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L-Band High Power Amplifiers for CEBAF Linac

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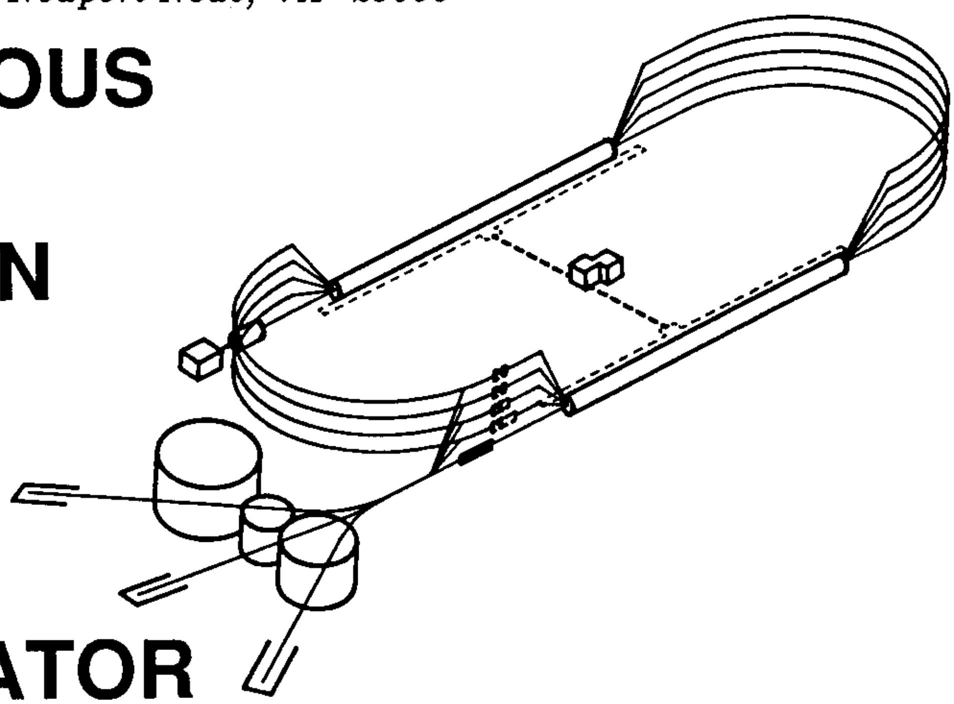

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Newport News, Virginia

L-BAND HIGH POWER AMPLIFIERS FOR CEBAF LINAC *

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Abstract

The high power portion of the CEBAF RF system utilizes 340 5kW klystrons providing 339 separately controlled outputs. Modulating anodes have been included in the klystron design to provide for economically efficient operation. The design includes shunt regulator-type modulating anode power supplies running from the cathode power supply, and switching filament power supplies. Remotely programmable filament voltage allows maximum cathode life to be realized. Klystron operating setpoint and fast klystron protection logic are provided by individual external CEBAF RF control modules. A single cathode power supply powers a block of eight klystrons. The design includes circulators and custom extrusion and hybrid waveguide components which have allowed reduced physical size and lower cost in the design of the WR-650 waveguide transmission system.

Introduction

The accelerator requires multiple high power RF sources for injector and linacs. A design providing a single klystron for each superconducting cavity was selected so that required phase and amplitude adjustment could be accomplished at low power levels.

Configuration

CEBAF's two linacs consist of 20 cryomodules, each with eight superconducting cavities. Individual cavities receive up to 5 kW of CW RF at 1.497 GHz. Including the injector, a total of 340 klystrons are required. Because of the basic linac design of eight cavities per cryomodule, an eight klystron HPA (High Power Amplifier) was appropriate.

In operation, varying amounts of RF power will be required. While a klystron's output power is directly dependant on drive, one disadvantage is that DC input power remains constant regardless of the output power. In a system with 340 klystrons, each with a maximum DC input power of 15 kW, some method of reducing power consumption when less than maximum RF power is required becomes very desirable. It is for this reason that a modulating anode was included in the klystron design. This allows us to reduce klystron beam current to the minimum required for the required RF power.

