Cryoelectra

RF Technology for Particle Accelerators

Robustness of the 3rd Generation of High-Power Solid-State RF Amplifiers for 500 MHz

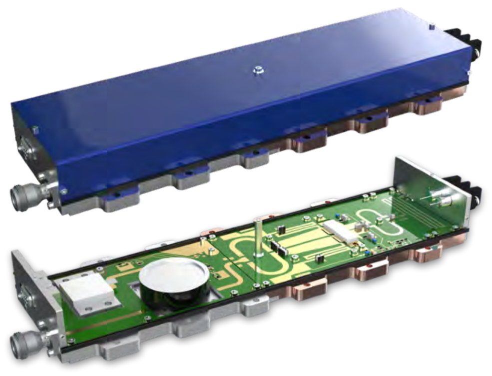
Presenters: Nico Pupeter, Mirco Nedos
Authors: N. Pupeter, M. Nedos (Cryoelectra GmbH, Wuppertal, Germany)

Abstract: With its third generation of 500 MHz solid-state RF amplifiers, Cryoelectra has achieved a level of reliability such that virtually no RF units have failed over more than 14 million transistor operating hours. This was made possible by the patented design of the RF power modules, as well as by sophisticated manufacturing technology and the quality assurance measures implemented. The RF power module contains 16 RF units, each with a single transistor. Their output signals are combined at the center of the module by a coaxial combiner. The outer part of the combiner also serves as a water-cooled heat sink for the power dissipated by the RF units and the terminating load of the circulators. The RF outputs of up to 15 RF modules are connected directly to a waveguide combiner to reduce power losses and eliminate sources of error. This poster presents current MTTF values as well as measures which improved them.

1st Generation

- single transistor modules
- power density 18 kW/m²
- 75 kW cw output power

Single Unit RF Module

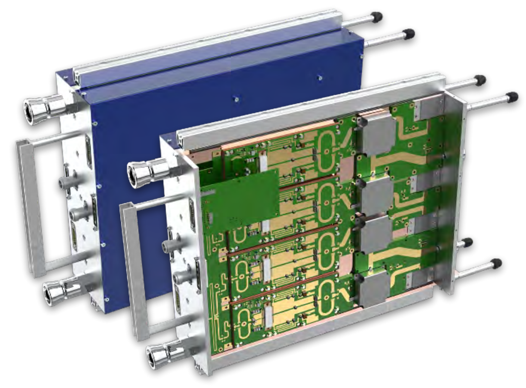


- DC to RF Efficiency: ~ 60%

2nd Generation

- 8 transistors per module
- power density 28 kW/m²
- 100 kW cw output power

Planar RF Module



- DC to RF Efficiency: ~ 60%

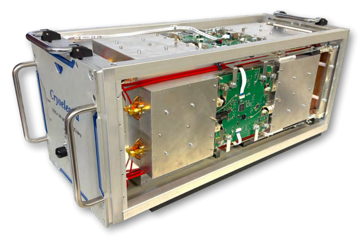
3rd Generation

- 16 transistors per module
- power density 41 kW/m²
- up to 160 kW cw output power

