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GaN transistors for RF Energy



Wolfspeed  **DR. STEPHAN HOLTRUP | NOVEMBER 2022**



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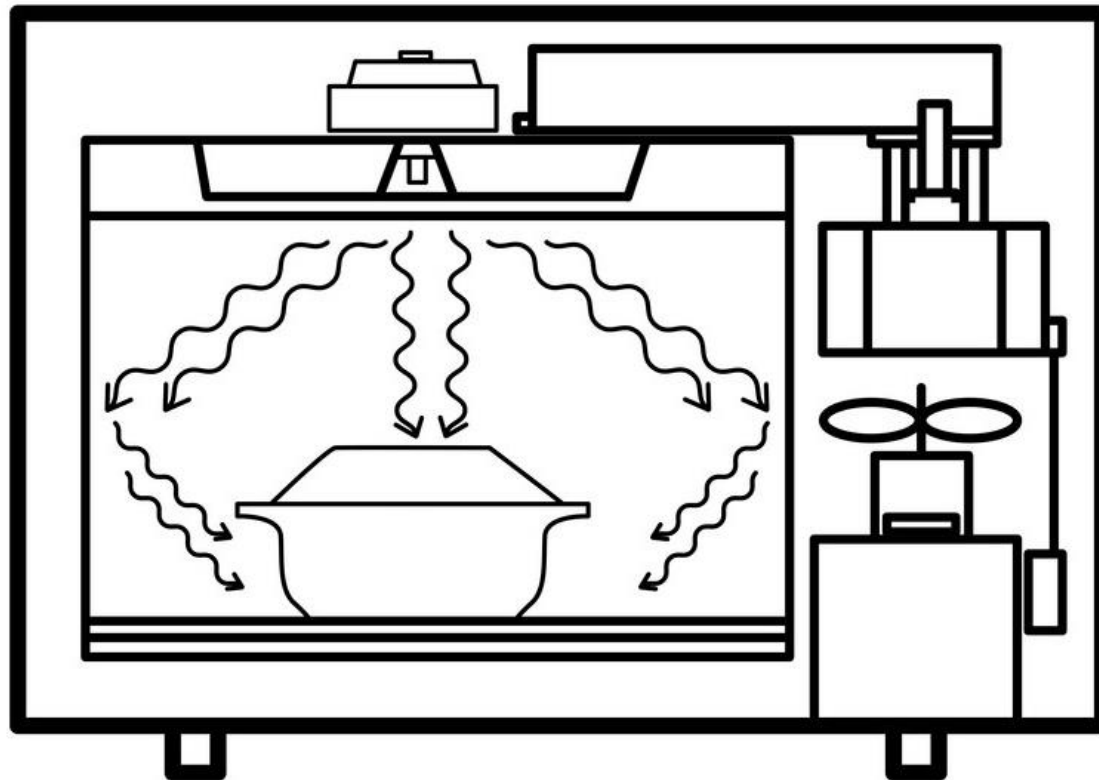
CONCLUSION



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A VERY COMMON RF ENERGY APPLICATION

Magnetron as RF power source driving the microwave oven



This is specific for magnetrons in domestic applications, Industrial versions feature higher lifetimes and better power control

