

500 MHZ Solid State Amplifier Design Results of the 4KW Prototype



M. Gaspar, M. Pedrozzi

4KW Validation Prototype - Components Produced and Tested

PC Master Controller: 2 Available and Already Tested (PSI Design)

Power Supply Controller: 25 Boards Available (Programmed and Tested) (PSI Design)

Power Splitter: 2 8-Way Prototypes Working (PSI Design)

New 18-way Design in Progress (PSI Design)

250W Amplifier Module: 22 Modules Available (Assembled and Tested) (PSI Design)

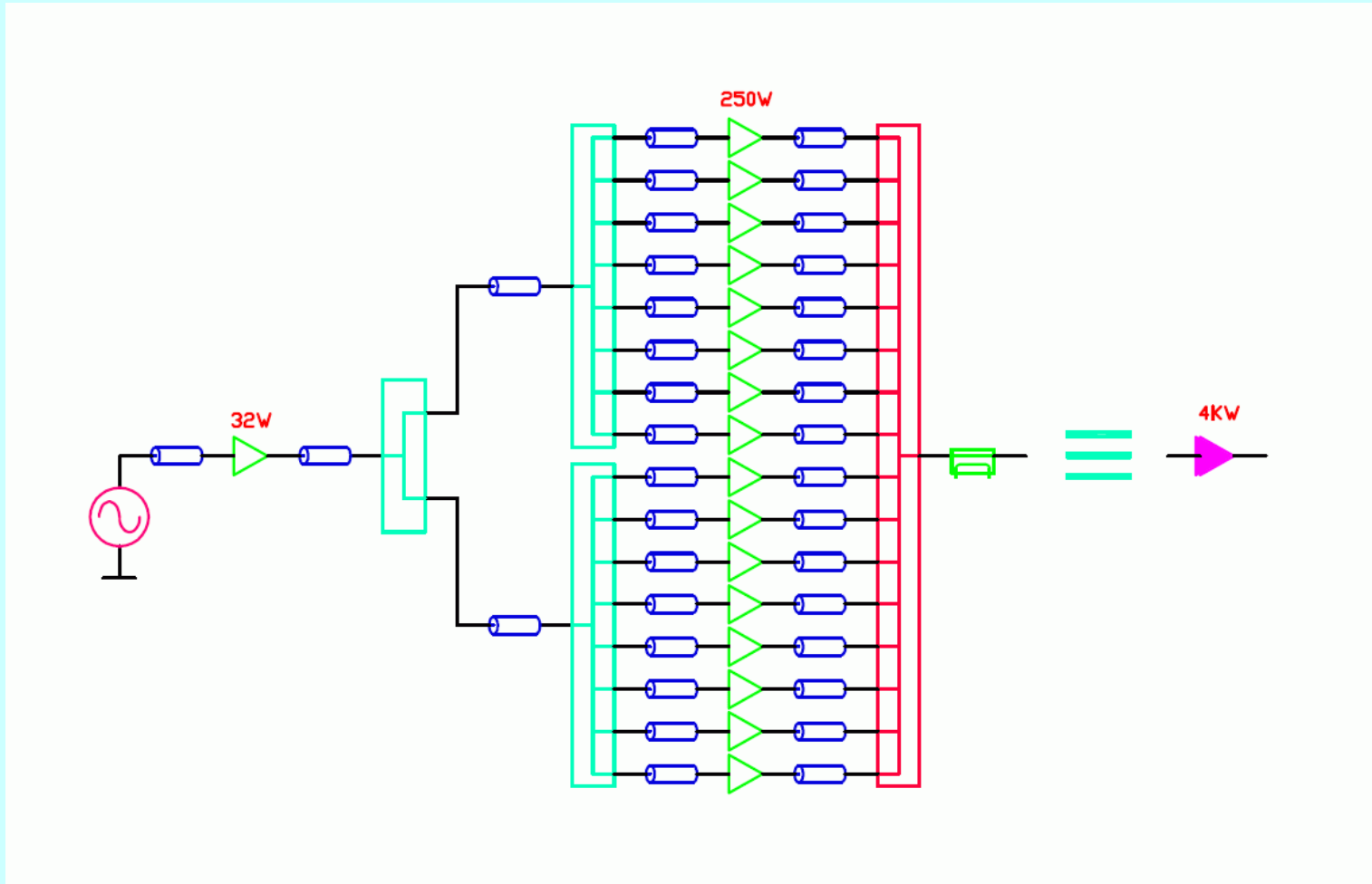
High Power Coupler: 1 Piece Available and Calibrated. Tested OK @ Pout=4KW (Industry)

