High-Efficiency Power Amplifier for LTE/ W-CDMA System

● Yoshiaki Kumagai ● Yasuhito Funyu ● Hiroaki Maeda

Long Term Evolution (LTE) systems are attracting attention as next-generation mobile communication systems. Such systems have come to transfer and manage large volumes of data at high speed. Therefore, base stations have urgent requirements for devices that are friendlier to the environment, easier to install and cheaper to run. Further, there are needs to reduce size and power consumption. This can be done with the overlay service which supports both W-CDMA and LTE systems, and which uses antennas that are employed in the conventional 3G service and thus allows system introduction costs to be reduced. Conventional mobile communication systems are composed of a baseband portion and a radio frequency (RF) portion installed in the same building. In recent systems, the RF portion of more and more devices is housed in an outdoor case separate from the baseband portion, and they are connected with an optical fiber. This type of RF unit is generally called a remote radio head (RRH) device. The RRH is also known as remote radio equipment (RRE). Fujitsu has developed multimode technology RRE which supports W-CDMA and LTE for NTT DOCOMO. To achieve small devices with low power consumption, the efficiency of the power amplifier (PA) has been improved by adopting digital pre-distortion (DPD) and GaN Doherty PAs. This paper describes the principle, methods of operation, characteristics and configurations of such devices.

1. Introduction

The underlying tendency of the mobile communication system market is toward growth and the diffusion of multimedia services has been driving an increase in speed and capacity of communication. In Japan, NTT DOCOMO started providing Long Term Evolution (LTE) services, which has further accelerated the increase in speed and capacity. Increased speed and capacity leads to increased power consumption at base stations. Therefore, to reduce environmental impact and operational costs, it is necessary to reduce power consumption of the radio frequency (RF) portion, which accounts for most of the electric power consumed.

To have a seamless transition from the existing services, the RF portion should be shareable with the existing systems so that LTE band expansion can be achieved in line with the diffusion of terminals and the existing 3G system facilities can be used effectively.

To meet these requirements, Fujitsu has developed multimode optical remote radio head (RRH)[1] that supports both Wideband Code Division Multiple Access (W-CDMA), a 3G service, and LTE. In the development, digital pre-distortion (DPD)[2], which has already been used for W-CDMA, has been applied to achieve small devices with low power consumption. The RRH is also known as remote radio equipment (RRE). In addition, a new crest factor reduction technique has been developed for multimode configuration to improve the efficiency of the power amplifier (PA).

This paper describes the principle, methods of operation and configurations of such devices.

2. RRH configuration

Conventional mobile base station equipment had the baseband (BB) portion and RF portion installed in the same place. The RRH separates the RF portion from the base station main unit by connecting the BB and RF portions with an optical fiber and thus allows such portions to be installed more freely. It also reduces the power consumption of the base station by installing the RF portion close to the antenna to reduce the cable loss.

Figure 1 shows a block diagram of RRH. The equipment is composed of an interface unit called common public radio interface (CPRI), receiving circuitry combined with low-noise amplifier (LNA), transmitting circuitry combined with a PA, and an antenna duplexer. For the digital interface unit that connects the radio equipment control (REC) and radio equipment (RE), a standard CPRI interface is used.

CPRI supports two transmission rates: 1.2288 Gb/s for W-CDMA and 2.4576 Gb/s for the LTE-only and W-CDAM/LTE multimode configurations. The transmission rate is automatically recognized according to the scheme, thereby allowing transition from the W-CDMA to W-CDAM/LTE services.

DPD is used for the transmitter and Doherty configuration with gallium nitride (GaN) devices used for the PAs.

The receiver supports both W-CDMA and LTE systems without hardware changes by collectively capturing signals in the 20 MHz band and using filter settings according to the respective systems. In this way, both circuit size and power consumption have been reduced as compared with schemes that perform demodulation separately for the two systems.

The major specifications are shown in **Table 1** and the appearance of the equipment in **Figure 2**. The housing is made waterproof to ensure environmental resistance, thereby providing high reliability. In addition, the fan-less structure has eliminated the need for maintenance.