UPSIDES

- **Cheap**
- Efficient under ideal conditions



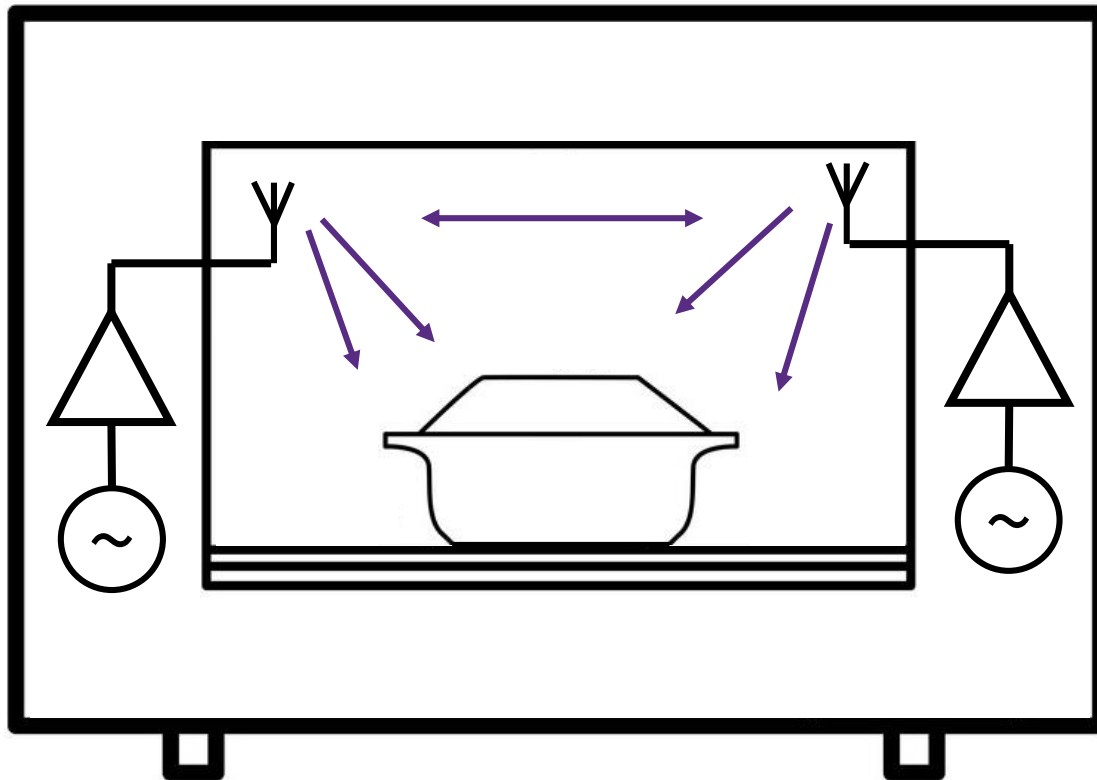
Downsides

- Lifetime ~ 600 h
- Unspecific frequency spectrum
- Load pulled
- Power degradation
- Inconsistent
- Fixed Maximum power (> 800W)
- Pulsed power control
- Absorber required
- Catastrophic failure



Solidstate as RF power source driving the microwave oven

Key benefits: precise control, reproducibility, improved homogeneity

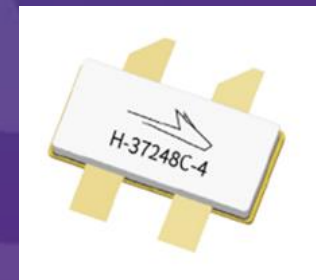


UPSIDES

- Precise power delivery
- Phase and frequency control
- Multichannel capability
- Consistent
- Closed loop system
- Measurement
- Lifetime

DOWNSIDES

- You have to take control
- **Cost**



A VERY COMMON USECASE – CONSUMER MICROWAVE OVEN



9.7B \$

**TOTAL REVENUE IN
2021**

113 \$

**AVERAGE PRICE IN
2021**

86M pcs

**PIECES SOLD IN
2021**

Is this the only application to be addressed?

<https://www.statista.com/outlook/cmo/household-appliances/small-appliances/microwave-ovens/worldwide#volume>



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THERE ARE MANY MORE APPLICATIONS FOR RF ENERGY

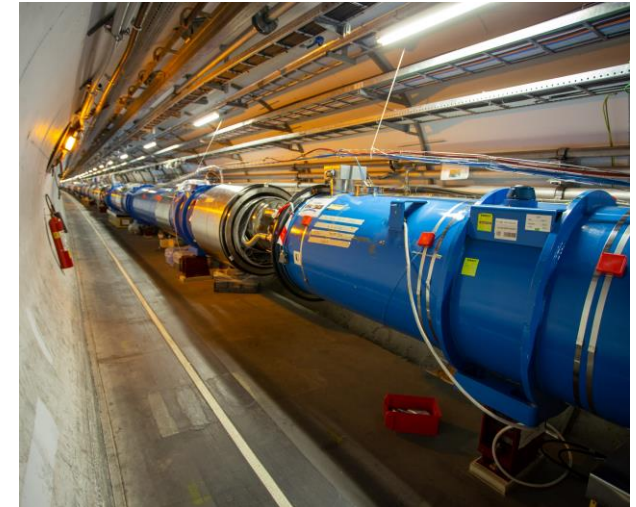
OVERVIEW OF VARIOUS RF ENERGY APPLICATIONS



PLASMACUTTER



INDUSTRIAL FOOD PROCESSING

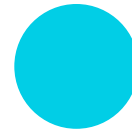
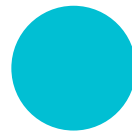


PARTICLE ACCELERATOR



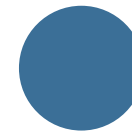
**Medical Plasma
treatment**

Hyperthermia

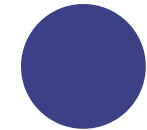


**Commercial
cooking**

**Plasma for surface
treatment**



**New Applications:
Power to X
Electrification**





WHY USING RF/MICROWAVE FOR HEATING APPLICATIONS?

