Session 1A7
Microwave and Optical Devices, Propagation

Fabrication of Multimode Interference Devices Based on Ge-doped Silica-on-silicon Waveguides by HC-PECVD and RIE

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Multimode interference devices based on Ge-doped silica-on-silicon waveguides are fabricated by HC-PECVD and RIE. The thin film deposition and etching process are optimized to achieve good optical devices. Silica layer particle control is studied for the thin film deposition. It is found that the preheating time is related to silica layer particle distribution. Using photoresist as masks for RIE simplifies the process. The waveguide shape profile is optimized by different RIE parameters. The optimal process balances the waveguide shape, surface smoothness, and etching rate. Good performance multimode interference devices have been realized.

On the Spatial Characterstics of Cellular Mobile Channel in Low Antenna-height Environments

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In order to exploit the spatial dimens ion efficiently, reliable channel models are required which can lead to the design of effective signal processing schemes. Physical channel models are the continu- ing efforts in this regard. Several approaches have been suggested for the distribution of scatterers. The two most common distributions are the uniform [1] and Gaussian [2, 3]. The latter has been identified as more practical in the literature. Gaussian Scatterer Density Model (GSDM) [2] proposes Gaussian Distributed Scatterers clustered around mobile station (MS). Since, in low antenna-height indoor environments, scatterers also exist in the vicinity of base station(BS). So a more generalized scattering model is needed for such environments.

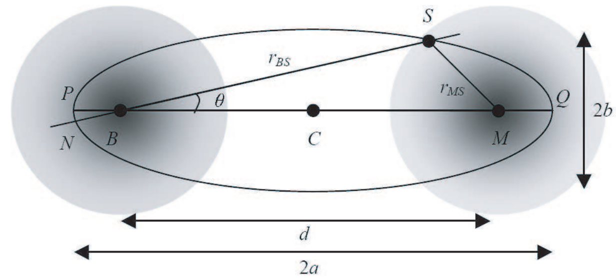

Figure 1: Physical channel model.

In this paper, we use the generalized Eccentro-Scattering physical channel model proposed in [3] to derive the probability density function (pdf) of the Angle of Arrival (AoA) of the multipath signals at BS from Gaussian distributed scattering regions around MS and BS for indoor environments.

We assume Gaussian distributed scatterers to be confined in an elliptical shaped scattering disc (see Fig. 1) whose eccentricity can be altered according to the maximum delay and the distance between MS and BS. A Gaussian model of the spatial pdf of scatterers around MS and BS can be written as,

$$p_{R_{BS},\Theta}(r_{BS},\,\theta) = \frac{\parallel r_{BS} \parallel}{2\pi\sigma_{MS}^2} \exp\left\{-\frac{\parallel r_{BS} - r_{BM} \parallel^2}{2\sigma_{MS}^2}\right\} \tag{1}$$

$$p_{R_{BS},\Theta}(r_{BS},\,\theta) = \frac{\parallel r_{BS} \parallel}{2\pi\sigma_{BS}^2} \exp\left\{-\frac{\parallel r_{BS} \parallel^2}{2\sigma_{BS}^2}\right\} \tag{2}$$

where σ_{MS} and σ_{BS} are the standard deviations of the distributions of scatterers around MS and BS, and θ is the AoA of the multipaths at BS from the scatterer S. All other parameters are explained in Fig. 1. From (1), (2) and Fig. 1, the final closed-form expression for the pdf of AoA can be written as

$$\begin{aligned} p_\Theta(\theta) = &\frac{\Omega}{2\pi}\left[1+\exp\left(\frac{-d^2}{2\sigma_{MS}^2}\right)-\exp\left(\frac{-(4a^2-4ad\cos\theta+d^2)^2}{8\sigma_{MS}^2(2a-d\cos\theta)^2}\right)-\exp\left(\frac{-(4a^2-d^2)^2}{8\sigma_{BS}^2(2a-d\cos\theta)^2}\right)\right] \\ &+\frac{\Omega d\cos\theta}{2\sqrt{2\pi}\sigma_{MS}}\exp\left(\frac{-d^2\sin^2\theta}{2\sigma_{MS}^2}\right)\left\{\mathrm{erf}\left(\frac{d\cos\theta}{\sqrt{2}\sigma_{MS}}\right)+\mathrm{erf}\left(\frac{4a^2-4ad\cos\theta+d^2\cos 2\theta}{2\sqrt{2}\sigma_{MS}(2a-d\cos\theta)}\right)\right\} \end{aligned} \tag{3}$$

where Ω is the normalizing constant. Eq. (3) is helpful in finding correlation statistics of the channel.

REFERENCES

1. Liberti, J. C. and T. S. Rappaport, "A geometrically based model for line-of-sight multipath radio channels," in *Proc.* 46^{th} *IEEE Veh. Technol. Conf.*, 844–848, April-May 1996.
2. Janaswamy, R., "Angle and time of arrival statistics for the Gaussian scatter density model," *IEEE Trans. Wireless Commun.*, Vol. 1, No. 3, 488–497, July 2002.
3. Khan, N. M., M. T. Simsim, and P. B. Rapajic, "A generalized spatial model for all cellular environments," in *Proc. IEEE SympoTIC'04*, Slovak Republic, 33–38, October 2004.