Offers for production of a klystron built to our specifications were submitted by several manufacturers, with the Varian VKL-7811W ultimately being selected.[5] Once the klystron was defined, power supply requirements were also defined. Ripple requirements for the various supplies[6] were largely mandated by the klystron's phase stability with respect to supply variations and the ability of the RF control module to track these perturbations.

TABLE 1. POWER SUPPLY SPECIFICATIONS.

Cathode	
Input	480 V AC 30
Output V	-11.6 kV DC, taps at 11.0, 10.4, 7 kV
Output I	10.6 A max.
Ripple	0.1% P-P
Filament	
Input	208 V AC 30
Output V	programmable, 0-9 V DC
Output I	9 A max.
Isolation	20 kV
Ripple	2% P-P
Modulating Anode	
Input	-11.6 kV DC
Output V	programmable, 0-(-6) kV
Output I	5 mA source, 15 mA sink
Ripple	0.1% P-P

Controls

Drive to each klystron is provided by an RF control module, consisting of RF, analog, digital, and I/O portions. The heart of the module is an 80186 microprocessor. While the module was not part of the HPA procurement, its interaction with the HPA had to be coordinated. The HPA had to provide and accept signals that the module would generate or require.

Early in the design, it had been decided that "per klystron" parameters would be controlled and monitored by the module, while "per HPA" signals would connect to CAMAC. The module is responsible for protecting the klystron from excessive beam and body current and reflected power, and also for monitoring and setting modulating anode and filament voltages. The HPA's power supplies and klystron monitoring directly interface with the module.

Each system includes eight klystrons along with associated waveguide components (coaxial to waveguide transition, circulator, directional coupler) and auxiliary power

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supplies, so eight modules, located in racks adjacent to the HPA, are required. The CAMAC interface is also located in these same racks, and takes care of status monitoring and main on-off functions.

Figure 1. Overall view of the HPA during installation.

Figure 2. Four of eight klystrons installed along with associated waveguide.

Power Supplies

With the exception of cathode voltage, which is tap settable only, voltages are remotely programmed. The modulating anode setpoint determines a basic operating point and power consumption for the klystron. As life expectancy of the cathode is closely tied to cathode temperature[5], a remotely programmable filament power supply was included.

The filament supply is a resonant mode switcher.[3] Because the klystron filament supply must float atop the −11.6 kV cathode voltage, its ferrite switching transformer does double duty, providing both step-down and high voltage isolation in one compact, lightweight design. Eight such power supplies are included, each a separate plug-in printed circuit board. The basic design was suggested in our specifications, though ETM Electromatic developed the final design. The board provides remote read-back of actual set voltage and local monitoring of individual filament currents. The power supply initially operates in a current limited mode, then converts to voltage regulated when the cathode nears operating temperature.

Eight klystrons are powered by a single cathode power supply.[2] The original design included no crowbar, so each klystron is connected through a 50 ohm isolating resistor to provide some protection in the event of klystron arcing. We have since designed our own crowbar circuit and have begun adding it to each of the cathode supplies.

High voltage relays to allow remotely isolating bad klystrons were not included in the design of either the HPA or the eight outputs of the cathode power supply. In the event of a defective klystron, this makes it impossible to remotely isolate a single unit from high voltage. Assuming a klystron still holds off high voltage but is otherwise defective (say with high body current), the modulating anode can be adjusted for lower beam current, and most likely lower body current. In worse cases the filament can be turned off, and in the most severe case all eight klystrons would go off-line until planned maintenance.

Rather than a separate power supply, the modulating anode supply is a shunt regulator card operating off a feed from the cathode power supply. The design consists of a series string of MOSFETS. Again the basic design was suggested by our specifications, with ETM developing the final design. While initial klystron tests had used a standard switching supply with some success, a major requirement of the supply was that it be capable of sinking the modulating anode intercept current. For a standard supply this required a fairly low resistance bleeder resistor hung on the output. A shunt regulator was the ideal choice for our requirements since it effectively provided a very low bleeder resistance.

An instrumentation interface board that, in addition to the filament and modulating anode parameters, also provides samples of body current and cathode current for each klystron is included. All "per klystron" signals including waveguide directional coupler samples, are fed to the RF control module. In the event a klystron problem cannot be corrected through manipulation of drive or beam current, the module can kill high voltage, shutting down all eight klystrons in the HPA.