Penetration depth (skin depth):

$$D_p = \frac{1}{\omega} \left[2\mu_0\mu' \epsilon_0 \epsilon' \left(\sqrt{1 + (\tan \delta)^2} - 1 \right) \right]^{-1/2}$$

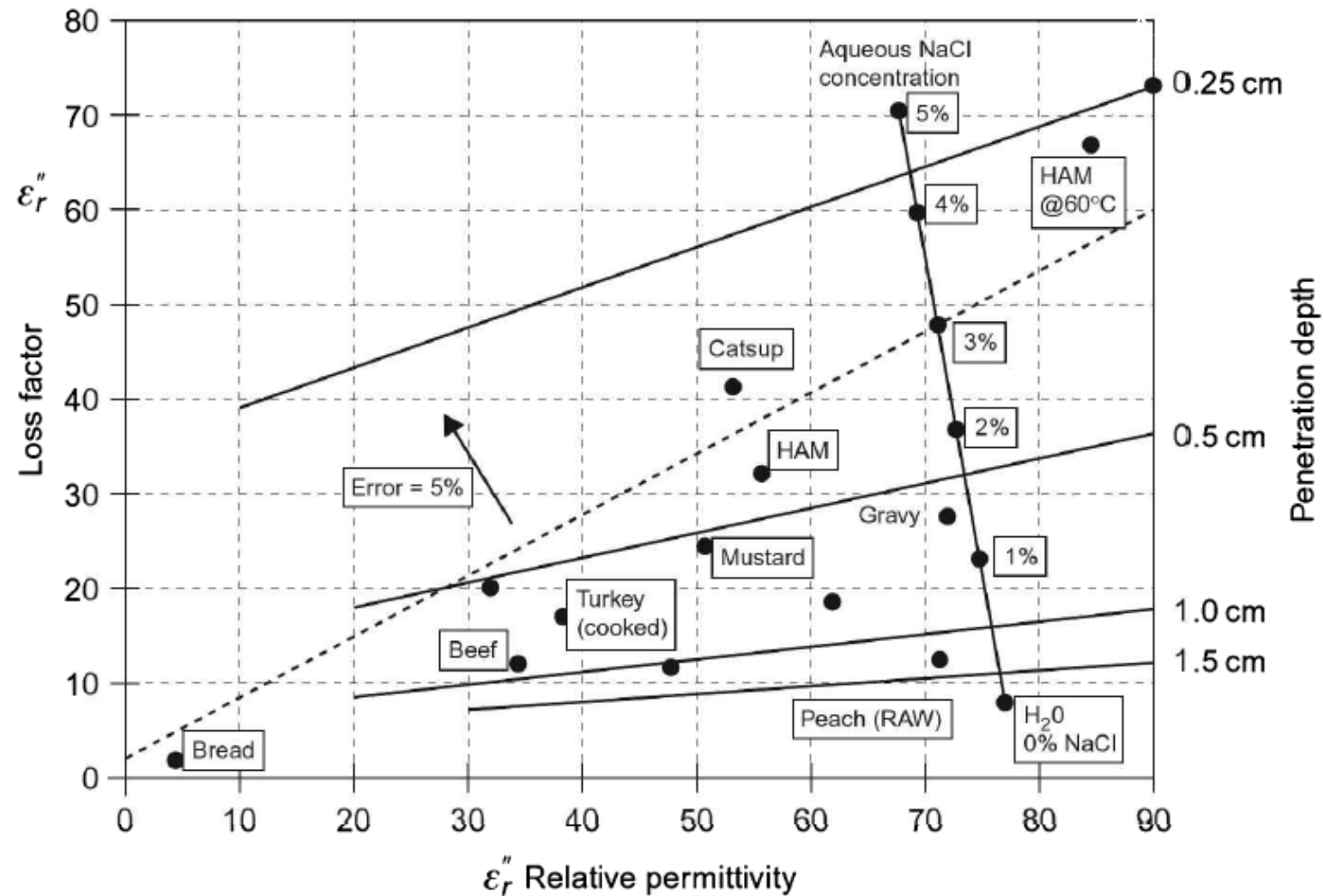
$$\approx \lambda_0 \sqrt{\epsilon' / 2\pi \epsilon''}$$

