COMPLEX PERMITTIVITY DETERMINATION FROM MEASURED SCATTERING PARAMETERS OF TEM WAVEGUIDES

Stefano Ferraris, **Patrizia Savi, Ivan Maio**

Dipartimento di Elettronica, Politecnico di Torino, Italy, e-mail: patrizia.savi@polito.it

***Dipartimento di Economia e Ingegneria Agraria, Forestale e Ambientale, Universita' degli Studi di Torino, e-mail: stefano.ferraris@unito.it**

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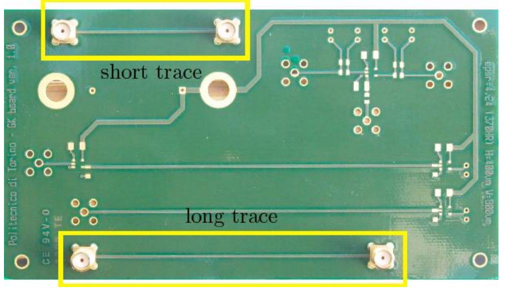
Outline

1. Motivation
2. Objectives
3. Nicholsson-Ross and Double Delay method
4. Results
5. Conclusions

Motivation

Estimation of permittivity over a wide frequency band

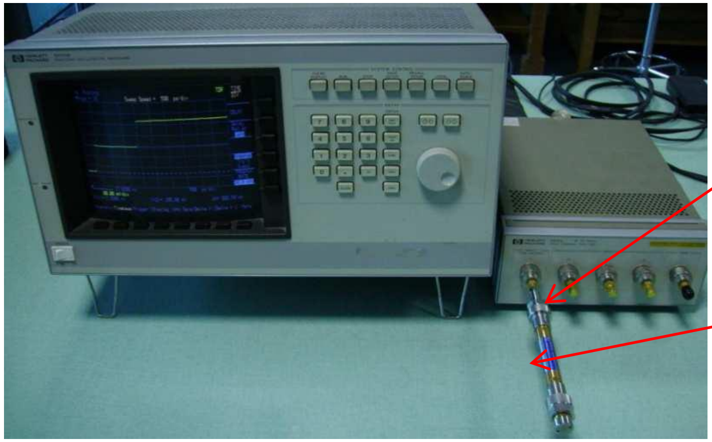
- Characterization of dielectrics in Electronic packaging



- Measurement of the permittivity of soils

Objective

Network Analyzer



launchers

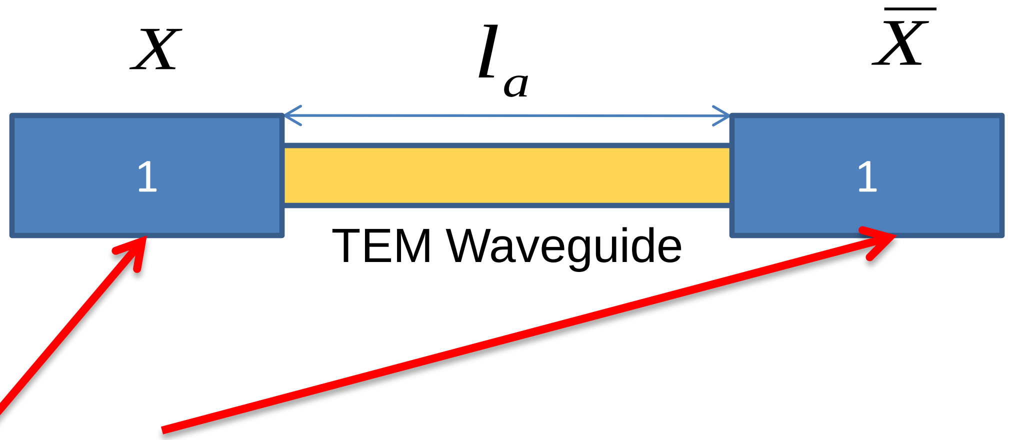
TEM waveguide filled with the dielectric under test

S_{ij} measurement of waveguide+launchers

Permittivity

PROBLEM: how to eliminate the contribution of the launchers

The Nicholson-Ross method

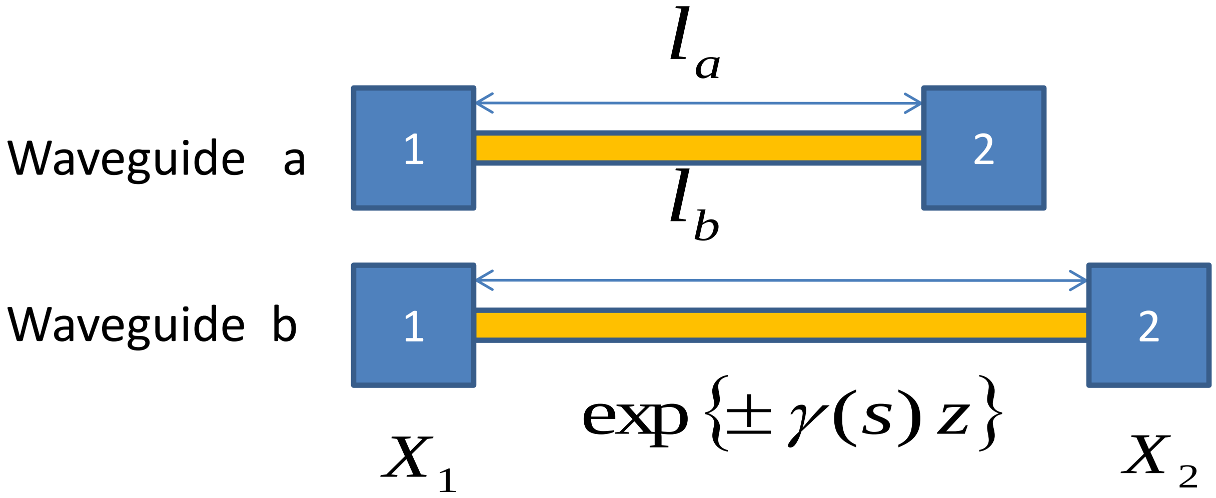


- **Launchers are pure impedance discontinuity**

- Symmetric configuration

A.M. Nicolson and G.F. Ross, Measurement of the intrinsic properties of materials by time-domain techniques, IEEE Trans. on Instr. and Measurement, 19(4):377--402, Nov 1970.

The double-delay method



- Arbitrary launchers
- Asymmetric configuration

J.C. Rautio, A de-embedding algorithm for electromagnetics, International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering, 1(3):282--2S7, 1991.

