INDUCTIVE OUTPUT TUBE BASED 300 KW RF AMPLIFIER FOR THE DIAMOND LIGHT SOURCE

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Abstract

All currently operating synchrotron light sources use klystron amplifiers to generate the RF power for the accelerator cavities. In TV broadcasting on the other hand, Inductive Output Tubes (IOT) are replacing the classical klystron based systems in all new high power UHF transmitters since more than ten years. The Diamond Light Source will be the first synchrotron to be operated using IOTs. For each accelerating cavity a total of four IOTs will be combined with a waveguide combiner to achieve the RF power requirement of 300 kW at 500 MHz. All IOTs will be supplied from a common crowbarless high voltage power supply. Three such systems will be installed starting in October 2004.

The paper gives an overview of the system design as well as the status of the factory installation and testing at the end of June 2004.

IOT VERSUS KLYSTRON

The main reason for the broadcast industry to change-over from klystron to IOT amplifiers was the increase in efficiency. The klystron is a class A amplifier with a constant power consumption from the beam power supply. With a modulated signal as needed for TV the efficiency is very low. With an IOT the amplifier set point can be adjusted for class B or C operation, resulting in an efficiency improvement, mainly for low power operation. Another advantage of using an IOT is the broader availability of this type of tubes, which are produced in high quantities for TV. The same tube types with no or only marginal modifications can be used for RF amplifiers for other applications than TV.

The handling of klystrons is difficult if there is no crane access for the RF area. Klystrons are typically transported in horizontal position and must be tilted for the installation. The typical weight of a klystron is around 1200 kg, requiring handling equipment. The replacement time for a klystron is at least one day, whereas an experienced technician can replace and restart an IOT amplifier in less than one hour.

The main disadvantages of using IOT is listed as follows:

- Low RF gain (22 dB versus > 40 dB)
- Limited power range, max. 80 kW per tube

Taking all of these factors into consideration, Diamond decided in favour of an IOT based amplifier for the storage ring RF.

IOT Data

The Amplifier is based on the TH793 IOT from Thales Electron Devices. This is the highest power IOT available on the market. Table 1 shows the tube data.

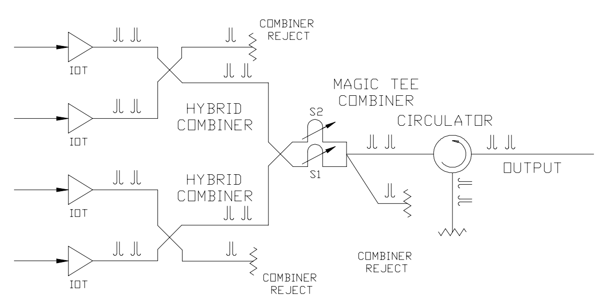
Table 1: TH793 Specifications

Output Power	80 kW cw
Operating Frequency	470 .. 760 MHz
Power Gain	22.5 dB
Beam Voltage	36 kV
Beam Current	3.3 A
Efficiency	67 %

System overview

To achieve 300 kW output power, a combination system which combines the output of 4 tubes is required. To minimize losses inside the combiner, Thales decided to use a waveguide combiner system similar to that used for very high power TV transmitters. The first combination step is performed with classical 3 dB hybrid combiners. The second step is made with a switchless magic-T combiner. This combiner type has two phase shifters implemented, allowing to compensate unequal power on both input ports. The phase shifters are built with movable Teflon blocks inside the waveguides.

Figure 1: RF Diagram



The switchless combiner provides 100% of the input power to the output port with two IOTs as long as these two IOTs are on the same input combiner. Thus operation at reduced power levels can continue without all tubes. With a single tube fault, a total output power of 187.5 kW is still achievable. The combiner also allows single tube operation for testing.

Table 2 shows the possible operation modes in respect to the number of IOT in operation. Due to the symmetry of the combiner, it only lists the number of IOTs on the two input combiners.

Table 2: Operation Modes

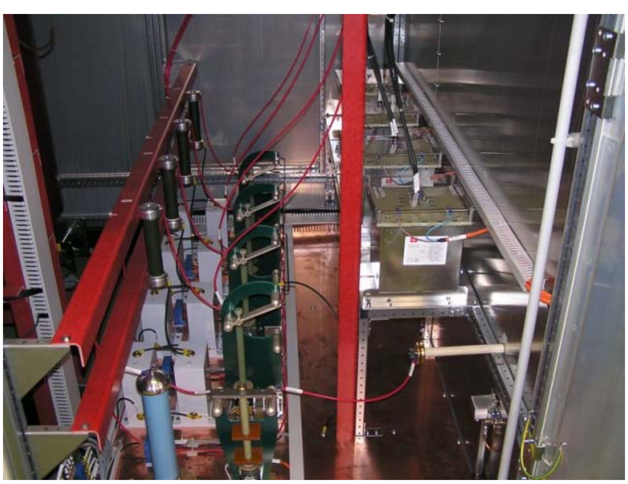
IOT in Operation		Power into Combiner Rejection Load [kW]	Output Power [kW]
One Half	Second Half		
2	2	0	300
2	1	40	187.5
2	0	0	150
1	1	80	75
1	0	40	37.5

POWER SUPPLY

Figure 2: Power Supply Unit

All four IOT of one amplifier are fed from a single high voltage power supply. This power supply, which is based on the Thales Pulse-Step-Modulator (PSM) technology, is already in use for klystron amplifiers at various synchrotron light sources with flexible voltage and power ratings, where it has proven to be very reliable. A fully solid state switched mode power supply without the need for a crowbar, it has proven to be very reliable. It consists of series connected switched mode power supplies with IGBT transistors.

