Modular Multi-Purpose RF Amplifier

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Abstract:

RF amplifiers for accelerators are typically custom designs, built in low quantity, and therefore expensive. To reduce their cost, Diversified Technologies, Inc. (DTI) has developed a modular amplifier design, which can produce outputs at different frequencies by changing the output tube and drive amplifier, while retaining the common power supplies, communication, and controls.

DTI has built this amplifier to support both CW and pulsed operation, capable of 20 kW CW at 704 MHz with an amplitude variation of less than 0.01%, or in pulsed mode at 150 kW, 1.5 ms, and 1.3 GHz. This paper discusses the design of the amplifier, which will be tested in the next few weeks.

Keywords: IOT, amplifier, accelerator, power supply, solid state switch

Overview

DTI has developed a cost-effective modular RF power amplifier to meet the requirements for accelerators and other high-power applications (Figure 1). This amplifier consists of solid-state power supplies, control circuitry, and RF drive, along with a high-power RF tube. It uses a switching power supply, and operates the RF tube in Class C, with high bandwidth capability.

Figure 1. Modular multiple-frequency RF amplifier, CW version. The left cabinet holds the inverter, controls and tank for the HV power supply (behind a panel). The middle cabinet holds the solenoid supply, control box for faults and auxiliary supplies, RF metering, RF predriver, and RF driver. The right rack contains a 704 MHz IOT and cavity.

Substantial cost savings come from the standardized control and monitoring systems. All of the amplifiers will have the same control interface, network interface and software drivers. The control system is designed for an EPICS environment.

A similar standardization and cost savings comes from the low-level RF (LLRF) control system, which provides the phase, amplitude, and resonance controls needed for an accelerator. The core of the LLRF control will be the same for all systems, allowing reuse of the digital signal processing control algorithms.

Frequency Range: The amplifier is capable of operating at frequencies from 10 MHz to 1.5 GHz and more, simply by changing the RF tube (whether a tetrode, IOT, or klystron), the drive amplifier, and the mixers and feedback on the digital control board.

Configurations: The amplifier was tested in two configurations, both using IOTs. The first delivered 20 kW CW at 704 MHz, with amplitude and phase variation better than 0.01% and 0.05° RMS, a substantial increase in the state-of-the-art. The major specifications for this CW amplifier are listed in Table 1.

The second configuration of the amplifier produced a 150 kW pulse at 1.3 GHz, and is directed towards the International Linear Collider, focused on a design using concept of a single tube per cavity. This has two potential advantages. First, the feedback will be much simpler for one cavity, instead of the vector sum of 26 cavities. Second, a larger number of smaller transmitters may reduce the overall cost of the RF transmitters, simply by economy of scale.

The main technical issue for the single-cavity amplifier was determining the maximum power that can be produced by an IOT. This power was demonstrated to be substantially

Table 1. Specifications for the 704 MHz CW implementation of the RF amplifier.

Frequency	704 MHz
Power	20 kW CW
Phase variation	0.05° RMS
Amplitude variation	0.01% RMS

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increased over the IOT rated value through cathode-pulsing the tube (demonstrating an increase of nearly 3 dB). Cathode pulsing produces much less stress on the tube insulator than grid pulsing, and allowing higher voltage and output power. Additionally, the modulator functions as opening switch to protect the tube in event of an arc. Since the switch can operate several times faster than a crowbar, the lifetime of the tube is also substantially increased.

System Components

The principal component in each configuration is the RF tube. The system also includes the RF drive and feedback, DC power supplies, modulator, fast fault control, and PLC. We discuss these below.

RF Tubes: The RF tube could have been either an inductive output tube (IOT) or a klystron. We chose IOTs because low phase variation is crucial for the CW amplifier. The IOTs used are the CPI K275W and VKL-9130 for 704 MHz and 1.3 GHz, respectively, with commercial RF drive amplifiers for each configuration.

Digital Low-Level RF Control: The feedback needed to achieve the very-small RF phase and amplitude variation comes from a low-level RF control board. A digital control board is desirable for the accuracy required and ease of modification. We utilized a board [2] developed by L. Doolittle of Lawrence Berkeley Laboratory.

Power Supplies: The high voltage supplies differ for the two implementations, while the supplies for the heater, grid bias, ion pump, and magnet are common to both. The specifications for the supplies are listed in Table 2.

DTI has built the HV supply for the CW amplifier and the supplies for the heater, grid bias, and ion pump, all of which float at cathode potential.

Table 2. Power Supply Specifications for the Two Initial Implementations.

Supply	V (V)	I (A)	Ripple
High voltage (CW)	30 kV	1.33	3 V
High voltage (pulsed)	50 kV	80 mA	-
RF drive (CW)	32	70	3 mV
RF drive (pulsed)	48	0.9	-
Heater	10	15	-
Grid bias	200	+0.2/-0.1	7 mV
Ion pump	3 kV	1 mA	-
Magnet	8	27	-

Figure 2. High-voltage cabinet for the pulsed amplifier. The modulator is at the middle left, and has blue switch plates. This cabinet is air-insulated.

Modulator: The pulsed amplifier has a solid state, series switch modulator, rated at 50 kV and 50 A for cathode-pulsing. It also protects the tube in event of an arc by opening in 1 μs. The modulator is contained in high-voltage cabinet for the pulsed amplifier, as shown in Figure 2.

Fault Control and Communication: In the event of a fast fault, the tube should be protected by shutting down the high voltage supply (for the CW amplifier) or opening the modulator switch (for the pulse amplifier). The response time for this is about 1 μs. The fault detection is handled by a fast-fault control board. Slow faults, such as the ion pump current, are handled by a programmable logic controller (PLC). The PLC also monitors the system status. It is compatible with EPICS, used at Argonne and other large accelerators. Any safety-related faults, such as cabinet interlocks, are hard-wired.

Status

This modular amplifier was tested in both CW and pulsed configurations at DTI in mid-2009, and met all of its specifications for operation in each mode. The CW amplifier configuration has been installed at Argonne National Laboratory, to support testing of RF components for a potential energy-recovery-linac upgrade, to increase the brightness of the Advanced Photon Source by two-to-three orders of magnitude.