RM02C-3

EFFICIENT THREE-STATE WCDMA PA INTEGRATED WITH HIGH PERFORMANCE BiHEMT HBT / E-D pHEMT PROCESS

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Outline

- Motivation
- Pros and Cons
- Background: Switched Doherty
- Our Approach: BiHEMT
  - pHEMT Bias / Control / Switch
  - HBT Bias / RF Amplifier / ESD
- Example PAs
- Test Data
- Conclusion

Motivation

- CDMA talk-time is strongly influenced by PA current
- Average PA current is dependent on power efficiency at low power levels (in addition to full power PAE)
- Efficient PA operation over more than two power states requires low current control and switch devices.
- HBT devices perform very well as linear power amplifiers
- HBT bias circuits have historically required a regulated reference voltage that can be eliminated by the use of internal current sources.
- The BiHEMT process and circuit approach reported here enables an integrated solution to meet these needs.

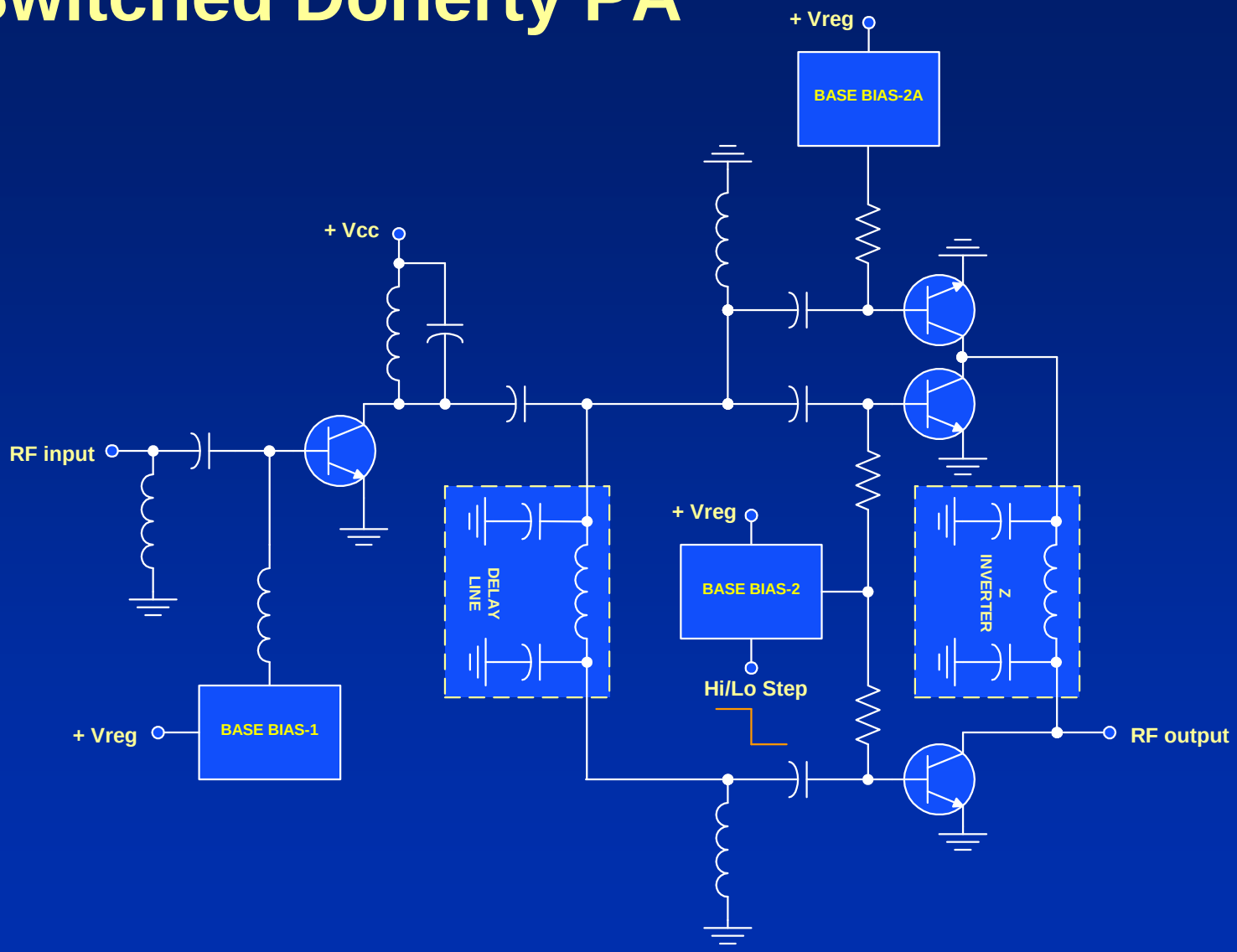
Goals

- Eliminate need for precise V_{REF}. (typically 2.85 ±0.10 V)
- Eliminate need for low IREF. (< 1mA desired)
- Provide PA enable/disable control with very low off-mode current. (~ 100μA control current)
- Provide additional talk-time and extremely low quiescent current in an “ultra low” power mode. (~ 6mA)

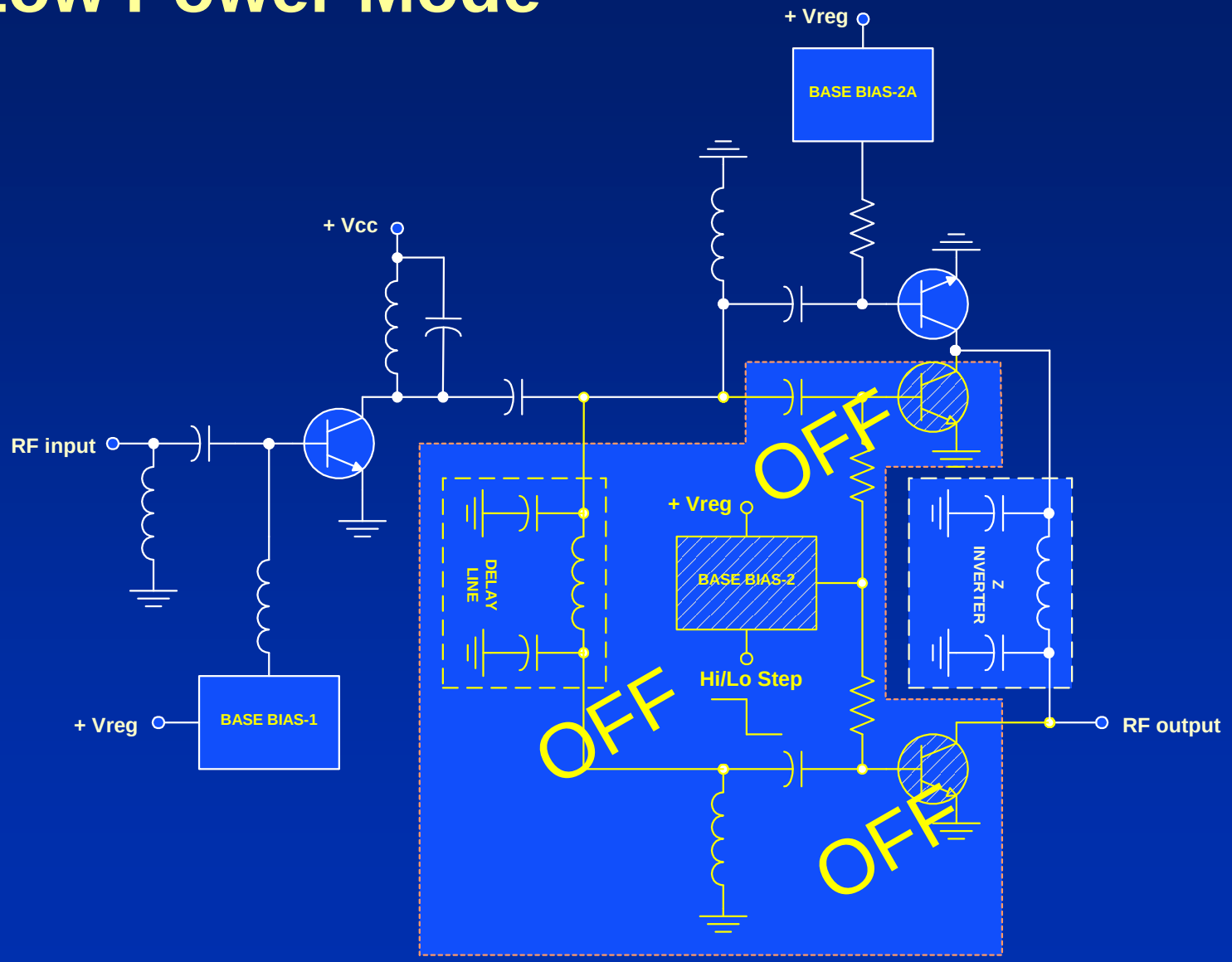
Pros & Cons

- BiHEMT multi-state PA challenges:
  - Increased process complexity
  - Increased cost / area
- Performance advantages include:
  - HBT PA stages (high performance with low standby leakage current)
  - Mixed HBT / pHEMT bias circuits with integrated current sources
  - RF and DC switches in pHEMT
  - Control circuitry in pHEMT
  - Compact size compared to separate pHEMT and HBT chips . . . a cost reduction

