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INNOVATIVE SCANNING METHOD IN NON-DESTRUCTIVE ROOF MOISTURE DIAGNOSTICS

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University of Pécs – Faculty of Engineering and Information Technology
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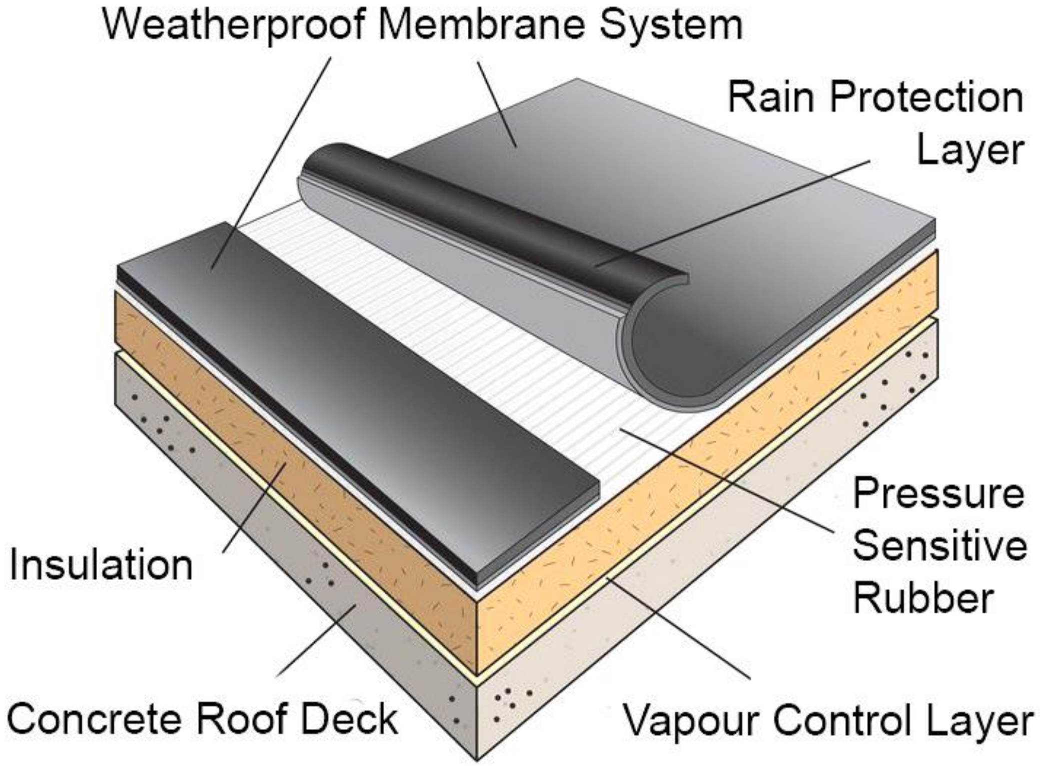
Flat Roof and Preventive Maintenance

"If it ain't broke don't fix it" – old US saying (…not for roofs).



- ❑ Complex structure
- ❑ Extreme envirinment (cold, hot, wet, wind)

Moisture → failure of the roofing system

- ❑ Reduces thermal insulation
- ❑ Causes corrosion (fastening system / structural deck)
- ❑ Cause blistering, splitting, deflection, delamination

Importance of moisture origin

- ❑ From the outside
- ❑ Built-in
- ❑ Generated internally
- ❑ Condensed in roofing system.

Different intervention required

Non-destructive moisture detection → major part in preventive maintenance program.

