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# Solid State RF Power
# The Route to 1W per Euro Cent

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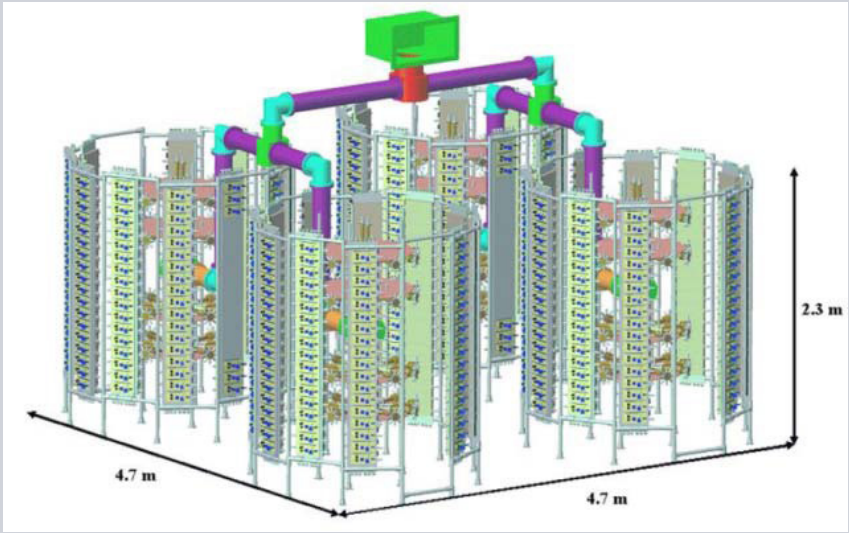
# Design of Solid State Amplifiers Today

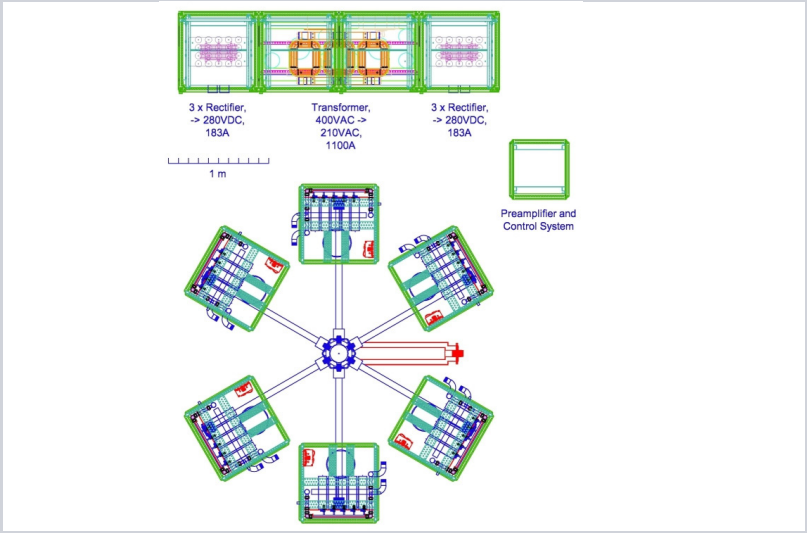
## 190 kW SOLEIL Solid State Amplifier




POLYFET Si LDMOS (LR301),
682 modules x 1 transistor,
315 W power each

J. Jacob, WEXPA02, Proceedings of EPAC 2006, Edinburgh, Scotland

## CRE312 - 72 MHz 150 kW Solid State Cyclotron Amplifier




Si VDMOS transistors,
6x2x10x4 combiner tree
~400 W each

M. Getta et al. TU5PFP081 Proceedings of PAC09, Vancouver, BC, Canada

# Cost position?

Cost position

?

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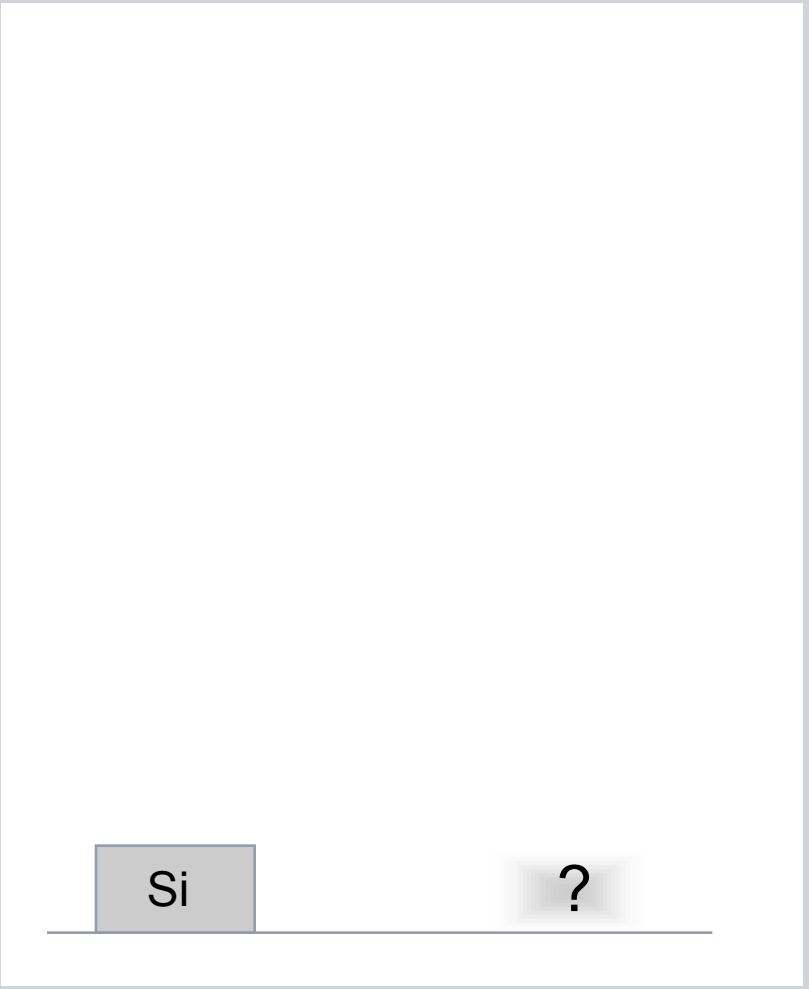
# Cost position?

