New Multiple-Frequency Technology for Non-Contact Measurements of Large-Scaled Tobacco Samples

- Reasons for development
  - Applications
  - Ability to use a non-invasive method
- Technology
  - Microwave interactivity with water
  - MW Transmission
  - New multiple Frequency Approach
  - 2-Parameter Measurement
  - Calibration/ Sampling / Referencing
- Setup & Operation
  - Setup/ Operation
  - Specification
- Results
  - A-B-Diagram
  - Precision
  - Accuracy
- Conclusion

Applications

Exact moisture measurement of large bulky objects is important to determine:

- the product's quality and value;
- its storage life;
- further processing-ability of the product.

Tobacco Processing

- **Green Leaf Processing (GLP)**
  Incoming Tobacco of Farmer Bales/ Outgoing C48 Boxes
- **Warehousing**
  Incoming Tobacco C48 Boxes
- **Start of the Primary Process**
  Incoming Tobacco Bales
- **Cast Leaf**
  C48 Boxes
- **End of the Primary Process**
  C48 Boxes
- **Secondary Manufacturing**
  Incoming C48 Boxes

Filter Tow Production

Incoming Cellulose Stacks/
Outgoing Filter Tow Bales

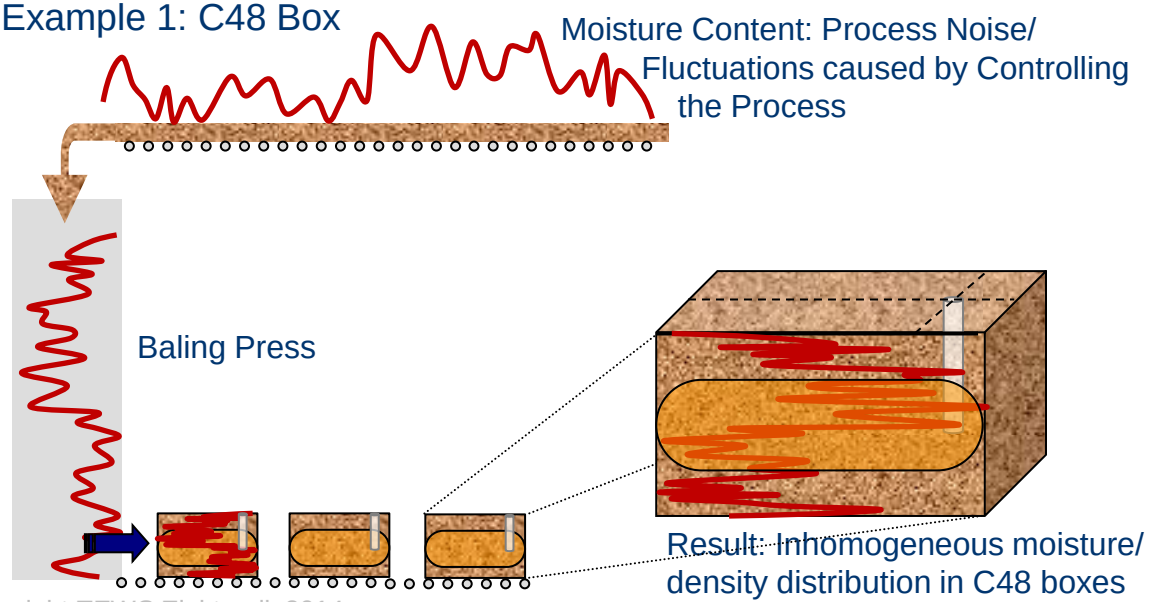
Issues of Invasiveness Relative to Moisture Measurents – Sample Method

- invasive methods partly destroy the bale/ box or it‘s package
- invasive methods may waste material
- invasive methods are time consuming

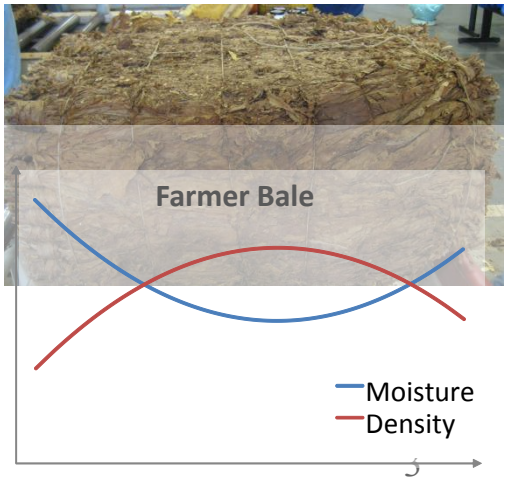
  ➡ it is not possible to take samples from every single bale/ box
- only small portions of the whole bale can be referenced in the laboratory

  ➡ the lab results do not represent the average moisture of the whole bale/ box, if moisture and/ or density are distributed inhomogeneously inside

Example 1: C48 Box

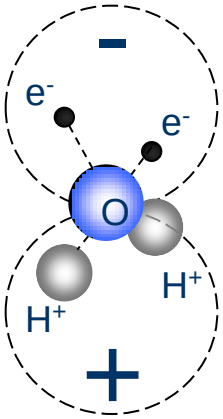


Example 2: Farmer Bale

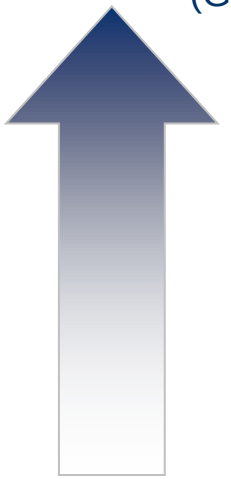


Microwave – Water Molecule Interaction

H_2O Molecule



Electromagnetic Field (GHz Range)

