A KLYSTRON AMPLIFIER TO POWER THE CEBAF ACCELERATOR

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Abstract

The Varian VKL-7811W klystron is designed particularly for accelerator service. Although the klystron's configuration employs components common to similar production tubes used for communication service, it does have features unique to the Continuous Electron Beam Accelerator Facility (CEBAF) application. The tube provides 5 kW CW at 1500 MHz with a permanent-magnet-focused, four-cavity klystron circuit. Special features include a modulating anode incorporated for power control and the capability of operation into high-VSWR load impedances. Modulating anode performance is described showing power and phase variation with anode voltage. Also described is the klystron performance with high-load VSWR. The effect of VSWR amplitude and phase on output power is discussed and a klystron protection scheme is described.

Introduction

The accelerator for the Continuous Electron Beam Accelerator Facility will be powered by multiple low-power CW microwave sources; 410 5 kW power sources at 1497 MHz will be used. The klystron power amplifier is a natural choice for meeting the power requirements. Klystrons are routinely used for communications applications having very similar requirements, and as such have demonstrated a distinguished record of long life with highly reliable operation. Klystrons should provide similar performance for the CEBAF application.

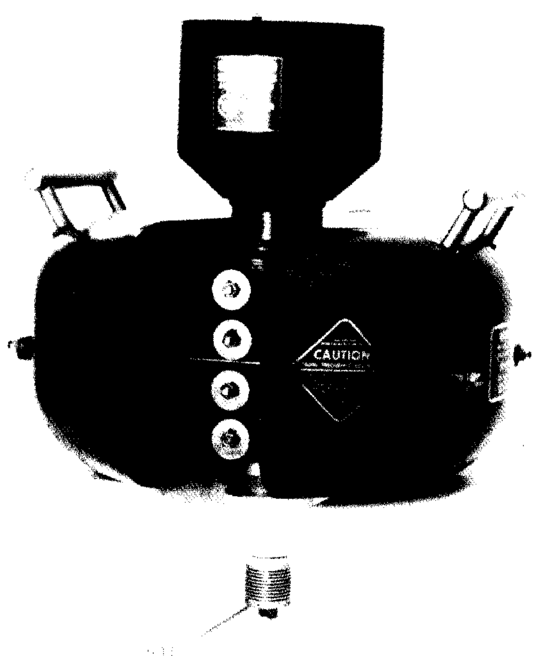

FIGURE 1. 2 kW KLYSTRON AMPLIFIER FOR SATELLITE COMMUNICATIONS TRANSMITTERS

To achieve optimum performance, some unique accelerator application characteristics need special attention. Two particular areas of concern impose specific requirements on the klystron. First, a modulating anode is needed for power control and second, the tube must operate into loads of very high VSWR. The Varian VKL-7811W klystron has been designed specifically to meet these requirements and is expected to perform as reliably in the CEBAF application as it has when used as a communications device.

Klystron Design

The VKL-7811A klystron (see Figure 1) has been used for years as a power amplifier for communications transmitters. This design was the basis for the VKL-7811W which was optimized for accelerator use. The VKL-7811W is a four-cavity klystron tuned to the accelerator frequency of 1497 MHz. Modifications for accelerator service include a modulating electrode incorporated to allow beam power control, and rf circuit changes to optimize performance for operation with varying beam current and into a high VSWR load. Water cooling is also included to facilitate operation at the CEBAF facility, to improve thermal stability, and to allow more accurate control of power amplitude and phase. The general characteristics of the VKL-7811W klystron are listed in Table 1.

Table 1
VKL-7811W Klystron Characteristics

	Min	Typical	Max	Units
Output Power	5	6	---	kW
Drive Power	---	1	---	W
Frequency	---	1497	---	MHz
Bandwidth (-1 dB)	---	4	---	MHz
Beam Voltage	---	11	---	kV
Beam Current	---	1.15	---	A

Other Features: Modulating Anode
Permanent-Magnet-Focused
Water-cooled
Operates into high load VSWR

A computer simulation program was used to predict detailed design performance. This computer program is routinely used for design optimization and also allows calculation of expected performance.