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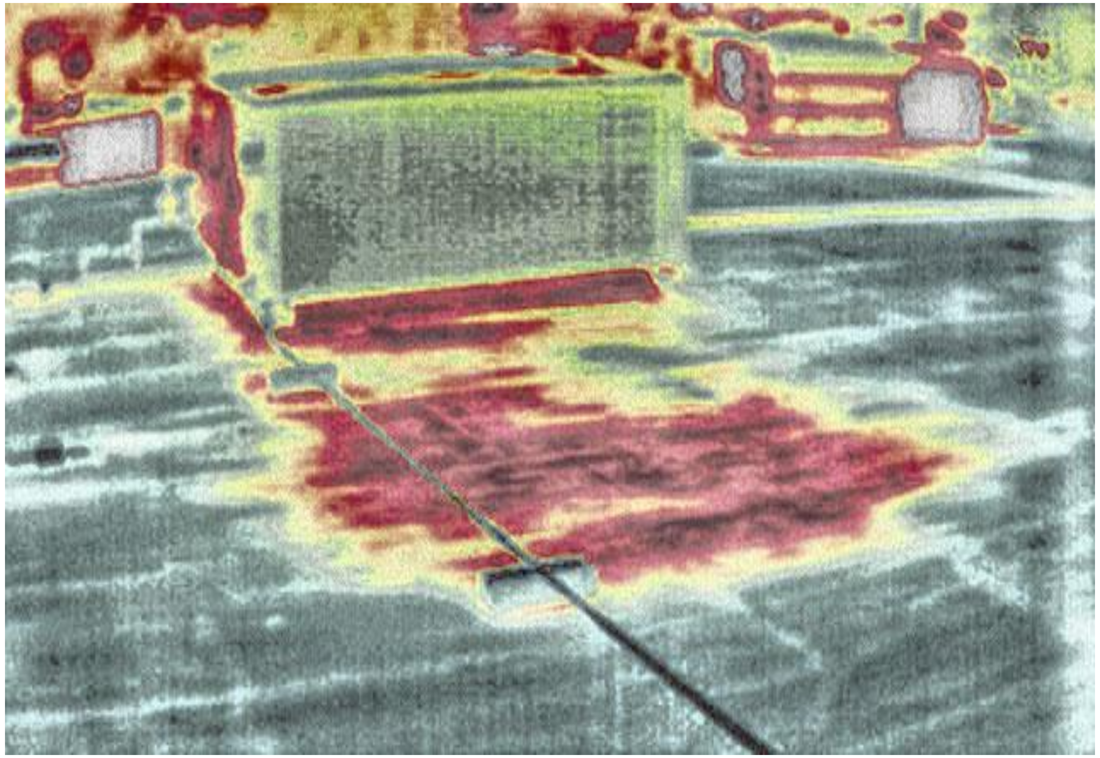
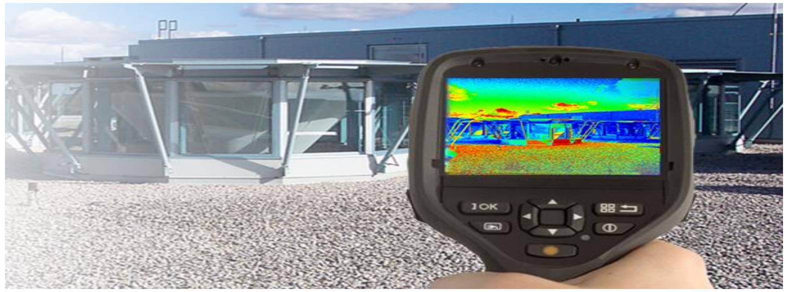
- **Moisture Detecting Methods**
- Measurement Principle of Permittivity Test
- Principle of Detecting Moisture Distribution

