Active shaping of an electromagnetic field- EMC applications

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Objectives

To control an electromagnetic field (or voltage) in different environments (transmission lines (TL), free space).

1. Control an electromagnetic field in a TL network
   - ▷ Software correction of a defective network
   - ▷ Detection and localization of defects
2. Control an electromagnetic field in free space environment

Introduction

- The idea of identifying a source that produces a specified electromagnetic field at a given point in space has received a considerable attention over the past 20 years or so. It has been popularized by the time reversal (TR) method, first applied in acoustic and has since spread in various other domains, including electromagnetic compatibility (EMC).
  The advantage of such method is its simplicity. However, its major drawback comes from the fact that it becomes less reliable when imposing complex conditions on the time duration, the target field or when dealing with multiple points in space. Consequently, the need for novel techniques dedicated to accurately tackle such problems is necessary.

Methods

- The methods to control an EM field are:
  - ▷ Time Reversal (TR)
  - ▷ Linear Combination of Configuration Fields (LCCF)

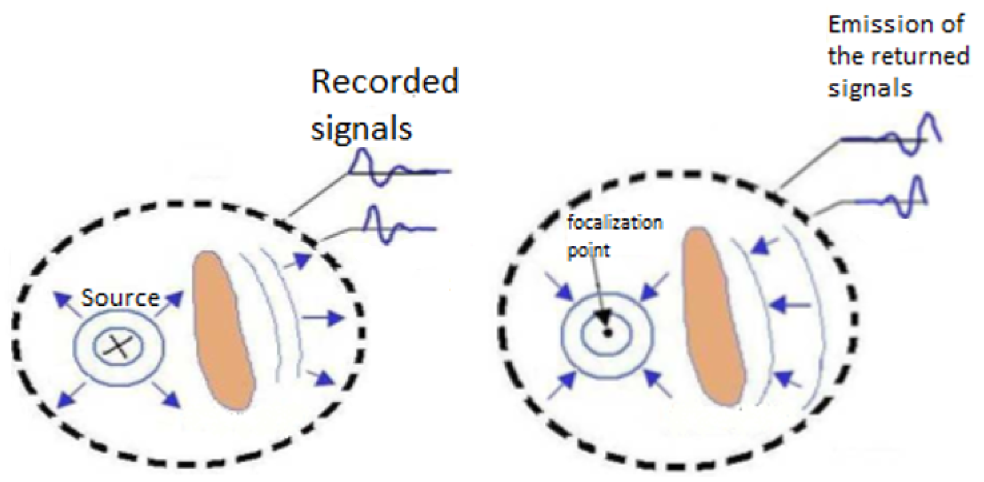


Figure: TR principle

TR	LCCF
Inaccurate due to numerical errors	Compensates numerical errors
Tackle only lossless problems	Tackle problems with arbitrary losses
Less reliable with a complex EM field	Reliable with a complex EM field
Requires perfect Huygens surface	Perfect Huygens surface is not required

Table: Comparison between TR and LCCF

Mathematical Section: LCCF theory

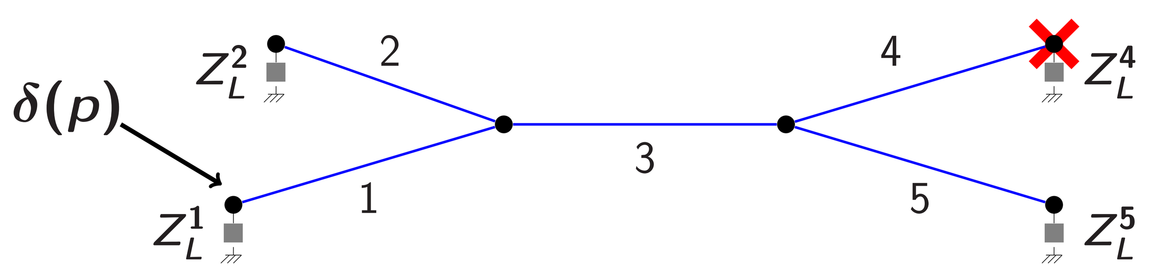


Figure: The configuration of the TL network used

- The LCCF steps are:
  1. Construct the LCCF transfer matrix A: Inject an impulsion and record at a specified point.
  2. Construct the vector b: Inject a signal $\mathfrak{s}_1$ and record at the same point considered in the 1^{st} step.
  3. Solve the linear system:

$$As = -b + F$$

to find s the signal to be injected after $\mathfrak{s}_1$ in order to obtain the target field F.

