AMPLEON

Microwave Journal Educational Webinar

Ampleon Brings RF Power Innovations towards Industrial Heating Market


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Ampleon at a Glance

Our Company

- European Company / Headquarters in Nijmegen/Netherlands
- 1,250 employees globally in 18 sites
- Worldwide Sales, Application and R&D
- Own manufacturing facility
- Partnering with leading external manufacturers

Our Businesses

- Building transistors and other RF Power products for over 50 years
- Industry Leader for 35 years, addressing
  - Mobile Broadband
  - Broadcast
  - Aerospace & Defense
  - ISM
  - RF Energy

Technologies & Products

- Broad LDMOS and GaN technology portfolio
- Comprehensive package line-up
- Outstanding product consistency

Customers

Ampleon and RF Energy

- Recognized as thought leader
- Co-founder of RF Energy Alliance
- Working with the leaders in new application domains

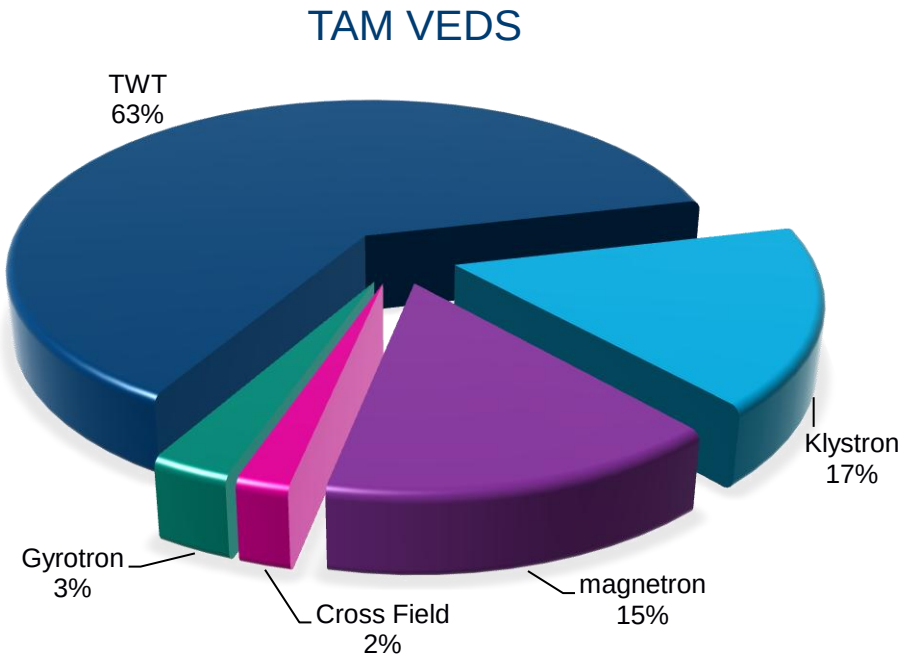
RF Power Industrial market dominated by vacuum tubes

- Current solutions mainly based on ‘old’ vacuum tube principles
- Somewhat fragmented market with large and many small vendors
  - TWT (Traveling Wave Tubes)
  - Klystron
  - Magnetrons
  - CFA (Crossed Field Amplifiers)
  - Gyrotrons

2020 TAM VED's about ~$1B

$1.2B in 2014

Source ABI research



Not included: domestic magnetrons, Aerospace market

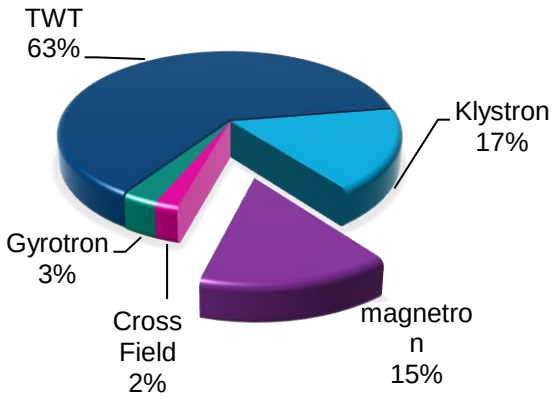
Solid state penetrates the market

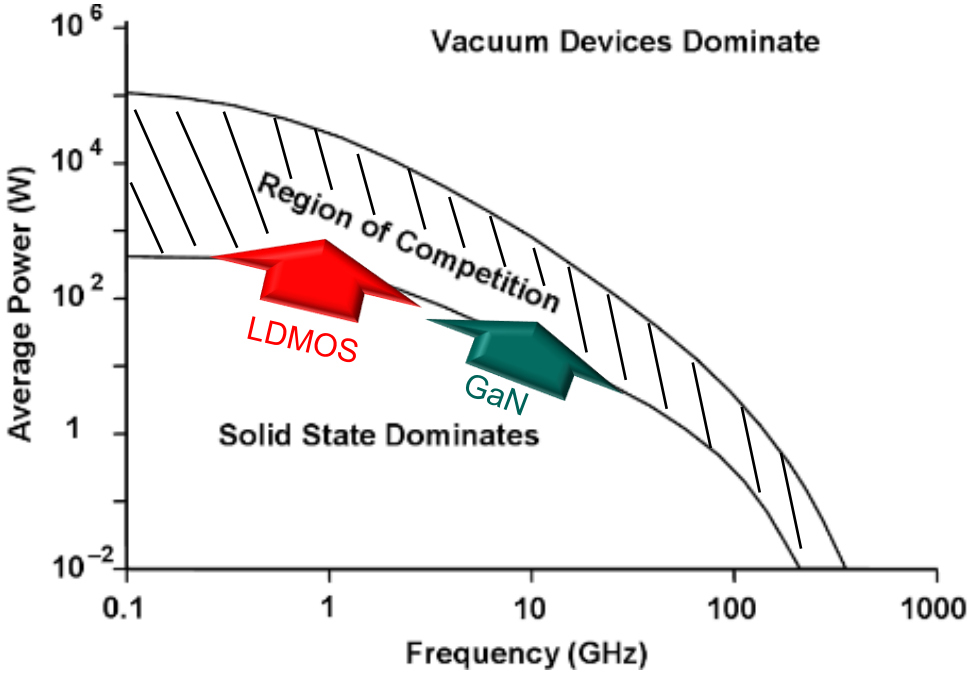
GaN Gallium Nitride

expected to focus on > 4 GHz (X/Ku-band)

LDMOS

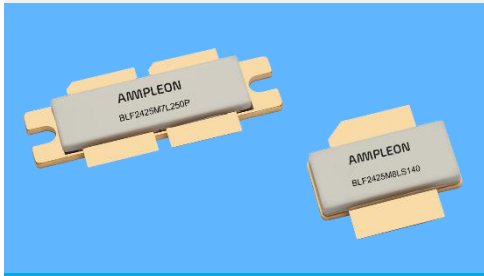
focus on 433-2700 MHz

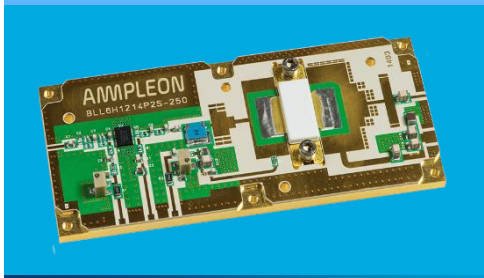




Magnetron Tube vs Transistors / Pallets

- Vacuum tubes deliver a lot of power for money
- Efficiency is close to 70% / 2.5 GHz - 80% / 915 MHz





However!

