Improved Magnetic Sensor for Oil and Natural Gas Well Logging

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Team roles

Marion: Team Lead

Circuit simulation, resonance measurements, materials research

Matthew: Documentation

Uniform magnetic field design, reports

Elizabeth: Webmaster/Communications

Signal/data processing, web page design

Motivation of project

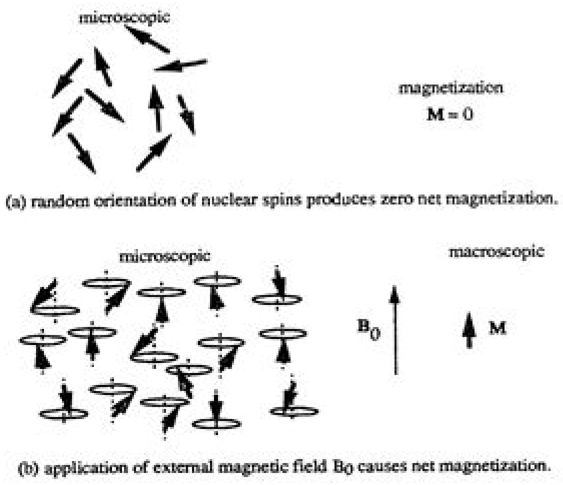
Motivation: Reduction of unwanted resonances (additional signals) of magnetic core used in the inductive sensor used for Oil and Natural Gas Well Logging

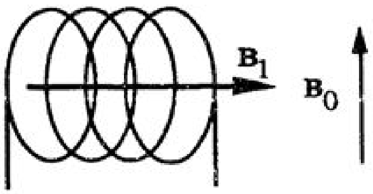
Project objectives:

- Produce a low magnetic field sensor
- Identify source of unwanted resonances in magnetic core of sensor
- Redesign measurement setup to include uniform external magnetic field
- Automation of signal processing

Background NMR Spectroscopy

- Permanent magnet induces a static magnetic field which magnetizes materials in underground formation
- When a perturbing external RF field is induced in an orthogonal direction, causes change in the spin states
- When the field is removed, it relaxes the spin states creating an RF signal at the resonant frequency of the spin flip
- Soft magnetic core in inductive sensor captures the EM to recreate the RF signal at spin flip





S.Sgobba, Proceedings-CERN Yellow Report, CERN-2010-004 39-63

Requirements

Functional

- Soft magnetic properties
- Rod-like geometry
- Reduce unwanted resonances
- Low hysteresis losses
- Uniform magnetic field of 400 G encompassing length of ferrite core

Non-Functional

- Must be one of the materials currently being explored by the client
- Preparation onsite at Client’s lab, Ames Lab or the Microelectronic Research Center (MRC)

Constant Magnetic Field

Problem

- Induces static magnetic field in the core material
- Magnetizes materials in underground formation
- Produces small amount of spin polarization in particles in formation
- Orthogonal magnetic field can disturb magnetic equilibrium
- Change in equilibrium governed by properties of formation and can be measured
- 400 Gauss allows the probe to have a wide detection range including both oil and water resources

Simulations

- All simulations done with COMSOL Multiphysics
- COMSOL simulates in SI units, input and output requirements in CGS
- Simulated magnetic field: $B = \mu * \mu_0 * B_{rmax}$
- Specific permeability: μ
- Permeability in free space: μ_0
- Magnetic remanence: B_{rmax}

Possible solutions

Solenoid:

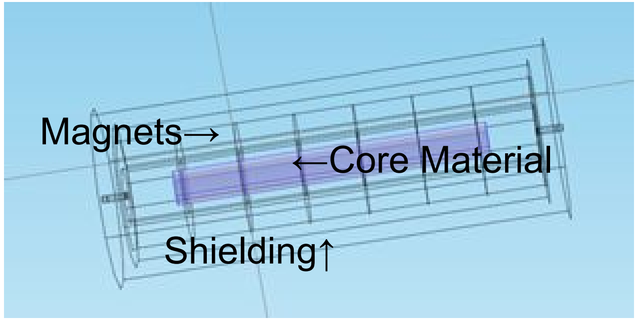
- Cheap, known, customizable with changes in current
- Turn density for small magnetic field low, uniformity unlikely

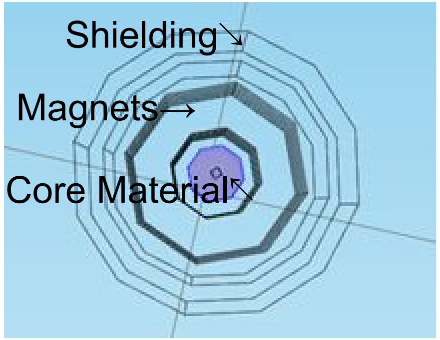
Permanent magnet:

- Uniformity can be assured
- More expensive, unknown solution, unique solution for each material

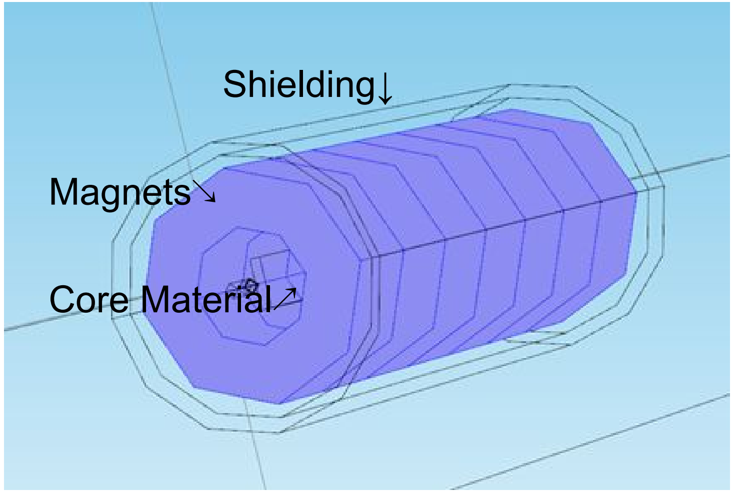
Material

- ISU Ferrite
- Cylinder placed in geometric center
- 5 & 3/8th inch height by 3/8th inch radius
- ISU Ferrite relative permeability: 225
- Other material simulated to a solution but not constructed
  - Limited by money
  - Limited by time
  - Limited by geometry of material