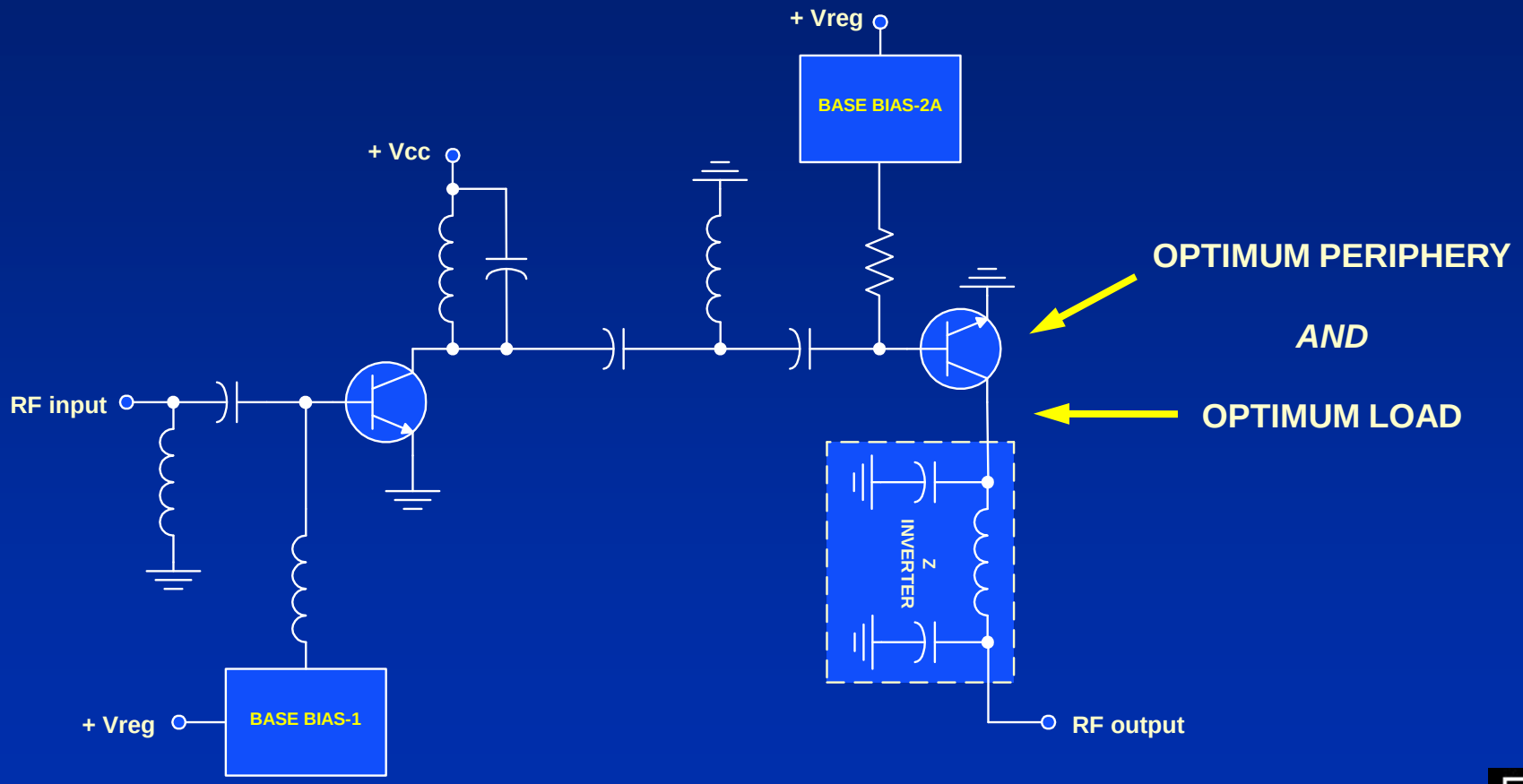
BACKGROUND:
Switched Doherty PA



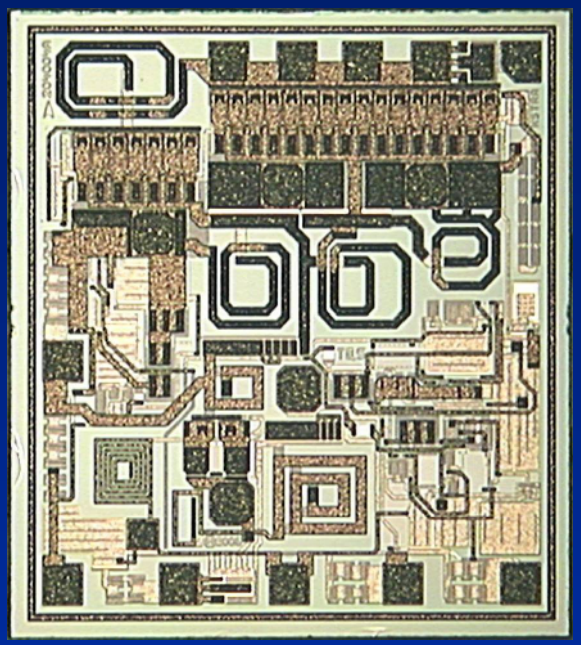
BACKGROUND:
Low Power Mode



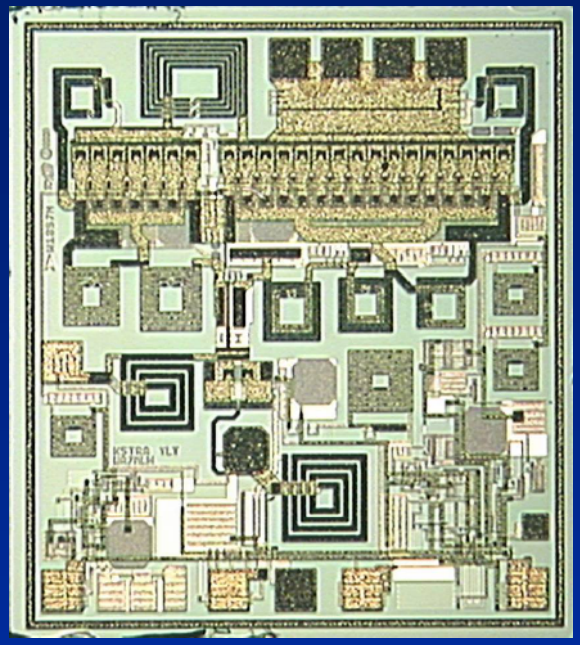
BACKGROUND:
Low Power Mode



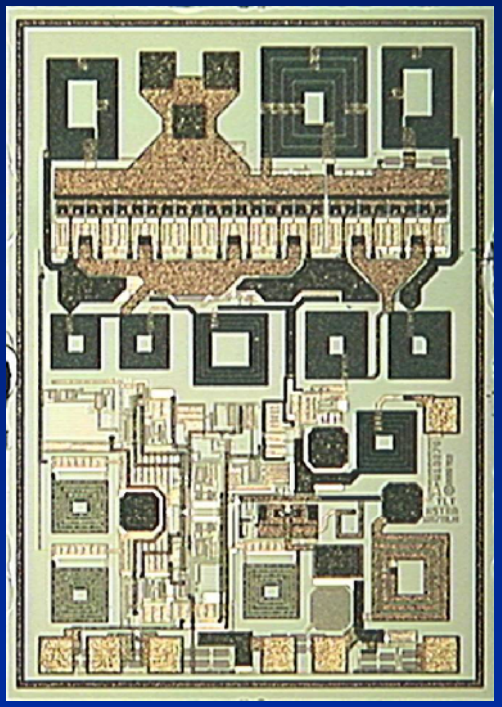
Switched Doherty PA Chips



PCS 1st GENERATION



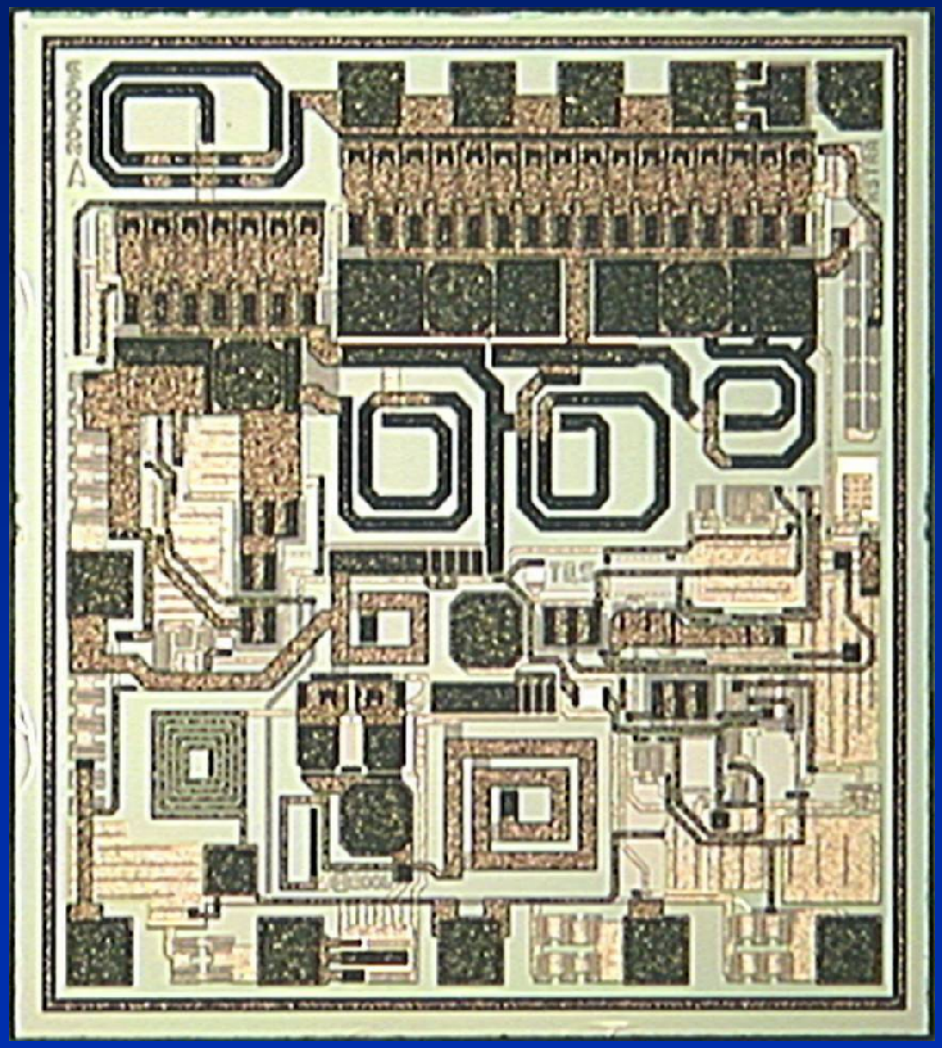
PCS 2nd GENERATION



CELLULAR
2nd GENERATION

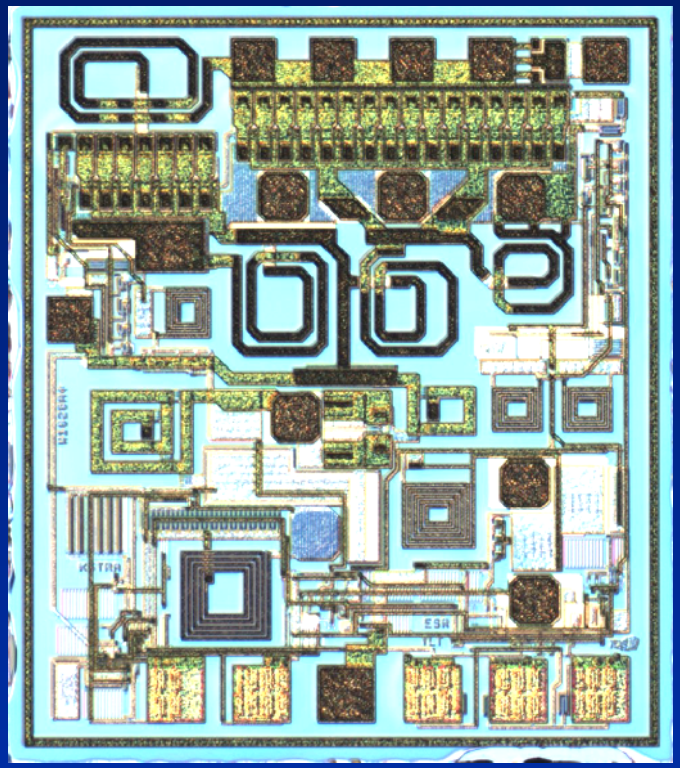
- **PRESENTED IMS2007 RFIC**
- **WCDMA**
- **2-STATE POWER CONTROL**
- **HBT PROCESS**
- ***BASIS FOR BiHEMT 3-STATE***

PCS 1st Generation Switched Doherty

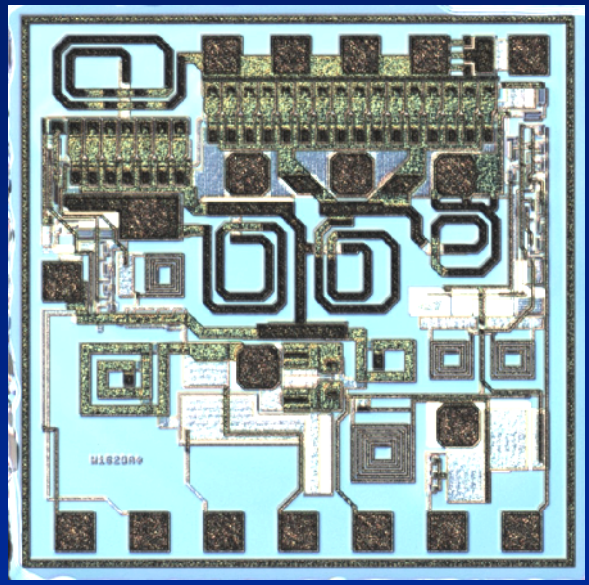


- 1120 x 1200 um^2
- HBT process
- 6480 um^2 final
- 550 um^2 driver
- external 2nd harmonic tuning

