Alternative solution to the gamma bench for the dielectric characterization of materials

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Abstract:
In the field of civil engineering, the reception of new pavements depends on physical parameters control, in particular the density of cores with nuclear gamma bench in the laboratory. This control ensures a good implementation of the road to give an optimal lifetime. To replace the laboratory gamma bench, an Ultra Wide Band (UWB) electromagnetic system, consisting in two Vivaldi antennas [1.4-20 GHz] and a vector network analyzer (VNA) is proposed to assess the permittivity then the density (or equivalent compactness) via Mixing dielectric models. The first results of modeling and measurements on laboratory samples show that the system makes it possible the evaluation of relative permittivity of different stratified materials.

Introduction

Standard method to assess density in the laboratory [1]

From pavement cores

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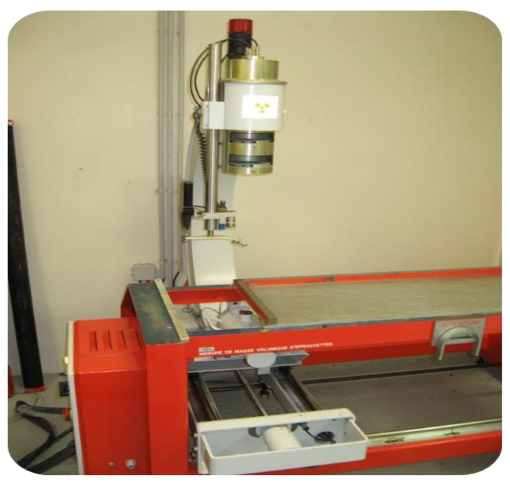
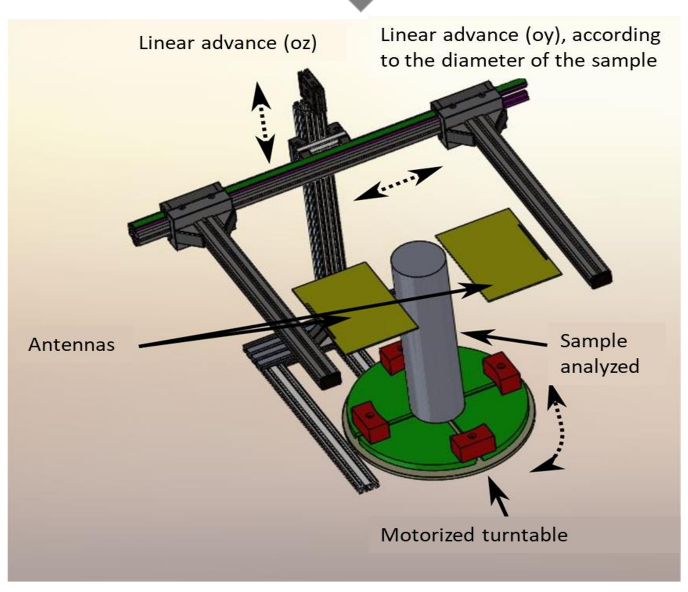


Gamma bench

- ✓ density accuracy (~1%).
- × exposure to ionizing radiation
- × several constraints (high costs, use, storage, transport…)

