Thermal Power Reuse in Power Amplifier Design

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***Abstract* — We report in this research alternative efficiency enhancement for power amplifier (PA) with thermal power reuse. Unlike the conventional efficiency enhancement techniques such as switching-mode, Doherty, or Chireix PAs, thermal power generated by the transistor itself is converted by a thermoelectric generator into DC power. It provides electronic insulation between the transistor and the heat sink. More importantly, it provides a "non-circuit" approach that could be further combined with "circuit" approaches to achieve a high efficiency power amplifier for various applications.**

***Index Terms*—Power added efficiency (PAE), power amplifier, and thermoelectric generator**

I. Introduction

POWER AMPLFIIER (PA) is an indispensable component in both wireless communications systems and radio frequency (RF) therapy systems. It is also the most power consuming component in such systems. The PA's efficiency will largely influence the efficiency of the whole system. Besides, for portable devices, smaller battery could be used if higher system efficiency is achieved with the same working time per charge. Therefore, many efforts have been put in increasing the efficiency when designing a PA, in which the common ways mainly focus on the circuit techniques and transistor technologies. Class-E and -F PAs utilize the advanced impedance matching networks, while Doherty and Chireix PAs utilize the multi-transistor arrangement [1]-[3]. Moreover, gallium nitride and silicon carbide transistors have been proposed as the two latest transistor technologies for PAs and successfully commercialized [4]-[5].

Without doubt, PA consumes most of the DC power in any system. Nowadays, "green" becomes a very important issue in any research field, and RF and microwave engineering has no exception. The efficiency of a PA is measured by power added efficiency (PAE), which represents the conversion efficiency of DC power to the increase of RF power. As illustrated in Fig. 1, if the PAE is 40%, 60% of DC power is wasted and is converted to thermal power or heat. Large heat sink is attached on the transistor especially for the PAs in the base-station. The heat of the transistor(s) in the PA has to be discharged, otherwise the transistor will be burnt because of the high temperature. We propose a method that the wasted heat could be reused to generate DC power. This DC power can supply the PA itself or other electronic component in the system and in this way the overall efficiency of the whole system can be improved.

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II. Implementation

For the high power transistors, packages are well designed. The soldering pad of either emitter or drain is enlarged so that

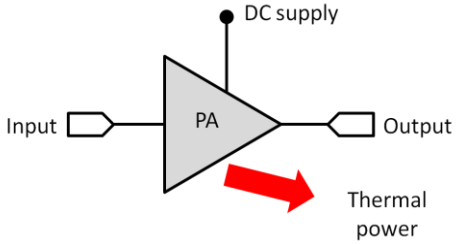

Fig. 1. Power amplifier with input signal port, output signal port, and biasing terminal. The thermal power or the heat of the transistor has to be discharged.

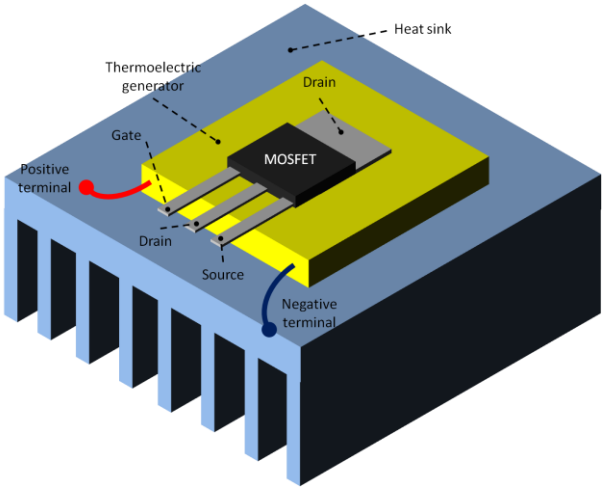

Fig. 2. Diagram of the arrangement of transistor, thermoelectric generator, and heat sink in this study.

it is easy to be attached on a heat sink. The heat sink should be large enough to maintain at around room temperature. In normal PA operation, heat is generated by the transistor and the temperature different between the pad and the heat sink is created. Heat is conducted from the transistor to the heat sink by the principle of thermodynamic.

