HIGH POWER CW KLYSTRODE® AMPLIFIER FOR 267 MHz

M. B. SHRADER, D. H. PREIST AND R. N. TORNOE
VARIAN POWER GRID TUBE PRODUCTS
301 INDUSTRIAL WAY
SAN CARLOS CA 94070

ABSTRACT

A 250 KW CW 267 MHz Klystrode has been designed and built as part of a major program in conjunction with the Chalk River National Labs (CRNL), Chalk River, Ontario, Canada. The high CW power design has evolved from previous work for UHF television and the SDI program. A major step was taken on this program to simplify and reduce the complexity of the RF input circuit. CW power in excess of 250 KW and efficiencies in excess of 70% were readily obtained with power gain in excess of 21 dB. Three tubes and associated circuitry were tested and delivered as part of the effort.

INTRODUCTION

Klystrode® technology has continued to expand both in UHF TV service and in the high power accelerator field. The basic Klystrode operating principles are now well understood and accepted in the U.S., and their application is expanding overseas. The operating principles have been described in numerous publications by the authors and others. REF [1]-[9]. The Klystrode depends upon density modulation of an electron beam at the cathode by a control grid and acceleration of the bunched beam into an output cavity. These simple basics have survived for over a decade and continue to make possible unique compact highly efficient UHF RF power sources at many different power levels and frequencies.

CRNL PROGRAM

In September of 1989 Varian Power Grid Tube Products entered into an agreement with Atomic Energy of Canada Ltd. (AECL) to design, develop and produce three 267 MHz, 250KW CW Klystrodes. The Klystrodes were to be delivered to CRNL and used to drive a test accelerator. This program, which was partially supported by the U.S. SDI Organization, represented the first effort at obtaining high CW power (>50KW CW) from a Klystrode. The program was also the first to have as an objective the study of the suitability of CW Klystrodes as accelerator drivers without the use of isolators between the source and accelerator cavity.

Previous to this program the highest power Klystrode developed was a 500KW peak 50KW average power 425 MHz Klystrode sponsored by SDI and Los Alamos National Labs (LANL) under Contract No. 9-XSD-7840D-1 REF [9]. This tube, which met or exceeded the contract goals, served as the basis for the design and the procurement specification for the new 250KW CW 267 MHz Klystrode.

OBJECTIVES OF THE PROGRAM

Power Output - CW:	250KW
Operating Frequency:	267 MHz
Efficiency:	70%
Beam Voltage:	65 KV
Beam Current:	5.5A
Power Gain:	20 dB Min.
Tuning Range:	±2 MHz
Bandwidth 3 dB:	±1 MHz

TUBE DEVELOPMENT

The development plan involved scaling the existing 425 MHz LANL/SDI Klystrode REF [9] downward in frequency and upwards by a factor of 5 in average power handling capability. The plan called for using the identical electron gun from the 425 MHz tube, scaling the input and output cavities to the proper frequency and designing a new and much larger collector to handle the CW power.

Fig. 1 is a photo of the complete tube, gun, output cavity and collector: dramatic evidence of the compactness of the 250 KW Klystrode when compared to a 3-story high klystron which would be required for the same power and frequency.

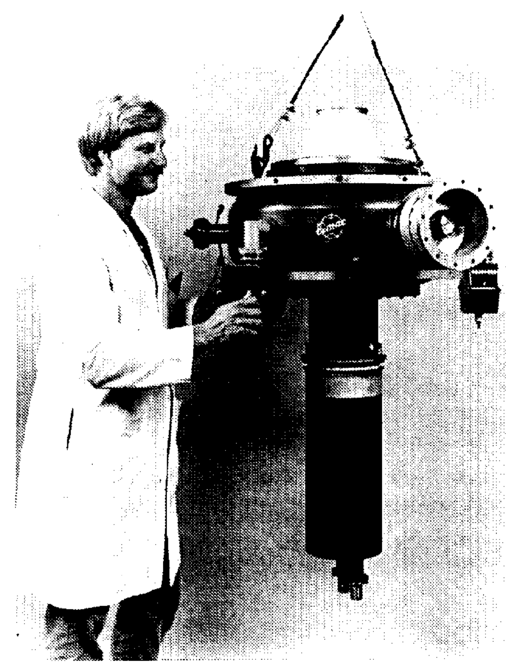

FIG 1
250 KW Klystrode

INPUT CIRCUIT PROGRAM

Testing of the complete amplifier system began in the summer of 1991. The output circuit of the 250KW Klystrode is a simple single tuned cavity similar to those used on high power klystrons. The input circuit was scaled in frequency from the 425 MHz SDI tube and from the EIMAC UHF TV Klystrode manufactured by Varian. The input circuit relied on a folded coaxial cavity which was designed to present the proper phase and amplitude RF voltages between the grid and cathode, to furnish the RF drive, and the proper phase and amplitude voltage between grid and accelerating anode to permit stable operation. Depending on these phase and amplitude relationships, the input circuit could either be regenerative or degenerative with stability depending on how the coaxial lines were tuned.

