Recent Research Activities on Antennas in Japan

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***Abstract*—Some research activities on antennas are reviewed from the author's point of view. The academic organizations are described first, and the recent developments of researches on antennas and the relative topics in Japan are briefly described with emphasis on the Japanese contributions to this field.**

***Index Terms*—Antennas;Propagation;Japan;Review**

I. ORGANAIZATIONS AND ACADEMIC ACTIVITIS FOR ANTENNAS AND PROPAGTION RESEARCH

The organization most involved with the antennas and propagation research activities is the Institute of Electronics, Information and Communications Engineering (IEICE). The institute is composed of 4 societies and one group, and each society consists of several technical committees. The Technical Committee on Antennas and Propagation, which is called "AP ken" in Japanese, is one of the most active committees in the Communications Society which is the largest society in the IEICE (Fig. **1**). The AP ken has about 30 committee members including chair, vice chair and secretaries. It organizes technical meetings almost every month around Japan [1]. 200-300 papers are presented in the technical meetings every year. The technical meetings are sometimes held in foreign countries and regions in Asia with technical co-sponsorship of the local committees in these countries and regions. All the papers presented at the technical meeting are published in the IEICE Technical Report on Antennas and Propagation. The AP ken also holds workshops, tutorial lectures and other academic activities to promote the academic exchanges among professors, researchers and students. The IEICE holds the General Conference and Communications Society holds the Society Conference every year. More than 500 papers per year related to the topics of antennas and propagation are presented in these two conferences in recent years.

The International Symposium on Antennas and Propagation (ISAP) is now one of the most important conferences in the world focusing on the technologies related to antennas and propagation, electromagnetic theory, and related fields. The first ISAP was held in 1971 in Sendai, the hometown of the Yagi-Uda antenna. Before 2004, the ISAP was held in Japan every 2 to 7 years. Since 2004, the ISAP has been held every year in the countries and regions of the Asia-Pacific area. The Communications Society is the organizer of the ISAP when it is held in Japan. The AP ken members as well as a lot of people from both universities and industries contributed their great efforts to the success of the past ISAP held in Japan. The last ISAP was held in 2012 in Nagoya. The registrant was 563 and 417 papers from 31 countries and regions were presented in the symposium. All the papers presented in the previous ISAP are included in the ISAP Archives on line which are now open as a trial service [2]. The future ISAP will be held in Nanjing in 2013, Kaohsiung in 2014, and Hobart, Tasmania in 2015.

The Communications Society publishes 2 journals monthly. One is the IEICE Transactions on Communications, and the other is the Japanese Edition of Transactions on Communications. In 2010, 44 papers in the Transactions on Communications and 49 papers in the Japanese Edition were published on the topics of electromagnetics, antennas and propagation.

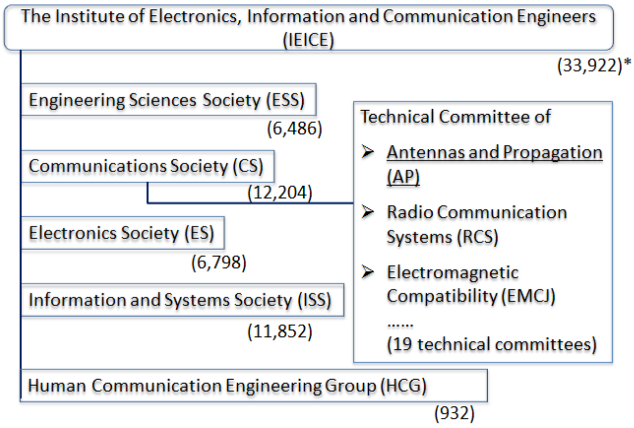

Fig. 1. Organizations of IEICE (March 2012).

II. RESEARCHES ON ANTENNAS

A. Antennas and array antennas in microwave and millimeter wave

Development of small antennas for mobile terminals is still one of the challenging issues. Some approaches of developing small antennas using folded structure were demonstrated [3] and a small broadband antenna was developed using a composite right/left-handed transmission line for mobile handsets [4]. Array antenna with compact array spacing is also studied by many researchers. A method to reduce the mutual coupling in a compact array of folded monopole antennas by linking two shorting strips with the bridge line was proposed in [5]. A small integrated diversity antenna using dipole and monopole modes was developed and a design method to reduce correlation coefficient between antenna elements was demonstrated [6]. A substrate with PMC characteristics composed of capacitance grids was proposed and the design method using an equivalent circuit model was provided [7]. Some experimental studies were carried out to evaluate the antennas for mobile terminals. MIMO capacity of

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2x2 dual-polarized antennas was measured in a residential area to investigate the effect of imbalance of received power by the multiple antennas [8]. A new power polarization profile was proposed to evaluate polarization dispersion characteristics based on the measurement data in an urban macrocell environment [9].

