Base Station | Power Amplifier | High Efficiency

Collaboration Projects

Wideband and High Efficiency Feed-Forward Linear Power Amplifier for Base Stations

This paper presents a new feed-forward linear power amplifier configuration for achieving high efficiency operation that can offer power consumption reduction of base station equipment for future broadband mobile communications systems. This research was conducted jointly with Wireless Technologies & EMC Research Lab. (Professor Toshio Nojima), Graduate School of Information Science and Technology, Hokkaido University.

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1. Introduction

There are many base stations for providing mobile communications services. Base stations of IMT-Advanced (4G) systems seem to have various types: some will be newly installed, and some will be installed in existing base stations. In both cases, from the viewpoint of offering easy-installation, base station equipment is required to be smaller, lighter, and attain lower power consumption, which leads to a reduction in carbon dioxide. Base station equipment generally comprises a transmitter amplifier, receiver amplifier, duplexer[*1], modulator, demodulator, antenna, and other components. It is the transmitter amplifier that consumes the most part of the electric power in the base station equipment. It is therefore indispensable to reduce the power consumption of the transmitter amplifier.

3rd Generation Partnership Project (3GPP) and other standard specifications require suppression of out-of-band power leakage. It therefore uses a linear amplifier that employs a nonlinear distortion compensation technique as the transmitter amplifier.

There are several distortion compensation techniques such as Feed-Forward (FF) [1] and Digital Predistortion (DPD) [2]. Although FF is superior to DPD with respect to distortion compensation capability, DPD is superior to FF with respect to power consumption. A self-adjusting FF Power Amplifier (FFPA) is used in PDC and some IMT-2000 base stations [3] because of strict specifications for out-of-band power leakage. However, DPD is currently used in IMT-2000 base stations for reduced power consumption [4].

Base station equipment requires wideband distortion compensation, because IMT-Advanced systems may support the maximum bandwidth of about 100 MHz [5]. If DPD is to be used to achieve wideband distortion compensation, it requires a high-speed signal processor and wideband digital analog converter (hereinafter referred to as "signal processing device"), which results in consuming a large amount of electric power. Unless the power consumption of the signal processing

*1 **Duplexer**: A device that comprises a transmitter filter and receiver filter. It allows a single antenna to be used for both transmission and reception.

device is reduced, DPD dissipates electric power and makes it difficult to obtain the advantages of DPD. On the other hand, if FFPA can reduce the power consumption, it is a candidate for wideband transmitter amplifiers.

FFPA comprises a signal cancellation circuit with a main amplifier and distortion cancellation circuit with an error amplifier (**Figure 1**). To improve FFPA efficiency, it is indispensable to improve the efficiencies of the main amplifier and the error amplifier. The error amplifier must amplify the input signal without generating any nonlinear distortion components at least, the nonlinear distortion components generated by the error amplifier should be negligibly small [1]. Therefore, the error amplifier uses a class-A amplifier*2. It is difficult to apply a high efficiency amplifier which operates at around the saturation output point*3 to the error amplifier. On the other hand, improving the maximum efficiency of the main amplifier is the key issue to improve the efficiency of the FFPA [6]. FFPA can offer the efficiency of 20% when the main amplifier attains the maximum drain efficiency*4 of 80% at the output backoff*5 of 4 dB [6].

There have been several reports on improving the efficiency of FFPA by employing a Doherty amplifier [7] as the main amplifier [6][8][9]. However, it is difficult to achieve FFPA efficiency of 20% for over 10 W output power by using Doherty amplifiers [8][9]. This is because Doherty amplifiers offer the efficiency of at most 50% for high power operation.

A Harmonic Reaction Amplifier (HRA) (**Figure 2**) was proposed as a high efficiency amplifier [10]. The HRA attained the maximum power added efficiency of 75% and the saturation output power of 34 dBm in a 1.7 GHz band [10]. The HRA is a strong candidate for the main amplifier of the FFPA since the HRA has a higher maximum efficiency than Doherty amplifiers under high output power operation.

This article presents a new FFPA configuration that employs an HRA as the main amplifier. A 2 GHz band FFPA is fabricated and a high efficiency performance is experimentally confirmed. This research was conducted jointly with Professor Toshio Nojima of Hokkaido University, who has a deep understanding with regard to linear and high efficiency amplifiers.

2. Proposed High Efficiency FFPA Configuration

Figure 3 shows the proposed FFPA configuration, which employs an HRA as the main amplifier. A 2 GHz band, 20 W class FFPA is fabricated. The main amplifier consists of a preamplifier and the HRA. The error amplifier consists of a preamplifier and a final stage amplifier. The final stage amplifier is a class-A amplifier. The vector regulator consists of a voltage-controlled variable attenuator and a voltage-controlled phase shifter.

