INDUCTIVE OUTPUT TUBES FOR PARTICLE ACCELERATORS

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Abstract

The Inductive Output Tube (IOT) is not widely used as an RF power source in particle accelerators yet, but this is about to change rapidly. Two classes of IOTs are available so far for this application. One of them consists of UHF external-cavity devices, frequency-tunable and producing output power levels up to 80 kW. The second class has been developed only recently. These are L-band IOTs with internal output cavities for 1.3 and 1.5 GHz, respectively, featuring output power levels between 15 and 30 kW CW.

BACKGROUND

Almost twenty years of successful operation in television transmitters have led to high refinement of IOT technology and to proven reliability for this novel RF amplifier type. This is one reason why IOTs are more and more considered for use in particle accelerators. The other reason is the fitness of the IOT to meet specific accelerator requirements: high efficiency, no need for power back-off to achieve fast feedback regulation, and the possibility to pulse the RF without using a high-voltage modulator.

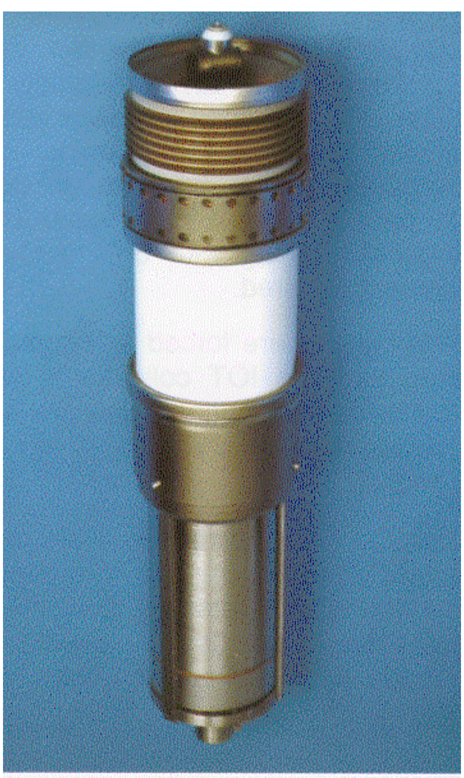

Figure 1: UHF 80 kW CW IOT

UHF-BAND IOTS

CPI/Eimac UHF IOTs cover the frequency range from 470 MHz to 860 MHz with tunable output cavities. They can be used as CW amplifiers with up to 80 kW output power, or up to 130 kW for pulsed applications. Within the UHF band, 500 MHz and 805 MHz are two typical frequencies used in particle accelerators. Figure 1 shows the tube itself; figure 2 depicts the so-called hardware, consisting of the IOT inside the complete accessory set (focusing magnet, input circuit, twin-cavity output circuit, output coupler and water-cooling set).

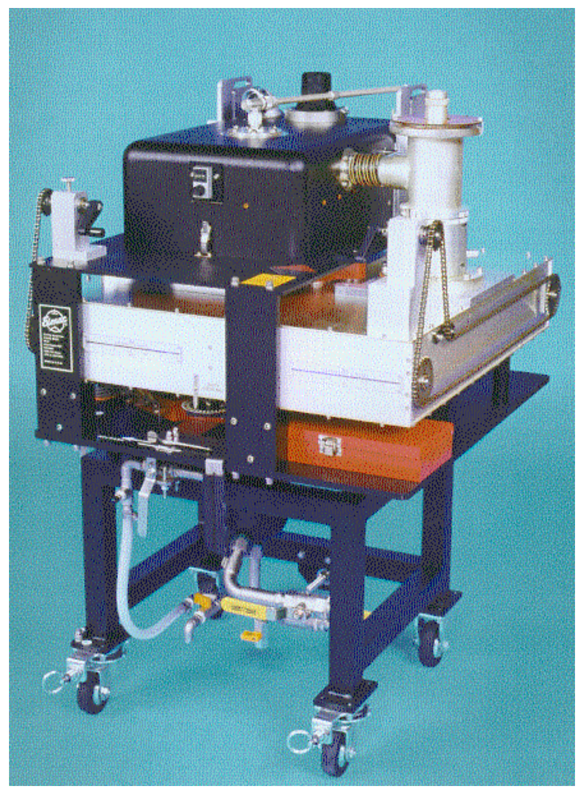

Figure 2: 80 kW UHF IOT Hardware Set

Sets like this one are in operation in several particle accelerator applications:

CW operation

- 5 MeV CW Microtron, MELCO, Kobe, Japan. Two IOTs combined generate 100 kW of RF power at 500 MHz.

