Development of WiMAX Remote Radio Heads

Takumi ASAINA*, Tadashi ARAKI, Hideyuki MUKAI, Isao KATSURA, Takashi YAMAMOTO, Shuichi NISHIMURA, Shigenori KATSUMI and Satoshi KIDO

As the demand for radio data communication increases, WiMAX service has expanded throughout the world. Since the radio frequency resources are limited, efficient use of the radio frequency will become more important as the service expands. For this reason, the multi-antenna technology is expected to be a solution to improve transmission efficiency. Along with the increase in the transmission rate and frequency bandwidth of radio broadband service, rising power consumption by radio systems has become another problem. To this end, we have been studying technology that improves the energy efficiency of power amplifiers used in base stations.

In this paper, we describe our new WiMAX remote radio head that features low power consumption and a multi-antenna system with 4 channels.

Keywords: WiMAX, multi-antenna, DPD, RRH, amplifier

1. Introduction

Worldwide Interoperability for Microwave Access (WiMAX)*, a wireless Metropolitan Area Network (MAN) system, has both features of the fast response that is achieved by cable media, such as Fiber-to-the-Home (FTTH), and the convenience of wireless media that enable mobile access. The global standard for WiMAX is specified in IEEE 802.16. Accordingly, WiMAX services have become popular on a global scale. The benefits of always-on Internet access are not only available to mobile PCs. The use of WiMAX in machine-to-machine (M2M) services for connections with vending machines, electricity meters and so on is also being explored [(1),(2)]. Since the number of available spectrum bands is limited, a technology that uses them efficiently is essential to achieve high-speed communications that will support the many mobile stations used in M2M applications.

As the speed of wireless communications has increased and wireless broadband communications has emerged, the increase in the overall power consumed by wireless systems has become a major concern. We see it important to reduce the power consumption of high-power amplifiers used in base stations, and are working on developing a technology to substantially improve amplifier power efficiency. We have applied the technology first to a prototype remote radio head (RRH) for cellular base stations, and have been able to verify that the RRH marks the industry's highest class efficiency[(3)].

Consequently, we have developed a spectrum-efficient four-transmit, four-receive channel RRH for WiMAX base stations with the aim of applying our high-efficiency amplification technology to wider areas that have high anticipated growth.

2. Device Features and Specifications

WiMAX is a wireless communications protocol designed for high-speed wide-area data communications. Employing Orthogonal Frequency Division Multiple Access (OFDMA) as an access scheme, it uses the same time-division multiplexed frequency spectrum for the downlink (DL) and uplink (UL). Accordingly, WiMAX is a Time Division Duplex (TDD) system. Although the power efficiency of the Orthogonal Frequency Division Multiplexing (OFDM) scheme used in OFDMA is not high, OFDM improves the spectrum utilization efficiency per antenna because of the high volume of information carried by one carrier. The TDD system enables the DL signal transmission route to be estimated from the UL signals and therefore is suited to spectrum-efficient multi-antenna technology. Full-scale introduction of multi-antenna technology using four or more antennas for efficient use of spectrum is being studied for the next-generation WiMAX specifications[(4),(5)]. It is expected that multi-antenna technology will be increasingly used.

We had an early interest in the usefulness of the WiMAX technology, had conducted tests on prototype WiMAX base stations and had developed adaptive array antennas for WiMAX. Learning from this experience, in deploying high-efficiency amplification technology in WiMAX applications, we decided to develop RRHs that are compatible with multi-antenna base stations and cover a 200 MHz wide band with low power consumption, improvements in the spectrum utilization efficiency and more convenient management and operation.

2-1 Remote radio head (RRH) technology

Cellular and WiMAX antennas are usually installed on a building rooftop or on a tower to ensure a clear, unblocked propagation path to each mobile station. In the meantime, the conventional way to install the main base station equipment, including a high-power amplifier, is to install it at a location away from the antenna, such as an indoor location or in a simple station cabinet. In such an installation, it is necessary to convey high-frequency RF signals between the antenna and the main equipment via a coaxial cable. Since large transmission losses are unavoidable if the cable is long, the high-power amplifier is designed to transmit higher power signals than the antenna output to compensate for the loss. This results in the problem of increased power consumption. To minimize losses, a large cable can be used. However, large cables are not easy to install and so major installation work becomes a necessity.

