Frequency Domain Sensing Method for Water Content Determination

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Outline

1. Introduction
2. In-situ soil moisture measurements
3. Modelling and Inversion approach in the frequency domain
4. Field capable sensor
5. Outlook and conclusion

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Water issues in environmental science

Groundwater resource managment in Jordania (Centre for Environmental Biotechnology, UFZ)

Soil moisture dynamics and soil-landscape modelling, Schäfertal, Harz (Dept. Soil Physics, UFZ)

Monitoring managed aquifairs (MARSOL)

Water scarcity and global change in the Mediterranean region (Dept. Catchment Hydrology, UFZ)

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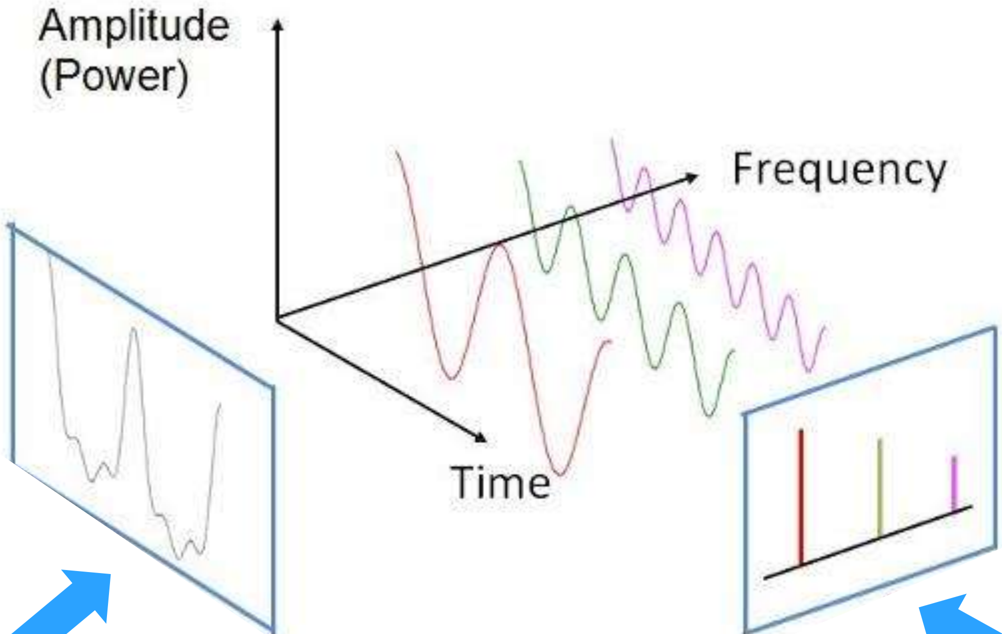
Frequency and time domain methods (1)

Fundamental Introduction



Time
Domain

Frequency
Domain

Fouriertransform

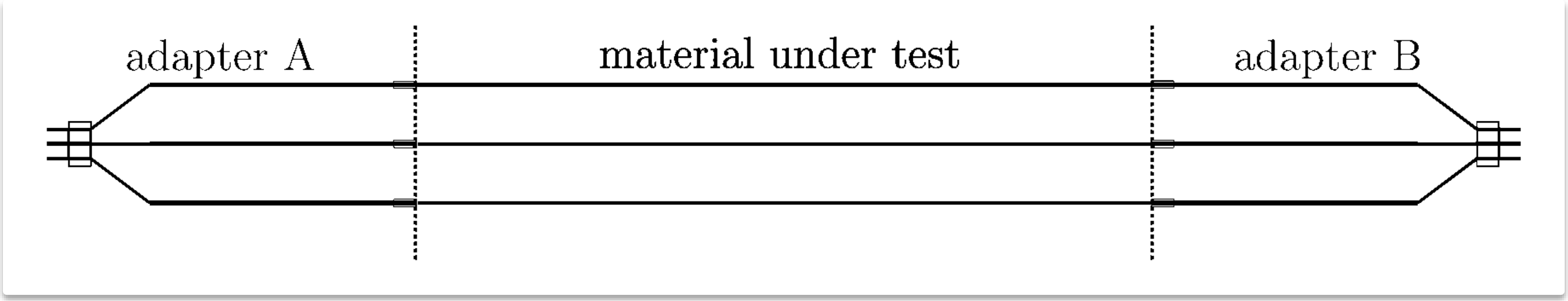
Price low

Price high
(new low-cost soon available!)

From http://www.rf-mw.org/

Frequency and time domain methods (1)
Applications in Soil moisture measurement

- Time domain methods (TDR,TDT)
- Significant in the vadose zone
- Inversion: Lundstedt 1996, Todoroff 2001, Schläger 2005, Leidenberger 2006



- Frequency domain methods (FDR, FDT)
- Significant for use of long lines
- Inversion: Lunstedt 2003, Gorriti 2005, Minet 2010

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In-situ soil moisture measurements

Problem identification

Using long measurement line (e.g. Taupe cable) with conventional TDR approach

- Information quality problematic

Increasing of information quality using more measurement data

- Reflection + transmission data
- Dispersive media modeling with frequency domain approach
- Improved calibration
- Known input signal for inversion