Investigating the Standard Deviation of the Distribution of Scatterers in Cellular Environments

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Physical and statistical properties of the scatterers existing between transmitter and receiver have to be studied in order to design reliable channel models. Wireless signal propagation changes in different environments according to scatterers' density. It is reasonable to assume that the majority of scatterers are located closer to mobile station (MS) and the density of scattering points decreases as the distance from MS increases [1, 2]. Gaussian, Laplacian, exponential, and hyperbolic distributed scatterers are examples of scattering models employing this principle of tapering-off of scatterers. For instance, Gaussian Scatter Density Model (GSDM) [1, 3] assumes Gaussian (normal) distribution for the scattering points around MS. Thus, the value of standard deviation of the distribution of scatterers, σ, plays an important role in determining the width of the scattering region and, hence, in applying the model to a specific environment.

If the density of scattering points decays sharply as the distance from MS increases, then the probability density function (pdf) of Angle of Arrival (AoA) of the multipath signal at BS will have rapidly decaying tails. Thus, the model accounts only for scatterers in the close vicinity to MS, which will have the major effect on the received signal at BS. On the other hand, if the density of scattering points decays slowly as the distance from MS increases, then the pdf of AoA of the multipath signal at BS will have heavy tails. In this case, the model accounts also for farther scatterers from MS, which have considerable effect on the received signal at BS.

A general rule of thumb was proposed in [1] for the first order approximation of the standard deviation based on experimental data. It was assumed that the stronger multipath echoes that arrive at BS shortly after Line of Sight (LoS) signal are due to scattering points close to MS while multipath echoes with larger delay values are due to scattering points farther from MS. The study in [3] found that the pdf of AoA depends on a single parameter which represents the ratio of the distance between BS and MS, D, and the standard deviation of the distribution of Gaussian distributed scatterers around MS, σ. Recently, a model for NLoS propagation in street-guided environment has been reported in [2], where it was found that $\sigma = 1/6\times$ street width is the best value for the standard deviation to fit field measurements of Power Azimuthal Spectrum (PAS). In [4], the value of standard deviation was related to cross correlation of the fading between antenna elements spaced by distance d, $\rho(d)$, and the wavelength of the carrier frequency, λ, as, $\sigma = \sqrt{\frac{\lambda^2 ln(\rho(d))}{-4\pi d^2}}$. Here, several techniques are studied for predicting accurate values for the standard deviation of the distribution of scatterers. We examine several measurement campaigns for different cellular environments in order to deduce information about the actual distribution of scatterers in these environments.

REFERENCES

1. Lotter, M. P. and P. van Rooyen, "Modeling spatial aspects of cellular CDMA/SDMA systems," *IEEE Commun Lett*, Vol. 3, No. 5, 128–131, 1999.
2. Chen, Y. and K. Dubey, "Parabolic distribution of scatterers for street-dominated mobile environments," *IEEE Trans. Veh. Technol.*, Vol. 54, No. 1, 1–8, January 2005.
3. Janaswamy, R., "Angle and time of arrival statistics for the Gaussian scatter density model," *IEEE Trans. Wireless Commun.*, Vol. 1, No. 3, 488–497, July 2002.
4. Ward, C., M. Smith, A. Jeffries, D. Adams, and J. Hudson, "Characterising the radio propagation channel for smart antenna systems," *Electronics & Communication Engineering Journal*, Vol. 8, No. 4, 191–200, August 1996.

Mathematical Modeling of Nonlinear Waves and Oscillations in Gyromagnetic Structures by Bifurcation Theory Methods

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Abstract—The vector field bifurcation approach and its numerical implementation for the rigorous mathematical simulation of nonlinear phenomena in microwave and mm-wave ferrite or composite semiconductor/ferrite devices are developed. The bifurcation points of nonlinear Maxwell's operator for the three-dimensional boundary problems, stated and solved rigorously (i. e., considering the full Maxwell's equations together with the nonlinear equations of motion for magnetization in ferrites and transport carriers in semiconductors) are analyzed using numerical methods. The electromagnetic field is represented as decomposed into a series of weakly nonlinear wave fields. The solutions of a linearized Maxwell's operator matrix equation are determined. The propagation constants of weakly nonlinear waves in waveguiding structures (WGS) or eigenfrequencies of weakly nonlinear oscillations in resonator structures (RS) are found. Using the bifurcation dynamics of Maxwell's equations the nonlinear wave interactions in the strongly nonlinear planar ferrite insert, loaded into strip-slot RS, are analyzed (from the harmonic frequency terms at the 'soft' non-linear stage into the region of 'hard' nonlinearity). The nonlinear propagation of electromagnetic waves in the strip-slot ferrite RS are modeled. The nonlinear wave phenomena, including the parametric excitation of oscillations and the wave instability process are investigated taking into account constrained geometry WGS and RS.