Detecting Methods 1 - IR Scanning





IR scanning → temperature differentials

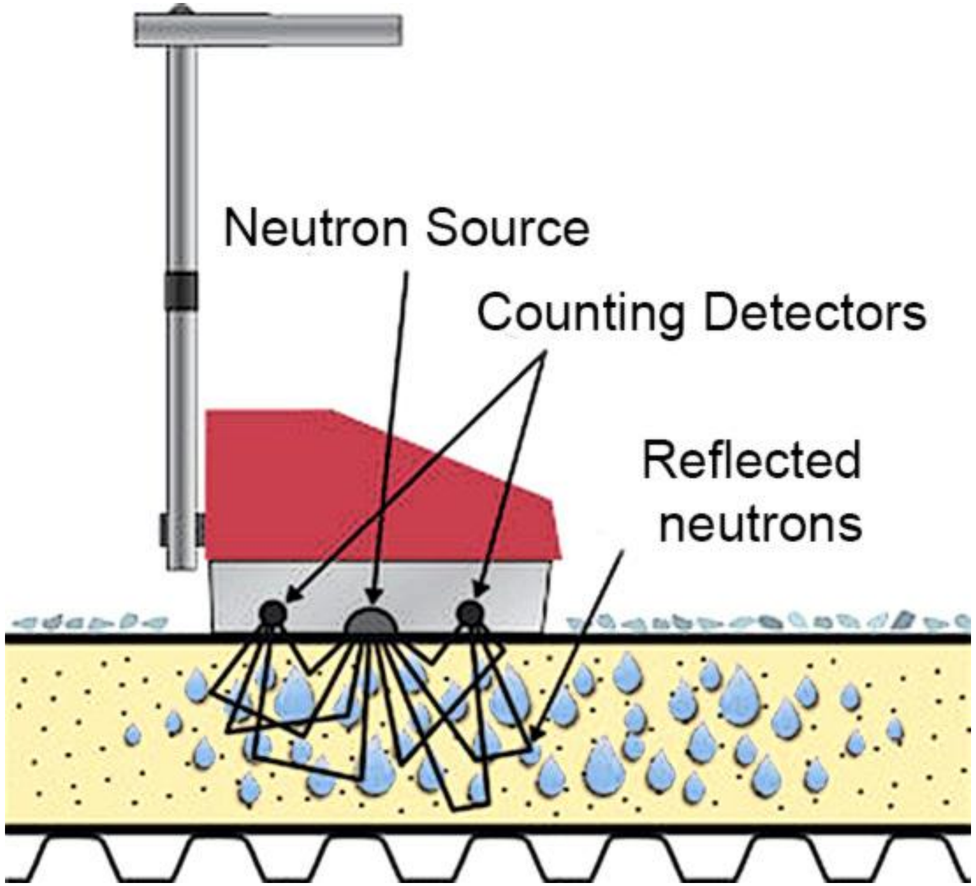
Effective after sunset!

- roof system cools quickly at dry areas
- wet insulation or membrane → longer cool (worse heat insulation & larger mass)

Significant uncertainty! ('Hot spots' origins: moisture, under deck heating, cooling vents, ***etc.***)

Detecting Methods 2 - Nuclear

Scanning



- ❑ Counted neutrons, reflected from hydrogen atoms
- ❑ Wet area → higher level of slowed neutrons
- ❑ Rarely used on roofs in residential environment (because of the applied nuclear technology)

Detecting Method 3 – Impedance Test

Measurement of electric conductivity

- ❑ Difficult to use
  (membrane system: wrong electric conductivity)

Measurement of electric permittivity.

- ❑ RF signals usually from rubber electrodes
- ❑ Significant uncertainty
  (weighted average measurement)
- ❑ New test & evaluation method
  (reduced uncertainty)

- Moisture Detecting Methods
- **Measurement Principle of Permittivity Test**
- Principle of Detecting Moisture Distribution

Permittivity Test 1

$$\varepsilon = \varepsilon_s \cdot \left(1 + 3 \cdot \frac{\varepsilon_w - \varepsilon_s}{\varepsilon_w + 2 \cdot \varepsilon_s} \cdot w_T\right)$$

- ε_s average permittivity of dry construction (3…5)
- ε_w permittivity of water (80)
- w_T moisture content (volume %).