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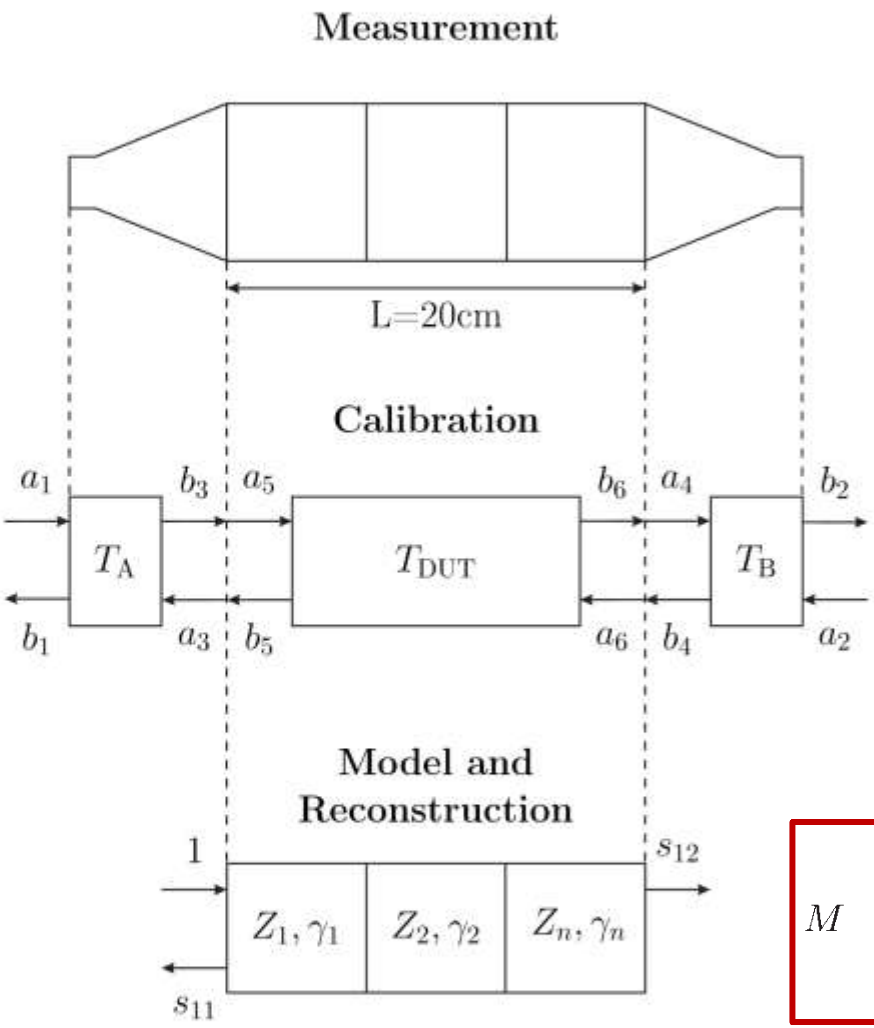
Modelling approach in the frequency domain (1)

Forward scattering model



$$\gamma_n = \frac{j\omega}{c_0}\sqrt{\epsilon_n} \qquad Z_n = \frac{Z_0}{\sqrt{\epsilon_n}}$$

⇩

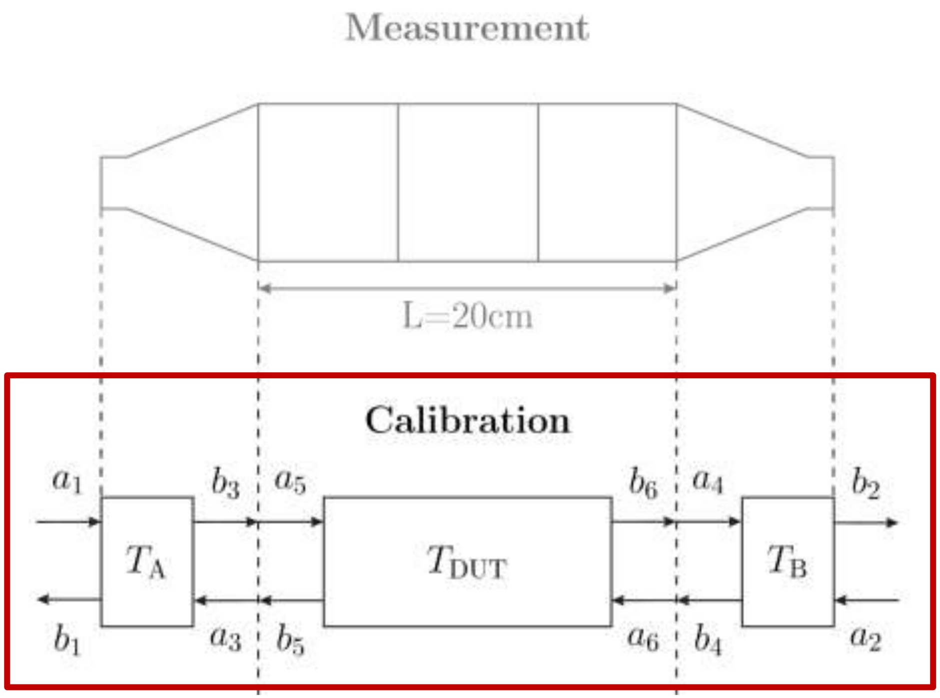
E_n^+) and E_n^-)