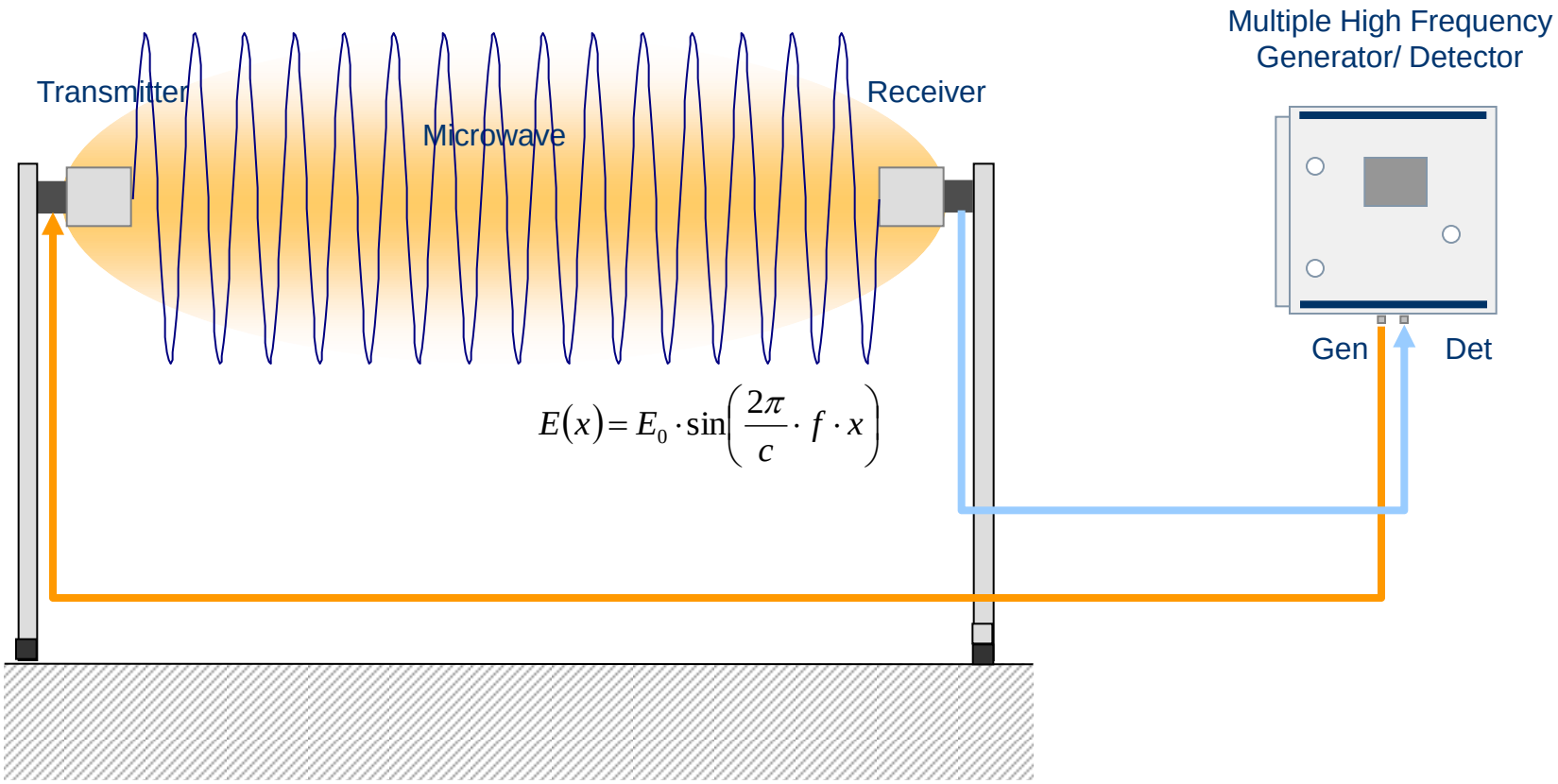


Due to the high polarity of water molecules, the microwave method is highly selective for water

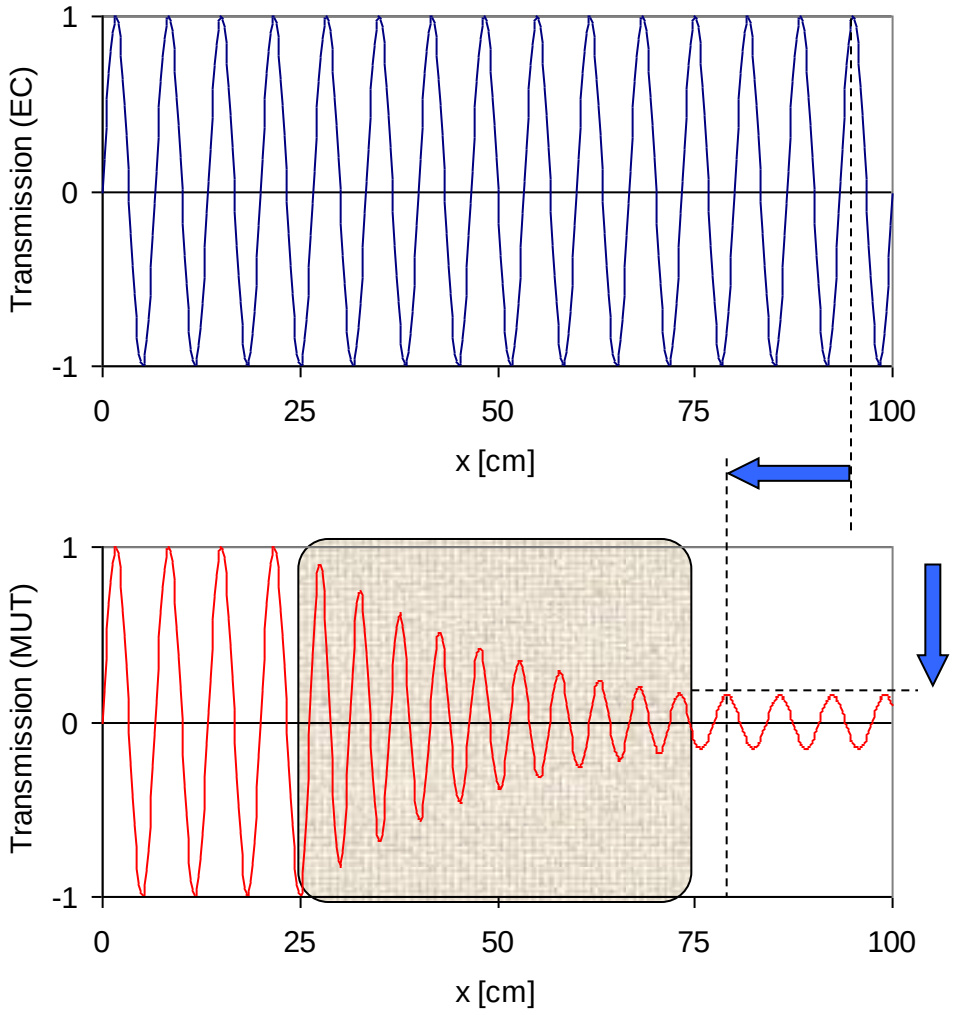
- Low-powered microwave field: <0,05mWatt
- Water molecules align with electromagnetic field
- Rapid change of field direction (GHz range)

  leads to rapid molecule rotation
- Each water molecule
  - → consumes energy
  - → generates a superposing MW field
- Thus, the presence of water molecules leads to
  - → MW attenuation
  - → MW phase shift

MW Transmission Measurement: Setup



MW Transmission Measurement: Principles



Empty Check (EC):

$$E_{EC}(x) = E_0 \cdot \sin(k \cdot x) \qquad k = \frac{2 \cdot \pi \cdot f}{c_0}$$

f: Frequency
c_0: Light Speed

Material under Test (MUT):

$$E_{MUT}(x) = E_1 \cdot \sin(k \cdot x + \Delta\varphi)$$

⇩ ⇩

Attenuation:

$$E_1 = E_0 \cdot e^{-k \cdot n'' \cdot \Delta x}$$

⇩

$$B = n'' \cdot \Delta x$$

B-Value

Phase Shift:

