COMMISSION C : Radio Signals and Systems

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C1. Wireless Power Transmission

Wireless power transmission (WPT) via microwave has long history especially in Japan. In 80's, point-to-point WPT via microwave experiments were carried out in Japan. In 2000's, new WPT applications were proposed in Japan, for example, Ubiquitous Power Source (UPS), wireless charging for electric vehicles, wireless buildings, and etc.. After proposal of resonant coupling power transmission by MIT in U.S. in 2006, various WPT systems which include the WPT via microwave and resonant coupling power transmission are studied in Japan in recent three years.

Kyoto University's group carried out some WPT experiments via microwave. They carried out the field experiment of the UPS for emergency in 2009, in which the microwave power was transmitted from airship above 50m and the mobile phones were charged only with microwave power from the airship[Shinohara, 2010].

There are some kinds of the WPT via microwave researches in Japan. New rectenna for weak power receiving and rectifying was developed in Okayama University[Hiramatsu, 2009]. They also proposed and developed ultrasonic WPT system[Shigeta, 2009]. Tokyo University's group carried out a micro aerial vehicle flight experiment whose power was transmitted wirelessly from phased array on the ground[Oda, 2010]. The same group started researches of mid range WPT with resonant coupling technology[Koizumi, 2010].

We can transmit the wireless power via microwave, however, present radio wave regulation does not allow the WPT as commercial use. On the contrary, we can use the resonant coupling because there is no radiation from resonators. The efficiency of resonant coupling is higher than that of microwave power transmission. Therefore, it is easy to make products of WPT. There are many researches and commercial products in Japan in recent three years.

- New design theory based on BPF theory is formulated by Ryukoku University's research group.
- Tokyo University's group actively carry out some experiments of the resonant coupling WPT application for an electric vehicle[Imura, 2010].
- Famous Japanese companies, for example, Panasonic, Sony, Toshiba, Toyota, Nagano Nihon Musen, etc., made new resonant coupling WPT applications public.

Based on the Japanese WPT activities, WPT working group was established in Broadband Wireless Forum (BWF) in 2009. Radio regulations, consideration of electromagnetic limits for human body, and other equipments are discussed in the working group of BWF[Shoki, 2010].

(N. Shinohara)

C2. Satellite Communication Systems

Research and development projects in the field of satellite communication systems, such as wideband internetworking satellite communication, mobile satellite communication, integrated mobile communication and improvement of ground station technology has been executed in Japan for these three years.

(1) Wideband internetworking satellite communication (WINDS)

Wideband Internetworking engineering test and Demonstration Satellite (WINDS) is an experimental satellite aiming at research and development of broadband satellite communications system which takes part in construction of worldwide broadband networks and it was launched into geostationary orbit at 23, Feb., 2008.

After launching the satellite, fundamental and application experiment is now performing. In these experiments, health check of onboard Ka-Band Active Phased Array Antenna (APAA) was confirmed in orbit, and shown a good result Moreover, data communication of 1244Mbit/s (world record) was succeeded combining two 622Mbit/s waves with the bent-pipe mode using Satellite-Switched Time Division Multiple Access (SS-TDMA) system.

(2) Mobile satellite communication(ETS-VIII)

The Engineering Test Satellite VIII (ETS-VIII, Japanese name “KIKU-8”) was developed by the JAXA, NICT, and Nippon Telegraph and Telephone Corporation (NTT) and was launched into geostationary orbit at 146 degrees east longitude on 18 Dec. 2006. The aim of this project is to develop the following new technologies; in-orbit experiments such as Large-scale satellite-mounted Deployable Reflector(LDR) (19m x 17m), mobile satellite communications using small ground stations such as handheld terminals (about 300g).

Concerning the electrical characteristics of the LDR and beam forming network was evaluated [Suzuki, 2008], and the location of beam spot was changed around 0.15 degree by the thermal distortion of the large reflector [Satoh,, 2008]. Experimental result of portable terminal was reported and shows good characteristics such as the degradation of BER around 1dB compared to the identical in the case of without error correction [Yamamoto, 2008].

(3)Satellite terrestrial integrated mobile communication system

For the purpose of communication method at the disaster and digital divide measures in the local area, satellite/terrestrial integrated mobile communication system (STICS) is now under researching. In this system, dual mode handheld terminal with satellite and terrestrial communication function is used. In the satellite, 30m class reflector antenna is assumed to enable satellite communication with handheld terminal. The frequency is shared with satellite band and terrestrial band. Now, several frequency shearling method was proposed [Minowa, 2008] [Umehira, et al., 2009] and measurement experiment of interference wave such as terrestrial communication was carried out [Tsuji, 2009].