⇩

$$M := \frac{1}{2}^{N+1} \begin{pmatrix} 1 & 50 \\ 1 & -50 \end{pmatrix} \left[\prod_{k=1}^{N} \begin{pmatrix} E_k^+ & Z_k E_k^- \\ \frac{E_k^-}{Z_k} & E_k^+ \end{pmatrix} \right] \begin{pmatrix} 1 & 1 \\ \frac{1}{50} & -\frac{1}{50} \end{pmatrix}$$

Modelling approach in the frequency domain (2)

Calibration approaches



- Gated Reflect Line calibration

  or
- Thru Reflect Line calibration

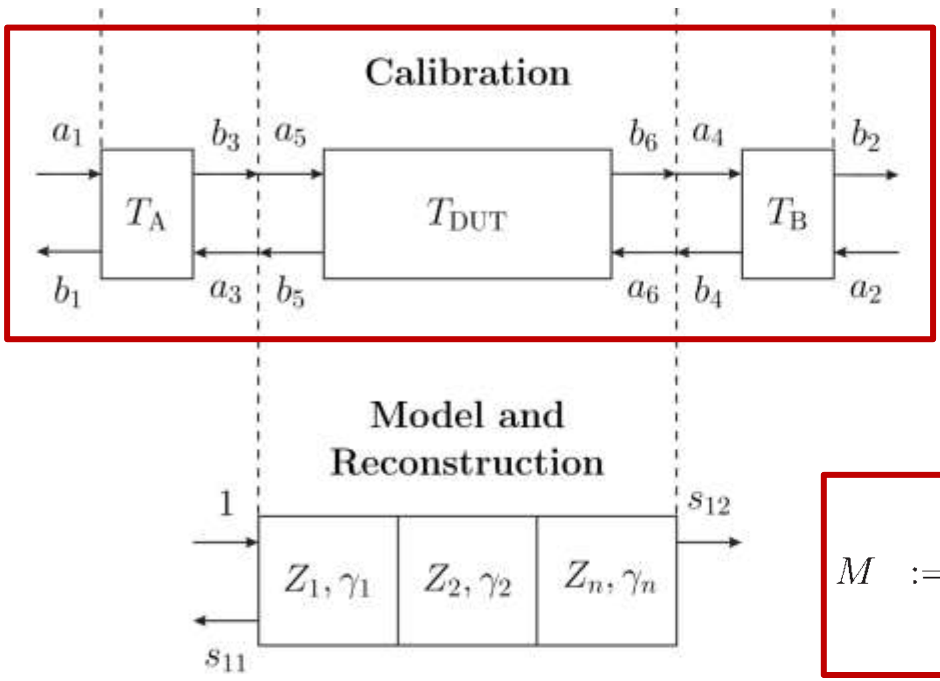
- Removes influences of the adapters at every frequency point separately
- Simple calibration standards are sufficient
  1. Time gated open ended line
  2. Thru
  3. Air line

Inversion approach in the frequency domain (1)

Objective function

$$F = \|s_{11} - \tilde{s}_{11}\|_2^2 + \|s_{22} - \tilde{s}_{22}\|_2^2 + \|s_{12} - \tilde{s}_{12}\|_2^2 + \|s_{21} - \tilde{s}_{21}\|_2^2$$

$$\forall \ni \quad s_{ij} = (s_{ij}(f_1), s_{ij}(f_2), \ldots, s_{ij}(f_{\mathrm{FP}}))$$



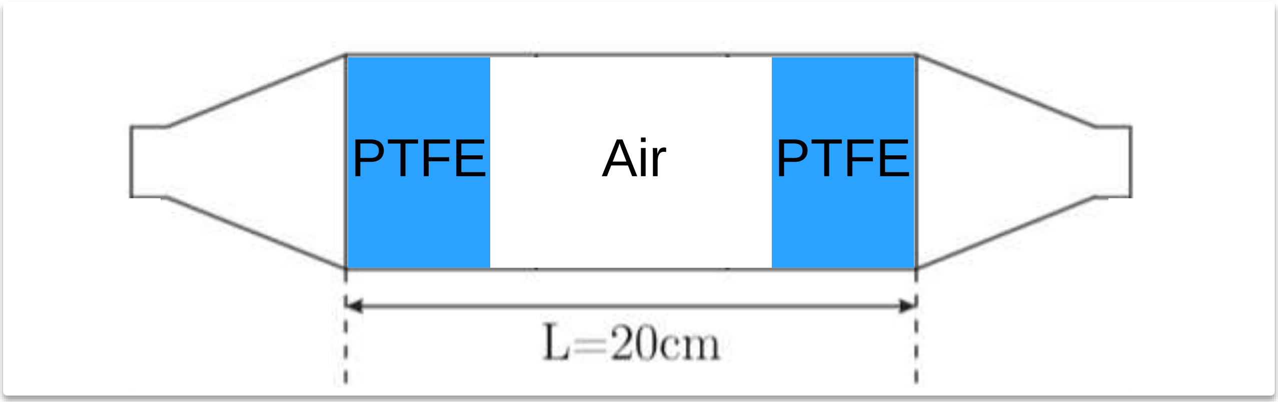
Solving using SCE algorithm

(Shuffled Complex Evolution)

$$M := \frac{1}{2}^{N+1} \begin{pmatrix} 1 & 50 \\ 1 & -50 \end{pmatrix} \left[\prod_{k=1}^{N} \begin{pmatrix} E_k^+ & Z_k E_k^- \\ \frac{E_k^-}{Z_k} & E_k^+ \end{pmatrix} \right] \begin{pmatrix} 1 & 1 \\ \frac{1}{50} & -\frac{1}{50} \end{pmatrix}$$