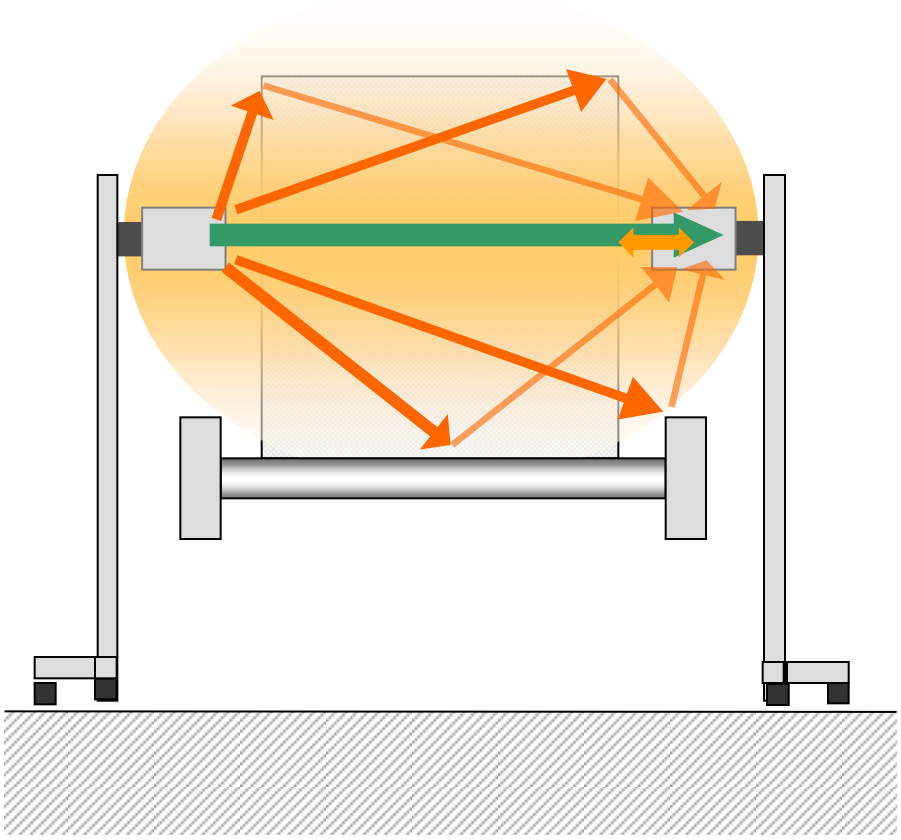
$$\Delta\varphi = k \cdot (n' - 1) \cdot \Delta x$$

⇩

$$A = (n' - 1) \cdot \Delta x$$

A-Value

New Multi-Frequency Approach



Issues with single frequency measurement:

- parasitic reflections/ refractions (red arrows) interfere with main signal (green arrow)
- interferences significantly **decrease** measurement accuracy

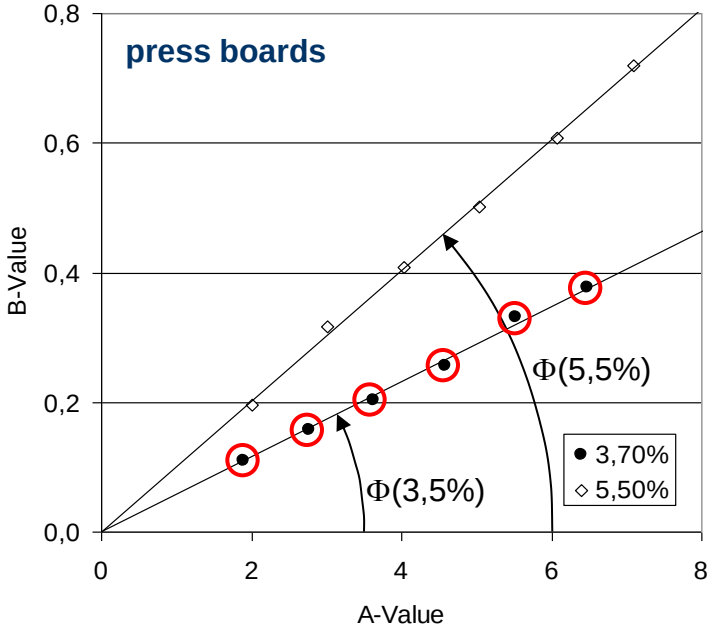
Multiple frequency approach*:

- Measurements with **multiple** frequencies
- sophisticated filter technique:
  interferences are canceled out;
  main signal is retained.

* for example MW-T TEWS Elektronik (*US2010295556 A1*)

Two-Parameter Measurement - Density/ Mass Independence

A-B-Diagram



A-Value: $A = (n' - 1) \cdot \Delta x$

B-Value: $B = n'' \cdot \Delta x$

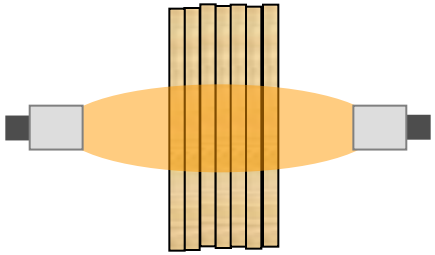
MW Moisture Value:

$$\Phi = \arctan\left(\frac{B}{A}\right) = \arctan\left(\frac{n''}{n' - 1}\right)$$

