COMMISSION B : Fields and Waves (November 2004 - October 2007)

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

The problem is to obtain the step response of a system when its amplitude function is given [Hosono and Hosono, 2004]. Two conventional methods are (1) factorization method that uses the factorization of the amplitude function, and (2) ω domain method that uses the Kramers-Kronig relation to get the phase function from the attenuation function. Both methods are poor as computer algorithms. They introduced a new algorithm that uses the kramers-Kronig relation extended to complex frequency domain, and that can easily be carried out by a computer. As an application, the problem of negative group velocity have been analyzed, and it is showed that the group velocity of a wave packet is nothing but the phase velocity of the enbelope.

Gaussian pulse has no beginning point, so has no Laplace transform and is non-physical. Hosono and Hosono [2007] proposes $(\sin t)^n$ pulse (referred to as pseudo-Gaussian pulse or PGP) as an approximation of the Gaussian pulse. PGP has the Laplace transform and approaches the Gaussian pulse as $n \to \infty$. The propagation of PGP-modulated wave packet in the highly anomalous dispersion band of a Lorentz medium is investigated by numerical inversion of Laplace transform. Their results are greatly different from the conventional results obtained by the saddle point method. Their results show that the velocity of a Gaussian wave packet cannot be explained only by the concept of the group velocity as has been done so far.
(T. Yamasaki)

1.2 Periodic Array Structures

Ozaki *et al.* [2007] proposes a new technique for the scattering problems of multilayered in-homogeneous columnar dielectric gratings loaded rectangular dielectric constant both TM and TE waves using the combination of improved Fourier series expansion method, the multilayer method, and the eigenvalue matrix method. Numerical results are given for the power transmis-sion coefficients in the parameters of rectangular cylinders to obtain the basic characteristic of the power transmission coefficients and reflection coefficients switching or frequency selective devices for both TM and TE waves. The influence of the incident angle and frequency of the transmitted power are also discussed in the connection with the propagation constant in the free mode.

Yamasaki *et al.* [2005] proposes a new method for the electromagnetic fields with inhomogeneous media mixed a positive and negative regions by the combination of improved Fourier series expansion method using the extrapolation method which obtains the correct value of the eigen-value and eigenvectores for the case of TM wave. Numerical results are given for the power reflection and transmission coefficient, the energy absorption, the electromagnetic fields, and the power flow in the inhomogeneous medium mixed the positive and negative regions including the case when the permittivity profiles touches zero for the TM wave. The results of the proposed method are in good agreement with exact solution which is obtained the modified multilayer approximation method.

The scattering from a periodic array of elliptical cylinders with coated circular shaped dielectric body has been analyzed by moment method together with lattice sums technique [Sesay and Yokota, 2007]. This coated material can act as a wavelength selection surface and can be apply in the design of transmitting narrow band filters. We can also conclude that the variation in the relative permittivity of the coated cylinder strongly influence the resonance scattering characteristic, reflection and transmission properties of the periodic structure.

The scattering of an electromagnetic wave from the periodic array of the dielectric cylinder has been examined numerically [Yokota *et al.*, 2007]. The reflection and transmission properties have been shown.

(T. Yamasaki and M. Yokota)

1.3 Cavity Structures

The plane wave diffraction by a terminated, semi-infinite parallel-plate waveguide with four-layer material loading is rigorously analyzed by the Wiener-Hopf technique [Shang and Kobayashi, 2007]. Exact and approximate solutions are obtained. The scattered field inside and outside the waveguide is evaluated explicitly. Numerical results on the radar cross section are presented and the far field backscattering characteristics are discussed.

Two canonical cavities formed by a semi-infinite parallel-plate waveguide and a finite parallel-plate waveguide are considered, and the problem of plane wave diffraction is analyzed rigorously by using the Wiener-Hopf technique [Kobayashi and Koshikawa, 2006]. Numerical examples on the radar cross section are presented, and the far field backscattering characteristics are discussed.

The problem of axial symmetric scattering inside a circular waveguide with an interior planar termination is rigorously analyzed by using the Wiener-Hopf technique [Kuryliak *et al.*, 2005]. The scattered field inside and outside the waveguide is evaluated analytically. Numerical examples on the far field pattern are presented, and the radiation characteristics of the waveguide are discussed.

Electromagnetic scattering from conducting polygons is studied [Ohnuki and Hinata, 2005a]. Tehir computational technique can perform precise EM simulation and the radar cross sections for various shapes and sizes of targets maintain more than eight-digit accuracy in double precision.

Radar cross sections of conducting polygons are investigated by using the point matching method [Ohnuki *et al.*, 2006]. Computational results are highly accurate in order to study the scattered waves from the shadow region. The proposed method will clarify the contribution of the waves to the far field in terms of the size of the scatterer and the incident polarization.

(K. Kobayashi and T. Yamasaki)

1.4 Canonical Structures

The plane wave diffraction by a semi-infinite parallel-plate waveguide with sinusoidal wall corrugation is analyzed by means of the Wiener-Hopf technique together with the use of a perturbation scheme [Zheng and Kobayashi, 2007]. The scattered field inside and outside the waveguide is evaluated analytically. The final solution is valid for the corrugation amplitude small compared with the wavelength.

The E-polarized plane wave diffraction by a finite parallel-plate waveguide with three-layer material loading is rigorously analyzed by means of the Wiener-Hopf technique [Zheng and Kobayashi, 2006]. The scattered field inside and outside the waveguide is explicitly derived. Numerical examples on the radar cross section are presented, and the far field scattering characteristics of the waveguide are discussed. Also, the diffraction by a finite parallel-plate waveguide with three-layer material loading is rigorously analyzed using the Wiener-Hopf technique for the H-polarized plane wave incidence [Shang and Kobayashi, 2006].