Inversion approach in the frequency domain (2)

Reconstruction test with measurement cell



	Model	Reconstruction
d_1 in cm	5	4.926
d_2 in cm	10	10.135
d_3 in cm	5	5.015
ϵ_1	2	1.983
ϵ_2	1	1.018
ϵ_3	2	2.03

Permitivity and length d of the layers

- Nondispersive 3 layer setup
- Calibrated full 2-port data
- 300kHz to 2GHz

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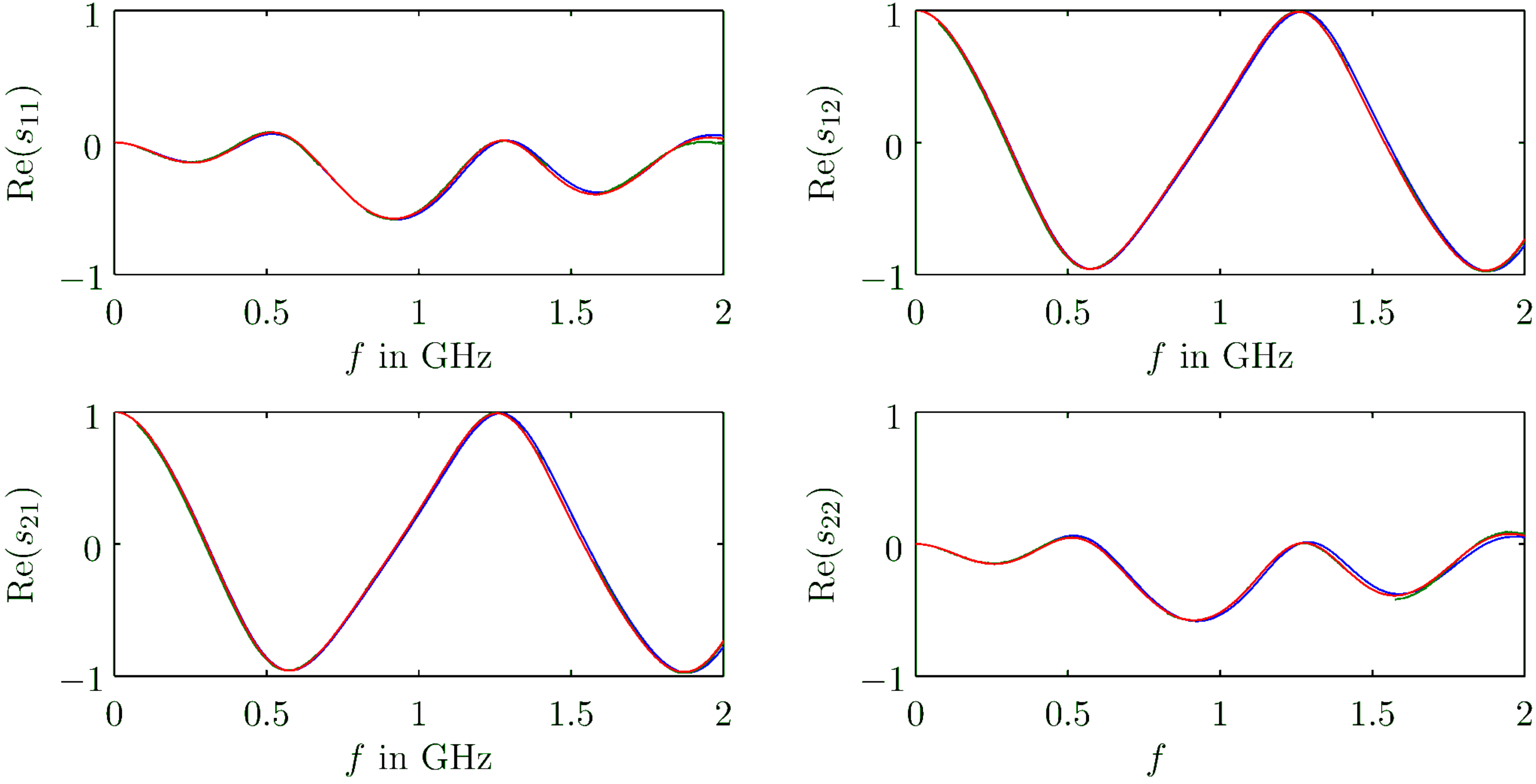
Inversion approach in the frequency domain (3)

