THE UNIVERSITY OF BRITISH COLUMBIA
Department of Electrical & Computer Engineering

ELEC 311 – Electromagnetic Fields and Waves

2025 W1

A Supplement to

Chapter 13 – Guided Waves

in W. H. Hayt, Jr. and J. A. Buck, *Engineering Electromagnetics*, McGraw-Hill, 2019, pp. 456-514.

The purposes of this supplement are:

· to assist the reader in identifying key points to be recognized as they apply the SQ3R (Survey, Question, Read, Recite, Review) process to reading and reviewing the chapter and

· to provide comments and supplemental information that fill in apparent gaps in the textbook.

Introduction

This chapter considers several structures for guiding electromagnetic waves and the principles by which they operate. Individual sections include:

13.1 Transmission Line Fields and Primary Constants
13.2 Basic Waveguide Operation
13.3 Plane Wave Analysis of the Parallel-Plate Waveguide
13.4 Parallel-Plate Guide Analysis Using the Wave Equation
13.5 Rectangular Waveguides
13.6 Planar Dielectric Waveguides
13.7 Optical Fibre

13.1 Transmission Line Fields and Primary Constants

This section:

- establishes the equivalence between the equivalent circuit and electromagnetic field models of wave propagation along transmission lines
- the common element captured by both models is the energy stored in the electric and magnetic fields; the lumped element model is simply a more compact representation of the phenomenon described in detail by the fields
- demonstrates how *R, L, G,* and *C* can be calculated given the physical dimensions of
    - parallel-plate transmission line,
    - coaxial line (high, low, and intermediate frequencies),
    - two-wire or ladder line (high and low frequencies),
    - microstrip line (low frequencies)

Comments

The relationships between *R, L, G*, and *C* and the physical dimensions of common transmission lines are well described in the course lecture slides.

We didn't consider microstrip lines in Chapter 10 but they are of great practical importance in microwave circuits and systems. The middle figure below, taken from another text, shows a stub-matching circuit rendered in microstrip. The lowest figure shows a more complicated microstrip circuit which, among other structures, incorporates radial stubs.

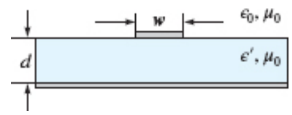


Figure 13.5 Microstrip line geometry.

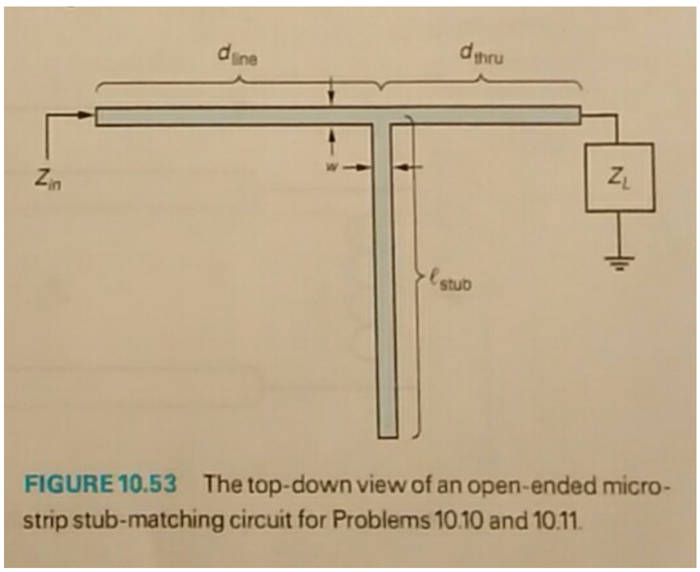
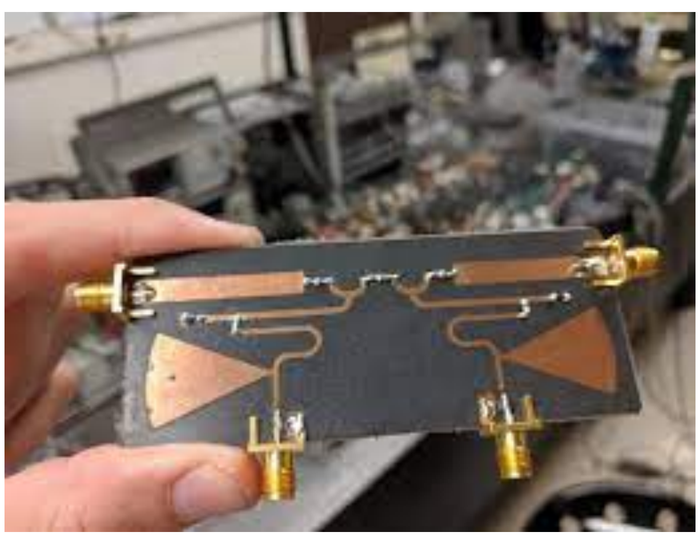


FIGURE 10.53 The top-down view of an open-ended micro-strip stub-matching circuit for Problems 10.10 and 10.11.



