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C1. Radio Communication Systems

Research and development activity in the field of radio communication systems, such as the fourth-generation mobile/cellular radio and wireless LAN systems has been still high in Japan for these three years. OFCDM or MC-CDM(A) systems which use multi-carrier transmission with multiplexing both on time-domain and frequency-domain were well investigated for the 4G cellular systems [Atarashi et al., 2003]. Adaptive antenna or diversity techniques are also important issues for the systems [Ktaoka et al., 2004], [Mikami et al., 2004].

Studies on OFDM or multicarrier transmission for general radio systems including the cellular and WLAN systems are also active. The PAPR (peak to average power ratio) and nonlinear distortion of power amplifier are important problems for this kind of systems, and some PAPR reduction schemes [Tomisato et al., 2003], [Fujii et al., 2003] and distortion compensation techniques [Hosono et al., 2002] were proposed.

Frequency domain equalization, which can be applied not only for multi-carrier but also for single carrier, is one of the interesting research fields in these three years. Some applications on those combining with diversity reception [Adachi et al., 2003] were investigated. Another remarkable field is interference cancellation. A unique adaptive algorithm for OFDM was proposed [Uesugi, 2003] and theoretical expressions of the performance of those for CDMA receivers were derived [Suzuki, 2003].

Adaptive antenna and MIMO studies have been very active. Capacity and performance of MIMO channel were measured in indoor environment [Sakaguchi et al., 2004], [Benjebbour et al., 2003]. Analog smart antennas and their theories were established [Ohira, 2003], and the adaptive beamforming algorithms were developed [Sun, 2004]. Some adaptive array techniques were investigated on OFDM systems to mitigate the interference due to delay spread longer than guard time [Hori et al., 2002], [Higuchi et al., 2004].

Wireless ad-hoc network [Ueda, 2002] and multi-hop radio system [Kishi, 2002] are other recently studied interesting issues in these research fields and several papers have been published.

(M. Taromaru)

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C2. Radio Circuits for Mobile Terminals

The third-generation mobile communications (3G) system, W-CDMA, started in May 2001. However it was only the system level launch. It was not enough miniaturization and cost for mass subsribers. Today, 2005, W-CDMA is becoming real consumer mobile communication system as the second-generation (2G) mobile communication system. To reduce parts count and materials cost, radio functionalities have been integrated rapidly toward System on Chip. For this objective, good technical harmonization of semiconductor (SiGe, EF-CMOS less than quarter micron rule), radio architecture (direct conversion receiver) and radio circuits (integrated VCO, high power amplifier) make a contribution [Itoh et al. 2004].

Regarding to semiconductor techniques in Japan, lithography rule for large scale logics was shifting to sub-micron [STARC, 2004]. This made radio digital baseband ICs small and inexpensive enough for mobile terminals. Inflection from 0.13um to 0.09mm is one of the important technical drivers for the 3G mobile terminals. In Japan, most of research efforts for high integrated RF-IC employ BiCMOS/SiGe BiCMOS process thanks for its high RF performances [Yoshida et al. 2004]. With rapid progress of RF performances of CMOS toward sub-micron rule, high gate/capacitor density of the standard CMOS process make strong motivation for RF-CMOS techniques [Ugajin et al. 2004]. This RF-CMOS was applied for short distance communications as Bluetooth and WLAN [Komurasaki 2003], because of lower performance compared with SiGe circuits. However RF-CMOS circuits developments for 3G mobile terminals are under high motivated efforts.

Regarding to radio architecture, the 3G direct conversion receiver (DCR) was firstly applied for the commercial model in Japan [Itoh et al. 2002]. For realization of the DCR architecture, even harmonic diode mixer for extreme low second order distortion, LTCC module integration and SiGe high performance MMIC were developed. In addition to the diode configuration of the DCR, Gilbert type active mixer was developed for fully integration of the DCR [Yoshida 2004]. The fractional-PLL with delta-sigma modulation is an important technique for randomization of periodical spurious that makes interference of radio. However we can find less specific improvements in this field.

