COMMISSION B : Fields and Waves (Nov. 2007 - Oct. 2010)

Edited by Toru Sato

This report presents a summary of Japanese contributions, including those of international collaborations, in the field related to URSI Commission B during the last three years. It is not intended to be an exhaustive survey of all relevant works, but rather an omnibus of important works around the authors of each section or subsection. If important contributions in some field are missing, it is due to the limited knowledge and effort of the editor.

B1. Scattering and Diffraction

1.1 Basic Electromagnetic Fields Analysis

Hosono and Hosono [2009] clarified the physical meaning of the energy velocity in lossy Lorentz media. First, two expressions for the energy velocity, one by Brillouin and another by Diener, are examined. They showed that, while Diener's is disqualified, Brillouin's is acceptable as energy velocity. Secondly, they showed that the signal velocity defined by Brillouin and Baerwald is exactly identical with the Brillouin's energy velocity. Thirdly, by using triangle-modulated harmonic wave, they showed that the superluminal group velocity plays its role as a revelator only after the arrival of the signal traveling at the subluminal energy velocity. In short, nothing moves at the group velocity, and every frequency component of a signal propagates at its own energy velocity.
(T. Yamasaki)

1.2 Periodic Array Structures

In microwave and optical engineering, there are many devices with periodic structures including resonators, filters, and couplers composed of gratings as well as reflector antennas. Therefore the analysis of the scattering by periodic structures is one of the important subjects in electromagnetic theory and optics. Various analytical and numerical methods have been developed thus far and the diffraction phenomena have been investigated for a number of periodic structures.

The Wiener-Hopf technique is known as a powerful tool for analyzing electromagnetic wave problems related to canonical geometries rigorously, and can be applied efficiently to problems of the diffraction by specific periodic structures. Zheng and Kobayashi [2009a] analyzed the E-polarized plane wave diffraction by a semi-infinite parallel-plate waveguide with sinusoidal wall corrugation using the Wiener-Hopf technique together with the perturbation method. The problem is formulated in terms of the simultaneous Wiener-Hopf equations by introducing the Fourier transform for the unknown scattered field and applying approximate boundary conditions in the transform domain. Employing the factorization and decomposition procedure together with a perturbation series expansion, the zero- and first-order solutions of the Wiener-Hopf equations are obtained. Explicit expressions of the scattered field inside and outside the waveguide are derived analytically by taking the inverse Fourier transform and applying the saddle point method. Far field scattering characteristics of the waveguide are discussed in detail via representative numerical examples.

The plane wave diffraction by the same waveguide geometry is analyzed for the case of H polarization by the same authors [Zheng and Kobayashi, 2009b] using a similar but more complicated analysis procedure. This diffraction problem is reconsidered for both E and H polarizations in [Zheng and Kobayashi, 2009c], and investigated from different aspects.

Ozaki *et al.*[2009] propose an improved method to analyze the scattering problem of multilayered periodic arrays, by dielectric gratings with dielectric rectangular cylinders sandwiched between two multilayers, by combining an improved Fourier series expansion method and multilayer method. In our improved method, the order of simultaneous equation is the same as that of previous methods, but it differs in the position of summarized matrix. Numerical results are given for the influence of incident angle and frequency of the transmitted power in terms of permittivity of the rectangular cylinders in the middle layer sandwiched between two multilayers yielding the basic characteristic of resonance peak for switching or frequency-selective devices for both TM and TE cases.

Shadow theory has been applied to the analyses of the dielectric diffraction gratings [Wakabayashi *et al.*, 2010]). The matrix-based formulation has been proposed to get the diffraction amplitudes at a low grazing limit of incidence. It has been demonstrated that the scattering factors defined in the Shadow Theory imply the Green's functions in the spectral domain.

The contributions of the quadrupole moments in the effective constitutive characteristics of three dimensional periodic array of skew pairs of metallic helices have been studied by using the quasi-static Lorentz approach combined with the method of moments [Asai ans Yamanaka, 2010]. It has been shown that there are geometrical parameters where the contributions of quadrupoles have values comparable to the effective medium parameters. Asai and Yamanaka [2008] analyzed the effective constitutive characteristics of three dimensional periodic array of metallic helices by the quasi-static Lorentz approach. It has been shown that the contributions of quadrupoles are negligible for the cases of helices with more than a certain number of turns.

Yokota and Sesay [2008] examined a two-dimensional scattering of a plane wave from a periodic array of dielectric cylinders with arbitrary shape using multigrid-moment method. The scattered field is expressed in terms of the integral form by an infinite summation of the surface integral over the cross section of the reference cylinder. The integral form is converted into the matrix equation by using moment method. The integration in the elements of the matrix equation is evaluated by the lattice sums technique in order to obtain precise solution. The multigrid method is applied to the matrix equation to improve the CPU time. As numerical results, the CPU time and residual norm are examined for a given number of iteration and cycle index. After that, the effects of shape and material of the periodic structure on the power reflection coefficient of the fundamental Floquet mode are shown. The results also indicate the effect of changing the relative permittivity of the dielectric coated body and the reflection coefficient.
(K. Kobayashi, T. Yamasaki, and M. Yokota)

1.3 Cavity Structures

The analysis of electromagnetic wave scattering by open-ended metallic waveguide cavities is an important subject in the prediction and reduction of the radar cross section (RCS) of a target. This problem serves as a simple model of duct structures such as jet engine intakes of aircrafts and cracks occurring on surfaces of general complicated bodies.