3. Technology to improve efficiency of power amplifier of RRH

Mobile communication systems have come to have high speed and capacity, leading to increased power consumption of base stations. The RF portion accounts for most of the base station power consumption, which means that reducing the power consumed by the RF portion is important for reducing the base station power consumption. LTE uses adaptive modulation for improving the frequency utilization efficiency and supports modulation schemes up to 64

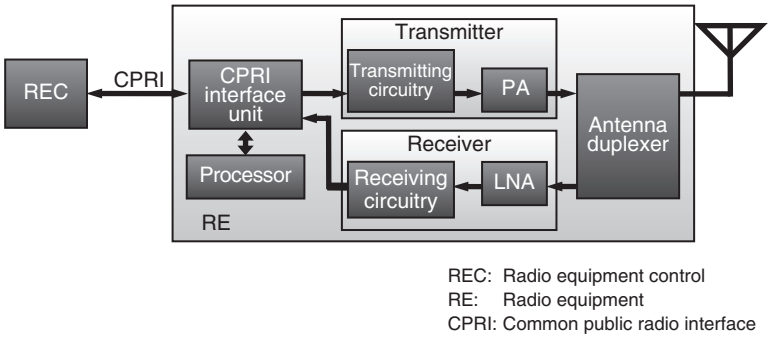

Figure 1
Block diagram of RRH.

Table 1
Major specifications of RRH.

Item	Specifications
Transmit frequency band	2130–2150 MHz
Receive frequency band	1940–1960 MHz
Transmission output	20 W × 2
Interface	CPRI (1.2288/2.4576 Gb/s)
Input voltage	−40.5 V to −57 V
Power consumption	185 W
Volume	19.4 L
Weight	17.7 kg
Antenna configuration	2Tx2Rx
Supported modulation scheme	QPSK, 16QAM, 64QAM

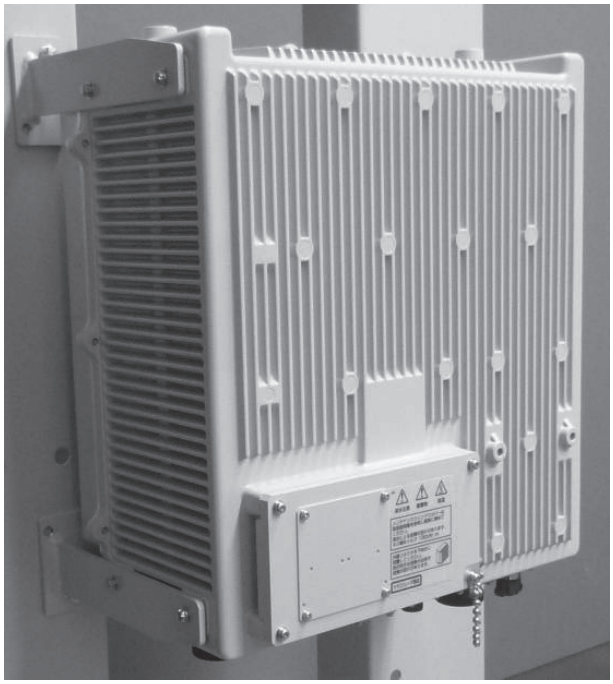

Figure 2
Appearance of RRH.

quadrature amplitude modulation (QAM). With 64QAM, the amplitudes of the orthogonal carrier waves are respectively assigned with eight values and their combinations are used to allow transmission of data of 64 values (six bits) at one time. The tolerance for symbol determination is small and high signal quality is said to be necessary.

In this way, low power consumption and high linearity are required of the RF portion. In terms of power amplification technology, however, they are generally in a trade-off relationship and achieving both is a challenge.

The present RRH we have developed has achieved low power consumption and low distortion by adopting proprietary distortion compensation technology and high-efficiency power amplifier technology. The following subsections describe these technologies in detail.

3.1 Digital distortion compensation technology

Based on its past results of applying digital distortion compensation to W-CDMA equipment, Fujitsu has developed a new carrier synthesizer for multimode W-CDMA/LTE equipment and sought to improve the distortion compensator as well.

Figure 3 shows a block diagram of the transmitter to which DPD has been applied. The digital unit is composed of a carrier synthesizer and distortion compensator.

1) Carrier synthesizer

The carrier synthesizer applies the desired filters to the IQ data extracted in the CPRI unit according to the respective W-CDMA and LTE signals for waveform shaping.

Signals of mobile communication systems have large differences between the average power and peak power and the average power must be lowered with reference to the saturation power. This leads to increased power consumption of PAs. The difference between the saturation power and the actual output power is referred to as back-off. In the carrier synthesizer, peak components of signals are reduced by a crest factor reduction (CFR) circuit, thereby decreasing the PA back-off to reduce power consumption.