Formulas

The Nicholsson-Ross method

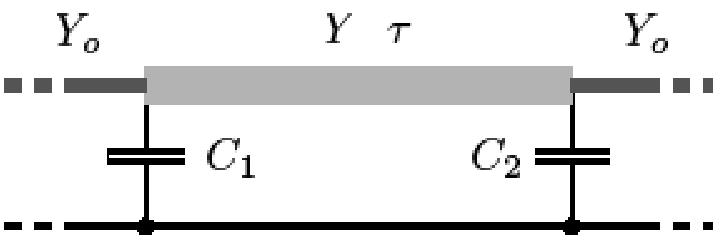
$$T_a = X \begin{bmatrix} e^{-\gamma(s) l_a} & 0 \\ 0 & e^{+\gamma(s) l_a} \end{bmatrix} \overline{X}$$

The double delay method

$$\left[T_b\, T_a^{-1}\right] X_1 = X_1 \begin{bmatrix} \exp(-\gamma(l_b - l_a)) & 0 \\ 0 & \exp(+\gamma(l_b - l_a)) \end{bmatrix}$$

A numerical example: on the importance of reactive effects

A simple model: Ideal LC transmission line and 2 capacitors



$$Y_0 = \frac{1}{50}\,\Omega^{-1}$$

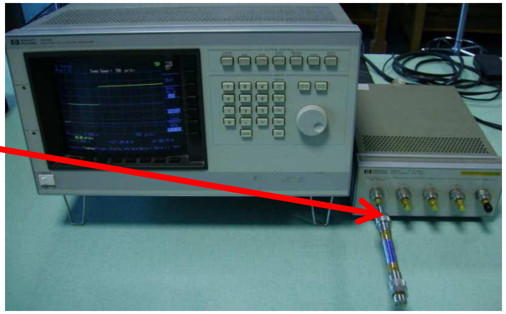
$$Y = \frac{1}{60}\,\Omega^{-1}$$

$$\tau = 0.3ns$$

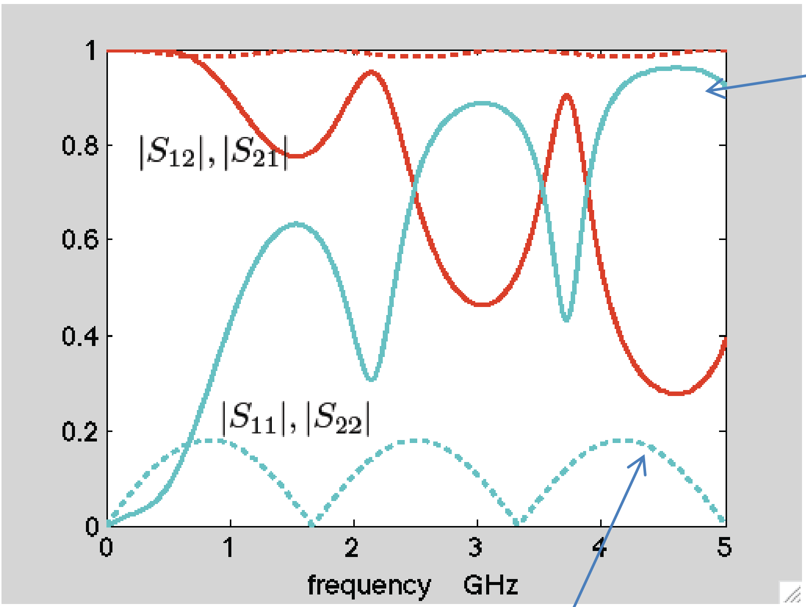
$C_1 = C_2 = 0$ Pure impedance discontinuity

$C_1 \neq 0, \quad C_2 \neq 0$ Discontinuity with capacitive effects

Capacitors take into account the effect of reactive field at the waveguide-NA interface