- Warrantee lifetime is limited to ~5K hours

  Transistors operate for >15 years 24/7

- Power, Size, Cooling capability depends on the operating frequency

  Transistors are scalable and modular

- Power is nearly uncontrollable and degrades over time

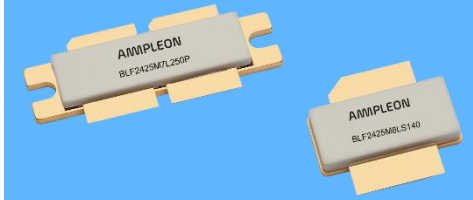
  Intelligent distributed control of power, frequency and phase

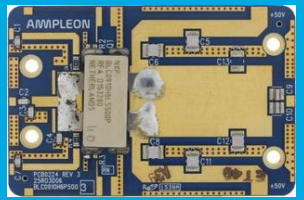
- High voltage power supply resulting in bulky and heavy transformers

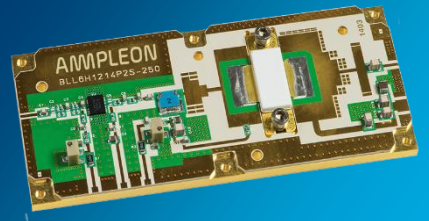
  Transistors only require low voltage supply's

- No feedback on the delivered power and reflected power

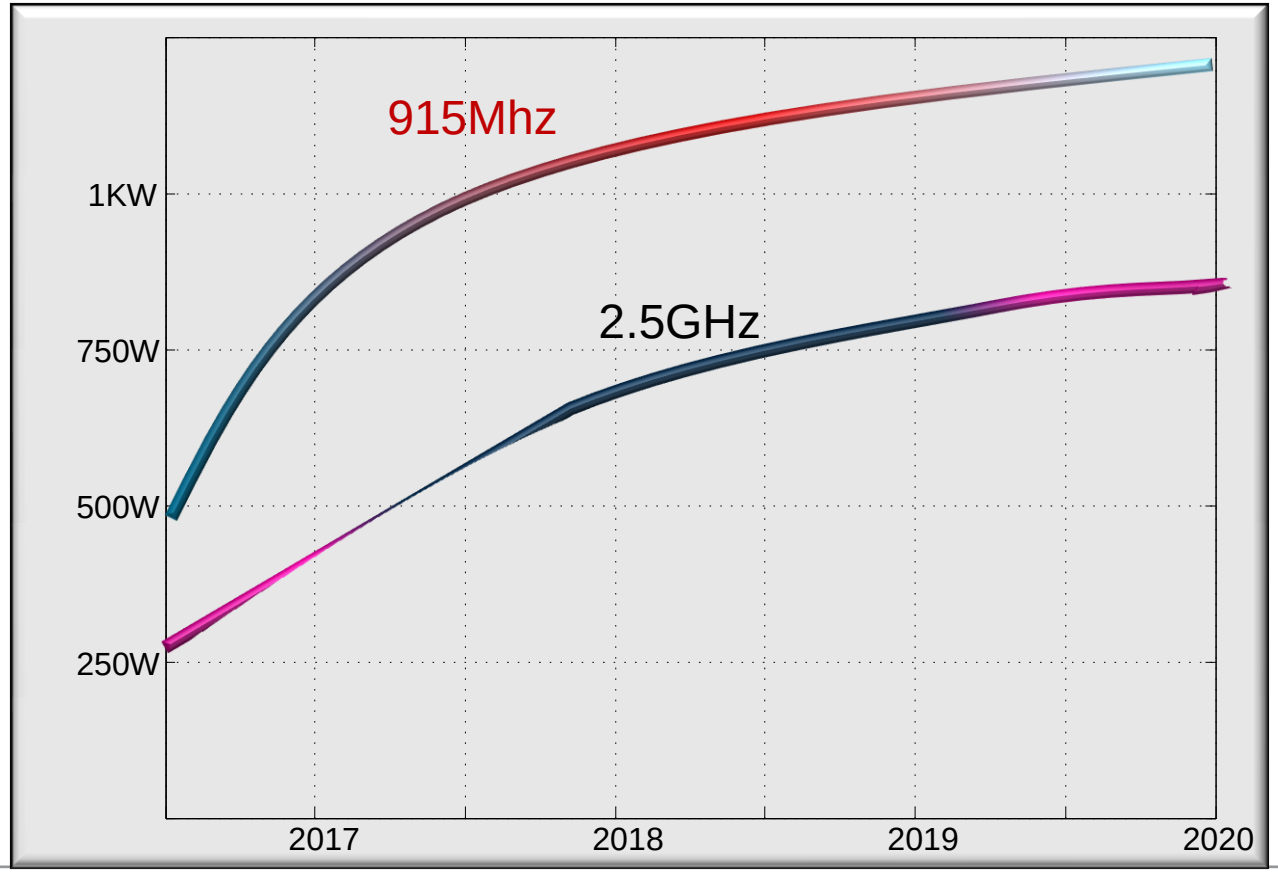
  Built-in test & monitoring for power and phase