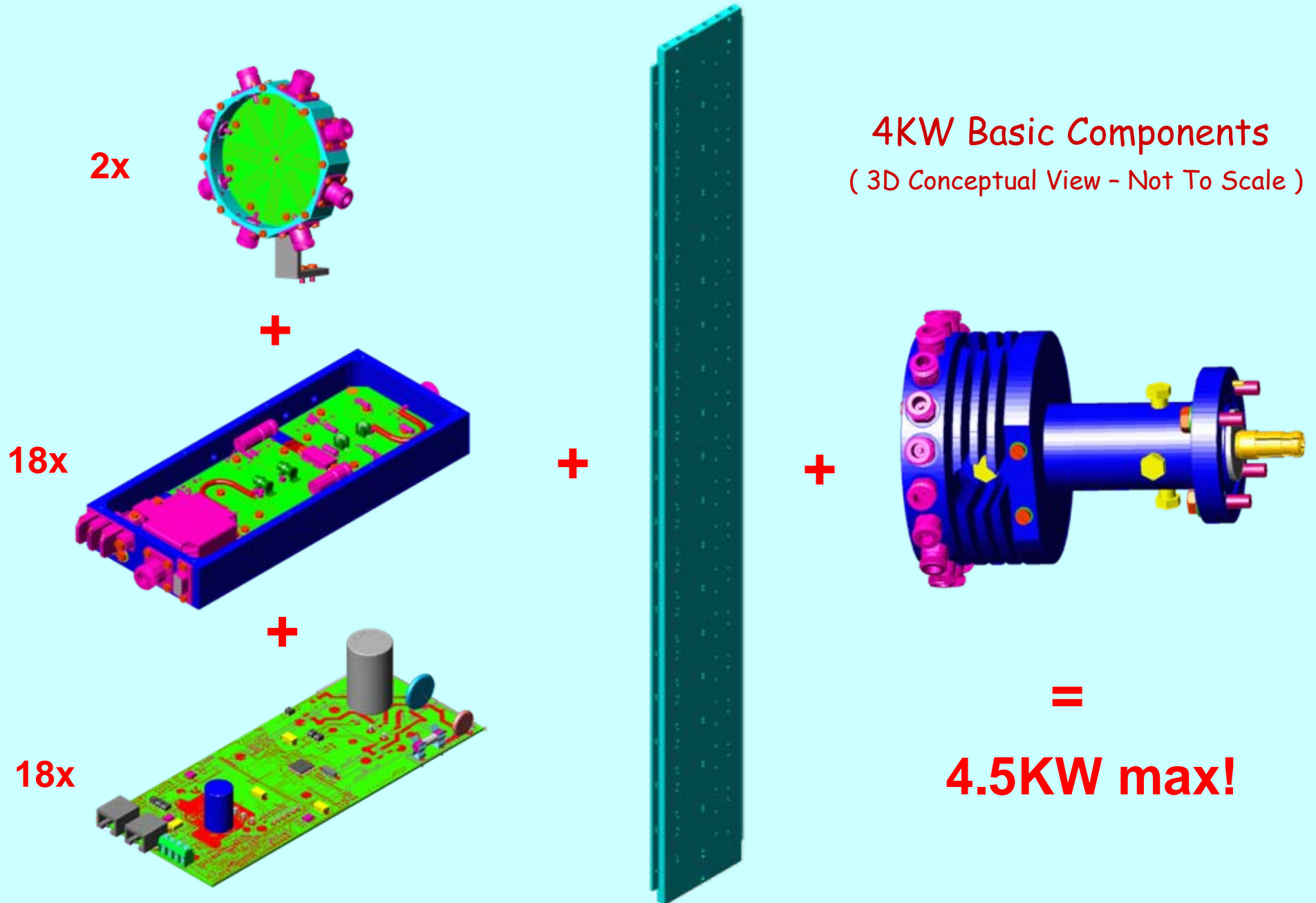
New Design in Progress (PSI Design)

Output Power Combiner: 2 18-Way Combiners Ready (Finished and Tested) (PSI Design)

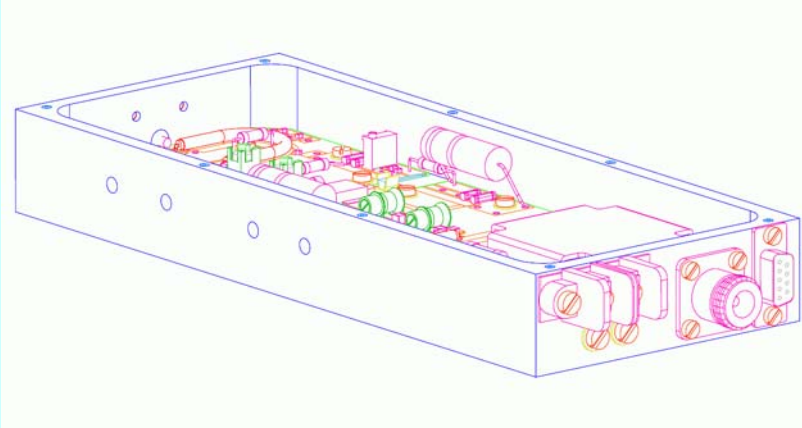
Also Successfully Tested under Maximum Output Power

4KW Amplifier Configuration

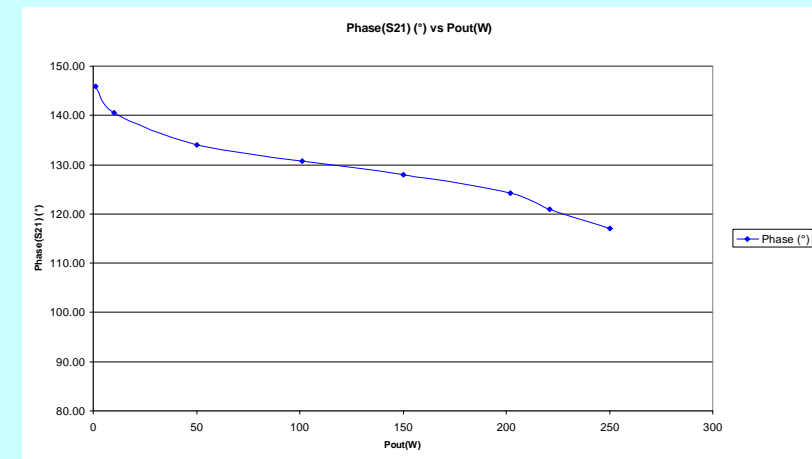
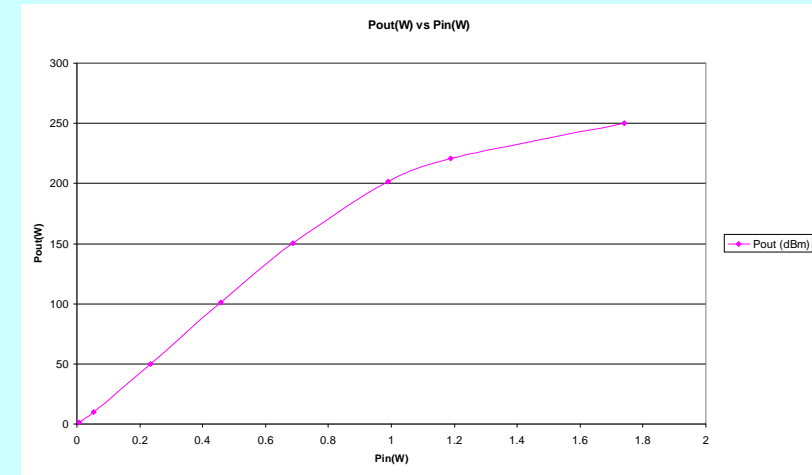