1. Introduction

The research of bifurcations in nonlinear dynamical systems with distributed parameters, described by nonlinear differential equations in partial derivatives, involves serious mathematical difficulties. As for distributed systems a characteristic determinant is an analogue of frequency characteristics, that's why it is possible to analyze distributed self-sustained oscillation systems using the linearization method combined with the characteristic determinant analysis (at first it was shown in [1] for the one-dimensional case). Hitherto the bifurcation analysis was used to investigate nonlinear dynamical systems with lumped parameters, described by nonlinear ordinary differential equations (ODEs). When the ordinary differential equation is of second order a qualitative analysis is possible on the two-dimensional phase surface [2]. The linearization method in combination with the frequency-domain analysis is used for the analysis of self-sustained oscillating systems and automatic control systems [2]. Determining the solutions of nonlinear differential equations in fixed points using numerical computation is a very complicated problem even for ODEs, because at the branching points qualitative modifications of solutions can happen due to variation of parameters.

The behavior caused by the instability of waves and oscillations in nonlinear or parametric systems, containing nonlinear magnetic or semiconductor media, is complex [3]. The physical theories of the instability of magnetostatic or spin waves were developed using the approximate analysis of the equation of motion of the magnetization vector in ferromagnet for one-dimensional structures only [4, 5]. The analysis of the transition region from the stable regime to the onset of labile oscillating mode caused the instability is the most complicated problem. This analysis can only be based on the solutions of full nonlinear Maxwell's equations, complemented by the nonlinear equations of motion of the magnetization vector in a ferromagnet [3]. The goal of this paper is to develop a new approach based on the bifurcation theory [6, 7] for accurate electromagnetic modeling of nonlinear wave phenomena in gyromagnetic or semiconductor waves in waveguiding structures (WGS) or resonator structures (RS) using a numerical approach for the analysis of the linearized matrix equation and bifurcation points of the nonlinear Maxwell's operator. It opens up new prospects of bifurcation analysis and rigorous mathematical modeling of strongly nonlinear electrodynamical systems using the bifurcation dynamics of Maxwell's equations.

2. The Numerical Method of Linearization of Nonlinear Maxwell's Operator in Combination with the Analysis of the Characteristic Determinant

The numerical method to determine the propagation constants of weakly nonlinear waves in WGS (or eigenfrequencies of weakly nonlinear oscillations in RS) loaded with strongly nonlinear gyromagnetic or semiconductor boundary media consists in the following.

The three-dimensional boundary problems, stated rigorously (i. e., considering the full Maxwell's equations with the nonlinear equation of motion for magnetization in ferrites or the equation of transport carriers in semiconductors, with boundary conditions following from conditions of non-asymptotic radiation) was reduced to the boundary problem for a system of nonlinear DEs together with the system of the nonlinear algebraic equations using the cross-sections method in [8, 9].

The system of nonlinear DEs together with the system of nonlinear algebraic equations [8, 9] is represented in a symbolic form, as:

$$\frac{dy_i}{dz} = F_i(y_1, y_2, \dots, y_n), \qquad \Psi_j(y_1, y_2, \dots, y_n) = 0, \tag{1}$$

where $i = 1, 2, \dots, m$; $j = m+1, m+2, \dots, n$; $y_i = y_i(z)$ are unknown functions of the longitudinal coordinate z compiled on the functions $a_n^t(\omega_m)$, $b_n^t(\omega_m)$, $a_n^z(\omega_m)$, $b_n^z(\omega_m)$, given in references [8, 9].

Let $y_i = 0$ $(i = 1, 2, \dots, n)$ be the solution of the system (1), satisfying the boundary conditions as given in reference [8, 9]. Then the functions F_i and Ψ_j $(i = 1, 2, \dots, m; j = m+1, m+2, \dots, n)$ identically vanish, consequently, the solution $y_i = 0$ $(i = 1, 2, \dots, n)$ of the system (1) is fixed (stationary) relative to the coordinate variable z.

As the first approximation, reduce the system of nonlinear differential equations (1) to a system of linear differential equations. For this purpose it is necessary to represent functions F_i and Ψ_j by their generalized Taylor's series in the neighborhood of fixed (stationary) points $x_i = 0$, and to take into account the first order partial derivatives. This procedure results a system of linear differential equations:

$$\frac{dy_i}{dz} = \sum_{K=1}^{n} \frac{\partial F_i(0, 0, \dots, 0)}{\partial y_K} \cdot y_K, \qquad \sum_{K=1}^{n} \frac{\partial \Psi_j(0, 0, \dots, 0)}{\partial y_K} \cdot y_K = 0, \tag{2}$$

where $i = 1, 2, \dots, m; j = m+1, m+2, \dots, n$.

