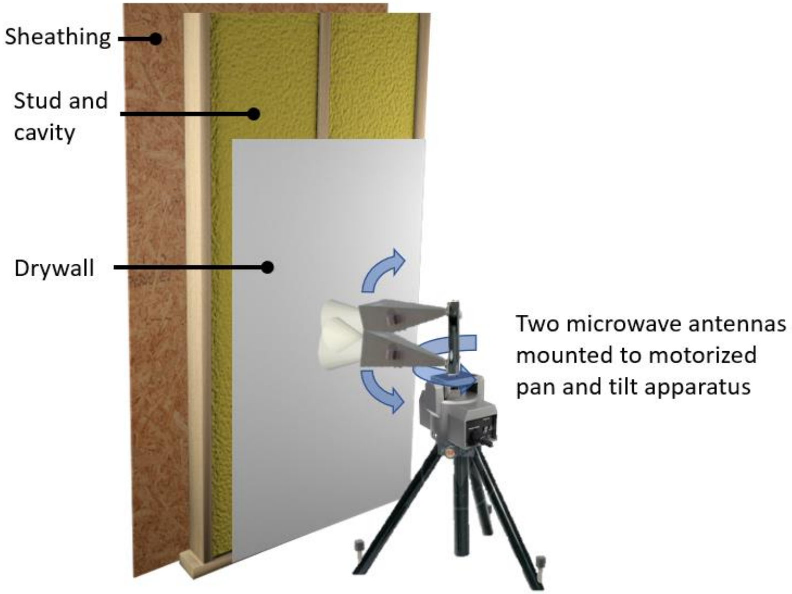
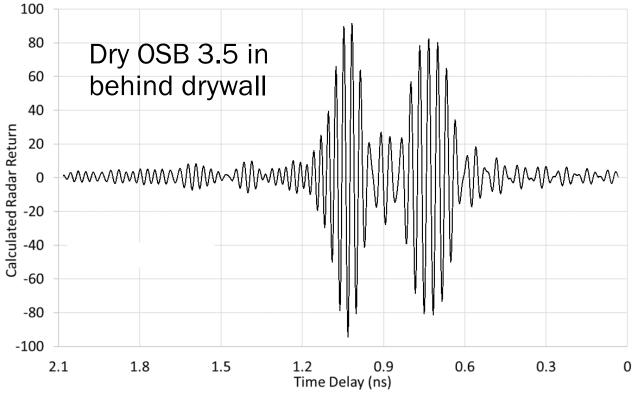
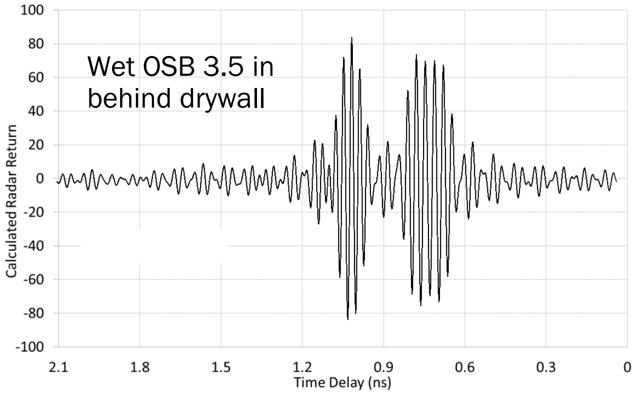
Non-destructive Microwave Reflection-Based Moisture Detector for Durable Building Envelope Retrofits







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BTO-03.01.03.12.26, AOP

Project Summary

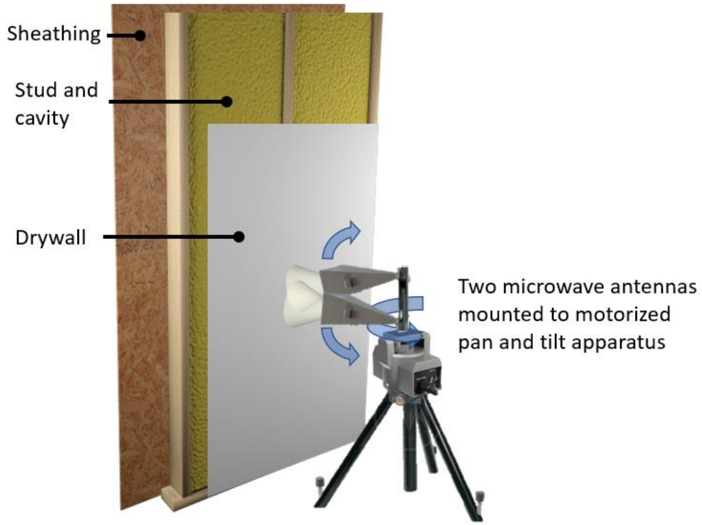
Objective

Use microwave radar for non-destructive moisture content measurement of materials in building envelopes without removal of cladding or drywall

- Detect moisture content of wood sheathing through interior or exterior layers of the wall
- Moisture content accuracy of ±5% of reading

Outcome

Nondestructive diagnostics tool that enables quick and easy moisture assessment of building envelopes without having to remove the cladding. The tool will give building owners and designers confidence about the longevity of the retrofit investment.