- FEL, Japan Atomic Energy Research Institute, Tokai, Japan. Two IOTs are used independently as RF sources for pre-acceleration in super conducting cavities (499.8 MHz). Two more IOTs will be deployed later this summer.

Pulsed Application

- Electron gun, Spring.8, Japan. 120 kW peak, 20 µs, 60 pps.

Table 1 shows a selection of CW operational data at 500 MHz. Moderate Class C biasing results in high efficiency with still very reasonable gain figures.

Table 1: Class C results at 500 MHz

Power Level (kW)	**50**	**60**	**67**	**80**
Beam Voltage (kV)	**30**	**30**	**35**	**35**
Beam Current (A)	**2.14**	**2.67**	**2.6**	**2.98**
Grid Current (A)	**0.14**	**0.24**	**0.14**	**0.22**
RF Drive Power (W)	**190**	**267**	**275**	**380**
Power Gain (dB)	**24.2**	**23.5**	**23.9**	**23.2**
Efficiency (%)	**77.9**	**74.9**	**73.6**	**76.7**

L-BAND IOTs

For most of the time that IOTs exist, it was assumed that the concept was more or less restricted to UHF. 1 GHz was considered a magical threshold for the device. Challenging the assumed limits, CPI/Eimac has designed and built L-Band IOTs, mainly to serve the interest of the particle accelerator community in cost-effective and efficient RF amplifiers in that frequency range. The new L-Band IOT maintained the well-appreciated UHF-Band properties, such as efficiency and linearity. The development project concentrated on minor changes to optimize the beam conversion efficiency at 1.3 GHz, and on an integral cavity that replaced the double-tuned external UHF output circuit. The cathode-grid configuration of the UHF version remained unchanged, because of its well-proven long-life properties. Considerable effort was also made to reduce the cost and the physical size of the hardware. The resulting Eimac L-Band IOT system is compact, money-saving and provides high performance as shown in figure 4. Three L-Band tubes, operating at 1.3 GHz, have been built and tested. An output power level of 30 kW was successfully achieved with 64% power efficiency. The product is ready for implementation in the field.

Figure 3: 30 kW CW L-Band IOT

One of the L-band IOTs is shown in figure 3. In comparison to figure 1 it becomes obvious how much of the UHF-IOT technology has been maintained.

One of the challenges in making an IOT work at 1.3GHz was how to couple the RF into the tube. Since one of the key design goals was to maintain as much of the well-proven standard CW IOT design as possible, the input circuit would have to work with the existing gun assembly. The unique design of the Eimac input circuit utilized in the UHF television IOTs worked well to transfer the 1.3GHz signal into the tube. With some minor modifications to this circuit, and the use of a modified stub tuner, the gain of the L-band IOT is comparable to the one achieved in UHF.

Table 2: 1.3 GHz test results

ltage(kV)	Current(A)	Drive(W)	Output(kW)	Gain(dB)	Eff(%)
24	0.79	208	10.0	17	52.7
25	10	3	15.1		54.9
26	46	3	20.6		54.3
32	1.35	192	25.7	21	59.5
34	1.39	253	30.2	21	63.8

The test results shown in table 2 are taken in Class B operation.

Figure 4: L-band IOT in hardware set

L-Band IOTs feature water-cooled output cavities and collectors. Electron gun, input circuit and the coaxial output line including the ceramic output window are air cooled. The combination of air and water-cooling provides ample redundancy for stable operation for up to 30 kW CW output power. The hardware set, shown in figure 4, has been kept simple, with cost-effectivity in mind.

SUMMARY

Highly efficient IOTs are available for particle accelerator applications in UHF and L-band. They cover CW output power requirements of up to 80 kW in UHF and up to 30 kW in L-band. Pulsed power up to 130 kW can be provided in UHF.

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