

# IMPROVED 1.3 GHz INDUCTIVE OUTPUT TUBE FOR PARTICLE ACCELERATORS

A. Wheelhouse, e2v technologies, Chelmsford, Essex, UK

## Abstract

There is an increasing requirement for RF power sources in the L-band frequency range for operation in particle accelerators. Previously (at PAC 2005), the design, development and initial testing of a new L-band 16kW CW inductive output tube (IOT) was described. This paper discusses the detailed performance characteristics of the latest EEV IOT116LS embodying the most recent design improvements and presents data demonstrating its suitability for operation at 1.3GHz in the next generation of light sources.

## INTRODUCTION

The design of the IOT116LS (figure 1) was based around the established IOT technology used worldwide in the TV broadcast (470 - 860 MHz) market and the existing high power klystron designs used in the scientific market. Additionally the integral output cavity incorporates a capacitive plunger, so that the cavity can be accurately tuned to the specified frequency of 1.3GHz. The IOT116LS was specifically designed for CW operation at 1.3GHz at power levels of up to 16kW, and at PAC 2005 preliminary test results were reported [1]. Since then further development work has taken place to ensure that the IOT meets the demands required from it by synchrotron light source applications that are presently being specified or built around the world. In particular great care and attention has been paid to improving the frequency stability performance of the tube, under both warm-up conditions and operational conditions where the power level may be varied, so as to maintain the required r.f. voltage in the cavity of the accelerator ring. Additionally further characterisation work has been performed to gain a better understanding of the performance of the IOT116LS and the results are discussed.

## DESIGN IMPROVEMENTS

Measurements were reported at PAC2005 on the first number of prototype IOTs, and it was shown that the design of the tube gave good performance in terms of power and efficiency. The requirement for operation at synchrotron light sources such as Energy Recovery Linac Prototype (ERLP) and Fourth Generation Light Source (4GLS) being developed at Daresbury in the UK, require the power level being supplied into the high Q superconducting cavity to be variable, so as to take account of any effects due to microphonics. However it was discovered that in varying the output power on the IOT116LS, the frequency response of the single internal output cavity was seen to shift. Measurements showed

that for a variation in output power from 16kW down to 5kW there was a frequency drift of more than 2MHz. As the tube was designed with only a single output cavity, the bandwidth at the 1dB is typically 3 MHz as shown in figure 2, compared to 6 – 8 MHz on a double cavity system used in TV broadcast IOTs. This meant that the output power from the tube dropped off more rapidly than anticipated as the drive power was reduced, and that the gain also reduced. Similar performance characteristics were discovered when performing cold switch-on tests, as shown in figure 3. It would be anticipated that the output power of the IOT when driven by a constant drive power (equivalent to that required for the tube when stable), would start high and gradually decrease in line with the decrease in the quiescent current as it stabilises. However the output power starts low due to the frequency shift of the output cavity and increases to the operating output power over ~3 minutes.



Figure 1: 1.3GHz IOT in its circuit

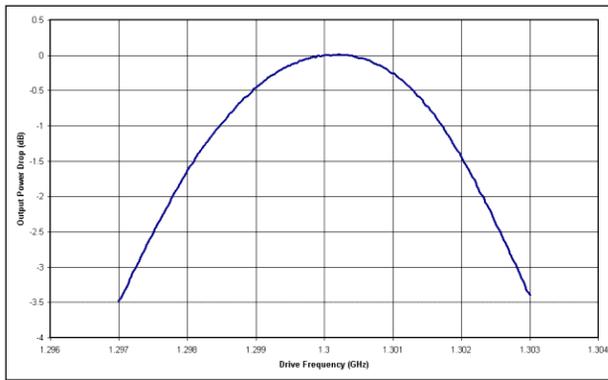


Figure 2: Bandwidth characteristic of the IOT116LS at a beam voltage of 25kV, 16kW CW.

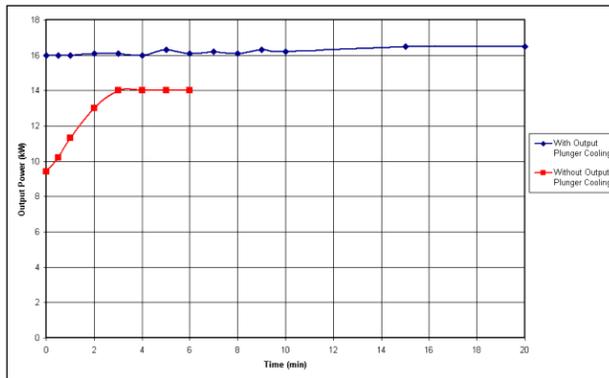


Figure 3: Switch-on characteristics for the IOT116LS with and without water-cooling to the output plunger.

