ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA027

SOLID STATE AMPLIFIER DEVELOPMENT FOR THE SWISS LIGHT SOURCE*

M. Gaspar†, T. Garvey, Paul Scherrer Institut, Villigen, Switzerland

Abstract

The Paul Scherrer Institute (PSI) currently operates a klystron amplifier on the booster ring of the Swiss Light Source (SLS). In order to have an optional RF source for the booster cavity, we have been developing a compact 500 MHz 65kW solid state RF amplifier. An important goal in this development is the optimization of efficiency at any given operating point. In order to achieve this, each RF module has been equipped with its own DC power supply (PS Controller), providing sufficient intelligence to adjust the drain and bias voltages in a fully independent and automatic way. With this technique it is possible to maximize the overall efficiency at any given RF output power. Considerable effort has been made in order to obtain extensive measurements from each individual module with the aim of investigating the behaviour of such a large number of combined arrays. We will discuss the amplifier design and present the results of measurements.

THE CONSTRUCTED 65 kW POWER AMPLIFIER SYSTEM

INTRODUCTION

Since the introduction of solid-state amplifiers on the synchrotron light source SOLEIL there has been considerable interest in use of such devices at other light source laboratories [1]. A modest R&D effort was started at the Paul Scherrer Institute (PSI) in order to develop this technology at 500 MHz resulting in a 4.5 kW prototype [2,3]. More recently, supported by the Swiss Commission of Technology and Innovation, we have developed a 65 kW amplifier described in this paper. This technology has been transferred to AMPEGON AG, our industrial partner for this project, for industrialization and commercialisation.

DESIGN DESCRIPTION

A large variety of tests were performed to evaluate the 65 kW amplifier system described here. Long duration tests were done with the amplifier delivering output powers of, 60 kW, 64 kW, and 68 kW. The system performed in an extremely stable fashion under all conditions.

Figure 1 shows a block diagram of the system. In this configuration all the 108 output amplifier stages, those that contribute to the system output power, are placed in parallel and are all combined by a large high power combining structure [4].

Figure 2 shows the conceptual design of the proposed system. In the middle, one sees the high power combiner tree, a fundamental component of existing high power distributed amplifiers based on solid-state technology. The RF amplifier modules and the PS Controllers are mounted around the combiner tree on 2 meter tall aluminium bars which are water cooled.

Figure 3 shows the constructed high power solid-state amplifier system. The amplifier itself is placed to the right. It is composed of six 2 m long cooling bars. Each cooling bar supports 18 RF amplifier modules on one side and 18 PS Controllers on the other side.

The RF output of the amplifier system is connected to a 100 kW water cooled load through a 3 m long high power EIA $6\frac{1}{8}$ coaxial transmission line, seen at the top. The water cooled load is placed at the left of the amplifier, and behind the rack.

The 19" rack to the left houses part of the components required to connect the amplifier to the mains, other components for monitoring and communication purposes and the pre-amplifiers with their power supplies. The amplifier system is connected to the rack at the top through a cable support.

The complete amplifier system weighs approximately 900 kg.

MEASUREMENT RESULTS

Figure 4 shows a typical output power scan, P_{out} and Efficiency vs. P_{in}. A complete power scan such as shown in Fig. 4 may take a full day to be done because of the time required for the measurements of the calibrated water cooled load to stabilize.

Figure 5 shows a frequency scan, P_{out} and Efficiency vs. P_{in} realized with a fixed power supply value, V_{dd} = 48 V, and for two different output power levels, P_{out} = 20 kW, a low efficiency operation, and P_{out} = 50 kW, a high efficiency operation. Assuming a good trade-off between gain and efficiency, a bandwidth better than 20 MHz at P_{out} = 50 kW is available with an efficiency better than 45%. At lower output power, as P_{out} =20 kW, the efficiency reduction is not an issue any more, thus much wider bandwidths are available.

The graph of Fig. 6 shows the quite high quality of the output frequency spectrum. This illustrates the noise near the carrier. Measurements over a wider span show that the second harmonic is present at -45 dBc and the third harmonic is absent, probably due to the limitations of the transistor to generate it.

The amplifier system was operated at full reflection, with a short circuit applied at the output, for about 15 minutes at

* We acknowledge the financial support of the Swiss Commission for Technology and Innovation under grant number 13192.1 PFFLM-IW.
† marcos.gaspar@psi.ch

