Chiral'96 — Book of Abstracts

NATO Advanced Research Workshop

23–30 July 1996 ⋆ Moscow → St. Petersburg (Russia)

A. Sihvola, S. Tretyakov, A. Vinogradov, A. Priou (editors)

Helsinki University of Technology
Faculty of Electrical Engineering
Electromagnetics Laboratory

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Abstract
Chiral'96 will be an international workshop that focuses on the electromagnetics of chiral, bi-isotropic, and bi-anisotropic media. This NATO-ARW (Advanced Research Workshop) meeting will be held aboard a river-boat that travels from Moscow to St. Petersburg in Russia during 23–30 July 1996. The present report is the collection of abstracts of contributions that have been accepted and invited to be presented at the meeting. After the meeting, full proceeedings will be published.

Keywords:
Chiral materials, bi-anisotropic media, electromagnetic theory

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Optically induced fast rotating spatially uniform structure in chiral media: SHF electromagnetic waves propagation

I.N. Akhramenko and I.V. Semchenko
Gomel State University, Physics Department
Sovyetskaya Str. 104, Gomel, 246699, Belarus

Modulation of the optical properties of non-linear chiral medium with two light waves of right-handed and left-handed circular polarizations is considered. In this paper conditions have been established under which the induced anisotropy becomes spatially uniform. In that case the gyrotropy contribution is compensated by the difference of modulating wave numbers.

Some techniques have been used to proceed to a rotating coordinate system which have allowed to determine the accurate type of solution of Maxwell's equations that becomes possible in a case of uniaxial rotating anisotropy forming in the media. Boundary problem solution has been found allowing to analyze the features of transformation and reflection of the signal wave.

Optical properties of crystals with induced spatially uniform rotating anisotropy were discovered to be similar to those of cholesteric liquid crystals (CLC). Effects of selective reflection and polarization plane rotation were demonstrated to be possible. Moreover, selective amplification of test electromagnetic wave of given frequency and polarization was demonstrated to be possible too. It has been demonstrated that the phase conjugation of electromagnetic waves with the resulting transformation of the wave front in the SHF and the IR- band can occur in crystals with induced spatially uniform rotating anisotropy.

The effect of attenuation of the test wave absorption in the selective reflection range in the medium with the induced rotating anisotropy has been predicted. It has been demonstrated that the suppression of the test wave absorption is caused by the polarization of the eigenmodes. Earlier similar effects were observed in the case of a discrete periodic arrangement of the absorption centers (Borman's effect for X-rays in crystals) as well as during a periodic variation of the orientation of absorption oscillators in space (CLC). In our studies it has been demonstrated that the polarizing effect of the absorption attenuation can occur also in the case of the periodic variation of the orientation of absorption oscillators in time.

Mutual coupling in arrays of planar chiral structures

Luk R. Arnaut

Department of Electrical Engineering and Electronics
The University of Manchester Institute of Science and Technology
P.O. Box 88, Manchester M60 1QD, United Kingdom

In the study of high-density composite media, the quantisation of the effect of mutual coupling (multiple scattering) is important to compute accurate estimates of effective medium parameters. Recently, we have developed an analytical technique to compute coupling between two general bianisotropic particles (*J. Electro. Waves Applic.*, 1996, to appear). The coupling between multiple particles is much more complicated, but can be done relatively easily if these form regular arrays. In this paper, planar arrays of planar chiral structures (swastikas) will be analysed. Modified dipolarisability dyadics for this arrangement are computed and compared with direct numerical computations using a moment method technique. It will be shown that, even for high densities, the restriction to first-order coupling is sufficient to obtain accurate estimates for the total coupling and effective medium parameters.

Radiation of electromagnetic sources moving in chiral media with surfaces

K.A. Barsukov and A.A. Smirnova

St. Petersburg Electrical Engineering University, 5 Popov Str., St. Petersburg, 197376, Russia
Fax (7-812)-2349656

In the last years the chiral electrodynamics has been developed in connection with varied possibilities for science and engineering. In particular the questions of the generation of electromagnetic waves for both continuous chiral media and media with surfaces were discussed. So the Cherenkov radiation arising when a point charge moves through the chiral medium was also considered. Naturally, in real devices, a modulated current must move in a channel in the medium or in the vicinity of its surface. Here we hope that chiral media will find applications in free-electron lasers. We propose to consider the next three problems for finding basic particularities of an interaction of a moving charge with media with surfaces:

1. The radiation of linear current and charged sources moving along the plane surface of the chiral medium. The essential particularity of the problem is an exponential decrease of the radiation energy depending on the distance from the surface with different dependence for left-handed and right-handed polarized wave.

2. The radiation of the charge moving along the axis of circle channel in a chiral medium. In this case the radiation energy depends on the ratio of the radius of the channel to the wavelength. The radiation energy is described by the factor that is different for the left-handed and right-handed polarized waves in difference from one in a continuous medium.

3. The radiation of the charge moving along the axis of a circular waveguide with a chiral medium. In this case the spectrum of the Cherenkov radiation is a discrete one with different frequencies for left and right polarizations.

Stereoglasses with composite and chiral liquid crystals

V.V. Belyaev[1], Y.V. Devyatkin[2], V.G. Nazarenko[3], G.B. Nosov[4] and A.S. Sonin[4]

[1] Central R&D "Cometa", 5 Velozavodskaya st., Moscow 109280, Russia
E-mail: ieasbond@monk.lz.space.ru, Fax (7–095)274-08-96
[2] Microcosm Ltd, Moscow, [3] Institute of Physics of NASU, 46 pr. Nauki, Kiev 252650, Ukraine
[4] Organic Intermediates and Dyes Institute, 1/4 B. Sadovaya st., Moscow 103787, Russia

Stereoglasses for PC monitors provide volume vision and reconstruction of virtual reality for educational, military, training and other purposes. Usual glasses with liquid crystal electrooptic shutters require polarizers. For this reason they have low transmittance and alternative light flux on each eye. It induces fatigueness of operator.

We have tested a series of various types of modern composite materials — polymer dispersed liquid crystals. They are transmittant in on-state (65–80%) and opaque in off-state. The switch time (1–7 ms) is sufficient for the stereoeffect. Main advantage of the stereoglasses is very weak variation of light flux on user's eye and absence of fatigueness.

Modelling composite media including chiral or pseudo-chiral scatterers

L. Bideo, S. Bolioli, and P.F. Combes
CERT/ONERA, 2 avenue E. Belin, 31055 Toulouse, France
Université P. Sabatier, 118 route de Narbonne, 31062 Toulouse, France
Tel: 33-62-25-27-22, Fax: 33-62-25-25-77, E-mail: Lionel.Bideo@onecert.fr

Chiral media present two basic properties: the optical activity and the circular dichroism. In the microwave range, such media may be manufactured by including metallic helices in a dielectric host. Other similar effects can be obtained by using omegas (pseudo-chiral) instead of helices. The problem consists in the optimisation of the helices' size (radius and step) and their distribution (density and orientation versus the incident wave vector).

The models based on diffusion (RAYLEIGH-BOHREN) and the generalised MAXWELL-GARNETT ([1]–[2]) approach are the most commonly used to describe the electromagnetic properties of such chiral or pseudo-chiral composites. Generally, they give better results for scatterers with dimensions small compared to the wavelength and for sparse concentration. In such formalisms, it is not easy to describe accurately the interactions between elements. To get better accuracy, especially for dense concentration, the polarizability may be computed using numerical techniques (method of moments or finite elements) [1]. A next step for treating the composite problem (multiple scatterers), particularly for regular distributions, is completely numerical.

Whatever the global modelling, one needs first to understand the behaviour of the single particle. Concerning the helix it has been showed [3], [4] that a one turn element, with a pitch equal to the diameter, provides an almost isotropic distribution of the scattered energy, as well as an important chiral performance. This efficiency has been related to the excitation and resonance conditions.

A regular sparse array of such helices has been treated successfully using the generalised MAXWELL-GARNETT [5] approach, but the results were not so satisfactory for random distributions. The fully numerical technique based on the method of moments has been developed and applied to these cases. It has been showed that random distributions are not optimised for chirality. Also, for dense regular arrays, the behaviour is closed to the single helix one. The chiral efficiency appears to be proportional to the square of the total number of helices, and so, it is possible to describe the properties of large arrays using the results computed for smaller ones. Then it has been possible to optimise the helix distribution to get better chirality.

To develop this model, new GREEN functions have been written, which take into account the dielectric host and the air-composite interfaces. A good agreement between experimental and computed results has been obtained on a 89×89 array of helices.

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Effective material parameters of plane stratified bianisotropic superlattices

G.N. Borzdov

Department of Theoretical Physics, Byelorussian State University
Fr. Skaryny Avenue 4, 220050 Minsk, Belarus
Fax: (7) 0172 26 59 40, E-mail: root%bark.bsu.minsk.by@relay.ussr.eu.net

The superlattices formed by the periodical set of N plane bianisotropic layers with different thicknesses are theoretically studied in the long-wave limit (wavelength far larger than the structure period). We consider the layers from the materials with the constitutive equations

$$\mathbf{D} = \bar{\bar{\epsilon}} \cdot \mathbf{E} + \bar{\bar{a}} \cdot \mathbf{H} \quad \text{and} \quad \mathbf{B} = \bar{\bar{b}} \cdot \mathbf{E} + \bar{\bar{\mu}} \cdot \mathbf{H}$$

where dielectric permittivity $\bar{\bar{\epsilon}}$, magnetic permeability $\bar{\bar{\mu}}$, and pseudotensors of gyrotropy $\bar{\bar{a}}$ and $\bar{\bar{b}}$ are complex nonsymmetric tensors. The effective tensors of permittivity, permeability and two pseudotensors of gyrotropy characterizing the structure under consideration in the long-wave approximation are found in the coordinate-free form. The derived formulae make it possible to analyse the properties of superlattices of the most general type, which are made up of absorbing anisotropic and gyrotropic magnetic crystals subject to influence of external electric and magnetic fields and elastic deformations. Some examples are given to show the convenience of obtained expressions for calculation of parameters of superlattices. The derived general formulae are consistent with the expressions for known particular cases.

Inverse problem of reflection and transmission for a bi-anisotropic medium

G.N. Borzdov

Department of Theoretical Physics, Byelorussian State University
Fr. Skaryny Avenue 4, 220050 Minsk, Belarus
Fax: (7) 0172 26 59 40, E-mail: root%bark.bsu.minsk.by@relay.ussr.eu.net

In this paper, we present the exact solution of the inverse problem of reflection and transmission for a bianisotropic medium with the constitutive equations

$$\mathbf{D} = \bar{\bar{\epsilon}} \cdot \mathbf{E} + \bar{\bar{a}} \cdot \mathbf{H} \qquad \text{and} \qquad \mathbf{B} = \bar{\bar{b}} \cdot \mathbf{E} + \bar{\bar{\mu}} \cdot \mathbf{H}$$

The solution makes it possible to determine uniquely the permittivity tensor $\bar{\bar{\epsilon}}$, permeability tensor $\bar{\bar{\mu}}$, and two pseudotensors of gyrotropy $\bar{\bar{a}}$ and $\bar{\bar{b}}$, which generally have 36 independent complex components, provided the reflection and transmission coefficients of the medium are given (measured). As is known, the above constitutive equations describe moving media as well as stationary chiral media and can be replaced by one four-dimensional equation. By making use of this equation and the four-dimensional formulation of the impedance and characteristic matrix methods, we obtain the solution in the Lorentz-covariant form so that it is applicable to both stationary and uniformly moving dispersionless media. If the medium is spatially dispersionless in its rest frame, one can use this solution to find all 36 components of the tensors $\bar{\bar{\epsilon}}$, $\bar{\bar{\mu}}$, $\bar{\bar{a}}$, and $\bar{\bar{b}}$ at a given frequency ω by measuring, in that frame, the reflection and transmission coefficients of the medium at several different boundaries, planes and angles of incidence.