⇨ Φ is independent of the thickness (*) Δx

⇨ Φ is independent of the density

⇨ Φ is a Measure of the moisture

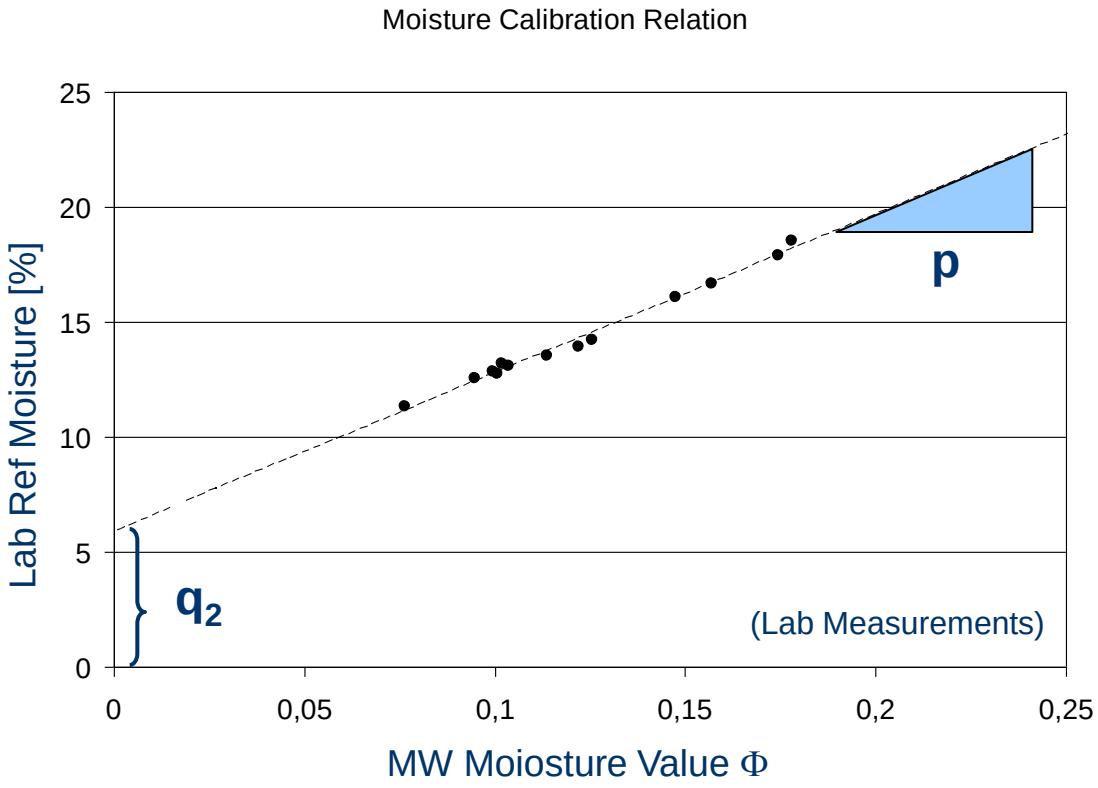


(*) number of boards

Calibration

Linear Calibration Relation: $Moisture[\%] = p \cdot \Phi + q$

Temperature Dependency: $q = q_1 \cdot T + q_2$



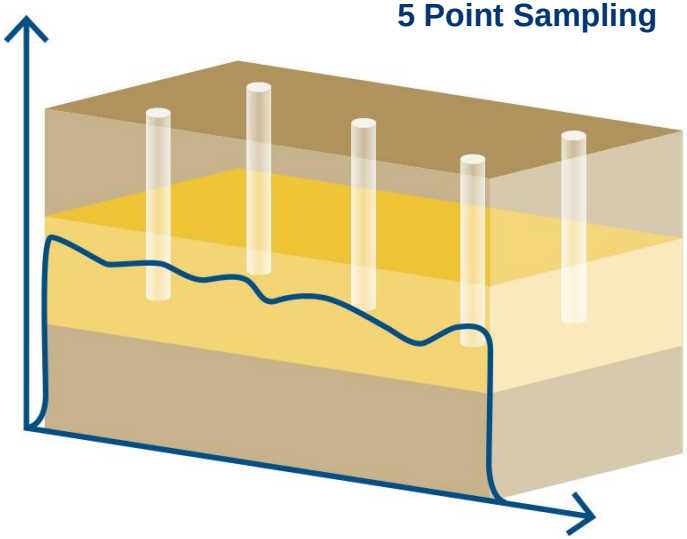
MW Moisture Measurement:

- Independent of density
- Independent of thickness
- Independent of temperature (temperature compensation can be done by temperature measurement)
- May be dependent on tobacco type (Virginia, Burley, Oriental, etc.)

Sampling & Referencing

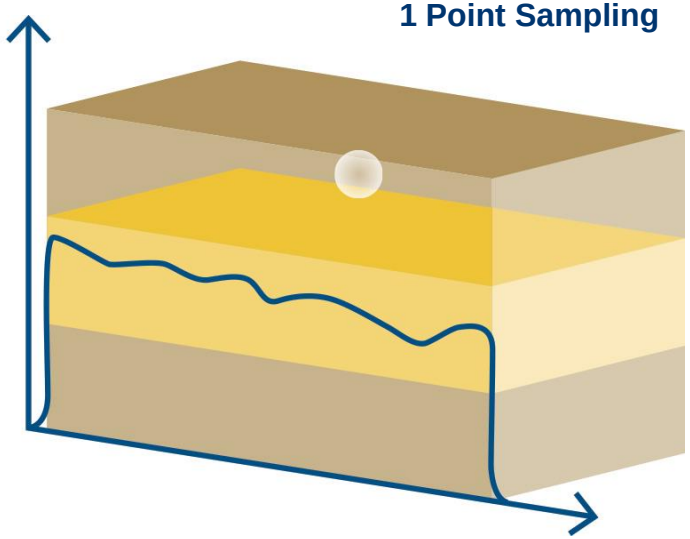
MW measurement: large measurement volume (orange)

5 Point Sampling



Example: measurement accuracy (RMSD): ±0,3 %

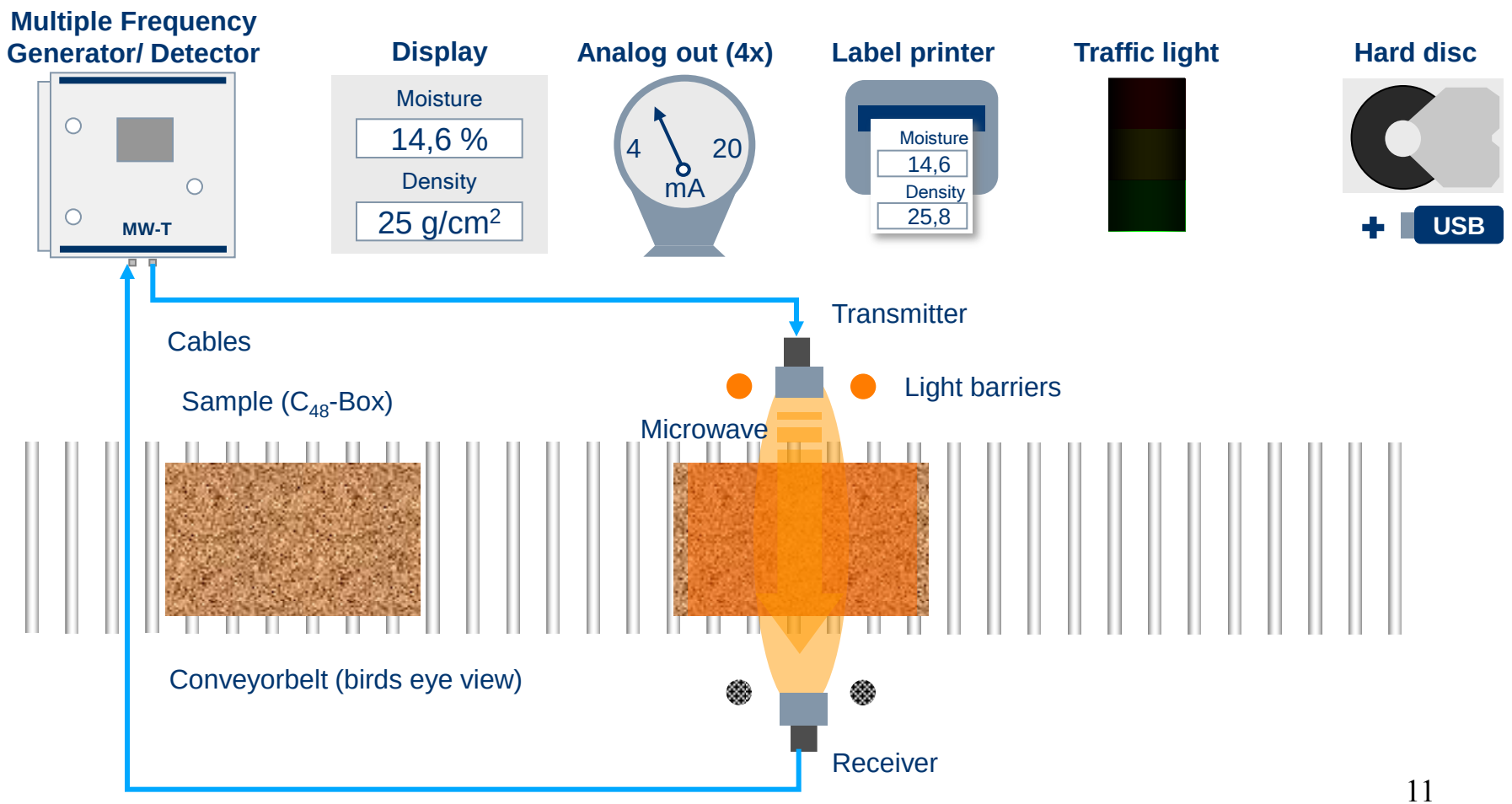
1 Point Sampling



Example: measurement accuracy (RMSD):
~ ±0,5% - ±0,6% (independent of origin or grade)

