A PRECISION 75KW, 25KV POWER SYSTEM FOR A KLYSTRON AMPLIFIER.

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Abstract

A compact water-cooled 75kW, high voltage power supply system is described. The system must deliver an output voltage up to 25kV, and current up to 4A to power a Klystron Amplifier. The load demands very high voltage stability, low output voltage ripple, and low stored energy. The solution presented is based around Lambda's proven 303 series DC supplies to provide the bulk high voltage power, an advanced controller for high performance operation, and a precision filter/feedback assembly for low ripple and high accuracy.

INTRODUCTION

A Klystron Amplifier presents a challenging load for a power supply. Like any vacuum tube, the Klystron can be susceptible to ARC damage, so the stored energy in the supply must be limited to around 20J or less, or diverted with a crowbar circuit. Voltage ripple in the output of the supply results in frequency variations in the output of the amplifier, and must be minimized for stable tube operation. Voltage drift must be minimized, again to limit frequency drift in the amplifier output. These parameters present competing requirements for a power source, and must be carefully addressed during the design.

DESIGN APPROACH

In order to minimize cost and level of customization, the design must be based around a standard product. At the required 75kW power level, Lambda's ALE 303 series supply is an ideal bulk power source. The 303 is a compact, water-cooled high voltage supply capable of delivering a continuous output of 50kW at voltages up to 50kV [1], requiring only 2 parallel units to deliver the 75kW average system power. With a history of operation in both capacitor charging and DC applications over many years, the 303 represents reliable and proven solution for powering a broad range of high power loads.

The ALE design team's extensive experience with DC supplies operating in parallel has lead to the development of a synchronization feature enabling the output of 2 or more parallel supplies to be phase shifted by an appropriate amount, effectively reducing the output ripple. This technique requires a separate system controller to provide the required control signals for each 303 supply, and to monitor the overall output of the system. For the Klystron Amplifier, the HV output from two 303 series supplies is combined in a low energy filter circuit, which also features a high precision, high stability feedback network.

303 SUPPLY WITH SYNC OPERATION

A standard 303 series supply operates with a simple heuristic voltage regulation, which generates an error signal based on the supply's measured and programmed output voltage. Output current is either on or off based on the error signal, which works well in capacitor charging applications and for some DC loads. However where multiple DC supplies are connected in parallel, or where high ripple performance and low stored energy are required, other schemes can offer superior results. One such scheme that has been employed in the past uses an external system controller to synchronize the output of a number of supplies, and to generate the necessary error signals for voltage and current control. This technique can be applied with many individual supplies, and represents a very flexible and scalable approach.

The system controller operates by providing a short sync pulse to each 303 in a system which results in a short burst of power being generated. If continuous sync pulses are sent to a unit, it will generate full power, but as the pulse rate is decreased, the power generated also decreases. The rate of sync pulses is determined by the voltage and current control loops within the controller. Another major advantage with the external controller is that the output of the supplies in a system can be phase shifted for lower ripple. The number of different phases is determined by the application/requirements and the number of units in the system (see example in Figure 1).

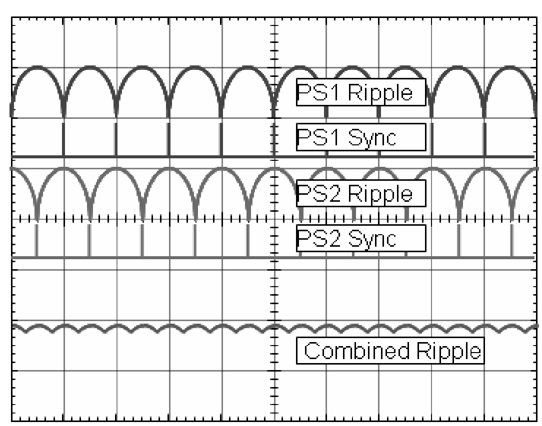

Figure 1. Example of Phase Locked 303 Operation.

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SYSTEM CONTROLLER

The system controller is a 4U (7"/178mm) high, 17"/432mm deep rack mount module. The controller is connected to all of the components in the system, and provides both local and remote control and monitor of all functions. The controller is connected to each 303 remote control interface, external sync trigger, and line feed-forward signal. The control interface connection enables HV ON, OFF, output Inhibit and status monitor functions. The external sync trigger is used to synchronize the main power inverter, and ultimately DC output waveforms between the two 303 supplies in the system. Connections between the controller and filter are provided for the system output voltage and current feedback. The controller features local controls allowing the user to operate the system from the front panel, in addition to comprehensive remote controls enabling connection to an external control system. The user can set voltage and current trip limits, and well as the output setting from the controller front panel, which also provides digital voltage and current readouts. Individual stabilized voltage and current control channels ensure stable output parameters over the full rated range of the system.

