Scattering matrix representation for the incidence of electromagnetic waves on multiconductor transmission line structures.

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Abstract - In the present contribution, we demonstrate how circuits described by a coupled transmission line model with distributed sources can be represented by a classical $\underline{\underline{S}}$-matrix description. This approach allows one to use commercially available time and/or frequency domain simulators to study the circuit behaviour.

GEOMETRY AND FORMULATION OF THE PROBLEM

In [1, 2, 3, 4] amongst others circuit models are derived to account for the influence of an incident field impinging on a multiconductor transmission line system (MTL). This MTL with constant cross-section consists of N conductors. In many papers, the conductors are assumed to be cables above earth and located in free space ([1], [2]), in other contributions, the conductors may be embedded in a planar stratified medium ([3], [4]). In both cases, the coupled transmission line model one obtains to account for the influence of the incident field has the following form (the z-direction equals the propagation direction) :

$$\begin{aligned} \frac{d\underline{V}(z,\omega)}{dz} + \underline{\underline{Z}}(\omega)\underline{I}(z,\omega) &= \underline{V}_g(z,\omega) \\ \frac{d\underline{I}(z,\omega)}{dz} + \underline{\underline{Y}}(\omega)\underline{V}(z,\omega) &= \underline{I}_g(z,\omega) \end{aligned} \qquad (1)$$

$\underline{V}(z,\omega)$, $\underline{I}(z,\omega)$, $\underline{V}_g(z,\omega)$, $\underline{I}_g(z,\omega)$:
vectors of N elements,
$\underline{\underline{Z}}(\omega)$ ($\underline{\underline{Y}}(\omega)$) :
NxN impedance (admittance) matrix.
$\underline{V}_g(z,\omega)$ and $\underline{I}_g(z,\omega)$ are frequency and z-dependent, distributed sources. As most commercially available circuit simulators do not allow transmission line circuits with distributed sources, one is obliged to develop a new simulator or one has to look for an alternative formulation. In the next section (1) will be transformed into a description that can be handled by modern circuit simulators .

SCATTERING MATRIX DESCRIPTION OF THE PROBLEM

It is generally known that a circuit with active components can be described by an $\underline{\underline{S}}$-matrix formalism in the following way :

$$\underline{B}(\omega) = \underline{\underline{S}}(\omega)\underline{A}(\omega) + \underline{C}(\omega). \qquad (2)$$

$\underline{A}(\omega)$, $\underline{B}(\omega)$, $\underline{C}(\omega)$: vectors of N elements,
$\underline{\underline{S}}(\omega)$: (NxN) − matrix.
$\underline{\underline{S}}(\omega)$ is the global scattering matrix and $\underline{C}(\omega)$ the external source vector. $\underline{\underline{S}}(\omega)$, $\underline{A}(\omega)$, $\underline{B}(\omega)$ and $\underline{C}(\omega)$ may be frequency dependent.

In the following the voltage wave vectors of the structure, described by equation (2), are defined with respect to the characteristic impedance matrix $\underline{\underline{Z}}_c$ of the structure. $\underline{A}^1(\omega)$ and $\underline{B}^1(\omega)$ ($\underline{A}^2(\omega)$ and $\underline{B}^2(\omega)$) represent the incident and reflected voltage wave vectors at the beginning (end) of the conductors (see Fig. 1). As the conductors may be coupled, the voltages and impedances in Fig. 1 at the line ends are represented by matrices. With these definitions, one obtains the following $\underline{\underline{S}}$-matrix description for the MTL structure under study (The superscript indicates the port number, the subscript gives the dimension of the matrix ; d is the length of the considered MTL-

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section and $\underline{\underline{A}}_v$ is the complex voltage propagation matrix of the MTL).

