Proceedings of Asia-Pacific Microwave Conference 2007

Dual-band Feedforward Linear Power Amplifier Using Equal Group Delay Signal Canceller

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Abstract— In this paper, the design of a novel dual-band feedforward linear power amplifier (FFW LPA) is presented. The frequencies of operation of the implemented dual-band FFW LPA are the digital cellular (f0=880MHz) band, and the IMT-2000 (f0=2.14GHz) band, which are separated about 1.26GHz. Using high power amplifiers (120W PEP) for commercial base-station application, the IMD cancellation loop shows 20.45dB and 25.04dB suppression for the cellular and IMT-2000 bands, respectively, over a correction bandwidth of 100MHz. From the adjacent channel leakage ratio (ACLR) measurement with CDMA IS-95A 4FA and WCDMA 4FA signal, we obtained 16.5dB improvement at the average output power of 41.5 dBm for digital cellular band, and 18.6dB improvement at the average output power of 40dBm for IMT-2000 band under simultaneous operation.

Keywords - Dual-band, feedforward, power amplifier

I. Introduction

In past years, mobile communication was limited to low data rate signals exchange such as voice or text data. However, higher data rate signal exchange has become essential part of mobile communication due to the fact that several additional applications, such as mega pixel digital cameras, mp3 players, and TV receivers are integrated into the mobile unit to satisfy various demands from the users.

To provide additional services including multimedia data, a service provider has to utilize more than one frequency band. A new service requires a considerable investment in research and development for each application. For that reason, active studies are being done on broadband, multi-band devices that can cover more than one frequency band under simultaneous operation. However, due to the rigid linearity requirements of the base-station power amplifier, the research has been limited to the mobile station power amplifier [1]. This paper addresses the design of simultaneous multi-band base-station linear power amplifiers (LPAs). Feed-forward (FFW) is one of the most widely used techniques with excellent linearity improvement [2]-[3]. However, previous works were mainly focused on the extension of operation frequency and on the efficiency improvement in one band of operation [4]-[6].

This work was supported by the second stage of Brain Korea 21 Project

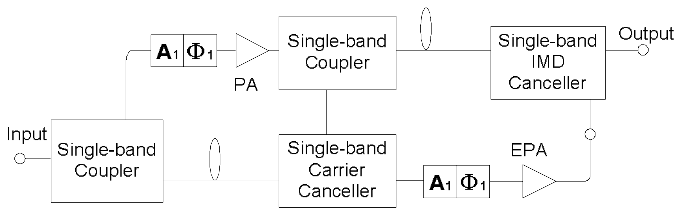

Figure 1. Conventional single-band FFW LPA.

We propose the design of equal group delay dual-band signal cancellation circuits to construct a dual-band FFW LPA. To provide the experimental verification, we implemented the dual-band FFW LPA, and showed the loop cancellation and ACLR improvements in both bands under simultaneous operation.

II. Design of a Dual-band FFW LPA

A. Circuit Configuration of a Dual-band FFW LPA

Fig. 1 shows a conventional single band FFW LPA, and Fig. 2 shows the block diagram of the proposed dual-band FFW LPA. Circuit components in the conventional FFW LPA amplify, divide, and combine the signals in just one band of operation. The dual-band FFW LPA consists of a broadband Wilkinson power divider, diplexers, a broadband directional coupler, an equal group delay dual-band carrier canceller, an equal group delay dual-band IMD canceller. Variable attenuators, phase shifters, main power amplifiers (PAs), and error power amplifiers (EPAs) are provided for each band of operation.

The proposed dual-band FFW LPA has the same structure as the conventional one, with the major difference being that the PA and EPA are replaced by the dual-band PA and EPA using diplexers. High power diplexers must be used with the PAs and EPAs. However, the other diplexers can be easily implemented with low Q components because the signal level is low at the input. Also, dual-band signal cancellers replace single band couplers and single band signal cancellers.

