GaAs HBT PA module design for CDMA handsets

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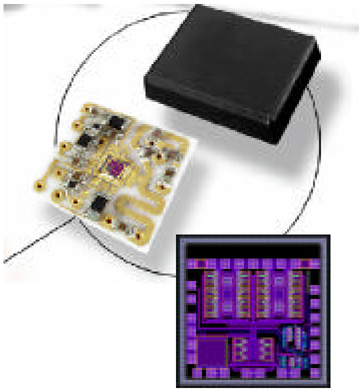
ABSTRACT

The paper describes common issues faced designing GaAs HBT Power Amplifiers for 2G CDMA handsets & how to solve them. Common issues developed are non-linear noise performance, current consumption & ACPR at all power levels, Icq versus temperature, all related to the bias circuit. Then requirements more specific to 2.5G applications are explored, solutions for better Icq control, Efficiency and ACPR performance with temperature & power are proposed.

1. Designing PA for 2G application. Avoiding caveats

1.1 Current module developed, IS95 cellular and PCS devices

In the past year, Philips Semiconductors has developed cellular and PCS IS95 devices using AlGaAs technology and providing 28dBm of linear power with 28dB gain {25dB for the PCS device} in an operating voltage above 3.2V (usually 3.2-4.2V). These modules are hybrid 50 Ohm terminal devices with LGA connection with a form factor of 6x6x1.7cu.mm. LTCC or laminates are used with 0402 SMDs. The AlGaAs die size is 1.25x1.25sq.mm.
Figures 1 and 2 show the RF performance measured on the a device
Figure 4 shows a typical line up using two active stages and the devices matched on the module and on the die. One important feature is the 2^{nd} harmonic trap essential to ACPR performance.



The following list mentions the major specification issues to manage:

- Current IS95 specification requires ACPR < -45dBc/30KHz firm
  - Reduce NL behavior using proper de-coupling & bias circuit
- Output Noise Floor in Rx band (relevant for Rx sensitivity) < -136dBm/Hz
  - Limit noise generated by bias circuit
- Performance over temperature: -30/+110degC mounting base
  - Bias circuit design to regulate Icq with temperature
- Current consumption over “CDG” curves: Nc>33%+@28dBm, Icq<50mA
  - Icq reduction requires multiple operating modes
- Harmonics in AMPS mode: H2,H3<-35dBc
  - Harmonic loading and traps required for improved linearity

1.2 On the importance of the bias circuits

Figure 3 shows a typical bias circuit used. It provides a compromise between linearity performance, temperature compensation and noise. The bias circuit also needs to accommodate several operating modes for high and low power operation, this is required for efficient operation over a wide range of power levels, typically for CDMA systems the dynamic range is on the order of 60dB. There are several limitations that need to be accounted for: The Vbe and hfe variations with temperature as well as the Vbe stack-up (only 2*Vbe are possible with a 3V supply). The resistor between the emitter follower and the diode is essential to a balanced performance at all temperatures. In most cases there is an additional current mirror that feeds back the current to the base of the emitter follower circuit to have a better temperature behavior; without it wouldn’t be possible to meet all requirements at the same time.

1.3 Designing for Noise

The disadvantage of the bias circuits described is that, for the 1^{st} stage, the emitter follower transistor that is driving the current to the RF transistor generates a lot of noise (figure 3). By properly adjusting the value of the buffering resistor between the emitter follower and the diode, it is possible to reduce the noise contributions (figure 5). However, increasing this resistor too much is detrimental to the linearity performance and also has an effect on the temperature characteristics of the bias circuit.
The following table shows two devices that have been built and compared with simulation. The measured noise floor was very close to the simulated value.

R value (1^{st} stage)	5 Ohm		60 Ohm
Measured Noise power	-132.3 dBm/Hz		-136.1 dBm/Hz
Simulated Noise power	-132.4 dBm/Hz		-135.1 dBm/Hz
Highest contributors	Q-Emit.follower biasQ1-himod	~25nV	**Not significant**
	Ballast resistor for Q1	~10nV each	Same
	Bias roes, biasQ1-himod	~9nV	**Not significant**
	Q-Emit.follower biasQ1-lomod	~9nV	**Not significant**
	RFQ1 – 1st stage	~7nV each	Same

1.4 Designing for a low Icq (and high efficiency) at all power levels

As the provided histogram shows (figure 6), in a CDMA system the power generated by the PA is low most of the time (power level mode centered around 0~5dBm). This shows the importance of designing for a low Icq. We have done so by designing PAs with several operating modes allowing for a low Icq while still meeting ACPR at the higher power levels. Another method that can be used to reduce dissipation at lower power levels is to use a DC/DC down converter, which adjusts Vcc as a function of power level. As can be seen on figure 6, the dissipation at lower power levels is significantly lower when using the DC/DC converter compared to operating at a constant battery voltage (3.2V in the provided measurements). The resulting average power dissipated can significantly improve the handset talk time. As the following table can show/ (Note that in those measurements we have used a PA version optimized and tested for a higher 30dBm power level. The battery life increase is hypothetical and was computed for a handset dissipating 1W without the PA).

