

# Overview and Status of RF Systems for the SSC LINAC

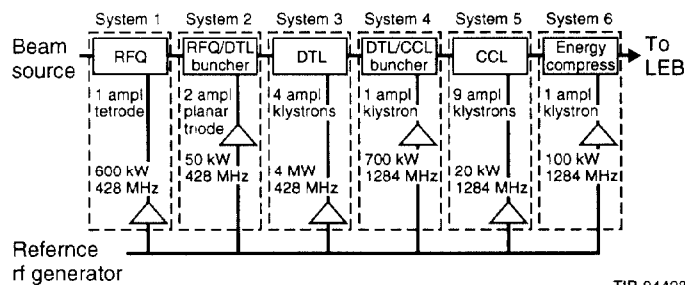
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## Abstract

The Superconducting Super Collider (SSC) Linear Accelerator (Linac) produces a 600-MeV, 35- $\mu$ s, H<sup>-</sup> beam at a 10-Hz repetition rate. The beam is accelerated by a series of RF cavities. These consist of a Radio Frequency Quadrupole (RFQ), two bunchers, and four Drift Tube Linac (DTL) tanks at 427.617 MHz, and two bunchers, nine side-coupled Linac modules, and an energy compressor at 1282.851 MHz. The RFQ amplifier and the low-frequency buncher cavity amplifiers use gridded tubes, while the other cavities use klystron amplifier systems. The RF control system consists of a reference line and cavity feedback and feedforward loops for each amplifier. The RF amplifier system for each of these accelerator cavities is described, and the current status of each system is presented.

## I. INTRODUCTION

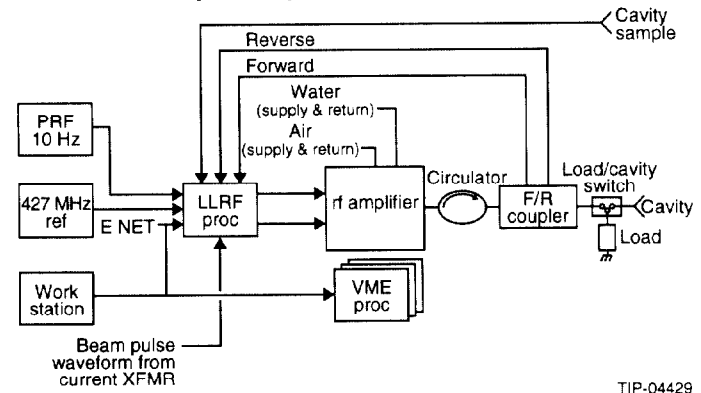
The operation of the SSC Injector Linac [1] requires a series of 18 power amplifiers that can be defined in six groupings, or RF systems, as shown in Figure 1. The operating frequency is tripled at the output of the 70-MeV Drift Tube Linac (DTL), from 427.617 to 1282.851 MHz. This wide spread in operating frequencies, and the wide range of peak amplifier power requirements (50 kW to 20 MW), leads to the selection of a diversity of technologies in the implementation of these amplifiers. A 400-W solid-state pre-amplifier and two UHF grid-tubes, and a high- $\mu$  triode driving a super-power beam power tetrode, are used to provide a 600-kW power source for the 2.5-MeV RFQ Linac. The RFQ RF Amplifier, and each of the other amplifiers, has its own independent Low-Level RF (LLRF) processor, (Figure 2). There are two double-gap buncher cavities in the RFQ/DTL input matching section. Each buncher is driven by a 50-kW power source, consisting of a 250-watt solid-state linear pre-amplifier using RF power MOSFETs; a one-tube, 5-kW planar triode intermediate power amplifier stage; and a two-tube, 50-kW planar triode final power amplifier stage. The four Alvarez tanks in the DTL are driven by four high-gain, 4-MW klystrons. Nine 20-MW, 1282.851-MHz klystron amplifiers are used to power the Coupled-Cavity Linac (CCL), accelerating beams of H<sup>-</sup> ions from 70 MeV to 600 MeV.