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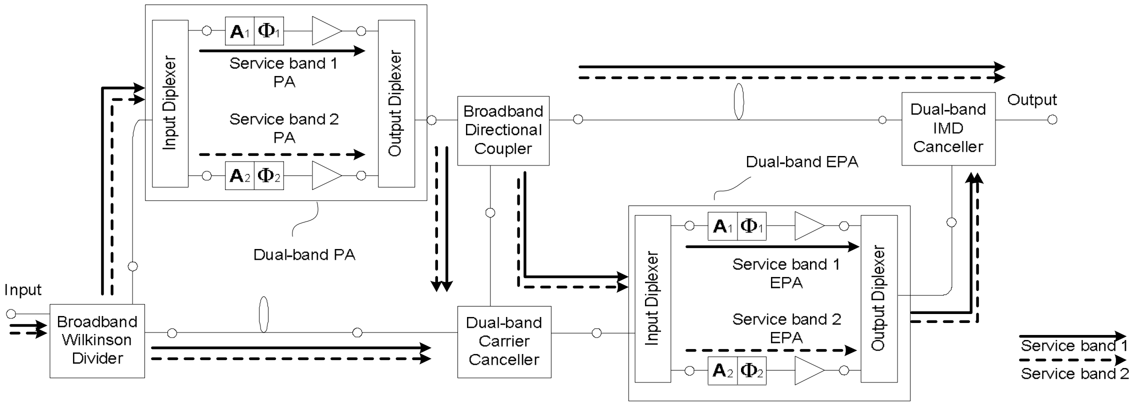


Figure 2. Block diagram of the proposed dual-band FFW LPA.

B. *Theory of operation of a dual-band FFW LPA*

The principle of operation of the dual-band FFW LPA is similar to the conventional single-band FFW LPA except for the dual-band PA and the dual-band signal canceller. If we denote the two band of operation as service band 1 (solid line) and service band 2 (dotted line) in Fig. 2, section with both lines means that there are dual-band signals, and section with only one line presents that there is a single band signal through the frequency selective characteristic of the diplexer.

When designing a dual-band PA, the isolation characteristic of a diplexer should be carefully considered since the proposed configuration is designed for the high power application [7]. In this work, the diplexer has an isolation of 45dB rejection for digital cellular band and 35dB rejection for IMT-2000 band. This result is enough not to introduce any interference in the other band of operation for 120W PEP base-station power amplifiers designed in the convention manner.

C. *Equal group delay dual-band signal canceller*

To obtain broadband signal cancellation, broadband amplitude, phase, and group delay matching are essential, and must be matched in each band simultaneously. Due to the fact that the conventional signal canceller cannot satisfy the out-of-phase and equal group delay matching at the same time inherently, an equal group delay signal canceller has been proposed [6]. The principle of the equal group delay signal canceller is that the reflection coefficients of transmission lines of same length, *l*, that are terminated with short and open condition, respectively, have out-of-phase and equal group delay characteristic at the same time. Fig. 3 shows the block diagram of the equal group delay dual-band signal canceller. Dual-band carrier canceller consists of broadband Wilkinson combiner, broadband 90˚ hybrids using vertically installed planar (VIP) circuit. Dual-band IMD canceller consists of broadband directional coupler, broadband VIP 90˚ hybrids [8].

When the dual-band signals are applied to the two input ports (*G, H*) of the dual-band carrier canceller in Fig. 3(a), signals of each band are fed to broadband VIP 90˚ hybrid of which the coupling and the through port are terminated with

