500MHz Solid State RF Amplifier

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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

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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
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?
RF Cavity Combiner

Efficiency [%]

Frequency [MHz]

S1xxx [dB]

Frequency [MHz]
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

![Diagram showing efficiency vs DC output power for different voltages](image.png)

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Efficiency [%]

DC Output Power [kW]

- 42.5V
- 43.5V
- 45.0V
- 48.0V
- 50.0V
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)
Summary

- Ampegon has been working to develop its 2\textsuperscript{nd} 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
Thank you.