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Doctoral Thesis Ing. KAMIL PITRA
„(Sub)Millimeter-Wave Antennas"

– Report –

The doctoral thesis (dissertation) of

Ing. KAMIL PITRA

is entitled

"(Sub)Millimeter-Wave-Antennas"

and focuses on the design and optimization of circularly polarized antennas for THz frequencies.

THz waves, specifically their efficient generation, has been an area of engineering science which caught constantly increasing interest by researchers around the world for at least a decade. The interest is driven by a variety of promising fields of application in metrology, life sciences, security, and many more. Although a lot has been achieved so far, more powerful, more efficient, less space consuming sources are needed to satisfy the requirement of the various applications. Thus, the topic of this thesis is current, of high importance and, as such, well-chosen.

In this thesis, a simplified theory of THz sources is presented and a specific antenna for THz sources is designed and optimized. The design of the antenna under investigation focuses on achieving circular polarization from a linear antenna. In order to suppress surface waves on an electrically dense dielectric substrate, periodic structures are utilized. The design takes into account the relation between the electromagnetic bandgap properties and the unit cell geometry. In order to properly focus the radiated energy, a partially reflective surface acting as a planar lens is designed and optimized.

The dissertation is purposefully structured and clearly arranged in eight sections.

Section 1 gives a brief *introduction* to THz frequencies with a useful list of eleven pieces of reference literature ranging from Siegel's IEEE article of 2002 to almost current letter articles.

The *state-of-the-art* is also briefly reported in section 2 with sixteen more pieces of reference literature. Although these references could serve as a basis for further reading, they are not very current (the newest one dates from 2007) while the explanations given as a frame of reference are a bit too brief. More details and a few figures would have made this section more valuable for the reader.

Section 3 concisely states the *objective* of this doctoral work.

Section 4, entitled "*Novel Multi-Layer THz Source*," again very briefly describes the structure and the operation principle of the device under investigation. This structure consists of three so-called regions: (a) the photoconductive mixer with a dual-slot antenna, (b) the THz antenna with crossed slots with mushroom-like electro-magnetic bandgap (EBG) structures, and (c) the partially reflective surface which acts as a planar lens. Although, these three regions (or "layers") are further described in the following sections, a more elaborated introduction at this point would have been appropriate.

With section 5, "*THz Source and THz Circularly Polarized Antenna*," the main part of the doctoral work starts. Photomixing in general (chapter 5.1) and the photoconductive mixer in particular (section 5.2) are briefly described. A THz source overview consisting of an equivalent-circuit model of the photoconductor and the antenna is given in chapter 5.3. Chapters 5.4, 5.5., and 5.6, finally, describe the various types of antennas utilized: a dual-slot antenna, a four-leaf-clover-shaped dipole, and a cross-slot patch antenna, respectively. The designs are explained, structural values are given, and results from numerical simulations (carried out with CST) are presented. Especially the different radiation patterns are shown and compared to each other. Once again, the work suffers in places from its briefness: "All unknown values *(which?)* can be calculated *(how?)* using equations *(show!)* given in [39], [40]." It has to be mentioned that the results presented in this section were published in

PITRA, K. et al., H. Design of Circularly Polarized Terahertz Antenna with Superstrate (Cover) Layer, in *Proceedings of the International Conference on Electromagnetics in Advanced Applications(ICEAA)*, Torino, Italy, 2013, page 363-363,

with the doctoral candidate as the first author.

Section 6, "*Periodic Structures and Planar Lens*" marks the core piece of the dissertation. An *overview of metallo-dielectric periodic structures* is given, *surface waves* are explained, and the *design and analysis of mushroom-like EBG structures* is made. The introduction of the irreducible Brillouin zone and of the dispersion diagram could have been at greater length since they are essential for the understanding of subsequent chapters. This section also comprises the experimental part of the doctoral work: the experimental verification of the design method at frequencies around 10 GHz. Measurement results for the TM surface wave transmission magnitude vs. frequency (5 ... 13 GHz) for the "mushroom-like" EGB structure are shown and compared to TM surface wave propagation numerical simulation results (at 9, 10, and 15 GHz). An Agreement between the measurement and the simulations could be confirmed. Thus, based on the confidence built by this comparison, further simulations were carried out varying the geometrical dimensions of the structure.

The final chapters of this section make the step towards *THz superstrates* (6.6) leading to *THz planar lenses* (6.7) where the radiation patterns show significant changes in the radiation behavior of the antenna with the superstrate in comparison the one without (Fig. 6.29). The antenna with superstrate excels in low side-lobe level and a considerable improvement of gain ($G_{improve}$ = 13.3 db).

Section 7, finally, combines the various building blocks: the dual slot antenna, the circularly polarized THz cross-slot patch antenna, the THz mushroom-like EBG structure, and the THz superstrate cover. CST simulation prove the generation of left-handed circular polarized THz radiation. Experimental verification, again, took place at a frequencies around 10 GHz. The reflection coefficient and the axial ratio, respectively, vs. frequency were measured, compared to CST simulations and presented in Fig. 7.9 and 7.10, respectively. Also the radiation patterns (normalized gain) were measured and simulated and compared to each other (Fig. 7.11). Unfortunately, a discussion of this final figure is missing. Good agreement (of the left-handed circularely polarized light – while the right-handed one is suppressed) of measurements and simulation at the center but some discrepancies at the side lopes would have been worth to be explained since it marks the capstone of the work.

Section 8 concludes the thesis.

It can be stated that the objective of the doctoral work including the sub-goals as outlined in section 3 has been reached/fulfilled. The design and optimization process was conducted in a meaningful manner, at critical steps experimental verification has been incorporated, before the optimization of the device took place.

Theoretical considerations, numerical simulations, and experimental verification were carried out by the candidate covering the entire spectrum of an engineering science design process. Although at some points the dissertation suffers from briefness where more details would have been interesting for the reader, it lead to original results presented at two major international conferences. Journal publications are lacking at this time. Also no outlook for further work to be conducted is given.

Nevertheless, candidate Ing. KAMIL PITRA clearly shows his capability of conducting engineering-science research. Thus, I recommend without hesitation that this thesis is accepted by the Faculty as a document satisfying the requirements for the award of a doctorate.

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