Nondestructive Detection of Voids Using Electrical Capacitance Tomography

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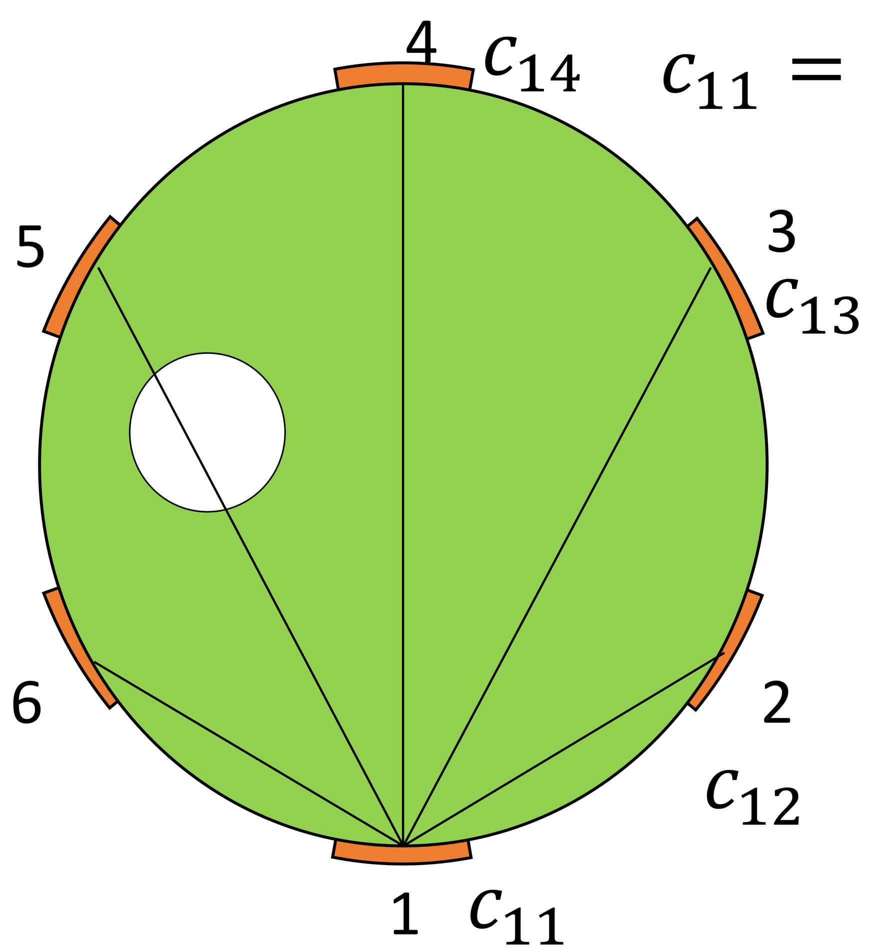
Objective

Real time and quantitative measurement of voids in plant tissues.

Model Geometry and Maxwell Capacitance Matrix



$$c_{11} = \Sigma_{i \neq j} c_{1j}$$

$$\begin{pmatrix} c_{11} & \cdots & c_{1N_e} \\ \vdots & \ddots & \vdots \\ c_{N_e 1} & \cdots & c_{N_e N_e} \end{pmatrix}$$

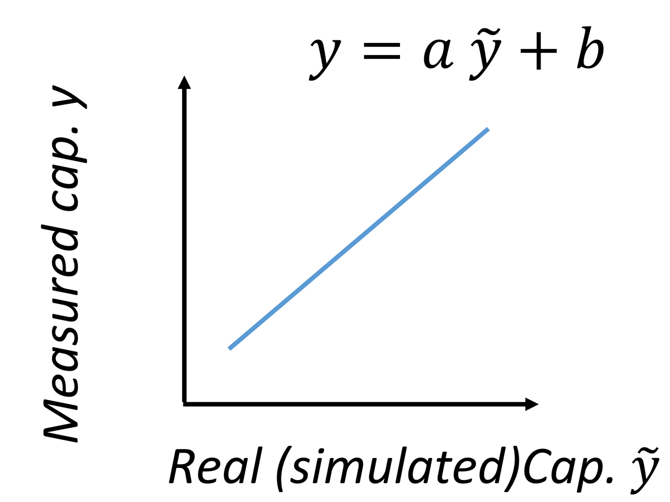
- c_{ii} - ground all conductors except i^{th} one
- Ground all conductors expect i, j (connected together) and measure $c_{ii} + c_{ij} + c_{ji} + c_{jj}$