OUTPUT FILTER

The filter assembly is housed in an 8U (14"/356mm) tall rackmount chassis. The filter comprises a CLC filter network, along with a Ross VD30 precision voltage divider [2], and hall effect current sensors. The filter is connected to each 303 supply via the main coaxial HV output and the HV return cables. Within the filter, the HV output and return for each 303 supply are connected in parallel. The main function of the filter is to reduce the output voltage ripple of the system within the defined specification, and also to provide precision feedback signals enabling accurate control. A filter schematic is shown in Figure 2.

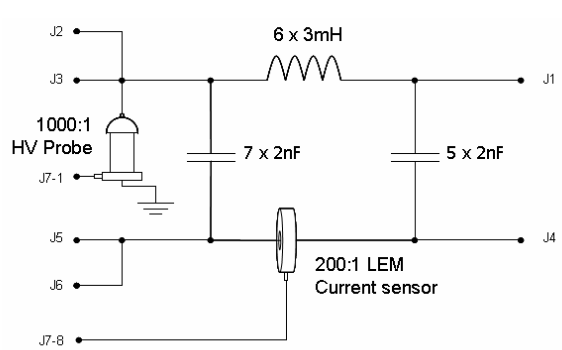

Figure 2. Simplified Filter Schematic.

The filter network is a simple PI CLC filter which is designed to offer approximately 32dB of attenuation at 120kHz ripple frequency of two phase shifted supplies.

SYSTEM TESTING AND RESULTS

The two 303 supplies, system controller and filter were set up in the high voltage laboratory, and connected to an oil/water cooled high power 8.3kΩ resistive dummy load. The most challenging operating requirement of the supply is to achieve the specified output ripple of 200ppm, and the biggest concern at the start of testing is whether the output line and high frequency ripple components will be within specification. High frequency ripple was measured using a Ross HV probe and a Tektronix Oscilloscope. The measured ripple waveform is illustrated in Figure 3, which shows a peak to peak ripple of approximately 4V.

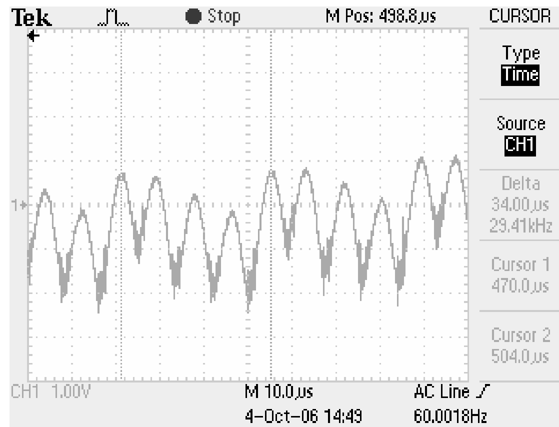

Figure 3. High Frequency Ripple waveform

Line frequency ripple was measured using the same technique, with the scope set to average out the high frequency components so the line frequency ripple is clear (see Figure 4).

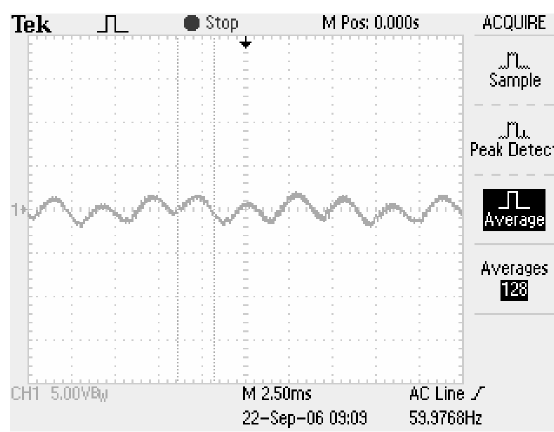

Figure 4. Line Frequency Ripple

Figure 5 shows the measured line frequency ripple is in the region of 5V p-p which is too close to the specification for comfort. In an effort to reduce the line frequency ripple, the controller and 303 supplies were modified to operate with a feed-forward control scheme. This involves measuring the AC ripple present on the 303 internal DC bus, and feeding the signal to the controller

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which then compensates for line ripple. Figure 5 shows the impact of the feed-forward control scheme, which has reduced line frequency ripple to around 1V peak to peak.

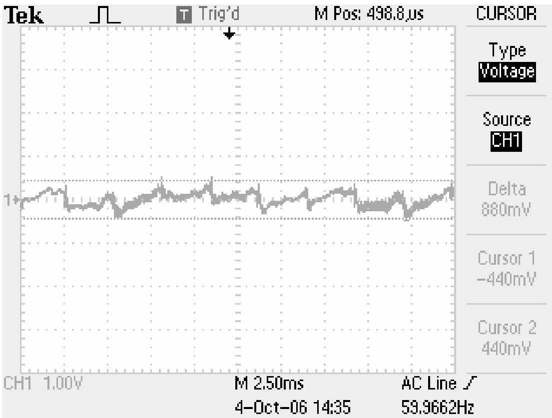

Figure 5. Ripple with feed forward control.

