An Overview of Modal Transmission Schemes

Frédéric Broydé and Evelyne Clavelier

- ❒ Introduction
- ❒ Survey of modal signaling in untransposed interconnections
- ❒ Internal crosstalk cancellation schemes
- ❒ An extension of modal signaling
- ❒ Mitigation of external crosstalk
- ❒ Conclusion

1. Introduction

❐ This paper is about modal transmission used to reduce echo and internal crosstalk in a multichannel electrical link providing $m \geq 2$ channels.

❐ MTL theory defines and investigates the propagation modes of the interconnection. It is the basis of modal transmission, since, in modal transmission, each channel is allocated to a propagation mode.

❐ We assume that:

◆ the link is linear and uses an interconnection having n TCs where $n \geq m$;

◆ the interconnection does not use frequent permutations of the conductors to obtain certain propagation properties.

❐ The main advantages of modal signaling are that the $m - 1$ shields or wide TC-to-TC spacings used in a fast m-channel single-ended or differential link are not needed, and that only m leads are required.

❒ We shall use the following definitions:

◆ *echo* is the phenomenon by which a signal sent or received at an end of the link, in one of the channels, is followed by the reception of a delayed noise in the same channel, at the same end of the link;

◆ *reflection* is the phenomenon by which a wave propagating in a given direction produces a wave propagating in the opposite direction;

◆ *internal crosstalk* is the phenomenon by which a signal sent in one of the channels produces noise in another channel;

◆ *external crosstalk* is the occurrence of noise caused by interactions between the link and other circuits of the device in which it is built;

◆ *TC-to-TC coupling* collectively designates mutual capacitance between the TCs and mutual impedance between loops each comprising one of the TCs;

◆ a *transition matrix from modal electrical variables to natural electrical variables* is one of the matrices **S** and **T** satisfying

$$\begin{cases} \mathbf{T}^{-1}\mathbf{Y}'\mathbf{Z}'\mathbf{T} = \Gamma^2 \\ \mathbf{S}^{-1}\mathbf{Z}'\mathbf{Y}'\mathbf{S} = \Gamma^2 \end{cases} \quad \text{where} \quad \Gamma = \mathrm{diag}_n(\gamma_1, \ldots, \gamma_n) \tag{1}$$

is the diagonal matrix of order n of the propagation constants;

◆ the *characteristic impedance matrix* $\mathbf{Z}_C$ is given by

$$\mathbf{Z}_C = \mathbf{S}\,\Gamma^{-1}\,\mathbf{S}^{-1}\mathbf{Z}' = \mathbf{S}\,\Gamma\,\mathbf{S}^{-1}\mathbf{Y}'^{-1} = \mathbf{Y}'^{-1}\mathbf{T}\Gamma\mathbf{T}^{-1} = \mathbf{Z}'\,\mathbf{T}\Gamma^{-1}\mathbf{T}^{-1} \tag{2}$$

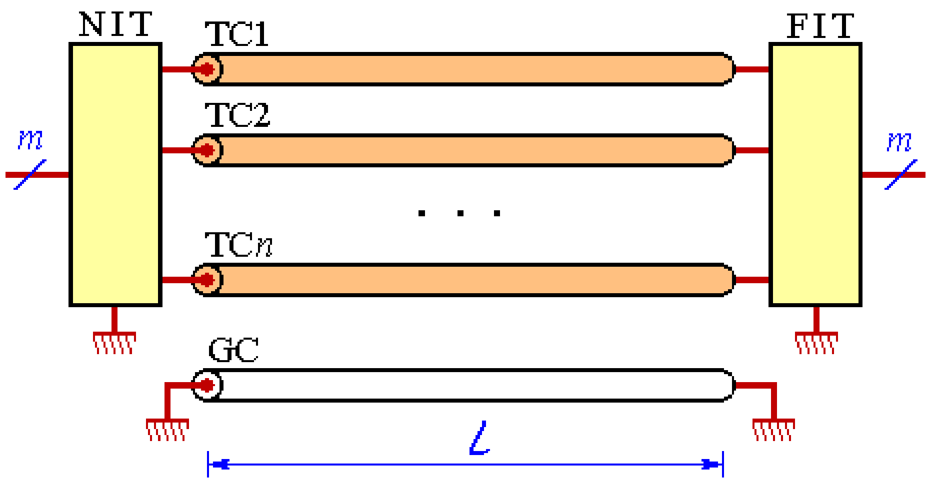
◆ $\mathbf{i}_M = \mathbf{T}^{-1}\,\mathbf{i}$ is the column vector of the *modal currents*;

