KLYSTRODE[R] EXPERIMENTAL RESULTS

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A 500KW peak power 50KW average 425 MHz Klystrode[R] has been designed and built as part of a major program on Klystrode development at the EIMAC Division of Varian, San Carlos, CA. The high power Klystrode design evolved from earlier work on the new line of UHF TV Klystrodes which are now operating in the field. The 500KW program has been supported by the SDI Program under the direction of Don Reid of LANL, Contract No. 9-XSD-7840D-1. Experimental testing has proceeded in three phases. The initial testing was done on a beam simulation device to determine the characteristics of the gridded gun. The second phase consisted of low duty cycle full voltage and current RF testing on the Klystrode built for the contract. The third phase will continue the testing at the full specification conditions.

Introduction

In October of 1981 a new UHF RF source for accelerator applications was proposed at the Linear Accelerator Conference held in Santa Fe, New Mexico. This device presented by the authors was called an IOT or Inductive Output Tube. Experimental data at the 30KW level indicated that this device could be scaled to deliver up to 1MW CW at 450 MHz and reduced powers to 1 GHz. The advantages foreseen at that time were size, weight, and efficiency. What was described at this conference was the first Klystrode[R] amplifier to be built and tested giving significant power in the UHF spectrum. The name Klystrode was invented several years later to more accurately describe the operating principles which resemble a conventional gridded tube and a klystron.

Basic Operating Principles

The operating principles have been described in numerous publications since 1981 (see references). A brief description is included. Referring to Figure 1, it can be seen that the Klystrode consists of a spherical cathode and closely spaced spherical grid. The grid-cathode or gun assembly is designed so that a resonant coaxial line cavity external to the tube vacuum envelope can be used to put RF voltage at the operating frequency between grid and cathode. The input circuit also has the dual function of isolating the beam voltage from the body of the Klystrode. This is accomplished by providing suitable clearances between cylinders to withstand the required voltages in air or with SF_6. A DC bias supply and resultant DC voltage is placed between grid and cathode so that without RF drive the beam is completely cut off.

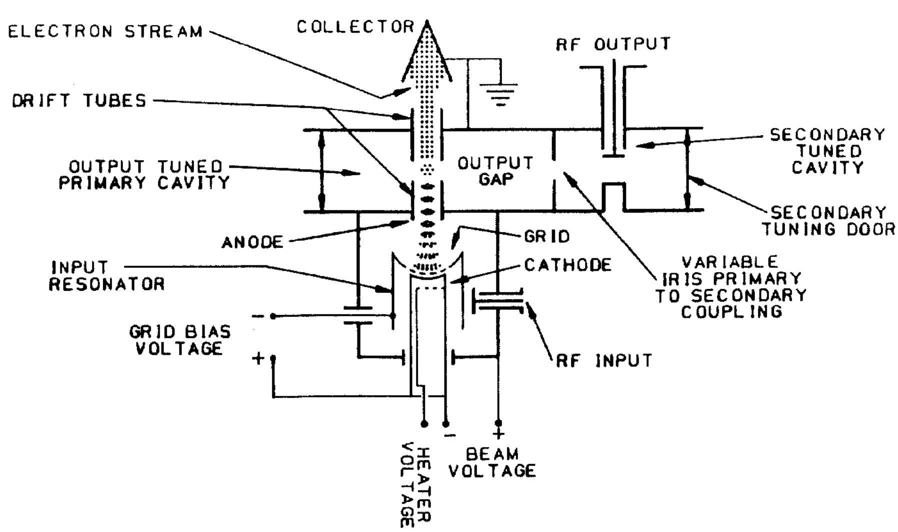

FIGURE 1

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With the application of RF driver power, electron bunches at the RF drive frequency rate are formed and then accelerated by the accelerating anode to a high velocity. The bunched electrons then pass through a very short drift space which is beyond cutoff at the operating frequency and give up their kinetic energy to a resonant cavity in the same manner that electrons bunched by velocity modulation give up their energy in a klystron. The spent electrons then proceed to a collector and are collected as in a klystron.

Figure 1 is a schematic of a Klystrode with a double tuned iris coupled output cavity. This type of cavity was designed to give broad band operation in UHF television service. The basic Klystrode concept has a number of fundamental advantages:

1. Efficient electron bunching because the grid effectively shuts off electrons between bunches.

2. Low magnetic field requirements since the beam only travels a short distance.

3. A collector design which can be much smaller since it does not have to handle full beam power as does a klystron.

4. Class B operation which allows efficient modulation of the output power. The beam current is a function of the RF drive (eg. only as much beam current is generated as is required to deliver the power output).

