

Linear Power Amplifier with Second-Harmonic Short at Load Termination

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Abstract

This paper investigates the effect of second harmonic short termination at the load on PAE and linearity of CDMA handset power amplifier. The termination is applied to a linear power amplifier and the performances of the two amplifiers are compared. The implemented HBT MMIC power amplifier with the second-harmonic short exhibits a power gain of 25 dB, a power-added efficiency of 45%, and an ACPR of -42 dBc at 28 dBm output power under an operation voltage of 3.4 V and a P1 dB is also 28 dBm. The PAE is improved by 5%, from 40% to 45% for the same conditions.

1. Introduction

Advanced multifunctional handsets require high efficiency power amplifiers with a low supply voltage. Since the power amplifiers are the highest power consumption component in portable equipment, the efficiency is directly related to the limit on talk time or battery life. For the power amplifiers of code-division multiple access (CDMA) type modulation, linearity is the most important figure of merit. In this system, highly efficient linear amplifiers are required instead of saturated amplifiers. In order to obtain the high efficiency, various types of power amplifiers have been reported [1]-[2]. In particular, several power amplifiers equipped with a second harmonic short at the input and/or output to increase their efficiency have been reported [3]-[4] but, the explicit comparisons between the normal amplifier and the second harmonic shorted one were not reported yet. In this letter, we have demonstrated a second harmonic short at the load of the CDMA power amplifier. The power amplifiers demand a lower adjacent channel power ratio (ACPR) performance in order to minimize spectral regrowth and to maintain modulation accuracy of the transmitter. We have found that the second harmonic short at the load increases linearity as well as efficiency.

2. Circuit Design

The schematic of the designed power amplifier is shown in Fig. 1. It consists of a driver stage, a power stage, an inter-stage matching, input and output matching networks, and bias circuits for the two stages. The output matching network and harmonic short circuit are off-chip and are implemented using inductors including bond wires, capacitors and transmission lines. The output matching network is determined by ADS simulation of the power amplifier using the

HBT power cell model provided by foundry. The short is implemented using series L-C resonator at the output of the amplifier with the resonant frequency equal to the second harmonic. As shown in Fig. 2, the magnitude of the second harmonic load impedance is nearly zero. By the harmonic suppression at the output by the harmonic short, the current waveform is shaped to a half sine wave as seen in Fig. 3. This half sine wave current waveform reduces overlap with voltage waveform. Therefore, this class F-like behavior improves power amplifier efficiency. It is well known fact that the 2nd harmonic short improves linearity of an amplifier [5], and the configuration improves simultaneously the linearity and efficiency.

3. Chip implementation and measured results

A two stage HBT MMIC power amplifier is designed and fabricated using an AlGaAs/GaAs HBT technology in WINSEMI's commercial HBT process. The die micrograph is shown in Fig. 4. The 1.0x1.0 mm² die is mounted directly on FR4 PCB. A 2x40 um² x 10 unit-cell HBT is used for the drive stage, a 2x40 um² x 64 unit-cell HBT for output stage. To reduce RF power loss, output matching circuit and LC resonant circuit for the second harmonic short are off-chip components. To get high efficiency performance, we gradually lowered the bias point to get the lower limit of ACPR=-42 dBc, which is the specification of CDMA system. Without the 2nd harmonic short, we could get a 40% PAE at an output power of 28 dBm with class AB operation at the ACPR condition. With the 2nd harmonic short, we could operate the amplifier at a lower bias point than the amplifier without the 2nd harmonic short under a similar ACPR condition, which implies that the 2nd harmonic short improves the efficiency of the amplifier. Gain, PAE, and ACPR of the amplifiers are measured at V_{cc}=3.4 volt for reverse-link IS-95A signal with a chip rate of 1.2288 Mcps at Korean cellular band (center frequency=836.5 MHz) and are depicted in Fig. 5 and 6. The power amplifier exhibits a P1 dB of 28 dBm, a power gain of 25 dB, and power-added efficiency of 45% - 5% higher than that of the amplifier without the 2nd harmonic short at an ACPR of -42 dBc.

4. Conclusions

Through the 2nd harmonic short at the output, we could improve the linearity as well as efficiency. In this paper, the first explicit comparisons between the amplifiers with and without second

harmonic short were achieved. With the 2nd harmonic short, bias point could be lowered than an amplifier without 2nd harmonic short for the similar ACPR condition. It is due to the class F-like current waveform shaping. PAE of the power amplifier with the 2nd harmonic short is increased about 5% compared with the amplifier without the 2nd harmonic short. The efficiency of the power amplifier is as high as 45% with ACPR less than -42 dBc at an output power level of 28 dBm.