◆ $\mathbf{v}_M = \mathbf{S}^{-1}\,\mathbf{v}$ is the column vector of the *modal voltages*;

◆ *matched* means having an impedance matrix equal to $\mathbf{Z}_C$, a matched termination producing no reflection.

2. Survey of modal signaling in untransposed interconnections

❒ In conventional *modal signaling*:



◆ the interconnection model used to design the link is a uniform MTL model, i.e. an MTL model in which $\mathbf{Z}'$ and $\mathbf{Y}'$ are uniform;

◆ each of the m transmission channels is allocated to a modal electrical variable, that is a modal voltage or modal current;

◆ the NIT and the FIT must perform the necessary conversions, which are linear combinations defined by a transition matrix from modal electrical variables to natural electrical variables (that is $\mathbf{S}$ or $\mathbf{T}$).

❒ Some early modal signaling appeared about 20 years ago as a way of eliminating crosstalk in a uniform interconnection. They used incorrect assumptions such as:

- ◆ "there is no crosstalk between modes as there is between non-modal propagation";
- ◆ "in general, *n* conductors and ground have *n* orthogonal modes";
- ◆ "the common-mode is one of the propagation modes".

❒ The *ZXtalk method* combines modal transmission with the use of a NIT and/or of a FIT behaving substantially as a matched termination. It takes into account the frequency dependence of $\mathbf{Z}_C$ and the possible frequency dependence of the transition matrix from modal electrical variables to natural electrical variables used to define the transmission channels.

❒ It is subdivided into a *general ZXtalk method* and a *special ZXtalk method* in which the link is such that **S** or **T** is considered to be equal to the identity matrix.

❐ Other authors have investigated the implementation of modal transmission schemes to digital links and shown the advantages of this approach (5 references).

❐ Three high-speed modal chip-to-chip links have been built and described.

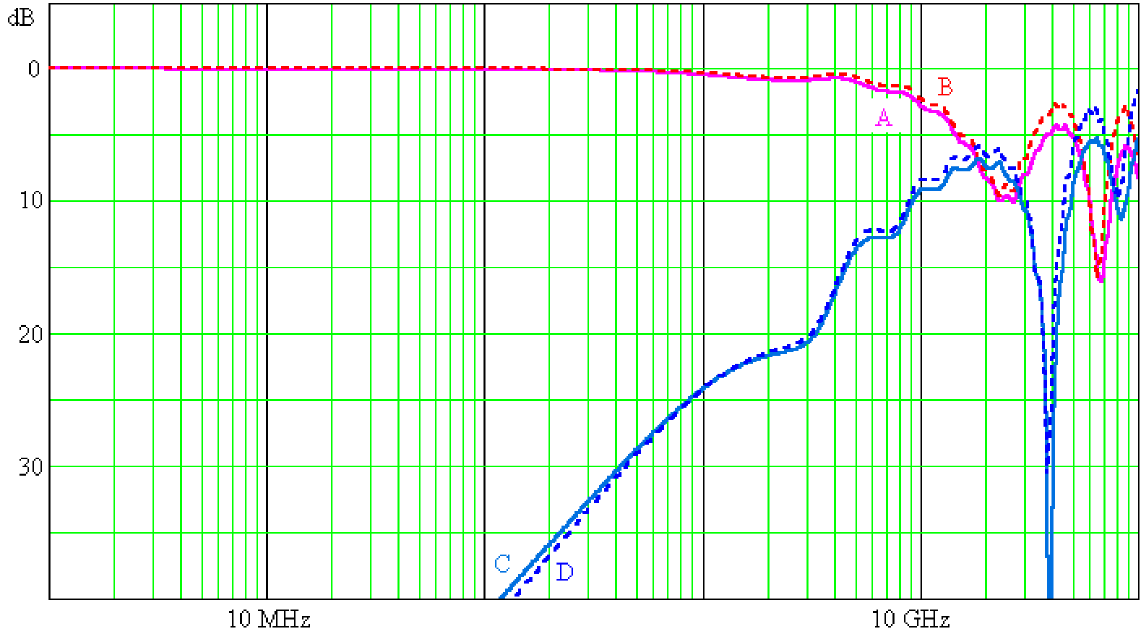
❐ The initial presentation of the ZXtalk method used:

- ◆ the concept of total decoupling, because it provides an independent propagation of each eigen-voltage with the associated eigen-current;
- ◆ an approximate model of an interconnection built in a PCB or MCM, which accurately takes high-frequency losses into account, and uses a characteristic impedance matrix and a transition matrix from modal electrical variables to natural electrical variables which are computed as if losses were not present.

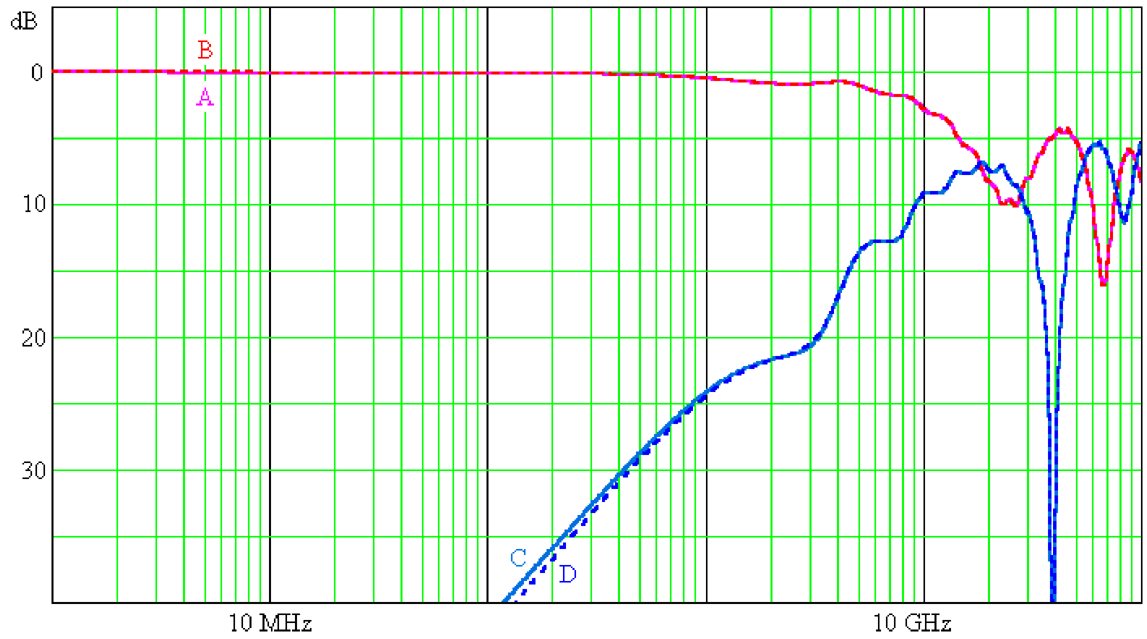
❐ A recent paper presents new results on total decoupling and a detailed justification of this approximate model.