Alternative method

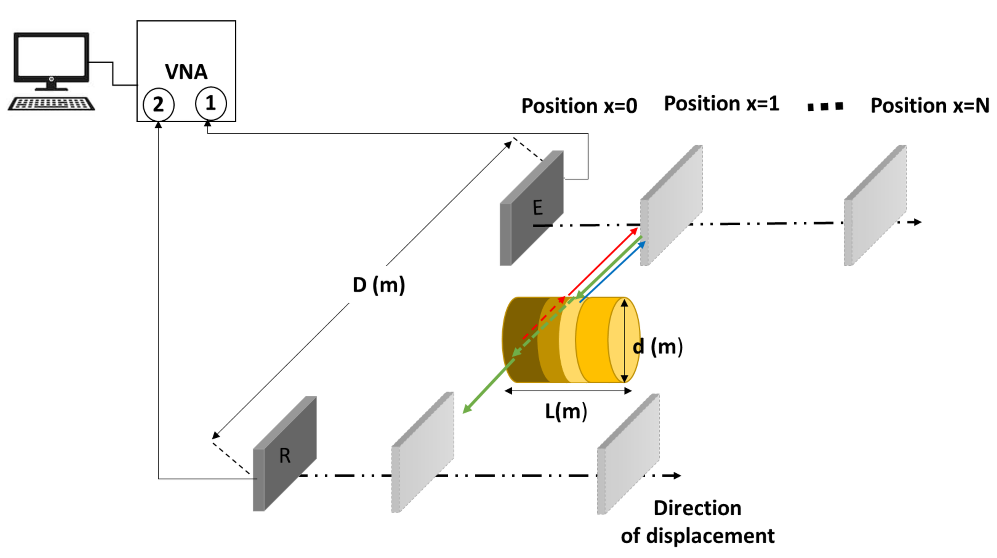
Electromagnetic bench



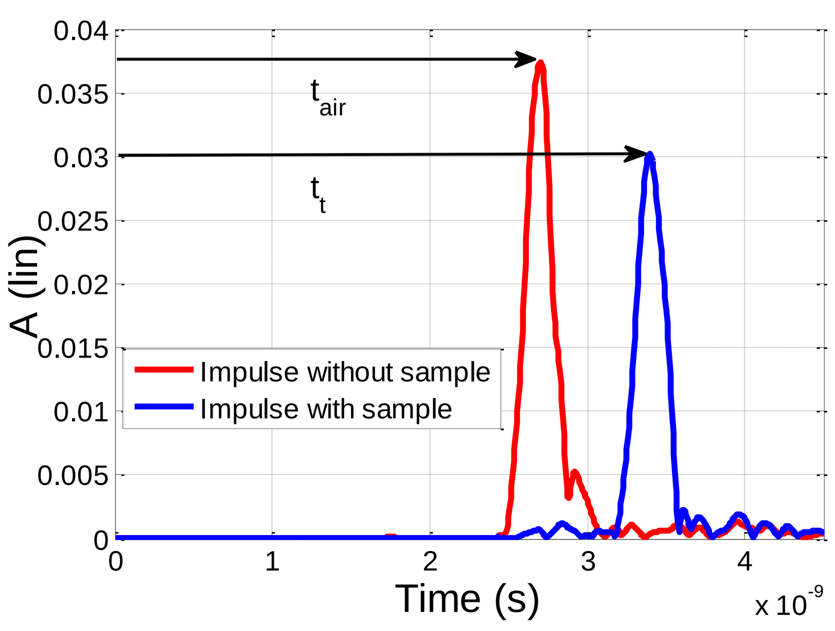
(Cerema (CECP-Rouen))

