Variable-Load Constant-Efficiency Power Amplifier for Mobile Communications Applications

Giorgio Leuzzi, Claudio Micheli

University of L'Aquila, Department of Electrical Engineering, Monteluco di Roio, 67040 L'Aquila, Italy, +39.0862.434444

***Abstract* — A SiGe HBT Class-B power amplifier has been developed with a voltage-controlled variable loaf, for constant efficiency also a low power levels. The output matching network includes varactor diodes that can change the load impedance at the collector of the transistor. The load line can therefore be adjusted to provide a variable output power saturation level, shifting the peak of the efficiency to the desired power level. Constant efficiency over a wide input power range is obtained. This amplifier minimises power consumption for variable output power applications, as required in mobile communications systems.**

I. INTRODUCTION

Mobile communications systems operate at variable output power, depending on the distance from a base station. However, power amplifiers have maximum efficiency when the output power is close to the saturation, while efficiency decreases dramatically for decreasing operating power levels. For low power consumption and maximum battery life it is desirable that the output power amplifier of a mobile communications system keeps a constant efficiency within a wide range of operating power levels.

Two approaches have been demonstrated so far ([1] and references therein): an adjustment of the drain or collector supply voltage of the amplifier, and a switch between two impedance levels of the load. Both arrangements shift the power level where the saturation of the amplifier occurs: in the first case the load line is shifted to the left on the I/V plane of the output characteristics of the transistor (fig.1); in the second case, the slope of the load line becomes less negative (fig.2). In both cases, saturation occurs at a lower input (and output) power level, and so does the peak of the efficiency. Both approaches however have drawbacks: in the case of a variable drain or collector supply voltage, a high conversion efficiency variable power supply is required. In the second case, a low-loss switching network is required between the drain or collector of the transistor and the two output matching networks.

In this paper, a new approach is proposed: a variable matching network including voltage-controlled varactors is used to vary the impedance level of the output load, and therefore the slope of the output load line, yielding a variable saturation power and therefore constant peak efficiency within a range of operating power levels. An application to a SiGe HBT amplifier in hybrid form, using commercial components only, is also shown as a demonstration of the feasibility of the approach.

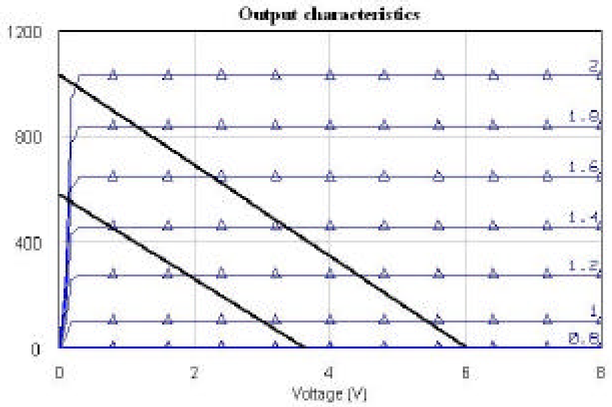

Fig. 1. Load lines for variable collector or drain supply voltage.

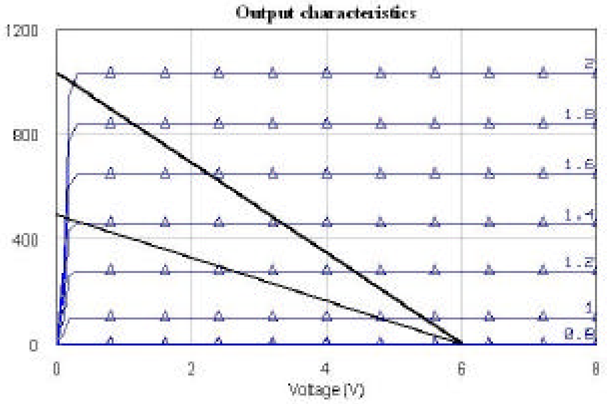

Fig. 2. Load lines for switched matching networks.

II. THE VARIABLE MATCHING NETWORK

A viable topology for a variable-load output matching network is shown in fig.3a. A p-network configuration transforms the 50O external load into the optimum load as required by the drain or collector of the transistor for maximum output power or maximum power-added efficiency. Obviously, the value of the optimum load depends on the operating power level. Therefore, a variable transformation must be implemented. This is obtained by means of variable shunt capacitances, that can be practically obtained by means of varactor diodes with variable reverse-bias voltage, controlled by external circuitry (fig.3b). In this arrangement however the RF voltage swing across the varactors is very large, causing a periodic change of the capacitance, and possibly even forward conduction, with consequent distortion of the signal.