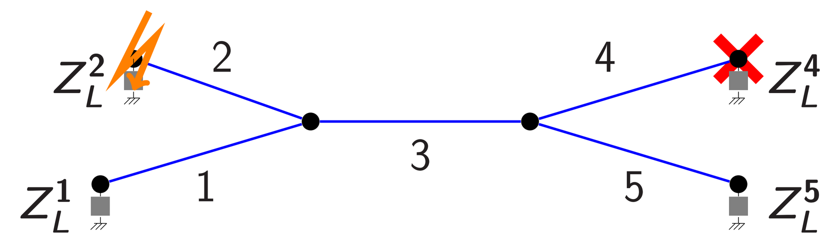
- Nullifying at several points requires the following system to be solved:

$$\begin{pmatrix} A_1 \\ \vdots \\ A_M \end{pmatrix} s = -\begin{pmatrix} b_1 \\ \vdots \\ b_M \end{pmatrix} + \begin{pmatrix} F \\ \vdots \\ F \end{pmatrix} \Leftrightarrow \mathscr{A}s = -\mathscr{b} + \mathscr{F} \qquad (1)$$

- The system (1) is not square and has to be solved in the least square sense.
- (1) requires to be regularized (Tikhonov), it takes the form:

$$(\mathscr{A}^T\mathscr{A} + \epsilon I)\, s = \mathscr{A}^T(-\mathscr{b} + \mathscr{F}), \epsilon > 0$$