(4) Ground station technologies

For the sensor network via a communication satellite system was proposed which is called “Hyper Multi-point SATCOM System”, it can treat wide range data from several ten byte to several megabyte maximizing frequency efficiency.

Variable polarization frequency division multiplexing (VPFDM) was proposed for the purpose of accurate polarization tracking using electrical steering antenna such as mechanical steered polarization tracking antenna. Because polarization multiplexing, technical standard of cross polarization level in Very Small Aperture Terminal (VSAT) was defined to be 27dB, and it is difficult to establish such value in the electrical steered antenna. Validity of this system is confirmed by the experiment.

The helicopter-satellite communication system (HELISAT) was proposed and developed. In the helicopter, satellite communication was difficult by periodical interception by helicopter rotor blade. In this system spatial communication method was developed that synchronize rotating blade. Moving picture transmission of 1.5Mbit/s was succeeded using this system [Fujino, 2008].

(Y.Fujino)

C3.Microwave Active Circuit

The frequency bands allocated to mobile communications have been increasing with the growing demand for high-speed and high-capacity data transmission services. In particular, future mobile terminals will be anticipated to function seamlessly in various mobile communication systems that have inherent specifications such as the operating bands, the bandwidths, or the modulation/demodulation schemes. In this sense, the following two topics are one of the most significant issues in recent microwave active circuits: One is to provide multi-band operation, and the other is to achieve highly-efficient operation.

There have been reports on the architecture to provide multi-band/multi-mode operation for mobile terminals [Shimozawa, 2009], [Okazaki, 2010], which describe a quadrature mixer/modulator and multimode transceiver IC having a low spurious local oscillator configuration; and a reconfigurable architecture for configuring low-noise amplifier that incorporates integrated matching networks with MEMS switches. As a practical example of multi-band devices for mobile terminals, there have been proposals on a highly efficient multi-band power amplifier with a reconfigurable configuration comprising band-switchable matching networks and a biasing network [Fukuda 2010]; and a multi-band operation power amplifier integrated into a LTCC substrate [Furuta, 2010].

Aggressive R&D activities have given remarkable outcomes with regard to the highly-efficient operation. Typical topics during this period are divided into two regions: nonlinear distortion compensation techniques and harmonic tuning. With regard to the nonlinear distortion compensation techniques, a 3.5-GHz feed-forward power amplifier for mobile base stations has been proposed to demonstrate an experimental investigation on the wideband intermodulation distortion compensation characteristics [Suzuki, 2010]. In contrast to the feed-forward configuration, the digital predistortion (DPD) has also attracted much attention from the standpoint of the affinity with the digital signal processing in the modulation/demodulation circuits of the base stations. A fast calculation scheme has been presented for the coefficient values of a frequency characteristic compensator in the DPDL based on a quadratic function using the relationship between the coefficient values of the frequency characteristic compensator and the intermodulation distortion components [Ohkawara, 2009]. With regard to the harmonic tuning, highly-efficient power amplifiers have been demonstrated such as C-band GaN HEMT high power amplifier with a new circuit topology for simultaneous high efficiency matching at both fundamental and 2nd-harmonic frequencies, yielding the drain efficiency of over 57% with 100W output power [Otsuka 2008]; a new feed-forward amplifier employing a harmonic reaction amplifier as the main amplifier, yielding the efficiency of 19.3% with 20W output power [Suzuki, 2009]; and 2-GHz band GaN HEMT, an inverse class-F amplifier, yielding the power added efficiency of over 70% [Yoshida, 2010].

Besides the above mentioned areas, high-performance active devices have been proposed to open up entirely-new areas of microwave applications such as a high integrated SiGe-MMIC transceiver for 5.8GHz dedicated short range communications terminals [Shinjo, 2008], a Ka-band high-power protection switch utilizing new open/short-stub selectable circuit [Hangai, 2009], and a push-push VCO using branch line hybrid phase shifters [Kawasaki, 2010].

(S. Narahashi)

C4. Wireless Interconnection for Microelectronics

Though signal speed and integration level continue to increase in LSI technology, interconnections from/to the LSIs become serious problems. Conventional wire bonding has speed limit and signal degradation due to inductance of metal wires. Co-integration of optical devices has been long history of R&D [Haurylau 2006], but material level heterogeneous integration is still far from practical uses.

Recent approaches are wireless interconnection between IC chips. There are several approaches.

One is by radio wave propagation with conventional antennas [Sasaki, 2009]. With on-chip dipole antennas, which length is 6mm and the distance is 5mm, S21 is -10dB on high resistivity substrate [Kikkawa, 2010] . The transmission efficiency is so low that the system requires amplification of the received signal. However, the signals are transmitted to almost all directions, the system will be convenient for one to multi-port applications such as system clock delivery in digital circuits. However, the size of the antenna will be a problem.