An investigation of the problem was performed to see what had the greatest effect on the frequency performance of the output cavity. The prototype tubes had been designed in such a way that the cooling to the anode, the output drift tube body and the output-coupling loop could be varied. Frequency and temperature variation of the tube were monitored whilst the cooling was varied and the drive power was varied. It was determined from this set of experiments that the greatest contribution to the frequency variation in fact was the plunger within the integral output cavity. The design of the tube was altered to include cooling to the plunger. The result was a tube with no measurable frequency drift whilst the drive power was varied from 2.5kW to 16kW, and a tube that switched straight on at the required operating output power as shown in figure3.

Furthermore an extended power run was performed at 16kW for a 2-week period, with no significant variation in the power level or the performance of the tube seen.

### IOT116LS CHARACTERISATION

Having made these improvements to the IOT116LS it was then possible to characterise the design with a greater deal of confidence. Figures 4 to 5 show that the transfer characteristic for the IOT is very linear from 2kW up to 16kW, whilst operating with beam voltages of 25kV and 28kV, respectively, and for various quiescent currents from ~200mA to near cut-off. Under the 25kV conditions

the gain at 16kW was seen to decrease from 20.8dB at 220mA of quiescent current, to 19.3dB at 10mA, and for 28kV from 21.3dB at 190mA, to 19.5A at 20mA. Additionally output power levels of up to 20kW have been achieved at both 25 and 28kV.

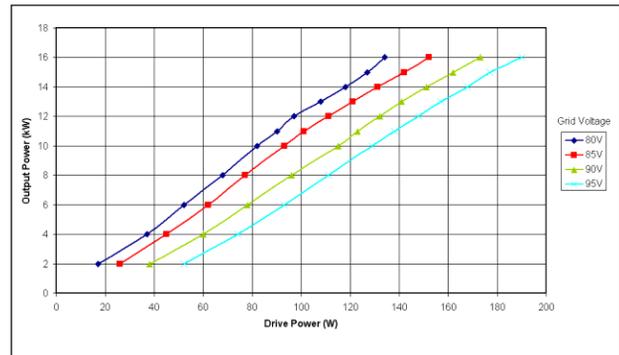


Figure 4: IOT116LS transfer characteristic at a beam voltage of 25kV for various grid voltages.

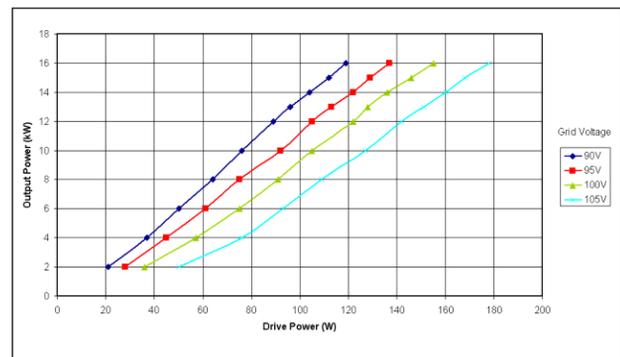


Figure 5: IOT116LS transfer characteristic at a beam voltage of 28kV for various grid voltages.

Figures 6 and 7 show the corresponding efficiency curves for 25 and 28kV, respectively. These correspond well with the computer modelling performed on MAFIA, and show that there are no significant cathode-grid transit time effects as the beam voltage is lowered.

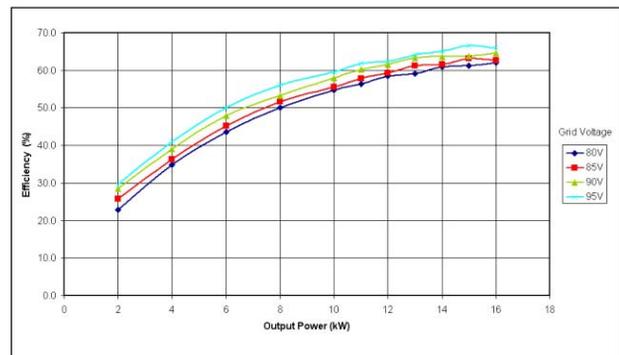


Figure 6: IOT116LS efficiency characteristic at a beam voltage of 25kV for various grid voltages.