Generally, suppressing the peak components causes a deterioration in signal quality. Based on a circuit that has already been used for 3G, a new peak suppression technique has been developed for multimode W-CDMA/LTE equipment. This

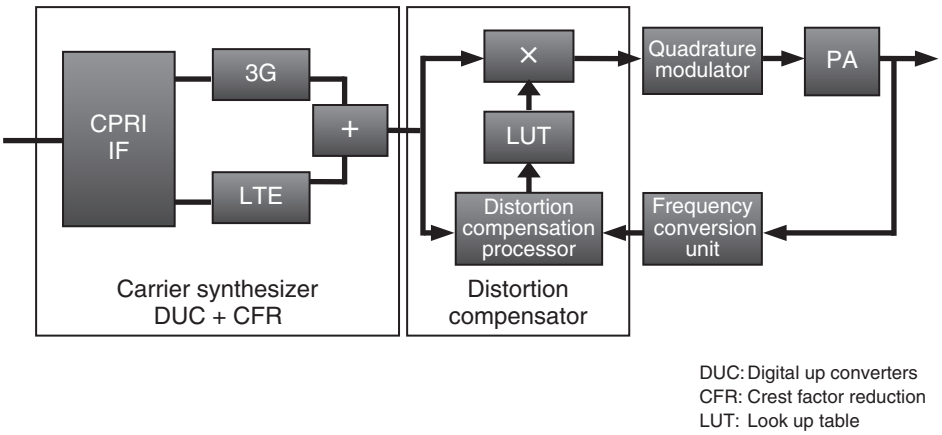

Figure 3
Block diagram of transmitter.

technique has successfully suppressed peak components while satisfying the signal quality specifications of the 3rd Generation Partnership Project (3GPP).

2) Predistorter

Distortion compensation by DPD is intended to provide linear quality in PA output by previously inputting in the distortion compensator the inverse characteristics of the non-linear distortion generated in the PA. Compared with the feed forward system, which was conventionally used, output loss can be reduced and the efficiency significantly improved.

The inverse characteristics of PA distortion are determined by multiplying the coefficient for correcting amplitude and phase according to the power. Then the coefficient is controlled according to the situation so that the difference between the input signal and the feedback signal from the PA will be minimized. With this control, the linearity is constantly ensured in spite of any change in the environment including the ambient temperature.

PAs have a characteristic called "memory effect," in which the distortion depends on the status of past input signals, and its influence becomes larger when they are operated at a higher efficiency. The predistorter has a configuration in view of the memory effect of PAs and seeks to reduce the power consumption of PAs by functioning at an operating point with a higher efficiency.

3.2 High-efficiency power amplifier technology

1) GaN device

For the PAs, GaN high electron mobility transistor (HEMT),[3),4)] which was developed and commercialized by Fujitsu Laboratories, has been used. The GaN-HEMT features good performance including lower power consumption and higher gain than the conventional silicon high-power transistors. The present PAs have realized reduced power consumption by applying GaN-HEMTs to the driver stage and final stage amplifiers.

2) Doherty amplifier

The Doherty amplifier is used for the final stage amplifier. This amplifier is capable of significantly reducing the power consumption even with mobile communication system signals with large differences between the average power and peak power.

Figure 4 shows a block diagram of the Doherty amplifier.

The Doherty amplifier consists of a peak amplifier with class-C bias and a carrier amplifier with class-AB bias. When the amplitude of a

modulated wave signal is small, only the carrier amplifier is operated for amplification and not the peak amplifier. The peak amplifier is set in class-C bias mode, in which bias current is not run, and low power consumption is achieved in the small amplitude range. As the amplitude becomes larger, the peak amplifier gradually starts amplification and the resultant output is combined with the amplified power from the carrier amplifier, which is output. When the amplitude further increases to reach the range where a signal of the maximum amplitude is input, both the peak and carrier amplifiers perform saturated power amplification and operate at a high efficiency.

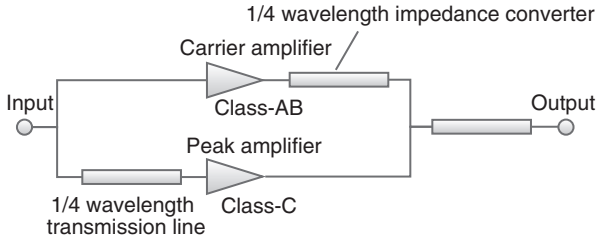

Figure 4
Block diagram of Doherty amplifier.

In this way, the Doherty amplifier achieves low power consumption by providing the most suitable amplification of the carrier and peak amplifiers according to the amplitude of a signal with a temporally varying amplitude. The present PAs support both W-CDMA and LTE systems. They optimize power consumption in view of the peak suppression and adjacent channel leakage ratio (ACLR: ratio of the power level of the modulated wave in the transmission band to the power level of the spurious wave generated in the adjacent channel due to non-linearity of the amplifier) characteristic.