Let us represent the system of differential equations (2) in expanded form:

$$\begin{cases} a_{11}(z) \cdot y_1 + a_{12}(z) \cdot y_2 + \dots + a_{1n}(z) \cdot y_n = y_1', \\ a_{21}(z) \cdot y_1 + a_{22}(z) \cdot y_2 + \dots + a_{2n}(z) \cdot y_n = y_2', \\ \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \\ a_{m1}(z) \cdot y_1 + a_{m2}(z) \cdot y_2 + \dots + a_{mn}(z) \cdot y_n = y_m', \\ a_{m+1,1}(z) \cdot y_1 + a_{m+1,2}(z) \cdot y_2 + \dots + a_{m+1,n}(z) \cdot y_n = 0, \\ a_{m+2,1}(z) \cdot y_1 + a_{m+2,2}(z) \cdot y_2 + \dots + a_{m+2,n}(z) \cdot y_n = 0, \\ \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \\ a_{n1}(z) \cdot y_1 + a_{n2}(z) \cdot y_2 + \dots + a_{nn}(z) \cdot y_n = 0, \end{cases} \tag{3}$$

where the coefficients $a_{ij}(z)$ $(i, j = 1, 2, \dots, n)$ compiled on the partial derivatives from (2). The system of equations (3) can be represented in matrix form as:

$$A \cdot y = \frac{dy}{dz} \tag{4}$$

where y is the vector with components $y_1, y_2, \dots, y_m$; $\dfrac{dy}{dz}$ is the vector with components $y_1', y_2', \dots, y_m'$;
$A = A_{11} - A_{12} \cdot A_{22}^{-1} \cdot A_{21}$,

$$A_{11} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & \dots & a_{2m} \\ \cdot & \cdot & \cdot & \cdot \\ a_{m1} & a_{m2} & \dots & a_{mm} \end{pmatrix}, \qquad A_{12} = \begin{pmatrix} a_{1m+1} & a_{1m+2} & \dots & a_{1n} \\ a_{2m+1} & a_{2m+2} & \dots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{m,m+1} & a_{m,m+2} & \dots & a_{mn} \end{pmatrix},$$

$$A_{21} = \begin{pmatrix} a_{m+1,1} & a_{m+1,2} & \dots & a_{m+1,m} \\ a_{m+2,1} & a_{m+2,2} & \dots & a_{m+2,m} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \dots & a_{nm} \end{pmatrix}, \qquad A_{22} = \begin{pmatrix} a_{m+1,m+1} & a_{m+1,m+2} & \dots & a_{m+1,n} \\ a_{m+2,m+1} & a_{m+2,m+2} & \dots & a_{m+2,n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix},$$

We find the partial solutions of the system of equation (4) in the form:

$$y = \alpha \cdot e^{\lambda \cdot z}, \tag{5}$$

where α is the vector with components $\alpha_1, \alpha_2, \ldots, \alpha_m$. Substituting (5) into (4), we obtain the following eigenvalue matrix equation:

$$A \cdot \alpha = \lambda \cdot \alpha, \tag{6}$$

where λ and α are correspondingly the eigenvalues and eigenvectors of matrix A. Using a numerical method (for example, the QR-algorithm) to solve the matrix equation (6) the eigenvalues λ_m and eigenvectors α of A can be determined.

The solutions (5) of the linearized Maxwell's operator (6) are treated as weakly nonlinear waves. The electromagnetic field in WGS is decomposed into a series of weakly nonlinear wave fields. The eigenvalues λ_m of matrix A are the propagation constants of the weakly nonlinear waves in WGS (or the eigenfrequencies of weakly nonlinear oscillations in RS). The components of the eigenvectors α of matrix A are the transverse and longitudinal components of weakly nonlinear waves .

The computational algorithm, using the linearization of nonlinear Maxwell's operator and the decomposition into a series of weakly nonlinear wave fields, is more complex than those for the propagation constants and fields of eigenwaves of WGS, filled with a linear medium. But the convergence of this algorithm and its stability for rounding errors is better. It permits to solve the threedimensional diffraction boundary problems for WGS or RS loaded with strongly nonlinear gyromagnetic or semiconductor insertions having sizes comparable to the wavelength. This is important for CAD of prospective ferrite or composite semiconductor/ferrite devices at microwave or mm-waves.

3. Numerical Simulation of the Parametric Excitation of Oscillations in Nonlinear Gyromagnetic Structure Using Bifurcation Points

The rigorous mathematical modeling of parametric oscillations in strip-slot RS loaded with a planar magnetized ferrite (Fig. 1) is based on solving the nonlinear diffraction boundary problem by the crosssections method of [8], using the decomposition algorithm on nonlinear autonomous blocks [10].

For the computational algorithm the transverse and longitudinal components of weakly nonlinear waves are used. It results a stable and computationally efficient algorithm for computing the instability of waves or oscillations in WGS or RS containing strongly nonlinear gyromagnetic media.