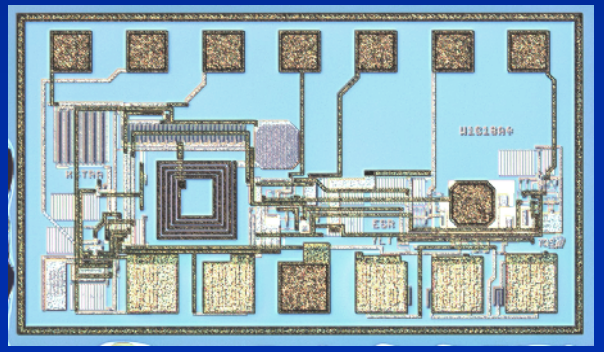
BiHEMT 3-State PA



FULL BiHEMT IMPLEMENTATION



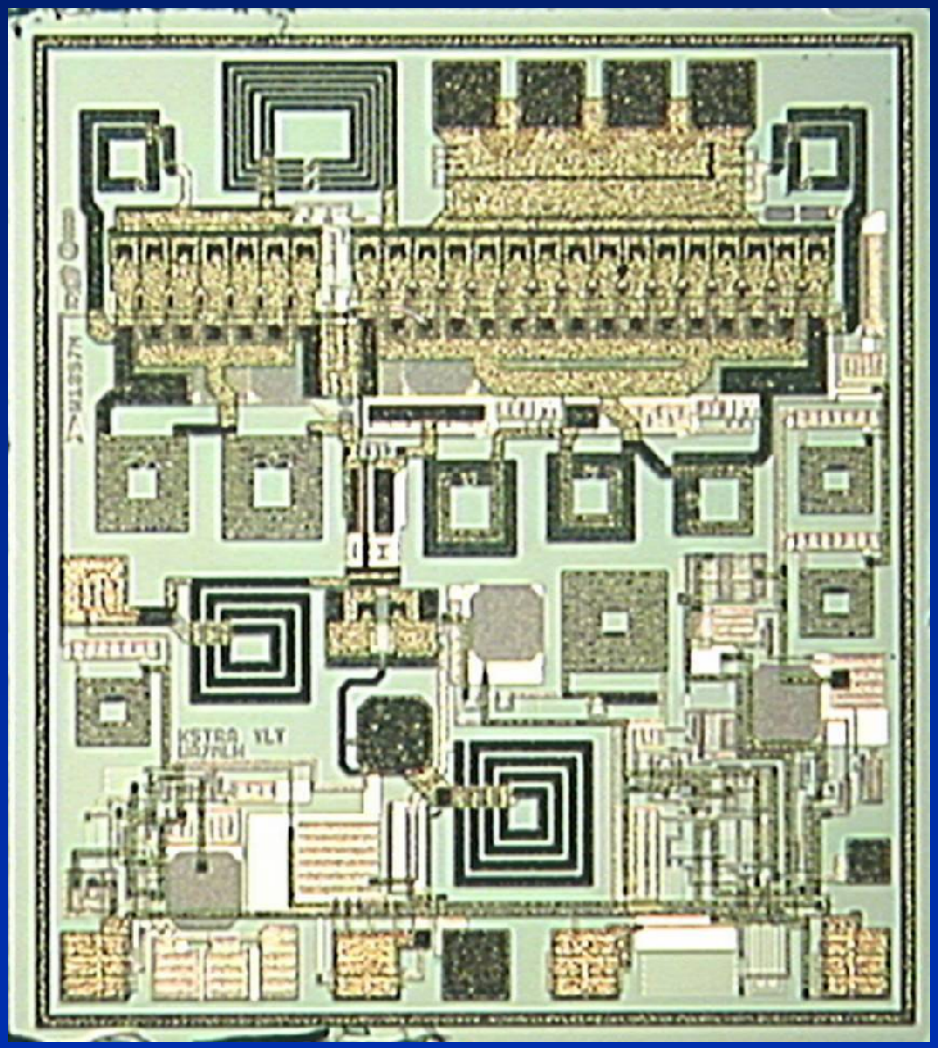
HBT CIRCUITRY



pHEMT CIRCUITRY

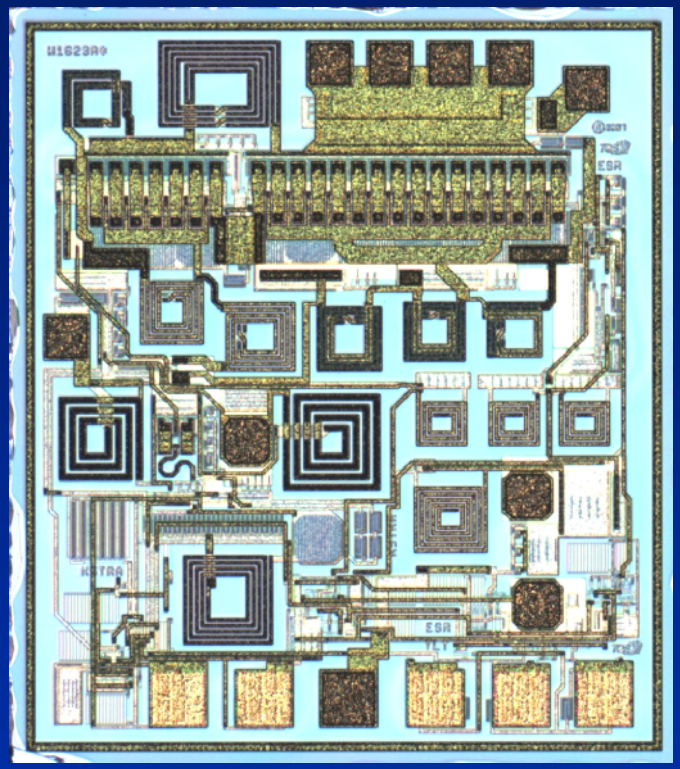
- **BASED ON *1st* GENERATION PCS SWITCHED DOHERTY PA**
- **1200 x 1370 um^2**

PCS 2nd Generation Switched Doherty

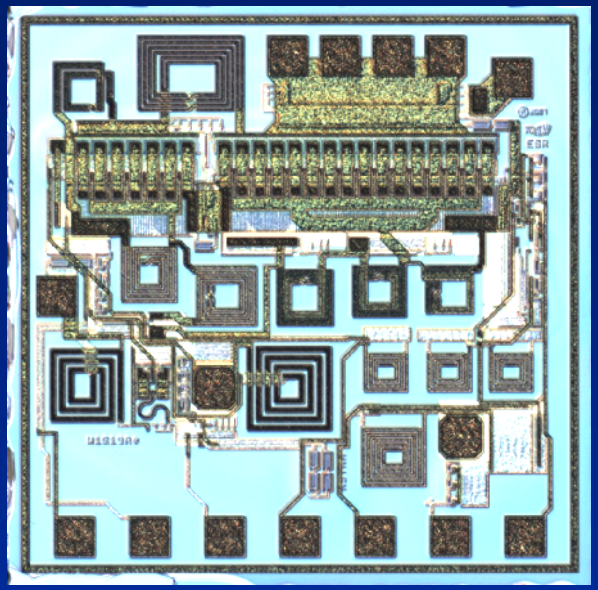


- 1170 x 1230 um^2
- HBT process
- 6480 um^2 final
- 550 um^2 driver
- internal 2nd harmonic tuning

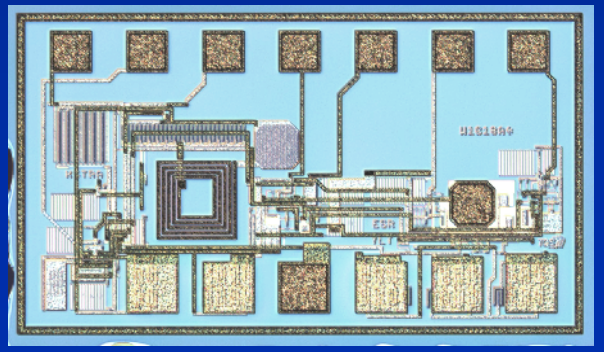
BiHEMT 3-State PA



FULL BiHEMT IMPLEMENTATION



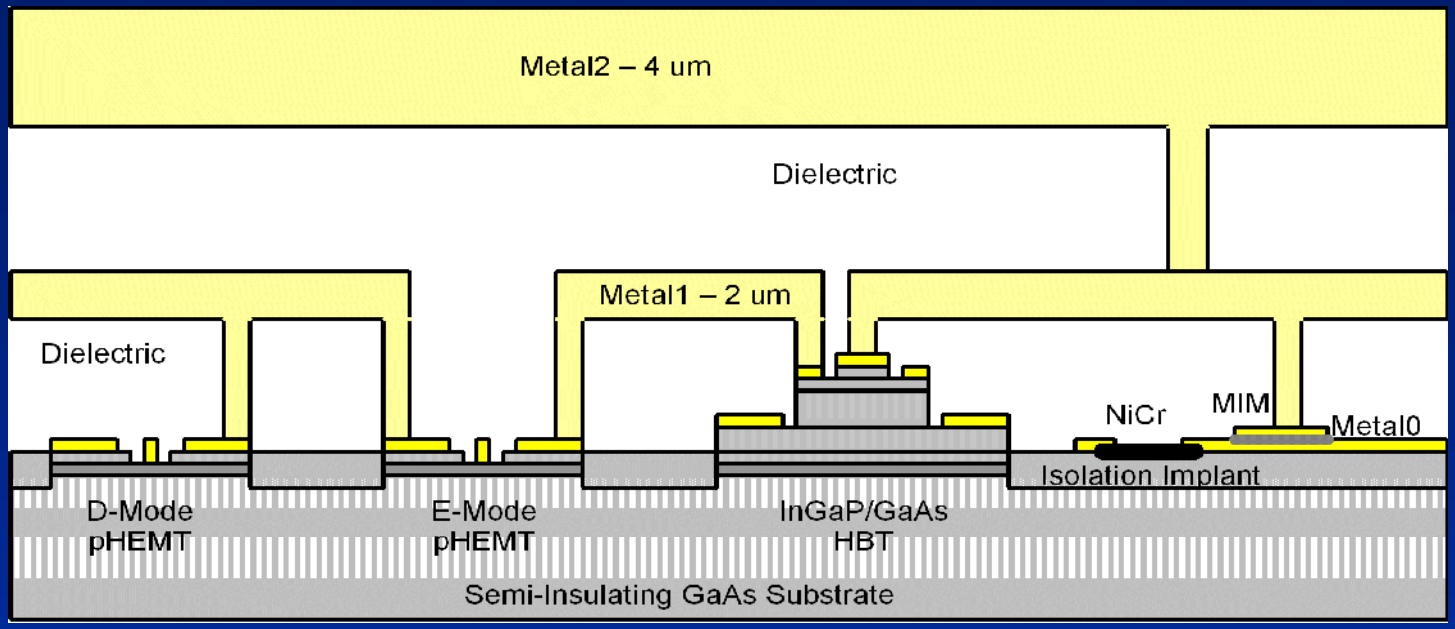
HBT CIRCUITRY



pHEMT CIRCUITRY

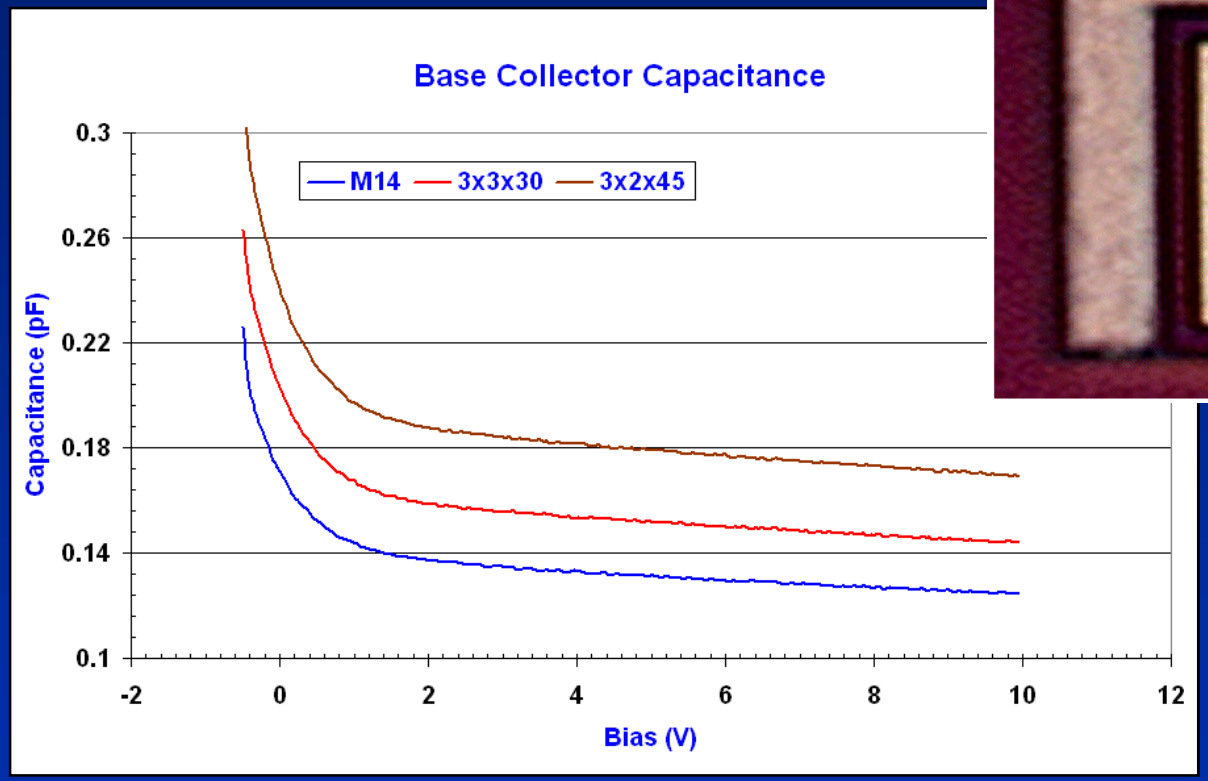
- **BASED ON *2nd* GENERATION PCS SWITCHED DOHERTY PA**
- **1200 x 1370 um^2**

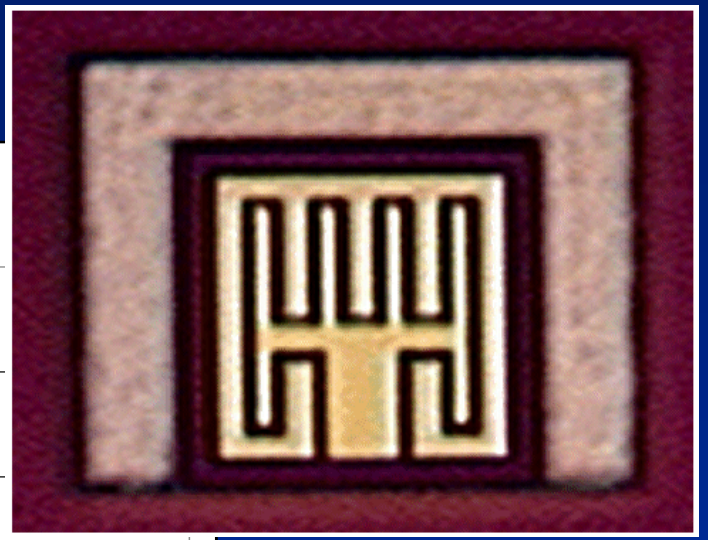
BiHEMT Process Cross-Section



- BiHEMT provides co-integration of HBT and E/D pHEMT processes
- PN ESD diodes provide pHEMT interface protection
- HBT uses upper epi layers
- Triquint standard metal / dielectric stack is used:
  - 2 plated metal layers (2um and 4um)
  - BCB dielectric spacer (~ 1.5 um)
  - 500 Å Si_3N_4 MIM capacitors

