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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.

B1. Scattering and Diffraction

1.1 Basic Electromagnetic Fields Analysis

Interaction between human bodies and electromagnetic waves is the subject widely interested by the many researchers.

Yokota M. et al. [2010] considered the scattering problem of two circular cylinders, which are the simplest models for modeling many human bodies, by using Method of Moments (MoM). As numerical results, the received power for two circular cylinders is examined from the viewpoints of changing the position of the cylinders. Also, the superposition of the scattered field by each cylinder is compared with that of the original situation.

Yokota M. et al. [2012] considered numerical analysis of the propagation loss characteristic when the distance between transmitter and receiver is comparatively short. Human body is modeled by lossy dielectric cylinder, and the propagation loss characteristics for the passerby density and distance are examined. In order to verify the numerical results, the experimental data is measured.

The scattering from multi-sphere system is the classical problem which can be solved analytically by the addition theory of vector spherical harmonics. However, since the expression is so complicated that it is not easy to obtain concrete numerical values by using these analytical results.

Dong, N. T. et al. [2012] presented an efficient algorithm for calculating addition coefficients which is based on the recursive relations of scalar addition coefficients. Their numerical results agree with those of previous published results but the algorithm proposed here reduces the computational time considerably. This paper also discusses the strengths and limitations of other formulations and numerical techniques found in the literature.

The application of integral equation method to the problems of nano-photonics or nano-optics has been recently hot subject in the electromagnetic theory.

Tanaka K. et al. [2011] investigated the nano-focusing of surface plasmon polariton by a conical metal-coated dielectric probe numerically using the three dimensional volume integral equation. They found that the intensity distribution near the probe tip was found to be very sensitive to the shape of the probe tip.

Tanaka K. et al. [2012] found dark spots that are interference patterns among plasmon-enhanced local fields. They also found that two kinds of interference patterns (dark spots) are created in the free space in the vicinity of the nano-rod. One is created near the rod-end and has a disk shape. The other is created around the nano-rod and has a toroidal shape. Both kinds of patterns have nanoscale dimensions, because they are generated by interference between near fields that have large wavenumbers. (K. Tanaka)

1.2 Periodic Array Structures

Light scattering and propagation in periodic array structure such as photonic fiber and photonic crystal waveguides is both theoretical and practical interest in many areas of physics and engineering. Applications include integrated optical circuit, optical resonator, and other optical devices. Consequently, in the design of photonic crystal structures with periodic constants identical to the optical wavelength, it is important to investigate the stop band region or photonic band-gaps.

In the scattering problem, Sesay and Yokota [2010a, 2010b, and 2010c] proposed 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. They [2013] also examined two-dimensional scattering of a plane wave from a dielectric gratings structures containing photonic crystal grating by same methods.

Jandieri and Yasumoto [2011] proposed method to the analysis of electromagnetic radiation from a line source located inside the cylindrical EBG (electromagnetic band gap) structures of cylindrical periodic layer with defects. The defects are introduced by removing the particular circular rods from each circular ring. They [2013] also analyzed the scattering by finite array of magnetized ferrite circular cylinders based on the model of cylindrical structures, and it is validated by the tests of the reciprocity relation and the optical theorem for the convergence and accuracy of the method.

Nakayama and Tamura [2012a, 2012b] proposed a new expression for the image integral equation, which was solved numerically for a sinusoidal surface for any angle incidence, and it is obtained that a reliable solution can be obtained for any real angle of incidence including a critical angle. They [2013] also newly proposed the reflection extinction theorem, stating that the radiation from the image surface becomes a plane wave and cancels a reflected wave.

Hirayama et al [2011] proposed a solution based on the hybrid Trefftz finite element method (HTFEM) for plane wave scattering characteristics of doubly periodic structures.

On the other hand, in the guiding problem, Ozaki and Yamasaki investigated propagation constants at the first stop band region and the energy distribution at the guided area for the case of dielectric circular cylinders or dielectric triangular cylinder [2012a] and rhombic dielectric structure [2012b] along a middle layer for both TE and TM modes by using the combination of improved Fourier series expansion method and multilayer method. Ozaki and Yamasaki [2013] also examined influence of rhombic dielectric structures compared with deformed rhombic dielectric structure in the middle layer, and investigated the distribution of energy flow for dielectric waveguide with defects for TE and TM mode.

Nakatake and Watanabe [2011] presented a formulation of two-dimensional photonic crystal waveguide devices formed by circular cylinders, and it is introduced the periodic boundary conditions and the input/output properties are obtained by the recursive calculation for each straight waveguide section, as same with the conventional FSEM.

Naka and Nakamura [2013] proposed an efficient 1×2 optical power splitter constructed by a two-dimensional photonic crystal. The power splitter has a microcavity making a resonant tunneling which is coupled to an input and two output waveguides by FDTD method.

(T. Yamasaki)

1.3 Cavity Structures

Kobayashi [2012] carried out a comparative radar cross section (RCS) study of two canonical cavities formed by a semi-infinite parallel-plate waveguide and by a finite parallel-plate waveguide using the Wiener-Hopf technique. Exact and approximate solutions are obtained, and the scattered field inside and outside the cavities is evaluated analytically. Numerical examples on the RCS are presented for various physical parameters, and backscattering characteristics of the two cavities are compared in detail. As an example of parallel-plate waveguides that can form cavities, Kobayashi [2013] considered a finite parallel-plate waveguide with four-layer material loading, and analyzed the plane wave diffraction rigorously with the aid of the Wiener-Hopf technique. Representative numerical examples on the RCS are presented and far field scattering characteristics of the waveguide are discussed.

(K. Kobayashi)

B2. Inverse Scattering

2.1 Iterative Approach

Microwave imaging for breast cancer detection has been investigated using a hybrid method of forward–backward time-stepping algorithm and genetic algorithm [Moriyama et al., 2011a]. A two-dimensional numerical breast phantom with high contrast between fat and fibroglandular tissues and low contrast between fibroglandular and tumor tissues has been used to confirm the efficacy of the proposed method.

Moriyama et al. [2011b, 2011c] have considered an enhanced version of the iterative multiscaling approach in the time domain. In addition to the standard zooming procedure, a segmentation procedure makes the approach more efficient. The effectiveness of the proposed method has been demonstrated from numerical simulations.

Real-coded GA with discrete chromosomes has been applied to the estimation of reinforcing bars [Tanaka et al., 2011]. Because the fitness to the same discrete chromosome is not necessary to calculate, the computing time for exploration can be greatly shortened.

Moriyama et al. [2012] have developed a time-reversal approach for reconstructing electrical parameters of a stratified slab from time-domain reflection and transmission data. The impressed source as well as the equivalent sources corresponding to the measured reflected and transmitted fields have been time-reversed.

Takenaka et al. [2012a, 2012b, 2013a, 2013b] and Moriyama et al. [2013] have investigated the method of reconstructing material parameters of a dielectric cylinder, and a stratified dielectric slab based on the field equivalence principle. The approach does not require the explicit knowledge of incident fields. A genetic algorithm and a time-reversal approach have been applied to the minimization of a functional to estimate the electrical parameters. Numerical simulations have demonstrated the effectiveness of the approach.

Tanaka [2013] has examined the performance improvement of an iterative inversion algorithm of estimating the relative permittivity of a lossy dielectric cylinder using the modified frequency-hopping technique and the adaptive regularization method. The proposed method has provided high-quality reconstructions with the property of faster convergence than the conventional method.