250W Amplifier Module



3D-View of 500MHz Amplifier Module

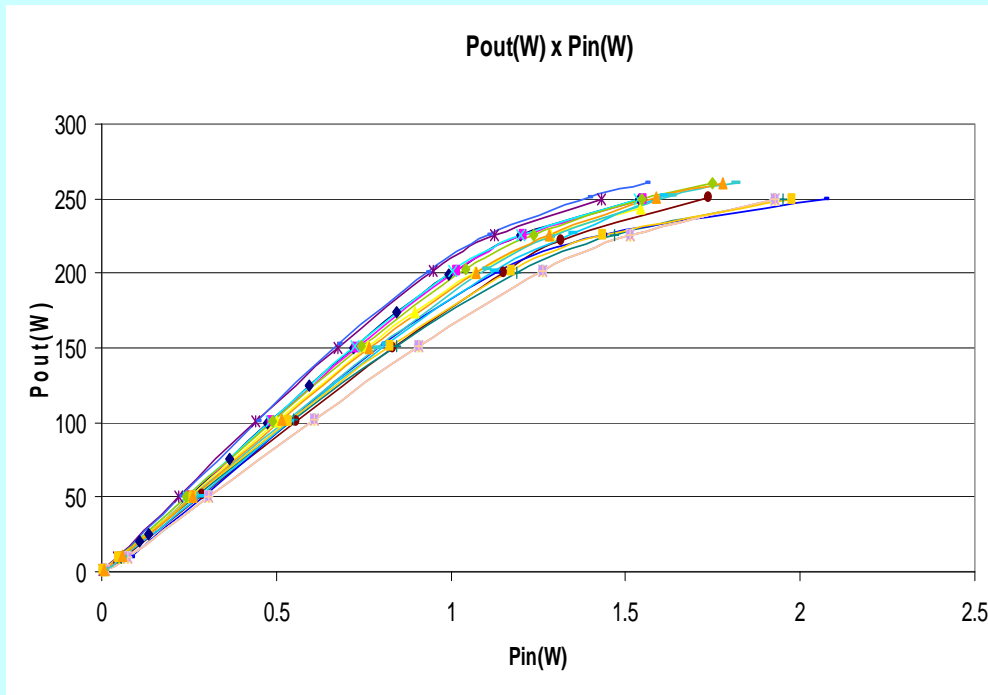


Key Performance Parameters

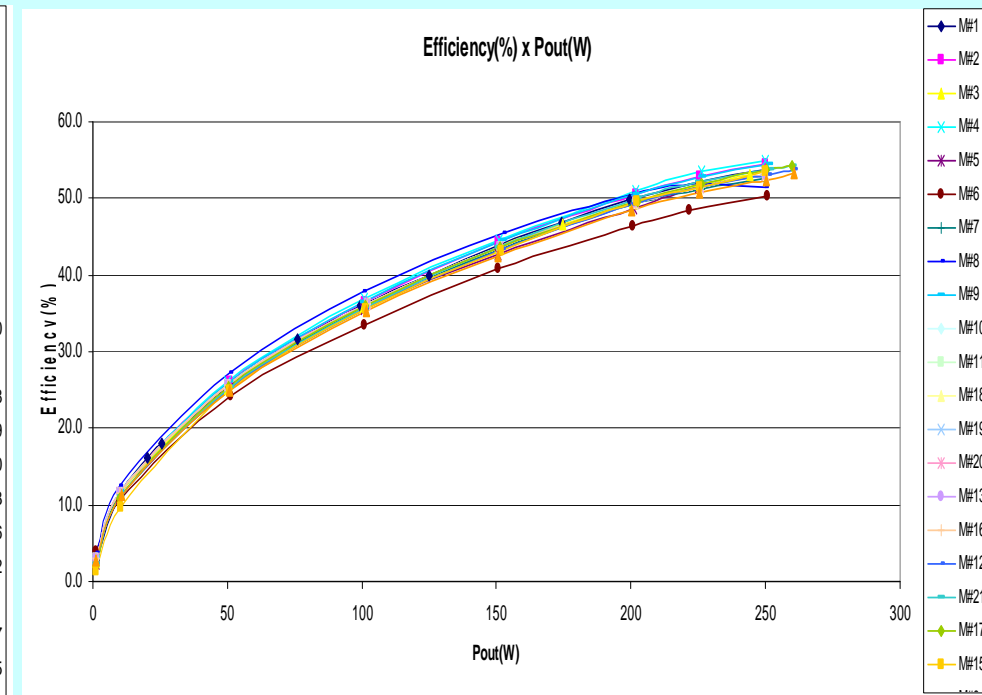
	Operation	Max
Output Power (with Circulator)	250W	280W
Gain	22dB	20dB
Efficiency	~ 54%	~ 50%