Measurement accuracy depends on measurement accuracy of reference method

Setup & Operation



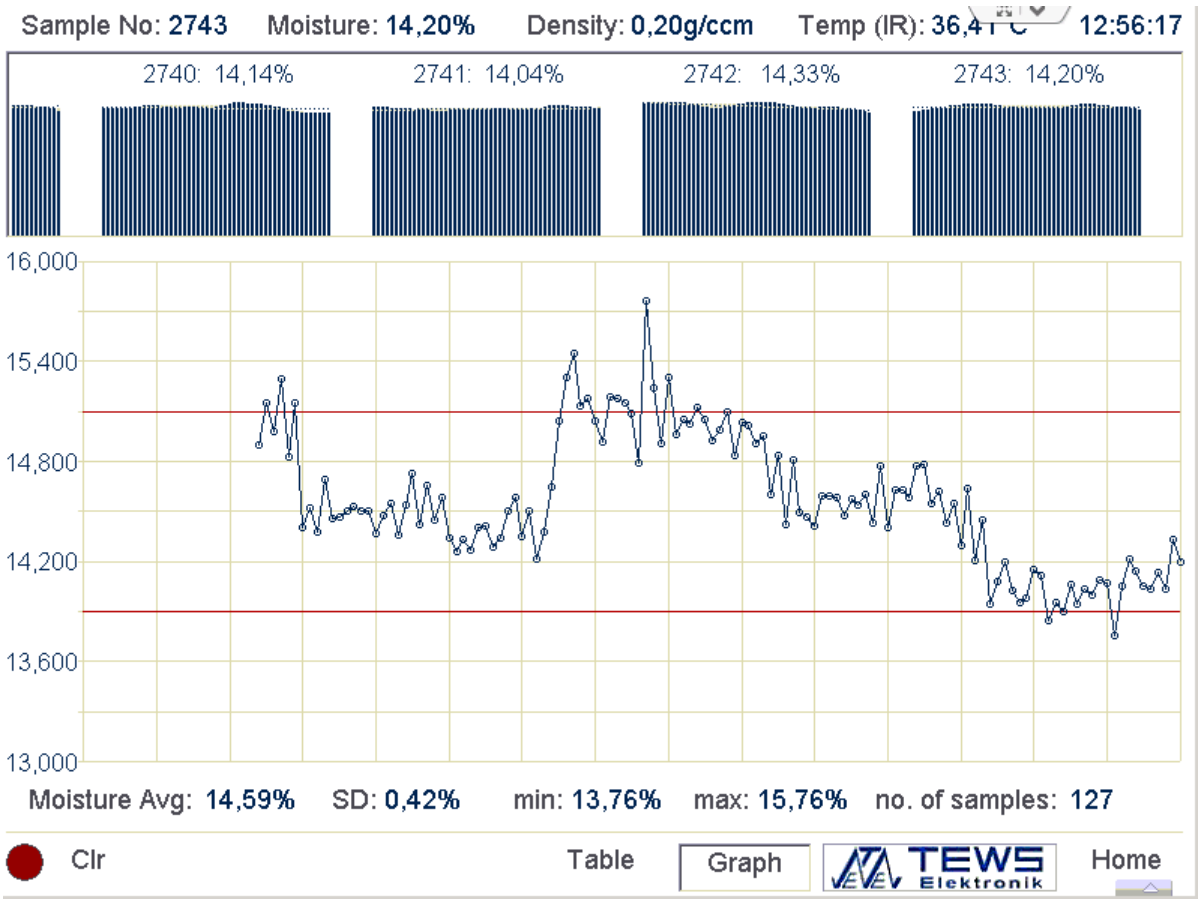
Measurement Screen

Profiles

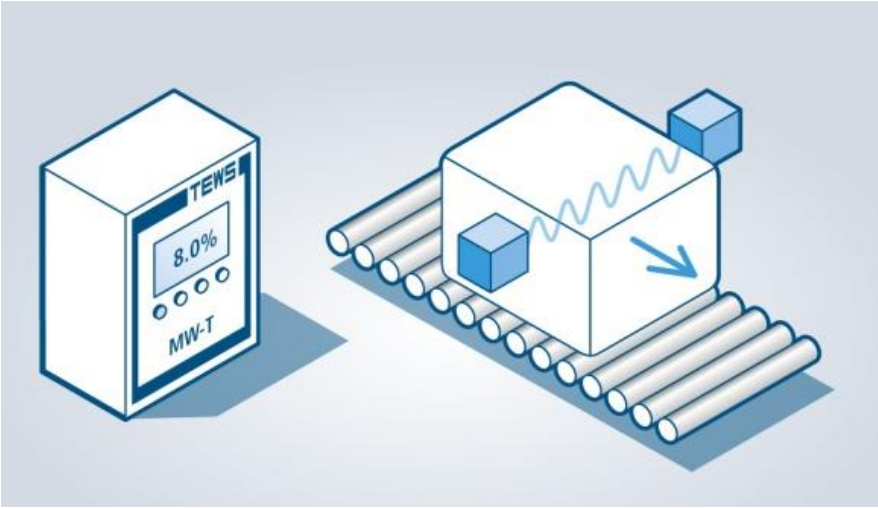
Moisture profiles of individual samples

Batch

Each dot represents the average moisture of one sample



Specification



- Fully automated measurement system;
- Measurement of moisture and mass-per-unit area are independent of each other;
- Large measurement volume;
- >40 measurements per second;
- Profile measurement for moisture and density;
- Robust measurements;
- High accuracy;
- Interfaces: mA-interface, RS232/422/485, network TCP/IP, Profinet, Profibus.