To address these problems, base stations with a new design scheme have been increasing in number recently. In this new base station installation, the high-frequency signal transmitter/receiver is separated from the base station as an independent unit and is located beneath the antenna. Signals are conveyed between this unit and the base station via a fiber-optic interface. **Figure 1** shows an example. This type of wireless transmitter/receiver unit, known as a remote radio head (RRH), consists of a transmitter containing a high-power amplifier, a receiver that receives and amplifies radio waves sent from mobile stations, a base station interface and other features. By installing the transmitter/receiver unit close to the antenna, it becomes possible to reduce the transmission losses in the coaxial cable. Consequently, the amplifier output is lowered and the power consumption is reduced. The transmitter/receiver unit is connected to the main base station equipment via an optical fiber. Benefits of this arrangement include ease of installation, minimum signal degradation and improved RF signal quality.

2-2 Multi-antenna technology

Radio waves emitted from a base station spread out and reach a mobile station via multiple paths. In addition to a direct path, the radio waves are also reflected by building walls, etc. Time delays and amplitude differences occur along some of these paths, but all waves are received indiscriminately at the receiving end. Therefore, phase differences resulting from the delays enhance or attenuate the signals. Multi-antenna technology refers to a wireless transmission technology using multiple antennas on either or both sides of the base station and mobile station. Radio waves are emitted from spaced antennas with the amplitude and phase individually controlled. Benefits of this technology include expansion of the RF signal coverage area, cancellation of interference and increased throughput.

(1) Expansion of the coverage area

In cases where the transmission characteristics between a base station and a mobile station are known, the phase and amplitude of each signal emitted by multiple antennas can be adjusted for enhancement or attenuation at the receiver location. This enables radio waves to reach distant mobile stations.

(2) Interference cancellation

Since the number of spectrum used by WiMAX is limited, the same frequency may be used repeatedly by neighboring cells. In such a case, the RF signal quality of a cell may be degraded by interference from other cells. For example, assume that base stations A and B are connected to mobile stations A2 and B2, respectively. The communication signal used between base station A and mobile station A2 can act as an interference wave and degrade the quality of communications between base station B and mobile station B2. Use of multiple antennas for signal phase and amplitude adjustment enables interference reduction by attenuating the signal at the locations of mobile stations connected to other base stations, as shown in **Fig. 2**.

(3) Increased throughput

As with the wireless LAN, WiMAX is compatible with the multiple input multiple output (MIMO) technology. It uses multiple antennas to transmit and receive multiple data streams in the same frequency, as shown in **Fig. 2**. An analysis using transmission characteristics determined in advance plus multiple received signals enables separation of multiple mixed data streams. The capacity to increase the streams, commensurate with the number of antennas, leads to increased throughput.

The newly-developed RRH is provided with four transmit/receive channels to support WiMAX base stations using the above-mentioned multi-antenna technology. In the RRH configuration, a calibration circuit is incorporated to ensure uniform characteristics for all transmit/receive channels.

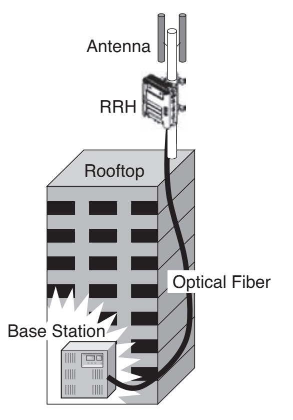

Fig. 1. Structure of Remote Radio Head

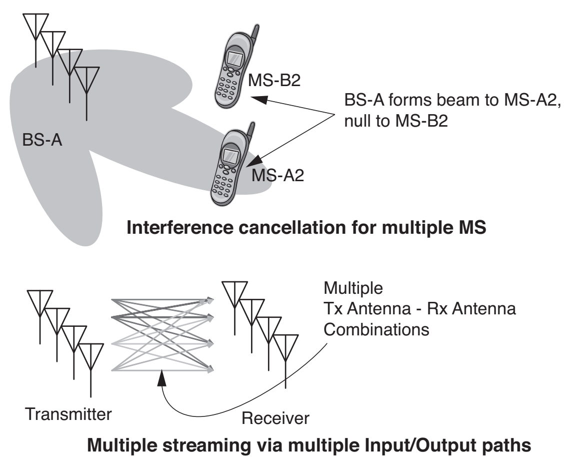

Fig. 2. Example of Multi Antenna System

2-3 Broadband/high-efficiency technology

WiMAX is a global standard specification. However, in each country or region, spectrums are controlled independently and assigned differently. In general, since a bandwidth assigned to a communication common carrier is several tens of megahertz, a capacity of several tens of megahertz is sufficient for a specific region. However, to reduce management and installation costs, the capacity to cover any region is required. For this reason, the RRH, as a single unit, is designed to cover the entire 2.5 GHz band envisaged by the WiMAX Forum, which is from 2.5 to 2.7 GHz.