Modulating Anode Performance

Klystron performance has been determined for various conditions of modulating anode voltage. Biasing the anode negative with respect to ground reduces the beam current and, consequently, the rf output power. The detailed effects on power and gain are shown in Figure 2. Performance as a function of modulating anode voltage is shown in Figure 3. Both beam current and rf power variations are plotted, as well as the phase shift of the output signal. The bandpass characteristics are shown in Figure 4. While the bandpass does narrow somewhat as the power is reduced, it still allows at least ±2 MHz around the operating frequency.

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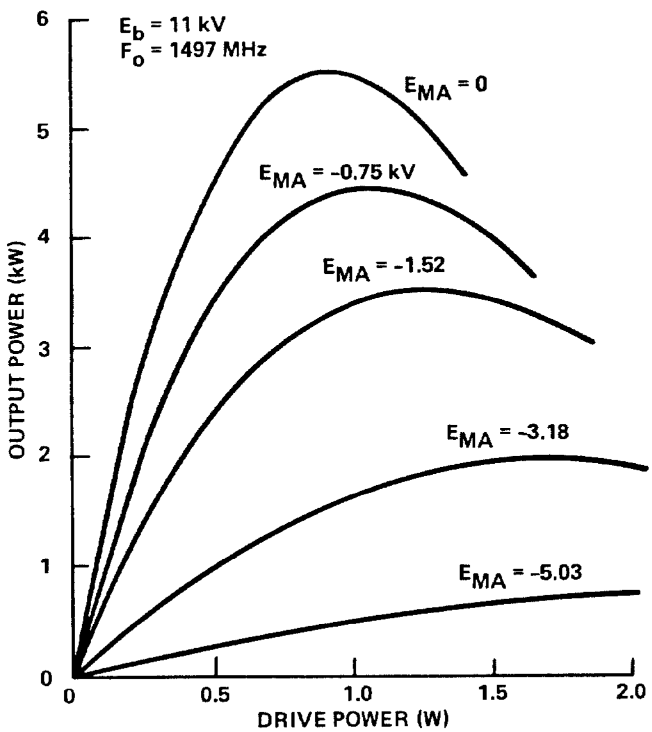

FIGURE 2. VKL-7811W GAIN CHARACTERISTICS

Narrowing of the bandpass as the modulating anode reduces the power is characteristic of klystrons, but the effect has been greatly reduced in this case by appropriate interaction circuit design. Beam loading effects are minimized by resistive cavity loading and stagger tuning.

Load Impedance Considerations

The accelerator application raises particular concerns about load impedance variation. For some operating conditions, the accelerator will present a very high VSWR to the klystron driver. This problem can be addressed by using a high-power circulator between the tube and the accelerator. The klystron would then see a relatively-matched load for all operating conditions and would provide full output power, with the high reflected power absorbed in the circulator termination. High-power circulators are costly items, however, so consideration of an alternate approach is appropriate. The klystron can operate into a high-VSWR load as long as the reflection phase presents a low impedance to the klystron output gap. The power generated is reduced, but the performance is otherwise unchanged. This approach requires careful transmission line design between the klystron and the accelerator to assure proper signal phasing, but it appears to be an appropriate technique. The VKL-7811W is designed for use in this manner.

The klystron output transmission line's electrical length is controlled to allow consistant phasing from tube to tube. In addition, the window location is selected to be at a voltage null to avoid damage by the high VSWR. Finally, an rf probe is included in the output transmission line after the window, at the proper location for the sampled voltage to be proportional to the klystron gap voltage. In the event of high VSWR with shifted phase, such that a high impedance is presented to the klystron, this signal can then be used in a protection circuit to avoid klystron damage. A high load impedance would cause excessive rf gap voltage leading to electron reflection with possible circuit damage. To protect against this potentially