Team and Partners

Oak Ridge National Laboratory

- Building Envelope Materials Research Group
- RF and Intelligent Systems Group

Stats

Performance Period: 10/1/21 – 9/30/24

DOE budget: $850k, Cost Share: $0k

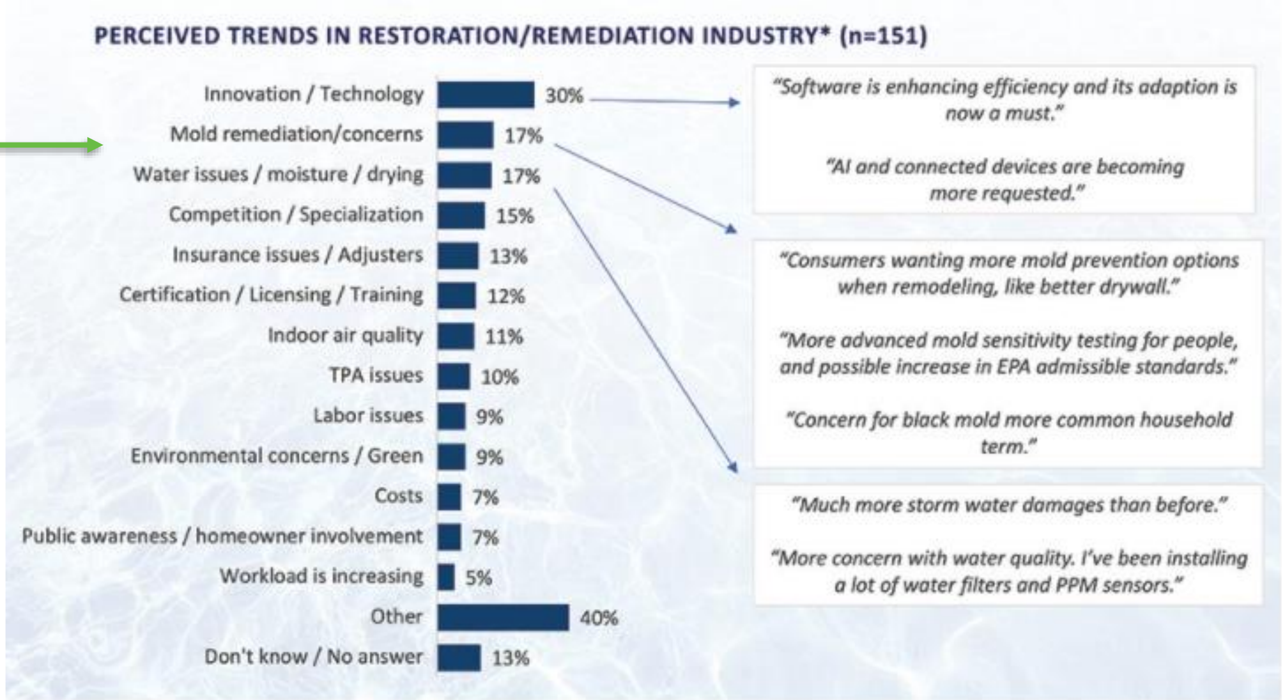
Milestone 1: Distinguish radar signal from wet vs dry OSB while behind drywall

Milestone 2: Measure moisture content of OSB with accuracy of ±5% of reading

Milestone 3: Validation of system on whole wall assemblies

No non-destructive way to measure moisture of sheathing in-situ

- Remediation due to moisture damage is a multibillion-dollar industry
- Trends in the industry are seeing more focus on mold, moisture and drying
- Before retrofits occur - it is critical to determine the moisture durability of the existing envelope
  - Problems can be repaired
  - Increase lifetime of retrofit measures
- Current techniques for measuring moisture content of building materials *require removal of the cladding* or are only qualitative



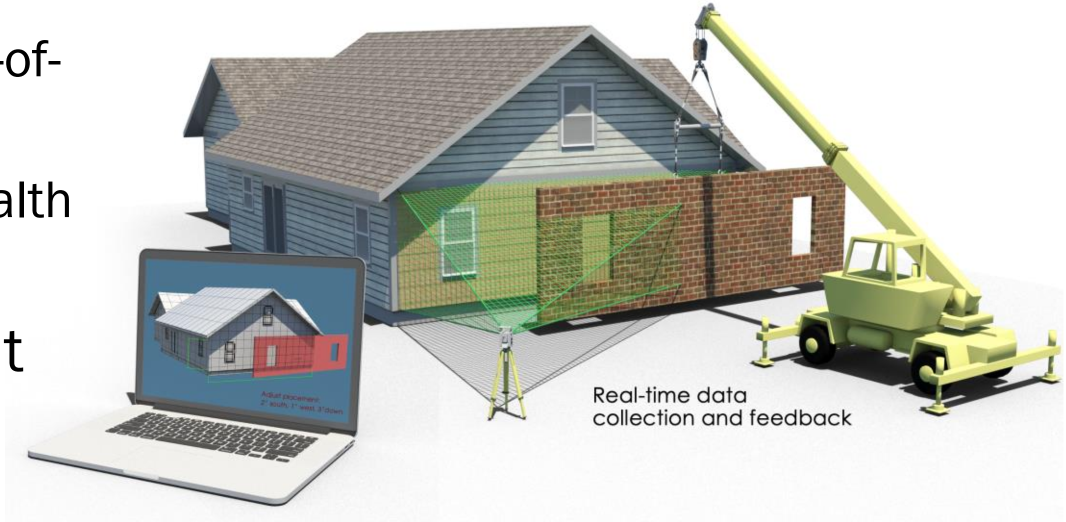
https://www.randrmagonline.com/articles/88256-state-of-the-restoration-industry

Moisture Pins require access to wood inside walls

Infrared imaging can identify cold spots that could be caused by moisture problems – only qualitative and need to be confirmed by destructive testing.

