Evolution of High Power LDMOS Transistors at NXP

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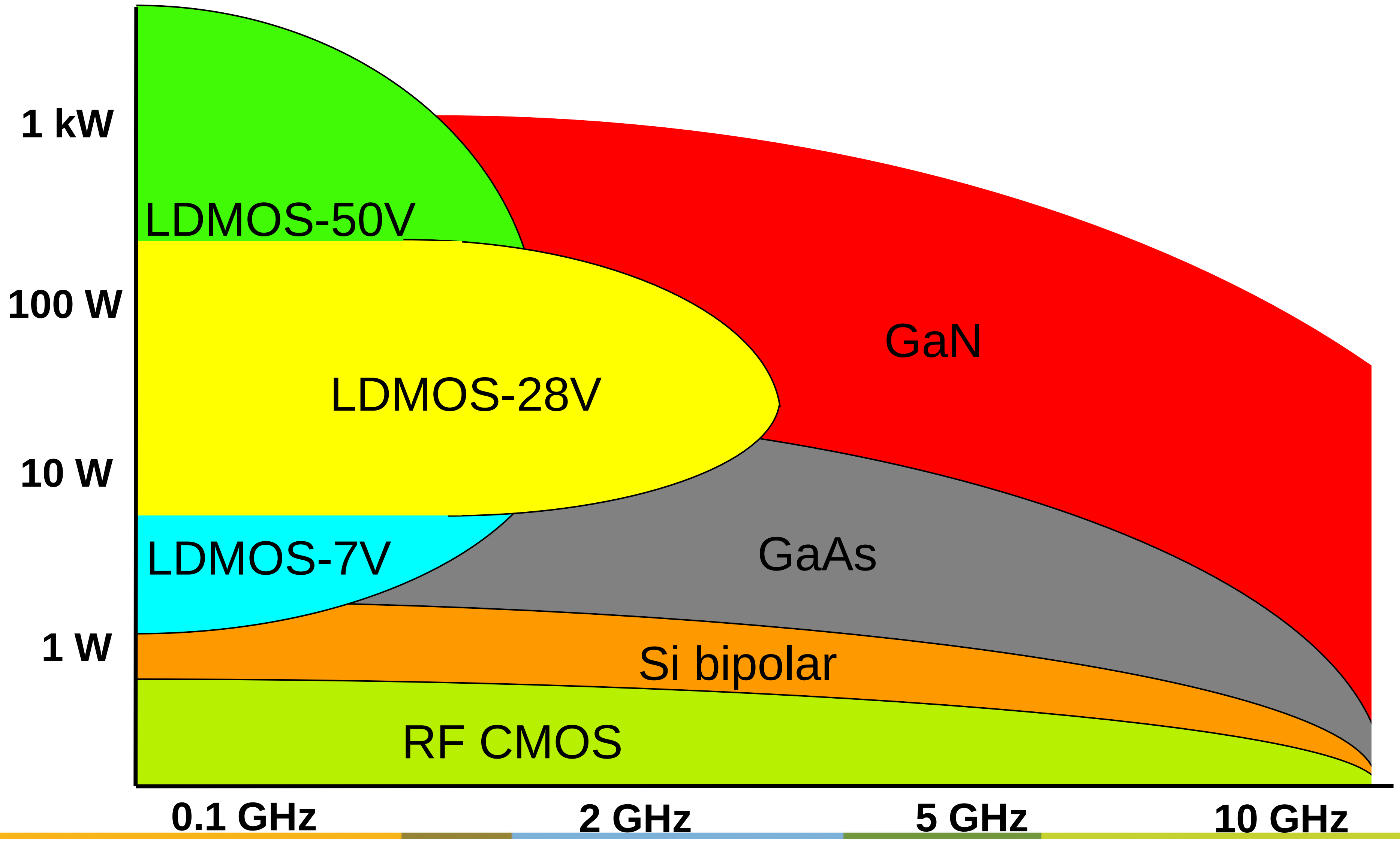
Question – what can we do to help?

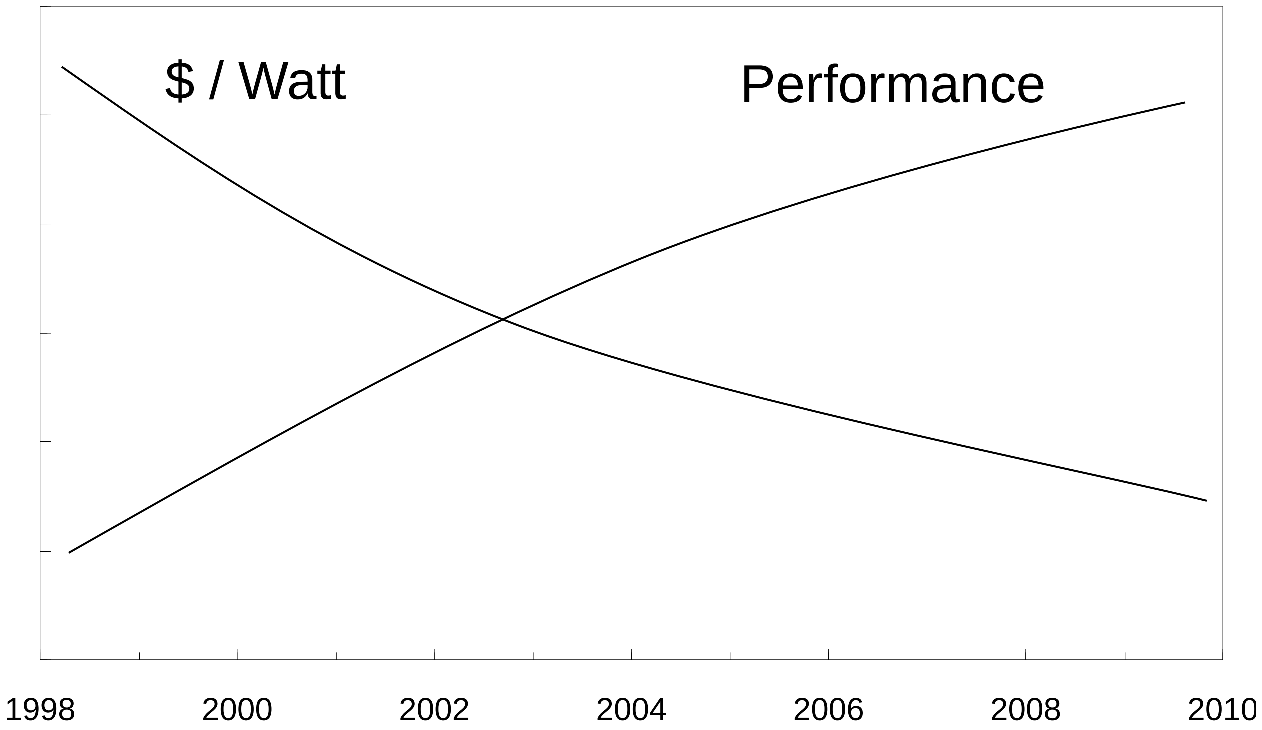
Motivation

- Tubes were historically the technology of choice for amplifiers in accelerators
- However, the industry is seeing more and more designs using solid state
- Tube pricing is expected to increase as the business contracts and supply reduces
- Solid State pricing is on a cost reduction path
- Overall cost of ownership is lower with solid state
- Solid State amplifiers have higher reliability
- If you lose a tube – the ring is down. If an amp module blows, overall power doesn't drop significantly and you can replace during yearly maintenance.