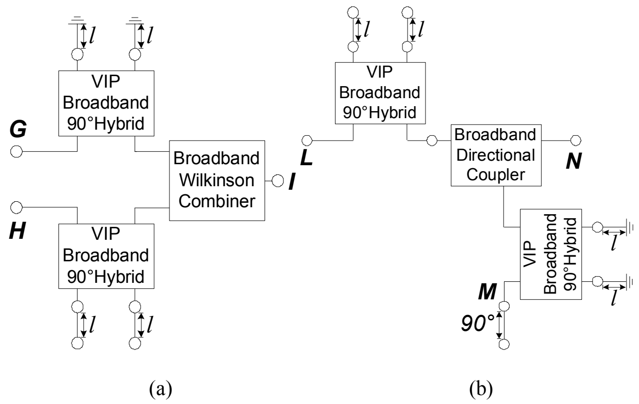


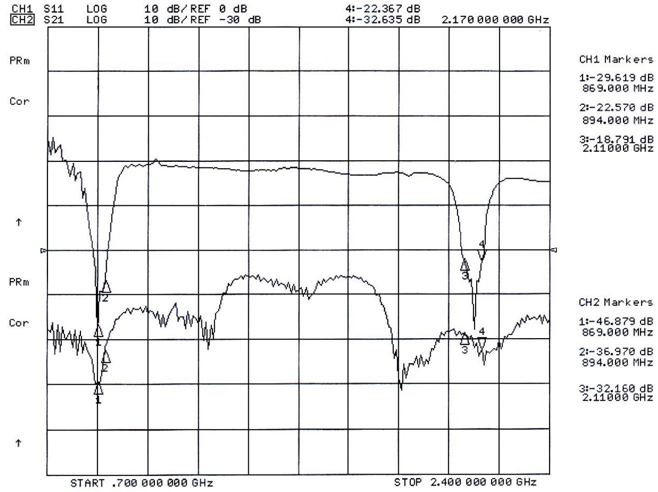
Figure 3. Dual-band (a) Carrier signal canceller. (b) IMD signal canceller.

open and short condition, respectively.The two output signals of the broadband VIP 90˚ hybrid are out-of-phase, and fed into in-phase broadband Wilkinson combiner. Since the two input signals in the final output port (*I*) experience the same group delay time and are out-of-phase, so a near perfect signal cancellation is obtained for dual-band operation. Amplitude matching is achieved by the variable attenuators in front of the PA. The broadband VIP 90˚ hybrid is used to obtain good reflection characteristic, and it can be replaced with small size commercial broadband 90˚ hybrid component.

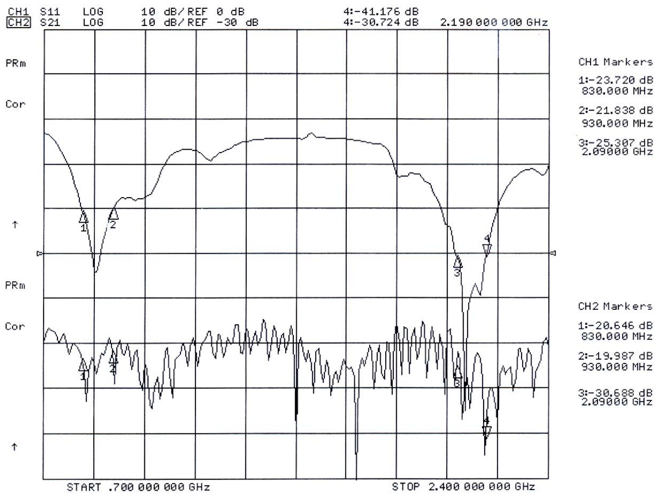
The operating principle of the dual-band IMD canceller is almost the same except 90˚ phase compensation of a loose coupling broadband directional coupler in performed. The match of magnitude between two paths is obtained with variable attenuators in front of the EPA.

III. IMPLEMENTATION AND MEASUREMENT

To prove the validity of the proposed configuration, we implemented dual-band FFW LPA for digital cellular and IMT-2000 band, which are separated about 1.26GHz between center frequencies, and measured the performance of the implemented linearization system with the commercial power amplifier of 120W PEP for base-station.



(a)



(b)

Figure 4. Dual-band (a) Carrier cancellation loop. (b) IMD cancellation loop results.