Principle of the electromagnetic bench

1. Diagram of the electromagnetic bench

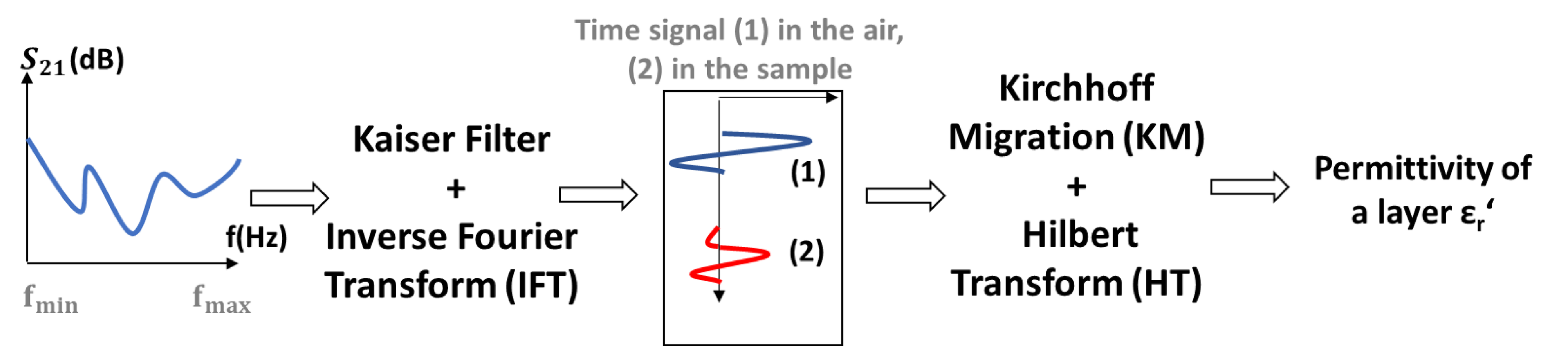


2. Pulse modules transmitted (IFT (S21(f)) with and without sample



- Transmitted pulse (IFT (S_{21}(f)) leads to the real part of the permittivity (ε_r') of the sample.

3. Signal processing



Permittivity

$$\varepsilon_r' = \left(\left(t_t - \frac{D-d}{c}\right) * \frac{c}{d}\right)^2$$

Where
- t_t : total propagation time in air and in the sample,
- D : distance between the two antennas,
- d : diameter of the sample,
- c : velocity in vacuum.

Compactness/density

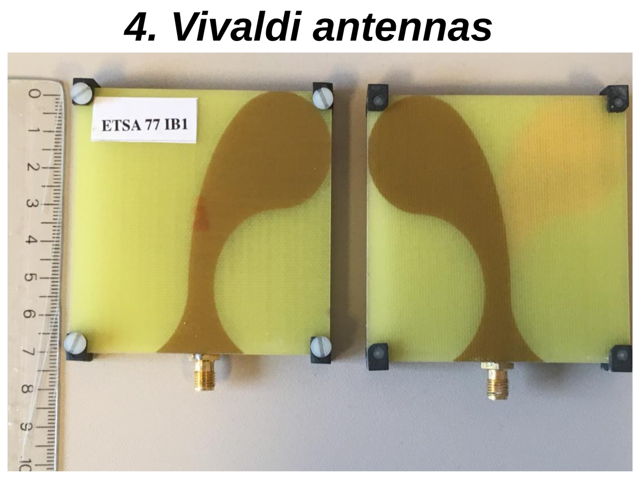
$$C = \frac{(\varepsilon_r^\alpha - 1)Z}{\varepsilon_a^\alpha + \varepsilon_b^\alpha \frac{\rho_a T_b}{\rho_b T_a} + \varepsilon_f^\alpha \frac{\rho_a T_f}{\rho_f T_a} + \varepsilon_e^\alpha \frac{\rho_a T_w}{\rho_w T_a} - Z}, \text{ [2] } \quad \text{Or } C = 100\frac{\rho_a}{\rho_r}$$

Where
α : coefficient between 0 and 1,
ρ_i : the density of i^{th} constituent,
$Z = \left(1 + \frac{\rho_a}{\rho_f}\frac{T_f}{T_a} + \frac{\rho_a}{\rho_b}\frac{T_b}{T_a} + \frac{\rho_a}{\rho_w}\frac{T_w}{T_a}\right)$
(**a**: aggregates, **b**: bitumen, **f**: fillers, **w**: water)

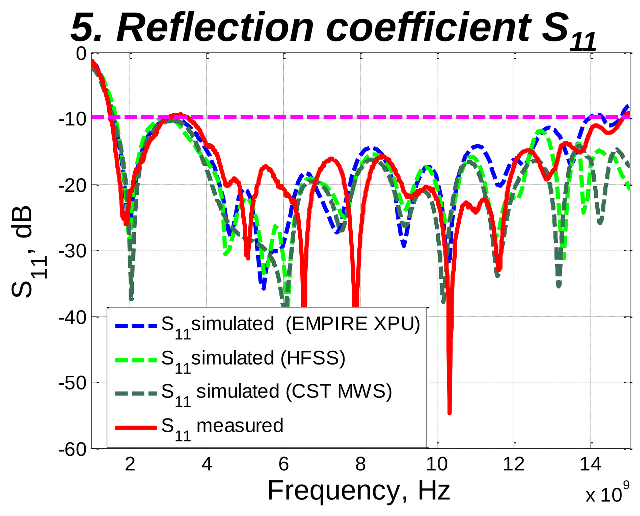
Where
ρ_a: Bulk density,
ρ_r: Real density