Heat capacity of water & steam

- 4184 J kg⁻¹K⁻¹ at 20 °C (water)
- 1.996 J kg⁻¹K⁻¹ at 20 °C (steam)

Food process temperatures

- T_{pasteurize} = 71 °C, T_{sterilize} = 121 °C
- Sterilize, e.g.
- ΔT = 101 K → 338 kJ kg⁻¹ + 39 kJ kg⁻¹
- Amount of energy required to heat transfer medium

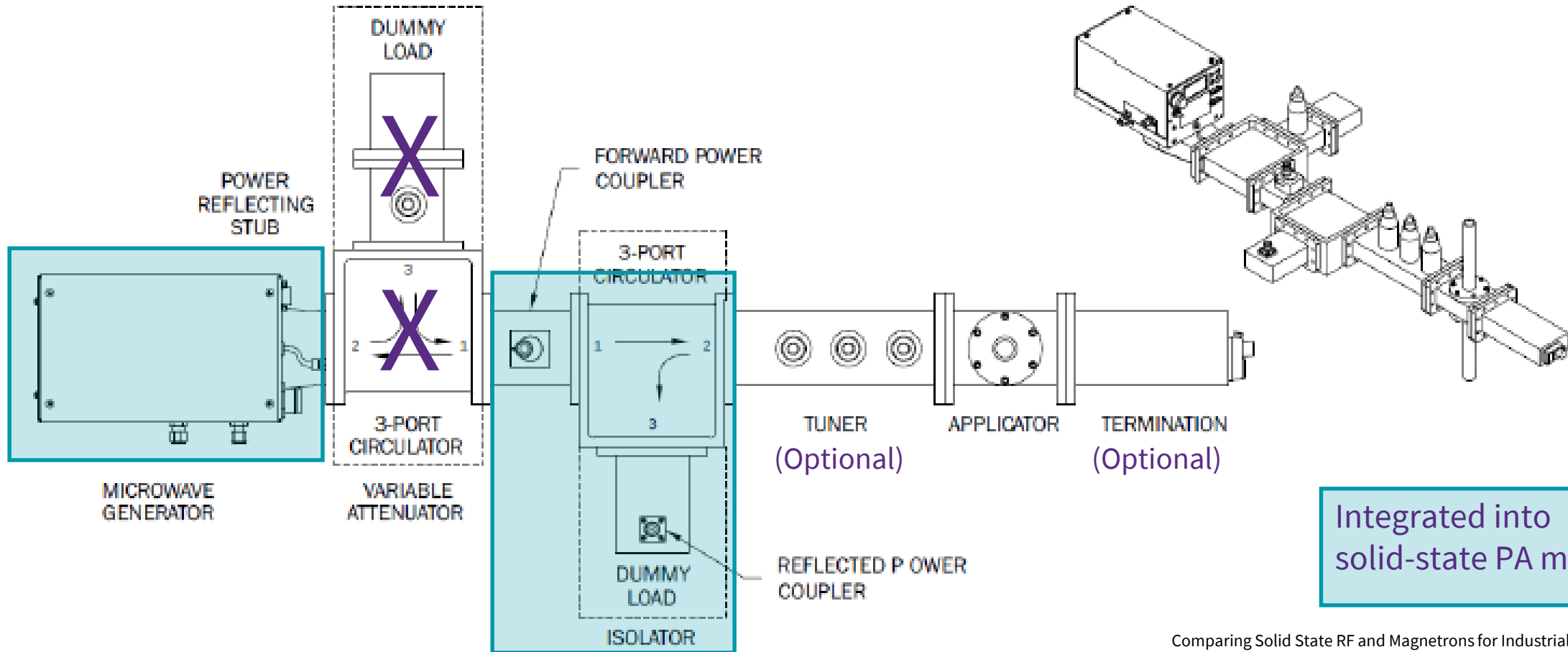
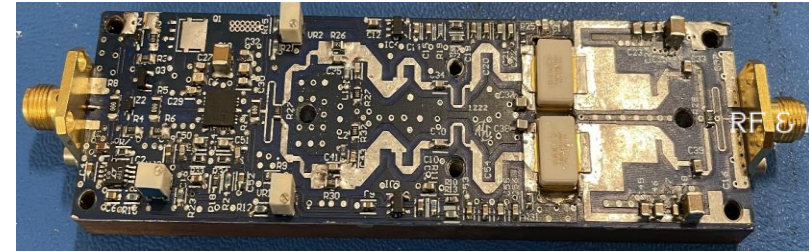




SINGLE CHANNEL – CHANGING TO SOLID-STATE

Application with high power densities

- Plasma (Jets, Downstream, Ionbeam), Ablation, APC, ...