Another approach is the use of inductive coupling with coils [Miura, 2005]. On-chip coils are placed on two wafers, and they are coupled with magnetic flux. Since the flux extends towards both upper and lower directions of the coil, the signal can be delivered through several wafers. Thus, they are appropriate for stacked multi-chip systems. The confinement of the energy is a problem in regard to the transmission efficiency. Therefore, the amplification at receiving point is also required. The size of the coils are 100 - 200μm square and the distances between the coils are limited to be 20-120μm. Due to this short transmission distance, the wafers are placed face to face or thinned down to 20-50μm. Using 65nm CMOS technology, they have shown 1.1Gbps data transmission with 0.55V power supply.

The other approach is capacitive coupling [Fazzi, 2007]. To reduce the capacitor area, the distance between the electrodes should be as short as possible. Their target distance is 0.4μm for 8μm square electrodes. Since the technology requires face to face wafer stacks and precise chip-alignment, it will be used in limited areas such as 3-dimensional wafer stacks.

The final approach is resonator couplings. Recently, wireless power transmission between two LC resonators becomes popular in power electronics [Karalis, 2008]. Experiments are carried out with 10MHz signal (λ=30 m) where the coil diameter is about 30 cm and the transmission distance is around 1 m. If the frequency is increased up to 60GHz, the resonator can be formed by small ring-type resonator (open-ring resonator) with the diameter of 240 μm on silicon or sapphire wafers. According to simulations, radiation loss is estimated to be less than 1dB even through 200 μm wafers with a 3dB bandwidth of 5GHz [Ohno, 2009]. Experiments at 15GHz signals showed S21 of -1.7dB [Okuyama, 2009]. Due to this high transmission efficiency, the structure needs no amplification. Therefore, it will be used for assembling in microwave systems including passive components like antenna. Due to the use of resonance, the structure is tolerant to misalignment [Abe, 2010-1], but the loss due to the finite conductivity of silicon wafers will be a problem [Abe, 2010-2]. Then, high resistivity silicon wafer will be needed. To solve this problem, meta- material concepts are proposed [Takahagi, 2010].
(Y.Ohno)

C5. Millimeter-wave and terahertz CMOS circuits

Recently, millimeter-wave and terahertz CMOS circuits are actively studied aiming for ultrahigh-speed wireless communication and noninvasive imaging. Although GaAs and InP circuits were conventionally used for millimeter-wave bands, CMOS circuits can operate in millimeter-wave region owing to device miniaturization using standard process. However, although standard CMOS process only offers process design kits (PDK) for relatively-low radio frequency (RF) including device models and layouts, they apply only below 30GHz. As a result, even though current advanced CMOS process has potentials to operate millimeter-wave and terahertz frequencies, the dedicated PDK for them has to be established, first. In 2008, Manzawa, et al, proposed bond-based design for millimeter-wave CMOS layout in order to overcome incomplete back annotation in millimeter-wave region [Manzawa, 2008], and proposed high-attenuation power line for millimeter-wave decoupling [Manzawa, 2009]. Owing to these two techniques, reproducible CMOS design can be realized even in millimeter-wave bands. For low-power millimeter-wave wireless communication, Oncu et al. proposed 60GHz pulse transmitter[Oncu, 2009-1], pulse receiver [Oncu, 2009-2] and wireless high-definition multimedia interface (HDMI) [Oncu, 2010]. Utilizing these technique, low-power communication technique was demonstrated even in millimeter-wave bands. Recently, terahertz CMOS circuits which operate over 100GHz have attracted attentions. Fujimoto et al. proposed device modeling technique applicable to terahertz region [Fujimoto, 2010-1] and 120GHz transceiver chip sets [Fujimoto, 2010-

2] and demonstrated terahertz communication with 9Gbps data rate and bit-error rates of below 10-9.

From now on, aiming at higher-speed communication and new sensing, CMOS circuits operating at higher frequency will be actively studied and will open up new applications. (M. Fujishima)

C6.Silicon based RF integrated circuits

In this period, many RF integrated circuits which realized by compound semiconductor have been superseded with scaled CMOS and Si-Ge BiCMOS. The cut-off frequency of Si-Ge bipolar transistor was already achieved 400 GHz and that of scaled CMOS was 250-300 GHz in 40-32 nm process design rule. Especially, many RF integrated circuits designers and researchers focused on cellular-phone, and millimeter-wave applications.