Furthermore, Fujitsu's proprietary circuit to reduce the memory effect of PAs has been applied to the amplification circuit. This has successfully mitigated the load on the DPD circuit and achieved excellent predistortion characteristics characteristics.

4. Characteristics of RRH

The frequency spectrum of the developed RRH is shown below. This equipment accommodates both W-CDMA and LTE and **Figure 5** shows the spectrum observed when

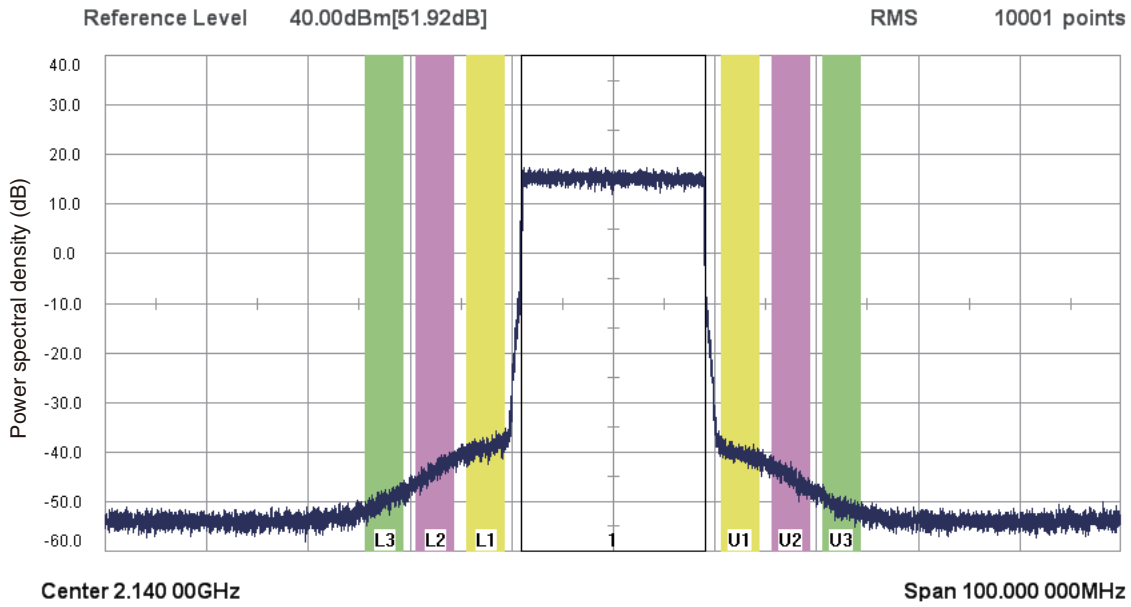

Figure 5
Frequency spectrum LTE (20 MHz).

the LTE signal is transmitted. The ACLR characteristic of −45 dBc or lower, which is a 3GPP requirement, is satisfied by applying predistortion and sufficient predistortion is obtained.

LTE systems support up to 64QAM so as to increase the transmission capacity as compared with W-CDMA systems. A constellation diagram for 64QAM transmission is shown in **Figure 6**.

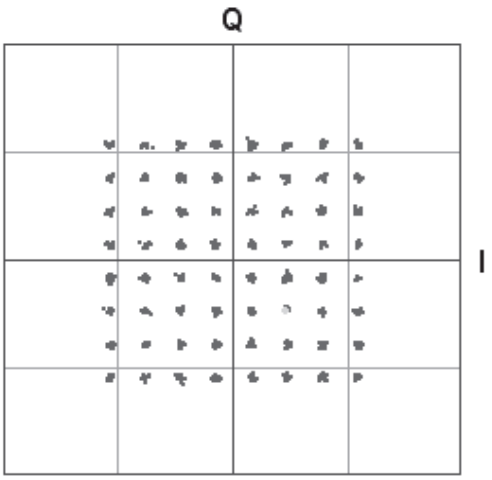

Figure 6
Constellation (64QAM).

While up to 16QAM has been supported with a W-CDMA High-Speed Downlink Packet Access (HSDPA) system, 64QAM requires more stringent characteristics because of the greater number of signal points. Error vector magnitude (EVM), which represents signal quality, is the result of normalizing the displacement between the ideal modulated signal and actual modulated signal.

As a consequence, the EVM standard of 8% or lower has been realized and a signal quality capable of accommodating an increase in transmission capacity has been achieved.