Integrated into
solid-state PA module

Comparing Solid State RF and Magnetrons for Industrial Applications,
J. F. Gerling, IMPI 55 - SSRFE Section Short Course, June 2021

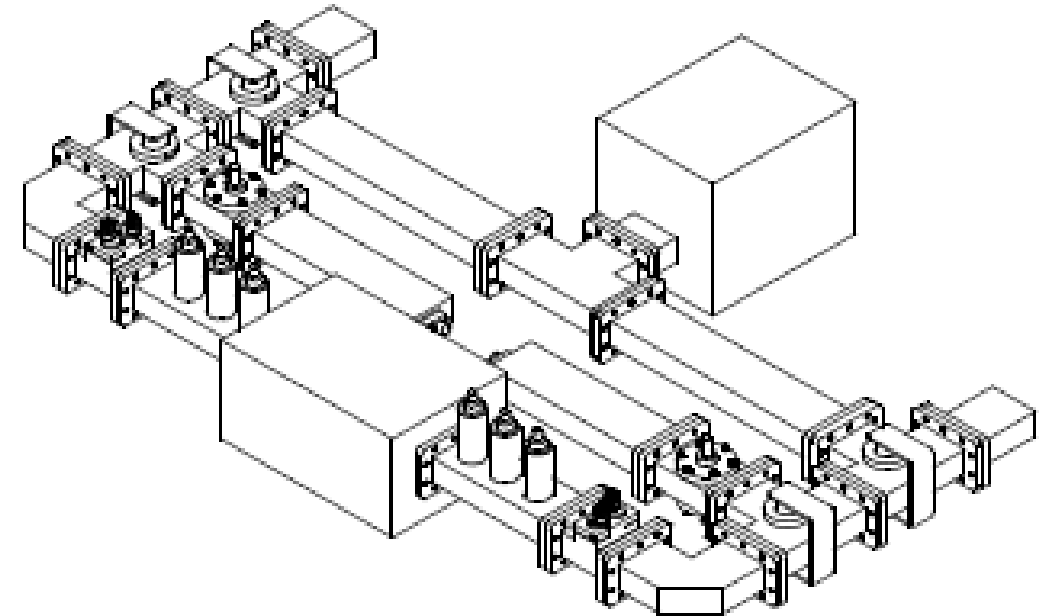
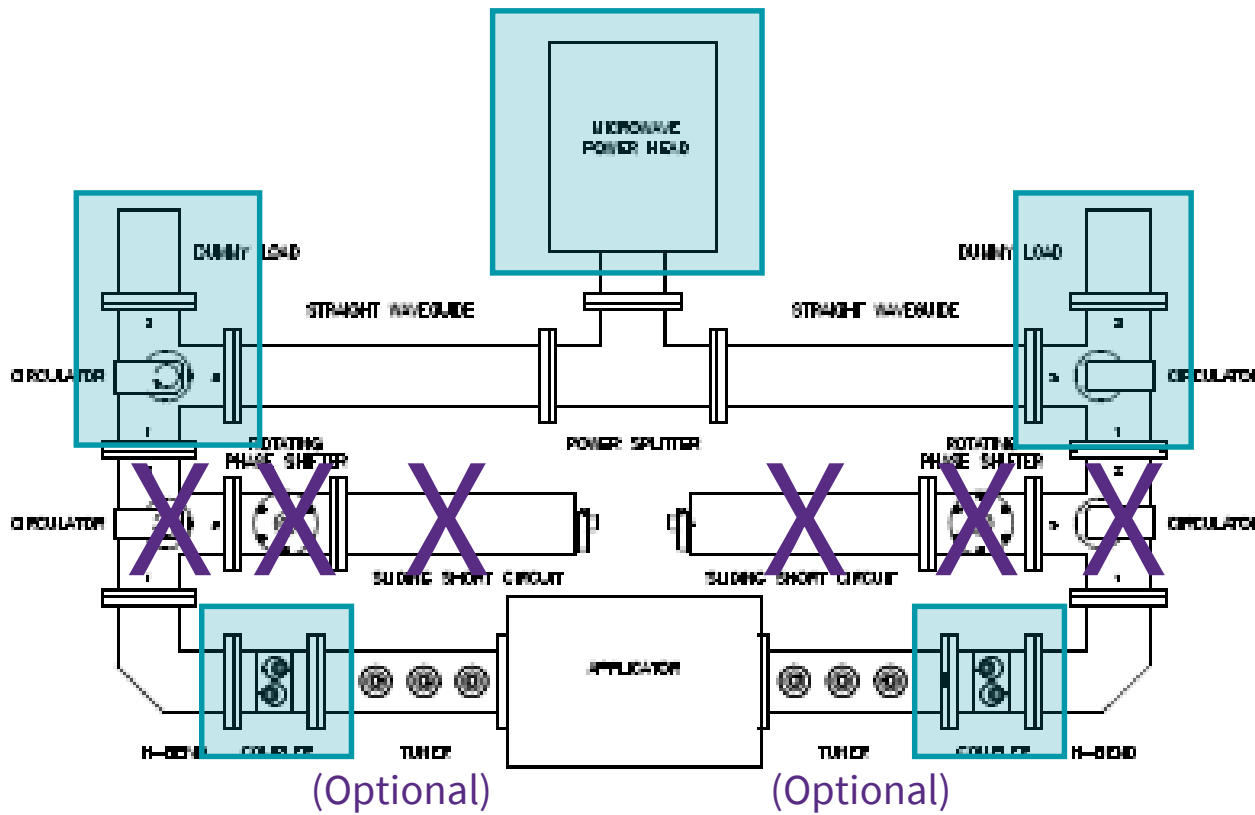