- Number of electrodes (N_e) = 6
- Output is Maxwell capacitance matrix
- With float at infinity matrix reduction sum of terms in a row or column will become zero

Surrogate Model (CST solver)

- Parametric sweep of full wave model
- Swept variables – (R, θ, V_r)
- Full wave solver is a function f: $(d, R, \theta) \rightarrow \mathbf{C_m}$

Correlation for Sensitivity



$$\Delta C = \frac{y - y_l}{y_h - y_l} = \frac{\tilde{y} - \tilde{y}_l}{\tilde{y}_h - \tilde{y}_l}$$

- Measurement reference comprises of one in free space (ϵ_l) and another with the measurement domain filled with a material of permittivity ϵ_h.
- This provides $\frac{\Delta \tilde{y}}{\Delta \epsilon} = S$ for a small change in the capacitance in a particular location.

Forward Model

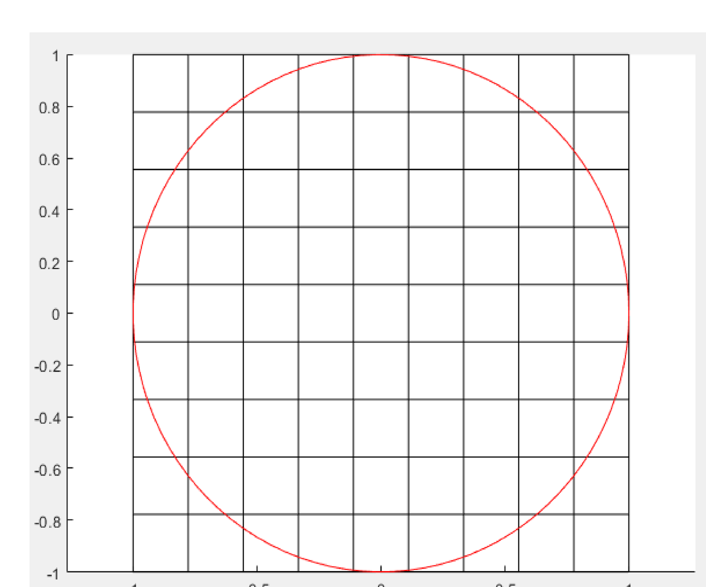
For every capacitance value, $\frac{\Delta C}{\Delta \epsilon} = \frac{S}{\tilde{y}_h - \tilde{y}_l}$

$$y_i(\boldsymbol{\epsilon}) - y_i(\boldsymbol{\epsilon_0}) = \sum_j \frac{\partial y_i(\boldsymbol{\epsilon_0})}{\partial \epsilon^{(j)}} \left(\epsilon^{(j)} - \epsilon_0\right)$$

$$y_i(\boldsymbol{\epsilon_h}) - y_i(\boldsymbol{\epsilon_0}) = \left(\epsilon_{high} - \epsilon_0\right) \sum_j \frac{\partial y_i(\boldsymbol{\epsilon_0})}{\partial \epsilon^{(j)}} = \left(\epsilon_{high} - \epsilon_0\right) P_i$$