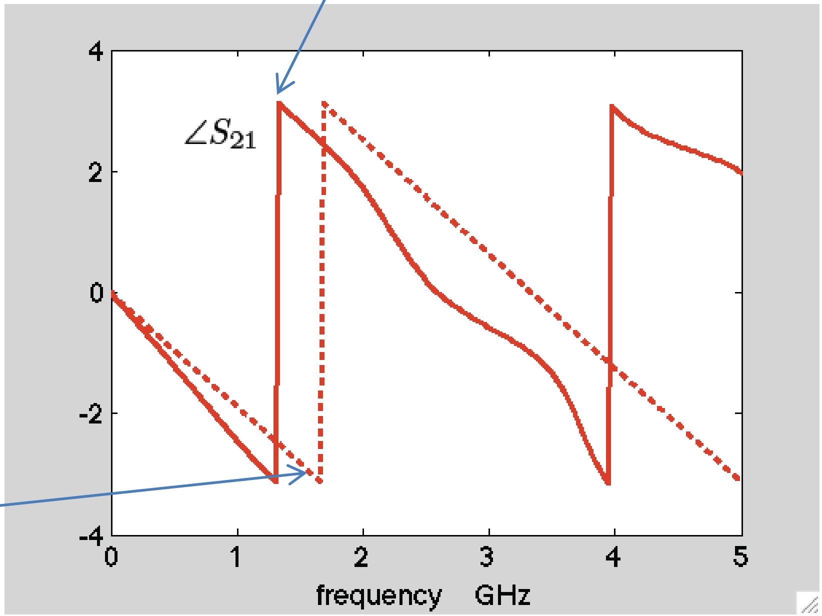


A numerical example – cont'd



Discontinuities with capacitive effects

$$C_1 = 1\,\text{pF}, \;\; C_2 = 2\,\text{pF}$$



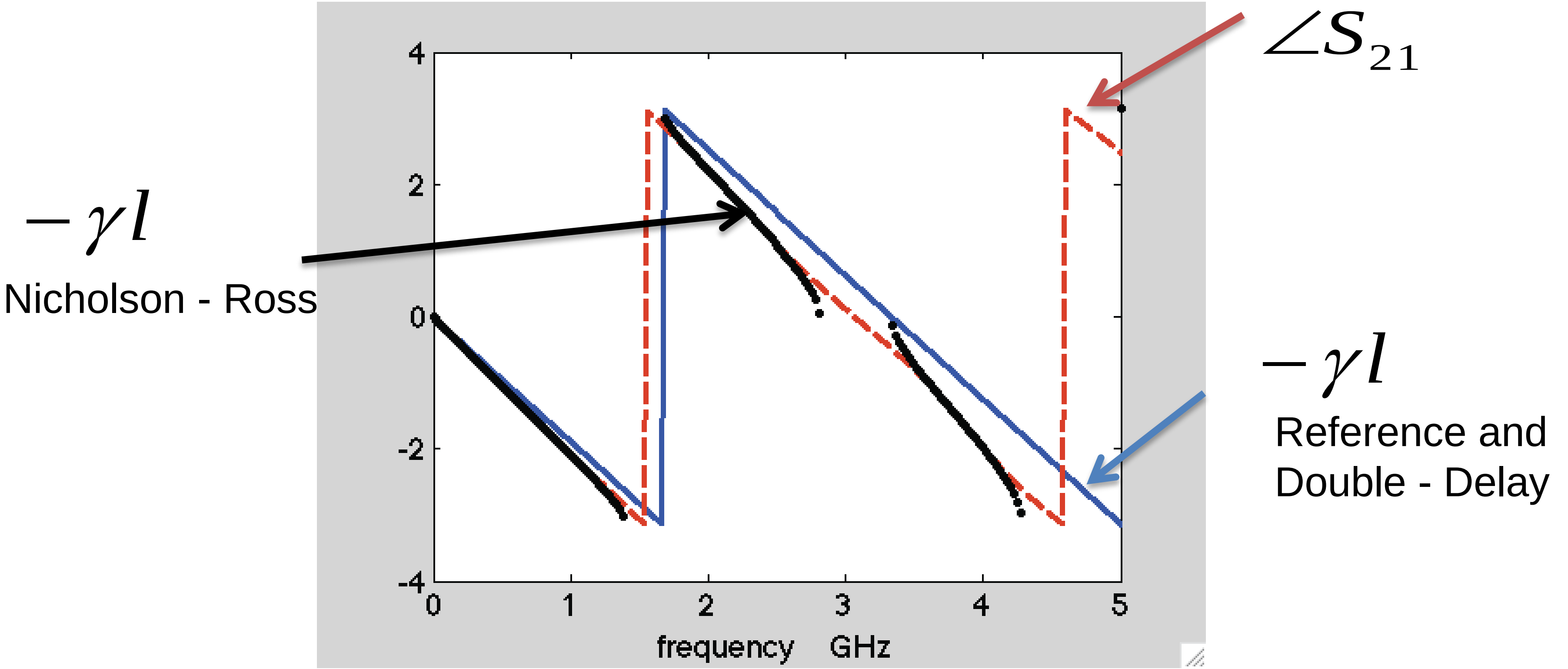
Pure impedance discontinuities

$$C_1 = C_2 = 0$$

Launchers have strong effects, neglecting them (Nicholsson – Ross) does not work

A numerical example – cont'd

$C_1 = C_2 = 0.5\,\text{pF}$

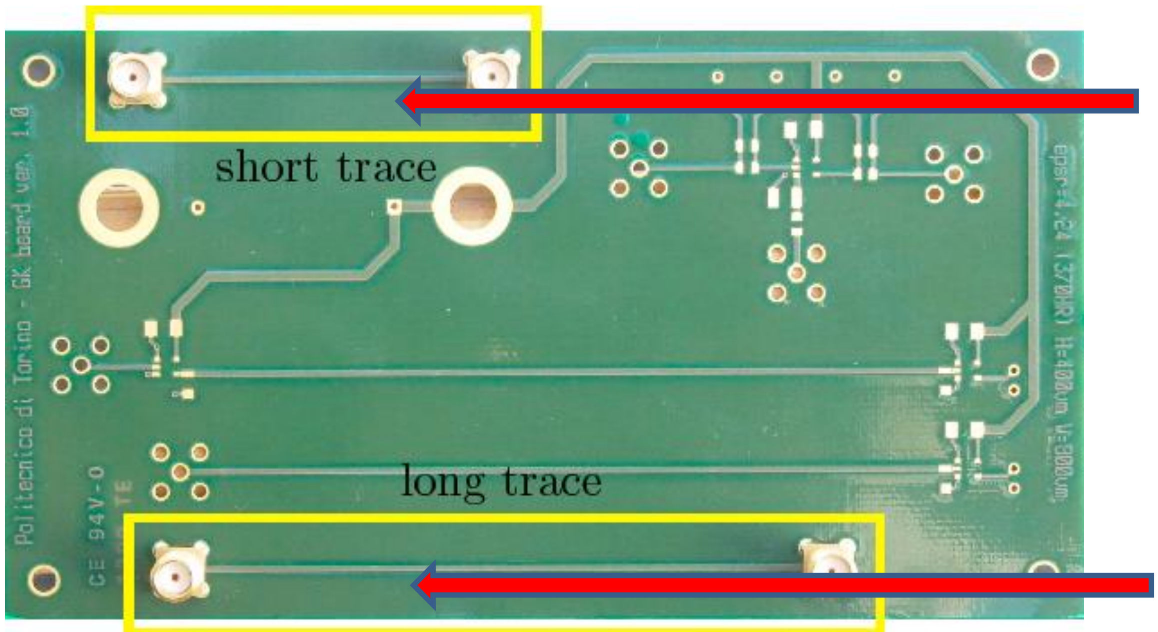


NR method does not admit solution everywhere

Does not converge to the actual phase of the propagation function (blue curve)

