STATUS OF MICROWAVE FERRITE TECHNOLOGY IN EUROPE

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Abstract

An overview of microwave ferrite-related activity in France, Germany, Spain, Poland and the UK is given. The topics include: ferrite materials and measurements, filters, junction circulators, numerical methods for gyrotropic planar circuits, coupled-line circulators and frequency-selective limiting.

6. Introduction

Microwave ferrite materials and applications can be regarded as a mature technology. Over the last fifty years microwave ferrite research has brought about a more thorough understanding of magnetism, has created passive nonreciprocal components that did not exist before, and has produced a number of very successful companies. In recent years, developments in technology, e.g. MMICs, and moves to utilise higher frequencies in the microwave spectrum have identified new challenges for this "mature" technology. Along with this need for a fresh look at nonreciprocal components, there is also the need to bear in mind the changing market place from high-specification, high-cost defense components to lower specification, low cost, high volume components for mass markets. This paper provides a brief overview of recent ferrite-related activities in Europe which will assist in the development of new components to meet the new challenges. In the interests of brevity detailed results are not included here but will be included in the presented paper.

2. Ferrite Materials and Measurements

A number of companies in Europe make a range of bulk ferrite and garnet materials, and development continues to improve the quality of the materials. Also, thick-film ferrite deposition techniques such as screen printing, tape casting and arc plasma spraying are also being investigated[1]. In Poland, novel techniques have been developed for the measurement of the components of the permeability tensor of a ferrite sample using dielectric ring resonators[2]. Also, dielectric resonators may be tuned using ferrite inserts and a variable dc magnetic field[3].

3. Filters

A tunable filter has been reported[4] which consists of a rectangular waveguide with a periodic change in the broad dimension, loaded in each broad section with a ferrite block. By varying the static magnetic field applied to the ferrite block either transversely, parallel to the broad walls, or longitudinally along the waveguide axis, the centre frequency of the filter can be tuned. For example, the centre frequency of a two-section filter can be tuned over a band of approximately 8% about a centre frequency of 30GHZ. The ferrite used was TT86-6000, and the applied field was in the range $0 \leq H_{dc} \leq 100$ Oe. Another tunable filter structure[5] being investigated consists of a magnetised ferrite disk in an off-centre circular aperture in a broad-wall waveguide coupler. Above-resonance operation is used, and the theory is being developed to allow experimental parameters such as the external applied magnetic field and frequency to be used in the design process.

4. Junction Circulators

At the Technical University of Hamburg 3-port E-plane[6] and H-plane[7] waveguide circulators have been analyzed using a method based on the equivalence principle and cavity field expansions. The structures considered consisted of full-height and partial-height and composite ferrite/dielectric posts, and the predicted behaviour showed good agreement with previously published experimental results. E-plane waveguide circulators with 20-dB isolations over a 6% relative bandwidth in waveguide sizes R140 to R900 have been developed by GEC-Marconi[8].

A synthesis procedure for compact broadband 3-

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port circulators has been described[9] in which undersized ferrite disks are used with radial lumped-element resonators and narrow coupling angles. Use is made of the fringing capacitance at the interface between the resonator and the surrounding substrate which has a higher dielectric constant than that of the resonator, and a 1-2 GHz design is described. In principle, any shape of ferrite may be used in a 3-port or 4-port junction circulator and although a circular shape such as a disk or ring remains the most popular, because it is straightforward to make and to analyze, other shapes such as a triangle, a wye or a square may be used provided the 3-fold or 4-fold rotational symmetry of the junction is retained. Another shape is the clover-leaf (3-fold or 4-fold) and the cut-off space for such resonators with electric or magnetic walls has been analyzed by Helszajn and Lynch[10] using a finite element method. A hexagonal shape of ferrite has been used in a 3-port stripline circulator in which a stub is placed symmetrically between each port in the central conductor metallisation[11]. The analysis was based on mode matching at the interface between the equivalent transmission line and junction region, and results presented for the frequency range 2-4GHz.

Lumped-element circulators have been fabricated using thick-film ferrite techniques for components with 10% bandwidth within the frequency range 200 MHz to 2GHz[12]. These electrically-small circulators typically have an insertion loss of less than 1dB and isolation greater than 20 dB[12].

Within the European Community specific frequency bands within the range 65-80 GHz have been allocated for vehicular communication and cruise control radar systems. Ferrite components for these frequency ranges present problems due to the mechanical precision required and the fact that the saturation magnetisation of commercially available ferrites has an upper limit of 5000-5500 Gauss. Some preliminary work to "push" the design of broadband tracking circulators to higher frequencies (18-40 GHz) has shown some promising initial results[13], and further work is required. At high microwave frequencies, in order to alleviate the mechanical tolerances, it is possible in principle to select a larger ferrite disk by using a higher order mode of circulation instead of the "dominant" mode. This has been explored theoretically[14] for a 94GHz design and the "trade off" is that a larger disk size (R = 0.467mm) results in a narrower bandwidth (3GHz isolation > 15 dB) than the disk which gives the dominant mode of circulation (R = 0.270mm) which has an isolation > 15dB over 8GHz.