Frequency dependency (Debye's complex relaxation model)

$$\varepsilon = \varepsilon(\infty) + \frac{\varepsilon(0) - \varepsilon(\infty)}{1 + j\Omega} \leftarrow \Omega = \frac{\omega}{\omega_R} \qquad \varepsilon = \varepsilon' - j \cdot \varepsilon''$$

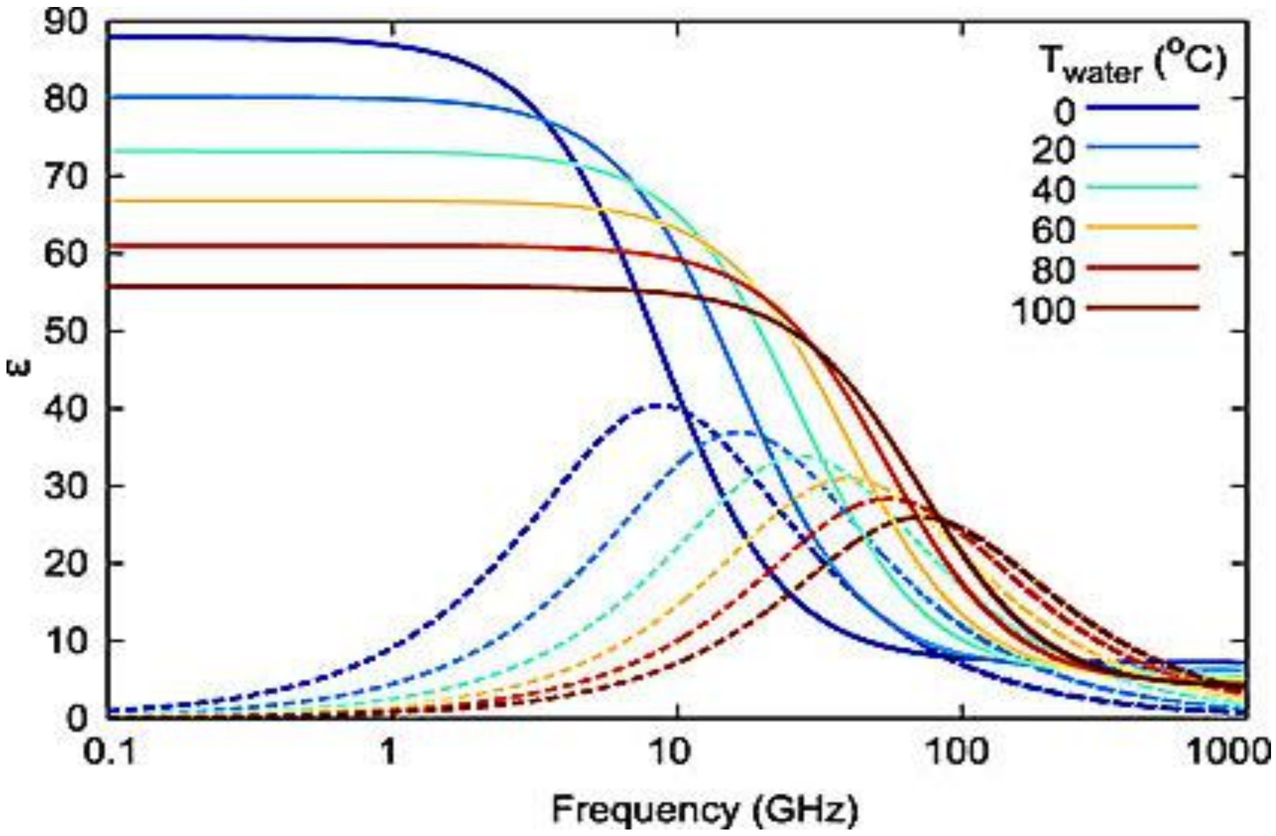
$$\varepsilon'(\omega) = \frac{\varepsilon(0) + \varepsilon(\infty) \cdot \Omega^2}{1 + \Omega^2} \qquad \varepsilon'' = [\varepsilon(0) - \varepsilon(\infty)] \cdot \frac{\Omega}{1 + \Omega^2}$$

Temperature dependency (Kittel model)

$$\omega_R = \frac{k}{3 \cdot \eta \cdot V_m} \cdot T \approx 2.93 \cdot 10^7 \cdot T$$