250W Amplifier Module

Performance of all available RF Modules



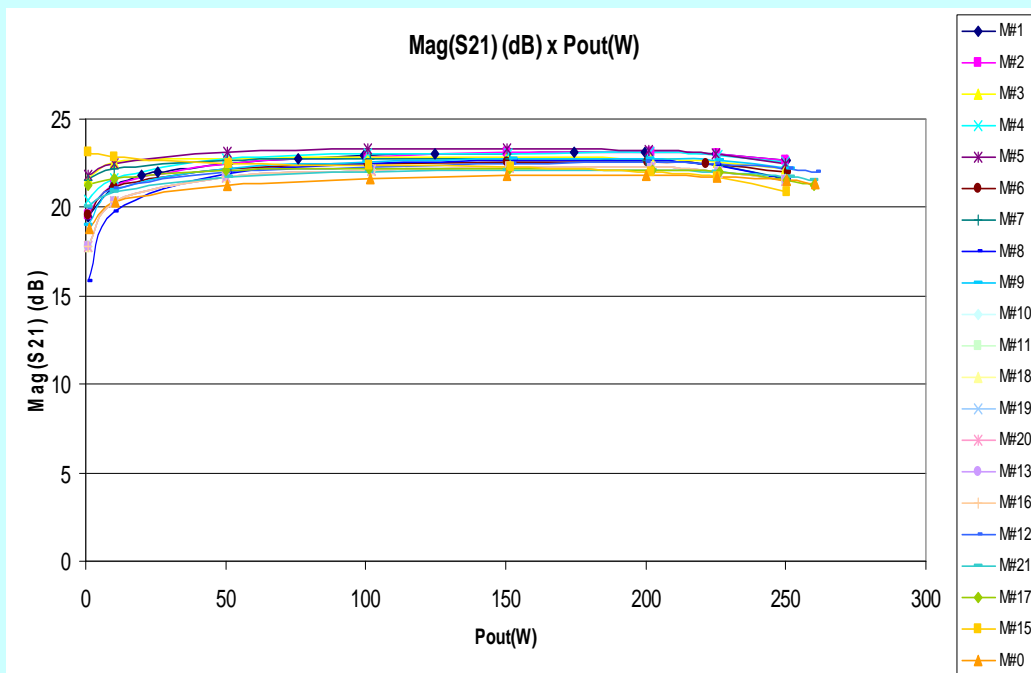
Output Power versus Input Power



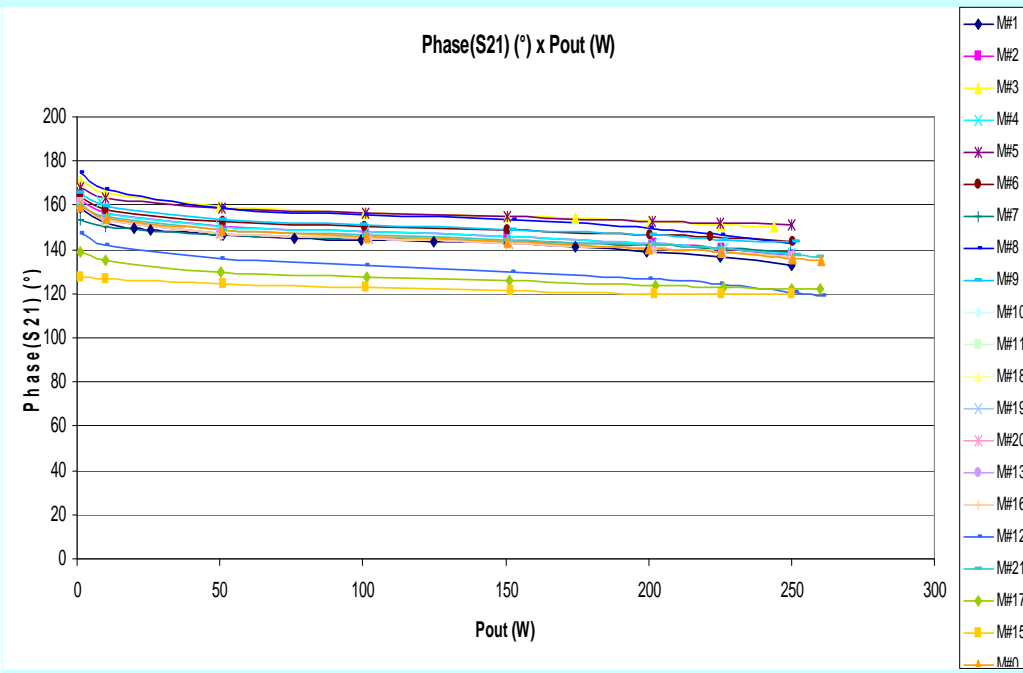
Efficiency versus Output Power

250W Amplifier Module

Performance of all available RF Modules



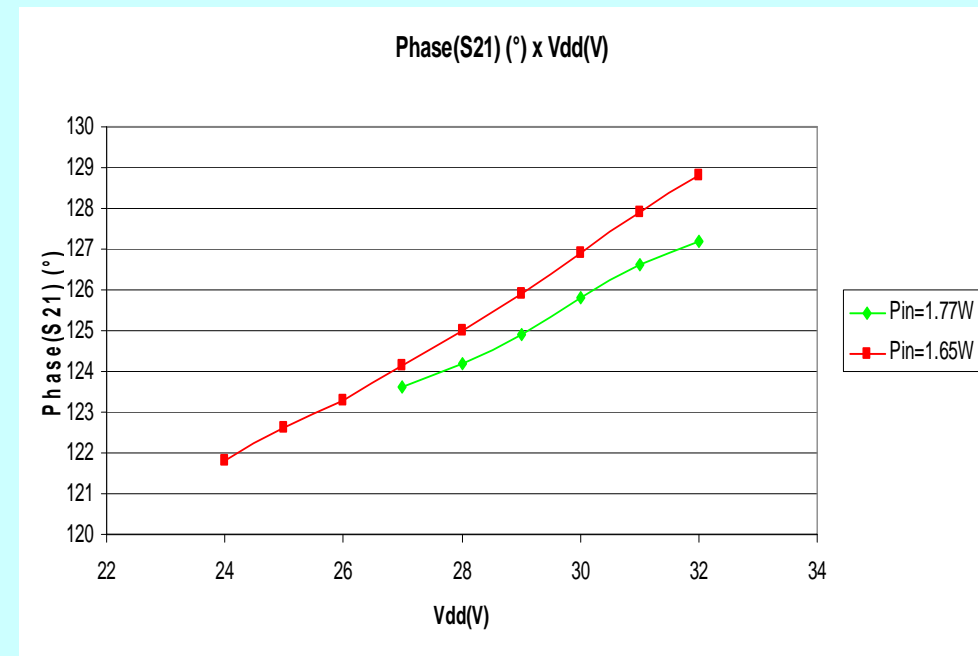
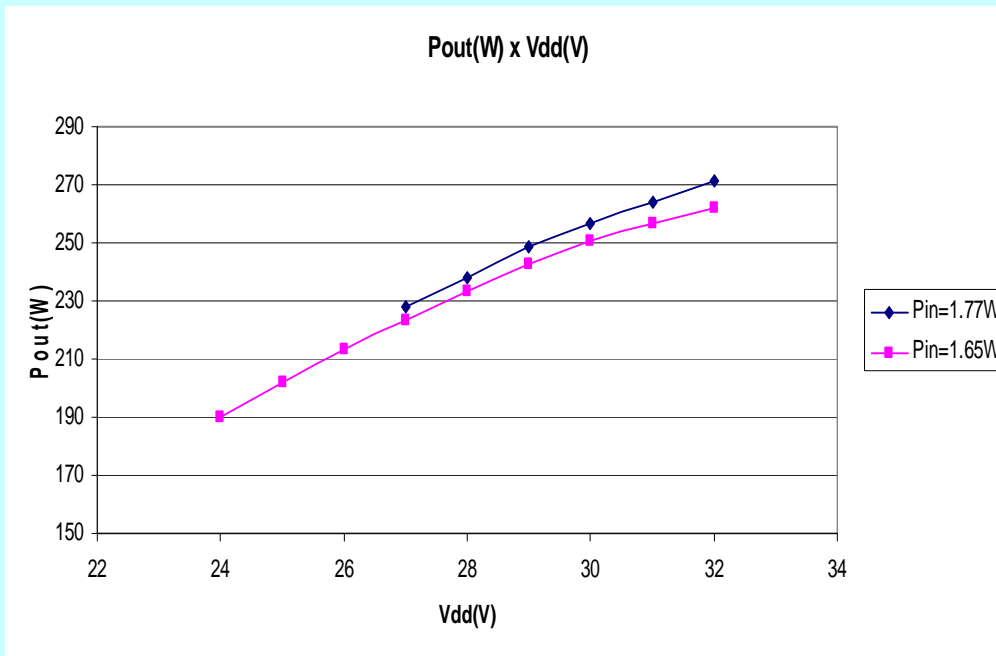
Gain versus Output Power