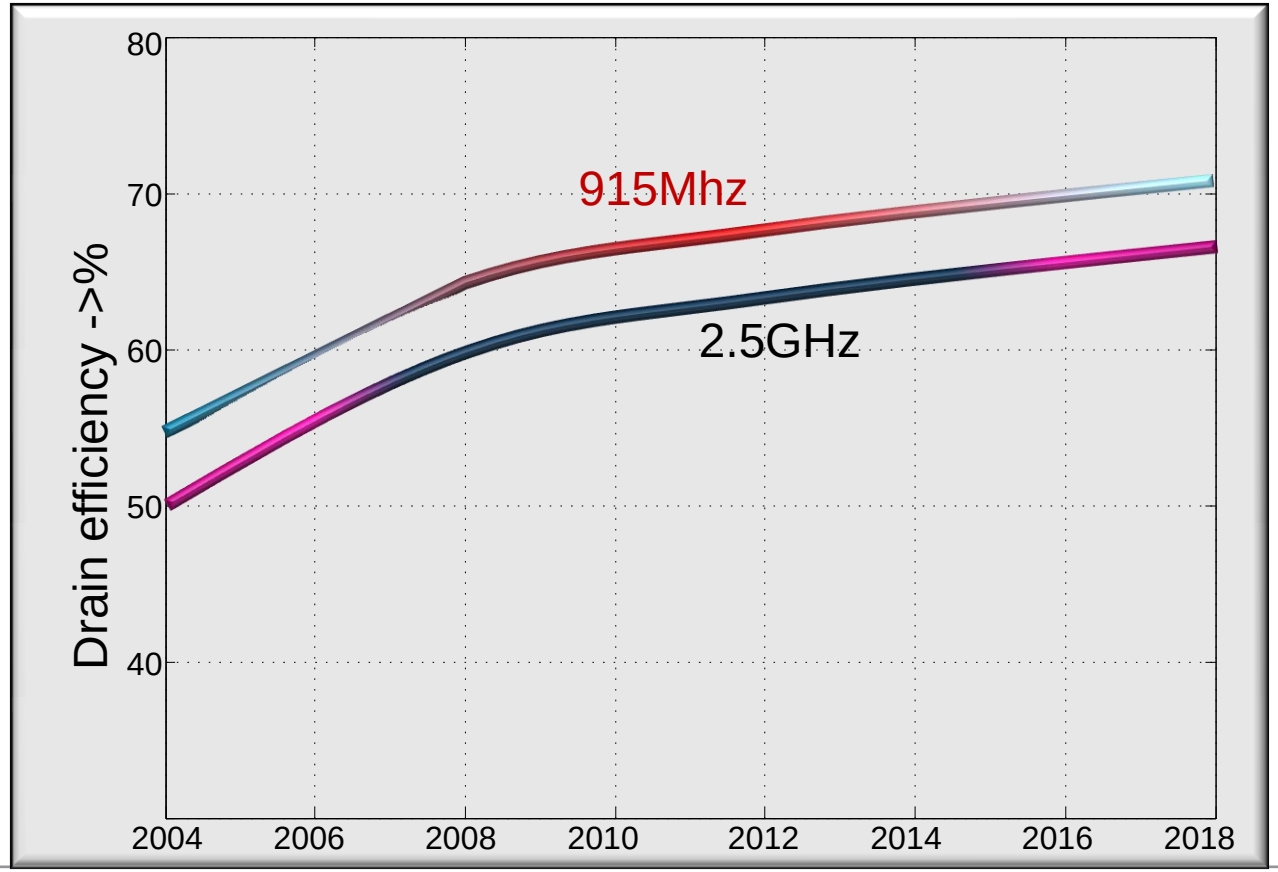


Power development LDMOST transistors



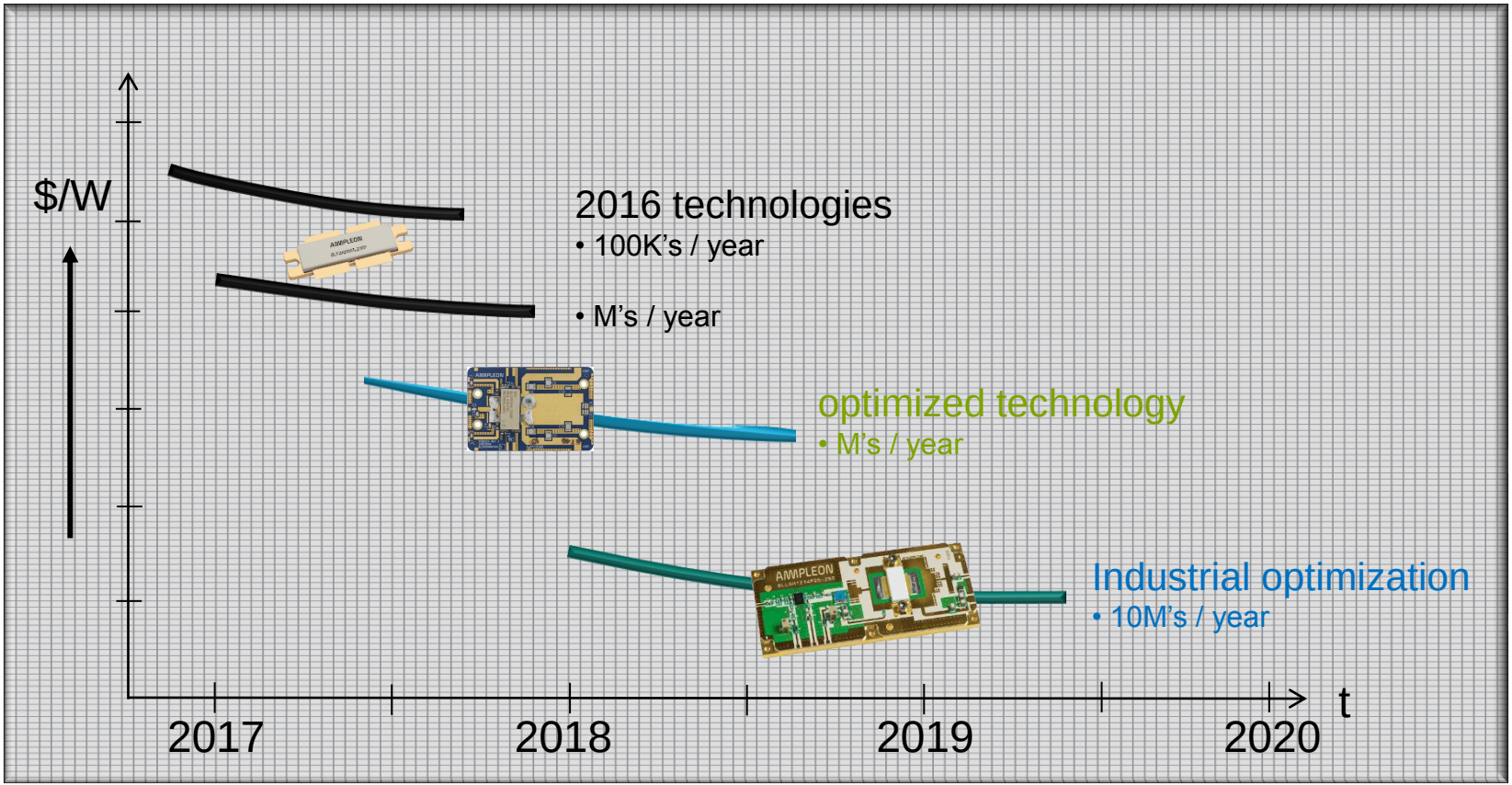
Power

Key Trends in LDMOS Technology Development



Efficiency

Cost of ownership



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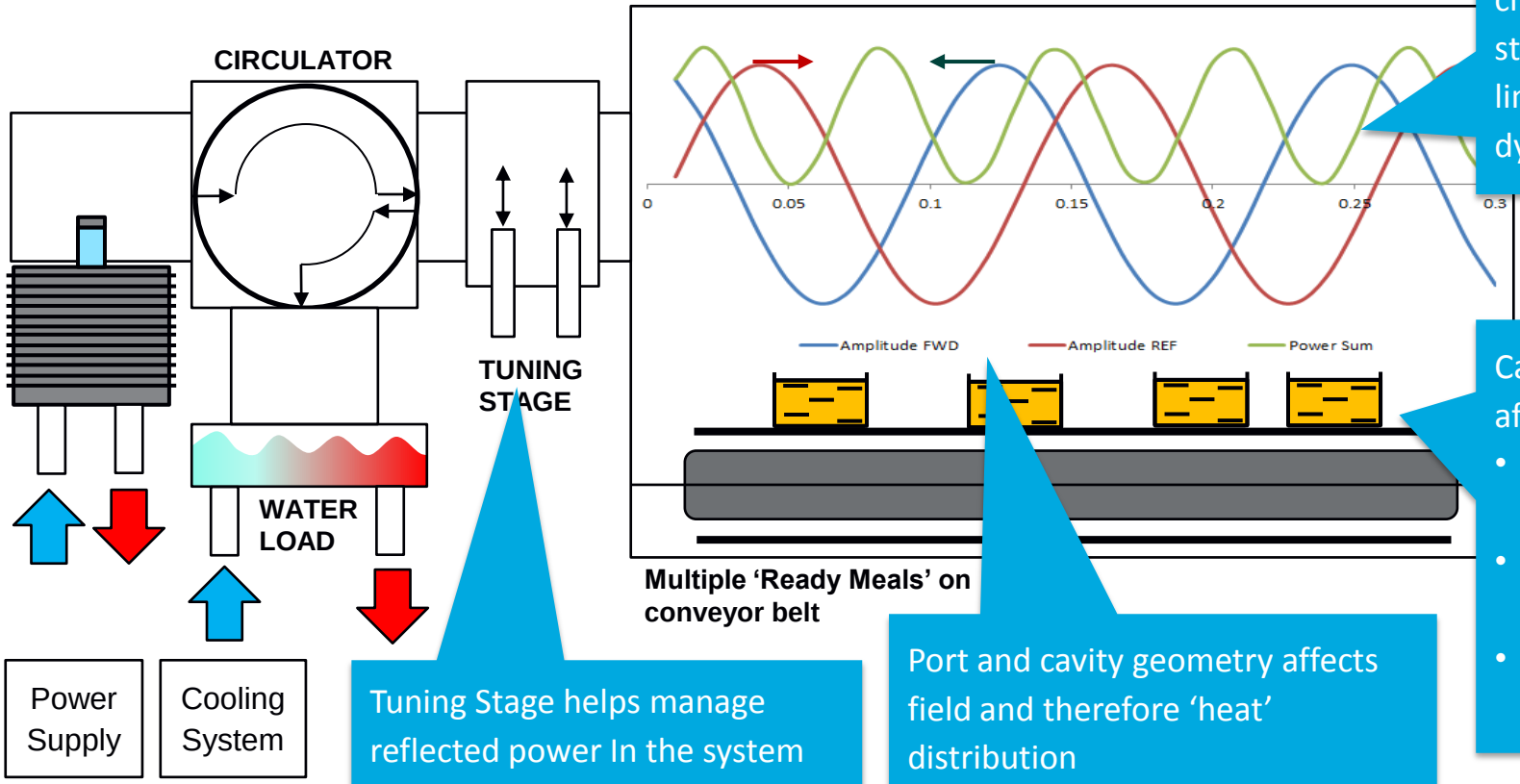
How does it work?

Robin Wesson

Lets Get Specific – Known Problems with Magnetrons

- Magnetrons are unstable - frequency of operation varies with:
  - Load Impedance
  - Temperature
  - Power supply
- They have relatively short lifetimes
  - 10K hours in typical industrial applications
- They are not phase stable
- Well before their lifetime, the power is degraded, requiring near constant adjustment of process parameters to ensure a stable quality result
- The unstable energy (power, frequency, phase) is the cause of unreliable heating results
  - Due to interactions of the signal with a resonant structure – the oven

Industrial Heating System Optimisation Today



Fundamentally we have a dynamically changing resonant structure – with limited to zero dynamic controls?