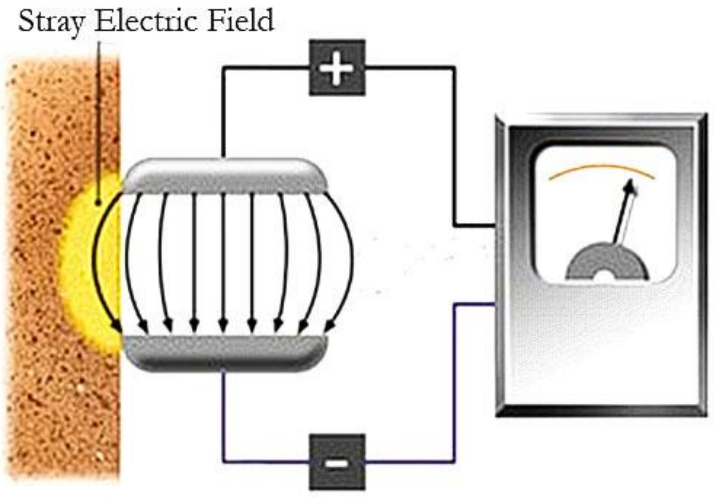
- k Boltzmann constant
- η viscosity
- V_m volume of the molecule
- T temperature

Permittivity Test 2



When $\omega \ll \omega_R$

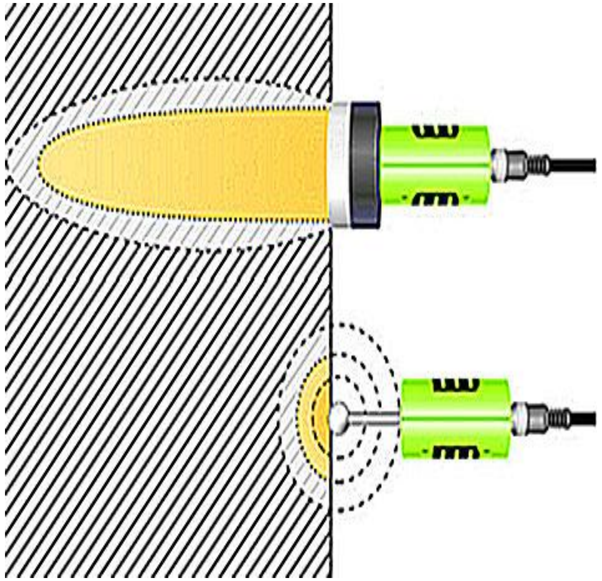
- ❑ Frequency independent real value
- ❑ No dielectric loss (no imaginary component)
- ❑ No phase delay (no imaginary component)
- ❑ Negligible temperature dependency



SWOT Analysis

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Int. Origin (env. attrib.)	**Strengths** ❑ Mobile scanner ❑ Clear indications ❑ Easy to use	**Weakness** ❑ Relative detection ❑ Uncertainty in test ❑ Weighted measurement
Ext. Origin (env. attrib.)	**Opportunities** ❑ Flat roof diagnostic ❑ Instantaneous test ❑ Easy roof inspection	**Threats** ❑ Inhomogeneous mateials ❑ Small+Close = Big+Distant ❑ Uncertain meaning of test value

$$M = \frac{G_0}{d} \cdot \int_0^d h(x) \cdot w_T(x) \cdot dx$$



- ❑ Moisture Detecting Methods
- ❑ Measurement Principle of Permittivity Test
- ❑ **Principle of Detecting Moisture Distribution**

Detecting Moisture Distribution

Single test value (simple mean) $$M_k = \frac{G_0}{d} \cdot \int_0^d h_k(x) \cdot w_T(x) \cdot dx$$