UWB Antennas developed

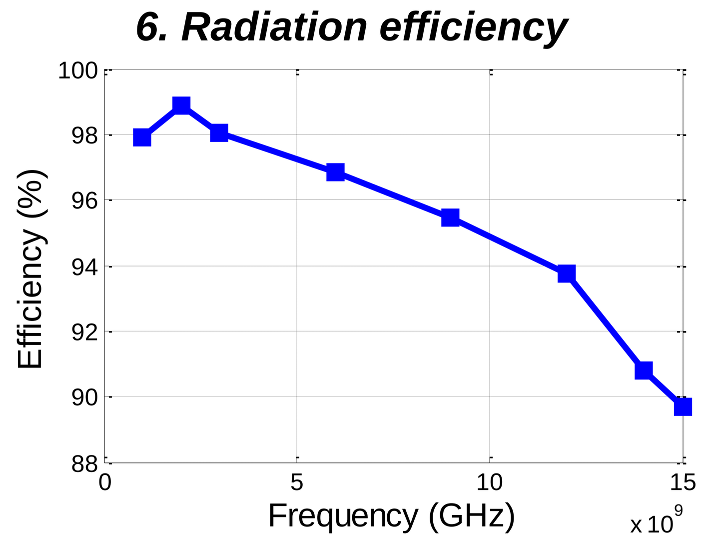
4. Vivaldi antennas



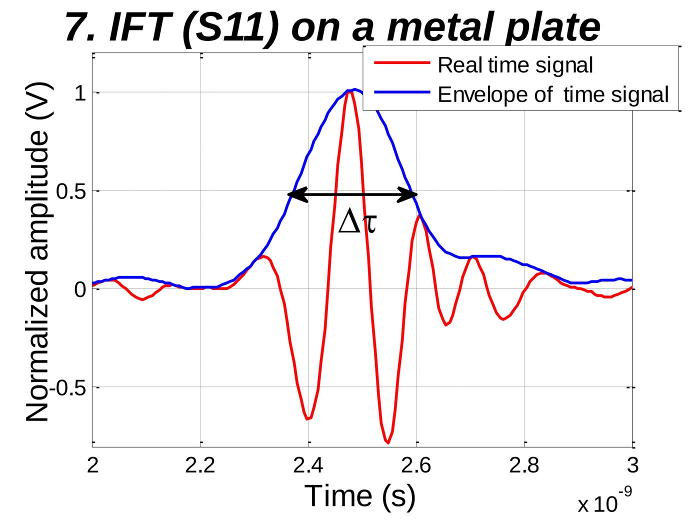
5. Reflection coefficient S_{11}



6. Radiation efficiency



7. IFT (S11) on a metal plate



Références

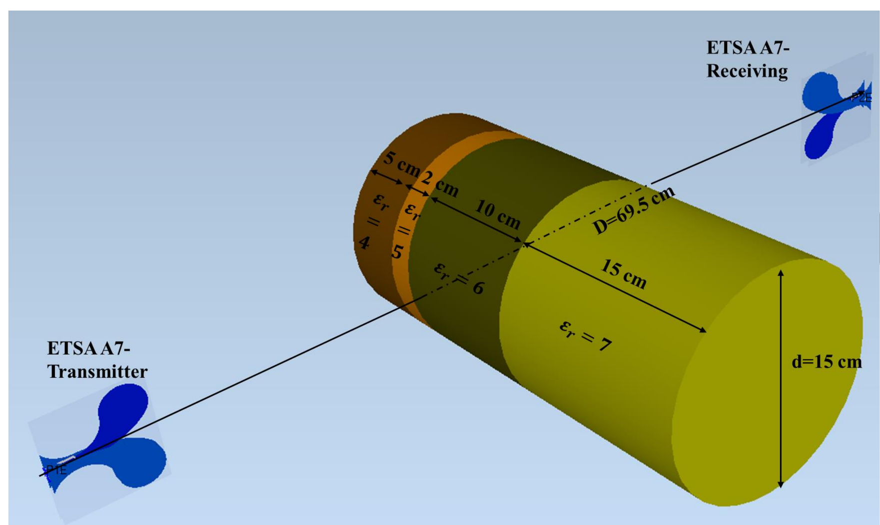
[1] J. Baron et J. Peyernard, « *Mesure de la densité par diffusion gamma à l'aide d'un appareil expérimental,* » Bulletin de liaison des laboratoires routiers, Tech. Rep., 1968,

