# Insulation Bushing Optimization for Maximum Effectiveness of Pulse Transmission

Dalibor Štverka

*Abstract* – **Insulation bushings are very important part of many radio frequency and microwave devices using coaxial or one-wire structures (TDR devices, antennas, coaxial - waveguide joints, etc.). It insulates the active wire from the rest of the device body and affects essentially the behaviour of the final configuration. By means of FDTD numerical simulation was tested several types of the bushing and chosen the optimum shape and performance for maximum effectiveness of transmission and reception for subnanosecond pulses (100 ps to 800 ps).**

*Keywords* – **Insulation bushing, FDTD, coaxial structure, one-wire structure, rotational coordinates, transmission, reception effectiveness.**

## I. INTRODUCTION

The life without numerical simulations is quite hard to imagine today. It helps us with much lower costs and in much shorter time than real experiments to simulate many natural and technical phenomena. In electromagnetic computations there were invented many numerical methods to simulate static problems or electrodynamics. To be able to simulate behaviour of any structure impinged by an electromagnetic wave we must use a method working with time domain. The most performed method up today is FDTD (finite difference time domain), which is simple enough that even individual can effectively create his own simulation program.

When solving a time domain problem in a coaxial or one wire structure we can use Cartesian discretization of curvilinear shapes whereas to simulate an open space the AL (absorbing layer) in the conventional form can be applied [1]. Such 3D approach is very demanding for computer memory and finally not effective for simulations. The other approach is to use FDTD in cylindrical coordinates [1], [2], [3], [5] with an older type of ABC (absorbing boundary condition) [2] or with newly proposed [5] cylindrical PML (perfectly matched layer).

The task primarily solved in this paper was to examine the wave interactions with combined coaxial - one wire structure. The situation is shown in Fig. 1. The structure is excited in its coaxial part by means of short negative Gaussian pulse. The first question is what the transmitted pulse (wave) really looks like when it leaves the bushing. The second question is what the pulse looks like when it comes back through the bushing after the reflection from the end of the wire.

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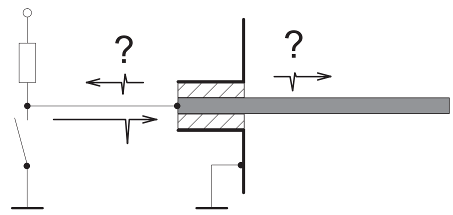


Fig. 1. Principal scheme of the structure

## II. NUMERICAL MODEL

To be able to answer effectively such questions we have created a numerical model - Fig. 2. We can see the model is not absolutely identical to real configuration. Since the excitation has been possible to make only within FDTD lattice we must place the Gaussian pulse source inside the bushing insulator - the point S.

Besides this we have 2 probing points P1 and P2 for scanning the field inside and outside the bushing. The rotation axis of the structure corresponds with the *z* axis. The total FDTD lattice area dimensions were necessary to chose according to length of pulses meant to use for simulations. So the real dimensions were: total radius and length of the computed area $r_{\max} = 80\Delta x$, $z_{\max} = 550\Delta x$, the central wire radius was $r_w = 3\Delta x$, the outer radius of the insulator was $r_b = 9\Delta x$ and the length of the wire $l_{\max} = 500\Delta x$ while the cell dimension $\Delta x = 1mm$. Four projected variants of bushing are depicted in Fig. 3. The "A" variant with cylindrical insulator is very simple to construct. The other "B, C, D" variants are conical with different performance of the aperture (horn). The dielectric constant of the insulator was chosen $\varepsilon_r = 2$ to simulate commonly used PTFE.

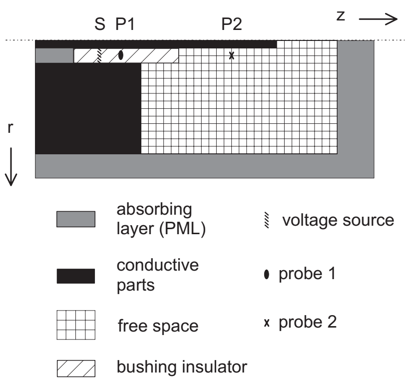


Fig. 2. Model of the analyzed structure

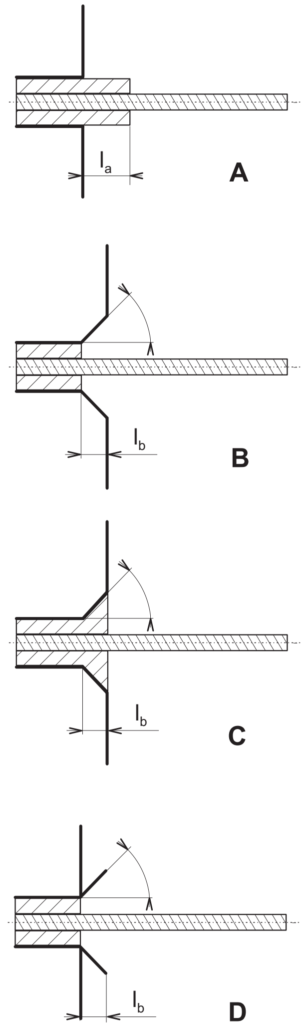


Fig. 3. Variants of insulation bushing

The model (Fig. 2) was implemented in Matlab and built a simple simulation instrument to solve shape optimization of insulation bushing for short pulses.