The SH elastic wave diffraction by a finite crack located at the plane interface between two dissimilar materials is analyzed for the plane wave incidence by means of the Wiener-Hopf technique [Voytko, *et al.*, 2006]. Exact and asymptotic solutions are obtained. The scattered far field is evaluated asymptotically using the saddle point method. Numerical results on the diffracted pattern are presented for broad frequency range, and the far field scattering characteristics are discussed.
(K. Kobayashi)

B2. Inverse Scattering

UWB (ultra-wideband) pulse radar is a promising candidate for environment measurement in robotics. Radar imaging for nearby targets is an 'ill-posed inverse problem', on which vari-ous studies have been undertaken. Conventional algorithms require too much computational time for ready application to real-time tasks in robotics. Sakamoto [2007a] developed the SEABED algorithm to resolve this problem, which is based on a reversible transform IBST (Inverse Boundary Scattering Transform) between real and data spaces. The effectiveness of the SEABED algorithm was investigated only with numerical simulations. Sakamoto *et al.* [2005a, 2005b] applied the SEABED algorithm to experimental data and confirmed its fast imaging capability. Experimental data contains noise, and images estimated by the SEABED algorithm in a noisy environment are degraded because the IBST uses differential operations that is sensitive to noise.

Sakamoto and Sato[2006a], and Sakamoto[2007b] expanded the IBST to FIBST (Fractional IBST). The FIBST enables us deal with the intermediate space between the real and data spaces, and data in the intermediate space is guaranteed to be smooth regardless of the target shape. Furthermore, Sakamoto and Sato[2006b] expanded the FIBST to 3-D FIBST to apply to 3-Dimaging. And then, Sakamoto *et al.*[2006] analytically clarified the theoretical limit of the smoothness in the data space. This theoretical limit can be used to prevent image distortion of the SEABED by adaptively changing the correlation length of a smoothing function. Kidera *et al.*[2006a, 2007a, 2007b] proposed an derivative-free imaging algorithm, Enverope, that is robust for noisy data. This method estimate target image by using enverope of multiple circles whose center is at antenna position and radius corresponds to delay time. Kidera *et al.*[2007c] expand the Enverope algorithm to 3-dimensional case

The SEABED algorithm works quickly, but its image has a certain error because the scattered waveform is different from the transmitted one depending on the shape of targets. These differences cause estimation errors in the SEABED method. Kidera *et al.*[2005, 2006b] pro-posed a waveform compensation method with an integral of Green's function along the ray path. By using this method, the accuracy of the SEABED was improved to about 0.01 wave-length with a mono-cycle pulse waveform. Kidera *et al.*[2007d, 2007e] introduced this accurate technique to the Enverope algorithm and confirmed its quick and accurate imaging capability with numerical simulations and experiments. However, for the application of this method to 3-dimensional problem, the calculation time cannot be neglected. Kidera *et al.* [2007f] simplified this waveform compensation method by using the spectrum shape of the scattered waveform, and realize robust 3-dimensional imaging with 3-D Enverope algorithm.

The conventional SEABED algorithm and the Enverope algorithm require antenna scanning that takes long time, and spoil the fast processing of the algorithm itself. Kidera *et al.*[2006c, 2007g] investigated the UWB radar imaging with linear antenna array, which does not need antenna scanning. They used RF switches to arbitrarily select a pair of transmit and receive antennas, and realized quick 3-dimensional radar imaging. Sakamoto and Sato[2007a] introduced spread spectrum signals to realize code-division multiple transmission for UWB radar imaging, which does not need RF switches. And they found a sub-optimum code set for the system. By using the proposed code set, the direct waves without scattering cancel one another and the signal-to-interference ratio was improved. Sakamoto and Sato[2007b] proposed a method for UWB imaging of human bodies by using walking motion instead of antenna scanning. This method was developed by expanding the conventional SEABED algorithm, and does not need antenna scanning only with a pair of antennas to obtain cross-section image of a human body. This technique can be applied for security systems.

Orbit estimation of space debris, which is unnecessary objects orbiting around the earth, is an important task in avoiding the collision with spacecrafts. Kamisaibara Space Guard Center radar system was built in 2004 as the first radar facility devoted to the observation of space debris in Japan. In order to detect smaller debris, it is effective to improve SNR (Signal-to-Noise Ratio) using coherent integration. However it is difficult to apply the coherent integration to the real data because the motion of the target is unknown at the first step. Isoda *et al.* [2006] proposed fast algorithms for signal detection and orbit estimation for faint radar echoes from space debris by utilizing the characteristic of the motion of space debris.

Ishida and Tateiba [2005] introduced a T-matrix expression of the scattered wave and expressed the equivalent current in terms of orthonormal basis functions. Using the expressions, they have formulated the inverse scattering problem of reconstructing a two dimensional object. As a result, we can directly connect the noise-removed scattered waves to the measured equivalent current. They proposed an iterative algorithm that the object and the unmeasured equivalent current are updated by decreasingthe cost functional in the least square approximation. The algorithm avoids employing a nonlinear optimization algorithm, solving the direct scattering problem, and using a special additional regularization. Numerical examples show that the algorithm works well under noisy conditions.

An algorithm for reconstructing a dielectric cylinder is formulated and discussed through numerical examples [Ishida and Tateiba, 2005]. An extended T-matrix is introduced in order to remove ineffective data of scattered waves and to explicitly separate the measured and the un-measured elements related to the equivalent currents. The object and the unmeasured elements are obtained by solving two linear equations repeatedly. The algorithm avoids employing a nonlinear optimization algorithm, solving the direct scattering problem, and using a special additional regularization. Numerical examples show that the algorithm works well under noisy conditions, and gives a good profile for a high-contrast object by use of multifrequency scattering data.