[2] S. Araujo, « *Evaluation de la compacité des enrobés bitumineux et caractérisation large bande des propriétés diélectriques des roches,* » Thèse. Université de Rouen, 2017.

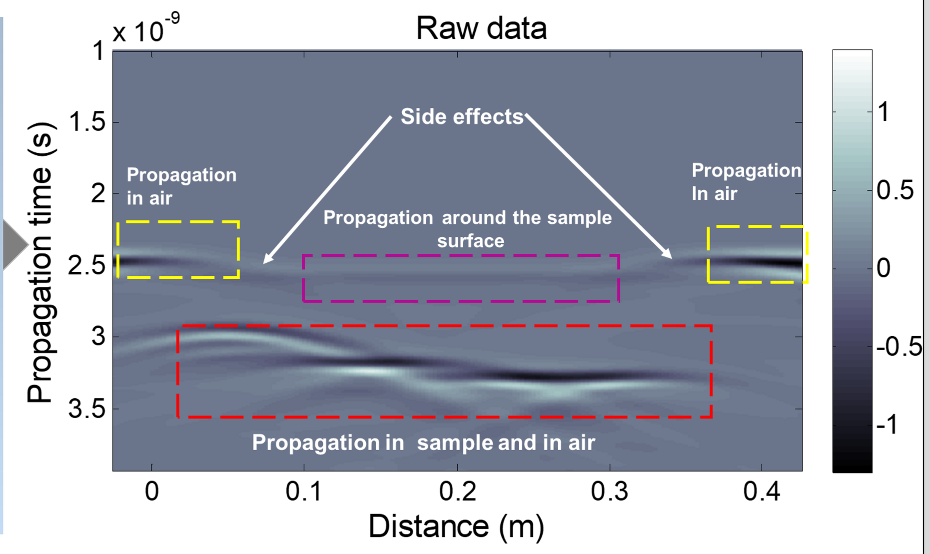
[3] C. Fauchard, B. Li, L. Laguerre, N. Heritier, N. Benjelloun, and M. Kadi, "Determination of the compactionof hot mix asphalt using high-frequency electromagneticmethods,"NDT & E International, vol. 60, pp. 40–51,2013