Example 1 - FR4 PCB

The unknown permittivity is estimated from the S_{ij} parameters of a test trace



$$L_1 = 1.5 inch$$

$$\frac{w}{h} = 2$$

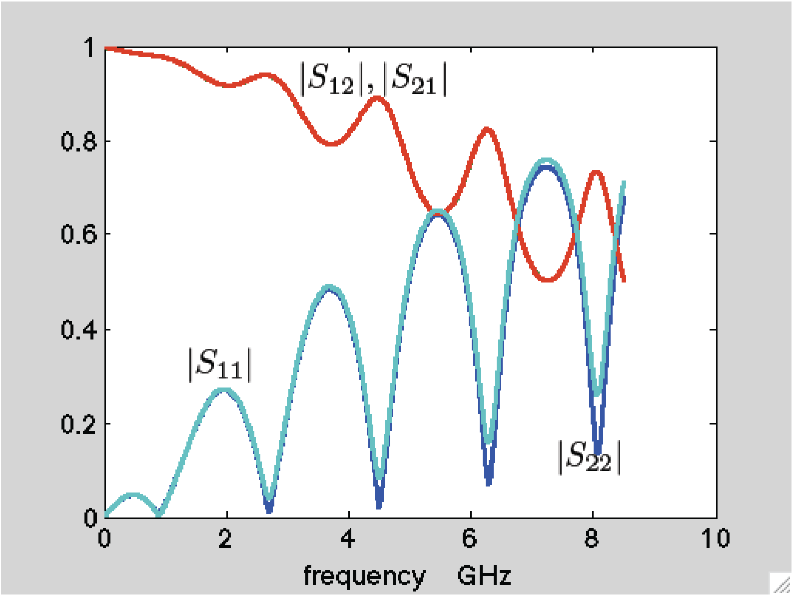
$$L_2 = 3 inch$$

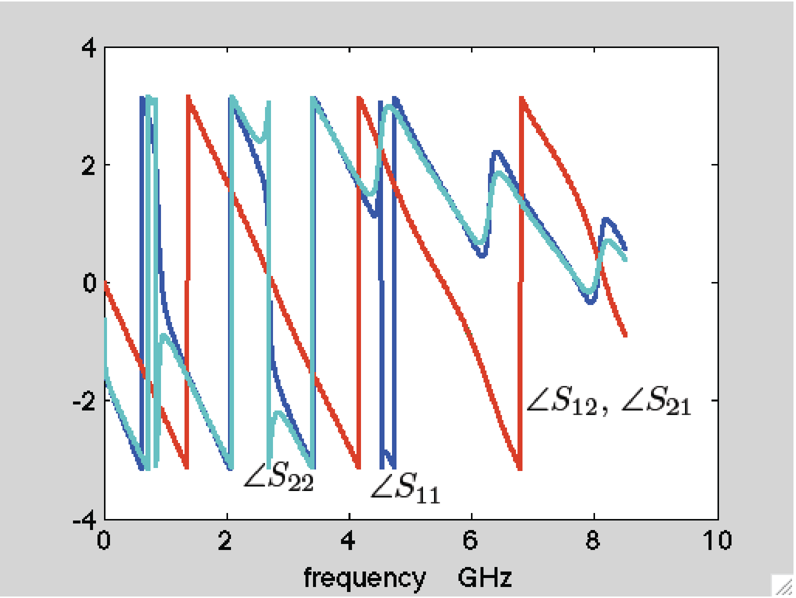
SMA	trace	SMA

DE - EMBEDDING

Example 1 - FR4 PCB

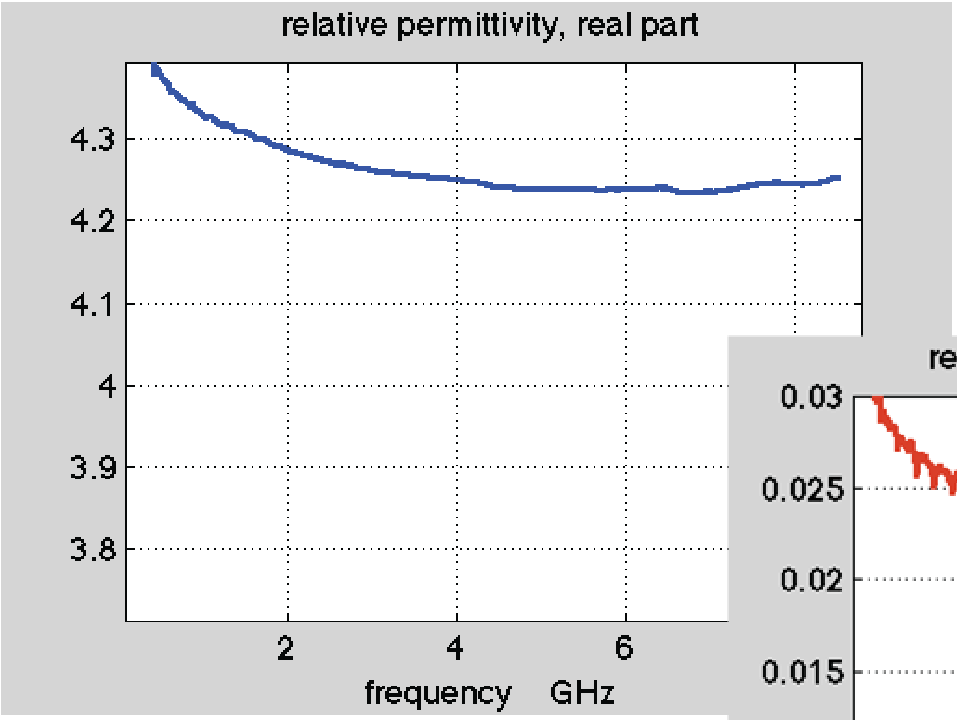
Measured scattering functions for the short microstrip trace

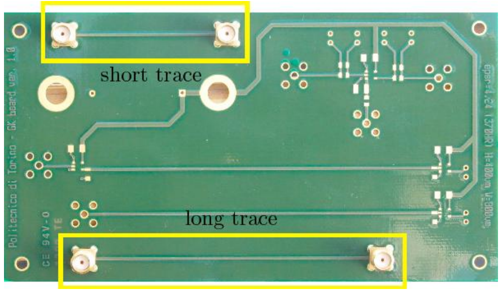


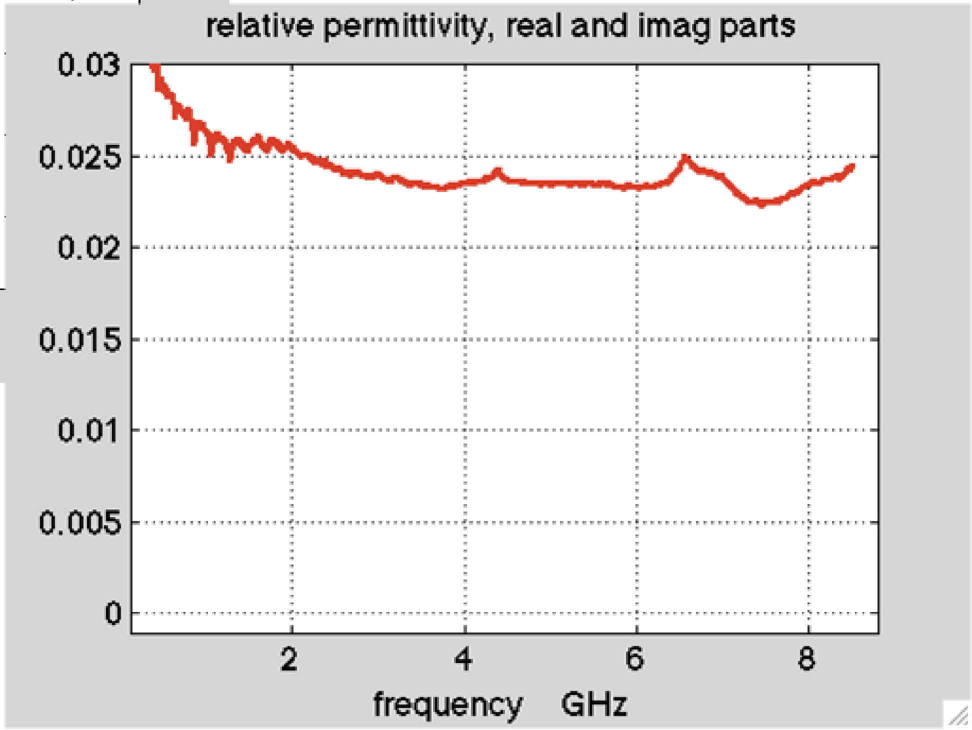


This response is close to the response of example 1 with capacitive discontinuities