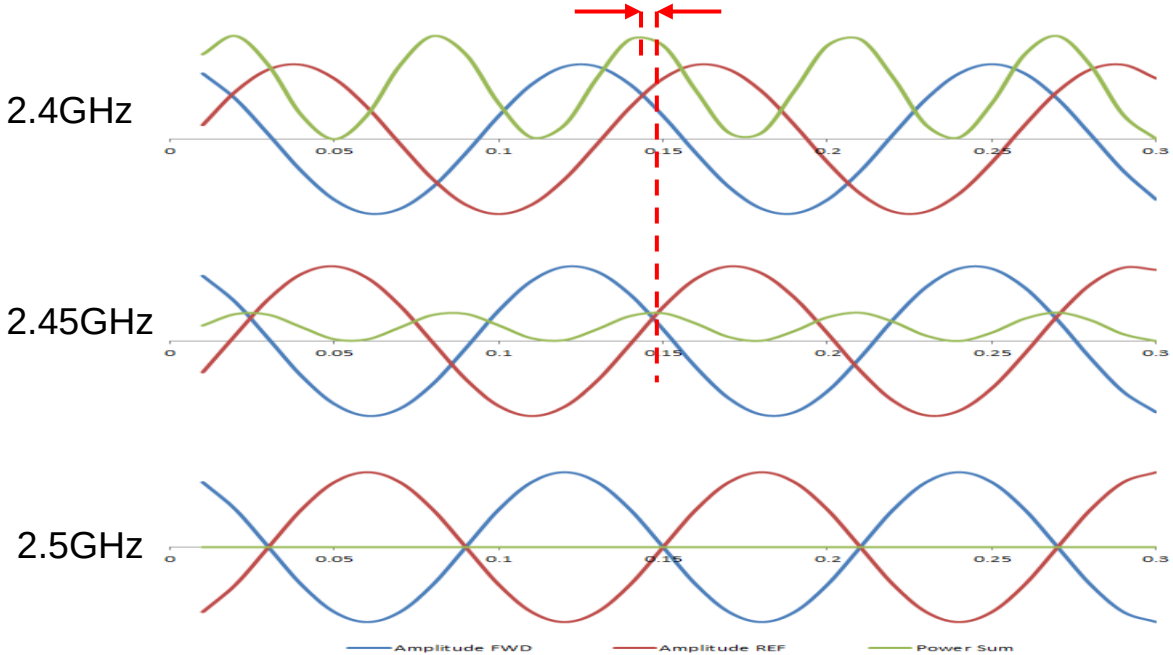
Cavity Loading also affects…

- Port impedances
- Field distributions
- Reflected Power Levels

Tuning Stage helps manage reflected power In the system

Port and cavity geometry affects field and therefore 'heat' distribution

Standing Waves over Frequency (simple 1D 30cm cavity model)

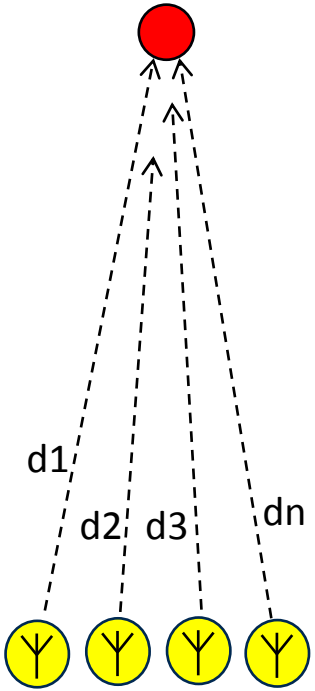


Observations: The hotspots do move *some* within the band allocated….

But <u>power</u> in the hotspots varies more – implies a complex tuning process

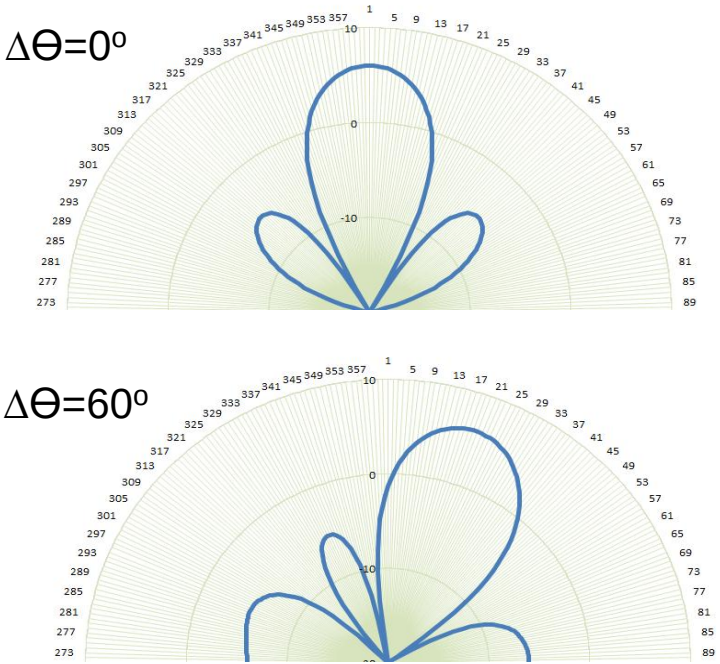
More dynamic field affecting variables might be beneficial?

