28V High Efficiency High Linearity InGaP/GaAs Power HBT

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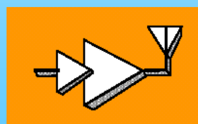
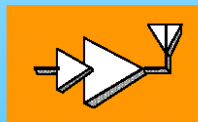
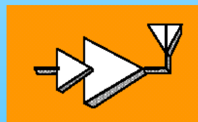


Agenda

- Introduction
- 28V Operation InGaP/GaAs HBT Design
- Circuit Design and Assembly
- Experiment Results
- Conclusion



Introduction



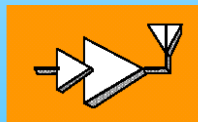
28V InGaP/GaAs HBT Power Transistor

Background

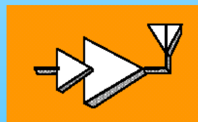
- The best InGaP/GaAs HBT designed for 3-8V operation achieved excellent linearity and 10^{10} hours @ T_j=150°C
- 28V HBT was demonstrated as a discrete device for higher power operation
- Flip chip was attempted to reduce thermal resistance

EiC's Present Effort

- Build MMIC compatible with existing assembly approach
- Design SOA (safe operation area) and ruggedness
- Provide high linearity

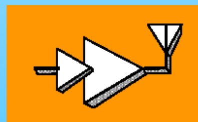


28V Operation InGaP/GaAs HBT Design



Design of 28V InGaP/GaAs HBT

- BV_{cbo}~70V, BV_{ceo}~35V
- Conventional 100μm thick substrate MMIC approach is adopted
- Thermal resistance design of HBT layout was done with proprietary program
- SOA (Safe Operation Area) through proper ballasting was designed with another proprietary program
- Initial “wafer level reliability” study result is very similar to the low voltage InGaP/GaAs HBT



Measured I-V Curve vs. Designed SOA for A_e=1500μm^2

I-V Curve

Icc (mA)

450
400
350
300
250
200
150
100
50
0

0 5 10 15 20 25 30 35 40 45 50

Vce

SOA boundary

Ib=1mA
Ib=2mA
Ib=3mA
Ib=4mA
Ib=5mA

Class A Quiescent Bias Point

Total Emitter Area 1500um2. This is the building block for larger size HBT

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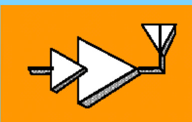
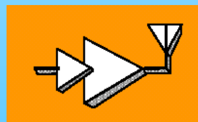


Power HBT Design

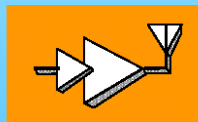
- Multi-finger building block is paralleled in large size HBT
- Patented feed structure to provide minimum phase lag from the input feed to the HBT fingers and minimum variation of phase of RF signal at each finger



Circuit Design and Assembly

On-chip Circuit Design

- Bias circuit (based on current mirror), RF choke and input pre-match circuit are designed on the same chip with the power HBT
- Temperature compensation is achieved through the current mirror
- Output matching is done off-chip
- Input matching is completed by off-chip matching



Basic Circuit Design

RFIN

Partial Input Matching

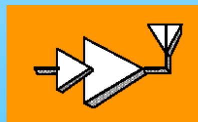
RFOUT

Vref

Vbias

Choke

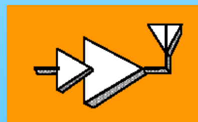
Temperature compensated



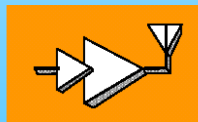
Assembly

- Standard MMIC assembly procedure is followed:
  - The IC die is 4 mil thick
  - AuSn eutectic attachment is used
  - 1mil gold wire bond connects the die to the hybrid circuit