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Figure 1. Block diagram showing the six LINAC RF systems.

Each amplifier is controlled and monitored by two single-card processors (Figure 2). A VME-based processor controls and monitors all amplifier power supply/modulator functions, and a VXI-based processor controls all RF functions. The primary purpose of the LLRF is to control the cavity fields in amplitude and phase to 0.5% and 0.5°. The LLRF and its stable RF reference source have been previously described [2-4].



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Figure 2. Typical LINAC RF system.

## II. RFQ AMPLIFIER

The purpose of the RFQ amplifier [2-6] is to provide power to enable the RFQ to increase the energy in the beam from 35 keV to 2.5 MeV. The amplifier must provide a minimum of 225 kW at 427.617 MHz, at each of two input ports of the RFQ. The amplifier will operate inside a closed loop system that, when combined with the low-level RF circuitry, will maintain the RF output to 0.5% and the RF phase to 0.5°. The amplifier must meet the requirements of Table 1.

Table 1  
RFQ RF Amplifier Specification Requirements

Operating Frequency	427.617 MHz
Bandwidth	300 kHz
Power Output	600 kW peak
Gain	77 dB nominal
Pulse Length	100 microseconds
Pulse Repetition Rate	0-10 H
Pulse Droop	1% maximum
Linear Range	15% to 85% of peak power rating

The RFQ amplifier was built in a joint venture with the Los Alamos National Laboratory. It consists of a 400-W solid-state amplifier, a triode-cavity intermediate amplifier, and a 600-kW maximum power output amplifier using a Burle 4616 tetrode tube. Its design and test results are discussed in Reference [6].

The amplifier and associated control processors were integrated into an RF system (Figure 2) in late 1992. The RF system was finally integrated with the RFQ Linac [3] in Feb.-Mar. 1993. The SSC RFQ LINAC achieved its first 2.5-MeV beam operation on April 9, 1993.

\*Operated by Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

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### III. RFQ/DTL MATCHING SECTION AMPLIFIER

Two buncher cavities are used for matching from the RFQ into the DTL. Since this operation is critical to the preservation of beam transverse emittance [1], an independently controlled RF amplifier is used to power each buncher cavity. The open-loop operational requirements for each amplifier are listed in Table 2.

Table 2  
RFQ/DTL MS Amplifier Specification Requirements

Operating Frequency	427.617 MHz
Bandwidth	10 MHz minimum
Power Output	50 kW peak
Pulse Length	100 $\mu$ s
Pulse Repetition Rate	0-10 Hz
Linear Range	<0.5 dB from 10 kW to 42 kW

In October 1992, AccSys Technology, Inc., was contracted to design and manufacture two amplifiers for the matching section. Their design uses three stages of amplification. The first stage is a 250-W amplifier using MOSFET technology and is operated class AB1. The second stage is a 5-kW power amplifier using an EIMAC YU-176 planar triode, running class AB2. The final stage has a pair of YU-176 triodes in a cluster-cavity arrangement, also running class AB2. The amplifier has an embedded control unit for local test and fault location. However, when it is installed in a LINAC RF system (Figure 2), control and monitoring of the amplifier are assumed by the VME/VXI processors.

The amplifiers are in the final phase of assembly and test. Delivery to the SSC Laboratory is scheduled for early June 1993.

### IV. DTL RF AMPLIFIER

Four DTL RF amplifiers [2] supply power to four Alvarez accelerator tanks in the DTL [1]. The DTL amplifier klystrons, power supply/modulators, and waveguide components are being obtained from industry after competitive bids. The DTL klystrons, designated TH2140, were purchased from Thomson Tubes Electroniques. Four tubes have completed acceptance testing. The TH2140 has an integrally wound focusing magnet that is comprised of three coils; gun, body, and collector solenoids. The collector, the body, and the upper focusing coil are liquid cooled. The tube assembly weighs 3300 lbs. The RF output is constructed in WR 1800 waveguide. Key characteristics of the TH2140 are listed in Table 3. An important feature of the design is a long-life cathode [7].