Use of Phase - Antenna Array Model

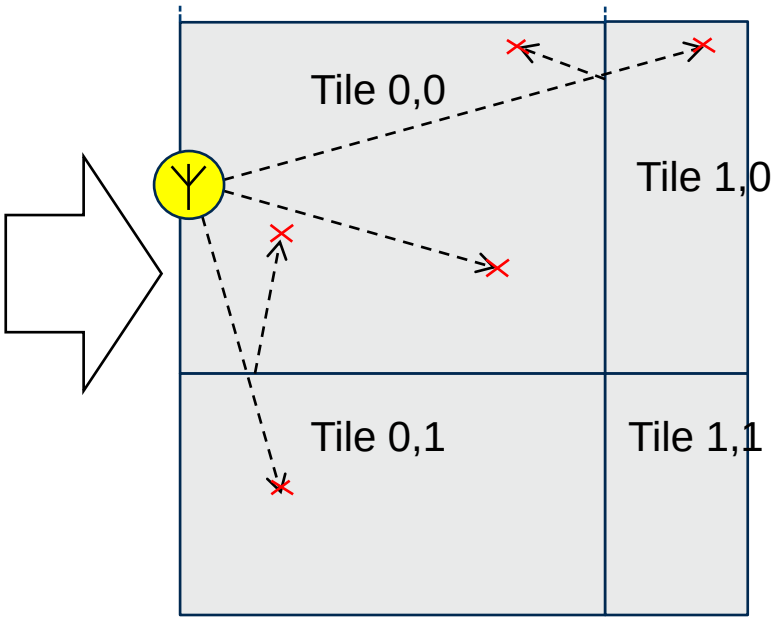


$P(n)=(\lambda/4\pi d(n))^2$

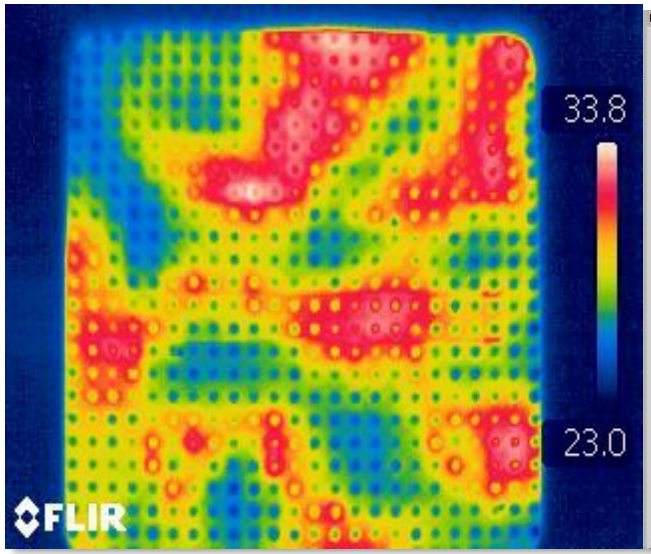
$\Theta(n)=2\pi d(n)/\lambda$

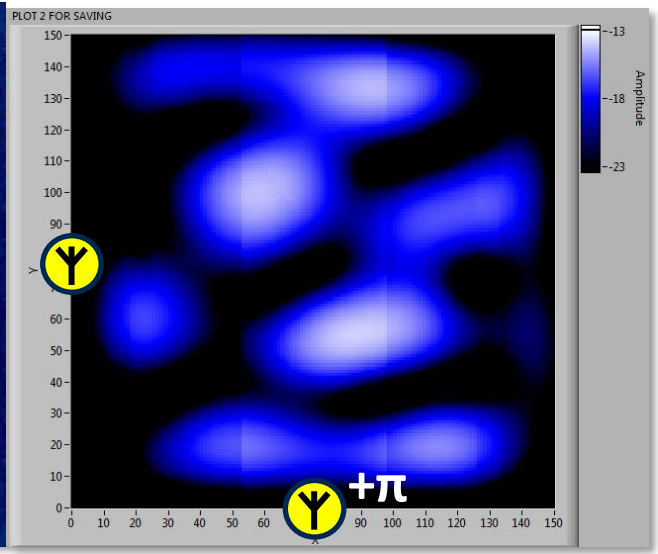


Folded Geometry Superposition Variant of Simple free space path loss model



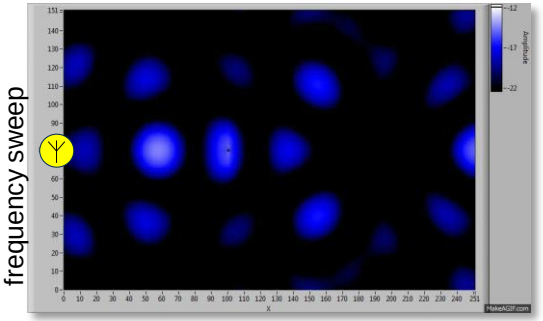
Antenna Array Model – Cavity Extension



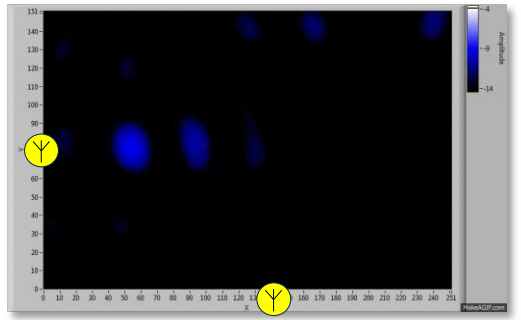


Dual Antenna Model, Antennae in X,Y plane, 2450MHz with a pi phase shift on path 2 between image 1 and image 2

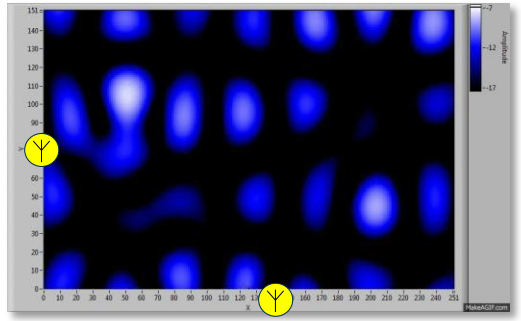
Single channel frequency sweep



Dual channel frequency sweep



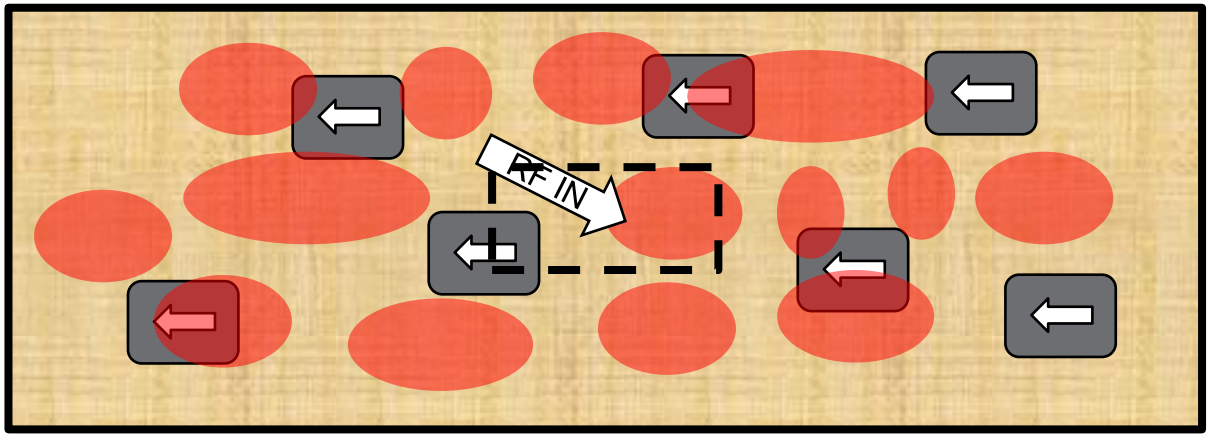
Dual channel Phase sweep



Hotspots in Industrial Heating

In domestic microwave heating, removing the turntable and mode stirrer requires new mechanisms for hotspot spreading

- Frequency modulation via electronic control
- Phase variations in multi-channel systems



In typical industrial heating systems the objects to be heated move through fields:
Homogeneity less critical than in a consumer oven with no moving parts?

- We expect not.

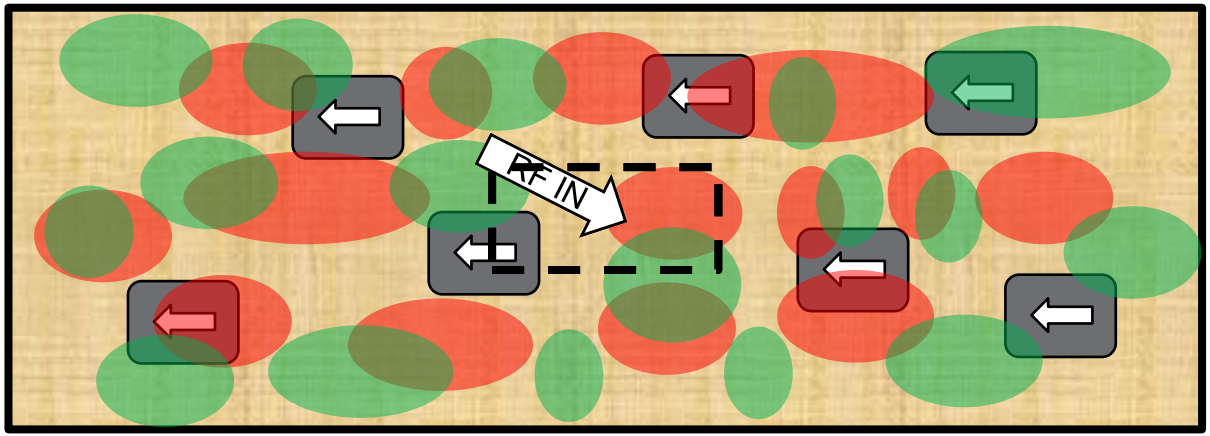
Multiple Frequencies in Sequence

Operation at

Operation a

Putting two stable modes of excitation sequentially into a single cavity…

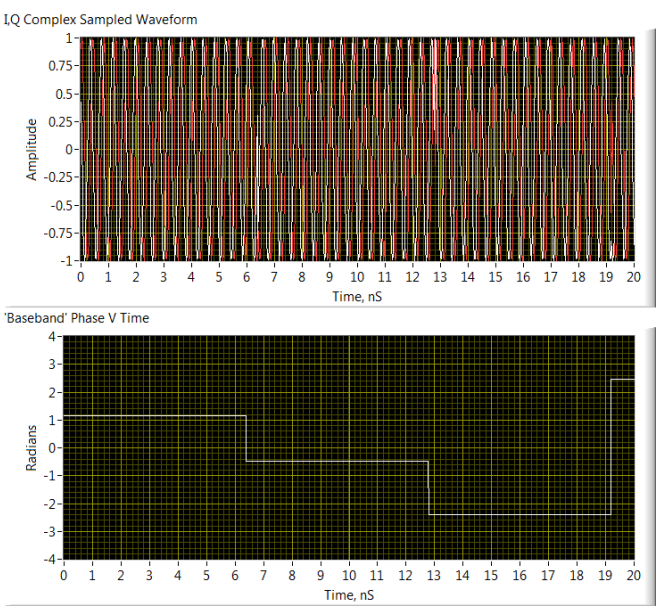
- Still guarantees repeatable operation
- Doubles up the hotspots