The RRH employs a gallium nitride high electron mobility transistor (GaN-HEMT) as the final transmission amplifier to achieve wide-band operation and high efficiency. Compared with the commonly used silicon laterally diffused metal oxide semiconductor (Si-LDMOS), GaN has higher matching impedance. Therefore, the characteristics of GaN can be adapted to wide-band operation. The signal distortion resulting from wide-band and high-efficiency operation is compensated for by digital signal processing, digital predistortion.

2-4 Device specifications

Figure 3 shows a block diagram of the RRH. Specifications for the RRH are given in **Table 1**. An aluminum enclosure is used to house a four-channel RF transmitter/receiver unit, a calibration transmitter/receiver unit, a base station interface and a digital signal-processing unit. The RRH is small, light, with low power consumption and a wide operating temperature range.

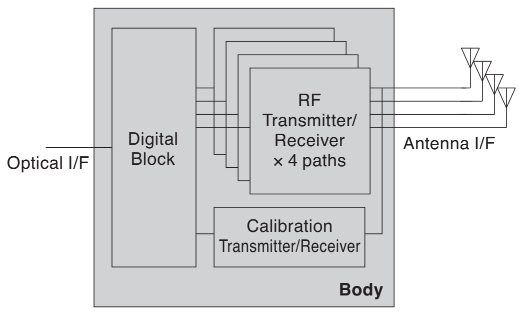

Fig. 3. Functional Diagram of WiMAX RRH

Table 1. Specifications of Manufactured RRH

Wireless Scheme	IEEE802.16e (Mobile WiMAX)
Frequency Band	2496MHz ~ 2690MHz
Channel Bandwidth	5MHz, 10MHz
Number of Antenna Paths	4
Output Power	16W (4W × 4)
Power Consumption	<150W
Base Station I/F	Standard Optical Interface
Size	420(H) × 350(W) × 125(D)mm
Weight	12.5Kg
Operating Temperature	-40 degree C ~ +50 degree C

3. Detailed Design of the RRH

The newly-developed prototype RRH is detailed below.

3-1 RF System

Figure 4 shows the block diagram of the RF System. Since a TDD system is implemented, each transmit/receive circuit connects to a shared transmitting/receiving antenna via a transmit/receive changeover RF switch. In addition to common transmit/receive channels, a calibration transmit/receive circuit is provided, which connects to the transmit/receive circuits via directional couplers inserted between the RF switches and antenna outputs.

With a conventional transmit channel, a baseband signal processor sends digital in-phase/quadrature (IQ) signals to a DA converter, which converts them to analog IQ signals. These signals are then converted to 2.5 GHz band RF modulated signals by an quadrature modulator (MOD). A driver amplifier boosts the signal power to a level sufficient to drive the power amplifier. Subsequently, the GaN-HEMT power amplifier in the final stage increases the signal power to the 4 W output. The receive channel uses a low-noise amplifier (LNA) to boost the weak received RF signals to a proper level. The received signals are then converted to intermediate frequency signals by a down converter. After passing through a band pass filter (BPF), they are sampled by an AD converter.

The newly-developed RRH supports multi-antenna technology (four antennas). However, the signal processing performance using multiple antennas depends on RF characteristic variations among the transmit/receive channels. To calibrate the variations, the RRH has calibration transmitters and receivers and measures the characteristic differences of the individual Transmit/Receive channels. Receive channels are calibrated by inputting signals generated by the reference transmitter to each receive channel. To calibrate the transmit channels, the signal transmitted by each transmit channel is input to the reference receive circuit for measurement. The reference transmitter and receiver make up the calibration transmit/receive circuit.

The calibration receiver is also used for transmission digital predistortion. Distortion caused by the final amplifier is periodically measured by the calibration receiver

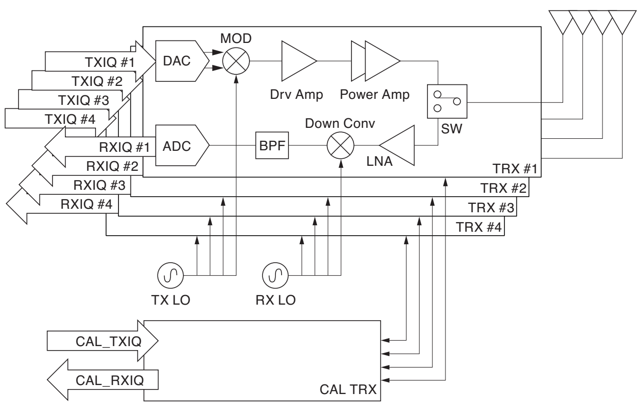

Fig. 4. Functional Diagram of RF System

and the measurement result is conveyed to the digital predistortion signal processor in the digital block.