As an example of waveguide geometries that can form two-dimensional cavities, Zheng and Kobayashi [2008] considered a finite parallel-plate waveguide with four-layer material loading, and analyzed rigorously the problem of the E-polarized plane wave diffraction using the Wiener-Hopf technique. Introducing the Fourier transform for the scattered field and applying boundary conditions in the transform domain, the problem is formulated in terms of the simultaneous Wiener-Hopf equations, which are solved via the factorization and decomposition procedure together with a rigorous asymptotics. The scattered field is evaluated explicitly by taking the inverse Fourier transform and applying the saddle point method. Representative numerical examples of the radar cross section (RCS) are shown for various physical parameters and the far field scattering characteristics are discussed in detail. The diffraction by the same waveguide geometry is analyzed for the case of the H-polarized plane wave incidence by Shang and Kobayashi [2008] using the Wiener-Hopf technique. This diffraction problem is reconsidered for both E and H polarizations in [Zheng *et al.*, 2010], and investigated from different aspects.

As a related cavity geometry, Shang and Kobayashi [2009a, 2009b] have considered a terminated, semi-infinite parallel-plate waveguide with four-layer material loading, and solved the plane wave diffraction rigorously using the Wiener-Hopf technique for both E and H polarizations. Introducing the Fourier transform for the unknown scattered field and applying boundary conditions in the transform domain, the problem is formulated in terms of the simultaneous Wiener-Hopf equations satisfied by the unknown spectral functions. The Wiener-Hopf equations are solved via the factorization and decomposition procedure leading to the exact solution. The scattered field in the real space is evaluated by taking the inverse Fourier transform and using the saddle point method. Representative numerical examples of the radar cross section (RCS) are presented, and the far-field scattering characteristics of the waveguide are investigated in detail.
(K. Kobayashi)

B2. Inverse Scattering

High-speed ultra-wideband (UWB) radar imaging has been of great interest. SEABED method is one of such promising methods, and can estimate target shapes quickly [Sakamoto *et al.*, 2010b, Cresp *et al.*, 2010]. However, to realize real-time imaging, measurement time as well should be shortened. Bi-static SEABED method has been developed to achieve fast measurement using a multi-static radar with switches [Kidera *et al.*, 2008b]. Another approach, a code-division multiple transmission UWB radar system was proposed, which does not need switches, to achieve even faster measurement [Sakamoto and Sato, 2009b].

Since SEABED method uses derivative operations, it becomes unstable for noisy data. To improve its noise tolerance, an extended version of SEABED, namely Envelope method, was developed [Kidera *et al.*, 2008e, Saho *et al.*, 2008] which employs envelopes of circles instead of derivative operations. To improve the accuracy of the Envelope method, waveform distortion was suppressed [Kidera *et al.*, 2007]. Then, the Envelope has been further extended to apply to through-the-wall imaging (TWI) [Kidera *et al.*, 2008a,d, 2009c].

Both the SEABED and Envelope methods require what is called quasi-wavefront (QW) that is a surface obtained by connecting peak points of signals. This process is not always easy to realize due to interference of waveforms. Optimization-based QW estimation method was developed to avoid this difficulty [Sakamoto *et al.*, 2008b,c,e]. Then, range point migration (RPM) method was developed [Kidera *et al.*, 2008c, 2010a,b,c]. This method does not need QW because it calculates derivatives with distribution functions.

These SEABED-class methods all require large-scale antenna arrays that make the system costly. A simple two-antenna UWB radar imaging system has been proposed for a uniformly moving target [Sakamoto and Sato, 2008a], and applied to experimental data [Sakamoto and Sato, 2008d]. This method was extended to apply to arbitrary translational motion [Sakamoto *et al.*, 2009d, Matsuki *et al.*, 2010]. Another approach to reduce the number of antennas was proposed by employing multi-path echoes from environments [Sakamoto and Sato, 2009a]. This method uses only a single antenna, but needs a priori information about the environment. This environment-related information can be estimated without calibration process using the optimization-based method [Sakamoto and Sato, 2010a]. Then, a human body tracking method has been proposed using the same principle [Sakamoto and Sato, 2010c]. Furthermore, this approach makes it possible to image targets in a shadow region [Fujita *et al.*, 2010, Kidera *et al.*, 2009a,b]. In addition, some feasibility studies have been conducted to apply these methods to actual human bodies [Sakamoto *et al.*, 2009c, Saho *et al.*, 2010].

Ishida [2009, 2010] formulated an algorithm for reconstructing a dielectric cylinder with the use of the T-matrix and the singular value decomposition (SVD) and discussed it through numerical examples under noisy conditions. The algorithm consists of two stages. At the first stage the measured data of scattered waves is transformed into the T-matrix. At the second stage the cylinder is reconstructed from the T-matrix. The singular value decomposition is applied in order to separate the radiating and the nonradiating currents, and the radiating current is directly obtained from the T-matrix. The nonradiating current and the object are reconstructed by decreasing a residual error of the current in the least square approximation, where linear equations are solved repeatedly. Some techniques are used in order to reduce the calculation time and to reduce the effects of noise. Numerical examples show us that the presented approach is simple and numerically feasible, and enables us to reconstruct a large object in a short time.
(T. Sakamoto and N. Nakashima)

B3. Computational Techniques

3.1 Integral Equation Methods

Integral equation methods are widely used in analyzing various wave propagation and scattering problems. There are a number of papers treating complicated two- and three-dimensional problems based on different integral equation methods.