The DTL klystron modulator (Table 4) was purchased from the Balboa Division of Maxwell Laboratories, Inc., after an intensive technical and cost competition. It is a line-type modulator with a 20-section pulse forming network (PFN). The PFN is a 30.5- $\Omega$ , 20-section Rayleigh-type network with tunable inductors to achieve the 0.5% voltage ripple requirement and to compensate for pulse transformer droop. The PFN is charged on-command by two Maxwell CCDS-835 power supplies operating in parallel. The CCDS-835 40-kHz series resonant switching power supply. It has a constant current charge rate of 8 kJ/s and can regulate the network voltage to better than 0.1%. This design approach minimizes the number of high-voltage components in the power supply and eliminates the requirement for high-voltage charging switch tubes and their associated circuits.

Modulator parameters will be monitored through a remote control interface by a VME-based processor. The remote control interface will collect all the interlock/fault/ monitoring information from the individual modulator assemblies and route them to the appropriate VME module in the processor crate. Protection from computer and/or operator error will be provided by hardware circuits.

The DTL modulators have passed all critical design reviews, and fabrication and assembly are proceeding on schedule for acceptance test and delivery in late July 1993.

The output waveguide assemblies consist of arc detectors, forward and reverse power detectors, a Y-junction circulator/isolator, waveguide switch and full power dummy load, and various bends and straight WR1800 waveguides. The high-power circulator/isolator is being built for the SSC by Ferrite Components, Inc. The first unit has completed factory tests, demonstrating isolation greater than 25 dB and insertion loss less than 0.1 dB. All of the DTL waveguide components have been purchased for delivery in June-July 1993.

Table 3  
DTL Klystron (TH2140) Characteristics

Frequency	427.6 MHz
Output Power Peak	4.0 MW
Output Power Average	5.0 kW
Pulse Width (Max)	110 $\mu$ s
Duty Factor	0.125
Beam Perveance	$1.4 \times 10^{-6}$
Efficiency	50%
Gain	48 dB
Drive Power	60 W
Bandwidth (-1 dB)	1.0 MHz
Cathode Voltage	125 kV
Cathode Current	64 A
VSWR (Max)	1.30:1
Heater Voltage	25 V
Heater Current	25 A
Cathode Loading	1.0 A/cm <sup>2</sup>
Theoretical Life	100 000 h

Table 4  
DTL Klystron Modulator Characteristics

Type	PFN/Thyratron
Thyratron Tube	ITT F-307
Peak Pulse Power	8 MW
Klystron Peak Beam Voltage	125 kV
Klystron Peak Beam Current	64 A
HV Pulse Flat-Top Width (100%)	90 $\mu$ s
HV Pulse Top Ripple	<0.5% (p-p)
HV Pulse Droop	<1.0%
Klystron Voltage Rise Time	<10.0 $\mu$ s
Klystron Voltage Fall Time	<20.0 $\mu$ s
Pulse Repetition Rate	1 to 10 Hz
Klystron Duty Cycle	0.00105 max
Recharge Time	95 ms
Klystron Peak Beam Voltage Time Jitter	10 ns
Klystron Peak Beam Voltage	
Pulse-to-Pulse Amplitude Variations	0.2%
Approximate size (LxWxH)	11 x 6 x 9 ft
Weight	26 180 lb

### V. CCL RF AMPLIFIER

A 20-MW, 1282.8-MHz klystron amplifier [2] will be used to power each of nine Coupled-Cavity LINAC (CCL) structures [1]. The system design architecture (Figure 2) of the CCL RF amplifiers is practically identical to that of the DTL amplifiers. The VME/VXI control processors run the same software for both amplifiers. This commonality is, of course, an important economical factor in the construction of the SSC LINAC.

The CCL Klystron tube, designated the TH2143, is the product of an upgrade design program [7] conducted by Thomson Tubes Electroniques. Improvements in the gun voltage standoff and the

RF output structure enable these klystrons to provide 20 MW of peak power (Table 5) at pulse widths of 100  $\mu$ s. Three tubes completed qualification and acceptance testing by early April 1993.