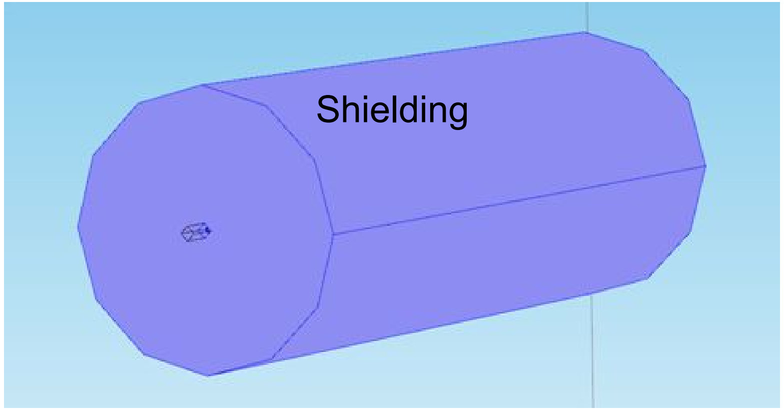
Magnets



- Neodymium Boron Iron (N 42)
- Relative permeability: 1.05
- Magnetic remanence: 13,000 Gauss
- Several stacked together
- Surrounds material as a hollow column
- 2 inch outer diameter, 1 inch inner diameter, 1 inch height

Shielding

- Giron
- Surrounds geometry as a cylinder
- Relative permeability: 7000
- Saturation: 20,000 Gauss
- Woven laminate material
- Flexible and cuts neatly
- 1 millimeter thick



Geometry

- Wire wraps around ISU Ferrite
- 1/16th inch hole in each end of shielding for wire
- Variables
  - Number of magnets stacked together
  - Space from end of magnets to shield lengthwise
  - Space from edge of magnets to shield radially
  - Thickness of Giron shielding (number of sheets)

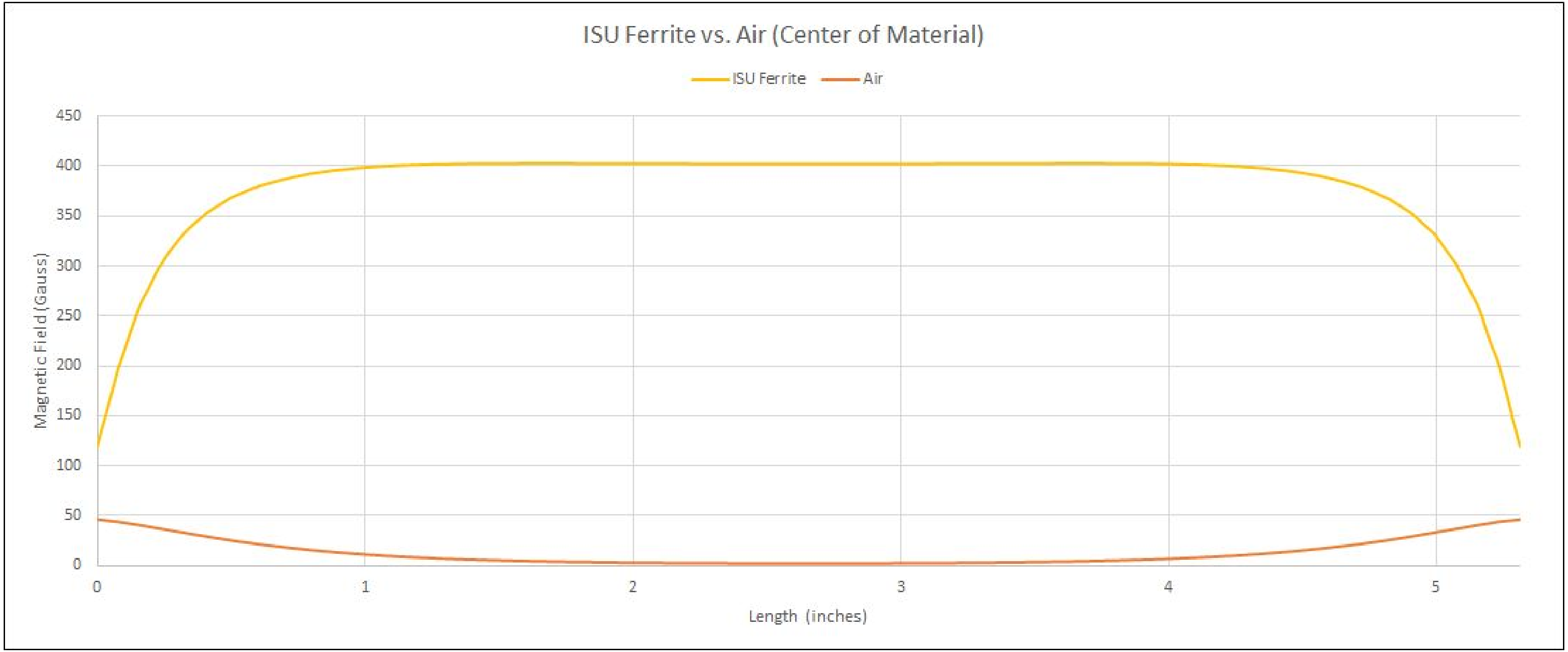
Simulation results

- All measurements compared with same geometry to air
- Linear magnetic field characteristics (Gauss vs. distance)
  - Length along center of material
  - Length radial width of material at geometric center out 1 inch
  - Length radial width of material at geometric center
  - Length radial width 1.25 inches from geometric center
  - Length radial width 2.5 inches from geometric center

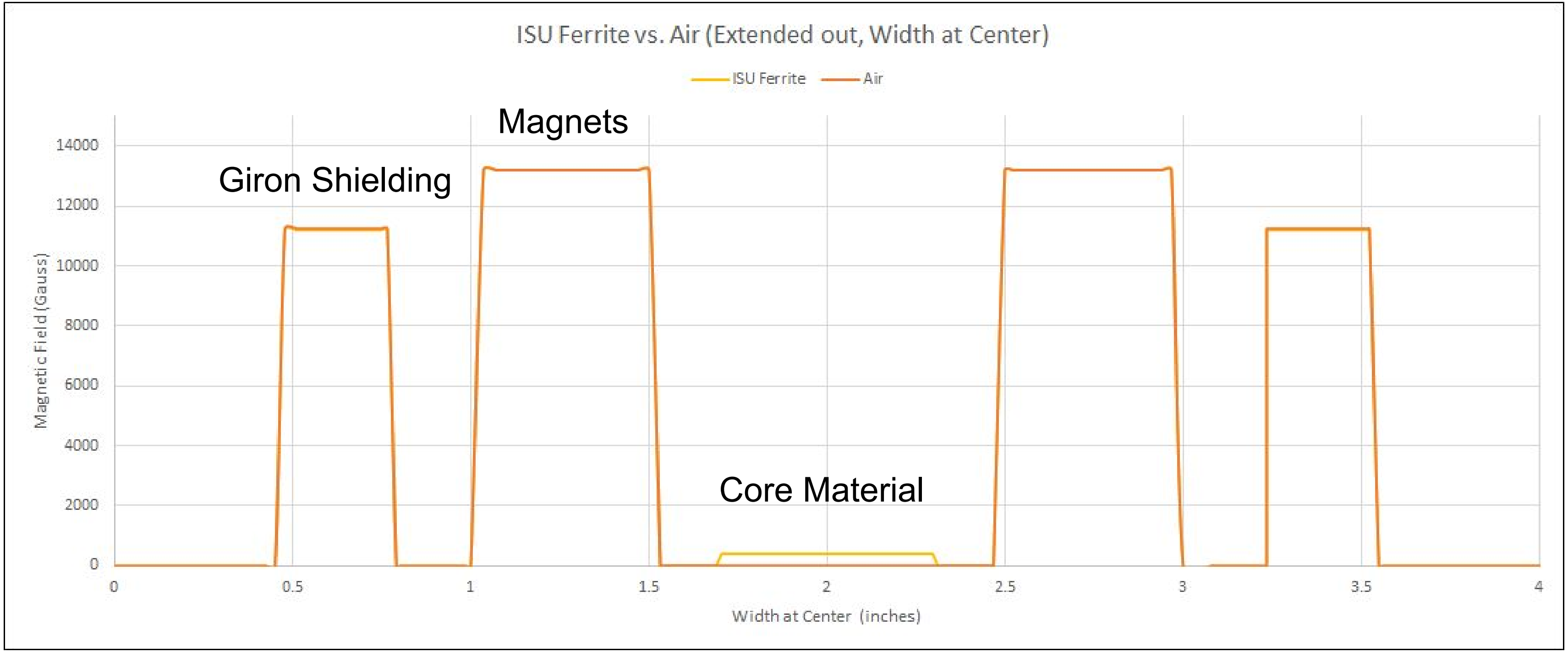
ISU Ferrite (constructed)