A summary of measured system operating parameters in a resistive dummy load are presented below;

Output Voltage Range:	-10 to -25kV
Output Current:	0 to 4A max
Average Power:	75kW
Ripple and noise:	<0.015% p-p
Efficiency:	90%
Power factor:	0.92
Stability:	10ppm/ºC
Load regulation:	0.0001%
Line regulation:	0.0001%
Stored energy:	7.5J

CONCLUSION

A high performance 75kW, 25kV Klystron Amplifier power supply system is presented. The complete system is housed in four 19” rack mount modules with a combined height of less than 50”/1.3m or 26U.

The main power elements of the system are based around Lambda Americas proven 303 series DC power supply. Each 303 supply is a compact water-cooled DC current source, capable of delivering up to 50kW continuous output power, in a 7U rackmount chassis

The 303 series supplies are controlled from a central system controller, employing phase shifting and feed-forward for ultra low output voltage ripple, and the high stability required.

Precision voltage and current feedback signals and high frequency filtering are provided by a filter/HV divider, which completes the system.

The system presented meets all of the specified operating parameters in a compact and cost effective solution. Figure 6 shows a graphic image of the complete power supply system.

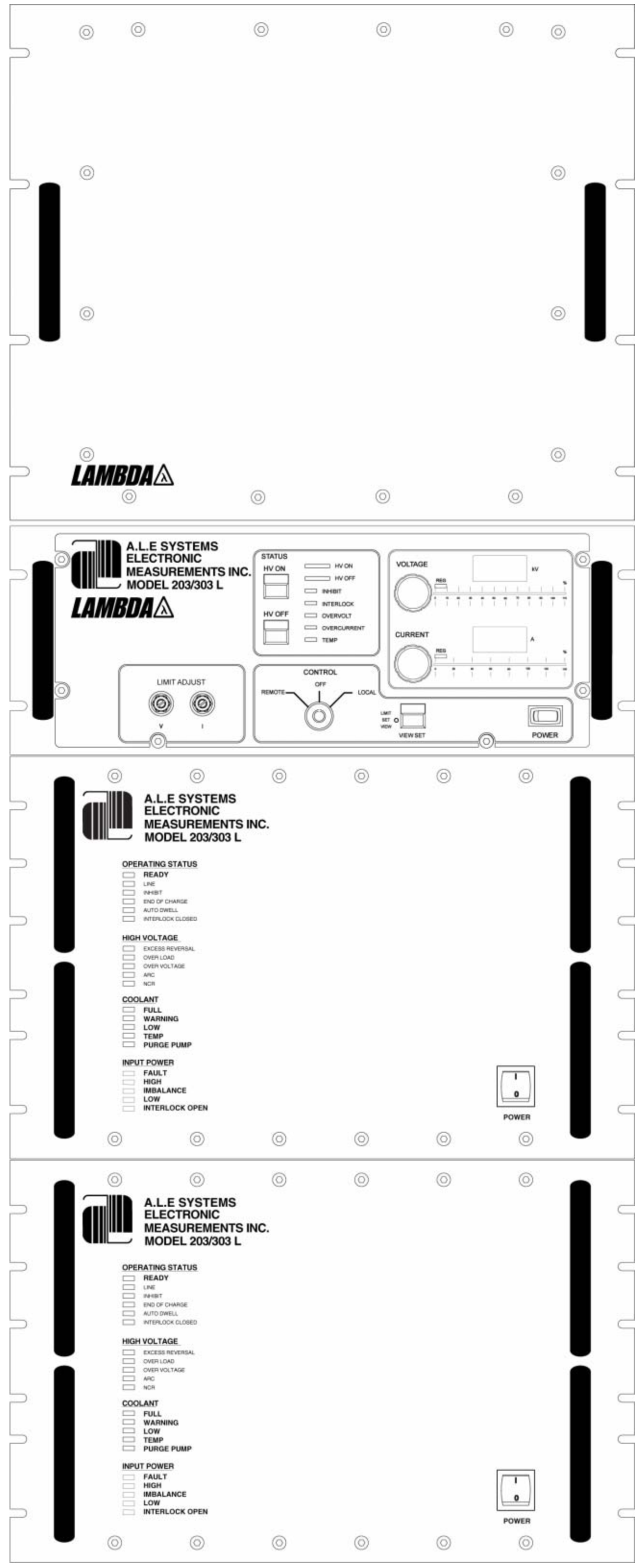

Figure 6. 75kW Power Supply System

REFERENCES

[1] ALE Series 303 data sheet.
[2] Ross Engineering Data Sheet B-1011-B

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