Microwave Wood Moisture Sensors for Dry Kilns

William W. Moschler
Tennessee Forest Products Center
University of Tennessee

Gregory R. Hanson
Oak Ridge National Laboratory

T. F. Gee, S. F. Smith, J. B. Wilgen
Oak Ridge National Laboratory

Funding Sources

- Project funded by DOE through American Forest and Paper Association/Agenda 2020 Program and with support from industry partners.

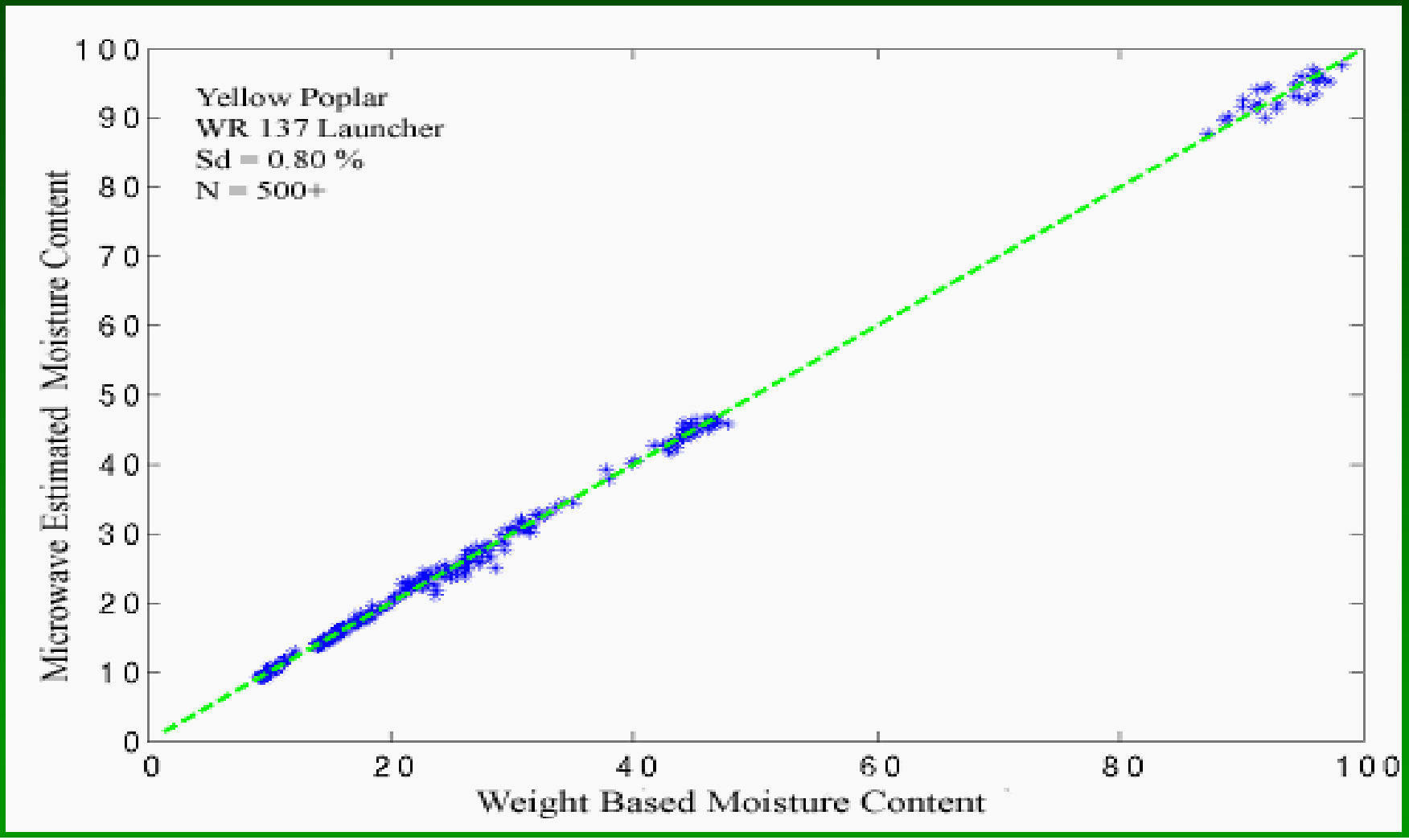
Industry Partners

- Doug Parent, *Communications and Power Industries, Inc.*, Los Angeles, CA
- Rob Girardi, *Kiln Drying Systems, Inc.*, Arden, NC
- Dave Straka, *Averitt Hardwoods*, Clarksville, TN
- Greg Hart, *International Paper*, Simpsonville, SC
- Eric Dobson, *Navigational Sciences, Inc.*, Charleston, SC

