COMMISSIONING OF THE CORNELL ERL INJECTOR RF SYSTEMS *

S. Belomestnykh#, J. Dobbins, R. Kaplan, M. Liepe, P. Quigley, J. Reilly, C. Strohman, V. Veshcherevich
CLASSE, Cornell University, Ithaca, New York, U.S.A.

Abstract

Two high power 1300 MHz RF systems have been developed for the Cornell University ERL Injector. The first system, based on a 16 kWCW IOT transmitter, is to provide RF power to a buncher cavity. The second system employs five 120 kWCW klystrons to feed 2-cell superconducting cavities of the injector cryomodule. The sixth, spare klystron is used to power a deflecting cavity in a pulsed mode for beam diagnostics. A digital LLRF control system was designed and implemented for precise regulation of the cavities' field amplitudes and phases. All components of these systems have been recently installed and commissioned. The results from the first turn-on of the systems are presented.

INTRODUCTION

A prototype of the ERL injector [1], under commissioning at Cornell University's Laboratory for Accelerator based Sciences and Education (CLASSE), is the first step toward the future X-ray light source based on the Energy Recovery Linac (ERL) [2]. The injector faces a challenging task of producing high-current, ultra-low-emittance beam. This, in turn, imposes very stringent requirements on its RF systems [3]. There are three different types of cavities, all operating at 1300 MHz: buncher cavity [4], 2-cell superconducting (SC) cavities [5], and deflecting cavity [6]. Due to different power requirements for buncher and SC cavities, two different RF systems have been developed. The buncher RF is based on a 16 kWCW IOT transmitter. The injector cryomodule (ICM) RF system employs five 120 kWCW klystrons. The sixth, spare klystron is used to power a deflecting cavity in a pulsed mode for beam diagnostics. A new generation of the Cornell low level RF (LLRF) controls is used for precise cavity field regulation. All components of the RF systems have been recently installed and are in the commissioning stage.

BUNCHER CAVITY RF

Main specifications of the buncher RF system are listed in Table 1. As power requirements for this system are quite moderate, an IOT-based high power amplifier (HPA) was chosen. The HPA was manufactured by Thomson-BM. The system includes a 16 kWCW tube TH 713 (manufactured by Thales-ED) incorporated into a modified version of the DCX SIIA broadcast transmitter system. The high voltage power supply is manufactured by NWL. The block diagram of this system is shown in Figure 1. The results of the factory acceptance test and commissioning in a temporary location at Cornell were reported previously in [7]. Recently HPA was moved to its final location and re-commissioned. The commissioning of the complete system is scheduled for summer of 2008.

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#sab@lepp.cornell.edu

Table 1: Buncher RF Specifications

Number of cavities	1
Nominal accelerating voltage	120 kV
Maximum accelerating voltage	200 kV
Shunt impedance, $R = V^2/2P$	2.1 MOhm
Maximum dissipating power	9.6 kW
Maximum transmitter output power	16 kW
Amplitude stability	$8{\times}10^{-3}$ (rms)
Phase stability	0.1° (rms)

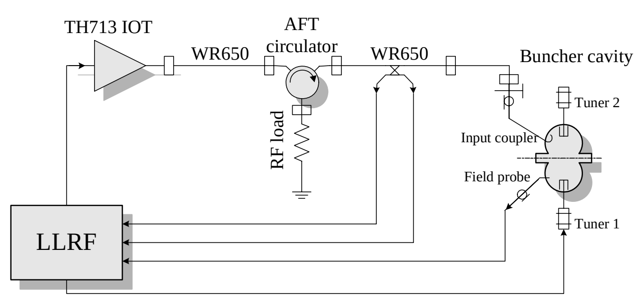

Figure 1: Block diagram of the buncher cavity RF system.

INJECTOR CRYOMODULE RF SYSTEM

ICM houses five two-cell SC cavities, each delivering up to 100 kW of RF power to beam. As each cavity operates independently, the system consists of five identical channels. RF power is delivered to cavities via twin input couplers [8], each carrying up to 50 kWCW. Main parameters of this system are given in Table 2 and its block diagram is presented in Figure 2.

The twin-coupler cavity design requires a complicated RF power delivery system [9]. Many components of the system were tested at high power level prior to installation. Among these key components in the power split are an adjustable short slot hybrid and a motorized 2-stub waveguide phase tuner. Other critical component is a 170 kWCW circulators manufactured by the Ferrite Co.

