Solid State RF High Power Amplifier Developments at SOLEIL

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CWRF10

CELLS-ALBA Barcelona Spain

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History Review

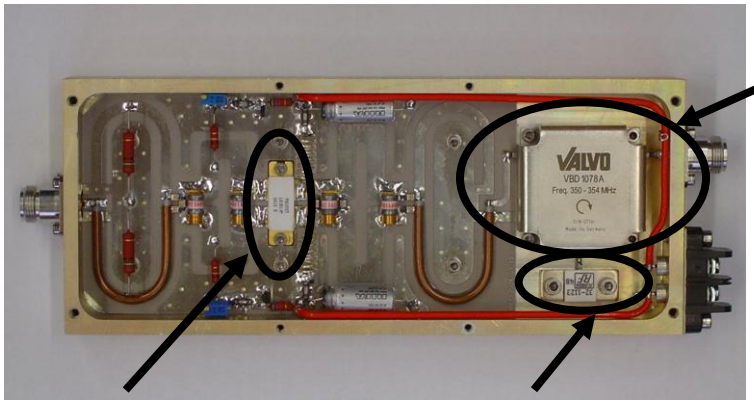
- 2004 Success of Booster 35 kW SSA (Solid State Amplifier) encouraged us to design 180 kW SSA. (Unconditional Stability, Drop-in Circulator etc.)
- SR: Four 180 kW amplifiers
- Vacuum tubes (Klystron, IOT, Diacrode) not commercially available at 352 MHz
- Selection of solid state technology
- Challenge: No Transistor available
- Collaboration with Polyfet to develop the highest power UHF LDMOS LR301

Advantages of SSA

- High Reliability
- Modularity
- No DC High Voltage → No X Ray Radiation
- No High Power Circulator
- Easy Maintenance
- Very Simple Spare Parts
- Good Performance
- Low Phase Noise

352 MHz 2.5 kW Amplifier

315 W Module



Low Loss Wideband Circulator

LDMOS

50 Ohm Termination

Main Specifications
RF power 315 W CW
Frequency 352 MHz
Gain 13 - 14.5 dB
Phase tolerance 15°
Efficiency 63%
Unconditional Stability

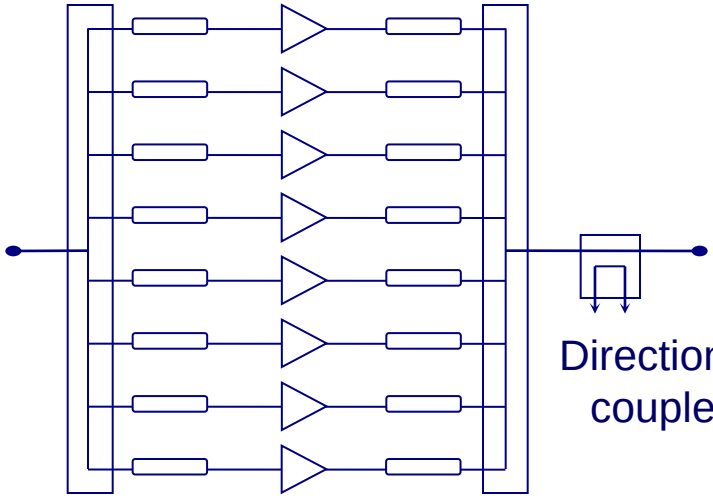
DC/DC Converter

Input 280V DC

Control & Measurement

Output 28V DC

2.5 kW Group



Directional coupler

8-Way Splitter

8 x 315 W

2.5 kW Combiner

N-Way Power Combiners

Combination Advantages :