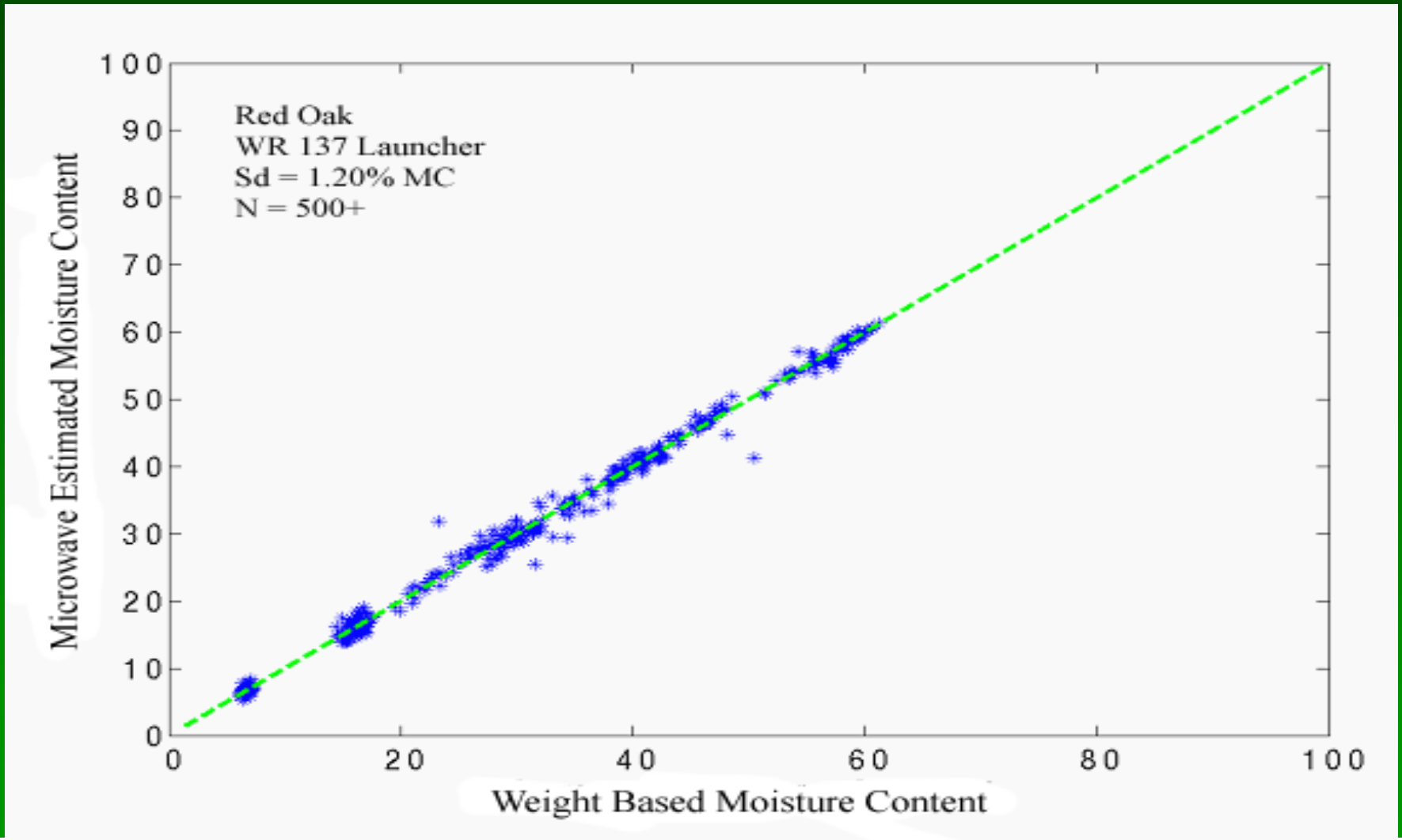
Project Accomplishments

- In this project we developed a microwave based moisture content measurement system that works on lumber over a range of 6% to over 100% moisture content.
- Two different designs of moisture content sensors were developed. One of these sensor designs will slip into the sticker space between the boards on a standard lumber stack.
- A battery powered prototype circuit board that works with the sensors to generate and to record the microwave signals for the sensors was designed, built, and tested.