The spectrum for W-CDMA/LTE shared use is shown in **Figure 7**. The figure indicates characteristics for W-CDMA 5 MHz × 2 carriers + LTE 10 MHz. The required ACLR standard of 3GPP is satisfied by applying distortion compensation in the same way as for LTE-only systems. When the RRH is shared by W-CDMA and LTE, the characteristics required for the respective systems have been satisfied.

The equipment power consumption in this condition is 185 W with the transmission output of 20 W × 2, or the total transmission output of

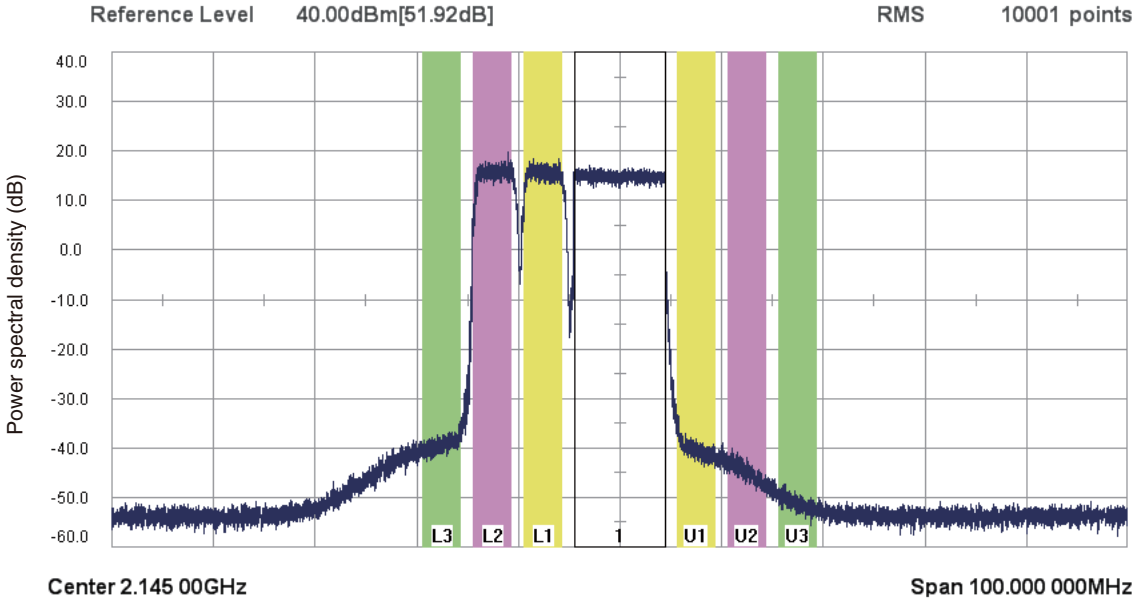

Figure 7
Frequency spectrum W-CDMA/LTE shared.

40 W. The power consumption is total power consumption including the receiver. The power consumption is lower than the conventional optical RRH of W-CDMA and the stringent wireless characteristics have been achieved as well as a volume of 19.4 L and weight of 17.7 kg.

5. Conclusion

This paper has presented the RRH developed for NTT DOCOMO by describing digital predistortion, which is a high-efficiency technology for amplifiers applied, configuration of PAs and equipment characteristics.

By applying the high-efficiency technology, the developed equipment has realized power consumption lower than the conventional W-CDMA optical equipment while satisfying more stringent wireless specifications than the conventional equipment. Reductions in both size and weight have also been achieved. The equipment has been given a fan-less, waterproof structure, which has improved maintainability and reliability and successfully ensured a high degree of freedom of installation.

Shared use of RRH by W-CDMA and LTE has been realized, which has allowed the equipment installed for W-CDMA to be applied as it is to LTE and made seamless transition to LTE systems possible.

The present equipment developed is capable of supporting 800 MHz to 2 GHz bands simply by changing the frequency-dependent portion and of easily realizing future LTE frequencies. Fujitsu intends to continue working to reduce the power consumption of wireless amplifiers and contribute to the reduction of environmental impact for the fourth-generation mobile communication system (IMT-A).

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Yoshiaki Kumagai
Fujitsu Ltd.
Mr. Kumagai is currently engaged in development of base station wireless equipment for LTE systems.

Hiroaki Maeda
Fujitsu Ltd.
Mr. Maeda is currently engaged in development of high-efficiency transmission amplifiers for base stations.

Yasuhito Funyu
Fujitsu Ltd.
Mr. Funyu is currently engaged in development of digital pre-distortion amplifiers for base stations.