LDMOST and other RF Power Technologies

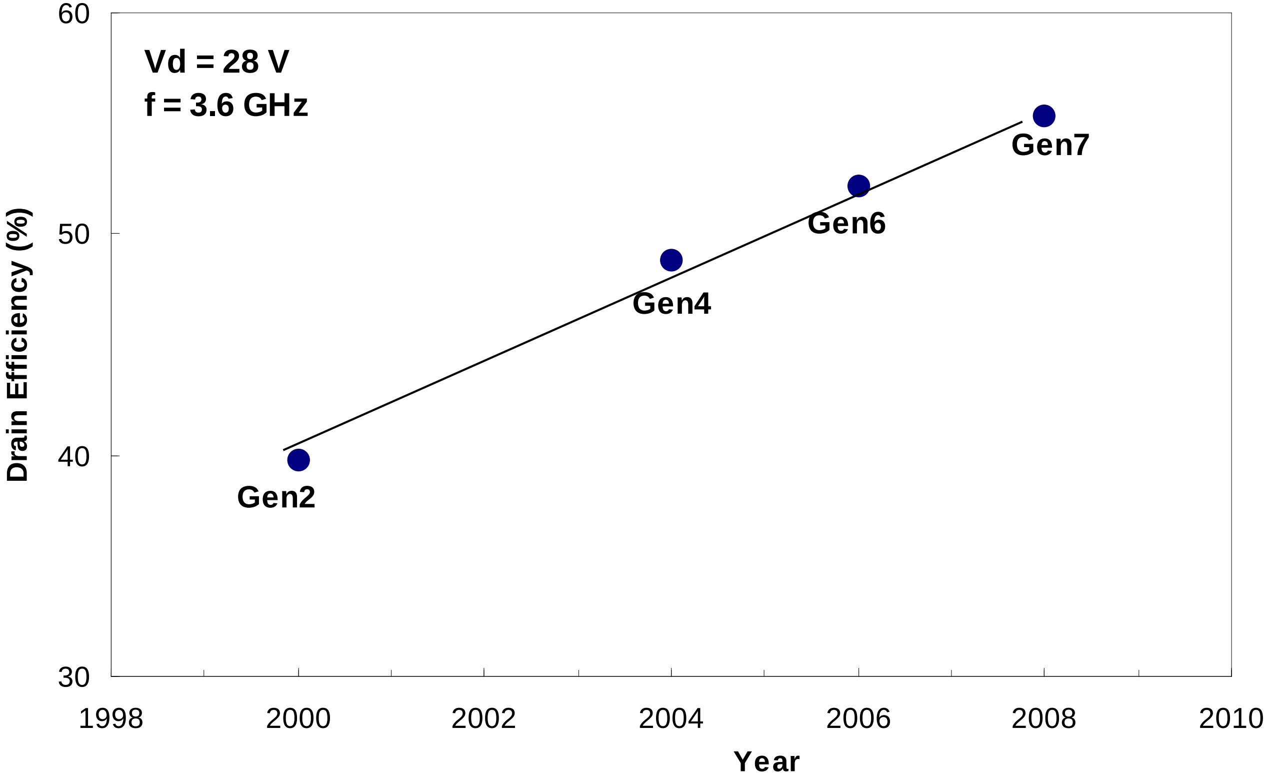


Trends in LDMOS Cost vs Performance

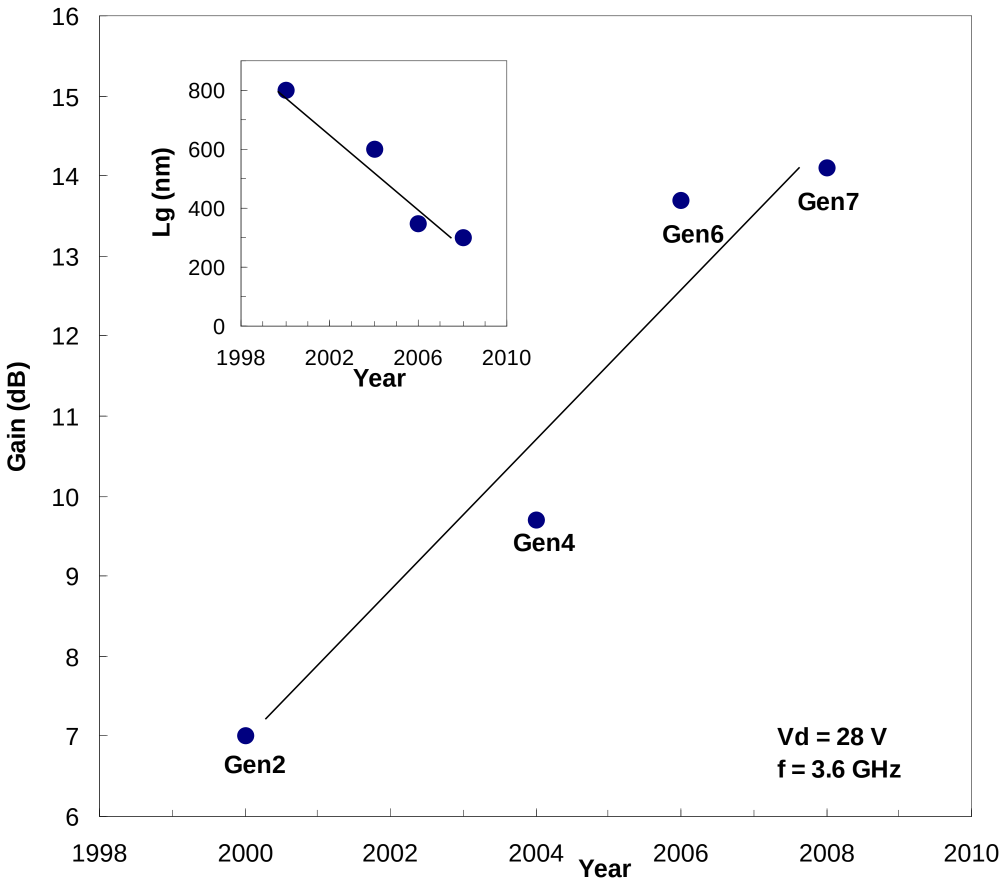


This behavior has enabled entire industries where no commercially available / viable solution was possible before

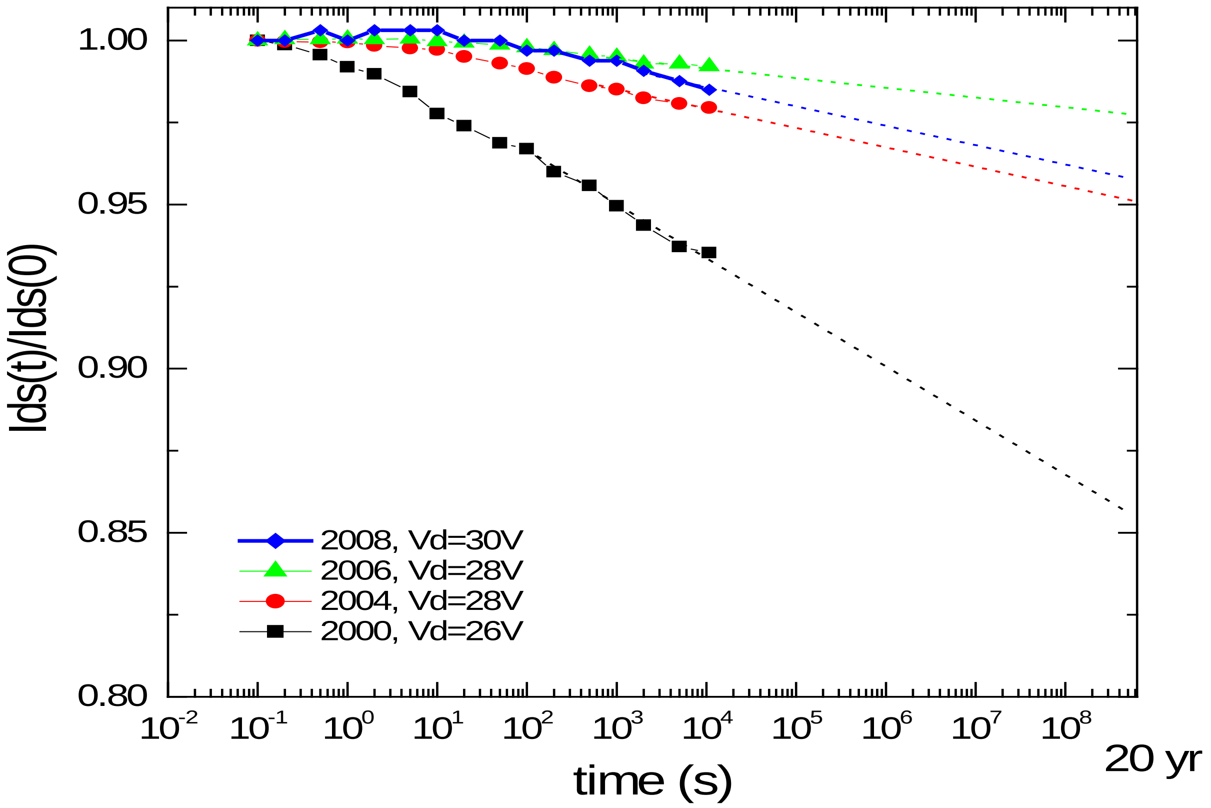
Trends in Drain Efficiency



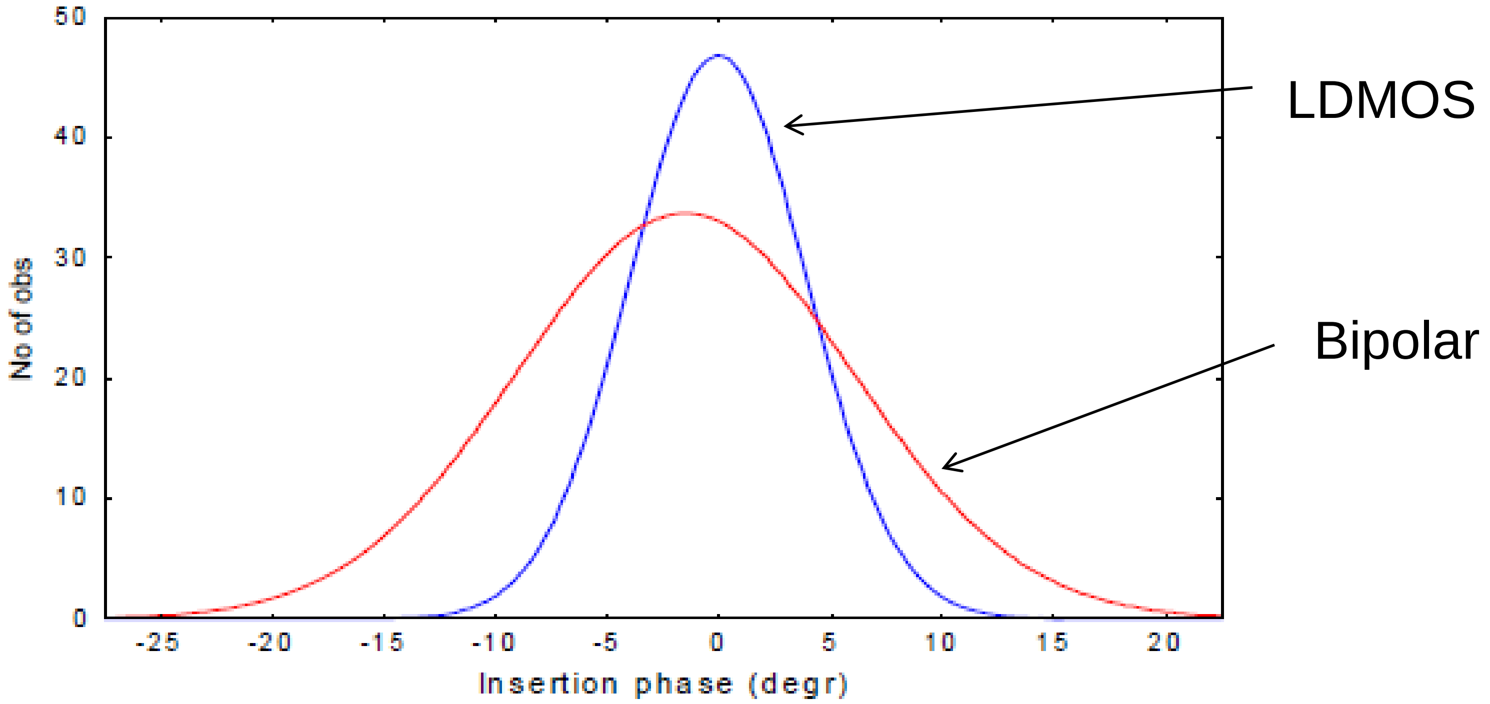
Trends in Gain (chart is at 3.6 GHz)