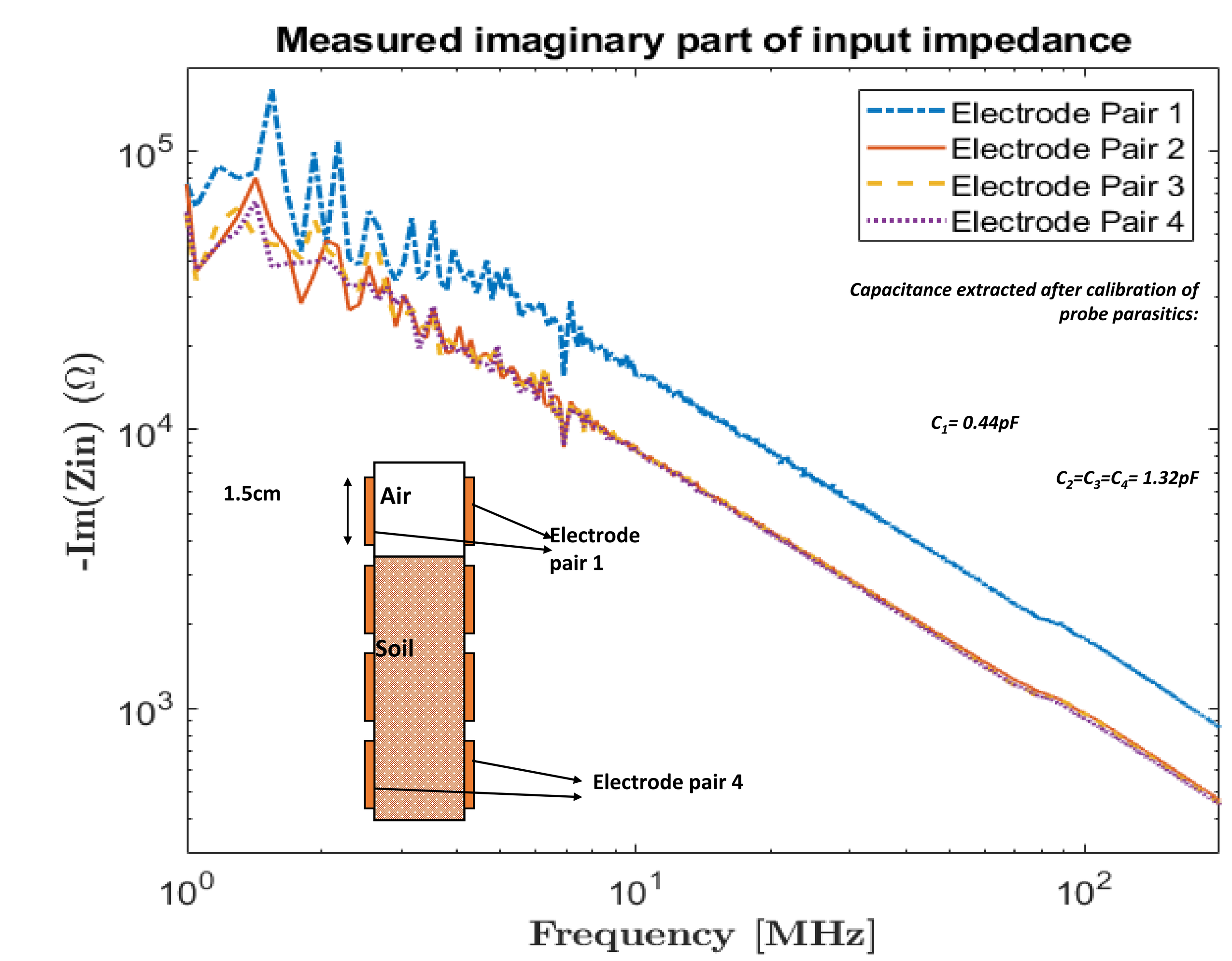
$$\frac{y_i(\boldsymbol{\epsilon}) - y_i(\boldsymbol{\epsilon_0})}{y_i(\boldsymbol{\epsilon_h}) - y_i(\boldsymbol{\epsilon_0})} = \frac{1}{P_i} \sum_j \frac{\partial y_i(\boldsymbol{\epsilon_0})}{\partial \epsilon^{(j)}} \left(\frac{\epsilon^{(j)} - \epsilon_0}{\epsilon_h - \epsilon_0}\right)$$

$$\boldsymbol{\epsilon} = \left[\, \epsilon^{(1)}\ \epsilon^{(2)} \ldots \epsilon^{(N)} \right]^T$$
$$\boldsymbol{\epsilon_0} = \left[\, \epsilon_0\ \ \epsilon_0 \ldots \epsilon_0 \right]^T$$
$$\boldsymbol{\epsilon_h} = \left[\, \epsilon_h\ \ \epsilon_h \ldots \epsilon_h \right]^T$$