It is also a big challenge to design antennas for cellular base stations to meet the requirement of multi-frequency bandwidth, broad band, sector beam and compact size. A novel small-sized shaped beam base station antenna was developed to reduce inter-sector interference for next generation high speed wireless data communication systems [10]. A MIMO mode selection in a vertically split array (MMS-VSA) antenna was proposed [11], which increases the number of MIMO branches without increasing the antenna installation space and without reducing the 3G coverage area by employing mode selection in the vertically split array. A new filter integrated antenna was proposed which can suppress the mutual coupling between TX and RX antenna elements when TX and RX antenna elements are closed mounted in a base station [12]. A composite right/left-handed phase shifter was developed and studied which can realize different beam tilt angle in multi-frequency band to suppress the interference to the adjacent area in lower frequency band in mobile base station antennas [13].

A circularly polarized reflectarray antenna for satellite broadcasting reception was developed using ring elements and the reflection phases was controlled by varying the radius of ring elements [14].

Researches on antennas and antenna array for millimeter-wave are concentrated toward antenna performance of high gain, high efficiency, and high mass productivity. A 76 GHz phased array antenna using waffle-iron ridge waveguides with non-metal contacts was developed, which has the advantage of avoiding losses due to the imperfect metal contacts [15].

B. Technologes of antenna measurement

New technologies have been developed to measure the antenna performance more and more accurately and rapidly.

It is required to measure the far field on a spherical surface inclosing the measured antennas rapidly to know the radiation pattern and radiation efficiency of the antenna. A simultaneous measurement method using a parallel modulated probe array was proposed for this purpose. A 3-D antenna radiation measurement system based on this technique is capable of measuring a 3-D radiation pattern in 10-20 seconds [16]. Fig. **2** shows the product developed by Device Co. based on this method, which is composed of 16 modulated probes and each probe is excited by local signal with different local frequency, and is capable of measuring a 3-D radiation pattern of θ and ϕ polarizations within about 16 seconds at frequency range of 800 MHz to 2.6 GHz.

Several studies on techniques of array antenna measurement and calibration were also carried out. A novel amplitude-only measurement method was proposed for phased array calibrations which is capable of determining a complex element field at every phase shift of a digital phase shifter in phased arrays [17]. On-board calibration methods were proposed for the element phase differences resulting from mechanical distortions, and for setting the best-fitted phase distribution obtained from the measured phases [18]. A radio frequency (RF) controlled spatial fading emulator was developed [19]. The emulator can control RF signals directly in the spatial domain to produce an accurate radio propagation channel model, which includes the uniform and non-uniform angular power spectra (APS) in the horizontal plane. Fading correlation and MIMO channel capacities of measured MIMO antennas in the case of up to three spatial clusters can be measured by using the emulator.

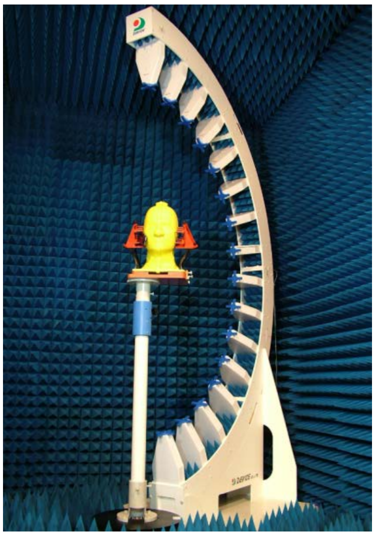

Fig. 2 A fast 3-D radiation pattern measurement equipment using parallel modulated probe array.

Suppression of radiation from the unbalanced current is a big challenge in measurement of small antennas in application of mobile terminals when the measured antenna is mounted on an electrically small "ground plane". A modified extended S-parameter method for multi-port measurement was proposed to solve this problem, and a general N-port formulation was applied to the measurement of radiation pattern of electrically small antennas [20].

Measurement of the specific absorption rate (SAR) and power absorption in phantom near antennas to evaluate the antenna performance in EMC aspects is another topic of antenna measurement. Liquid-type human-body equivalent antennas were developed using finite-difference time-domain analysis and measurements at the very high frequency band [21]. A simplified local SAR measurement method by using a lightweight phantom composed of wave absorber was proposed, where the relative permittivity and conductivity of wave absorber is determined in order to equalize the surface electric field of the wave absorber and the standard liquid phantom [22].