Phase Delay versus Output Power

250W Amplifier Module

Forced Compression as a Useful Method

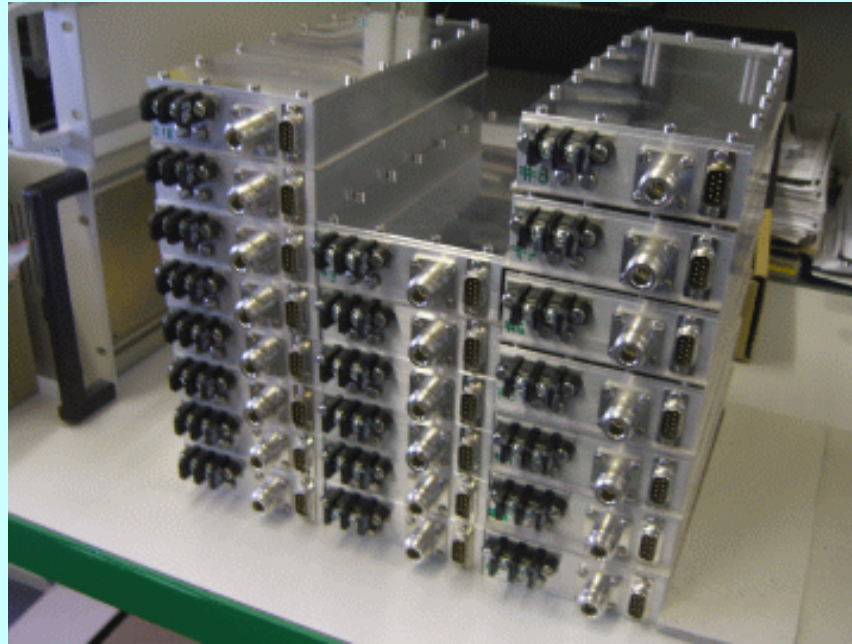


Output Power Variation due to Forced Compression

Phase Delay Variation due to Forced Compression

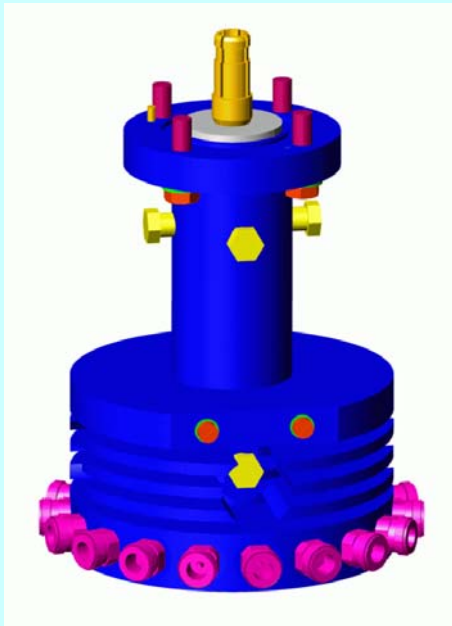
1. Since our Power Supply Controllers allow the Power Supply Voltage (Vdd) to be changed remotely we use Forced Compression to equalize the output powers of all amplifiers and then maximize the Combining Efficiency.
2. Notice that the Phase Delay is not very much influenced by variations in Power Supply Voltage. So Forced Compression is a viable method.

