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Title: Upgrading the LAMPF 201 MHz RF Generators

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UPGRADING THE LAMPF 201 MHZ RF GENERATORS

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Abstract

Radio-frequency generators, operating at 201 MHz, power the first four stages of the Los Alamos Meson Physics Facility (LAMPF) accelerator. Each generator consists of four stages of series-connected, vacuum-tube amplifiers. The first amplifier is a grid-modulated tetrode that produces 500 W peak-power. The second amplifier is a drive-modulated tetrode that produces 5 kW peak-power. The third stage is a grid- and plate-modulated tetrode that produces 130 kW peak-power. The last stage is a plate-modulated triode that produces 2.5 MW peak power.

A modernization program has been initiated to improve the reliability of each of these stages. The first two stages of each generator are being replaced with a single, drive-modulated, solid-state amplifier. Specifications for the amplifier design, and requirements for integration into the system are presented. The third stage will be converted to a drive-modulated system using the current tetrode. This modification involves the development of a 17 kV, 15 A switching supply to replace the present plate modulator. Design requirements for this switching supply are presented. The final stage will remain plate modulated but will contain a new driver unit for the modulator tube.

Introduction

The Los Alamos Meson Physics Facility (LAMPF) is a half mile long particle accelerator which produces an 800 MEV proton beam with an average current of 1 mA. The first RF section of the accelerator consists of four Alvarez drift tube structures. Each of these structures is excited by four, series connected vacuum tube amplifiers operating at 201.25 MHz. The high average flux of the facility requires these amplifiers to operate at a 14.3% duty factor.

The first amplifier contains a Burle 7651 tetrode. This amplifier boosts the 30 W input drive to 500 W. The second amplifier also uses a Burle 7651 tetrode which boosts the 500 W output of the first stage to 5 kW. The third amplifier stage uses a Burle 4616 tetrode which generates 130 kW peak power. The final stage uses a Burle 7835 triode that produces 2.5 MW peak power. A block diagram of this system, including power supplies and modulators, is shown in Fig. 1. A modernization program has been initiated to improve the reliability of each of these stages. Additionally, diagnostic improvements are being implemented at each amplifier level. This will improve troubleshooting techniques and allow trending and failure prediction capabilities that were not previously available.