- No reliability concern about the assembly approach

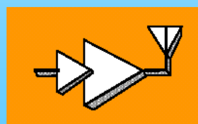


Experiment Results



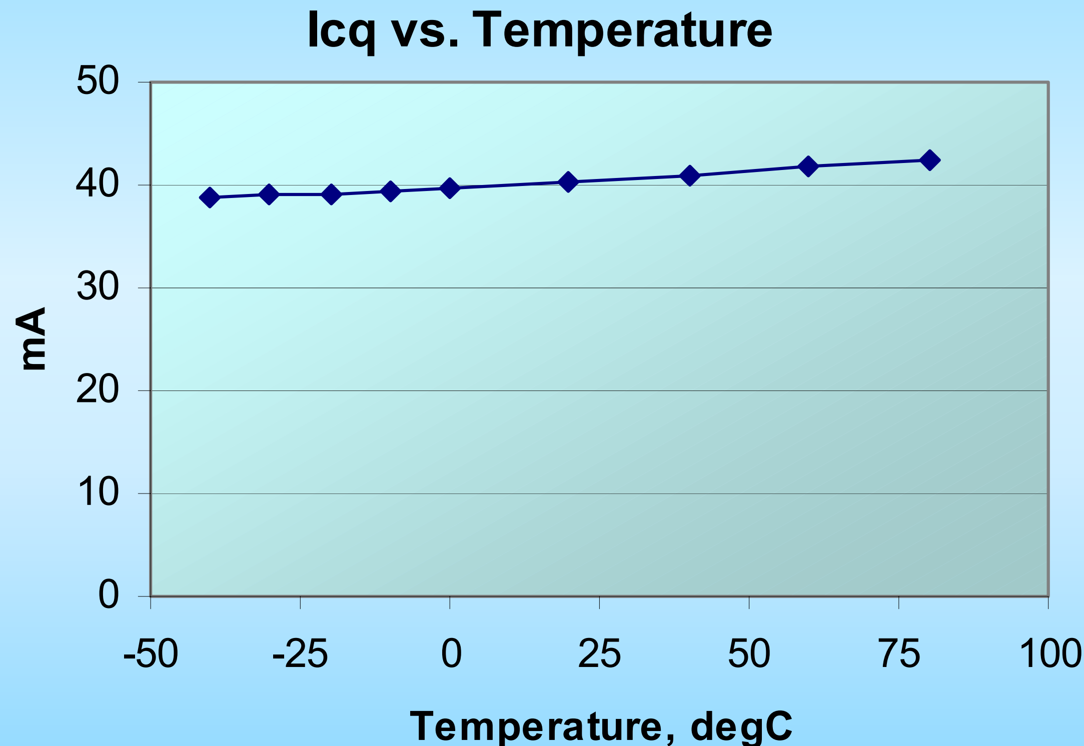
Highlights

- Thermal resistance of 30-35°C/W was measured for the building block of A_e=1500 μm^2 HBT
- Output power scales with HBT size to 25W at 900MHz, while maintaining the efficiency over 60%.
- Two tone test IMD3 maintains below –40dBc until reaching saturation power.
- At 900MHz under CDMA2000 9 fwr ch condition, 4.5W with η_c=42% was measured with ACLR1=-45dBc / ACLR2=-58dBc, and 35% at ACLR1=-50dBc
- At 2GHz under CDMA2000 9fwr ch condition, 0.5W with η_c=32% is achieved at ACLR1=-50dBc
- At 2GHz under WCDMA, 23dBm with η_c=18% at ACLR1=-45dBc

