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Novel Ballast Resistor Network for Power Amplifier Design

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Abstract—A novel ballast resistor network is proposed to achieve a better thermal management in HBT power cells without degrading the RF performances. Experiments were conducted on two HBT power amplifiers. They occupy same area. One was designed using conventional ballast network. The other uses proposed novel network. Temperature comparisons were made based on the same current density. Infrared camera images show that a more uniform temperature distribution is obtained in novel ballast network power amplifier. Our results demonstrate that the proposed novel ballast network has promising applications in high power amplifiers.

Index Terms—Ballast resistor, thermal management, HBT

I. INTRODUCTION

THE development of wireless communications requires higher output power and higher current density operations. The advances of InGaP/GaAs heterojunction bipolar transistor (HBT) technology in the past decades have made these possible and practical. To achieve power on the order of watts, the general way is to connect many HBT unit cells in parallel. However, the thermal effect is more serious in HBTs than that in silicon BJTs, particularly in multi-finger HBTs [1]. A different form of current crowding, named thermal runaway or hot spot occurs when the parallel cells do not have identical heat sinks [2-4]. The cells in the center of an array tend to operate at a higher temperature than those at the edges of the array. As temperature rises, the turn-on voltage of base-emitter junction is smaller. Hence, more collector current will flow in the center cells, generating more heat. A positive feedback is formed. The thermal conductivity of GaAs material is only about 1/3 that of silicon, which makes this situation more critical. Eventually, this leads to a catastrophic failure.

One popular method to reduce the HBT's thermal effects is to implement an emitter or/and a base ballast resistor at each HBT unit cell. If collector current gets increased due to the rise of temperature, the voltage drop over the ballast resistor is increased too. Thus the voltage falls between base and emitter is reduced, the collector current is decreased therefore. The

base-emitter junction voltage, which determines the collector current, is automatically controlled against thermal runaway by the ballast resistor.

Using this network, the thermal runaway problem is alleviated in HBT cells. However, people always keep seeking new ways to achieve a better thermal management.

II. PROPOSED NOVEL BALLAST NETWORK

In this letter, we propose a novel ballast resistor network to alleviate the thermal effects in HBTs in a better way than the conventional network. The schematic of our design is shown in Fig. 1. We rearrange the conventional base ballast resistors into a tree-like structure. A base ballast resistor is connected to each HBT unit cell with a smaller value. Then every two such adjacent branches merge into one with another ballast resistor, and so on and so forth until connect to biasing source. The effective resistor looking from each HBT unit cell towards biasing source is still the R_B in the conventional network.

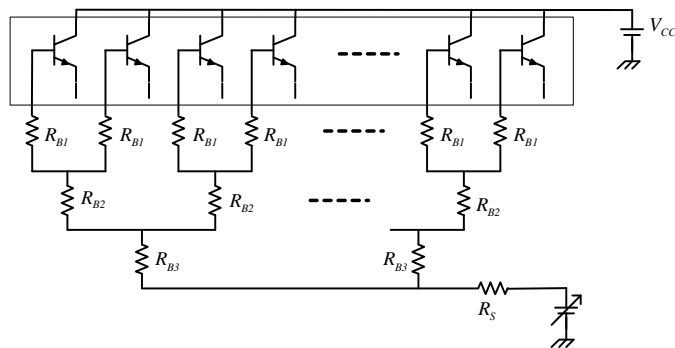


Fig. 1. Proposed novel ballast resistor network.

In the conventional network, the base ballast resistor is owned by its corresponding HBT unit cell. In the novel network in Fig. 1, each unit cell interacts the adjacent cell by the ballast resistor in upper level. Then each pair affects their neighboring pair by the resistor in upper level. So on and so forth, the coupling network is formed through this distributed network. If there is a temperature rise in one HBT unit cell, the heat can be more easily dissipated through this strong-coupling network by adjusting the current flowing in different cells. Thus, a more uniform temperature distribution will be expected in this novel network than the conventional one at same operating conditions. A lower peak temperature will be realized in the novel network. This will improve the device reliability as well as its

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mean-time-to-failure.

Since the equivalent base ballast resistor value, looking from the transistor towards DC biasing source, is not changed, the RF parameters f_s, f_{max} are not affected. Thus, this novel network will not degrade the RF performances. In addition, the RF signal arrives at each cell using same transmission time. The network can uniform the distribution of RF signal.

III. SIMULATION AND EXPERIMENT RESULTS

A simulation of temperature distribution was performed in COMSOL. To save the simulation time, a string of 8 transistors under two different ballast networks is used. The result is shown in Fig. 2. It shows that under same operation conditions, a more uniform temperature distribution is achieved in novel ballast network.