- 7 magnets
- 1/64th inch space from end of magnets to shield lengthwise
- 15/64th inch space from edge of magnets radially to shield
- Giron is 8 millimeters thick (8 sheets)

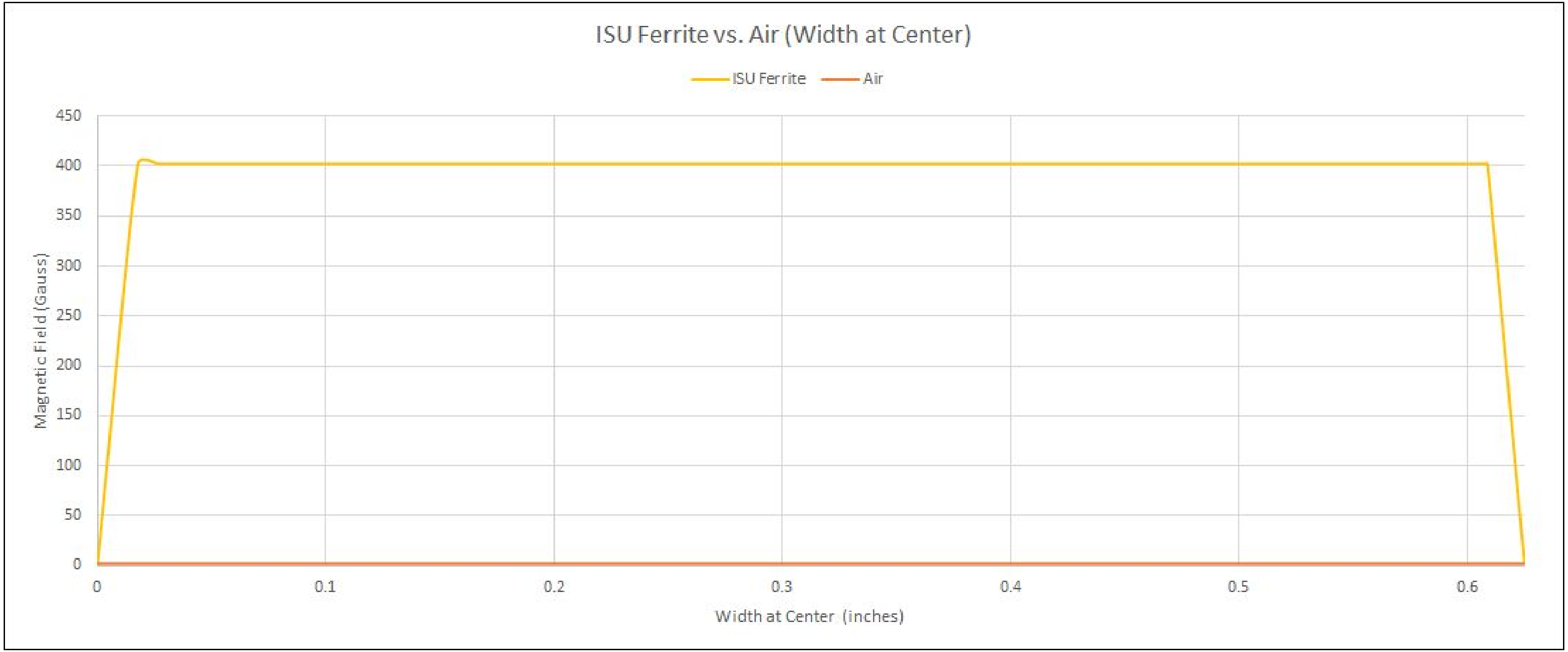
ISU Ferrite length along center



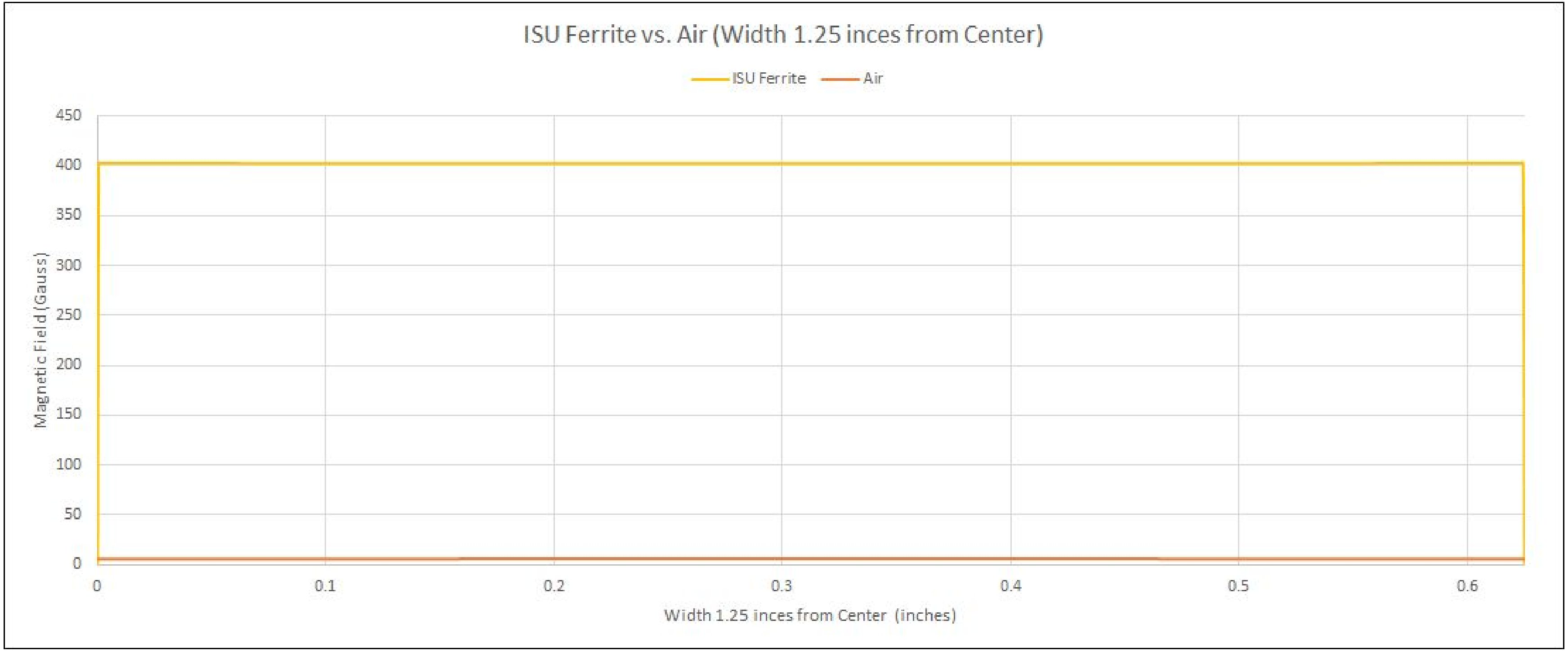
ISU Ferrite radial width at center out 1 inch