Data Analysis Methods

1) A-B-Diagram

- Verification of density/ thickness independence in A-B-diagram

2) Precision

- Measurement of a sample, sequentially

$$\text{Precision} = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(MW_i - \langle MW \rangle \right)^2}$$

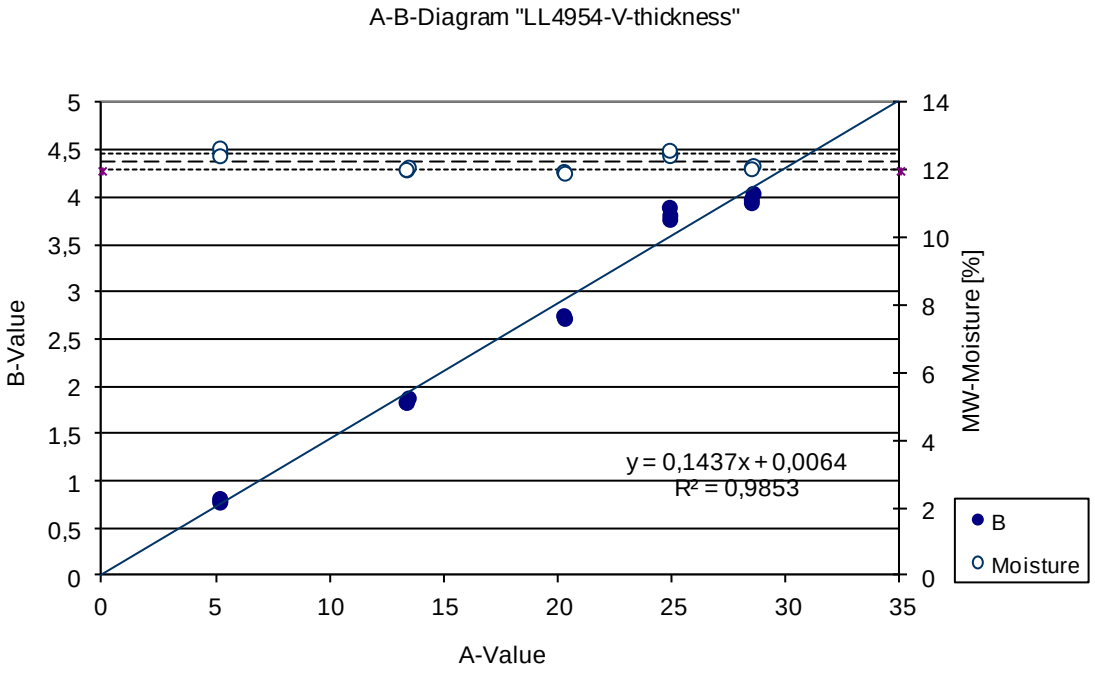
3) Accuracy

- MW results are compared to lab data

$$RMSD = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(MW_i - Ref_i \right)^2}$$

1. A-B-Diagram: Proof of Thickness Independence

C48 Boxes of Tobacco (Poland)



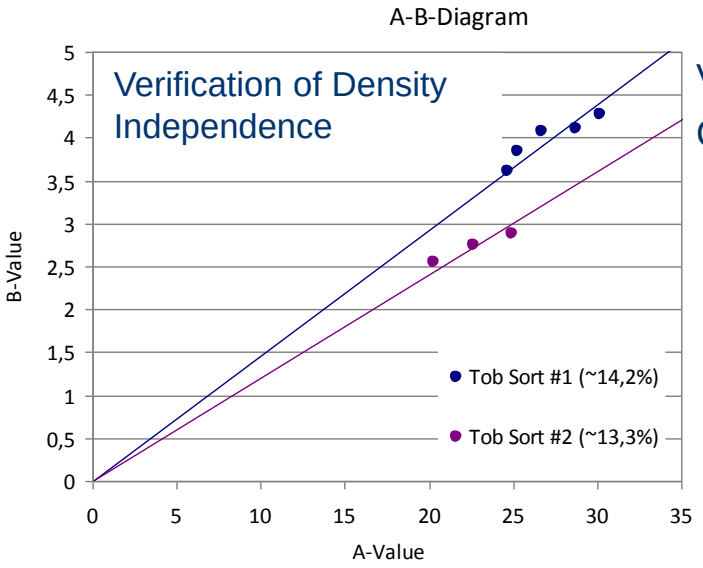
MW moisture = (12,26 ± 0,26) %

Thickness = 0,26 * A

Accuracy: ±8mm

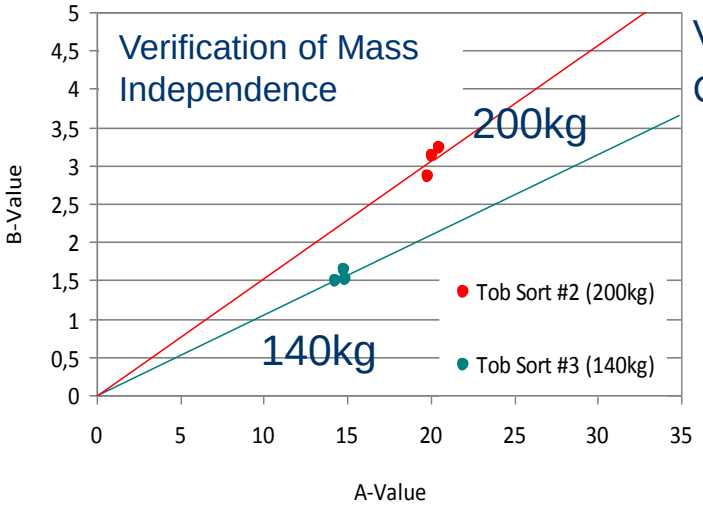
1. A-B-Diagram: Proof of Density/ Mass Independence

C48 Boxes of Tobacco (Indonesia)



Varying density

Constant moisture

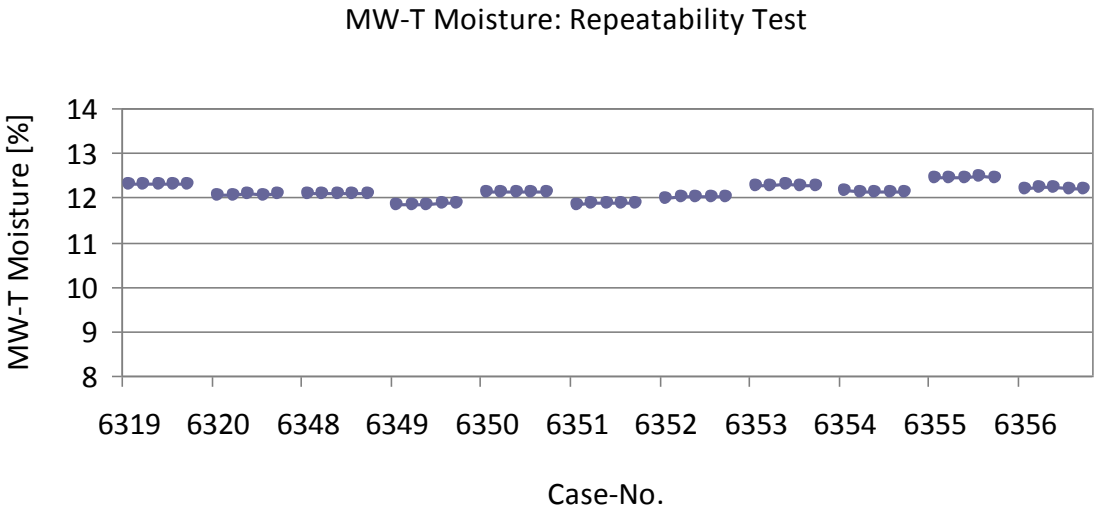


Varying moisture

Constant mass

2. Precision

Primary Processing (Bangladesh)
– Outgoing C48 Boxes



11 Boxes measured 5 times, each

➡ Precision = ±0,02%

Worldwide:

➡ usually < ±0,1% for C48 boxes;

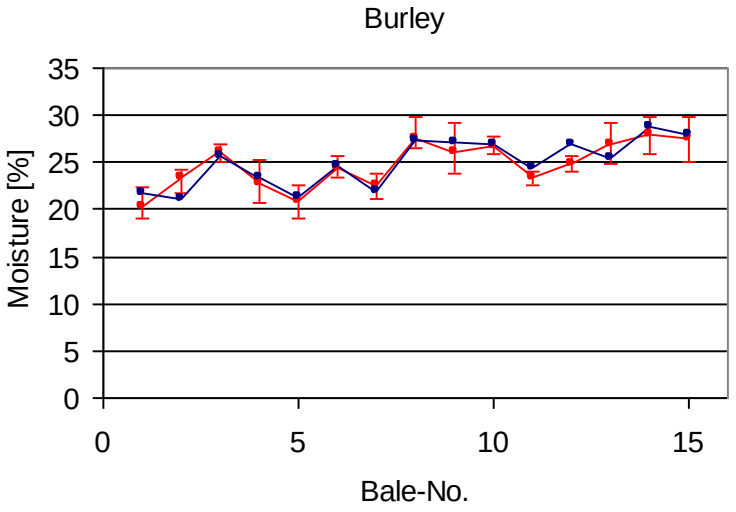
~0,1 – 0,3% for green leaf bales

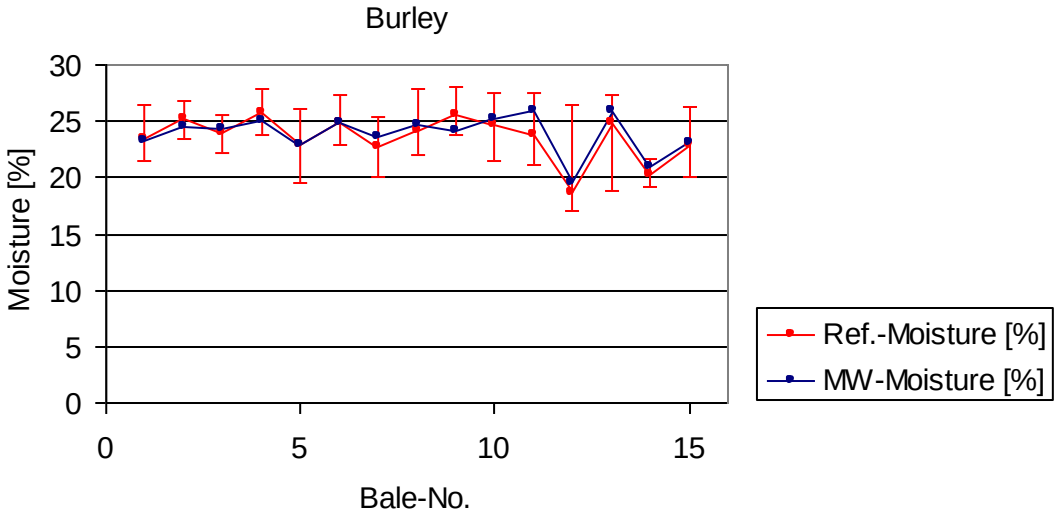
3. Accuracy: Green Leaf Tobacco Bales

Brasil

RMSD ~ ±1%

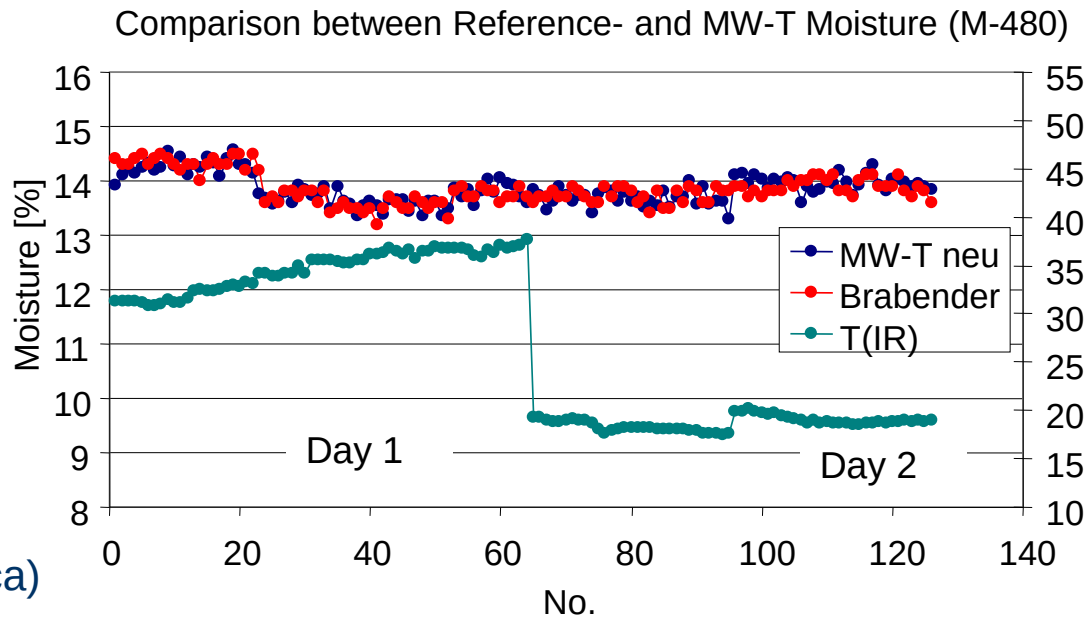
Reference Uncertainty ~ ±1%





3. Accuracy: C48 boxes (fine cut, outgoing)

C48 boxes (South America)