Finite Difference Time Domain (FDTD) modeling of EM bench

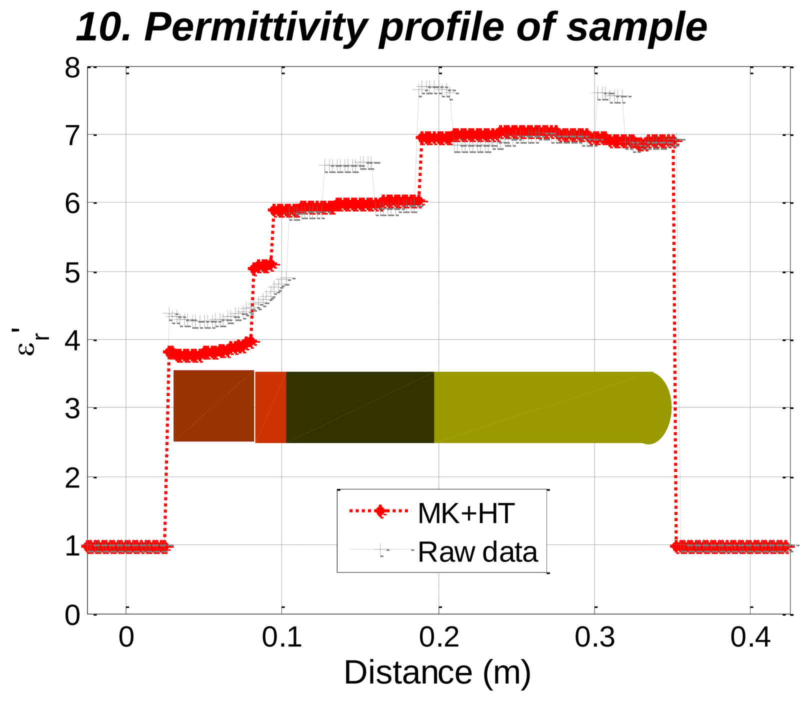
8. Sketch of EM bench



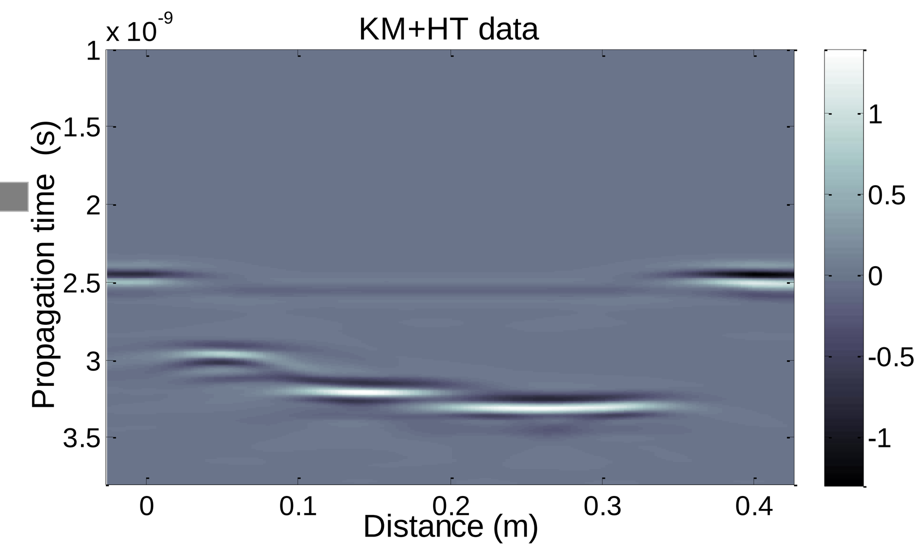
9. B-scan along core



10. Permittivity profile of sample

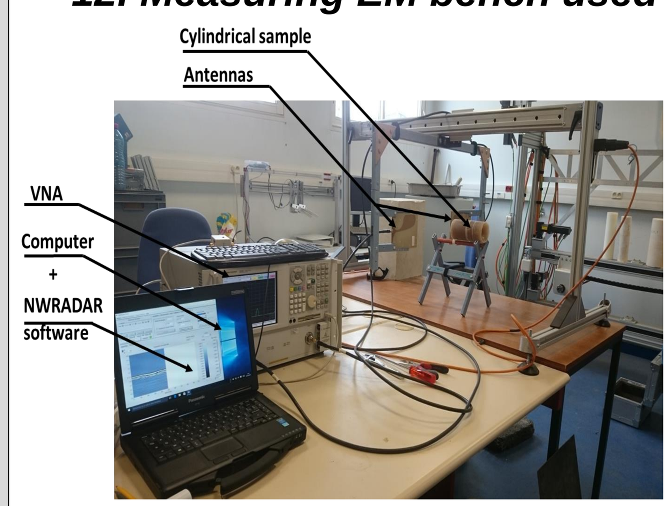


11. B-scan after processing (Kirchhoff+Hilbert)

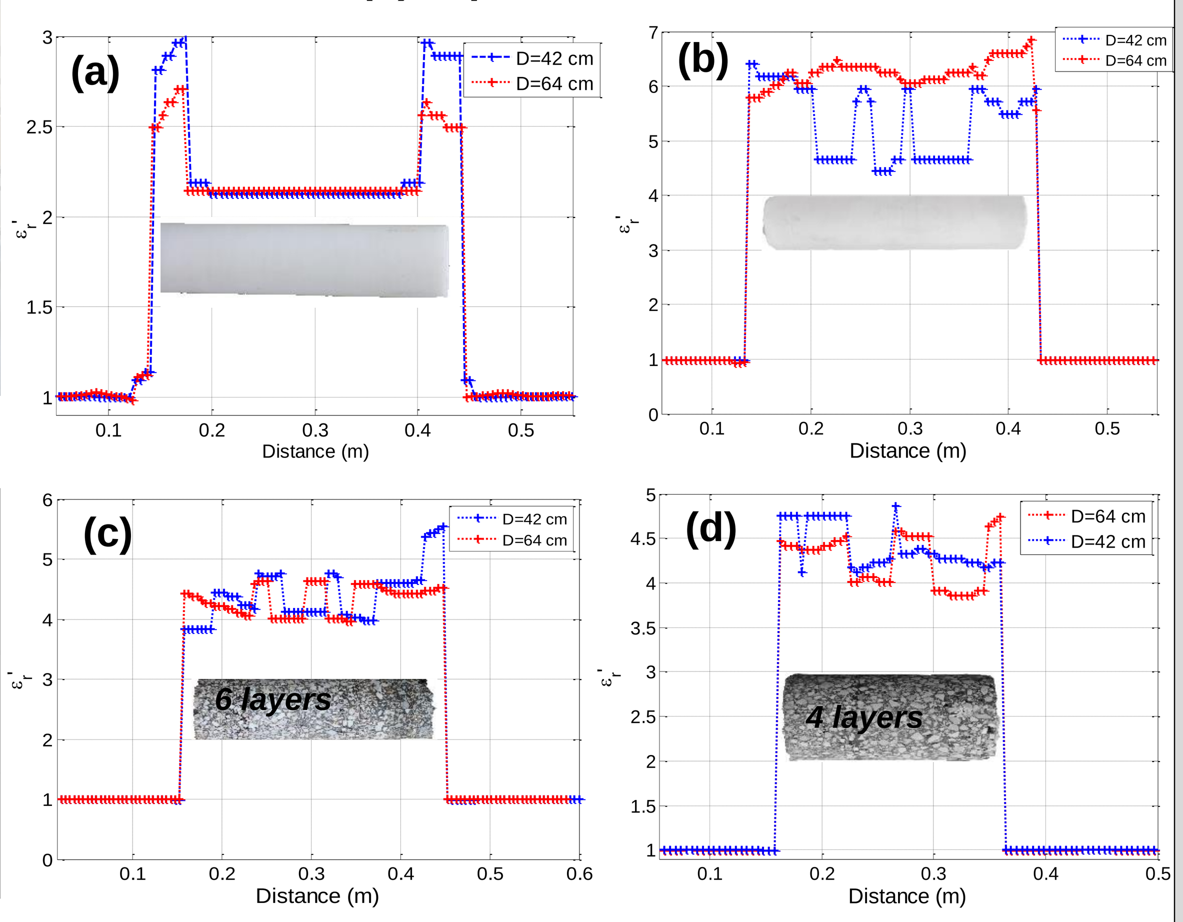


Laboratory measurement: 1st test

