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OPERATIONAL EXPERIENCE WITH IOTS AT ALBA SYNCHROTRON

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Abstract

ALBA is a 3GeV Synchrotron light source in operation since 2012. The RF systems are based in IOT transmitters and a total of 13 80kW IOT amplifiers are used to power the Storage Ring and Booster cavities at 500MHz. The transmitters were initially configured to operate the TH-793-1 and TH-794 from THALES Electron Devices. On 2015, the amplifiers have been adapted to operate also the TH-795 from THALES and the L4444C from L3 Technologies Electron Devices. In this paper, a brief overview of the differences between these 4 IOT models will be presented, as well as operation results for each type of IOT from the point of view of reliability and durability.

INTRODUCTION

The ALBA transmitter was developed in collaboration between Thomson Broadcast & Multimedia (TBM, now Ampegon), Thales Electron Devices (TED) and CELLS. It was originally designed to fit the TH793-1 IOT [1], but it was also a requisite that it would be flexible enough to accommodate different tubes.

TUBE DESCRIPTION

THALES TH793-1 and TH794

Thales proposed IOTs based on electron beam density modulation. A spherical impregnated cathode emits electrons when heated. A pyrolytic graphite grid controls the flow of electrons. The electron beam density is modulated by the grid voltage resulting electron bunches interaction with the output cavity. [2]

The TH793-1 features a plug-in design, making it very easy to exchange tubes. The tube is inserted in the input and output circuit of from the top without dismounting any components. The RF signal is coupled to the grid by means of a coaxial waveguide. Electrical isolation is achieved by means of a small separation fitted with insulating materials. There is a stub tuner at the input to help the impedance match. The input tuning is achieved by modifying the dimensions and position of both the coaxial line and the stub, so total of 4 parameters need to be adjusted which provides a precise tuning of the input bandwidth.

The output circuit consists of two cavities with a fixed coupling in between, achieving a -1dB bandwidth of 7 MHz. Tuning is achieved by changing the size of both cavities, and bandwidth is controlled with the coupling angle between the secondary cavity and the output waveguide, which is adjustable.

Compared to previous designs from the broadcast market, the input window ceramic has a conic shape and the output window was enlarged from 100mm to 114mm to reduce RF field intensity on it. The TH794 is a similar tube with improved electron gun design and manufacturing process. Particularly, the grid to cathode distance has been optimized without sacrificing performance. Given their similarity, the TH793-1 and the TH794 are referred to as TH794 in the rest of the paper.

THALES TH795

The TH795 returned to the 100mm output window and the cylindrical input window of the broadcast tubes. As a result the tube could no longer be installed in the ALBA output circuit. Consequently, an adaptation kit was made to make installation in the available circuits possible (see Fig. 1). The adaptation kit consists of two metallic rings that fill the gap between the primary output cavity and the smaller contacts of the TH795. The addition of this kit does not add significant difficulty to the installation of the tube. To overcome the larger field in the output window due to the size reduction, an increase of bandwidth to 7.5MHz was suggested, which on simulation causes a penalty of approximately 0.3dB in gain and 3% in efficiency, in order to increase the reliability.

Figure 1: a) TH794 b) TH795 c) TH795 adaptation kit.

L3 L4444C

The L4444C (Fig. 2) features a removable cavity design. The input cavity sits on top of the tube. RF power is coupled to the grid through the walls of the input cavity. The loop that feeds the RF power to the input cavity is electrically isolated, from the tuneable coaxial cavity, that is floating at cathode potential, providing a means to directly couple the RF drive signal to the cavity set between grid and cathode. The cavity is tuned inductively by movable doors enabling desired frequency operation.

The output circuit consists of a single output cavity to reduce losses, assembled around the output window. The size of this cavity can be modified to tune the system to the desired frequency and bandwidth is controlled with the coupling angle between the output cavity and the output waveguide, which is adjustable.

Figure 2: The L4444C IOT.

Adaptation of the ALBA Transmitter

In order to accommodate the L4444C in the ALBA transmitter, some modifications were required:

1. Replace the electron gun cooling blower by a more powerful one
2. Update the transmitter control PLC software
3. Add cable adaptors to interface different connector types.
4. Change water and air cooling terminations to adapt to new connectors
5. Move the trolley stand 7.5 cm to the right
6. Adjust interlock levels and calibration of measurement elements.