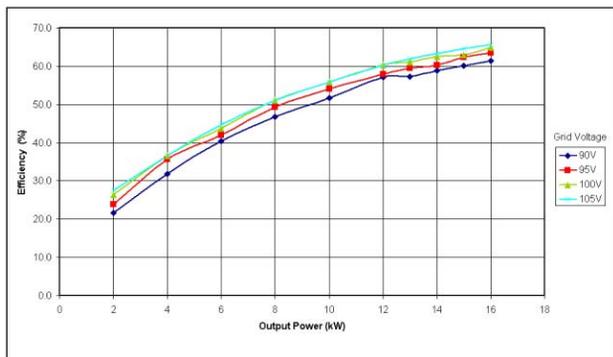


Figure 7: IOT116LS efficiency characteristic at a beam voltage of 28kV for various grid voltages.

The phase characteristics with respect to output power, beam voltage and grid voltage are shown in figures 8 – 10. For an output power variation of 1kW to 16kW there is less than 1.5° phase change, and the phase change for a constant output power of 16.2kW was measured at 0.006°/V and 0.2°/V for changes in beam voltage and grid voltage, respectively. These phase measurements have been found to be repeatable on a number of tubes and this level of a phase variation is well within the capability of standard available phase correctors. These phase variations will be of more importance at Daresbury Laboratory, as for their ERLP, presently being constructed, they plan to pulse one or more of the IOTs, whilst using the same high voltage power to provide the beam voltage on all their IOTs, which will mean that there will be some beam voltage variation due variation in beam current supply loading.

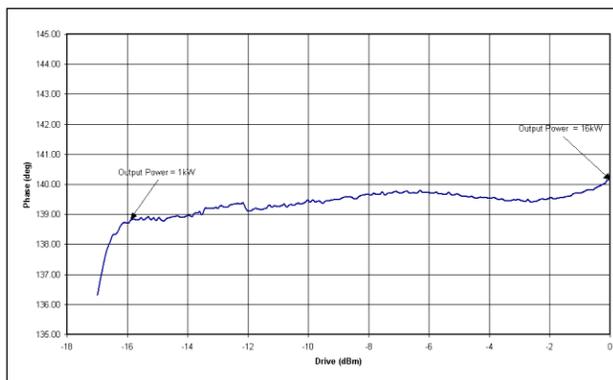


Figure 8: IOT116LS phase characteristic versus output power at a beam voltage of 25kV.

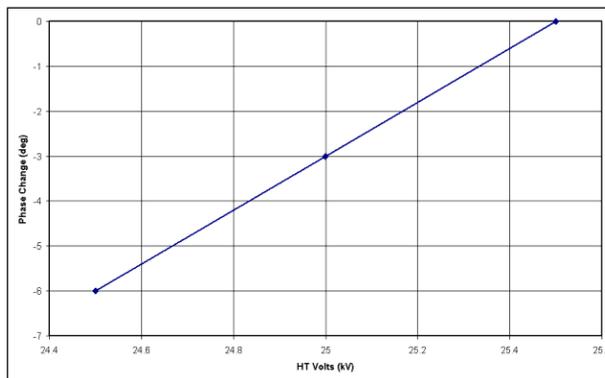


Figure 9: IOT116LS phase characteristic versus beam voltage for an output power of 16.2kW.

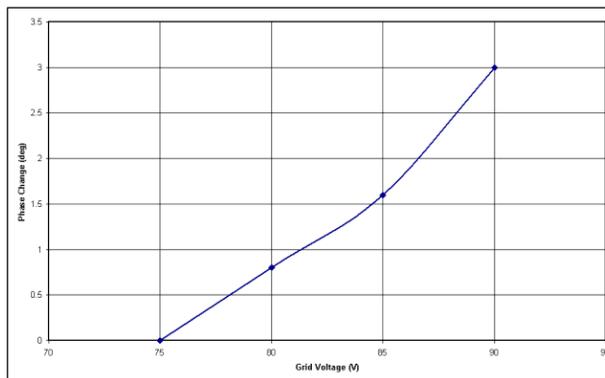


Figure 10: IOT116LS phase characteristic versus grid voltage for a beam voltage of 25kV and an output power of 16.2kW.

### SUMMARY

From the discussion above it can be clearly seen that improvements have been made to the IOT116LS, which show that it is ideal in meeting the requirements of the synchrotron light source community in providing an r.f. power source at 1.3GHz for their accelerating cavities.

### REFERENCES

- [1] E. Sobieradzki and A.E. Wheelhouse, “A 1.3GHz Inductive Output Tube For Particle Accelerators”, PAC 2005 - Proceedings, Knoxville, Tennessee, May 2005, p. 3883.

### ACKNOWLEDGEMENT

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