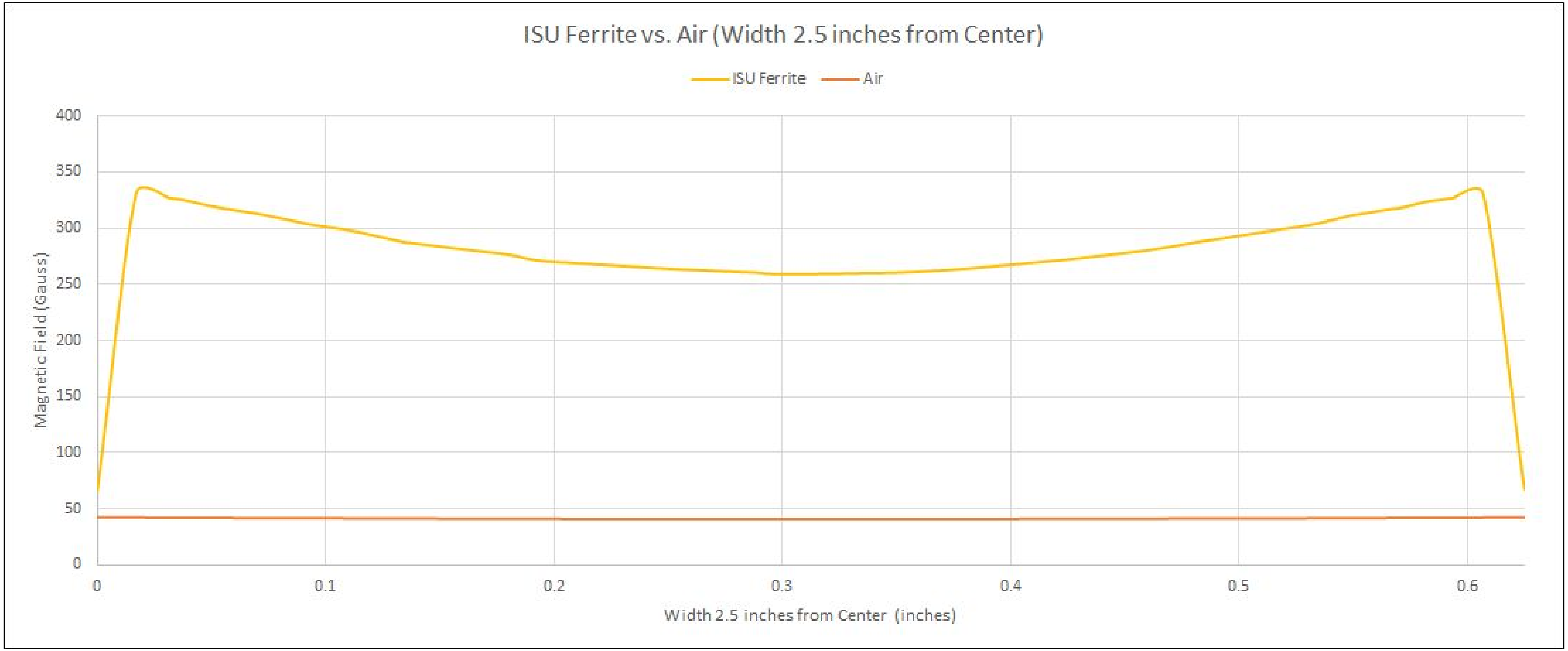
ISU Ferrite radial width at geometric center



ISU Ferrite radial width 1.25 inches from center



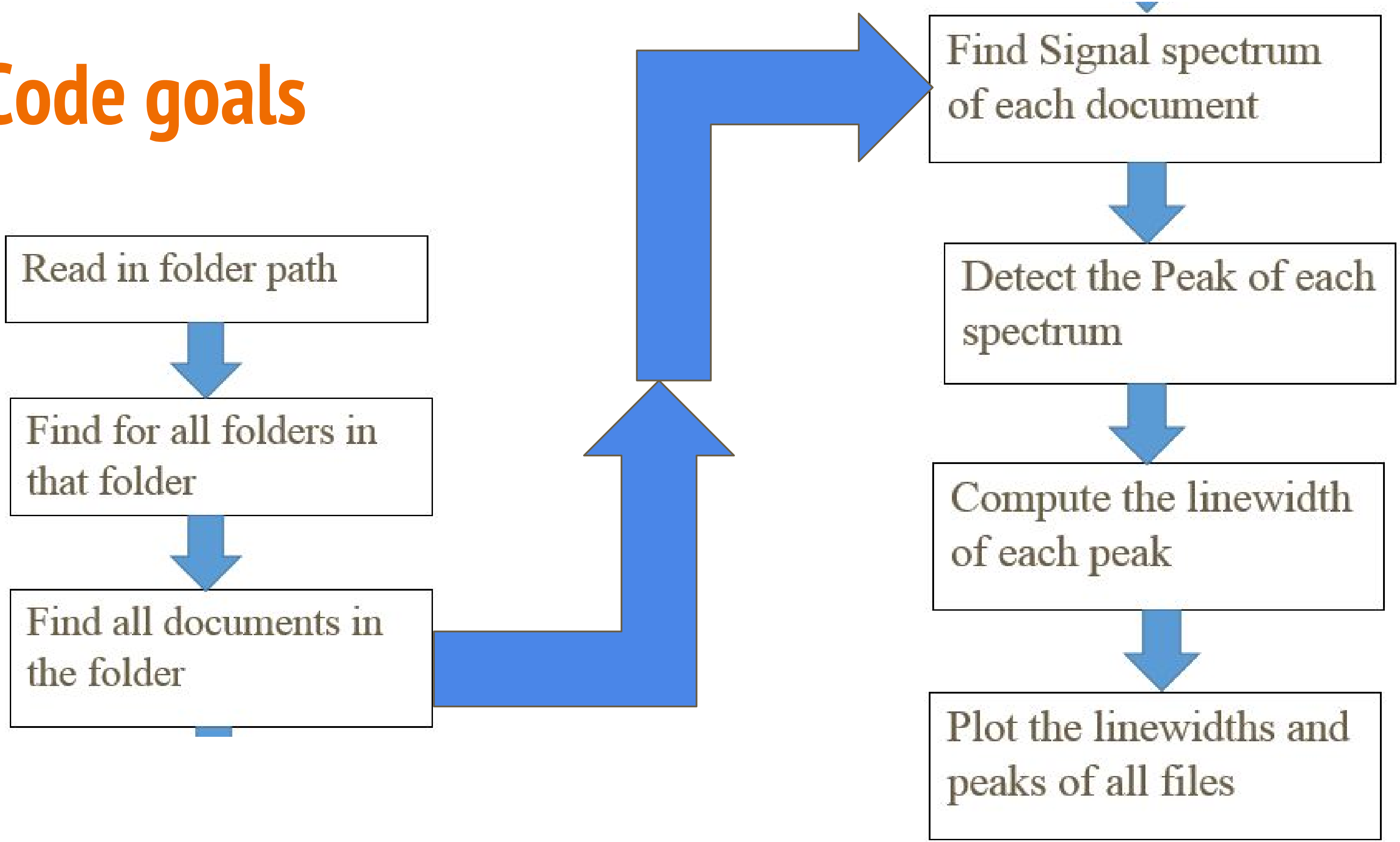
ISU Ferrite radial width 2.5 inches from center