Results: Null Voltage ($F = 0$) / Defect Detection



Branch nb	1	2	3	4	5
Length	5	6	4	2	5
Z_C	50	50	50	50	50
Z_L	0	45	0	50	0

Table: Characteristics of the TL network

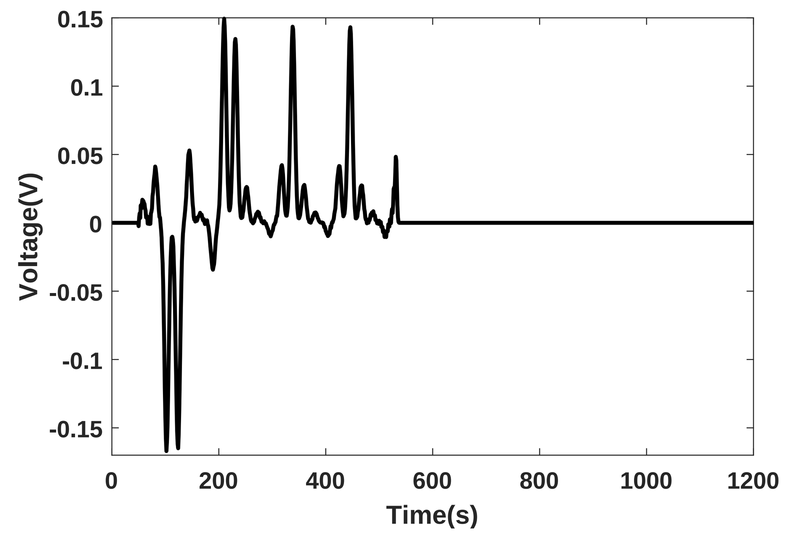


Figure: The LCCF source

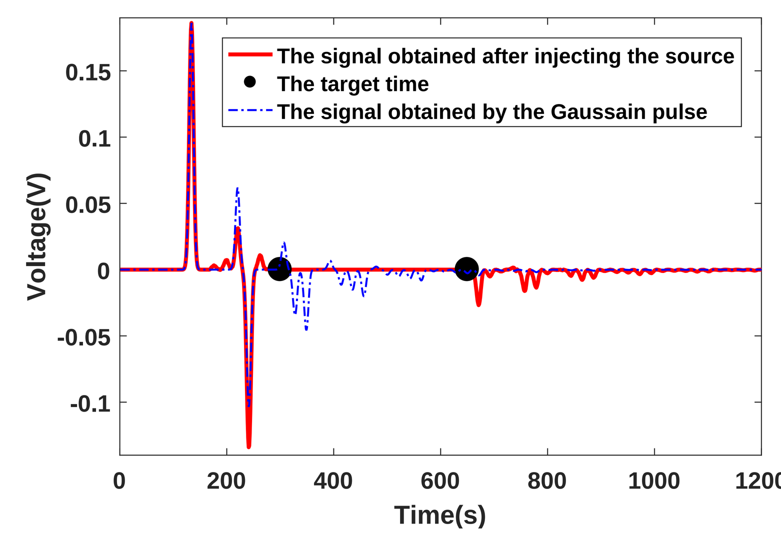


Figure: Nullifying at the the end of line 4

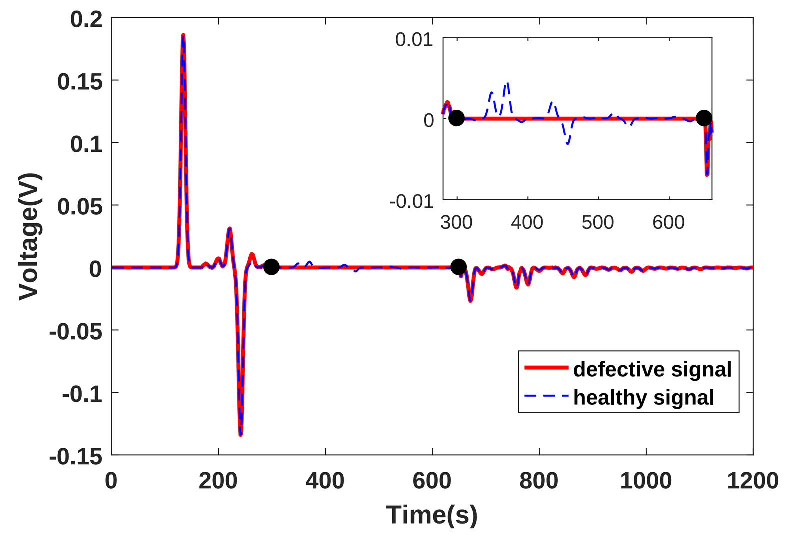
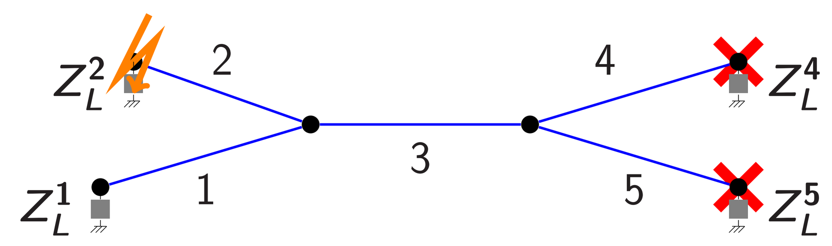


Figure: Detecting a defect in the TL network

- The LCCF source characteristics:
  - ▷ Non-trivial
  - ▷ Its amplitude remains in the same order of magnitude as the Gaussian pulse (1V).
- A non-null voltage implies that a defect is presented in the TL network.
- The LCCF method outperforms the reflectometry technique due to its high sensitivity to soft defects.

