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500MHz Solid State RF Amplifier

CWRF Hsinchu, Taiwan

Bodo Fritsche, Marcel Frei, Simon Keens

Science MedTech Industry Broadcast

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First Generation 65kW Amplifier

What we got:

- Frequency: 500MHz
- RF Power: 65kW (CW)
- Efficiency: > 52%
- Spurious: < -75dBc
- Very reliable

- Installed at PSI in 2014

Our appreciation for the support from PSI, especially Mr. Garvey and Mr. Gaspar.

This work has been supported by the Swiss Commission on Technology and Innovation.

Challenges and Problems

- Modules have to perform the same:
  - Gain
  - Phase
  - Output power
  - Efficiency
- Production scatter and tolerance of components
  - LDMOS (gain, impedances, etc.)
  - Phase of circulators (?)
  - Capacitors
  - Components must be assembled by hand

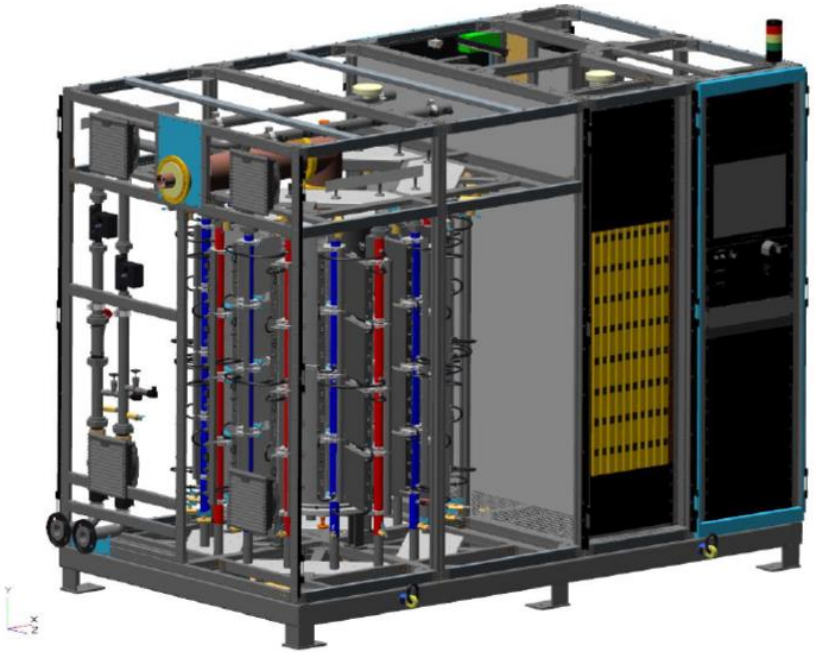
Impacts for production:

- Expensive hand craft required
- Each module needs to be individually adjusted and tested
- Some modules just do not perform that good -> rework needed
- Number of modules required is insufficient to justify significant investment in automation

Commercialised Amplifier Concept

Key requirements

- "Turnkey" system operation
  - RF modules
  - Power supplies
  - RF driver
  - All splitters / combiners
  - Control system
  - Mains distribution
  - Safety interlocks / supervisions
  - Water cooling system
  - Closed cabinet: EMV/dirt/dust protection
  - No external circulator needed
- Easy maintenance / repair
- Control system
  - TCP/IP remote control
  - Interface to EPICS