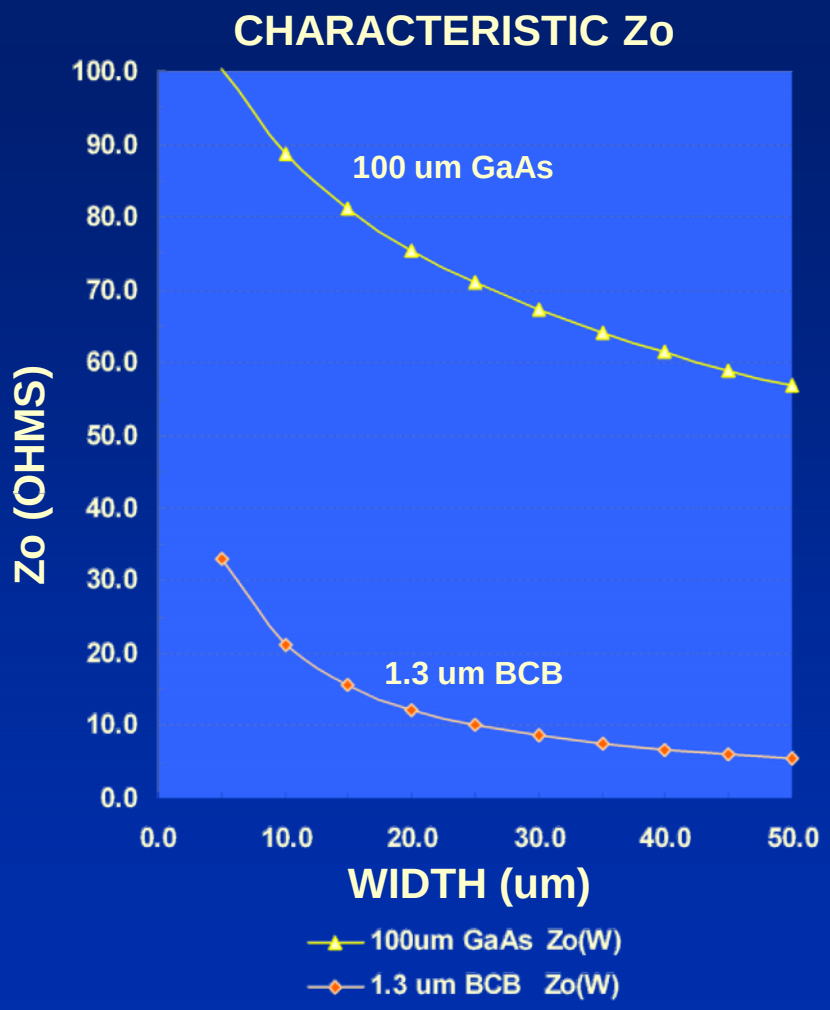
"FISHBONE BASE" GEOMETRY FOR LOW C_{BC}

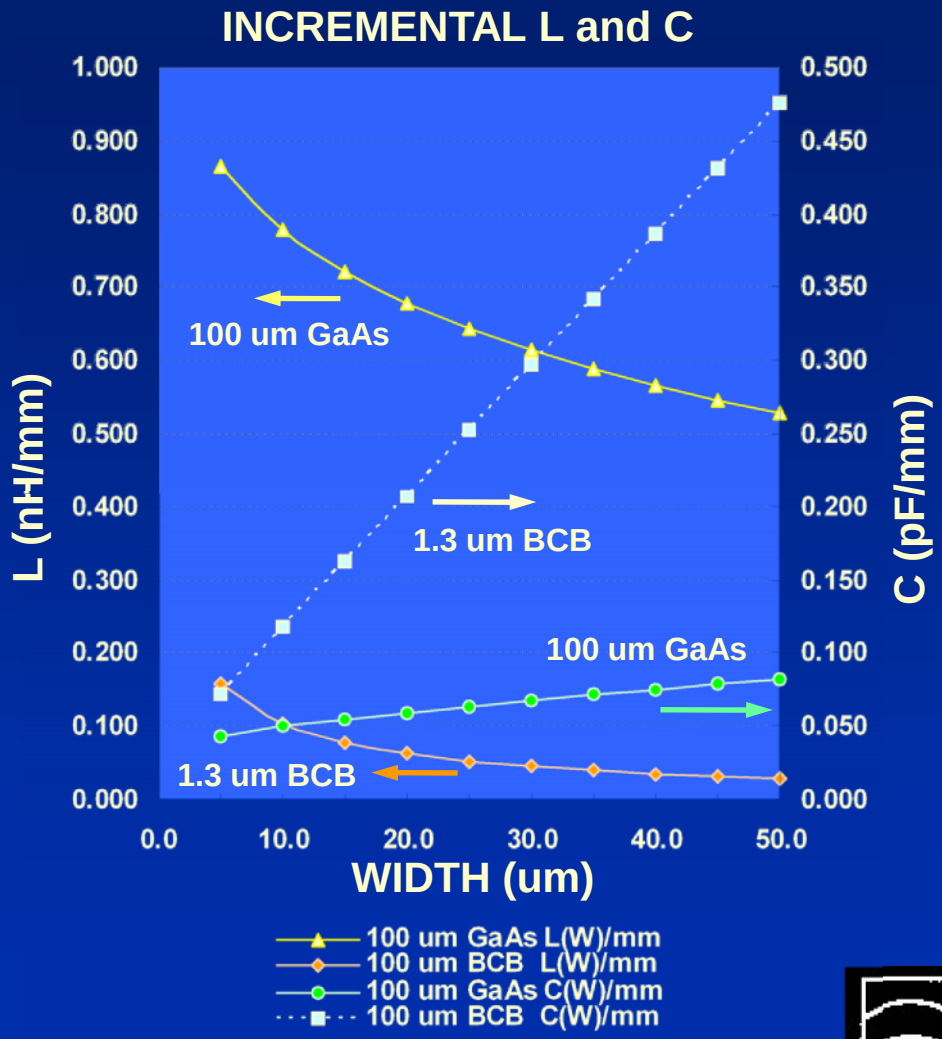




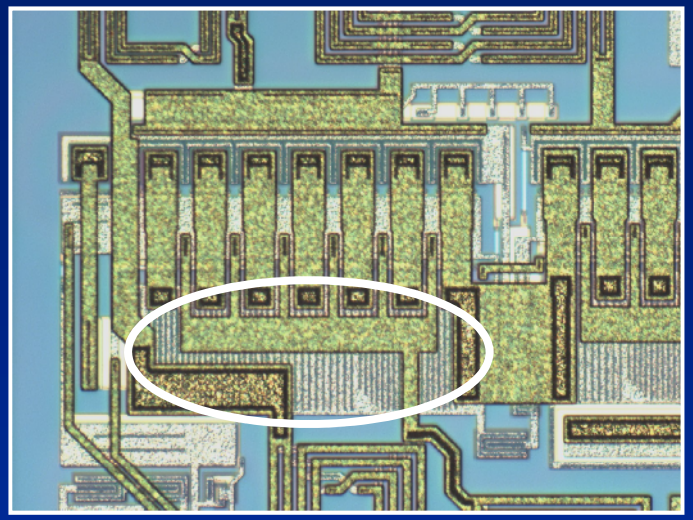
- 75% of *STANDARD CELL* C_{CB}
- 57% of *HAIRPIN CELL* Rb'
- SOA is 2X *HAIRPIN CELL*
- >1 dB gain increase
- >2 % η_a increase

Low Interconnect L *from* Low Zo Lines

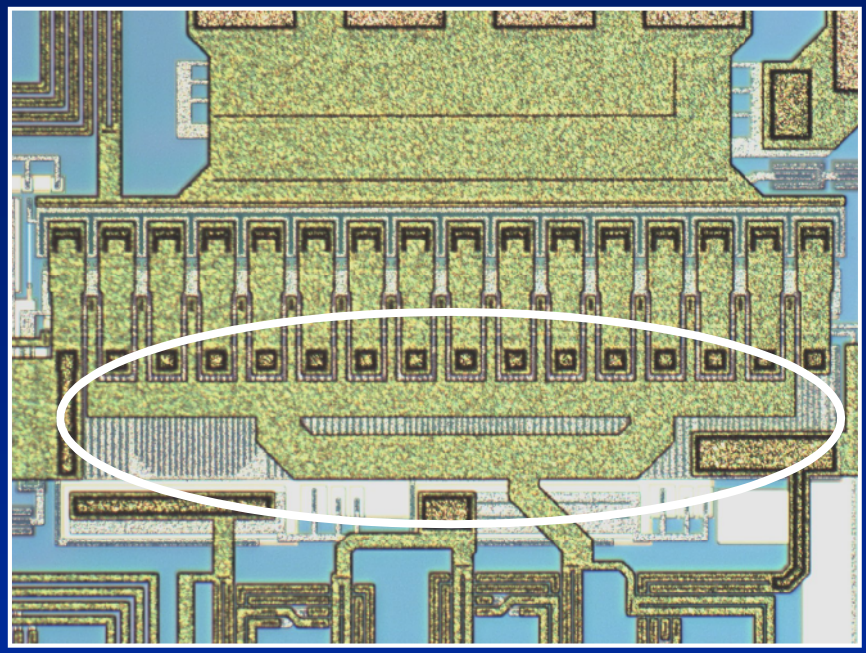




Base Manifold in Low Zo Lines



LOW POWER SIDE



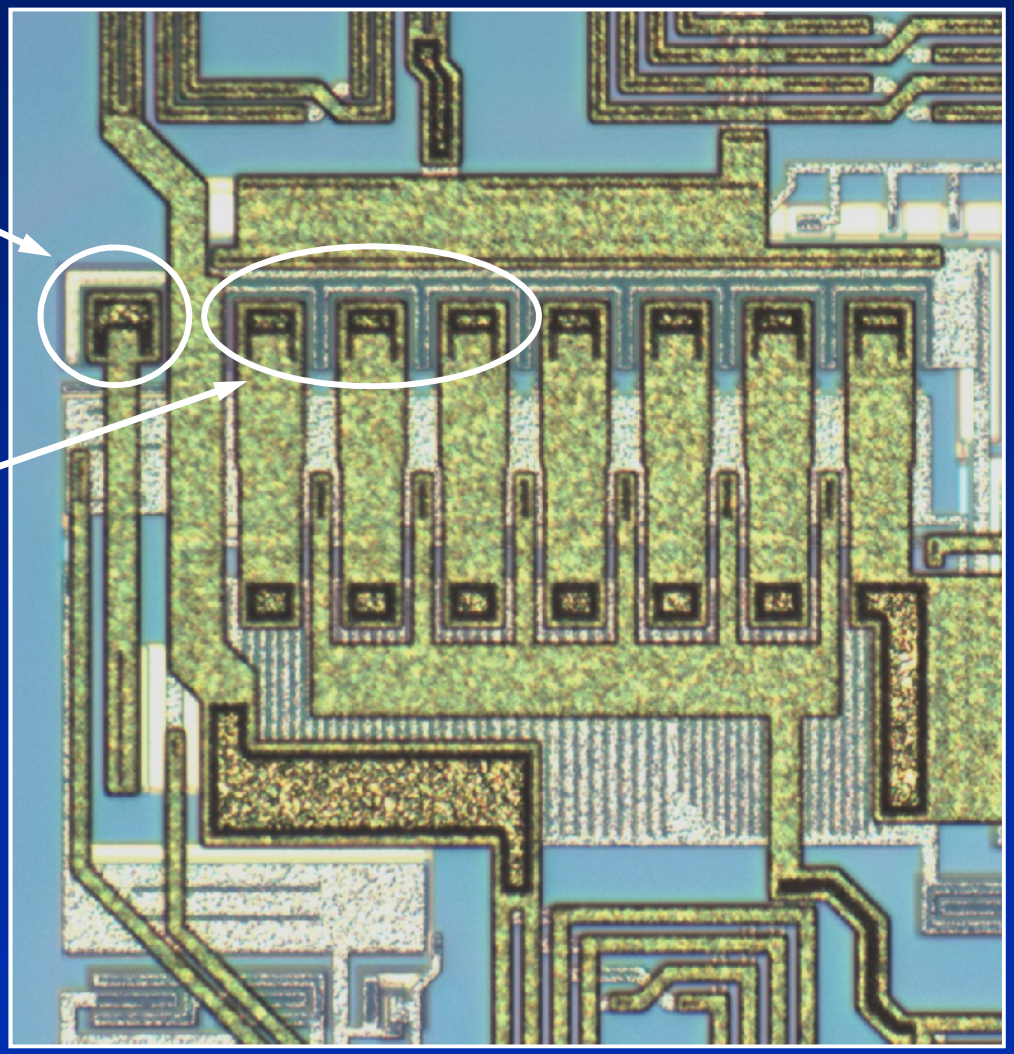
HIGH POWER SIDE

- Lateral manifold contributes to non-uniform L SERIES
- A low Zo transmission line can reduce L / mm
- This is realized with ***METAL-2 / BCB / METAL-1*** stack
- Increased shunt capacitance is parasitic result
- Lumped equivalent model is convenient