MULTI CHANNEL – CHANGING TO SOLID-STATE

Applications with large area of impact

Food processing, large panel wood drying, industrial inline processing, etc..

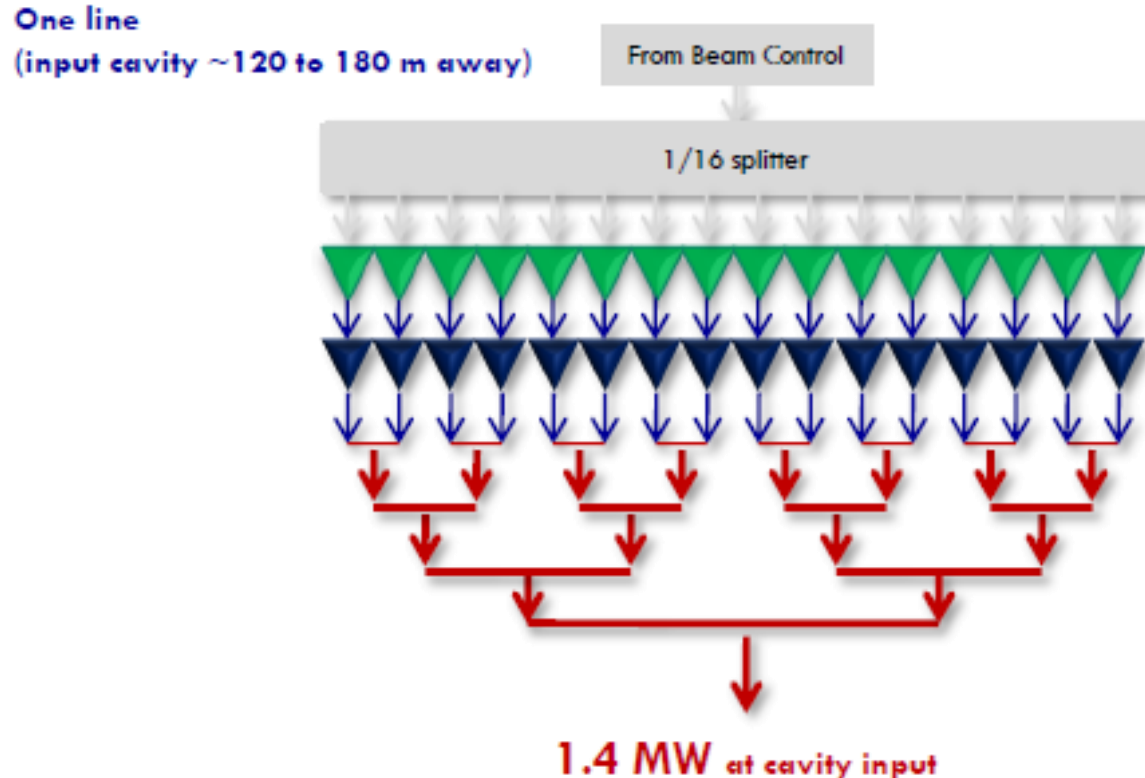
Integrated into solid-state PA module



RF ENERGY TECHNOLOGY: CERN CAVITY HPA RFP