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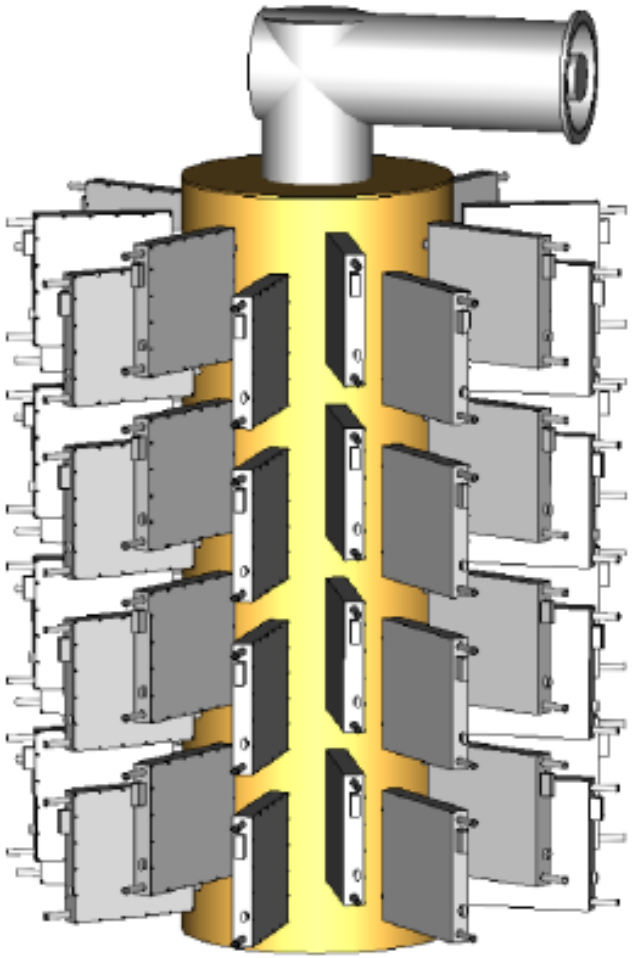
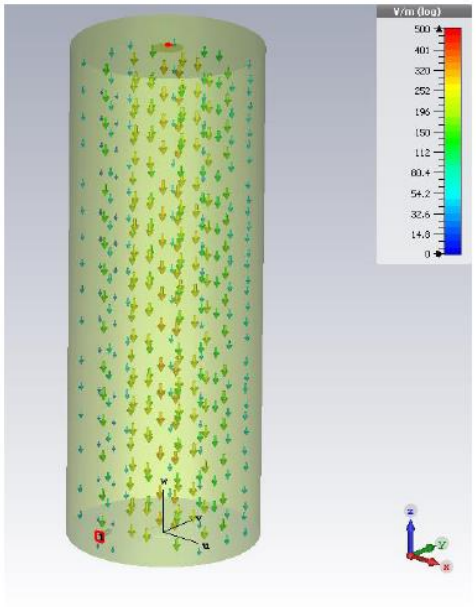
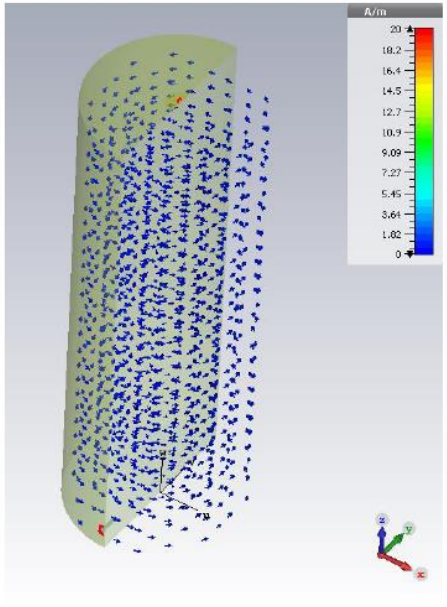
2nd Generation RF Power Module

- 2x850W RF out
- DC to RF Efficiency >65%
- Integrated water cooling
- Build in circulator
- Modbus interface to read values:
  - LDMOS temperature
  - Circulator temperature
  - Drain current
  - Drain voltage ok
  - V_{bias} ok
- External enable/disable of bias
- LDMOS and RF PCB soldered into housing for lowest possible thermal resistance
- Pick & place assembled to have low production scatter
- Fully automated test routine after manufacturing

Simulated Cavity Combiner







Requirements:

- Efficiency >98%
- Number of ports variable
- Direct connection of modules
- Lossless geometry
- bandwidth

RF Cavity Combiner

Key Characteristics
- Up to 128port direct combining
- RF Inputs: Snap-N
- RF Output: 6 1/8” EIA
- 99% Efficiency
- Q-Factor (loaded): 112
- 3dB bandwidth >4MHz
- Resonance frequency can be adjusted

- Simulated using CST software
- Measured with low power

-> How to terminate 128x snap-N with 50Ohm?