In the near-field measurement of antennas and EMC problems, the probe antenna is usually made as small as possible to increase the spatial resolution. However, the metal cable of the small probe can cause a large measurement error due to the scattering and disturbance by the metal cables of the probe antenna. The photonic technique using electro-optic modulator is very effective to solve this problem because the optical fiber is used to feed the small probe with the electro-optic modulator instead of the metal cable. The related researches on this technique started in Japan in early 1990's [23]. Recently, this method has been applied to the antenna measurement [24], and to the evaluation of human exposure to electromagnetic fields [25], where a small electro-optic probe [26] and application of assessment for terminals and base stations were studied, demonstrating that the method is effective in shortening the measurement time while maintaining accuracy. Furthermore, some new electro-optic devices for measuring microwave/millimeter-wave antenna characteristics were also proposed and demonstrated utilizing advanced photonic technologies [27], [28]. However, this technique has still some problems such as low sensitivity, limitation of the high frequency and high cost to construct the measurement system. The Technical Committee on Photonics-applied Electromagnetic Measurement (PEM ken) was established recently in the IEICE Communications Society for promoting the researches on the electromagnetic measurement using photonic techniques [29].

C. Antenna systems and applications

The approach using reflectarray as a passive repeater to improve propagation channel and to eliminate blind spots of wireless communications in urban areas was studied by Tohoku University together with NTT DOCOMO under the support of the Ministry of Internal Affairs and Communications (MIC). Some characteristics of reflectarray were developed such as dual band, frequency selective performance, wide scattering angle and so on [30]. An experimental campaign was carried out by using a 8X8 MIMO sounder for characterization of the developed reflectarray for eliminating blind spots at 11 GHz band in Non-line-of-sight (NLOS) areas [31]. It was demonstrated when the reflectarray was mounted on the top of a tall buildings, the electric field at the street just under the building, which was the NLOS area, was increased and the channel capacity was also increased due to the effect of reflectarray.

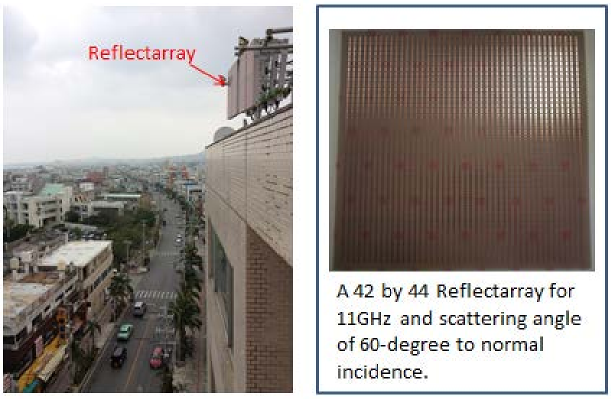

Fig. 3 Experimental campaign for characterization of reflectarray mounted on buildings for improving propagation channel in urban arrears.

Antipodal Fermi antenna composed of antipodal feeding section with a tapered slot antenna called "Fermi antenna" having a taper profile given by the Fermi-Dirac function as well as the corrugation on the side of the substrate has been extensively studied as the broadband directive antenna [32]. The antipodal Fermi antenna shown in Fig. 4 has been applied to the sensor element of passive millimeter-wave imaging system since the Fermi antenna has broadband characteristics to obtain enough power, axially symmetric directivity, suitable beam width for optimum coupling with dielectric lens, and narrow width geometry. Fig. 5 shows the 77 GHz passive millimeter wave imaging system for security purpose, which has been developed by Tohoku University together with manufacturing companies to find the concealed objects in clothes with a high spatial resolution of 10 mm [33].

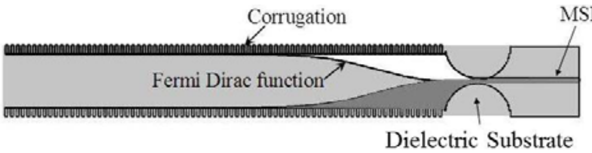

Fig. 4 Geometry of antipodal Fermi antenna [32].

Fig. 5 Photograph of 77 GHz millimeter wave passive imaging system developed by Tohoku University, Maspro Denkoh Corp. and Chuo Electronics Co., Ltd. [33]

A research project on RF coexisting technology on high speed baseband CMOS for millimeter wave radio systems was carried out in Tokyo Institute of Technology, which was sponsored by the Ministry of the Education, Culture, Sports, Science & Technology (MEXT) and cooperated with five companies. The project was aimed to design outdoor and indoor communication systems beyond Gbps based upon these ICs as well as the planar waveguide antennas. A compact one-box type wireless terminal which accommodates two (Tx and Rx) arrays is designed as is shown in Fig. 6. The high speed data rate of 1 Gbps has been attained. Aperture efficiency of more than 80% is obtained over 1.5GHz in the 38GHz band. The isolation between Tx and Rx antennas of more than 65 dB is realized in the same polarization by the conducting wall between apertures and also the radome [34], [35].