Regarding to circuit technique, the integrated VCO technique contribute miniaturization of mobile terminals. For stabilization of phase noise in wider frequency range, variable current cell was developed for the 3G utilization [Itoh 2002].

For next generation of radio communications like SDR (Software Defined Radio), broadband radio circuits were developed for re-configurable radio architecture [Araki 2004]. In an aspect of radio architecture analog based approach is very saturated. Most of RF circuits except power amplifiers can be integrated on LSI easily today. Under rapid evolution of sub-micron CMOS, research interests are dedicated to paradigm shift on radio architecture from analog to digital. Digital oriented RF architecture will be important research for the next several years.

(K. Itoh)

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C3. RF Integrated Circuits

The research interests of RF integrated circuits (ICs) for wireless terminals are moving from single-band / single-mode to multi-band /multi-mode transceiver ICs. Recent wireless LAN ICs were developed as “Combo Chip” which covers 2.45GHz (IEEE 802.11b/g) and 5.2GHz (IEEE 802.11a) [McFarland, 2004], and Cellular phone ICs were developed as multi-band (0.8-2.1GHz) and multi-mode (GSM/PCS) chips [Kim, et al., 2004].

For the next generation systems (Beyond 3G or 4G), SDR (Software Defined Radio) and/or cognitive radio transceiver were discussed and the transceiver ICs for these application were reported [Madihian, 2002], [Araki, et al., 2004], [Abe, et al., 2001]. For these applications, a quadrature-mixer IC having 0.8-5.2GHz broad-band characteristic was reported [Kageyama, et al., 2004]. Direct conversion configuration became common for these Tx/Rx ICs [Nakajima, et al., 2004].

CMOS has been widely used for these ICs but SiGe still be used especially for narrow-band / wide dynamic range applications (i.e. Cellular phone/DTV) to achieve lower 1/f noise and higher saturation characteristics.

(N. Suematsu)

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C4. Direction of Arrival Estimation

Research activities for direction of arrival (DOA) estimation in Japan were very active in the past three years. The research topics expand to include experimental verification and system calibration of the test-bed for high-resolution DOA estimation systems, which is the feature to be mentioned. Many researches were reported in annual conference of IEICE, monthly technical meetings of Antennas and Propagation (AP) and Radio Communication System (RCS) technical group of IEICE, and so forth. Also we can see their high activities through two international conferences held in Japan, ISAP-i02 and ISAP2004 sponsored by IEICE, which had several sessions for DOA estimation.

As the trends of DOA estimation researches in these three years, implementation problems of DOA estimation techniques and their performance evaluation were highlighted. NTT began the field experiment of adaptive beamforming techniques by using DOA estimation results for the next generation base-station of the cellular phone in the spring of 2003. It was a promising event. Effects of fabrication error and mutual coupling of array elements were studied [Inoue, et al., 2001], [Inoue, et al., 2003]. To realize high resulution DOA estimation, several new array calibration techniques have been proposed; mutual coupling compensation by using generalized mode-vector [Yuan, et. al., 2004], the technique for array with coupled objects [Yamada, et al., 2004], and so forth. For progress in researches of DOA estimation algorithms, the following researches would be mentioned; New signal subspace method without eigen-decomposition [Xin, et al., 2004] that can successfully reduce computational burden without performance degradation, improved DOA tracking algorithm based on the signal subspace method [Kikuma, et al., 2004], DOA and angular spread estimation by using extended mode vectors [Hotta, et al., 2004], and so forth.