3-2 Digital block

The digital block comprises a base station interface, a digital signal processor and a monitor controller that controls the entire block. Digital IQ signals sent from the base station via optical fiber are compensated for by the signal processor and then sent to the DA converter in the RF transmit channel. On the receiving side, data input from the AD converter is transformed to digital IQ signals and transferred to the base station. Crest factor reduction (CFR) and digital predistortion (DPD) are carried out during transmit-channel signal processing to reduce the power consumption and improve the communications quality.

(1) Crest factor reduction (CFR)

Modulation schemes used in today's mobile communications systems, such as OFDM employed by WiMAX, have a large peak to average power ratio (PAPR), which is a major cause of low amplifier efficiency. Restricting signal peaks results in degraded signal quality. To address this problem, efforts have been made to develop CFR for minimized quality degradation even at a low PAPR (**Fig. 5**). Noise shaping, peak windowing and various other CFR techniques have been proposed. In addition to these techniques, we have also developed a new CFR technique suited to WiMAX systems. A low PAPR has been achieved using smaller circuitry than in conventional products.

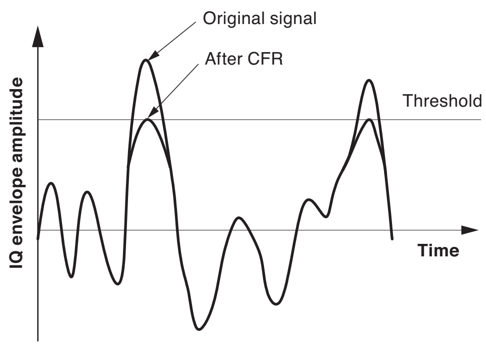

Fig. 5. Crest Factor Reduction (CFR)

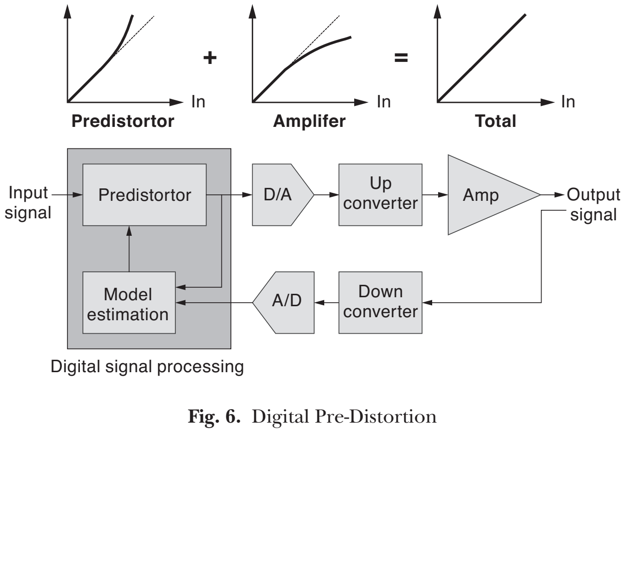

Fig. 6. Digital Pre-Distortion

(2) Digital predistortion (DPD)

Key performance factors of an amplifier are power efficiency and linearity, which are traded off against each other. Power consumption can be reduced by improving the power efficiency. However, this will affect the amplifier linearity and cause degradation in terms of the distortion characteristics. Since distortion characteristic degradation results in low communications quality and a broadened frequency spectrum of RF signals, the allowable degradation limit is strictly controlled by the applicable laws and standards in each country.

In recent years, DPD techniques have been used to compensate for signal distortion caused by amplifiers. DPD incorporates a distortion compensation circuit known as a predistortor in the amplifier input stage. To enable a predistortor to thoroughly negate the signal distortion in an amplifier, it is necessary to accurately estimate the amplifier's distortion characteristics. For this purpose, a statistical technique is used. More specifically, changes in the output signal amplitude and phase of the amplifier, which occur in response to the amplitude of the input signal, are measured to create a distortion characteristics model of the amplifier. The predistortor creates a model that is the inverse of the distortion characteristics model of the amplifier, and preliminarily distorts the input signal in the inverse direction to the distortion caused by the amplifier, thereby enabling the amplifier to eventually produce a distortionless output signal (**Fig. 6**).