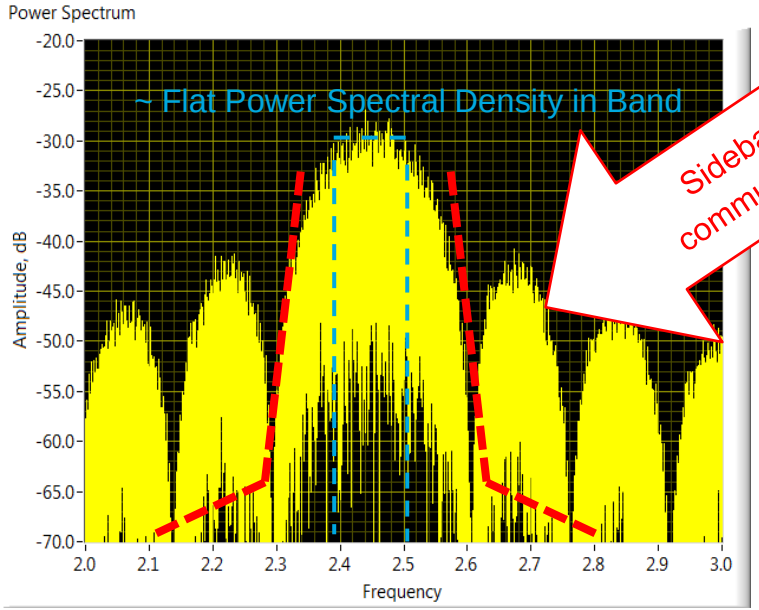


Switch fast enough between frequencies…. That's what we call modulation in the wireless communications world.

Use of Modulation

In communications, phase and frequency modulation are closely related





By definition, frequency = rate of change of phase

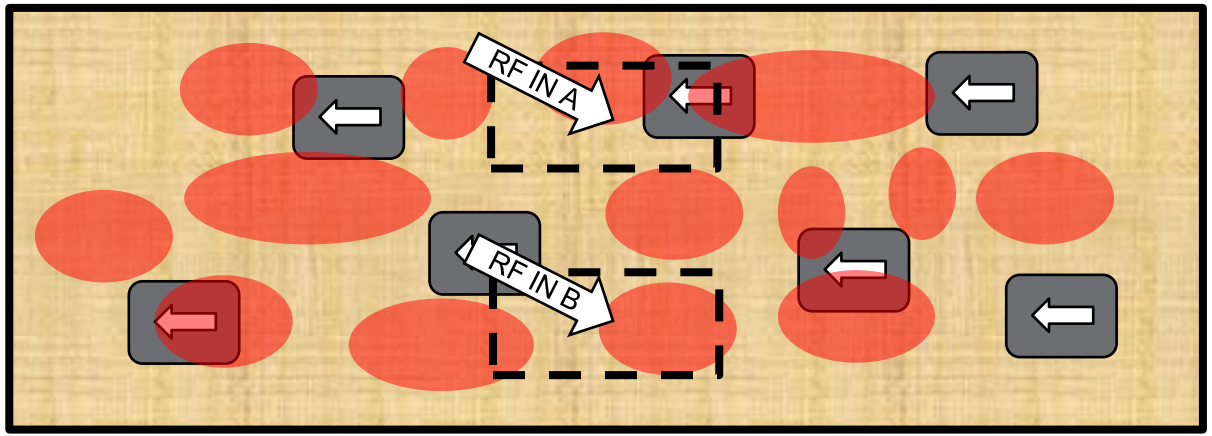
Phase modulation therefore modulates frequency

- Wideband modulation excites all modes of hotspots (nearly) simultaneously

Options with Multiple Ports

Multiple Ports bring many more options for heating field excitation.

- Multi-frequency
  - RF IN A = Frequency 1
  - RF IN B = Frequency 2
- Phase Control
  - RF IN A = Frequency 1, Phase 1
  - RF IN 2 = Frequency 1, Phase 2

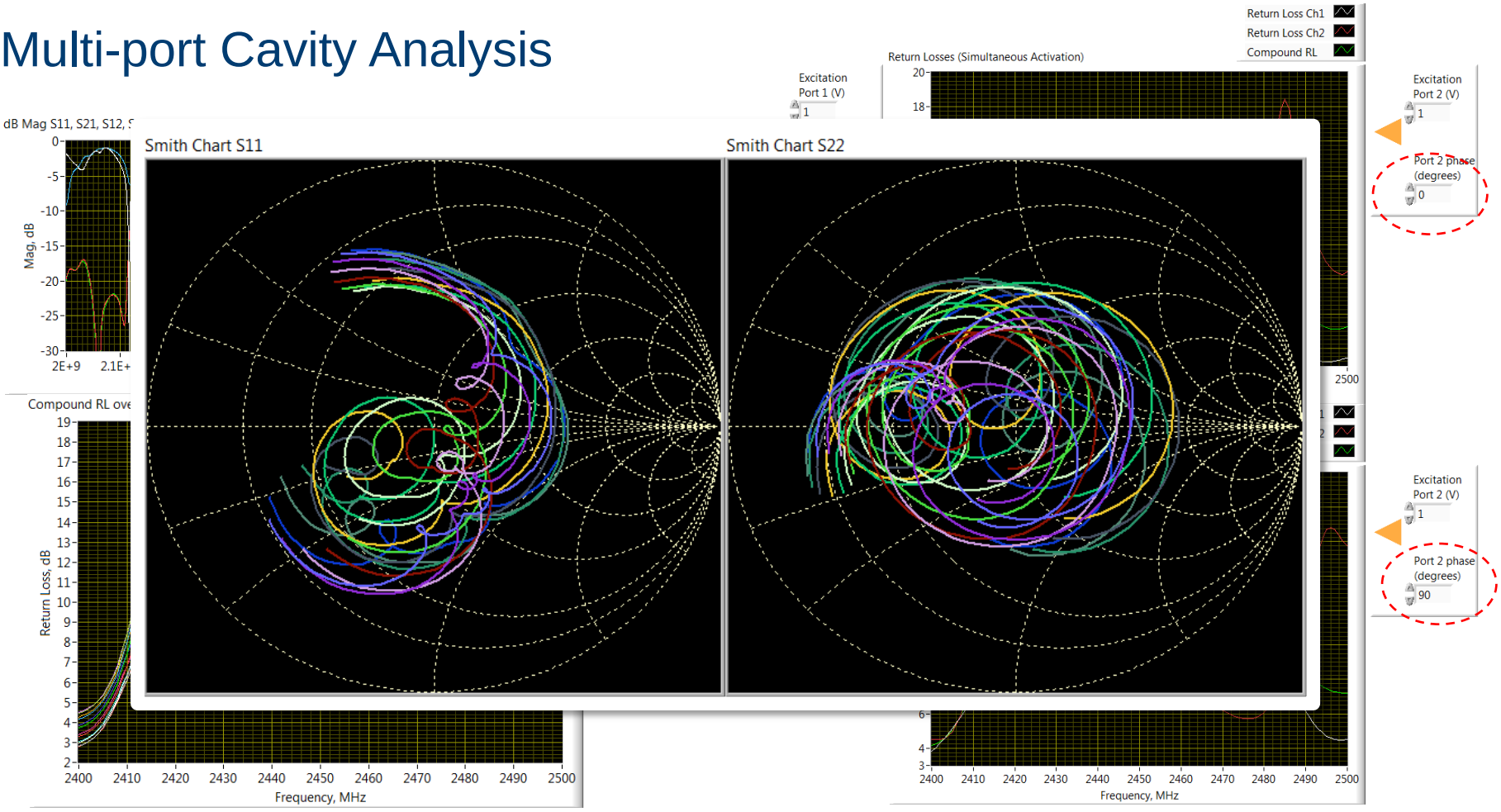


Assuming 10 degree phase step and 1MHz frequency step…

- 1 Port gives 101 states
- 2 ports gives ~14K states
- 3 ports gives ~1.1M states
- 4 ports gives ~100M states