P is the average power used by the PA	Suburban operation	Urban operation
Operation stand-alone, Vcc=3.2V Vref=2.8V constant	P=1.21W	P=1.13W
Operation varying Vcc optimized with TEA1210TS DCDC converter	P=.31W Battery life increase by 69%	P=.16W Battery life increase by 84%
Operation stand alone, Vcc=3.2V, varying Vref to optimize Icq	P=.48W	P=.33W

2. The future of PA for mobile phones: A 2.5G solution

2.1 2.5G and implications to future PA development

1XRTT is the first phase of CDMA2000 (2.5G in the US). It is a CDMA system using the same spreading rate as IS95 and many PA features will remain applicable.

One of the consequences of 1XRTT is that the PA will not be punctured as in IS95, to allow for data transmission as well as voice. The importance of reducing Icq will be greatly increased to achieve a good battery lifetime.

The other consequence comes from the use of HPSK, which has a higher pk/avg ratio under some conditions. For a dedicated-only channel the pk/avg ratio is 5.4dB (@99%) against 3.8dB for IS95. The higher pk/avg ratio will make it more difficult to meet higher efficiencies and the required ACPR at the same time.

Those two consequences will require Power Amplifiers to use more advanced features to improve ACPR, Efficiency and better control of Icq. Examples of possible features are described in the next paragraphs.

Figures 7 and 8 show the respective performance of one of our devices under IS95 and 1XRTT (dedicated-only) signals. As was expected the 1XRTT ACPR performance is met 2dB below the IS95 power rating, reflecting the higher pk/avg ratio.

2.2 From AlGaAs to InGaP

Most GaAs manufacturers, are moving, or have moved, from building AlGaAs devices to InGaP devices. The anticipated next step beyond InGaP is InP, when cost effective, it will provide higher thermal performance allowing higher reliability, current density, and smaller die, while providing also a lower Vbe.

One of the primarily reasons to move from AlGaAs to InGaP is an increase of gain, increase reliability and holding hfe constant with temperature. Holding hfe with temperature is good for obvious reasons: It allows a better Icq bias control. However it has an even more important desired effect: The Rcesat of AlGaAs is highly dependent on temperature. This is due to the dependence of Rcesat on hfe as, at a given Vbe, both Vcesat and Icesat would increase when hfe is decreasing.

If hfe drops with temperature, or is naturally low, the saturation of the amplifier occurs sooner, reducing P1dB. This is what happens with AlGaAs circuits at high temperatures; holding Icq to a constant level leads to a decrease in ACPR and efficiency due to lower P1dB. Figure 9 shows in effect how differently Vcesat behaves with temperature in AlGaAs and InGaP. Those curves were derived from models from two manufacturers of GaAs devices.

Looking at figures 10 and 11, the consequences on P1dB and ACPR are obvious, eating into the minimum Icq required for performance. The curves were derived from simulation for a 28dBm IS95 power amplifier using 5800sq.um of total output emitter area. The output stage Icq is held close to 75mA. . The lower overall Vcesat in InGaP allows a higher power capability for the same load line. InGaP allows the reduction of Icq while still meeting all specifications at higher temperatures and therefore meet ever-increasing device talk time requirements.

2.3 An differential amplifier based bias solution

The circuits that are commonly used to bias transistors for linear operation (figure 3) all have the drawback to be sensitive to hfe and Vref (Vbb) variations from wafer to wafer, as well as temperature variations of Vbe and hfe at different locations within the device. GaAs is not as good thermal conductor as Silicon and the bias circuits that are adequate for Silicon are not as easy to implement successfully.