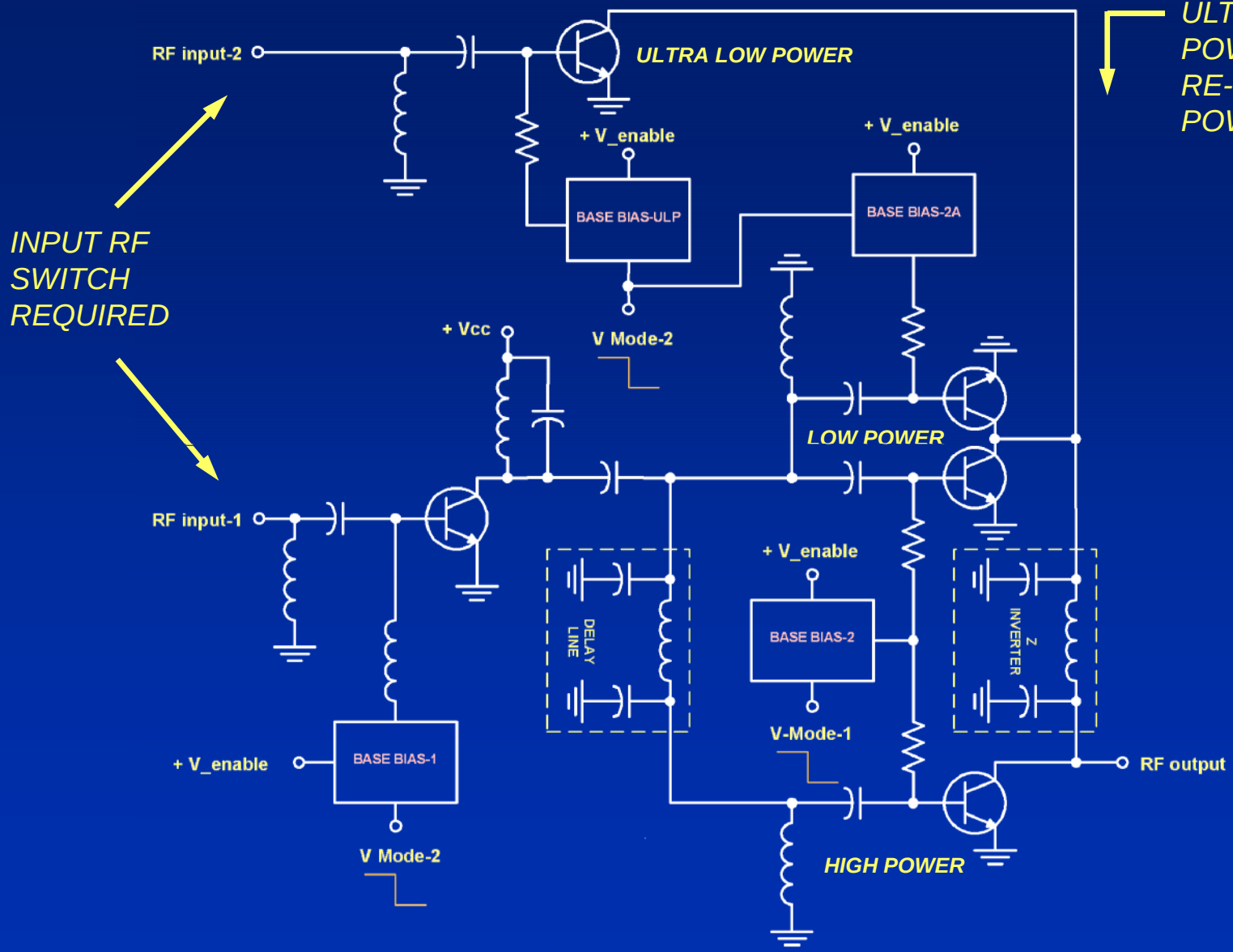
Low and Ultra-Low Power Cells

ULTRA LOW POWER CELL

LOW POWER CELLS



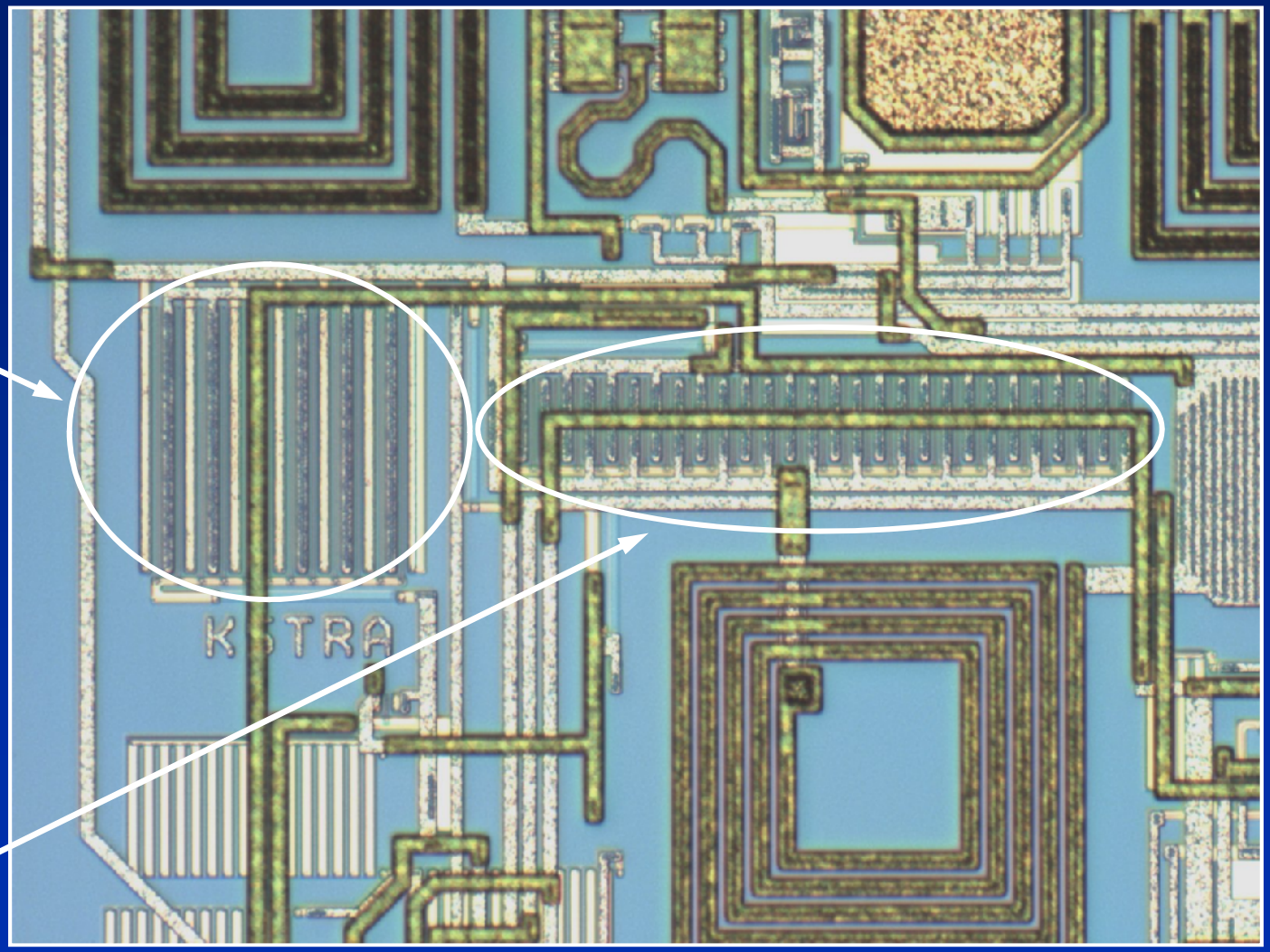
TriState Switched Doherty PA



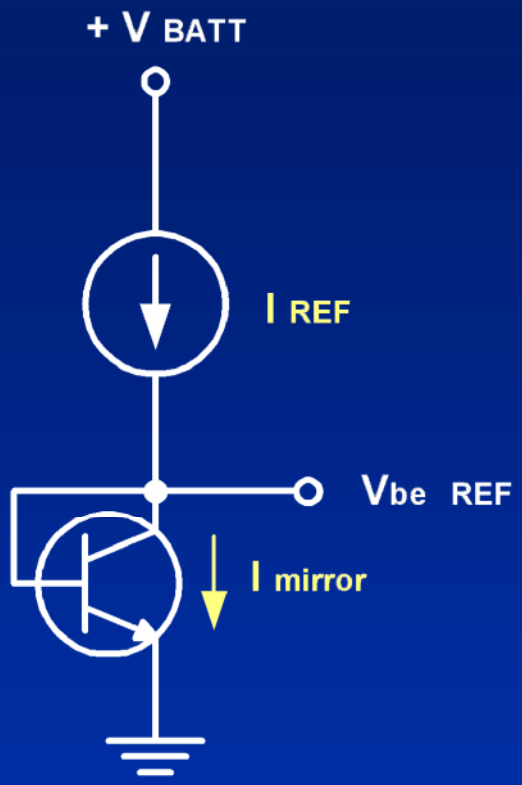
ULTRA LOW POWER MODE RE-USES LOW POWER LOAD Z

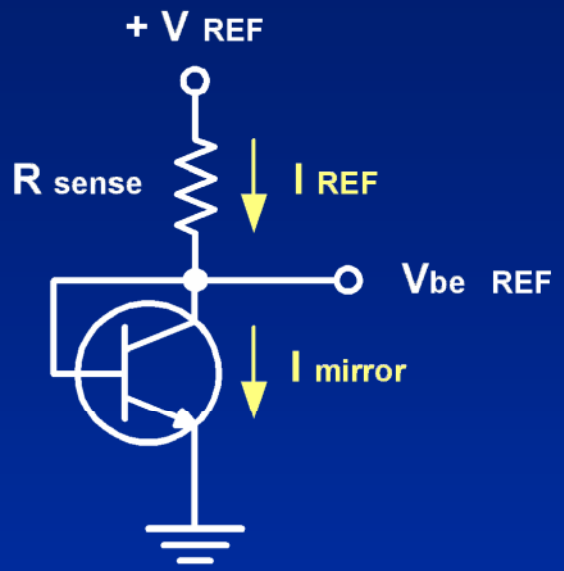
INPUT RF SWITCH REQUIRED

Input RF Switch



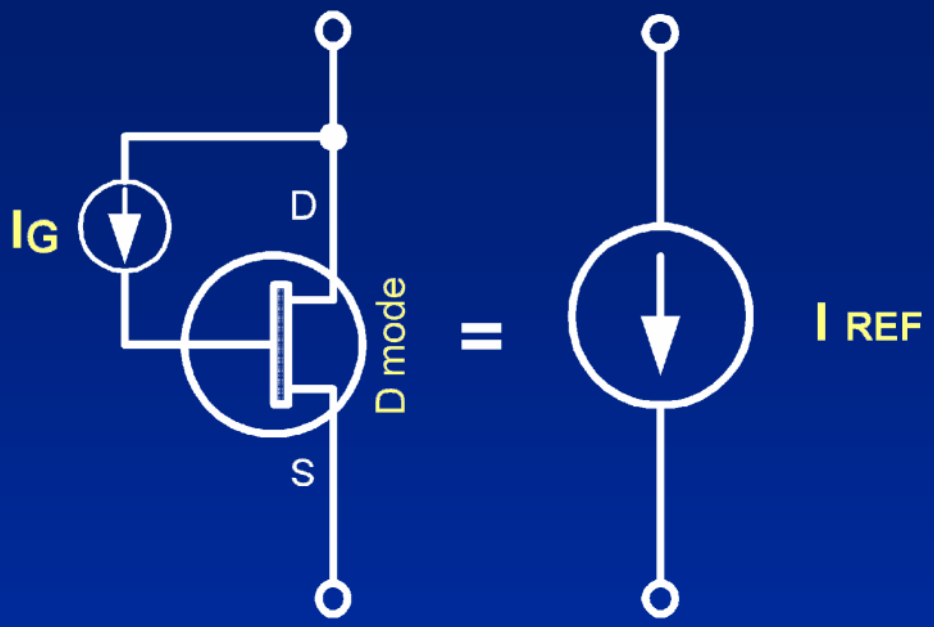
V_{REF} Elimination by Integrated Current Source





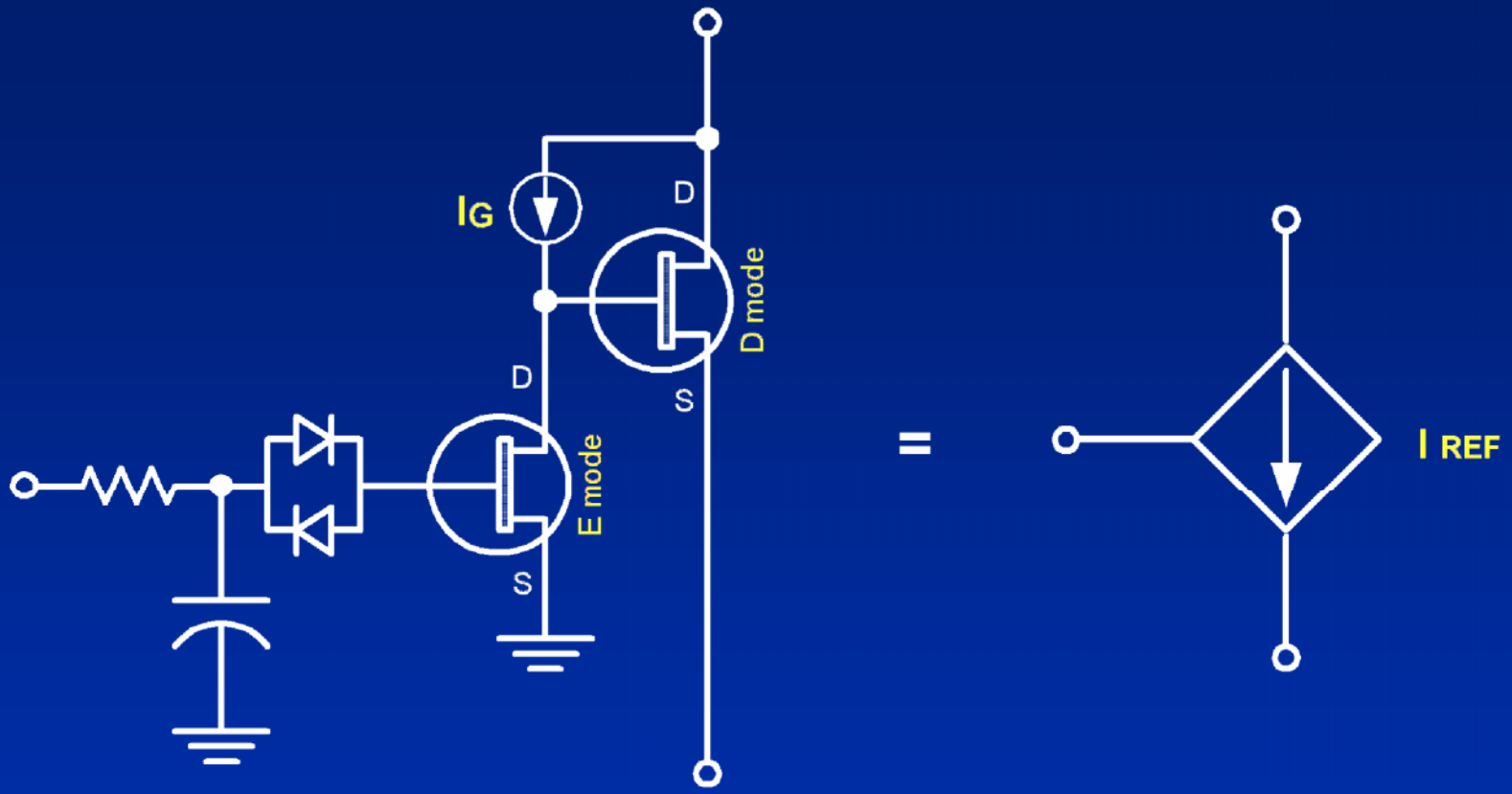
- Conventional HBT current mirror reference is set by V_{REF} and R_{SENSE}
- Current source (I_{REF}) eliminates external voltage dependence
- This approach also works well with closed loop HBT bias circuits

