A Novel Power Amplifier Module for Quad-band Wireless Handset Applications

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Abstract **— This paper presents a novel power amplifier module (PAM) designed for GSM850MHz, GSM900MHz, DCS1800MHz and PCS1900MHz handset applications. The module combines an InGaP HBT GSM/DCS/PCS power amplifier IC, two integrated couplers, a dual-band logarithmic RF power detector/controller and some additional passive components. The logarithmic RF power detector was implemented in the module to accomplish linear-in-dB output power dependency. The module features closed loop automatic power control, fully integrated impedance matching at input and output ports with DC blocks and plastic encapsulated on a 10mmX10mm GTek substrate. The module offers higher accuracy of output power (*Pout*) control, smaller size, lower bill-of-materials and a shorter *Pout* calibration time to handset manufacturers. Compared with other conventional power amplifier modules in the market, due to higher accuracy our novel design significantly reduces the power consumption during normal operation. It is a very desirable RF PAM to handset designers because of its unique features. Our design makes it possible for the handset manufacturers to calibrate *Pout* at one or two points, with error as low as +/-0.3dB, thus reducing test time in mass production. Under a low single supply voltage of 3.2V, the PAM provides 35dBm output power, 55% PAE in GSM900 band and 33dBm and 50% PAE in DCS1800 band.**

I. INTRODUCTION

As the wireless communication systems migrate to 3G, it is desirable to increase the degree of integration of RF front-end ICs, such as low noise amplifiers (LNA), power amplifiers (PA) modules, SAW filters, duplexers, and T/R switches. RF design engineers are challenged to provide System-in-Package (SIP) solution to customers. This is particularly true for PA modules. The PA module is a challenging device to many designers because of its many strict system specifications and high degree of integration. The PA is the most critical device in the front-end. It determines very important system parameters such as talk time, standby time, cost, and size. It is a great deal of work for handset designers to develop a PA and the surrounding circuitry. This makes the drop-in type of PA module very desirable.

In general, the output power of amplifier versus control voltage is not a well-defined function. It takes the handset designers significant time to calibrate and control the output power. Analog Devices provides a solution to this problem with its logarithmic power detector and PA controller (AD8315 IC). AD8315's unique feature makes it useful in managing *Pout*. Our novel PAM has incorporated the modified version of AD8315 IC.

II. LOG-AMP AND POUT CONTROL

Usually, a transfer function between output power (*Pout*) and control voltage (*Vapc*) of HBT PA is not a linear function. As shown in Fig. 1, the Pout curve is not an easily defined or simple function. This makes it difficult for handset manufacturers to accurately control the output power. Essentially, they have to transform the curve in Fig.1 into a simpler function such as the linear function shown in Fig. 2, $Pout=a*Vset+b$, where a and b are constants that can be determined by a two point measurement. Once a and b are found, *Pout* is easily calibrated because it is a linear function of *Vset*.

A translinear circuit, such as a logarithmic amplifier (Log-Amp), can implement the above transformation. AD8315 was designed based on a logarithmic amplifier. It is a complete sub-system for RF power detecting and controlling. Fig. 3 shows a simplified block diagram of the power detector and PA controller.

The logarithmic amplifier is used to detect the coupled RF power level and produce an output current *Ip*. The control voltage *Vset* is transformed into output current *Iset*. *Iset* is compared with *Ip* to produce an error current *Ie*. *Ie* is then transformed into an output voltage *Vapc*. *Vapc* is used to force the *Pout* to the desired level. Therefore, Pout, in dBm, is always linearly dependant on *Vset*. Fig. 4 demonstrates an ideal closed loop configuration of a single band power amplifier that includes an RF PA, a coupler, a Log-Amp power detector and PA controller. The coupling factor of the coupler must be designed to allow for the maximum dynamic range of the detector.

III. CIRCUIT DESIGN CONSIDERATION

A. PA Design

Our module is primarily designed for a quad-band GSM/DCS/PCS worldwide wireless handset market. Output power for the GSM850, GSM900 bands in a 50Ω system is 35 dBm, for DCS1800 it is 33dBm, and for

0-7803-7694-3/03/$17.00 © 2003 IEEE

PCS1900 it is 31.5dBm. Considering the high gain requirement of about 30dB at full output power levels, a three stage amplifier was designed. The first stage provides linear gain while the second stage provides enough power to drive the third stage, which works, in a deep saturation state. The third stage transistor is the most important element in a PA circuit. It is directly related to the PA performance. For our application, it is designed to provide high power and high efficiency while operating with a low voltage power supply of 3.2V. Our 3-stage PA schematic is shown in Fig.5.