Kobayashi *et al.*[2009] considered the diffraction of an electromagnetic field by a locally inhomogeneous body in a perfectly conducting waveguide of rectangular cross section. This problem is reduced to solving a volume singular integral equation (VSIE). The examination of this equation is based on the analysis of the corresponding boundary value problem (BVP) for the system of Maxwell's equations and the equivalence of this BVP and VSIE. The existence and uniqueness for VSIE in the space of square-integrable functions are proved. A numerical Galerkin method for the solution of VSIE is proposed, and its convergence is proved.

The singular volume integral equation describing the electromagnetic wave scattering in three-dimensional bounded inhomogeneous anisotropic media is considered by Samokhin and Kobayashi [2010]. The problem of finding the spectrum of the pertaining integral operator is analyzed. A closed-form expression describing the continuous part of the spectrum on the complex plane is presented. Subsequently the Chebyshev iterative method for non-selfadjoint operators is investigated in this paper. Some numerical results are presented, and the convergence of this procedure is discussed for different physical parameters of the problem.

A wideband fast multipole algorithm (FMA) is presented for the computation of two-dimensional volume integral equations [Nakashima and Tateiba, 2009a]. The wideband FMA can be realized by switching between the diagonal and non-diagonal forms according to cell size and required accuracy. In order to improve the efficiency of the algorithm, they use interpolation and filtering techniques and introduce a simple and efficient way to store sequences of the special functions and their discrete Fourier transforms. The computational and memory complexities are O(N), where N is the number of square elements followed by the discretization of the volume integral equations.

Fast and efficient linear iterative solvers for complex and dense linear system of equations are necessary in the computation by means of integral equation methods. In 2008, P. Sonneveld and M. van Gijzen presented the breakthrough nonstationary linear iterative solver "IDR(s) method" for nonsymmetric linear system of equations. After that, variant algorithms of the IDR(s) method have been proposed. Nakashima *et al.*[2009b, 2009d, 2010a] evaluate performance of the IDR(s) method and its variants through the computation of electromagnetic wave scattering from over 10^4 dielectric cylinders. Numerical experiments reveal that minimization schemes for residual vectors refine the convergence of the original IDR(s) method. However, the may deteriorate in 1 digit independently of parameter s.

In the integral equation methods, a time transient of multiple scattering is mathematically equivalent to an iterative progressive numerical method (IPNM). The original IPNM was proposed by L. Shafai for the fast computation of large scale electromagnetic wave problems in antennas and scattering. Nakashima and Tateiba [2009c] remark the similarity between the original IPNM and the Jacobi method which is one of the classical linear iterative solvers. Nakashima *et al.*[2010b, 2010c] modify the original IPNM and present 9 type variant algorithms from the standpoint of the classical and the IDR-based linear iterative solvers. They report the performance of the variant algorithms through the computation of electromagnetic wave scattering from conducting objects.

Recently, the number of customers who use cellular phones indoors is rapidly increasing. In this case, mobile terminals used in a stationary condition receive a level variation different from that in a moving condition. Yokota *et al.*[2010] proposed that a physical channel model for a static terminal used in indoors. The proposed model can consider physical parameters such as moving people, their moving speed in order to evaluate various situations preciously, and an experimental verification is done. The model is two dimension, and assumes that a moving person is represented as a disk with diameter of Δw [m] and its moving person absorbs a part of the power of the paths across his width of Δw. They verified the equivalent human body diameter of Δw from numeric viewpoint based on electromagnetic field theory as a human body to be loss dielectric cylinder.
(K. Kobayashi, N. Nakashima and M. Yokota)

3.2 Modal Expansion Methods

Radar cross sections of polygonal cylinders are investigated by using a kind of mode matching methods [Ohnuki *et al.*, 2010]. Applying two types of novel field-decomposition techniques, electromagnetic scattering analysis can be performed very precisely. Computational accuracy of our proposed method and the proper choice of field-decomposition techniques for a rectangular cylinder with various shapes of wedge cavities and bumps is discussed.

Electromagnetic scattering problems of polygonal cylinders can be analyzed with high degree of accuracy by the point matching method [Ohnuki *et al.*, 2009]). In this method, the electromagnetic fields can be expanded by using the modes which satisfy the wave equation in the local coordinate systems. The way to estimate proper mode numbers due to computational accuracy is discussed.

The fast inhomogeneous plane wave algorithm is an alternative approach of the diagonal factorization of the Green's function which is represented by the infinite integration in the complex plane [Ohnuki, 2009]. Therefore, the error control method is different from that for the fast multipole method. They compared the two algorithms, FIPWA and FMM, in terms of the error control, and clarify the error properties for applying to electromagnetic scattering problems. The condition that two translators become numerically equivalent is discussed.
(T. Yamasaki)

B4. High Frequency Technique

The paper by [Sato and Shirai, 2008] proposes a simple accuracy improvement of the ray-launching analysis by efficiently including the multiple reflection effect inside lossy wall. The Green's function problem in the presence of a lossy dielectric slab has been considered to derive the transmitted ray component with the internal multiple reflections. So as to realize the appropriate ray shooting inside lossy material, alternative real refraction angle is introduced, instead of the conventional complex refraction angle. By approximately including multiple reflections effect inside wall for indoor environment, an easy and efficient modification of simplified 2D ray-launching method has been presented in [Sato and Shirai, 2009a]. To precisely carry out the ray-launching procedure inside lossy wall, a simple modification using true real refraction angle is first introduced, instead of complex one. Furthermore, an efficient approximation is carried out to bundle or collect the inner multiple reflected rays into the primary one. This "collective ray" approximation is applied to not only reflected but also transmitted rays. Consequently, it is confirmed from the detailed considerations that the ray representations obtained by introducing the real refraction angle are well suitable for indoor propagation analysis, and in particular the "collective ray" solution can be utilized confidently even when the internal reflections strongly contribute to the propagation feature of the considered indoor environment.