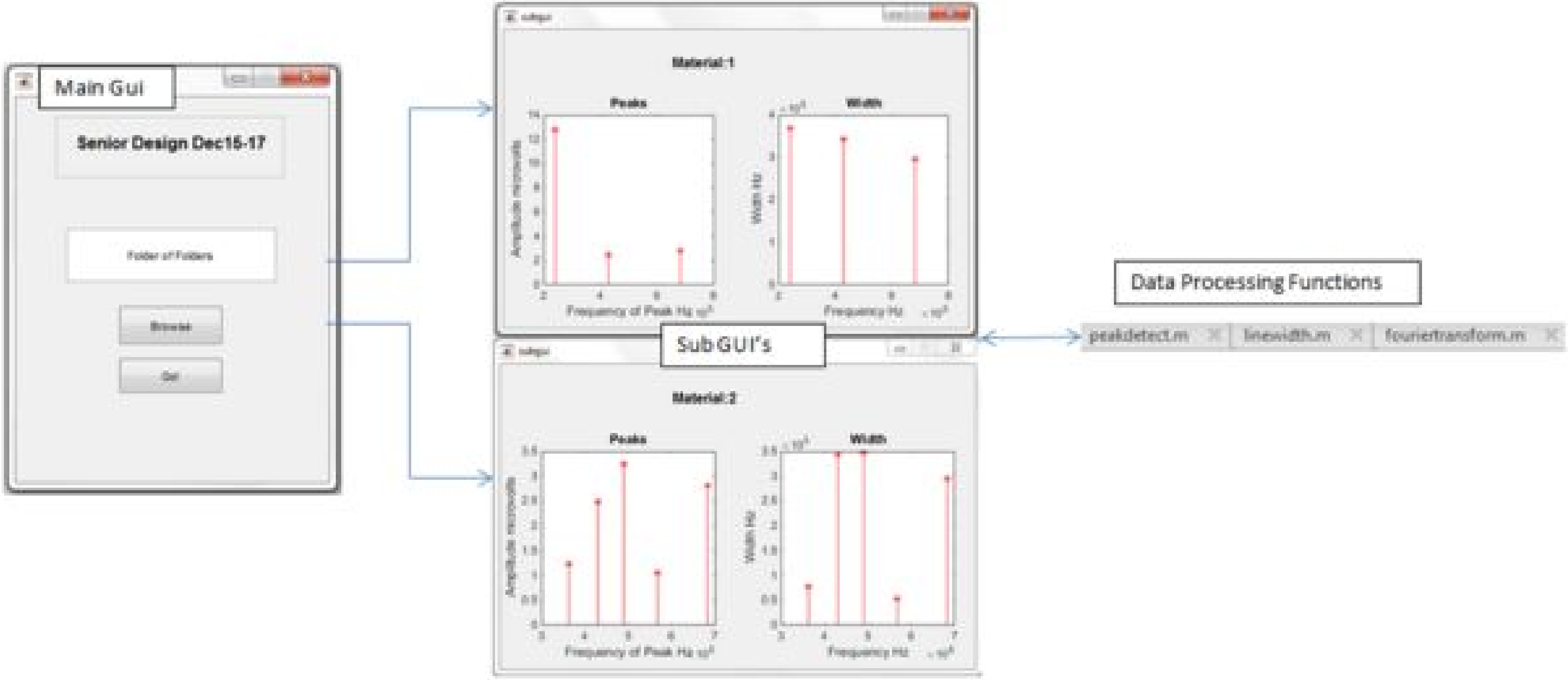
Purpose of Code

Many Measurements on many materials are done in this testing. The original method of data processing required the measurer to stay there and input each data set one at a time. With our new software the measurer inputs only the path to a single file and then is free to to do other work during the processing.

Code goals


Read in folder path
Find for all folders in that folder
Find all documents in the folder
Find Signal spectrum of each document
Detect the Peak of each spectrum
Compute the linewidth of each peak
Plot the linewidths and peaks of all files