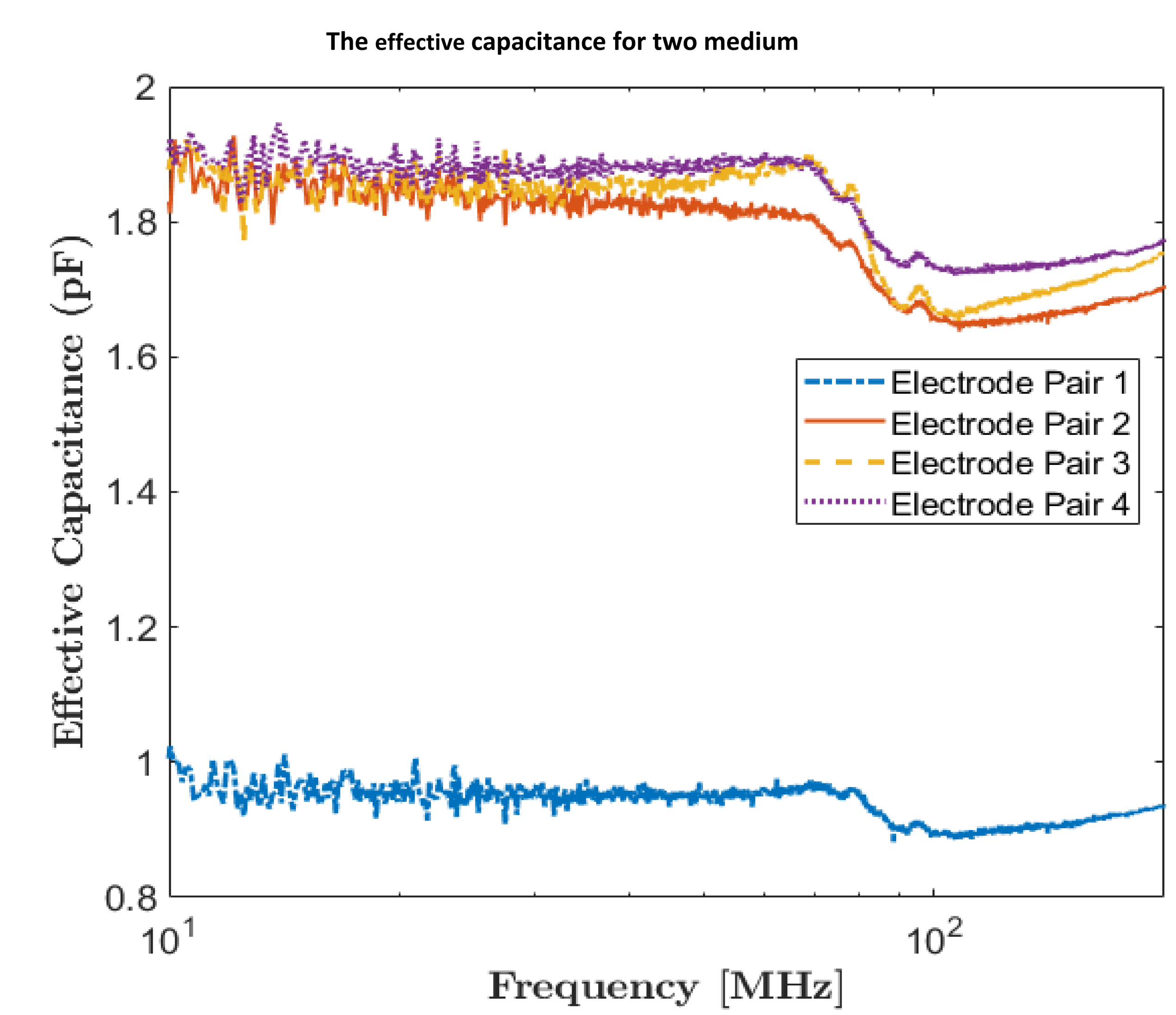


- 10 x 10 grid
- Change permittivity in each grid
- Calculate y' using forward model

Initial Measurement



(a)



(b)

Figure1 (a) Reactance analysis over frequency, (b) Effective Capacitance observation for the two media

Conclusion

It is obvious that the voids in plant tissues have significant effect on permittivity distribution inside the stem which can be detected non-destructively using capacitance tomography.

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