(T. Sakamoto and K. Ishida)

B3. Computational Techniques

3.1 Finite-Difference and Finite-Element Methods

Finite-element methods have been applied to designing photonic devices based on linear and/or nonlinear photonic crystal waveguides [Fujisawa, T. and M. Koshiba, 2005, 2006a, 2006b,

Rodrguez-Esquerre, V.F. *et al.*, 2005b], nonlinear slot waveguides [Fujisawa, T. and M. Koshiba, 2006c], and nonreciprocal magneto-photonic crystal waveguides [Kono, N. and M. Koshiba, 2005a, 2005b]. A full-vectorial finite-element method has been formulated in a cylindrical coordinate system for computation of bending losses in photonic wires [Kakihara, K. *et al.,* 2006a]. Acurvilinear triangular-prism element has been developed for computation of band structures in a photonic crystal slab [Hirayama, K. *et al.*, 2006]. An efficient frequency-dependent finite-element time-domain method for the analysis of dispersive media has been presented [Rodriguez-Esquerre, V.F. *et al.*, 2005a].
(M. Koshiba)

3.2 Integral Equation Methods

Singular volume integral equations describing the electromagnetic wave scattering in three-dimensional bounded inhomogeneous media are considered [Budko *et al.*, 2007]. The problem of finding the spectrum of these operators has been analyzed for the low-frequency case. A closed-form expression describing the spectrum in the complex plane is obtained. Numerical results on the convergence of the proposed method are also presented.

Three mathematical models based on approximate surface integral equations for the electromagnetic analysis of scalar wave scattering from thin extended target are considered [Nazarchuk and Kobayashi, 2005]. Such models include different systems of the second kind singular integral equations determined by the target media. Verification of the mathematical models and their comparison are performed in the case of a penetrable cylindrical shell in homogeneous non-magnetic media.

Nakashima and Tateiba [2005] describe an estimation of the computational and memory complexities of Greengard-Rokhlin's Fast Multipole Algorithm (GRFMA). GRFMA takes a quad tree structure and six calculation processes. They consider a perfect a-ary tree structure and the number of floating-point operations for each calculation process. The estimation for both complexities shows that the perfect quad tree is the best and the perfect binary tree is the worst. When GRFMA is applied to the computation of realistic problems, volume scattering are the best case and surface scattering are the worst case. In the worst case, the computational and memory complexities of GRFMA are $O(L\log^2 L)$ and, $O(L\log L)$, respectively. The computational complexity of GRFMA is higher than that of the multilevel fast multipole algorithm.

A Monte Carlo simulation is done for electromagnetic (EM) wave scattering from randomly distributed 4225 cylinders [Nakashima and Tateiba, 2006, 2007]. The scattered field is computed by means of the boundary element method (BEM) with our fast techniques: a multilevel fast multipole algorithm (FMA) and a generalized minimal residual (GMRES) iterative solver with two-step preconditioning (TSP). Numerical examples show the normalized power densities for scattered far and near fields for regularly and randomly distributed cylinders. The characteristics of scattered fields by random medium is discussed.

The scattering of a Gaussian beam by a dielectric cylinder has been analyzed by the moment method combined with the multigrid method [Yokota, 2004]. It has been shown that the modified multigrid method has a little advantage to the conventional one. The effect of the reduction of the CPU time for the multigrid method appears as the number of unknowns is large. It has also been shown that the scattered light is concentrated near the optical axis by using the dielectric cylinder with a smaller curvature [Aoyama and Yokota, 2006].

The scattering of a two-dimensional Gaussian beam by arbitrary configuration dielectric cylinders has been considered and the effectiveness of the multigrid-moment method has been shown from

the residual norm and the CPU time viewpoints [Yokota and Aoyama, 2007]. It has been seen that the convergence speed is improved in comparison with that obtained by conventional method.
(K. Kobayashi, N. Nakashima and M. Yokota)

3.3 Modal Expansion Methods

Ohnuki and Chew [2005] focused on the truncation error of the multipole expansion for the fast multipole method and the multilevel fast multipole algorithm. When the buffer size is large enough, the error can be controlled and minimized by using the conventional selection rules. On the other hand, if the buffer size is small, the conventional selection rules do not hold anymore, and the new approach which have recently been proposed is needed. However, this method is still not sufficient to minimize the error for small buffer cases. The technique clarifies this fact and show that the information about the placement of true worst-case interaction is needed. A novel algorithm to minimize the truncation error is proposed.

The computational error of the multilevel fast multipole algorithm is studied [Ohnuki and Chew, 2006]. The error convergence rate, achievable minimum error, and error bound are investigated for various element distributions. They discuss the boundary between the large and small buffer cases in terms of machine precision. The needed buffer size to reach double precision accuracy is clarified.
(T. Yamasaki)

B4. High Frequency Technique

The approximation principle of Physical Optics (PO) has been reviewed in view of diffraction theory [Ando, 2005]. Two key error factors are identified for PO, that is, 1) errors in edge diffraction coefficients and 2) fictitious penetrating rays [Shijo and Ando, 2005]. Improved methods named PO-AF (Aperture Field) and PTD (Physical Theory of Diffraction) -AF are proposed as the methods which suppress the fictitious penetrating rays from PO and PTD respectively. In deep shadow regions of the reflector antenna, PO-AF and PTD-AF approach to PO-EEC (Equivalent Edge Current) and UTD (Uniform Theory of Diffraction) respectively, while the continuity is assured. The effectiveness is numerically demonstrated for two dimensional scatterers. In high frequency, calculation load of the conventional boundary value problems which solve induced currents on the scatterer becomes large. Although there are the induced currents all over the surface of the scaterer, the important contribution of the electro-magnetic waves seen from the observing point is localized. This occurs due to the cancellation effect by rapid phase variation between adjacent currents. The visualization technique was pro-posed for PO which extracts only the important currents which contributes to the fields at the observer point [Shijo *et al.*, 2004]. EYE function used as the weighting is determined so as not to disturb the cancellation effects while retain the enough resolution. The visualization demonstrated local property of the HF phenomena and defects associated with the ray techniques. The PO visualization even suggests the ways out of PO errors, the fictitious penetrating rays. The practical application in [Shijo *et al.*, 2004] includes visualization of slot array with the finite ground plane.