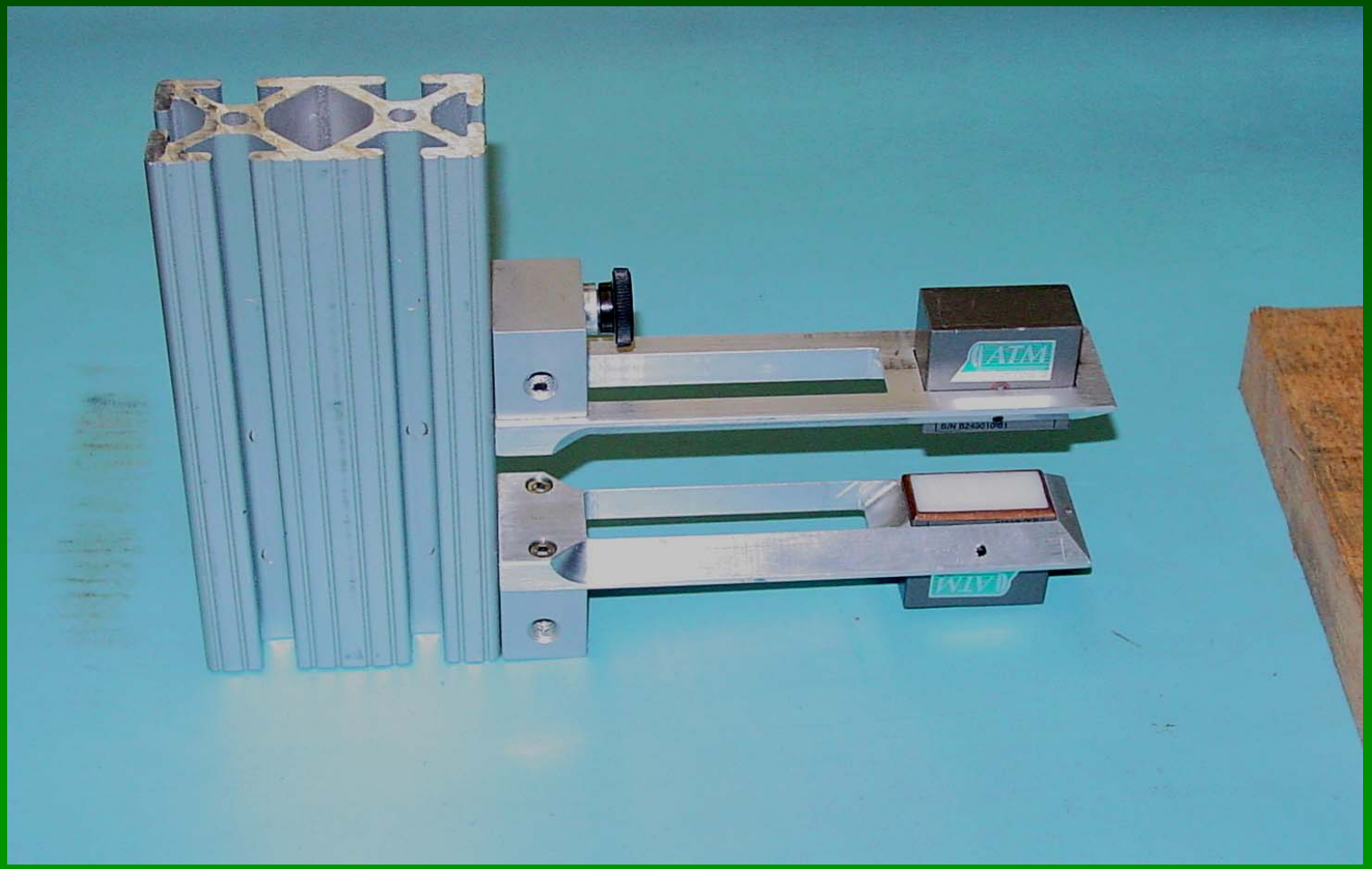
Sensor Test Results for Yellow Poplar



Sensor Test Results for Red Oak



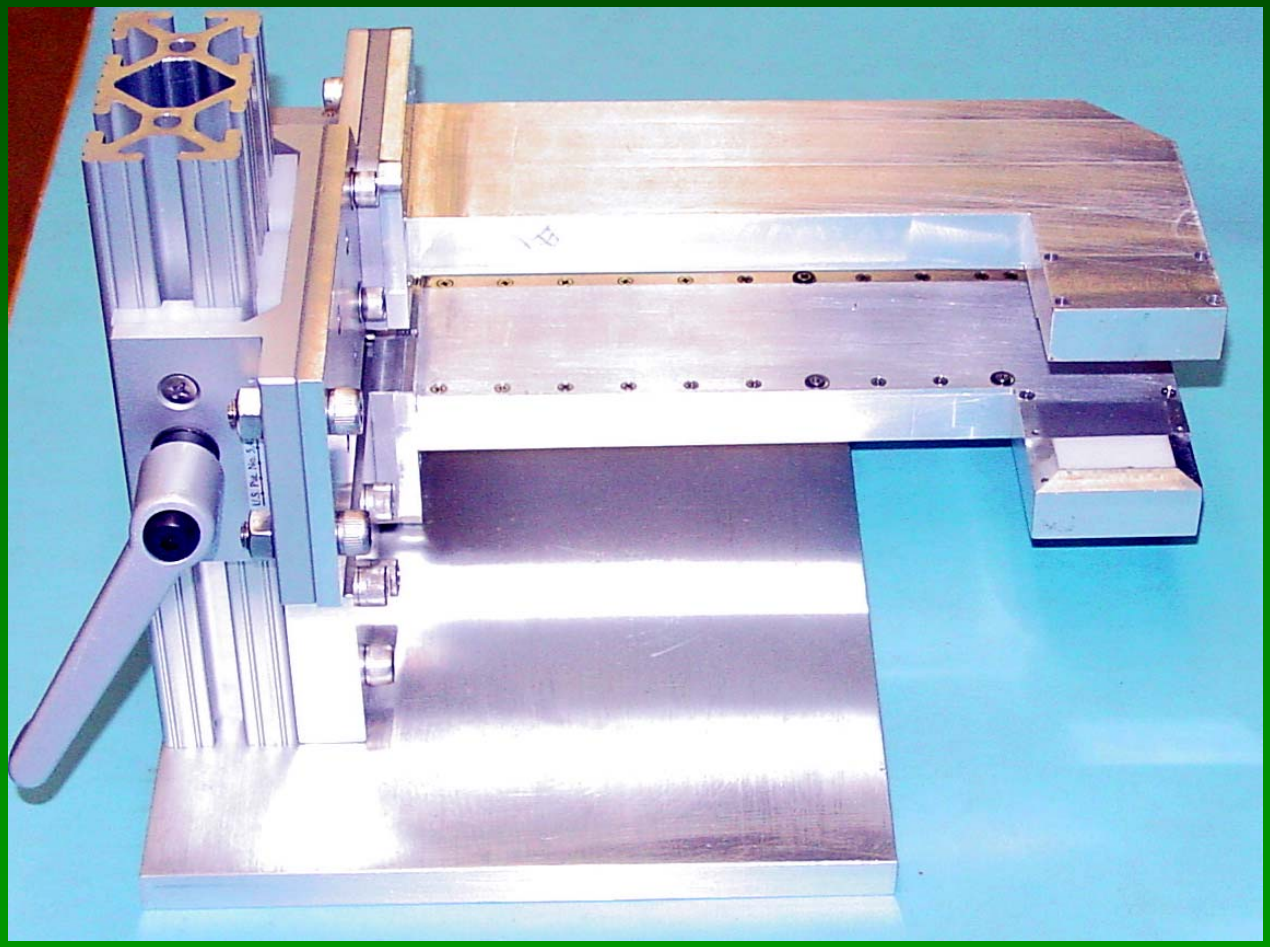
MC Sensor, Design 1, WR 137



Sensors, Design 1, Some Technical Details

- Both the launcher and the receiver are filled with a dielectric to match antenna to boards.
  - Filling minimizes reflections at surfaces for lower MCs (helps performance for dry boards)
  - Filling offers opportunity to seal the wave guide and launcher against the harsh kiln conditions.
- Sized for 4.5 to 6.0 GHz operation. Aperture cross section: 1.37″ x .62″
- Design strength: Works very well, cheap, easy to produce, small.