250W Amplifier Module

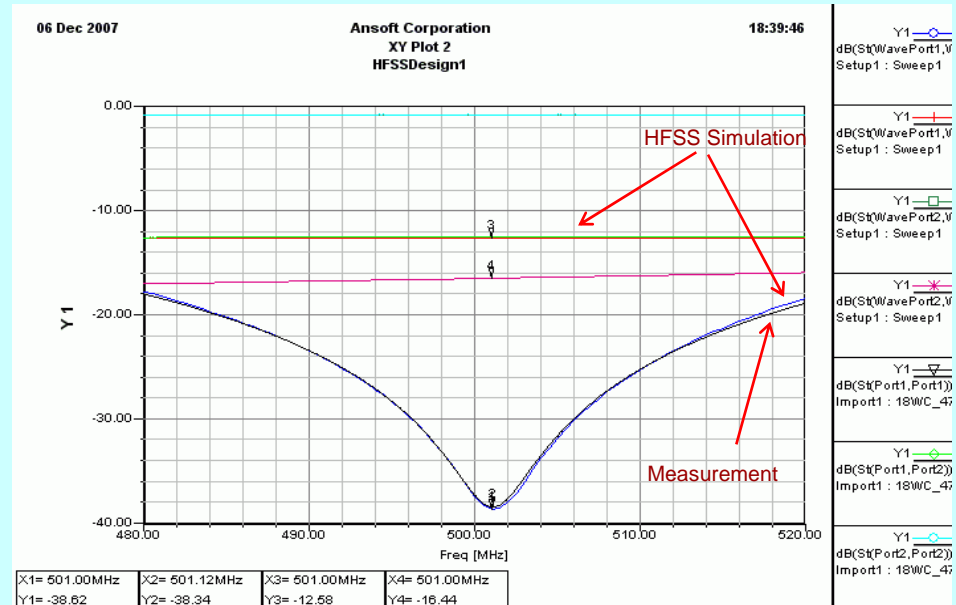


- Total 22 Modules Produced Now (18 for Amplifier, 4 Spares).
- All Modules Fully Assembled and Tested.
- Performance Agrees With Previous Results from Prototype.
- Remote Monitoring Working all right.

18 Way Combiner - 500MHz



PSI development



Key Performance Parameters

BW > 10MHz ($S_{11} < -30\text{dB}$)

Precision Required for 18 Ways Realized with no Extra Costs

Efficiency > 99.6% (Overall Loss < 20W @ $P_{\text{out}}=4.5\text{KW}$)

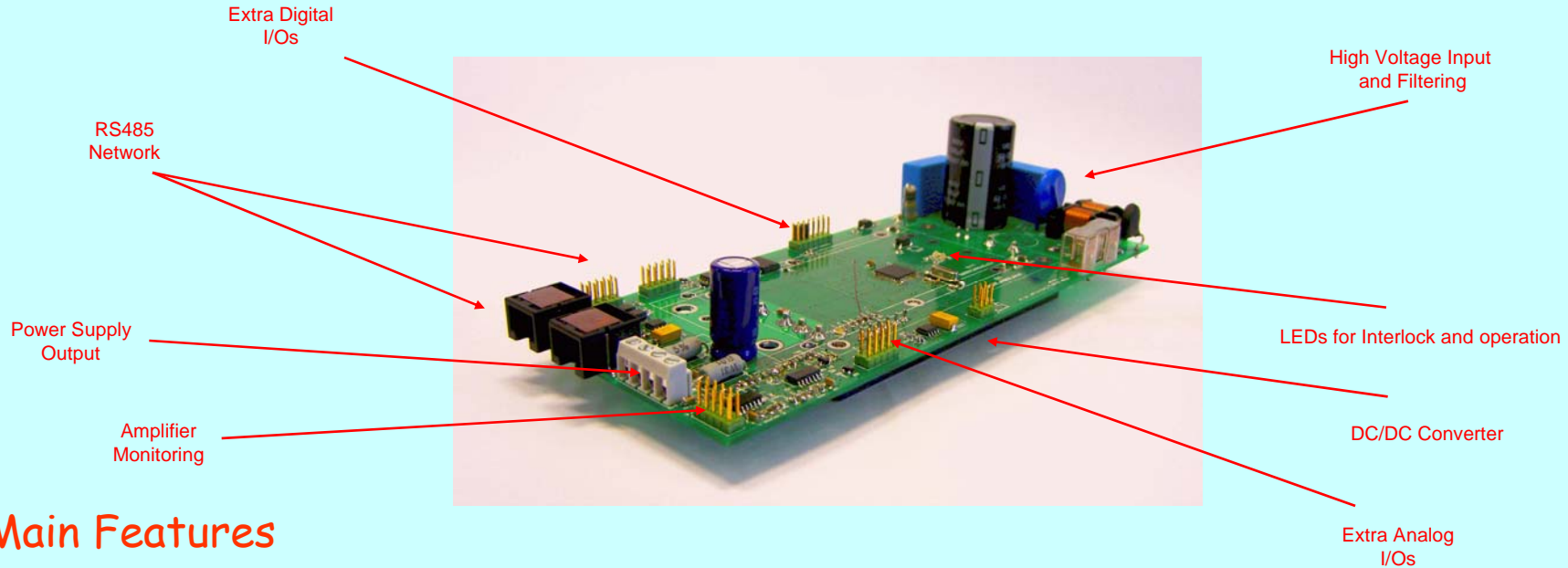
High Power Temperature Measurement Results

Inner Conductor Temperature @ $P_{\text{out}}=4\text{KW}$ = 65°C (estimated)

Outer Conductor Temperature @ $P_{\text{out}}=4\text{KW}$ = 43°C

Power Supply Controller

(and Complete Monitoring System)



Main Features

Output Power: 600W

Output Voltage Range: 16.7V to 33.5V

Input Voltage Range: 200V to 400V

Efficiency: ~ 90%

Can be Remotely Programmed and Monitored

Extra Analog and Digital I/Os

Multi-tasking Script Operating System (SOS)