Moreover, it is one of the features in Japan that high-resolution DOA estimation techniques with parasitic antenna array were intensively studied. Hand-held DOA finder with electronically steerable parasitic array radiator (ESPAR) was developed [Ohira, et al., 2001]. High-resolution techniques such as the MUSIC algorithm were found applicable to the ESPAR system [Plapous, et al., 2004], and spatial smoothing preprocessing scheme for coherent wave detection became also available [Hirata, et al., 2004]. Besides the ESPAR antenna with varactor, beam steering antenna with MEMS [Tran, et al., 2003] and 2D-DOA estimation algorithm for switched parasitic antenna was also considered [Matsumoto, et al., 2004].

Furthermore, DOA estimation techniques as wireless propagation channel sounding for coming wireless systems, such as MIMO system [Takada, et al., 2001] and UWB system [Haneda, et al., 2003], were also extensively studied.

(H.Yamada)

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C5. Base Station for Cellular Phone System

NTT DoCoMo commercially began the FOMA service that was the third generation cellular phone system on October 1, 2001. The FOMA service enabled high-speed packet transmission in the mobile environment. The modulation method become digital from the second generation cellular phone. In the third generation cellular phone system, some base station employs not only the modulation scheme but also the digital modulation circuits. In addition, the digital signal processing technology was applied to the transmission amplifier. The transmission amplifier of the digital pre-distortion technology was built in the FOMA base station sub system in July, 2002 [Oishi, et al., 2002]. The digital pre-distortion technology is a highly efficient transmitting power amplification technology that also compensates for signal distortion in third-generation cellular phone systems. A large capacity base station with more than 2880 user being accommodated was achieved by the low power consumption LSI technology and the digital processing high efficiency amplifiers. Recently, there is a movement to try to share the interface between wireless front end by a digital method with the base station such as CPRI (Common Public Radio Interface) and OBSAI (Open Base Station Architecture Initiative). This tendency will give an impetus to the digitalization of the transmission amplifier further. Therefore, some people forecast that the digital pre-distortion method becomes a main current though the feed forward type amplifier was a main current as the method of the base station amplifier up to now. [Vasillakis, 2003]

(T. Maniwa)

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C6.Space Time Domain Processing

Space-time signal processing techniques have been playing an important role, particularly as demands for mobile communications increase. The space domain signal processing brought by the application of array antennas enables us to add one more dimension on the time domain signal processing. It results in further performance improvement under serious multipath fading environments in wireless communication systems.

Recently, in addition to the conventional concept of the space-time signal processing, some new concepts combining space-domain signal processing with time-domain coding so called as Space Time Block Code (STBC) have attracted much attention of researchers. Particularly in the last three years, many practical researches have been conducted towards its implementation and practical use in the real systems. For example, STBC is applied to multi-carrier systems that are employed in digital broadcastings, wireless local area networks (WLAN) and so on. In these systems, Orthogonal Frequency Division Multiplexing (OFDM) is combined with STBC by using multiple antennas to obtain the diversity gain effectively in rich multipath fading environments [X.N.Tran et al, 2005],[M. Fujii, 2003].

Multi-carrier systems such as OFDM, Multi-Carrier Code Division Multiple Access (MC-CDMA) are widely paid attention for the applications in mobile systems. Naturally, these schemes are extended over the space domain in order to obtain further performance improvement. However, in these systems, space time signal processing causes heavy computational load. Some researches try to reduce the complexity by using a frequency-domain signal processing technique [F. Adachi et al, 2003], [T. Itagaki et al, 2004].

Non-linear signal processing techniques applied on the space- and time-domain signal processing yields quite interesting new features. Some of such applications allows us to demodulate Direct-Sequence Spread Spectrum (DS/SS) signals without any knowledge of the signal even the spreading code [Y. Kamiya et al, 2001], [Y. Kamiya et al, 2003]. It demodulate DS/SS signal asynchronously and blindly while it accomplishes the equalization of delayed signals and beamforming, simultaneously. These features are advantageous because of the following reason. In DS/SS systems, conventionally, space-time signal processors require a training sequence inserted in communication signals. In other words, the processors require the bit-timing synchronization. However, it should be noted that this fact implies that the processors cannot perform the signal processing until the synchronization is acquired even though the space-time signal processing is performed to enable the demodulation under severe environments. These new configurations based on non-linear signal processing solve this paradoxical problem.