There are two incident electromagnetic waves: the signal wave of frequency ω_1 and the pumping wave of frequency ω_2 are incident on the input cross-sections S_1 of RS (Fig. 1). The waves are the fundamental and higher-order modes of strip-slot WGS, having magnitudes $C^+_{n(\alpha)}(\omega_1)$ and/or $C^+_{n(\alpha)}(\omega_2)$, where α is the index of the cross-sections, n are the indices of eigenwaves of strip-slot WGS [8, 9].

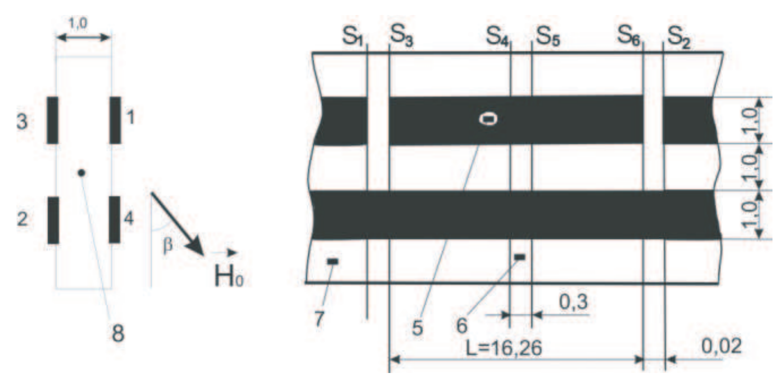

Figure 1: Resonator structure with nonlinear ferrite insert: 1, 2, 3, 4—coupled strips of strip-slot WGS; 5—strip-slot resonator; 6—planar magnetized ferrite insert ($\varepsilon = 9$, $H_0 = 278$ A/mm; $M_0/\mu_0 = 160$ A/mm; $\omega_r = 3{*}10^9$ Hz; $\beta = 45°$); 7—dielectric substrate ($\varepsilon = 9$; $\mu = 1$); 8—point of field observation; $f_1 = 5$ Hz, $f_2 = 10$ GHz; all sizes are in mm.

The instability of parametric excitation process of oscillations in ferrite RS depending on the bifurcation parameters is simulated using the numerical method of bifurcation points analysis, developed by us [11]. The results of computing of the instability regions for parametric excitation of oscillations in ferrite RS by the incident pumping wave, depending on the magnitude $C^{+}_{2(1)}(\omega_2)$ and the normalized frequency (the signal frequency ω_1 with respect to the pumping frequency ω_2) are shown in Fig. 2. The onset and the breakdown of parametric oscillations caused the wave instability in nonlinear ferrite structure in the neighborhood of bifurcation parameters were simulated into the region of 'hard' nonlinearity taking into account constrained geometries RS, and it is represented in Fig. 2.

It follows from the results of the mathematical modeling that the unstable regions for parametric excitation of oscillations in ferrite RS are near the values of the eigenfrequencies of fundamental and higher-order modes of oscillations of the strip-slot line resonator: $\omega_1 = m\omega_2/2$, $m = 1, 2, 3, \ldots$ The threshold magnitude $C^{+}_{2(1)}(\omega_2)$ is rising steeply as m increases. The minimum threshold of $C^{+}_{2(1)}(\omega_2)$ is given by $\omega_1 = \omega_2/2$.

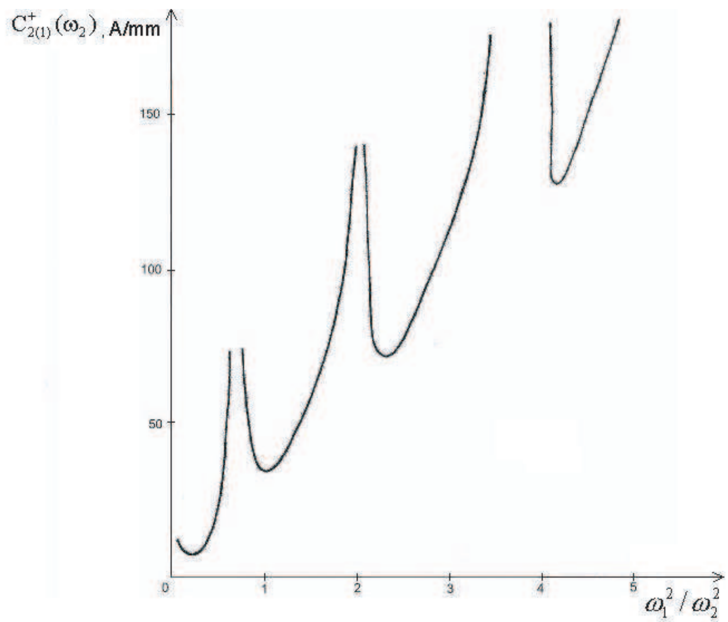

Figure 2: Instability regions for parametric excitation of oscillations in nonlinear ferrite RS, depending on bifurcation parameters: $C^{+}_{2(1)}(\omega_2)$—magnitude of incident pumping wave; ω_1—eigenfrequency of fundamental modes of oscillations the strip-slot line resonator (length of the resonator = half-wave for signal wave at f_1 = 5 GHz); ω_2 —frequency of pumping wave.

