# Compact Dual-Band Antenna Base Station for Simultaneously Transmitting Microwave and Millimeter-Wave Signals in Radio-on-Fiber Systems

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## Abstract

A compact base station (BS) prototype is developed for microwave/millimeter-wave dual-band radio-on-fiber systems. Collection and delivery of 60-GHz-band and 2.4-GHz-band signals between a central station and the BS through 2-km fiber-optic link is successfully demonstrated.


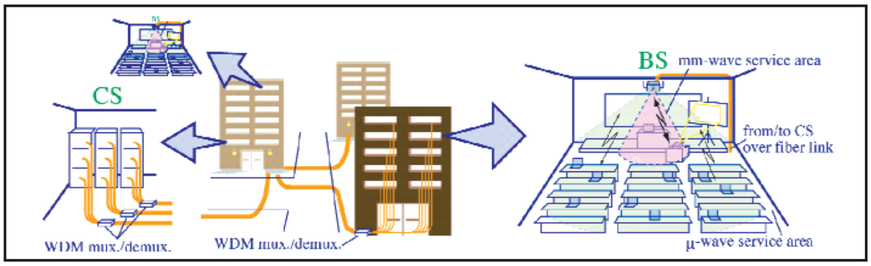


*Fig. 1 : Dual-band ROF system.*

## Introduction

In commercial wired broadband access services such as digital subscriber line (DSL, up to 50 Mb/s), fiber-to-the-home (FTTH, 100 Mb/s), gigabit Ethernet (GbE, 1 Gb/s), the data rate has been getting faster for last several years. In wireless access services in Japan, on the other hand, personal digital cellular (PDC, 9.6 kb/s), personal handyphone system (PHS, 128 kb/s), cdmaOne (IS-95, 128 kb/s), and the third generation mobile phones (W-CDMA, 2 Mb/s and CDMA2000, 2.4 Mb/s) are commercially available. Access points and terminals for wireless local area network (LAN) have been also widely used not only in office but also recently in home and public areas, and the 54-Mb/s wireless LAN (ex. IEEE802.11a/g) will be of the highest data rate at present. To realize wireless broadband access (over 100 Mb/s), it is expected that a millimeter-wave (mm-wave) radio communications can eliminate the data-rate discrepancies between the wired and wireless links because of its potentially broad transmission bandwidth. Mm-wave-band radio-on-fiber (ROF) system can effectively cover wide service areas with many remote antenna base stations (BSs) [1]. For the early deployment of commercial ROF systems, the BSs should be as simple and cost-effective as possible [2]. Furthermore, to provide a wide variety of services through the ROF networks, it is desirable that radio signals in different frequency bands are simultaneously transmitted. Therefore, we have proposed such multi-band ROF systems [3]. A dual-band ROF, which simultaneously transmits both mm-wave-band signals for high-speed data but also conventional microwave-band signals are simultaneously transmitted over the ROF links, will be one of the simplest solutions to provisioning future wireless broadband access.

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In this letter, we introduce our system concept of the dual-band ROF transmission and the compact BS prototype developed for the dual-band ROF systems [4]. Collection and delivery of 60-GHz-band and 2.4-GHz-band signals between a central station (CS) and the BS through 2-km-long fiber-optic link is successfully demonstrated. To the best of our knowledge, it is the first time to make the compact BS prototype for the dual-band ROF systems.

## System Concept of Dual-Band ROF Transmission

Fig. 1 illustrates our system concept of the dual-band ROF transmission, where the in-building network is a typical example. The system consists of one CS, dual-band BSs, and optical fiber links, in which ROF signals are transmitted with wavelength division multiplexing (WDM) technique. In the case that the network topology is assumed to be star, we have proposed the configurable WDM multiplexer/demultiplexer for ROF signals, which simply consists of an arrayed waveguide grating, an optical circulator, and an etalon filter [5]. To successfully perform the WDM ROF transmission, a pair of downlink and uplink optical carriers must be individually assigned to each dual-band BS with different wavelength. The dual-band BS covers two service areas, that is, high-speed and conventional data-rate service areas respectively by using mm-wave- and microwave-band signals. The size of service areas can be adjusted by each radio power radiated from the BS, which may be controlled in the CS. To accelerate the realization of the dual-band ROF transmission, the dual-band BS should become as compact as possible.

## Compact BS Prototype

Fig. 2 shows the photograph of the compact dual-band BS prototype developed for practical use. The BS prototype has a function of duplex transmission, that is, simultaneous downlink and uplink transmission. It has three optical ports, a power switch, and an AC power port. The size is 220 mm x 150 mm x 70 mm. The BS prototype mainly consists of a high-speed photodetector with the 3-dB bandwidth of 60 GHz, an electroabsorption modulator (EAM), dual-band power combiner and splitter, microwave- and mm-wave-band amplifiers, filters, and antennas. The EAM is specially designed for 60-GHz-band modulation, which simultaneously enables a microwave-band modulation [2, 3]. Therefore, the EAM can modulate an optical carrier with an electrically multiplexed signal of microwave- and mm-wave-band signals. The dual-band power combiner and splitter, which are the same configuration because of their reciprocity, are specially designed for minimizing the influence due to undesirable reflection among microwave and mm-wave ports. The electrical amplifiers, filters, and antennas in microwave band are commercial ones used for 2.4-GHz band in the IEEE802.11g wireless link. And those in mm-wave band are designed for 59-60 GHz (downlink) and 61-62 GHz (uplink). The BS prototype also contains an internal power circuit, which is supplied from an external electric power of AC 100 V (50/60 Hz). Note that the prototype does not include any optical source not only to make it compact and simple but also to endow it with an expandability of wavelength design in future WDM networks.