An example of the visualization is depicted in Fig. 4., where is the *Er* component of the field excited by 100 ps pulse. We can see the wave - structure interactions in the bushing ("A" type) and the deformations of the wave shape.

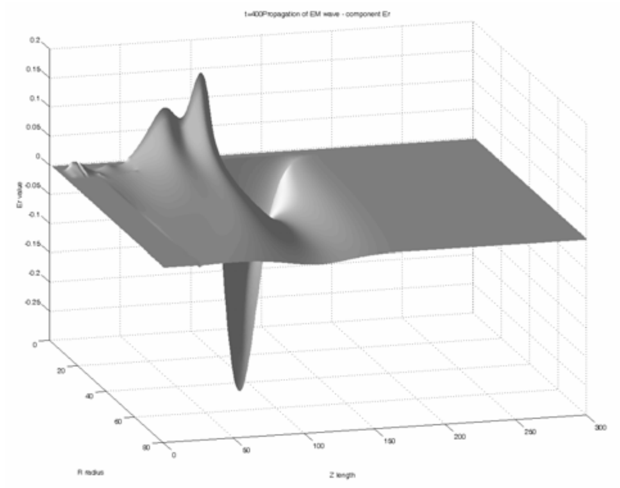

Fig. 4. Wave shape captured after transmission

## III. Results of Numerical Simulation

### *A. Transmission*

To be able to compare the bushings and to work on their optimization, we must define the transmission effectiveness:

$$\tau = \frac{Etr_{peak}}{Es_{peak}} \tag{1}$$

where $Etr_{peak}$ is the peak of $E$ (electrical field intensity) component captured outside the bushing in point P2 (see Fig.2), while $Es_{peak}$ is peak of $E$ captured close to source inside the bushing (point P1). $E_{peak}$ we can generally define as:

$$E_{peak} = \left\| E_{\max} \right| + \left| E_{\min} \right\|_{TD} \tag{2}$$

which means a sum of absolute values of extremes within computed time domain.

The graph of transmission effectiveness $\tau$ for cylindrical shape bushing - type "A" - is shown in Fig. 5. Due to the outer insulator elongation ($l_a$ varies from 0 to 35 mm) the $\tau$ increases. The effect is more significant for shorter pulses.

In other graphs - Fig. 6 and 7 - there are characteristics of $\tau$ of "B to D" version bushings due to opening angle $\alpha$, whereas $l_b = 10mm$.

The figures (Fig. 5 to 7) distinctly show that for shorter pulses (100 ps) transmission it is better to use the variant "A" with longer insulator, for pulses 200 ps is better to use variant "C". For longer pulses (400, 800 ps) is the shape of bushing less important.