RF Tower Module push-pull

- DC to RF Efficiency: ~ 60%

RF Tower Module single-ended

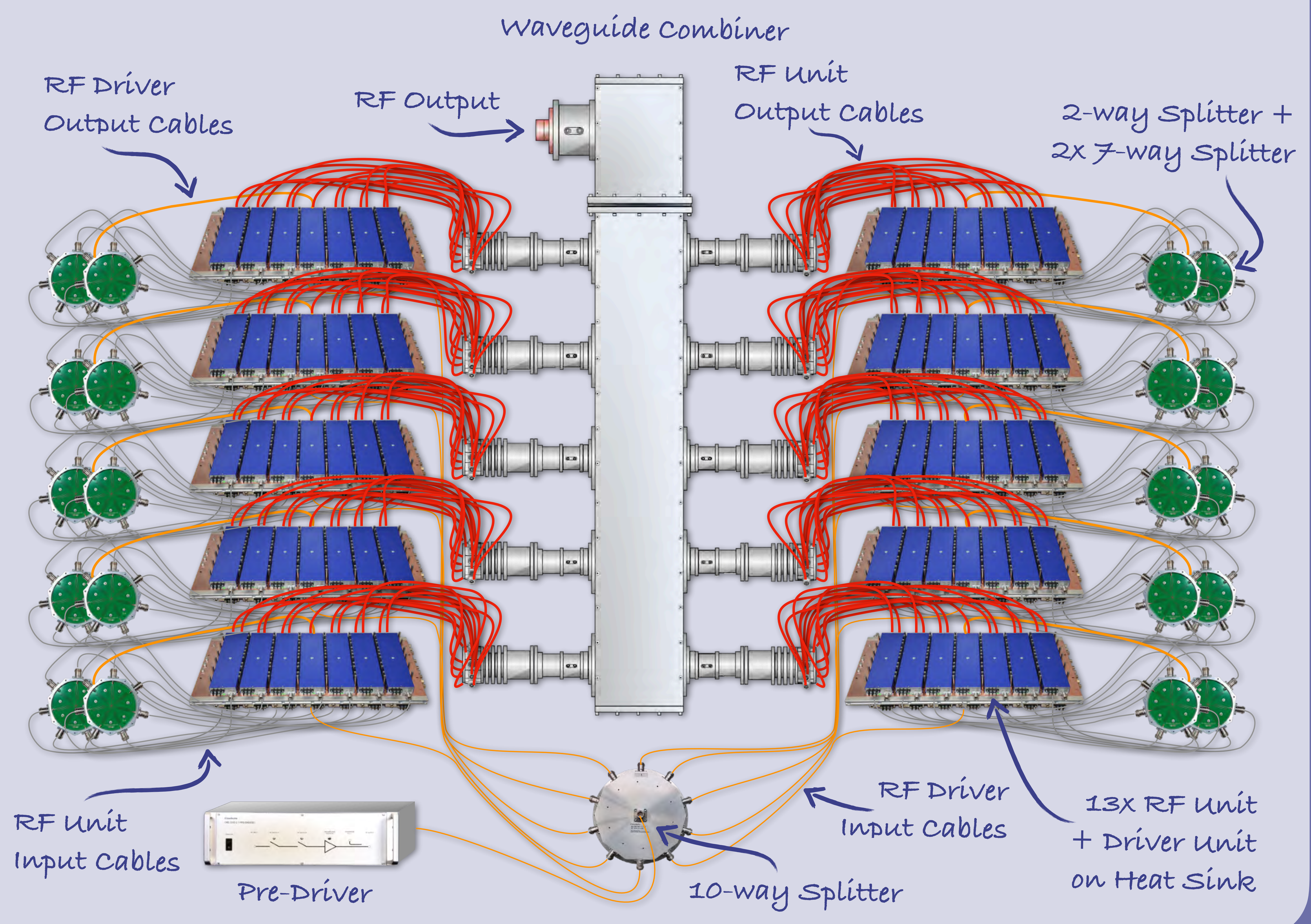


- DC to RF Efficiency: ~ 71%

Continuous Development — 2013 — 2016 — 2021 — 2025 — time

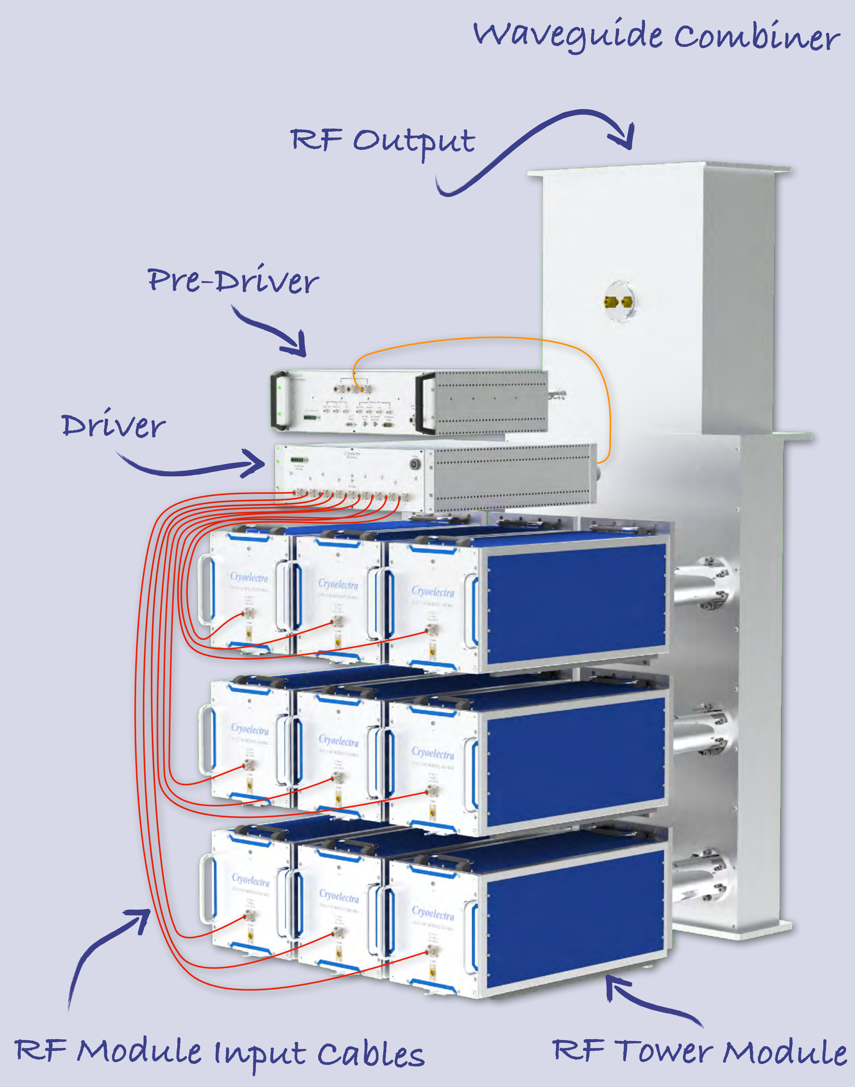
2013

1st Generation Solid-State Amplifier - CRE-331D 75kW cw - RF Scheme



2025

3rd Generation Solid-State Amplifier - CRE-331S 120kW cw - RF Scheme



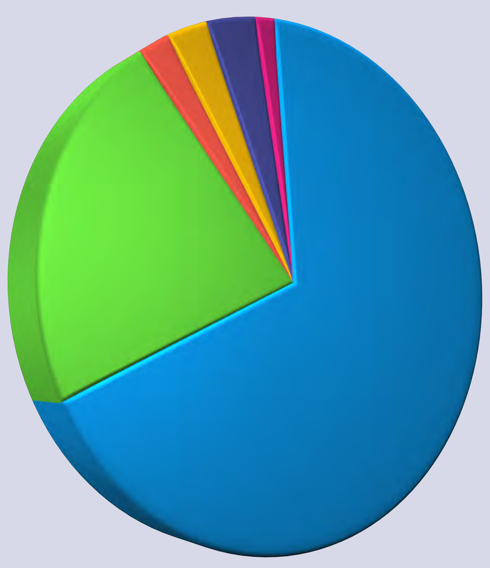
Identified Failure Sources, Lessons Learned and Improvements