The CCL klystron modulator (Table 6) and the DTL klystron modulator (Table 4) are similar in every way except that the CCL supplies four times the pulse energy at nearly twice the pulse voltage of the DTL modulator. The CCL uses five of the Maxwell CCDS-835 high-voltage power supplies operating in parallel.

A tenth CCL klystron amplifier is used to power the two CCL input matching section buncher cavities. This amplifier operates a TH2143 klystron at a reduced beam voltage of 125 kV, supplying a saturated peak output power of 2 MW. The output of the klystron is split in a variable waveguide power divider and routed to the two buncher cavities. One output goes directly to the first buncher cavity, and the other divider output is routed through a variable waveguide phase shifter to the second buncher. Three tubes have been tested at the reduced beam voltage and have demonstrated linearity of control in the desired region of 1.2-MW power output. The flexibility of the CCL modulator and its command charge power supply allows this reduced pulse operation without modification to the modulator.

Table 5  
CCL Klystron (TH2143) Characteristics

Frequency	1282.8 MHz
Output Power Peak	20 MW
Output Power Average	22 kW
Pulse Width (Max)	110 $\mu$ s
Duty Factor	0.11%
Beam Perveance	$2.3 \times 10^{-6}$
Efficiency	>40%
Gain	50 dB
Drive Power	200 W
Bandwidth (-1 dB)	8 MHz
Cathode Voltage	230 kV
Cathode Current	238 A
VSWR (Max)	1.30:1
Heater Voltage	28 V
Heater Current	28 A
Cathode Loading	4 A/cm <sup>2</sup>
Theoretical Life	50 000 h

Table 6  
CCL Klystron Modulator Characteristics

Type	PFN/Thyratron
Thyratron Tube	ITT F-331
Peak Pulse Power	46 MW
Klystron Peak Beam Voltage	230 kV
Klystron Peak Beam Current	200 A
HV Pulse Flat-Top Width (100%)	60 $\mu$ s
HV Pulse Top Ripple	<0.5% (p-p)
HV Pulse Droop	<1.0%
Klystron Voltage Rise Time	<10.0 $\mu$ s
Klystron Voltage Fall Time	<20.0 $\mu$ s
Pulse Repetition Rate	1 to 10 Hz
Klystron Duty Cycle	0.00075 max
Recharge Time	95 ms
Klystron Peak Beam Voltage Time Jitter	10 ns
Klystron Peak Beam Voltage	
Pulse-to-Pulse Amplitude Variations	0.2%
Approximate Size (L x W x H)	12 x 6 x 10 ft
Weight	29 200 lb

## VI. SUMMARY STATUS

The design and production status of the LINAC RF amplifiers is summarized in Table 7. The RFQ and the DTL/RFQ matching section amplifiers will be used in the SSC Central Facility at Waxahachie, Texas, to complete the initial beam commissioning of the accelerator structures up to the 25-MeV input to the first DTL accelerator. Then the systems will be disassembled and transported to the LINAC building on the SSC injector site.

The Transport Line Energy Compressor Amplifier requires a 100-kW power output at 1282.8 MHz. This amplifier will be required on-site and operating in the first quarter of 1995 for the final stages of the 600-MeV beam commissioning.

Table 7  
Status of LINAC RF Amplifiers

UNIT	STATUS
RFQ Amplifier	Completed; in service.
RFQ/DTL MS Amplifier	Fabrication completed; delivery in early June.
DTL Klystron	Four Units delivered; two spares in fabrication.
DTL Modulator	Design complete; in serial fabrication.
DTL Waveguide Assemblies	Procurement cycle complete; delivery in June-July 1993
CCL Klystron	Three units delivered; seven units and two spares in serial fabrication.
CCL Modulator	Design complete; in serial fabrication.
CCL Waveguide Assemblies	In the procurement cycle.
Energy Compressor Klystron	In the procurement cycle.
Energy Compressor Modulator	In the procurement cycle.

## VII. REFERENCES

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