Trends in IDQ Degradation

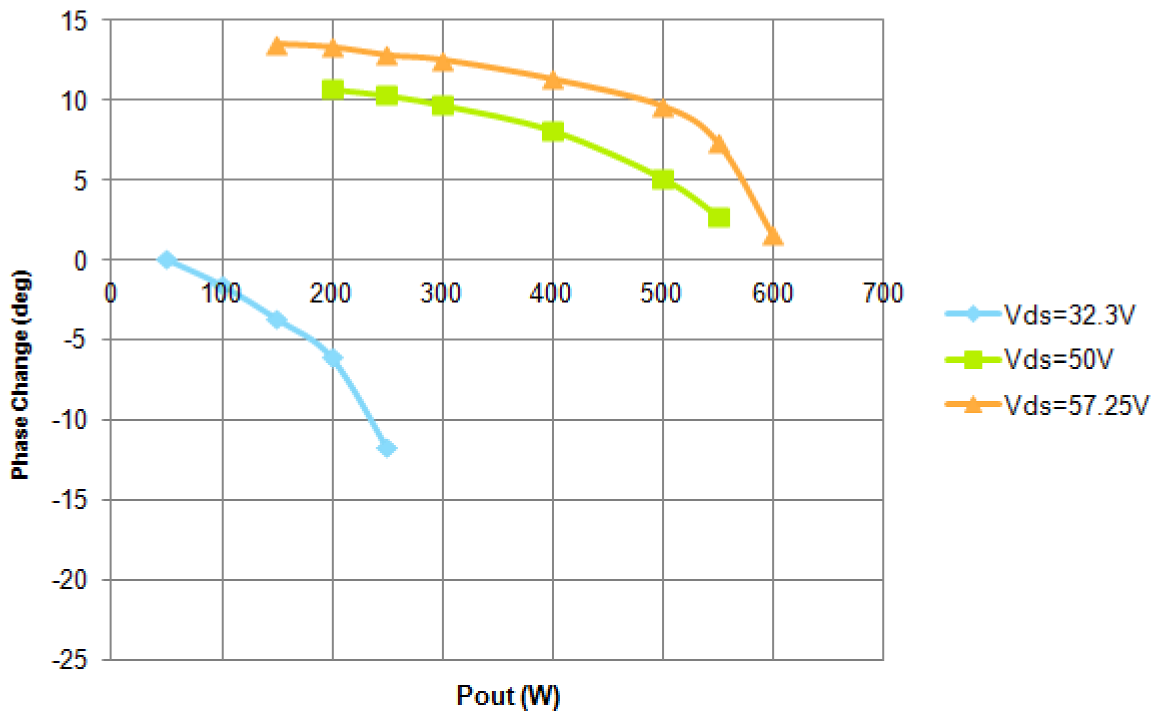


Phase Variation



Batch to batch insertion phase distribution of both LDMOS and bipolar devices at S-Band frequencies

Phase variation for 650MHz BLF888B amplifier



- Phase changed less than 1 degree running at 500W for 1 hour
- Phase changed 0.5 degrees for a 3 degree change at the baseplate
- Phase changes over power and over supply voltage according to the graphs

Other Trends – Thermal Impedance

Year	Device	Rth (K/W)
2000	BLF647	0.6
2005	BLF369	0.26
2009	BLF578	0.14
2012	BLF178XR	0.12

Lower Rth along with higher efficiency allows much cooler, more reliable operation per Watt of RF power

Other Trends - Ruggedness

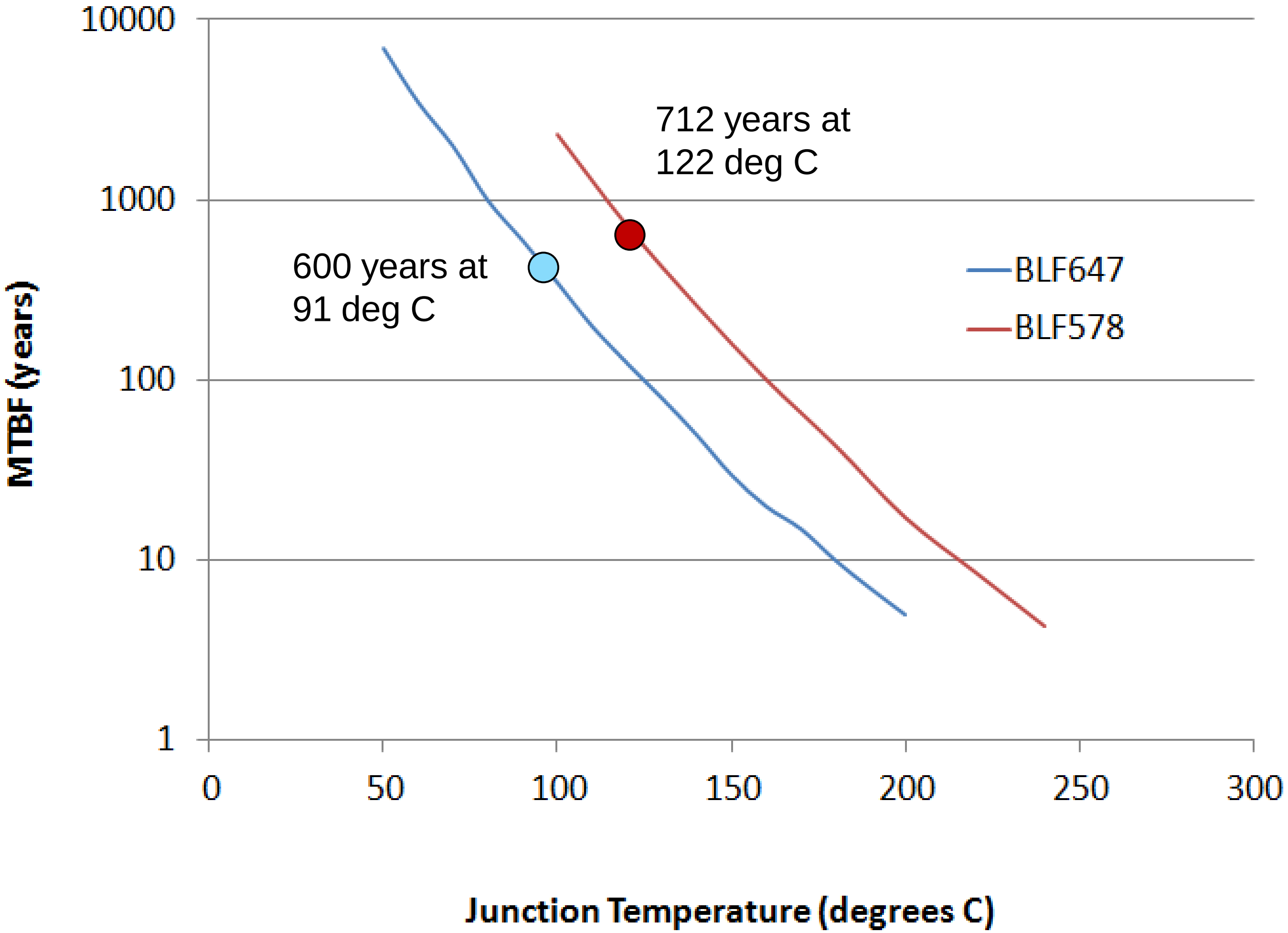
Year	Device	VSWR
2000	BLF647	10:1
2005	BLF369	10:1
2009	BLF578	13:1
2010	BLF888A	40:1
2012	BLF178XR	65:1 *