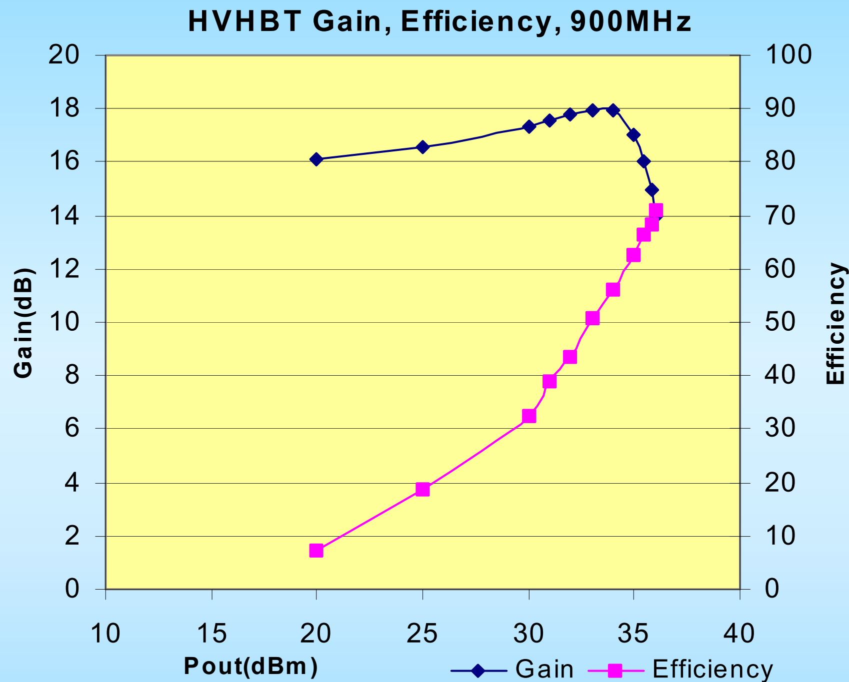


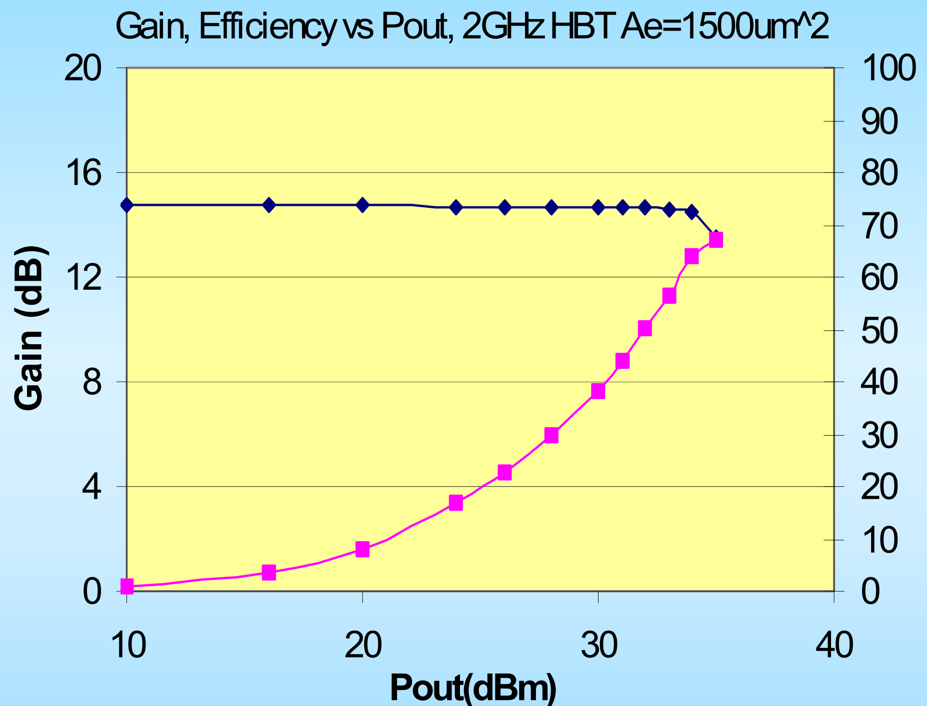
Temperature Compensated Bias Circuit

- <9% change of Icq over –45 to +85°C range



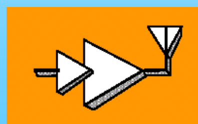
Gain / Efficiency of HBT with A_e=1500 μm^2