Interlock Reaction Time: ~ 1 μ S

Full Monitoring Loop Time: ~ 150mS

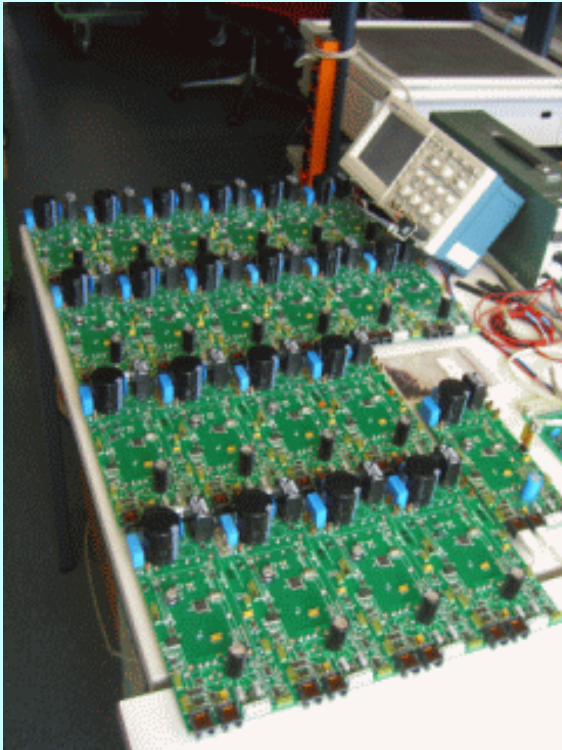


Design Finished

25 Pieces Available Now

19 Pieces – No Failures in Long Duration Tests

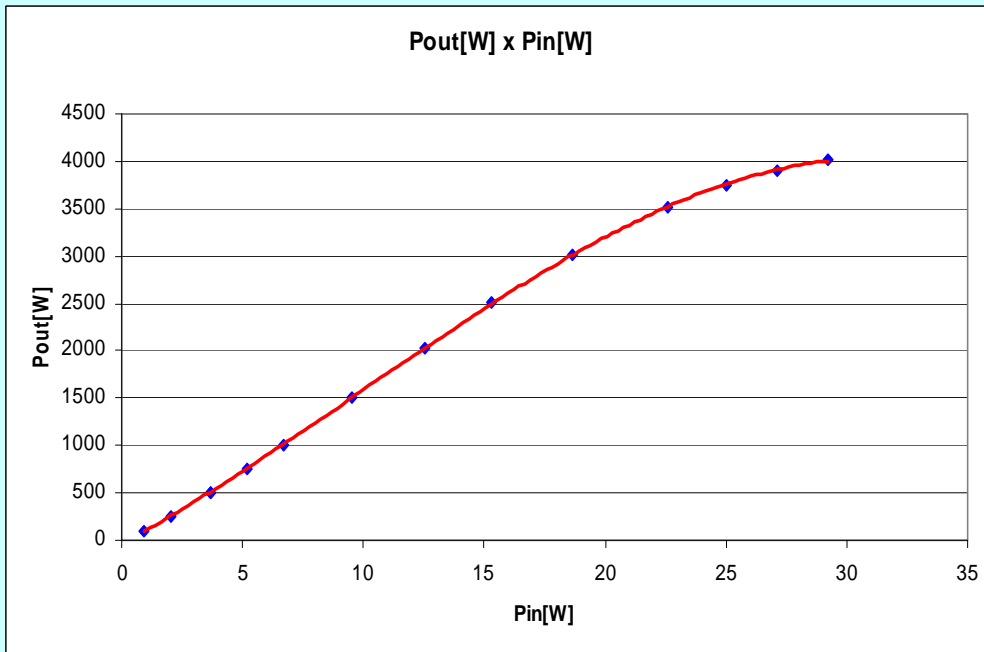
Power Supply Controller



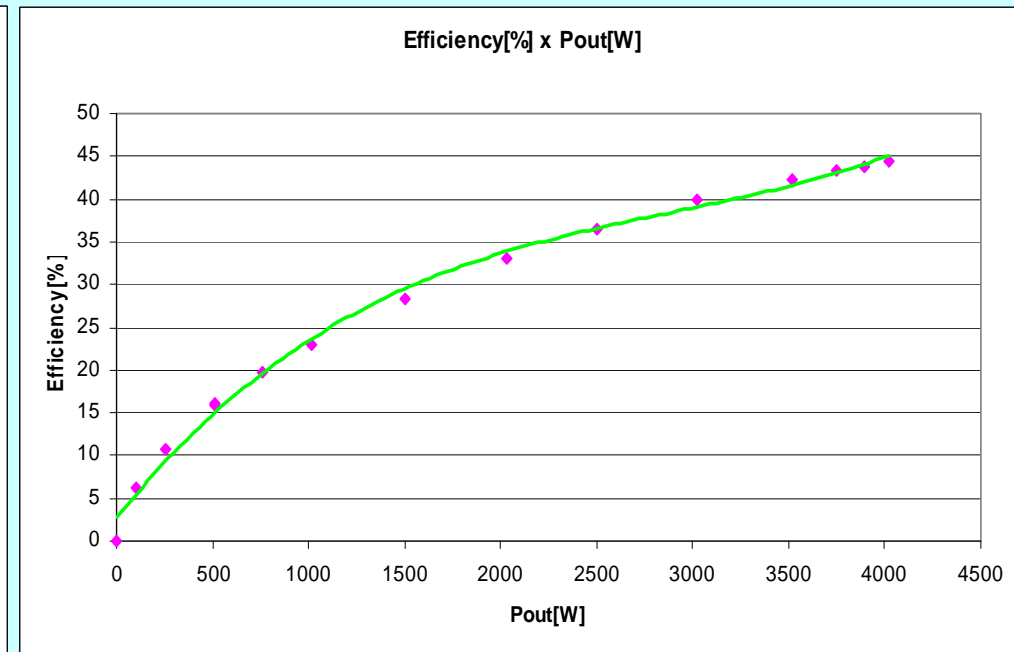
- Total 25 Boards Produced (18 for Amplifier, 7 Spares).
- Operating System Installed.
- All Tests Completed (Power and Monitoring).
- 19 Boards Passed Initial Long Duration Tests without Failures.

