COMMISSION E:

Electromagnetic Environment and Interference
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Natural EM Noise

Electromagnetic Phenomena Associated with Earthquakes

Before the major earthquakes (EQs) (1 month ~ few days), unusual electromagnetic effects have been observed despite that the complete physical mechanism have not understood well. One of these effects is anomaly occurred in the different regions of the ionosphere. In Japan, the densest VLF/LF transmitter signal receiving network have been deployed by UEC (University of Electro-Communications) and it continuously monitors the lower ionospheric conditions. Distinctive ionospheric perturbations in the nighttime D region (~80 km) were observed prior to major seismic activities such as Tohoku-Oki Earthquake in 2011.

Hobara et al. [2013] study the ionospheric perturbations by the Japanese VLF/LF transmitter amplitude data together with frequency dependent filtered surface displacement data from high density GPS network for inland earthquakes in Japan during several consecutive years to study the LAI (Lithosphere-Atmosphere-Ionosphere) coupling mechanism. They found that both ionospheric perturbations and surface displacements occurred almost simultaneously about one week before for some of the shallow earthquakes indicative of coupling between the precursory ground movement and relevant ionospheric perturbations. Either ionospheric or GPS anomalies were also found for other earthquakes. Chen et al. [2014] analyzed surface displacement data and for Tohoku-Oki earthquake. They found that the horizontal displacements integrated with the vertical movements from the residual GPS data are very useful to construct comprehensive images in diagnosing the surface deformation from destructive earthquakes along the subduction zone.

Kawano et al., 2015 carried out the statistical study of ionospheric perturbations associated with 243 major earthquakes around Japan both for inland and sea earthquakes. These earthquakes were characterized into three different groups based on the Centroid-Moment-Tensor (CMT) solution. As a result, the reverse fault type earthquakes have the highest occurrence rate of ionospheric perturbation, which indicates the coupling efficiency of seismic activity into the overlaying ionosphere probably controlled by preparation process of earthquakes.

Estimating the location and spatial extent of the lower ionospheric perturbations by using VLF/LF transmitter signal observations is a challenging task due to the large spatial separation between transmitters and receivers in general. This problem is very important to obtain the quantitative information of possible ionospheric perturbations in D region before earthquakes. Inui and Hobara [2014] characterize the spatial-temporal dependence of ionospheric perturbations from known perturbation sources i.e. solar eclipse passing through the VLF/LF transmitter receiving network in Japan by comparing the results from observation with the numerical model by FDTD method.

Another important problem is to quantitatively estimate the external forcing effects from various physical parameters to the VLF/LF transmitter signal amplitude to improve the detection efficiency of unknown ionospheric anomalies such as pre-seismic ionospheric perturbations. Tatsuta et al. [2015] investigate the effect of geomagnetic storms to the VLF/LF transmitter signal amplitude for different transmitter-receiver paths (high latitude, mid latitude, and trans equatorial paths) and found that detection rate of anomalies varies with latitudes of propagation paths.

Statistical properties of pre-seismic anomalies in ULF geomagnetic fields have been reported by Han et al. [2014] They performed the superposed epoch analysis and found that ULF anomalies appear 6~15 days before sizable earthquakes. Moreover, Molchan's error diagrams is derived containing precursory information of earthquakes and discuss how they can be used in short-term earthquake forecasting.

As were mentioned above currently research on statistical properties of electromagnetic anomalies based on long-term data set are conducted for understanding physical mechanisms of these phenomena and LAI coupling, whilst multi-parametric approach to identify these anomalies is important for future earthquake prediction in high accuracy.

Rozhnoi et al. [2014] report on fluctuations VLF transmitter signals that correlate both spatially and temporally with the passage of the tsunamis recorded by the Deep-ocean Assessments and Reporting of Tsunamis bottom pressure stations. Measured signals were consistent with the hypothesis that the ocean tsunami following the Chile earthquake on 27 February 2010 radiated internal gravity waves which propagated through the lower ionosphere.

Lightning and related phenomena

From 2013 to 2016, so much progress in lightning research related to EMC issues is seen in the literatures. In this section, some of such progress are reviewed mainly on lightning location system research particularly in Asian region.

An international collaborative research between Osaka University and New Mexico Institute of Mining and Technology improved greatly the VHF DITF developed by the research group of Osaka University and observed lightning discharges with an "upgraded VHF digital interferometer" system [Akita et al., 2014]. Stock et al. [2014] also reported an algorithm implemented on the same hardware described in Akita et al. [2014]. The algorithm employed by Stock et al. [2014] was more close to that reported by Sun et al. [2012] than that reported by Akita et al. [2014]. They also succeeded in locating in 2D lightning discharges in details. The detailed procedures to locate VHF sources, including noise reduction, are available in Stock et al. [2014] and Akita et al. [2014].

