initial parameters of the cross-section: width and thickness of the signal conductors $w=100 \mu m$, $t=100 \mu m$, respectively, the distance between conductors $s=100 \mu m$, distance from the ground plane to the signal conductors $h=200 \mu m$.

B. The circuit of connections of the meander line

Fig. 2 shows electrical circuit of line connections for simulation. The line consists of two parallel conductors, connected at the far end. At the near end of the line one of the conductors is connected to the source of pulse signals, shown in the scheme as an ideal e.m.f. source and the internal resistance $R_1$. Another conductor is connected to the receiver, shown in the scheme as resistance $R_2$.

![Circuit of connections of the examined structure](image)

Exciting pulse has a trapezoid shape with parameters: amplitude 1 V, duration of the flat top 100 ps, and the rise and fall – 50 ps each. Fig. 3 shows shapes of EMF of the e.m.f. source and voltage at the line beginning (in the node $V_1$). The values of $R_1$ and $R_2$ in order to minimize signal reflections at the ends of line conductors are equal to the geometric mean of wave impedances of even and odd modes of the line.

II. SIMULATION OF THE WAVEFORM AT THE END OF A MEANDER

To understand the waveform changes and the possibilities of their use, we carried out the detailed simulation of a waveform at the end of a meander line turn under successive growth of the line length from 1 to 50 mm with different steps. Fig. 4, 5 depicts the obtained waveforms at the end of the line (in the node $V_3$) for $l = 1, 2, \ldots, 10$ mm, and Fig. 6 shows signal waveforms for $l = 15, 20, \ldots, 35$ mm.

Fig. 4 shows the appearance of distortions and their subsequent increase with the increasing of $l$. There is an overshoot at the rise of a signal, and undershoot at the fall, which are caused by the presence of crosstalk at the near end of the coupled line. The maximum level of overshoot and undershoot is about 15% of the signal level at the beginning of the line (0.5 V). Similar distortions are also seen on Fig. 5, however, they change their character. So, on the signal front begins to appear stronger crosstalk (at the beginning there is a positive step, but in the end – overshoot), on the signal fall we observe the reverse situation (in the beginning there is a undershoot, in the end – the negative step). The increase of $l$ up to 10 mm leads to increase of distortion up to 20%.

In Fig. 6 there also are distortions on the rise and fall of the signal, but the emission level decreases as $l$ increases. Thus, for $l=15$ mm distortion level is still high (Fig. 6(a)), however, when $l=20$ mm (Fig. 6(b)) the overshoot level is less than 5% of the signal level at the beginning of the line. If $l=25$ mm (Fig. 6(c)), there is a small gap between the signal and the step at the front, it shows the ending of influence on the shape of the crosstalk signal. As can be seen, with $l=30$ mm and 35 mm, source signal is not distorted by the crosstalk, but positive polarity pulse appears before it, and negative one after it. A further increase in $l$ leads only to a pulse shift (except the first one) along the time axis and it does not affect the shape of the main signal.

To explain the reasons for the observed waveform changes, we should note that, basically, the waveform at the end of the line is the sum of the signal itself, passed along the first and second half-turns of line, and the crosstalk from the signal rise and fall at the near end of the line. The overlapping of the crosstalk to the signal depends on the delay in the line and the sum of rise ($t_r$), top ($t_d$) and fall ($t_f$) times. There will be no overlapping under condition

$$2\tau l \geq t_r + t_d + t_f,$$

(2)

where $\tau = \tau_e = \tau_o$ with (1).
Fig. 4. Waveforms at the end of the meander line for $l=1$ (a), 2 (b), 3 (c), 4 (d), 5 (e) mm

Fig. 5. Waveforms at the end of the meander line for $l=6$ (a), 7 (b), 8 (c), 9 (d), 10 (e) mm
Thus, an appropriate choice of half-turn length ($l$) can provide signal transmission in the meander turn without shape distortions by the near end crosstalk [6, 8]. Then, the condition (2) for the cases when $l=30$ and 35 mm is performed with a margin and the signal is not distorted (it is sufficient to provide $l \geq 29.98$ mm to perform it). For the first time the condition (2) was obtained by the authors in [7, 9], but we did not conduct researches, studying distortions under close couplings between the line half-turns.