Code structure

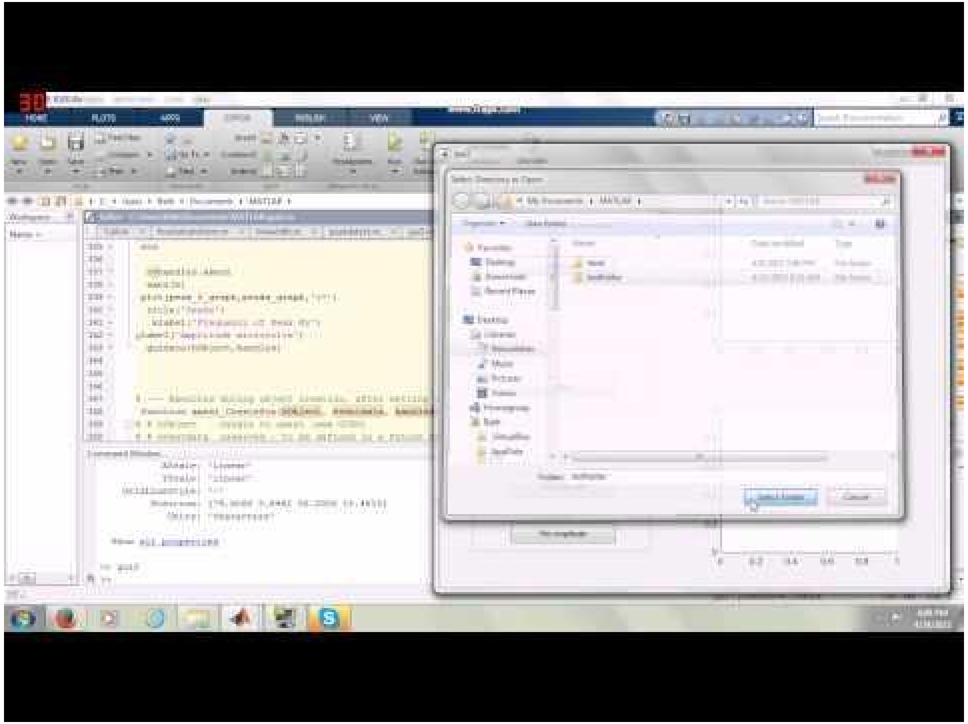


Code test plan

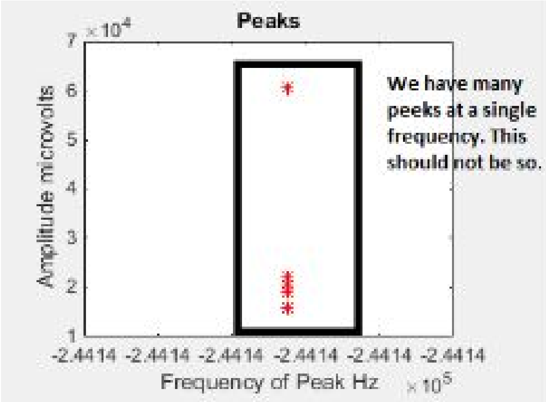
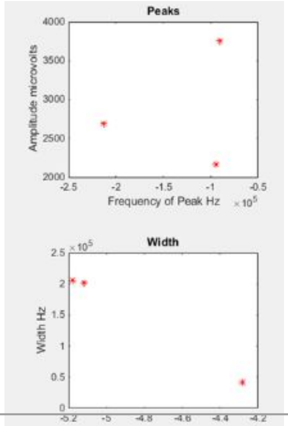
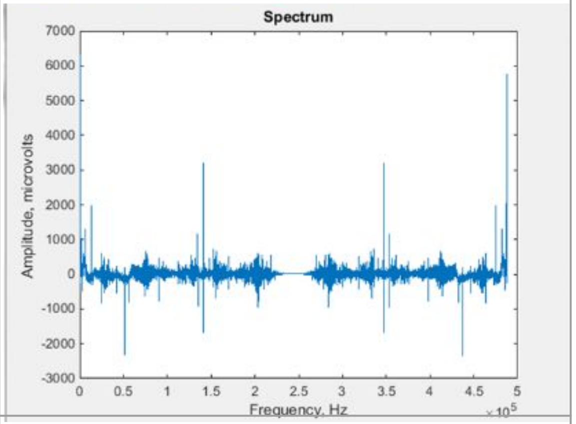
To test the results of this code, we run the code on a folder that has already been processed the slow way via the machine and compare the results.

Function	Test	Result
Create Graphical User Interface	Visual Confirmation	Good
Read in Folder Path	Typed in path and printed the resulting string to the screen	Good
Allow User to browse for a Folder	Browsed for a folder	Good
Determine all folders within Original Folder	Printed these to screen	Good
Call Graphical User Interface for each sub folder	Visual Confirmation	Good
Determine the files in the subfolder	Printed these to the screen	Good
Read in data from file an	Included a line that printed the values to the screen and looked	Good
Fourier transform data	Plotted the results of known data and compared to the existing plots	Good
Find all of the peaks	compared array of peaks to the plot	Good
Find peak closest to the impulse frequency	compared with previous processing of data sets	Good
Find the Half Width Maximum of the peak	compared with previous processing of data sets	Good
Iterate through all files in folder	Visual confirmation	Good
Plot the peaks of all files	Visual confirmation	Good
Plot the widths of all plotted peaks	Visual confirmation	Good
Create a file with all of the peaks	Visual confirmation	Good
Create a file of all the widths	Visual confirmation	Good
Iterate through all subfolders	counted graphs compared to number of subfolders	Good

