Czech Technical University in Prague,
Faculty of Electrical Engineering

Master's thesis

Dual Circularly Polarized Waveguide Antenna

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MASTER'S THESIS ASSIGNMENT

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

I. Personal and study details

Student's name:	**Šimák Martin**	Personal ID number:	**483523**
Faculty / Institute:	**Faculty of Electrical Engineering**		
Department / Institute:	**Department of Electromagnetic Field**		
Study program:	**Electronics and Communications**		
Specialisation:	**Radio Communications and Systems**		

II. Master's thesis details

Master's thesis title in English:

Dual Circularly Polarized Waveguide Antenna

Master's thesis title in Czech:

Duálně kruhově polarizovaná vlnovodová anténa

Guidelines:

Research different polarizers in a metallic waveguide, consider round or square transversal shape of the guide. Inspired by circularly polarized patch antenna with chamfered corners, adapt this technique to the waveguide technology (the frequency should be used to be appropriate for easy fabrication, say around 5 GHz). Perform 2D eigenmode analysis of round and square waveguides with inserted metal triangles, and compare the results with the theory of patch antennas of such shapes. Choose one of the waveguide with the polarizer and optimize it to provide the best bandwidth and radiation properties, also design the transition from coaxial cable, preferably with the ability to excite both RHCP and LHCP patterns. Add a small horn (say 15 dBi) to the waveguide and finally optimise the whole structure. Build and measure the whole structure, compare to simulation results.

Bibliography / sources:

1/ Polarizers on sections of square waveguides with inner corner ridges | IEEE Conference Publication | IEEE Xplore
2/ Compact reconfigurable waveguide circular polarizer | IEEE Conference Publication | IEEE Xplore
3/ Design of Wideband Quad-Ridge Waveguide Polarizer | IEEE Conference Publication | IEEE Xplore
4/ Optimum-Iris-Set Concept for Waveguide Polarizers | IEEE Journals & Magazine | IEEE Xplore
5/ Novel square/rectangle waveguide septum polarizer | IEEE Conference Publication | IEEE Xplore
6/ Broadband Septum Polarizer With Triangular Common Port | IEEE Journals & Magazine | IEEE Xplore
7/ New Tunable Iris-Post Square Waveguide Polarizers for Satellite Information Systems | IEEE Conference Publication | IEEE Xplore
8/ Hexagonal waveguides: New class of waveguides for mm-wave circulaly polarized horns | IEEE Conference Publication | IEEE Xplore
9/ Hexagonal Waveguide Based Circularly Polarized Horn Antennas for Sub-mm-Wave/Terahertz Band | IEEE Journals & Magazine | IEEE Xplore
Bow-Tie-Shaped Radiating Element for Single and Dual Circular 10/ Polarization | IEEE Journals & Magazine | IEEE Xplore
11/ A Wideband Circularly Polarized Horn Antenna With a Tapered Elliptical Waveguide Polarizer | IEEE Journals & Magazine | IEEE Xplore

Name and workplace of master's thesis supervisor:

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Date of master's thesis assignment: **04.09.2024** Deadline for master's thesis submission: ________

Assignment valid until: **15.02.2026**

doc. Ing. Pavel Hazdra, Ph.D.
Supervisor's signature

Head of department's signature

prof. Mgr. Petr Páta, Ph.D.
Dean's signature

III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

Date of assignment receipt

Student's signature

Contents

Introduction

Write a couple of words on literature survey. Present the difference construction and design choices, compare them both theoretically and by the results presented in gathered papers.
[1]

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Chapter 1

Theory of operation

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Throughout the theory chapter, I will omit using the common 'notation candy' of *del*, or *nabla*, for the vector differential operator ∇ which gives rise to the formally proper differential operators of gradient (∇), divergence ($\nabla\cdot$), curl ($\nabla\times$), and sometimes even the Laplace operator ($\nabla\cdot\nabla$ or ∇^2). Instead, I will use the standard notations of grad, div, curl, and Δ, respectively. There are various reasons for this decision, e.g., that the definition of such an operator is inherently dependent on the working coordinate system, while the differential operators can be broadly extended beyond Cartesian or even Euclidean geometries, or that it promotes a notational ambiguity with the covariant derivative used in differential geometry. The main reason, however, is simply that the fundamental nature of the operator is undefinable and thus unclear.

Inspired by [2] and [3].