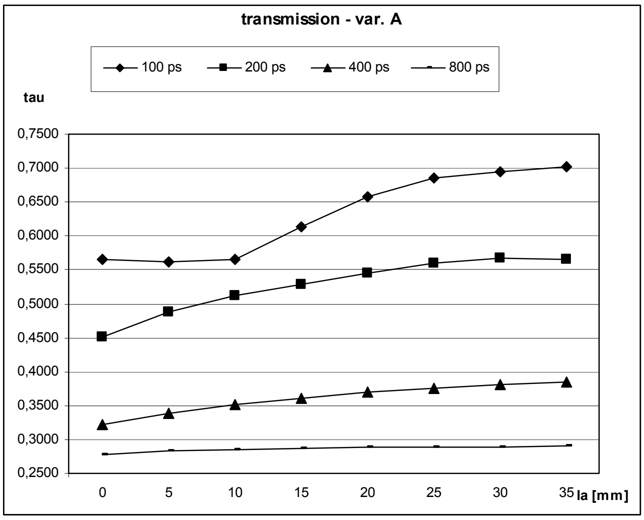


Fig. 5. $\tau$ characteristics of cylindrical bushing

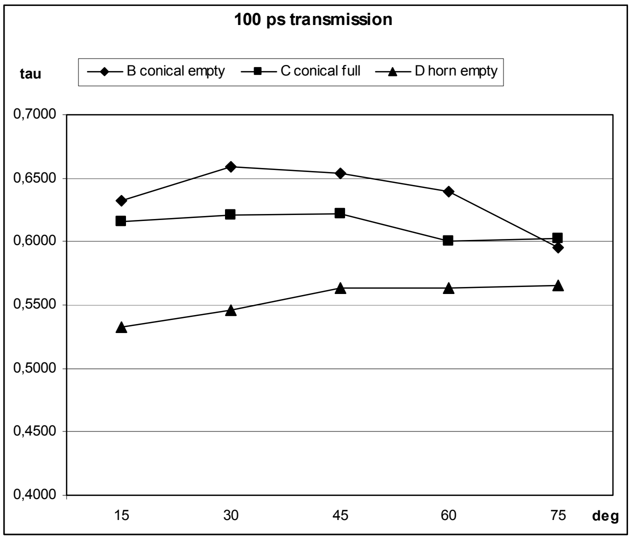


Fig. 6. $\tau$ for conical and horn bushing - 100 ps

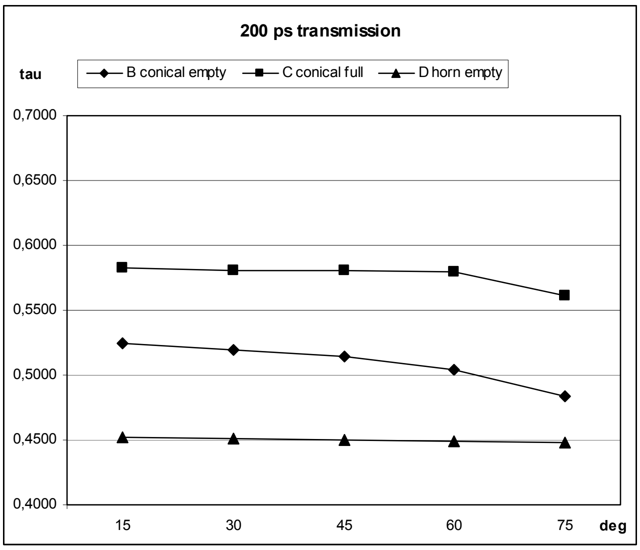


Fig. 7. $\tau$ for conical and horn bushing - 200 ps

*B. Reception*

Similarly to transmission effectiveness we can define reception effectiveness:

$$\rho = \frac{Erec_{peak}}{Etr_{peak}} \tag{3}$$

where $Erec_{peak}$ is the peak of $E$ (electrical intensity) component captured inside the bushing in point P1, while $Etr_{peak}$ is the peak of $E$ captured outside the bushing (point P2).

In Fig. 8 is shown the graph of reception effectiveness $\rho$ for cylindrical shape bushing - type "A". In comparison to transmission the characteristics are more flat.