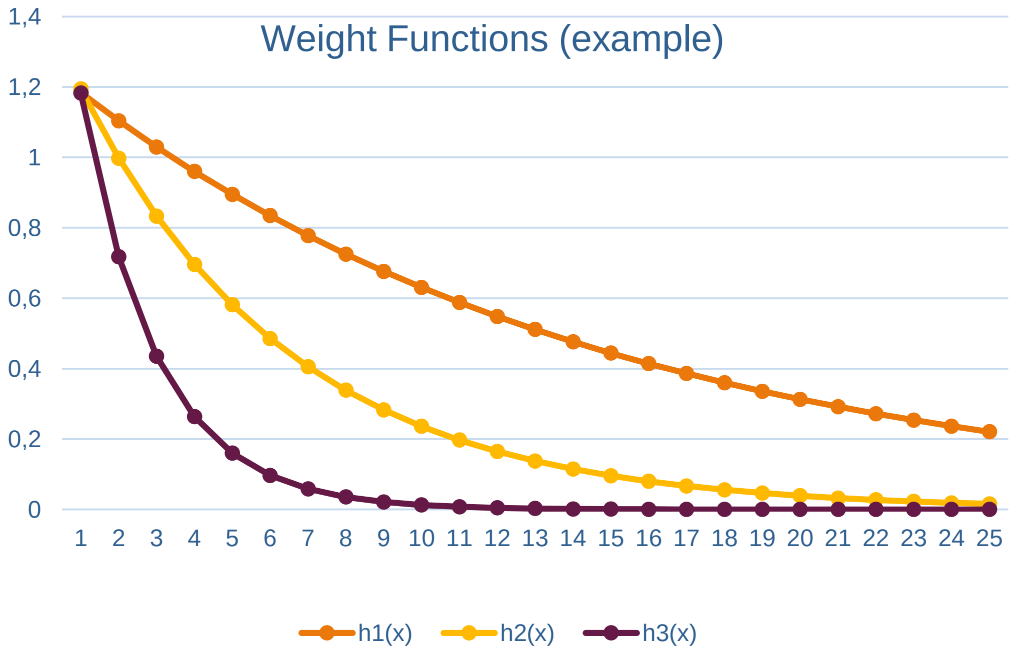
Approx. of k-th test value $$M_k \cong \frac{G_0}{d} \cdot \sum_{i=1}^{n} h_{ki} \cdot w_{Ti} \cdot \Delta x \;\rightarrow M_k \cong \frac{G_0}{n} \cdot \sum_{i=1}^{n} h_{ki} \cdot w_{Ti} \;\; (where\; d = n \cdot \Delta x)$$

Distribution series $$\begin{bmatrix} M_1 \\ \vdots \\ M_n \end{bmatrix} = \frac{G_0}{n} \cdot \begin{bmatrix} h_{11} & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{n1} & \cdots & h_{nn} \end{bmatrix} \cdot \begin{bmatrix} w_{T1} \\ \vdots \\ w_{Tn} \end{bmatrix} \rightarrow \begin{bmatrix} w_{T1} \\ \vdots \\ w_{Tn} \end{bmatrix} = \frac{n}{G_0} \cdot \begin{bmatrix} h_{11} & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{n1} & \cdots & h_{nn} \end{bmatrix}^{-1} \cdot \begin{bmatrix} M_1 \\ \vdots \\ M_n \end{bmatrix}$$

Simulation Example

$$h_i(x) = G_i \cdot e^{-A_i \cdot x}$$

i	1	2	3
G_i	1.27	1.43	1.95
A_i	0.7	1.8	5



$$\overline{\overline{H}} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} = \begin{bmatrix} 1 & 0.79 & 0.63 \\ 0.78 & 0.43 & 0.24 \\ 0.37 & 0.07 & 0.01 \end{bmatrix}$$

