

THE CEBAF RF SEPARATOR SYSTEM UPGRADE*

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Abstract

The CEBAF accelerator uses RF deflecting cavities operating at the third sub-harmonic (499 MHz) of the accelerating frequency (1497 MHz) to “kick” the electron beam to the experimental halls. The cavities operate in a TEM dipole mode incorporating mode enhancing rods to increase the cavity’s transverse shunt impedance [1]. As the accelerators energy has increased from 4 GeV to 6 GeV the RF system, specifically the 1 kW solid-state amplifiers, have become problematic, operating in saturation because of the increased beam energy demands. Two years ago we began a study to look into replacement for the RF amplifiers and decided to use a commercial broadcast Inductive Output Tube (IOT) capable of 30 kW. The new RF system uses one IOT amplifier on multiple cavities as opposed to one amplifier per cavity as was originally used. In addition, the new RF system supports a proposed 12 GeV energy upgrade to CEBAF. We are currently halfway through the upgrade with three IOTs in operation and the remaining one nearly installed. This paper reports on the new RF system and the IOT performance.

INTRODUCTION

The CEBAF accelerator has been operating for 10 years steadily increasing the beam energy from 4 GeV up to 5.75 GeV. In that time the original RF amplifiers used to separate the electron beam have been pushed to their operational limit. This has resulted in increased system down time. Three years ago the RF group began an investigation to find a replacement power amplifier for the RF system. An additional requirement was to make the new amplifier compatible with the CEBAF energy upgrade. We settled on what is known as an Inductive Output Tube (IOT). The concept of the IOT was first proposed in the late 1930’s – early 1940’s but it was only in the last 20 years that they have become commercialized, primarily used in the broadcast industry [2, 3]. The system will ultimately incorporate four IOTs operating from a single high voltage power supply. The IOT and power supply is completely autonomous from the RF controls and self protected. The RF control system for the separator RF cavities has also changed. Where as before we had one cavity/amplifier, we now have multiple cavities/amplifier and control the field on the vector sum. To support this RF system we have incorporated inline high power coaxial phase shifters for system alignment. The existing LLRF controls have been modified to support these changes. Three of the IOTs are now operational and the system has been very reliable.

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RF SYSTEM

The CEBAF accelerator has the capability of extracting any one of the 5 passes and sending it to an experimental hall [4]. Each pass has a bank of RF separator cavities that can kick the beam out. The three highest energy passes all are powered by an individual IOT. While the IOT is capable of 30 kW we have limited them to 10 kW. The lowest energy passes (1 and 2) share an IOT in a slave configuration. Figure 1 shows the RF system for pass 5, the highest energy pass. A single IOT output is split 3 ways and then drives the three cavities. In two of the legs, electronically controlled high power coaxial phase shifters have been installed for phase adjustments. In addition, the RF cables from the splitter to the cavity coupler were meticulously measured and trimmed to within ~ two degrees of one another. In a similar fashion the cables for the cavities’ transmitted powers have been measured and cut to a similar accuracy. Field control is maintained by summing the transmitted signals and controlling on the average. Cavity control is presently provided by the original analog CEBAF LLRF system, though this will change in the near future with the addition of a new digital controller [5].

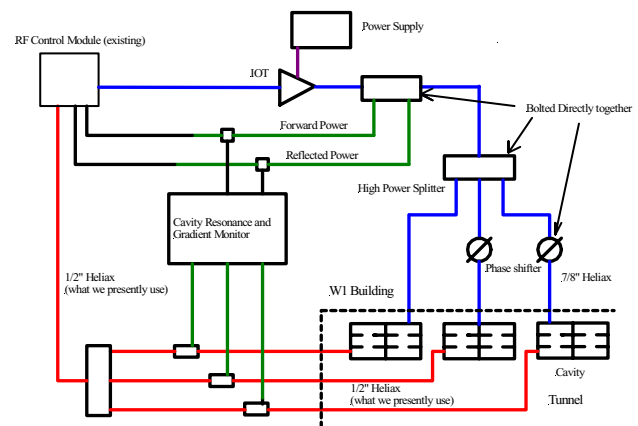


Figure 1: 5th Pass Separator RF System.