5. References

[1] Jiang Cao, *et. al*, "A two stages MMIC CDMA Power Amplifier using harmonic load pull simulation technique," *Microwave Conf.*, 1999 Asia Pacific, 1999, pp. 437 – 440.
 [2] Thomas Fowler, *et. al*, "Efficiency improvement techniques at low power levels for linear CDMA and WCDMA power amplifiers," *IEEE 2002 RFIC-S.*, Dig., pp. 41-44.
 [3] Arvind Raghavan, *et. al*, "A 2.4 GHz high efficiency SiGe HBT power amplifier with high-Q LTCC harmonic suppression filter," *IEEE MTT-S Int. Microw. Symp. Dig.*, 2002, 2, pp. 1019 – 1022.
 [4] Marco Spirito, *et. al*, "Power amplifier PAE and ruggedness optimization by second-harmonic control," *IEEE J. Solid-State Circuits*, 2003, 38, (9), pp. 1575 – 1583.
 [5] Woonyun Kim, Sanghoon Kang, Kyungho Lee, Minchul Chung, Youngoo Yang, and Bumman Kim, "The Effects of Cbc on the Linearity of AlGaAs/GaAs Power HBTs," *IEEE Trans. Microwave Theory and Tech.*, 1995, 49, (7), pp. 1270-1276.