(M. Tanaka)

2.2 Other Approach

Over the past three years, numerous investigations have been conducted on ultra-wideband (UWB) radar imaging and inverse scattering using non-iterative algorithms. Among them, reversible transform-based methods such as boundary scattering transform (BST) have been widely studied. Although such methods are applicable only to targets with clear boundaries, the use of a reversible transform enables fast computation that is necessary in various real-time applications. New reversible transforms have been developed for a multi-static configuration [Sakamoto and Sato 2012] and the polar coordinate system [Sakamoto et al. 2013] to enable fast imaging in various system configurations.

One of the challenges to overcome in applying the reversible transforms to actual scenarios is related to target motion. For a target undergoing an unknown translational motion, an algorithm for a two-dimensional model was developed to estimate target motion for UWB radar imaging using only three antennas [Matsuki et al. 2010, 2011], whereas many conventional reversible transform-based methods assume numerous antennas. By employing five antennas, this method was extended [Sakamoto and Sato 2011, 2011b] to enable estimates of both the translational and rotational motion. The method involves estimating the time evolution of the local curvature of a target to separate the motion of the target itself from the motion of the echo reflection point. The performance of the method was also confirmed from experimental measurements [Sakamoto and Sato 2011c]. Finally, the method was extended to three-dimensional imaging of moving targets [Sakamoto et al. 2011, 2012].

Another approach to handle target motion was studied in [Sato et al. 2012, 2013, 2013b]. This approach separates the motion of different parts of a human body in the Doppler frequency domain. The head, torso and limbs are independently extracted in the frequency domain; the position of each part of the body is estimated using three receivers that form an interferometer. The images generated using this method have radial velocity information, which can be used in classifying the various target actions [Saho et al. 2012b, 2013c].

Like other wireless systems, UWB radar suffers from multipath interference in an indoor environment. However, the multipath components can be separated and used in the time domain because UWB signals inherently have a short pulse width. Using multipath signals, this short-pulse characteristic can be exploited to image targets located in a shadow region that does not have a line-of-sight path to the antennas [Fujita et al. 2011, 2012]. This method requires a priori information of the indoor environment. In contrast, another method [Kidera et al. 2011] does not need any prior environment information in the imaging process. To compensate for waveform distortion, an extended Capon method was developed to estimate accurate target shapes [Kidera et al. 2011b]. To achieve even higher imaging quality in a multi-path environment, DORT (the French acronym for Decomposition of the Time Reversal Operator) algorithm was extended to a multipath scenario [Sakamoto and Sato 2011c and 2011d].

These reversible transform-based algorithms have found applications in concealed weapon detection. The proposed method and various measured datasets [Sakamoto et al. 2012b, 2012c, 2013b] were used to demonstrate the effectiveness of the non-iterative inverse scattering in imaging a human body with concealed objects. This technology has been further extended to be able to image an arbitrarily moving target [Sakamoto et al. 2013c] by estimating its speed.
(T. Sato)

B3. Computational Techniques

3.1 Integral Equation Methods

Integral equation methods are widely used for various problems including wave propagation and scattering. The method of moments (MoM) is one of the most useful integral equation method in analyzing antennas, microwave and millimeter wave planar circuits, etc., and is therefore implemented to various commercial simulation softwares. In spite of powerful computation capability and a wide variety of applications, it is the heavy-load computation to solve dense linear equations generated by the MoM. Much attention is now paid to reduce computational costs by improving preconditioning, iterative solvers, fast algorithms, and their combinations.

Chiba et al. [2011a] develop the inner-outer flexible generalized minimal residual algorithm (GMRES) solver implemented with the fast multipole method (FMM) techniques and demonstrate the relationship between the overall performance of the inner-outer flexible GMRES and the accuracy of the FMM operator within the inner solver in analyzing large-scale scattering problems. As a result, the authors reveal that a moderately accurate FMM operator in the inner solver serves as an optimal preconditioner. The flexible GMRES is further accelerated by introducing a multistage preconditioner in Chiba et al. [2011b]. Chiba et al. [2011c] investigate the performance of the induced dimension reduction (IDR) method for solving electromagnetic scattering problems by the MoM based on combined field integral equations, by comparing with other Krylov solvers, such as GPBiCG and GMRES, and reveal that, with an appropriate setting of the parameters in the IDR(s), the solver has robust convergence behavior as compared to GPBiCG, and GMRES(m).

Nakashima and Tateiba [2011] present variants of iterative progressive numerical methods

(IPNMs), and evaluate their performance in analyzing 27 regularly placed PEC spheres, comparing with the standard boundary element method (BEM). Then, Nakashima et al. [2012] develop the IDR-based IPNMs which has much better performance against the BEM.

An error prediction equation of the multilevel fast multipole algorithm (MLFMA) is presented by Kishimoto and Ohnuki [2012], and they successfully develop selection method for truncation number of MLFMA with desired digits of accuracy.

(Y. Ando)

3.2 Modal Expansion Methods

Many practical engineering applications require the numerical solution for the analysis of the EM field by a moving source and/or a moving body. The Overset Grid Generation method coupled with FDTD method for the analysis of the EM field with moving boundaries considering Doppler Effect was proposed by M. Kuroda and H. Iwamatsu. By overlapping one moving sub mesh on a static main mesh, each mesh is calculated alternately by using interpolation technique. For higher velocity value, Lorentz transformation is applied to the FDTD method.

S. Sahrani, H. Iwamatsu, and M. Kuroda proposed the Overset Grid generation method coupled with FDTD method for the analysis of the rotating body [Sahrani, S. et al., 2011a, 2011b, 2011c, 2012a, 2013a]. S. Sarrani and M. Kuroda applied this technique for a moving dielectric body [Sahrani, S. et al., 2013b]. A. Hirata, Y. Shimizu and M. Kuroda expanded this technique for variable capacitor [Hirata, A. et al., 2013, Shimizu, Y., 2013].

And also, this technique is applied for the analysis of the EM field in a street cross section from moving vehicle and moving source [Sahrani, S. et al., 2013c].

(M. Kuroda)

3.3 Finite-Difference and Finite-Element Methods

The Finite Difference Time Domain (FDTD) method holds an unchallenged position as a method of dealing with the interaction problem between electromagnetic fields and human body because realistic modeling of the human body is very simple in the FDTD framework. Hirata et al. [2010] investigated noise propagation characteristics on the frequency-dispersive realistic human body model induced by an electrostatic discharge using the FDTD method. The local exposure system for rat-head was developed and designed using both the FDTD calculation and the experiments for the purpose to establish the safety standards of electromagnetic exposure limits to the human body radiated from cellular phone [Arima, et al., 2011]. The FDTD method was also applied to develop a liquid-type equivalent human body valid for the frequency range between 30 and 100MHz [Shinba, et al., 2012].

Obata et al. [2012] developed an FDTD technique to simultaneously calculate the fields radiated from some electromagnetic sources using OFDM (Orthogonal Frequency Division Multiplexing) and CI (Carrier Interferometry) pulse excitation schemes.

Locally One-Dimensional FDTD (LOD-FDTD) method which is a class of implicit FDTD methods, was improved to three dimension and applied to the wideband analysis of waveguide grating [Shibayama et al., 2011]. His group implemented the LOD-FDTD scheme in the body-of-revolution coordinate [Shibayama et al., 2012].