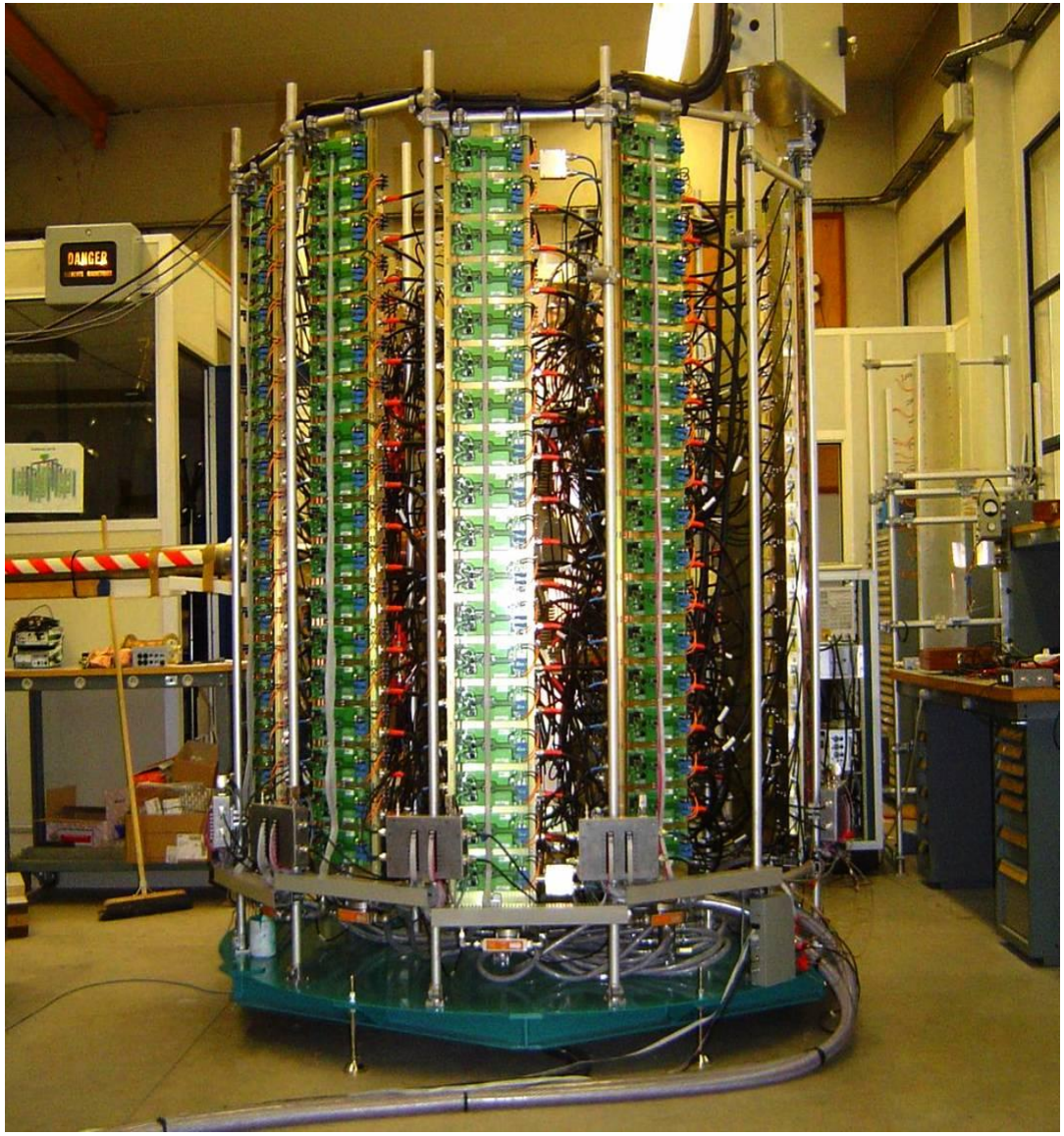
- TEM Quarter Wave-Length Mode
- Lowest Losses and Lowest Cost
- Best Balance and Minimum Dimension
- Without Rejection Power Load