Goals

- Develop a non-destructive moisture detector
  - Measure quantitative moisture content
  - Detect moisture content through outer layers of envelope such as cladding or drywall without removal
  - Does not require cladding removal: faster than state-of-the-art methods
  - Detect problems before mold and rot and related health and structural impacts occur
- Enable retrofit envelope efficiency improvement through measurement and knowledge
  - Can increase confidence in existing envelope's moisture performance
  - Can ensure retrofits have long-term durability



Alignment and Impact

Moisture radar use case goal:

License Moisture radar to sensing manufacturer (FLIR, FLUKE) that will commercialize product.

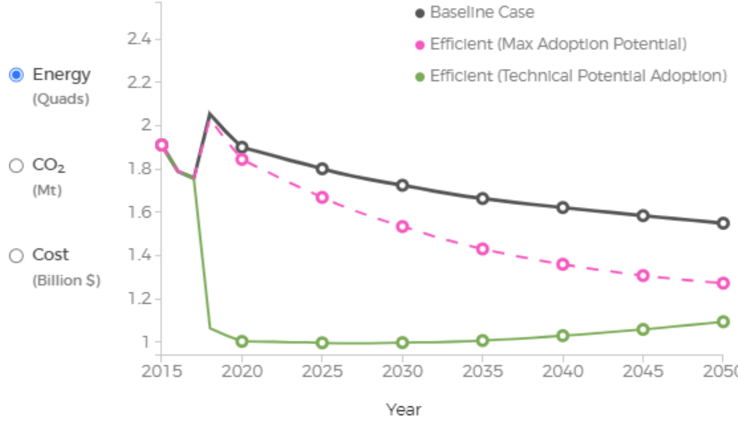
Moisture Radar Users:
- Building Energy Inspector/Auditor
- Retrofit Contractor/Firm
- Consulting Firm

Report moisture assessment results to:
- Home/Building Owner
- Facility Manager
- Retrofit Contractor

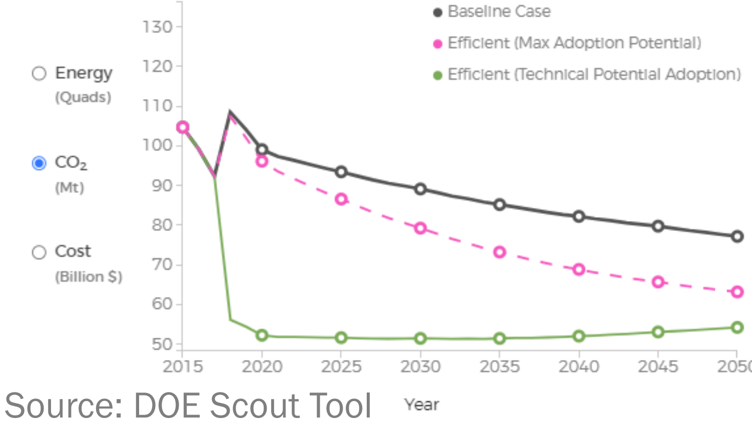
Find and remove moisture source, remediate moisture damage, and continue with retrofit (if applicable)
- Restoration Company
- Contractor

Contribution to EERE/BTO Goals

Enable increased building energy efficiency by 2050 – Save 0.84 Quads/yr



Greenhouse gas emissions reductions - 42.59 Mt CO_2 saved over baseline by 2050



Source: DOE Scout Tool

Current state of the art for moisture measurement

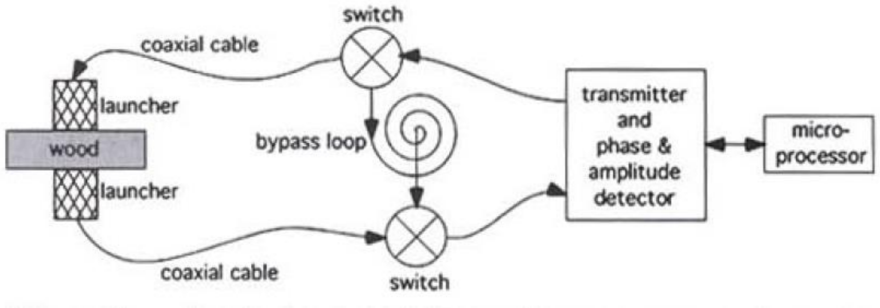
Contact/Destructive

- Gravimetric
- Electric resistance
- Dielectric

Source: DOE

Non-Contact/Non-destructive

- Infrared imaging based on evaporative cooling
  - Qualitative
  - Identifies a potential area of high moisture
- Microwave transmission/reflection
  - Quantitative
  - Literature only looks at outer building cladding moisture using Ground Penetrating Radar
  - ORNL developed a microwave moisture detector for wood kilns (with accuracy of 0.8% of gravimetric)