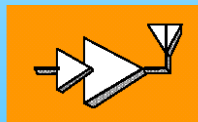
P_{out}=36dBm, G=14dB, η_c=71%

P_{out}=35dBm, G=13.5dB, η_c=67%



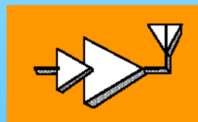
Thermal Resistance

- 30 to 35°C/W thermal resistance is measured from the HBT of Ae=1500um^2
- Measurement relies on the Vbe vs.Temperature relationship
- At full power operation, temperature rise is 50°C

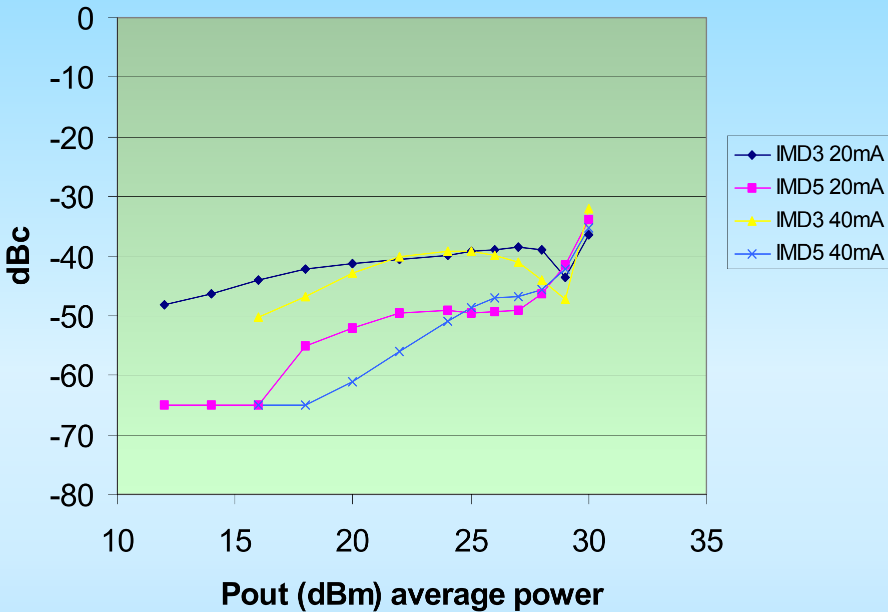


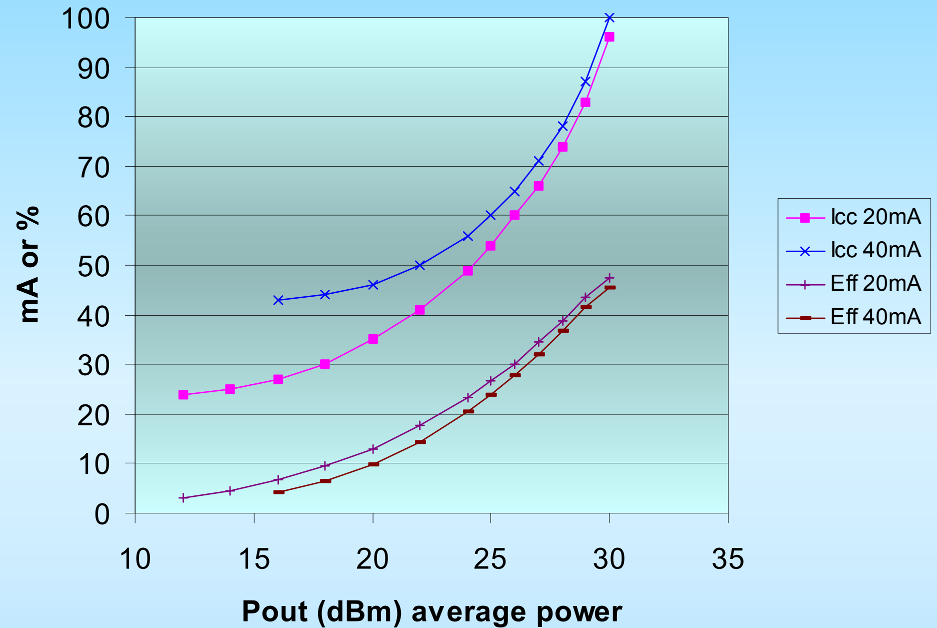
Output Power vs. HBT Size @900MHz

Emitter size	1500	3000	6000	12000
Pout(dBm)	35	38	41	44
Gain(dB)	16.8	15.34	13.18	9.92
η_c %	70	71	68	61



