Experimental Demonstration of a Pulsed, Self-Biasing Depressed Collector

Mark A. Kemp, Aaron Jensen, and Jeff Neilson
Electrodynamics Department
SLAC National Accelerator Laboratory
Menlo Park, CA, USA
mkemp@slac.stanford.edu

Abstract: *High peak-power RF sources common to accelerator applications have ever-increasing electrical efficiency requirements. As such, SLAC is investigating methods to increase RF source efficiency for pulsed systems. A novel self-biasing depressed collector has been proposed. This paper is a description of the experimental demonstration of the technique.*

Keywords: electron tubes; high-voltage techniques; klystrons; pulse transformers; pulsed power systems

Introduction

SLAC National Accelerator Laboratory (SLAC) is undertaking an effort to increase the electrical efficiency of high power RF systems. In addition to exploring techniques to improve the RF efficiency of klystrons, a complementary approach of using a depressed collector to recover the spent beam is being studied. Previously, a novel self-biasing, pulsed depressed collector scheme was presented [1-3]. Recent progress has been made on experimentally demonstrating some of the features of this technique. In addition, collector optimizations are underway for achieving high collector efficiency for the high perveance, high power SLAC 5045 klystron. This paper presents the results from these two efforts.

In short, the self-biasing pulsed depressed collector approach utilizes a step-down transformer and a load capacitance to dynamically bias the collector stages, see Figure 1. The energy recovered in the collector is transferred to this capacitor during the pulse. After the pulse, the energy is transferred to the modulator for use in subsequent pulses. One advantage of this approach is that the rise and fall times of the modulator can be recovered. In addition, the biasing network is independent of the driving modulator. Therefore, it does not induce cathode ringing during the pulse [1].

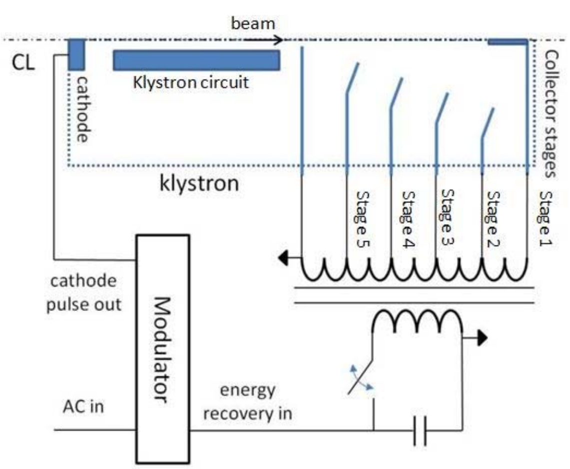

Figure 1. Schematic of the self-biasing, pulsed depressed collector.

Table I. Typical parameters for two S-band SLAC klystrons.

	SLAC 5045	**SLAC Subbooster**
RF Efficiency	45%	30 %
Beam Voltage	350 kV	25 kV
Perveance	2 $\mu A/V^{3/2}$	2.6 $\mu A/V^{3/2}$
Average Output RF Power	27 kW	50 W
Peak Output RF Power	65 MW	65 kW
RF Pulse Width	3.5 µs	3.5 µs
Pulse Repetition Frequency	120Hz	240Hz

Experimental Demonstration of Self-Biasing Technique

Because the self-biasing approach presented in [1] had not been previously substantiated through experiment, a simple single stage collector was implemented on a SLAC subbooster klystron (see Table 1). The goals of the experiment were to 1) demonstrate the ability to control the stage potential over time, 2) demonstrate energy recovery to the load capacitor, and 3) demonstrate agreement between the model and the experiment. The goal for this quick test was not to demonstrate the highest possible collector efficiency nor modify a subbooster for use in the field.

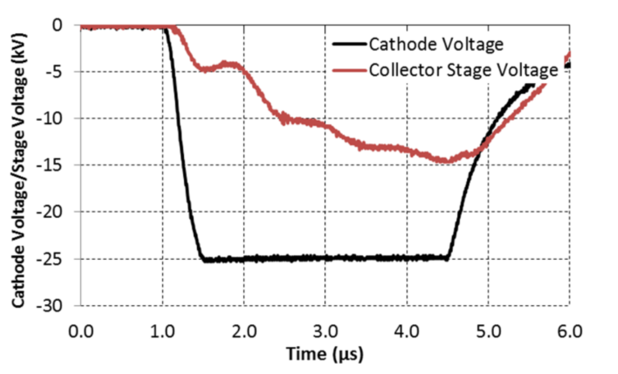

Figure 2. Typical measured stage potential for the SLAC subbooster depressed collector.

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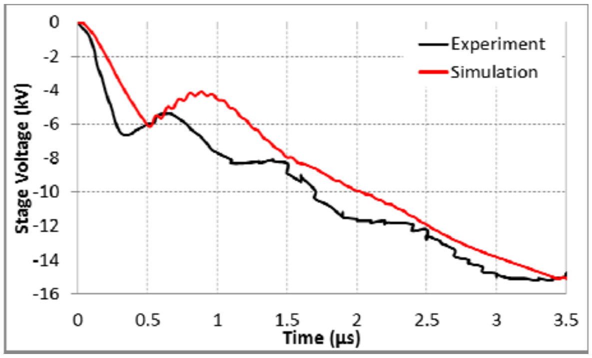

Figure 3. Comparison of a typical measured stage potential versus a simulated stage potential.

The measured stage potential for a typical shot is shown in Figure 2. As shown, the stage voltage gradually increases over the length of the pulse as the load capacitor charges up. In addition, it was shown that a "square" biasing potential could also be generated by taking advantage of the leakage inductance of the transformer. This impedance can be tuned to produce an ideal temporal shape of the stage bias.

A full 2D gun to collector simulation was conducted. The collector was modeled in Magic 2D. To simulate the time-varying stage potential, Magic was paired with a SPICE circuit model of the transformer and capacitive load. Figure 3 shows a typical match between experiment and simulation.

SLAC 5045 Klystron Depressed Collector Design

While the subbooster klystron is a convenient test platform for demonstrating some principles of pulsed depressed collector operation, the ultimate goal is to implement a collector on a SLAC 5045 tube. Initial calculations show that the waste heat for the entire station (including power supply and modulator) can be reduced by over 30% (see Table II).

One assumption used in this calculation is a collector efficiency of around 75%. To substantiate this initial calculation, detailed PIC simulations of a 5045 depressed collector are underway. Using a Particle Swarm Optimization algorithm and the 22-node SLAC "klyster" computer cluster, optimizations are ongoing on producing the collector electrical design.

Table II. A retrofit SLAC 5045 RF station compared to the existing station.

	Existing SLAC Station	Retrofit Station
Klystron RF Efficiency	0.45	0.45
Collector Ideal Efficiency	**0.00**	**0.75**
Overall System Efficiency	0.25	0.33
Avg RF Out (kW)	27	27
AC in (kW)	**107**	**82**
Waste Heat Per Station (kW)	**80**	**55**

The final presentation will include detailed results from the subbooster experiments and simulations. In addition, the results for the 5045 collector optimization will be given. Next steps and details on the overall depressed collector project at SLAC will be presented.

Acknowledgements

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References

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