N-Way Power Splitters

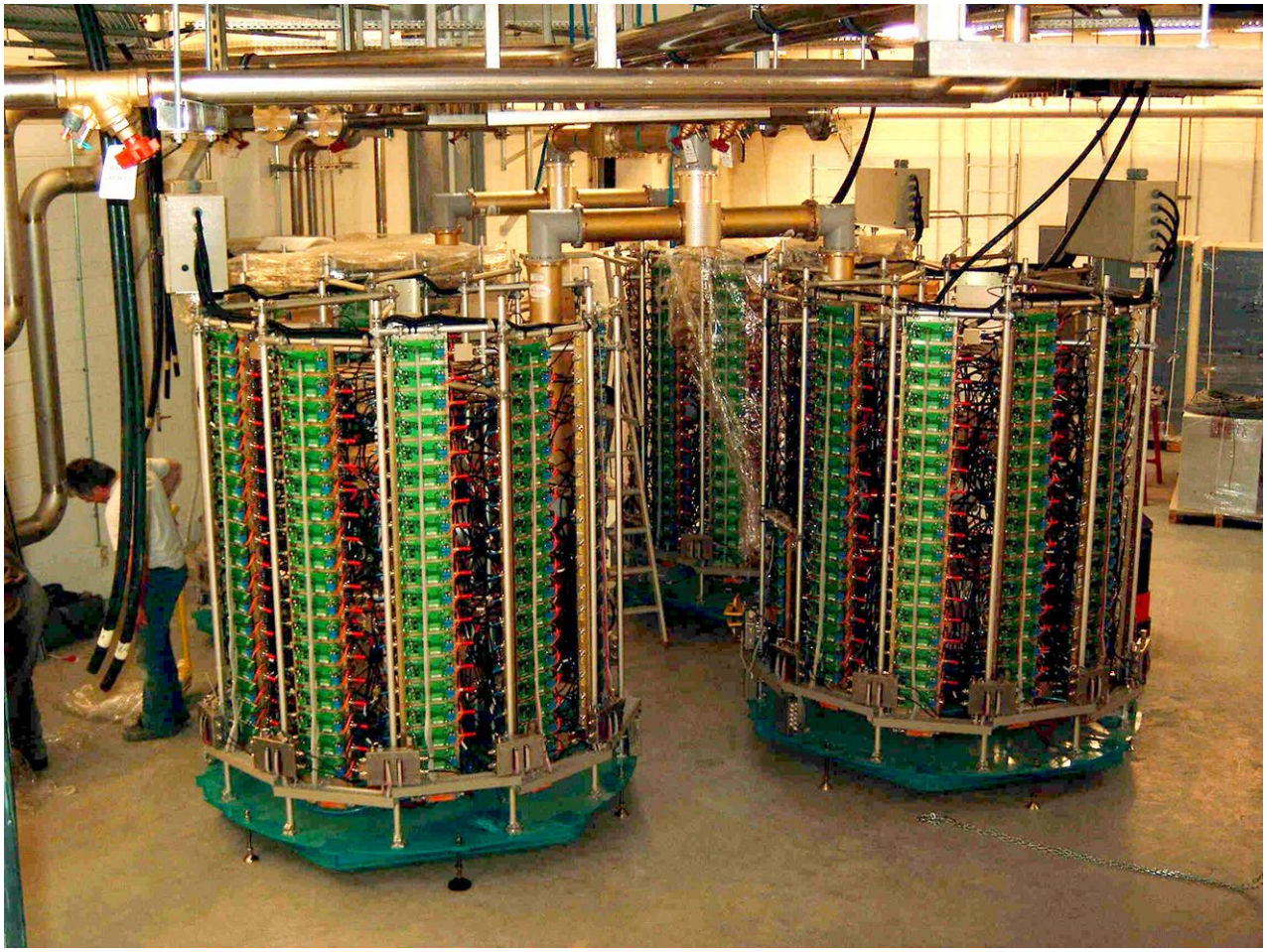
160-Way Power Combiners

10-Way and 8-Way Power Splitters

352 MHz 50 kW Amplifier



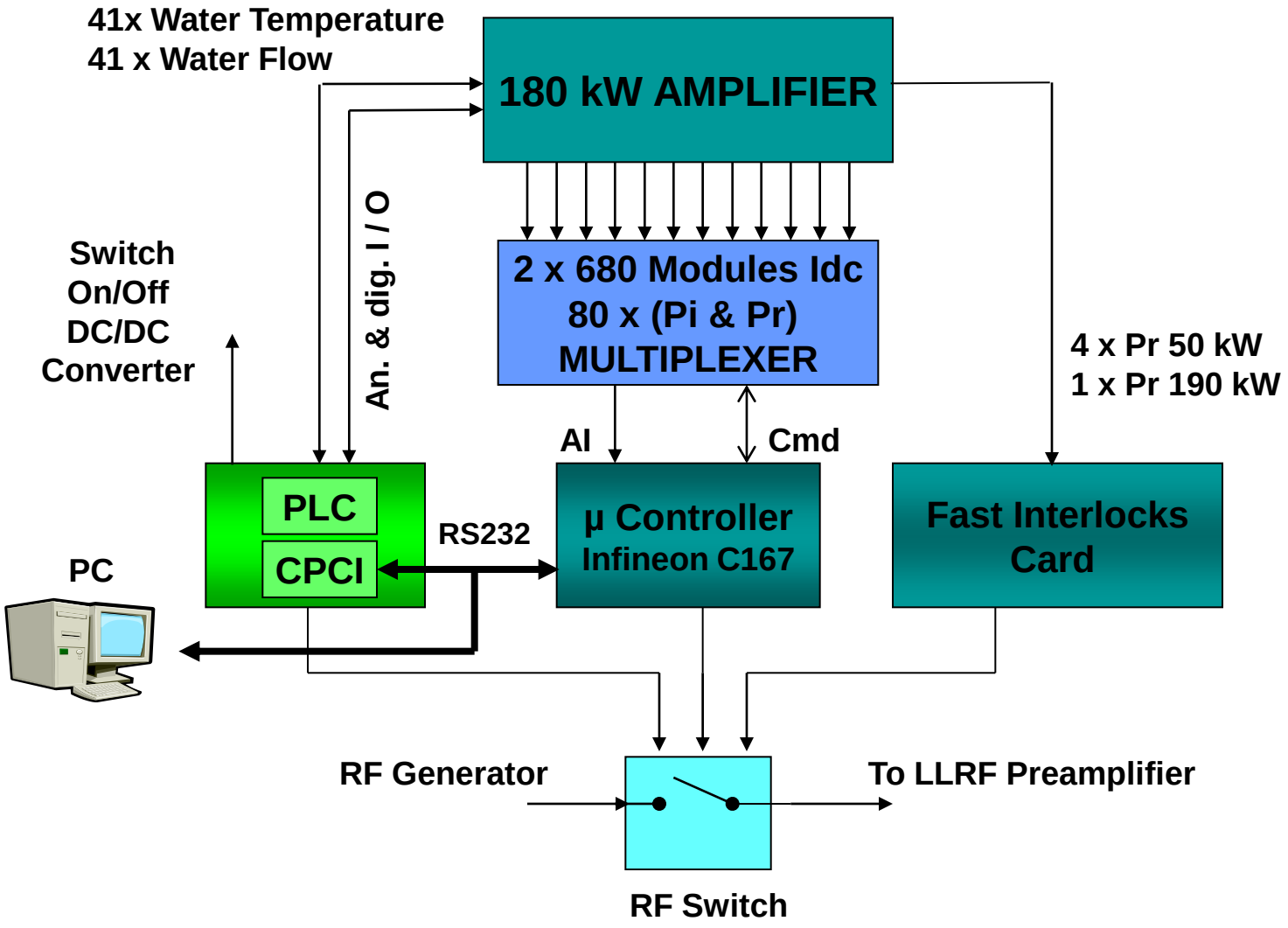
352 MHz 180 kW Amplifier under Installation



