Adaptable Course Materials: Creating an Open Textbook for Electromagnetics

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***Electromagnetics* Volume 1 (Beta)** (CC BY-SA 4.0) is a 224 page Beta version of an open educational resource intended to serve as a primary textbook for a one-semester first course in undergraduate engineering electromagnetics. It includes: electric and magnetic fields; electromagnetic properties of materials; electromagnetic waves; and devices that operate according to associated electromagnetic principles including resistors, capacitors, inductors, transformers, generators, and transmission lines. This book employs the "transmission lines first" approach, in which transmission lines are introduced using a lumped-element equivalent circuit model for a differential length of transmission line, leading to one-dimensional wave equations for voltage and current. This is intended for electrical engineering students in the third year of a bachelor of science degree program.

Availability: The Beta version of the book, freely and publically available as PDF in Virginia Tech's Institutional Repository at https://doi.org/10.7294/W4WQ01ZM and for $27.55 from Amazon.com ISBN:978-0997920123).

Vol. 1 (BETA) & future versions: The BETA version of Volume 1 is being field tested in Virginia Tech's ECE 3105 Spring 2018 course. Spring 2018 field testing includes mixed methods approaches: classroom observation, student survey, and student focus groups intended to identify student perceptions, usage patterns, and areas for improvement of the text.

Vol. 1 (BETA) will be updated and re-released in Summer 2018. The following will also be added: index (within the book), problem sets, solution manual, and LaTeX source code. A Vol. 2 (Beta) second semester text is planned for release in 2019.

Project funding and technical assistance:
This text is the result of a collaborative partnership between Virginia Tech's University Libraries' Open Education Faculty Initiative Grant Program and VTPublishing, and the author.

Project Intent and Intended Future Collaborative Development:
This textbook is part of the Open Electromagnetics Project led by Steven W. Ellingson at Virginia Tech. The goal of the project is to create no-cost openly-licensed content for courses in undergraduate engineering electromagnetics.

The project is motivated by two things: lowering learning material costs for students and giving faculty the freedom to adopt, modify, and improve their educational resources.

Use, sharing, contributions to, and customization of this book or portions of this book or figures are an inherent part of the intent of the way this book has been published. Potential collaborators are invited to contact the author.

Openness (with regarding to content)

As an **Open Educational Resource (OER)**, this textbook is not only freely available, it is also licensed to be modified and shared.

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>
> Open educational resources include full courses, course materials, modules, textbooks, streaming videos, tests, software, and any other tools, materials, or techniques used to support access to knowledge." [1]

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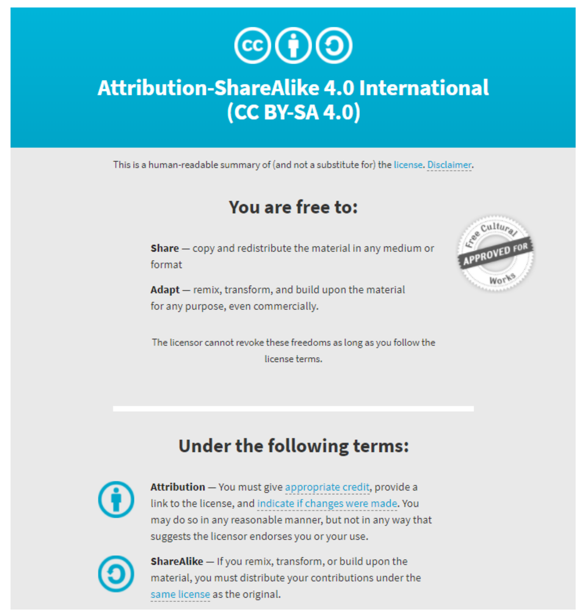