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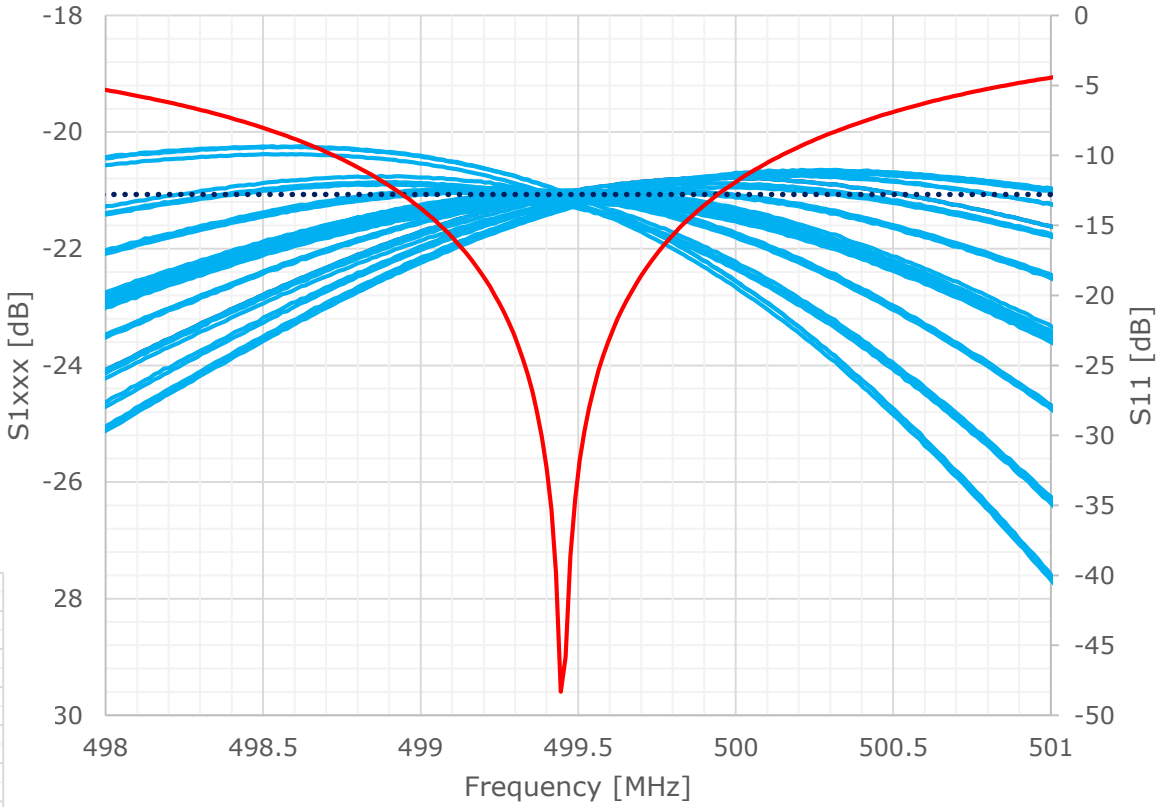
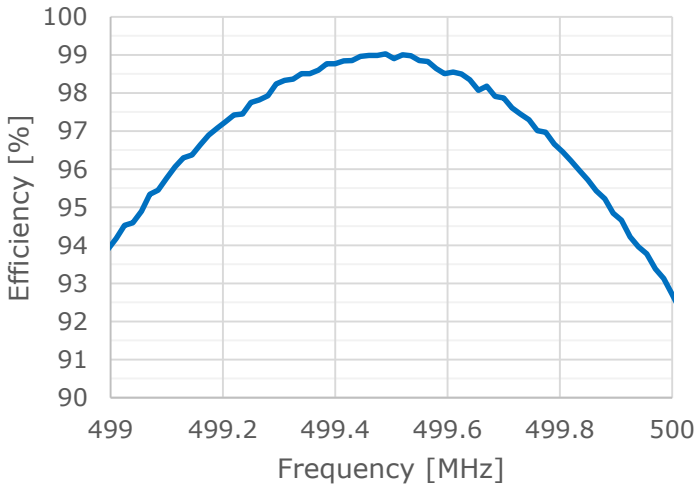
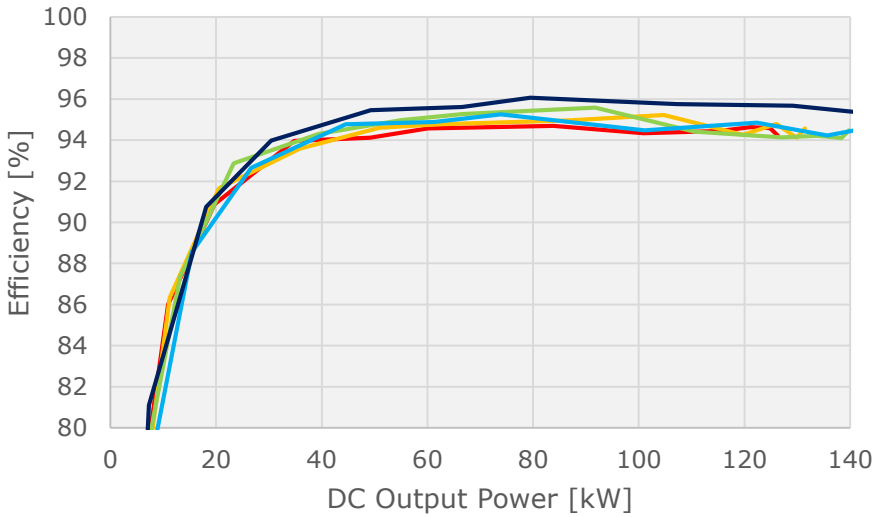
RF Cavity Combiner