Electromagnetic metamaterials, often called simply as metamaterials, have been investigated for antennas, microwave devices, and many other applications in the optical region. Examples include the creation of artificial dielectrics, superlens devices and an artificial magnetic conductor (AMC), as well as electromagnetic band gap (EBG) structures. Uno [2013] reviewed recently developed electromagnetic modeling methods of metamaterials and their inherent basic ideas, with a focus on full wave numerical techniques including the FDTD method, the finite element method and the method of moments. Uno and his colleague developed for calculating the dispersion diagram of metamaterials composed a lossy or frequency-dispersive materials that exhibits Debye-type and Drude-type dispersions using the finite difference frequency domain method [Hanif, et al., 2011, 2012a, 2012b]. Dispersion relations for these problem were originally obtained by solving the corresponding non-linear equations. They indicated that the nonlinear equation is reduced to a linear eigen-matrix equation by introducing an auxiliary variable. The FDTD method can applicable to the same problem, however generated modes cannot be classified in general. Sakamoto et al. [2013] proposed a classification technique based on the group theory.
(T. Uno)

B4. High Frequency Technique

4.1 Wave Optics

The high frequency localization by using the Fresnel zone numbers has been developed and expanded for various calculations. Complementary use of Local-MoM (Method of Moment) and PO-MoM is proposed and applied to the two-dimensional curved surface [Ito, K., T. Shijo, and M. Ando, 2011]. This combined method provides a nearly frequency-independent characteristic. Later, this method is expanded for the three-dimensional case with some revisions regarding dealing with diffraction points and weighting function. The revised method is applied to the localization of radiation integral for the scattering from the three-dimensional rectangular plate [Kohama, T., and M. Ando, 2012]. Good approximation and reduction effect of the number of unknowns have been confirmed. This Fresnel zone criterion is applied into not only localization of integration area but also the segmentation of its area is proposed. This idea is realized and applied to the PO computation of the monostatic radar cross section (RCS) for the 2-dimensional conducting strip and rectangular cylinder [Kohama, T., and M. Ando, 2013]. The frequency-independent characteristic such as the accuracy and computational time is observed.

The error of the Modified Edge Representation (MER) integration around reflected point from the curved scatterer and its correction term are empirically derived in an analytical form [Lu, P., and M. Ando, 2012]. The stability of diffraction component at RSB and ISB calculated by MER has been examined which depended on the integral path of scatterer’s periphery especially closed to reflection point [Lu, P., and M. Ando, 2013a, b]. The high frequency localization by using the Fresnel zone numbers is applied to the Equivalent Edge Current (EEC) derived from Keller-type Geometrical Theory Diffraction (GTD). The RB/SB singularities and the ambiguity of current definition are removed [Ando, M., M. Ali, P. Lu, and T. Kohama, 2013].

Hybrid method of Iterative Physical Optics (IPO) and Modified Physical Optics (MPO) is applied to the Radar Cross Section (RCS) analysis of the open-ended cavity [Hasaba, R., and M. Ando, 2012]. For convex and concave surfaces, MPO with enhanced accuracy and IPO taking multiple-reflections into account, are selectively and independently applied for convex and concave parts of the scatterer. The RCS from relatively small scatterers with the dimension of the order of a few wavelengths can be successfully predicted.
(M. Ando)

4.2 Ray Optics, and Others

High frequency asymptotic ray technique is still a powerful tool for analyzing electromagnetic scattering by large objects.

For metal cylindrical objects, Geometrical Theory Diffraction (GTD) is applied to estimate the diffraction field for reconstruct the targets [Shirai and Hiramatsu, 2012]. For dielectric objects, on the other hand, equivalent currents on the body could be a method for analyzing the scattered field [Nguyen and Shirai, 2012 a,b].

Ray tracing method is successfully applied to estimate the path loss for indoor communication system with inclusion of multiple bouncing effect inside building walls [Sato and Shirai, 2011a].

The problem of high-frequency scattering by a coated conducting cylinder covered with a thin lossy dielectric material as compared with a wavelength has been discussed in the papers by [Goto et al., 2012a, 2013a, Loc and Goto, 2013]. The asymptotic analysis technique is applied to analyze the transition region near the shadow boundary (SB). The extended UTD (uniform geometrical theory of diffraction) solution and the modified UTD solution derived by retaining the second order term are uniformly applicable in the transition region near the SB and in the deep shadow region in which the conventional UTD shadow region solution produces the substantial errors when the source and/or the observation points are located relatively close to the coating surface. The validity of the asymptotic solutions has been confirmed by comparing with the exact solution calculated from the eigenfunction expansion.

By extending the asymptotic analysis technique applied in [Goto et al., 2012a, 2013a, Loc and Goto, 2013], and by proposing the new analysis methods, the problem of HF scattering by a coated conducting cylinder covered with a thick lossy dielectric material as compared with a wavelength has been discussed in the papers by [Loc and Goto, 2012, Goto and Loc, 2013b]. The geometrical optics (GO) series solution including a multiply reflected GO (multiply RGO) is applicable in the deep lit regions far away from the geometrical boundaries (GBs) produced by the incident wave on the coated cylinder from the tangent direction. The extended UTD series solution including a multiply reflected surface diffracted ray (multiply RSD) is applicable in the transition regions near the GBs and the deep shadow regions far away from the GBs. Both the multiply RGO and the multiply RSD include the scattering phenomena inside of a dielectric medium. The validity of the asymptotic series solutions has been confirmed by comparing with the exact solution calculated from the eigenfunction expansion.

The problem of high frequency scattering by a conducting circular cylinder has been discussed in the paper by [Goto and Loc, 2013c,e]. The asymptotic analysis technique is applied to analyze the transition regions divided by the shadow boundary (SB) into the shadow and the lit side. The uniform asymptotic solutions include a novel extended Pekeris caret function to which the second order term in the argument of the exponential in the integrand is added as compared with the Pekeris caret function including the conventional UTD solution. By applying the residue theorem and the saddle point technique to the novel extended Pekeris caret function, the surface diffracted ray solution and the reflected geometrical ray solution which are effective exterior to the transition regions are derived. The asymptotic solutions have the advantage that it can apply as compared with the conventional UTD solution when the source and/or the observation point are located relatively close to the cylinder surface. The validity of the asymptotic solutions has been confirmed by comparing with the exact solution calculated from the eigenfunction expansion.

The problem of ground wave propagation over land-to-sea mixed path has been discussed in the paper by [Kawano et al., 2011a]. When the radio wave traverses a coastline from the land to the sea, the ground wave is strongly affected by the abrupt change of the surface impedance of the earth. By applying the method of stationary phase to the integral for the mixed-path ground wave propagation, the novel asymptotic solution consisting of the first-order and second-order diffraction terms has been obtained. The novel asymptotic solution agrees with the asymptotic solution derived by applying the aperture field method (AFM) and the method of stationary phase. The validity and the utility of the novel asymptotic solution have been confirmed by comparing with the mixed-path theory and the experimental measurement performed in Kanto area including Tokyo bay.