The PO has a major fault in the high frequency because the numerical surface integration becomes too heavy. Therefore, many mathematic, asymptotic or wave theoretic, works for the surface to the line integral reduction have been reported until now. Besides the above engineering advantages, the line integral expression is an effective extraction mechanism of the PO errors, since the discussion of the analytical and explicit expressions of equivalent edge currents is more general and clear than that of the numerical comparison of values after the PO surface integration. The modified edge representation (MER) [Rodriguez *et al.*, 2005] is the concept to be used in the line integral approximation for computing the surface radiation integrals of diffraction. The MER as applied to the physical optics (PO-MER), has remarkable accuracy in the surface-to-line integral reduction even for the curved surfaces and for sources very close to the scatterer. The unique concept of the modified edge representation (MER) was proposed for the surface to the line integral reduction of the physical optic (PO) [Rodriguez *et al.*, 2007]. The equivalence between the MER line and the PO surface integration was analytically derived by using the Stokes theorem relations as well as asymptotic treatments, for the smooth scattering surfaces without inner stationary phase points (SPP). In this research, findings related with the MER line integration around the inner SPP are extended to curved surfaces. The accuracy and the applicability of the SGO(scattering geometrical optics) extraction in terms of the MER line integration are numerically investigated for different radii of curvatures of the scattering surfaces. The MER line integration provides an alternative way to the stationary phase method or the classical geometrical optics for calculating SGO. In addition, this numerical result indirectly identifies the entity of the MER line integration along the periphery of the scattering illuminated region, irrespective of the position of observer, as not other than diffraction.

The Modified Edge Representation (MER) line integration was introduced in [Rodriguez *et al.*, 2005] and [Rodriguez *et al.*, 2007] as an alternative methodology, for the physical optics (PO) radiation pattern calculation of curved surfaces. In the high frequency diffraction analysis, this unique technique is one of the methods of equivalent edge currents (EECs), but in contrast with the conventional EECs, not only diffracted fields but also the geometrical components (GO) are expressed in terms of line integrations. The paper by [Rodriguez and Ando, 2007] presents the Physical Optics field calculation in terms of only line integrations by using the Modified Edge Representation technique (MER), the alternative way of the surface integration. Not only the diffracted fields as in the conventional method of equivalent edge currents (EEC) but also the scattering geometrical optics fields are expressed in terms of the MER line integrals. The far field patterns of parabolic reflector antenna with the defocused dipole feed are discussed and the satisfactory agreement with those obtained by the Physical Optics surface integration is demonstrated.

Locality in high frequency diffraction is embodied in the Method of Moments (MoM) in view of the method of stationary phase. In [Shijo *et al.*, 2005], local-domain basis functions accompanied with the phase detour, which are not entire domain but are much larger than the segment length in the usual MoM, are newly introduced to enhance the cancellation of mutual coupling over the local-domain; the off-diagonal elements in resultant reaction matrix evanesce rapidly. The Fresnel zone threshold is proposed for simple and effective truncation of the ma-trix into the sparse band matrix. Numerical examples for the 2-D strip and the 2-Dcorner reflector demonstrate the feasibility as well as difficulties of the concept; the way mitigating computational load of the MoM in high frequency problems is suggested.

Target reconstruction algorithm from its monostatic radar cross section (RCS) has been proposed for polygonal cylinders with curved surfaces [Shirai *et al.*, 2005]. This algorithm is based on their previous finding that the main contribution to the back scattering is due to edge diffracted fields excited at a facet of nearly specular reflection direction. Dimension of this constitutive facet of the target is estimated from the local maxima and its lobe width in the angular RCS variation. Half and quarter circular cylinders are used as canonical scattering objects, and their measured and numerically simulated monostatic RCS values have been studied extensively to find scattering pattern characteristic difference between flat and circularly curved surfaces. Thus estimated constitutive facets are connected in order, and this procedure will be continued until the distance between the first and the final edges would be minimized. Their algorithm has been tested for other targets, and it is found that it works well for predicting metal convex targets with flat and curved facets. A simple target reconstruction algorithm is also proposed for cylindrical metal scatterers using monostatic RCS data in the time domain as well as in the frequency domain. By using the time domain RCS response at the local frequency maxima at possible specular reflection angle, the locations of the facets can be estimated by measuring the wavefront arrival time difference from the scattering center [Shiarai and Hiramatsu, 2005].

The radio propagation characteristics for line-of-sight (LOS) inter-vehicle communication (IVC) at 60 GHz on an actual road with an undulating surface have been investigated in [Amornthipparat *et al.*, 2006] and [Yamamoto *et al.*, 2007a]. Radio propagation tests between two moving vehicles were carried out on a test course. From this, it was found that the measured received power on the actual road and the results calculated for a flat road approximately follow logarithmic normal distributions. To investigate this phenomenon in detail, a propagation test between two stationary vehicles on a road was performed. Furthermore, calculations using geometrical optics taking road undulation into consideration demonstrated that undulation in the road can cause variations in the received power that follow a logarithmic normal distribution. The received power for moving vehicles on an undulating road was also calculated using the model. In [Yamamoto *et al.*, 2007b], the authors also applied a ray-tracing method to estimation of the received power when there was a blocking vehicle between communicating vehicles. The uniform theory of diffraction (UTD) technique was used for the calculation of waves propagating through the intermediate vehicles. In comparison with measured data, the propagation path model is capable of accurately representing the received power in a non line-of-sight (NLOS) situation with an obstructing vehicle.