Transmission based moisture measurement ORNL, 2007

Novelty of moisture radar

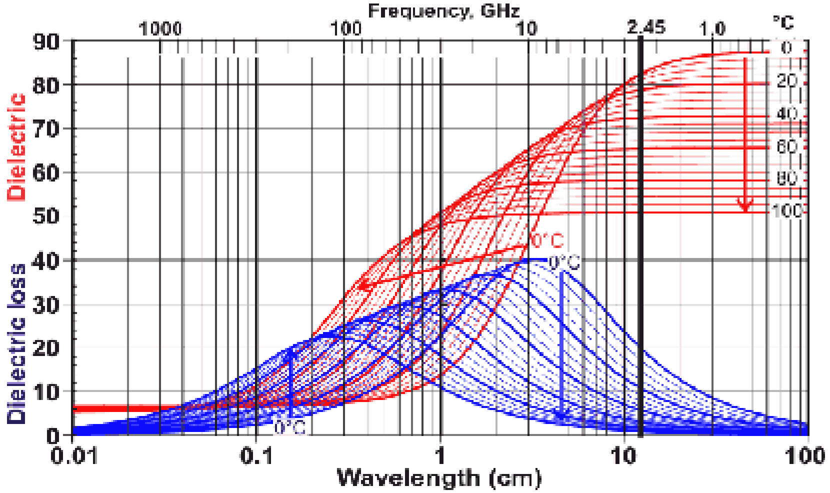
Measure moisture content of critical material behind outer cladding or interior surface

- Some materials are transparent to microwaves
- Microwaves interact with moisture!

Microwave ovens “jiggle” water at 2.4-2.5 GHz which heats the water

What is the ideal frequency for a moisture detector?

Absorption of microwaves by water



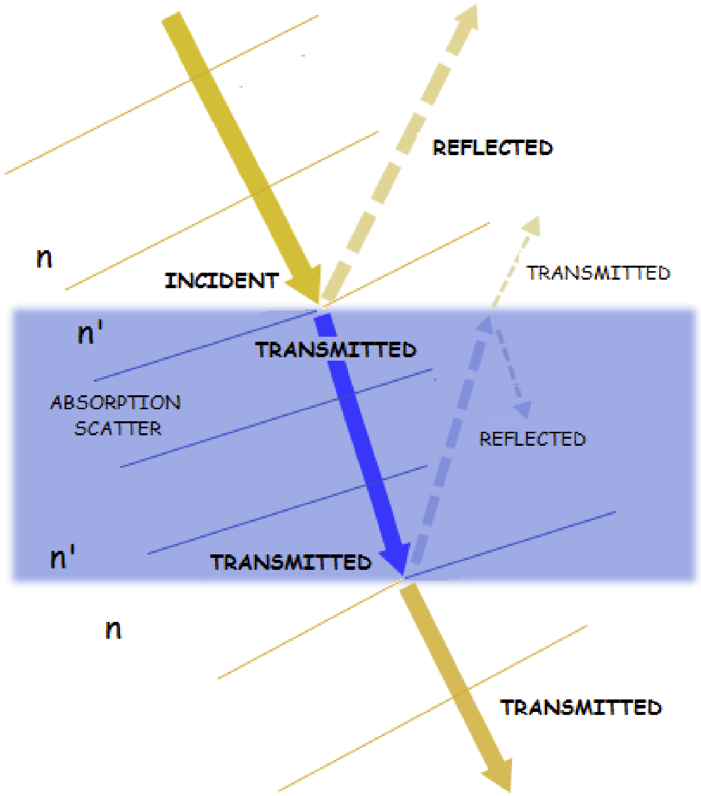
By Martin Chaplin - http://www.lsbu.ac.uk/water/microwave.html, Fair use, https://en.wikipedia.org/w/index.php?curid=37563254

Characterize microwave interaction with building materials

Determine frequency dependent absorption (A), reflection (R) and transmission (T) for building materials

$$A = 1 - R - T$$

- Find optimum frequency
- Determine which materials microwave can "see" through
- Determine if A, R or T change with moisture content in sheathing
- Investigate grain direction influence on A, R or T



Build and test microwave radar to measure moisture in envelopes

- Find optimum frequency that does the following:
  - Can see through cladding or drywall
  - Is sensitive to moisture content of wood
  - Is low power according to 47 CFR 15.509
- Correlate measured microwave reflection with moisture content.
- Test system with whole-wall samples in the lab with different wood moisture.
- Test system in the field

Frequency in MHz	EIRP in dBm
960-1610	-65.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	-41.3
Above 10600	-51.3

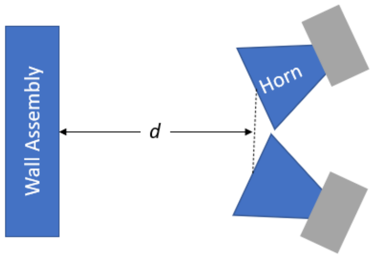
Power cannot exceed limits outlined by 47 CFR 15.509 “Technical requirements for ground penetrating radars and wall imaging systems.”

Progress: Microwave interaction with different materials

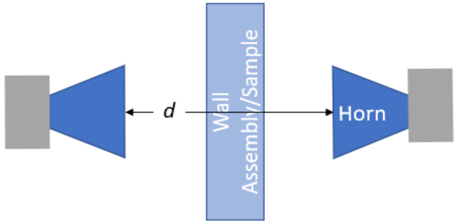
Measured Reflection (R) and Transmission (T) signal strengths for various materials at 5.8, 24 and 60 GHz.