In 2012, Phased Array Weather Radar [Yoshikawa et al. 2013] was developed by Toshiba, NICT and Osaka University. The observation results are impressive and succeed in capturing the descending process of precipitation core of thunderstorms. The project with RIKEN started in 2013 [Miyoshi et al. 2016] and use the data from the Phased Array Weather Radar for data assimilation with K-Computer system. The LF based lightning location system called BOLT locates in 3D pulse peak signals on electric field change waveforms of each sensor by the TOA. Initial observation results of BOLT were compared with the PAR observation results [Yoshida et al., 2014].

Winter thunderstorm activities—relatively rare in the world—occur around the coast line in the north-west part of Japan. The winter lightning is characterized by e.g. its large electrical energy and predominance of positive lightning polarity, which is very different from conventional lightning in summertime. Thus many field campaigns have been conducted by Japanese group to elaborate on lightning physical properties by using modern technological systems such as digital interferometer, VLF interferometer, ELF observation network etc. The damages to the power grid and wind turbine system are also significant and spatial distributions of the energetic lightning deduced by ELF remote sensing technique is useful to mitigate future lightning damages [Hobara et al., 2013, 2015].

Recent findings of TLEs (Sprite and Jets) and high energy phenomena have also been observed in Japan and many research activities are going on in relation with associated electromagnetic emissions including JAXA's Global Lightning and Sprite Measurements (GLIMS) mission onboard ISS (International Space Station) [Sato et al., 2014].

Lightning application to the severe meteorological phenomena such as tornadoes and heavy precipitations have received a lot of attention in recent years for short-term forecasting of severe weather and for mitigating damages from natural disasters. Japanese total lightning network recently deployed by UEC group in collaboration with Earth Network started operation and successfully observed the sharp increase in lightning flash rate (lightning jump) immediately before the severe weather onset such as tornadoes and gust wind [Hobara et al., 2015].

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Man-made EM Noise and Electromagnetic Compatibility (EMC)

Commission E in Japan is holding technical meetings monthly in collaboration with the Technical Committee on Electromagnetic Compatibility (EMCJ) of the Institute of Electronics, Information and Communication Engineers (IEICE), and the Technical Committee on Electromagnetic Compatibility of the Institute of Electrical Engineers of Japan (IEEJ-EMC). Some of the meetings are collocated with other related technical groups.

The followings are the excerpted contents of the technical reports presented at the meetings held between November 2013 and October 2016. Recent trends of the research topics are, in addition to the traditional topics such as emission and immunity measurement and evaluation technologies of circuit and system EMC or EM absorbers and shields, new topics on EMC design technology related to IC and chips, automotive EMC technology, and power electronics EMC also attract the interest. Another new area is the information security related to electromagnetic waves and couplings.

E1. Electromagnetic Information Security

Information leakage from digital circuits has been investigated by research groups at Tohoku University [Aoki, Homma, Sone] and related groups in Tohoku Gakuin [Hayashi], Okayama University [Iokibe]. Iokibe *et al*. evaluated the internal activities of AES cryptographic circuit as equivalent current sources, and revealed that the variation of the supply current was the source of information leakage. Sone, Hayashi *et al*. demonstrated fault injection method with intentional electromagnetic interference (IEMI). They demonstrated the leakage of password through software keyboard input on a tablet PC, and discussed countermeasures for it.

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E2. Integrated Circuits and Chip Level EMC

The focus of research has shifted from “noise emission” to “immunity” of integrated circuits. Toyota *et al*. injected the electrical fast transient / burst (EFT/B) signal to FPGA and investigate the coupling conditions. Wada and Matsushima applied the direct RF power injection (DPI) method, IEC 62132-4, to LDO (low drop out) voltage regulators and constructed a macro model for immunity simulation.

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E3. Printed Circuit Board (PCB) EMC, Transmission Lines and Cables

Many technical reports have been presented on PCB EMC design and transmission lines and cables. Tobana discussed radiated emission from PCB traced on a slot. Maekawa investigated PCB layout design in relation to signal bit-error- rate (BER) and intra EMC of digital wireless equipment. Sekine *et al*. discussed extraction of circuit characteristics of signal transmission utilizing S parameters. Mechanism of the common mode excitation and its reduction techniques were discussed by Kami, Kayano, Kasuga, Sasaki, *et al*. Design of power distribution network on multi-layer PCB and application of EBG (Electromagnetic Band Gap) structure was discussed by Toyota *et al*. EMC design of multi-layer PCB was started on digital circuit design. But now the importance of EMC design in analog and power electronics circuits with low frequency operation is strongly increasing.