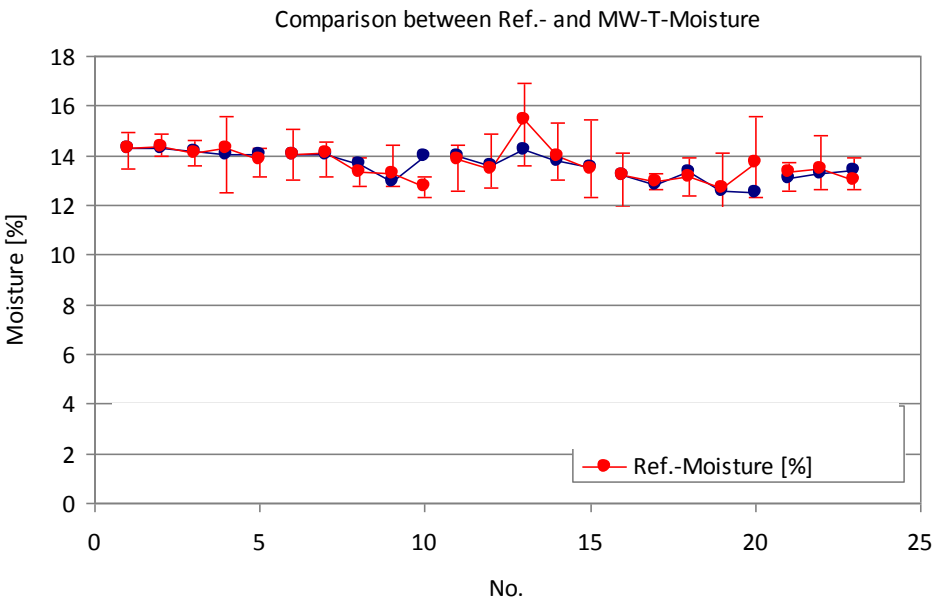


RMSD ~ ±0,25%

Reference Uncertainty ~ ±0,15% - ±0,20%

3. Accuracy: C48 boxes (Primary, incoming cut tobacco)

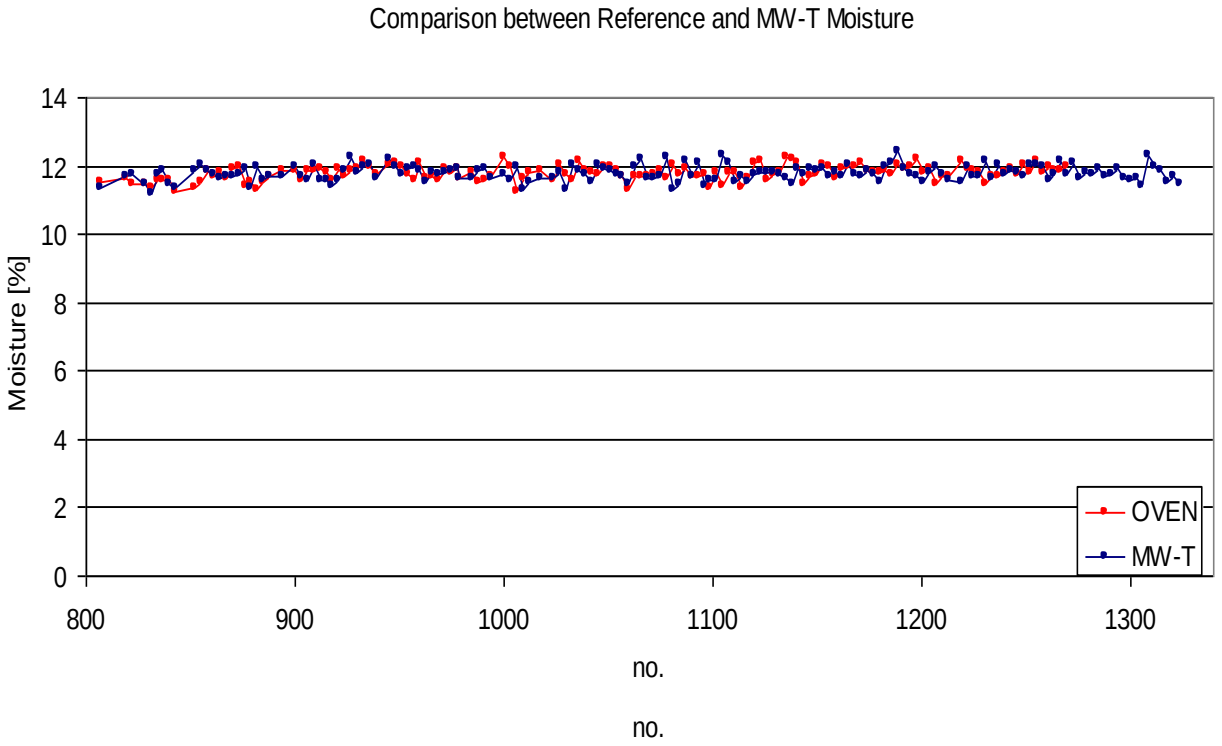
C48 Boxes of Tobacco (Indonesia)



RMSD = ±0,2%

3. Accuracy: C48 boxes (Primary, outgoing cut tobacco)

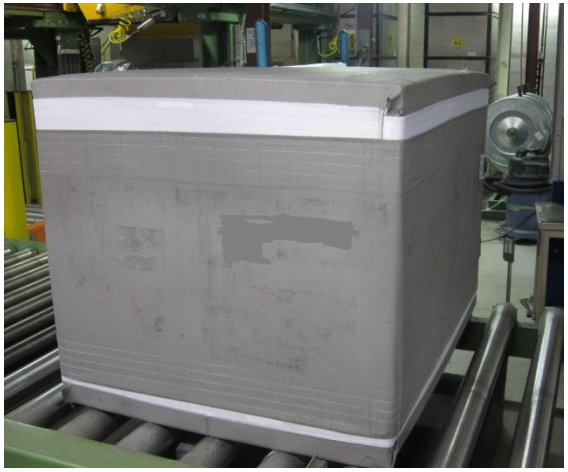
Primary Processing –
Outgoing C48 Boxes (China)



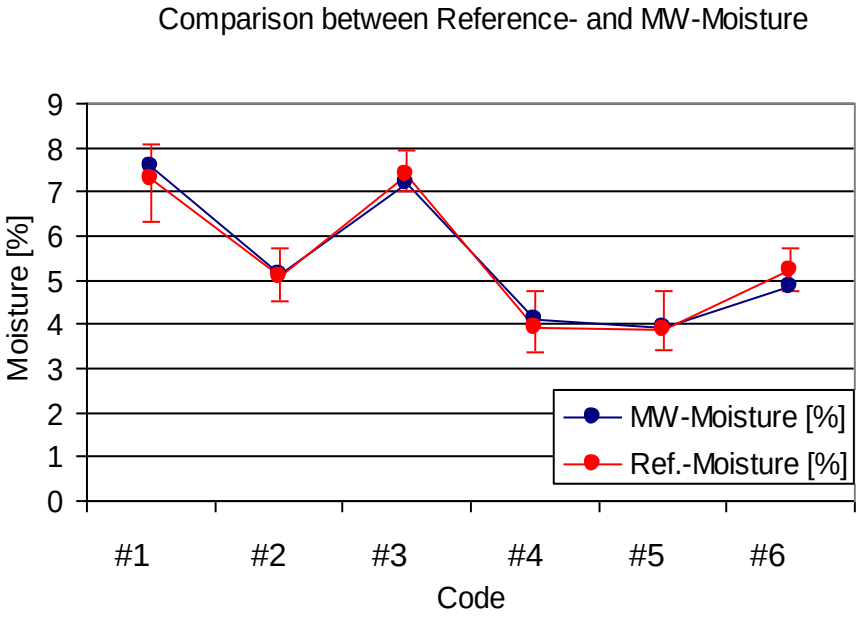
RMSD ~ ±0,29%

Reference Uncertainty ~ ±0,2%

3. Accuracy: Filter Tow Bales



Filter Tow Bale



RMSD = ± 0,2%

Conclusion

Multiple Frequency Approach

- Accurate & robust moisture measurements because of the **new multiple-frequency approach;**
- Fully automated, non-contact, non-invasive, non-destructive;
- Thickness/density independent because of the two-**parameter measurement;**
- Fast: >40 measurements per second;
- Large measurement volume;
- Averages and profile measurements;
- 100% control.