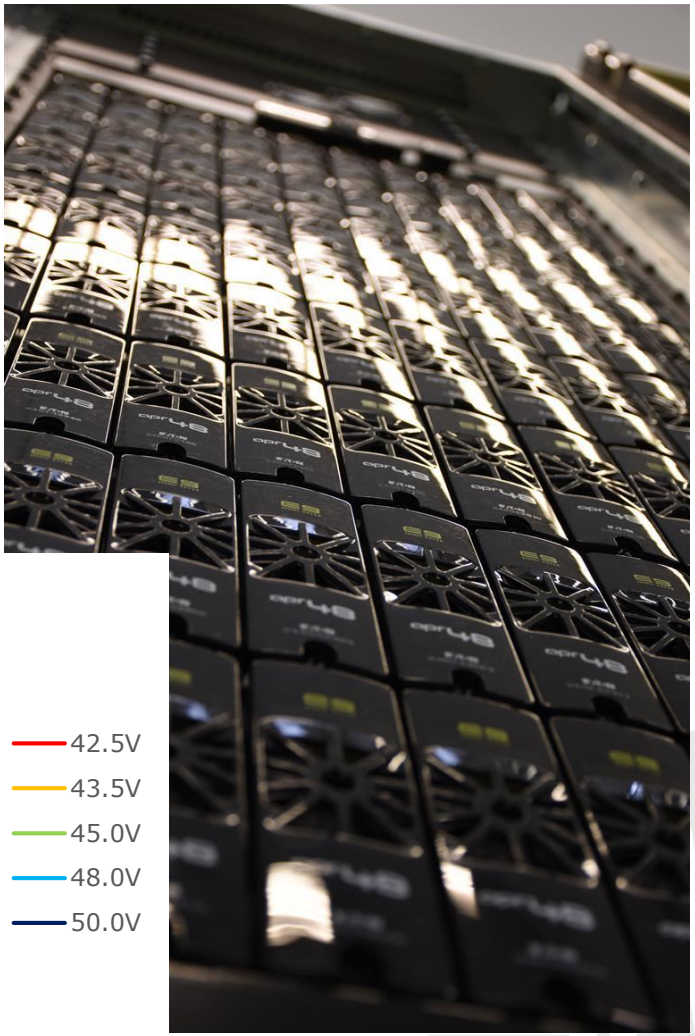




Choice of DC Supply

Eaton DC Supply
- APR48es rectifier units
- Up to 96% Efficiency
- 42.5…56V output
- Wide AC input range
- Short circuit proof
- Hot plug&play
- Power saving mode





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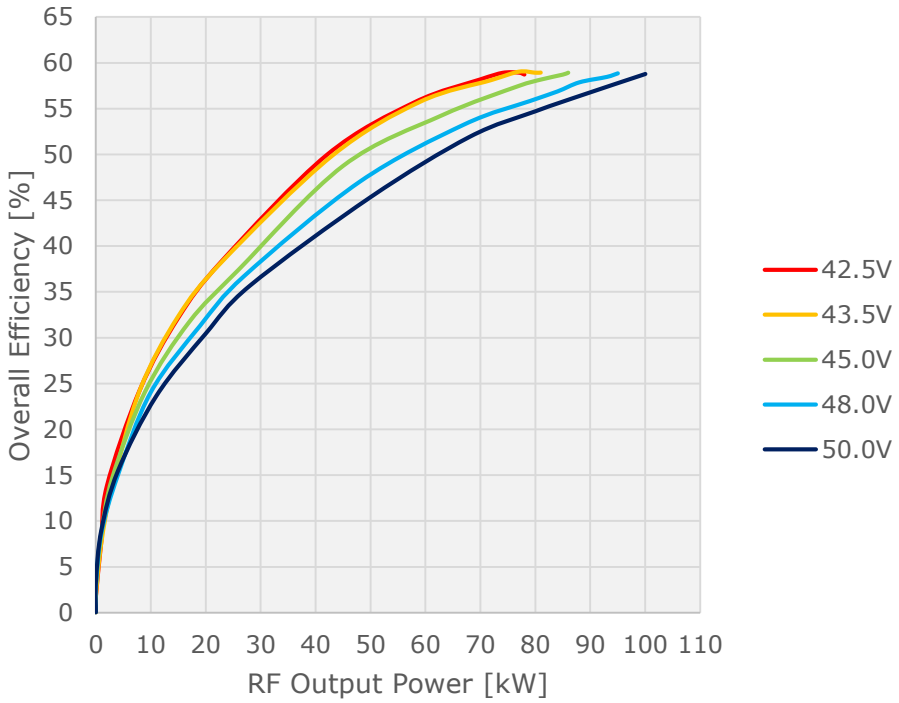