Example 1 - FR4 PCB





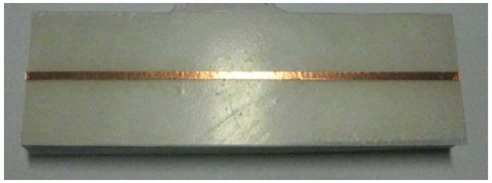


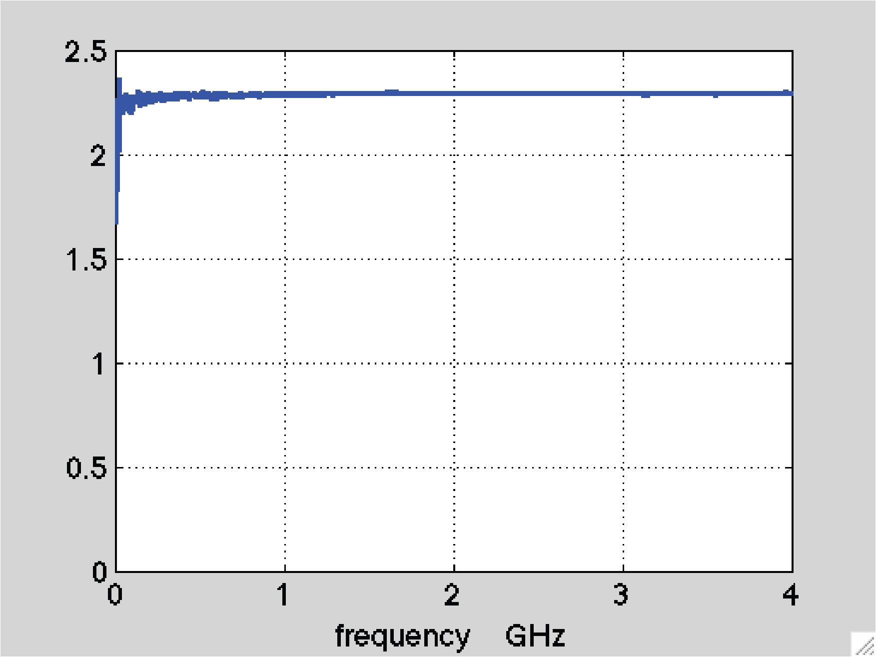
$$\varepsilon \cong 4.25$$

$$\tan\delta \cong 0.023$$

Example 2 – LDPE

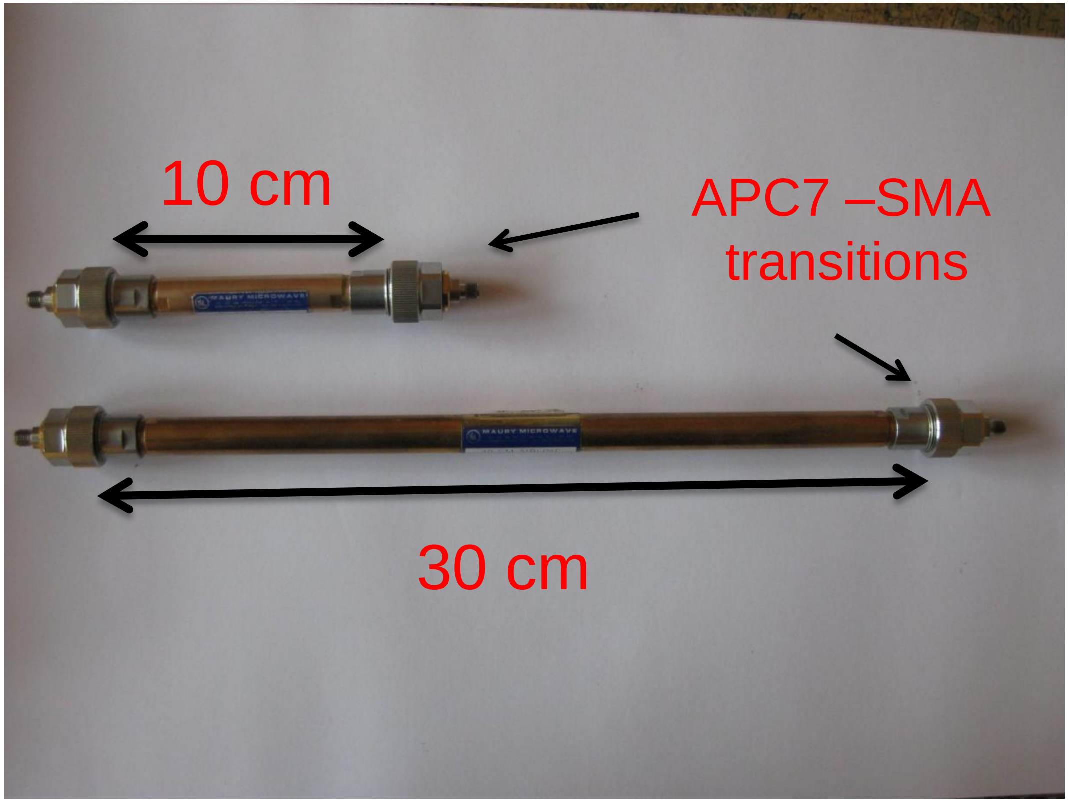
(Low density Polyetilene)





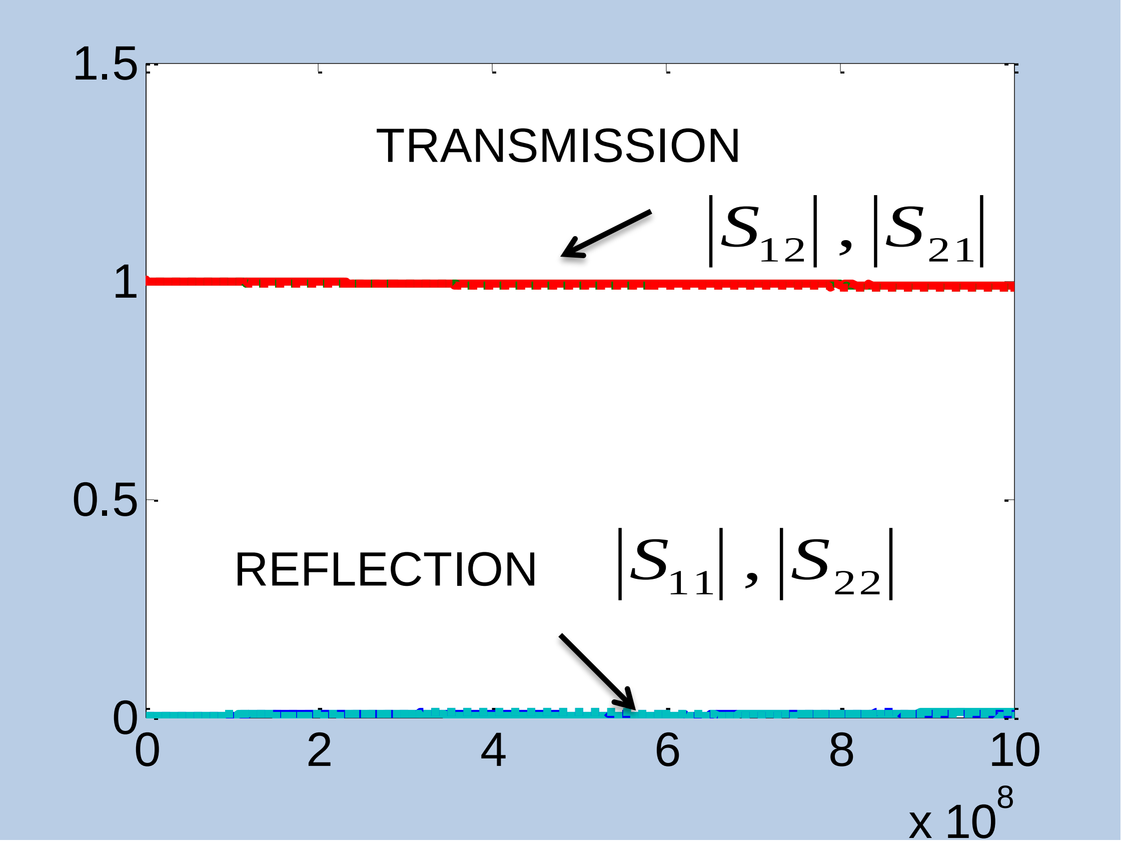
Example 3 – Coaxial airline

The double delay method has been applied to the S parameters measured with two coaxial airline (Maury) of different lengths.