- Design fault: Height is 1.25″ - won't fit in standard 3/4″ sticker space

MC Sensor, Design 2, Folded, Tapered Wave Guide



Sensors, Design 2, Some Technical Details

- Launcher and receiver waveguide are filled with dielectric to match sensor to dry boards and to seal all internal surfaces against kiln conditions.
- Sized for 4.5 to 6 GHz operation. Aperture cross section: 1.37″ x .62″ Wave guide turns microwaves to allow long axis of aperture to be across the grain direction.
- Design strengths: Works well. Fits into standard kiln sticker space. Probably stronger and more durable than Design 1.
- Design faults: More expensive to manufacture than design 1. Could alter air flow pattern around sensor area.

Microwave Circuit Development

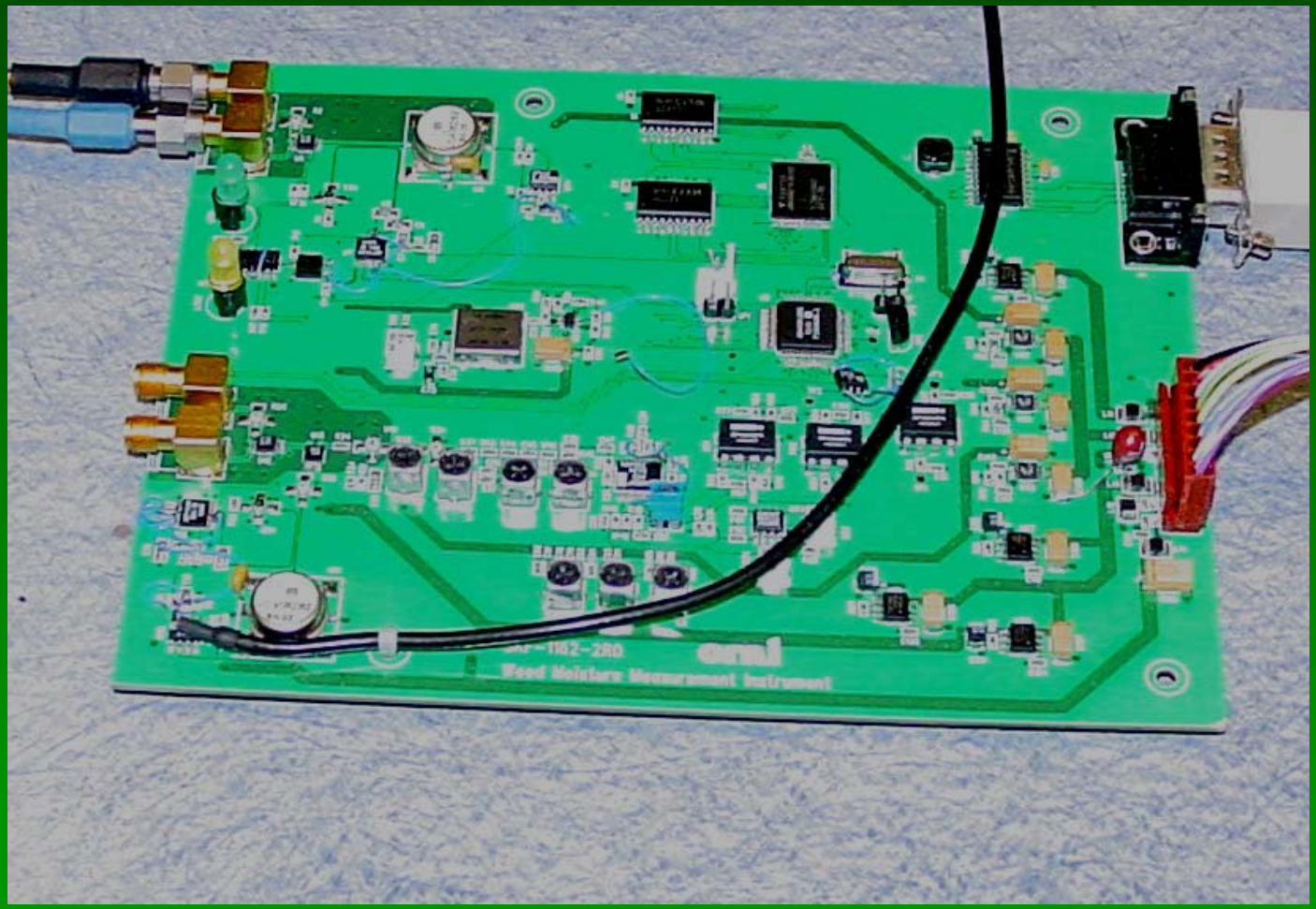
- The results from the sensor development phase of this project were encouraging.
- But during the development phase the sensors were activated and tested with a commercial vector network analyzer.
- Commercial network analyzers cost in the neighborhood of $25,000 to $75,000. Commercial network analyzers are a laboratory instrument and will not work in a dry kiln (an assumption).
- In order to utilize the sensors developed we had to develop a small, relatively inexpensive, battery powered substitute for the network analyzer.