By including multiple reflection effect inside wall for indoor environment, an efficient modification of 2D ray-launching method, has been proposed in [Sato and Shiarai, 2009b] which focuses on the derivation of the approximate solution for H (or Vertical) polarized incident case. An efficient approximation is carried out to bundle or collect the internal multiple reflected rays into the primary one. This approximation is called "collective ray" approach. It is confirmed from the detailed considerations that the "collective ray" solutions for H-polarization can be confidently utilized in particular when the internal reflections strongly contribute to the propagation characteristic of the considered indoor environment.

The paper by [Sato and Shirai, 2009c] attempts to find out a useful marker with specific propagation feature for appropriately modeling outdoor/indoor interface environments, by analyzing diffraction problem for finite number of empty slits in an infinitely long PEC screen. The analysis has been focused on E polarized plane wave incident case. The analysis utilizes the Kobayashi Potential (KP) method, which is a rigorous eigen-function expansion in terms of Weber-Schafheitlin type integrals with discontinuous features. The contribution of the multiple scattering between the slits is represented by the asymptotic approximation for the distance of them. The analysis has been extended to H-polarized plane wave incident case [Sato and Shirai, 2009d]. The Kobayashi Potential (KP) is utilized to obtain the analytical representations of the diffracted fields. In particular, the paper investigates how the multiple scattering between the slits influences on the diffraction characteristics. The paper by [Sato and Shirai, 2010a] investigates specific propagation feature under outdoor/indoor interface environments, by analyzing diffraction problem for finite number of material filled slits in an infinitely long PEC screen. The slits array is considered as a simplified indoor/outdoor interface model, i.e. glass windows with PEC frames. The Kobayashi Potential (KP) method is utilized in the analysis. The contribution of the multiple scattering is approximately obtained by the high frequency asymptotic approximation with respect to the distance between the slits. Influence of the existence of the PEC frame surrounding the window glass, i.e. the multiple scattering between the adjacent slits on the propagation feature has been investigated for both empty and material filled cases, and for both E and H polarization cases.

Electromagnetic plane wave diffraction by a wide slit on conducting plane with finite thickness has been discussed in the paper by [Sato and Shirai, 2010b]. Here, high frequency asymptotic ray technique is applied to analyze the diffraction phenomenon. According to the ray-mode coupling analysis, the total diffracted field in each region is considered as a summation of successive modal radiation contribution due to the original modal excitation by the incident plane wave. The successive process for generating higher modal reflection and radiation fields continues until all the energy inside the slit region is completely consumed. The accuracy of the present high frequency solution is confirmed by comparing with the other analytical one.

Local-MoM is proposed which reduces computational load of the MoM by solving only local areas around stationary phase points [Ito and Ando, 2010, Ito *et al.*, 2010]. Range of MoM areas are explicitly determined in terms of Fresnel zone number. Fresnel zone criterion can also be applied to curved surfaces. Local-MoM solves much less unknowns as compared with the standard MoM but still retains comparable accuracy of the MoM. The different forms of Fresnel zone [Ando *et al.*, 2008] can be a criterion for MoM regions in PO-MoM hybrid method as well. Complementary use of Local-MoM and PO-MoM enhances the reduction effect of number of unknowns for all the observation angles; this combined method provides nearly frequency-independent characteristic. Application to concave surface with multiple reflections and expansion to three- dimensional structure is left for the future work.

The local errors in the MER integral reduction due to the higher order terms contribution are identified and defined in the PO surface integration [Ando *et al.*, 2008, Rodriguez *et al.*, 2008, Kumamaru *et al.*, 2008, Rodriguez *et al.*, 2009]. In order to assess the diffusion area where these terms are confined, the Fresnel criterion is introduced as a function of the source/observer position, the local shape of the scattering surface and also the frequency. The extended application of the PO surface to MER line integral reduction, named as ”combined PO/MER expression” is proposed in the article [Rodriguez *et al.*, 2009] to compensate the MER reduction errors.

Simple equivalent surface currents perturbed from the Physical Optics (PO) are proposed [Shijo *et al.*, 2008, Ando, 2008, Omaki *et al.*, 2009], which predict accurate scattering fields without a special knowledge about the high frequency asymptotic theory such as the Geometrical Theory of Diffraction (GTD). A novel and empirical concept of ”modified surface-normal vectors,” is introduced in the classical definition of the PO current which is defined in a way that the reflection law is satisfied at each point of interest in the integration region. This empirical and geometrical replacement of the surface-normal vectors drastically enhances the accuracy of the PO to a level of GTD.