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E4. Automotive EMC

Due to the progress of electronics in the control of automobiles and the trend of the conversion to electric vehicles, the research topics on automobile EMC is increasing. Due to the high performance of the power electronics devices, the noise frequency spectrum is spreading widely. At the same time, discussion on the reliability of the in-vehicle network is also active. There are many examples of examining and combining low noise design of power electronics equipment and sustaining EMC of electronic equipment in automotive environment.

Efforts to improve the repeatability of conducted and radiated emission measurement and radiated immunity tests have been continued. Recently, reports on studies on immunity test methods for automotive equipment are on the rise. In order to secure the safety performance of automobiles including automatic operation, the importance of immunity test and high immunity EMC design will increase the importance in near future. In particular, to support a system combining onboard electronic equipment with high functionality, the EMC test method for automotive networks is being studied and standardization is on going also in IEC, and future progress is expected.

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E5. Power Electronics EMC

As mentioned in the previous section, the requirement for supplying power to electronic equipment with low noise is becoming stricter. At the same time, researches on new power devices such as SiC and GaN are progressing. In these devices, low on-resistance and low loss due to high-speed operation are significant advantages, but also they cause large electromagnetic noise generation.

Funaki and Ibuchi clarified the mechanism of noise generation by utilizing equivalent circuit modeling of power electronics devices and operation mode analysis, and compare the characteristics of new devices such as SiC and the conventional Si devices, and investigated low noise design. In addition to that, there are also presentations on low noise design and common mode reduction methods of power electronics circuits.

Another trend in the field of power electronics is WPT (wireless power transmission). With improvement of efficiency of WPT, studies on noise reduction technique are in progress.

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E6. EMC Problems Related to Communication Systems

In the previous National Report, this item was "EMC Problems Related to Telecommunication Systems." In addition to telecommunication, disturbance problems in communication in relatively near field such as interference in the vicinity of the WPT system, intra EMC, Indoor communication, Human Body Communication, Inter-vehicle Communication, and so on are treated in many cases these three years.

The era in which IoT attracts attention, the concept of communication is also about to change dramatically. Accordingly the change of EMC research related to communication is also required.

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E7. Numerical Techniques for EMC Simulation

As for EMC simulation, in addition to the conventional large-scale electromagnetic field analysis and numerical analysis, system analysis of the right place is being carried out by combining transmission line theory, circuit analysis, antenna analysis by MoM, and so on. Asai presented some new techniques and interesting review on Multi-domain Simulation.

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E8. EMC Measurement Technology & EMC Test Facilities

During the past three years, many researches on EMC measurement technology and EMC tests has continued as below. The field includes; near field measurement and EM field probes; EM environment; antenna calibration; radiated emission measurement; conducted emission measurement; and immunity test facilities, etc.

The frequency range of the conducted emission and immunity measurements is going to exceed 300 MHz, and at the same time the frequency of the radiated emission standard covers less than 30 MHz range. It can be said that it is time to review the traditional standard measurement methods.

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E9. EM Wave Absorbing and Shielding Materials’ Design

Many research results on EM wave absorber and EM material properties have been published. In addition to new methods for material constant measurement and proposal of analytical methods, there are also many proposals for functional materials such as new wave absorbers, shielding materials, surfaces with frequency selectivity.

Yamaguchi *et al*. have studied materials exhibiting large magnetic permeability over a wide frequency range and propose a method of reducing noise by putting them to the surface of IC chips and the vicinity of circuit boards.

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E10. Electrostatic Discharge (ESD) Measurement and Simulation

Fujiwara, Wang, Ishida *et al*. have continuously investigated ESD simulation and measurement methods. Recently they applied it to test of wearable equipment such as artificial arms, and proposed immunity test arrangement.

The FDTD method is widely used for ESD simulation. Asai *et al*. combined the FDTD method and the circuit simulation method, LIM (latency insertion method), so that the analysis efficiency was improved by taking advantage of the circuit analysis and electromagnetic field analysis.

Kawamata examined electromagnetic radiation mechanism by micro gap ESD experimentally and clarified the influence of electrode surface condition.

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