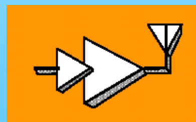
Two Tone Test Result @ 2GHz



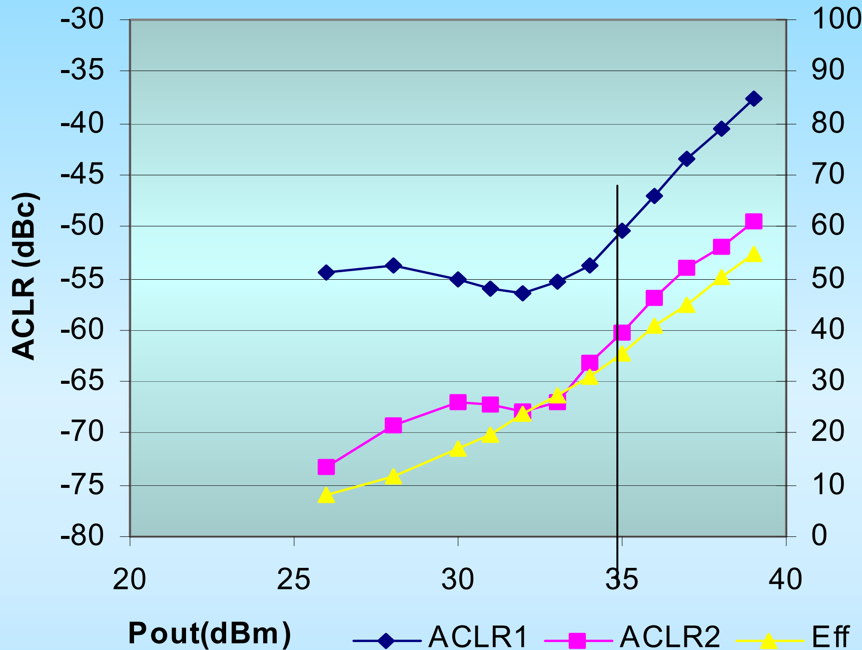


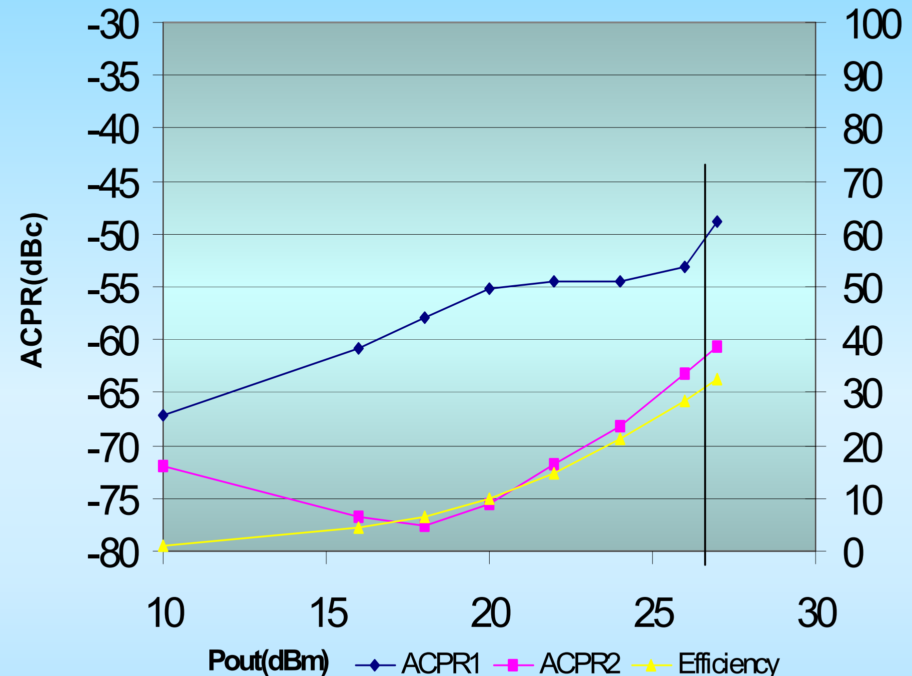
Single tone CW P1dB is 32.5dBm; Gss=13.2dB

