Proceedings of the 46th European Microwave Conference

Undergraduate Teaching for Digital Signals on Transmission Lines

R.J.Collier
School of Engineering and Digital Arts
University of Kent
Canterbury, United Kingdom

***Abstract*—This paper sets out the case for an increase in the teaching of pulses on transmission lines, since this is now their major usage. Following this, the paper contains some examples of the typical problems that could be used in teaching and the basic principles that they illustrate. In the conclusion, the paper has some general comments about the modern relevance of transmission lines.**

Keywords—Teaching; Digital Signals; Transmission Lines.

I. INTRODUCTION

In most of the Universities, familiar to the author, there is a trend to devote fewer lectures to the topic of transmission lines and this may well be true for most of Europe. Part of this trend is the increasing pressure on degree course organisers to include many of the latest developments. This can result in the lecturer having to remove much of the traditional material and often the more mathematical sections are either reduced or just the key results quoted. As far as the subject of transmission lines goes, the frequency domain solutions are usually preferred to the time domain ones, for instance see [1],[2],[3],[4], [5]. As a result some basic principles, like the multiple reflections that can occur in some switching circuits, are rarely mentioned. Although the frequency domain solutions are important, they are mainly concerned with the use of sinusoidal signals to measure circuit properties. However, the predominant use of transmission lines involves digital signals in both computers and the internet and therefore a student would benefit from understanding both the pulsed response, as well as the sinusoidal one. One of the reasons for the reticence of lecturers to introduce pulses on transmission lines is the further spectre of the possible need for Laplace Transforms, which adds to their complexity. This paper will give a few examples of the sort of problems that can be discussed without some of these heavy-weight mathematical techniques. First of all the topic can be usefully introduced without attenuation, by starting with the simple equivalent circuit of a lossless length of line. A pleasing aspect of the wave equation, which can be derived from this equivalent circuit, is that its solutions are valid for any shape of the wave. So as long as some care is taken with any time delays in the multiple reflections, there is no need to use Laplace Transforms as many of the solutions are simpler and clearer without them. What follows in this paper are some typical problems which can be given to students who are starting to understand transmission lines. These problems also can be investigated in laboratory practical work, using a suitable long length of line to make the measurements possible with conventional inexpensive pulse generators and oscilloscopes

II. TRANSMISSION LINE PROBLEMS WITH PULSES

The three problems in this section are designed to illustrate some of the characteristics of digital signals on transmission lines. The problems all involve a cable 50m long. This length was chosen arbitrarily to make a laboratory demonstration possible. The first problem illustrates the energy that flows in and out of a transmission line when a pulse is applied. It also illustrates the equal amount of energy that is also lost in this process. The next problem shows the effect of a mismatch and the resultant multiple reflections. Finally the last problem shows the effect of matching the source. These last two problems are taken from [6].

A. Problem 1

In all the three transmission lines shown (Fig. 1), the velocity of propagation is 10^8 ms^{-1} and the characteristic impedance is 50Ω. The pulse generator shown in the circuit diagram in Fig. 1 a), sends a single pulse of amplitude 10V and 10μs duration. Find the voltage across the resistor, for the first 20 μs after the pulse begins, see Fig. 2 a).

The energy lost in the resistor is equal to the energy stored in the line during the pulse. This energy is always lost in the resistor, even if its value is not equal to the characteristic impedance, although in this case, there will be multiple reflections. A student should be able to prove this.

B. Problem 2

Find the voltage waveform across the 300Ω resistor shown in Fig. 1 b), for the first 10μs after the switch is closed. The full solution is found in reference [6], see Fig. 2 b).

The solution shows that the circuit does not reach the steady state value of 49 volts across the resistor for at least 10 μs. It also has a maximum of 84 volts and a minimum of 24 volts. Both of these values may well be undesirable in a digital circuit. A similar situation will take place when the circuit is switched off, or in other words, the equivalent of a pulsed response.

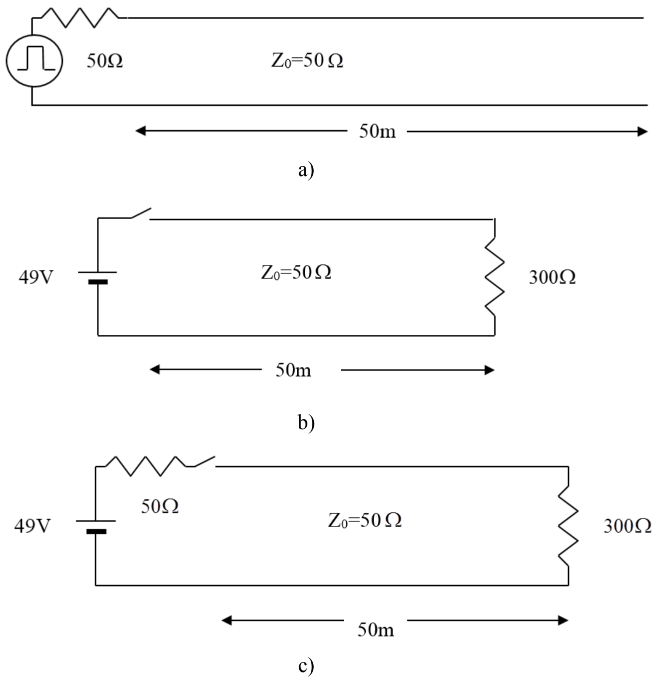

Fig. 1. Transmission Lines for Problem a) 1, b) 2 and c) 3.