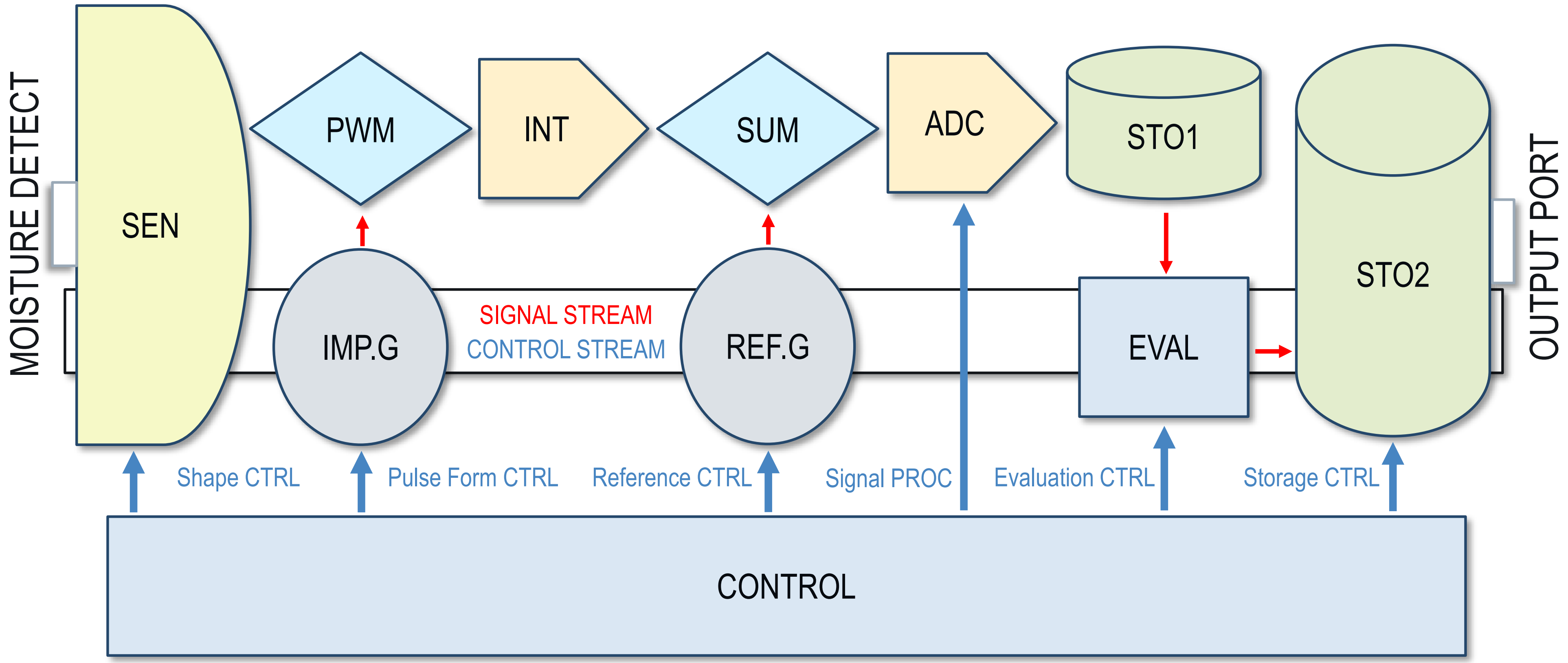
$$\begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}^{-1} = \begin{bmatrix} 0.70 & -2.18 & 5.44 \\ -5.00 & 14.28 & -16.77 \\ 6.78 & -14.56 & 12.51 \end{bmatrix}$$

$$\overline{w}_T = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \rightarrow \overline{M} = \begin{bmatrix} 1.00 \\ 0.78 \\ 0.37 \end{bmatrix} \rightarrow \overline{w}_{Tcalc} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\overline{w}_T = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \rightarrow \overline{M} = \begin{bmatrix} 0.79 \\ 0.43 \\ 0.07 \end{bmatrix} \rightarrow \overline{w}_{Tcalc} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\overline{w}_T = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \rightarrow \overline{M} = \begin{bmatrix} 0.63 \\ 0.24 \\ 0.01 \end{bmatrix} \rightarrow \overline{w}_{Tcalc} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

BACKUP: Operation of Device



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Conclusion

- Traditional non-destructive moisture detection is accompanied with significant uncertainty due to the moisture inhomogeneity in dept.
- The uncertainty can be reduced by post processing of the measurement values resulted by the non-destructive scanning method.
- The uncertainty depends on the number of partial tests, i.e. the number of weight functions, applied in test.

Thank you for your time!