… to search for optimum heating patterns

Multi-port Cavity Analysis

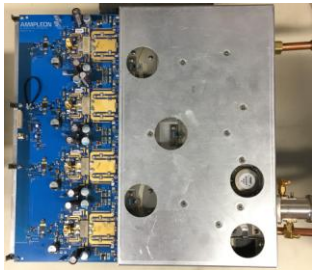


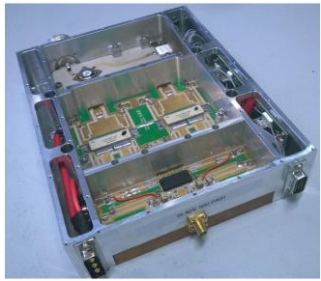
Key Concepts

- Physics of heatflow shows you can heat homogenously with any kind of heat source – if you do it slowly enough.
  - Time for heat to penetrate to the core of the target
- We've seen how heat delivery with RF into a resonant structure fundamentally implies hotspots, ie non homogenous heat delivery
  - If the hotspots can be 'spread' to provide a more even heat input, less time is needed for heat flow to deliver a target temperature in the coolest parts
- In an industrial environment, low homogeneity of heat delivery is managed by physical movement through the line, and time for heat flow.
  - If heat was delivered more evenly, more watts can be applied to a shorter line?
  - Ie… more throughput in less space?
- Heating faster with equal or better homogeneity (than is possible with todays industrial systems…) requires something new

RF Energy Evaluation Tools

How can our solid-state sources help you evaluate…



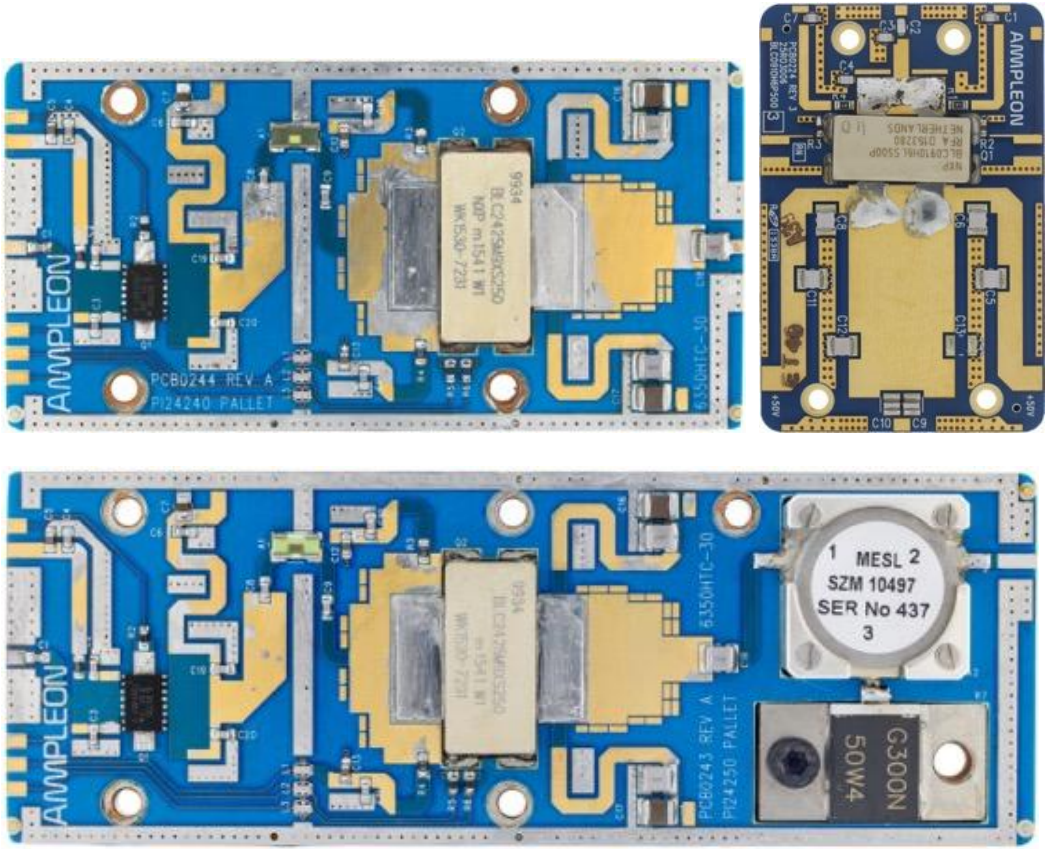


- Reliability (> 10 year lifetime in continuous operation)
- Fault-tolerance (can operate with faulted PA modules)
- Intelligent distributed control with built-in test & monitoring
- Operation from reliable, light-weight, efficient switch-mode power supplies
- Stable, precise control of power, frequency, phase, modulation
- Modularity and scalability
- High-speed arc detection & shutdown
- Stability at all power levels
- Standard pallet designs

System Building Blocks - PA Pallets

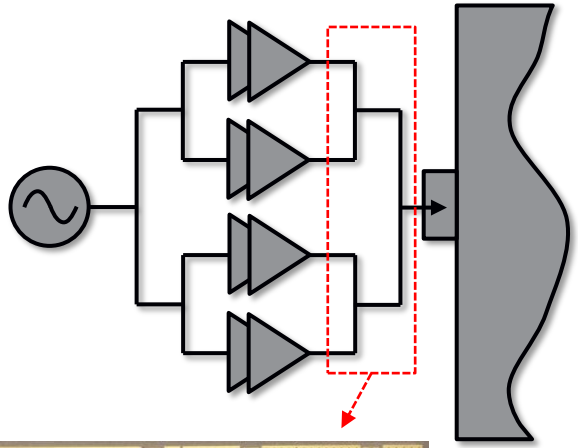
Ampleon Standard building blocks

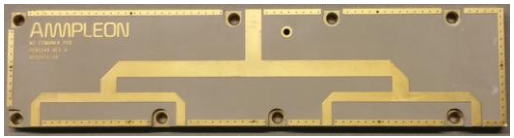
- 2.45 GHz
  - 250 W CW
  - 250 W CW (with isolator)
  - 500 W CW
  - 1.2 kW pulsed (with isolator)
- 915 MHz
  - 500 W
  - 500 W (2-stage)