Modifications 1 and 2 where designed to fit all tube models. Modifications 3 and 4 are implementing with interface elements that can be easily added or removed as needed and modifications 5 and 6 have to be done every time the transmitter is adapted to house a different kind of tube. Modifying the transmitter to house a different type of IOT takes approximately 2 hours.

Table 1 summarizes the main differences discussed previously and also includes typical settings for heater and focusing magnet, as well as cooling requirements.

Table 1: Comparison Table

	TH794	TH795	L4444C
Output cavities	2	2	1
BW -1dB [MHz]	7	7.5	4
Heater current [A]	24.5	24.5	23
Heater voltage [V]	12.5	12.5	6.5
Focusing current [A]	18	23	26
Focusing voltage [V]	5.5	7.3	5.2
Collector cooling [l/m]	58	58	46
Anode cooling [l/m]	2	2	2.2

OPERATION

Once assembled and tuned, all three IOT models have similar operating parameters. Table 2 shows data taken during acceptance tests of 3 units at 40 kW and Table 3 shows data of the same units at the nominal power of 80kW.

Table 2: Operation Parameters at 40 kW

	TH794	TH795	L4444C
Output power [kW]	40	40.2	40.1
Cathode voltage [kV]	-35.8	-36.1	-36.8
Cathode current [A]	2.0	2.3	1.9
Input power [W]	176	208	197
Bias voltage [V]	93	96	126
Grid current [mA]	0	0	0
Body current [mA]	20	17	17
Gain [dB]	23.6	22.9	23.1
Beam efficiency [%]	55.9	48.0	57.3
Bandwidth [MHz]	6.61	7.47	1.91
Serial number	720785	830634	100017

Table 3: operation parameters at 80 kW

	TH794	TH795	L4444C
Output power [kW]	80	80.6	80.1
Cathode voltage [kV]	-35.8	-36.1	-36.7
Cathode current [A]	3.3	3.4	3.15
Input power [W]	379	379	461
Bias voltage [V]	93	96	126
Grid current [mA]	-36	-80	-53
Body current [mA]	29	24	88
Gain [dB]	23.2	23.3	22.4
Beam efficiency [%]	66.9	66.6	69.3
Bandwidth [MHz]	6.61	7.47	1.91
Serial number	720785	830634	100017

Tube Arcing

The most usual failure of the IOT's in ALBA has been internal HV arcing. Usually, the transmitter stops before causing fatal damage to the tube, and operation can be resumed quickly. In the case of the TH794 though, a pause of at least 15 minutes is required prior to activating the HV supply again, presumably to allow the vacuum inside the tube to recover. This is not required in the case of the TH795 and the L4444C.

Table 4 shows the hours accumulated by each tube type during accelerator operation for experiments and the number of arcs registered during that time:

Table 4: HV Arc MTBF Data

	TH794	TH795	L4444C
Number of hours	160450	15970	82825
Number of arcs	349	29	127
Mean time between arcs [days]	19.2	21.5	27.6

Time distribution of the arcs over time is a differentiating point (Fig. 3). In the case of the TH794 arcs happen during the entire life of the tube. Most arcs happen during the first months because tubes more prone to arcing tend to break sooner, are removed from operation, or operated at lower cathode potential and power to improve reliability.

In the case of the L4444C, some arcs occur right after installation, but tubes older than 9 months arc occasionally.

For the TH795, there is not enough data yet to make a reliable statistic, as only two units have reach a significant age.

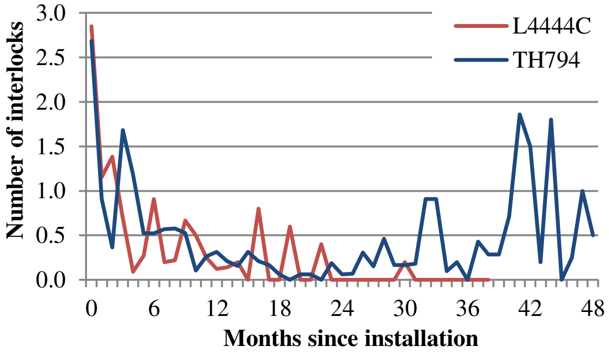

Figure 3: Distribution of HV arcing over time since installation of the tube.