The spatial dispersion drastically complicates solving direct and inverse problems of reflection and transmission, since the parameters $\bar{\bar{\epsilon}}$, $\bar{\bar{\mu}}$, $\bar{\bar{a}}$, and $\bar{\bar{b}}$ introduced for a harmonic plane wave, depend on the wave vector $\mathbf{k}$ as well as the frequency ω. Instead of using a separate set of such tensors for each eigenwave, it is more appropriate to extend the localized material equations on some superpositions of waves by introducing generalized material tensors. In this paper, we present also the relations which make it possible to find these generalized material parameters as well as the properties of eigenwaves in a spatially dispersive bianisotropic medium provided its reflection and transmission coefficients are given (measured).

On chirality measurements in circular waveguides

Gerald Busse, Jens Reinert, and Arne F. Jacob
Institut für Hochfrequenztechnik, Technische Universitaet Braunschweig
Postfach 3329, D-38023 Braunschweig, FR Germany

To measure and invert the scattering parameters of a chiral slab in a circular waveguide is a promising way to accurately determine the chirality parameter of chiral media. While the theoretical aspects of the extraction procedure were treated elsewhere [1], this study is devoted to practical aspects and results. To this end, a chiral material is manufactured of small randomly oriented injection molded foam spheres each including a three-turn copper helix. Thus, shape, size, and chirality of the slabs can be easily varied. The latter is done by substituting chiral spheres, i.e. spheres containing a copper helix, by empty ones. Our measurement setup consists of two connectable circular waveguide sections both matched at one end by tapered absorbers to suppress longitudinal resonances. The connection to the coaxial measurement system is realized by radial linear antennas matched over broad band by tuning screws. To exclude systematic errors a calibration is performed using the well known TRL-method. Following the procedure outlined in [1] reflection of and co- and crosspolarized transmission through chiral slabs of at least two different lengths are measured to determine the chirality and the product of permittivity and permeability. In order to obtain unambiguous solutions scattering parameters were taken for more then two slab lengths and, in addition, for different rotation angles to average out sample variations and inhomogeneities. Results, i.e. the chirality parameter as a function of frequency in the fundamental mode region, were obtained for different chiral concentrations. A spurious passband below the cutoff frequency of the empty waveguide confirms that measurements were performed above the material resonance.

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Experimental confirmation of a numerical constitutive parameters extraction methodology: uniaxial bianisotropic chiral materials

Chee Y. Chung and Keith W. Whites
Department of Electrical Engineering, University of Kentucky
Lexington, KY 40506–0046, USA

A uniaxial bianisotropic chiral (UBC) material can be constructed, among other ways, by aligning "uniaxial helices" (or other uniaxial chiral particles) in a regular lattice such that their axes are parallel to each other. This type of material has possible electromagnetics applications as polarization transformers, filter devices and absorbers, among others. We have previously modeled this UBC material numerically and extracted its effective constitutive parameters (Chung and Whites, "Effective constitutive parameters for an artificial uniaxial bianisotropic chiral medium," accepted for publication, J. Electromagn. Waves Appl.). A number of tests were undertaken to validate this methodology and the results were promising. Since then, two UBC slabs were fabricated by embedding uniaxial helices in an epoxy host. This experimental effort was carried out to further verify the accuracy of the methodology and to identify new useful phenomenon.

In this presentation, the fabrication of the UBC samples and the measurement of their scattering will be discussed. A free-space measurement facility, comprised mainly of two lensed-horn antennas and an HP8510B network analyzer, was used to measure the scattering response of these samples. The calibration method and the accuracy of this measurement system will be discussed in this talk.

The scattering from these manufactured slabs was predicted using our numerical effective constitutive parameters extraction methodology. Excellent correspondence was observed between the predicted scattering parameters and those measured for the two UBC samples. This data will be presented. It was found that these slabs could possibly be used to construct adjustable electromagnetic filter devices since the minimum in the reflection coefficients occur at different frequencies as the slabs are rotated about a normal to the slab surface. Finally, a comparison of the case when mutual coupling between inclusions is ignored will also be shown.

This experimental validation is strong evidence that these samples can indeed be macroscopically described as UBC materials and that our methodology for artificial material parameter extraction is valid and accurate.

Electromagnetic properties of artificial chiral structures formed by multifilar wire helix grating

A.D. Chuprin, A.D.Shatrov, and A.N. Sivov

Institute of Radioengineering and Electronics, Russian Academy of Sciences
1 Vvedenskogo Sq., Fryazino, Moscow region, 141120 Russia
E-mail: vss137@ire216.msk.su

Multifilar wire helix grating is one of actual chiral objects that allows rigorous electromagnetic approach to be applied. Depending on the grating geometry, such structures demonstrate different reflecting features, first of all connected with circular polarization. Part of the features is listed below. For definiteness, the helices are taken to be right-handed.

1. *Frequency-polarization modulation.* For circularly polarized incident waves having the same handedness as the incident wave, slight variations in the frequency cause a great change in the orientation of the electric field vector of the transmitted and reflected waves, whereas for the opposite handedness, the orientation practically does not change.

2. *Semitransparent screen for circularly polarized wave.* The grating illuminated by a circularly polarized wave reflects and transmits circularly polarized waves, with both waves having the same handedness as the incident one. Thus, no depolarization of a circularly polarized wave takes place.

3. *Circular polarization selective structure.* For an appropriate geometry, the wire helix grating totally reflects left-hand circularly polarized waves and partially transmits the right-hand ones. A pair of such gratings forms a transmission type resonator which totally reflects the wave of left handedness and totally transmits the wave of the opposite handedness.

4. *Isotropic twist polarizer.* Unlike the usual anisotropic twist polarizer (formed, e.g., by a cascade of linear wire gratings) and rotating the electric vector through a given angle only for a certain orientation of the electric field vector of the normally incident linearly polarized wave, proposed structure rotates the electric vector in transmitted wave through a given angle for **arbitrary** orientation of the electric vector of the incident wave.

5. *Circular polarizer – power divider.* Conventional thick grating of linear conductors is known to divide a circularly polarized wave into two parts having equal amplitudes, with the transmitted wave being *TE-polarized*, whereas the reflected one being a *TM-wave.* The helix grating divides the power of the incident *TE-polarized* wave into two equal parts as well. But both transmitted and reflected waves are circularly polarized and have the opposite handedness.

Thus the wire helix grating is an effective tool to deal with circularly polarized waves. It handles a circularly polarized wave in such a manner as a linear wire grating does a linearly polarized wave.

Electromagnetic scattering by three-dimensional arbitrary shaped chiral objects

A.G. Dmitrenko, A.I. Mukomolov, and V.V. Fisanov

Siberian Physical & Technical Institute and Department of Radiophysics
Tomsk State University, Revolution Sq. 1, Tomsk, 634050, Russia
E-mail: helen@eccspti.tomsk.su

Last years the attention of many investigators is directed to studies of the electromagnetic phenomena in regions fully or partially occupied by the chiral medium [1]-[3]. Progress in the synthesizing of artificial microwave chiral materials [4] makes expectations to create waveguide components and antennas with new properties quite real and reinforces the interest in learning of all aspects of electromagnetic interaction with chiral media including the scattering problems.

In this paper a numerical method will be presented for analysis of electromagnetic wave scattering problems on 3-dimensional arbitrary shaped chiral bodies. The method is a version of the discrete sources method [5], which is extended towards the chiral bodies. The main ideas of the method are the following. The scattering field in the outer space is presented as a sum of the auxiliary electrical dipole fields with unknown moments. These dipoles are placed inside the body on an auxiliary surface, which has the similar form with the scatterer form and oriented tangentially to the auxiliary surface. The field inside the body is presented as a sum of analogous dipoles placed outside the scatterer on another auxiliary surface which has similar form too. The unknown vector dipole moments are defined as solutions of the linear algebraic equations system derived with taking into account boundary conditions by the collocation method. This solution is computed via minimization of the functional which is the square error of the algebraic equations system by conjugate gradient method.

The method was realized as the application package in Fortran. With this package the Bistatic Cross Sections were calculated for co- and cross-polarized field components of set of bodies (finite elliptical cylinder, 3-axial ellipsoid). The dependence of BCS from chirality parameter was investigated. The numerical results will be presented and discussed.

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Small elements with chiral properties in microwave open resonator

Igor O. Dorofeev

Siberian Physical & Technical Institute, Revolution Sq. 1, Tomsk, 634050, Russia

The switching of elements of small electric sizes, possessing the property of magneto-electric interaction in microwave open resonator is considered. These elements in common case can be characterized by tensors of electric polarizability, magnetic polarizability and cross-polarizability. The variations of resonant frequencies of main axial modes of quasioptical open resonator under the influence of chiral elements are calculated by the perturbation method [1]. Both isolated modes and interaction of polar-degenerated modes on chiral elements are considered. A few types of interactions can be selected. First, the interactions between the electric field components and the magnetic field components of coupled modes. Secondly, the interactions between the components of electric and magnetic fields of both isolated and coupled modes. The last cases for chiral elements are most interesting. In order to find the connections of the perturbation frequencies of the open resonator axial modes with the components of the polarizability tensors, we considered different orientations of the elements in the mode fields and their different placements in the resonator volume.

Some results of experimental investigations on axial mode spectrum of open resonator, composed of two spherical mirrors in $5-5.5$ GHz frequency bandwidth with chiral elements in form of small helices [2] are discussed. In order to increase geometrical sizes of the elements, we used a rather low frequency band for open resonator as the most optimal from our point of view. But there are no problems to interpret these results on high frequencies. We used TEM modes with the 0,0,14 and 0,0,15 indices. The resonant frequency variations of these modes under the influence of chiral elements, placed between the mirrors, are measured.

These results can be used in measurements of the characteristics of small chiral elements of complex forms whose rigorous mathematical models are not available.

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Scattering by frequency selective surfaces supported by an isotropic chiral slab

Tuncay Ege, A. Oguzhan Koca
University of Gaziantep, Electrical and Electronics Engineering Department
27310 Gaziantep, Turkey. E-mail: tuncay@gubim.bim.gantep.edu.tr

Transmission and reflection characteristics of plane wave scattering by the novel frequency selective surfaces (FSS) comprising of an infinite two dimensional arrays of conducting circular rings, rectangular patches, cross dipoles and rectangular loops backed by an isotropic chiral slab are presented.