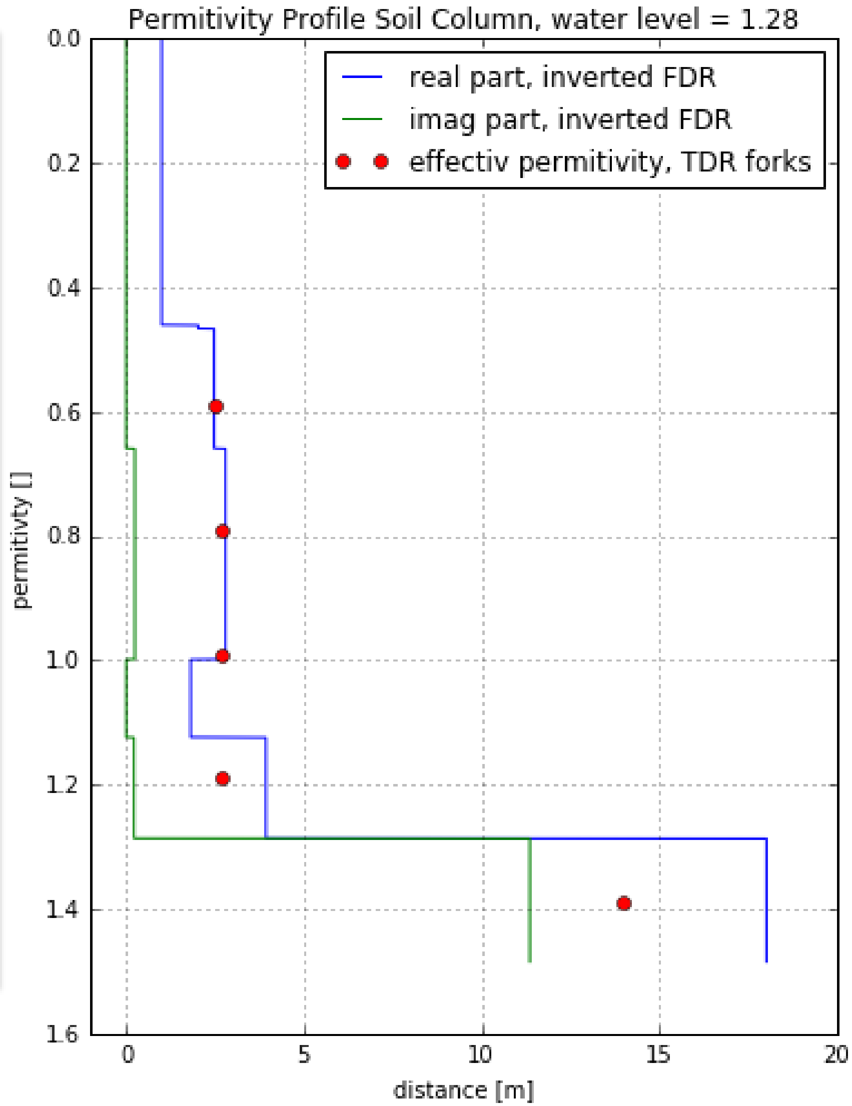
Reconstruction test with measurement cell



PTFE-layer (d1=5cm) - air-layer (d2=10cm) - PTFE-layer (d3=5cm). Full scattering parameters set (real part) of the measurement (——), modeling (——) and the reconstruction (——).

Field capable Sensor (1)

TAUPE cable in Soil column



400 mm air

790 mm sand

210 mm saturated sand

Adapter P1:

27 mm

1.002 - j 6.86

Adapter P2:

31 mm

1.03 - j 8.47

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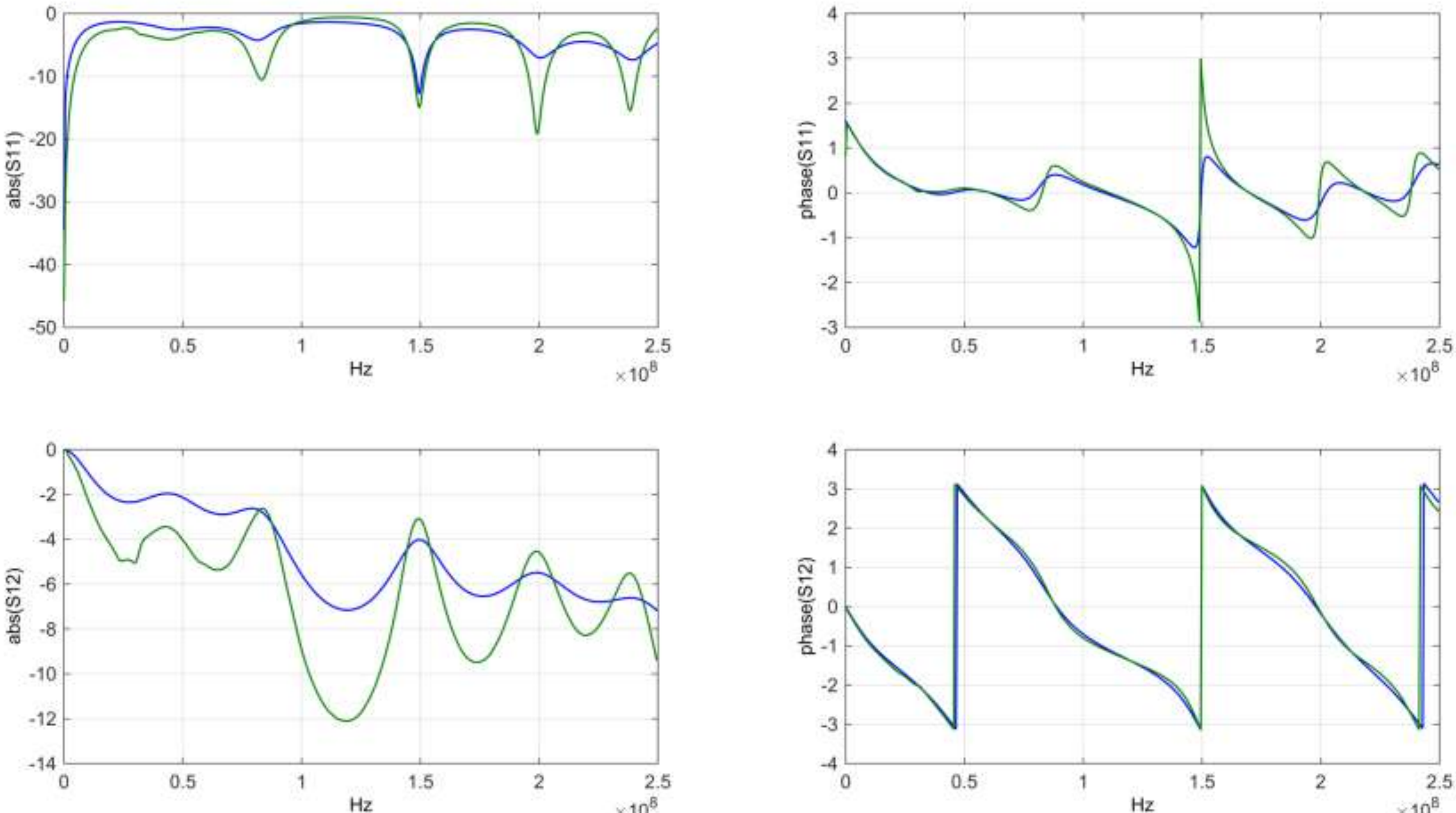
Field capable Sensor (2)