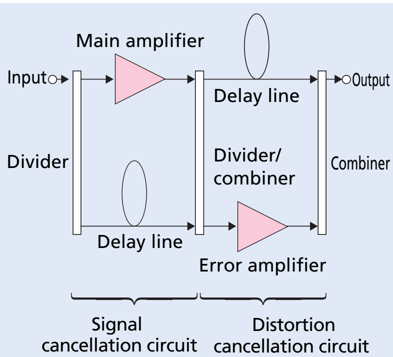

Figure 1 FFPA basic configuration

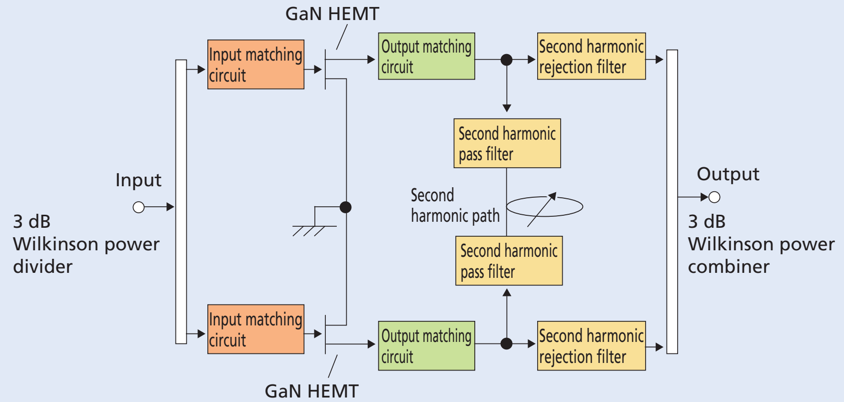

Figure 2 HRA basic configuration

*2 **Class-A amplifier**: An amplifier configuration in which the DC bias current of the transistor drain terminal or the collector terminal is set to about 1/2 the saturation current. The maximum theoretical efficiency of a class-A amplifier is 50% and linear amplification is possible.

*3 **Saturation output point**: The point in the amplifier input-output characteristics at which the output power saturates.

*4 **Drain efficiency**: The ratio of the output power to the supply power of the amplifier.

*5 **Output backoff**: Generally, the difference between the amplifier output power and the specific output power. In this article, high efficiency amplifiers are used, so it is taken as the difference between the output power and the saturation output power of the amplifier.

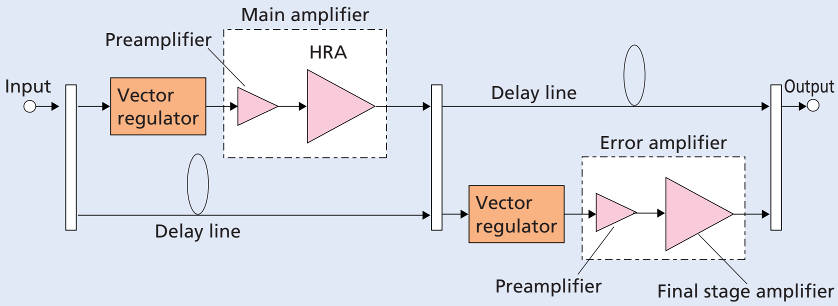

Figure 3 High efficiency FFPA configuration

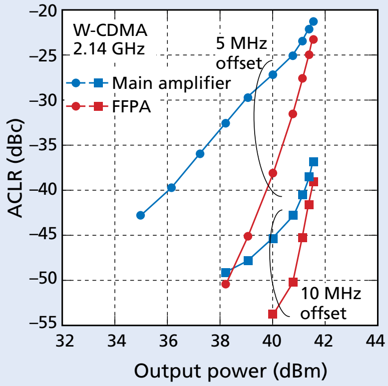

Figure 4 ACLR performance of the proposed FFPA and the main amplifier

The fabricated HRA uses Gallium Nitride High Electron Mobility Transistors (GaN HEMT). GaN HEMTs are known to have excellent linearity and high efficiency. They have been undergoing research as high power microwave semiconductors in base stations in recent years [11]. The HRA is designed for a fundamental frequency of 2.14 GHz and a second harmonic frequency of 4.28 GHz. Also, the matching frequency of the input matching circuit is 2.14 GHz, and the matching frequencies of the output matching circuit are 2.14 GHz and 4.28 GHz. The length of the second harmonic path is adjusted to maximize the drain efficiency of the HRA. For the input side power divider and the output side power combiner are a Wilkinson power divider[*6] and combiner that both have a design frequency of 2.14 GHz.

3. Experimental Results

The fabricated 2 GHz band HRA achieves a gain of 22 dB, a saturation output of 43.5 dBm, and a maximum power added efficiency of 68%. The bias condition of the GaN HEMTs is equivalent to class AB[*7] (drain voltage of 50 V and drain current of 100 mA).

The vector regulator of the signal cancellation circuit and the distortion cancellation circuit are manually adjusted to minimize the in-band component and the out-of-band distortion component while monitoring the output terminals of signal cancellation circuit and FFPA with a spectral analyzer. The test signal is a W-CDMA signal with a center frequency of 2.14 GHz, a bandwidth of 3.84 MHz, and a root rolloff coefficient[*8] of 0.22.