Failure Sources in 1st Generation Amplifiers	Improvements	Design Changes for 3rd Generation Amplifiers
The **RF output cables** are very sensitive to bending, which can lead to higher losses. The increased temperature puts stress on the solder joint at the RF connector of the RF unit, and the connector's screws may also come loose due to temperature cycles.	The cables may be bent only once; avoid bending them further after operation under load. On the RF unit side, a different connector was selected to ensure better thermal contact with the housing components. The geometry of the soldering surface was improved, and a different type of solder was used.	No RF output cables are used. The RF units are mounted directly on the main heat sink, which serves as a low-loss combiner. This results in a lower thermal load at the device output and higher overall efficiency of the amplifier.
The heat generated in the **circulator** puts a stress on the solder joints.	The geometry of the solder pad was improved, and the solder used was changed to SAC 305.	The circulator is directly mounted on the main heat sink.
The heat generated in the **DC fuses** can break the fuse in normal operation.	Fuses must be cooled by forced ventilation. Fan installed.	DC fuses integrated into the RF module that are thermally connected to the main heat sink to dissipate heat during normal operation.
The **solder joint beneath the transistor** degrades due to thermal stress. Voids result in reduced thermal conductivity. The solder thickness is critical and must be maintained.	InFORMS® and preforms are used for soldering, employing a sophisticated soldering technique that excludes oxygen, thereby preventing voids and significantly extending the service life of the solder joint.	InFORMS® and preforms are used for soldering, employing a sophisticated soldering technique that excludes oxygen, thereby preventing voids and significantly extending the service life of the solder joint.
Power supply of the control PC (SIMATIC IPC) failed during operation.	The control concept has been modified. The amplifier can be operated via the remote control system without the local control PC.	The control concept has been modified. The amplifier can be operated via the remote control system without the local control PC.
The solder joints of the **mica capacitor** degrade due to thermal stress.	The soldering process has been improved through the use of Preforms, and the solder changed to SAC 305.	The new single-ended RF unit does not require a mica capacitor.

1st Generation RF Unit Failure Statistics

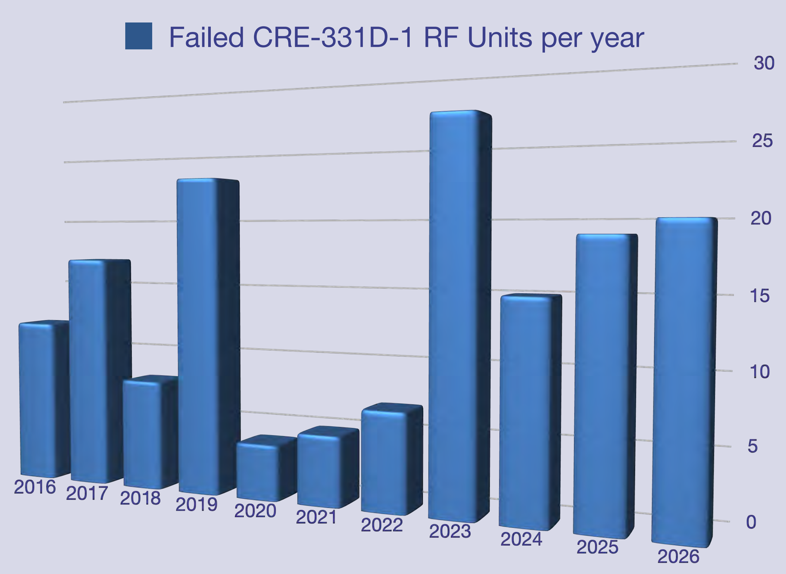
Failed Components of RF Unit

- Circulator / Circulator Soldering
- Output Connector Soldering
- Transistor
- Misc
- Mica Capacitor
- Input Connector Soldering



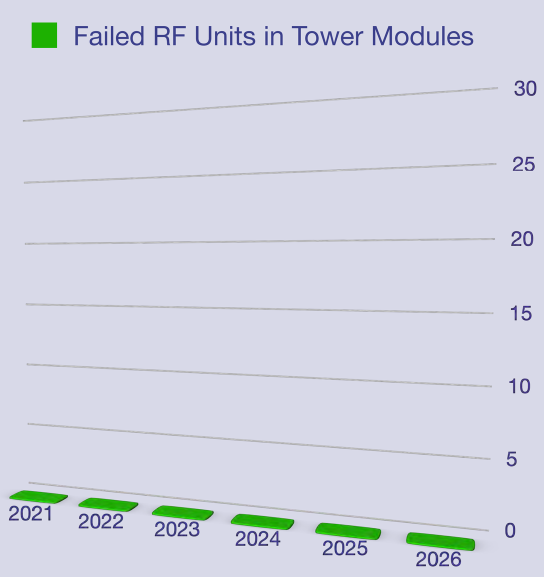
The 910 RF units of type 331D-1 have logged a total of 54,040,000 operating hours, with 157 of them having failed during that time. Based on the historical data, the **MTTF is 344,200 hours**.