Source for a particle accelerator at 200MHz, presented CWRP Workshop 2016



2 x

4 stages of 3 dB combiners = - 0.6 dB
120 to 180 m Coaxial lines = - 0.2 dB

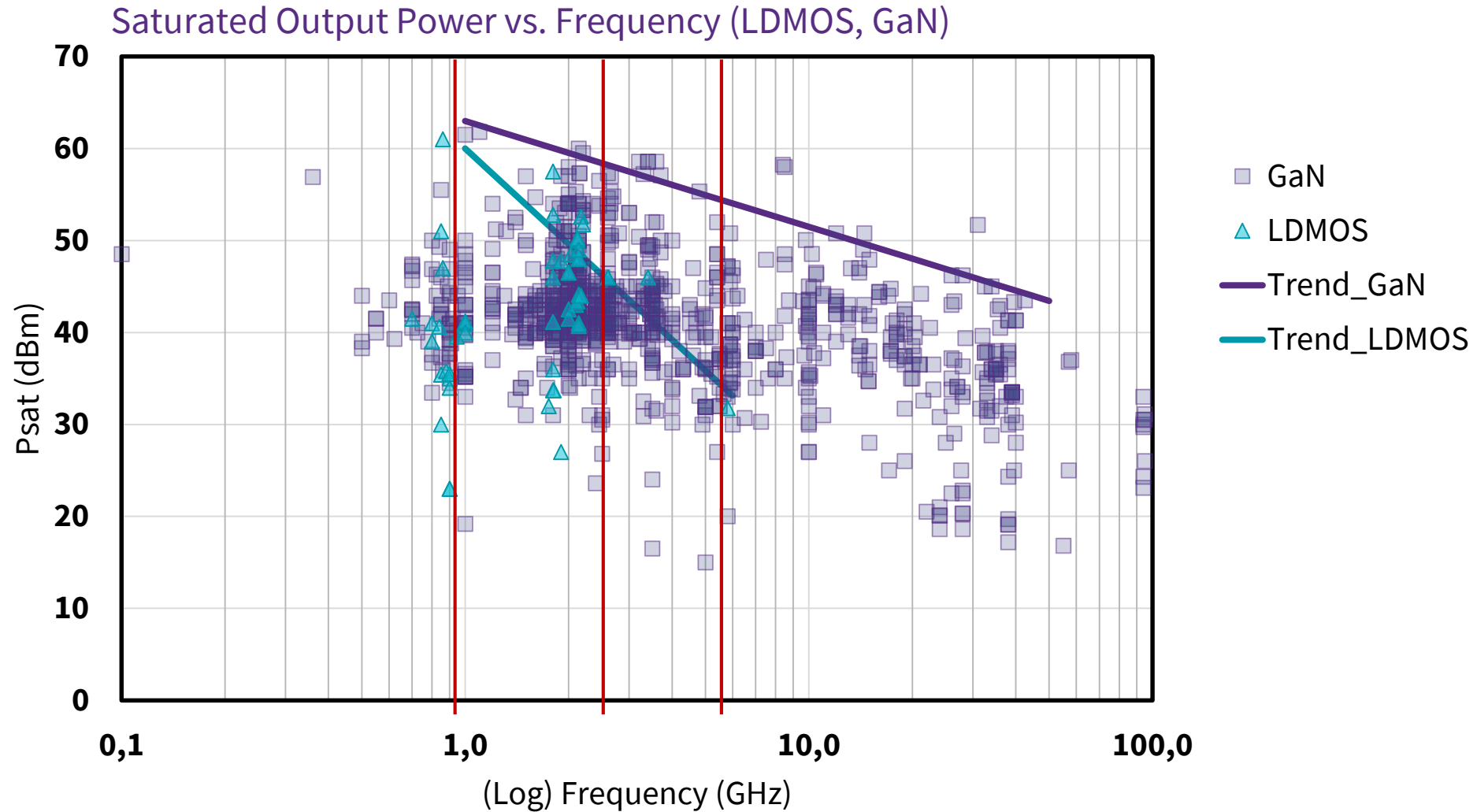
Final Amplifier output = 1.6 MW + 0.8 dB = 1.7 MW / 16 = 110 kW