4. Conclusion

Using the achievements of modern mathematics in the area of vector field bifurcation theory opens new possibilities for computer analysis of the onset of nonlinear waves in WGS with bounded gyromagnetic media having a strong nonlinearity. This approach has a high likelihood of success in investigating nonlinear phenomena in new microwave/millimeter-wave ferrite devices [12] for frequency multiplexing/filtering, limiters, noise rejectors, signal-noise ratio enhancers, and pulse compressing devices.

REFERENCES

1. Landa, P. S., *Self-oscillations in Distributed Systems*, Moscow, Nauka, 320, 1982.
2. Andronov, A. A., A. A. Vitt, and S. E. Haikin, *The Theory of Oscillations*, Moscow, Nauka, 568, 1981.
3. Gurevich, A. G. and G. A. Melkov, *Magnetic Oscillations And Waves*, Nauka, Moscow, 1994.
4. Su, J., S. A. Nikitov, R. Marcelli, and P. De Gasperis, "Parametric and modulation instabilities of magnetostatic surface spin waves in ferromagnetic films," *J. Appl. Phys.*, Vol. 81, 1341–1347, 1997.
5. Nazarov, A. V., C. E. Patton, R. G. Cox, L. Chen, and P. Kabos, "General spin wave instability theory for anisotropic ferromagnetic insulators at high microwave power levels," *J. Magnetism and Magnetic Materials*, Vol. 248, 164–180, 2002.
6. Krasnoselskiy, M. A., *Functional analysis*, Nauka, Moscow, 1964.

7. Vainberg, M. N. and V. A. Trenoguin, *Theory of Nonlinear Equations Solutions Branch Points*, Nauka, Moscow, 1969.
8. Makeeva, G. S. and O. A. Golovanov, "Accurate electromagnetic modeling of nonlinear wave interactions in ferrite included in strip-slot waveguiding structures," *Proc. 9-th Int. Conf. Ferrites (ICF-9)*, San Francisco, California, USA, 671–676, 22–27 Aug. 2004.
9. Makeeva, G. S., O. A. Golovanov, and M. Pardavi-Horvath, "Rigorous nonlinear analysis of propagating waves in the strip-slot waveguiding structure with a strongly nonlinear semiconductor discontinuity progress in electromagnetics research symposium," *PIERS 2005*, Hangzhou, China, 22–26 Aug. 2005.
10. Golovanov, O. A., "Nonlinear autonomous blocks and their usage for studying irregular waveguides and resonators with nonlinear media," *Izvestiya vysshikh uchebnykh zavedenii. Radiofizika*, Vol. 33, No. 7, 793–804, 1990.
11. Makeeva, G. S., O. A. Golovanov, and M. Pardavi-Horvath, "Numerical analysis of wave instability in strongly nonlinear ferrite structures using bifurcation points of the nonlinear maxwell's operator," *Progress in Electromagnetics Research Symposium, PIERS 2005*, Hangzhou, China, 22–26 Aug. 2005.
12. Marcelli, R. and S. A. Nikitov, Eds, "Nonlinear microwave signal processing: towards a new range of devices," *NATO ASI Series, 3. High Technology*, Kluwer Academic Publishers, Dordrecht, 20, 509, 1996.

Miniaturized Cross-slotted Dual-mode Filter for Mobile and Satellite Communications

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A new, compact, narrow band, low loss, dual-mode cross-slotted filter is proposed and developed. The compactness and improved filter characteristics of this square filter makes it suitable for mobile and satellite communications. The dual-mode filter consists of simple star-type geometry slot lines crossing a square patch. Two additional fringe slots are also introduced on each side of the square patch. The external coupling is capacitive and was achieved through external lines, which are placed at a right angle. The conventional square patch dual-mode filters offer simple design and good power handling capability, however they require larger size than the dual-mode loop filters for the same frequency band. The novelty of this proposed structure consists in significant size-reduction and the ability to control the central frequency and the bandwidth; our proposed dual-mode filter is 37% smaller than a conventional patch dual-mode filter for the same frequency band. The filter was simulated using Sonnet Software, both lossless and lossy cases being considered, and was fabricated on a Rogers?substrate with a dielectric constant of 10.8. The star-type geometry dual-mode filter presents two transmission zeros on each side of the pass-band, and improved filter characteristics over the conventional ones. The perturbation was introduced using a difference between the lengths of the diagonal slots. It is found that the resonant frequency of the filter with 1% fractional bandwidth could be shifted down to below 900 MHz, for the use in the mobile and satellite communications.

