MATERIAL CHARACTERIZATION OF MICROWAVE ABSORBERS AND FERROELECTRICS (+ ENGINEERING EDUCATION RESEARCH?)

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Real fun – engineering education ...

- I will only mention a few areas and ideas that I am working in the hope that others will find them interesting and maybe start a collaboration 😊

- Two questions:
  - *How much time do students* really* spend studying...*
  - *How well are students prepared for life-long learning (metacognition, critical thinking, study skills, ...)*
  - *... threshold concepts and concept inventories, assessing project management and teamwork, role of internships in student self-efficacy, ...*
Real fun – engineering education ...

■ Subset of the problem – does anyone read anymore?

Problem statement:

a) How long do students take to finish various reading assignments?

b) How can this information be used to judge whether the assignment results in a reasonable “load” for students?

c) Can/should we make such “load” expectations more explicit to students?

d) Will such intervention be useful to student learning?

New tools – perusal.com – may make it possible to answer these questions
Real fun – engineering education ...

<table>
<thead>
<tr>
<th>Assignment (# of words)</th>
<th>Raw time (my calc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1 – communication (8000)</td>
<td>94 (85 w/min)</td>
</tr>
<tr>
<td>W3 – career planning (5800)</td>
<td>76 (76 w/min)</td>
</tr>
<tr>
<td>W4 – ethics 1 (5200 words)</td>
<td>66 (79 w/min)</td>
</tr>
<tr>
<td>W5 – ethics 2 (9200 words)</td>
<td>89 (103 w/min)</td>
</tr>
<tr>
<td>W6 – patents (5500 words)</td>
<td>70 (79 w/min)</td>
</tr>
<tr>
<td>W7 – life long learning (2500)</td>
<td>55 (45 w/min)</td>
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</tbody>
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Reasonable reading speed (?) is around 200 words per minute for general text; I’ve come across “50 – 75” words per minute for technical material or 5 to 6 minutes per page

(https://secure.execute.read.com/facts/ )
Real fun – engineering education ...

- How is this useful? Could lead to better estimate of expected “time-at-task” for reading and other expected work outside of classroom

- Much to be investigated:
  - What is the literature on this topic?
  - How is “technical” reading different from “general”
  - How reliable is perusal in estimating reading time?
  - ...

- Bigger question: how much does reading help student learning?
Real fun – engineering education ...

- How do we assess life-long-learning?
- Surveys (instruments) exist but nobody seems to be using them?
- Interesting paper (Cal Poly) and even more interesting conclusion:

  “Perhaps most important (result) was the lack of any significant changes in either the LLS (Life-Long-Learning-Scale) or the ALS (Autonomous Learner Scale) with the year of study in the engineering curriculum.”

- So, what happens to students in terms of LLL between freshman and senior years?
- Do things improve with graduate vs. UG students?
- Collected some data but not processed yet – join the fun!
Organization

- Intro to absorbers
- Microwave material characterization
- Results & Conclusion
- Intro to ferroelectric materials
- Characterization
- Conclusions and future work
Shielding – looks simple ...

- Shielding importance
  - Regulatory (EMI)
  - Antennas
  - Microwave packaging (suppressing resonances)
  - Signal integrity
  - RAM (radar absorbing)

- Applications from defense to consumer electronics

- Measurements – anechoic chambers

- Note: shielding vs. absorption (not standardized)
What is your ideal absorber?

- Cheap
- No reflection
- Everything absorbed
- Small dimensions (thickness)
- Transparent at optical frequencies
What is your ideal absorber?

- Minimize the front-face reflection and impedance matching at the air to absorber interface,
- Increase the absorption of electromagnetic waves through high values of dielectric and magnetic losses,
- Wideband frequency of absorption
- It does not require the use of an external magnetic field.
- And: lightweight, fine thickness (i.e. thin), cost effective, durable etc.
Electromagnetic (EM) shielding

- EM shielding:
  - Reduce the EM field in a space by blocking the field with barriers made of conductive or magnetic materials.
  - Application: to isolate electrical devices or wires from their surrounding environment.

- Shielding materials classification
  - Reflectors: only reflect the EM signal, can be achieved through use of metallic surfaces.
  - Absorbers: the energy is reduced inside the materials → harder to achieve.
Absorber Forms

■ Magnetic absorbers: has ferromagnetic properties with high permeability and high magnetic loss.
  - Greatly compress the wavelength
  - Best for cavity resonance damping (why?)
  - Heavy and expensive

■ Dielectric absorbers: loss is purely dielectric
  - Higher conductivity preventing usage in contact with electronic equipment
  - Lack of performance in cavity resonance applications
  - Low cost and weight

■ Moldable: both magnetic and dielectric
What’s new?

■ Novel approach to designing absorbers by combining conductive (dielectric) and magnetic losses
■ Combine carbon fibers with magnetic loading
■ Flock(ing) – orient CF normal to surface
■ Developed by Tangitek, (various US Patents)
- **Step 1**: CF is flocked (electrostatically deposited) on an adhesive substrate backing. The substrate can be paper, epoxy, and cloth, nonconductive and conductive materials. The flocked CF are deposited more-or-less vertically.

- **Step 2**: flocked CF structure is preserved by spray coating it with an insulating coating. The individual CF are insulated from each other, resulting in a nonconductive top surface in the x-y plane that is required for high performance absorbers.

- **Step 3**: magnetic particles (iron microspheres) are electrostatically deposited onto the vertical flocked CF. Iron microspheres are covered with insulating materials.