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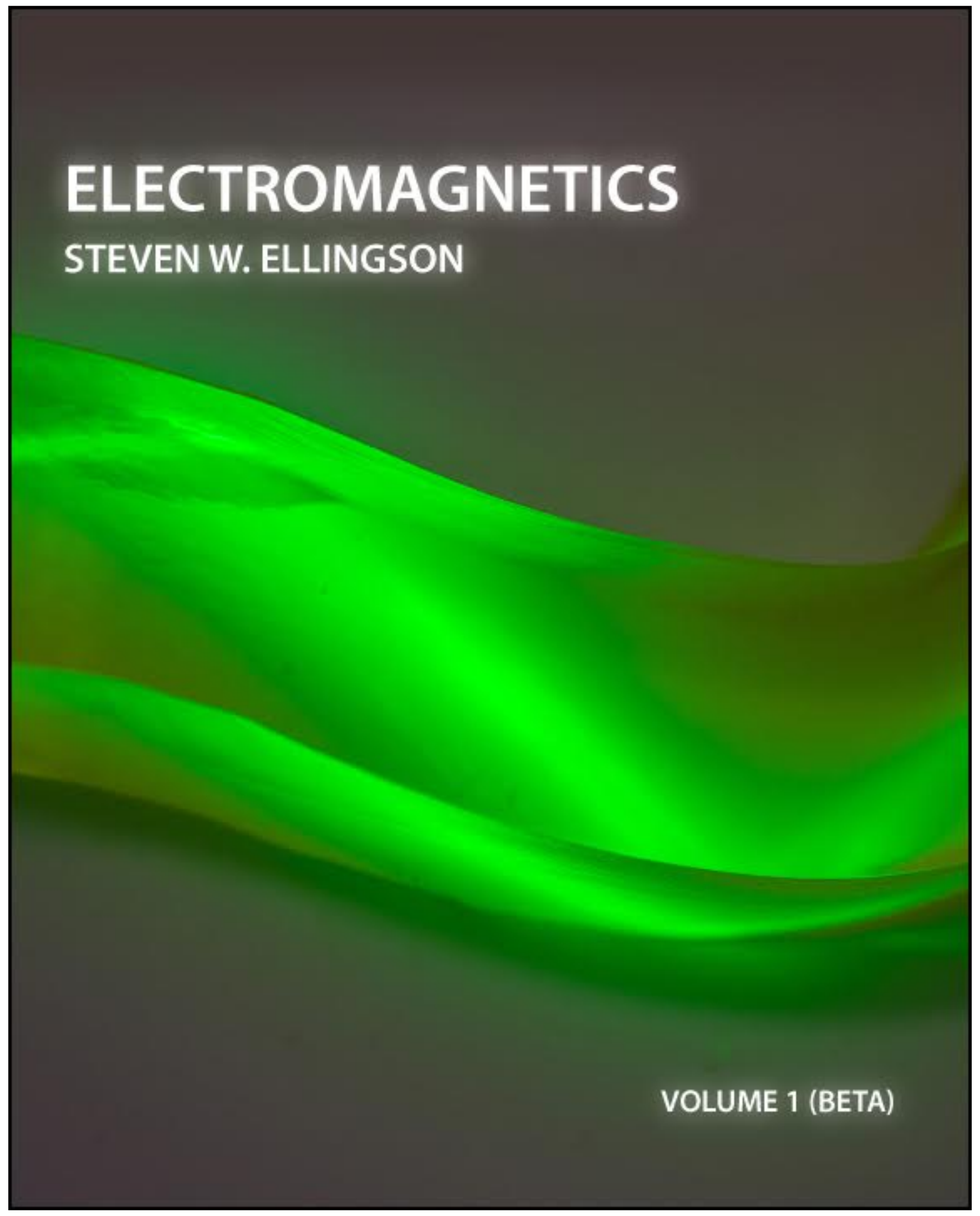

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Why Create an Intentionally Remixable Learning Resource?

Electromagnetics Vol 1 (Beta) employs the popular "transmission lines first" structure, in which transmission line theory is addressed first, followed by electrostatics, etc. as seen below:

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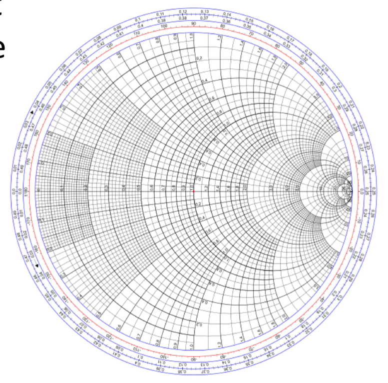
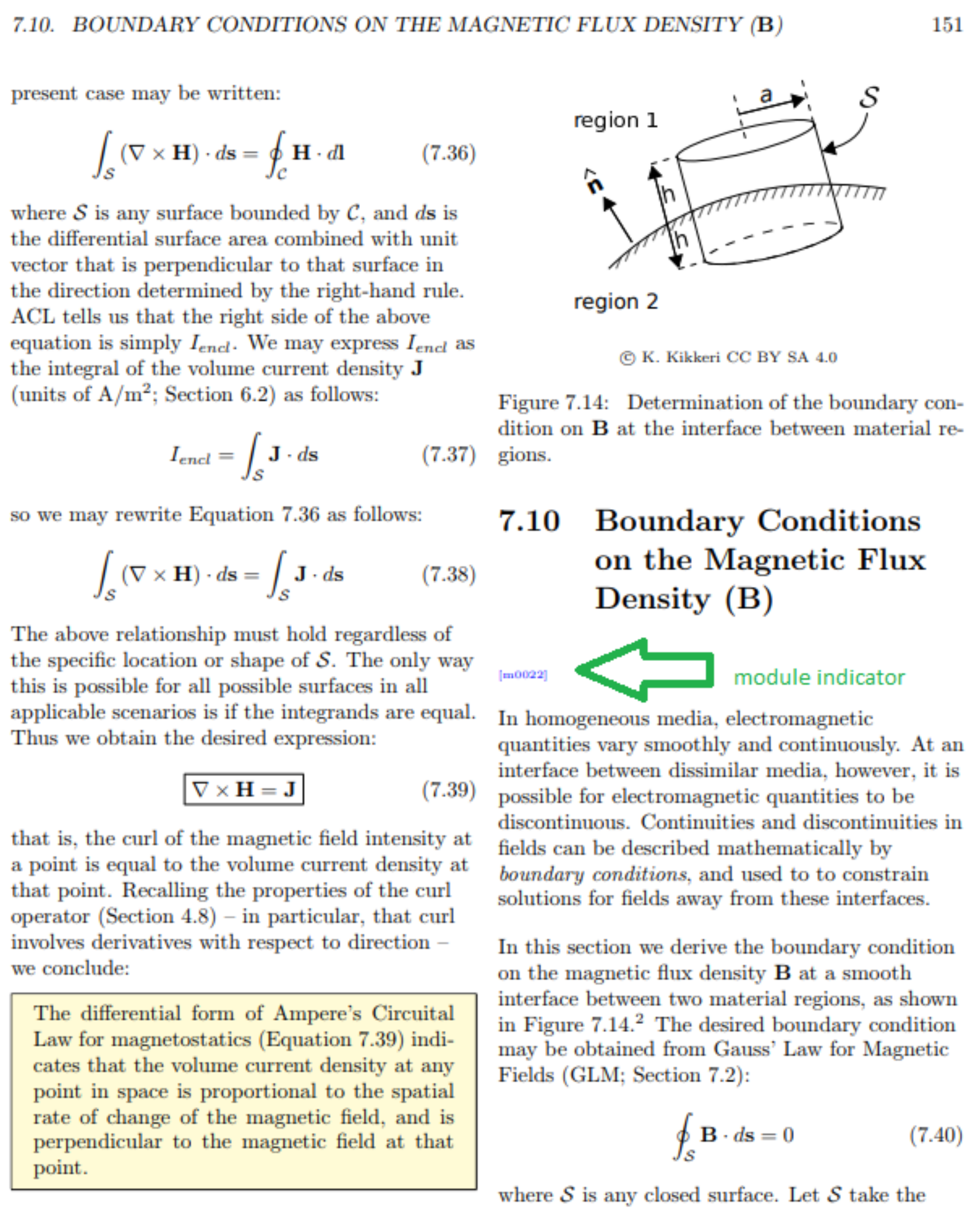
However, many institutions prefer a "waves first" structure, in which transmission lines are addressed after electromagnetic waves. "Transmission lines first" vs. "Waves first" is certainly not the only issue for which educators and textbooks vary. Another issue is whether and when to address *Smith Charts*. Many courses introduce Smith Charts as an integral part of a transmissions lines curriculum, whereas others regard Smith Charts as a separate topic or exclude it altogether. The most recent Virginia Tech curriculum excludes Smith charts from the two electromagnetics courses, so there is no Immediate plan to include Smith Charts in a planned Release of *Electromagnetics*, but we do plan to Include Smith Chart material in the remix system To support advanced courses that do address Smith Charts, and as a service to those who a interested in a remix of *Electromagnetics* that does contain this material.



A Smith chart ©Wldwd CC BY SA 3.0
https://commons.wikimedia.org/wiki/File:Smith_chart_gen.svg

Technical Solutions to Enabling Openness and Remix

Remix System
All books resulting from this project will be different remixes of the same common body of material. Here is a brief overview of the remix system. The system is comprised of "modules" which normally correspond to sections within a book.