Results: Software Defect Correction



Branch nb	1	2	3	4	5
Length	5	6	4	2	5
Z_C	50	50	50	50	50
Z_L	0	10	0	50	0

Table: Characteristics of the TL network

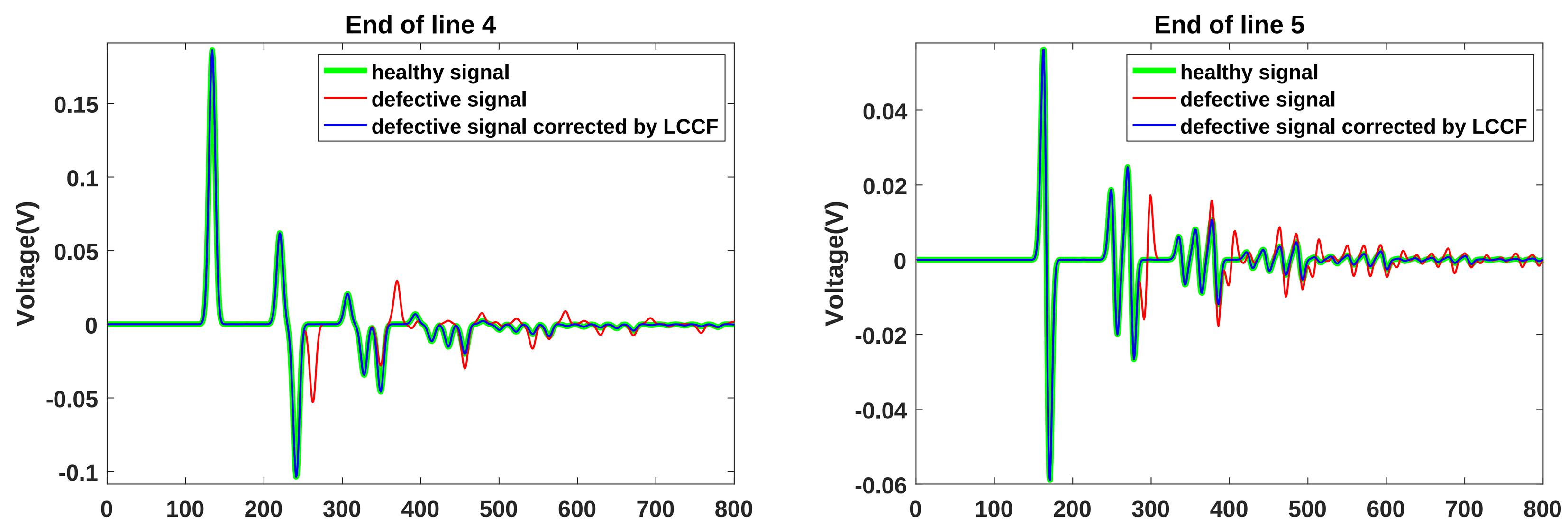


Figure: Software correction at the end lines 4 and 5

- By the LCCF method, we can compute the new voltage source to be injected in order to obtain the voltages of the healthy network.

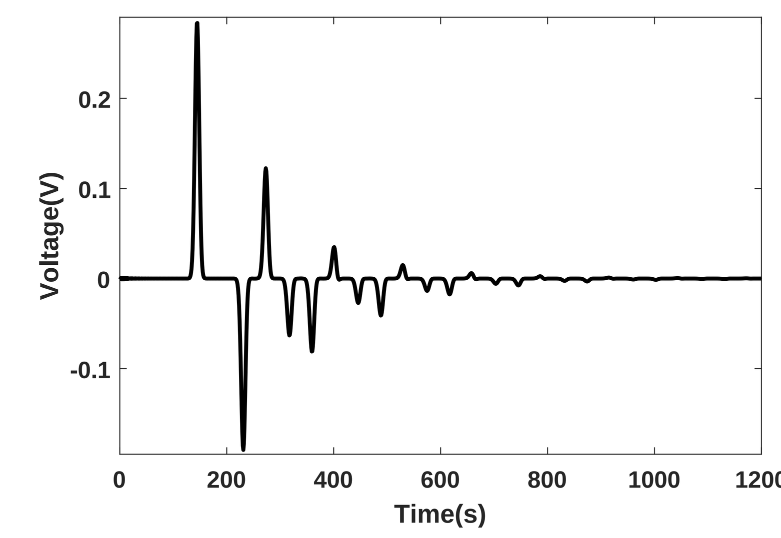


Figure: The LCCF source

Conclusion

- To summarize, using the LCCF technique we can:
  - ▷ Detect defects (hard or soft).
  - ▷ Bring a software correction to defective complex TL networks.
- Future work:
  - ▷ Locate the defects in TL networks
  - ▷ Control an electromagnetic field in 3D
  - ▷ Control an electromagnetic field in the frequency domain
  - ▷ Experimental Tests

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