In the formulation, modal techniques which are employed in the analysis of FSS printed on dielectric substrates are used since the existence of the chiral slab does not spoil the transverse nature of the problem which has been frequently exploited in the solution of the conventional problem. However, since chiral medium can support only left circularly and right circularly polarized waves having different wave numbers; in this case, the transverse components of the scattered E and H fields are expressed as infinite sums of left and right circularly polarized "TE-" and "TM-"Floquet modes propagating in the forward and backward directions in the chiral slab and in air on either side. These Floquet modes also satisfy the periodicity requirements imposed by the problem. Boundary conditions combined with the orthogonal property of the Floquet modes over a single, periodic cell leads to a Fredholm integral of first kind for the unknown current density induced on a conducting element by the incident plane wave. The resulting integral equation is then solved by Method of Moments, thereby expressing the current distribution on a conducting element by a series of cosine and sine terms with unknown coefficients. Upon finding the unknown current coefficients by means of matrix inversion, the reflection and transmission characteristics are computed in a straightforward manner.

Results indicate that resonances with narrower bandwidths than that of conventional FSS (dielectric backing) are achievable if the FSS is supported by an isotropic chiral slab. Furthermore with chiral backing multiple reflection resonances (full reflection) can be obtained even when the surface is illuminated by a normally incident plane wave.

Results also show that polarization conversion is possible when a chiral backed FSS is employed. That is, a TM wave incident on a FSS backed by a chiral slab can turn to a TE wave (with full transmission) in air on the other side.

Jones transmission and reflection matrices for low-symmetric absorbing gyrotropic crystals

E.A. Evdischenko and A.F. Konstantinova
Crystallography Institute, Russian Academy of Sciences, 117333 Moscow, Russia
E-mail: tronin@saxslab.incr.msk.su

Transmission and reflection matrices are obtained for low-symmetric absorbing gyrotropic crystal plates. Multiple reflection are allowed. Eigenwaves ellipticities are different. Matrices are represented as the sums of four matrices, and each of them has its own physical meaning. Derived transmission and reflection matrices permit to solve the problem about light propagation through a crystal plate with any collection of optical properties. Besides, it is possible that the allowance of multiple reflection and the eigenwaves irreverse can be taken properly into account.

Electromagnetic surface waves at a plane boundary of semi-infinite Faraday chiral media

Vasilii V. Fisanov and Dmitrii A. Marakasov
Siberian Physical & Technical Institute and Department of Radiophysics
Tomsk State University, Revolution Sq. 1, Tomsk, 634050, Russia
E-mail: helen@eccspti.tomsk.su

Faraday chiral medium belongs to the class of bi-anisotropic media. It has been offered as a generalization of the isotropic chiral medium with the Post–Jaggard constitutive relations in two modifications: *chiroplasma* (the permittivity is a dyadic) and *chiroferrite* (the permeability is a dyadic) [1]. As any artificial material, the Faraday chiral media samples have finite sizes, and therefore the boundary effects (surface waves etc.) are quite important. In the ordinary chiral medium surface waves exist only at the impedance boundary [2]. For the Faraday chiral medium one may expect the appearance of the interface guided waves on the analogy of the gyroelectric media. Such waves (also named by surface plasmons) are known both in gaseous and solid magnetoplasmas [3,4]. In the paper we seek the electromagnetic surface waves on the plane interface between chiroplasma or chiroferrite and an isotropic achiral medium for the case in which the static magnetic field is parallel to the boundary but perpendicular to the propagation direction. Beforehand two free bulk plane waves of the Faraday chiral medium are investigated in the plane transversal to the static magnetic field, their wave numbers are found as solutions of a biquadratic equation. Therefore a surface wave is such paired superposition of bulk waves, which has the common real propagation coefficient. The boundary conditions result in a set of homogeneous algebraic equations, whose nontrivial solution is obtained by setting the determinant equal to zero. From here the specifying propagation coefficient dispersion equation is derived which can be written as a biquadratic equation. In general, the equation coefficients are very involved, however we can gain an insight into the properties of surface waves for special cases of the perfectly conducting boundary.

The electric wall solutions are the most lucid. For the magnetic wall the equation discriminants are compact enough in order to simplify the subsequent analysis. As in the case of bulk waves, the analysis of the propagation constants allows to find the pass and stop frequency bands on the plane of dimensionless frequency parameters of the media. The chiroplasma electric wall surface wave is the unidirectional one, on the contrary, the chiroferrite electric wall surface wave is symmetrical one. The chiroplasma electric wall surface wave propagation coefficient depends on the propagation coefficients of the ordinary, extraordinary, surface waves of the magnetoactive plasma, and also on the square of the chirality admittance. If the chiral parameter vanishes, the propagation coefficient value tends to that of the surface wave in plasma [3]. The chiroplasma electric wall surface wave exists only on the frequencies less than the electron gyrofrequency, and this may be the backward wave provided the chirality admittance is large enough.

In conclusion, we produced the complete spectrum of the transversely propagating characteristic bulk and surface waves and made the background for consideration of the radiation and diffraction problems in the Faraday chiral media halfspace.

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Bessel-Gaussian and Bessel light beams in gyrotropic medium

A.M. Goncharenko, N.A. Khilo, E.S. Petrova
Division for Optical Problems of Informatics (DOPIT), Belarus Academy of Sciences
P.O. Box 1, Minsk 220072, Belarus
E-mail: dopit@bas.minsk.by

Bessel-Gaussian and Bessel light beams, that is beams with amplitude distribution in a kind of Bessel or the product of Bessel and Gauss functions, have begun to be studied recently (see [1-3]). The interest to such beams is because of their unusual diffractional properties. For example, for Bessel beams divergence is theoretically equal to zero. For Bessel-Gaussian beams divergence also can be reduced in comparison with Gaussian beams. However, features of propagation as well as transformation of Bessel and Bessel-Gaussian beams in anisotropic, particularly, in gyrotropic, media are not enough completely investigated now. We start with constitutive relations, connecting vectors of fields, and with the Maxwell equations to obtain a set of equations for vectors **E** and **H**. Further we assume, that the incident amplitude distribution is described by Bessel-Gaussian function. Solving a set of equations we obtain analytically expressions for amplitude of field inside a gyrotropic medium. Based on obtained expression, we investigate in detail polarization and space properties of the Bessel-Gaussian beams. Particularly, comparative numerical analysis of Bessel-Gaussian and Gaussian beams has been performed. It has shown an opportunity of essential divergence reduction. It is interesting that under some conditions of excitation the polarization of Bessel beams in gyrotropic medium can be arbitrary, that essentially differs from the case of plane waves.

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Reflection from an anisotropic chiral medium

E.B. Graham and R.E. Raab
Physics Department, University of Natal
P/Bag X01, Scottsville, 3209 South Africa

The transmission and reflection amplitudes at an interface are obtained when appropriate boundary conditions are imposed on the characteristic waves in each of the two adjoining media. These waves are the solutions of Maxwell's equations, augmented with suitable constitutive relations. Standard Maxwell boundary conditions require, at a source-free interface, continuity of the normal components of **D** and **B** and the tangential components of **E** and **H**. However, when these boundary conditions are used in theories of reflection from chiral media, conflicting results have been obtained which depend on the choice of the constitutive relations for the **D** and **H** fields. In addition to the analytical and experimental methods that have been applied to distinguish the correct forms of the constitutive relations for an isotropic chiral medium, space-time symmetry considerations may also be used. We have found that reflection matrices which satisfy the constraints of Reciprocity (that is, time-inversion) can be obtained from the Maxwell boundary conditions only when the constitutive relations meet covariance requirements. Such relationships are derived for an anisotropic chiral medium in terms of macroscopic electric and magnetic multipole tensors of the medium. The properties predicted by this theory for reflection from CdS (a uniaxial crystal with C_{6v} (6mm) symmetry) are compared with experiment. The theory has also been applied to explain reflection from the magnetoelectric crystal Cr_2O_3.

Point charge moving uniformly in a linear weakly bi-isotropic medium

Pierre Hillion

Institut Henri Poincaré, 86 Bis Route de Croissy, 78110 Le Vésinet, France

We give the expressions of the electromagnetic field generated by a charge moving uniformly in a linear, weakly bi-isotropic, nondispersive medium. In such medium, significant are only those fields that depend linearly on chirality and we consider successively sub- and superluminal motions.

Then, in the rest frame K_0 of the moving charge the partial differential equation for the electric potential is a Poisson (resp. a 2D wave) equation for subluminal (resp. superluminal) motions with the same solution as for an isotropic medium. So the Cherenkov radiation appears as an electromagnetic wake due to the particular property that wakes appear only in the solutions of 2D wave equations. In the rest frame Maxwell's equations do not depend on time and it is a matter of elementary algebra to get the components $\mathbf{b}, \mathbf{d}, \mathbf{h}$ of the electromagnetic field in terms of the electric field $\mathbf{e}$.

To get the radiation generated by the moving point charge in the laboratory frame K, one has just to apply the Lorentz transforms between the expressions of the electromagnetic field in K_0 and K. As expected, a comparison of radiation in isotropic and weakly bi-isotropic media shows that a weak chirality introduces only a slight distortion in the far field.

ELECTROMAGNETIC PROPERTIES OF CHIRAL ELLIPSOID SCATTERERS

D. I. Kaklamani, G. J. Karonis, N. K. Uzunoglu and P. V. Frangos
Department of Electrical and Computer Engineering, National Technical University of Athens
9 Iroon Polytechniou Str., 15773 Zografou, Greece, Tel/Fax: +30 1 3816908, e-mail: dimitra@naxos.esd.ece.ntua.gr

Due to many potential electromagnetic (EM) applications of chiral objects or media, including reduction of radar cross-section by using chiral coatings, propagation of EM waves in chirowaveguides, development of chirostrip antennas and chirodomes, and due to the fact that many common materials exhibit an inherent chirality, a lot of research work has been done in the past years, concerning radiation from EM sources in isotropic unbounded chiral media and scattering from cylindrical, spherical or spheroidal chiral objects (see [1] for an overview). Furthermore, the fact that a general ellipsoid shape can simulate a variety of common objects, such as discs, needles etc., is the motivation of the present work, where the EM properties of chiral objects are examined, for the case of ellipsoidal shapes. Namely, coupling of an incident wave originating from sources in the far field region with a chiral ellipsoid placed in the free space is analyzed, using Fourier analysis, in conjunction with an integral equation technique, similar to the method introduced in [2].