Regarding in the cellular-phone, almost all RF integrated circuits were realized by silicon based integrated circuits due to Japanese WCDMA market extension. A quad-band WCDMA transceiver, which including low-noise amplifiers and direct conversion receiver and transmitter, was reported using 180 nm BiCMOS process [Kamizuma, 2008], was achieved 3 % EVM and -46 dBc ACLR. On the other hand, using 130 nm CMOS process, eight-band WCDMA/GSM transceiver, which including low-noise amplifiers and direct conversion receiver and transmitter, was reported [Yoshida, 2008]. The achieved performances of this transceiver were 2.4 % EVM and -49.7 dBc ACLR. WiMAX is one of the candidates of next generation metropolitan area network application. The fully integrated WiMAX transceiver which consist of two receivers and one transmitter was also reported using 65 nm CMOS process [Deguchi, 2010], was really possible to adopt product.

Regarding in the millimeter-wave applications, 77 GHz automotive radar transceiver was realized by fully integrated circuits using CMOS and beyond 100 GHz RF circuits blocks were reported. Automotive 77 GHz FM-CW transceivers were reported using 90 nm CMOS with 920 mW power dissipation [Kawano, 2009] and 520 mW power dissipation [Mitomo 2009]. The latter one was reported to possible to measure the distance approximately 8 m with 6 cm error. To realize of the demand of high data rate communication, higher carrier frequency is necessary. A 120 GHz ASK transmitter and receiver chipset with 9 Gbps communication rate was reported [Fujimoto, 2010] using 65 nm CMOS under 100 mW power dissipation. Also, many research reports of millimeter-wave circuit building blocks were available such as wide-tuning range millimeter-wave oscillator [Nakamura, 2009].

(N.Itoh)

C7. Microwave Frequency Conversion and Generation

（1）Land mobile communication

In the RF region, evolution of the cell-phone system accelerated the RF system architecture including the frequency conversion and generation circuits, in past. For the third generation system based on CDMA, direct conversion transceivers and fractional-

PLLs were technically improved under strong business competitions. Thus we could see important improvements on above topics in mid-2000s. However we are facing technical saturations on this area, although there are continuous research activities for mass-RF-IC markets.
In the late-2010, the new cell-phone system named "LTE(Long Term Evolution)" was started in Japan for 37.5Mbps down-link. To achieve high speed transmission, high resolution modulation like 64QAM is employed in LTE. So high accurate modulation mixer technique is key to realize the system. Also the digital pre-distortion system in transmitters need the same requirement on modulation HWs. Estimation and correction methodology by digital signal processing are proposed, and validation results are demonstrated for the practical LTE systems [Yamaoka, 2010] .

For future wireless systems with high efficient frequency-use efficiency, cognitive radio systems are studied continuously. For the systems, RF-ICs are required to achieve ultra-wideband characteristics for frequency flexibility in radio communications. Also extreme dc current compensation is required for future hand-terminal utilizations [Shinjo, 2009], [Taniguchi, 2009].

(2) Millimeter wave system
Based on the rapid evolution of the silicon devices like deep sub-micron CMOS or SiGe BJT, research works for millimeter wave systems are very active. Also compound devices like InP HEMT or GaN HEMT are considered especially for power utilizations in millimeter wave. In parallel with above evolutions of semiconductor devices, HDTV systems are wider accepted in Japanese homes and wireless transmission requirements are becoming strong for Gbps data used in high vision TVs [Kukutsu, 2010]. Distribution of high definition TV programs is planned with future 10G-Ethernet (10GE) on passive optical network. For the connection to above 10GE, 10Gbit/s wireless link is studied at 120GHz band. For the utilization, 120GHz band digital modulator and demodulator were developed with 0.1 micron InP HEMT[Takahashi, 2009], [Takahashi, 2010]

In addition to 120GHz band utilization mentioned above, 77GHz band utilization for high speed communications and short range radar are considered. Low phase noise oscillator techniques are very important to achieve high accurate digital modulation as 64QAM or high resolution radar equipments. For improvement of phase noise, harmonic oscillation and high Q resonation inside oscillator were proposed, and developed 77GHz planer oscillators achieved phase noise around -110dBc/Hz at 1MHz offset is achieved without large sized bulky resonators [Watanabe, 2009], [Mizutani, 2010].

(3) Circuit theory
Phase noise of oscillators has been represented by well-known Leeson's formula with oscillators' Q. However, we had no clear definition of oscillators' Q. In [Ohira, 2007], theoretical formulas of oscillators' Q was defined under the circuit theory. In addition to the above fundamental work, formulations of oscillators' Q were done for practical oscillator configurations[Ohira, 2008],[Morimasa, 2010]. Also the paper [Morimasa, 2010] theoretically clarified the relationship between resonator's Q and oscillator's Q at

first.

Diode balanced mixers are very classical circuits from 1920s. However there are no formulas that indicates output power of the mixers in closed forms. Output power of the balanced diode mixers and even harmonic mixers are formulated with the switch model for diodes. The derived formulas represented output power of the mixers [Itoh, 2009].
(K. Itoh)

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