Fig. 4(a) shows the 1st loop signal cancellation result using the proposed dual-band carrier canceller measured with a network analyzer. The proposed canceller cancels the input signal more than 36.9dB for 869~894MHz and 32.1dB for 2.11~2.17GHz, simultaneously. Fig. 4(b) just shows the IMD signal cancellation characteristic using the proposed dual-band IMD canceller. The input signal is cancelled more than 21.8dB within 880±50MHz and more than 30.7dB within 2.14±0.05GHz. The frequency bandwidth that the signal is cancelled more than 20dB is over 113.27MHz and 173.85MHz for digital cellular and IMT-2000 band, respectively.

For the experimental verification, we have measured the output power spectral density of the dual-band FFW LPA with and without FFW loop using a forward-link CDMA IS-95A 4-carrier signal for digital cellular band and WCDMA 4-carrier signal for IMT-2000 band at the same time. These measurement results are shown in Fig. 5 and Fig. 6, respectively. Fig. 5 shows the measured power spectral density of the implemented dual-band FFW LPA for digital cellular band at an average output power of 41.5dBm before and after cancellation. The ACLR at 3.125MHz offset is -49.5dBc, improved about 16.5dB by the cancellation. The amount of improvement is smaller than expected from the result of network analyzer because of the limitation of the measurement setup.

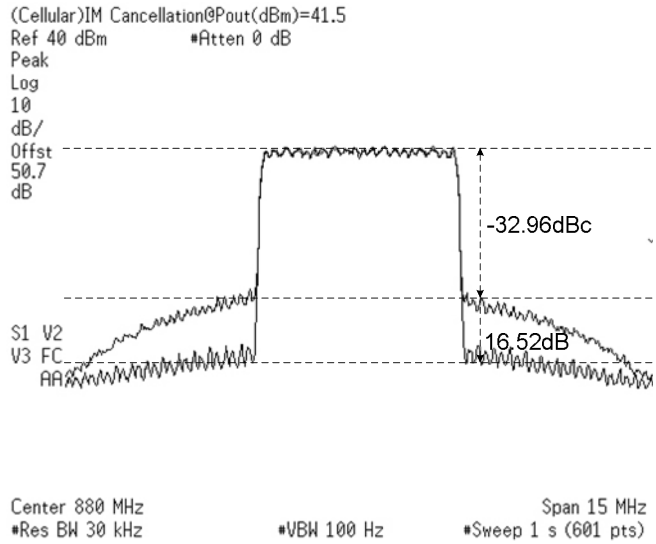


Figure 5. Measured power spectral density of the dual-band FFW LPA with and without FFW loop at digital cellular band at an average output power of 41.5dBm.

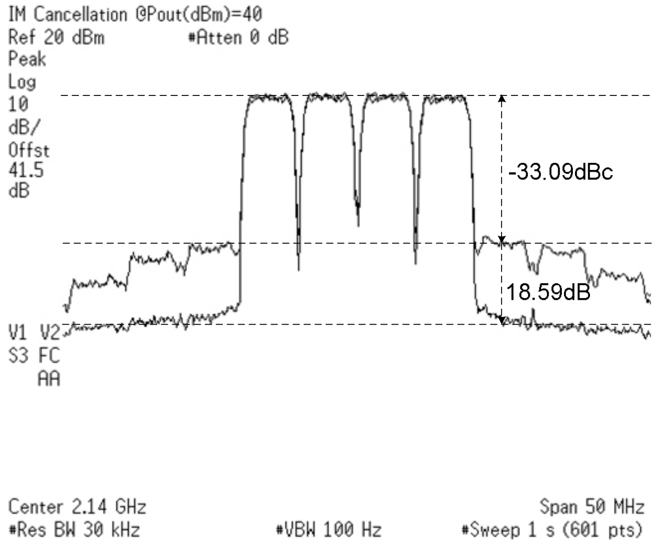


Figure 6. ACLR characteristic of the dual-band FFW LPA with and without FFW loop through the output dynamic range at an average output power of 40dBm.