Thermoelectric generator is a piece of the semiconductor device with p-doped and n-doped semiconductors and based on the principle Seebeck effect [6]. It generates DC power by the temperature difference between the two sides of the thermoelectric generator. In this study, a piece of thermoelectric generator is attached between the transistor and the heat sink is shown in Fig. 2, where the package of the transistor is a standard thought-hole package TO-220. Heat sink use aluminum alloy as the material and has uniformly straight fin arrangement.

III. PA Design

A single-ended PA is designed to verify the concept and its

circuit diagram is shown in Fig. 3. The central frequency is chosen at 10MHz. A low cost MOSFET for switching purpose is used and its model number is International Rectifier IRF510. This MOSFET is chosen since its cost is much lower than that of any RF MOSFET. Two transformers with ferrite cores are used as impedance matching networks. The package of the MOSFET is a standard thought-hole package TO-220. The metal tab with a hole that is one of the two drain terminals is mounted on heat sink. Conventionally, a piece of spacer with thermal conductance and electric insulation is placed between the metal tab with a hole and the heat sink. It is a must since the piece of spacer not only electrically isolate the component from the heat sink but also conduct thermal power from the MOSFET to the heat sink. In this study, a piece of thermoelectric generator is used to replace the piece of spacer. Fig. 4 shows the measured PAE against output power with different biasing voltages.

All the peak PAE is about 50%. In every measurement, temperature different as well as generated DC power increases with time. After about 30 seconds, the temperature difference as well as generated DC power become constant.

The DC power generated by the thermoelectric generator could be applied to three different ways:

The first and also the straightest way is to use the reusing thermal power to supply other electronic component. The ground terminal of the thermoelectric generator is floating. The thermoelectric generator is considered as independent DC power source for external electronic devices.

Secondly, the reusing thermal power is stored in a rechargeable battery that can be commonly found in portable devices. The rechargeable battery in the portable device is charged by external DC source. The role of the reusing thermal power is assisting the DC source such that the working time per charge will become longer.

Thirdly, the reusing thermal power is used to re-bias the MOSFET in the PA. It also serves as assisting DC supply for the PA. An isolated DC-DC converter with dual-input and single output is required for this application. The dual-input is connected to the thermoelectric generator and the external DC source. The output is connected to PA's biased port. The DC power consumption from external DC source becomes less and therefore the PAE of the PA module will become higher.

IV. Near Career Plan

Upon my graduation from City University of Hong Kong, I am now pursuing M.Eng degree in Cornell University in the U.S. MTT-S scholarship will motivate me to continue my career in the research field and help lighten my work by allowing the publication of this paper in the MTT-S website. I appreciate it that MTT-S can also support me in covering part of the expenses for my travel to MTT-S IMS conference. It will be an excellent opportunity to join the most prestigious microwave conference in the world and to meet with many scholars in this field.

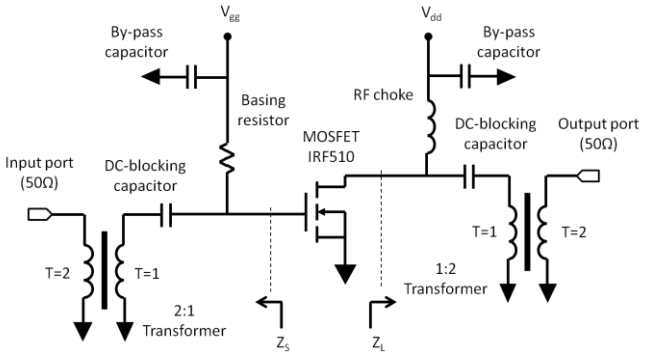

Fig. 3. Circuit diagram of the 10MHz PA in this study.

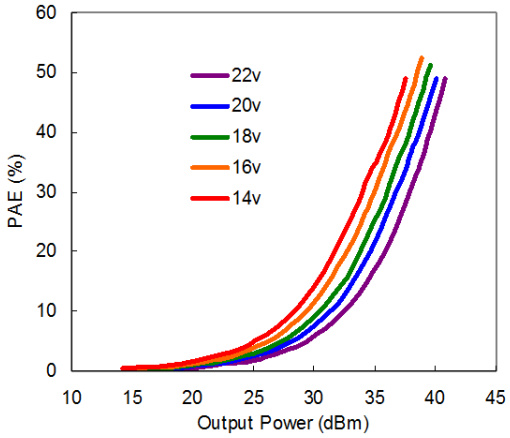

Fig. 4. Measured PAEs against output power of the PA with different biasing voltages.

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