Figure 3: High Voltage Distribution



Since the IOT tubes are connected to the HVPS via solenoid actuated high voltage isolators, enabling the operation of any combination of IOT tubes. All currents and voltages are measured individually for all tubes, achieving a high degree of protection. An automatic wire test assembly makes it possible to test the fast switching off remotely from the control system.

Figure 4: Filament and Grid Power Supplies

The IOT filament, grid and ion pump is supplied from power supplies placed on cathode level. The power supplies are controlled and monitored from the control computer by serial fibre optic links. This allows the remote adjustment of the tube parameters from the control system.

Control System

The control system is based on the EPICS control system. The Input/Output Controler (IOC) runs on a VME-Bus system with a Power-PC CPU. This system provides the control and acquisition functionality and the interface to the DLS control system.

The interlocking functionality is covered by the Interlock Control System (ICS), a special hardware developed by Thales. It is built as a modular system in a 19-inch crate, which can be equipped with interface boards for digital input and output signals.

The ICS allows a very flexible and fast interlocking functionality, based on a state-machine with up to 9 sequential states. The interlocking logic is programmed as a static logic into programmable logic devices (PLD). Completely different sets of interlocking logic are possible for different operation modes. Different modes, such as operation on dummy load, can have different interlocking functionality in this manner. The interlocking function is defined for each signal separately in an Excel table. The generation of the database for the EPICS-IOC and the ICS is done automatically with a Visual-Basic script, and the software into the ICS can be downloaded from a Windows-PC with an adapter cable. Therefore any later change of logic signals can be done easily without special software.

Analogue inputs are processed on analogue interface boards, providing galvanic insulation and adjustable thresholds for interlocking. Each channel is equipped with a debug connector for easy system debugging.

System Layout

The Diamond building is a steel construction with a ceiling supported by vertical columns. Thus the positioning of the system in the building was an important task during the design phase. The waveguide run has to pass above a corridor to the labyrinth and then inside the tunnel. The complete building and machine were modelled by Diamond using the ProEngineer 3D CAD software package. Thales uses the same software for the mechanical design, allowing easy integration of the RF system into the overall building computer model.

Figure 5 shows a 3D view of the RF system. The first combiner hybrids are placed vertically. The IOT tubes are placed alternately in two rows on the entry ports of the combiners. The magic-T combiners are placed horizontally underneath the intermediate floor in this area.

Figure 5: 3D Computer Model of the RF system

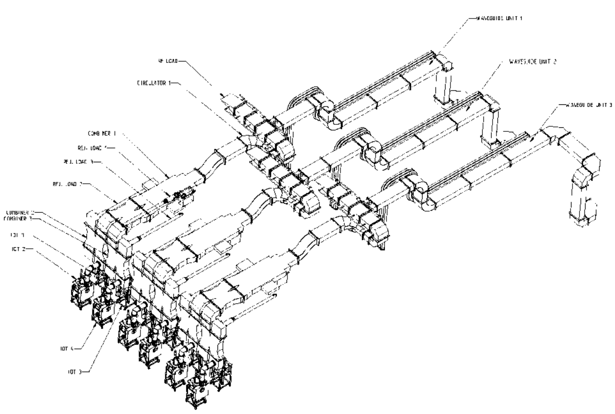


Figure 6: 3D Computer Model inside Building

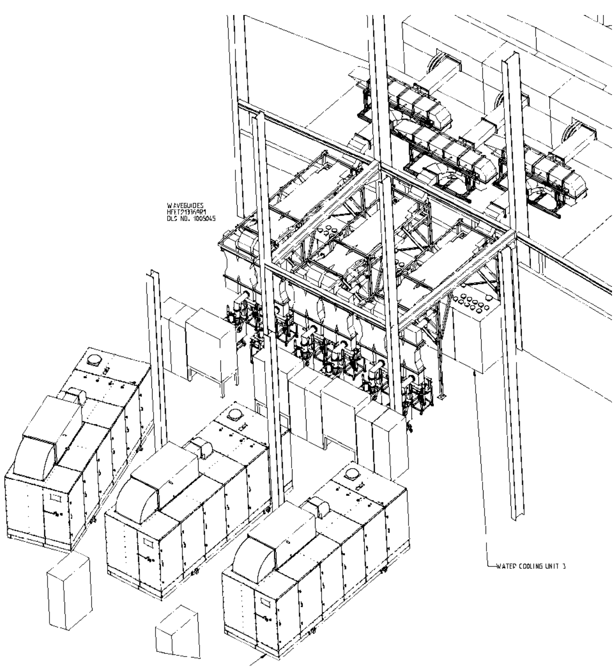


Figure 6 shows the system integrated into the building structure. The power supply units, placed to fit the cable trenches in the concrete slab, can be seen in front. The circulator and circulator loads will be placed on a platform above the corridor which goes all around the building on the inner side of the tunnel. In this area crane access is provided, simplifying the installation of the components. The rest of the system has to be installed without crane. The heaviest equipment will be the magic-T combiner weighting 300 kg. It will be hanged inside a metal frame structure. All components in the RF area will be handled and installed with a fork lift.

The power supply units will be put in place without the transformers, which subsequently will be placed on wheels and pulled into the power supply enclosures.

PROJECT STATUS

The complete combiner system was produced in the Thales Factory in Southwick. MA, where it was tuned and tested shipped to Turgi Switzerland. In Turgi, Thales has all the required infrastructure needed for testing high power equipment. End of June 2004, the first system is under installation in the factory in Turgi, where it will be tested under full power on the circulator load starting in July.

Figure 7: Factory Installation

After finishing the factory testing all three systems will be installed simultaneously at Diamond starting in October 2004. The target is to have all three systems ready for operation end of Mai 2005.