Switch from Si to wide bandgap semiconductors



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## Cost position?

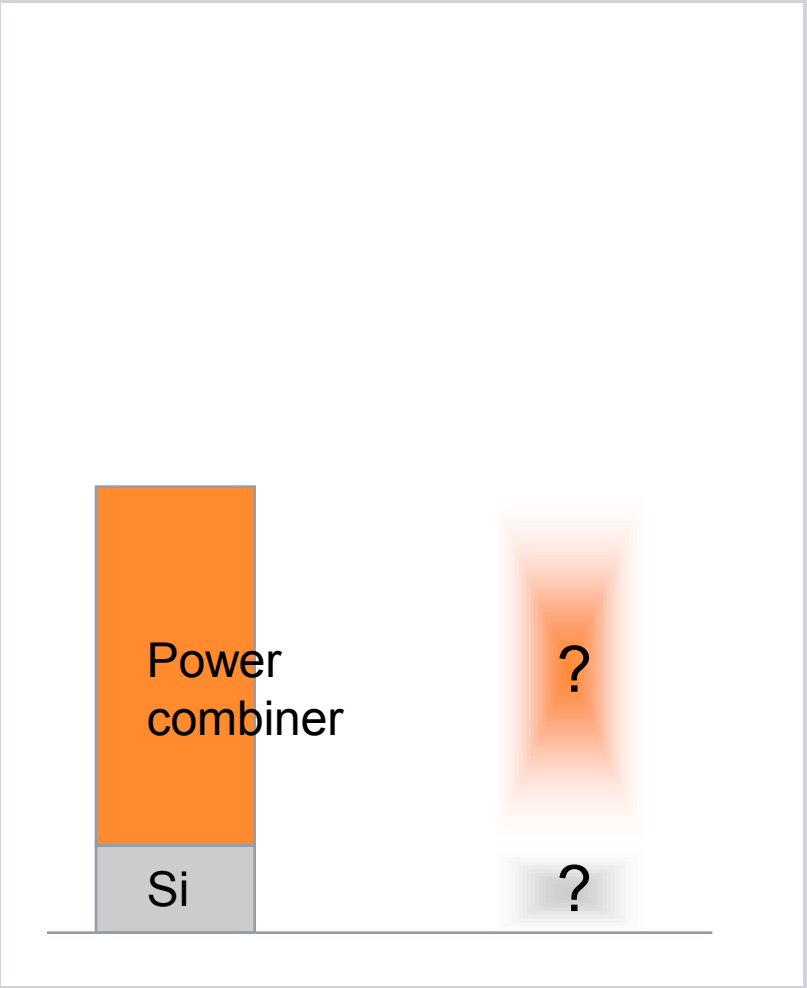
Switch from Si to wide bandgap semiconductors