We have developed new DPD circuits optimized for multi-antenna applications, with a part of the circuits shared by multiple antennas. This new product, with no increase in circuit size in comparison with conventional products, successfully removes distortion in four-antenna applications.

3-3 Enclosure

RRH enclosures are required to be small, light and easy to install outdoors. The newly-developed RRH is fanless and miniaturized thanks to an aluminum enclosure with integrated heat radiation fins, which releases the heat generated by the power amplifier directly into the external ambient air. Since an aluminum enclosure readily absorbs heat, a plastic sun shade can be attached for when the enclosure is exposed to direct sunlight. Connectors are all highly waterproof for outdoor installation so that the enclosure can be in service for an extended time.

4. Evaluation

The RRH has been evaluated by commercially available measuring instruments and software used to simulate a base station.

4-1 Evaluation environment

Figure 7 shows an environment used to evaluate downlink performance. In that configuration, the pattern generator (PG) functions as a signal source, the simulated base station connected to the RRH via an optical fiber sends signals to the RRH, and the spectrum analyzer (SA) receives RF signals from the RRH. Evaluation signals are WiMAX digital IQ signals, which are created by simulator software combining different modulation schemes and are preset in the PG. Signals produced by the PG are sent to the simulated base station and then to the RRH, where they become 4 W RF signals in each channel. The SA receives the signals from the antenna connector on the RRH via a coaxial cable.

The SA analyzes transmission masks, spurious emissions and the adjacent channel leakage ratio (ACLR), which represents the magnitude of distortion, uses the accessory vector signal analyzer (VSA) system for modulation analysis and evaluates the error vector magnitude (EVM).

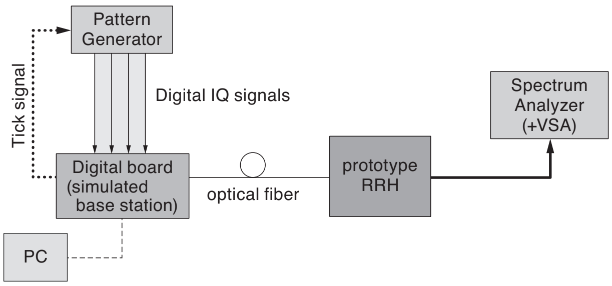

Fig. 7. Evaluation Environment of Prototype

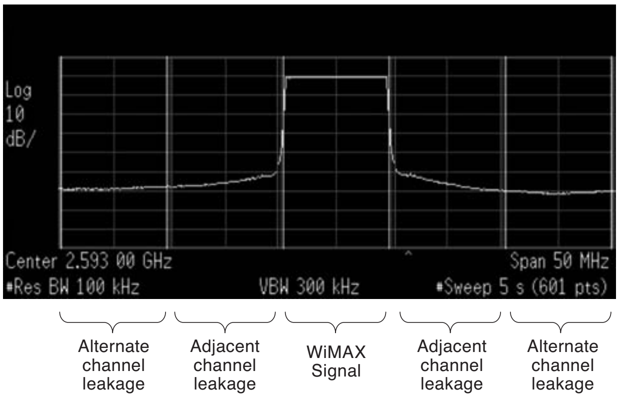

Fig. 8. DL Frequency Spectrum (10 MHz)

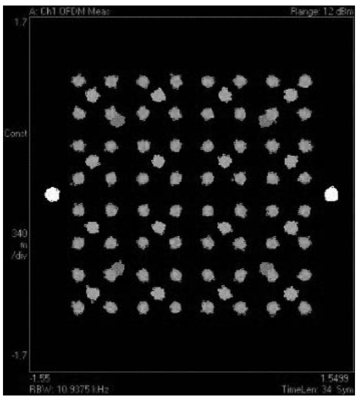

Fig. 9. DL Signal Constellation

4-2 RF performance evaluation

Characteristic evaluation results for the principal performance items are presented below.

Figure 8 shows the transmission spectrum for a 4 W output with the WiMAX signal band set to 10 MHz and DPD applied. The ACLR characteristics meet the ETSI standards[8]. **Figure 9** shows the constellation of QPSK, 16QAM, 64QAM modulation signals: a map that plots the amplitude and phase of transmitted signals that are demodulated by a measuring instrument; all signal points corresponding to modulation signals can be identified clearly, demonstrating that the RRH meets the EVM requirements specified by the WiMAX Forum.