When the electromagnetic wave is incident on the cylindrically curved surface, the total scattered field excited by the incident wave is obtained from geometrical rays, edge-diffracted rays, edge-surface diffracted ray, WG modes, and a combination of these [Goto *et al.*, 2008a,b, 2009a]. The high-frequency asymptotic analysis methods have been studied for the scattered fields by a cylindrically curved conducting surface excited by the incident wave on the curved surface from the convex side [Goto *et al.*, 2009a]. The novel hybrid ray-mode solution has been derived for the scattered fields near the concave surface by solving a canonical problem formulated under the assumption that the cylindrically curved conducting surface possesses only one edge. Then by applying the ray tracing technique and the idea of Keller's GTD (Geometrical Theory of Diffraction), the solutions derived for the canonical problem are extended to account for the problem of the radiation from and the scattering by the other edge of the cylindrically curved surface. The validity of the novel asymptotic representations has been confirmed by comparing both with the numerical results obtained from the method of moment and the experimental results performed in the anechoic chamber.

By extending the corresponding frequency-domain asymptotic solution, a novel time-domain asymptotic solution for a transient scattered field by a cylindrically curved conducting surface has been derived [Goto *et al.*, 2009b,c]. The transient scattered field is excited by the high-frequency modulated pulse source. By comparing the asymptotic solution with the reference solution calculated numerically, it is shown that the novel time-domain asymptotic solution is highly accurate and very efficient in terms of the computation time. Also a novel time-domain asymptotic solution has been derived for a transient whispering-gallery (WG) mode radiation from the aperture plane of a cylindrical concave conducting boundary [Goto *et al.*, 2008c, 2010a,b]. The WG mode is excited by a Gaussian-type modulated pulse source. The WG mode radiation field propagates with the phase velocity coincident with the speed of light and the newly derived group velocity. The validity of the time-domain asymptotic solution is confirmed by comparing with the reference solution calculated numerically.

When the radio wave traverses a coastline from the land to the sea or viceversa, the ground wave is strongly influenced by the abrupt change of the surface impedances. In the papers by [Kawano *et al.*, 2008a,b, 2009a], the integral representation has been derived for the ground wave propagation over land-to-sea mixed-paths. Then by using the method of the stationary phase applicable uniformly as the stationary phase point approaches the endpoint, the high-frequency asymptotic solution has been derived for the ground wave propagation over the mixed-path. The validity of the various representations has been confirmed by comparing both with the conventional mixed-path theory and with the experimental results performed in Kanto areas including the sea near Tokyo bay. By examining the asymptotic solution in detail, the cause or the mechanism of the recovery effect occurring on the portion of the sea over the land-to-sea mixed-path has been clarified.

A novel high-frequency asymptotic solution has been obtained for scattered fields by a junction of planar impedance surfaces assuming that the transmitting and the receiving antennas are placed at some heights from the sea level [Kawano *et al.*, 2009b] and at sufficiently higher positions from the surface of the earth [Kawano *et al.*, 2010a,b,c]. An integral representation for scattered fields derived by using the aperture field method is evaluated asymptotically by applying the saddle point technique applicable uniformly as the saddle point approaches the endpoint of the integral. The novel asymptotic solution includes the higher-order term to obtain the accurate solution [Kawano *et al.*, 2010b,c]. The validity and applicable range of the novel asymptotic solution have been confirmed by comparing with the reference solution calculated from the numerical integration of the integral for the scattered fields. Also shown is the physical interpretation of the asymptotic solution proposed in this study.

The problems of the electromagnetic wave that is incident on a plane dielectric interface consisting of two different mediums have been the important research subjects for many years. It has been shown that the lateral displacement (or Goos-H?nchen shift) occurs when incidence takes place at or very close to the critical angle of total reflection. When the cylindrical wave or the spherical wave is incident on a plane dielectric interface from a denser (1st) medium to a rarer (2nd) one, the observer placed in the 2nd medium may receive only the transmitted geometrical ray in the short distance and both the transmitted geometrical ray and evanescent wave in the long distance. In the work by [Quang *et al.*, 2010], a novel uniform asymptotic solution has been derived for the transmitted and scattered waves observed in the 2nd medium. Outside the transition region, the uniform asymptotic solution approaches the conventional transmitted ray solution in the short distance and the transmitted ray and the evanescent wave solution in the long distance. The validity of the uniform asymptotic solution has been confirmed by comparing with the reference solution calculated from the numerical integration of the integral representing the transmitted and scattered fields.
(T. Ishihara)

B5. Wave Propagation and Scattering in Random Media

Tateiba [2010] discussed the studies conducted until now mainly by himself and reviewed on (1) derivation of arbitrary order moment equations and solutions of some equations, (2) scattering by many particles and the effective medium constant of random medium, (3) scattering by a conducting body in random media and (4) spatially partially-coherent wave scattering, with application to satellite communications, artificial material development, and sensing and radar technology. The leading research results are presented with many references; and also unsolved subjects in the above four studies are touched.

Hanada *et al.*[2008a, 2008b, 2009a, 2009b, 2009c, 2009d] numerically analyzed the BER for GEO Satellite communications in Ka-band at low elevation angles under atmospheric turbulence whose effects include both spot dancing and wave form distortion of wave beams. The statistical characteristics of random fluctuation of the dielectric constant in atmospheric turbulence are assumed to be given by the Kolmogorov model which is known to be a good approximation and the Gaussian model. From these analysis, they discussed influences of spot dancing, wave form distortion and the spatial coherence of received wave beams caused by atmospheric turbulence on BER for the satellite communications.

