MODULAR MULTI-PURPOSE RF AMPLIFIER*

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Abstract

RF amplifiers for accelerators are typically expensive. To reduce their cost, Diversified Technologies, Inc. (DTI) is developing a modular amplifier design. This amplifier can produce outputs at different frequencies by changing the output tube and drive amplifier, while retaining the common power supplies, communication, and controls.

DTI is completing two initial versions of this amplifier. One will produce 20 kW CW at 704 MHz with an amplitude variation of less than 0.01%. The other will deliver pulses 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.

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.

OVERVIEW

DTI is developing a cost-effective modular RF power amplifier to meet the requirements for accelerators and other high-power applications. This amplifier consists of solid-state power supplies, control circuitry, and RF drive, along with a high-power RF tube.

The amplifier is efficient. It uses a switching power supply, and operates the RF tube in Class C, with high bandwidth capability.

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. While the up and down conversion stages will be frequency-dependent, most of the overall design can remain unchanged.

Frequency Range

The amplifier will be capable at operating at frequencies from 10 MHz to 1.5 GHz and more by changing the RF tube, the drive amplifier, and the mixers and feedback on the digital control board.

For frequencies below 400 MHz a tetrode will be used., with different resonators depending on the frequency. For frequencies between 400 MHz to 1.5 GHz the amplifier will use an IOT. Above 1.5 GHz, the amplifier will use a klystron.

Initial Configurations

The amplifier will have two initial configurations, both using IOTs. One will deliver 20 kWCW at 704 MHz, and could be used for a continuous superconducting accelera-tor such as an energy-recovery linac. Argonne National Laboratory is considering an energy-recovery-linac upgrade [1] to increase the brightness of the Advanced Photon Source by two-to-three orders of magnitude. For this application the amplitude and phase variation will need to be 0.01% and 0.05° RMS, a substantial increase in the state-of-the-art. For comparison, the most recent superconducting accelerator built, the Spallation Neutron Source, requires amplitude and phase variations of 1% and 1°. The major specifications for this CW amplifier are listed in Table 1.

The amplifier power of 20 kW is larger than the 5 kW typically needed when an accelerating cavity is matched. The greater power allows for mismatch of the cavity while still producing the required accelerating fields. Note that the resonant frequency of the accelerating cavity

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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

needs to be precisely controlled, since the bandwidth is only a few hertz out of 704 MHz.

The second configuration of the amplifier will produce a 150 kW pulse at 1.3 GHz, and is directed towards the International Linear Collider. In the present design, each klystron drives 26 cavities. We propose an alternate concept of a single cavity per tube. This has two potential advantages. First, the feedback will be much simpler, since it is needed for just 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 by economy of scale.

The specifications for this amplifier configuration are listed in Table 2. The main technical issue for the single-cavity amplifier is determining the maximum power that can be produced by an IOT. We anticipate that this power can be substantially increased over the rated value by cathode-pulsing the tube. This produces much less stress on the tube insulator than grid pulsing, and so allows higher voltage and consequently higher 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 increased, further allowing for higher power.

Table 2: Specifications for the 1.3 GHz Implementation of the RF Amplifier

	IOT Specs	**Test Objective**
Frequency	1.3 GHz	1.3 GHz
Peak power	90 kW	150 kW
Average power	30 kW	2.3 kW
Voltage	42 kV	50 kV
Pulse width	pulsed	1.5 ms

SYSTEM COMPONENTS

The principal component 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

For the frequencies here the RF tube could be either an inductive output tube (IOT) or a klystron. We chose IOTs because their phase is less sensitive to power-supply ripple than a klystron, and low phase variation is crucial for the CW amplifier. Furthermore, IOTs are less expensive and more efficient than klystrons. The tradeoff is that IOTs require a higher-power drive amplifier. However, the required drive power of a few hundred watts is not difficult to produce. The IOTs used are the CPI K275W and VKL-9130 for 704 MHz and 1.3 GHz, respectively.

RF Drive Amplifier

For the 704 MHz amplifier the RF drive amplifier needs to supply at least 130 W to produce 20 kW. A larger drive power, however, gives greater IOT efficiency, so we have specified the drive amplifier to deliver 200 W. We chose a Pineapple Technology PA1K, which is capable of delivering more than 400 W.

The 1.3 GHz amplifier needs a drive power of 400 W to produce 150 kW. We will make this RF predrive amplifier by combining two Microsemi PSM 1214-800P modules.

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 have installed a board [2] developed by L. Doolittle of Lawrence Berkeley Laboratory. For simplicity, however, the initial tests will be done without feedback.

Power Supplies

The IOT needs several DC supplies. The supplies for the high voltage and RF drive 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 3 below. DTI has built the HV supply for the CW amplifier (Figure **2**) and the supplies for the heater, grid bias, and ion pump, all of which float at cathode potential (Figure 3).

The CW amplifier needs to have low variation in the RF amplitude and phase. To minimize this variation, the ripple in the supplies for the high voltage, grid bias, and

Table 3: 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	-

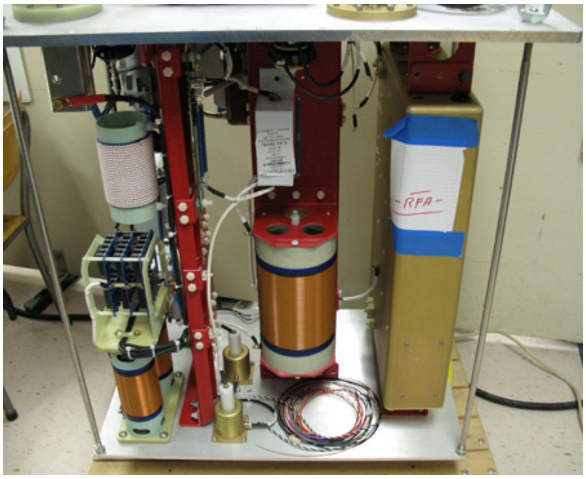

Figure 2: Tank for the CW amplifier. This tank holds the high-voltage power supply, and auxiliary floating supplies. The tank is insulated with oil.

RF drive needs to be minimized, since ripple will modulate the RF output. Though the RF control board provides feedback to compensate for the ripple, the best performance will occur when the feedback has a clean signal to start with.

To reduce the ripple, the supplies use pi-section filters, which give much greater ripple attenuation than a simple capacitor filter. They also store less energy. For a tube arc in the CW amplifier, less than 1 J and 0.2 A^2s will be coupled into the tube despite there being no opening switch or crowbar.

Modulator

The pulsed amplifier has a modulator, which is made of series-connected insulated-gate bipolar transistors. This modulator switches the 50 kV and 5 A required 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 4.

Figure 3: Floating supplies for the heater, grid, and ion pump.

Fault Control and Communication

In event of a fast fault the tube should be protected by shutting down the high voltage (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.

Figure 4: High-voltage cabinet for the pulsed amplifier. The modulator is at the middle left, and has blue switch plates. This cabinet is air-insulated.

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

The amplifiers are nearing completion. Almost all of the hardware has been built. The high-voltage power supply has been tested at power, and we are testing the floating supplies to adjust their feedback. We are finishing the wiring. The modulator will be tested in the next week, and the RF driver will be tested after that. We anticipate full RF testing within a few weeks.

REFERENCES

[1] Michael Borland, “Possible Upgrade of the Advanced Photon Source with an Energy Recovery Linac”, Proceedings of this Conference.

[2] LRF evaluation board, http://recycle.lbl.gov/llrf4/