REFERENCES

1. Zhu, L., P. M. Wecowski, and K. Wu, "New planar dual-mode filter using cross-slotted patch resonator for simultaneous size and loss reduction," *IEEE Trans. on MTT*, Vol. 47, 650, 1999.
2. Casinese, A., A. Andreone, M. Barra, C. Granata, P. Orgiani, F. Palomba, G. Panariello, G. Pica, and F. Schettino, "Dual mode superdonducting planar filters based on slotted square resonators," *IEEE Trans. on Applied Superconductivity*, Vol. 11, No. 1, 2001.
3. Hsieh, L. H. and K. Chang, "Dual-mode quasi-elliptic-function bandpass filters using ring resonators with enhanced-coupling tuning stubs," *IEEE Trans. on MTT*, Vol. 50, 1340, 2004.
4. Curtis, J. A. and S. J. Fiedziuszko, "Miniature dual mode mnicrostrip filters," *IEEE Microwave Symposium Digest*, 1991.
5. Banciu, M. G., G. L. jewski, A. Ioachim, L. Nedelcu, N. Militaru, A. Shen, and R. Ramer, "New planar compact dual mode filters for mobile communications," *CAS Proceedings to International Semiconductor Conf.*, 2004.
6. Guglielmi, M. and G. Gatti, "Experimental investigation of dual-mode microstrip ring resonators," *The 20th European Microwave Conference Digests, Budapest-Hungary*, 901–906, 1990.

Near-field Scatterers and Mutual Coupling in Multi-antenna Systems

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Communication systems use antenna arrays to increase the communication capacity by exploiting the spatial properties of the multi-path channel. Providing high capacity requires independence of the channel matrix coefficients, a condition generally achieved with wide antenna element spacing. For many subscriber units, such separations are unrealistic, and the resulting antenna mutual coupling can impact the communication system performance. The prior studies have presented important findings concerning the effect of mutual coupling on spatial correlation in closely spaced antenna arrays. But, they often disagree in terms of whether mutual coupling is advantageous or disadvantageous. In the multi-antenna systems, the mutual coupling is due to antenna element separation, geometry of array and antenna elements, frequency, substrate thickness and constant and near field scatterers-NFS. All these parameters are known for a given array, except near field scatterers. In order to get better insight into the mutual coupling effects in the multi-antenna system, we include the near-field scatterers in theoretical investigation. The occurrence of NFS can not be controlled, they appear randomly. Thus we investigate impact of NFS on the spatial correlation for different distribution functions of near-field scatterers. In addition, the modal analysis approach is presented in order to obtain closed-form expressions for the spatial correlation function for narrow-band signals for a wide variety of scattering distribution functions. We investigate spatial correlation in the multi-antenna system for different NFS distribution in the close vicinity of receive antenna arrays. Relatively close NFS can cause array blindness, but at the same time they can perturb antenna pattern to result in lower spatial correlation level. The scatterers relatively far from antenna array can behave like multi-path scattering object and increase the environment richness. Our simulation results confirm that near field scatterers increase the mutual coupling between the antenna elements. Hence, they act as decreasing factor on spatial correlation for rich far-field scatterers environments. While, for poor scattering environment they act as increasing factor on spatial correlations.

Current-induced Bistability and Dynamic Range of Microwave Generation in Magnetic Nano-structures

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We give a simple picture of magnetization dynamics in magnetic multi-layers under the action of spin-polarized current. Based on the idea that the main effect of the current I is the creation of negative damping $GI\_ = \_ - sI$, we explained both the current-induced bistability and microwave generation in a finite range of currents. In the absence of current the magnetization vector in a "free" layer of a magnetic layered structure has at least two equilibrium orientations: one stable ("bottom" state), corresponding to the minimum of the magnetic energy and one unstable ("top" state), corresponding to the maximum of the energy. Since the effective damping created by spin-polarized current is negative, at a certain critical current $I_{c\_} = \_G/s$ the total effective damping $Gtot\_ = \_G\_ + \_GI$, where G is the natural positive damping, could become negative not only for the "bottom" state of magnetization orientation, but also for the "top" state. When that happens the "bottom" (initially stable) state loses itsstability, while the "top" (initially unstable) state, in contrast, becomes stable. The change of stability for each state happens, in general, at the different values of current. The "bottom" state becomes unstable at $I_{c\_} = \_Imin$, thus allowing precession of magnetization with microwave frequency, while the "top" state becomes stable at $I_{c\_} = \_Imax$, thus stopping any magnetization precession. If $I_{min\_} < \_I_{max}$ there exists a finite range $I_{min\_} < \_I\_ < \_I_{max}$ of currents in which the system demonstrates microwave oscillations of magnetization. In the opposite case $Imin\_ > \_Imax$ the precessional dynamics could not exist at all, and with the current variation in the interval $I_{min\_} < \_I\_ < \_I_{max}$ the system becomes bistable, i. e., it switches between two stable states corresponding to the minimum and maximum of the magnetic energy. We derived simple analytical expressions for both threshold currents $Imin$ and $Imax$ and compared our results with available experimental data.