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA027

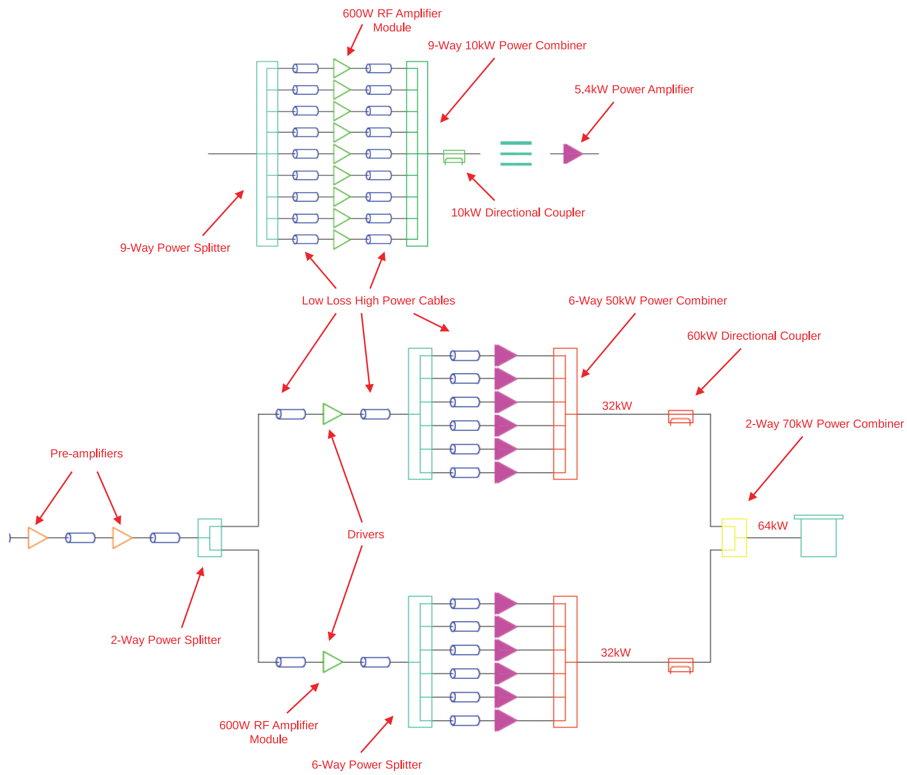

Figure 1: Block diagram of 65 kW 500 MHz amplifier system.

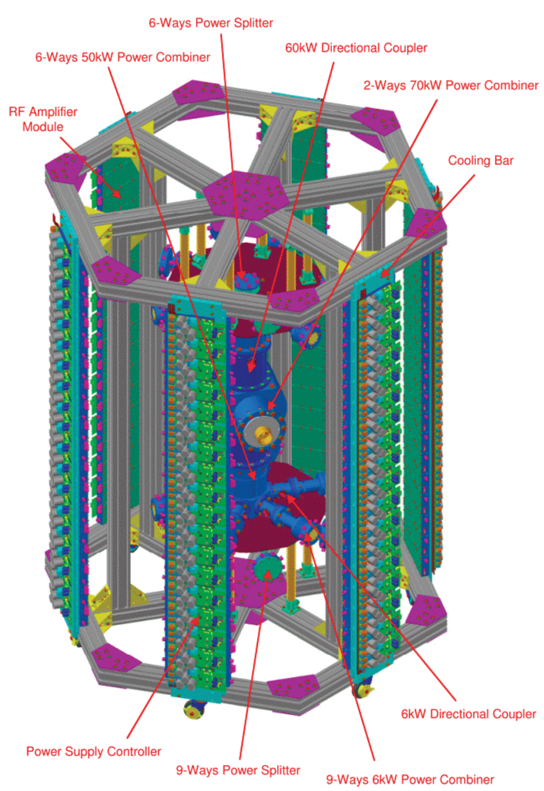

Figure 2: 3D View of 65 kW 500 MHz amplifier system.

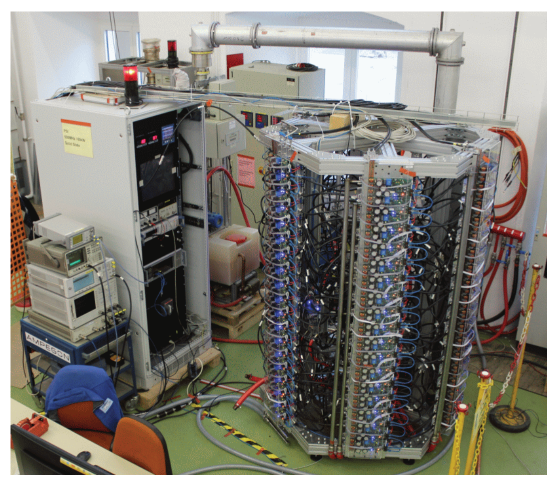

Figure 3: The complete 65 kW solid-state power amplifier (SSPA) in operation and delivering $Pout = 64kW$

output powers of, 10 kW, 20 kW, 30 kW, and 40 kW. Full reflection tests were also done at output powers of 50 kW and 60 kW for shorter time durations of 1 minute and 30 seconds, respectively, with no recorded damage.