First and Second Pass

The first and second passes share a single IOT. Since required RF power goes as the square of the beam energy this can be implemented fairly easily. The energy essentially doubles between pass one and two thereby a 6 dB coupler is needed to divide the output of the IOT. For 6 GeV operations pass one needs approximately 400 watts so pass two would need 1600 watts. Figure 2 shows the First and second passes with one IOT. A coaxial jumper will allow one to choose to operate both passes or just one pass. The RF from the pass not in operation is then fed to

a high power load. A high power phase shifter is used in pass one to adjust the cavity for the proper kick. Pass two is globally adjusted with the RF control module.

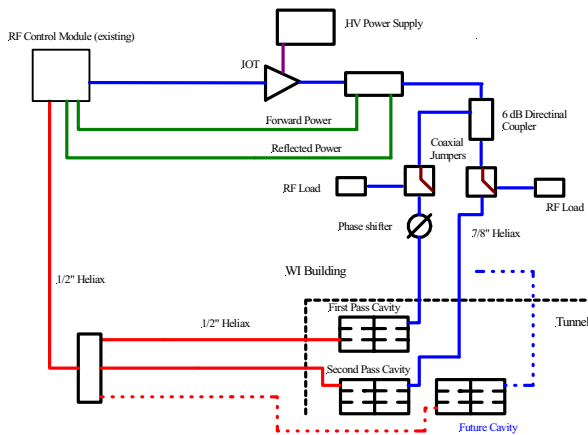


Figure 2: 1st and 2nd pass RF Separator System.

Inductive Output Tube

The inductive input output tube design has been around for many years; but only relatively recently has it been a suitable choice for the broadcast bands. Three reasons for this are its potential for high efficiency, linear operation, and ability to cover the full range of UHF TV broadcast frequencies. The frequency range for these IOTs is from 470 MHz to 860 MHz, with bandwidths of ~ 6 MHz. Output power typically is more than 30 kW. The only downside of IOTs is their relatively low gain, typically 22-23 dB.

After a competitive bid we purchased the Litton L4482. **Litton was purchased by Northrop Grumman, and later became part of L-3 Communications. We have tubes bearing all three names.** Table 1 shows the IOT specifications.

Table 1: IOT Specifications

Requirement	Value
Beam Voltage	21 kV
Beam Current	0.79 A
Quiescent Current	0.15 A
Collector Dissipation	6750 kW
Load VSWR	1.5:1 Max
Center Frequency	499 MHz
Output Power	10 kW
Bandwidth	5 MHz
Gain	23.5 dB
RF Efficiency	60.28%

Figure 3 shows the IOT assembly and trolley. It features a replaceable beam stick (tube) and is solenoid-focused (two coils). It has adjustable external cavities (single-tuned input dual-tuned output). The system requires both air (cavities) and water (body and collector) cooling. Like a klystron, the tube operates with a grounded collector, with cathode, filament, bias, and ion pump all at HV. Collector water fittings have been

modified for our use. Each IOT has a corresponding floating deck unit (FDU) in the rack next to it which has the bias, filament, ion pump power supplies and instrumentation & control. System interlocks include cathode and body current, arc detectors and reflected power. There are no circulators in the system, so a reflected power interlock is set to trip at 500 watts. Due to the low gain the IOTs need a rather large driver amp that is capable of 50 watts to reach full output power. Figure 4 depicts the IOT/Trolley and rack containing the FDU and instrumentation.

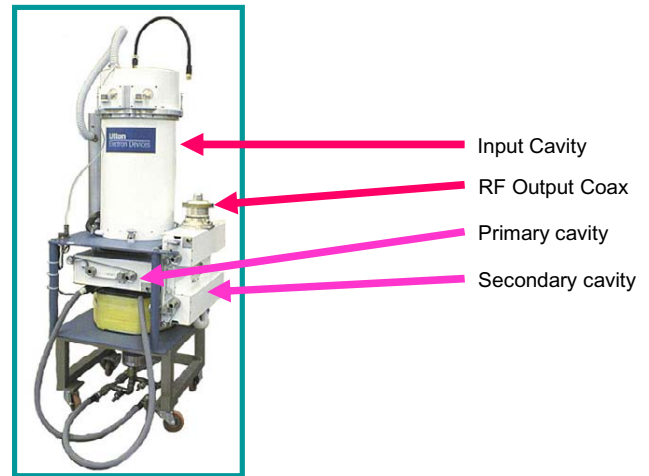


Figure 3: IOT Assembly and trolley.