Four input coupler were tested at high power in a specially designed liquid-nitrogen-cooled cryostat [10].

The test of the pair of prototype couplers revealed week points in the coupler cooling design, which has been improved. The test of two modified production couplers showed stable operation and reasonable heat handling. Maximum RF power level during the test was 61 kW. The test showed that couplers meet requirements of the ERL Injector.

Table 2: Specifications of the ICM RF system

Number of cavities	5
Accelerating voltage per cavity	1 – 3 MV
2-cell cavity length	0.218 m
R/Q (linac definition)	222 Ohm
Qext	$4.6\times10^4 – 4.1\times10^5$
RF power per cavity	100 kW
Maximum useful klystron power	≥ 120 kW
Amplitude stability	9.5×10^{-4} (rms)
Phase stability	0.1° (rms)

The cryomodule RF system utilizes six klystrons K3415LS manufactured by e2v. The 7-cavity tube has saturated output power of about 160 kWCW. To provide very stable regulation of the cavity field, the klystron must have a non-zero gain and therefore cannot operate in saturation. The maximum useful output power for this tube was defined as a power with an incremental gain of 0.5 dB/dB of drive and specified to be no less than 120 kWCW. At this power level the efficiency should be at least 50% and the tube bandwidth not less than ±2 MHz at -1 dB level and not less than ±3 MHz at -3 dB level. All klystrons passed the factory acceptance test meeting the specs at 135 kW and were delivered to Cornell. The tubes are installed (Figure 4) and five of them have been tested so far. Figure 3 shows typical transfer curves of the e2v klystrons.

LOW LEVEL RF

The LLRF electronics for ERL injector is a new, improved generation of LLRF previously developed for CESR [11]. The new electronics, like the old one, uses VME form-factor. However, instead of relying on an off-board VMEbus CPU for network connectivity and for slow analog I/O, it has an on-board CPU for networking. It also has 16 ADC channels and 8 DAC channels for slow analog I/O. The CESR system uses a pair of circuit board that are coupled through the DSP link ports, while the ERL system uses a single board. The number of ADC channels was increased from 4 to 6. The DSP has been upgraded from a pair of 100 MHz Analog Devices ADSP-21160 SHARC chips to a single 500 MHz ADSP-TS201 TigerSHARC. The FPGA has been upgraded from a pair of Xilinx Virtex-II chips to a single Virtex-IV chip. The sampling rate for the PID controller in the FPGA has been increased from 1.5 MHz to 12.5 MHz.

The ERL RF synthesizer is the master oscillator for the ERL injector. A low-noise ovenized oscillator provides the primary 10 MHz reference, which is used to stabilize a 200 MHz VCXO. 50 MHz and 12.5 MHz signals are then generated via appropriate dividers. These signals are used as sampling and clock signals by LLRF digital control boards. The 12.5 MHz signals are also sent to two high frequency PLL circuits, which generate the 1300 MHz RF and 1287.5 MHz LO signals. An Agilent E5052A Signal Source Analyzer was used to measure the phase noise and jitter. The 1300 MHz signal rms jitter integrated from 10 Hz to 100 kHz is 288 fs. The LO signal rms jitter is 294 fs.

The RF Monitor and Interlock circuit provides means of monitoring the RF signals independently of the LLRF operation. There are 11 linear-in-amplitude RF detectors, klystron VSWR and circulator load trip detection, and cavity phase and tuning angle monitors. This unit also provides the transmitter fast interlock and RF shutdown functions. There are 12 opto-isolated input channels, 3 internal trips (klystron VSWR, circulator load reflection, CPU watchdog), and an external trip from the LLRF controller. The unit is controlled by an Arcturus Coldfire board, which also provides RS232 and Ethernet interfaces.

During the first test of the new LLRF with one of the SC cavities the amplitude stability of 10^{-4} rms and the phase stability of 0.05° rms were achieved, exceeding the ERL injector requirements.

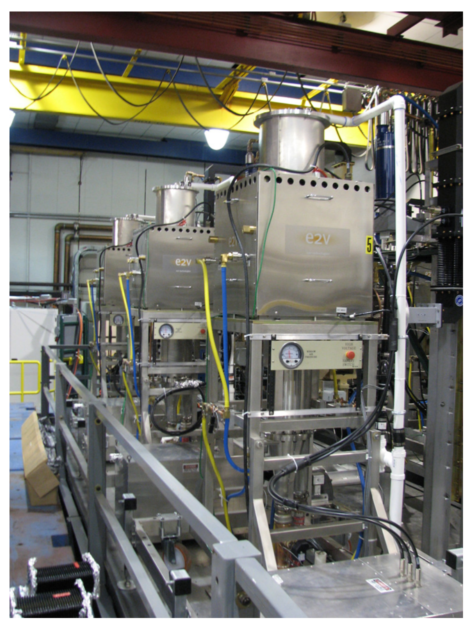

Figure 4: e2v klystrons on a klystron mezzanine.