The problem of reflection and scattering by a discontinuity of a planar impedance surface has been discussed in the papers by [Kawano et al., 2011b,c, 2012]. Both the transmitting and the receiving antenna are placed sufficiently above the planar impedance surface. An integral representation for the scattered field 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 HF asymptotic solution includes the higher-order terms to obtain the accurate solution. The validity and the utility of the novel asymptotic solution have been confirmed by comparing with the reference solution calculated numerically from the Helmholtz-Kirchhoff integral.

The problem of HF Gaussian beam wave that is incident on a plane dielectric interface from a denser medium to a rarer one has been discussed in the papers by [Quang et al., 2011a, 2012a]. The asymptotic analysis technique is applied to analyze the transition region near the critical angle of the total reflection. The uniform asymptotic solution for reflection and beam shift of the Gaussian beam consists of the geometrically reflected beam, the lateral beam if any, and the transition beam which plays an important role in the transition region near the critical angle of the total reflection. The latter two beams are represented by using the parabolic cylinder function. The validity and the physical phenomena of the uniform asymptotic solution for the Gaussian beam reflection have been confirmed by comparing with the reference solution obtained numerically from the integral representation.

By extending the asymptotic analysis technique applied in [Quang et al., 2011a, 2012a], and by proposing the new analysis technique, the problem of HF cylindrical wave that is incident on a plane dielectric interface from a rarer medium to a denser one has been discussed in the papers by [Quang et al., 2011b,c,d, 2012b]. The uniform asymptotic solution for the transmitted waves observed in the rarer medium can connect smoothly the solution in the near region to the solution in the far region through the transition region. The uniform asymptotic solution is represented by using the parabolic cylinder function. The validity and the applicable range of the uniform asymptotic solution have been confirmed by comparing with the reference solution calculated numerically from the integral representation of the transmitted wave.

The problem of HF Gaussian beam wave that is incident on a plane dielectric interface from a rarer medium to a denser one has been discussed in the paper by [Quang et al., 2012c]. The validity and the applicable range of the asymptotic solution have been confirmed by comparing with the reference solution calculated numerically. Like the reflected Gaussian beam [Quang et al., 2011a, 2012a], the beam shift is also appeared in the transmitted beam.

Ray mode coupling technique which is established by Poisson summation formula, has been utilized to obtain the excitation coefficient of modes at the open end of the parallel plane waveguides [Abe et al., 2012]. These derived excitation coefficients are then used for calculating the scattering field from window frame on the building walls which are modeled by thick slit [Sato and Shirai, 2011b,c, 2013a, Sato et al., 2012, Shirai and Sato, 2011, 2012].
(H. Shirai)

B5. Transient Fields

Recently, pioneering computational studies on solving coupled Maxwell and Schrödinger equations have started to emerge: An electron wave packet inside a nanotube has been discussed using a coupled analysis, in which Maxwell and Schrödinger equations are solved by the Transmission Line Matrix scheme and by the Finite Difference Time Domain scheme (FDTD), respectively. Some other coupled analyses have been also reported. However, these coupled analysis requires to update the wave function and electromagnetic fields in addition to the vector potential A and scalar potential. The paper by [Ohnuki et al., 2013] proposes a new coupled solver for Maxwell and Schrödinger equations. In their method, the Hamiltonian in the presence of an electromagnetic field is represented by the length gauge form, which enables us to simplify the computational process significantly. It has been shown that the computational time of their new method is reduced almost by half as compared with conventional methods while keeping the same accuracy.

Analysis of nanoscale electromagnetic problems plays an important role in developing ultra-high density recording and microfabrication technologies. Conventionally, the time domain response of electric fields near a nanoscale object has been investigated by using the finite difference time domain (FDTD) method or the boundary integral equation method (BIEM) with the Fourier transform. The paper by [Kishimoto et al., 2012] propose a novel computational technique for analysis of the nanoscale electromagnetic problems. Their proposed method is based on the combination of BIEM in the complex frequency domain and fast inverse Laplace transform (FILT). The advantages of our proposed method are: (1) The computational error is easy to be controlled, (2) There is the no restriction of selecting time step size, and (3) An arbitrary observation time can be selected. For solving problems with a large number of unknowns, the fast multipole method (FMM) can be applied to the BIEM part and the computational cost can be further reduced.

The problem of high-frequency (HF) truncated Gaussian-type modulated pulse plane wave that is incident on one of the edges of a cylindrically curved conducting surface has been discussed in the papers by [Goto et al., 2011a,b,c, Goto and Loc, 2012b]. The asymptotic analysis technique is applied to analyze the transient scattered field elements [Goto and Loc, 2012b] under the assumption that the bandwidth of the pulse wave is wideband. The time-domain (TD) asymptotic solution is represented by a combination of the transient whispering-gallery mode radiation field (transient WG), the transient edge-surface diffracted ray (transient SDR), and the transient edge diffracted and reflected ray (transient EDR) including the edge diffracted ray. The asymptotic analysis technique is applied to analyze the transient WG [Goto et al., 2011a,b] and the transient SDR [Goto et al., 2011c] under the assumption that the bandwidth of the pulse wave is ultra-wideband (UWB). The TD asymptotic solution with higher-order approximation provides the new physical phenomena that the instantaneous angular frequency of the transient WG increases as a function of a time and that of the transient SDR decreases as a function of a time. The validity of the TD asymptotic solution for each transient pulse element has been confirmed respectively by comparing with the reference solution obtained from the numerical integral of the inverse Fourier transform which is represented by the product of the corresponding frequency-domain (FD) asymptotic solution and the frequency spectrum of a pulse source function.

The problem of transient scattered field excited by a thin cylindrically curved conducting surface with edges has been discussed in the paper by [Goto and Loc, 2013d]. By applying the asymptotic technique to the transient scattered field integral, the TD asymptotic solution has been derived. The TD asymptotic solution is represented by a combination of the transient EDR, the transient WG, and the transient SDR. The validity of the TD asymptotic solution has been confirmed by comparing with the numerical reference solution which is calculated from a combination of the FD numerical solution computed from the method of moment (MoM) and the fast Fourier transform (FFT) numerical code. The TD asymptotic solution has the advantage that the transient scattered field can be interpreted in detail for each scattered field element as compared with the numerical reference solution.

The problem of the transient scattered field by a coated conducting cylinder covered with a coating medium has been discussed in the papers by [Goto et al., 2013f,g]. By extending the corresponding frequency-domain asymptotic solutions in [Goto and Loc, 2013a,b], the time-domain

(TD) numerical solutions have been derived. The transient scattered field is excited by the truncated Gaussian-type modulated ultra-wideband (UWB) pulse source. The validity of each TD numerical solution has been confirmed by comparing with the numerical reference solution calculated from a combination of the eigenfunction expansion and the fast Fourier transform (FFT) numerical code. The TD numerical solutions in [Goto et al., 2013f,g] have the advantage that it dissociates for each transient scattered field element and can interpret the transient scattered field in detail as compared with the numerical reference solution.