4 X 726 LDMOS modules including 43 standby modules

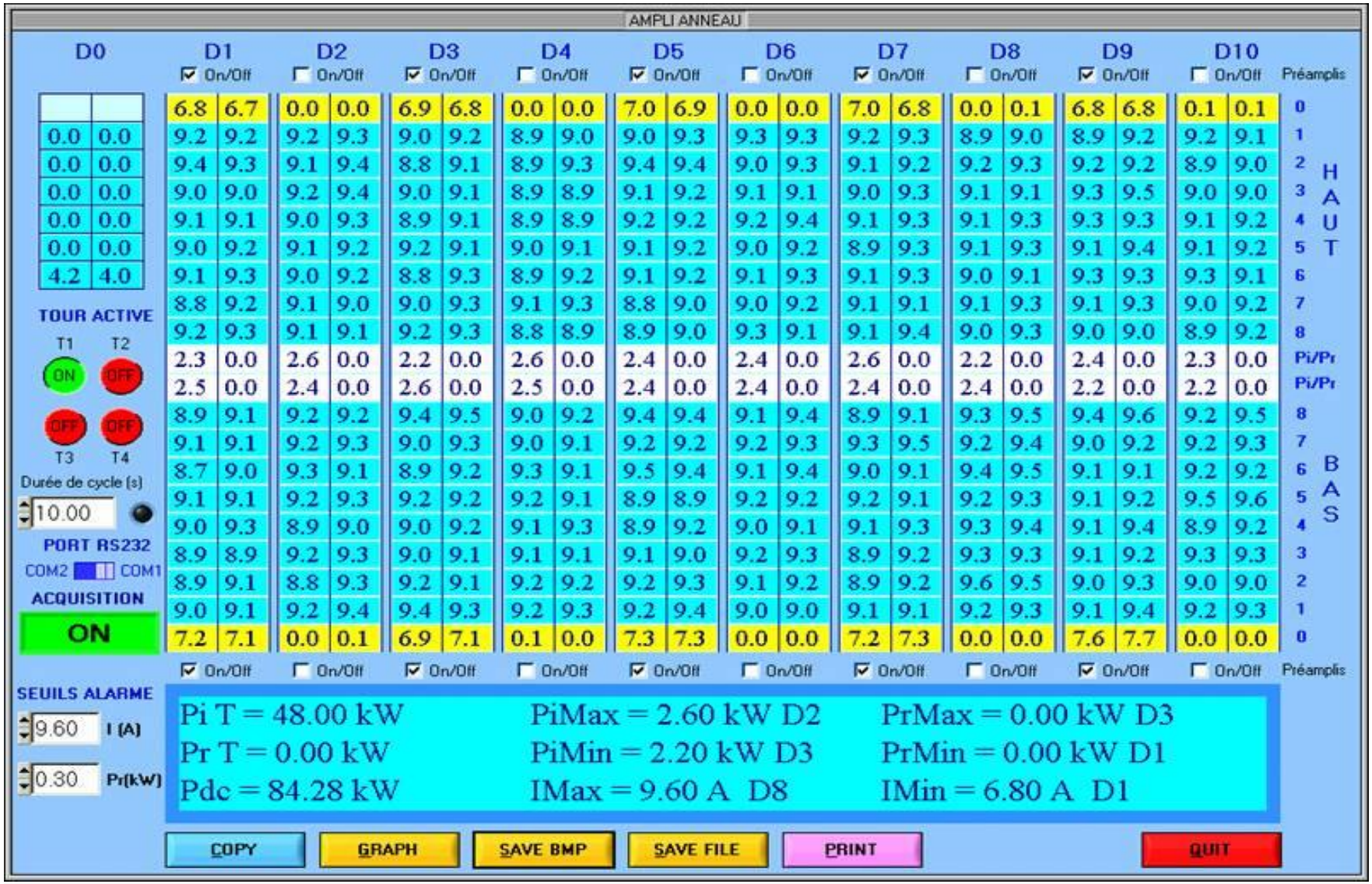
Supervision and Protection

(5808 Idc + 320 Pi + 320 Pr)