Complexity

Modular approach

Herd of Elephants vs Army of Ants

Single stage RF power combiner



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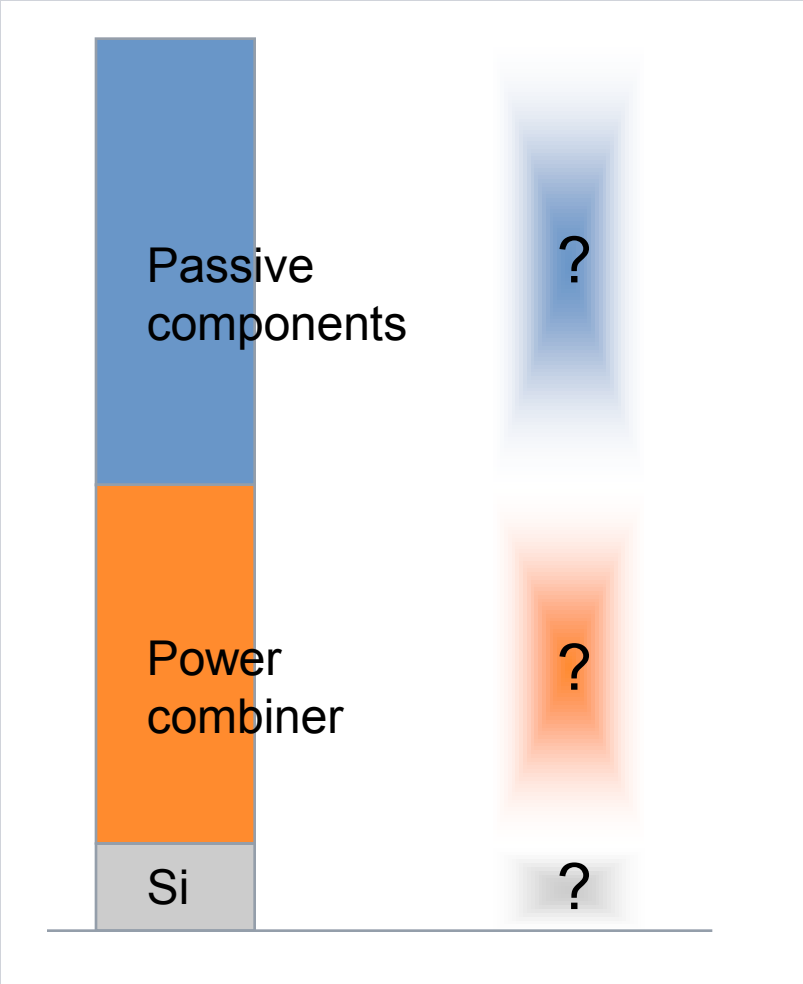
## Cost position?

Switch from Si to wide bandgap semiconductors

Herd of Elephants instead of Army of Ants modular approach

Single stage RF power combiner

Minimal use of specialized passive components: economics of scale



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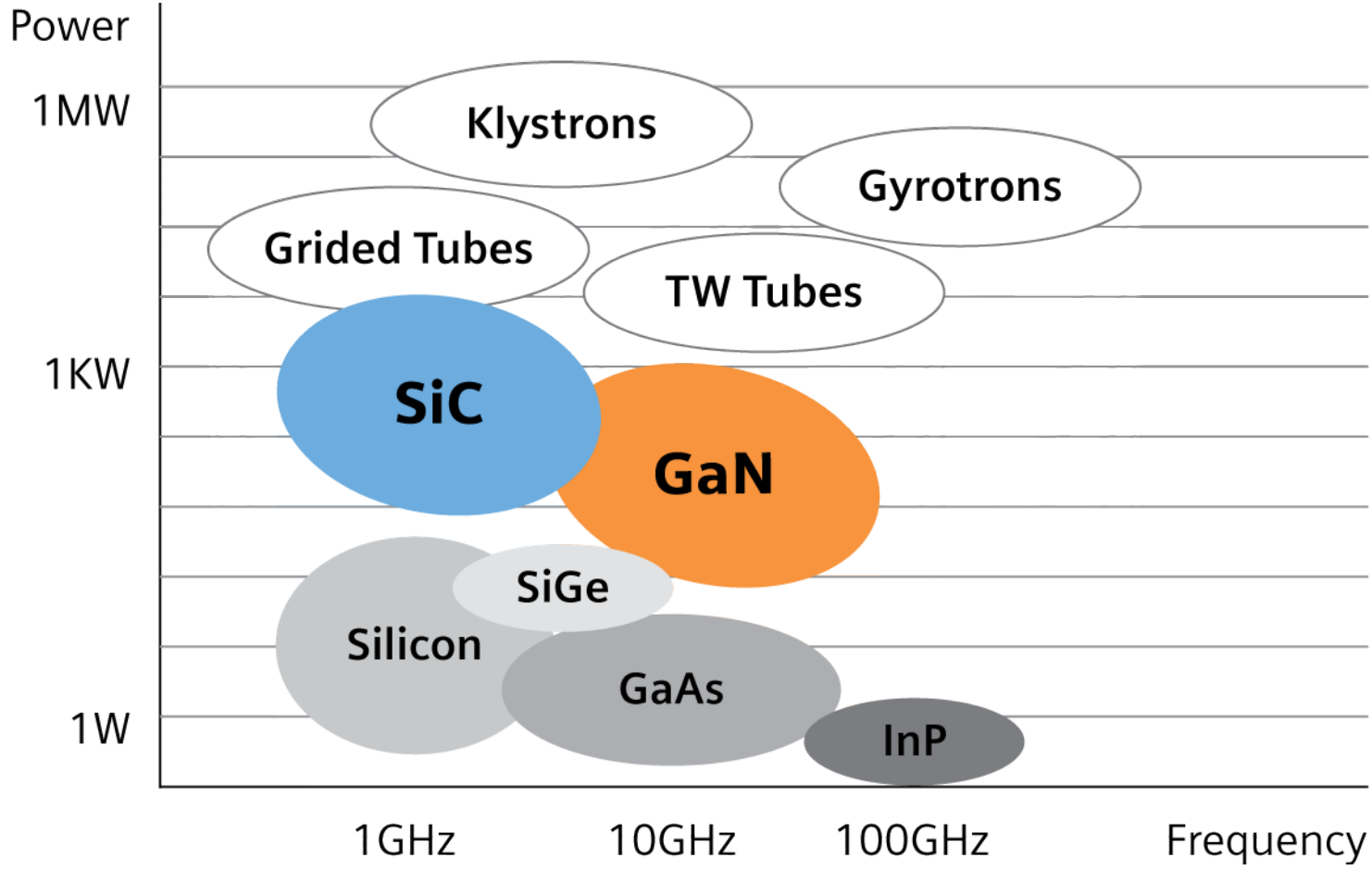
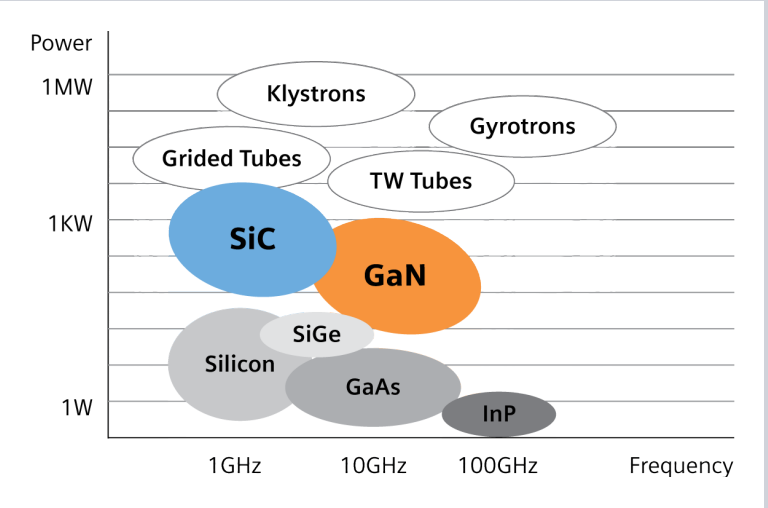
# RF Power Devices – State of the Art