An InGaP HBT process was used for power amplifier ICs. The HBT process offered an advantage of operating with a single low voltage power supply, high power density, and high efficiency. Matching circuits were synthesized with the input and inter-stage matching circuits realized on-chip. The output matching circuit was implemented outside of the GaAs IC on a module substrate to reduce power loss by taking advantage of high-Q ceramic components. The package parasitics were included in the circuit design from the very beginning and bond wire inductances were used to help implement the matching networks.

An RC feedback loop was also employed on-chip to ensure the stability of the PA. The first stage emitter was connected to ground through a bond-wire instead of a via hole to prevent common mode oscillation. Some resistances were provided at the base of each stage to provide more stability for the PA.

Before incorporating the GSM900 and DCS1800 power amplifiers into PAM, their individual performances were investigated using evaluation boards. The output matching circuit was implemented using surface mount components and adjusted for optimum performance. Typical performance of the GSM900 PA with *Vcc* = 3.2V versus automatic control voltage, *Vapc*, is shown in Fig. 6. It is found that the large signal gain is 30dB, *Pout*=+35dBm with 55% PAE. By sweeping Vapc from 0 to 2.8V with Pin=+5dBm, the output power of the GSM900 PA changes from -40dBm to +35dBm. The dynamic range for power control was more than 75dB.

B. Bias Circuit

Much effort was made to design an efficient bias circuit for the PAM. Both amplifiers employ the current mirror biasing schemes in order to provide thermal stability of the amplifiers. *Vapc* provided by AD8315 sets the gain of the amplifier. Because of the current capability of customized AD8315, *Vapc* currents were limited to less then 10mA while PAs were driven to saturation. The current mirror circuit schematic is shown in Fig. 7. This bias circuit provides temperature compensation for the bias current, *Iapc*.

C. Quad-band Module Design

As seen in Fig. 6, the function of *Pout* vs. *Vapc* has quite a steep turn-on region where the output power reaches its maximum with a relatively small change in *Vapc*. It is customary to include external power control circuitry in the handset to linearize the dependence of the PA output power to the control voltage, *Vapc*. This results in increased complexity and cost of system design. Our goal was to include the power management circuitry in the PAM to provide the SIP solution to handset designers. Using our AD8315 we have realized this goal.

The top-level block diagram of the complete PAM is illustrated in Fig. 8. The outputs from the GSM900 and DCS1800 power amplifiers are fed into the off-chip output-matching network. The signal is then coupled into the input of the logarithmic power detector of a customized AD8315. The power control circuitry of AD8315 sets the appropriate *Vapc* to obtain the output power, *Pout*. By design we can adjust the coupling coefficient such that the *Vset* voltage range is from 0V, corresponding to the PA being shut-off, to 2V for maximum output power. Therefore, *Vset* will control the output power of the PA module linearly.

The module was designed for quad-band wireless applications that include GSM850, GSM900, DCS1800 and PCS1900 frequency bands. The band select voltage, *Bsel*, controlled by a logic level signal is used to select the active operating frequency band of the PAM. The entire PAM can be enabled or disabled by the *Enbl* pin.

The output power performance of the multi-chip PAM was measured as a function of the control voltage *Vset* for GSM and DCS/PCS bands. The corresponding curves are plotted in Fig. 9 and Fig. 10, respectively. Both measurements were performed with the input power level set to +5dBm and a power supply voltage of 3.2V. Comparing the graphs in Fig. 6 and Fig. 9 it is obvious that the closed-loop system exhibits perfectly linear behavior. Therefore, our multi-chip PAM does not need any extra circuitry for power management. The active *Vset* range is from about 0.3V to 2V and the linear output power dynamic range for both bands is around 50dB. Fig. 11 shows pictures of the PAM. The size of the PAM is 10mmx10mmx1.5mm. The PAM features a single low voltage power supply, high efficiency, and linear-in-dB output power level control vs. *Vset*. Needless to say, this PAM is desirable for handset designers. It eliminates the need for a power management circuitry, therefore reducing overall size, system complexity, development time and cost.