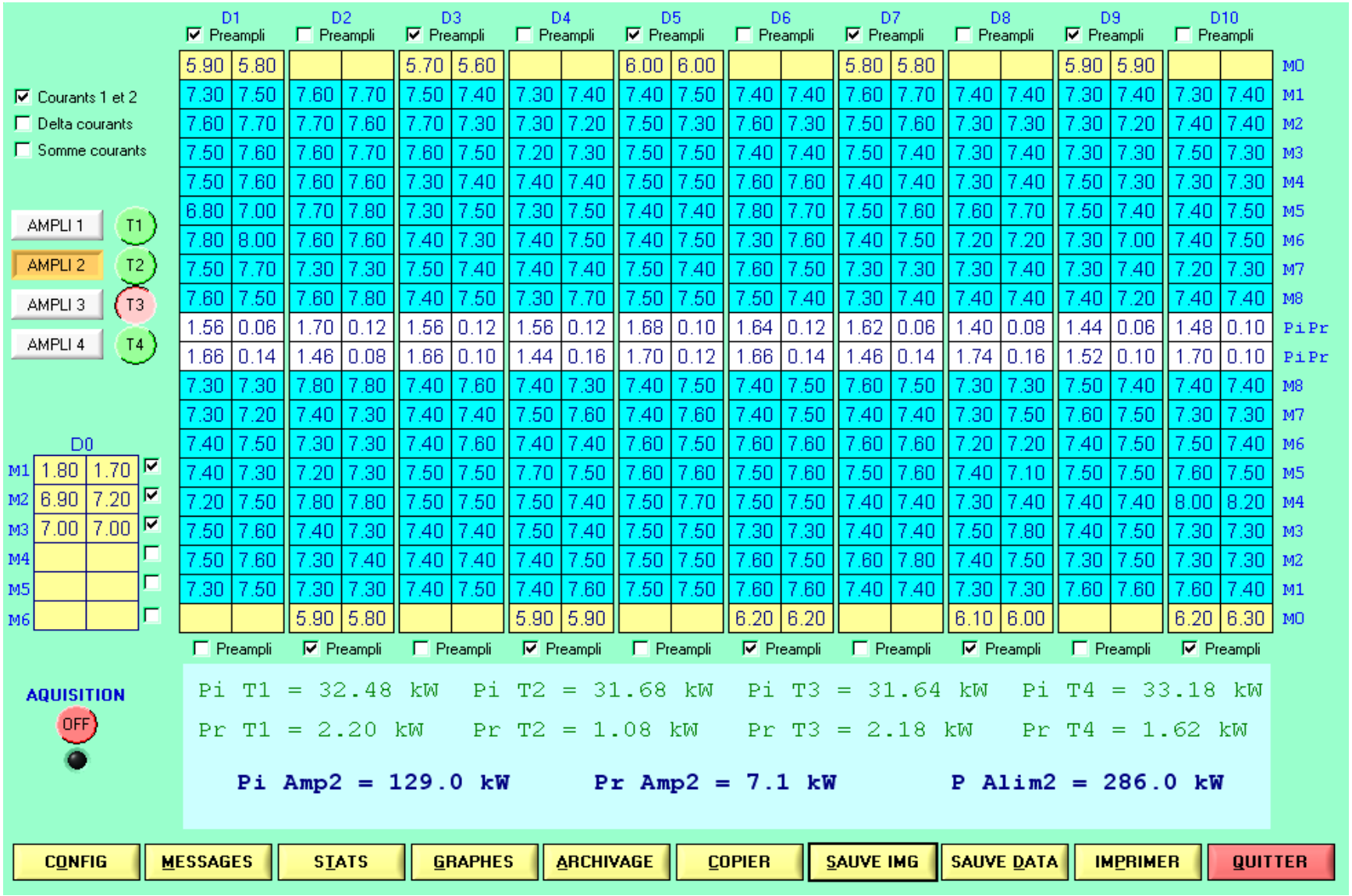


2 Sets of 180 kW Amplifier

Power and Current of 50 kW Amplifier



Power and Current at 500 mA



Amplifier Performance

- Nominal Power: 180 kW
- Efficiency: ~ 50% including losses of circulators and DC /DC converters (54% without DC/DC converters)
- Gain: 53 dB
- Linearity: $\Delta G = 2$ dB; $\Delta \Phi = 10°$
- Phase Noise (rms) < 0.04°(< 8 kHz);
  < 0.06° (< 1 GHz)
- Harmonics: - 50 dBc
- Parasitic Modulation: - 60 dBc (> 200 kHz random phase)

Average Failure Rate

RF Power Modules

	Amplifier 1 ** & 2 (CM1)			A 3 & 4 (CM2)
	2006 - 2007	2008	2009	2008 - 2009
Operation hrs	~ 6 000	~ 6 000	~ 6 000	~ 8 000
Transistor *	4%	3%	0.9%	1.3%
Soldering *	<1%	2.2	3.5%	<1%

* A few modules failed due to filter, capacitors problem etc.
** The failure rate of Amplifier 1 is much higher than others

Other components

DC/DC	2 / ~ 3000
2.5 kW Power Combiner	4 / 320
Multiplexer	1 / 180

Module Failure Rate

- Transistor failure rate ~ 1.5 % per year

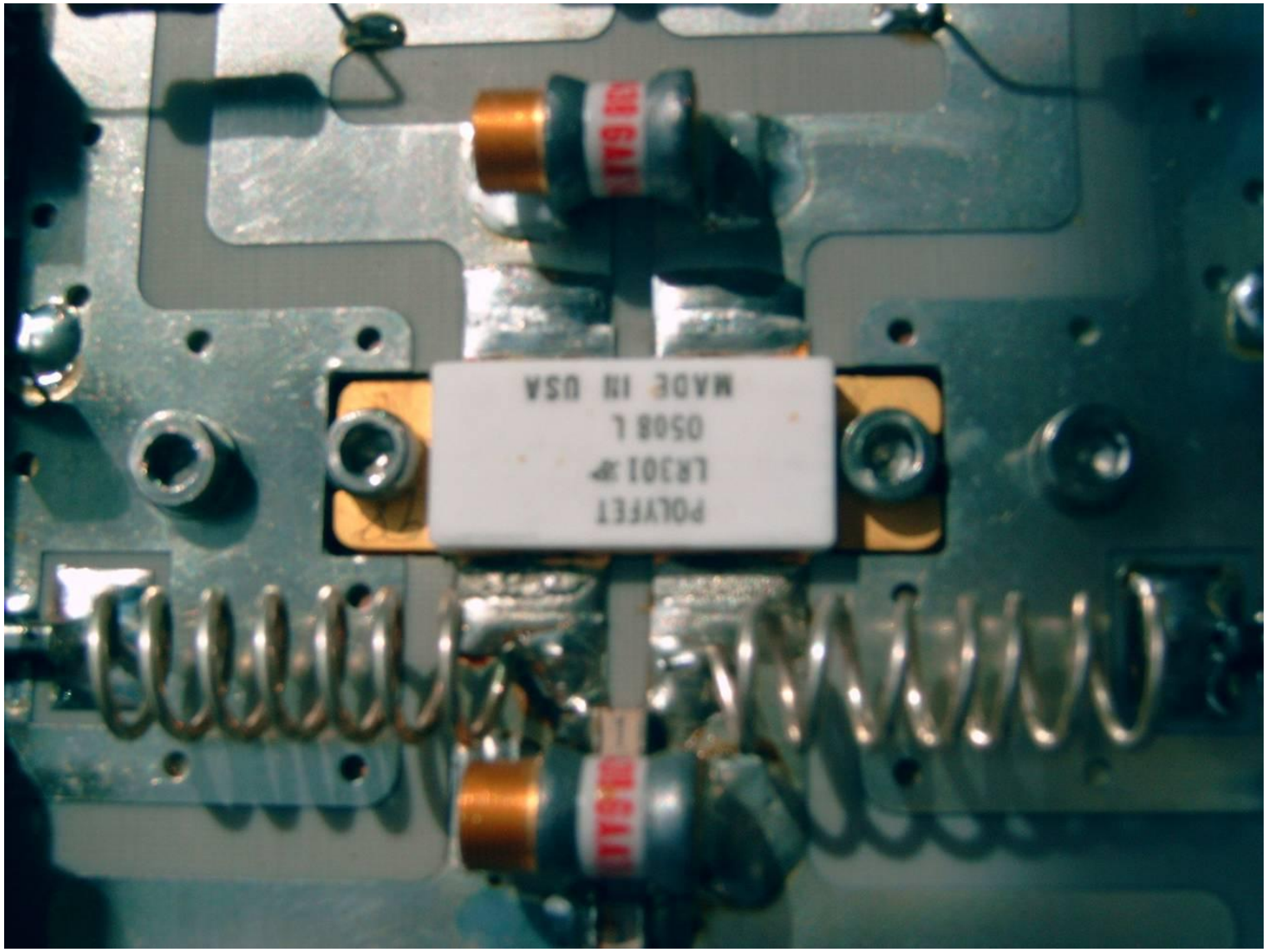
→Replacement of ~ 50 transistors per year (maintenance cost: ~ 5000 Euros)