4KW Solid-State Power Amplifier

Measurement Results



Output Power versus Input Power



Overall Efficiency versus Output Power

SOSDAQ

Linux Data Acquisition and Monitoring Software Results @ Pout=4KW

System Overview

Level 2 Target 2 Status Running Interlock 0

Time	Module	Idd1	Idd2	Temp	D0in	Porfl	Pifwd	Pofwd	Ilock	Vaoutl	Extirq	Vainl	Imask	Istep	Iplus	Pwron	Iog	Vref	Rcon	Itime	Vdd	Vddset
20080911180226076	2	7.4	7.4	27.0	900.0	2.2	1.8	237.1	0	0.0	0	113.1	0	21030	0	1	0	152.0	148	139	27.6	27.8
20080911180226136	4	6.8	7.5	26.6	902.0	4.6	2.2	241.2	0	0.0	0	112.8	0	21028	0	1	0	152.0	148	150	27.4	27.8
20080911180226256	5	7.4	7.6	27.2	895.0	4.2	1.7	243.8	0	0.0	0	113.9	0	21268	0	1	0	153.0	148	155	28.4	28.9
20080911180226380	6	7.2	8.0	31.1	898.0	4.3	1.4	222.3	0	0.0	0	114.0	0	21262	0	1	0	152.0	148	155	30.9	31.1
20080911180226500	8	8.0	7.6	25.3	892.0	4.7	2.2	227.6	0	0.0	0	113.6	0	21272	0	1	0	153.0	148	156	30.0	30.3
20080911180226620	9	7.4	7.3	30.6	903.0	4.3	1.8	238.6	0	0.0	0	113.7	0	21266	0	1	0	152.0	148	155	29.8	30.3
20080911180226740	10	7.0	7.6	29.9	900.0	4.3	1.5	216.4	0	0.0	0	113.7	0	21270	0	1	0	150.0	148	148	31.2	31.1
20080911180226860	12	7.4	7.4	27.6	900.0	2.2	2.3	212.8	0	0.0	0	113.9	0	21266	0	1	0	153.0	148	149	29.5	29.4
20080911180226980	13	7.4	7.4	29.2	899.0	4.9	2.1	241.4	0	0.0	0	112.3	0	21036	0	1	0	152.0	148	157	27.2	27.8
20080911180227100	14	7.6	7.4	31.7	894.0	4.6	1.9	233.1	0	0.0	0	129.3	0	21025	0	1	0	153.0	148	155	26.5	26.9
20080911180227224	15	7.7	7.5	24.7	898.0	3.5	1.5	225.6	0	0.0	0	112.8	0	21422	0	1	0	153.0	148	148	29.9	30.3
20080911180227344	17	7.5	7.7	31.7	896.0	3.1	1.8	228.0	0	0.0	0	113.3	0	21274	0	1	0	153.0	148	148	30.8	31.1
20080911180227464	18	7.7	7.4	30.5	897.0	4.5	1.7	222.3	0	0.0	0	113.1	0	21281	0	1	0	151.0	148	149	29.9	30.3
20080911180227592	19	7.3	7.0	24.9	894.0	3.1	1.9	228.9	0	0.0	0	113.3	0	21034	0	1	0	153.0	148	151	24.9	25.2
20080911180227712	20	7.4	7.8	34.2	900.0	3.9	1.6	227.6	0	0.0	0	113.7	0	21273	0	1	0	153.0	148	149	30.7	31.1
20080911180227840	21	7.4	6.9	26.4	893.0	3.8	1.8	245.2	0	0.0	0	113.1	0	21521	0	1	0	155.0	148	147	27.2	27.8
20080911180227952	24	7.6	7.6	26.0	898.0	0.2	2.0	243.2	0	0.0	0	113.2	0	21351	0	1	0	152.0	148	146	29.7	30.3
20080911180228064	25	7.6	7.3	26.1	891.0	4.8	2.2	240.8	0	0.0	0	112.3	0	21361	0	1	0	151.0	148	147	26.7	26.9
20080911180228180	22	0.0	0.1	-25.3	900.0	-0.1	0.1	1.5	0	0.0	0	113.6	0	-31687	0	1	1	141.0	148	157	0.0	2
20080911180228288	2002	ctrl	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Transferring data from pc7095.psi.ch...

Main Features

Client-Server Design

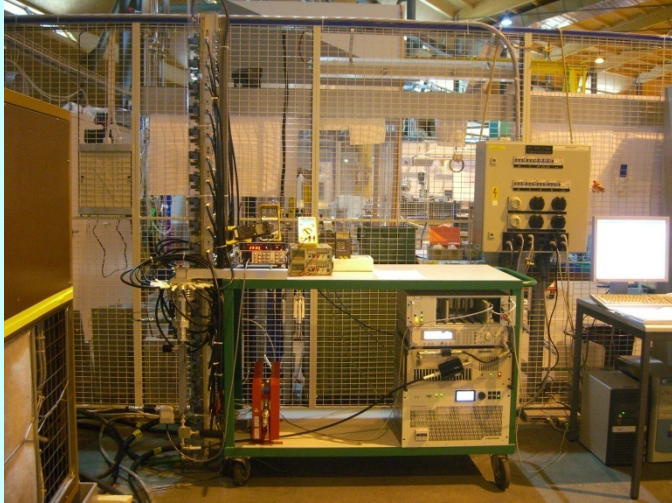
Graphical User Interface provided by Web-Browser

Data Interpolation, Translation and Interlock Checks Easily Configurable.

Hardware and Software Devices Allowed.

Easily Expandable for Larger Installation.

4KW Solid-State Power Amplifier Teststand in SLS



22KW Water Cooler

4KW Solid-State Power Amplifier

Interlocks Plus Low Level RF

Water Flux Measurement

Water Temperature Sensors

Monitoring PC (Linux)



Conclusions

- 18 RF Modules Successfully Combined and Tested Under High Power.
- Very Stable Operation. About more than a Month of Operation and Tests.
- All Produced Modules showed very Similar Performance as the First Prototype RF Module.
- Forced Compression Proven to be Easy and Useful Method to Improve Amplitude Equalization of all RF Modules and to Optimize Overall Efficiency. At $P_{out}=4KW$ the Output Power of all Modules could be Equalized to about $\pm 5\%$ around the Average value.
- Power Supply Controller Heavily Tested. Monitoring and Data Acquisition Concept Proven.
- 18-Way Power Combiner Successfully Tested under High RF Power.
- Long Duration Tests in Preparation.
- Complete Amplifier proven to be Very Compact and Light.