C. Problem 3

In this problem, the source has been matched to reduce the multiple reflections. Find the voltage across the 50Ω resistor. The circuit diagram and the solution are shown in Fig. 1 c) and Fig. 2 c). The full solution is in reference [6].

The returning reflection reduces the voltage across the 50Ω resistor from 24.5 to 7 volts. The energy in the transmission line is 12μJ, and if the source is switched off this energy would be divided between both of the resistors.

III. CONCLUSIONS

These three problems were chosen to illustrate the sort of time domain waveforms that easily occur in digital circuits. Clearly, there are many more examples that could have been chosen. These solutions assume a loss-less transmission line and are relatively easy to find. They could also form the basis for a feasible laboratory demonstration. If losses are to be included, then the Laplace Transform solution will be needed [6] and the main difference will be in the shape of the leading edge of the pulse, as well as an exponential decay of the pulse along the line. Often the stored energy in circuits is overlooked in design, with result that practical devices do not perform exactly as predicted by their computer designers. As this movement of stored energy in pulsed circuits is always linked with a loss of energy, this accounts, in part, for the high temperatures experienced in some components. The dispersion effects, particularly in two conductor transmission lines, account for the poor bandwidth suffered by users of the internet in remote places. Finally, the frequency domain solutions, elegant though they are, have to be linked to the time domain as in practice every source is switched on and off.

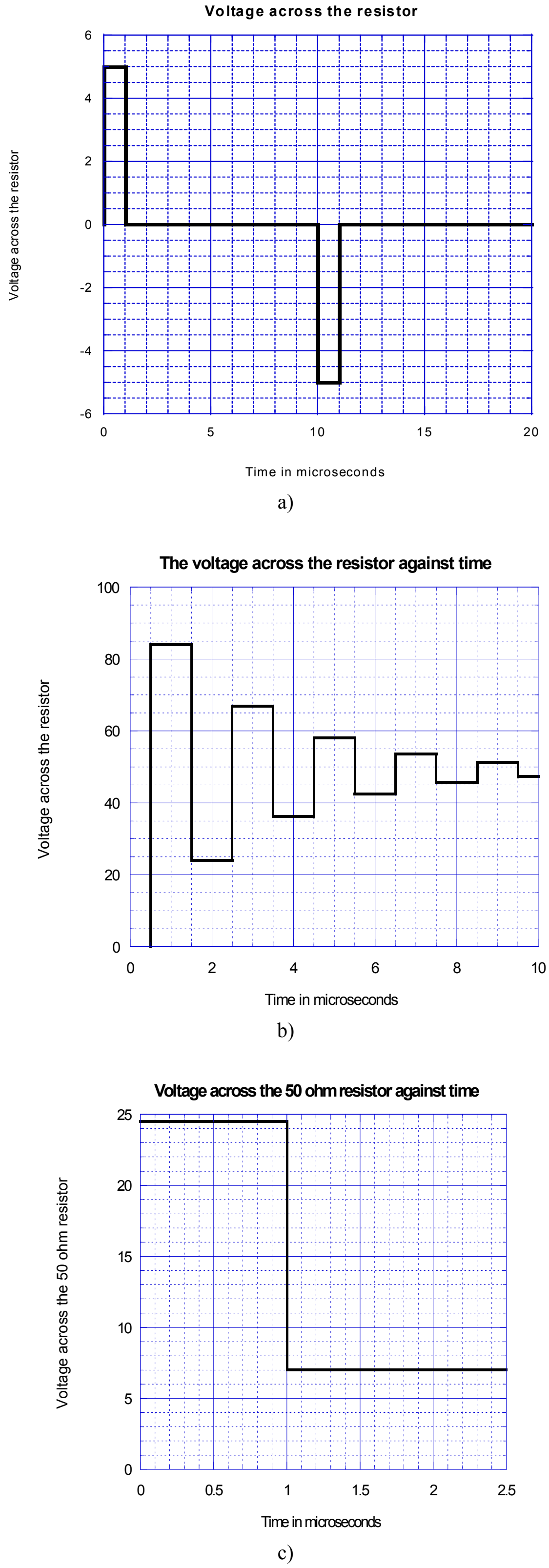

Fig. 2. Solutions for Problem a) 1, b) 2 and c) 3.

These switching transients can determine whether a circuit functions or not. This topic is therefore at the heart of all passive circuits and should not be given such minimal treatment in so many of Europe’s University degree courses.

ACKNOWLEDGMENT

The author would like to acknowledge the support of Dr P.R.Young and his encouragement to submit this paper, and the help of Mr A Cole in formatting it correctly.

REFERENCES

[1] S.Ramo, J.R. Whinnery and T. VanDuzer , Fields and Waves in Communication Electronics, Third Edition, New York, Wiley, 1993

[2] J.D.Krauss, Electromagnetics, Fourth Edition, New York, McGraw-Hill, 1992.

[3] R.E.Collin, Foundations for Microwave Engineering, New York, McGraw-Hill, 1992.

[4] T.H.Lee, Planar Microwave Engineering, a Practical guide to Theory, Measurement and Circuits, Cambridge, Cambridge University Press, 2004.

[5] D. Pozar, Microwave Engineering, Second Edition, New York, Wiley, 1998.

[6] R.J.Collier, Transmission Lines, Cambridge, Cambridge University Press, 2013.