* See Youtube Video: NXP's Unbreakable BLF578XR LDMOS Power Transistor

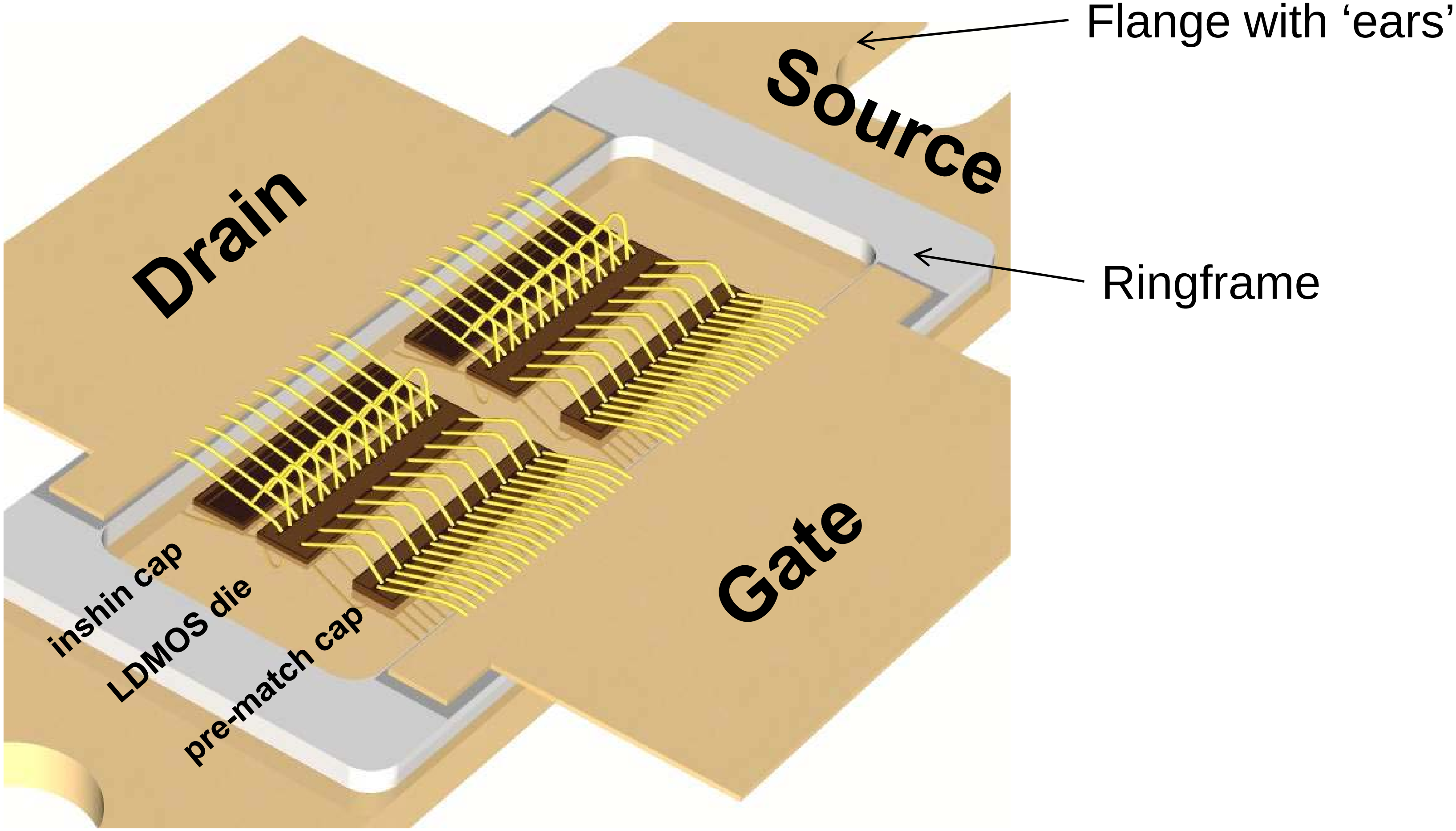
Solid State Lineup Comparison: Year 2000 vs Now

Final Stage	Output Power per stage	Devices Needed	Gain	Total transistor cost	Total Dissipation
BLF647	120W (run at 70W)	2637	16	$ House	185,000W (at 50%)
BLF578	1000W (run at 700W)	260	22	$ car	78000W (at 70%)

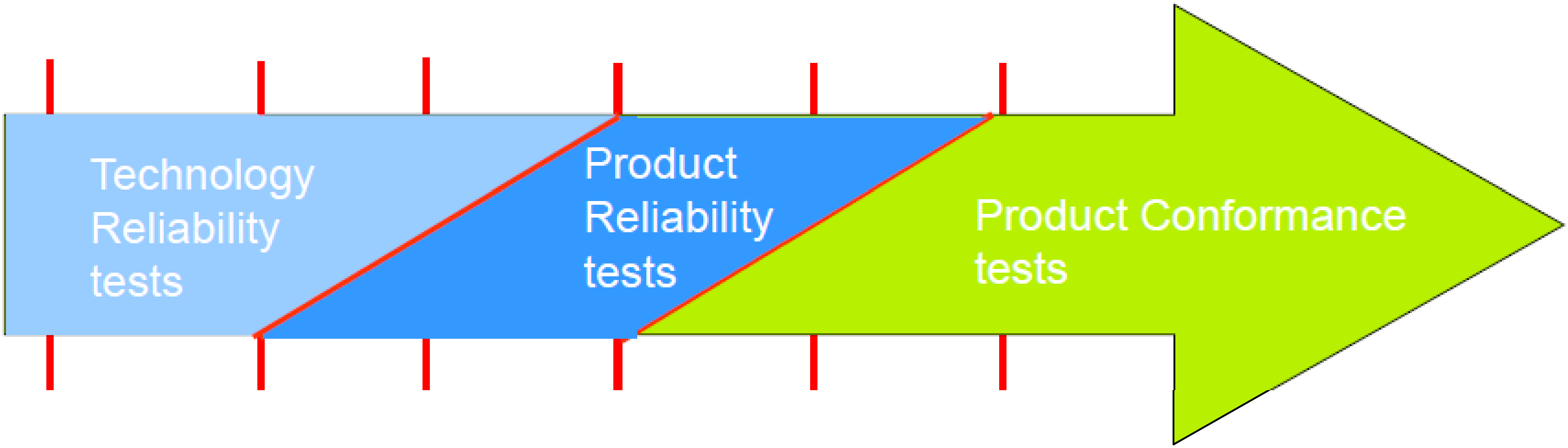
MTBF Comparison



LDMOS – What's under the cap?

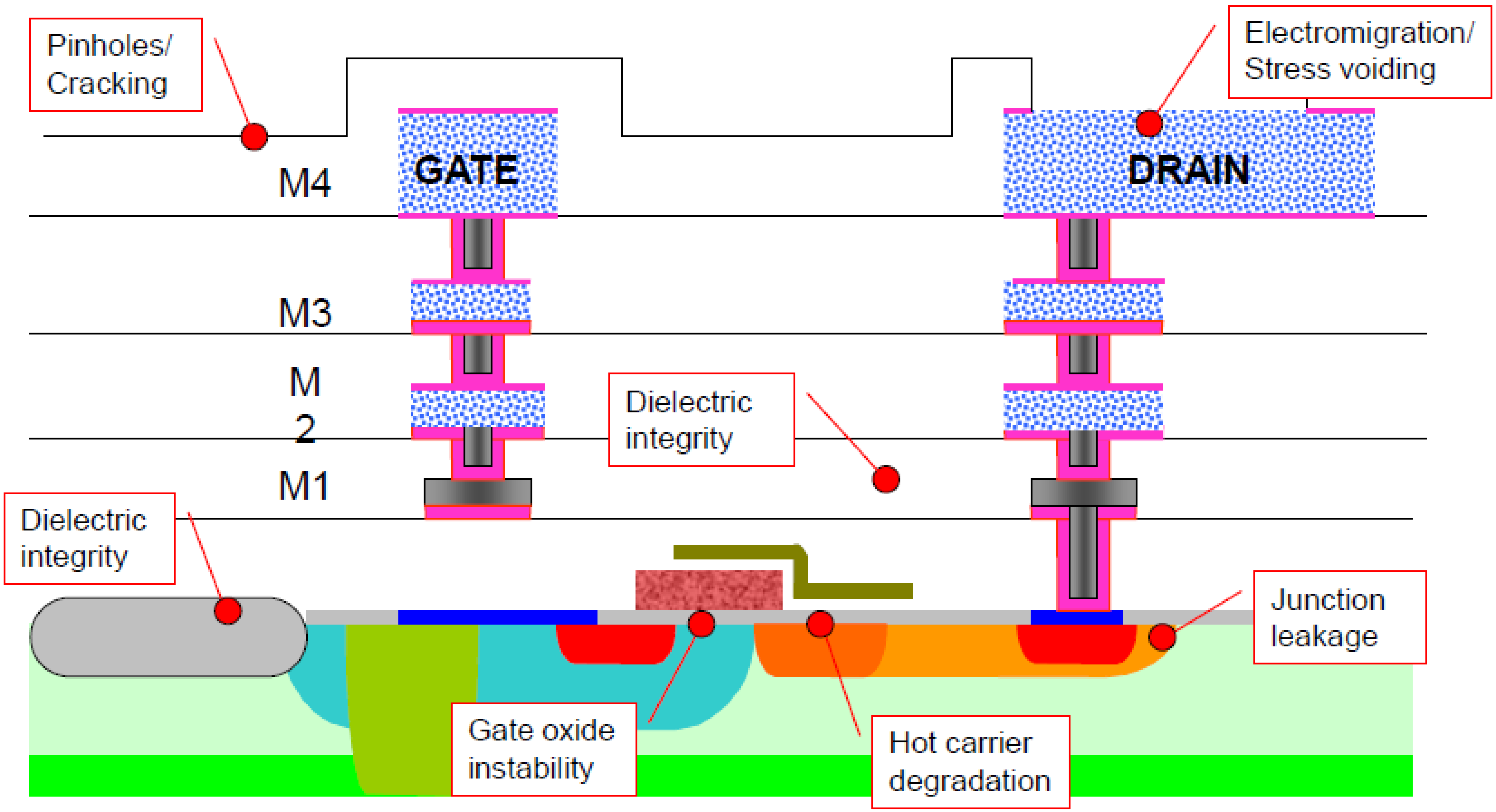


Proving Product Reliability – every step of the way



Create tests that stress the areas most likely to fail at each point and then come up with appropriate acceleration factors