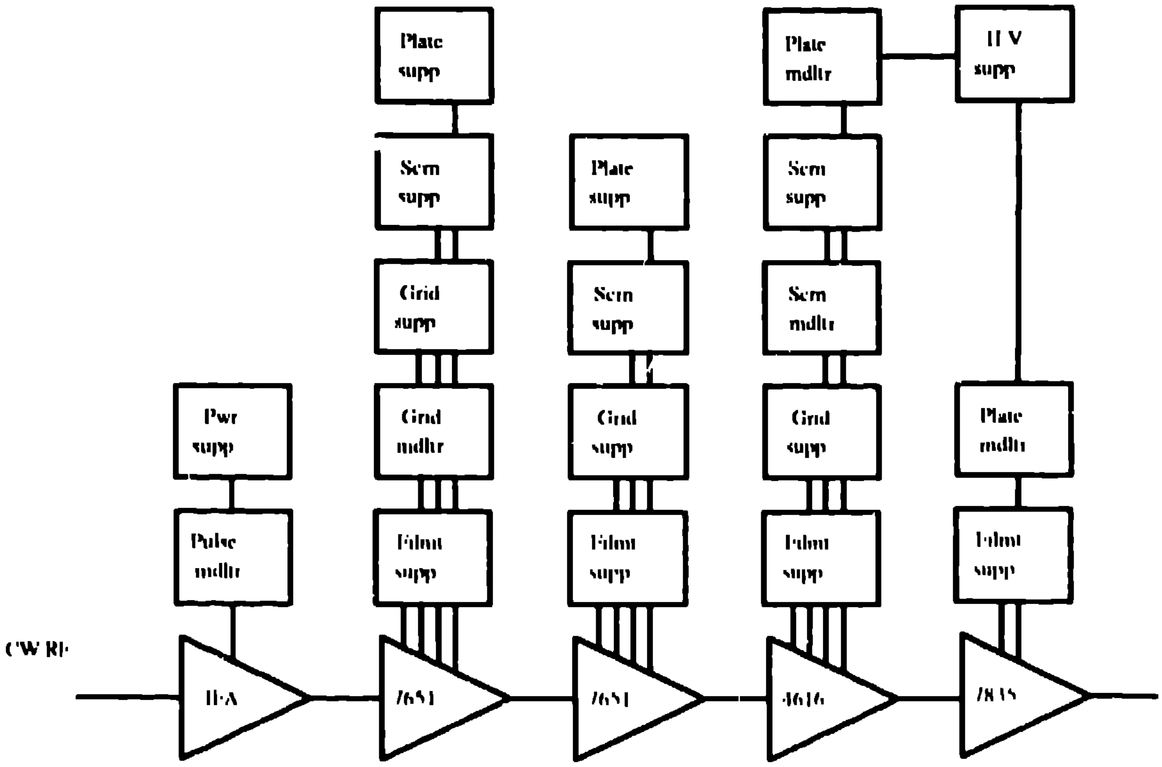

Fig. 1. 201 MHz amplifier system

<u>Burle 7651 Tetrode Replacement</u>

Modernization of the system will begin by replacing the first two vacuum tube stages with a single, solid state amplifier. Recent advances in high power, high frequency FETs have made solid state rf amplifiers an economically viable alternative to tubes. RF amplifiers in the multi kilowatt range are now available for $20/watt – $40/watt. A number of manufacturers of television transmitters [1,2], nuclear magnetic resonance equipment [3,4], and military devices [5,6] routinely produce amplifiers in this power and frequency range.

A request for proposals (RFP) for the development of a prototype 5.5 kW, 201 MHz amplifier for use at LAMPF was issued in January 1992. American Microwave

Technology was awarded this contract in August, with the prototype amplifier to be delivered in April, 199_. Table 1 lists the specifications for this amplifier.

Table 1.
Specifications for solid-state amplifier

1. Rated peak output power	5.5 kW
2. Operating frequency	201.25 MHz
3. Rated duty factor	15%
4. Maximum VSWR of external load	infinite
5. Gain	40 - 45 dB
6. Bandwidth	± 2 MHz (-3 dB)
7. Operating mode	Class AB
8. Harmonics and spurious noise	< 45 dBC at 5.5 kW
9. Linearity	≤ 1 dB
10. Rise/fall times during rf drive mod.	< 5 μs
11. Overshoot during modulation rise time	< 5 %
12. Amplifier cooling	45° - 65° F water
13. Operating altitude	7300 ft.
14. Ambient humidity	0 - 90%
15. AC input	208/480 V, 3-phase

This amplifier will operate in a drive modulated mode. Reliability is expected to increase dramatically, since each amplifier will replace two vacuum tubes and seven high and low voltage power supplies. Projected MTBF for the production amplifiers is expected to be in the 10,000 hr range. The order for the four production units will be placed after the prototype is successfully tested on the accelerator.

Improvements in the Burle 4616 Stage

The third stage of each 201.25 MHz RF generator uses a high gain Burle 4616 pulsed tetrode, amplifying the 5 kW output of the second 7651 tetrode to approximately 130 kW. The output is then applied to the input circuit of the Burle 7835 triode which drives the linac. The 4616 is both plate and screen grid modulated, using two separate modulators, and has fixed dc control grid bias. The 4616 screen grid is modulated separately to prevent screen over dissipation when the plate voltage is off.

The 4616 anode voltage is derived from the same capacitor bank as the 7835. This voltage is nominally in excess of 30 kV dc, so the 4616 is subjected to operation at high anode voltage. A floating deck modulator using a Varian/Eimac 4CW100,000D tetrode limits the 4616 anode voltage to a peak value of approximately 26 kV dc. At this voltage the 4616 stage can exhibit instability at certain output and input tuning and loading settings. Since our peak power requirements of this stage are below the manufacturers ratings, operation at lower anode voltage would improve the stage stability and lifetime of the 4616.

To maintain efficiency and stability in the PA, the 4616 stage is operated with sufficient drive to saturate the 7835 PA at a particular cathode current. Power to the linac is controlled by a closed-loop amplitude-control system which drives the 7835 plate modulator. The 4616 is not controlled by this loop. Any droop in the capacitor bank voltage over the duration of LAMPF's long pulse (1035 microseconds) will also affect the 4616 output power due to the common connection and lack of gain leveling in the 4616.