# Wide Bandgap RF Semiconductors

- SiC intrinsically 10x faster than silicon
- Significantly enhanced power density
- Radiation hardened
- High heat conductivity




| Materials Property | Si | SiC-4H | GaN |
|---|---|---|---|
| Band Gap [eV] | 1.1 | 3.2 | 3.4 |
| Critical Field [MV/m] | 30 | 300 | 350 |
| Electron Mobility [$cm^2/(Vs)$] | 1450 | 900 | 2000 |
| Electron Saturation Velocity [km/s] | 100 | 220 | 250 |
| Thermal Conductivity [$W/cm^2$ K] | 1.5 | 5 | 1.3 |

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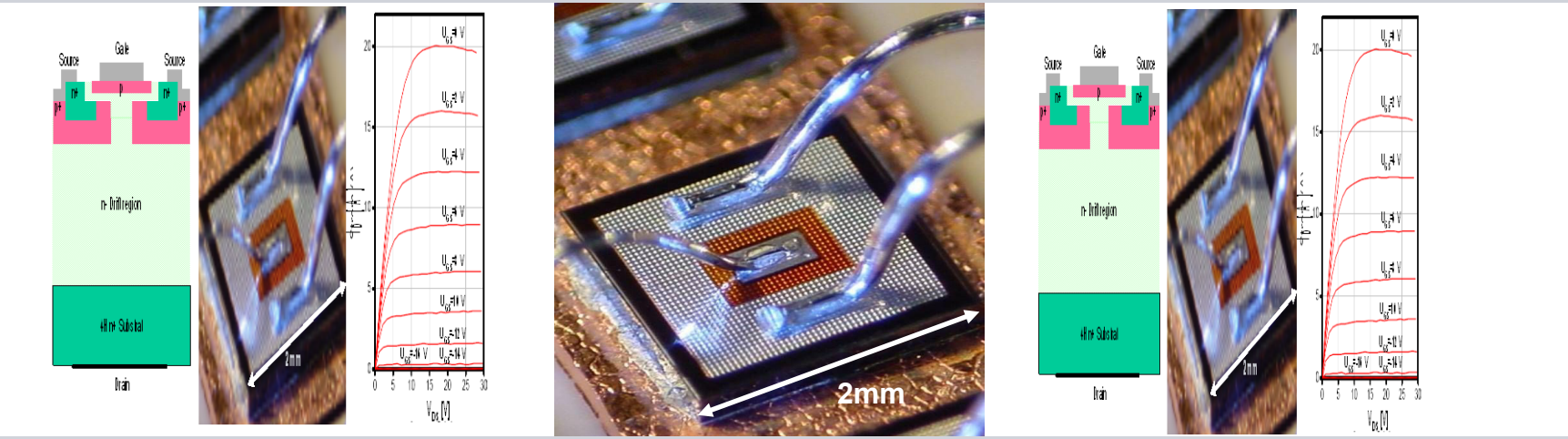
# SiC RF Power vJFET