This Probably Will Not Work in a Kiln?

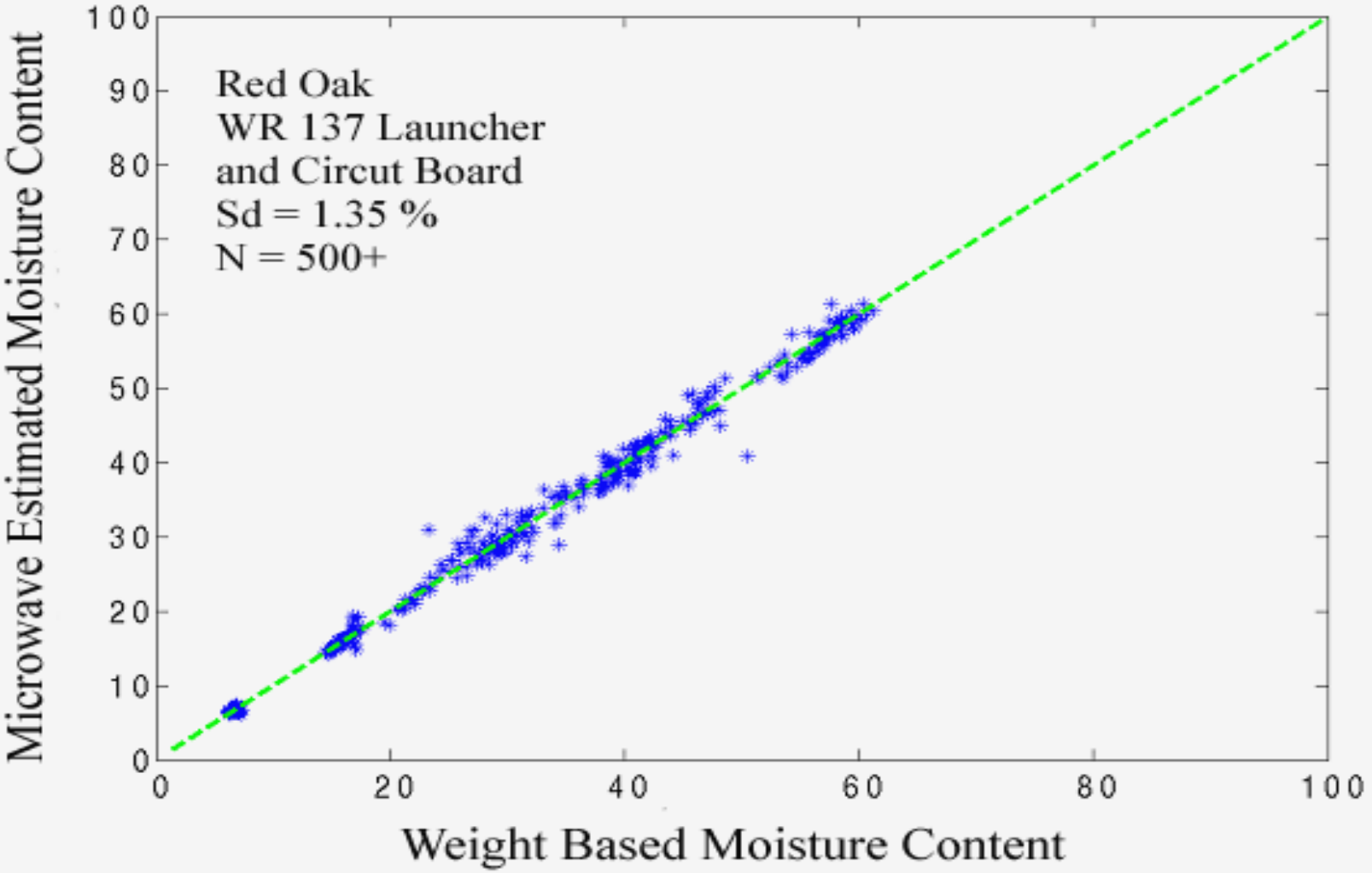
Microwave Moisture Measurement

- A microwave signal is generated by the electronics and transmitted from the launcher to the receiver. The electronics record the signal transmitted through the lumber.
- The microwave signal is swept over a frequency of 4.5 to 6 GHz. The complete transmitted spectrum is recorded by a computer connected to the receiver.
- By using selected information from both the amplitude the phase change of the transmitted signal, moisture content can be measured relatively independently of lumber specific gravity.