- Soldering failure rate ~ 1.5 % per year due to thermal fatigue and soldering fault.

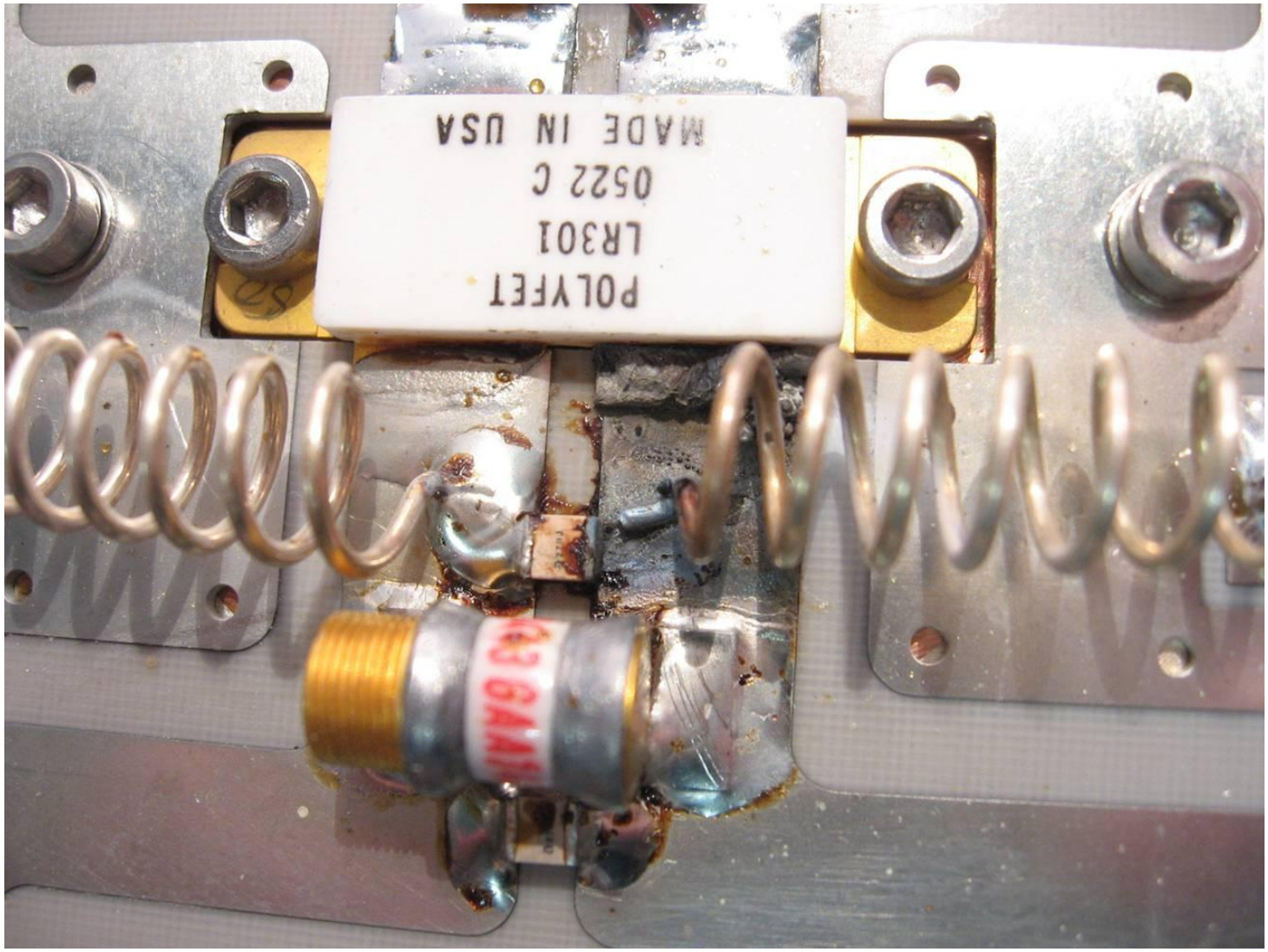
→ Re-solder and Take Super High Q Capacitors nearby Drains to repair them.