Most Probable Failure Points - Technology



Technology Reliability Test Plan

Diffusion failure mechanism	Accelerating test	Test carrier	Reference
Gate oxide instability	Stepped current Qbd/Ebd TDDB (T=125°C)	Area capacitors	SNW-FQ-101I SNW-FQ-101B
Junction leakage	ΔIdss (Vds=65V, T=250°C)	LDMOS	
Dielectric integrity	BTS (30s, 250°C@Vg)	(parasitic)(LD)MOS	SNW-FQ-101D
Passivation pinholes + cracking	Pressure Pot (T=121°C, 100% RH, P=205kPa)+ Cu discoloration (or mity etch)	LDMOS	JESD22-A102-C
Stress voiding	High Temperature Storage (1wk @ T=200°C)	NIST structure (M4 LDMOS gate fingers)	JESD22-A103-C

Quality Tests to release a Process

Test	Conditioning	Duration	Sample	Failure
High Temperature Reverse Bias Drain	Vds=60V, Vgs=0V, Ta=175°C	1000hrs 500hrs	72 24	0 0
	Vds=52V, Vgs=0V Ta=175°C	1000hrs	60	0
High Temperature Reverse Bias Gate	Vgs=8,3V, Vds=0V Ta=175 °C Vgs=11V, Vds=0V Ta=175 °C	2000hrs 500hrs 1000hrs 2000hrs	10 9 60 28	0 0 0 0
High Temperature Storage	Ta=150 °C	500hrs 2000hrs	10 78	0 0
	Ta=200 °C	1000hrs 2000hrs	17 8	0 0
Operating life Ton/off=50/10sec	T heat sink=70°C, Tj =200°C	500hrs 1000hrs 2000hrs	9 53 55	0 0 0
Temperature cycling test (Air to air)	25°C/ -65°C/ 25°C/ 150°C 5min/ 30min/ 5min/ 30min	2000cl	77	0
	25°C/ -65°C/ 25°C/ 200°C	500cl 1000cl	9 10	0 0
Thermal shock (Liquid to liquid)	25°C/ -65°C/ 25°C/ 150°C 5sec/ 5min / 5sec / 5min	500cl 1000cl	10 101	0 0
Highly Accelerated Steam test (only for ACP package)	85%/ 133°C, Vds=42V	96 hr.	60	0

A ‘failure’ occurs when a part shows > 5% change in any DC parameter, or when an RF parameter falls outside of specification

Carrier Device : Test 1 representative die in a small single ended package

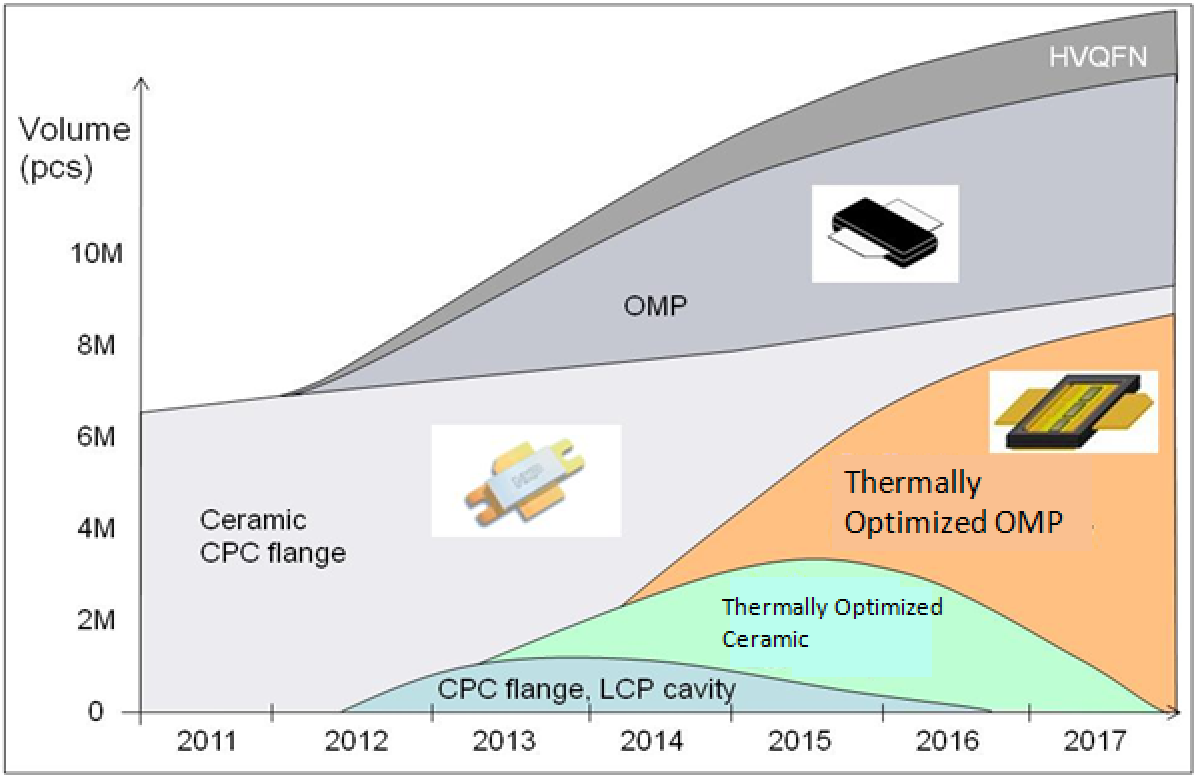
Quality Tests to release a Product

Accelerating test	Structural similarity group	Conditions
Operating life	**I**	T_j=200°C
	2	
High Temperature Reverse Bias Drain	**I**	V_{ds}=52V, T_a=175°C
	2	
High Temperature Reverse Bias Gate	**1**	V_{gs}=11V, T_a=175°C
	2	
Temperature Cycling (air to air)	**1**	T_a=-65/+200°C
	2	
Temperature Shock (liquid to liquid)	**1**	T_a=-65/+150°C
	2	

Accelerating test	Structural similarity group	Conditions
Highly-accelerated Temperature and Humidity Stress (HAST) **	**I**	T_a=130°C, RH=85%, Vds=42V
Vibration	**2**	2hrs/dir, 3 dir 20-80Hz; P=1.5mm;20G
Mechanical Shock	**2**	5 shocks; 1500G/0.5ms; both dir. 2hrs/dir, 3 dir 20-2000Hz; P=1.5mm;20G

Tests actual dies in actual package

Packaging Evolution and Developments



Where are we now?

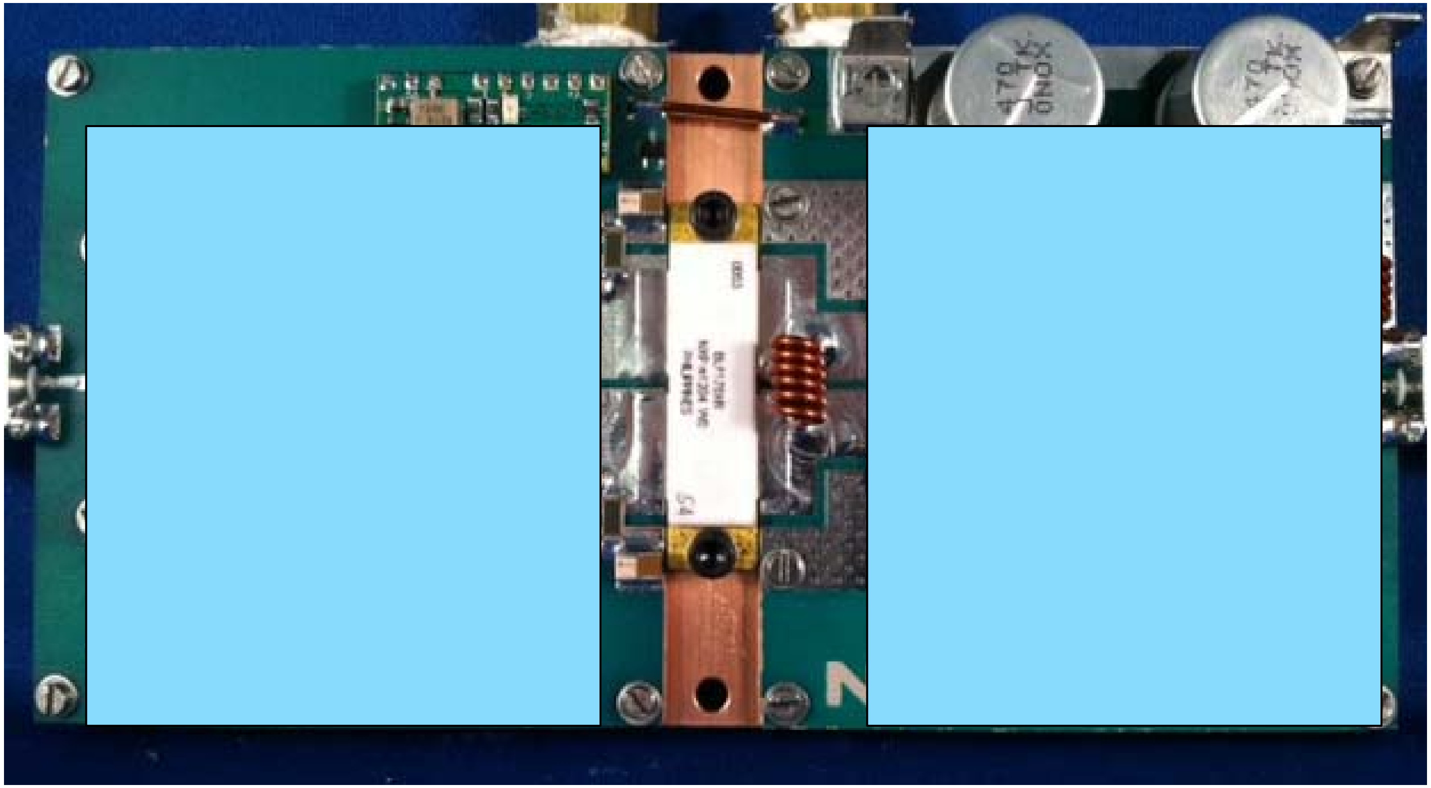
For designs < 150MHz: 1.2 kW Beast – the BLF178XR