Fukuda *et al.*[2008] evaluated the backscattered coefficient, which is closely related to the sea wave period, by computer simulation. The average received power is determined by radar altimetry simulation proposed by them. It is shown that the backscatter coefficient of the sea surface can be calculated on a relative basis. The possibility of observing the sea wave period by using satellite radar altimetry is demonstrated.

Meng *et al.*[2008] discussed wave scattering from a conducting circular cylinder surrounded by a phase changing screen. The numerical result shows that the scattering is enhanced in the neighborhood of backward direction and resembles that by the cylinder embedded in a random medium.

Furukawa *et al.*[2008] proposed a fiber with two inhomogeneous sector holes around the core, and propagation characteristics of polarization maintaining region and single-polarization maintain region and single-polarization region are numerically analyzed by circular Fourier expansion method. In each case of the single-polarization region and the polarization maintaining region a fiber is designed so as to satisfy the zero total dispersion at wavelength of 1.55 micrometer. Then, the shingle-polarization bandwidth for the single-polarization region and the modal birefringence for the polarization maintain region are examined as the specific characteristics in each region. In addition, the power concentrating into the core region and distributions of Poynting vector is also discussed.

Kameda and Furukawa [2009] proposed a new polarization splitter constructed from a circular core fiber (fiber1) and an elliptical core fiber (fiber2). The polarization splitters are designed so that the x-polarization and y-polarization are derived from the fiber2 and the fiber1, respectively. The device length and the bandwidth at the extinction ratio below -15dB are discussed by adjusting mainly the ellipticity of the core in the fiber2 and the relative index difference of the fiber2.

The peak value of transmitted pulse in printed circuit boards (PCB) is important for a pulse peak detection device. When an input line and an output line are connected to each pad with the direction of right angle, the propagating pulses with the narrow time duration separate into some parts and decrease the peak value of pulse response. Kobayashi *et al.*[2009] presented an improved line-pad connected structure. The microstrip line is in contact with a pad from outside by considering the pulse propagation time passing through the via structure. They obtained the large peak value of the pulse response for which the time duration is larger than 0.2ps.

Komiyama [2009] clarified the asymptotic behavior of the light power at large distance in a random waveguide system with a short correlation length and a mathematical mechanism of the asymptotic behavior. The discussion is based on the coupled mode theory. First, for the light propagation in an ordered waveguide system a new description in terms of the light power is presented. A solution of the integro-differential equation describing the light power is expressed as a contour integral in the Laplace transform domain. Singularities of the integrand are branch points and the branch cut integral determines the asymptotic behavior of the solution. The light power decreases in inverse proportion to the distance. Secondly the description is extended to the case of a random waveguide system. The differential equation of the recurrence type describing the incoherent power is reduced to the integro-differential equation and it is shown that the kernel is the product of the kernel for an ordered system and the damping term. The equation is solved by using the same procedure as that for an ordered system and a contour integral representation of the solution is obtained. Singularities of the integrand are poles and branch points. The poles arise from the damping term of the kernel and the residues of the poles determine the asymptotic behavior of the solution. The incoherent power decreases in inverse proportion to the square root of the distance.

The coupled mode equation describing the propagation of light in a disordered waveguide system composed of randomly different cores in size is analytically solved by the perturbation method and the average amplitude of light is derived [Komiyama, 2010]. In the summation of a perturbation series only successive scatterings from different cores are taken into account. The result obtained shows that the average amplitude behaves as if in an ordered waveguide system composed of identical cores at short distance and decreases exponentially with increasing distance at large distance. The result is compared with the result obtained by the coherent potential approximation and the both results are in good agreement with each other. The results are also compared with the results obtained by numerically solving the coupled mode equation.

Using light-wave in a radar or wireless LAN of diffused type, the receiving power fluctuates due to the speckle phenomena so that the phenomena can deteriorate the received signal. In designing a system, therefore, it is important to evaluate the characteristics of the speckle phenomena. Inaba *et al.*[2007] experimentally showed the dependence of the receiving power

fluctuation on scattering materials, and the system parameters of an illumination diameter, illumination area displacement, and a receiving aperture size.
(T. Yamasaki, N. Nakashima, and T. Takano)

B6. Guided Waves

6.1 Dielectric and Optical Waveguides

Novel multi-core fibers for space-division multiplexing [Koshiba, M. *et al.*, 2009] and mode-division multiplexing [Kokubun, Y. and M. Koshiba, 2009] have been proposed and a fiber-based mode multi/demultiplexer for mode-division multiplexing has been designed [Saitoh, F. *et al.*., 2010]. Dispersion, birefringence, and/or coupling characteristics of several types of photonic crystal fibers (PCF) such as holey fibers (HF) [Saitoh, K. *et al.*, 2008, Tsuchida, Y. *et al.*, 2008, Varshney, S.K. *et al.*, 2008b, 2009b], photonic band-gap fibers (PBGF) [Murao, T. *et al.*, 2008, 2009, Skorobgatiy, M. *et al.*, 2008, Varallyay, Z. *et al.*, 2009], hole-assisted fibers (HAF) [Saitoh, K., *et al.*, 2007], and leakage channel fibers (LCF) [Saitoh, K. *et al.*, 2009a, 2009b] have been investigated. Lasing [Iizawa, K. *et al.*, 2008, Varallyay, Z. *et al.*, 2008, Varshney, S.K. *et al.*, 2008a], amplification [Varshney, S.K. *et al.*, 2008c, 2009a], and nonlinear [McElhenny, J.E. *et al.*, 2008] characteristics of photonic crystal fibers have also been investigated. Various photonic devices based on coupled resonator optical waveguides (CROW) [Kawaguchi, Y. *et al.*, 2008, 2009, 2010, Rosa, L. *et al.*, 2009], slot waveguides [Komatsu, M. *et al.*, 2009], and silicon-on-insulator (SOI) ridge waveguides [Kakihara, K., *et al.*, 2008, Koshiba, M. *et al.*, 2008] have been proposed and characterized.
(M. Koshiba)