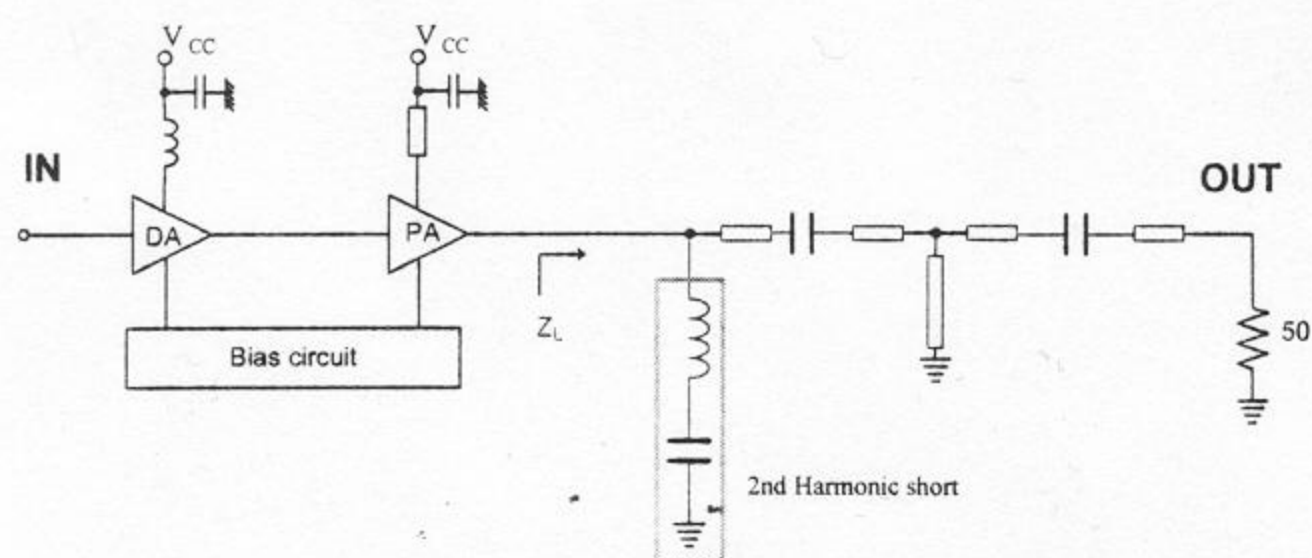


Fig. 1. Schematic of HBT power amplifier with second harmonic short at the load

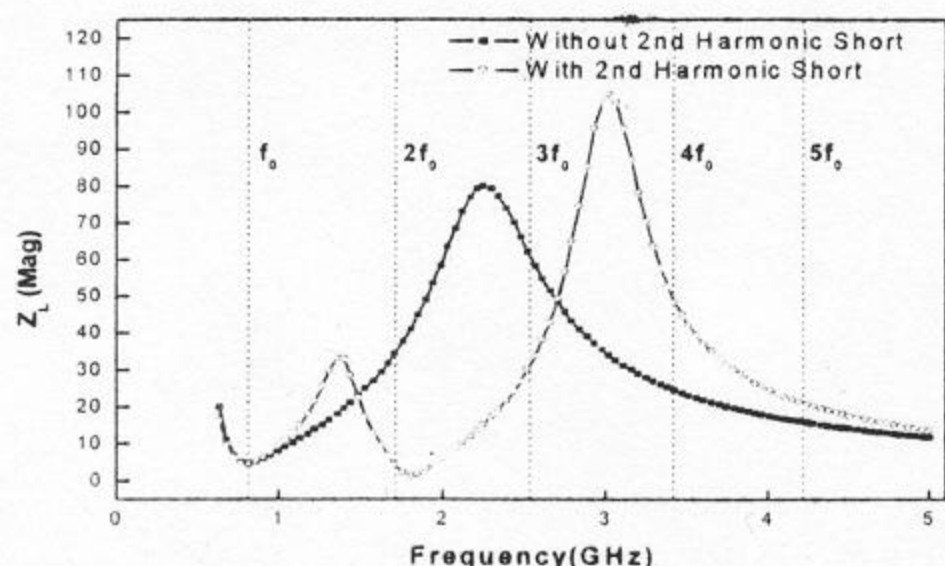


Fig. 2. The magnitudes of load impedances with and without harmonic tunings

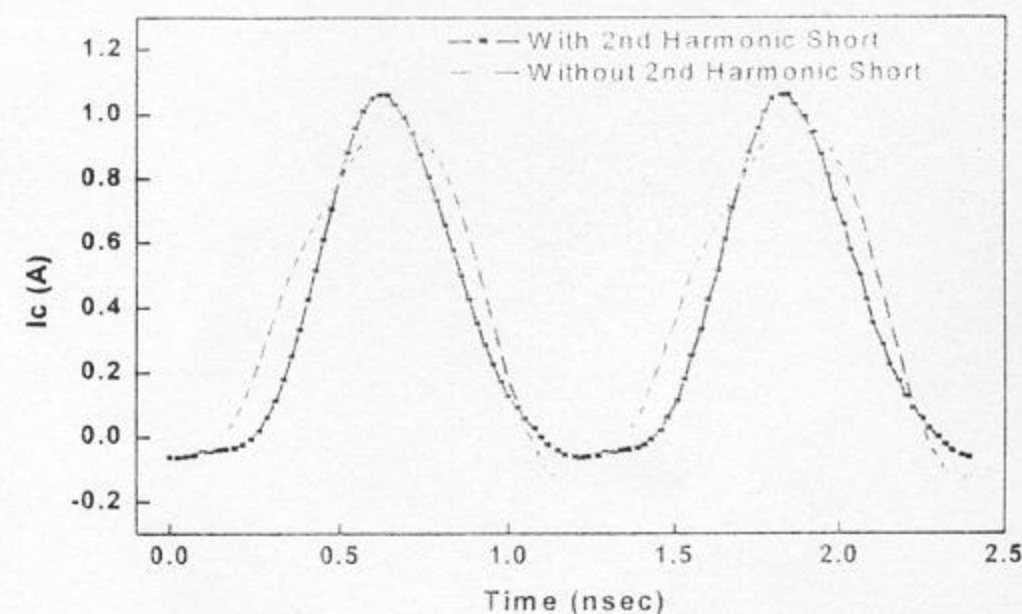


Fig. 3. Collect current waveform with and without the second harmonic short at the load