For indoor multihop-or relaying-based wireless systems, it is important to comprehend the complex propagation mechanisms, and, hence, a high speed propagation estimation method is required. Indoor electromagnetic wave propagation through dielectric walls is analyzed using a ray tracing method, which is based on a high frequency ray launching or SBR (shooting and bouncing ray) technique. In the previous SBR analysis for indoor environment with many walls [Sato *et al.*, 2005a], three fundamental GO components, direct, reflected and transmitted rays, have been considered. However, the contribution of multiple reflections inside the wall has not been included in the study. To derive the multiple reflections representation analytically, the Green's function problem for a line source in the presence of a dielectric slab is considered, and the asymptotic Green's function representation for each ray is obtained using the collective ray approximation [Sato *et al.*, 2005b]. Taking into account the derived complementary terms for the multiple reflections inside the slab, an accurate numerical result for a simple indoor model is obtained. In comparison with the FDTD result, the validity of this SBR solution with multiple reflections is confirmed.

In the ray-launching procedure, the complex refraction angle must be replaced real shooting angle, when one needs to calculate the transmitted ray through such high lossy wall [Sato *et al.*, 2006a]. However, it is not clear how one determines the appropriate real shooting direction inside the wall when the refracted angle becomes complex. In order to make this question clear, authors considered how to determine the appropriate real refracted angle by comparing the numerical ray-launching solution with an analytical reference one. Here, as the reference field representation, the asymptotic solution for the Green's function problem in the presence of lossy dielectric slab is utilized, where the contribution of the complex transmission coefficient for the high lossy slab is also taken into account in the reference one. Discussion on the accuracy of the transmitted ray through the lossy wall (slab) will be done not only for two dimensional problem but also for simplified three dimensional one [Sato *et al.*, 2006b]. The field interaction between multiple scattered rays and the edge diffracted rays are also analyzed and included to fill the field map [Otoi *et al.*, 2006]. The authors applied an accuracy improvement to the ray-launching solution by making the path length inside the wall slightly longer [Sato and Shirai, 2007a]. By this simple improvement, one can easily compensate for the shortage of the internal attenuation in the ray-launching approximation [Sato and Shirai, 2007b]. The validity of the improvement is confirmed by some numerical experiments.

When a cylindrically curved concave conducting surface is terminated abruptly at the edge, the whispering gallery (WG) mode propagating toward the edge direction is radiated into the free space from the aperture plane at the edge as is scattered by the edge [Goto and Ishihara,2005], [Ishihara *et al.*, 2006]. The uniform asymptotic solution for the WG mode radiation field applicable uniformly in the transition region near the geometrical boundaries has been derived in [Ishihara *et al.*, 2006], [Ajiki *et al.*, 2006a], and [Goto *et al.*, 2007a]. The uniform solution is represented by the summation of the geometrical ray solution converted from the modal ray of the WG mode and the uniform edge diffracted ray solution scattered at the edge [Ajiki *et al.*, 2006b], [Goto *et al.*, 2007a]. Also derived are the uniform asymptotic solutions for the scattered fields by a thin cylindrically curved conducting surface applicable near the geo-metrical boundaries produced by the incident waves (or rays) and near the cylindrically curved surface [Goto *et al.*, 2004]. The theories have been extended to the transient scattered fields by various complex objects [Goto *et al.*, 2006a], [Goto *et al.*, 2006b].The time-domain uniform asymptotic solution (TD-UAS) [Goto *et al.*, 2006c] for the transient scattered field excited by the high-frequency (HF) pulse wave have been derived in [Goto *et al.*, 2007b] and [Goto *et al.*, 2007c]. The TD-UAS is composed of the geometrical rays (GO), the edge diffracted (ED) rays, the surface diffracted (SD) rays, and the lowest order whispering gallery (WG) mode radiation field. The validity of the TD-UAS has been confirmed by comparing both with the hybrid experimental-numerical results obtained by using the frequency-domain (FD) experimental results measured in an anechoic chamber and the numerical code for the fast Fourier transform (FFT) and with the purely numerical reference solution.

The applicable range of the GTD in the asymptotic analysis of the scattered field by an aperture in a thin screen have been reexamined in [Kawano and Ishihara, 2004a]. It is clarified analytically the reason why the geometrical optics field disappears at the far field in the illuminated region. The authors have derived the criterion for applying the GTD. The theory is extended to analyze the scattered fields by a conducting strip whose width is sufficiently larger than the wavelength of an incident wave [Kawano and Ishihara, 2004b]. Two versions of the GTD solutions are derived analytically, one of which contains the geometrically reflected ray (the first version) and the other does not contain the reflected ray term (the second version). Without applying the "trick" introduced in the Keller's GTD, the reason why the geometrical ray term is disappeared in the second version of the GTD is clarified. Also derived is the novel criterion for applying the GTD.

The high-frequency uniform asymptotic analysis methods are applied also for scattered fields by the circular cylinders and the dielectric plane boundary. Novel uniform asymptotic solutions(UTD) for the scattered fields by an impedance cylinder and a dielectric cylinder with a radius of curvature sufficiently larger than the wavelength, are presented in [Ida *et al.*, 2004], [Ida *et al.*, 2005a], and [Ida *et al.*, 2005b]. The frequency-domain novel extended UTD and the modified UTD solutions, derived by retaining the higher-order terms in the integrals for the scattered fields, may be applied in the deep shadow region in which the conventional UTD solutions produce the substantial errors. The novel time-domain uniform asymptotic solutions are derived by applying the saddle point technique in evaluating the inverse Fourier transform. The accuracy of the uniform asymptotic solutions both in the frequency-domain and in the time-domain has been confirmed by comparing those solutions with the reference solutions calculated from the eigenfunction expansion and fast Fourier transform(FFT) method (time-domain). Also, the new uniform asymptotic solution, which uses the parabolic cylinder functions, for the Gaussian beam scattered at the plane dielectric interface has been derived[Yamada *et al.*, 2007]. It is shown that the asymptotic solution agrees very well with the reference solution calculated numerically. Also shown is the Goos-Hänchen shift appeared for the beam angle close to the critical angle.