To this end, the Green's theorem is applied for the vector function $\underline{A}(\underline{r}) = \underline{E}(\underline{r}) - \underline{E}_0(\underline{r})$, where $\underline{E}_0$ is the incident wave and $\underline{E}$ is the total electric field, which satisfies the wave equation

$$\nabla \times \nabla \times \underline{E}(\underline{r}) - 2\omega\mu_c\xi_c \nabla \times \underline{E}(\underline{r}) - k_c^2 \underline{E}(\underline{r}) = 0 \qquad \text{for } \underline{r} \text{ inside the ellipsoid} \qquad (1a)$$

$$\nabla \times \nabla \times \underline{E}(\underline{r}) - k_0^2 \underline{E}(\underline{r}) = 0 \qquad \text{for } \underline{r} \text{ outside the ellipsoid} \qquad (1b)$$

ξ_c being the chirality admittance, ε_c and μ_c being the chiral medium dielectric permitivity and magnetic permeability respectively and $k_c = \omega\sqrt{\varepsilon_c\mu_c}$ and $k_0 = \omega\sqrt{\varepsilon_0\mu_0}$ being the propagation constants in the chiral medium and the free space respectively. After satisfying the radiation conditions concerning both the total electric field $\underline{E}$ and the Green's function $\underline{\underline{G}}(\underline{r},\underline{r}')$ for $r \to \infty$ and imposing the continuity of the tangential components of $\underline{E}$, $\nabla \times \underline{E}$, $\underline{\underline{G}}(\underline{r},\underline{r}')$ and $\nabla \times \underline{\underline{G}}(\underline{r},\underline{r}')$ at the ellipsoid surface, an integral equation is derived, as

$$\underline{E}(\underline{r}) = \underline{E}_0(\underline{r}) + \iiint_V [(k_c^2 - k_0^2)\underline{E}(\underline{r}') + 2\omega\mu_c\xi_c \nabla' \times \underline{E}(\underline{r}')] \cdot \underline{\underline{G}}(\underline{r},\underline{r}')d\underline{r}' -$$

$$- \iint_S d\underline{r}'_s\, \omega\mu_0\xi_c \hat{n}_s \times \underline{E}(\underline{r}'_s) \cdot \underline{\underline{G}}(\underline{r},\underline{r}'_s) - \iint_S d\underline{r}'_s (1 - \frac{\mu_0}{\mu_c}) \hat{n}_s \times \nabla \times \underline{E}(\underline{r}'_s) \cdot \underline{\underline{G}}(\underline{r},\underline{r}'_s) \qquad (2)$$

where V, S refer to the ellipsoid scatterer volume and surface respectively. In order to proceed with the solution of (2), the unknown electric field is expressed through its three dimensional Fourier transform $\underline{C}(\underline{k})$, as $\underline{E} = \iiint d\underline{k}\, \underline{C}(\underline{k}) \exp(ik\hat{k} \cdot \underline{r})$. Then, the wave equation (1a) is rewritten in the phase space, as $-k^2 \hat{k} \times (\hat{k} \times \underline{C}(\underline{k})) + 2\omega\mu_c\xi_c ik\hat{k} \times \underline{C}(\underline{k}) - k_c^2 \underline{C}(\underline{k}) = 0$. Looking for nontrivial solutions of this homogeneous system and taking into account the unit vector $\hat{k}$ rotation in the phase space, the integration with respect to the k variable is restricted to a summation of two terms, corresponding to the values $k_i = (-1)^{i+1}\omega\mu_c\xi_c + \sqrt{k_c^2 + (\omega\mu_c\xi_c)^2}$ (i=1,2) and the unknown electric field is rewritten, as $\underline{E} = \sum_{i=1}^{2} \iint_{\Omega_K} d\hat{\underline{k}}\, \underline{C}_i \exp(ik_i\hat{k} \cdot \underline{r})$, where $\underline{C}_i$ are unknown coefficients. Accordingly, equation (2) is solved via Method of Moments, where all the involved integrals are computed analytically. The coefficients $\underline{C}_i$ are then determined numerically, after discretizing the integration $\iint_{\Omega_K} d\hat{k}$. Finally, the scattered field is derived, by substituting asymptotic expressions for $r \to \infty$ in (2) and numerical results are computed for several cases.

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Electrodynamics of chirowaveguides: mode excitation, mode orthogonality, mode interactions

E.O.Kamenetskii

Tel Aviv University, Department of Electrical Engineering - Physical Electronics
P.O.B. 39040, Ramat Aviv, Tel Aviv 69978, Israel

A number of problems related to chirowaveguides have been investigated and reported. Most of them are devoted to calculation of dispersion characteristics of chirowaveguides.In a variety of material and geometric effects in such waveguides the necessity of conceptual analysis is obvious. The aim of this paper is to formulate some principles in electrodynamics of chirowaveguides.

- MODE ORTHOGONALITY. Relations of mode orthogonality are useful to analyze a structure of mode fields.These relations are necessary to solve excitation problems and to calculate effects of irregularities in chiro-waveguides. The power (or vector formulated) orthogonality relations obtained in [1] for propagating modes may be easily extended for evanescent and complex modes in lossless chirowaveguides. Together with this type of orthogonality one can also obtain the scalar formulated orthogonality relations. In chirowaveguides these two forms of orthogonality relations (vector and scalar formulated) differ [2]. On the basis of orthogonality relations it is shown that in chirowaveguides the polarization of complex modes differs from the polarization of propagating and evanescent modes. An interesting result is a special type of the reflection symmetry for complex modes which transfer an active power flow in a chirowaveguide.

- MODE EXCITATION. In a general case of an excitation problem in chiro-waveguides special attention has to be paid on the role of longitudinal components of the excitation (electric and magnetic) currents [3]. In the region of excitation with longitudinal currents it is impossible to represent the full field as a series of normal mode fields. In anisotropic waveguides the decomposition is realized for $\mathbf{E}, \mathbf{H}$ fields, in contrast in chirowaveguides we have to decompose $\mathbf{D}, \mathbf{B}$ fields.

- MODE INTERACTIONS. Chirality may provide an interaction between two eigen polarization modes (TE and TM) of a conventional nonchiral waveguide [4]. In this paper mode interaction in chirowaveguides is analyzed, taking into account so-called induced polarization effects caused by discontinuities of longitudinal polarization currents [5]. Because of induced polarization effects, an asymmetry in mode coupling may take place.

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Magnetostatically controlled bianisotropic media — a novel class of artificial magnetoelectric materials

E.O.Kamenetskii

Tel Aviv University, Department of Electrical Engineering - Physical Electronics
P.O.B. 39040, Ramat Aviv, Tel Aviv 69978, Israel

Recently an idea of a novel class of artificial bianisotropic materials has been introduced. A theoretical analysis sufficiently demonstrates magnetoelectric effect in proposed media [1,2]. Now, after some productive discussions (with Prof. A. Lakhtakia, Dr. A. Sihvola, and others), it becomes clear that this idea would make it possible to realize (both on the theoretical and experimental levels) many different bianisotropic material parameters that we have not been able to create before. Further development of these materials may be very productive in terms of new linear and nonlinear effects. For practical realization of such artificial media we can use the planar technology well developed for magnetostatic wave (MSW) devices.

Proposed media are based on a composition of MSW resonators with metallic strips on their surfaces. Each MSW resonator with metallization is considered as a separate particle which exhibits a combined effect of electric polarization and magnetization. Because of small sizes of MSW resonators (in comparison with a wavelength), a concentration of particles may be very high. A resonance frequency of MSW resonators may be turned via a bias magnetic field. Nonlinear effects may be displayed due to possible nonlinearity of ferrites. The known experimental results demonstrate possible strong coupling between planar MSW waveguides. Such a phenomenon makes it possible to obtain the combined effect of all the obstacles in the lattice.

In up-to-date electromagnetics and material science the macroscopic magnetoelectric interaction of the fields is one of the most interesting subject [3,4]. Proposed magnetoelectric materials promise to give a series of new fundamental problems and applications.

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Development of Fedorov covariant methods and application to optically active crystals (a review)

A.F. Konstantinova, A. Yu. Tronin, and B.V. Nabatov

Crystallography Institute, Russian Academy of Sciences, 117333 Moscow, Russia

E-mail: tronin@saxslab.incr.msk.su

The report presents a review of crystal optical activity studies performed at the Institute of Crystallography either in direct collaboration with F.I. Fedorov and his students or influenced by his ideas. These studies give a detailed consideration of the boundary crystallo-optical problems accounting for anisotropy, gyrotropy and absorbance, the most complicated case of the oblique incidence on the uniaxial gyrotropic layer with random optical axis orientation and gyration tensor among them. The effect terdependent manifestation of gyrotropy and anisotropy have been discussed. Various experimental ellipsometric, spectrophotometric and spectropolarimetric methods for optical parameters determination have been proposed as well. The theoretical and experimental approaches have been applied to the studies of some gyrotropic crystals and crystalline thin films.

On electromagnetic theory of artificial nonchiral and chiral media with resonant particles (a review)

Mikhail V. Kostin, Victor V. Shevchenko
Institute of Radioengineering and Electronics, Russian Academy of Sciences
11 Mokhovaya str., Moscow, 103907, Russia

Analytical review of the original papers devoted to creation and development of composite media on the base of circular conducting elements is offered.

1. Theory of artificial diamagnetics on the base of closed circular elements.
2. Transition to model and theory of composite media on the base of broken circular elements, that is transition to artificial paramagnetics theory.
3. Theory of media containing elements in the form of single broken rings and in the form of twin concentric broken rings.
4. Correlation between effective magnetic permeability of composite medium and susceptibility of a single element.
5. Conditions of magnetic permeability resonant maximum appearance and frequency of maximum in dependence on the electric parameters of a single ring.
6. Theory of artificial chiral electromagnetic medium on the base of spherical helically conducting particles.

Experimental investigation of response of chiral media and "chiral media–ferrite" structures to microwave radiation and governing magnetic field

Galina Kraftmakher and Yuri Kazantsev

Institute of Radioengineering and Electronics, Russian Academy of Sciences
11 Mokhovaya str., Moscow, 103907, Russia

Microwave properties of two kinds of chiral media are under investigation. The first medium consists of volume aligning multigone helices of tungsten microwires with high concentration of helices between two dielectric films. It is a cylindrical sample from a group of isolated helices along general axis.

The second medium consists of planar aligned copper helices with thickness more than the skin-layer of the dielectric substrate. Same samples with single planar helix are also investigated.

Frequency dependencies of the reflection coefficients of the samples under investigation are studied in waveguide with moving short. Travelling-wave and standing-wave regimes are used. The samples are placed in the waveguide centre or near side wall, the samples orientation being changed. The external magnetostatic field influence on the frequency dependence is investigated as well. It has been discovered that there are resonances which are excited in the standing-wave regime by the microwave magnetic field and are displayed in resonator measurements as magnetic permeability resonance and there are resonances which are excited in the standing-wave regime by the microwave electric field and are displayed in resonator measurements as dielectric permittivity resonance.

Structures "chiral media–ferrite" in form of cylindrical samples with ferrite cores inside their cavities and of planar samples with thin ferrite layer are studied. Influence of magnetostatic field on resonances both of magnetic permeabilities and dielectric permittivities is considered.

Manufacture of microwave chiral materials and their electromagnetic properties

S.A. Kuehl,[1] S.S. Grove,[1] J.H. Cloete,[2] and I.P. Theron[2]

[1] Institute of Polymer Science, University of Stellenbosch
Stellenbosch, 7600, South Africa

[2] Department of Electrical Engineering, University of Stellenbosch
Stellenbosch, 7600, South Africa

The machine we reported on at Chiral'95 capable of mass producing chiral inclusions with high microwave activity will be reported in detail at Chiral'96. In following up previous work, we will discuss further work on both isotropic and anisotropic chiral media. Amongst some of the phenomena we wish to address at Chiral'96 is the location and clarification of resonance behaviour in chiral media manufactured from our type of chiral inclusions. The "lost power" effect seen when measuring the S parameters of oriented chiral media in free space will be discussed. Coupling behaviour in double wound helices and a study of helix geometry and concentration versus overall microwave rotation will be discussed. Additional work with chiral inclusions dispersed in low impedance lossy hosts will be discussed in order to address the claim that chirality can improve absorption process. Finally, work which has been done on the Vinogradov and Tellegen materials will be presented.