Further simulations were performed with $l=30$ mm to provide the condition (2). During the simulation the distance between the conductors $s$ was being decreased to strengthen the couplings. Fig. 7 shows waveforms computed at the end of line with changes of $s$ from 100 to 6 $\mu$m.

Fig. 7 presents that conductors’ coupling strengthening dubiously affects the waveform at the end of the meander line. Thus, reduction of $s$ leads to the increase of the positive level of crosstalk from the rise (the first positive pulse), while the level of the main signal (the second positive pulse), is decreased. Also, Fig.7 depicts that due to the coupling strengthening more heteropolar pulses appear because of the line reflections. The appearance of reflections is conditioned by the difference of impedance values of the even and odd modes of the line. As the coupling strengthens, the difference increases, thus, not only the number of pulses increases, but also their level, exceeding 40% of the signal level at the beginning of the line.

For clarity Tab. I summarizes $s$ depended: the maximum level of the main signal ($V_{S}$), crosstalk from the rise ($V_{CR}$) and coefficient of capacitive coupling ($K_{C}$) between the line half-turns.

<table>
<thead>
<tr>
<th>$s$, $\mu$m</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>20</th>
<th>10</th>
<th>8</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{S}$, V</td>
<td>0.467</td>
<td>0.460</td>
<td>0.447</td>
<td>0.426</td>
<td>0.383</td>
<td>0.330</td>
<td>0.313</td>
<td>0.29</td>
</tr>
<tr>
<td>$V_{CR}$, V</td>
<td>0.126</td>
<td>0.142</td>
<td>0.163</td>
<td>0.191</td>
<td>0.242</td>
<td>0.291</td>
<td>0.305</td>
<td>0.324</td>
</tr>
<tr>
<td>$K_{C}$</td>
<td>0.474</td>
<td>0.526</td>
<td>0.589</td>
<td>0.670</td>
<td>0.785</td>
<td>0.869</td>
<td>0.890</td>
<td>0.913</td>
</tr>
</tbody>
</table>

Table I shows that if $s$ is decreased, the main signal level is reduced more than in 1.5 times, comparatively to initial level with $s=100$ $\mu$m. Also we can see the increase in crosstalk from the signal rise. Thus, its level at the end of the $s$ variation is increased more than in 2.5 times. It can be noted that when $s=8$ $\mu$m, level of the main signal (0.313 V) is higher than the level of crosstalk from the rise (0.305 V), and for $s=6$ $\mu$m the balance is changed, and the crosstalk level (0.324 V) is higher than the level of the main signal (0.29 V). Obviously, in the range between 6 and 8 $\mu$m the optimal value of $s$ exists, which provides the same level for the signal and the crosstalk, which is a minimum. Searching for the optimum we obtained $s_{opt}=7.7$ $\mu$m, $K_{opt}=0.9$, $V_{opt}=0.309$ V. It should be noted that further strengthening of the line half-turns is redundant and leads to the increase of crosstalk level from the rise, which is not acceptable under the necessity to minimize the maximum level of output pulses.
Fig. 7. Waveforms at the end of a meander line with $s = \{100 \ (a), 80 \ (b), 60 \ (c), 40 \ (d), 20 \ (e), 10 \ (f), 8 \ (g), 6 \ (h) \} \ \mu m$

III. CONCLUSIONS

Thus, in the meander line turn with a close half-turns coupling, the UWB pulse may be decomposed into a sequence of pulses with levels of $60, 60, -40, 20, -10 \%$ of the level at the beginning of the turn. In such a case (2) is the necessary condition, and equal and minimum levels of the first two pulses are obtained if the capacitive or inductive coupling coefficient equals 0.9.

IV. REFERENCES