The problem of transmitted Gaussian pulse through a plane dielectric interface has been discussed in the paper by [Quang et al., 2013]. The asymptotic analysis technique is applied to analyze the transmitted pulse waves observed in the rarer medium when the Gaussian-type modulated pulse wave is incident on a plane dielectric interface from the denser medium. By extending the corresponding frequency-domain (FD) asymptotic solutions in [Quang et al., 2011d, 2012b], the time-domain (TD) asymptotic solution have been derived. The TD asymptotic solution is represented a combination of the geometrical ray and the transition wave in the near and the transition region and a combination of the lateral wave type transmitted ray, the transition wave, and the evanescent wave in the transition and the far region. The validity of the TD asymptotic solution has been confirmed by comparing with the reference solution calculated numerically. The lateral wave type transmitted pulse wave arrives at the observation point earlier than the evanescent pulse wave.
(K. Goto)

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

6.1 Wave Propagation and Scattering in Random Media

Fujisaki et al. [2010] evaluated the relations among 10-minute precipitation, rainfall intensity and rain attenuation by using experimental data of Ku-band satellite communication observed at three different locations in Kyushu Island, Japan.

Hanada et al. [2011] gave attention to the average value of received power which can be obtained by the second moment of a Gaussian wave beam, and then formulated BER derived from the average received power. They provided the method to estimate effects of atmospheric turbulence on satellite communications by analyzing the degradation in BER performance due to the decrease in the average received power. Hanada et al. [2012] predicted the vertical profiles of the structure constant from radiosonde data measured in Fukuoka, Japan by applying the above statistical method, and then analyzed BER for satellite communications in Ka-band at low elevation angles using the predicted profiles of the structure constant.

To analyze the depolarized EM waves, Nanbu et al. [2011a,b, 2012] first derived an integral equation using the dyadic Green's function on the assumption that there exists a random medium screen of which the permittivity is fluctuating randomly. Next they modified the integral equation on the assumption that the observation point is very far from the screen. On the basis of this modified integral equation, the depolarized EM wave was analyzed by using the perturbation method. Finally they represented the first order perturbation of the depolarized EM wave to discuss quantitatively the depolarization of EM wave propagated through the random medium screen.

By FDTD simulation, Miyazaki et al. [2011] studied propagation characteristics and received electric field distribution of WiMAX wireless data communication system with high bit rate more than 10 Mbps in artificial structures such as buildings, bridge and natural environment such as forest. By parallel FDTD methods, they [2012a] studied signal propagation and receiving characteristics of OFDM modulated wave and evaluated propagation, reflection, scattering, interference and delay of digital code signals in received code signals for several different complex models and inhomogeneous materials such as forests in long distance communication channels.

Considering propagation region as random media with randomly distributed rainfalls, Miyazaki et al. [2012b] evaluated attenuations of incident beam with 20 GHz carrier frequency in random media corresponding to rainfall rate 5-50 mm/h by three-dimensional FDTD method. In FDTD analysis, they [2012c] showed measurement system of rain attenuation using microwave Gaussian beam, and evaluated scattered fields first by single and two raindrops by FDTD method and Rayleigh scattering theory and next by many raindrops and specific rain attenuation.

For medical image diagnosis using computer, Miyazaki [2011a] showed effective image reconstruction theory by multiple coupled waveguide method, excluding random scattering noises, and discussed spatial grid filter system for precise imaging reconstruction. Based on spatial sampling theorem, he [2012a,b] showed precise image reconstruction theory of electromagnetic CT method, discussing scatterings and mode couplings in inhomogeneous guided modes in virtual waveguide array consisting of random media. Miyazaki et al. [2013a,b] studied by FDTD method reflection and transmission characteristics of waveguide-type spatial filter consisting of clad and core with relatively long length and complex refractive index of lossy clad for incident angles of the incident beam, comparing with approximate analytical method, such as physical and geometrical optics, for optimum design of structure of spatial filter to accomplish accurate image diagnosis by optical CT.

Miyazaki [2011b] studied temporal and spatial characteristics of electromagnetic scattering and reflection by driving car bodies and complex objects, and showed fundamental characteristics and application of scanning laser radars, and image recognition of car body and objects.

Uchida et al. [2010b,2011a] reported that the back scattering from a target is very small compared with those from random rough surface (RRS) and that the Doppler shift phenomenon can be included for the discrete ray tracing method (DRTM) analysis resulting in enhancing detectability of radars.

Because the terrestrial surfaces such as dessert, hilly terrain, forest, sea surface and so on are considered to be RRS [Uchida et al., 2010a], Honda et al.[2011] and Uchida et al. [2012, 2013a] reported that the propagation characteristics along not only homogeneous but also inhomogeneous RRS can be estimated numerically based on the EM field computations by using DRTM. New methods for generating inhomogeneous RRS were also reported [Uchida et al., 2011b, 2013b].

Nakayama [2011] discussed the low grazing angle scattering from translation invariance surfaces, such as periodic surfaces and homogenous random surfaces, where the shadow form of solution and scattering factor are introduced as new concepts. In order to obtain the scattering factor for a very rough periodic surface, Nakayama et al. [2012a,b] proposed an image integral equation, which gives a reliable numerical solution even at a critical angle of incidence. It is pointed out that the image integral equation can be obtained by a combination of the conventional integral equation and the reflection extinction theorem [Nakayama et al., 2013].

Tamura [2011] proposed a further improved technique on the stochastic functional approach for randomly rough surface scattering. By deriving modified hierarchy equations based on the diagonal approximation solution of random wave fields for a TM plane wave incidence or even for a TE plane wave incidence under large roughness, large slope or low grazing incidence, such a further improved technique can provide a large reduction of required computational resources, in comparison with the original improved technique. Numerical solutions satisfy the optical theorem with very good accuracy, even by using small computational resources. Tamura [2012] theoretically analyzed the reflection and transmission of a TE plane wave from a slab having a two-dimensional random medium with slanted statistically anisotropic fluctuation by means of the stochastic functional approach. Based on a generalized form of the random wave field together with a power spectrum of the fluctuation with a rotation angle, any statistical quantities are immediately obtained even in slanted fluctuation cases. The first-order incoherent scattering cross section is numerically calculated. It is then found that shift and separation phenomena of the leading or enhanced peaks at four characteristic scattering angles take place in the transmission and reflection sides, respectively. Moreover, Tamura et al. [2013a] additionally investigated a one-dimensional case with slanted fluctuation as a special case of two-dimensional random cases. Tamura [2013b] examined a characteristic of the so-called effective boundary condition, which is often employed in theoretical studies on randomly rough surface scattering. The case of scattering from periodic rough surfaces with perfect conductivity is discussed. The perturbation solution with all orders is explicitly given under the effective boundary condition. It is newly found that such a perturbation solution satisfies the optical theorem under the exact boundary condition.