IV. ASSESSMENT OF POWER CONTROL ACCURACY

To asses the linearity of the output power level versus Vset we plotted an error function defined as a deviation of the real output power from the ideal straight line. Such a graph for GSM900 is shown in Fig. 12. The calculated power (P_{cal}) was obtained by calibrating the output power at 5dBm and 32dBm then solving *Pout=a*Vset+b* equation to obtain *a* and *b*. A slope of the calculated power is equal to 46dBm/V and a corresponding intercept point is -19.1dBm. Thus, the calculated power P_{cal} expressed in dBm is

$$P_{cal} = 46 \cdot V_{set} - 19.1\,(\text{dBm}) \tag{1}$$

The error is then calculated by taking the difference between the actual output power *Pout* and calculated power P_{cal}

$$Error = P_{out} - P_{cal}\,(\text{dB}) \tag{2}$$

As shown in Figs. 9 and 12, the closed loop system maintains linearity error of +/-0.3 dBm throughout the entire power range and the battery voltage range of the GSM system. The high accuracy of output power control provides a lot of benefits to customers. First of all, it reduces *Pout* calibration time because it only needs one or two measurements to finish the calibration, which typically needs more than four measurements for other power control circuitry. Secondly, high *Pout* accuracy allows the customer to control the *Pout* close to the lowest transmit power level, which in turn saves battery life.

V. CONCLUSION

We have presented an advanced multi-chip quad-band PAM with unique linear-in-dB output power dependency from the set point voltage. The module incorporates a quad-band InGaP HBT PA and a state-of-the-art Si RF power detector and PA controller. The presented PAM offers 35dBm and 32.5dBm output power at 900MHz and 1800Mhz respectively. The novel output power control approach exhibits accuracy of +/- 0.3 dB. The PAM also features high efficiency, single positive power supply, single power control voltage, small size, and 50Ω to 50Ω match from input to output terminals. The dimensions of the PAM are 10x10x1.5 mm. We believe that our PAM provides OEMs a simple transmit solution, which will significantly reduce the overall cost and time-to-market for their products.

ACKNOWLEDGMENTS

The authors wish to thank Ray Shumovich, Roxann Blanchard, Eamon Nash and Jelena Madic for technical support.

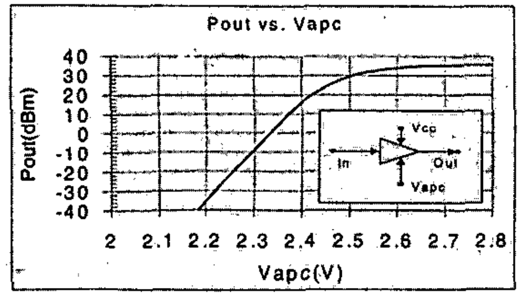

Fig. 1 A typical Pout vs. Vapc

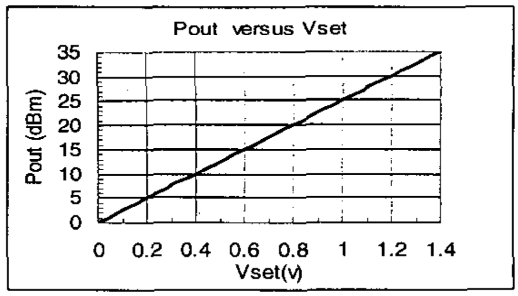

Fig. 2. Linearized Pout vs. Vset transformation

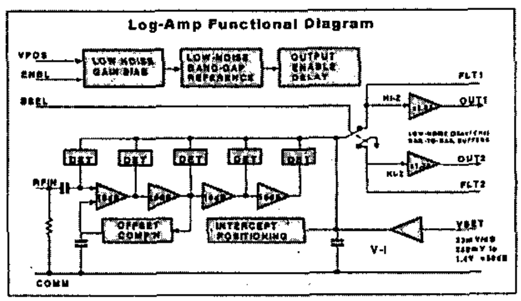

Fig.3 Log-Amp functional diagram

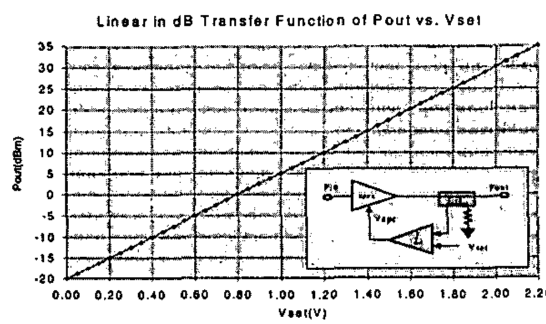

Fig.4 Demonstration of closed loop PA with a Log-Amp Power detect and PA controller