The new solutions for the medium-frequency and the high-frequency ground wave propagation in a surface duct over mixed-paths have been derived in [Kawano and Ishihara, 2005], [Kawano and Ishihara, 2006a], [Kawano and Ishihara, 2006b], and [Kawano *et al.*, 2007a]. It is shown newly that the solution for the ground wave propagation in a standard atmosphere can be obtained directly from the solution for the surface duct problem by applying the analytic continuation from the negative equivalent radius of curvature of the earth to the positive one. Through the theoretical and experimental studies, it is confirmed that the radio wave propagating over the sea in the land-to-sea mixed-paths is enhanced by the recovery effect [Kawano *et al.*, 2006a]. It is clarified that the ground wave is also enhanced in the surface duct in a long range propagation[Kawano *et al.*, 2007b]. It is shown that the unexpected attenuation and the anomalous variation with distance are appeared in the propagation in the urban area due to the emergence of the slow-wave type trapped surface wave[Kawano *et al.*, 2006b], [Kawano *et al.*, 2007c].

Propagation mechanisms which degrade the performance of mobile communication system in urban areas are basically wall reflections, building edges and roof diffractions. From the experiment results, the scattering from some objects in the environment can have strong impact on the urban propagation channel. Careful analysis of these results reveals that these scattered objects, which can be any surrounding metallic object, such as signboards, street lights, traffic lights and traffic signs, are involved in scattering transmitted signals to the receiver. Physical optics (PO), the approximation method for determining surface currents, is utilized to simulate the induced surface current to handle non-specular scattering [Lertsirisopon *et al.*, 2006]. The simulation results showed good agreement with the experimental results and in the same manner, the PO approximation method can be applied to study the scattering of surrounding objects in the wireless communication environment.

In the study in [Lertsirisopon *et al.*, 2006], to represent the data structures of scatterers, polygon meshes are used to model scatterer constructions including 2 dimensional (2D) and 3 dimensional (3D) geometrical objects. Polygon meshes represented by regular triangles can be easily generated by using intrinsic functions in MATLAB for 2D cases. For 3D cases, a mapping first of the 3D object to a 2D object is necessary to be able to use the MATLAB intrinsic functions. Then, the corresponding height is put back to the meshed 2D object to obtain the meshed 3D object. Using this "Polygon Meshed PO" method, the complex calculation of the induced current to examine the scattered field can also be simplified by summing the contribution on each triangle mesh. By defining the polygon mesh ratio as the ratio of the average triangle area to the square of the wavelength, the convergence of the simulated scattered field can be found. This simulation program will then be used to evaluate scattering objects that cause significant amount of scattering in the wireless communication environment specifically from previously mentioned objects in an urban propagation channel. By utilizing the size and shape of these surrounding metallic objects, and parameters used in the experiments, the scattered fields can be calculated and compared with experimental results to help verify observations in the experiments. In addition, this simulation tool can give us an idea on the amount of scattered fields caused by both regular and irregular shaped objects in certain scenarios. Knowing these scattering characteristics can help better explain the effects of surrounding objects on the propagation channel.

The high-frequency Physical Optics (PO) technique has been applied in designing the millimeter-wave system. Passive millimeter-wave (PMMW) imaging systems are now spreading to various applications such as security, intelligent transport systems (ITS), and military uses, giving a key advantage. However, conventional systems are very large because they require large antennas in an arrayed configuration. In order to realize commercially usable imaging array systems, miniaturizing antennas are essential. In the paper [Sato *et al.*, 2007], authors demonstrate their developed tapered slot antenna with its slot profile defined by the Fermi-Dirac function (Fermi antenna) for 94 GHz band PMMW imaging. The portion of this antenna has been designed by applying the PO. When measuring the radiation patterns of these antennas, the authors used MMICs with a low noise amplifier (LNA) and a square-law detector (DET) on the antenna substrate to increase receiver sensitivity. The sensitivity of these MMICs is as high as 450,000 V/W with the noise figure of 3.5 dB.

With the recent development of fast algorithms, the difference in capability between high-frequency techniques and numerical techniques becomes smaller. Therefore, the advantage of high-frequency techniques is in the much higher frequency range where fast algorithms still cannot compete due to the lack of current computational resources. However, the drive to-ward higher frequencies gives rise to another difficulty in solving the high frequency scattering problem. Ohnuki *et al.* [2005] clarifies the difficulties to apply conventional techniques to electromagnetic scattering problems under this condition, and develops a strategy to solve them in terms of high-frequency approximations.

(T. Ishihara and T. Yamasaki)

B5. Transient Fields

5.1 Scattering and Diffraction

Transient scattering from parallel plate waveguide cavities is studied by using the combination of a point matching technique and numerical inversion of Laplace transform [Ohnuki and Hi-nata, 2005b.] They thoroughly investigate the scattering mechanism for a half sine-pulse and modulated sine-pulse incidence. The advantages and disadvantages on the target recognition are clarified in terms of the internal object, incident waveform, and polarization.

5.2 Guided Waves and Propagation

Kobayashi *et al.*[2004] numerically analyze the transient response of pulse propagation in a multi-layered printed circuit board with a via and a bump. FDTD method is used for our models. It is found from numerical results that; (1) Even if the lengths of the striplines are equal, pulse waveforms passed through a via and a bump are different according to the direction of the striplines. (2) The propagating pulses are influenced by the pad size connecting the bump rather than the bump size. (3) For the model consisted of a via and a bump pulse distortion of responses are substantially improved, if the smaller bump part (including pads) can be designed.