6.2 Transient Fields in Guided Waves

Yokota and Ohtsuka [2009] examined two-dimensional photonic crystal (PC) waveguide with the microcavity numerically by FD-TD method. They used an absorbing boundary condition (ABC) at the edge of the window called Mur's ABC. The structure of the PC is the triangular array and the microcavity is made by removing the crystal in parallel with the PC waveguide. The effects of the radius of the surrounding pillars on the resonance are examined. Also, the structure which takes out the light is examined from the practical point of view.
(M. Yokota)

B7. Antennas

7.1 Fundamental and Wideband Antennas

Small antennas have been developed [Nakano *et al.*, 2007a,b, Mehta *et al.*, 2007, Mehta *et al.*, 2008, Deo *et al.*, 2009a,b, 2010, Nakano *et al.*, 2010a] for handset applications, where Deo *et al.*[2009a,b, 2010] and Nakano *et al.*[2010a] have realized a beam steerable function. Low-profile Antennas with wideband characteristics have also been developed [Nakano *et al.*, 2008a,b,d, 2009a,b, 2010b]. These antennas have an extremely small height of less than 0.07 wavelength at the lower edge frequency of the operating band, covering a wide frequency range of more than 90%. In addition, stop-band formation techniques for wideband antennas have

been established for suppressing interferences from nearby electric equipments [Nakano *et al.*, 2008c]. Discussion on circularly polarized radiation from a fundamental element, such as a loop, has been made [Hirose *et al.*, 2009a,b, 2010], and a loop array antenna has been realized [Hirose *et al.*, 2009c].
(H. Nakano)

7.2 Antenna Elements

High-performance antennas at light-wave frequency require optimal curved surfaces and high mechanical precision in order to realize high aperture efficiencies. Munemasa *et al.*[2007a] developed a novel micro light-wave antenna by employing the MEMS (micro electro mechanical system) processing technology. They described a transparent antenna that has a multilevel step structure with a diameter of 4 millimeters. The ideal curve of the antenna surface is discretized by steps of a constant height. The characteristics of the fabricated antenna have been measured. The measured gain is 84.1 dBi, which is 0.83 dB less than that of a reference antenna with a uniform field distribution. The aperture efficiency is 82.6%. The power radiation pattern is measured through the FTL (Fourier transform lens) method and is in good agreement with the simulation result.

Munemasa *et al.*[2007b] describes a technique for measuring the far -field radiation pattern (FFP), gain, and the transmissivity of each portion of an aperture of light-wave (optical) antenna. First, the compatibility of light-wave antennas to a system is mentioned. Then, the principles and setup for each measurement term are presented. A comparison with radio-wave antennas is also given.
(T. Takano)

7.3 Arrays and Phased Arrays

Two kinds of ultra-large antennas are required for SPS. The one is called a spacetenna which transmits an enormous amount of a microwave, and the other is called a rectenna which receives and rectifies the microwave. As all microwave power in a transmitted beam has to be received by the rectenna, the beam width should be quite narrow. Accordingly, the diameters of both antennas are quite large: For example, in the Reference System of NASA, the spacetenna and rectenna are, 1km and 3km in diameter, respectively. Moreover on the spacetenna, several requirements are imposed for space use. In order to construct an ultra-large antenna, several schemes were proposed, and technical issues were clarified. Novel technologies have been studied and proposed in Japan so far. Launch, assembling and testing of ultra-large antennas are also important. Takano [2008] describes the peculiarities of these antennas in comparison with conventional large antennas. Relevant technologies is also presented.

Okumura *et al.*[2008] proposes a novel design to reduce the number of driven elements by replacing them with passive elements or wires in an array antenna. The study is based on the analysis of electromagnetic wave fields in consideration of the coupling between the half-wavelength dipoles. An array antenna of two driven elements and two passive elements is considered as a model. After optimizing the element arrangement, the antenna gain can match that of the equivalent four driven element case. The simulation result is confirmed by experiment which uses dipoles with simplified matching technique. Feeding networks in a high power radiating system are analyzed in terms of the length and matching of feed lines, and the number of amplifiers.