500MHz SSPA System

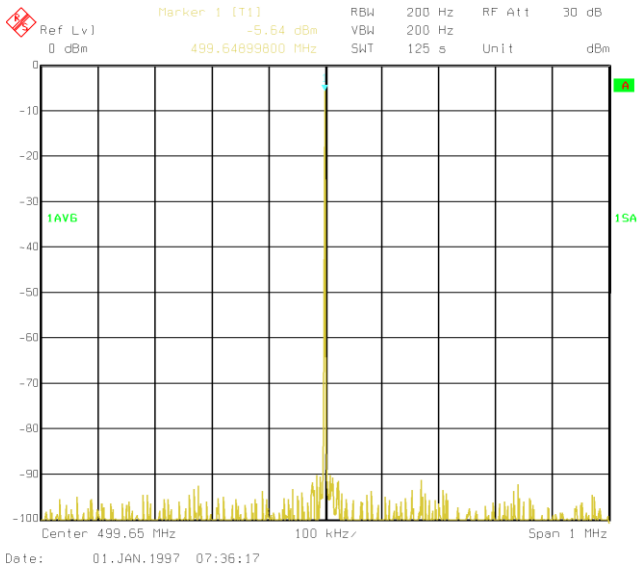
- Use of Ampegon's standard components
  - Highly modular UCS (Unified Control System)
  - EPICS interface
- Modular design
- 60kW and 80kW Systems are build identical
- Low maintenance requirements
- Multiple Outputs can be combined to obtain higher power levels