- Outer wall layers – Vinyl Siding, Brick, Drywall
- Inner wall layer – fiberglass insulation, wet and dry oriented strand board (OSB), wet and dry solid wood

Reflection



Transmission



Findings:

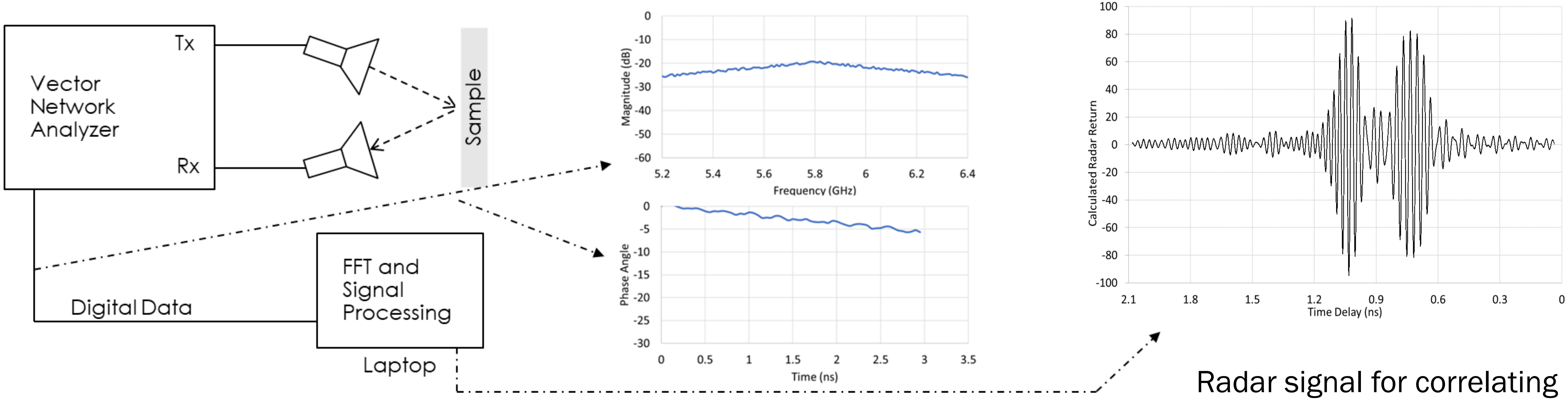
- Transmission of microwaves through drywall and vinyl is ~ 90%, favorable for non-destructive measurement of sheathing through these materials
- Transmission through brick is ~ 20%, NOT favorable for non-destructive measurements
- Absorption (A) of microwaves (A = 1 – R – T) varies depending on moisture content of OSB and solid wood
- Grain direction of solid wood impacts A, R, and T.

Initial material interaction tests show that there is promise for a microwave based non-destruction envelope moisture detector!

Progress: Microwaves can see sheathing behind drywall

Material/Microwave Interaction Findings: system Setup

System schematic



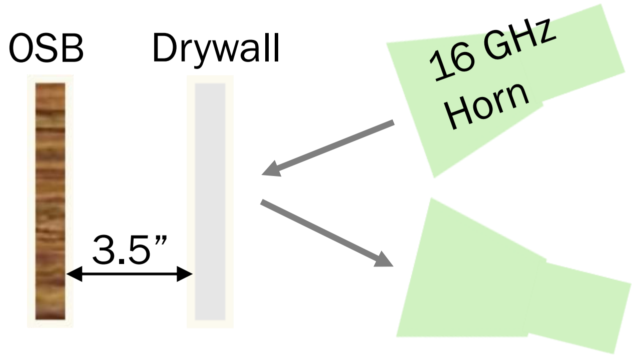
Radar signal for correlating to material moisture content

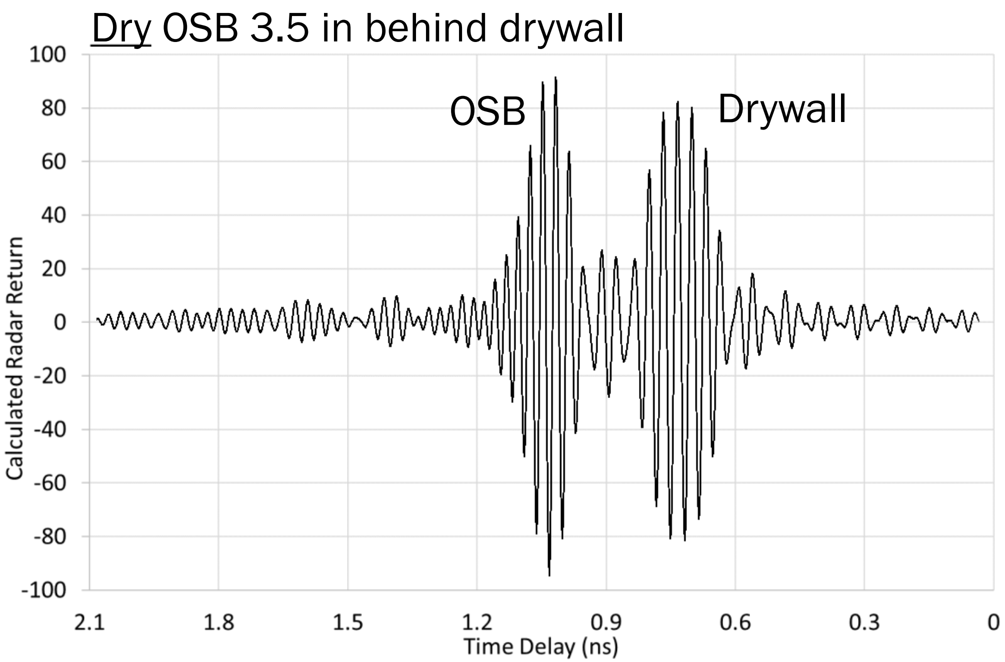
Progress: Microwaves can see sheathing behind drywall