$$\begin{pmatrix} \underline{B}^1(\omega)_{Nx1} \\ \underline{B}^2(\omega)_{Nx1} \end{pmatrix} = \underline{B}_{2Nx1}$$

$$= \begin{pmatrix} 0_{NxN} & \underline{\underline{Z}}_c^{-\frac{1}{2}} e^{-\underline{\underline{A}}_v d} \underline{\underline{Z}}_c^{\frac{1}{2}} \\ \underline{\underline{Z}}_c^{-\frac{1}{2}} e^{-\underline{\underline{A}}_v d} \underline{\underline{Z}}_c^{\frac{1}{2}} & 0_{NxN} \end{pmatrix} \begin{pmatrix} \underline{A}^1(\omega) \\ \underline{A}^2(\omega) \end{pmatrix}$$

$$+ \begin{pmatrix} -\frac{1}{2} \underline{\underline{Z}}_c^{-\frac{1}{2}} e^{\underline{\underline{A}}_v \mathrm{begin}} \int_{\mathrm{begin}}^{\mathrm{end}} e^{-\underline{\underline{A}}_v z} (\underline{V}_g - \underline{\underline{Z}}_c \underline{I}_g) dz \\ \frac{1}{2} \underline{\underline{Z}}_c^{-\frac{1}{2}} e^{-\underline{\underline{A}}_v \mathrm{end}} \int_{\mathrm{begin}}^{\mathrm{end}} e^{\underline{\underline{A}}_v z} (\underline{V}_g + \underline{\underline{Z}}_c \underline{I}_g) dz \end{pmatrix}$$

$$= \underline{\underline{S}}_{2Nx2N} \underline{A}_{2Nx1} + \underline{C}_{2Nx1}$$

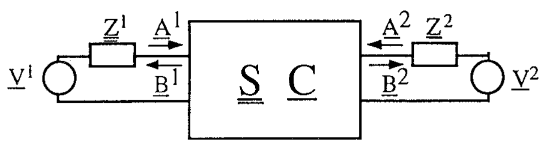

Fig. 1 : A 2N coupled port system characterised by a $\underline{\underline{S}}$- and $\underline{C}$-matrix.

This means that when the influence of an incident field on a MTL with N conductors is studied the active part of the structure is represented by a [2Nx1]-$\underline{C}$-matrix while the passive part is described by the [2Nx2N]-$\underline{\underline{S}}$-matrix. This system can be transformed to an equivalent network, described by an active [4Nx4N]-$\underline{\underline{S}}$-matrix and with 2N additional external sources :

$$\begin{pmatrix} \underline{B}_{2Nx1} \\ \underline{C}_{2Nx1} \end{pmatrix} = \begin{pmatrix} \underline{\underline{S}}_{2Nx2N} & \underline{\underline{1}}_{2Nx2N} \\ \underline{\underline{0}}_{2Nx2N} & \underline{\underline{1}}_{2Nx2N} \end{pmatrix} \begin{pmatrix} \underline{A}_{2Nx1} \\ \underline{C}_{2Nx1} \end{pmatrix} \quad (4)$$

where $\underline{\underline{1}}_{2Nx2N}$ is the 2Nx2N unitary matrix.

To obtain this, 2N additional ports are added to the circuit (Fig. 2). Each of these new ports is driven by a voltage source, whose variation as a function of frequency is given by one of the elements of the $\underline{C}$-matrix (one port for each element) multiplied by 2 times the square root of the reference impedance of the port. The impedance at each coupled port can be chosen freely . With this transformation, the internal active part $\underline{C}$ (i.e. the sources $\underline{V}_g$ and $\underline{I}_g$) are represented as completely outside sources. This approach makes it possible to use widely available simulators such as HP-MDS and Libra to characterise the structures described by equation (1).

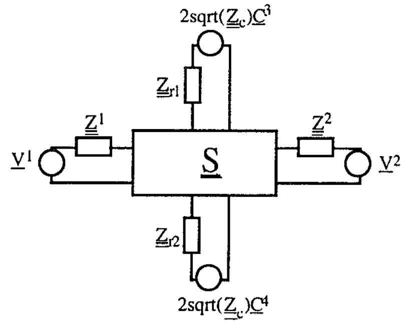

Fig. 2 : Active 4N coupled port system characterised by a $\underline{\underline{S}}$-matrix.

NUMERICAL RESULTS

Consider the configuration shown in Fig. 3. Two asymmetric strips are placed on a lossy substrate, they are 15 mm long and are terminated as shown in Fig. 4. The voltage source generates a sinusoidal wave of 10GHz with an amplitude of 2V. This structure is illuminated by a horizontal electrical dipole $\underline{J}_h = J\underline{u}_x \delta(x)\delta(z)\delta(y-2mm)$ with J=1mA mm, situated at 2 mm above the ground plane.