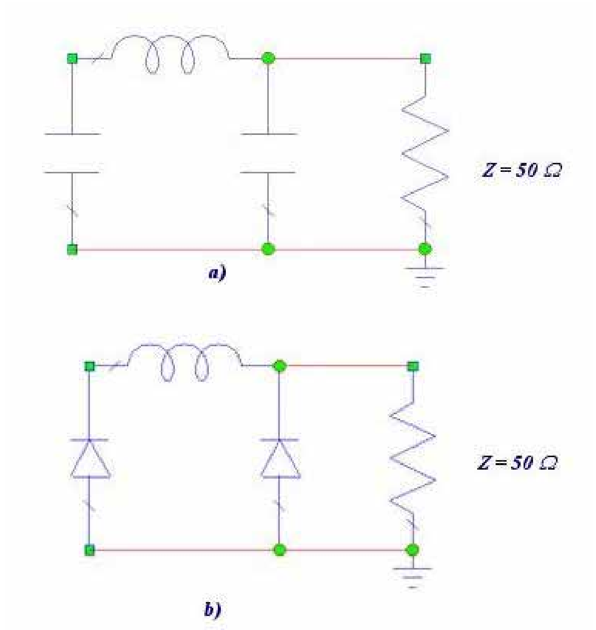

Fig. 3. A variable-capacitance matching network (a) and a practical implementation (b).

An alternative topology for the p-network is shown in fig.4a. The variable inductances are practically obtained by means of variable capacitances followed by a quarter-wavelength impedance transformer (fig.4b). The characteristic impedance of the ?/4 transformers must be low enough, so that the voltage swing across the variable capacitances is substantially reduced with respect to the voltage swing at the drain or collector of the transistor. This ensures that the capacitance of the varactors be almost constant in time, and that no distortion takes place. The quarter-wavelength transformers is synthesised by means of lumped elements when the operating frequency is low, in order to reduce the actual size of the matching network. Variable capacitances are once more obtained by means of varactor diodes (fig.4c).

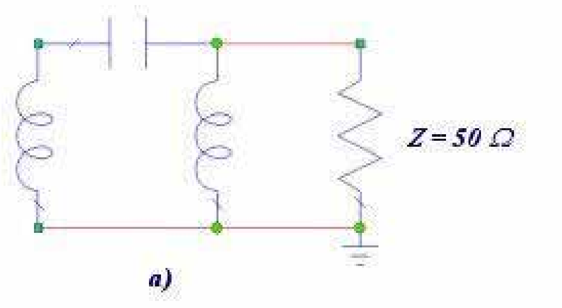

Fig. 4a. A variable-inductance matching network.

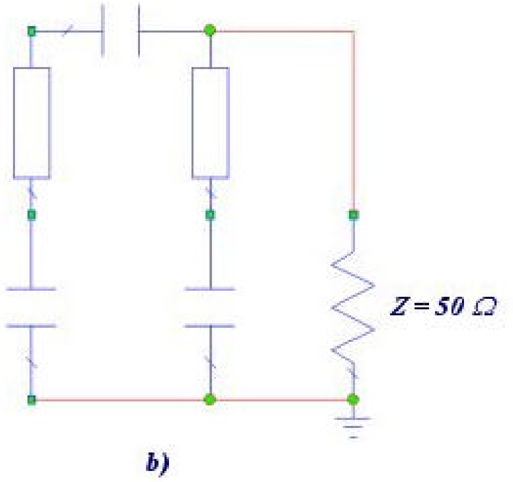

Fig. 4b. An equivalent implementation of the variable-inductance matching network.