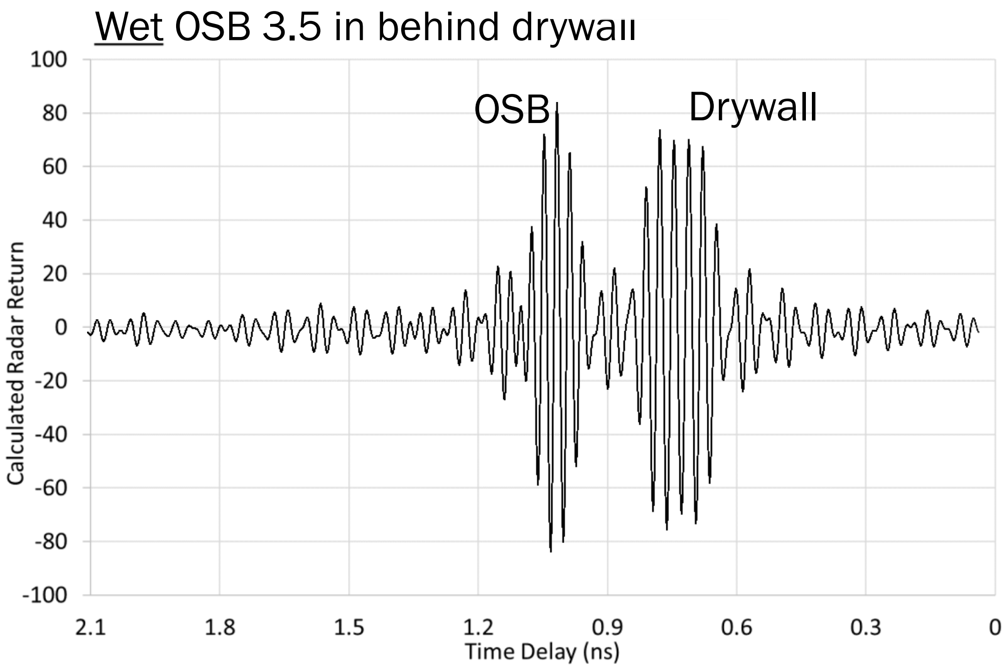
Material/Microwave Interaction Findings

Radar return signal can resolve drywall and sheathing layers in a wall with distinct pulses for each layer (required for non-destructive measurement). The higher the frequency, the higher the spatial/layer resolution.

Wet vs. dry OSB can be distinguished behind the drywall (see next slide).