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In TV service and in the 425 MHz Klystrode, this basic design has worked well giving good power gain and long term stability. On the CRNL program at 267 MHz the input circuit turned out to be a different story. It was soon discovered that a Ferrite isolator between the driver Klystrode and final amplifier was required to secure any degree of stability.

A fresh look at the input circuit was started as a parallel program in January of 1992 while testing of the HPA continued with the original circuit. A strip line mockup of a totally different approach was tested using a Klystrode gun tester which was built during the 425 MHz SDI program. The circuit involved a simple tuned circuit between grid and cathode and a novel means for handling the RF circuit between grid and accelerating anode. The details of this breakthrough in Klystrode circuit technology will be the subject of another paper.

Fig. 2 shows the new input circuit (square box) assembled on the high power Klystrode with lead shielding, magnetic coil and tube stand. Overall height of the complete amplifier is 72".

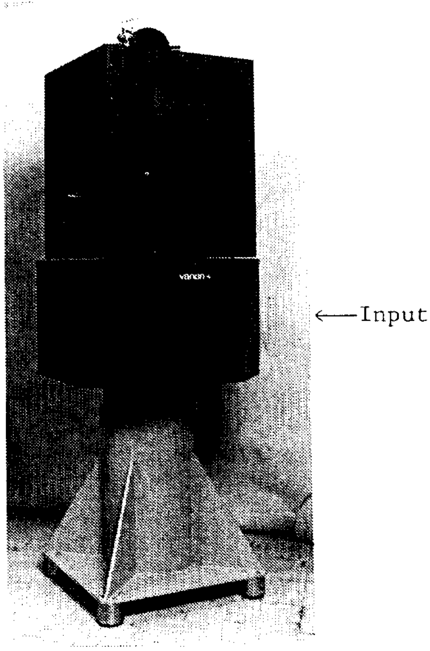

FIG 2
New Input Circuit
Assembled on Klystrode

TEST RESULTS

The test procedure followed a pattern of starting with low duty pulsing, and as the tube aged in and the proper loading and tuning were accomplished, the pulse length and repetition rate were increased until CW conditions were reached. Pulsing the low level drive stages and frequency sweeping made it relatively easy to monitor and adjust all of the tube and circuit parameters with little risk to the High Power Amplifier (HPA). Since one of the prime objectives of this program was to operate the HPA into an accelerator cavity without the use of an isolator, an output cavity sampling loop was installed internal to the tube. The purpose of the loop was to monitor the output cavity gap voltage, and through suitable control circuitry adjust the drive to the system to compensate for varying loads presented to the HPA. The data for the loop is presented; its effectiveness has yet to be determined when the HPA is coupled to the accelerator cavity.

Fig. 3 shows how the probe voltage varies with power output. Power output and beam current versus drive are also shown. Good linearity with no discontinuities or instability has been repeatedly demonstrated.

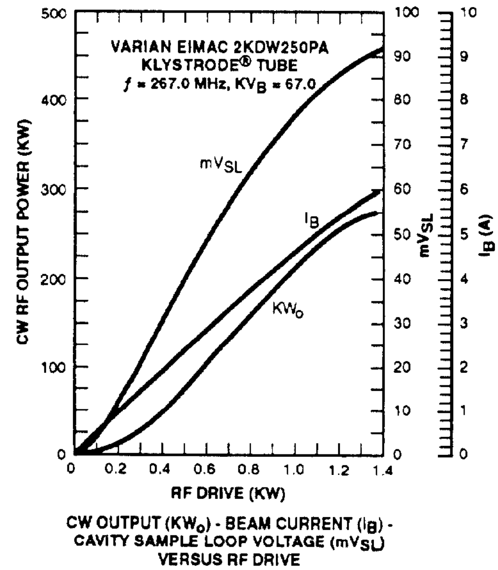

FIG 3

Figs. 4 shows overall bandwidth of the HPA. The ±1 MHz 3 dB requirement was exceeded. Fig. 5 is a plot of output phase change versus RF output. An 80% change in power output gives only a 25° phase change. Fig. 6 shows phase change versus a VSWR and phase angle of the load for VSWR of 1.5.