Reference Current Source



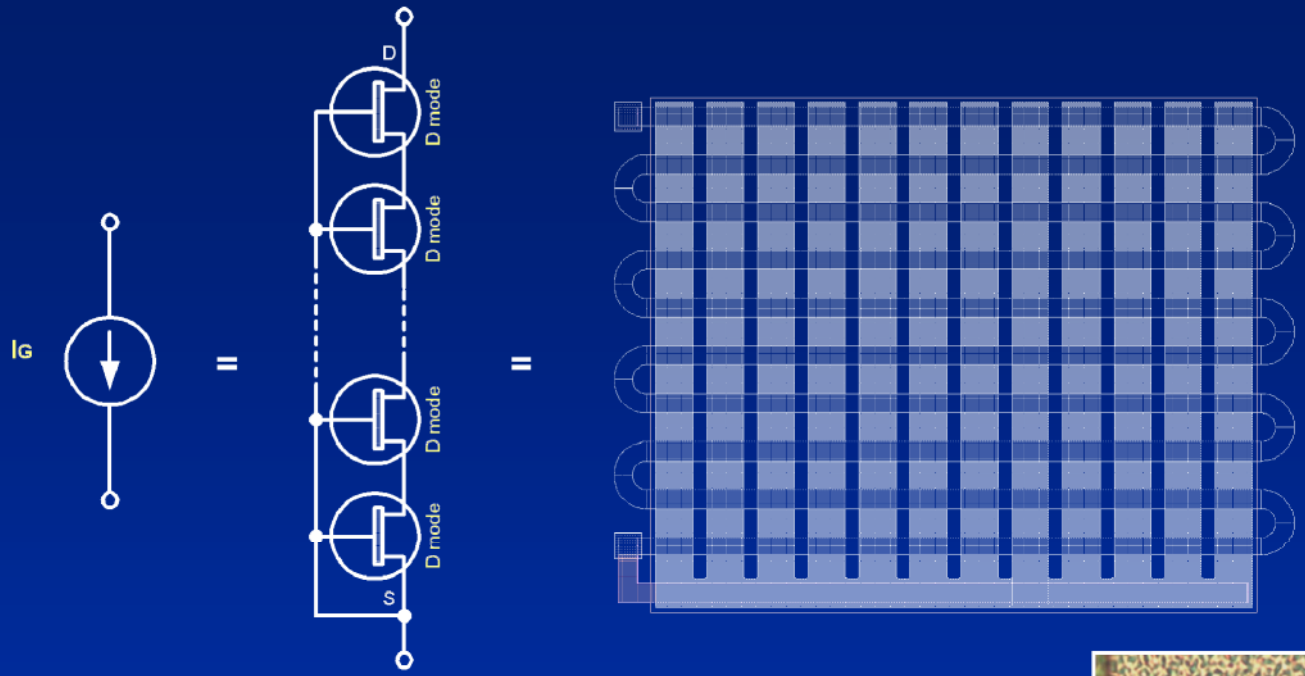
- A small D MODE FET operating at I MAX provides current source
- I REF is material and geometry dependent (insensitive to process)
- 1 σ ~ 6.6%
- Pull-up is meander channel, multi finger source (~ 500pA)

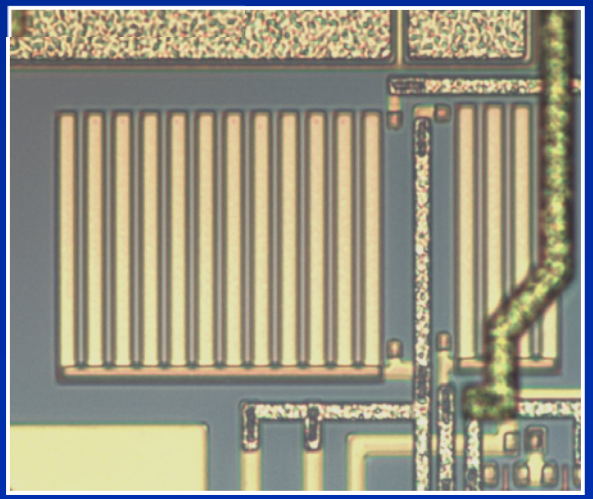
Gated Reference Current Source



A small E MODE FET is used to toggle the current source

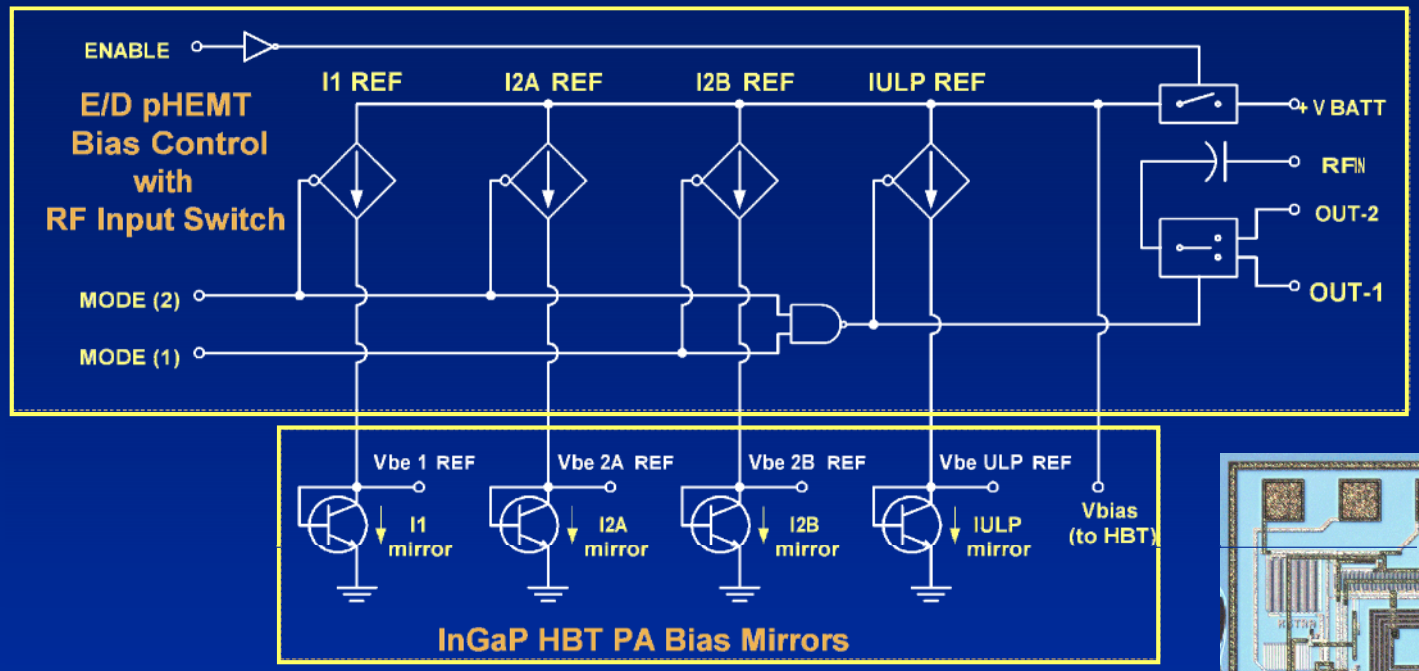
Low Current Pull-up Sources

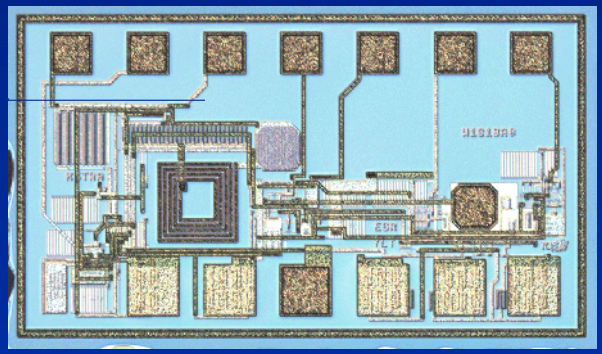




- Very long meander channel D-Mode FET
- Multiple gates connected to source
- Loose current distribution (based on I_{DSS})
- Used for pull-up sources

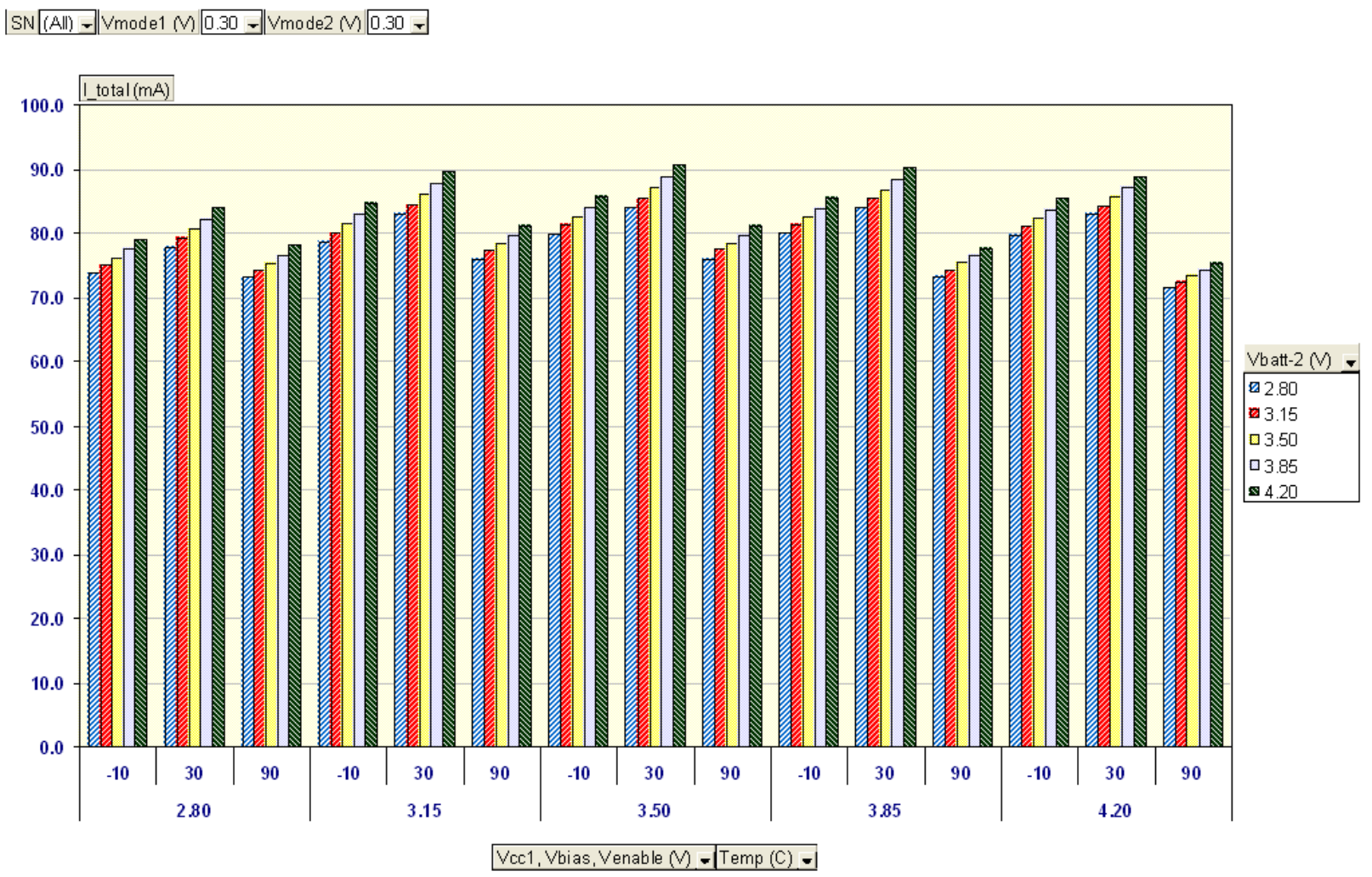
Bias Control in pHEMT – Mirror Reference in HBT