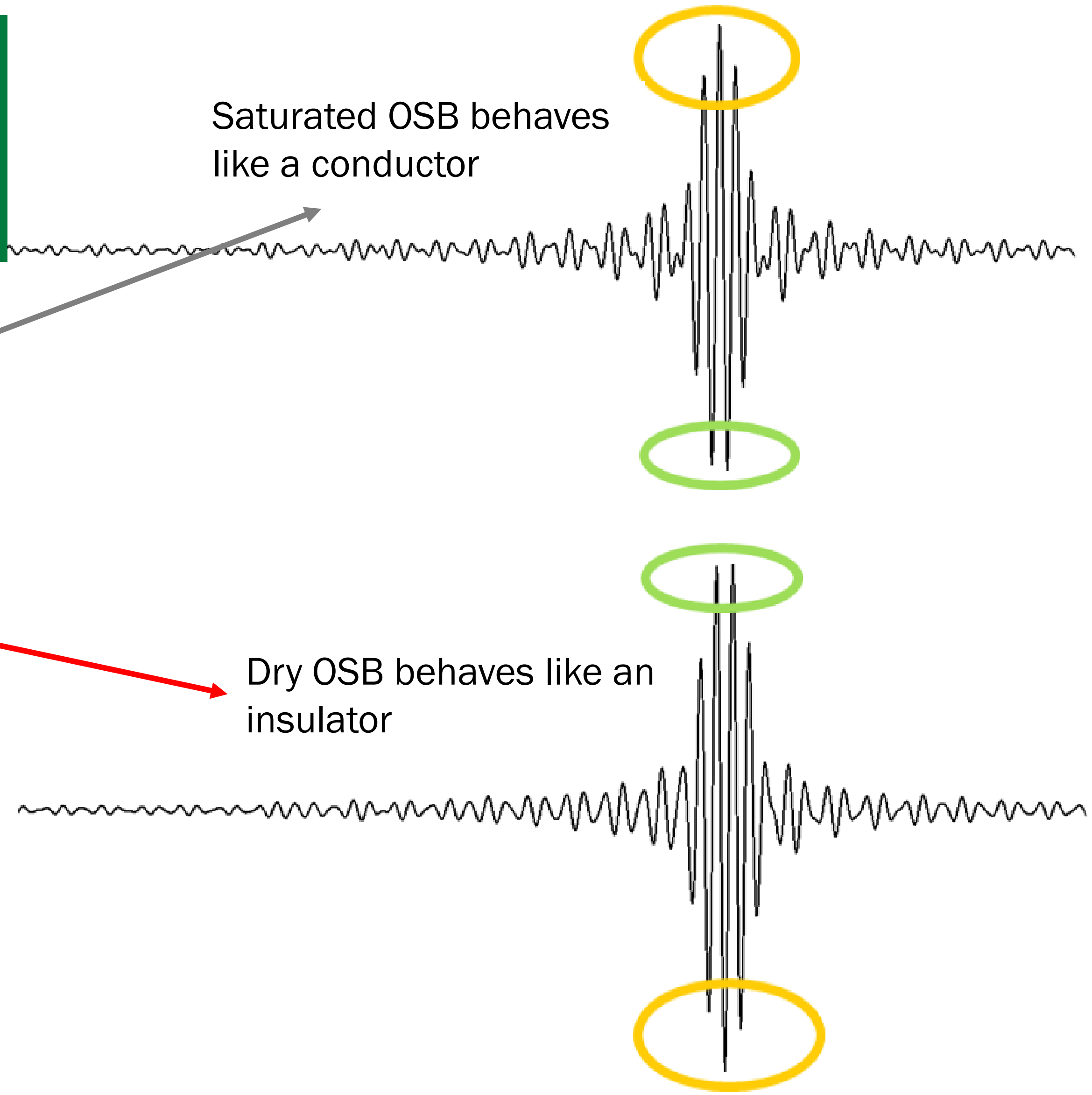




Progress: Reflection measurements change with moisture

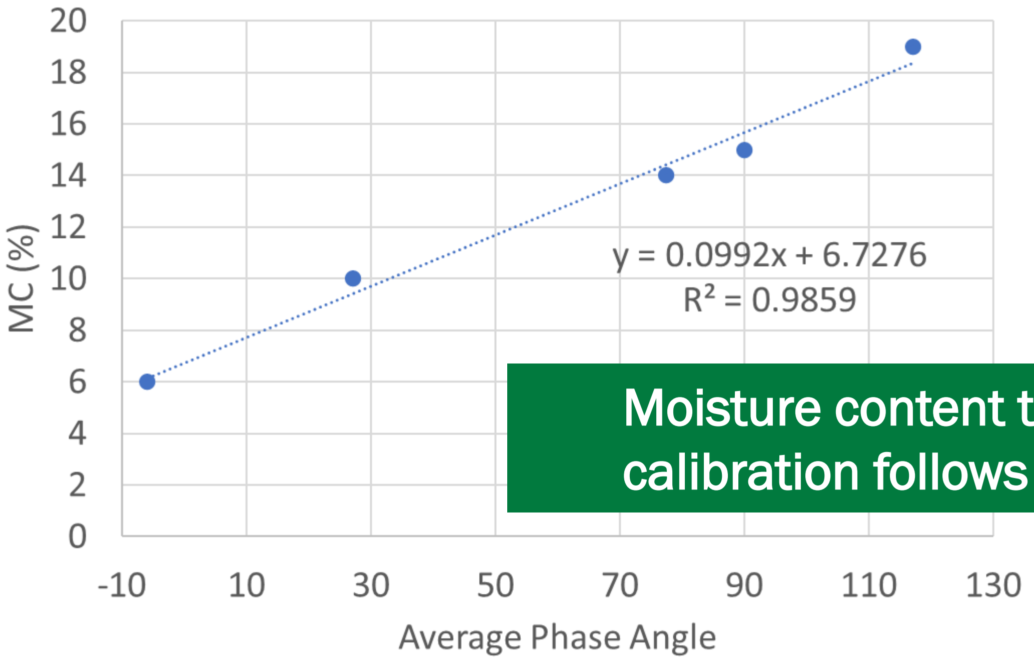
Waveform in the returned pulse from wood changes with moisture content and can be used to measure moisture content.

- A conductor has a reflection that is close to 0° out of phase – note the single peak at the top of pulse
- A dielectric (insulator) reflection is 180° out of phase – note the single peak at the bottom of the pulse
- This phase varies with the moisture of the wood and can be correlated to gravimetric moisture content for system calibration.



Progress: Measured phase can be correlated to moisture content

- Phase angle of return was measured at four rotational angles of front and back of OSB boards of differing moisture contents.
- OSB moisture content for each board was plotted as a function of average phase angle.



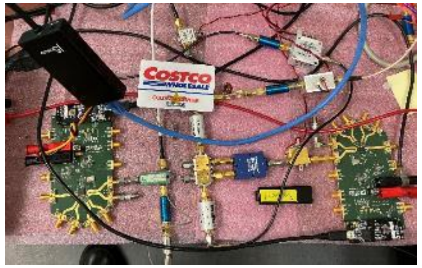
Moisture content to phase angle calibration follows a linear trend!

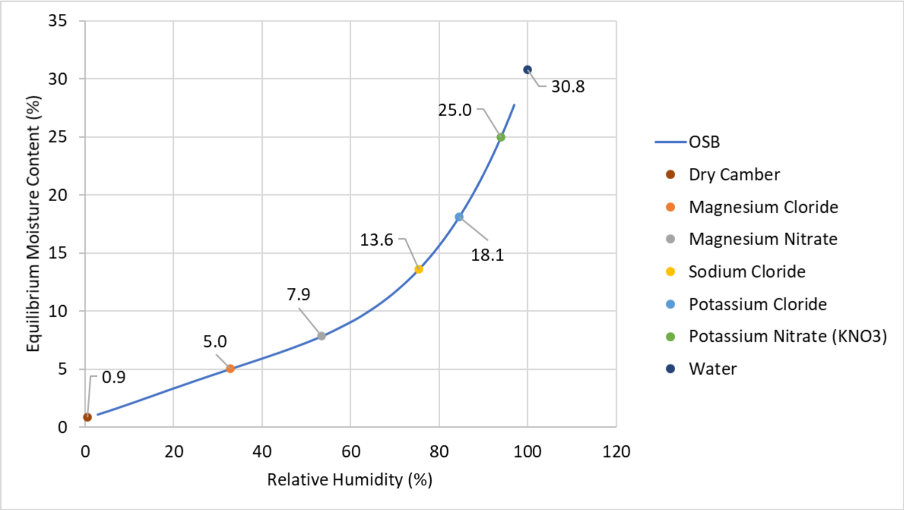
10-15.5 GHz System

Current/Future Work

- Determine optimum microwave frequency (investigate 24 GHz, which can better resolve wall layers)
- Develop system that is portable
  - Requires custom electronics and software
  - Cheaper than using a network analyzer
    - $500K → $4K
- Portable system: characterize OSB samples from 1%-30% MC and determine system accuracy with just wood and for wood behind drywall
- Conduct field trial and determine accuracy
  - Compare results (speed and accuracy) of using IR thermography and destructive moisture pin testing of in situ sheathing.