As previously mentioned, a benefit of the new class AB solid state amplifier will be the ability to drive-modulate rf power into the 4616. Work at the Brookhaven National Laboratory (BNL) AGS Linac has demonstrated drive modulation of a 4616 with fixed dc voltage on the anode and screen grid. This reduced the system complexity and the number of power tubes in the stage. Precautions were taken to prevent screen overdissipation and minimize the chance for screen current runaway by use of current-limited dc supplies and other protective devices [7].

At LAMPF, a new anode power supply to replace the modulator will be specified and procured. The tentative requirements for the power supply are 17 kV dc with 3 A average current, and 15 A peak current. Because of space constraints at the RF equipment aisle, we are considering a high frequency resonant power supply as an alternative to a more conventional 3ϕ ac power supply. The existing 4616 modulator chassis requires 10 square feet of floor space. A high frequency resonant power supply with lightweight magnetics and compact filter components will be supplied to fit into this space. The design of protective circuitry for fast shutoff and output crowbarring should be simplified due to the reduced stored energy. The design will still have to balance the amount of stored energy against allowable high frequency ripple in the output.

In the LAMPF accelerator, converting the 4616 to drive modulation will allow removal of three tetrodes (including a 4CW100,000D) and two triodes from each 201.25 MHz RF system. This improvement will eliminate twenty power tubes from the system. Accelerator reliability, maintenance, and overall electrical efficiency will also be improved by the removal of the associated filament, bias, screen, and plate power supplies. Power requirements will be reduced by 15 kW with the removal of 20 filament supplies and 40 kW with the removal of the pulse modulators. Significant gains in MTTR of the accelerator rf power system are expected to be the largest improvement. Amplitude and phase stability of the rf drive to the final power amplifier will also improve. Fig. 2 shows the system block diagram after the solid state driver is added and the 4616 modulators are removed.

Improvements in the 7835 Power Amplifier

The fourth stage of each 201.25 MHz RF amplifier chain is the final power amplifier, which is coupled to the linac through 14 inch diameter coaxial line. It contains a Burle 7835 super power triode which is plate modulated during the accelerator beam pulse. In addition to switching the anode voltage, this modulator operates quasi-linearly to provide closed-loop power control to the accelerator during the individual beam pulses. Drive modulation is impractical with the 7835 due to its tendency to self-oscillate when drive is removed and the anode is energized.