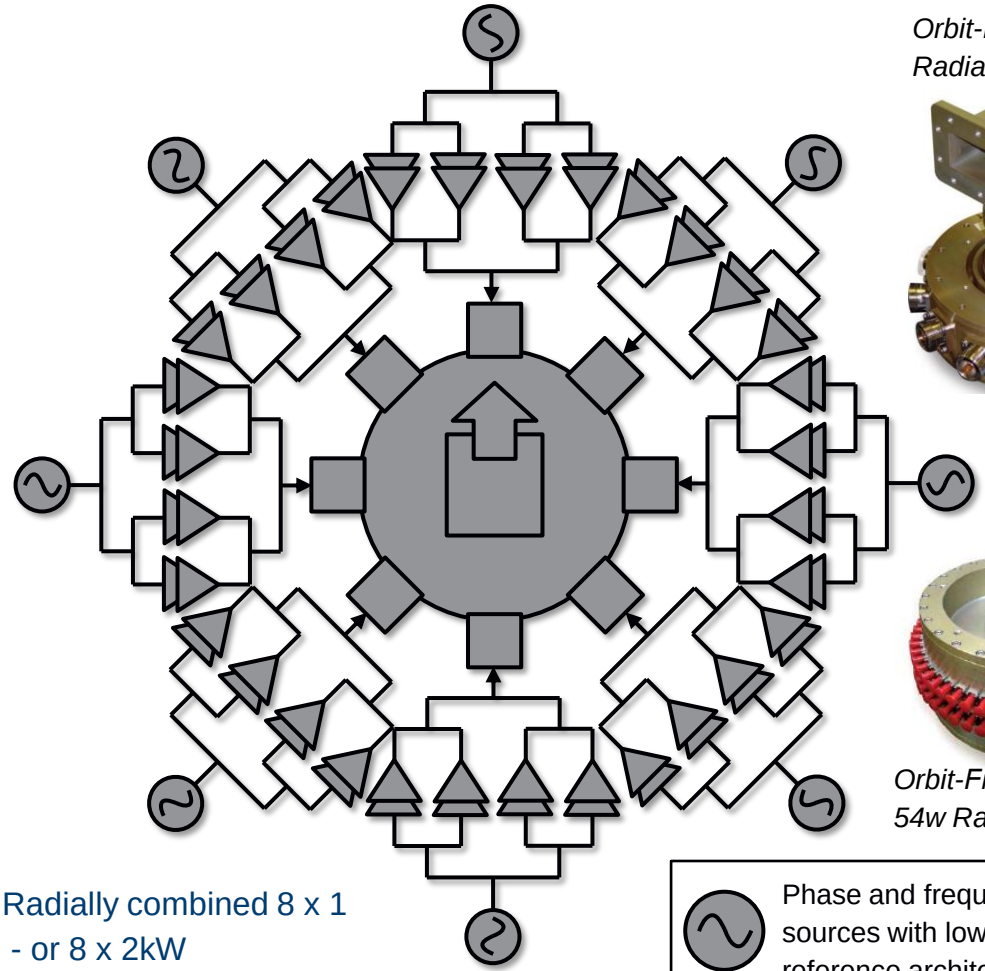
Scaling Pallets to Power

Combining at the PA level



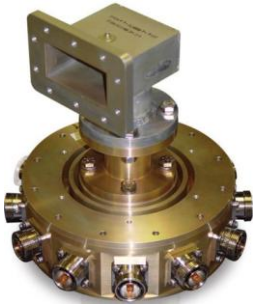


4x250W PA's combined to 1kW
(Also possible with 500W pallets for 2kW)



Radially combined 8 x 1
- or 8 x 2kW

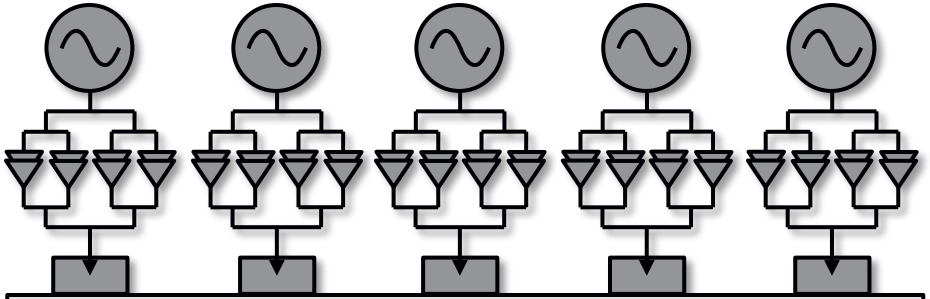
Orbit-Fr's Model 752
Radial Combiner



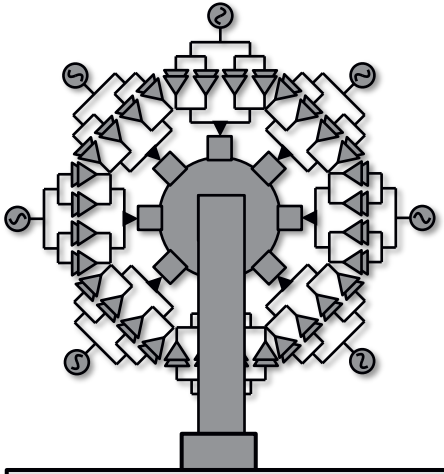
Orbit-Fr's Model 707
54w Radial Combiner

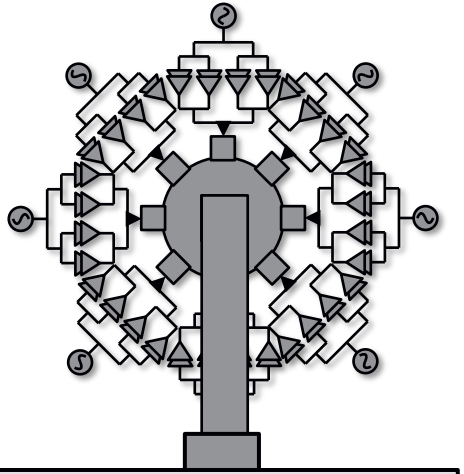
Phase and frequency agile RF sources with low frequency reference architecture

Scaling Pallets to Power



Combining in the cavity – combine n x unit power level, trading off power needed with the desired phase and frequency agility for the system





Higher power variant with 3 level combining: Planar, radial and cavity

Strategy:

- Fixed combining through multiple levels to create the ‘unit’ block of power required for the application
- Final Power combining ‘in the cavity’
- Consider the required field pattern flexibility (number of field-affecting variables)

Conclusion

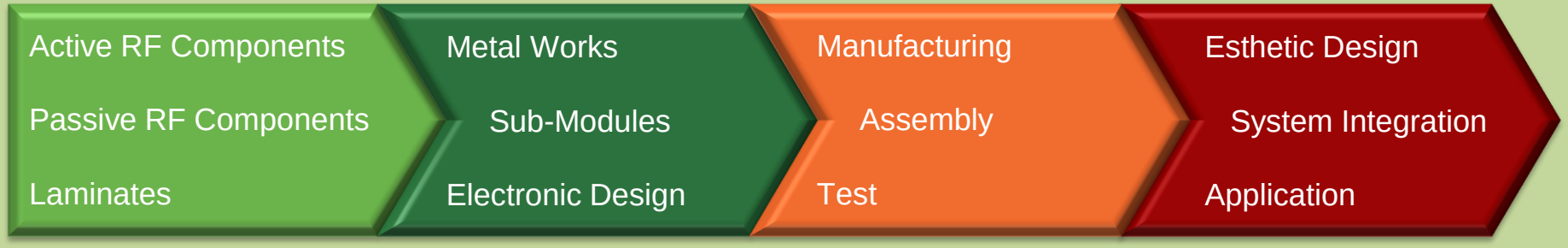
- RF Energy with Solid State technology enables a whole raft of advantages combined with new techniques in addition to the basic delivery of power to the system
  - Long lifetime of solid State
  - Stability of power delivery achieved through power control mechanisms
  - Stability of frequency and phase through use of phase locked loop synthesisers
  - Cavity Power delivery sensing (high power vector network analyser)
  - Phase and Frequency modulation to manage hotspot location at high speed
  - Phase locking of multiple sources (enables array beam steering techniques to be applied – albeit inside a cavity)
  - Due to coherent emission from multiple sources, power combining in the cavity is a real possibility
- These breakthrough capabilities can be explored with Ampleon demo modules – with our expert support in the field of Solid State RF Energy systems development
- A migration route to small scale prototyping – or low volume production – with pallet solutions

The RF Energy Alliance

Transformative Heating
&
Power Technology

RFENERGY ALLIANCE

RF Energy Value Chain



Suppliers

OEMs

RFENERGY ALLIANCE

RFEA: Standardizing solid-state RF energy components, modules and application interfaces to:

- Reduce system cost
- Minimize design complexity
- Ease application integration
- Increase market adoption & growth

Members

Promoters

AMPLEON

E·G·O
High-tech since 1931.

HUBER+SUHNER
Excellence in Connectivity Solutions

Panasonic

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What'll we think of next?

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Partners from RF to Light

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NXP

WPI

Midea

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AFT microwave

Cellencor
High Power Microwave Solutions

KennedyLabs
Material Matters

PPI Passive Plus Inc.
RF & Microwave Capacitors

RJR TECHNOLOGIES

iWin
Leading Global Communications
SEMICONDUCTORS

Roadmap

Q2 2016

RF PA Roadmap: Residential Appliances (2.45 GHz, consumer and professional)

Q4 2016

System Integration Guidelines

RF PA Roadmap: Industrial Applications (915MHz)

Q1 2017

S2RF Value Assessment Standard

2nd Revision Residential Appliances Roadmap (2.45 GHz, consumer and professional)

RF PA Roadmap: Residential Appliances

- Defines current and future power amplifiers modules for residential solid-state RF energy applications
- Demonstrates path to near term market viability
  - Cost-competitive with current magnetron solutions
  - Specifies over 40 characteristics to increase performance-to-price ration overtime
- First solid-state RF energy industry specification
  - Collective effort from representatives from across value chain
- “Residential efforts” will be leveraged also also for industrial implementations
- Full version available to members only

Join Today

RF ENERGY ALLIANCE

http://rfenergy.org/join-alliance

AMPLEON thanks you for listening…

- If you have questions
- Need to make a business case
- If you like to start using solid state
- Need help with architecture / designs

Please contact us

Thank you for your interest in our webinar

For any follow up questions you can contact

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Amplify the future