Thermal Fatigue

(After working for 20000 hrs)



Thermal Fatigue Failure



After 4 years of running, the operational experience proved to be fully satisfactory. Almost no down-time during operation.

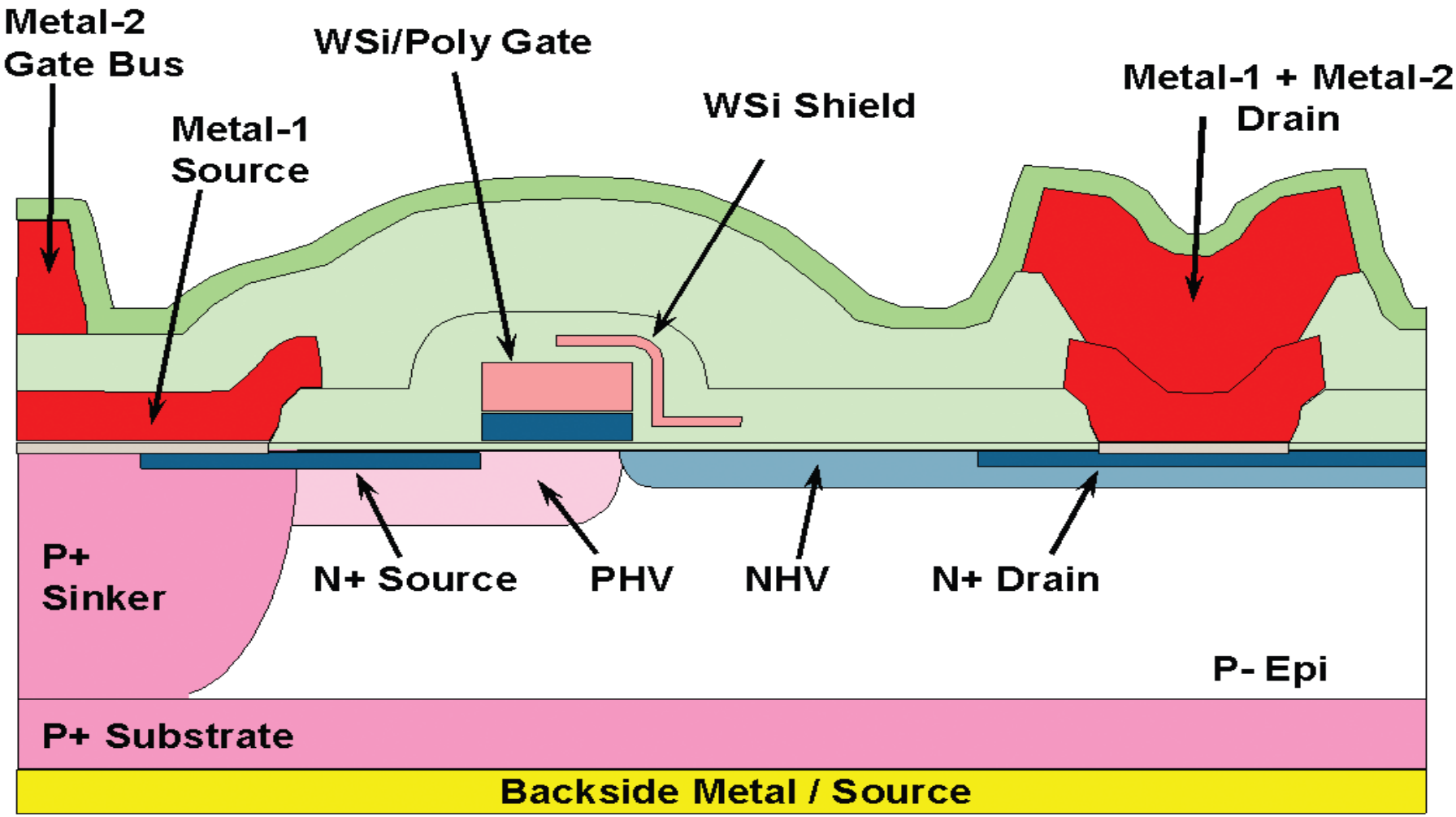
But we have continued developping a new generation solid state RF amplifier

Fortunately the 6th Generation LDMOS has come out

6th Generation RF LDMOS (Laterally Diffused MOS)

- High Gain with High Stability due to Shield between Gate and Drain
- 50 V DC Voltage: High Power with High Efficiency
- Excellent Linearity
- Excellent Ruggedness
- Integrated ESD Protection
- Broadband Operation up to 500 MHz

6th Generation RF LDMOS (Laterally Diffused MOS)



6th Generation RF LDMOS (Laterally Diffused MOS)

The Gain and Stability of a MOSFET depends on capacitance Crss between Gate and Drain