The newly-developed RRH has an automatic level control (ALC) capability to regulate the transmitted signal output level across a 200 MHz broad band by a high-accuracy level sensor circuit. Its level control performance is shown in **Fig. 10**.

Received signals show low-noise and high maximum input characteristics over a wide frequency band due to the low-loss RF front-end BPF and receiver amplifier provided with an optimal level diagram design. The receiver dynamic range is 55 dB or more. A suitable BPF has been selected for the frequency in use to reject unwanted waves outside the band and to meet the ETSI blocking performance standards. **Table 2** shows the test results for the items specified by the WiMAX Forum and ETSI standards. The results meet the standards well.

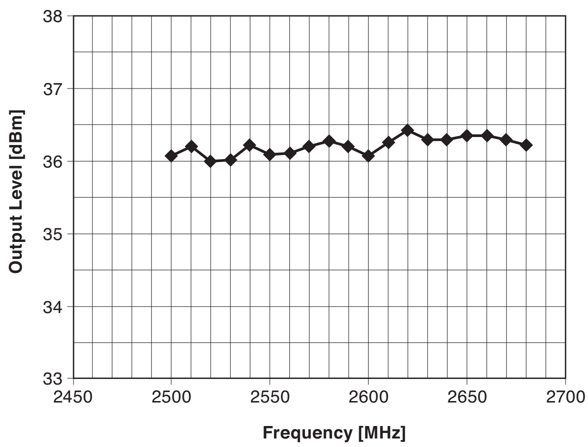

Fig. 10. Frequency Characteristic

Table 2. Estimation Results to WiMAX Forum/ETSI Standards

	item	limit	result
DL Sig	ACLR	< -44.2 dBc (adjacent channel) < -49.2 dBc (alternate channel)	pass
	EVM	< -18 dB @QPSK-3/4 < -30 dB @64QAM-5/6	pass
UL Sig	Interference input level	< BER 10^{-6} (under condition below) -40 dBm (WiMAX signal) -15 dBm (CW signal)	pass

Power consumption is reduced by controlling the power supply to each channel according to the TDD DL/UL sections. When outputting four channels of 4 W DL signals (DL signal length: 35 symbols; UL signal length: 12 symbols), the RRH consumes only 147 W at the maximum.

5. Conclusion

In this report we have presented the features, specifications and performance evaluation of the WiMAX RRH we have developed. In the evaluation, the RRH demonstrated a performance sufficient for practical use. In the future we intend to conduct market trend surveys in Japan and abroad and to continue our efforts to commercialize the RRH, seeking support from multi-antenna technology vendors.

* WiMAX and WiMAX Forum are trademarks or registered trademarks of the WiMAX Forum.

References

(1) WiMAX Forum whitepaper, "WiMAX Applications for Utilities," Oct. (2008)
(2) WiMAX M2M example http://www.sei-networks.com/product/wireless_J.html
(3) Hitoshi HIRATA, "Development of High Efficiency Amplifier for Cellular Base Stations," SEI technical review No.70, pp47-52 (2010)
(4) IEEE Standard 802.16-2009
(5) IEEE P802.16m/D4 February (2010)
(6) Masaki SANDA, Tadashi ARAKI, "Development of Prototype WiMAX Base Station," SEI Technical Review No.68, pp29-34 (2009)
(7) Mitsuru HIRAKAWA, "Development of Adaptive Array Antenna for Mobile WiMAX Uplink," SEI Technical Review No.68, pp22-28 (2009)
(8) ETSI EN 302 544-1, European Telecommunications Standards Institute

Contributors (The lead author is indicated by an asterisk (*)).

T. ASAINA*

• Manager
Radio Transmission Systems Department, Information & Communications Laboratories
He is engaged in the research and development of radio access equipment.

T. ARAKI
• Assistant General Manager
Radio Transmission Systems Department, Information & Communications Laboratories

H. MUKAI
• Assistant General Manager
Radio Transmission Systems Department, Information & Communications Laboratories

I. KATSURA
• Assistant Manager
Radio Transmission Systems Department, Information & Communications Laboratories

T. YAMAMOTO
• Radio Transmission Systems Department, Information & Communications Laboratories

S. NISHIMURA
• Radio Transmission Systems Department, Information & Communications Laboratories

S. KATSUMI
• Assistant Manager, FTTH Products, 1st Technologies Group
Sumitomo Electric Networks, INC.

S. KIDO
• Assistant Manager
3rd Development Section
Access Products
1st Technologies Group
Sumitomo Electric Networks, INC.