On the problem of constitutive relations for materials with spatial dispersion

A.N. Lagarkov, A.P. Vinogradov

Scientific Center for Applied Problems in Electrodynamics

Russian Academy of Sciences, Izhorskaja 13/19, Moscow, 127412 IVTAN, Russia

Recently there appears a set of experimental results bearing witness to the significance of spatial dispersion as electromagnetic waves propagate trough composite materials. Examples of such media are chiral medium, (Ω-medium [1], swastika-medium [2], artificial magnet [3], periodic structures, etc. In this communication we review the experiments and theory of the phenomena focusing on constitutive relations and boundary conditions. Obviously, the description of such media demands introduction of new parameters: chiral factor, Tellegen's factor, effective permeability and so on. We review analytical methods employed in this area. There is still a question: whether all these parameters are really necessary or we can restrict ourselves to a less number of parameters. For example, there is a well-known statement of Landau [4] that an introduction of high frequency permeability is not justified and one should confine to the tenser of permittivity depending on wave number. Another example is a discussion about Tellegen's factor [5,6]. We explore a minimum set of constitutive parameters demanded for proper description of the media. In particular, we produce some arguments in favor of introducing Tellegen's factor and high frequency magnetic permeability.

We conclude that, occasionally (bi-helix loaded composites, laminar systems), in the case of bounded system we cannot confine ourselves to permittivity tenser and need to introduce high frequency longitudinal permeability. We discuss an experiment on observation of longitudinal magnetic waves in artificial magnetic materials as well as possible ways of treating the results obtained.

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Pulse distortion by a lossy resonant chiral medium

S. A. Maksimenko[1], G. Ya. Slepyan[1], and A. Lakhtakia[2]

[1] Institute of Nuclear Problems, Belarus State University, 11 Bobruiskaya Str., Minsk, 220050, Belarus. E-mail: maksim%inp.belpak.minsk.by@mosvax.demos.su

[2] Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802-1401, USA. E-mail: axl4@psu.edu

Time-domain fields in a linear chiral medium have attracted recent attention [1]–[4]. Using different approaches, the problem of transient signal wavefront propagation has been discussed in [1–3]. Hillion [4] studied the distortion of a pulse through a chiral slab completely ignoring the dispersive characteristics of the medium. Thus, we reckon that the problem of propagation of *a pulse with finite duration and smooth envelope in a lossy dispersive chiral medium* has not yet been satisfactorily attended to. In this contribution, we seek to describe that problem with certain reasonable restrictions imposed on the constitutive parameters as well as on the initial pulse duration.

In the frequency domain, the electromagnetic field in a linear chiral medium is represented by two Beltrami fields of different helicities with corresponding wavenumbers $k_\pm(\omega)$ [5]. Since the frequency–domain Beltrami fields are the eigenfields in a chiral medium, evolution of the Beltrami pulses $A_0^\pm(t)\exp(-i\omega_c t)$ in time and space is determined by the functions

$$A^\pm(z,t) = \int_{-\infty}^{\infty} e^{-i\omega_c t'} G^\pm(z,t-t') A_0^\pm(t') dt', \tag{1}$$

where the temporal Green functions are given as

$$G^\pm(z,t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\omega t + ik_\pm(\omega)z} d\omega, \tag{2}$$

We chose single–resonance Lorentz models for the permittivity and the permeability in the Boys–Post representation: $\epsilon(\omega) = \epsilon_0[1-\omega_p^2/\Delta(\omega)]$ and $\mu(\omega) = \mu_0[1-\omega_m^2/\Delta(\omega)]$, where $\Delta(\omega) = \omega^2 - \omega_0^2 + 2i\delta\omega$. The well-known Condon model of optical activity was chosen for the chirality parameter: $\xi(\omega) = ac\eta_0^{-1}\omega/\Delta(\omega)$. Then, assuming the conditions $\omega_p^2/\omega_0^2 \ll \delta/\omega_0 \ll 1$ and $\omega_p \sim \omega_m$ to be fulfilled, we approximated $k_\pm(\omega)$ [5] as follows:

$$k_\pm(\omega) = \frac{\omega}{c}\{1 - [(\omega_p^2+\omega_m^2)/2 \pm ac\omega]/\Delta(\omega)\}, \tag{3}$$

Using (3), we succeeded in deriving of analytical expression for temporal Green functions (2) of the chiral medium considered.

Computation of (1) with these functions and Gaussian initial pulse demonstrated significant distortions of the propagating pulse shape resulted from the joint action of dispersion and chirality. Temporal profiles turned out to be different for initial pulses of opposite helicities. The effect of damping was seen to be strongly dependent on the relation between the pulse bandwidth $\Delta\omega$ and the resonance linewidth δ. When $\Delta\omega \gg \delta$, damping was significant; otherwise, the Beltrami pulses *almost held* their initial shapes, displaying only loss of intensity by virtue of absorption.

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A review of chiral composites modeling: from a single scatterer to an heterogeneous material

F. Mariotte and B. Sauviac
French Atomic Energy Commission, CEA/DAM/CESTA
B.P. n°2, 33114 Le Barp, France

This paper deals with simulations of isotropic composites with chiral inclusions: calculation of permittivity, permeability and chirality admittance as functions of frequency. The theoretical process in use can be divided in two main parts. Firstly we study the isolated inclusion in order to construct the electromagnetic representation of the chiral object scattering behaviour. Different approaches are reviewed. Secondly, we use the Maxwell Garnett mixing rule to average the effective properties of the final composite.

Scattering in chiro-ferrite loaded coupled line junction

Jerzy Mazur

Technical University of Gdańsk, Faculty of ETI, Narutowicza 11/12, 80–952 Gdańsk, Poland

Recent research [1] has demonstrated that coupled planar waveguides loaded with chiro-ferrite layers (CFCL) exhibit nonreciprocal behaviour which might be used for novel microwave components at higher frequencies. The principle of the nonreciprocal operation of these devices is based on the interaction between the Faraday phenomenon and chiral activity of the composed medium. A simple mathematical model explaining the scattering properties of the CFCL junction has been presented in [1]. However the proposed model does not fully exhibit the operation of the structure because the effects resulting from the interaction between the reverse waves propagated in the CFCL guide have been neglected. Therefore, the more general model which has no such constraint is developed using the coupled modes formulation. In principle this approach allows to define the scattering matrix of the junction which gives new insight into their nonreciprocal behaviour. Moreover, it makes possible to consider the operation of the junction from the point of view of the matching and optimum positioning of the ferrite and chiral slabs in the structure. As an example of the model applicability the numerical examination of the four port circulator models based on CFCL junctions is presented. Fig. 1 shows the preliminary frequency characteristics of the CFCL four port circulator designed in fin-line technology. The results show that the structure can be competitive to the ferrite devices which are constructed as cascade of the coupled ferrite line junction and 0°/180° hybrid.

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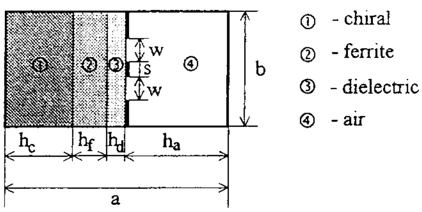


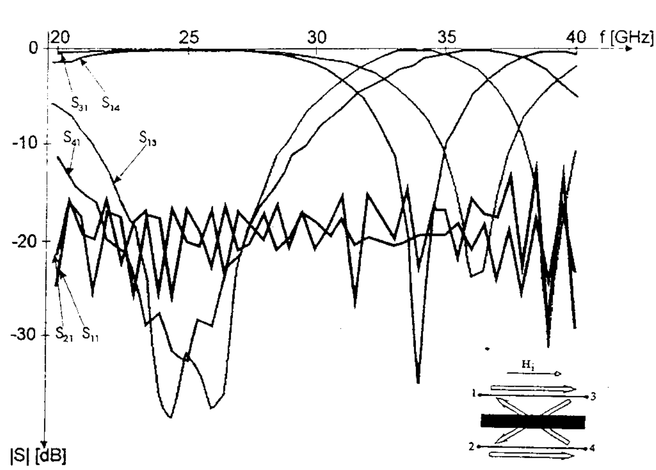


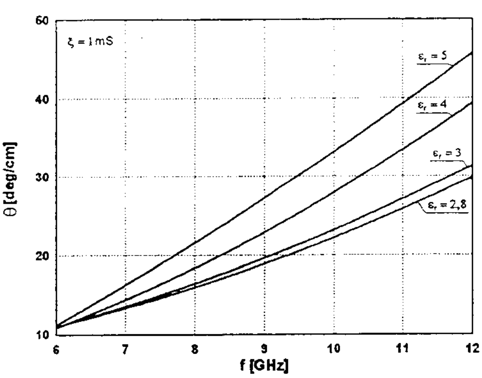
Fig.1 a) Cross-section of a CFCL finline used in design of the circulator.Dimensions in millimeters are $w = s = 0.5, h_c = 2.933, h_f = 0.5, h_d = 0.127, h_a = 3.56, a = 7.12, b = 3.4925$. Chiral medium parameters ; $\epsilon_c = 1, \mu_c = 1, \xi_c = 0.005$ mhO. Ferrite slab parameters; $\epsilon_f = 13.5$, saturation magnetization $M_s = 340\,\text{kA/m}$, biasing magnetic field $H_i = 0$. Dielectric permittivity of the finline substrate $\epsilon_d = 2.22$, b) Performance of a CFCL circulator. Characteristic impedance of the slot lines connected with junction is equal $Z_o = 125\,\text{Ohm}$.

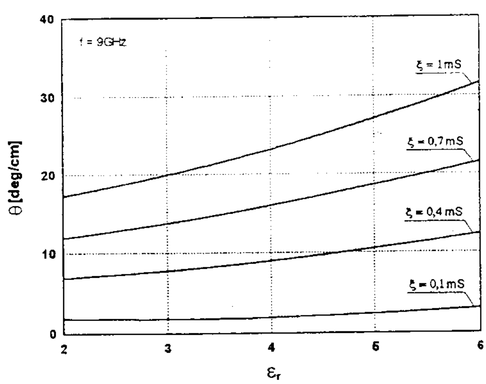
Electromagnetic wave propagation in circular waveguide loaded with a chiral rod

J. Mazur,[1] J. Popik,[2] and S. Haq[3]

[1] Technical University of Gdańsk, Faculty of ETI, Narutowicza 11/12, 80–952 Gdańsk, Poland
[2] Telecommunication Research Institute, Gdańsk Division, Poland
[3] Sowerby Research Centre, British Aerospace, FPC267, Filton, Bristol BS12 7QW, UK

Isotropic chiral media have raised considerable interest in recent years because of their natural property of rotating the polarization plane of a propagating electromagnetic wave. This phenomenon offers new possibilities for the design of microwave components as well as for measurement of the chiral material parameters. Although the phenomenon occurs for a variety of chirowaveguide configuration from a application viewpoint one of the most important is the circular waveguide containing the chiral medium. There have been several papers where the problem of electromagnetic wave propagation in circular waveguide completely filled with chiral medium has been reported. We have investigated the electromagnetic properties of a circular waveguide containing a chiral rod located concentrically within the guide using a cylindrical teflon sleeve. This guide demonstrates better features than completely filled structures. For instance, a fundamental modes propagate independently in the broader frequency range which together with better guide matching conditions enhance their potential for application. The rigorous mode matching approach is used to solve the problem. The numerical simulation is performed for a circular guide of radius $R = 10\,\text{mm}$ containing a teflon cylinder ($\epsilon = 2.02$) with a chiral rod of $r = 5\,\text{mm}$ for X-band measurements. The calculated dependence of the rotation angle θ versus frequency f for different values of chiral rod permittivity ϵ_c, with chiral admittance ξ_c fixed at $1\,\text{mS}$ are shown in Fig. 1. The results presented in Fig. 2 where variation of θ versus ξ_c and ϵ_c for fixed value of f are shown may be used as a comparison with measurements.