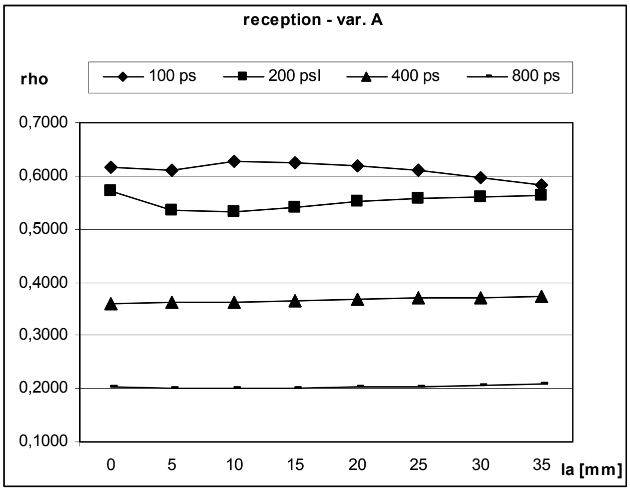


Fig. 8. $\rho$ of cylindrical bushing

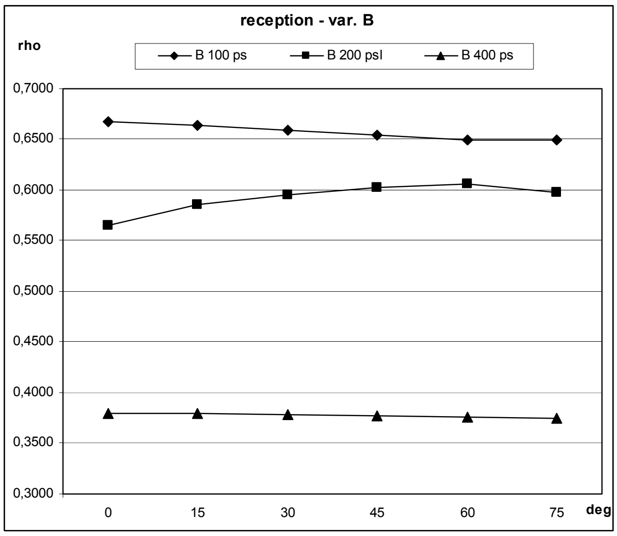


Fig. 9. $\rho$ of conical bushing - var. B

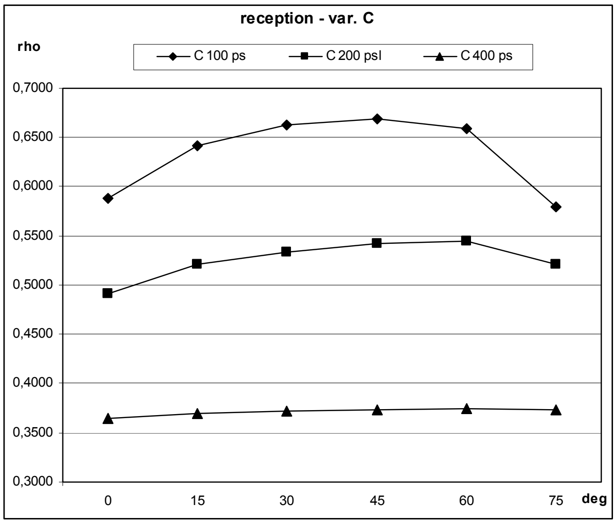


Fig. 10. $\rho$ of conical bushing - var. C

In Fig. 9 and 10 there are depicted angle characteristics of "B" and "C" bushings confirming that the shorter the pulse is the better is its reception.

Captured traces in Fig. 11 and 12 show that even when the effectiveness of reception of certain bushings are almost identical the signal (the order and the size of local extremes) could be quite different.

## IV. Conclusion

The results of numerical simulations showed that there is no universal solution for all pulse widths. Some of bushings are better for transmission, some for reception, however collected together the results of the bushing of variant "B" are the best from the proposed ones. It is evident that every type of bushing causes pulse and electromagnetic wave interferences which could help or make worse the transmission or reception.

It is very hard to provide similar task by means of standard practical experiments. The probe outside the bushing would affect drastically the field and the measurement results would be very much distorted.

However there are numerical results presented, the absolute values of $\tau$ and $\rho$ values are not so important. They differ due to the position of excitation and scanning points and they are used mainly for bushing mutual comparison. Similar results we could certainly obtain by means of other numerical techniques, but e.g. Fidelity (3D cartesian FDTD) from [6] has difficulties with proper definition of absorbing layers (PML) in exact position. So it is almost impossible to arrange the same numerical model as it was presented in this paper.

The cylindrical FDTD simulation method and model were primarily designed for insulation bushing optimization but they can be used for similar coaxial problems, open one-wire structures, antennas, wave-guides etc.

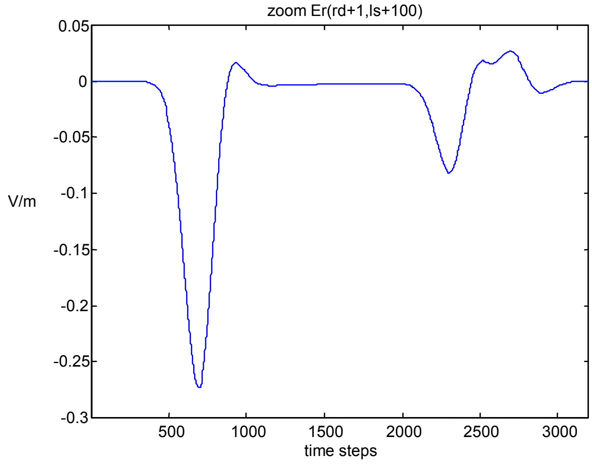


Fig. 11. Wave capture in P2 - var. B - 400 ps

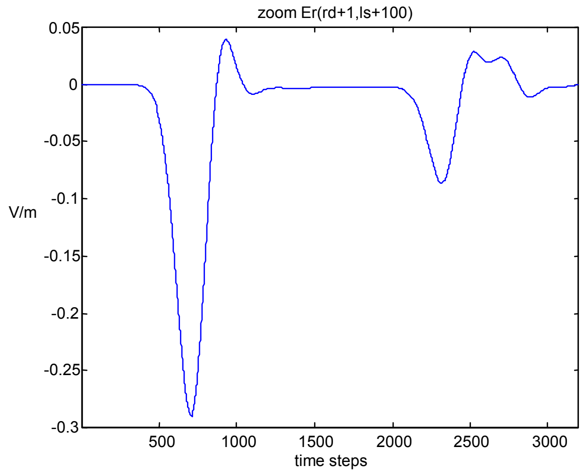


Fig. 12. Wave capture in P2 - var. C - 400 ps

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