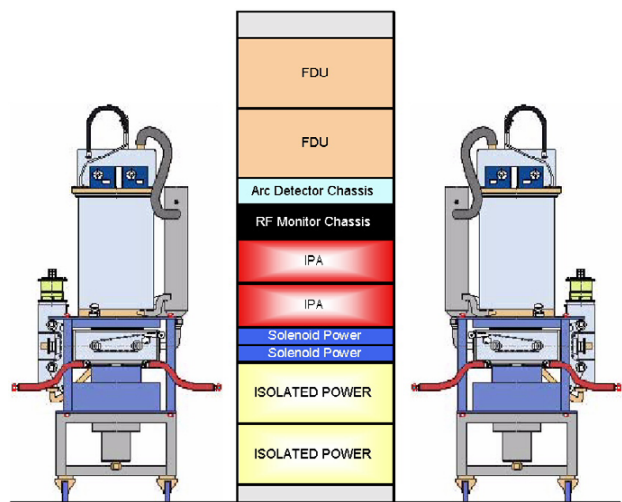


Figure 4: Shows a cartoon of the IOT and control racks.

IOT Controls

The power supply and the four IOTs are controlled using a commercial programmable logic controller (PLC, AutomationDirect 405 series). All of the digital, analog and system interlock inputs and outputs are monitored by the PLC. For the IOT controls each has an individual remote Terminator IO that floats on the high voltage deck of each IOT and is connected via fiber optic link to the main PLC. This controls the filament, bias and ion pump

parameters. In addition to the signals already mentioned above, each IOT is interlocked on water & air flow, ion pump current and cavity vacuum. A fast interlock chassis in the HV power supply monitors body and cathode current. The system is capable of both local and remote control. An Ethernet interface is used to talk directly to accelerator's EPICS control system.

Power Supply

The high voltage power supply is capable of driving four individual IOTs up to 21 kV at 4 A. The HV section is housed in a self-contained interlocked room (Figure 5). Features of the HV power supply include

- SCR front end
- Autotransformer
- 12 pulse step-up transformer
- rectifier, choke, capacitor
- Presently NOT regulated
- E2V thyatron crowbar
- LEM DC current transformers monitor cathode and body current
- Lockable HV cable disconnects for safe bypassing of unused IOTs



Figure 5: HV power supply.

Resonance Control System

The cavities are kept on resonance by a water temperature controlled resonance system. Figure 6 shows a block diagram of the water system. The resonance system uses a separate PLC (AutomationDirect 405 series). A PID algorithm inside the PLC regulates a 208 VAC, 3 kilowatt heater to maintain 120° F water at the heater's output. A mixing valve, which is controlled by a second PID loop in the PLC, then locally mixes the 120 F water with 95° F LCW (Low Conductivity Water) to maintain a constant water temperature exiting the cavity. Presently the system regulates about a fixed temperature. In the future it is intended to monitor the cavity reflected power and control the cavity frequency with the mixing valve. Similarly to the IOT/power supply PLC controls,

the set points can be controlled locally by touch panel or remotely through EPICS.

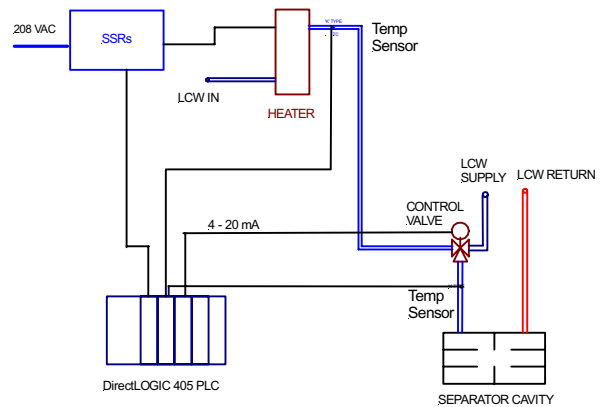


Figure 6: Cavity Resonance System.

SUMMARY

Three IOTs are presently operating on the higher energy passes. Two of them have been operating since October of 2003 and the third since April of this year. The last IOT (for pass 1 &2) is being installed. The resonance systems will be installed by the end of August 2004. The new systems have behaved flawlessly with little downtime. The only complaint so far has been too much kick -- a problem we are happy to fix after languishing with the old solid-state amplifiers.

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