Output power is average. Each tone power is 3dB lower; PEP is 3dB higher

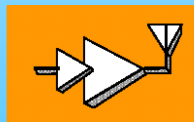


CDMA2000 Test Result

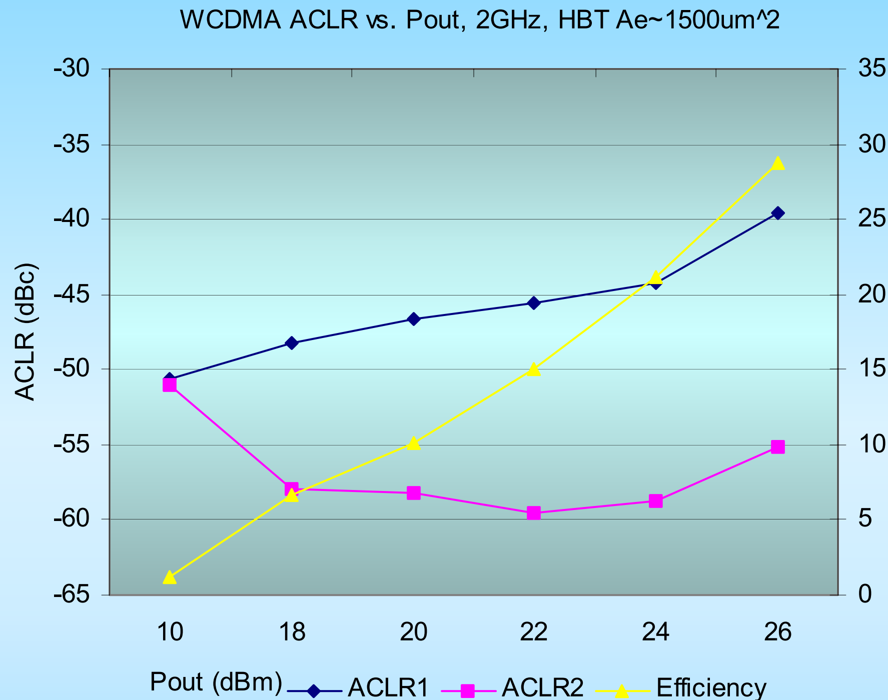




- Efficiency is 32 to 35% at ACLR1=-50dBc
- At 900MHz, 36.5dBm is achieved at ACLR1=-45dBc with 42% efficiency. 35dBm is achieved at ACLR1=-50dBc. HBT size is 4 building blocks.
- At 2000MHz, 27dBm is achieved with ACLR1=-50dBc from 1 building block.



WCDMA Test Method 1



- Peak to average ratio is 9.8dB
- P1dB is 32.5dBm
- At ACLR1=-45dBc, Pout is 23dBm with 18% efficiency

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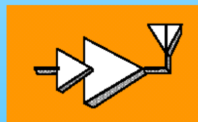


Conclusion

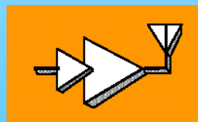
Key Advantages

- InGaP/GaAs HBT achieves high efficiency: over 60% at 2GHz
- Excellent linearity under modulated signals
- Long lifetime and stable gain is expected from the standard InGaP/GaAs HBT result

Major Achievement

- 25W is achieved in the standard MMIC approach

➢ InGaP/GaAs HBT can be further developed to serve the high power / high reliability applications



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