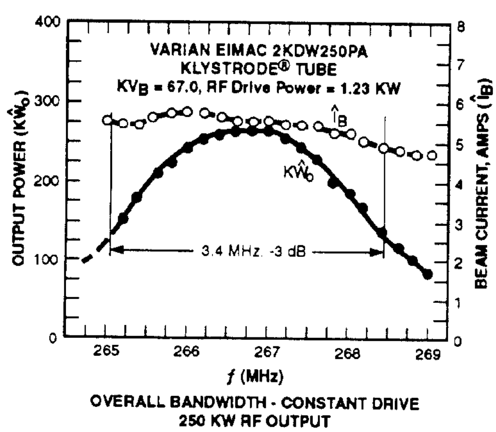

FIG 4

CW powers in excess of 280 KW were measured and efficiencies of 72-74% were readily obtainable. Power gain in all cases was greater than 21 dB. CW testing also included operating the amplifier into a 1:5 VSWR load with the phase of the load adjusted to present the highest and lowest impedance to the amplifier. Under these conditions 235 KW and 260 KW CW were obtained. The test was repeated with VSWR of 3:1 and 70 to 62 KW CW measured.

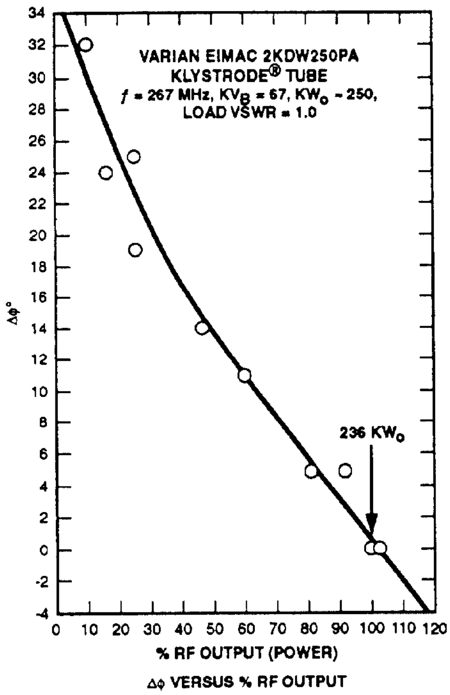

FIG 5

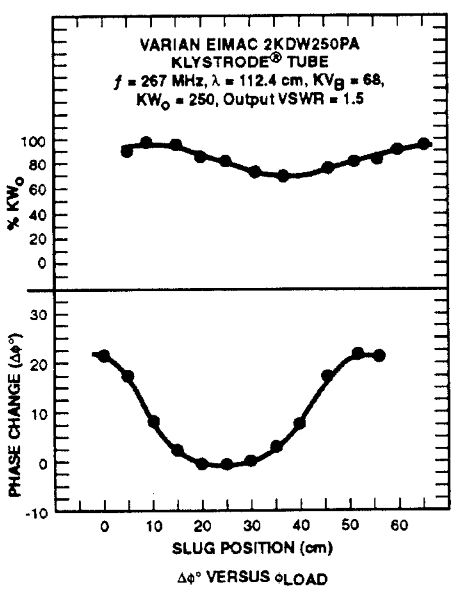

FIG 6

Normal operating beam voltage for 250 KW CW is 65-67 KV. The cavity and tube were high voltage processed to 100 KV and tested at 85 KV. This was accomplished with air insulation thus eliminating the need for oil or SF_6. A 24-hour burn-in run was successfully completed at the 250 KW CW level.

CONCLUSION

Klystrode technology has come a long way in the past decade, and the successful completion of this project has demonstrated that there is no technical reason why Klystrodes cannot generate high CW powers with excellent efficiency and reliability. The 250 KW CW Klystrode developed on this project points the way for the next logical step of 1 MW CW. The frequency of operation at this power level could be from 100 MHz to 800 MHz depending upon the need. The 70-74% efficiencies obtained give an attractive base for further increases in efficiencies by coupling Klystrode technology with multiple output cavities and/or multiple-stage depressed collectors. 80% efficiency and 1 MW CW would certainly be an appropriate target for the next step.

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