For 150MHz to 500MHz: the BLF578 and the BLF578XR

For 1.3 GHz – the BLF6G13L(S)-250P

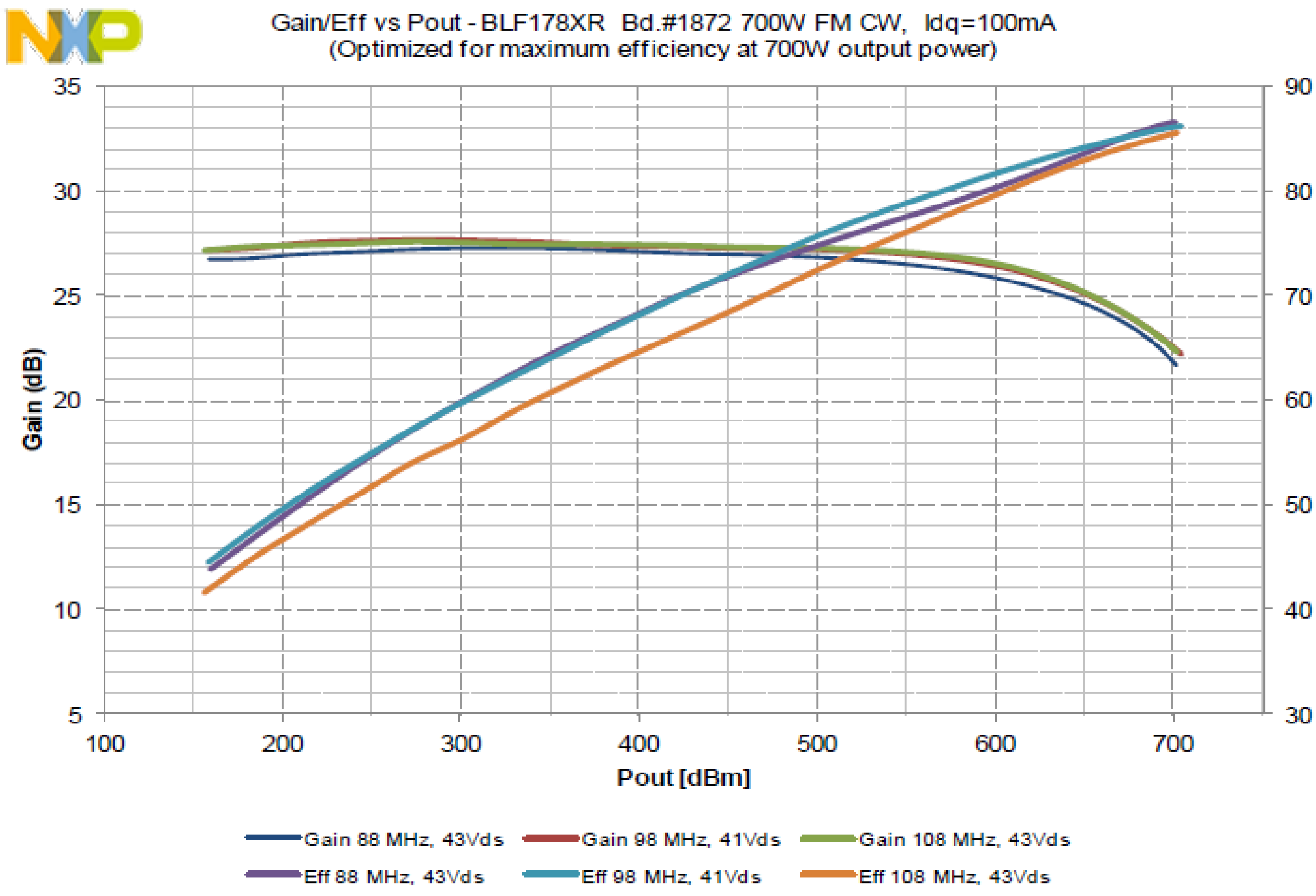
Roadmaps of products in other bands

BLF178XR for Designs around 100MHz

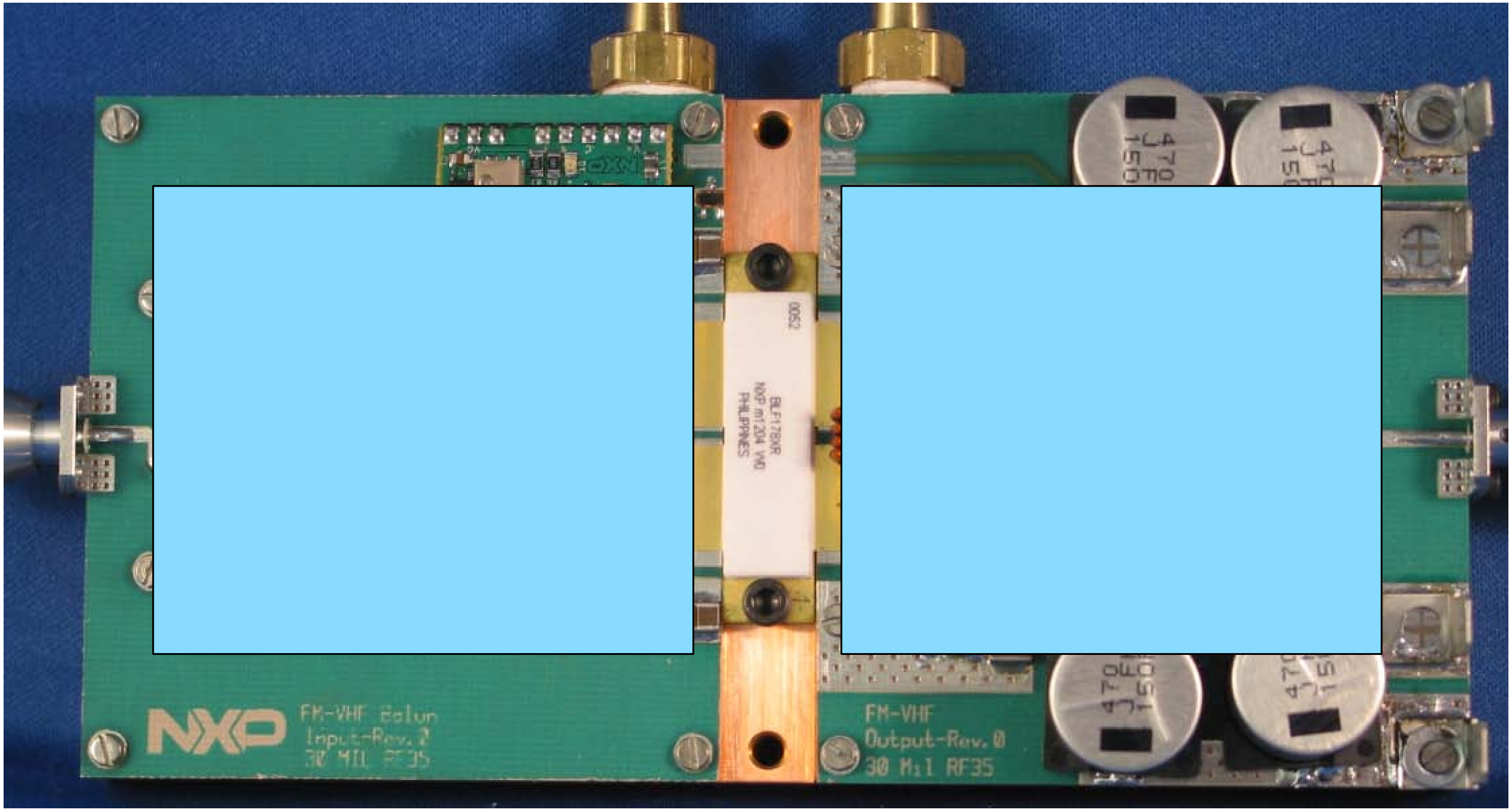


2 designs: Lower power, higher efficiency design and higher power lower efficiency design