With both AlGaAs and InGaP circuits, it is still impossible to stack up several Vbe (>1.3V). (InP technology will actually solve this with a lower Vbe). The solutions to the problems described will come from bias circuits with current reading using a current mirror, used in a feed-back control circuit similar to an operational amplifier. Those circuits are implemented directly in the GaAs circuitry, or in the case of a module implementation, in a mixed technology device is possible. In the case of AlGaAs, as hfe varies with temperature and the relative temperatures of the diode and the RF transistor are different, it is actually difficult to implement the circuit, it is more straightforward with InGaP. The circuit presented in figure 12 was modified from an earlier [1]; it provides independence of the bias current with hfe and Vbb. It provides two modes of operation for high and low power level and full temperature compensation.

2.4 Reducing Icq and increasing efficiency using advanced features

The improvements in bias circuits will not be enough to meet all future requirements of the 2.5G and 3G communication standards. Icq and Efficiency need greater improvements to meet phone maker requirements. Some examples of those circuit solutions used are: Gain switch, (PA bypass), 2nd Vmode for lower Icq, adaptive bias, coupling the PA with a DCDC converter.

CONCLUSION

2.5G systems are putting increased performance expectations on Power Amplifiers for Noise, Icq, ACPR and Efficiency over power level and temperature. Improved biasing topologies will help meet those new requirements. Based on the analysis of Rcesat, InGaP will provide a technology of choice for 2.5G handset Power Amplifiers.

FIGURES

Figure 1

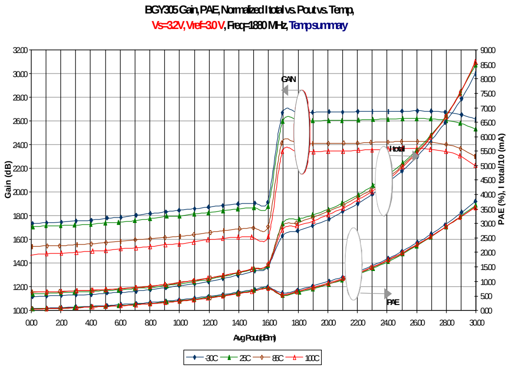


Figure 2

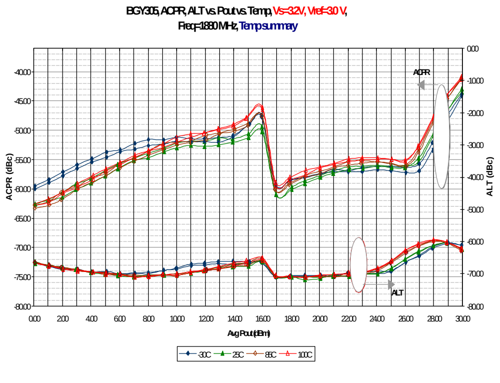


Figure 3

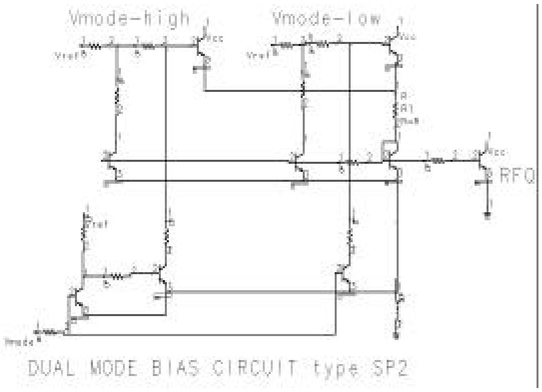
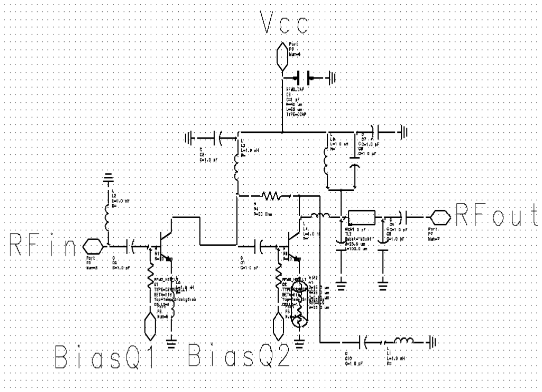


Figure 4



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[1] Bias Circuits for GaAs HBT Power Amplifiers, E. Jarvinen, S. Kalajo, M. Matilainen, 2001 IEEE MTT-S