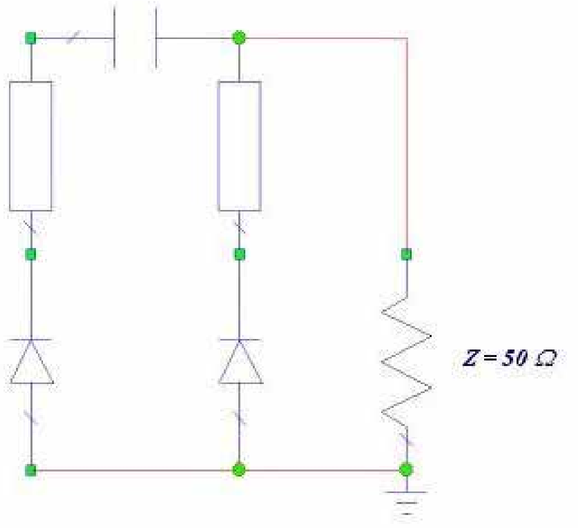

Fig. 4c. A practical implementation of the modified variable-inductance matching network.

III. A PRACTICAL APPLICATION

An example of application has been designed for demonstration of the feasibility of the approach. A packaged medium-power commercial SiGe HBT from Infineon has been used as the active device, at a frequency of 575 MHz, for easy hybrid fabrication. The varactors are commercially-available packaged devices from Infineon as well. In principle, the input matching network should be variable as well, for adaptive input match; however, a constant matching network has proved to be sufficient for reasonably good input match at all power levels of interest.

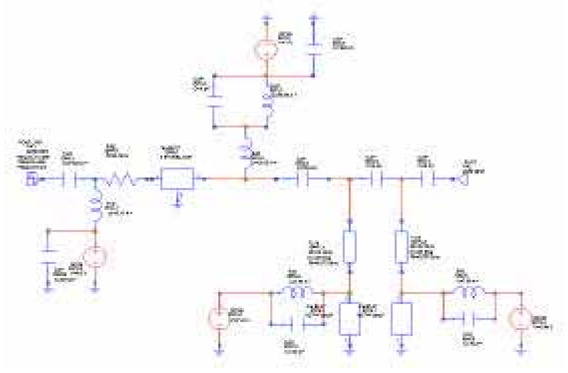

Fig. 5. The schematic of the variable-load power amplifier.

The schematic of the amplifier is shown in fig.5, where the diodes and the transistor are replaced by their nonlinear models; bias and control voltages are also shown. Several packaged diodes are connected in parallel in order to reach the desired capacitance value. A second-harmonic filter shunts the collector node, in order to suppress the second-harmonic voltage for high efficiency. The variable output load line is shown in fig.6 for several control voltages, and the corresponding voltage and current waveforms are shown in Fig.7 and Fig.8 respectively. It is apparent that the collector voltage always spans the maximum range, while the peak collector current depends on the value of the variable load. Simulated output power and efficiency *vs* input power are shown in fig.9 and in fig.10 respectively for different values of the load. Peak power-added efficiency has a constant value close to 60%, when the control voltage is adjusted. The results are Microwave Office simulations, based on nonlinear foundry models for the HBT and the varactors.

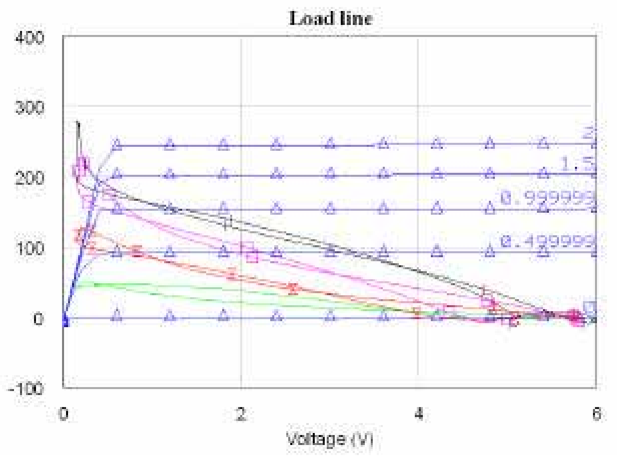

Fig. 6. Output load lines for different control voltages.