A research project of "Wideband Antennas" for mobile and vehicular applications has been continued in Hosei University, sponsored by Ministry of Education, Culture, Sports, Science and Technology, Japan, and several companies. Our goal is development of circularly polarized (CP) wideband antennas with a low-profile structure. So far, a low-profile "Equiangular Spiral with an EBG Reflector" has successfully realized our goal, where the height of the antenna is extremely small (0.07 wavelength), and the CP bandwidth is approximately 1: 3 [36].

In addition, a recent study has realized a conical CP beam across a wide frequency band using a low-profile "Archimedean Spiral with a Cavity" [37], shown in Fig. **7**. Currently, researches on CP "Metamaterial Spiral Antennas" are going on [38].

Fig. 6 A 38GHz compact one-box type wireless terminal which accommodates Tx and Rx array antennas.

Fig. 7 Spiral antenna for conical beam radiation.

D. Antennas used in and around the human body

Research on antennas for medical or healthcare applications has become more and more important. There are several different ways for cancer treatment including operation, radiation therapy, chemotherapy, ablation and hyperthermia. Two or more different ways are sometimes combined for clinical use. Hyperthermia is one of the promising modalities for cancer treatment, where the tumor is heated up to the therapeutic temperature between 42 and 45^{o}C without overheating the surrounding normal tissues. Moreover, the effect of other cancer treatments such as radiotherapy and chemotherapy can be enhanced with hyperthermia.

Fig. **8** shows a scheme for intracavitary heating for a bile duct carcinoma [39]. In this treatment, an endoscope is firstly inserted into the duodenum, and a long flexible microwave antenna is inserted into the forceps channel of the endoscope. Finally, the antenna is guided to the bile duct through the papilla of Vater, which is located in the duodenum. In this way, combined use of the microwave antenna with the endoscope will permit a more efficient and reliable application of hyperthermia.

Body-centric wireless communications [40] will have many potential advantages. As an example, in remote health monitoring, two different modes of communications are required: on-body communications (collecting medical data from body sensors) and off-body communications (exchanging data with outside networks). For on-body communications, low frequency bands (such as MHz band) may be more suitable, while for off-body communications, the 2.45 GHz ISM band is a good candidate [40]. Thus, a dual-mode antenna is a key component for remote health monitoring.

Fig. 9 shows the proposed dual-mode antenna [41]. In on-body mode, the antenna is similar to a pair of metal electrodes operating at 10MHz and in off-body mode, with an L-shaped slit embedded, the antenna can cover the 2.45 GHz ISM band. In order to verify the antenna, received voltage at 10 MHz, reflection coefficient and radiation patterns in the 2.45 GHz ISM band have been studied.

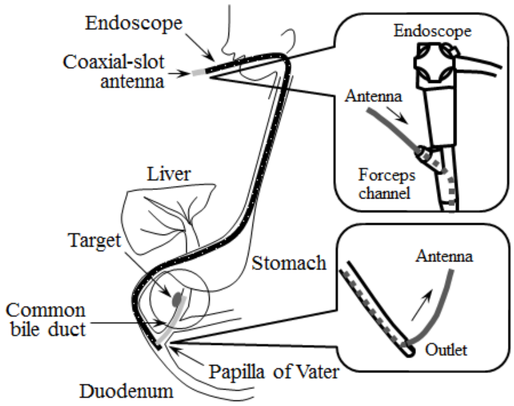

Fig. 8 Intracavitary heating for bile duct carcinoma with a coaxial-slot antenna.

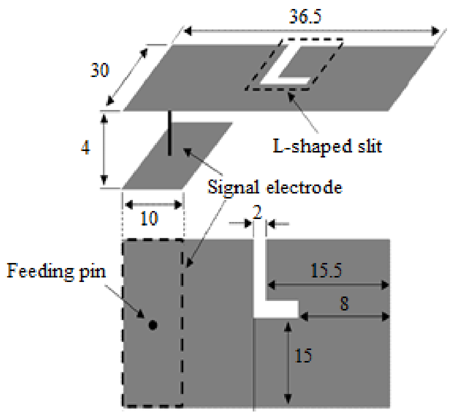

Fig. 9 Structure of the wearable dual-mode antenna: 3D view and top view (unit: mm).

III. SUMMERY

Some research activities on antennas in Japan were reviewed from author's point of view. The academic organizations and their activities in Japan were introduced, and the recent developments of researches on antennas and related topics were briefly described with emphasis on the Japanese contributions to this field.

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