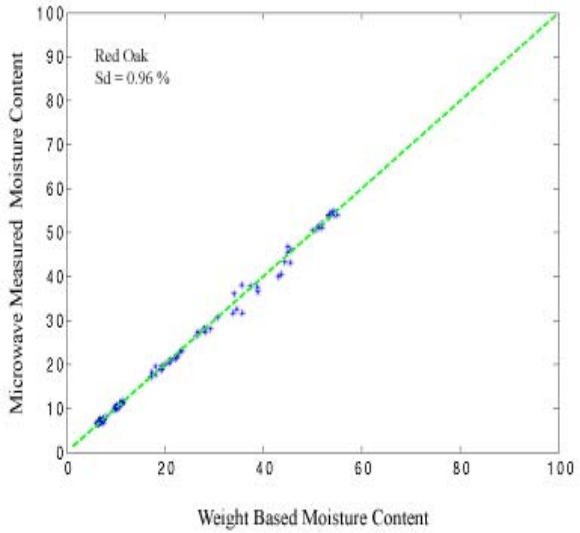
Prototype Microwave Electronics Board

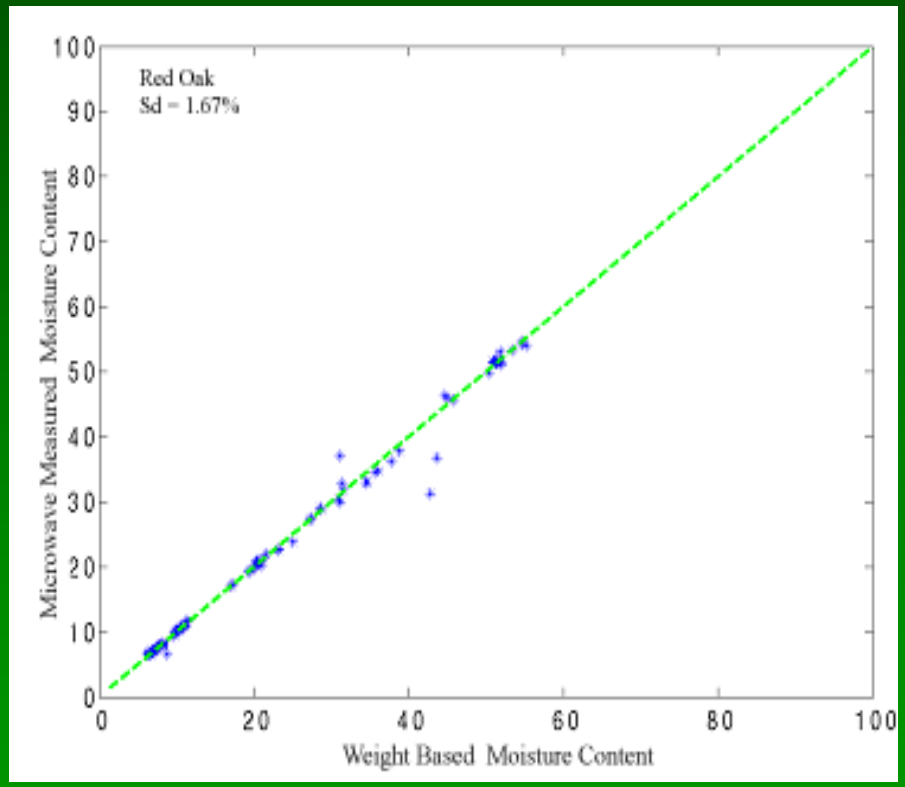


Complete MC System Results for Red Oak



We randomly held out 20% of the data. We "trained" the analysis algorithm on the other 80%of data. Then we used the algorithm to estimate the moisture content on the remaining 20% of the data.





Microwave Circuit Design Highlights

- The interferometer based design uses two synthesizer-controlled voltage-controlled oscillators (VCOs). One VCO provides a fast-settling stepped-sweep signal for 4.5-6.0 GHz. Second VCO is offset at 70MHz to provide local oscillator for superheterodyne receiver.
- The circuit uses microwave switches and a coaxial by-pass calibration loop to perform drift and temperature compensation for each measurement.
- The circuit incorporates a onboard microprocessor with built-in DAQ to control microwave frequency stepping, to record the data spectrum, and to do initial data processing

Microwave Circuit Design Highlights

- Our prototype circuit board is battery powered and is designed so that it can be potted in epoxy and located in the kiln. Maximum temperature tolerance of the components is 82 degrees C.
- The board is built from communications-grade microwave components to minimize cost.
- Incorporates electronic temperature measurement for temperature correction of MC measurement.

Further Work

- Our present prototype electronics operates in the range of 4.5 to 6 GHz. We cannot use this frequency range for commercially produced sensors. The FCC has 2 forbidden frequency bands in this range.
- Low power microwave application operation is allowed in the 5.46 – 7.25 GHz band. We have available a simplified circuit design that was built and tested for another project design. We can most likely build a circuit in the 5.46-7.25 GHz band that is cheaper than the present design and that will perform as well for this application.

Further Work

- Our estimate is that it will cost about $50,000 for design, build, and test a new circuit board (4 th generation board for this project) and to resize the sensors for the higher frequency.
- At that point we will have a complete moisture measurement system that will be a good basis for a commercial hand held meter and a commercial lumber scanning system that will work on both green and dry lumber.
- Further design and testing will be required to marry the sensors and circuit board into a neat package that can be used to dry lumber in a kiln.

Wireless Communication

- The sensors and circuit board system were designed from the start so as to be compatible with a future wireless communications system. Such issues as efficiency of use of microwave power, battery life, the ability to "sleep" and to wake up and make measurements at intervals, and on board data storage have been addressed in the basic design.
- Preliminary tests of wireless communication have been conducted in a kiln. These tests indicate that, while a kiln is a tough environment for low power communications, that such communications can be reliably performed.

Questions and Comments?