Some novel nonreciprocal components using either ferrite rings or disks have also been discussed.[15-17] The circulation conditions for 3-port ring structures have been derived assuming the inner and the outer surfaces of the ring to be magnetic walls, and asymmetrical and symmetrical non-reciprocal components have been proposed[15]. The performance of symmetrical 3-port ring circulators and of asymetrical 3-port disk circulators has been described in Ref.16. The latter components have three ports spaced apart by 60° rather than the more usual 120°, offering the opportunity for a more compact circuit layout in some circumstances. The initial assumption that the inner surface of a ferrite ring is a magnetic wall has subsequently been modified and a more accurate model has been developed which takes into account the permittivity of the dielectric medium in the centre of the ferrite ring[17]. The circulation conditions and performance data have been computed for some typical composite ferrite/dielectric circulators, and it has been shown that the earlier magnetic wall assumption is a valid approximation only for inner/outer radii ratios (R_i/R_o) less than 0.2[17]. For larger "holes" than this, the fuller ferrite/dielectric theory must be used. Semiconductor junction circulators are also possible[18], and, whilst they do not come under a title of "Ferrite Technology", in some respects they exhibit behaviour which is similar to that of ferrite circulators. Semiconductor circulators may offer new possibilities of nonreciprocal components that are compatible with MMICs.

5. Numerical Methods for Ferrite Waveguides

A finline field-displacement isolator has been analyzed, using a mode matching technique, by Köther et al (19). Using a multilayer structure including transversely-magnetised ferrite, dielectric and lossy thin films within a rectangular waveguide, they obtained an insertion loss of approximately 1dB with an isolation of greater than 38dB. Dillon and Gibson[20, 21] have used a finite element method for the analysis of axially-magnetised ferrite-loaded hollow waveguides. A suitable field transformation has been implemented so that the propagation constant becomes the eigenvalue solution. This allows preprocessing in terms of experimental parameters such as the saturation magnetisation, the applied bias field and the frequency.

At the University of Seville methods have been developed for the analysis of planar waveguides containing ferrites[22-26]. Most of this work has been carried out using spectral domain techniques and a first order differential formulation of the field equations to compute the spectral dyadic Green's function, but some papers use the simpler quasi - TEM model. A general algorithm for computing the bidimensional spectral Green's dyad has been described[22], and also propagation in parallel-plate waveguide with a

multilayered bianisotropic medium has been analyzed[23]. The latter approach can be applied to parallel-plate waveguides containing ferrite layers magnetised in arbitrary directions. A comparison between results using the quasi-TEM and the full-wave analyses for coplanar structures on longitudinally magnetised ferrites has been given[24,25], and an interactive procedure to deal with quasi-TEM lines with longitudinally magnetised ferrites has also been described[26].

6. Coupled-line Components

Apart from the classical Faraday rotation components in circular waveguide, and the Reggia-Spencer phase shifter in rectangular waveguide, which use a longitudinal magnetic field, the majority of the widely used ferrite components in waveguide, stripline and microstrip use a transverse static magnetic field to bias the ferrite. However, since the demonstration of novel isolators and 4-port circulators using coupled lines loaded with a longitudinally-magnetised ferrite layer[27,28] there has been renewed interest in longitudinally-magnetised ferrite planar waveguides. It has been shown[29] that the effect of the longitudinally-magnetised ferrite is to couple the normal modes of the unmagnetised coupled structure, and a 4-port circulator has been described[30].

7. Thin-Film Components

Magnetostatic waves (MSW) in YIG or doped-YIG epitaxial thin films offer opportunities for linear or non-linear signal processing applications. For example, development at GEC-Marconi[8] and DRA-Malvern has shown that narrowband filter characteristics can be defined for low noise VCO and tunable notch filter applications, alternatively wider bandwidth filter characteristics (up to 2GHz) can be realised where appropriate. With careful profiling of the d.c. bias field, a single magnetic film can be used to direct signals from a common input transducer to different output transducers according to their frequency. This channelised filter application is generally considered to offer benefits over other linear filter technologies. The nonlinear behaviour of these devices at high r.f. signal levels introduces a further range of applications[8]. Nonlinear instability in ferrites is well known and the behaviour depends upon device structure and magnetic bias field strength and orientation. In MSW devices these limiting mechanisms are narrow bandwidth phenomena even within a device designed for broadband operation. Thus, a device can continue to respond to small signals in a linear manner whilst limiting any coincident signals above a threshold level. This is termed "frequency selective limiting". These devices can be used either to attenuate high power signals with respect to adjacent small signals, or to suppress small signals relative to large signals. A range of applications can be envisaged for these components.

Conclusions

There is a broad spectrum of ferrite-related activity in Europe, with new developments in both theory and hardware. A cross-section of results from the work cited will be presented at the Symposium.

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