13.2 Basic Waveguide Operation

This section:

- introduces parallel-plate, rectangular, cylindrical (or circular), symmetric dielectric slab, and optical-fibre waveguides
- explains how non-TEM modes can propagate along such structures even when boundary conditions prevent TEM modes from propagating
- establishes the geometry of such propagation as a succession of bounces back and forth between the transverse or radial boundaries; the resulting wave is no longer uniform in the transverse direction
  - as the frequency increases, the bounces will become shallower and the wave will more closely resemble a TEM mode of propagation
  - as the frequency decreases, the bounces will become more acute until, at a certain *cut-off frequency,* wave propagation occurs entirely in the transverse direction; below this frequency no propagation can occur in either direction
  - above the cut-off frequency, propagation still occurs in the longitudinal direction but the field components have both transverse and longitudinal components (hence the moniker non-TEM wave)
- notes that two types of waveguide modes can be supported in a parallel-plate waveguide: TE and TM (relative to the direction of propagation)

Comments

Just as in Chapter 10, the text appeals to the reader's intuition before delving into the mathematical details.

13.3 Plane Wave Analysis of the Parallel-Plate Waveguide

This section:

- presents a detailed analysis of non-longitudinal plane-wave propagation in a parallel-plate waveguide
- re-establishes the geometry of such propagation as a succession of bounces back and forth between the plates; as before,
  - as the frequency increases, the bounces will become shallower and the wave will more closely resemble a TEM mode of propagation
  - as the frequency decreases, the bounces will become more acute until, at a certain *cut-off frequency,* wave propagation occurs entirely in the transverse direction; below this frequency no propagation can occur in either direction
  - above the cut-off frequency, propagation still occurs in the longitudinal direction but the field components have both transverse and longitudinal components (hence the moniker non-TEM wave)
- resolves propagation into both transverse and longitudinal components each with their own propagation vector **k**

- identifies the transverse resonance condition under which $E_{tan} = 0$ along the upper and lower plates
- notes the difference (and relationship) between the *phase velocity* and *group velocity* of the wave

Comments

The same concepts apply to hollow rectangular waveguide, too.

13.4 Parallel-Plate Guide Analysis Using the Wave Equation

This section derives complete expressions for each of the components of the electric and magnetic fields using the wave equation.

Comments

The result is consistent with the plane wave analysis presented in the previous section but a little more compact. The approach has the added advantage of being easily generalized to waveguides with other cross-sectional geometries, *e.g.*, rectangular, circular or elliptical

13.5 Rectangular Waveguides

This section:

- considers non-TEM mode propagation within hollow rectangular waveguide
- in this case, $E_{tan} = 0$ along both the upper and lower (horizontal) walls and the left and right (vertical) walls
- builds upon the last section by deriving complete expressions for each of the components of the electric and magnetic fields using the wave equation.
- notes that two types of waveguide modes can be supported in a hollow rectangular waveguide: TE and TM (relative to the direction of propagation) and establishes a naming convention based on the number of half-cycles *m* and *n* in the horizontal and vertical transverse resonances, respectively

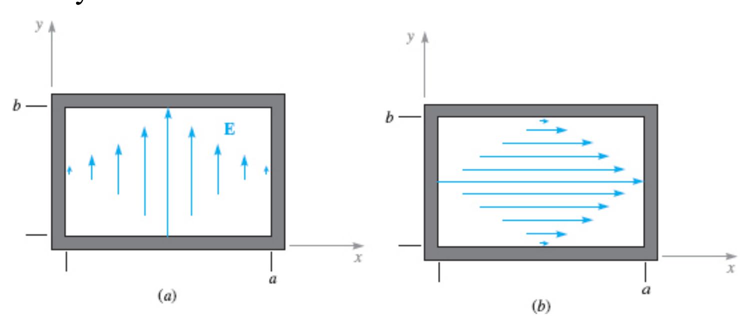


Figure 13.18 (*a*) TE_{10} and (b) TE_{01} mode electric field configurations in a rectangular waveguide.

- derives expressions for the cut-off frequencies of TE_{mn} and TM_{mn} modes in terms of the broad and narrow wall dimensions, *a* and *b*
- demonstrates how to calculate the phase and group velocities of particular TE_{mn} or TM_{mn} modes with frequency *f* propagating in a rectangular waveguide with dimensions *a* and *b*
- highlights the existence of a range of frequencies over which only a single mode propagates and why this is desirable

- considers the special cases of TE_{m0} or TM_{0n} modes

Comments

Rectangular waveguides are useful at frequencies in the range from ~2 GHz to ~300 GHz. They are noteworthy for both their low loss and high power handling capability compared to coaxial transmission lines.

*13.6 Planar Dielectric Waveguides**

This section:

- considers non-TEM propagation within planar dielectric waveguides
- establishes:
  - the geometry of such propagation as a succession of bounces back and forth between the upper and lower planar interfaces between the regions of higher and lower permittivity, and,
  - the conditions under which the boundary conditions in the transverse plane will be met along the upper and lower interfaces
  - the transverse resonance and cut-off conditions

Comments

ELEC 311 students are not responsible for resolving detailed problems concerning such structures.

*13.7 Optical Fibre**

This section generalizes the results of the previous section to structures with circular cross sections

Comments

ELEC 311 students are not responsible for resolving detailed problems concerning such structures.

References

Notably absent are references concerning microstrip circuit design. ELEC 311 students with an interest in this area may wish to consult

T. C. Edwards and M. B. Steer, *Foundations for Microstrip Circuit Design*, 4th ed., Wiley-IEEE Press, 2016, 688 pp.

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