1.1 Laws of electrodynamics

Lay out `the equations`, brr

$$\operatorname{div}\boldsymbol{D} = \rho_\mathrm{e}, \tag{1.1a}$$
$$\operatorname{curl}\boldsymbol{E} = -\boldsymbol{J}_\mathrm{m} - \partial_t\boldsymbol{B}, \tag{1.1b}$$
$$\operatorname{div}\boldsymbol{B} = \rho_\mathrm{m}, \tag{1.1c}$$
$$\operatorname{curl}\boldsymbol{H} = \boldsymbol{J}_\mathrm{e} + \partial_t\boldsymbol{D}, \tag{1.1d}$$

- J_e is total electric current made up of the source current J_s and conductive current J_c.
- ρ_m and $\boldsymbol{J}_\mathrm{m}$ are part of the 'generalized' current concept.
- Explain the concept of these equations being expressed in *free* charge and *free* current. Give example of the Maxwell's equations neglecting the matter properties,

to the convenience of which the *free* sources are introduced, and make comments how equally general and useful they are.

- Comment on mathematical completeness together with boundary conditions which are usually 'obvious', such as vanishing potentials at infinity etc. Source Griffiths for that from his formulation without material properties. This might need the inclusion of Lorentz's force law for absolute completeness of electrodynamics.

$$\operatorname{div} \boldsymbol{J}_{\mathrm{e}} = -\partial_t \rho_{\mathrm{e}} \tag{1.2}$$

1.1.1 Constitutive relations in time domain

$$\boldsymbol{D} = \hat{\epsilon} * \boldsymbol{E}, \tag{1.3a}$$
$$\boldsymbol{B} = \hat{\mu} * \boldsymbol{H}, \tag{1.3b}$$
$$\boldsymbol{J}_{\mathrm{c}} = \hat{\sigma} * \boldsymbol{E}, \tag{1.3c}$$

where $\hat{\epsilon}$, $\hat{\mu}$, and $\hat{\sigma}$ are generally second rank tensors and $*$ denotes *convolution*.

Talk about materials characterization

1. *dielectrics*, *magnetics*, and *conductors*, with regard to their *polarization*, *magnetization*, and *conduction*;
2. *linear* versus *nonlinear*, *homogeneous* versus *inhomogeneous*, *isotropic* versus *anisotropic*, and *dispersive* versus *nondispersive*. Mention the simplification of material tensors ($* \to \cdot$, $F(\boldsymbol{r}, t) \to F(t)$, matrix $\to$ scalar, $\partial_\omega = 0$).

In the simplest case of free space, (1.3a), (1.3b), and (1.3c) become

$$\hat{\epsilon} = \epsilon_0 \approx 8.854 \times 10^{-12}\ \mathrm{F\,m^{-1}}, \tag{1.4}$$
$$\hat{\mu} = \mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}, \tag{1.5}$$
$$\hat{\sigma} = 0\ \mathrm{S\,m^{-1}}. \tag{1.6}$$

1.1.2 Boundary conditions

Include if needed (probably will be).

1.1.3 Power and energy

Include Poynting theorem if needed.

1.1.4 Electromagnetic properties of matter

This one will, hopefully, be skippable. If not, talk about

- $\rho = \rho_{\mathrm{f}} + \rho_{\mathrm{b}} = \rho_{\mathrm{f}} - \operatorname{div} \boldsymbol{P}$ due to free and bound charges,
- $\boldsymbol{J}_{\mathrm{e}} = \boldsymbol{J}_{\mathrm{f}} + \boldsymbol{J}_{\mathrm{b}} + \boldsymbol{J}_{\mathrm{p}} = \boldsymbol{J}_{\mathrm{f}} + \operatorname{curl} \boldsymbol{M} + \partial_t \boldsymbol{P}$, where $\boldsymbol{M}$ is magnetic polarization (magnetization), due to free, bound and polarization currents,

from [3].

1.2 Electromagnetic waves

1.2.1 The wave equations

Inside regions with no *free* charge or *free* current,[1] Maxwell's equations take the form of

$$\operatorname{div} \boldsymbol{D} = 0, \tag{1.7a}$$
$$\operatorname{curl} \boldsymbol{E} = -\partial_t \boldsymbol{B}, \tag{1.7b}$$
$$\operatorname{div} \boldsymbol{B} = 0, \tag{1.7c}$$
$$\operatorname{curl} \boldsymbol{H} = \sigma \boldsymbol{E} + \partial_t \boldsymbol{D}. \tag{1.7d}$$

Furthermore, if the medium is *linear* and *homogeneous*, equations (1.7b) and (1.7d) simplify to

$$\operatorname{div} \boldsymbol{E} = 0, \tag{1.8a}$$
$$\operatorname{curl} \boldsymbol{E} = -\partial_t \boldsymbol{B}, \tag{1.8b}$$
$$\operatorname{div} \boldsymbol{B} = 0, \tag{1.8c}$$
$$\operatorname{curl} \boldsymbol{B} = \mu\sigma \boldsymbol{E} + \mu\epsilon\partial_t \boldsymbol{E}. \tag{1.8d}$$