Mechanical

The HPA is almost 133" x 94" x 36", and in spite of that, it is about as small as it can be made and still be somewhat convenient to work on. It was necessary to maintain the required magnetic separation[5] while mounting eight klystrons along with waveguide components, filament and modulating anode power supplies in a single package. The design was further complicated by the requirement that each assembly of four klystrons and waveguide pieces be movable ± 1" in the x and z-axes, and ± 2.5" in the y-axis. This requirement is necessitated by potential misalignments in penetration spacing and floor height variations.[4]

The klystron's 1-5/8" coaxial output is immediately transformed to WR-650 waveguide. The straight waveguide pieces were produced from aluminum extrusion, cut to length, flanges welded, surfaced, and then iridited for corrosion resistance. CEBAF opted for this route for two main reasons. Estimates for traditional welded waveguide came in at about $30/foot, versus $10/foot for extrusion. Secondly, traditional waveguide houses were, at best, reluctant to produce lengths over 12 feet, which would then require inaccessible flanges inside the penetrations. Gas and RF tight gaskets are included at all flanges, and pressurizing the waveguide gives an indication of potential RF leakage through a drop in pressure. To reduce cabinet height, increase system integrity by eliminating flanges wherever possible, and reduce costs, the coaxial to waveguide transition was specified with an integral 40 dB mono directional coupler.

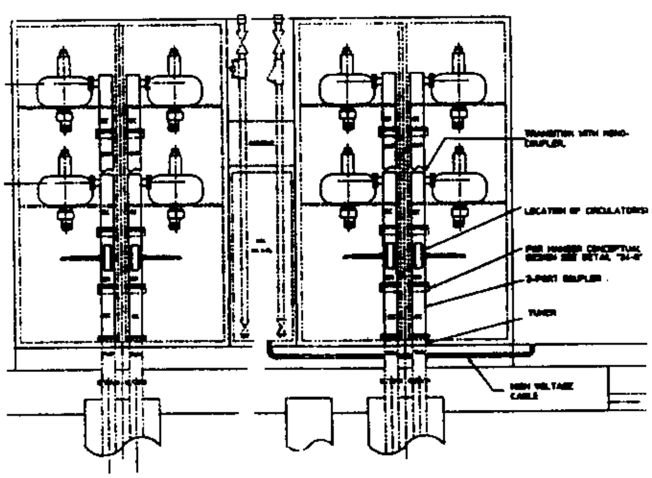

Figure 3. Location of klystrons and waveguide components.

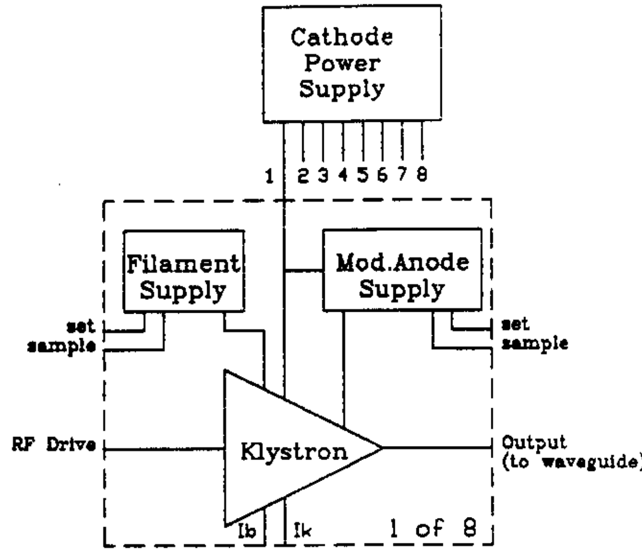

Figure 4. Simplified block diagram of power sections of HPA.

Final Comments

One other major constraint on this procurement was that the first units be delivered in a relatively short time. Some proposals had given 1.5 years as the design/delivery time, but the contract was awarded in July, with the first pair due by July 31. Even with this short time period, both vendors completed their designs and the finished products according to schedule. CEBAF has received the first two units and is now in the process of installing and performing final tests on them.

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