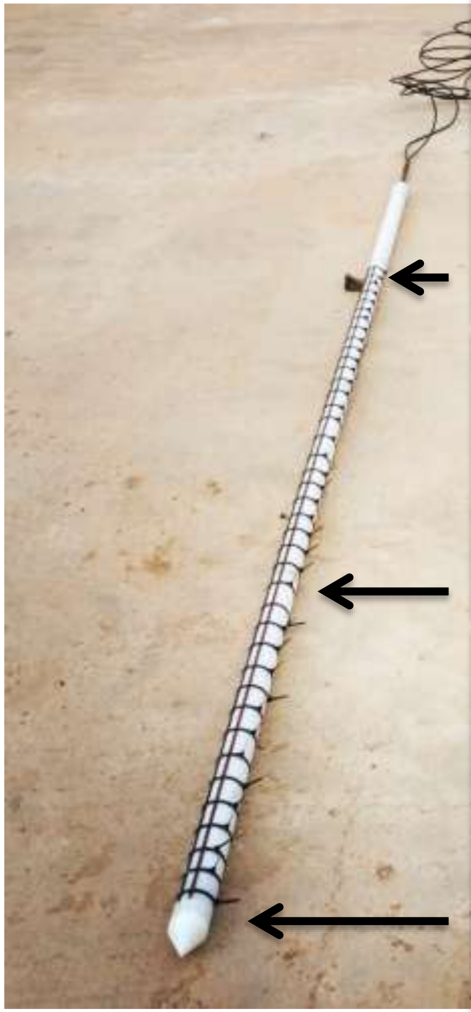
TAUPE cable reconstruction results



Soil column filled with 400 mm air, 790 mm sand and 210 mm saturated sand. Scattering parameters s11 and s12 of the measurement(——) and the reconstruction(——) .

Field capable Sensor (3)

Design with Transmission and Reflection data



- 4m HDPE tube with 3m sensor
- diameter 2.5``
- 3 copper wire glued in slits forming the waveguide
- One wire is isolated with rubber coat
- Adapter board from coax cable to waveguide on top and bottom

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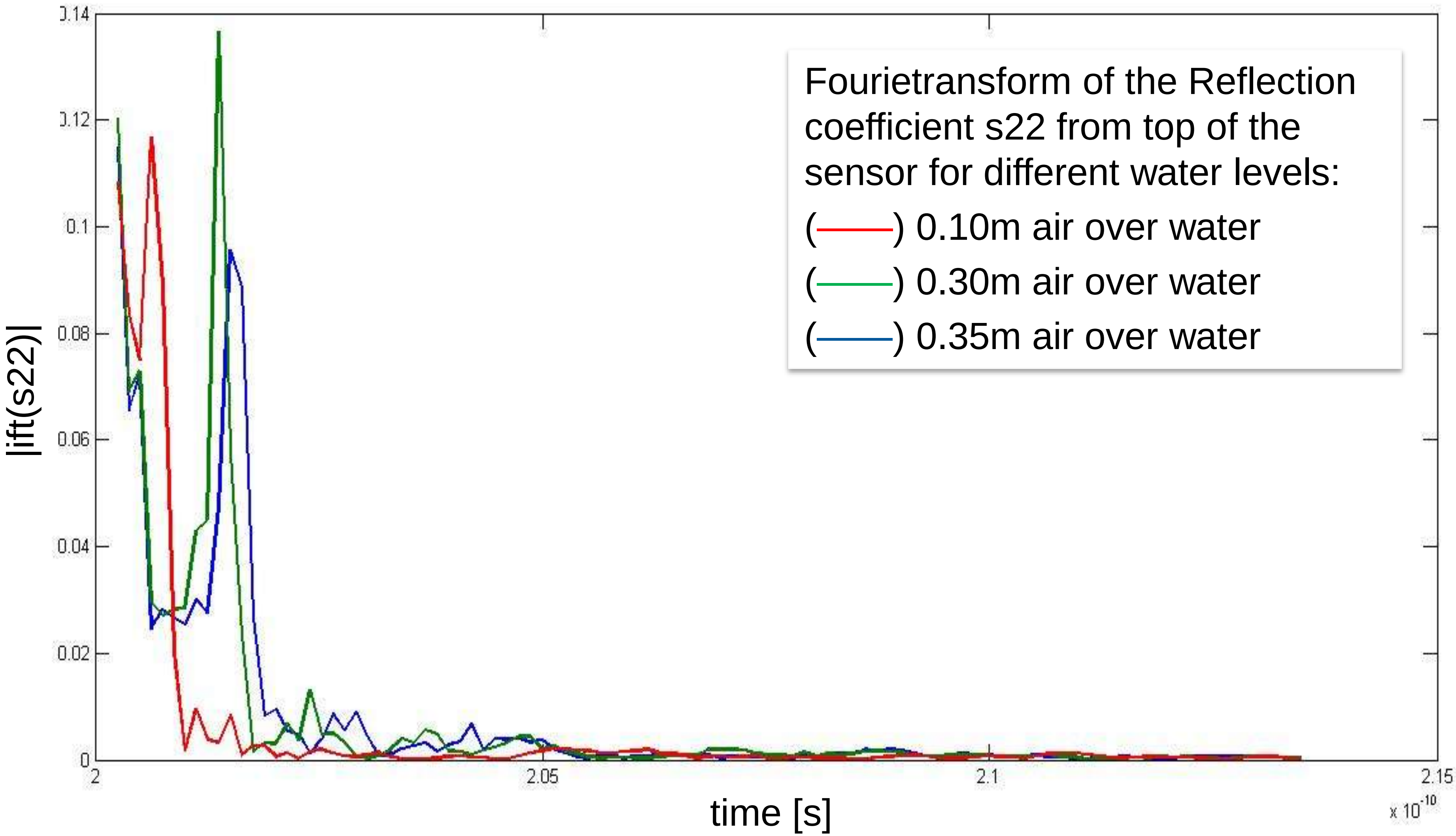
Field capable Sensor (4)