❒ As an example of the approximate model, this paper shows the signals at the ends of a 20-mm-long section of a multiconductor microstrip interconnection, used in a conventional single-ended signaling configuration in which each end sees an impedance matrix of 50 Ω × $\mathbf{1}_n$ with respect to the GC.

Attenuations at the far-end according to a lossless MTL model, when a signal is applied at the near-end of TC2. Curve A and C: exact signal on TC2 and TC3. Curve B and D: signals on TC2 and TC3.



Attenuations at the far-end according to said approximate model which accurately takes high-frequency losses into account, when a signal is applied at the near-end of TC2. Curve A and C: exact signal on TC2 and TC3. Curve B and D: signals on TC2 and TC3.



❒ The existence of this approximate model is important, because it entails that, in the ZXtalk method, the linear combinations performed by the NIT and FIT can be frequency independent and that the termination circuit in the NIT and/or FIT can be a network of resistors.

3. Internal crosstalk cancellation schemes

❒ Modal signaling may be viewed as a variation of the general crosstalk cancellation concept of noise subtraction.

❒ In noise subtraction, the knowledge of transfer functions or time-domain responses is used to eliminate internal crosstalk using signal processing.

❒ In general, noise subtraction leads to intensive real-time computations when the interconnection is not electrically short.

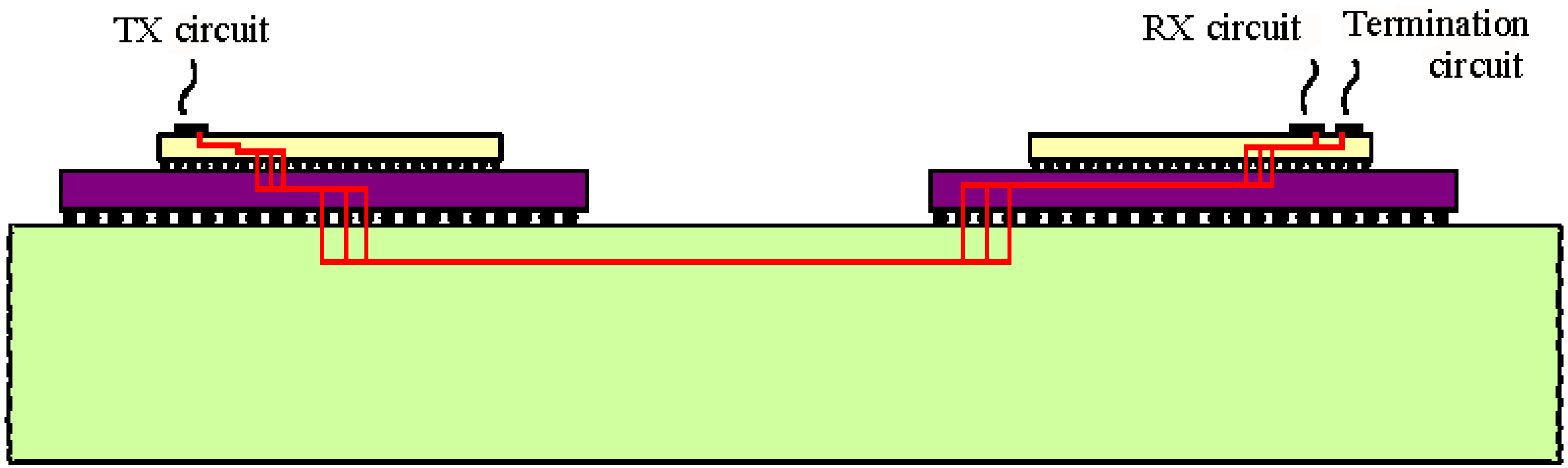
❒ Some new signaling schemes applicable to an arbitrary nonuniform interconnection use this type of crosstalk cancellation.

❒ Modal signaling is a special case of this general concept where the signal processing requirements are much lighter because the signal processing is based on modal transforms which are mildly frequency dependent and independent of the interconnection length.

4. An extension of modal signaling

❒ Up to now, our definitions of modal signaling and of the ZXtalk method are based on a uniform MTL model.