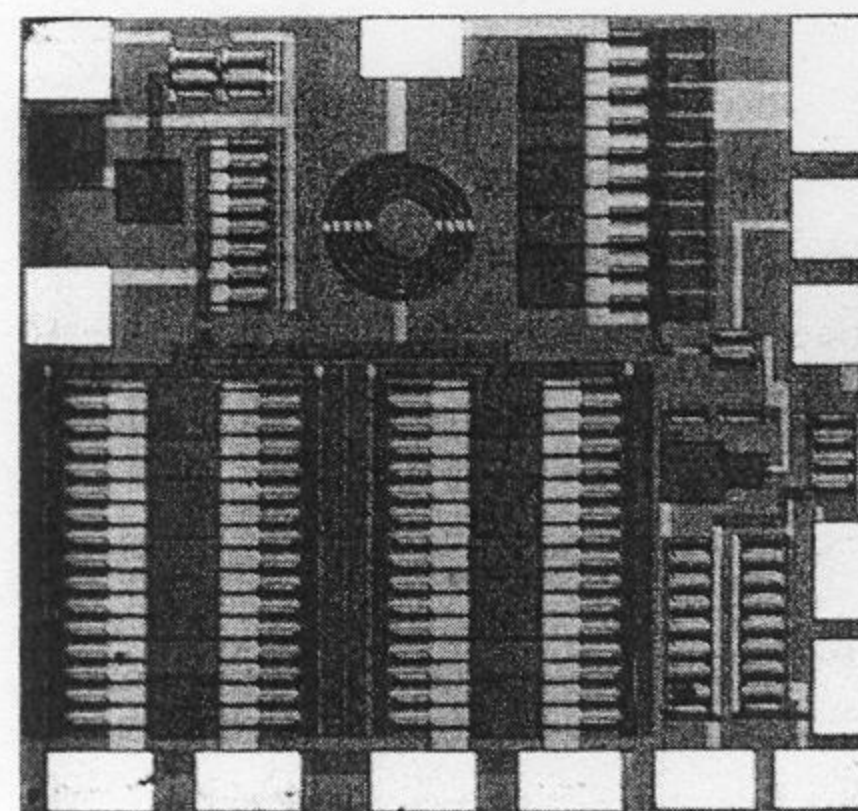


Fig. 4. Die micrograph

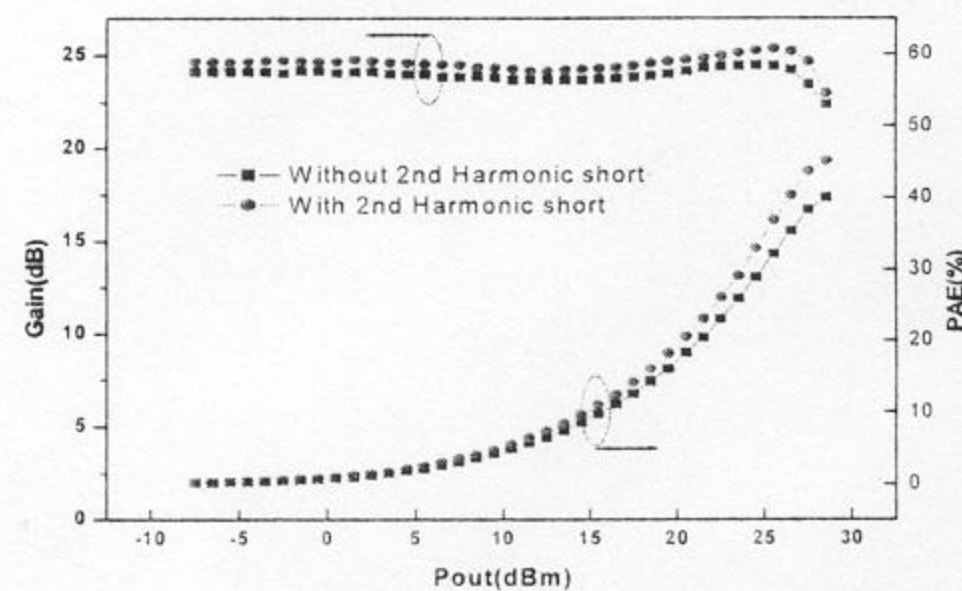


Fig. 5. Gain and PAE of the HBT power amplifier

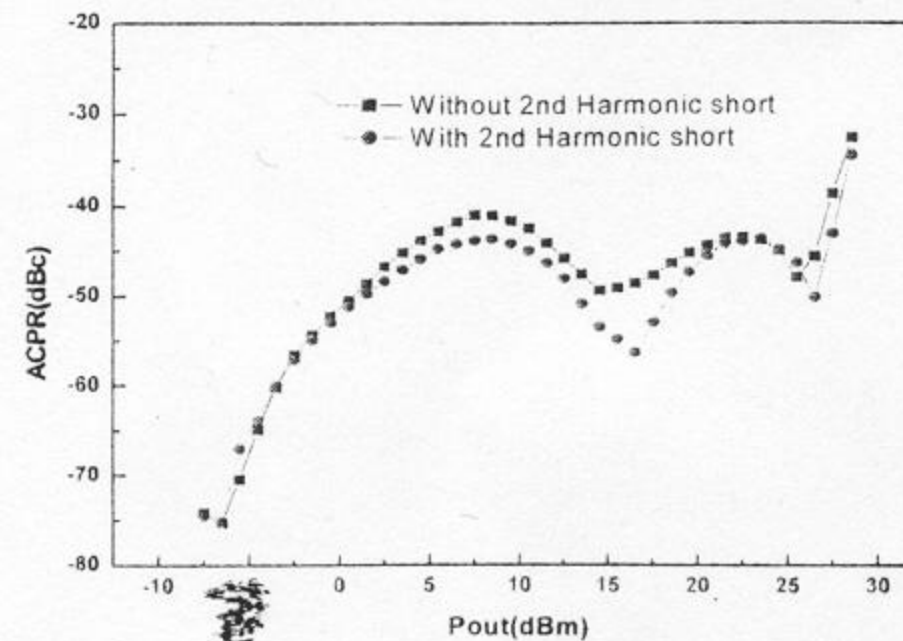


Fig. 6. ACPR of the HBT power amplifier