Application in Lavrion (Greece) and first tests

- Lagoon experiment for long term infiltration test
- 2 sensors installed in rocky soil
- TDR rods next to the FD sensor for comparing results
- First test by filling water in the hole and measuring the sinking water level constantly
- Gap between sensor and soil because of bigger borehole

Field capable Sensor (5)

First results of application in Lavrion (Greece)



Conclusion & Outlook

- Soil moisture measurement in environmental science highly important
- Lack of methods for long TEM-Lines (e.g. to estimate groundwater recharge processes)
- Full FD modeling method successfully developed
- Inversion method for FD measurement method successfully in laboratory scale experiments applied
- Field capable sensor is available

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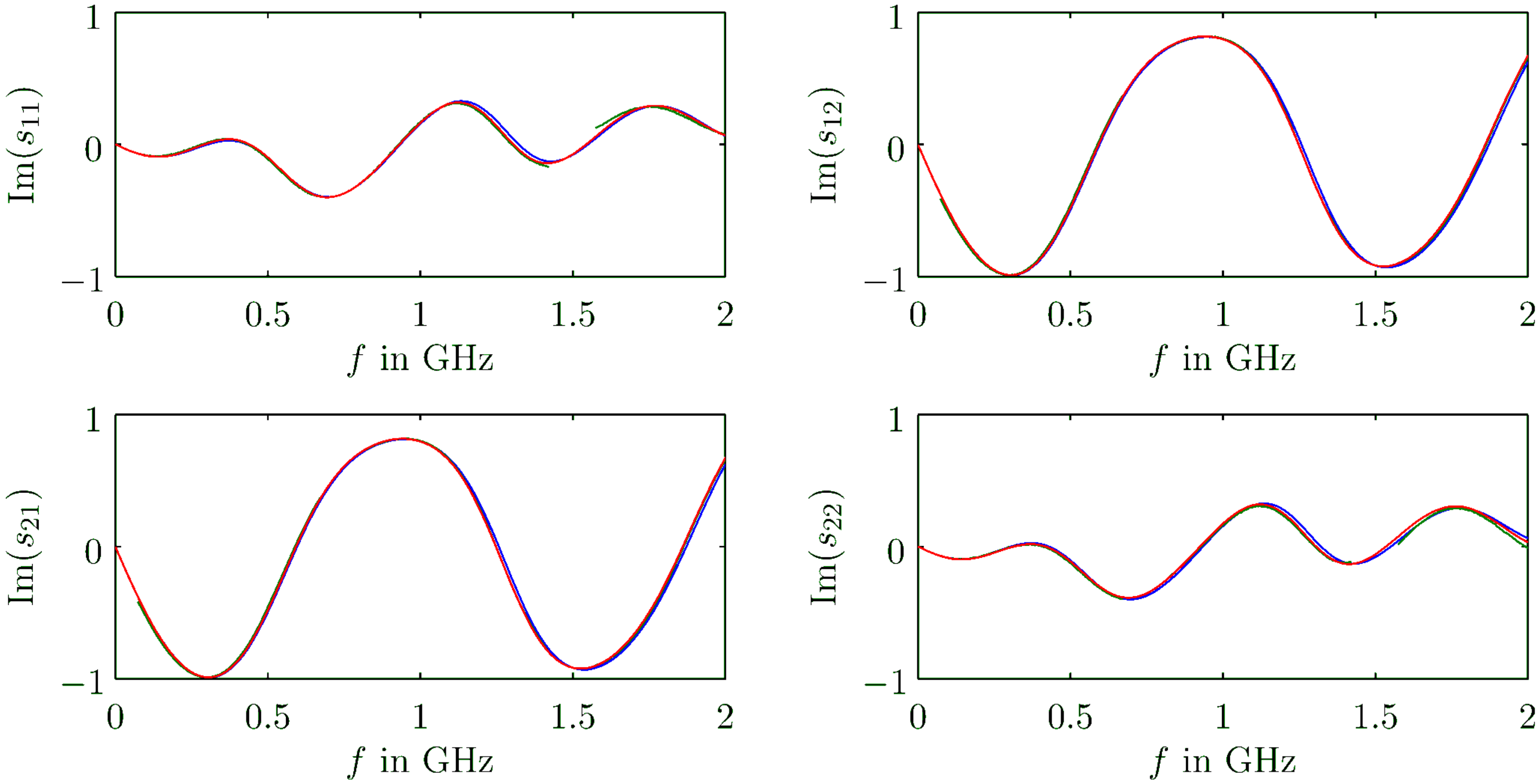
Modelling approach in the frequency domain (2)