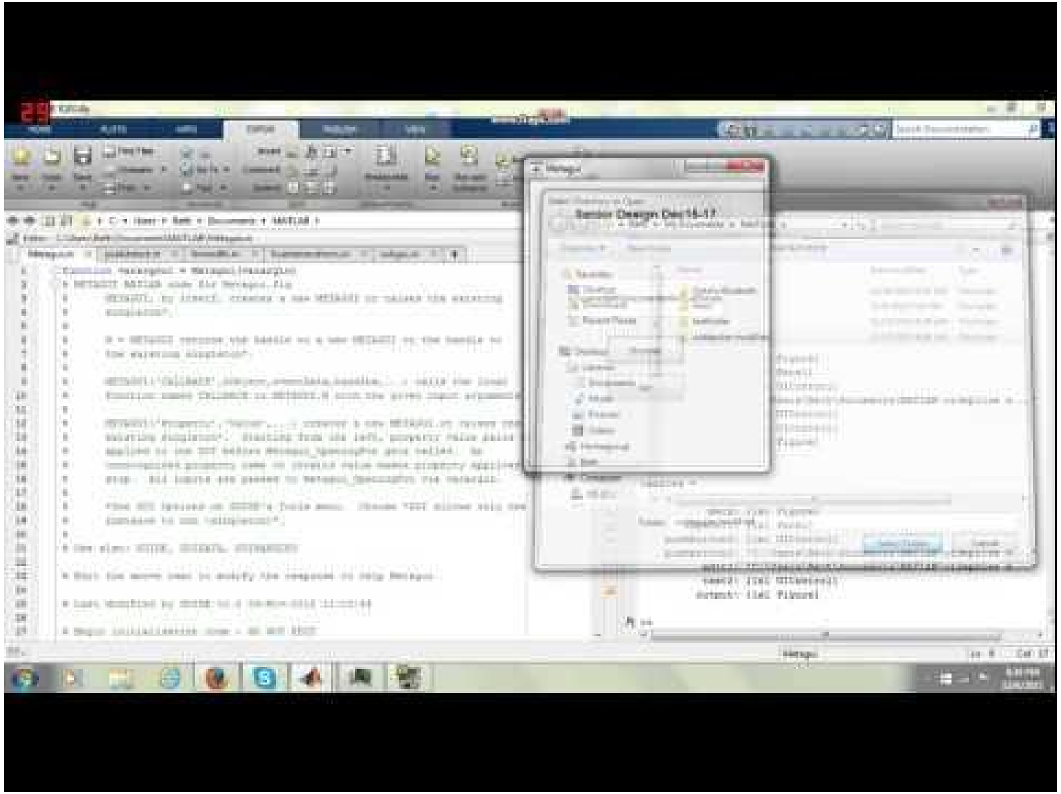
Code at the beginning of the semester



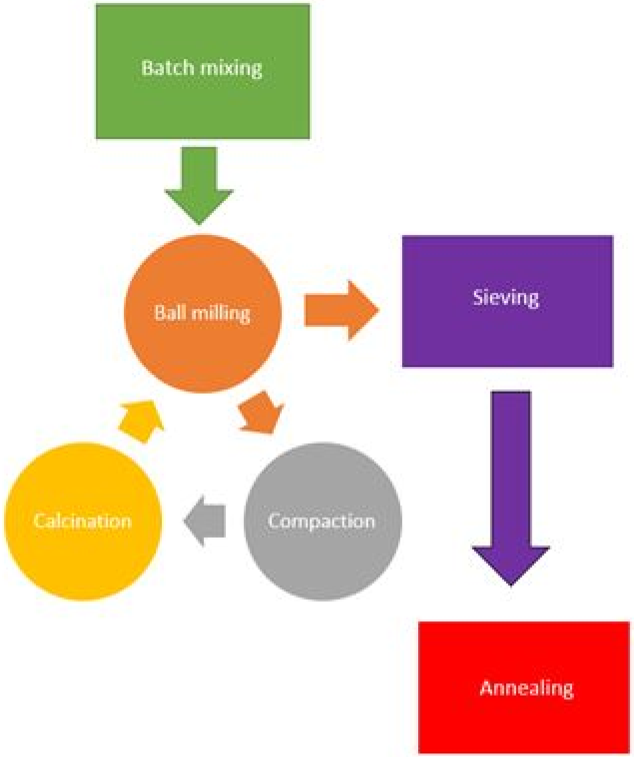
Code problems and solutions

<table>
<tr><td>Problem</td><td>All Peaks at the same Frequency</td><td>Different Frequencies for width and peak</td><td>Inaccurate Fourier Transform</td></tr>
<tr><td>Image</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Problem</td><td>Values not passed correctly between functions</td><td>Plotted side value instead of center value</td><td>Misinterpreted output of measurement equipment</td></tr>
</table>

Current Code



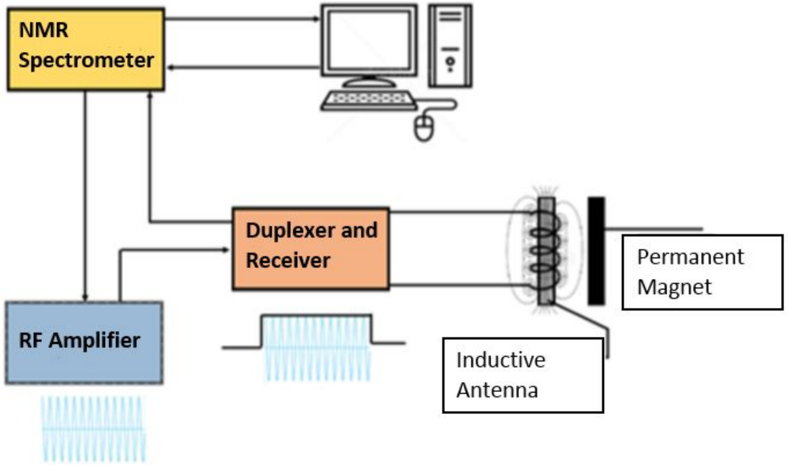
Sample preparation

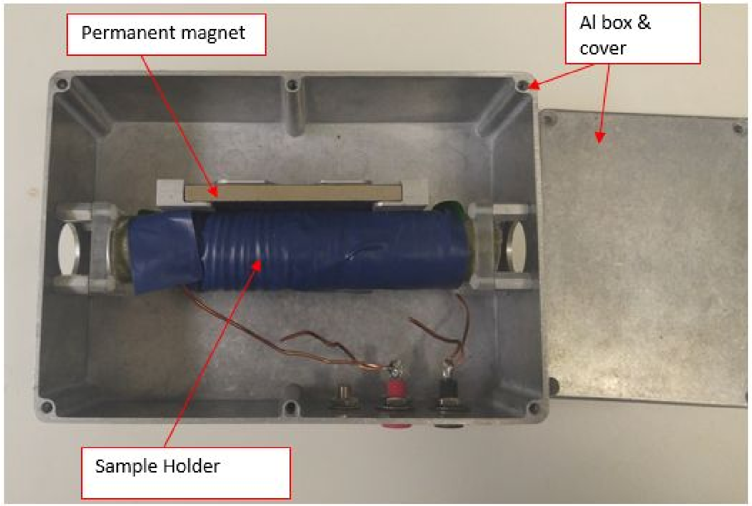


- First sample is ISU Ferrite
- Sample to epoxy ratio 25:75
- Calcination at 1050 - 1100 ºC
- Two phase microstructure with annealing