Komiyama [2011a,b, 2011a-d] derived an asymptotic expansion of the amplitude of the scattered wave by an imperfection core in a waveguide system and showed that the scattered wave is partially canceled by the direct wave at large distance. Moreover he derived the total power of light in the cross section of a waveguide system and showed that the total power of the sum of the direct and scattered waves decreases from that of the direct wave because of the cancellation, the difference of the total power transfers to the localized wave and the total power of light is conserved. Izutsu et al [2013] and Komiyama [2013a,d] dealt with the scattering of a scalar plane wave by a half plane with a sinusoidally deformed edge from a straight edge by a physical optics approximation, evaluated asymptotically a contribution of an edge to the field integral and clarified the basic properties of the scattering caused by the edge deformation. The results are in good agreement with the results obtained by the GTD method for low angle incidence. Komiyama [2011c,d, 2012e, 2013b,c] treated the scattering of light by the end-face of a waveguide system composed of a large number of cores by the volume integral equation for the electric field, derived analytically the first order term of the perturbation series and showed that the far scattered field does not almost depend on the polarization of an incident wave. (M. Tateiba)

6.2 Inhomogenenous, nonlinear and complex media

Kushiyama et al. [2010] propose a novel metamaterial structure for the purpose of applying it to a near-field imaging and/or diagnostics of electromagnetic properties by using a surface plasmon in microwave frequency range. The proposed structure consists of a conducting wire lattice with conducting spheres embedded at the mid-point of the wire. They show that this structure can successfully be applied to an excitation of the surface plasmon in microwave frequency range by adequately cutting into a thin slab. Kushiyama et al. [2012] demonstrate the excitation of spool surface plasmon polaritons (SPPs) on a wire-medium metamaterial slab in the microwave region experimentally. The excitation of spoof SPPs is also verified by using the grating coupling method, where we demonstrate transmission enhancement through the metamaterial slab by placing diffraction gratings on both sides of the slab. It is shown that the enhanced transmission can be attributed to the dispersion relation of the spoof SPPs by numerical investigation.

Matsumoto et al. [2013] examines that the effective permittivity of the one-dimensional periodic structure using the reflectance and transmissivity obtained by the FDTD method. By using the reflectance and transmissivity by the FDTD method, the effective permittivity of the dielectric slab, which has the same reflectance and transmissivity with that of periodic structure, is obtained by using the transcendental equation. The range of application and the validity of the effective permittivity are shown by comparing the Rytov approximation with the approximation obtained by the FDTD method. (M. Yokota)

B7. Guided Waves

7.1 Dielectric and Optical Waveguides

Coupled-mode and coupled-power theories are described for uncoupled single-mode multi-core fiber design and analysis [Hayashi, T. et al., 2011, 2013, Koshiba, M., et al., 2011, Matsuo, S., et al., 2011a, 2011b, Takenaga, K., et al., 2011a], an analytical expression of average power-coupling coefficients for estimating intercore crosstalk in multi-core fibers is derived [Koshiba, M., et al., 2012], and relationships between crosstalk and core density in multi-core fibers are fully investigated [Saitoh, K., et al., 2012]. To realize large effective area, low bending loss, low crosstalk, and/or high core density multi-core fibers, optimized design methods are developed [Imamura, K., et al., 2011, Hayashi, T., et al., 2012a, 2012b, Takenaga, K., et al., 2011b, Tu, J., et al., 2012, 2013] and to overcome the trade-off between core number and cladding diameter of a standard hexagonal layout, ten-core [Matsuo, S., et al., 2011c] and 12-core [Matsuo, S., et al., 2012] fibers without hexagonal closed-packed structure are designed and fabricated. Weakly-coupled multi-core fibers [Ishida, I., et al., 2013] and few-mode multi-core fibers [Sasaki, Y., et al., 2012, Takenaga, K., et al., 2012] are also designed and fabricated.

Polarization characteristics of photonic crystal fibers selectively filled with metal wires into the cladding air holes are investigated [Nagasaki, A., et al., 2011]. As for all-solid photonic band gap fibers, multiple resonant coupling mechanism for suppression of higher-order modes [Murao, T., et al., 2011a], formation mechanism of photonic band gap edge for maximum propagation angle [Murao, T., et al. 2011b], design principle for realizing low bending loss [Murao, T., et al. 2011c] are investigated. Effective area limit of large-mode-area all-solid photonic bandgap fibers is clarified for fiber laser applications [Saitoh, K., et al., 2010] and effectively single-mode all-solid photonic band gap fibers with large effective area and low bending loss are designed and fabricated [Kashiwagi, M., et al., 2012a, 2012b, Kong, F., et al., 2012]. Limitation of effective area of bent large-mode-area leakage channel fibers is investigated for compact Yb-doped fiber laser applications [Saitoh, K., et al., 2011] and a large-mode-area leakage channel fiber with superior bending characteristics is designed and fabricated [Pal, M., et al., 2012]. Dynamics of Raman soliton supercontinuum generation near zero dispersion wavelength [Roy, S., et al., 2011a] and strong infrared radiation through passive dispersive wave generation [Roy, S., et al., 2011b] of optical fibers are investigated based on a generalized nonlinear Schrodinger equation.

A compact polarization rotator based on surface plasmon polariton [Komatsu, M., et al., 2012] and a compact two-mode multi/demultiplexer for mode-division multiplexing [Uematsu, T., et al., 2012] are designed using a silicon nanowire, various optical logic gates are designed using a multi-mode interference waveguide [Ishizaka, Y., et al., 2011a, 2011b], and TE/TM-pass polarizers are designed using a lithium niobate on insulator ridge waveguide [Saitoh, E., et al., 2013]. A short polarization converter based on an L-figured waveguide operating over a wide wavelength range [Wakabayashi, Y., et al., 2013] and a bent embedded waveguide with a loaded metal film for reducing polarization dependent loss [Nito, Y., et al., 2013] are investigated. Structural dependence of leakage loss in lithium niobate ridge waveguides is investigated and loss-free waveguide structures are found [Saitoh, E., et al., 2011]. A minimum leakage loss condition is derived for bent rectangular tube waveguides [Yamauchi, J., et al., 2011]. Structural dependence of group velocity and leakage loss in one-dimensional photonic crystal coupled resonator optical waveguide with modulated mode-gap is investigated [Kawaguchi, Y., et al., 2012] and a coupled ring resonator based on one-dimensional photonic nanocavity is designed [Makino, S., et al., 2013b]. A horizontal slot waveguide composed of silicon and silicon nanocrystal is designed for nonlinear optical device applications [Komatsu, M., et al., 2013] and slow-light-enhanced nonlinear characteristics in a slot waveguide composed of photonic crystal nanobeam cavities are investigated [Makino, S., et al., 2013a]. A three-dimensional finite element method is formulated for realistic three-dimensional waveguide design and analysis [Ishizaka, Y., et al., 2012] and transmission-efficient structures of bent and crossing slot waveguides are found [Ishizaka, Y., et al., 2013].
(M. Koshiba)

7.2 Transient Fields in Guided Waves

Some papers on the analysis of the transient fields in the optical power splitters, which consist of the two-dimensional photonic crystal structures with microcavity, have been published.

Yokota and Nagata [2012a] examined numerically the frequency separation characteristics of the structure by the FD-TD simulations with Mur's ABC.

Naka and Nakamura [2013] also calculated the power transmission spectra and the field intensity in the structure by the FD-TD analysis with the perfect matched layers.

These results have shown that the transmission characteristics can be controlled by the microcavity structure.

(Y. Kogami)

B8. Antennas

8.1 Fundamental Antenna

Antennas for body area network have been developed [Li et al., 2012a, Lin et al., 2012a,b], where high-efficiency patch antenna [Li et al., 2012a], multi-band antenna having tuning varactor diode [Lin et al., 2012a], and dual-mode antenna for 10 MHz and 2.45 GHz [Lin et al., 2012b] have been proposed. Very small antennas for in-body wireless communications at 950 MHz band [Lin et al., 2013a] and 2.45 GHz band [Lin et al., 2013b] have been also developed using folded dipole antennas. Antennas for particular uses, i.e. RFID antenna for detection of urination and 430 MHz band receiving antenna for microwave power transmission to capsular endoscope have been proposed by Nakajima et al. [2013] and Kumagai et al. [2011], respectively.