LDMOS has lower Crss than VDMOS

The 6th Generation LDMOS has only about 20 - 30% of Crss than normal LDMOS

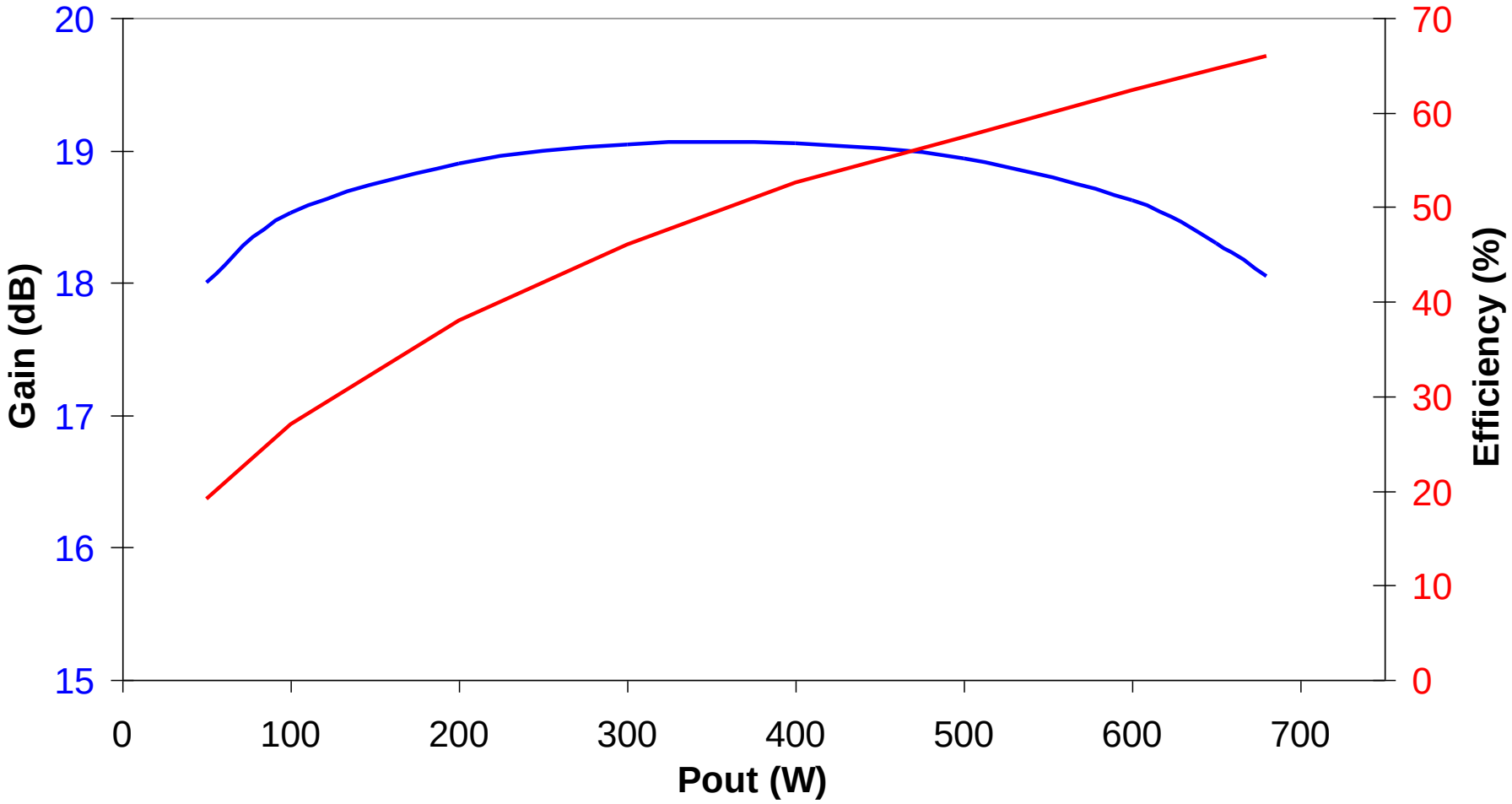
New Generation Modules developed in SOLEIL

Frequency	Output Power	Gain (1 dB)	Efficiency
MHz	W	dB	%
476*	350	19.8	69
500	700	17.9	67
352**	700	20.5	73
88	1000	26.1***	87***

* For LNLS 50 kW Amplifiers
** For ESRF 150 kW Amplifiers
*** Without Circulator and at 2 dB Gain compression

- Higher frequency: Lower Power, Efficiency and Gain
- 1.3 GHz module is being developed

Gain & Efficiency vs Power for 500 MHz Module



Advantages of New Module with 6th Generation LDMOS

- Tolerance: Gain +/- 0.1 dB, Phase +/- 2°
- Anti-Thermal Fatigue (Special PCB Laminate, Super High Q Capacitors etc. Temperature ~ 80°C)
- High Reliability, LDMOS MTBF > 2000 yrs
- Excellent Ruggedness
- High Efficiency
- Good Linearity with Low Phase Noise
- Compact (Double density of RF Power)

Collaboration LNLS-SOLEIL

- June 2008, collaboration agreement LNLS - SOLEIL to realize two sets of SSA in replacement of the two 476 MHz - 40 kW klystron amplifiers in the SR
- Beg. 2010, 2 sets of SSA fully assembled
- April 2010, successful tests of the first SSA on dummy load:

  - 50 kW CW @ 0.4 dB compression
  - Overall efficiency ~ 60%
  - Gain 40 dB (2 stages)

Collaboration LNLS-SOLEIL

April 23rd, 2010 at LNLS : SOLEIL – LNLS team

Collaborations:
- LNLS: 2 amplifiers of 45 kW at 476 MHz based on 350 W modules
- SESAME: 4 amplifiers of 150 kW at 500 MHz based on 700 W modules

Transfert of technology to ELTA-AREVA:
- ESRF contract for 7 amplifiers of 150 kW at 352MHz
- High Power Amplifiers at 500 MHz under industrialization

Thanks for your Attention