Grid Emission

Grid emission occurs when electrons are emitted from the control grid and might cause malfunction to either the tube or bias supply. It appears when emissive material evaporates from the cathode and deposits on the control grid, so the cathode temperature is a key factor to avoid this effect. HV and the electron beam can worsen it by causing ion bombardment: the electrons ionize gas molecules present in the tube, and the lower potential of the cathode attracts them towards the grid.

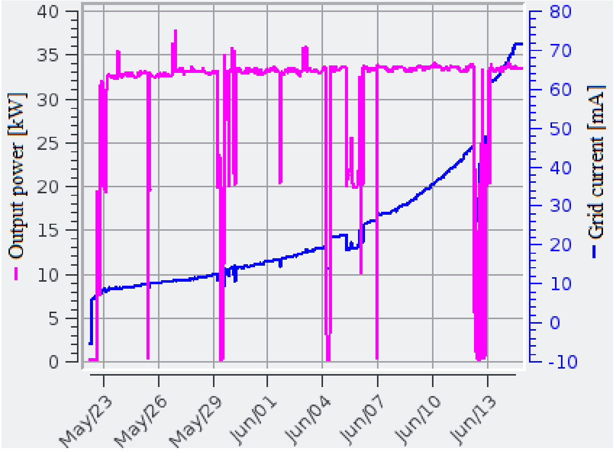

Figure 4: grid emission developing at constant power in L4444C 100014 between 2017 May 23rd and June 14th.

To overcome the situation, the heater current must be reduced to lower temperature in the cathode and grid, reducing electron emission from the grid. But this has to be done carefully, since reducing cathode temperature too much prevents the cathode from emitting enough electrons to achieve the nominal RF output power of the tube. Regular checking to optimise this value is done routinely at ALBA.

Tube Lifetime

TH795 and L4444C have shown excellent reliability in terms of fatal failures, with no tubes broken so far.

The TH794 on the other hand shows weaker performance in this area. Typical failure modes are fissures in the input window due to HV arcs, and cracking of the output window due to high RF field causing localized heating of the ceramic.

Table 5 shows the number of units received for each tube type, and how many of them have broken either the input or output window. A distinction is made for early failures (before 2000 hours of operation). Age is expressed in hours of cathode use.

Table 5: Tube Lifetime Data

	TH794	TH795	L4444C
Total number of units	33	3	15
Units failed before 2000h	7	0	0
Units failed after 2000 h	16	0	0
Average failure time of units older than 2000h	13340	0	0
Average age of available units	23498	7989	8583
Oldest unit	31910	12246	21519

CONCLUSIONS

The ALBA transmitter has proven to be flexible enough to accommodate, with little modifications, tubes from different manufacturers.

RF performance of the 3 tested tubes is very similar, with gains greater than 22 dB and high efficiency, above 66%.

HV arcing is the most common operational issue of IOT's. While the TH794 had issues in this area, often leading to permanent damage, the TH795 improves the arc MTBF a 12%. The L4444C on the other hand has more incidents in the beginning of the life of the tube, but they tend to disappear in the mid-term.

Another key aspect to watch closely during the life of the tube is heater power. A too high setting might cause grid emission, while a too low setting prevents the tube from reaching nominal power.

Finally, tube life time of IOT's has been discussed. Again, the TH795 represents a great evolution in this area compared to its predecessor. No TH795 or L4444C has broken so far.

REFERENCES

[1] P. Sánchez *et al.*, "The ALBA RF amplifier system based on Inductive Output Tubes (IOT)", in *Proc EPAC'08*, Genoa, Italy.

[2] Armel Beunas *et al.* ,"Overview on pulsed UHF sources at Thales Electron Devices", IVEC, 2013 IEEE 14th International Conference.

[3] `http://www2.l3t.com/edd/pdfs/datasheets/L4444.pdf`