Figure 5

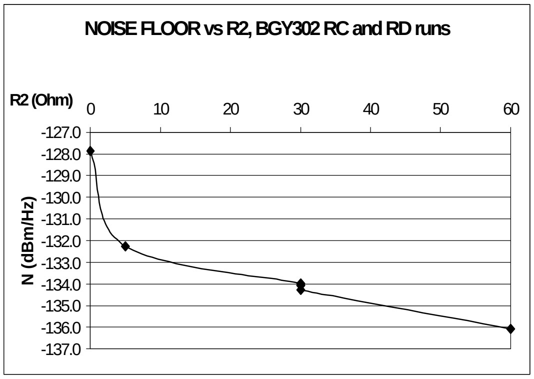

Figure 6

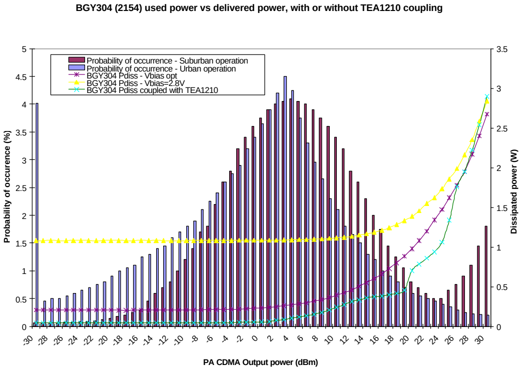

Figure 7

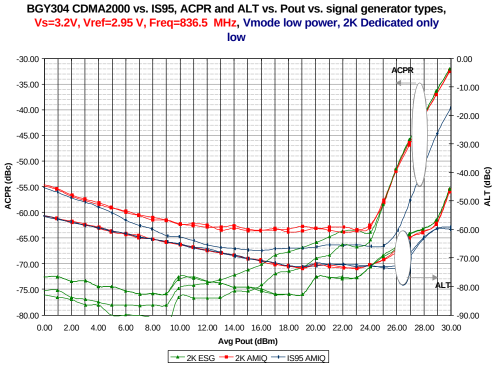

Figure 8

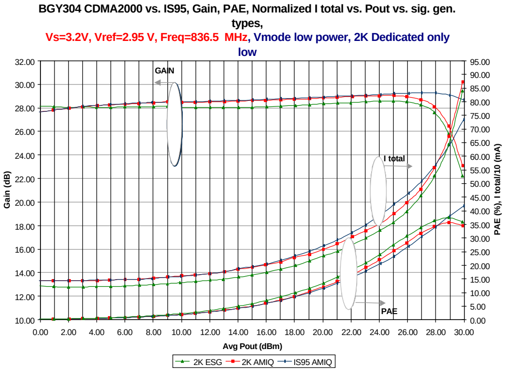

Figure 9

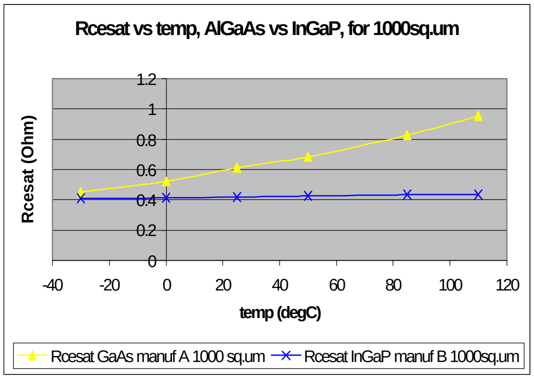

Figure 10

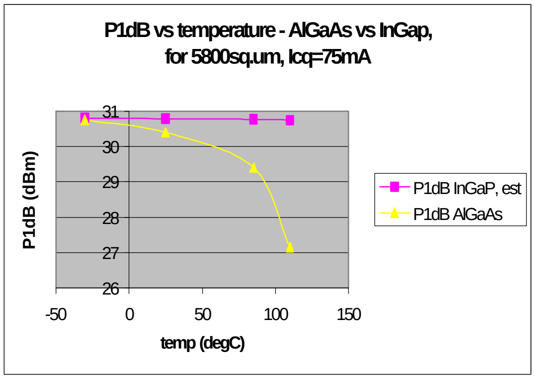

Figure 11

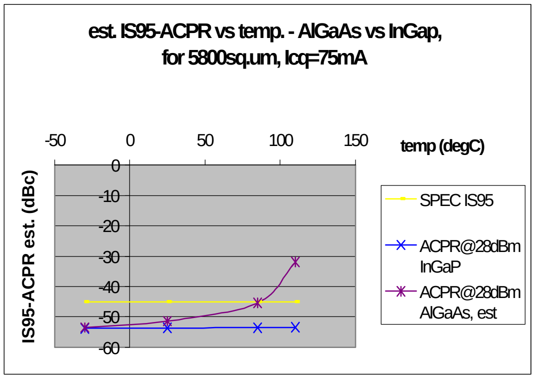

Figure 12