Normally on vertical junction FET (vJFET) with intrinsic body diode

- Based on commercial switch mode PSU power transistor design
- Optimized for low gate series impedance

2.4x2.4mm$^2$ die size

$U_{DS}$ = 1700V, $I_{Dss}$ = 60A

$U_{pinchoff}$ ~ -16V

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# SiC RF Power vJFET

High efficiency (>85%)
Class F mode operation

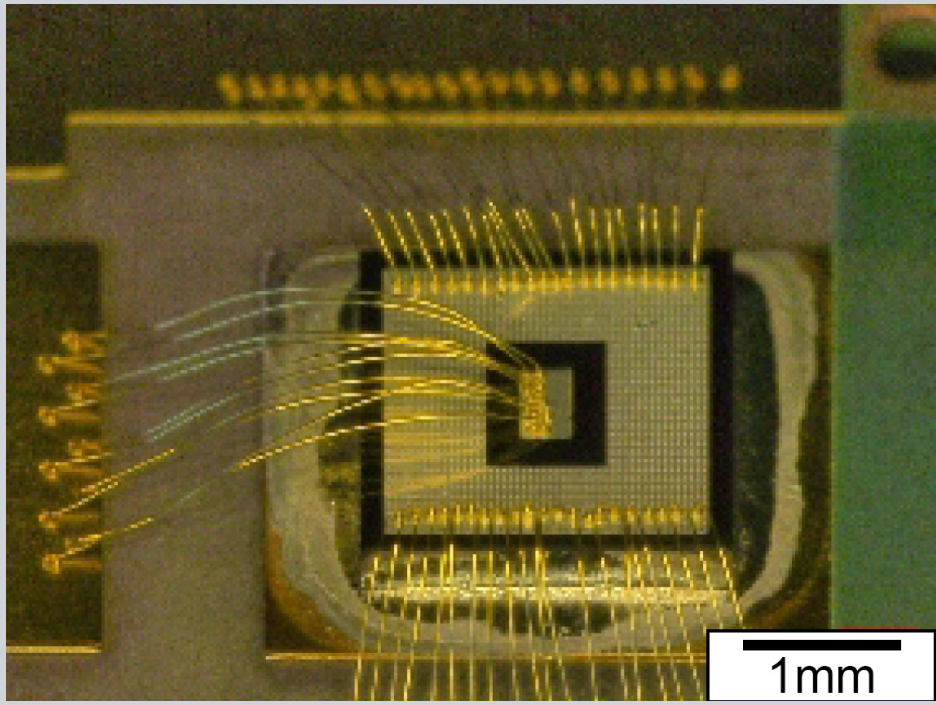
Hyperfast Schottky-like body diode enables four quadrant operation

Reflected RF power does not destruct device

No output circulators, protection measures needed

“Voltage source” low output impedance operation, no need to match RF load

High voltage operation (~700VDC) enables extremely high power at reasonable impedances



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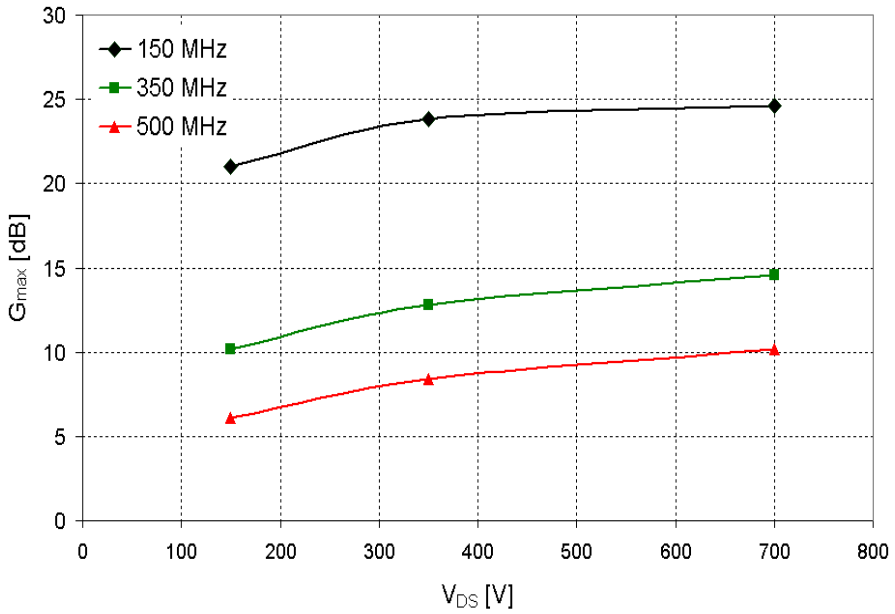
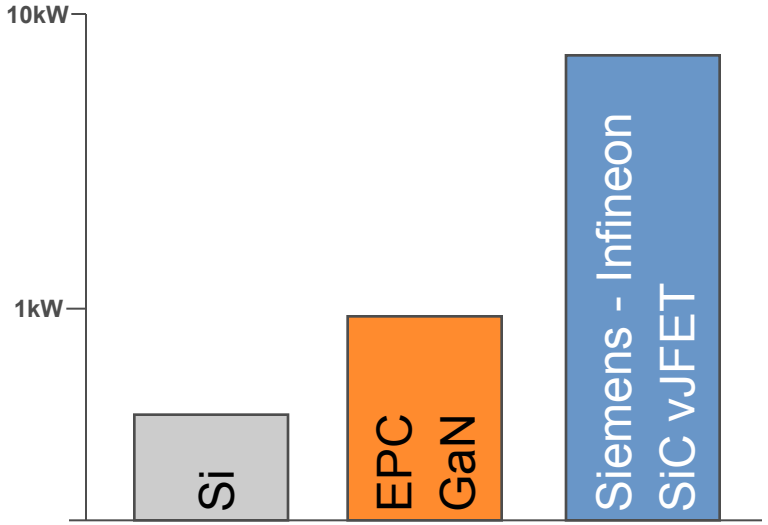
# Current Status




