Modeling of Nonreciprocal Six-Pole Transformer Based on Helicon Resonator

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Abstract—A model of a six-pole nonreciprocal transformer representing a helicon resonator with three inductance coils placed at 120° angles is discussed. Calculations of transformer’s inductive parameters and scattering matrix components are presented. It is shown that such a transformer appears to be a nonreciprocal Y-circulator.

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INTRODUCTION

Nonreciprocal passive devices with distributed parameters (gyrators, valves, circulators) based on magnetized ferrites with tensor parameters of magnetic permeability find wide application in the millimeter, centimeter, decimeter and partially meter wave bands. Adoption of these devices in meter and decameter wave ranges is limited by increasing device dimensions and available ferrite materials.

A solution to this problem consists in utilization of nonreciprocal effects during helicon waves propagation in magnetized plasma of a solid body [1–3]. In presence of an external constant magnetic field plasma of a solid body possesses tensor parameters of dielectric permittivity with complex conjugate non-diagonal components. Extremely low phase velocity of helicon waves (10^4–10^5 m/s) allows executing dimensional resonance of a helicon wave in plane-parallel plate whose thickness is somewhat less than electromagnetic wavelength. As a material for helicon resonator semiconductors with high electron mobility (for example, indium antimonide) are used.

Nonreciprocal transformer is an essential element of nonreciprocal passive devices of meter and decameter wave ranges. Such a transformer represents a system of inductance coils coupled via a helicon resonator. Due to propagation of circularly polarized helicon waves in a helicon resonator nonreciprocal inductive coupling between the coils is observed. Since geometric dimensions of nonreciprocal transformer are much less than electromagnetic wavelength, its characteristics are adequately described by theory of nonreciprocal passive circuits with concentrated parameters. A valve [1–3] and a gyrator [4] are implemented on a nonreciprocal transformer with two inductance coils. During design of helicon valves a study of a four-pole nonreciprocal transformer model with two orthogonal exciting coils is conducted.

This paper aims to model and study characteristics of a nonreciprocal transformer with three inductance coils placed at 120° angles to each other.

MODEL OF A NONRECIPROCAL TRANSFORMER

Structure of a nonreciprocal six-pole transformer that consists of a plane-parallel plate with three inductance coils is depicted in Fig. 1. External constant magnetic field is perpendicular to the plate.

Since a helicon wave in the plate is excited by magnetic field of inductance coils the gyrotropic medium may be described a tensor of equivalent magnetic permeability that reflects anisotropy of the medium in the plane perpendicular to the applied magnetic field. Given the z axis aligned magnetic field, such a second-order tensor of equivalent magnetic permeability may be represented as [3]

\[
||\vec{\mu}|| = \begin{bmatrix}
\mu_L & -j\mu_T \\
\mu_T & \mu_L
\end{bmatrix},
\] (1)