A phased array antenna (PAA) where almost all antenna elements are equipped with digital phase shifter is widely used for military applications. On the other hand, some research works are attempted to use PAA for commercial mobile satellite communications. In these conventional PAA, an element antenna with a pencil beam is used which is a microstrip antenna or a dipole antenna with a reflector. The radiation beam of the element antenna is vertical in direction and 120deg. in width typically. Therefore, when a mobile station points a satellite in elevation range from 30deg. to 60deg. with its radiation beam, the antenna gain is much deteriorated to be a serious problem. Suda *et al.*[2010] proposes a PAA using an element antenna which has the main beam in the satellite direction. The radiation pattern has the maximum at the offset directions from the zenith by a certain angles, or is conical with low radiation intensity in the zenith direction. No one has attempted to use such antenna for a phased array element, so far. They firstly analyzed the characteristics of the basic PAA where all the elements of split radiation patterns. A computed result is shown comparing the case of the proposed PAA with the case of a conventional PAA. It has been shown that the proposed antenna is superior to the conventional antenna in the gain of elevation angle below 30deg. Other problems of a PAA for commercial application are cost, weight, size, and power consumption. The PAA need a lot of phase shifters, which cause high production cost. For the countermeasure of this problem, they proposed a partial drive method, which thins array elements significantly. Then, the partial drive technique is applied to the proposed PAA to reduce the driven elements. The beam scanning characteristics are shown.
(T. Takano)

7.4 Systems

Space debris are increasing in orbits around the Earth. The measurement of space debris is a key issue for the investigation and monitoring of space environment. But the measurement opportunities and the detection ability are limited in existing radar systems. Yajima *et al.*[2007] proposed a bistatic radar which is composed of transmitter and receiver stations. A carrier modulated by PN-PSK signals is used in combination with a VLBI recorder for the purpose of the range measurement. The received radio wave is processed on the basis of VLBI techniques. Accordingly, the system is shown to have significant advantages over a monostatic radar. They actually formed a bistatic radar system, and observed imaginary space debris, a satellite in orbit in order to experimentally verify the validity. The configuration of the system, data analysis and the experimental results are described.

The performances of optical and radio frequency communication systems are compared for long distance applications, e.g. deep space communications, where the signal-to-noise ratio is crucial. They compared an optical communication system operating at 0.8μm using intensity modulation and direct detection with an avalanche photodiode, an optical communication system operating at 1.5μm using on-off keying and an optical preamplifier, and a radio frequency communication system operating in the X-band. Assuming typical system parameters for the link budget analysis, Toyoshima *et al.*[2007] found that for distances between the transmitting and receiving antennas (R) of 107 km- the signal-to-noise ratios for the optical systems are proportional to R-4, and that for the radio frequency system is always proportional to R-2. Despite the fact that the results are based on specific parameters, the maximum data rate achievable with the radio frequency system is higher than that with the optical systems for distances beyond 108 km. For near Earth communication links, an optical system with optical preamplification is preferable when the data rate is higher than several Gbit/s.

SELENE (Kaguya) is Japan ’s first large lunar explorer aims to obtain the scientific data to investigate the origin and the evolution of the moon and to acquire engineering techniques for the future moon exploration and utilization. The nominal mission phase finished at the end of October 2008, and the extended mission phase started from the beginning of November 2008. In order to perform the additional scientific observation, the Kaguya spacecraft had been put into several sets of different orbits compare to the nominal mission phase. At the end of extended mission phase, Kaguya made a controlled impact with the lunar surface on 10 June 2009. Namiki *et al.*[2009] described the results of the orbit determination of Kaguya from the nominal mission phase to the extended mission phase and the lunar impact analysis and its operation results. The present status of lunar gravity field estimation is also described.

SELENE Main Orbiter (KAGUYA) has separated two small sub-satellites; (1) the Relay Satellite ”OKINA (Rstar)”, and (2) the VLBI Radio Satellite ”OUNA (Vstar)”. These sub-satellites started to perform 4-way Doppler measurements using Relay Satellite Transponder (RSAT) and multi-frequency phase-delay differential VLBI using VLBI Radio Sources (VRAD) for lunar gravity mapping. Iwata *et al.*[2009] developed the frequency conversion system, multi frequency S/X-band vertical dipole antenna, and light weighted S-band patch antenna to perform these missions. Simple structured release mechanism has also been developed and confirmed its performance by ground test and orbital demonstration using micro-Lab Sat. Initial check out were executed and properties of satellite bus equipments, onboard mission instruments, and observation systems including ground stations were evaluated. Electric power and thermal control subsystems have shown that they conduct as designed and inspected in the ground tests. The release mechanisms have given the spin which can maintain the stability of the satellite attitudes. Communication functions of mission instruments conform to the link budgets. These results suggest that OKINA and OUNA have enough performances to produce efficient data by RSAT/VRAD gravity observations.

Liu *et al.*[2010] reported on the effect of in-situ phase characteristics of antennas onboard flying spin satellites on Doppler measurements for lunar gravity field. They analyzed the effect of the in-situ phase characteristics of dipole and patch antennas onboard two flying spin satellites, Rstar and Vstar, in the Japanese lunar mission, SELENE (KAGUYA), on 2-way and 4-way Doppler measurements, and detected higher harmonics of the spin frequency up to order 26 in Doppler frequency. They developed a low pass filter (LPF) using the Kaiser window, with the optimal parameters empirically determined, to remove the influence of the in-situ phase characteristics and to precisely conserve the lunar gravity field information itself. They processed the 2-way and 4-way Doppler data of SELENE by using the LPF. After LPF, a high accuracy of about 0.001 Hz was achieved for these Doppler measurements, and signals that reflect the gravity field on the far side of the Moon was firstly detected from the 4-way Doppler data. In addition, they also firstly obtained the in-situ phase characteristics of the antennas onboard flying spin satellites such as Rstar and Vstar with a root-mean-square error of about 2 degrees from the harmonics in Doppler frequency, which is very useful for developing antennas and structure of a satellite.
(T. Takano)

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