12. Measuring EM bench used



13 . Profiles of the measured permittivity: (a) Teflon, (b) limestone, (c) asphalt concrete C1, et (d) asphalt concrete C14

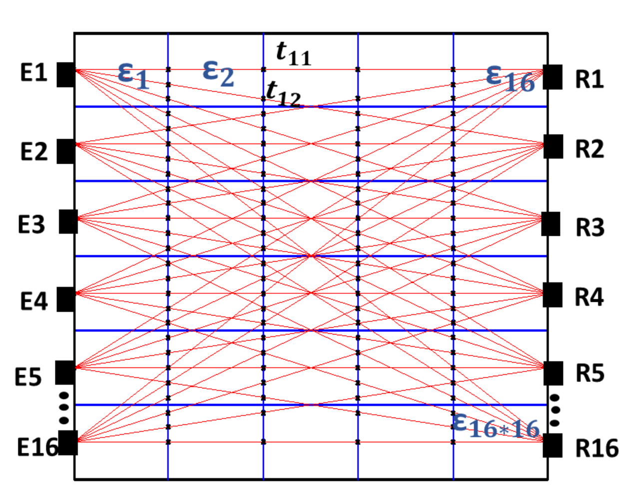


14. Results

Materials	Mean of ε_r'		Reference of ε_r' [3]
	D=64 cm	D=42 cm	
Teflon (d=8,5cm)	**2,15**±*0,07*	**2,14**±*0,02*	***2,15***±0,1
limestone (d=8 cm)	**5,72**±*0,37*	**5,2**±*0,7*	***5,74***±0,2