## ROF Transmission Experiment and Results

We performed the experiment to investigate the fundamental performance of the dual-band BS prototype, which was linked with two 2-km-long standard single-mode fibers (SMFs) to a CS [4]. For the downlink transmission, a microwave sinusoidal wave ($f_{micro1}$ = 2.45 GHz) and a mm-wave 155.52-Mb/s-DPSK signal ($f_{mm1}$ = 59.6 GHz) were electrically multiplexed in the CS. A downlink optical carrier (1552.52 nm) was modulated with an EAM in the CS by the electrically multiplexed signal, and transmitted through one SMF to the BS prototype. At the BS, the received optical signal was photodetected and demultiplexed to the original downlink microwave and mm-wave signals. The microwave signal power was monitored with an electrical spectrum analyzer and the mm-wave signal was demodulated to recover the clock and data. For the uplink transmission, on the other hand, another electrically multiplexed signal consisting of a microwave sinusoidal wave ($f_{micro2}$ = 2.45 GHz) and a mm-wave 155.52-Mb/s-DPSK signal ($f_{mm2}$ = 61.2 GHz) modulated an uplink optical carrier (1552.52 nm) in the BS. The modulated optical signal was transmitted through another SMF to the CS, photodetected and demultiplexed to the original uplink microwave and mm-wave signals. In the same manner of the downlink, the microwave signal power was monitored and the mm-wave signal was demodulated to recover the clock and data. At the same time, the bit error rates (BERs) of the recovered data were also measured. All of their measurements were simultaneously performed.

Fig. 3(a) shows the measured optical spectrum of the downlink ROF signal into the BS. When the downlink microwave signal regenerated at the BS achieved the desired power of 10 dBm, the optical modulation depth for the mm-wave downlink signal was about 30 dB. For the uplink microwave signal regenerated at the CS, the desired power of -65 dBm was also achieved, which is the required maximum receiving power for IEEE 802.11g. Fig. 3(b) shows the measured optical spectrum of the uplink ROF signal from the BS. As shown in this figure, the modulation depth for the mm-wave uplink signal was about 27 dB. In this condition, the down- and uplink mm-wave signals simultaneously achieved the BER of $10^{-9}$ at the optical received powers of -3 and -6 dBm, respectively. As the result, it was verified that the BS prototype preserved the required power levels enough for practical use.

## Conclusion

The newly developed compact BS prototype for the dual-band ROF systems has been introduced. Collection and delivery of 60-GHz-band 155-Mb/s-DPSK signals and 2.45-GHz signals between the CS and the BS through 2-km-long SMF link was successfully demonstrated.

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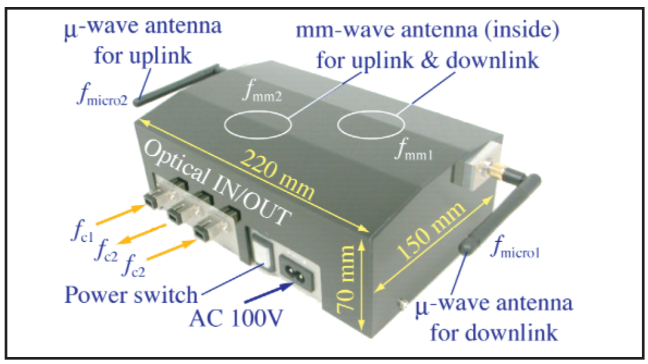


*Fig. 2 : Dual-band BS prototype.*

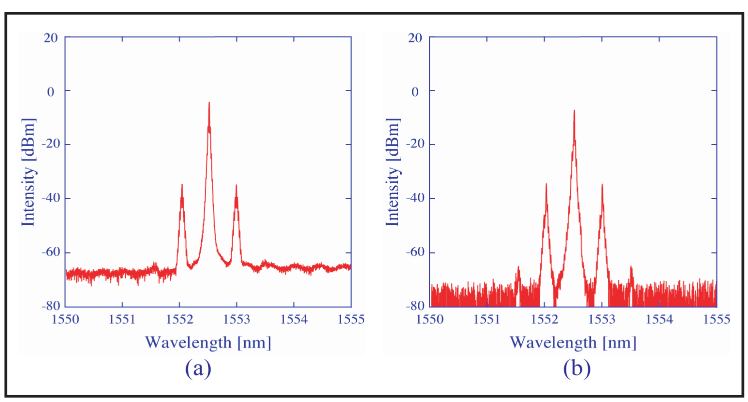


*Fig. 3 : Measured optical spectra of (a) downlink and (b) uplink ROF signals.*