SUMMARY

The 1300 MHz RF systems for the Cornell ERL injector have been installed and are under commissioning. All assemblies and components tested so far met their specifications. After the RF system commissioning is complete during summer of 2008, beam operation of the injector will be commenced.

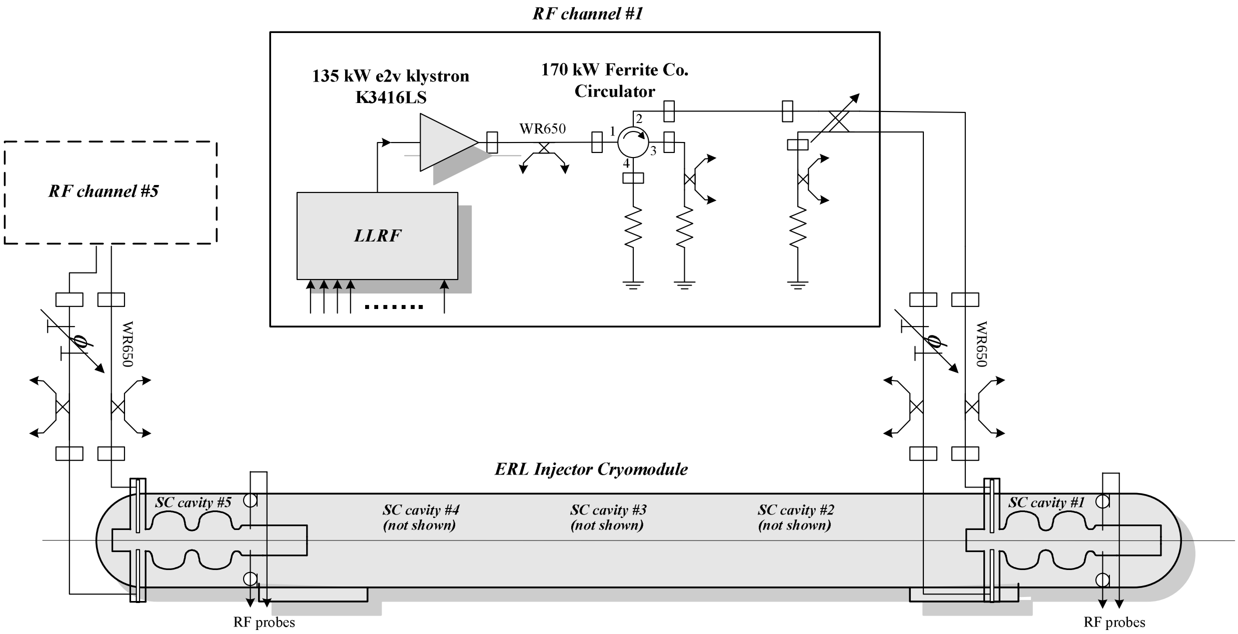

Figure 2: Block diagram of the ICM RF system

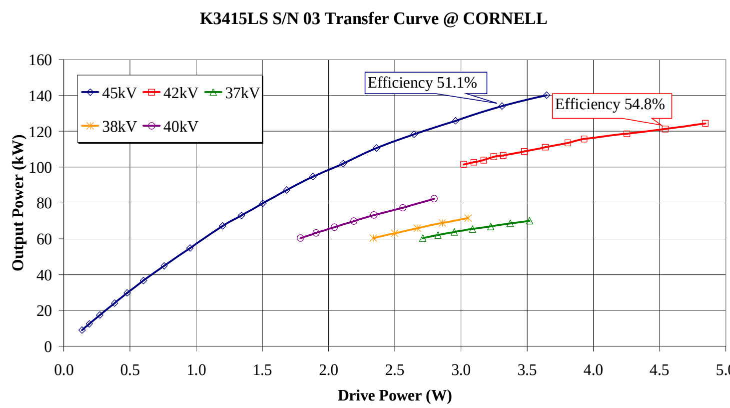

Figure 3: Transfer curve of the K3415LS klystron.

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