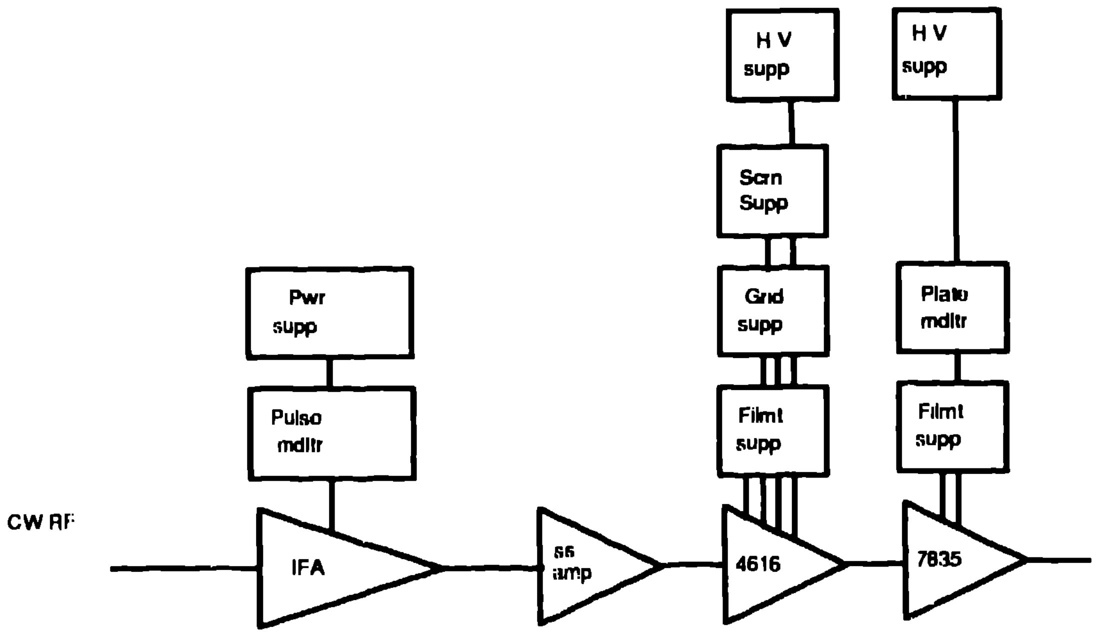

Fig. 2 201.25 MHz amplifier system after modulation improvements

Excessive anode dissipation due to operation at high rf duty is suspected to contribute to several recent 7835 ceramic failures. An anode dissipation monitoring system was being tested on one of the modules last year when such a failure occurred. At the time of failure, the 300 kW rated tube was dissipating 270 kW. The replacement tube operated successfully when we limited power output for a maximum dissipation of 250 kW. Monitoring systems will be installed on the remaining modules prior to the 1993 production cycle, and both real time and statistical plate dissipation data will be taken.

Another planned improvement for the final drive stage involves the plate voltage modulator for the 7835. The plate modulator consists of a parallel pair of Varian/Eimac 4CW250,000B tetrodes on a floating deck modulator chassis [8]. A video driver circuit screen modulates the 4CW250,000B's. The control grids are boot strapped to the screen grids to remove the cutoff bias during the on pulse and offer a low impedance path for grid current flowing to ground. A small 3-400Z triode is driven by a voltage isolated fiber optic signal across the floating deck. It drives the control grid of a 4CX3000A tetrode, configured as a follower, to provide modulated screen voltage for the hard tube modulators. The 4CX3000A screen voltage is supplied from a conventional 60 Hz ac power supply. Regulation of this supply can degrade if the phasing of the 120 Hz master clock for the accelerator is changed relative to the particular ac line phase. This dynamic regulation problem can cause incidental screen modulation which affects the rf power, since it is amplified through the plate modulator. This particular phenomenon is not well understood, but does stem from the use of a single-phase screen supply.

As a part of this program, an improved video-driver unit is being designed to eliminate these shortcomings. The first glass triode, the 3-400Z, will be replaced with a high-voltage power MOSFET, which readily interfaces with the incoming fiber optic link receiver. Initially we considered replacing both tubes in the video driver with solid-state devices. The hard tube modulators require screen drive pulses of 2000 V at 8 A. Series connected MOSFETs can withstand the voltage requirement as a switch, but the amplitude-linearity requirements are difficult to accomplish simultaneously. Also, direct connection of these semiconductors to the screen grid of the hard tube modulators could be unreliable due to the possibility of plate-to-screen arcs. Therefore, we will continue to use a vacuum tube between the first stage and the modulators. To eliminate the video-driver screen-voltage supply, a triode with a higher cathode emission is being considered to replace the current tetrode.

The improved 7835 plate modulator will have a simplified video driver, with only one tube driven by a MOSFET. Except for additional diagnostics, we anticipate no further changes to the modulator since long life has been obtained using the current 4CW250,000B tetrodes (typ. 15,000 hours). While the improvements to the plate modulator are relatively minor in comparison to the 4616 stage, we are attempting to address problem areas which will result in better accelerator MTTF and reduced maintenance downtime.

Summary

An extensive program is underway to modernize the 201.25 MHz rf generators at LAMPF. The first two stages will be completely replaced with a drive modulated, solid state amplifier. The third stage will be changed from plate and screen modulated to drive modulated and contain a low stored energy plate supply. The fourth stage will have an improved driver for the modulator tube. Diagnostics and instrumentation in all stages will be greatly expanded. These changes are expected to substantially improve reliability of the 201 MHz systems.

References

1. Harris Corporation, Broadcast Division, P.O. Box 4290, Quincy, IL 62305-4290

2. Larcan Communications Equip., Inc., 6520 Northam Drive, Mississauga, Ontario, Canada L4V 1H9

3. American Microwave Technology, 3080 Enterprise St., Suite A, Brea, CA 92621

4. R. F. Solutions, Inc., 16055 Caputo Dr., Unit D, Morgan Hill, CA 95037

5. Microwave Power Devices, 330 User Ave., Hauppauge, NY 11788

6. Power Systems Technology, 63 Oser Ave., Hauppauge, NY 11788

7. Personal communication, Vincent LoDestro, Brookhaven National Laboratory AGS Linac, June 1992

8. Faulkner, J. R., "A Unique High Duty Factor Series Hard-Tube Modulator for use in the Los Alamos Meson Physics Facility," IEEE Transactions on Nuclear Science, Vol. NS-16, No. 3, 1969.