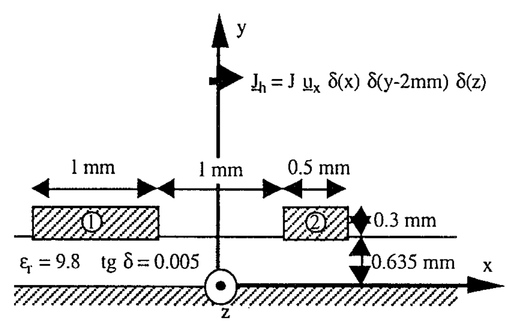

Fig. 3 : Cross-section of the structure under study.

Fig. 5 shows the induced voltage at the beginning and at the end of the left and of the right conductor respectively, in the presence of the electrical dipole. In Fig. 6 the dipole is removed. One notices that only in node 1 the incident field couples destructively, in all the other nodes, the voltage increases due to the presence of the interfering source.

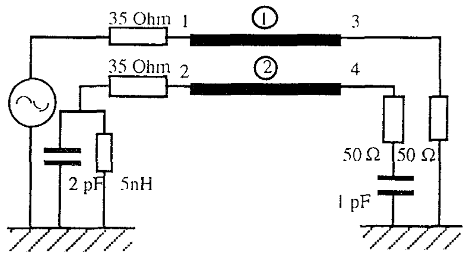

Fig. 4 : Line terminations of the structure under study.

CONCLUSION

A method to transform a circuit model with distributed voltage and current sources into a classical S-matrix description is demonstrated. It is shown that in this way it is possible to use commonly available circuit simulators to study the circuit behaviour.

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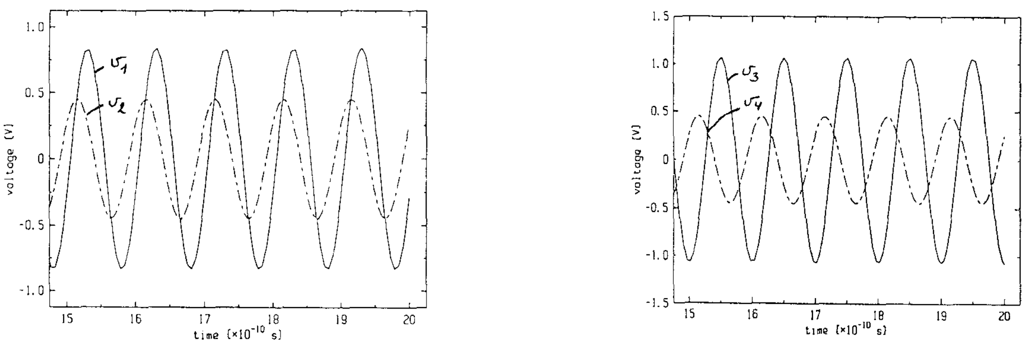

Fig. 5 : Voltage at the line ends, in the presence of the dipole.

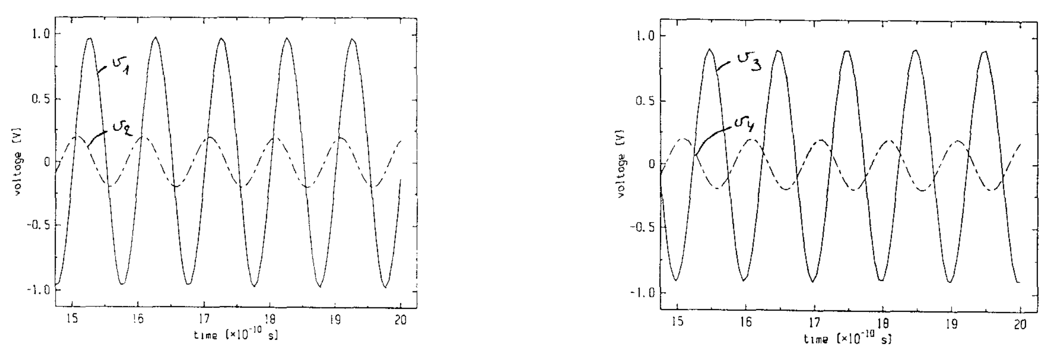

Fig. 6 : Voltage at the line ends, in the absence of the dipole.