5. Excellent isolation of the output circuit from the input due to the section of drift tube beyond cutoff.

6. Exceptionally small and light weight structure since only two cavities are required and the beam throw is short.

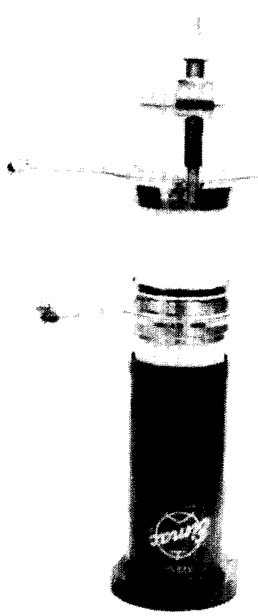

Figure 2

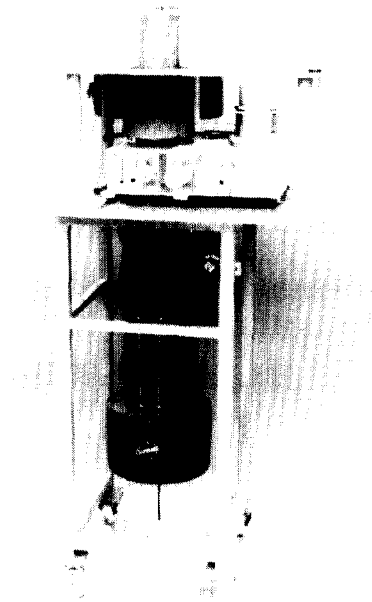

Figure 3

UHF Television

As stated in the 1981 Accelerator Conference, the Klystrode development was started as a company-sponsored project to improve the efficiency of UHF TV transmitters. Figure 2 is a photo of the resulting 60KW tube developed and Figure 3 shows the tube and hardware. Both are now in production and in commercial service. The improvement in transmitter operating efficiency has been spectacular. For example, with the new Klystrodes WCES-TV, Augusta, Georgia was able to increase their operating power to 120KW from 30KW on Channel 20 (506 MHz). This increase in power output of four times required only 10% more prime power than was required at the 30KW level with klystrons. Even competing with the most modern klystrons now in service with MOD anode pulses, the improvement with Klystrodes is still nearly 2:1. In addition, the Klystrode does not require a high voltage pulser because of its Class B operation.

Background for Current SDI Contract

It became obvious in 1985 that Neutral Particle Beams for space applications would require many megawatts of RF in the UHF region. Conventional RF sources available were at least an order of magnitude too heavy and too large to ever be practical in space. The Klystrode looked like a very attractive approach toward solving the problem and a proposal was made to Los Alamos National Labs and the SDI Organization to develop a high power Klystrode for this application. In July of 1986 Subcontract 9-XSD-7840D-1 was awarded to the EIMAC Division of Varian to develop such a device.

Objectives of the Contract

Subcontract 9-XSD-7840D-1 has the following basic objectives:

Operating Frequency:	425 MHz
Power Output:	500KW Peak
Pulse Length:	11 Milliseconds
Duty Factor:	10%
Efficiency:	70%
Power Gain:	20 dB
Operating Voltage:	85KV

Tube Design

At the beginning of the contract considerable test data had been accumulated on the UHF TV Klystrode amplifier operating at 470 to 785 MHz. As mentioned in the 1981 Accelerator Conference paper, it was decided to scale the gun parameters from the 60KW TV design thereby maintaining the current loading on the cathode and grid. Since the 60KW TV Klystrode amplifier was designed for the long life and reliability demanded by the broadcast user, the larger Klystrode amplifier tube was designed to give similar service. No attempt was made to push the state-of-the-art in any of the design parameters. The only departure from the television design was to reduce the gun perveance in order to get higher efficiencies instead of broader bandwidths. Klystrode amplifiers are similar to klystrons in this respect. The input circuit was patterned after the television design, but the output circuit is a single tuned resonant cavity and is part of the tube envelope.

Figure 4 shows the gun structure with pyrolytic graphite grid and cathode. The cathode is a standard tungsten matrix cathode like those that are used on high power klystrons. The grid is fabricated from pyrolytic graphite material with laser cut apertures. The low expansion, high heat handling capabilities of pyrolytic graphite make it ideally suited for this application.