Reflect-array element and passive antenna for elimination of blindness in cellular mobile communications have been proposed [Li et al. 2011, Qu et al., 2011]. Li et al. [2011] have proposed a reflect-array element having inter-digital gap loading structure which has an advantage of wide range of phase of scattered wave to be controlled. Dual antenna composed of patch array and planar Yagi antenna has been proposed for a passive scattering antenna [Qu et al., 2011]. MIMO printed antennas with parasitic elements have been proposed by Li et al. [2012b] to reduce the mutual coupling among elements for mobile terminals.

Millimeter-wave and light-wave antennas have been developed and discussed. Sato et al. [2011] have developed a taper-slot antenna having wide bandwidth and low cross polarization for passive millimeter imaging. Takano [2011] has discussed similarities and differences of light-wave antennas with optical telescopes and radio-wave antennas.

(K. Sawaya)

8.2 Wideband Antennas

Built-in antennas in mobile equipment are often subject to changes in input impedance due to the proximity of objects, e.g. a user's hand/head, a desk, etc. To mitigate these problems, M. Higaki et al. proposed a novel automatic tunable antenna system using a probe [Higaki et al., 2012] [Higaki et al., 2013]. The system controls two varactor diodes in the matching circuit according to the received power of the probe, and is frequency independent, consequently significantly wideband, and can operate from

700 MHz to 2.7 GHz. A prototype using a programmable logic device is also demonstrated.

In order to integrate mobile services such as mobile phones, GPS, television broadcasting, a multi-band antenna is needed. K. Saegusa et al. proposed a novel multi-band antenna using plural conductive wires with a coupling phenomenon [Saegusa et al., 2010]. This antenna is constructed in a simple structure of plural conductive wires. Using a coupling phenomenon between wires, the currents of particular modes are excited on the antenna to give the multi-band characteristics. The operating principle of the proposed antenna was presented as well as the design of operating frequencies, the bandwidth and the radiation characteristics in detail.

Then, K. Saegusa et al. manufactured and measured the antenna. It is confirmed that the measured radiation characteristics almost agree with the analytical ones. The radiation pattern can be controlled by adjusting the current distribution of internal resonances [Saegusa et al., 2011].

In feeding the above-mentioned antenna with a coaxial cable, a bazooka type balun may be used in order to suppress the leak current. However, the device works at only one resonant frequency. K. Saegusa et al. investigated a novel method to set multiple feed points on the antenna for multiple frequencies for both cases with and without a reflector [Saegusa et al., 2012]. This method is compatible with practical connections with transmitters and receivers.

(T. Takano)

8.3 Antenna Elements

Dipole, inverted L, microstrip, slot, meander line, loop, spiral, helical, and curl antennas have been researched from novel engineering aspects. (1) Nishimoto et al. [2013] have applied the Nystrom method to Hallen's integral equation for a dipole antenna to obtain an exact and finite solution. Takano has investigated an ultra-low profile dipole (ULPD). He has characterized a ULPD with two inputs and a practical ULPD with a single input [Takano, 2013]. (2) Inverted L elements have been discussed by two groups; Yagyu et al. [2012] have optimized a reception antenna for terrestrial television broadcasting, where an inverted L is used as the driven element. Noguchi et al. [2013] have derived the theoretical maximum bandwidth for a small antenna consisting of a folded structure. (3) To develop circularly polarized radiation elements, Nakamura et al. [2011] have attacked a microstrip antenna and Joseph et al. [2011] have analyzed a slot antenna. Saito et al. [2012] have designed a meander line antenna as an electrically small and low-profile antenna. (4) Wire loop antennas have been investigated by Toshiba and Shibaura Institute of Technology groups; Tsutsumi et al. [2013] have presented a bonding wire loop antenna in a standard ball grid array (BGA) package for 60-GHz short-range wireless communication, and Hirose et al. [2013] have discussed low-profile dual-loop antennas for circular polarization. (5) Nakano et al. [2013] [2011a] have realized metamaterial-basis loop and spiral antennas, both radiating a dual-band counter circularly polarized wave. Circularly polarized beams generated from spiral and curl elements have also been discussed by the same group [Nakano et al., 2011b, 2011c, 2011d].

(H. Nakano)

8.4 Arrays and Phased Arrays

A novel technique is described to replace some of the driven elements in an array antenna with parasitic elements [Takano et al., 2013]. First, the antenna characteristics are studied by simulation for a basic unit array with one driven and two parasitic elements. The entire antenna is backed with a flat reflector to conform to practical applications. The parasitic elements are excited by the neighboring driven elements through the electromagnetic coupling effect. It is shown that at the optimal coupling condition, the radiation patterns are almost identical with those of an array antenna whose elements are all driven without coupling. The simulation result is confirmed by performing an experiment at 5.8 GHz (λ = 51.7 mm). Finally, a 12-element array is formed by combining four unit arrays. The simulation results show that the maximum antenna gain is 19.4 dBi, indicating that there is no penalty with respect to the antenna gain of a fully driven 12-element array. Therefore, the array antenna can be considerably simplified by replacing 67% of its elements with parasitic elements.

Phased array antennas are quite attractive due to the agility of beam scan. Up to now, many attempts were studied to use this antenna in advanced radio communications, but almost all failed. The phased array antenna is also available to construct quite a large aperture in addition to beam agility. However, the disadvantages are cost, weight and size, and power consumption. To solve these disadvantages, the concept of a partially driven-array antenna (PD-AA) using dipoles in free space was formerly proposed. As an actual antenna should have a reflector to shield radiation in the back-side, a new type of PD technique is required. The coupling via a reflected wave in addition to a direct wave is proposed and clarified the coupling in order to realize a practical PD-AA with a reflector which may be called a PD-AAR [Takano et al., 2010]. A considerable number of driven elements in a fully driven array antenna can be replaced with undriven elements or parasitic elements by means of the active utilization of electromagnetic coupling between array elements.

In the former partial drive technique, a part of the radiating elements were driven, and the rest were excited by spatial coupling, as contributes to the cost reduction of array antenna (AA). But this configuration is limited in design freedom due to spatial coupling. A method is proposed to connect the driven and parasitic elements by using a transmission line in order to get sufficient coupling even in a printed antenna [Hosono et al., 2010]. Impedance matching can be achieved by adjusting the transmission line, as is effective to realize low profile antennas. A partially driven AA (PD-AA) using transmission line coupling shows almost the same characteristics as a fully driven AA. A meander transmission line can decrease the distance between antenna elements to suppress the grating lobes.

Satellite users tend to require a larger antenna so that the antenna should be folded small to be installed in a cargo room of a rocket in launch phase. A novel multiple folding scheme is proposed in order to realize efficient folding better than a folded parabola or a single fold array antenna [Takano et al., 2011a]. In the case of a multiple fold, however, the mechanical steps between panels cause significant phase deterioration. Then we propose a phase compensation method with deduced equations. The availability of the proposed schemes is shown by simulation.