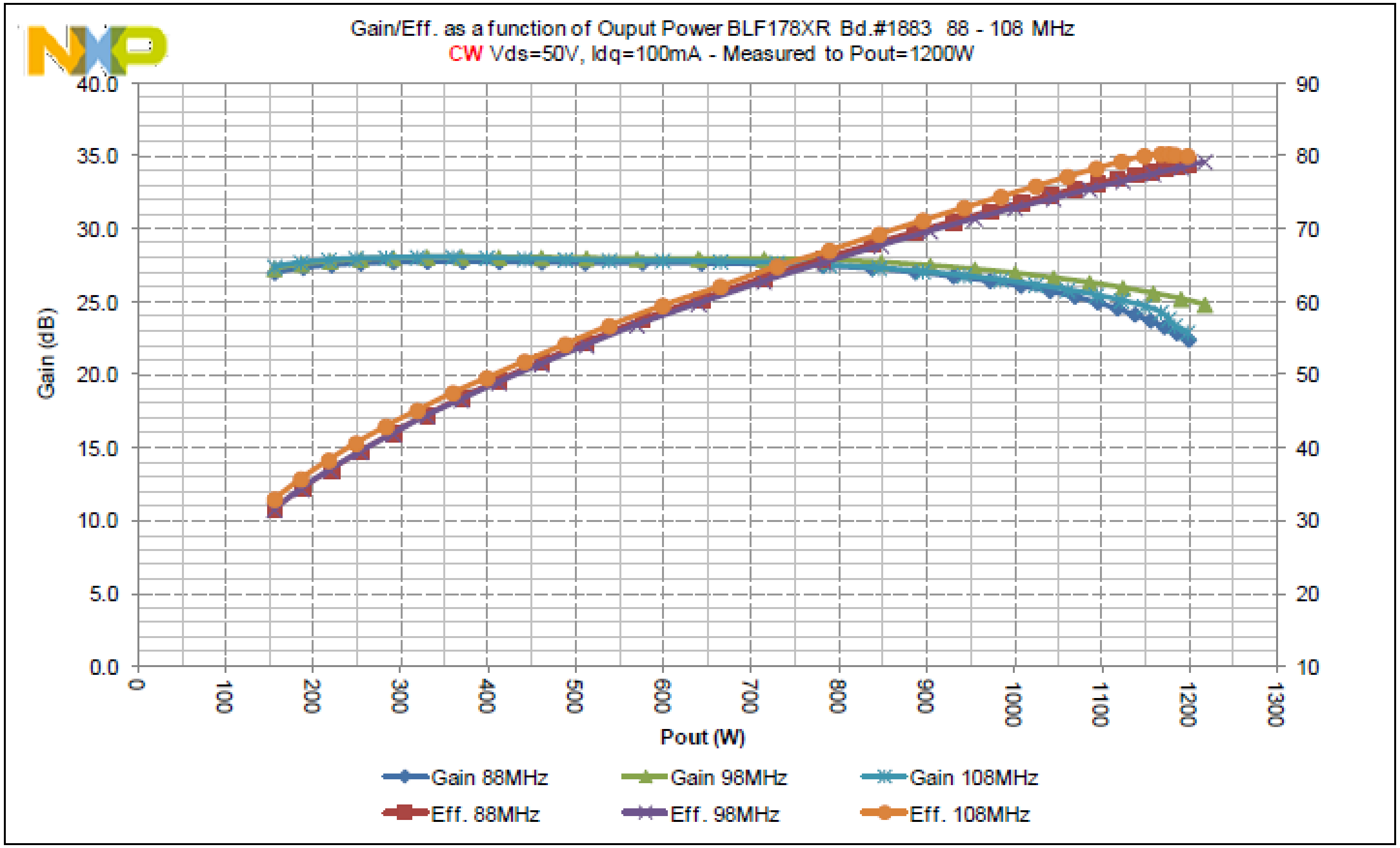
BLF178XR High Efficiency Design Performance



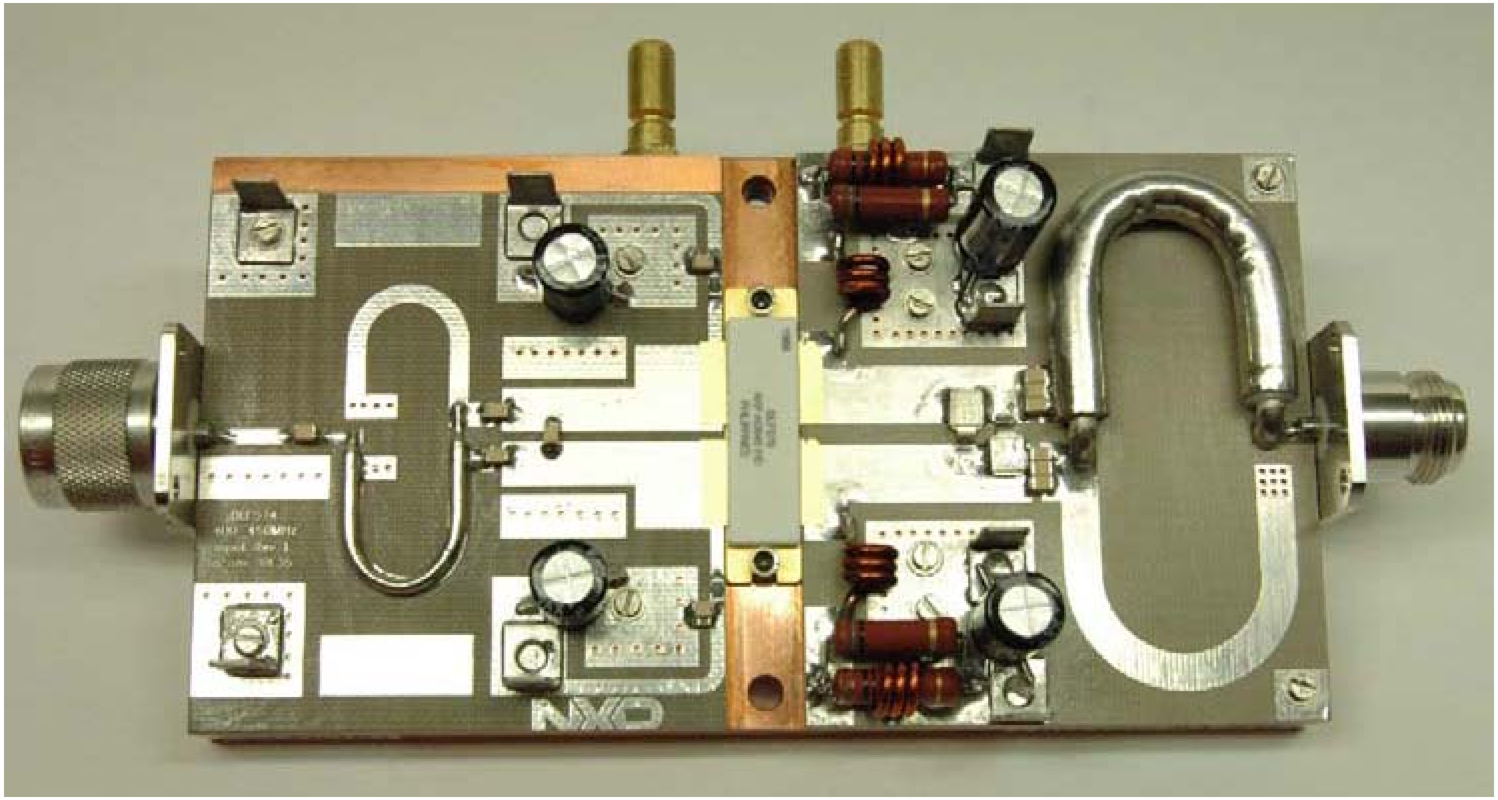
BLF178XR Higher Power Design



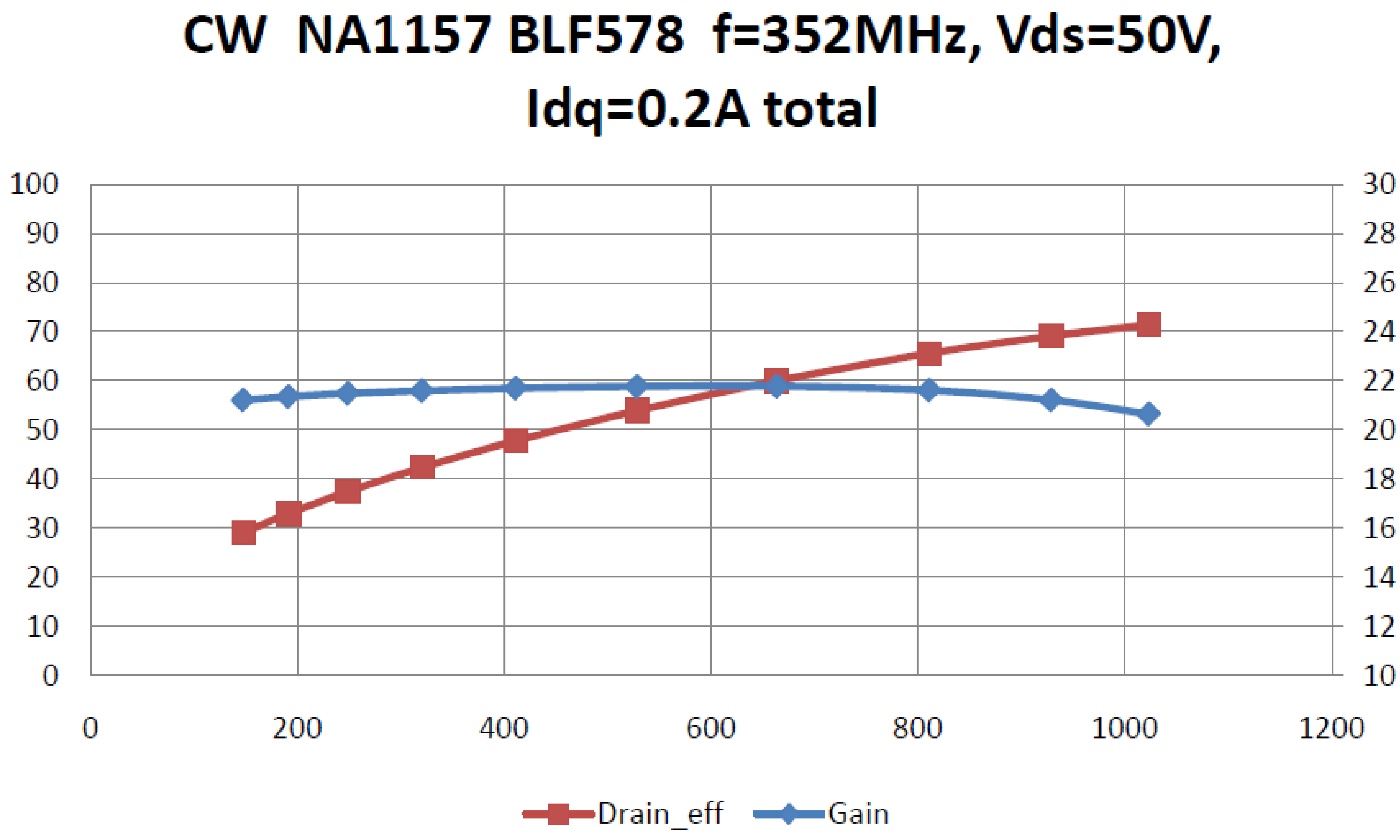
BLF178XR Higher Power Design Performance