Although space-time signal processing improves the performance of the receiver significantly, it causes large-scale configuration due to the usage of multiple antennas. Multiple antennas results in multiple RF front-ends and A/D converters. In order for reducing the hardware complexity of the space-time signal processing, combination with ESPAR antenna is attractive solution. ESPAR antenna achieves beamforming in the analog domain so that it enables us to reduce the RF front-ends and A/D converters. Its adaptive control scheme has been proposed in [J. Cheng, 2001]. After that, it is combined with the above-mentioned non-linear signal processing schemes [Y. Kamiya et al, 2003].

(Y. Kamiya)

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C7. Metamaterials

Interests on metamaterials in Japan have been growing rapidly among microwave engineers/scientists in the past three years. Novel RF devices and antennas based on left-handed materials or negative refractive index materials, PBG/EBG structures, artificial dielectrics, chiral materials, and the like have been proposed for potential applications in wideband communication and radar systems from microwave to optics frequency range. Domestic activities on metamaterial study in Japan have also been stimulated. Technical workshops on metamaterials have been organized in Microwave Workshop and Exhibition (MWE) 2003 in Yokohama, one of the biggest annual microwave workshops in Japan, which covers fundamentals and applications of the left-handed materials artificial dielectrics, periodic PBG/EBG structures and chiral materials. The Optics and Radio Wave Workshop has also been held in Sapporo in 2004 jointly by the four technical groups on microwaves, antennas and propagation, optelectronics, and satellite communication of the Institute of Electronics, Information and Communication Engineers (IEICE) and a focusing session entitled "Recent advances of PBG/EBG structures and metamaterials" has been held.

Extensive studies on left-handed materials and applications have been carried out. Zeroth-order resonance in the composite right/left-handed transmission line has been studied [Sanada et al., 2003], and radiation characteristics of the zeroth-order resonator have further been studied for antenna applications [Sanada et al., 2004]. The characteristics of the right/left-handed transmission line have been theoretically summarized in [Sanada et al., 2004] and purely distributed negative refractive index lenses have also been demonstrated experimentally [Sanada et al, 2004] based on the 2-dimensional planar composite right/left-handed transmission line structure. Wideband planar backward couplers have also been proposed [Caloz et al., 2004]. In addition, novel microwave devices and antennas have been proposed and demonstrated; nonreciprocal left-handed transmission lines using ferrite substrates [Tsutsumi et al., 2004], novel via-free planar left-handed transmission line structure and antenna applications [Sanada, et al., 2004], left handed transmission lines using gyrator [Okubo et al., 2004], ferrite left-handed transmission line circulators [Tsutsumi et al., 2004], ferrite loaded left-handed waveguides [Ueda et al., 2004], compact multi-layered left-handed transmission line structures [Horii et al., 2004], novel planar left-handed transmission line structures using enhanced capacitors with built-in shunt inductor on the ground plane [Sahara et al., 2004], planar left-handed dual-band branch line couplers [Matsunaga et al., 2004], and 2D beam scanning left-handed leaky-wave antennas [Aso et al., 2004].

Besides the left-handed materials, right-handed metamaterials and periodic PBG/EBG structures have also been studied. Compact artificial dielectric resonators with spurious suppression have been demonstrated [Awai et al., 2004] exploiting its huge permittivity and resonant mode control functionality. Loss study of artificial dielectrics based on metal strips has also been carried out [Kubo et al., 2004]. In optics frequency, studies on PBG structures [Hangyo et al, 2004] and optical fiber applications of PBG structures [Koshiba 2004] have successfully been carried out. In addition, photonic crystals in THz regions have been demonstrated [Takeda 2004] as well as in microwave regions [Kawasaki 2004].

(A.Sanada)

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