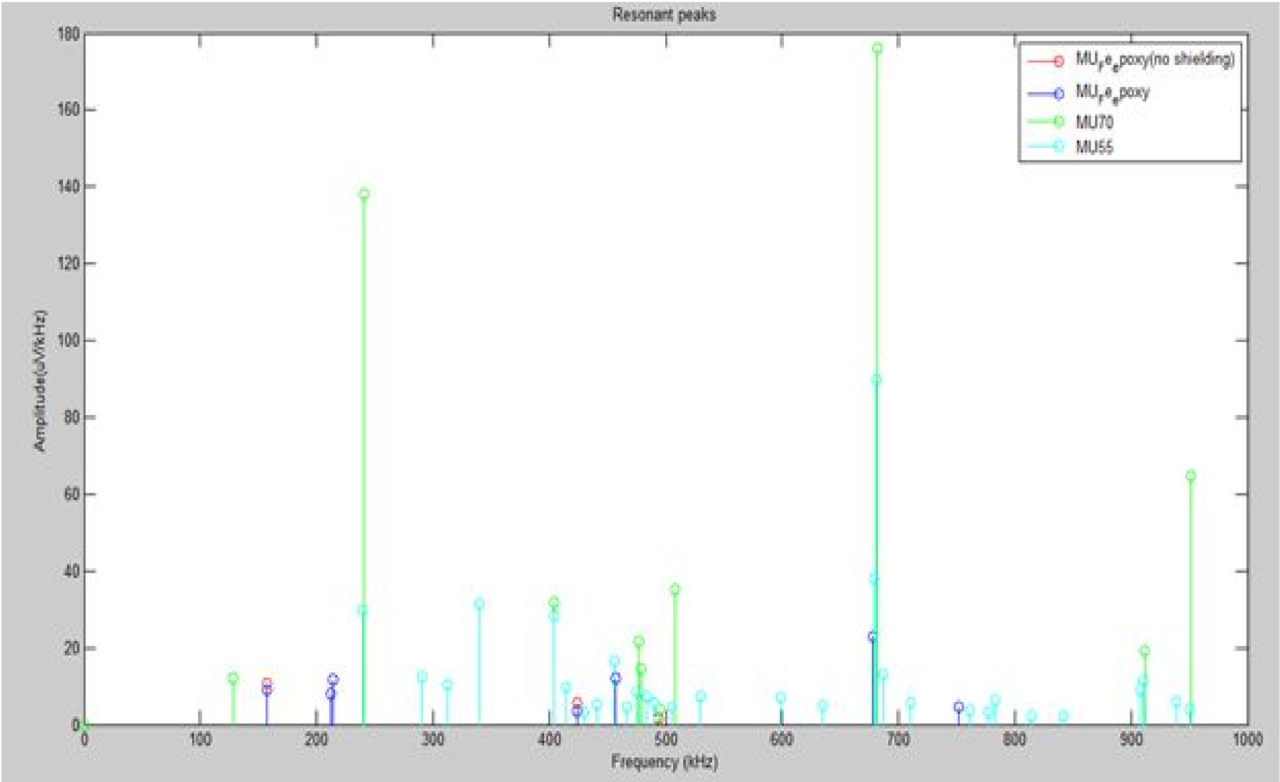
Measurement setup

- User defines a pulse frequency
- Information sent to NMR spectrometer
- Routed to the high power RF amplifier
- Sent to duplexer which filters out unwanted signals
- Sent to inductive antenna
- Response sent to receiver
- Routed to the NMR spectrometer



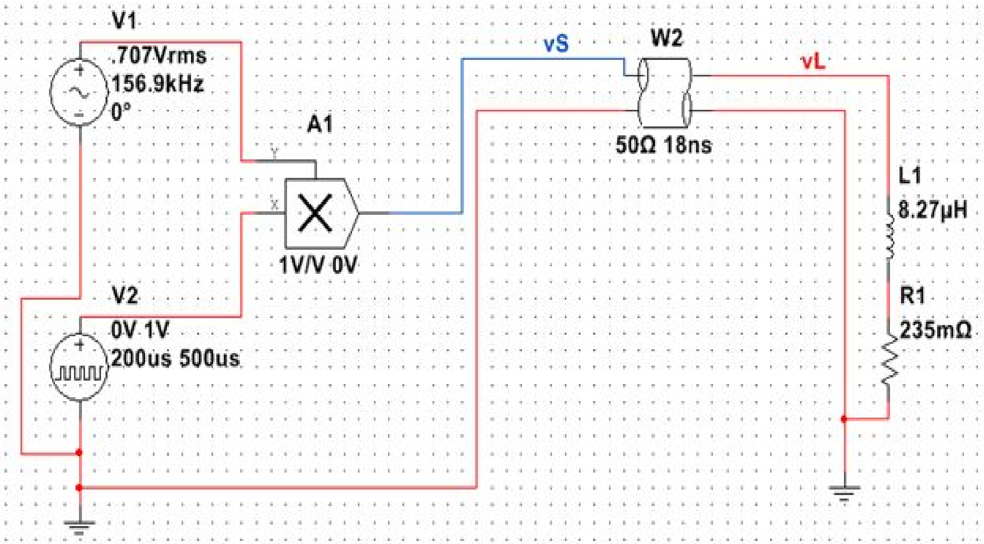


Measurements

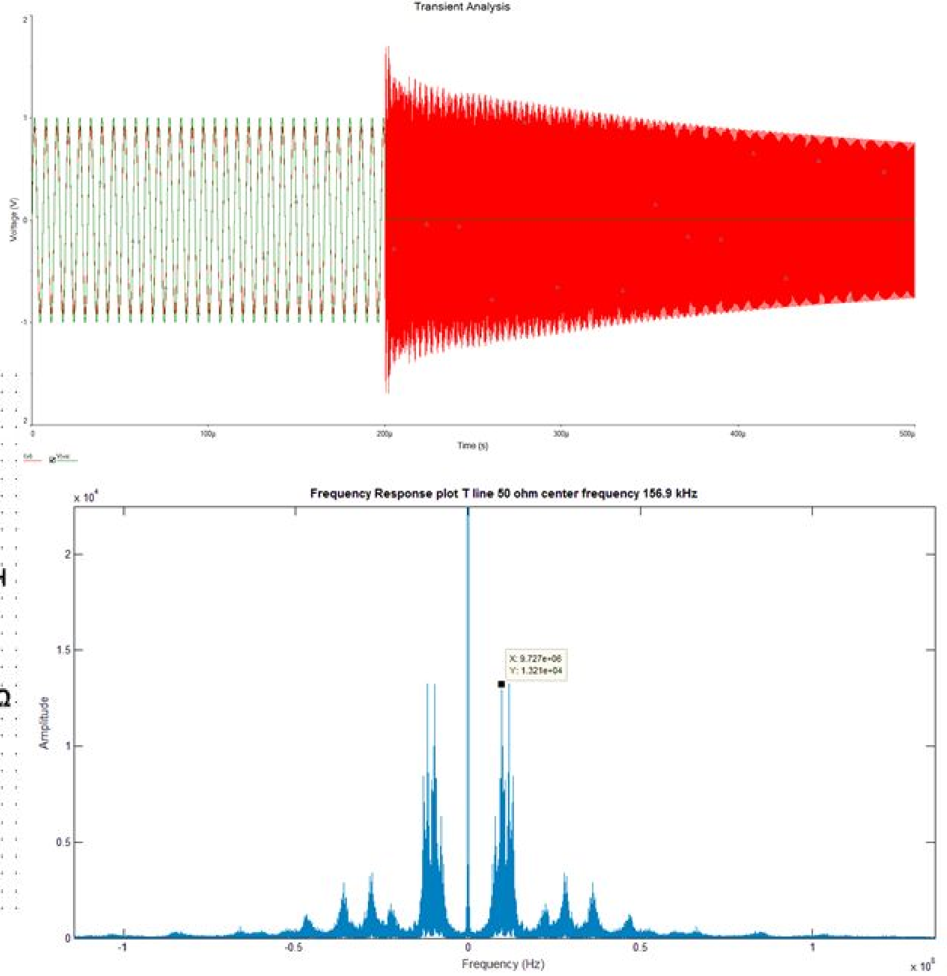


- Measured Ferrite Epoxy, MU70, MU55 samples with/without Al box
- Shielding increases the number of resonances being seen
- Resonances are weak and may be an amplification of the noise
- Need further measurements with uniform magnetic field to confirm

Circuit resonances



Circuit schematic for Ferrite Epoxy sample



Transient analysis and frequency spectrum for center frequency 156.9 kHz

Conclusion

- Found best solution for the uniform magnetic field- Permanent magnet
- Measured all samples provided by the client
- Identified all resonances from all samples provided by the client
- Found Ferrite epoxy to be the best material
- Efficient data processing using the GUI
- Found out that resonances are probably a material phenomena

Questions?