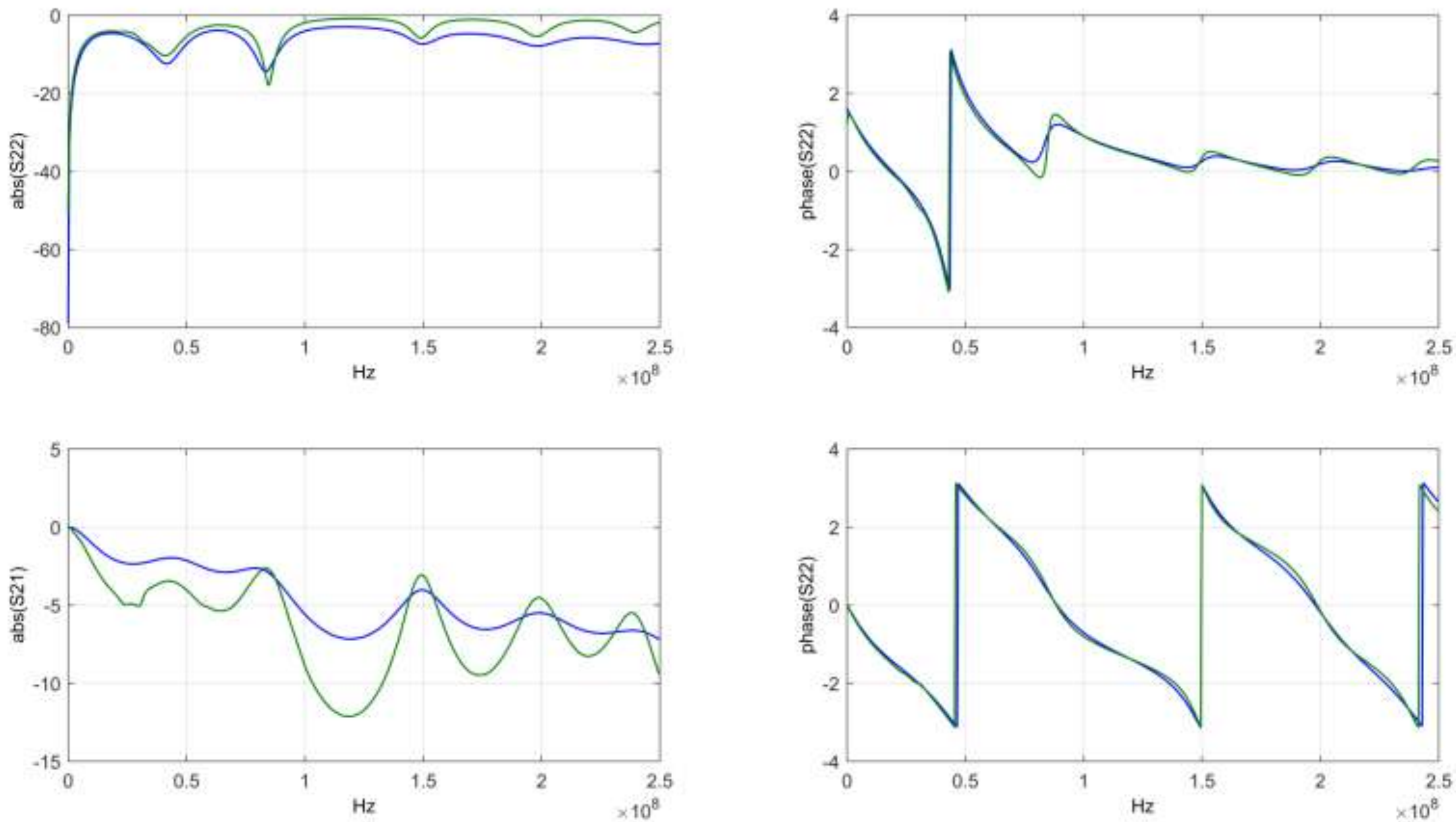
Test with measurement cell



PTFE-layer (d1=5cm) - air-layer (d2=10cm) - PTFE-layer (d3=5cm). Full scattering parameters set (real part) of the measurement (——), modeling (——) and the reconstruction (——).

Inversion approch in the frequency domain (7)

Soil column reconstruction results



S22 und S21

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Inversion approach in the frequency domain (6)

Soil column reconstruction results