Applying the curl to (1.8b) and (1.8d) and using the identity $\operatorname{curl}\operatorname{curl} = \operatorname{grad}\operatorname{div} - \Delta$ from vector calculus, we obtain

$$\Delta \boldsymbol{E} = \mu\sigma\partial_t \boldsymbol{E} + \mu\epsilon\partial_t^2 \boldsymbol{E}, \tag{1.9a}$$
$$\Delta \boldsymbol{B} = \mu\sigma\partial_t \boldsymbol{B} + \mu\epsilon\partial_t^2 \boldsymbol{B}. \tag{1.9b}$$

Therefore electric and magnetic fields in linear homogeneous media both clearly satisfy the wave equation with a linear damping term $\mu\sigma\partial_t$ introduced by conductive losses. Furthermore, electromagnetic fields propagating in regions of zero conductive current, such as free space or ideal insulators, take the shape of the wave equations

$$\Delta \boldsymbol{E} = \mu\epsilon\partial_t^2 \boldsymbol{E}, \tag{1.10a}$$
$$\Delta \boldsymbol{B} = \mu\epsilon\partial_t^2 \boldsymbol{B}, \tag{1.10b}$$

which are ubiquitous in theoretical physics. Following the general notation, we can write

$$\Box \boldsymbol{E} = 0, \tag{1.11a}$$
$$\Box \boldsymbol{B} = 0, \tag{1.11b}$$

where $\Box = \Delta - 1/c^2\partial_t^2$ is the d'Alembert operator. Recognizing these as the wave equations hence immediately gives rise to the formula

$$v = \frac{1}{\sqrt{\epsilon\mu}} = \frac{c}{\sqrt{\epsilon_r\mu_r}} \tag{1.12}$$

for the speed of electromagnetic waves in linear homogeneous media.

Compared with the original Maxwell's equations (1.1), these equations form two systems of partial differential equations of second order but are now decoupled and provide us with an additional solving method for given boundary-value problems. However, it is important to note that the wave equations (1.9a) and (1.9b) were derived from Maxwell's equation by differentiation. This impedes their mathematical equivalence. More specifically (as stated in [3]), whereas every solution to Maxwell's equations is also a solution for the wave equations, the converse is not true.

1.2.2 Monochromatic plane waves

Maxwell's equations along with the constitutive relations all the theory outlined so far involves description of general vector fields which vary in space and time. However,

[1] Expand on the notions of *free* and *bound* sources.

we have shown in Section 1.2, the fields, given certain conditions, exhibit wave behaviour. Nonetheless, these fields still take the form of general vector fields which is far too complex for analysis in any practical systems. Luckily, many of these systems, such as just about any laboratory conditions can produce, the time variations of the produced fields are of harmonious nature. We may, therefore, confine our attention to *time-harmonic* waves, also called *monochromatic* waves,[2] of given frequency ω.

- Chat about the possibility to express just about any function described as 'wave' by a Fourier transform, consisting of such monochromatic waves, https://en.wikipedia.org/wiki/Dirichlet%E2%80%93Jordan_test#Dirichlet_conditions_in_signal_processing.
- Chat about plane waves travelling in the direction of wave vector $\boldsymbol{k}$ and find a way to introduce it.
- Finish the *monochromatic* wave footnote.

[2]The etymology of this nomenclature comes from the Greek words *mónos* ('sole, single') and *khrôma* ('color').

Conclusion

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Glossary of Symbols

curl	curl
Δ	Laplace operator
div	divergence
grad	gradient
∂_ξ	partial derivative w.r.t. variable ξ

Bibliography

[1] L. A. Rud and K. S. Shpachenko, 'Polarizers on sections of square waveguides with inner corner ridges,' in *2011 VIII International Conference on Antenna Theory and Techniques*, Kyiv, Ukraine, 2011, pp. 338–340. DOI: 10.1109/ICATT.2011.6170775.

[2] C. Balanis, *Advanced Engineering Electromagnetics*. Wiley, 2012, ISBN: 9781118213483. [Online]. Available: https://books.google.com.tw/books?id=2eMbAAAAQBAJ.

[3] D. Griffiths, *Introduction to Electrodynamics* (Pearson international edition). Prentice Hall, 1999, ISBN: 9780139199608. [Online]. Available: https://books.google.com.tw/books?id=x0akQgAACAAJ.

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