CONCLUSIONS

The 65 kW amplifier described in this work has performed very reliably and stably during a wide variety of tests performed, including full reflection at 60 kW, reduction of cooling, operation outside the center frequency (fre-

6th International Particle Accelerator Conference IPAC2015, Richmond, VA, USA JACoW Publishing
ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA027

Table 1: Comparison Between Klystron Amplifier and SSPA

	Booster		Storage Ring	
	Klystron Amplifier (BO) Cycled Ramp 3 Hz	**SSPA 1x65** kW **System Cycled Ramp** 3 Hz	**Klystron Amplifier (SR3) CW**	**SSPA 2x65** kW **System CW**
P_{out} Nominal	36 kW	36 kW	100 kW	100 kW
Efficiency	11.2%	46.5%	40%	52%
Price (Relative)	100%	22%	100%	45%

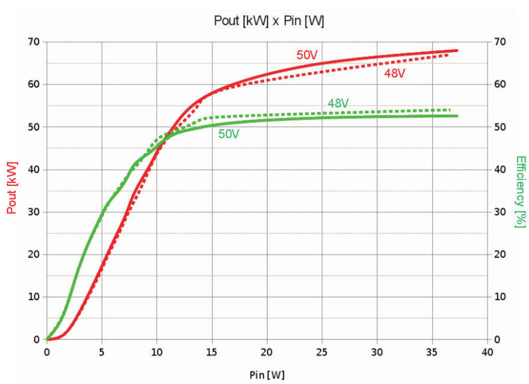

Figure 4: 65 kW system: P_*out* and Efficiency vs. P_*in*.

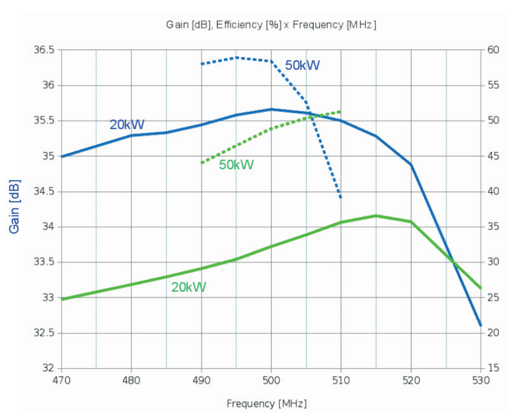

Figure 5: 65 kW system: Gain vs. Frequency.

quency scan) among others. At maximum output power of around 72 kW the efficiency of the whole system exceeded 53% which, for the present technology, is a good result. The work performed until now in system performance optimization shows that this is promising.

Table 1 shows a cost and performance comparison between klystron and SSPA amplifier systems for both booster and storage ring. The performance parameters and the estimated prices are, in the case of the klystron amplifier systems, obtained from the SLS at the moment of the realization of this work, and, in the case of the SSPA, obtained from the present project. In both applications, booster and storage ring, the SSPA proposed in this work is very competitive and cost effective. Another promising advantage of the SSPA is that its operating point can be dynamically op-

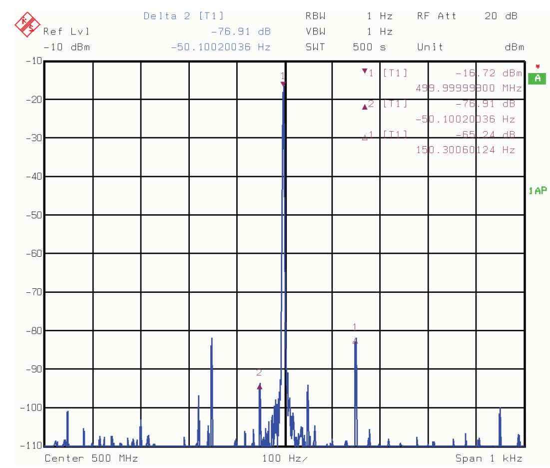

Figure 6: Output frequency spectrum, P_{out}=60 kW, BW = 1 Hz and Span =1 kHz.

timized to deliver efficiency values near or higher than 50% for a wide range of output power requirements [5].

ACKNOWLEDGMENTS

We would like to thank our technician Denis Colucci, our industrial partner AMPEGON AG, especially Bodo Fritsche, and the Abteilung Maschinen-Ingenieurwissenschaften (PSI) for their invaluable help in this project. We would also like to acknowledge the earlier contributions of Marco Pedrozzi.

REFERENCES

[1] P. Marchand, T. Ruan, F. Ribeiro, and R. Lopes, "High Power 352 MHz Solid State Amplifiers Developed at the Synchrotron SOLEIL", Physical Review Special Topics – Accelerators and Beams (2007).

[2] M. Gaspar and M. Pedrozzi, "60 kW Solid-State Booster Amplifier", 4th CW and High Average Power RF Workshop (2006).

[3] M. Gaspar *et al.*, "A Compact 500MHz 4kW Solid-State Power Amplifier for Accelerator Applications", Nucl. Instrum. Meth., A637, (2011) p. 8.

[4] K. J. Lee, "A 25 kW Solid State Transmitter for L-Band Radar", IEEE MTT-S Int. Microwave Symp. Dig., (1979) p. 298.

[5] M. Gaspar, "A Solid-State RF Power Amplifier System", Patent. WO2014173642 (A1), April 2014.