Fig. 6 shows the measured power spectral density of the implemented dual-band FFW LPA for IMT-2000 band at an average output power of 40dBm before and after cancellation. The ACLR at 5MHz offset is -51.7dBc, improved about 18.6dB by the cancellation.

IV. CONCLUSION

For simultaneous linear amplification of a two frequency band signal, we proposed the design technique of using a dual-band equal group delay carrier canceller, a dual-band equal group delay IMD canceller, and a dual-band FFW LPA as an extension of the single-band FFW technique. To prove the validity of the proposed design technique, we implemented a dual-band FFW LPA for the digital cellular band and IMT-2000 band, which are separated about 1.26GHz. We measured the performance of the implemented linearization system with separate commercial power amplifiers for each band, each rated at 120W PEP, and combined with a diplexer network. Simultaneous correction was obtained within each band to allow ALCR specifications to be met with multi-carrier CDMA and WCDMA signals.

The proposed design method of the dual-band FFW LPA can be extended to operate at center frequency separated by more than 1 GHz, with the bandwidth of diplexer and broadband directional coupler being the limiting factors. Moreover, due to the advantage of the equal group delay signal canceller, broadband operation may be extended for more than two bands of operation. Therefore, it is expected that the proposed system would show its superior ability as a multi-band base-station linear power amplifier in the broadband multimedia communication environment. There are several advantages to this proposed architecture, such as reduction of the number of antennas, high power coaxial cables, other additional elements of the RF system.

REFERENCES

[1] K. Kunihiro, Yamanouchi. S, Miyazaki. T, Aoki. Y, Ikuina. K, Ohtsuka. T, Hida. H, “A diplexer- matching dual-band power amplifier LTCC module for IEEE 802.11a/b/g wireless LANs” *IEEE Radio Frequency Integrated Circuits Symposium Digest*, pp. 303-306, June 2004.

[2] S. C. Cripps, *Advanced Techniques in RF Power Amplifiers Design*, Norwood, MA, Artech House, 2002.

[3] F. H. Raab, P. Asbeck, S. C. Cripps, P. B. Kenington, Z. B. Popović, V. Pothecary, J. F. Sevic, and N. O. Sokal, “Power amplifiers and transmitters for RF and Microwave” *IEEE Trans. Microwave Theory & Tech.*, vol. 50, no. 3, pp. 814-826, March 2002.

[4] Yong-Chae Jeong, Young-Jean Song, and In-Ju Oh, “A Novel Adaptive Feedforward Amplifier Using an Analog Controller” *Microwave Journal*, vol. 46, no. 4, pp. 76-85, April 2003.

[5] Si-Gyun Jeong, Seong-Hoon Jeong, Jeong-Hyeon Cha, Yong-Chae Jeong, and Chul-Dong Kim, “A Feedforward Power Amplifier with Loops to reduce RX Band Noise And Intermodulation Distortion” *Microwave Journal*, vol. 45, no. 1, pp. 80-91, January 2002.

[6] Yong-Chae Jeong, Dal Ahn, Chul-Dong Kim and Ik-Soo Chang, “Feedforward Amplifier using Equal Group-Delay Signal Canceller” *IEEE MTT-S Digest*, pp. 1530-1533, June 2006.

[7] Heung-Jae Choi, Hee-Young Jeong, Young Kim, Jong-Sik Lim, Chul-Dong Kim and Yong-Chae Jeong, “Dual-Band Predistortion Power Amplifier for Digital Cellular and IMT-2000 Base-station Application” *Asia Pacific Microwave Conference Digest*, vol. 1, pp. 208-211, December 2005.

[8] In-Seon Kim, Cheol-Soo Lee, “A Study on Broadband Hybrid Design Using Vertically Installed Planar Circuit with Partially Removed Ground Plane” *Journal of KEES*, vol. 16, no. 7, pp. 661-670, July 2005.