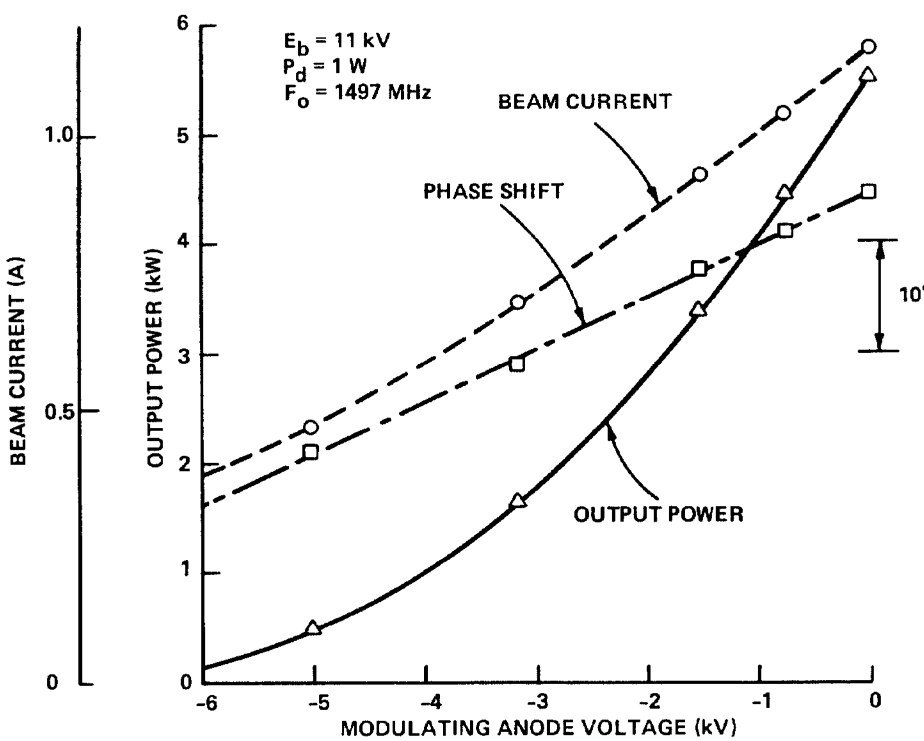

FIGURE 3. VKL-7811W MOD-ANODE CHARACTERISTICS

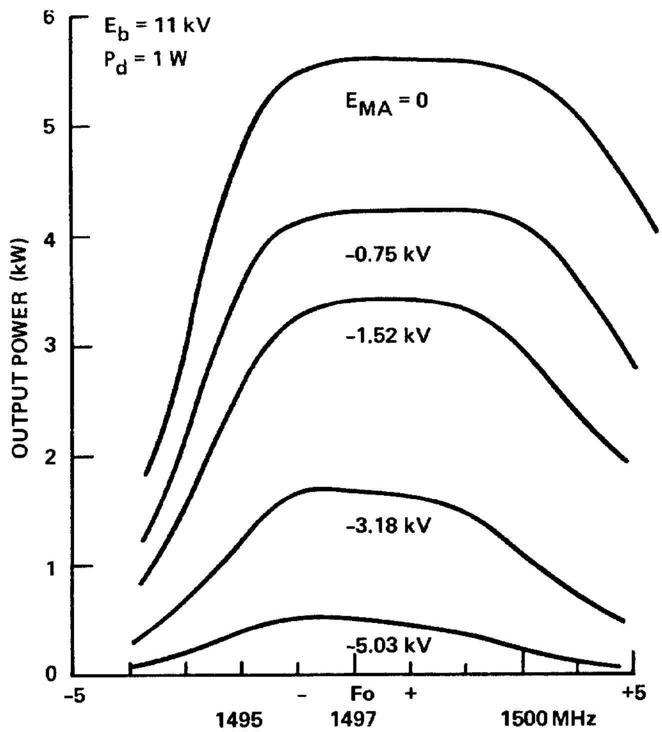

FIGURE 4. VKL-7811W BANDPASS CHARACTERISTICS

hazardous situation, the rf sample from the probe would be connected in a feedback loop to reduce the rf drive signal to the klystron, if the signal exceeds a preset value representing the maximum allowable gap voltage. The klystron is provided with this sensor appropriately calibrated.

Conclusion

The VKL-7811W is designed specifically for the accelerator driver application. While it is based on standard klystron technology successfully used for other applications, there are several specific requirements presented by the unique application which mandate design modifications. Fortunately, these modifications can be readily applied. Furthermore, they will have little effect on the complexity of the klystron and, consequently, little cost impact.