General optimization approach to the frequency domain inverse problem for stratified bianisotropic media

Martin Norgren

Dep.of Electromagnetic Theory, Royal Inst. of Technology, S-100 44 Stockholm Sweden

Synopsis

The inverse problem for stratified bianisotropic media is considered in the frequency domain. We consider an electromagnetic plane wave at oblique incidence on a stratified slab, of bianisotropic media modeled by the following constitutive relations

$$\vec{\mathbf{D}}(\bar{\mathbf{r}},\omega) = \bar{\bar{\varepsilon}}(z,\omega)\vec{\mathbf{E}}(\bar{\mathbf{r}},\omega) + \bar{\bar{\xi}}(z,\omega)\vec{\mathbf{H}}(\bar{\mathbf{r}},\omega), \tag{1}$$

$$\vec{\mathbf{B}}(\bar{\mathbf{r}},\omega) = \bar{\bar{\mu}}(z,\omega)\vec{\mathbf{H}}(\bar{\mathbf{r}},\omega) + \bar{\bar{\zeta}}(z,\omega)\vec{\mathbf{E}}(\bar{\mathbf{r}},\omega). \tag{2}$$

In the direct scattering problem, the reflection and transmission coefficient matrices are calculated with an imbedding method, through the concept of wave-splitting [1]. The inverse problem is to reconstruct the components of the parameter tensors $\left\{\bar{\bar{\varepsilon}},\bar{\bar{\mu}},\bar{\bar{\xi}},\bar{\bar{\zeta}}\right\}$, as functions of the position z, in the slab. Adopting an optimization method, an objective functional is defined

$$J = \sum_{i,j\in\{E,M\}} \sum_{\omega=\omega_{\min}}^{\omega_{\max}} \sum_{\theta,\varphi} \left|r_{ij}(\omega,\theta,\varphi) - r_{ij}^{m}(\omega,\theta,\varphi)\right|^2 + \left|t_{ij}(\omega,\theta,\varphi) - t_{ij}^{m}(\omega,\theta,\varphi)\right|^2, \tag{3}$$

where $r_{ij}(\omega,\theta,\varphi)$, $t_{ij}(\omega,\theta,\varphi)$ $i,j\in\{E,M\}$ are the directly *calculated* values of the reflection and transmission coefficients, respectively, and $r_{ij}^{m}(\omega,\theta,\varphi)$, $t_{ij}^{m}(\omega,\theta,\varphi)$ are the corresponding *measured* values; $[\omega_{\min},\omega_{\max}]$ is the frequency band and θ,φ represents the various directions of the illumination on the slab.

A key result is that the gradient of the objective functional J, with respect to the components of the parameter tensors $\left\{\bar{\bar{\varepsilon}},\bar{\bar{\mu}},\bar{\bar{\xi}},\bar{\bar{\zeta}}\right\}$, can be computed in an exact and explicit way, through the concept of some auxiliary functions. Then, with the gradient computed, the conjugate gradient method can be applied to minimize J.

It is also straight forward to treat bianisotropic material with dispersion, provided the dispersion model is known. In such a case, optimization can be performed with respect to helix resonance frequencies, damping coefficients etc.; hence, the method can be useful when solving various design problems, involving bianisotropic materials.

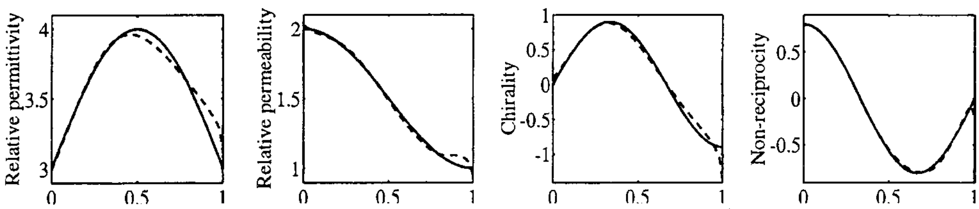


Figure 1 : The reconstruction algorithm tested on a bi-isotropic media. The true profiles are given by the solid lines and the reconstruted profiles by the dashed lines.

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Rectangular waveguide resonator with thin plate of Ω-medium

Dariusz Pietrzak and Jerzy Mazur
Technical University of Gdańsk, Faculty of Electronics
80–952 Gdańsk, Narutowicza 11/12 St., Poland

In this paper a rectangular cavity containing thin pseudochiral Ω-medium slab shown in the Figure 1 is investigated. The structure was analyzed with use of the mode matching technique and for the slab some approximative continuity conditions were derived to simplify the complexity of the problem. The computations were carried out for the first resonant mode.

It can be observed that the resonant frequency of the cavity tends to decrease moderately when pseudochirality is introduced. This variation of the frequency due to pseudochirality can be explained by the perturbation of the field in the resonator. Normally, provided that there is no pseudochirality, the only nonzero field components are E_y, H_x, H_z and the field distribution is similar to the TE_{101} mode in an empty resonator. Introduction of the pseudochirality does not change the field distribution meaningly but, as the Ω elements induce additional nonzero electric and magnetic polarization, the field becomes a hybrid one and the other components E_x, E_z, and H_y can be observed as shown in the Figure 2. This phenomenon gave reasons for further study of the problem since if the effect proves to be strong enough it will allow to measure material parameters of pseudochiral media.

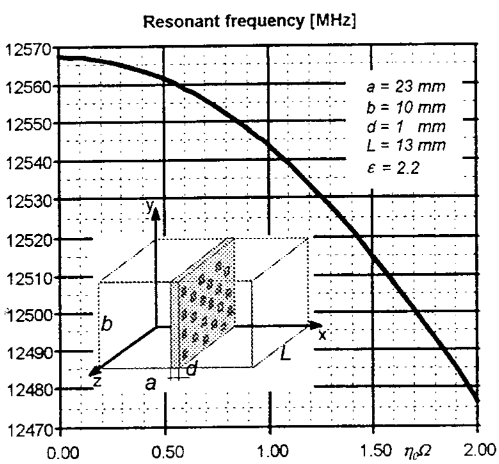
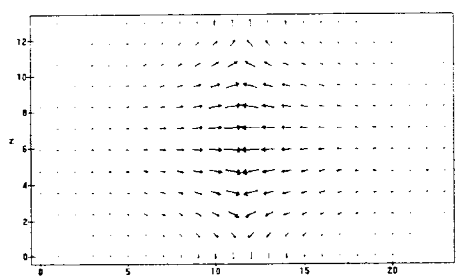


Fig. 1



Electric field distribution (E_{xz}) in x-z plane for $y = 1/2\, b$. Note that both components E_x and E_z are normally equal to zero in an empty resonator with TE_{101} mode.

Fig.2

The influence of induced chiral properties on the transformation of polarization of acoustic waves in piezoelectric semiconductors

Igor V. Semchenko and Sergei A. Khakhomov
Gomel State University, Department of Physics, Sovyetskaya Str. 104, Gomel, 246699, Belarus
Telephone: (7)-0232-579707, (7)-0232-576557, E-mail: root@tpf.gsu.gomel.by

The possibility of forming of rotating acoustic anisotropy and, consequently, chiral properties in crystals under external electric field influence was shown before. The availability of charge carriers in semiconductors allows to influence the character of interaction of acoustic waves with external fields. The charge carriers (in particular, conductivity electrons) interact with the electric field of wave in crystal. The character of interaction depends on the relative movement of wave. The character of interaction can be changed by the external constant electric field with strength $\mathbf{E}$. Owing to the external electric field influence the movement of electrons (drift) with the velocity $\mathbf{v} = -m\mathbf{E}$ is possible. Here m is the agility of electrons in crystal. In this work taking into account electron drift the interaction of ultrasound wave with rotating electric field in semiconductor in various frequency regions is considered. The following peculiarities of acousto-electron interaction are determined: independence of rotation ability of crystal with induced acoustic anisotropy from the electron drift direction; the change of sign of circular dichroism when the direction of the external longitudinal electric field changes. Such interaction when the complete transformation of an incident wave with the frequency ω to the wave with the opposite circular polarization and the frequency $\omega + 2Q$ or $\omega - 2Q$ takes place is investigated. Here Q is the frequency of rotating electric field. The thickness of crystal when complete transformation takes place depending on the parameters of drift is shown. The amplification of transformed wave when the direction of drift of electron coincides with the direction of the incident wave velocity when condition effects predominate over diffusion effects is possible.

Magneto-optical interaction of light with periodical bi-gyrotropic structure

D.I. Sementsov and O.V. Ivanov

Ulianovsk State University, K.Libkneht Str. 28-1, Ulianovsk, 432063, Russia

Phone: (8422)-325452, E-mail: all@themp.univ.simbirsk.su

The appearance of new magnetics transparent in infrared range enables to realize variety of easily controlled domain magnetic structures and stimulates magneto-optical research of media with periodic magnetic structures [1]. Special interest is presented by bi-gyrotropic media in which the analysis of electromagnetic waves propagation requires consideration of both electric and magnetic gyrotropies described by permittivity and permeability tensors. Propagation of light in a magnetic structure such as "static spin wave" is investigated. In this structure the projection of spins on the axis of periodicity z changes harmonically, and components of spins perpendicular to the axis are directed chaotically or are equal to zero. Off-diagonal components of permittivity $\bar{\bar{\epsilon}}$ and permeability $\bar{\bar{\mu}}$ tensors in this case are [2]:

$$\epsilon_{xy} = -\epsilon_{yx} = i\epsilon(f_0 + f_1 \cos qz)$$

$$\mu_{xy} = -\mu_{yx} = i\mu(g_0 + g_1 \cos qz)$$

The propagation of light in the crystal is described through circularly polarized eigenwaves E_+, H_+. The propagation constants of waves with the right $k_+(\omega)$ and left $k_-(\omega)$ circular polarizations have a gap at $k_+ = q/2$. In the specified points there are resonant zones with centers on the frequencies ω_+ and widths $\Delta\omega_+$:

$$\omega_\pm = \frac{cq}{2\sqrt{\epsilon\mu}}[\sigma^2 \pm (f_0 + g_0)]^{-1/2}, \qquad \Delta\omega_\pm = \frac{1}{2\sigma} \mid f_1 - g_1 \mid \omega_\pm$$

The imaginary part of the propagation constant differs from zero. A wave of the corresponding polarization with the frequency lying inside the resonant zone strongly attenuates propagating in the medium. Two variants of arrangement of the resonant zones are possible: with overlap, when the constant component of the magnetization is small: $f_0 + g_0 < (f_1 - g_1)/2$, and without overlap $f_0 + g_0 > (f_1 - g_1)/2$.