Miniaturized electronics





Challenges, Risks, Commercialization

Challenges and Risks

- Metal in walls scatter the microwave reflections so that moisture cannot be measured in these areas.
  - For pipe and wiring these areas can be avoided.
- Microwave frequencies and the FCC.
  - Use ISM bands, or low power according to 47 CFR 15.509
- Microwaves cannot see through some claddings like brick.
  - Measuring from the inside of the building could remedy this.

Commercialization

- Invention Disclosure #202305343 – “Non-destructive microwave radar moisture detector for durable building envelope retrofits”

Thank you

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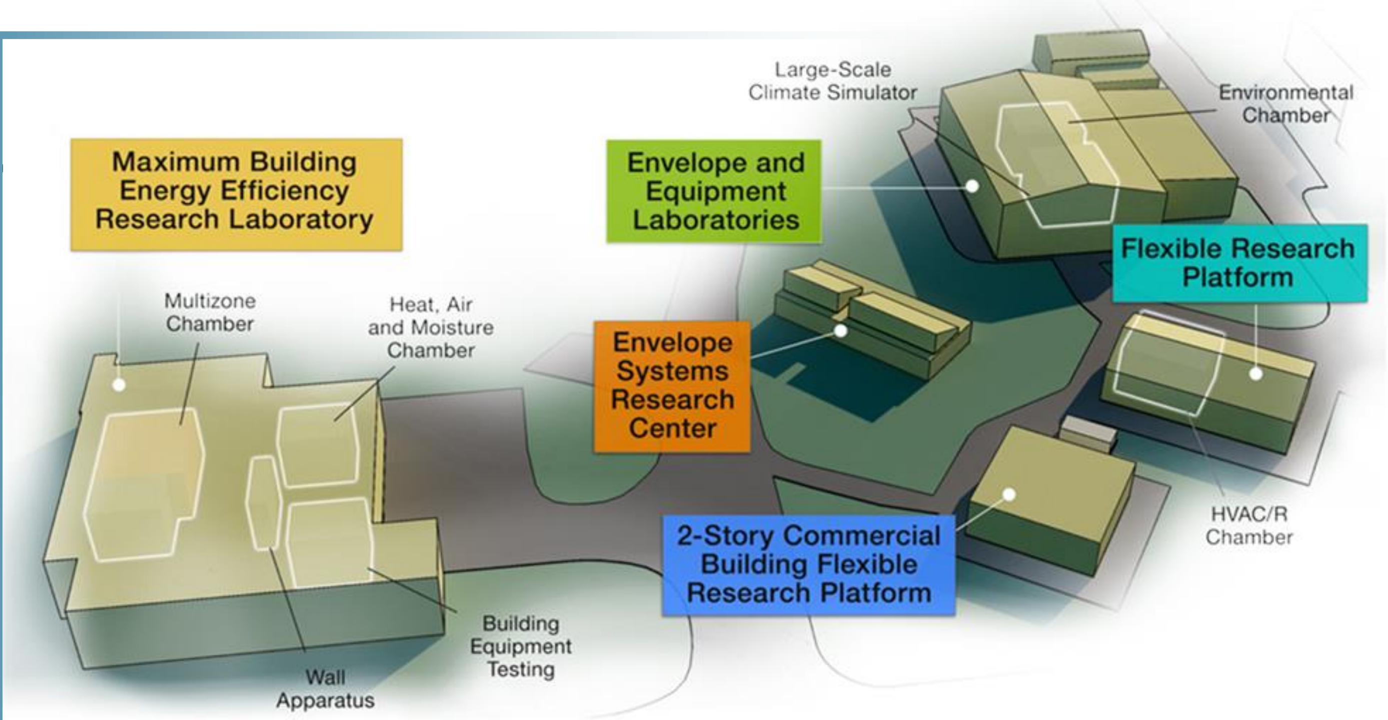

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results
236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned Budget	$250K				$300K				$300K			
Spent Budget	$235K				$137K				$---K			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
M1.3: Completed experimental setup for measuring microwave T and R.												
M2.1: Measured radar penetration depth as a function of wall type.												
M3.1: Summary of radar reflection magnitude as a function of material, etc.												
M3.3: Demonstrated measureable difference in reflected microwaves from wall assemblies of various MC.												
Current/Future Work												
M4.1: Develop software to measure return phase angle and correlate to MC												
M4.2: Measure MC at 16 GHz of multiple OSB samples between 1-30% MC with accuracy at ±5% of actual												
M4.3: Measure OSB MC at 60 GHz and compare results to 16 GHz												
M4.4: Build test stand for in-situ sheathing measurements												
M4.5: Using test stand measure MC of sheathing inside wall with accuracy of ±10% of actual												
M5.1 Secured suitable field test location												
M5.2 Measure MC of a portion of the envelope using IR thermography and electric resitance methods												
M5.3 Measure MC of portion of envelope with microwave method compare to 5.2 results												

Regular

Go/No Go

Team

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