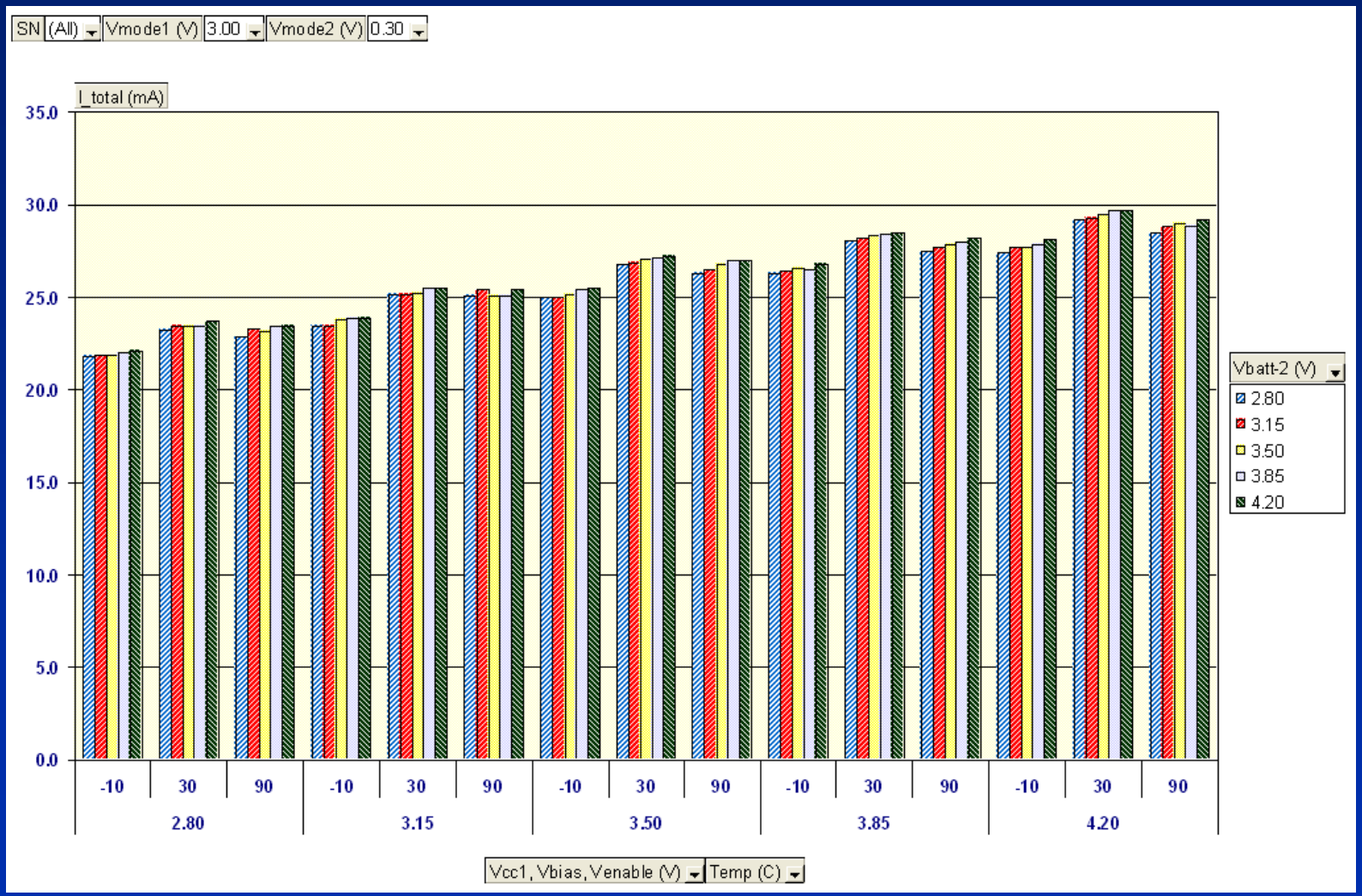


- pHEMT is best choice for bias control, logic and switches
- HBT bias circuits are simplified due to current source reference
- ESD protection of pHEMT from PN diodes