The lower bound[1] based on a 95% confidence level is **MTTF ≧ 310,510 hours**.

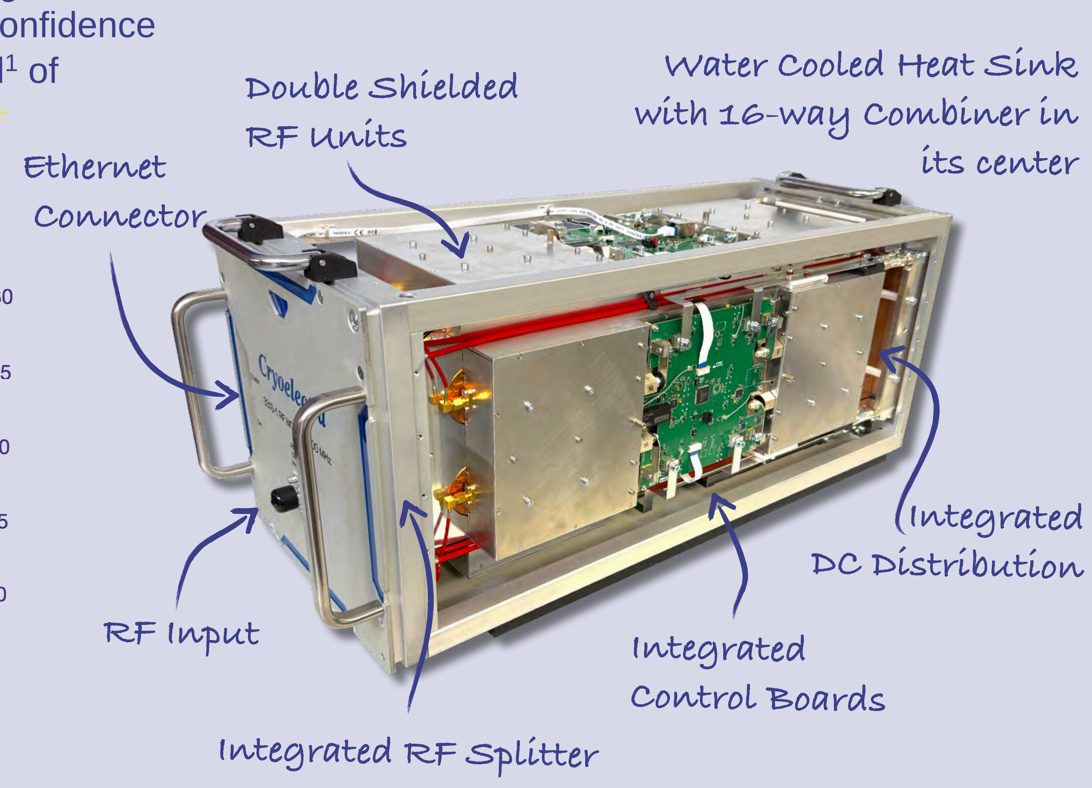


3rd Generation RF Unit Failure Statistics

A total of 2,160 RF units have collectively accumulated 18,850,800 operating hours without failure. Based on a 95% confidence level, this results in a lower bound[1] of **MTTF ≧ 6,292,600 hours.**



Gen 3.2 RF Tower Module Improvements



[1]) The one-sided lower confidence bound for the MTTF was determined from the cumulative operating time T, assuming independent, exponentially distributed lifetimes and a constant failure rate. For r observed failures and a confidence level C, $MTTF_L = 2T/\chi^2_{(r+1);C}$, where $\chi^2_{\nu;C}$ denotes the C-quantile of the chi-squared distribution with ν degrees of freedom. For zero observed failures, this simplifies to $MTTF_L = T/[-\ln(1-C)]$.