Example 3a – Coaxial airline: air

MEASURED SCATTERING RESPONSES
LONG AND SHORT AIRLINE

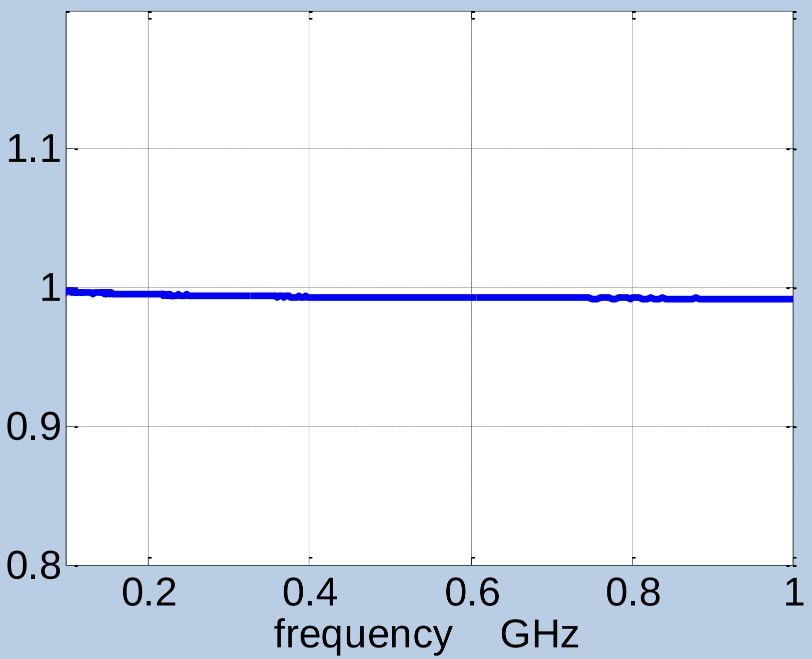


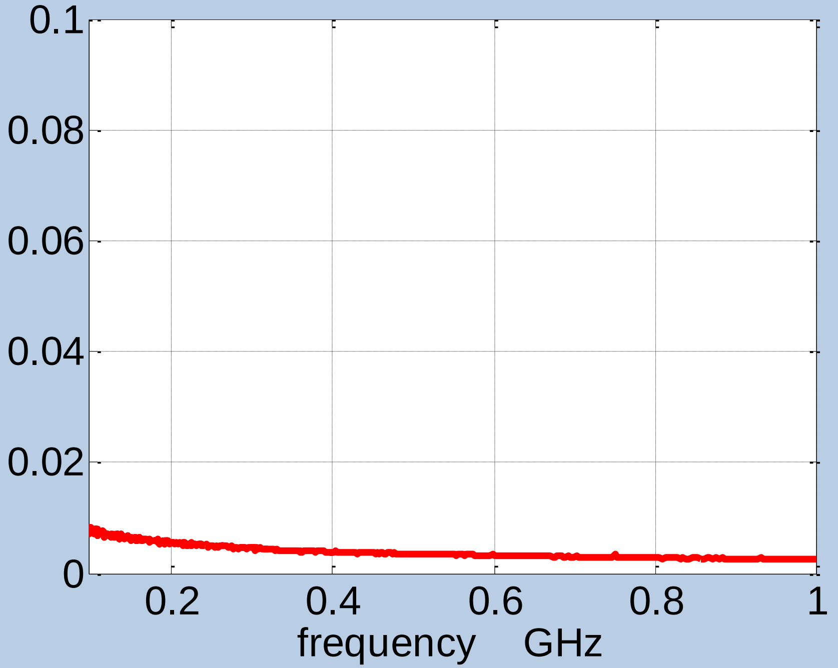
Example 3a – Coaxial airline: air

S PARAMETERS MEASUREMENTS

DE-EMBEDDING

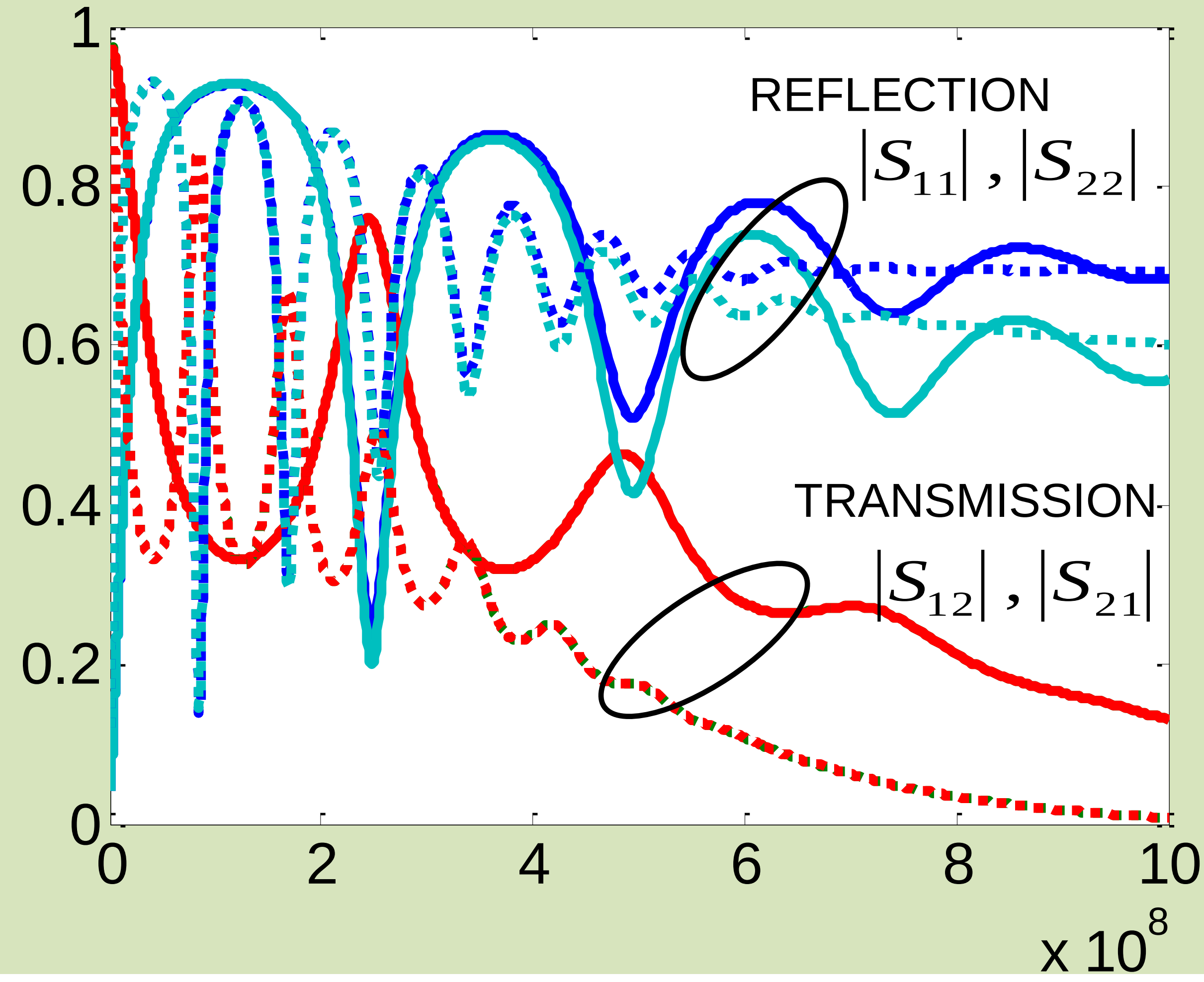
Permittivity – real part	**Permittivity – immaginary part**