- **Step 4**: fill the absorber layer with high-loss dielectric resin materials. This improves strength and durability of the absorber.
Magnified (20x) stacked focus side view of magnetically loaded flocked CF microstructures in air on a paper substrate
What are our (current) goals?

- Characterize MF-RAM absorber in microwave range
- Use extracted parameters to setup and verify EM simulations
- Systematically examine the influence of sample preparation
- Use EM simulations to design absorber structures
- Develop procedures for absorber design for specific applications
Characterize absorbers – sounds simple ...

- Absorber characterized by extracting EM properties:
  - *Complex permeability* ($\mu = \mu' + j\mu''$)
  - *Complex permittivity* ($\varepsilon = \varepsilon' + j\varepsilon''$)

- Depend on the applications, other derived EM properties of absorbers are used:
  - *Dielectric loss tangent* ($\tan \delta$)
  - *Magnetic loss tangent*
  - *Attenuation*
  - *Reflectivity*
Measurements

- Free space vs. waveguides
- NRL arch – “standard” for reflectivity measurements but not useful for extraction of material properties
Measurements

- Free space vs. waveguides
- True free-space is hard to do and works best at mm-waves
- We have several waveguide approaches: rectangular waveguide, and airline. 3D printed structures
- Implementation issues, e.g. sample mounting

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<thead>
<tr>
<th>Transmission Line</th>
<th>Free Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_r$ and $\mu_r$</td>
<td>$\varepsilon_r$ and $\mu_r$</td>
</tr>
</tbody>
</table>

- Broadband
  - Best for lossy to low loss MUTs; machineable solids

- Broadband; Non-contacting
  - Best for flats sheets, powders, high temperatures

Agilent app. note 5989-2589EN
Waveguide measurement

Thru – Reflect – Line (TRL) calibration is needed to move reference plane to the sample under test.

VNA returns the scattering parameters which are used in NRW algorithm to get the EM properties of the material.
  • Complex permeability
  • Complex permittivity
Nicolson-Ross-Weir (NRW) Extraction algorithm

- Measure [S] on VNA → parameters?
- Extract the electromagnetic properties directly from scattering parameters:
  - Input: S11, S21, sample thickness, frequency band
  - Output: Complex permittivity and permeability
EM Properties: known absorber

- MAST Technologies MR21-0003:
  - *From waveguide measurement and NRW extraction: Solid lines*
  - *From manufacturer: Dashed lines*
Extraction: MF-RAM absorber

- Magnetically loaded flocked carbon fiber absorber (MF-RAM) from TangiTek
Extraction: losses

- For MR21, losses come from magnetic loss tangent
- For MF-RAM absorber, losses come from both magnetic and dielectric loss tangent (below)
Reflectivity measurement

- Naval Research Laboratory (NRL) Arch is used to measure the reflectivity with different incident angles and different sample alignment.
Reflectivity: known absorbers

- MAST Technologies MR21-0003 with incident angle of $10^0$ and $90^0$-step sample rotation
Reflectivity: MF-RAM absorbers

- Magnetically loaded flocked carbon fiber absorber from TangiTek:
  - **Anisotropy properties:** different combination of tiles and tile rotation give changes in both resonance frequency and loss
  - **Fabrication factors such as carbon fiber length and magnetic loading density, etc. are not uniform across the sample**

Four-tile mat vs. single tile

Single tile with different orientation
Reflectivity: MLF-CF absorbers

- Effects of backing paper to absorber performance
  - Show absorption at higher frequencies (Ku Band)
  - Without backing, the absorbing frequency is shifted up

Different tiles with paper backing

Different tiles without paper backing
EM simulation: Waveguide

- Mimicking waveguide [S] measurement using EMPro
  - PEC for waveguide boundary
  - Material properties from extraction process
- Verify extraction

Simulation of MR21

![Graph showing |S21| (dB) and |S11| (dB) vs. Frequency (GHz)](image)
EM simulation: Waveguide

- Verify extraction
  - Magnitude difference of 0.1 dB
  - Phase difference of 2 degrees

- Absorber model for specific designs

Simulation of MLF-CF
EM simulation: NRL Arch

- Mimicking arch measurement using HFSS
- Floquet Ports for reflection loss (NRL arch) simulation
- Planar periodic structure (absorber)
- Analysis of the infinite structure is accomplished by analyzing a unit cell
EM sim: NRL Arch MF-RAM absorber

- Used EM parameters from waveguide extraction
- Out of 4 samples, there is one that has resonance at higher frequency (the one that we used to extract)
- Simulated graph is close to what we measured (not shown)

- Couple of publications for more details:


Conclusions - Absorber

- Novel magnetically loaded, flocked carbon-fiber-based absorber developed that combines dielectric and magnetic losses
- Straightforward to manufacture and cost-effective
- Thin and lightweight: ≈0.05 g/cm², ≈ 85% reduction vs. others
- Broadband absorption, at least comparable to existing absorbers
- Characterized in free space using NRL arch method which showed good absorption across X-band with maximum of -30 to -45 dB in 10 to 11 GHz frequency range.
- Anisotropy (rotation angle, combination, etc.) observed
- Complex permittivity and permeability extracted using waveguide measurements and NWR algorithm
- Extraction procedures verified by measurements and extraction of a known, commercially available absorbers. The procedure then applied to MF-RAM absorber EM simulation for waveguide measurement and arch measurement
Future work ...

- Advances state-of-the-art in terms of electrical and mechanical properties, but ...  
- Material development: improve manufacturing consistency  
- Work on avoiding anisotropic response  
- How does this work on “microscopic” level?  
- Further verification of extraction procedures  
- Improve measurement hardware (3D printing)  
- Make improvements to our arch and anechoic chamber  
- Etc.