Tomography technique: code multipath inversion developed

15. Example of a 2D model discretized in 256 cells



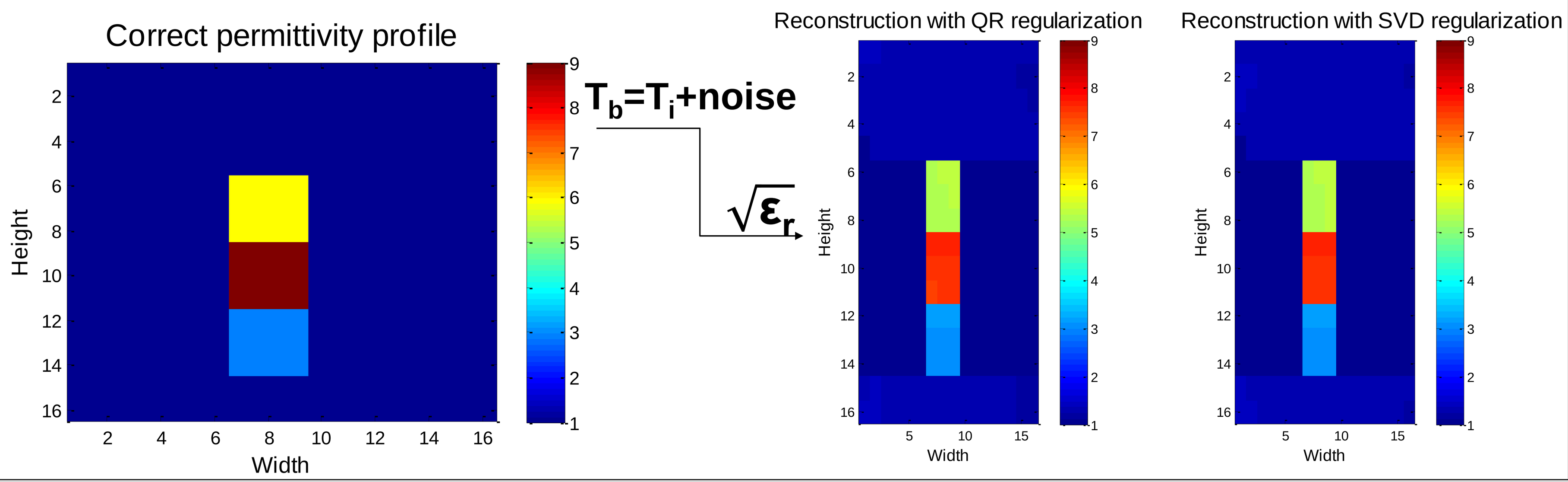
<u>**Hypothesis**</u>**: we assume that the line paths are linear.**

$$t_i = \sum_{j=1}^{N} m_{ij}\, l_{ij}$$

Where
l_{ij} : the length of the rai *i* in cell *j*
m_{ij}=1/v : slowness

$$[T] = \frac{1}{c}[L].[\sqrt{\varepsilon_r}]$$

We initialize the permittivity matrix $[\sqrt{\varepsilon_r}]$, we disturb after the calculated time **[T]** with a Gaussian noise, and we try to find the permittivity using the methods QR and SVD:



Conclusion

The principle of electromagnetic tomography is envisaged to replace the gamma bench to assess of the compactness of materials. In this first simplified approach, two Vivaldi antennas [1.4-15 GHz] were developed to measure the permittivity profile along cylindrical samples in the time domain. The FDTD modeling and the first measurement results show that the technique is encouraging. An experimental validation is in process on samples whose formulation is known.