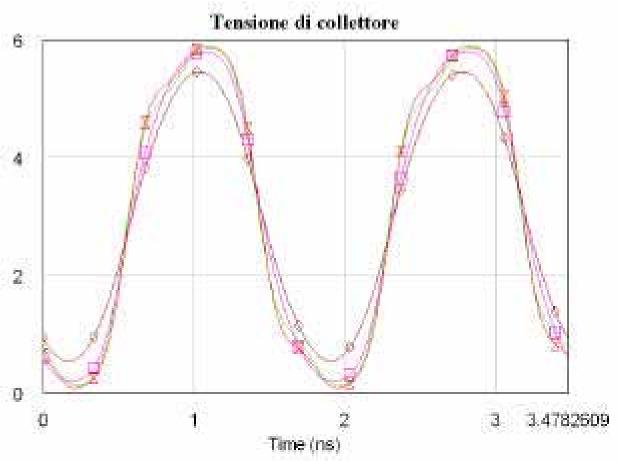

Fig. 7. Collector voltage for different control voltages.

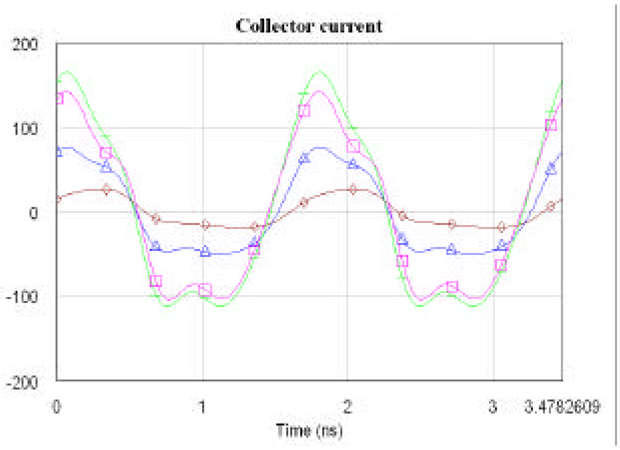

Fig. 8. Collector current for different control voltages.

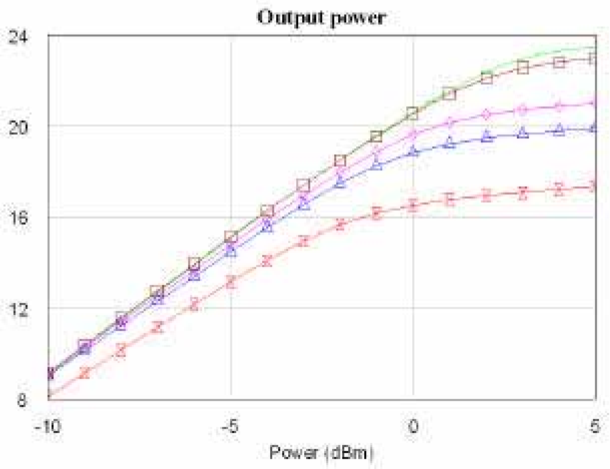

Fig. 9. Output power for different load control voltages.

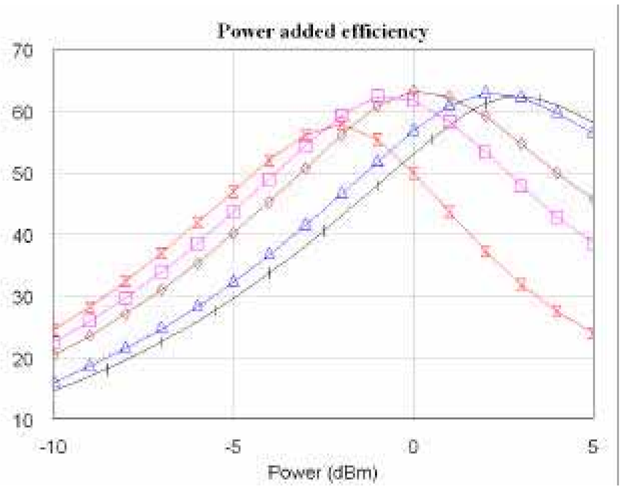

Fig. 10. Power-added efficiency for different load control voltages.

This first example of application demonstrates the capabilities of the proposed approach, and is promising for monolithic applications also at higher frequencies.

IV. CONCLUSIONS

A viable approach for the design of a constant-efficiency power amplifier has been illustrated, that can lead to reduced power consumption for mobile communications applications. A practical example in hybrid form has been designed, that confirms the capabilities of the approach.

REFERENCES

[1] T.Fowler *et al*., 'Efficiency improvement techniques at low power levels for linearCDMA and WCDMA power amplifiers', Proc. of the 2002 RFIC Symp, Baltimore, June 2002, pp.41-44.