7.10. BOUNDARY CONDITIONS ON THE MAGNETIC FLUX DENSITY (**B**) 151

present case may be written:

$$\int_{\mathcal{S}} (\nabla \times \mathbf{H}) \cdot d\mathbf{s} = \oint_{\mathcal{C}} \mathbf{H} \cdot d\mathbf{l} \quad (7.36)$$

where $\mathcal{S}$ is any surface bounded by $\mathcal{C}$, and $d\mathbf{s}$ is the differential surface area combined with unit vector that is perpendicular to that surface in the direction determined by the right-hand rule. ACL tells us that the right side of the above equation is simply I_{encl}. We may express I_{encl} as the integral of the volume current density $\mathbf{J}$ (units of A/m^2; Section 6.2) as follows:

$$I_{encl} = \int_{\mathcal{S}} \mathbf{J} \cdot d\mathbf{s} \quad (7.37)$$

so we may rewrite Equation 7.36 as follows:

$$\int_{\mathcal{S}} (\nabla \times \mathbf{H}) \cdot d\mathbf{s} = \int_{\mathcal{S}} \mathbf{J} \cdot d\mathbf{s} \quad (7.38)$$

The above relationship must hold regardless of the specific location or shape of $\mathcal{S}$. The only way this is possible for all possible surfaces in all applicable scenarios is if the integrands are equal. Thus we obtain the desired expression:

$$\boxed{\nabla \times \mathbf{H} = \mathbf{J}} \quad (7.39)$$

that is, the curl of the magnetic field intensity at a point is equal to the volume current density at that point. Recalling the properties of the curl operator (Section 4.8) – in particular, that curl involves derivatives with respect to direction – we conclude:

> The differential form of Ampere's Circuital Law for magnetostatics (Equation 7.39) indicates that the volume current density at any point in space is proportional to the spatial rate of change of the magnetic field, and is perpendicular to the magnetic field at that point.

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Figure 7.14: Determination of the boundary condition on **B** at the interface between material regions.

7.10 Boundary Conditions on the Magnetic Flux Density (B)

[m0022]

In homogeneous media, electromagnetic quantities vary smoothly and continuously. At an interface between dissimilar media, however, it is possible for electromagnetic quantities to be discontinuous. Continuities and discontinuities in fields can be described mathematically by *boundary conditions*, and used to to constrain solutions for fields away from these interfaces.

In this section we derive the boundary condition on the magnetic flux density **B** at a smooth interface between two material regions, as shown in Figure 7.14.[2] The desired boundary condition may be obtained from Gauss' Law for Magnetic Fields (GLM; Section 7.2):

$$\oint_{\mathcal{S}} \mathbf{B} \cdot d\mathbf{s} = 0 \quad (7.40)$$

where $\mathcal{S}$ is any closed surface. Let $\mathcal{S}$ take the

Each module consists of a plain text LaTeX file fragment (*not* a complete LaTeX document) and the figures reference the text. Some features unique to the system are implemented using commands embedded in comments in the LaTeX file. For example: commands that identify text that should appear within highlight boxes, or are treated as examples and set off from the main text. Anyone who has created a document using LaTeX that includes equations and figures already knows LaTeX editing skills required to write a module.

The first few lines of the remix specification file for *Electromagnetics* Vol. 1 (Beta)

```
INPUT   modules              # directory containing module subdirectories
OUTPUT  oem-v1beta           # working directory for this project
TITLE  Electromagnetics \\ Vol.~1 (Beta)
AUTHOR Steven W. Ellingson
DATE   \today
TABLEOFCONTENTS
CHAPTER Preface
  SECTION m0146_Preface-About_This_Book
  SECTION m0148_Preface-About_OpenEM
  SECTION m0153_Preface-About_Author
CHAPTER Preliminary Concepts
  SECTION m0037_What_is_EM
  SECTION m0075_Electromagnetic_Spectrum
```

Remix using Source Files
Alternatively, the source files for *Electromagnetics* will be made freely available at https://doi.org/10.7294/W4WQ01ZM with the revised Vol 1 in Summer 2018.

Remix by PDF Hacking
A third (but far less desirable approach) is to begin with the PDF, which may be reverse-engineered into a word processing program.

Suggested citation: Ellingson, Steven W. (2018) Electromagnetics, Vol. 1 (Beta). Blacksburg, VA: VT Publishing. https://doi.org/10.7294/W4WQ01ZM Licensed with CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0

References

[1] William and Flora Hewlett Foundation https://www.hewlett.org/strategy/open-educational-resources
[2] Best Practices for Attribution https://wiki.creativecommons.org/wiki/Best_practices_for_attribution