Example 3b – Coaxial airline: **methanol**

MEASURED SCATTERING RESPONSES
LONG AND SHORT AIRLINE

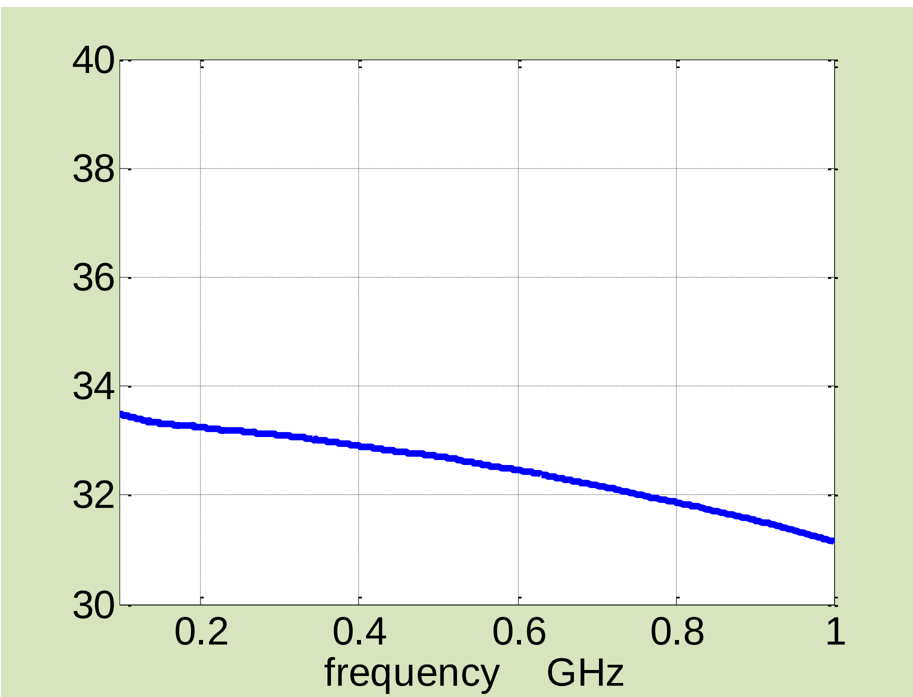


Example 3b – Coaxial airline: methanol

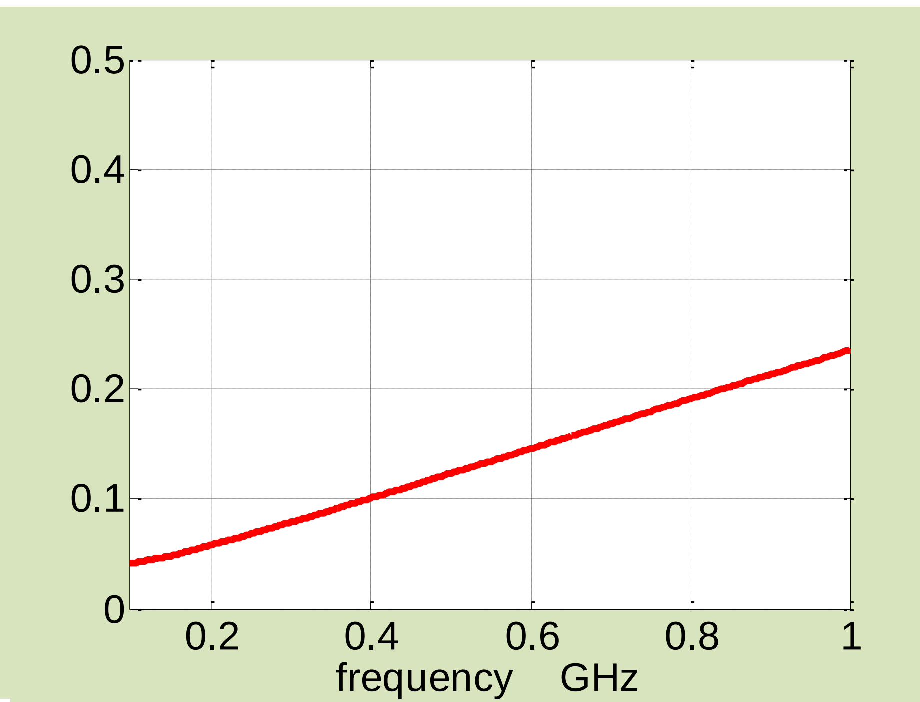
S PARAMETERS MEASUREMENTS

DE-EMBEDDING

Permittivity – real part

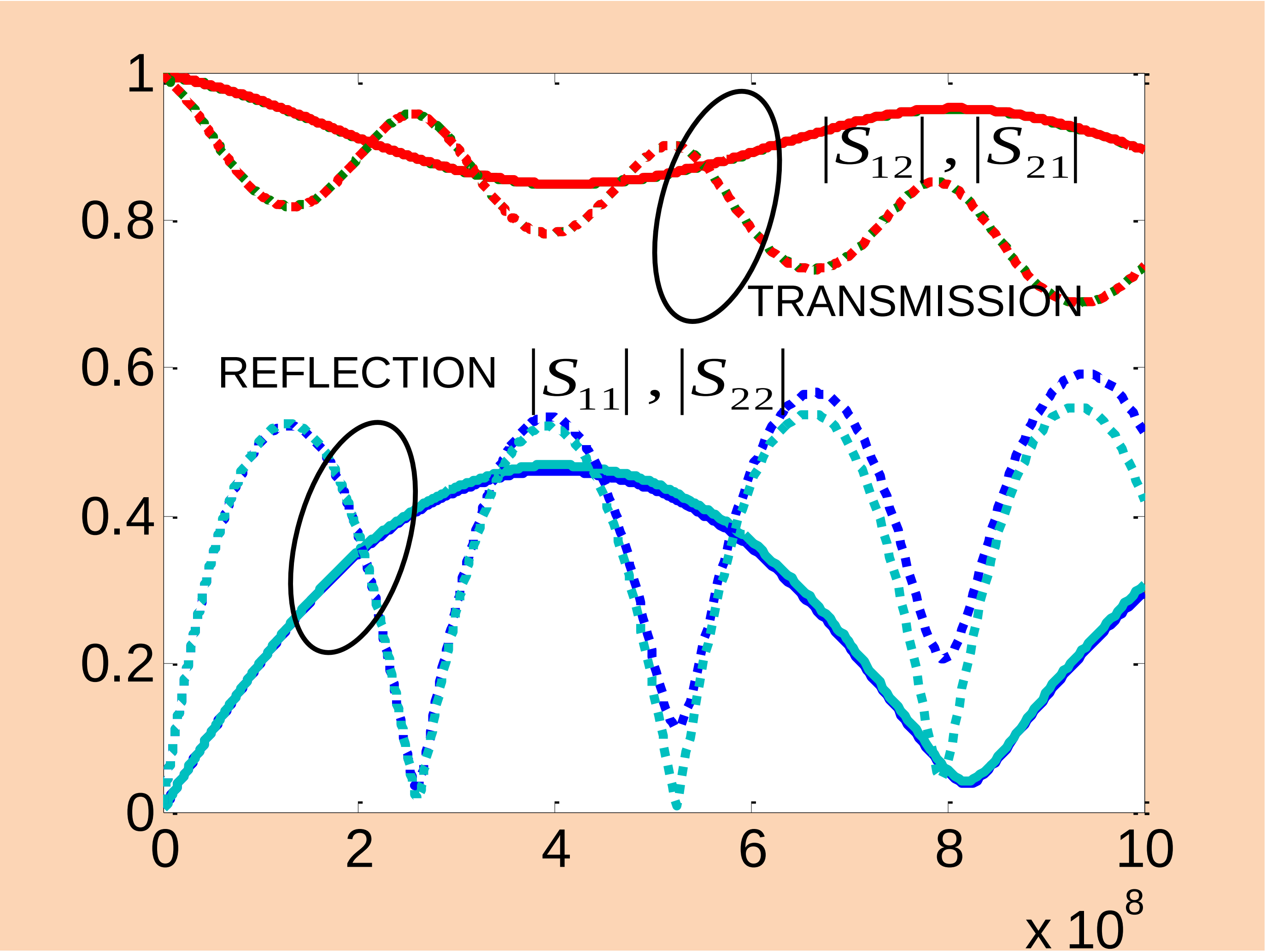


Permittivity – immaginary part



Example 3c – Coaxial airline: dry sand

MEASURED SCATTERING RESPONSES
LONG AND SHORT AIRLINE

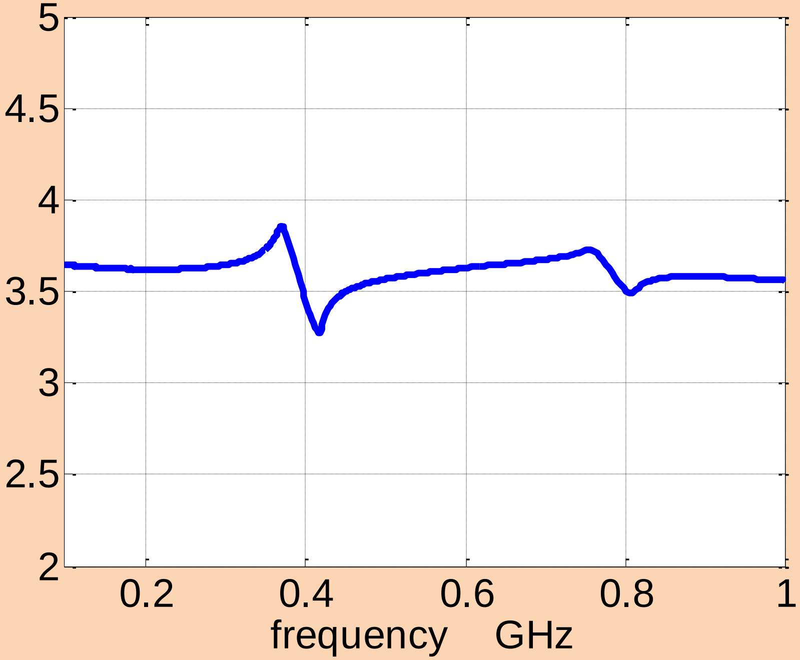