We consider features of resonant interaction of a light wave with a bi-gyrotropic layer having thickness L, when the layer is placed in a homogeneous isotropic medium with the permittivity $\bar{\bar{\epsilon}}$ and permeability $\bar{\bar{\mu}}$. The solution of the boundary conditions results in the following expressions for reflectivity and transmission of circularly polarized waves.

Thus the propagation of light in the resonant region is determined not by the sum of modulation parameters of electric and magnetic gyrotropies as in the case of the Faraday rotation but by their difference. Using Equations for the reflectivity and transmission it is possible to find intensity, rotation and ellipticity of the light.

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Effective-medium theories for bi-anisotropic materials: an iterative approach for calculating macroscopic parameters

Ari Sihvola
Helsinki University of Technology, Electromagnetics Laboratory
Otakaari 5 A, 02150 Espoo, Finland

Since bi-anisotropic materials couple electric response with magnetic excitation and vice versa, it is advantageous to use combined electric and magnetic quantities in the electromagnetic analysis of complex non-isotropic magnetoelectric media. This leads to six-vectors and six-dyadics in the formalism. Six-vector approach makes it easy to keep the equations in a compact form and the physics that the equations try to convey, remains visible, and comparable to the well-known corresponding isotropic dielectric cases. An example where six-dyadics are powerful, is the characterisation of composite materials and other heterogeneous media through effective-medium treatment. In several homogenisation theories, like Coherent Potential and Bruggeman models, the equations become non-linear also in the scalar (simple isotropic) case, and therefore it can be anticipated that the bi-anisotropic analysis is difficult. It will be shown in the presentation that a formalism can be found where an iterative approach for enumeration of the effective parameters is possible and the numerical convergence of the algorithm is stable for most practical cases.

Chiral effects in bi-anisotropic omega structures

Constantin R. Simovski, Alexander A. Sochava, and Sergei A. Tretyakov
St. Petersburg State Technical University, Radiophysics Department
195251 St. Petersburg, Polytekhnicheskaya 29, Russia

Omega media are composite materials formed by embedding small Ω-shaped conductive particles in an isotropic matrices. Such media are governed by bi-anisotropic constitutive relations. Their evident advantage for microwave applications compared to chiral media is the possibility to fabricate them with the use of planar technology. As will be shown in this report, certain structures of omega particles possess chiral properties, in a way similar to that in conventional chiral composites. In the past, attention was mostly concentrated on uniaxial omega media, which are formed of two orthogonal sets of omega inclusions.

Let the stems of particles in one set stretch along x-axis, and the loops of all the particles in the first set are in (xz)-plane. To ensure uniaxial symmetry, the second ensemble is obtained from the first one by turning that by the angle $\pi/2$ around z-axis, so that its loops lie in (yz)-plane. Corresponding constitutive relations we write for the harmonic time dependence as

$$\mathbf{D} = \overline{\overline{\epsilon}} \cdot \mathbf{E} + \frac{j}{c} K \overline{\overline{J}} \cdot \mathbf{H} \qquad \mathbf{B} = \overline{\overline{\mu}} \cdot \mathbf{H} + \frac{j}{c} K \overline{\overline{J}} \cdot \mathbf{E} \tag{1}$$

where K is the dimensionless coupling coefficient, c is the vacuum speed of light, $\overline{\overline{J}} = \mathbf{x}_0\mathbf{y}_0 - \mathbf{y}_0\mathbf{x}_0$ is the 90^o-rotator in the $(x-y)$ plane. It is known that eigenwaves polarization in such medium is linear for all possible directions of propagation.

Let us consider a "modified" omega medium in which the second ensemble of particles is obtained from the first one by turning not only around the z-axis, but also around the y-axis, so that its loops lie again in the $(y-z)$ plane, but on the opposite side. Then the dyadics $\overline{\overline{J}}$ must be replaced by $\overline{\overline{F}} = \mathbf{x}_0\mathbf{y}_0 + \mathbf{y}_0\mathbf{x}_0$ in the first equation of (1) and by $-\overline{\overline{F}}$ in the second one. The dyadic $\overline{\overline{F}}$ is symmetric and can be diagonalized: $\overline{\overline{F}} = \mathbf{x}_0'\mathbf{x}_0' - \mathbf{y}_0'\mathbf{y}_0'$. Here the axes x' and y' are bisectors between the x- and y-axes. We have

$$\mathbf{D} = \overline{\overline{\epsilon}} \cdot \mathbf{E} + \frac{j}{c} K \overline{\overline{F}} \cdot \mathbf{H} \qquad \mathbf{B} = \overline{\overline{\mu}} \cdot \mathbf{H} - \frac{j}{c} K \overline{\overline{F}} \cdot \mathbf{E} \tag{2}$$

The relations are the same as if the composite were formed by two orthogonal sets of uniaxial chiral particles oriented along x' and y', respectively. The particles in the two sets have the opposite chirality (left- and right- handed). When waves propagate along the x'- or y'- axes, the longitudinal helices do not interact with the fields, and the structure behaves as uniaxial chiral media with all the helices aligned along a common axis. For the z-direction of propagation chiral effect (polarization rotation) vanishes, and we have two linearly polarized eigenwaves with common propagation factor and different admittances. In that case, although $\mathbf{E} \cdot \mathbf{B} = 0$, the vectors $\mathbf{E}$ and $\mathbf{H}$ are not orthogonal.

We also consider planar omega structures. Let the x- and y-axes stretch along the stems of both ensembles of Ω-particles lying in parallel planes. At a first glance it may seem that such structure cannot produce chiral effects, but it is not so. The analysis shows that for this medium the dyadic $\overline{\overline{F}}$ in the last relations must be replaced by $\overline{\overline{G}} = \mathbf{x}_0\mathbf{z}_0 + \mathbf{y}_0\mathbf{z}_0$ and $\overline{\overline{L}} = \mathbf{z}_0\mathbf{x}_0 + \mathbf{z}_0\mathbf{y}_0$ in the first and the second equations, respectively. Both these dyadics contain symmetric parts which can be diagonalized, and one of the main axes is bisector between the directions of x'- (see above) and z-axes. We have

$$\mathbf{D} = \overline{\overline{\epsilon}} \cdot \mathbf{E} + \frac{j}{2c} K (\overline{\overline{F}} + \overline{\overline{J}}) \cdot \mathbf{H} \qquad \mathbf{B} = \overline{\overline{\mu}} \cdot \mathbf{H} - \frac{j}{2c} K (\overline{\overline{F}} - \overline{\overline{J}}) \cdot \mathbf{E} \tag{3}$$

The first term in brackets is responsible for chiral effects, and the second one corresponds to uniaxial omega structure.

Nonlinear characterization of chiral composites: the Bruggeman and the Maxwell Garnett Models

G. Ya. Slepyan[1], A. Lakhtakia[2] and S. A. Maksimenko[1]

[1] Institute of Nuclear Problems, Belarus State University, 11 Bobruiskaya Str., Minsk, 220050, Belarus, e-mail: maksim%inp.belpak.minsk.by@mosvax.demos.su

[2] Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802-1401, USA, e-mail: axl4@psu.edu

Diverse applications in solid state physics, optics and radiophysics have stimulated studies of composite materials of different types [1]. Qualitatively novel properties manifested by chiral composites have attracted particular interest in recent years. These are linear composites, formed by dispersing chiral inclusions in some dielectric or chiral host medium. The effective constitutive parameters (ECPs) of these linear composites are, of course, independent of the field strengths.

Nonlinear achiral dielectric composite materials have been quite heavily investigated during the last decade; see, e.g., [2]. Therefore, we proposed the concept of a nonlinear chiral composite as a suspension of chiral inclusions in a nonlinear dielectric host medium in a recent paper [3]. Now, we report on a weakly nonlinear chiral composite made of two component materials: one of the components is linear chiral with a constitutive parameters set $\boldsymbol{\xi}_{ch} = \{\epsilon_{ch}, \mu_{ch}, \beta_{ch}\}$, where β_{ch} is the chirality pseudoscalar in the Drude-Born-Fedorov representation; the other is nonlinear dielectric with $\boldsymbol{\xi}_{nld} = \{\epsilon_{nld0} + \epsilon_{nld1}|\mathbf{E}_{nld}|^2, \mu_0, 0\}$.

The general approach for estimating the ECPs of a composite material is as follows: First, the field scattered by a single inclusion in the host medium is found; then, the scattering contributions from all inclusions are summed and averaged over a vanishingly small region. We developed the Bruggeman model of certain nonlinear chiral composites, and also set up their Maxwell Garnett model. In particular, assuming the the host medium to be achiral and using the Maxwell Garnett model, we obtained

$$\xi_{MG} = \xi_{MG0} + \epsilon_{nld1} \frac{\partial \xi_{MG0}}{\partial \epsilon_{nld0}} |F_{11}(\boldsymbol{\xi}_{nld0}; \boldsymbol{\xi}_{MG0})|^2 |\mathbf{E}_{eff}|^2 \tag{1}$$

as the effective chirality parameter. Here, the additional subscript $_0$ marks quantities taken in the linear limit (see [1]),

$$F_{11}(\boldsymbol{\xi}_b; \boldsymbol{\xi}_a) = 3\epsilon_a [\omega^2 \epsilon_b \mu_a \mu_b \beta_b (\beta_a + 2\beta_b) - (2\mu_a + \mu_b)] / \Delta(\boldsymbol{\xi}_b; \boldsymbol{\xi}_a), \tag{2}$$

and

$$\Delta(\boldsymbol{\xi}_b; \boldsymbol{\xi}_a) = \omega^2 \epsilon_a \epsilon_b \mu_a \mu_b (\beta_a + 2\beta_b)^2 - (2\mu_a + \mu_b)(2\epsilon_a + \epsilon_b). \tag{3}$$

The main result of the presented work can be stated in the following manner: all three ECPs of a composite comprised by a linear chiral material and a cubic nonlinear dielectric material turn out to be nonlinear in identical fashion. This result holds for both the Bruggeman and the Maxwell Garnett models.

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Faraday effect and magnetogyration in superlattices in the long wavelength approximation

E.G. Starodubtsev, I.V. Semchenko, and G.S. Mityurich

Gomel State University, Gomel, 246699, Belarus

Practically all of the realized experimentally crystal layered-periodic structures or superlattices (SL) can exhibit induced gyrotropy properties. As far as we know, the given phenomenon in SL has not been studied. The subject of the paper is the investigation in the long wavelength approximation (LWA) of linear Faraday effects: ordinary and induced (in presence of additional controlling electric field [1]), and linear magnetogyration in SL.

In the LWA the wavelengths of electromagnetic waves are significantly large compared to the SL period and SL can be considered as a homogeneous medium with some effective characteristics. Effective tensors describing the Faraday effect and magnetogyration were determined on basis of the methods [2] and material equations [3]. We also used the usual boundary conditions [4] and the fact that in the LWA electromagnetic field does not change at distance of the SL period order.