It is of great importance to investigate the influence for the pulse wave propagation by vias and bumps in multilayer interposer used in SiP (System-in-a-Package) technology. Kobayashi [2006] analyzed the transient response of the pulse propagation characteristics of the via structure by using the FDTD method. The via structure is optimized by peak value of pulse responses, and the radius of via, the radius of pad, and the radius of clearance hole are investigated so as to maximize the peak value of pulse responses. It is found that the pulse width is limited by the radius of via and the radius of pad.

(T. Yamasaki)

B6. Wave in random, inhomogeneous, nonlinear and complex media

6.1 Wave propagation and scattering in random media

Tateiba *et al.* [2004] shows that scattering by a body in a random medium consists of the following two issues; one is scattering of spatially partially coherent wave by the body and the other is coupling between incident and scattered waves through the random medium. Investigating separately each issue makes the scattering more understandable. The numerical analysis of scattered power by conducting cylinders leads to the radar cross-sections quite different from those in free space, under the condition that the radar cross-section of the random medium is negligibly small. The causes of the difference are explained on the basis of above separation of the scattering, and it is emphasized that the spatial coherence length of incident wave is one of key parameters for estimating the cross sections.

Tateiba [2004] reviews the activity in his laboratory, which are categorized as: (A) electromagnetic (EM) wave theory with application to sensing, imaging and material estimate, and (B) high data rate satellite communications systems. Each research has five subjects and the pa-per addresses four subjects, which are (A-1) Effective parameters of a medium containing many particles, (A-2) Radar characteristics of a body surrounded by a random medium, (A-3) Statistical methods for measuring ocean waves in satellite altimetry, and (B-4) Atmospheric turbulence effects on high data rate satellite communications. Here A and B in parentheses indicate above two researches, respectively. To solve these subjects the author has proposed fundamental and original methods and thereby obtained many interesting results to scientists and engineers.

Electromagnetic wave scattering by many particles is treated in Tateiba and Matsuoka [2005] based on the method of analysis (DUR method) proposed by one of the authors and compared with conventional methods. It is explained that electromagnetic wave scattering can be treated systematically by the DUR method for the cases ranging from a periodic distribution of particles to a random distribution, and that the condition can be given when the particle distributions are random from a coherent field point of view. Next, two application examples of the DUR method are presented. One is the calculation of the effective permittivity of a random medium consisting of many dielectric spheres. In contrast to the calculation by conventional three multiple scattering analysis methods, the present calculation results can be applied to particles with higher permittivity and hence the method is the best one at this time. The other example involves microwave active sensing of the moisture content of soil. It is shown that the polarization ratio of the incoherent scattered power is useful for estimation of moisture content in the cases where the moisture content is more than 5% in the surface layer and where the surface is dry in the deep layer. Finally, it is pointed out that accurate analysis of electromagnetic wave scattering in random media is becoming increasingly important in the development of new materials and new technologies for high-speed, high-reliability communications and high-precision sensing.

Meng and Tateiba [2005a] discussed the scattering characteristic of a conducting circular cylinder embedded in a random medium by changing the scale-size of the medium. The numerical results of bistatic radar cross-section (RCS) show that sometimes the scattering enhancement phenomenon may not occur in the backward direction but in the other directions, where a scattering depression region may exist in the neighborhood of backward direction and scattering enhancement may be observed outside the depression region. The region of the enhancement may be much wider than that of the well known backscattering enhancement, although the enhancement peak is not so high. The complicated oscillation of bistatic RCS is considered to be caused by statistical interference of incident and scattered waves. For all numerical results, the intergral value of the bistatic RCS with respect to β is almost equal to that in free space, which fact shows that the results agree with the law of energy conservation.

A new phenomenon of scattering enhancement in a random medium is discussed by analyzing numerically a bistatic RCS of a conducting circular cylinder [Meng and Tateiba, 2005b, c]. The results show that sometimes the scattering enhancement phenomenon may not occur in backward direction but in the other directions, where a scattering depression region may exist in the neighborhood of backward direction and scattering enhancement may be observed outside the depression region. It is found that a radar cross-section (RCS) of a body embedded in a random medium may be nearly twice as large as that in free space, under the condition that the body size is smaller than the spatial coherence length of incident wave [Meng and Tateiba, 2006a, b]. If the condition does not hold, the RCS may oscillate with the size of the body and becomes much larger than that in free space in some cases. The paper shows numerical results of bistatic RCS of a larger size circular cylinder in a random medium. Complicated oscillation of the RCS is seeen, i.e., enhancement and depression, in different directions, and discuss the new scattering characteristics with change in the size of the body in a fixed random medium for E-wave incidence.

Meng and Tateiba [2007] discussed the scattering characteristics of a conducting circular cylinder embedded in a random medium by changing the fluctuation intensity and thickness of the medium. The numerical results of bistatic radar cross-section show that sometimes the RCS in the neighborhood of backward direction plays a violent oscillation and becomes much larger than that in free space. The complicated oscillation of the RCS is considered to be caused by statistical interference between incident and scattered waves.
(M. Tateiba and Z. Q. Meng)

6.2 Chiral media

The dispersion relation for a chiral slab waveguide consisted of the chiral media in the film and cladding has been examined [Yokota and Yamanaka, 2006]. It has been shown that the cutoff frequency depends on the chiral parameter and for higher frequency, the eigenvalue approaches to the different values from the achiral waveguide.
(M. Yokota)