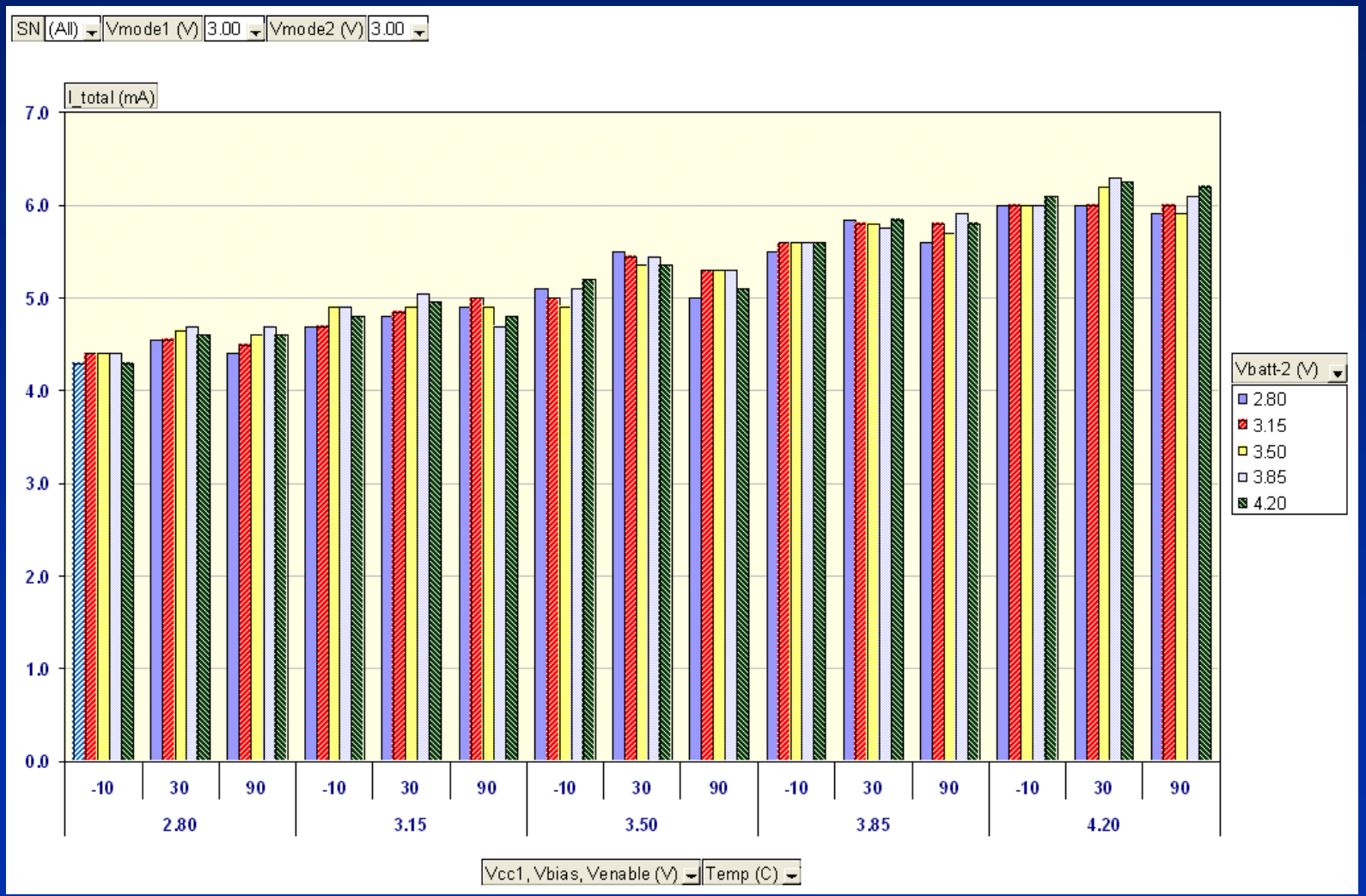
High Mode Current



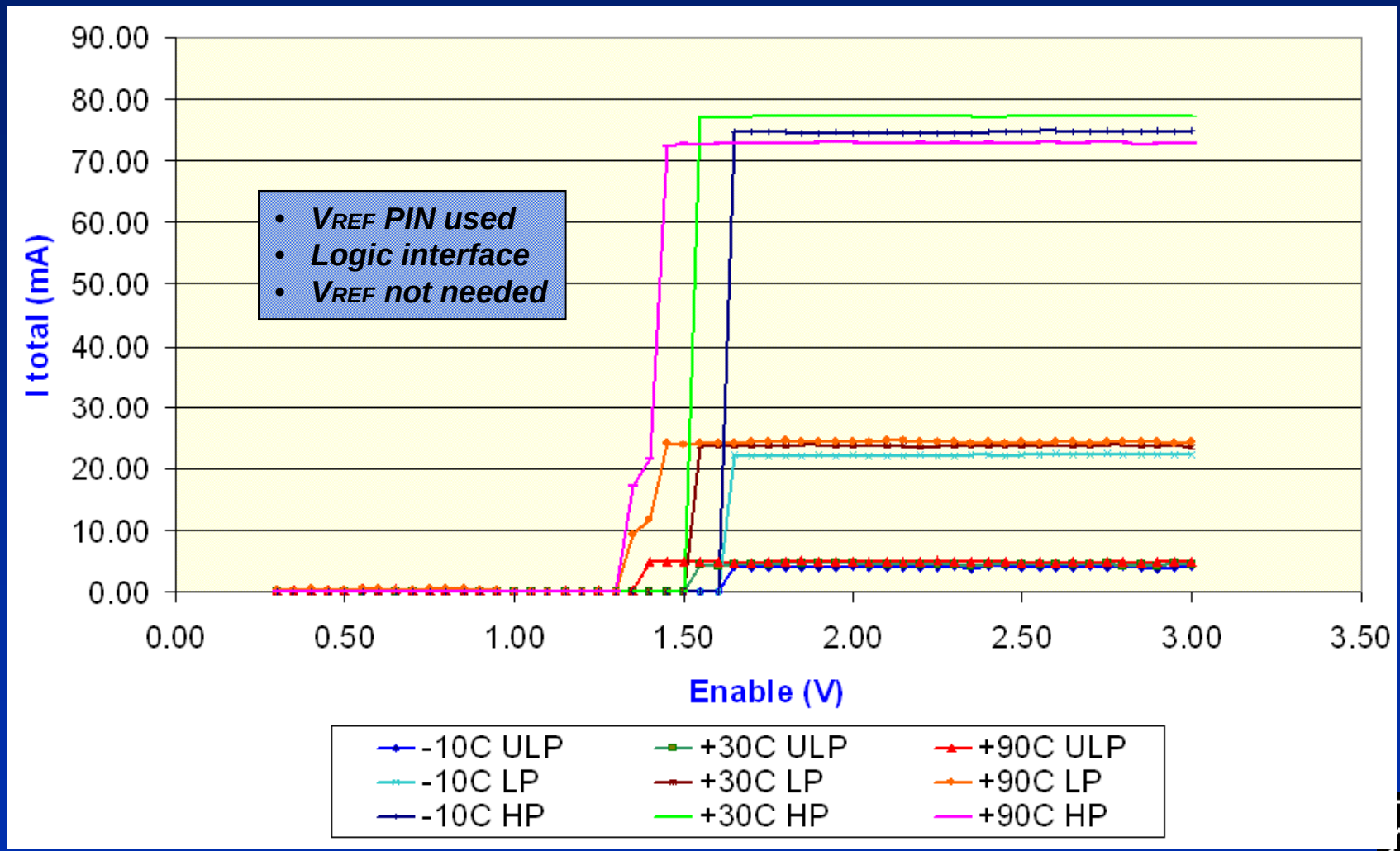
Low Mode Current



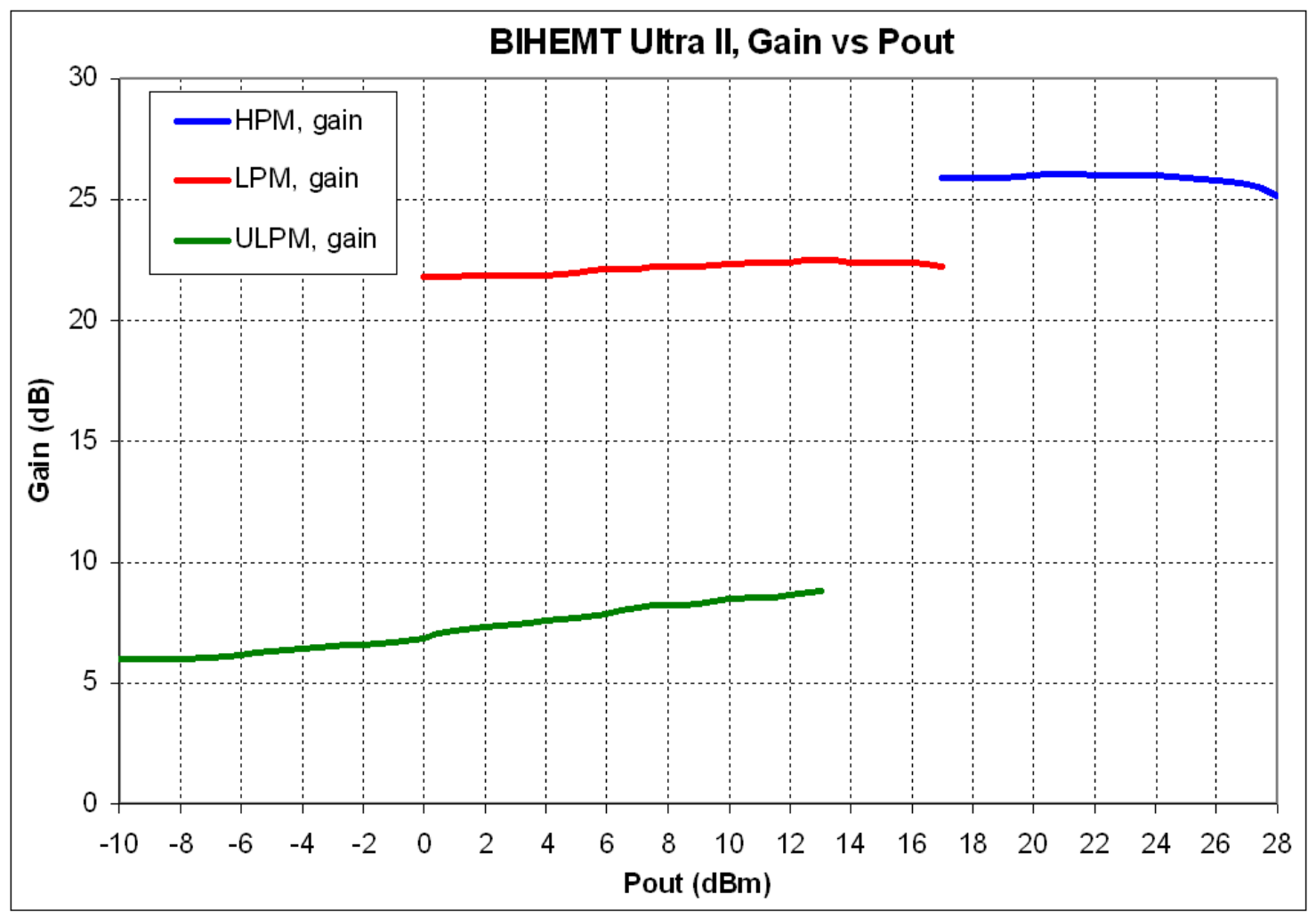
Ultra-Low Mode Current



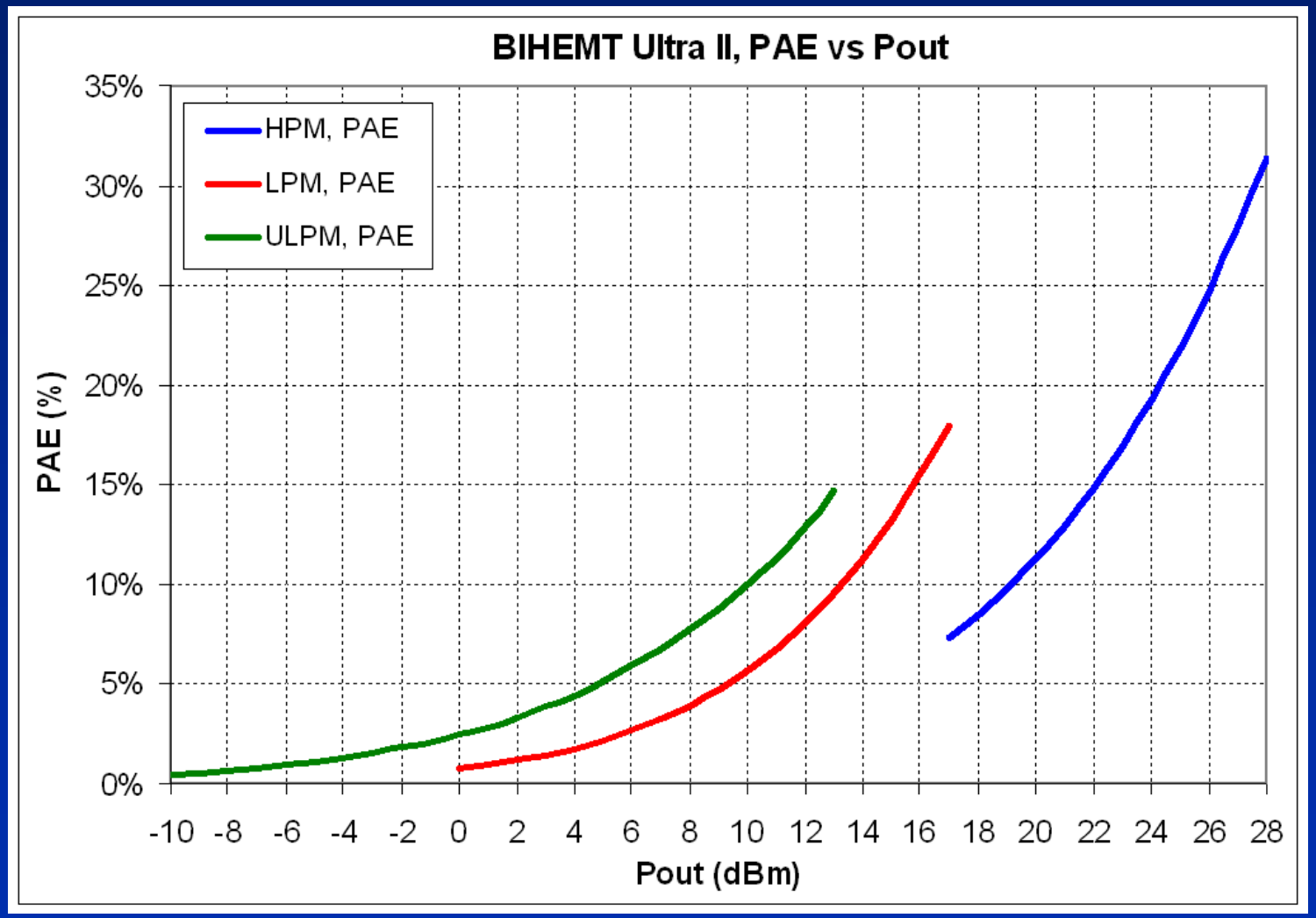
PA Enable


90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
I total (mA)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Enable (V)
• VREF PIN used
• Logic interface
• VREF not needed
-10C ULP
+30C ULP
+90C ULP
-10C LP
+30C LP
+90C LP
-10C HP
+30C HP
+90C HP

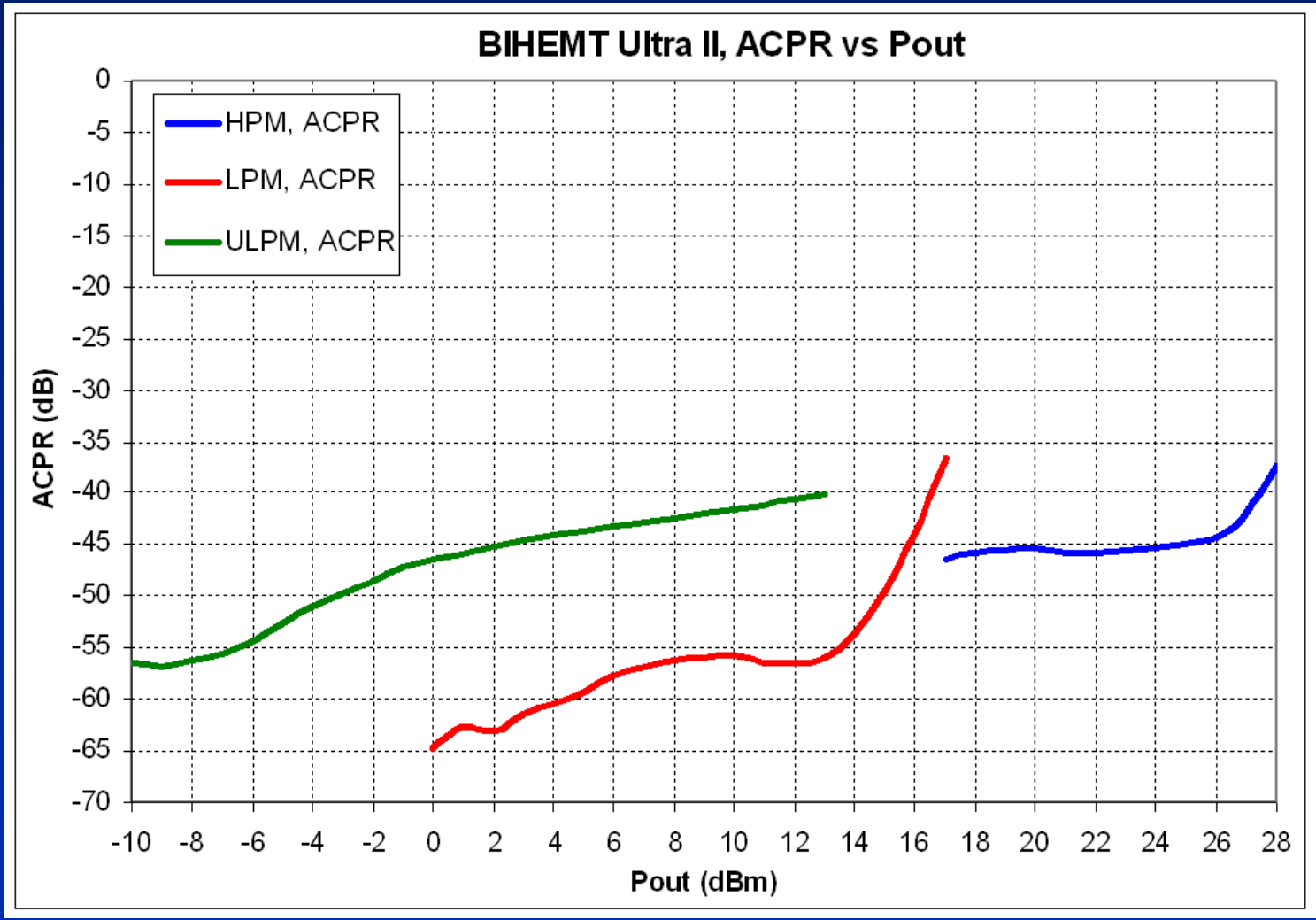
UMTS WCDMA (HSUPA)



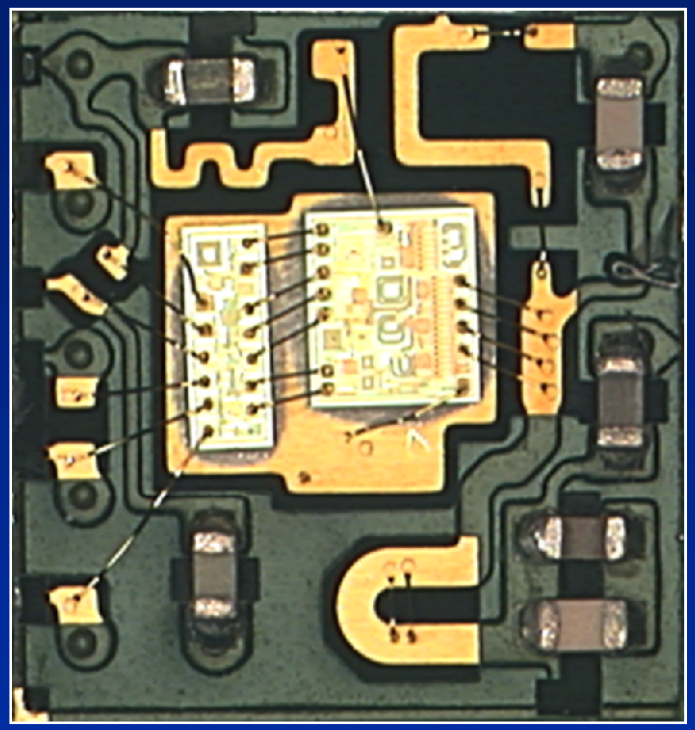
UMTS WCDMA (HSUPA)



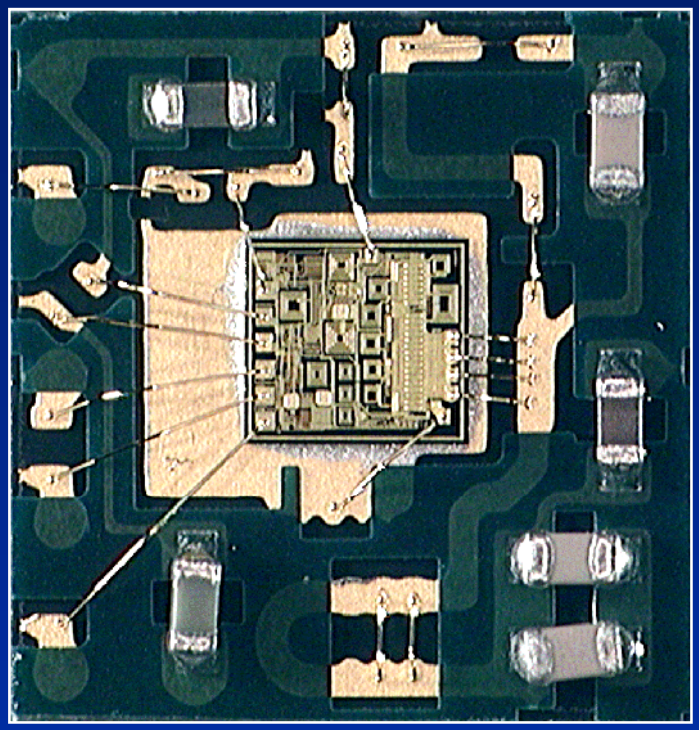
UMTS WCDMA (HSUPA)



Tri-State HBT / pHEMT 4x4 PA Module



2 CHIP SOLUTION
pHEMT and HBT PROCESS



1 CHIP SOLUTION
BiHEMT PROCESS

- Total die area is reduced by 20% with BiHEMT
- Total die footprint in module is reduced by 27% with BiHEMT
- Seven inter-chip wire bonds are eliminated

Conclusion

- Tri-State Switched Doherty PAs have been realized in new BiHEMT process.
- This process combines HBT and E/D pHEMT capability.
- V_{REF} requirement eliminated by use of pHEMT current sources.
- Good power efficiency and linearity achieved in 3 power modes.
- Low power quiescent current below 6 mA demonstrated.
- Several techniques to improve performance have also been presented:
  - A new HBT geometry provides reduced C_{BC}
  - Use of low Zo interconnect structures to reduce inductance in base feed manifold
- The results reported here represent a significant boost to CDMA talk-time.

ACKNOWLEDGEMENTS

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BiHEMT Tri-State Switched Doherty PA