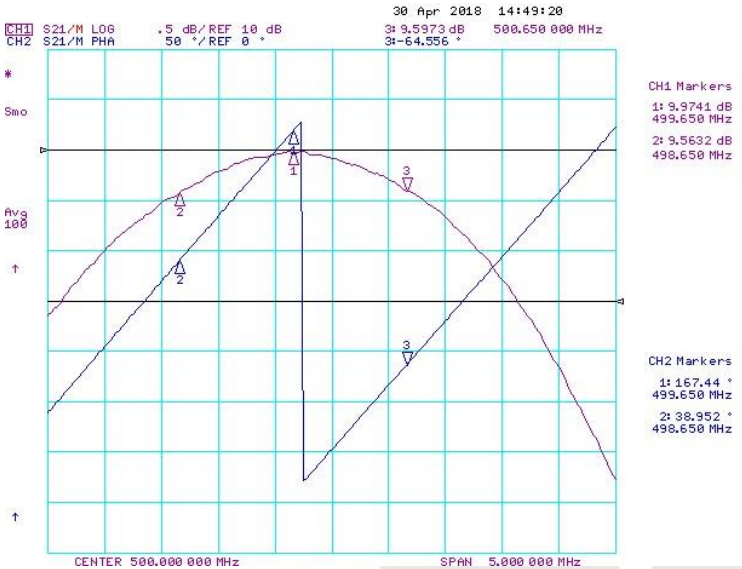
- Overall Efficiency: >58%
- Nominal RF power: 80kW
- Max RF power >100kW
- Group delay <200ns
- Spurious emissions >80dBc
- Harmonics >30dBc

500MHz 80kW SSPA System

Measurement Results
- Spectrum (1MHz bandwidth)
- Efficiency vs RF Output
- S21 parameter (magnitude and phase)







Other Solutions for High Power RF

RF systems based on tubes (including klystron, IOT…) can be still competitive.

- Operated worldwide for decades
- E.g. very high pulse power
- Small footprint at high powers
- More competitive at high frequencies

Ampegon can offer RF amplifiers using any amplifier technology: We can provide worldwide references for IOTs, tetrodes, klystrons, gyrotrons and solid-state systems for a wide range of applications.

Industrialization

- We supply complete turnkey systems
- Modular design philosophy allows customized system integration
- Mechanical design is completed using ProEngineer software
- Full digital record of design and construction documentation, as built, available in SAP
- Schematics and wiring diagrams produced using Zuken E³
- Customized software and Graphical User Interface (GUI) design
- Product Life Cycle process according to ETM3 is ISO9001 certified

- Powerful test environment
  - RF test load up to 3MW (CW or pulsed)
  - DC test load up to 1MW (avg), 25MW (pulsed)
  - 4MW (16kV) electrical power supply available
  - Practically limitless cooling capability (river Limmat)

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Summary

- Ampegon has been working to develop its 2nd Generation 500MHz RF amplifier, which is now being delivered to customers
- Performance meets target specifications
  - >80kW RF Output power
  - >57% Efficiency
  - Cavity Combiner is performing as simulated
  - 60kW and 80kW Systems build with identical combiner
- RF Amplifiers can be build in different technologies

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Thank you.

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