❒ It is possible to extend the general ZXtalk method to some interconnections which cannot be modeled with a uniform MTL. This extension is useful when one wishes to consider an interconnection spanning several substrates.



❒ The basic ideas of this extension are the following:

◆ we assume that the interconnection can be modeled as a non-uniform MTL, so that, at each point z we can formally define $\mathbf{S}$, $\mathbf{T}$ and $\mathbf{Z}_C$;

◆ the interconnection is proportioned such that $\mathbf{S}$ and $\mathbf{Z}_C$ are uniform;

◆ in this case, total decoupling can be obtained with a uniform $\mathbf{T}$ given by

$$\mathbf{T} = z_K \, \mathbf{Z}_C^{-1} \, \mathbf{S} \tag{3}$$

where z_K is an arbitrary nonzero scalar, which has the dimensions of impedance;

◆ we can then define $\mathbf{v}_M = \mathbf{S}^{-1}\,\mathbf{v}$ and $\mathbf{i}_M = \mathbf{T}^{-1}\,\mathbf{i}$, $\mathbf{v}_M$, and show that they satisfy

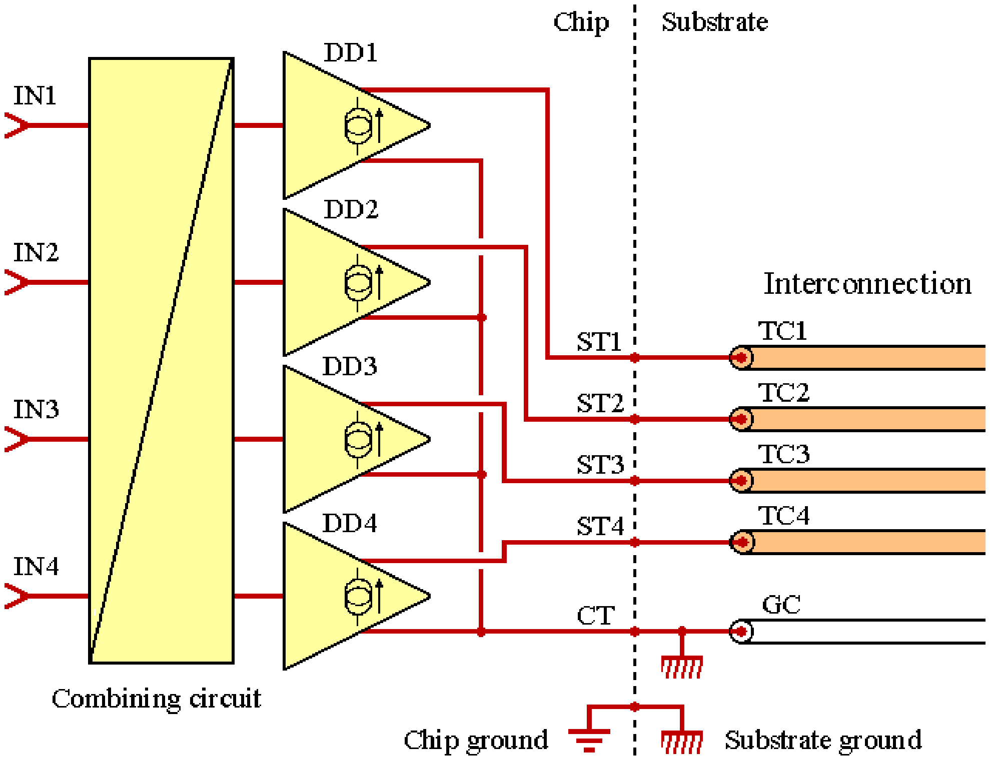
$$\begin{cases} \dfrac{d^2\,\mathbf{v}_M}{dz^2} - \Gamma^2 \mathbf{v}_M = \dfrac{d\,\Gamma}{dz}\,\Gamma^{-1}\,\dfrac{d\,\mathbf{v}_M}{dz} \\ \dfrac{d^2\,\mathbf{i}_M}{dz^2} - \Gamma^2\,\mathbf{i}_M = \dfrac{d\,\Gamma}{dz}\,\Gamma^{-1}\,\dfrac{d\,\mathbf{i}_M}{dz} \end{cases} \tag{4}$$