**SiC** 6mm² die

**7 $kW_{pk}$** (200µs burst)

~ 1 GHz unity gain frequency

**GaN** 1.5mm² die

**250 $W_{pk}$** (200µs burst)

~ 2 GHz unity gain frequency

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# SiC RF Power Modules

Parallel push-pull circuit assists class F operation

Stable under load impedance variations, device parallelization

8 transistors per module

On 60x80mm$^2$ $Al_2O_3$ carrier

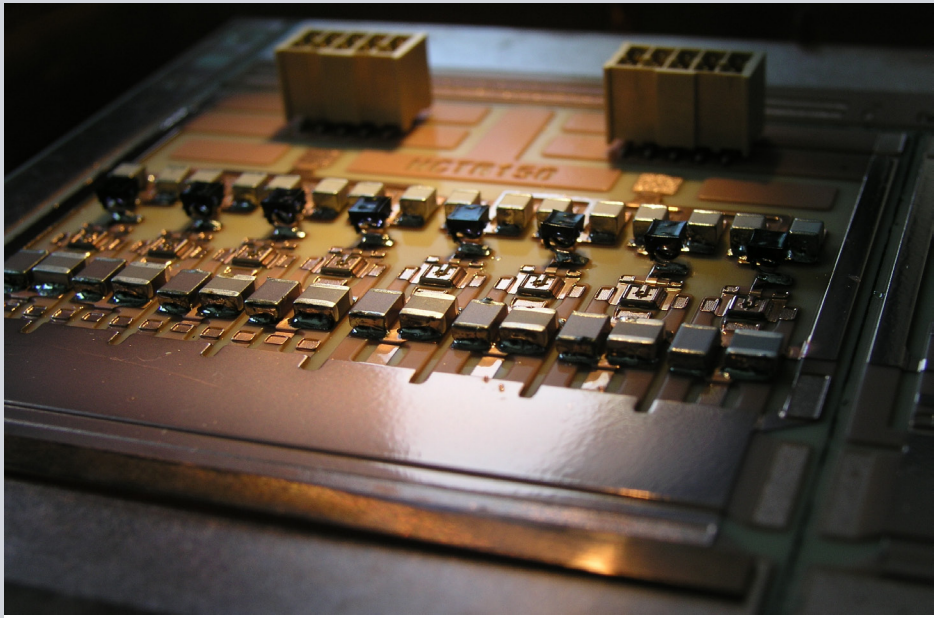
SiPLiT package: no bond wires

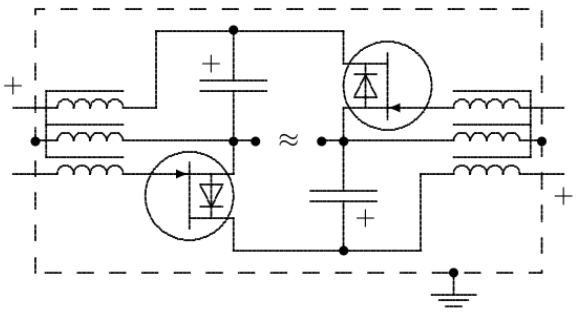
Commodity 700V DC supply

50 kW RF pulse power into 5Ω:
$700V_{pk}$, $140A_{pk}$

200 μs pulse duration, 1% dc

15dB large signal power gain





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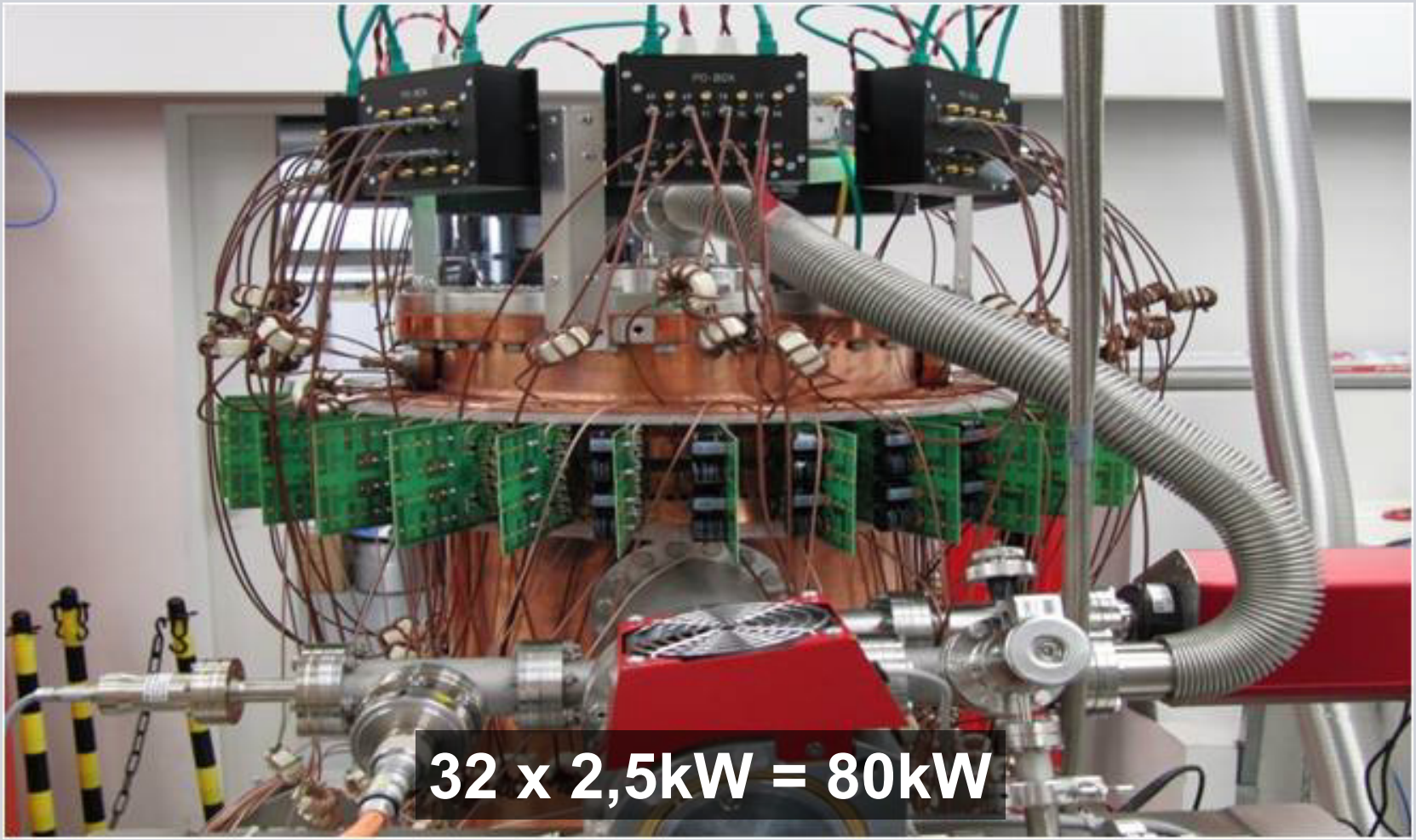
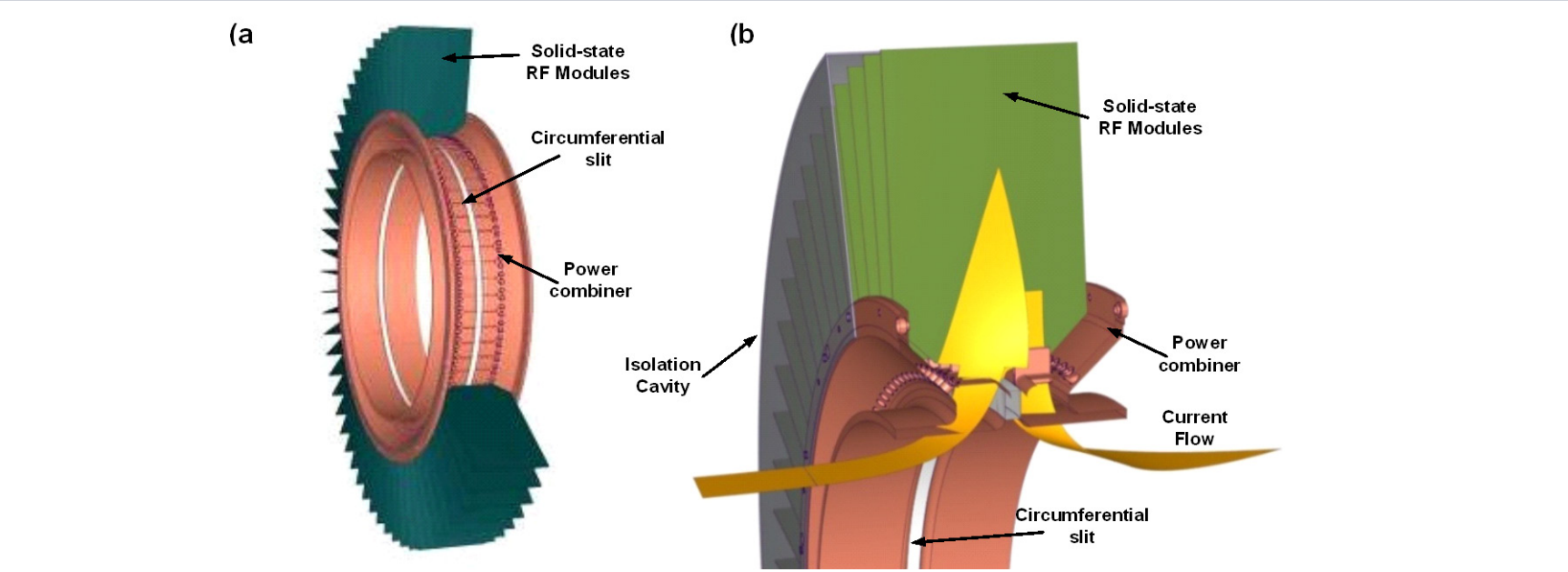
# RF Power Combiner Teststand