Winner: SSPA combining 5120x
1 kW solid-state final stages
delivering > 2 MW at cavity input
with lowest €/W

“Very careful verification
of the offer
(I am (was) a tube guy !)”
E. Montesinos

CERN LIU-SPS200 MHZ RF UPGRADESSPA AMPLIFIERS; Eric Montesinos, CWRP workshop, ESRF, Grenoble, June 2016

RF ENERGY TECHNOLOGIES: SOLID-STATE PA PERFORMANCE SURVEY



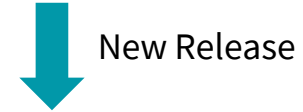
Hua Wang, et al., "Power Amplifiers Performance Survey 2000-Present," [Online]. Available: <https://ideas.ethz.ch/research/surveys/pa-survey.html>, accessed October 14th 2022.



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WOLFSPEEDS ACITVITIES FOR RF ENERGY APPLICATIONS

WOLFSPEED RF PROCESS TECHNOLOGIES



G50V3	G28V4	G40V4	G50V4	G28V5
<p>Features:</p> <ul style="list-style-type: none"> • 0.4 um Gate Length • 50 V bias • 150 V Breakdown • 10W/mm • DC – 8 GHz <p>Performance:</p> <ul style="list-style-type: none"> • Broad Band • High Power <p>Applications:</p> <ul style="list-style-type: none"> • Telecom Power Amplifiers • Radar • Backhaul • RF Energy 	<p>Features:</p> <ul style="list-style-type: none"> • 0.25 um Gate Length • 28 V bias • 120 V Breakdown • 4W/mm • DC – 18 GHz <p>Performance:</p> <ul style="list-style-type: none"> • Wide Band • Moderate Power <p>Applications:</p> <ul style="list-style-type: none"> • General Purpose Amplifiers • Wideband EP Power Amplifiers • Backhaul • RF Energy 	<p>Features:</p> <ul style="list-style-type: none"> • 0.25 um Gate Length • 40 V bias • 120 V Breakdown • 6W/mm • DC – 18 GHz <p>Performance:</p> <ul style="list-style-type: none"> • High Frequency • High Power <p>Applications:</p> <ul style="list-style-type: none"> • SatCom • Radar 	<p>Features:</p> <ul style="list-style-type: none"> • 0.25 um Gate Length • 50V bias • 150V Breakdown • 9W/mm @ 10GHz • DC – 16 GHz <p>Performance:</p> <ul style="list-style-type: none"> • Mid Frequency • High Power <p>Applications:</p> <ul style="list-style-type: none"> • Radar • SATCOM • RF Energy 	<p>Features:</p> <ul style="list-style-type: none"> • 0.15 um Gate Length • 28 V bias • 84 V Breakdown • 3 W/mm @ 35 GHz • DC – 40 GHz <p>Performance:</p> <ul style="list-style-type: none"> • High Frequency • Moderate Power <p>Applications:</p> <ul style="list-style-type: none"> • SatCom • Wideband Power Amplifiers

THE OPPORTUNITIES AHEAD ARE LIMITLESS – NEW RELEASE 2023



The products we design and build together will revolutionize energy use and shape the future of semiconductor markets.

The new product is specifically designed for industrial, scientific and medical applications at the 2.45 GHz band making those available across the globe.

It enables PA designs with highest energy efficiency and power levels up to 300W per single device.



SUMMARY

- Precise & agile power, frequency and phase control
 - electrical control of the field distribution in the applicator
- MTTF (GaN-on-SiC) > 1 million hours (114 years)
c.f. 'industrial' tubes 2000 – 8000 hours (1 - 3 years)
 - low maintenance and downtime, lower cost of ownership,
 - graceful degradation
- Many various RF Applications incl. different set of requirements
 - Solid state amplifiers offer a flexible, adjustable solution
- Wolfspeed GaN on SiC is offers high performance at high frequency and high-power levels.
- Wolfspeed has developed a customized device for operation in the 2.45GHz ISM band that uses the latest high performance process technology to deliver state of the art capability. The product is undergoing final testing and qualification and will be released to the market in 2023.



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Thank you for your attention!