Nonlinear Self-phase-locking in an Array of Current-driven Magnetic Nano-contacts

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Recently it was shown that spin-polarized current passing through a thin magnetic layer can excite microwave magnetization precession in this layer. It was also demonstrated experimentally that the frequency of microwave generation in a current-driven magnetic nano-contact can be phase-locked to the frequency of a small external sinusoidalcurrent added to the constant bias current. In this work we theoretically investigate the possibility of self-phase-locking of an array of magnetic nano-contacts by self-induced dipolar magnetic field. First, we consider an isolated nano-contact driven by a constant bias current and determine the conditions of its phase-locking to the frequency of a small external microwave signal, which can be created either by microwave magnetic field or by microwave modulation of the bias current. We show that, in contrast with the case of a usual microwave oscillator, the mechanism of phase-locking in a nano-contact is strongly nonlinear: due to the strong dependence of the precession frequency on the precession amplitude even small changes in the oscillation amplitude can result in matching of the generated frequency to the frequency of the external signal. This nonlinear frequency matching mechanism leads to a significant increase in the frequency bandwidth of phase-locking D (up to $\sim$ 300 MHz). Bandwidth D has a non-trivial dependence on the magnetization angle, showing a well-pronounced minimum for the magnetization angle at which the coefficient of the nonlinear frequency shift is zero. We used the results obtained for an isolated nano-contact to determine the conditions for self-phase-locking of an array of nano-contacts, and found that the self-phase-locking in an array is practically possible when the distance between individual contacts is ~ 10 times larger than the nano-contact radius even if the inhomogeneous distribution of the frequencies generated by individual nano-contacts is as large as 10%.

Adaptive Turbo Multiuser Decision Feedback Detection for DS-CDMA on Unknown Multi-path Channels

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In this paper we propose an adaptive turbo multiuser detection (MUD) on unknown multi-path channels. The analyzed multi-user scheme is Successive Decision Feedback Detector (S-DFD), which means that users are detected on one-by-one basis and they are cancelled successively by use of decision feedback. An adaptive LMS algorithm is used to estimate MUD coefficients. Binary Phase Shift Keying (BPSK) in combination with Direct Sequence Code Division Multiple Access (DS-CDMA) is analyzed, which means that information is first coded using convolutional encoder, and then modulated and spread using randomly chosen spreading sequences for each user.

Our analysis shows that the adaptive realization employing the LMS adaptive algorithm, out- performs (in terms of Bit Error rate (BER)) the conventional detection that combines a standard Minimum Mean Square Error (MMSE) solution and decoding concatenated in a turbo scheme. A standard solution means that the MUD coefficients are obtained applying the MMSE criterion and assuming perfect knowledge about the received spreading sequences after multi-path propagation and perfect decision feedback.

The reason behind this is that during the Turbo detection process the assumption about perfect decision feedback becomes highly unreliable that must be taken into account while determining S-DFD coefficients. Decision feedback error propagation becomes particularly severe at low Signal-to Noise Ratio (SNR) or highly loaded, heavy interference systems when number of users exceeds the spreading gain. On the other hand, the adaptive LMS detection does not assume the perfect decision feedback while adjusting the filter coefficients and it always set the coefficients providing that the output error is orthogonal on the received sequence. This means that it automatically takes into account the feedback error propagation providing an unbiased MMSE solution that does not assume perfect feedback and, consequently, deliver better BER results. In addition to better BER performance, another advantage of the adaptive detection is that it does not require knowledge about system parameters, such as spreading sequences, multi-path channels etc, but the MUD parameters are estimated during the training process.

In our work, we analyze various multi-user scenarios. This includes unsaturated systems, where number of users K is smaller than the spreading gain N ($\rho = K/N < 1$) and overloaded case, i.e., the number of users K is larger than the spreading gain ($\rho > 1$). We also analyze single- and multi-cell cases. In single cell situation, all users are assumed to be within one cell and during the multiuser detection process multi-user turbo detector detects all signals, one-by-one, in a turbo-like process. However, in a multi-cell scenario, there is a certain number of users located outside the cell of interest that cannot be detected and, consequently, they represent unknown interferers whose influence may significantly degrade the performance of the analyzed turbo MUD. Our simulation results show that the adaptive turbo MUD always exhibits better or at least identical BER performance relative to the conventional MMSE turbo MUD. We show that SNR gain grows with the increasing number of users within the system and the most remarkable improvement is obtained for the overloaded case. For this particular scenario, the conventional MMSE turbo MUD cannot perform detection properly, while the adaptive detector still achieves relatively good BER performance.

A Novel Approach for Tunable Filters

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The paper presents a new concept to implement tunable lowpass filters by employing slot resonators etched in the ground plane. The tunability is achieved with the use of switches to change the effective length of the slots on the ground. A tuning range of more than 60% has been obtained. The concept is attractive since the Q of the switching elements play a little role in determining the insertion loss of the filter. The structure is useful where the emphasis is on out-of-band interference suppression. The validity of the proposed concept is demonstrated by considering 4-slots and 10-slots lowpass filters. RF MEMS switches are integrated on the ground plane to short circuit the slots. The simulated and measured results of the tunable filters exhibit an excellent agreement with a remarkable insertion loss and tuning range performance.