# RF Power Combiner: Solid State Direct Drive™




- Much higher power levels possible by single stage combiner
- Low output impedance gives very low combined power reduction under point failures: reliability

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# Cost Position

## Minimal complexity

- High power density, power per device: low device count, low circuit complexity
- Straightforward single stage power combining, no power circulators, protection circuits
- RF power gating within amplifier stage: Simple DC power supply

## Economics of scale

- Bulk SiC, epitaxial GaN and Si have similar material and production cost per Watt RF
- Voltages, currents within range of standard consumer/industrial component specs
- Modular design covers diverse customer requirements with few module designs

## “green”, dependable

- High efficiency class F operation: low thermal load, energy costs
- Gracefully degrading RF power generator under point failures: preventive maintenance

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## Conclusions

**1 Watt / Euro Cent**

**?**

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## Conclusions

1 Watt per Euro Cent seems to be within reach

SiC and GaN are about cost competitive with Si

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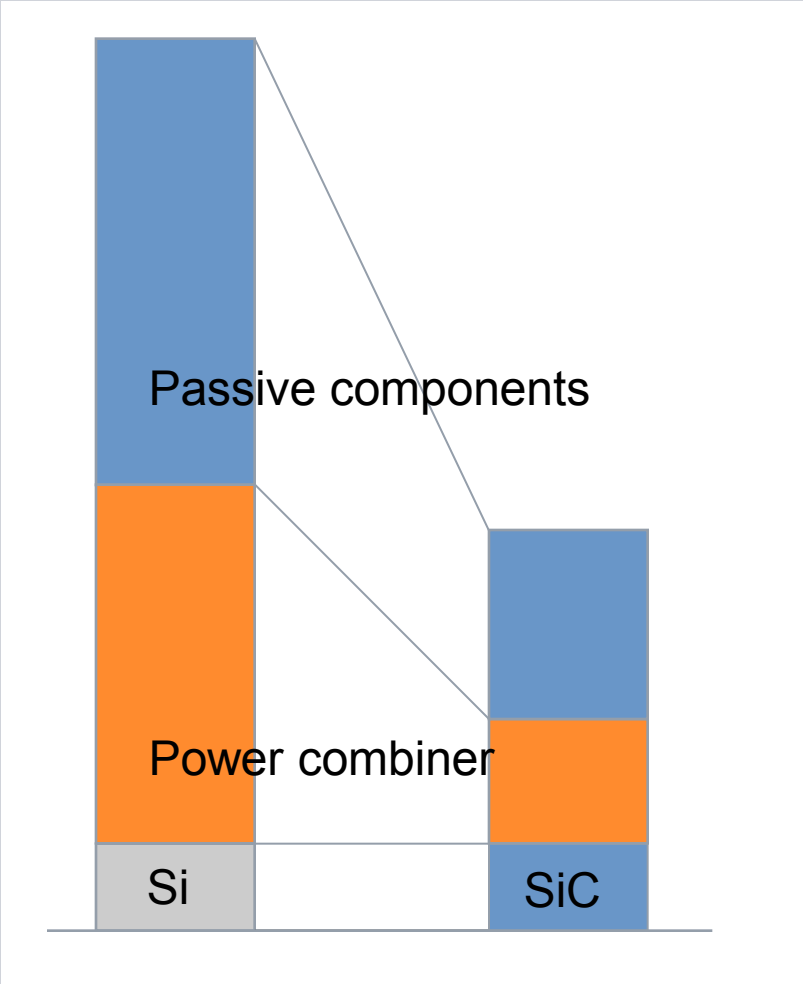
1 Watt per Euro Cent seems to be within reach

SiC and GaN are about cost competitive with Si

BUT

The big win is its secondary effects on the system complexity and cost



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# Thank you for your attention!

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