The main amplifier can offer high efficiency operation because the FFPA can reduce the out-of-band distortion components generated by the main amplifier.

Figure 4 shows the Adjacent Channel Leakage power Ratio (ACLR) measurements of the main amplifier and the FFPA. The definition of ACLR is shown in [12]. The FFPA achieves an ACLR with 5 MHz offset of –45 dBc at the FFPA output power of 39 dBm. The improvement in ACLR is 15 dB. Furthermore, the FFPA attains the ACLR with 10 MHz offset when the output power is 40.8 dBm and the ACLR improvement is 7 dB.

Figure 5 shows the spectrum of the main amplifier and the FFPA at the output power of 36.4 dBm. The spectrum of the main amplifier has a frequency-dependent distortion component, but the frequency-dependent distortion component is suppressed in the FFPA spectrum.

High efficiency amplifiers usually generate complicated nonlinear distortion components such as a frequency-dependent distortion component under lower output backoff [13]. The FF configuration can remove this kind of complicated nonlinear distortion component generated by the main amplifier. In that way, the frequency-dependent distortion component such as shown in Fig. 5 can be suppressed.

Although it is not shown in the figure, the operation bandwidth of the

*6 **Wilkinson power divider**: A power divider that divides the input signal among multiple output terminals, generally with equal power and delay.

*7 **Class AB**: Operating conditions in which the DC bias current of the transistor drain terminal or collector terminal is set to a value between class B bias of about 0 of the saturation current and the class A bias of about 1/2.

*8 **Root rolloff coefficient**: A filter that limits the transmission signal bandwidth; a coefficient that determines the frequency characteristics of the filter.

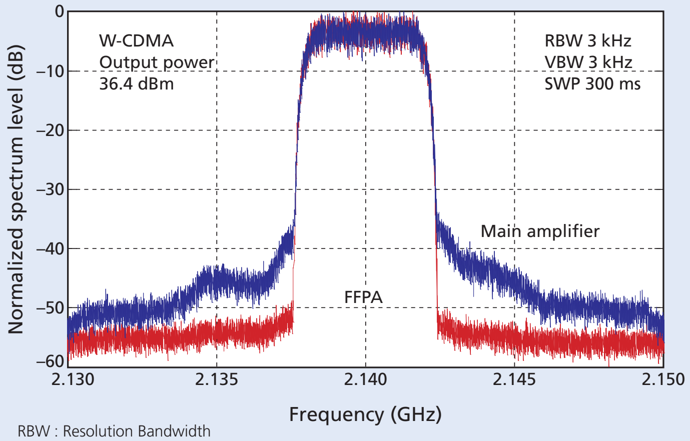

Figure 5 An example of the spectrum

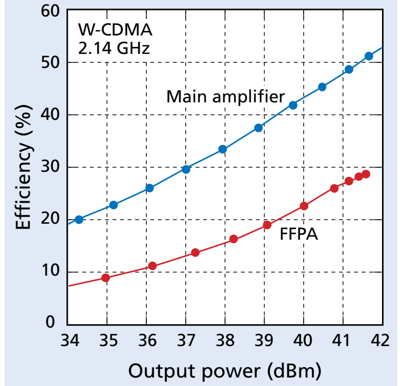

Figure 6 Efficiency performance of the proposed FFPA and the main amplifier

FFPA is 120 MHz over the range from 2.03 to 2.15 GHz at the ACLR of –45 dBc with 5 MHz offset. The experiment thus confirmed the wideband distortion compensation performance of the FFPA.

Figure 6 shows the efficiency performance of the main amplifier and the FFPA. Here, the FFPA efficiency is the ratio of the output power of the FFPA to the supply power of the main amplifier and the error amplifier. The efficiency of the main amplifier is the ratio of the output power of the main amplifier to the supply power of the main amplifier. The power consumption of the vector regulators does not take the efficiency calculation into account, because the level is very low. The efficiencies of the FFPA and the main amplifier are respectively 19.3% and 38% when the output power is 39 dBm and the ACLR is –45 dBc with 5 MHz offset. According to the previously reported FFPA efficiency range from 10 to 15% [14], the efficiency of the proposed FFPA configuration employing the HRA improves that of the conventional FFPA configuration.

4. Conclusion

In order to improve the FFPA efficiency, this paper proposed an FFPA configuration that employs an HRA as the main amplifier. A 2 GHz-band, 20 W class FFPA achieved the efficiency of 19.3% and the operation bandwidth of 120 MHz when the ACLR with 5 MHz offset is –45 dBc and the output power is 39 dBm. The proposed FFPA achieved, to the best of our knowledge, the highest efficiency of a 20 W class FFPA. In future work, there still remain technical issues that must be investigated such as nonlinear distortion compensation using a multicarrier W-CDMA test signal.

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