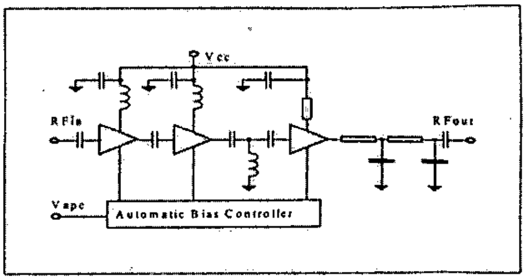

Fig. 5. A block diagram of the presented three-

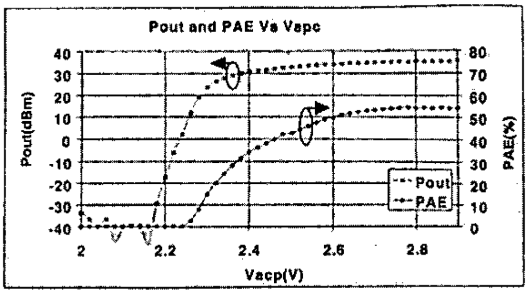

Fig. 6 GSM performance vs. control voltage

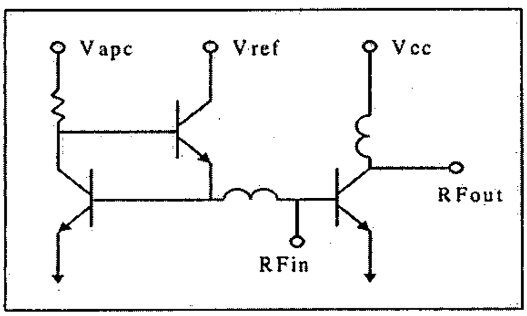

Fig. 7 The current mirror circuit schematic

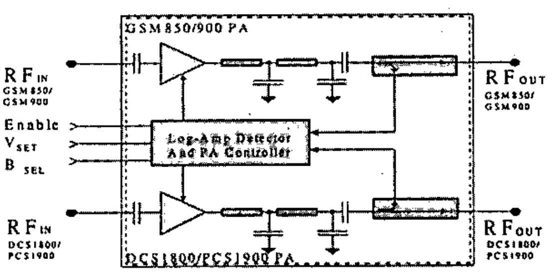

Fig. 8 Simplified schematic of the quad-band PA module

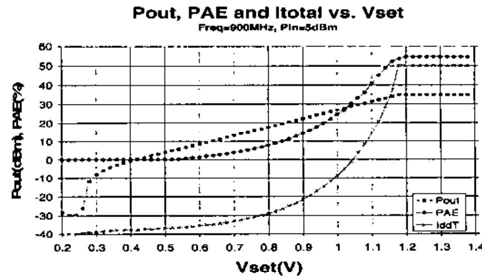

Fig. 9. Output power of the PAM in GSM band as function of the control voltage Vset.

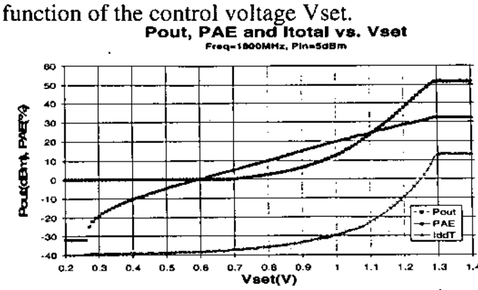

Fig. 10. Output power of the PAM in DCS band as function of the control voltage Vset

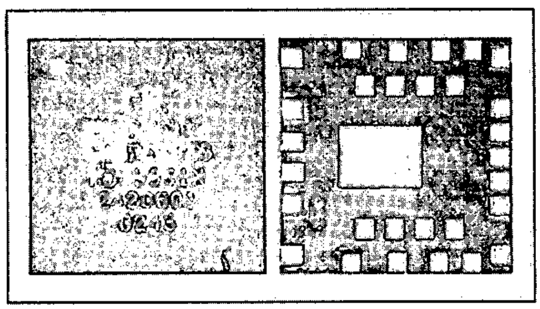

Fig. 11 Top and bottom view of the quad-band PA module

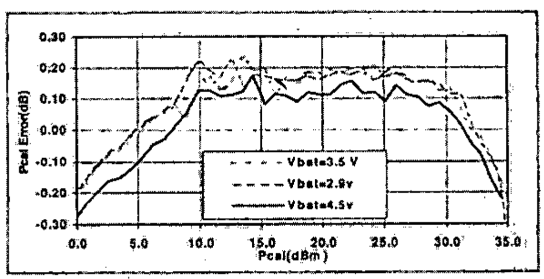

Fig. 12. P_{cal} error versus P_{cal} of the PAM in GSM band at Pin=+5dBm