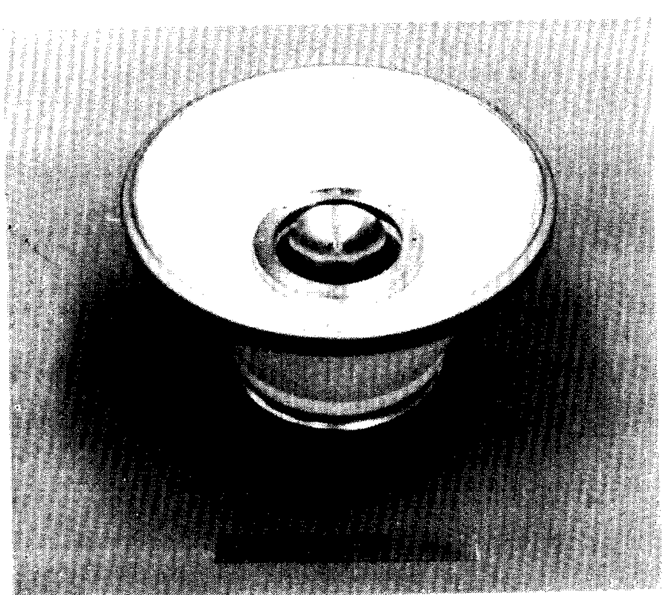

Figure 4

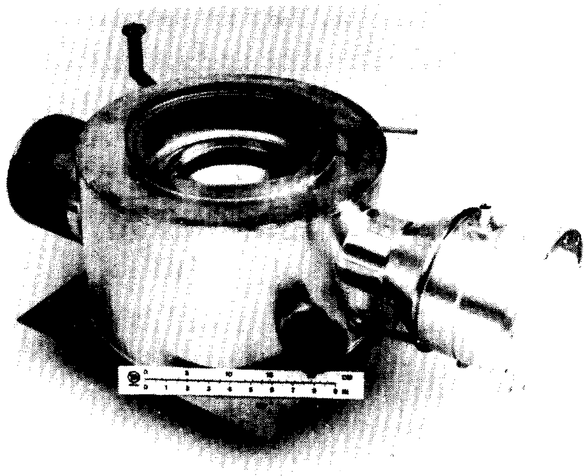

Figure 5

Figure 5 is a photo of the output cavity which is part of the vacuum envelope. It was decided early in the program to design the output cavity for 1 MW CW power handling capabilities and to ignore the resultant increase in weight for this first tube. The output line is a 6-1/8" coax with a cooled alumina window. The cooling was included for the 1 MW CW level and is not needed for the contract objectives. A movable inductive tuner is also included which can be used to tune the output cavity over a +3 MHz range.

A three dimensional cutaway drawing of the Klystrode amplifier is shown in Figure 6. The final design of the Klystrode amplifier differs somewhat from this drawing but the basic elements of the tube and input circuit are shown. Figure 7 is a photo of the Klystrode amplifier tube. It is quite obvious that it is the most compact high power UHF RF source built to date. It's nearest competition is 16 feet long and weighs almost 5,000 lbs.

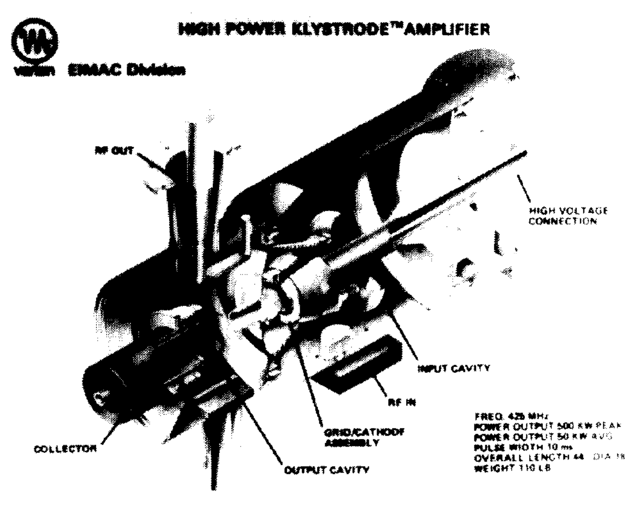

Figure 6

Figure 7

Test Results

Testing of the complete amplifier in a low duty (1-2%) test facility assembled under the contract began in November of 1988. Table 1 is a summary of the data taken thru December 1988. Increasing DC beam voltages were applied as the various corona discharges in the test set up and input circuit were cleaned up. It can be seen that the contract objectives have been met at low duty and short pulses (25 usec). It has been our experience on UHF TV that pulse data of this kind establishes the feasibility of the device in regard to power gain and efficiency, these being the main factors of concern.

Planned Test Program

Continued testing in the low duty facility is planned to optimize the output cavity loading and input circuit power gain. Neither of these parameters have been explored sufficiently to insure optimization. In addition the following characteristics will be measured:

1. Dynamic Range
2. Phase shift and amplitude shift with varying VSWR
3. Phase and amplitude shift with beam voltage changes
4. Bandwidth

At the completion of this testing the Klystrode amplifier will be moved to the EIMAC high power test facility where the 10% duty 11 millisecond pulses at 500KW peak power output will be run.

KLYSTRODE TEST RESULTS

Date	Power Output KW	Efficiency Percent	Beam Voltage	Gain dB
11/10/88	294	63	60	18.5
	305	67	65	18.6
	250	66	65	19.2
	350	67	70	19.0
	440	68	75	19.6
	500	68.5	75	21.0
	535	65	76	19.9
	550	71	85	20.9
12/16/88	637	68	85	20.5
03/14/89	725	67	90	20.3

Table 1

CONCLUSION

A significant advance in the state-of-the-art in generating high power RF in the UHF spectrum has been made. We believe that the full contract objectives will be met and that the ground work has now been established for further increases in power in both pulse and CW modes. In addition, plans are being formulated to extend the operating frequency of high power Klystrode amplifiers to 850 MHz. The results to date on both UHF television tubes and the SDI project have been very exciting, and we believe that the Klystrode amplifier will take a permanent place in the quest for compact, efficient sources for UHF power.

The authors would like to express our gratitude and thanks for the support of the Los Alamos National Lab and SDIO personnel, and in particular to Don Reid for his tireless efforts to seek better ways of generating RF and his willingness to support new approaches.

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