B7. Guided Waves

Recent progress on numerical modeling methods for photonic crystal fibers has been reviewed [Saitoh, K. and M. Koshiba, 2005d]. Koshiba, M. *et al.* have deeply investigated characteristics of several types of photonic crystal fibers: holey fibers [Florous, N.J. and M. Koshiba, 2005a, Florous, N.J. *et al.*, 2006a, Fujisawa T. *et al.*, 2006, Koshiba, M. and Saitoh, K., 2005, Saitoh, K. and M. Koshiba, 2005a, Saitoh, K.. *et al.*, 2005b, 2005c, 2005f, 2006a, 2006b, 2006d, 2007c, Tsuchida, Y. *et al.*, 2005, 2007, Varshney, S.K. *et al.*, 2007c], photonic bandgap fibers [Alam, M.S. *et al.*, 2005, Murao, T. *et al.*, 2006a, 2006b, 2007, Saitoh, K. *et al.*, 2006c, 2007a], and Bragg fibers [Skorobogatiy, M. *et al.*, 2004]. Various photonic devices based on photonic crystal fibers [Florous, N.J., 2005b, 2006f, 2006g, 2006h, 2006i, 2007a, 2007b, Morikawa,K. *et al.*, 2006, Saitoh, K. *et al.*, 2005e, 2007b, Skorobogatiy, M. *et al.*, 2005, 2006a, 2006b, Varshney, S.K. *et al.*, 2006a], photonic crystal waveguides [Florous, *et al.*, 2005c, 2005d, 2005e, 2006b, 2006c, 2006d, 2006e, Rodriguez-Esquerre, V.F. *et al.*, 2005, Yasuda, T. *et al.*, 2005, Yokoi, N. *et al.*, 2006], high index contrast waveguides [Kakihara, K. *et al.*, 2006b], slot waveguides [Fujisawa, T. and M. Koshiba, 2006d, 2006e, 2006f], magneto-photonic crystal waveguides [Kono, N. and M. Koshiba, 2007a, Kono, N. *et al.*, 2007b], and metallic nanostructured particles [Florous, N.J. *et al.*, 2007c] have been proposed. Design methods for photonic crystal fiber Raman amplifiers have been developed [Sasaki, K. *et al.*, 2007, Varshney, S.K. *et al.*, 2005a, 2005b, 2006b, 2006c, 2007a, 2007b]. Fundamental characteristics of localized acoustic modes in photonic crystal fibers have been invesrigated [Enomori, I. *et al.*, 2005].

(M. Koshiba)

B8. Antennas

8.1 Antenna Elements

Takano and Thumvichit [2004], and Thumvichit *et al.*[2006] developed ULPD (Ultra Low Pro-file Dipole Antenna) with a simplified feeding structure and a parasitic element. The con-cerns of ULPD antenna are the feeding method and the impedance matching, because the input impedance usually tends to be lowered by the existence of a metallic structure in its proximity. The proposed antenna has an excellent impedance matching and a coaxial feed built within the antenna structure so that the external matching and a balun are not required. They also ver-ified its characteristics via experiment and numerical computations [Thumvichit *et al.*, 2004, Thumvichit *et al.*, 2007]. Imura *et al.* [2006] examined excitation of dipole mode in asymmet-rical ULPD antenna.

8.2 Arrays and Phased Arrays

A gigantic antenna aboard a Space Solar Power System (SSPS) satellite, or a space-tenna is one of the most challenging devices to build. Takano [2006, 2007] describes the two kinds of huge antennas used in this system: An antenna aboard a satellite or a spacetenna, and an antenna on the ground or a rectenna. Takano [2004], Takano *et al.* [2004b], and Takano *et al.* [2006a] examine the requirements for a space-tenna from a SSPS, and system considerations for the configuration of space-tennas. Three kinds of configurations are presented and compared from the viewpoint of their realization. Sugawara *et al.* [2005] discussed construction method and analyzed radiation characteristics of an ultra-large array antenna for microwave power trans-mission. Takano *et al.* [2006a, b, c] consider constitution of ultra-large power transmission antennas with positive application of coupling between elements.

Takano *et al.* [2004a, 2005a], Okumura *et al.* [2006], and Radenamad *et al.* [2006] proposed the design to reduce the number of the fed elements using parasitic elements in an array antenna. They also studied gain enhancement of an array antenna using coupling optimization between elements [Takano *et al.*, 2005b].

In Japan, a new project for research and development has been started in collaboration of several organizations in order to realize practical active phased array antennas (APAA) which can be used in communications or public welfares. Takano *et al.* [2007a, b] describes the objectives, technical problems, organizations and schedule of the project, and propose cost reduction and usage convenience.

8.3 Reflector and Lens Antennas

Takano *et al.* [2004c] describes a large deployable antenna which is used at L-, C-, and Ka-bands on an artificial satellite in space. The main reflector with 10-m maximum diameter is formed using the tensioned truss concept which was proposed by one of the authors. Hanayama *et al.* [2004] examines characteristics of the antenna on HALCA satellite in orbit.

DECi-hertz Interferometer Gravitational wave Observatory (DECIGO) is the future Japanese space gravitational wave antenna [Kawamura *et al.*, 2006]. It aims at detecting various kinds of gravitational waves between 1 mHz and 100 Hz frequently enough to open a new window of observation for gravitational wave astronomy. The preconceptual design of DECIGO consists of three drag-free satellites, 1000 km apart from each other, whose relative displacements are measured by a Fabry-Perot Michelson interferometer.

The high performance antenna at light wave frequency requires optimal curved surfaces and high mechanical precision to acquire high aperture efficiency. Munemasa *et al.* [2005, 2006a, b, 2007a, b], and Takano *et al.* [2006d] developed a novel micro lightwave antenna by applying MEMS (Micro Electro Mechanical Systems) technology. The papers describe the antenna of transparent type which has a multi-level step structure with diameter of 4 mm.

In the Journal of the Japan Society of Infrared Science and Technologies which has strong activities in science, the special issue has been organized concerning information communications which is quite an engineering topic aiming at systems and services. Takano [2004] explains photonic technologies to support the lightwave wireless communications.

(T. Takano)

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