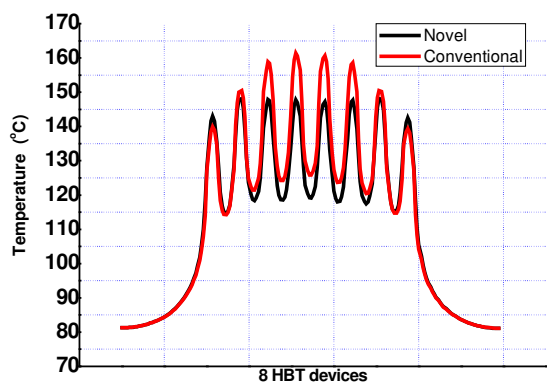


Fig. 2 Temperature variations in both networks measured at one current density, simulated by COMSOL.

To further verify our expectations, HBT devices designed respectively in those two different ballast resistor networks were prepared. The conventional ballast resistor network consists of 36 transistors. The novel one consists of 48. Both of them occupy same area.

The temperature images and profiles were obtained by infrared camera at MEFAS Inc. (www.mefas.com). We compare the temperature distributions between two networks under the condition that same current density in collector terminals. The collector voltage is biased at 3.5V in all the tests.

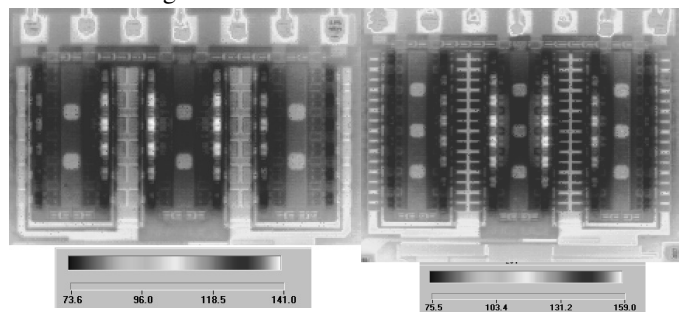


Fig. 3 Thermal images of conventional network at $I_c=375\text{mA}$ (left) and novel network at $I_c=500\text{mA}$ (right).

Four different collector current densities were applied in the

two ballast resistor networks respectively. Their thermal images were taken, shown in Fig. 3.

A line is cast through the transistors in the center row from top to bottom to read the temperature among the transistors in this row. One temperature profile figure is shown in Fig. 4.

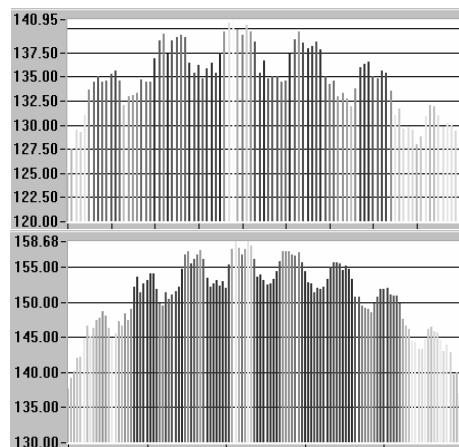


Fig. 4 Conventional network temperature profile of transistors in one row (upper) at $I_c=375\text{mA}$; Novel network temperature profile of transistors in one row (bottom) at $I_c=500\text{mA}$.

The highest and lowest temperatures in the transistors were read. The temperature variation is calculated as dividing the temperature difference by the minimum temperature, shown in Fig. 5. Note that infrared camera will enter saturation and be unable to detect higher temperature if current density is further increased.

At same collector current density, an almost same temperature variation is achieved in both ballast resistor networks. Considering the fact that novel network consists of more transistors than the conventional one in the same area, we claim that our proposed novel network achieves a more uniform temperature distribution than the conventional one.

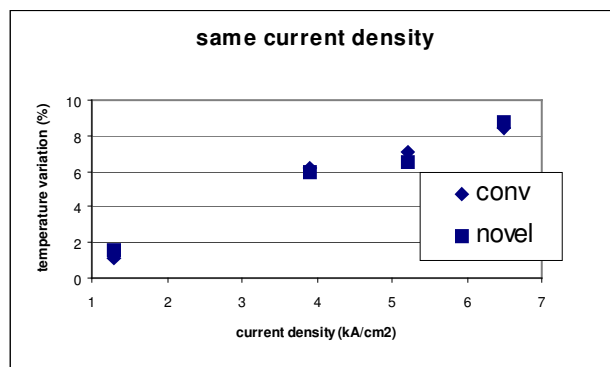


Fig. 5 Temperature variations in both networks measured at four different current densities, by experiments.

IV. CONCLUSION

In the proposed novel ballast resistor network, both DC and AC signals are fed into each transistor at same transmission length. While in the conventional one, it is not the case. Verified

by the experiments, the novel network not only stabilizes the thermal operation of the power cells, but also realizes a more uniform temperature distribution. This will improve the device reliability as well as its mean-time-to-failure. Also, die area is not compromised by capacitor layout area reduction in the novel network.

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