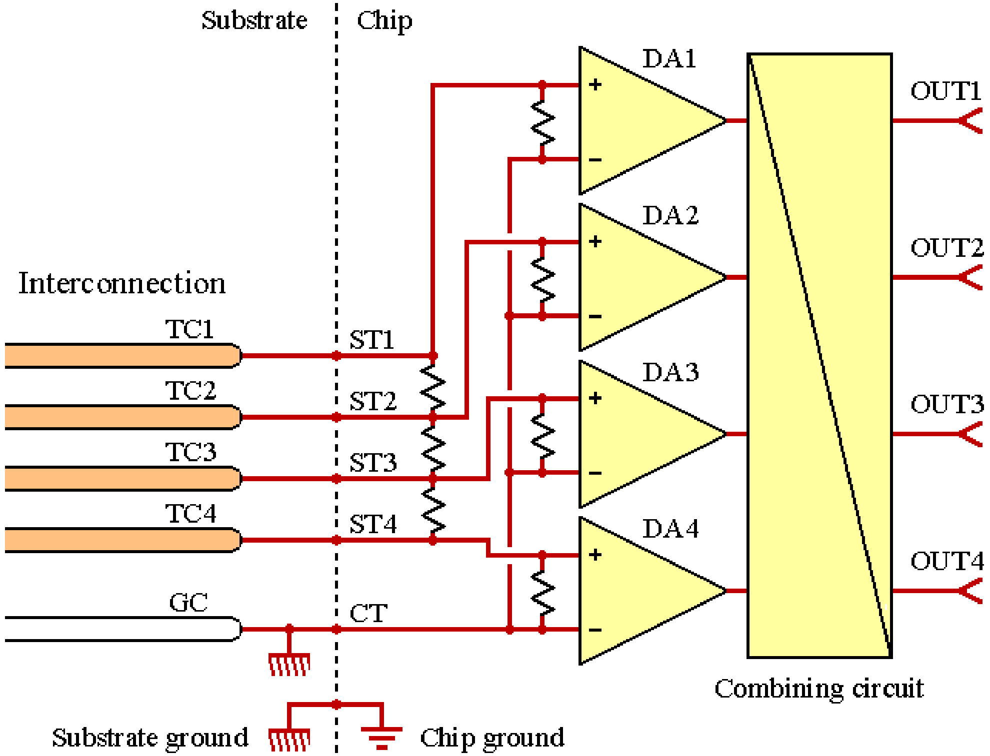
◆ Γ and $d\,\Gamma/dz$ being diagonal matrices, these equations are decoupled.

5. Mitigation of external crosstalk

❒ Modal signaling does not reduce external crosstalk. The dominant source of external crosstalk is usually common-mode coupling at the near-end or at the far-end.

❒ This TX-circuit provides a protection against common-mode coupling to an implementation of the ZXtalk method.





❒ This RX-circuit and termination circuit TX-circuit provide a protection against common-mode coupling to an implementation of the ZXtalk method.

❒ Both designs use CT and substrate ground configuration which minimizes common impedances.

❒ None of these designs relate to a pseudo-differential link.

6. Conclusion

❒ We have reviewed modal signaling schemes and we have presented some improvements to them.

❒ Modal links using a large number of TCs are more relevant to configurations where bends are not prevalent.

❒ Another factor playing against the widespread use of modal links other than differential serial links is the lack of standardized interface.

❒ There are many types of links for which these factors are immaterial, for instance in the substrate of an MCM or in flex top-side bridges between MCMs.

❒ In such applications, modal signaling can increase the wiring density and reduce costs.