The relations for determining all the components of effective third rank pseudotensors (for ordinary and induced Faraday effect) and tensors (for magnetogyration) describing the enumerated phenomena at arbitrary layers crystallography symmetry have been derived. Particularly, the given tensors for SL originated by cubic crystals of $GaAs$-type have been investigated. In such SL the form of the ordinary Faraday effect tensor is similar to that of some classes of uniaxial crystals. Symmetry properties of induced Faraday effect have no analogues among monocrystal media and these properties are intermediate between ones of cubic and uniaxial crystals. It was shown that registration of the dependence of polarization plane rotation angle on magnetic field strength on the longitudinal Faraday effect allows us to determine (control) the relative thicknesses of the layers originating SL. The opportunities of creating on the basis of SL materials with the given magnetogyration characteristics have been ascertained.

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Chiro-plasma surface wave

H. Torres-Silva
Facultad de Ingeniería, Dpto. de Electrónica
Casilla 6-D, Av. 18 de Septiembre 2222, Arica-Chile

In this paper we analyse the behavior of electromagnetic waves propagating along the interface between a linear chiro-dielectric medium and vacuum. The gyrodielectric tensor of a chiro-plasma is used to investigate the dispersion relation for bulk waves and surface magnetoplasmon polaritons in metals or doped semiconductors modified by the chirality factor.For bulk waves, which propagate parallel to the magnetic field, the medium is a cold magnetized chiral-plasma, which presents a new mode conversion. For waves which propagate perpendicular to the magnetic field, there is no mode conversion but a lower band of forbidden frequencies desappears when the chirality parameter increases. For surface waves, one notes that the dispersion relation obtained is non-reciprocal, i.e. positive and negative values of the wavenumber K are not equivalent. A new feature is immediately apparent, namely the dispersion curve consist of two parts with a gap between them. The low portion starts from the origin, rises just to the right of the light line, $\omega = kc$, bends over, and terminates when the curve intersects the dispersion curve for bulk magnetoplasmons (bulk polaritons). The upper branch starts on the line defined by $\epsilon_{xx} = 0$, rises, and then approaches the asymptotic frequency for unretarded surface magnetoplasmons defined by the equation $1 + \epsilon_{xx} - i\epsilon_{xz} = 0$. Here ϵ_{xx} is modified by the chiral parameter. In the large wave vector, unretarded limit, the electric vector of the upper branch executes a circular motion in the sagittal plane. At the small wavevector extremity of this branch, the electric vector is plane polarized perpendicular to the surface and this branch stops before it reaches the light line. Also we note that there are frequencies at which both a bulk wave and a surface wave can propagate, a situation which does not exist in the absence of a magnetic field and the chiral parameter. Calculations of the dispersion relation have been carried out for nInSb.

A relation between co- and cross-polarizabilities of small conductive bi-anisotropic particles

Sergei A. Tretyakov, Constantin R. Simovski, and Alexander A. Sochava

St. Petersburg State Technical University, Radiophysics Department

195251 St. Petersburg, Polytekhnicheskaya 29, Russia

Abstract: Polarization of small complex-shaped conductive particles by external electric and magnetic fields is considered. It is shown that under a certain restriction on the current distribution functions the co- and cross-polarizabilities are not independent, but related to each other. The physical meaning of the relation is discussed.

In the design of novel composite materials, especially for applications in microwave engineering, small bi-anisotropic inclusions are often used. Especially much attention is devoted to artificial chiral materials with inclusions in form of small spirals and wire-and-loop particles. Polarizabilities of individual inclusions, after the appropriate averaging, define effective properties of bi-anisotropic composites.

Consider a small conductive particle in a uniform isotropic dielectric excited by external time-harmonic electric and magnetic fields. To simplify the analysis we assume that the particle is made of a thin wire (whose diameter is much smaller than its length) which forms an arbitrary three-dimensional figure. This assumption allows us to consider the induced currents as vector functions of the position on the wire (measured by s).

The characteristic particle size a (the volume occupied by the particle is of the order of a^3) is assumed to be small as compared to the wavelength λ associated with the frequency ω of the time variation of the external fields. However, the wire length L may be comparable to λ.

Small particles of complex shape we characterize by four dyadic polarizabilities, which define the bi-anisotropic relations between induced electric and magnetic dipole moments $\mathbf{p}$, $\mathbf{m}$ and the external fields $\mathbf{E}$, $\mathbf{H}$ in the particle centre:

$$\mathbf{p} = \overline{\overline{a}}_{ee} \cdot \mathbf{E} + \overline{\overline{a}}_{em} \mathbf{m} = \overline{\overline{a}}_{me} \tag{1}$$

To model the processes of both the electric-field and the magnetic-field excitations we assume that the particle is positioned in the fields of two plane electromagnetic waves of equal amplitudes travelling in the opposite directions (of a certain axis z). To see how the particle reacts on electric or magnetic fields we position the particle in the maximum of the total electric or magnetic field of the standing waves.

Denote $f_e(s)$ and $f_h(s)$ the current distribution functions for excitations by external electric and magnetic fields, respectively. These functions are normalized so that their values at a certain point on the wire (arbitrary chosen as the terminal position) equal unity. If the current distribution functions along the wire satisfy the relation

$$\int_L f_e(s)d\mathbf{s} \cdot \int_L f_h(s)\mathbf{r}(s) \times d\mathbf{s} = \int_L f_e(s)\mathbf{r}(s) \times d\mathbf{s} \cdot \int_L f_h(s)d\mathbf{s} \tag{2}$$

($\mathbf{s}$ is the unit vector tangential to the wire, and $\mathbf{r}$ is the radius-vector of a point on the wire) the polarizability dyadics are related to each other as

$$\overline{\overline{a}}_{ee} \cdot \overline{\overline{a}}_{mm} = \overline{\overline{a}}_{me}^T \cdot \overline{\overline{a}}_{em} = -\overline{\overline{a}}_{em}^2 \tag{3}$$

The simplest example when the relation (3) holds is the case when the current distribution functions f_e and f_h just coincide. The relation (3) is not universal: it actually reflects a certain symmetry of particles.

Plane wave diffraction by wedge coated with thin bi-isotropic layers

S.G. Vashtalov and V.V. Fisanov
Siberian Physical & Technical Institute and Department of Radiophysics
Tomsk State University, Revolution Sq. 1, Tomsk, 634050, Russia
E-mail: helen@eccspti.tomsk.su

The diffraction problem is considered for the plane electromagnetic wave incident on a perfectly conducting wedge, the faces of which are coated with thin layers of the biisotropic material. The presence of the layers is taken into account with help of the approximate boundary conditions [1]. These conditions are valid with exactness to the terms of the first order the layer thickness. The cross polarization is absent in this approximation. For the E-polarized waves (vector $\_E$ is parallel to the edge of the wedge) the standard Leontovich impedance boundary conditions are received. For the H-polarized waves (vector $\_H$ is parallel to the edge) the generalized impedance boundary conditions of the second order are received. They contain the second derivative on the direction along the boundary.

The diffraction of H-polarized plane wave on such wedge is examined. The problem is considered with the help of the modified Maliuzhinets technique [2,3]. The Maliuzhinets functional equations are obtained for the transform of Sommerfeld integral.The general solution of these equations contains three arbitrary constants. The radiation condition and the contact conditions on the edge of the wedge are used in order to get these constants [2,3], from which the system of linear algebraic equations is received. The asymptotic analysis of the solution is carried out. The coefficient of diffraction is obtained.

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The dependence of electromagnetic properties of bi-helix inclusions upon their structure

A.P. Vinogradov, V.E. Romanenko
Scientific Center for Applied Problems in Electrodynamics
Russian Academy of Sciences, Izhorskaja 13/19, Moscow, 127412 IVTAN, Russia

The modern industry demands more and more new kinds of materials. In recent years much attention was paid to bi-isotropic, bi-anisotropic materials and materials loaded with inclusions of complex shape. These are Ω-media [1], swastika-media [2], and media loaded by bi-helix inclusions [3]. A common feature related these materials is a weak spatial dispersion. In other words in all the cases we have to go out beyond static consideration of interaction of fields with inclusions. The situation results in non-usual phenomena. The interest caused by the material with bi-helix inclusions is due to their paramagnetic properties [3]. In the first communication [3] we reported that in the case of "push-put" excitation the currents flow in opposite directions causing lumping of magnetic moments and cancellation of electric moments of separate spirals. Hence we may anticipate that the composite would have high permeability and low permittivity with impedance near unity. Thus this material is a good candidate for absorber in the range of resonance. It is important to learn controlling the position and width the resonance range.

Obviously that the induced magnetic moment depends on radius of spirals, pitch of spirals, total length and radius of wire. Moreover, while fabrication of bi-helix inclusions exhibiting a resonance at a specified frequency we have done our best to fix aforementioned parameters. Unfortunately, we watch that rejects were very high. The separate inclusions being made of the wire pieces of the same length, turned in to spirals with the same radius and pitch exhibit a resonance at quite different lengths. We carried out a computer simulation to find out a geometric factor influencing so strong on the inclusions properties.

We solve an exact diffraction problem (see [3]). The simulation shows that the key parameter is an angle between starting points of the spirals. Changing the angle we can vary the resonance frequency in a broad range. The reason of such a sensitivity is that the change in starting positions moves a position of points where the spirals are crossing. It is the region that determines mutual inductance and capacitance of the bi-helix inclusions. The later quantities determine in turn a resonant frequency. Thus we can conclude that the region near which spirals crossing each other determines a position of the resonance. Filling this region with dielectric or magnetic materials (glue or matrix material) we may anticipate significant change in the properties of the bi-helix inclusion. Such an assumption was confirmed by computer simulation.

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Planar inclusions for bi-anisotropic media and depolarization phenomena

S. Zouhdi and A. Fourrier-Lamer
Laboratoire de Dispositifs Infrarouge et Micro-ondes, T12, E2
4 place Jussieu, 75252 Paris Cedex 05, France
Tel. (33)-1-44.27.43.72, Fax (33)-1-44.27.43.82, E-mail: sz@ccr.jussieu.fr

A bi-anisotropic medium, which is a generalization of the well-known isotropic chiral media, is described in the general case, by four independent tensorial constitutive parameters:

$$\mathbf{D} = \overline{\overline{\epsilon}} \cdot \mathbf{E} + \overline{\overline{\xi}} \cdot \mathbf{H}, \qquad \mathbf{B} = \overline{\overline{\mu}} \cdot \mathbf{H} + \overline{\overline{\zeta}} \cdot \mathbf{E}$$

where $\overline{\overline{\epsilon}}, \overline{\overline{\mu}}, \overline{\overline{\zeta}}, \overline{\overline{\xi}}$ are the permittivity tensor, the permeability tensor, and coupling tensors of this medium. Such medium results, for example, when two-dimensional (2-D) structures of specific geometry are placed in a homogeneous host medium. An example of such objects was introduced in [1], where it was suggested to use inclusions shaped like the capital Greek letter Ω. The resulting medium is known as the uniaxial chiro-omega medium. In 1991, we patented a new kind of composite materials where the inclusions are also planar but could show more dissymmetry than the Ω-objects [2]. As is the case for the Ω-shaped inclusions, the orientation of the objects introduced by us can be along a preferred direction. Some applications have been proposed for uniaxial chiro-omega media: reciprocal phase shifterrs, polarization transformers, and non-reflecting shields [3].

In the present work we show the influence of the coupled magneto-electric dipoles induced by 2-D conducting structures on the polarization of a linearly polarized incident wave.

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