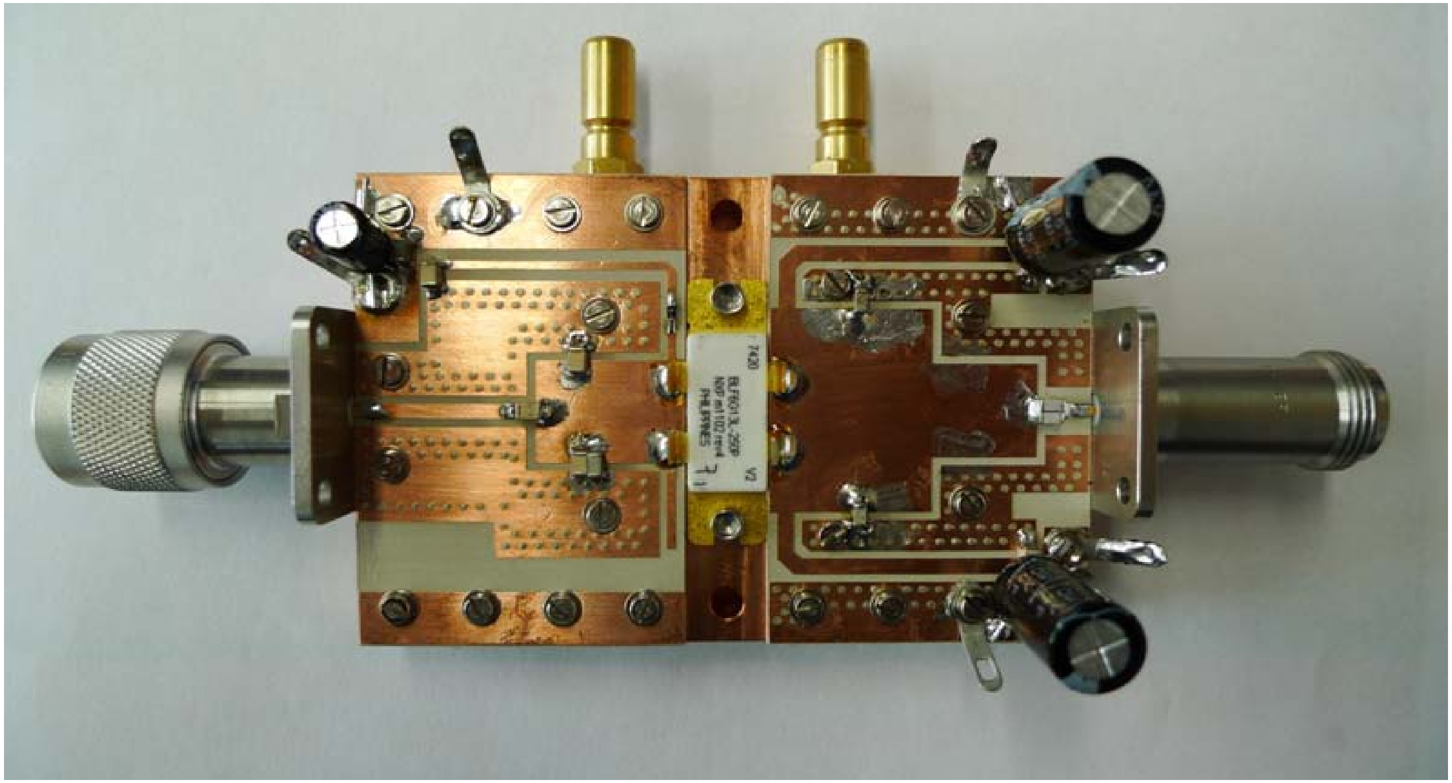
150 – 500MHz: The BLF578



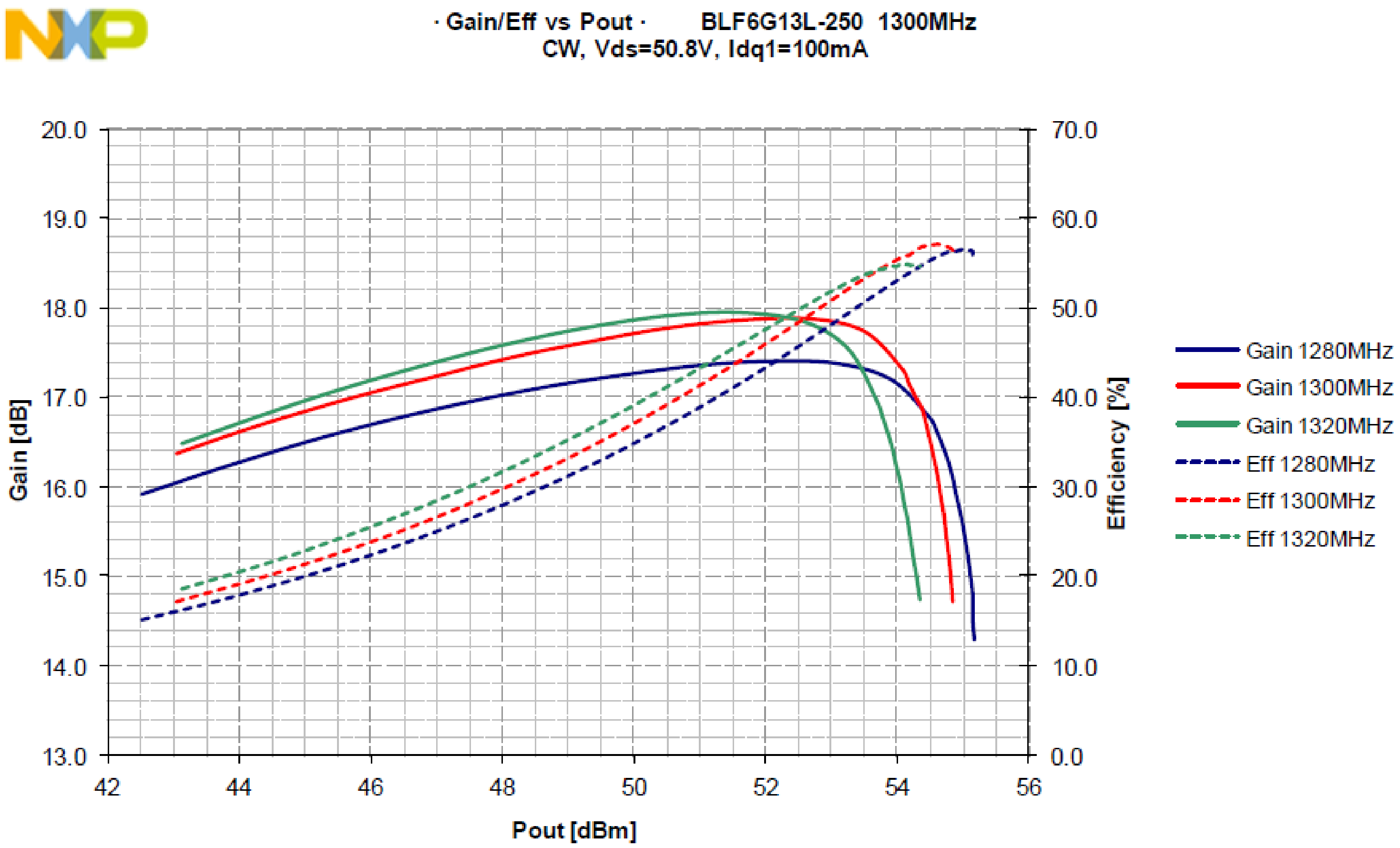
BLF578 352 MHz Amplifier



1300 MHz – the BLF6G13L(S)-250P



1300 MHz – the BLF6G13L(S)-250P



Where are we going?

- Future generations of LDMOS promise still higher power densities and efficiencies.
- As GaN comes on line, there’s an opportunity to radically increase power density.
- Higher levels of integration can incorporate more of the design, easing total amplifier design

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