Small satellites or micro satellites gather much attention due to easy manufacturing and management. On the other hand, satellite users tend to require a larger antenna in order to realize better resolution for earth observation or larger capacity of telecommunications. For that purpose, the antenna should be folded small to be installed in a cargo room of a rocket in launch phase. Antennas were folded so far but in simple manners. But in the case of a large antenna on a small satellite, the antenna should be folded much smaller than the former cases to result in a large ratio of the deployed aperture area to the folded size. This is realized only by multiple folding. In the case of a single fold, it is possible to eliminate mechanical steps between plates of the divided antenna parts. In the case of a multiple fold, however, the mechanical compensation is quite limited. Therefore, phase compensation by electrical means is inevitable. A novel folding scheme of an antenna structure, and novel radiating elements and arraying technology are proposed [Takano et al., 2011b]. As the results of a preliminary study, we show the availability of the proposed scheme. Moreover, it is shown that beam scanning capability of a phased array antenna is even improved than conventional phased array antennas.

In space activities, they require a high gain antenna (HGA) that is folded small in a rocket in launch phase. A novel multiple folding scheme is proposed in order to realize more efficient folding than a folded parabola or a single folding array antenna [Takano et al., 2011c]. Then a phase compensation method to the mechanical steps between panels by additional phasing to the driving microwave field is proposed. The numerical simulation shows the availability of the proposed schemes. Applications of the proposed antenna are studied in comparison with a parabolic reflector antenna. A remote sensing satellite as a suitable candidate is proposed.

The relation between the element current and the thickness of a dielectric substrate for a dielectric loaded partially driven array antenna using transmission line coupling is shown [Hosono et al., 2011]. Almost the same characteristics as a fully driven array antenna are denoted.

A high gain antenna with a large aperture is required on a satellite for satellite communications, remote sensing, microwave power transmission, or scientific exploration. An important problem is how to obtain a large aperture in an orbit while being folded small in a rocket in a launch stage. There have been proposed several schemes to fold and deploy large parabolas. The tensioned truss antenna was launched in orbit. In order to achieve even smaller folded volume, however, parabola antennas have difficulties due to the necessity of three-dimensional structure and mechanical stiffness. To solve the problems, a phased array antenna (PAA) with flat panel structure may be a good candidate. A multiple-folding (MF) scheme to realize a significant improvement of the folding ratio, together with the method to compensate the phase discrepancy between panels by phasing was proposed. The basic configuration of MF-PAA, and the analysis of principal characteristics and application forms were previously described. The concept of MF-PAA is generalized [Takano et al., 2012]. The characteristics are analyzed for various values of step size. An antenna composed of nine panels with actual steps is simulated so that more realistic estimation will be possible.

In the former partial drive technique, which contributes to the cost reduction of array antenna (AA), a part of the whole radiating elements are driven, and the rest are excited by spatial coupling. This technique can realize the performance approximately equivalent to that of a fully driven AA (FDAA).

But the configuration is limited in design freedom due to spatial coupling. In that case, it is necessary to optimally determine the height and the spacing of elements. Thus we have proposed a method to connect the driven and parasitic elements by using a transmission line in order to get sufficient coupling even in a printed antenna, and named it “a partially driven array antenna (PDAA) with transmission line coupling". The influence of the feeding method and the transmission path configuration on the antenna characteristics have been examined [Hosono et al., 2012].

Power Satellite System needs a huge on-board antenna called a spacetenna. This antenna may be realized by a phased array antenna (PAA) which adopts elements of a half-wavelength in scale. In this case, the number of elements is quite large so that the simplification of feeding system is inevitable. A large-scale phased array antenna that is divided into sub-arrays, and equipped with a phase shifter to each sub-array is dealt [Takano and Saegusa, 2013]. The effectiveness of the phase shifter reduction and the radiation characteristics in beam scanning are clarified.

A 77-GHz slot array antenna with a single-mode post-wall waveguide is presented for automotive radars [Shijo et al., 2011]. First, transmission losses and fabrication costs of various transmission lines in millimeter-wave band are compared. The measured transmission loss in the 77-GHz post-wall waveguide integrated in a PTFE substrate at 77 GHz is shown 0.20 dB/cm, which is less than that of the microstrip line. Then, the design method of one-dimensional slot subarray with the single-mode post-wall waveguide is discussed. Finally, an antenna system composed of four subarrays has been fabricated. The measured gain of the antenna system is 24.4 dBi gain at the designed frequency of 76.5 GHz, and the efficiency for aperture size of 55 mm by 9.2 mm is 67%.

A single-layer antenna composed of four subarrays and compact low-loss feed-line structures connecting to an RF-module for 77 GHz automotive radar systems is presented [Shijo et al., 2013]. This antenna is based on a slotted post-wall waveguide array, which is integrated in a ceramic-filled PTFE substrate. The antenna gain is higher than 16 dBi relative to the maximum available directivity of 20.4 dBi at 76.5 GHz. The proposed compact feed-line structures achieve the low transmission loss of less than 3.2 dB.
(J. Hirokawa)

8.5 Systems

Recently, the wireless power transfer systems including SSPS are very remarkable and the relating papers have been reported.

Transfer efficiency between a transmission coil and a reception coil is a function of the distance and the orientation between the coils. A wireless power transfer system using the third coil is proposed [Oodachi et al., 2010]. The proposed system can improve the transfer efficiency when the distance between two coils is large. Also, the proposed system can improve the transfer efficiency when one of the coils rotates and their axes become separated.

A wireless power transfer system using a transmission coil array is proposed [Oodachi et al., 2011]. The transmission coils of the array are excited with appropriate phase weights by transmission circuit, according to the orientation among the transmission coils and the receiving coil.

A wireless power transfer system is proposed to minimize the influence of a metal desk [Oodachi et al., 2012]. A transmitter of the proposed system is put on the desk. A receiver of the proposed system is put on the transmitter. Exploiting its thinness, a receiver of the proposed system is installed in a mobile terminal.

The receiver in a wireless power transfer system is composed of an antenna, high frequency transmission lines, a rectifying circuit, direct current transmission lines, and a load. The power may be formed as a radio wave in a microwave power transmission, or as a coupled field in a resonance-coupled system. In order to realize a high-efficiency power transfer, circuits were analyzed in terms of impedance. However, the impedance at the high frequency and direct current stages was not well summarized so that confusion is raised. A way of thinking about matching is proposed in each technical field [Takano, 2013a]. First, the impedance of an antenna is formulated from the viewpoint of energy transfer. Finally, the impedance of a rectifying circuit is analyzed to show the difference from that of an antenna.

Microwave power transfer from a satellite to Earth that is visualized as a solar power satellite system (SPSS) is described [Takano, 2013b]. After the system configuration is explained, unique engineering features are presented. Then, some contributions made by Japanese community are introduced, focusing on microwave and antenna engineering. As SPSS will handle high power levels at microwave frequency, and so components should be mass-produced to reduce the cost, it is necessary to shift paradigm on the technology involved. Finally, the roadmap to a commercial SPSS is discussed.

It is required to change a collimated beam in a normal state to another pattern in order to cope with system emergencies. An instantaneous expansion of the beam for a phased array antenna is proposed [Takano and Saegusa, 2012b]. The design principle of the antenna is described on the basis of the phase distribution of a spherical wave. The simulation results are presented.

Partial drive techniques enable to replace driven elements with parasites on the basis of positive utilization of element coupling, and are effective to simplify an array antenna. Three kinds of array antennas in partial drive schemes and corresponding coupling methods comprehensively described [Takano et al., 2012b]. Finally, the practical uses of each antenna are discussed.

(S. Makino)

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