Example 3c – Coaxial airline: dry sand

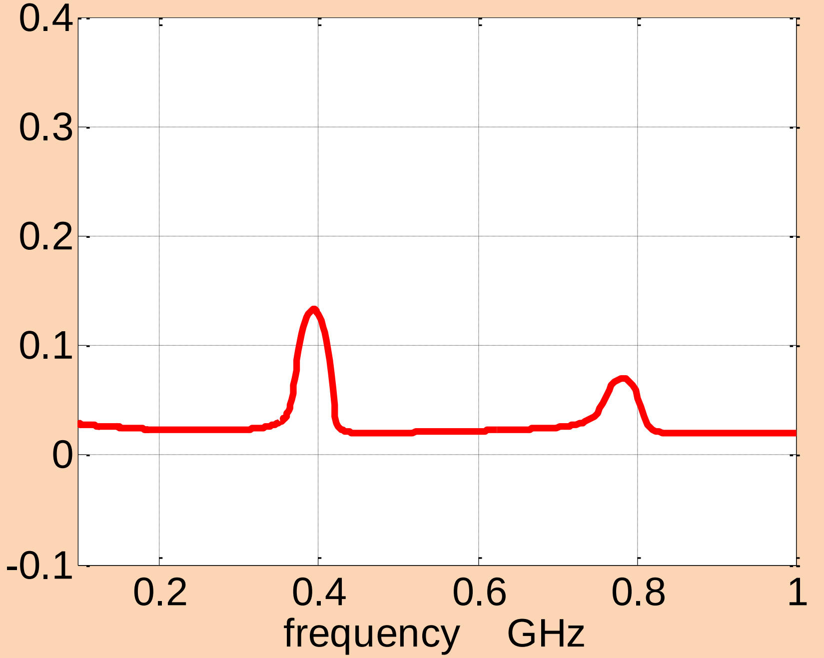
S PARAMETERS MEASUREMENTS

DE-EMBEDDING

Permittivity – real part



Permittivity – immaginary part



Conclusions

- The reactive effects of launchers must be accounted for in the estimation of the propagation function of TEM waveguides

- The double-delay method is an effective tool allowing for arbitrary and asymmetric lauchers and leading to accurate permittivity estimation over wide frequency bands