THE PROVISION OF HIGH POWER CW RF POWER FOR PARTICLE ACCELERATORS

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Abstract

High power cw RF power for particle accelerators has traditionally been provided by superpower klystrons, with output powers up to 1.3 MW. As these devices have been developed solely for this market, there is a limited and diminishing manufacturing base. The use of combinations of television Inductive Output Tubes (IOTs) is now being considered for new light sources and upgrades to existing facilities. The results of power tests, at 500 MHz and narrow bandwidths, of television IOTs with single output cavities are described, as are the results of simulations of combining multiple IOTs with a common output cavity.

1 INTRODUCTION

In the recent past high power cw RF power for particle accelerators, particularly light sources has been provided by high power klystrons. During the past year the number of manufacturers of these devices has decreased, so the possibility of using both high power and television Inductive Output Tubes (IOTs) has been being considered for the UK's new light source DIAMOND. This paper briefly explains the main differences between klystrons and IOTs, and demonstrates the means of obtaining the required RF output power, using DIAMOND as an example. It makes use of work from Marconi Applied Technologies in Chelmsford, Essex CM1 2QU, UK and Heinz Bolen of CPI in Palo Alto, CA 944303, USA.

2 RF REQUIREMENT OF DIAMOND

The DIAMOND Light Source is a 3 GeV, 300 mA storage ring with a circumference of 560 m. The energy loss per turn from the bending magnets is ~ 1MeV, with a further loss of 0.13 MeV from the initial 7 insertion devices (IDs) and 0.73 MeV from a full compliment of IDs.

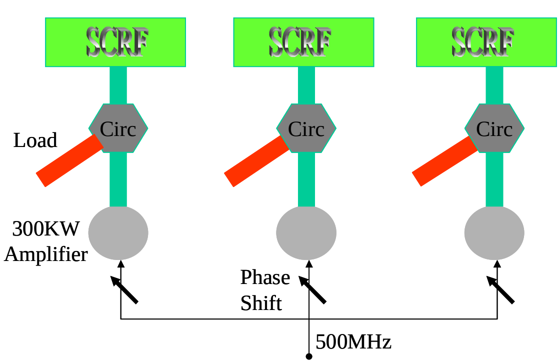

Figure 1: Generic Layout of RF Components

It has been decided to use superconducting (SRF) cavities of either the CESR or KEKB type at 500 MHz. The acceleration voltage of up to 4 MV only requires about 100 W of RF power. However the beam power at 300 mA is 536 kW, and if upgraded to 500 mA is almost 900 kW.

Figure 1 shows the generic layout of 3 SRF cavities in a single long straight each being fed by one 300 kW RF amplifier system.

3 KYSTRON – IOT COMPARISON

3.1 Klystron

The klystron is an RF amplifier that uses velocity modulation of a dc beam of electrons to amplify the RF input. It uses several bunching cavities, which are usually integral to the klystron, and is therefore a long device. If it is operated at reduced power there is a rapid reduction in the operating efficiency, for example during the life of a storage ring beam. It is a high gain device, typically 40dB.

The expected life of a superpower klystron is approximately 35,000 hours. The usual failure mode is loss of emission from the cathode. The klystron can be re-gunned, a maximum of twice, which costs approximately 60% of a new klystron.

Superpower klystrons operating at 500MHz with output powers of 300 kW are available from industry. However the manufacturing base is decreasing, consequently becoming more expensive. As there is a relatively small number produced, the lead-time and manufacturing time is long.

3.2 IOT

The IOT amplifier uses a grid to density modulate the electron beam, and so has no bunching cavities, making it a short device. It can have a higher output cavity gap voltage, which in part contributes to the higher efficiency than that of a klystron. The efficiency is approximately constant for reduced output power. However the gain is low at around 23 dB.

The expected life of an IOT is approximately 35,000 hours. The usual failure is loss of emission from the cathode. The IOT can be re-gunned, a maximum of twice, the cost is approximately 60% of a new IOT. The RF circuits are external to the television IOTs, and a replacement IOT is approximately 67% of the initial system.

At present most IOTs are produced for television transmission, consequently the maximum power generally available from the 3 manufacturers is 60kW cw power.

The input and output cavities are external to the IOT. As the television market is very large, with tens of these IOTs being produced each week.

Some manufacturers are willing to develop a high power IOT with cw powers in excess of 300 kW. However these would also have long lead-times and manufacturing times. Figure 2 shows the comparison of size between the klystron and IOT with the same output power.

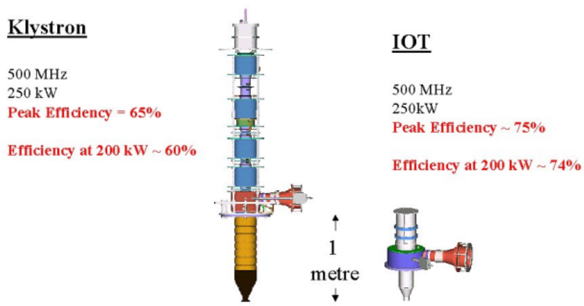

Figure 2: Comparison of size between the klystron and IOT with the same output power.

4 COMBINING TELEVISION IOTS

Television IOTs generally operate at high peak, medium average power, but not continuous wave (CW). They have a double cavity output circuit to obtain the necessary operating bandwidth for television operation, and the cavities can be tuned over the band 470 – 810 MHz. The IOTs only have an operating efficiency of ~50% in this application. However for operation in particle accelerator RF systems, particularly light sources, they need to operate CW, at a fixed frequency with a small bandwidth. This results in an operating efficiency greater than 70%.

To obtain the required power levels with current devices they will need to be combined.

4.1 Magic Tees

The simplest and easiest way to combine any power amplifier is to use magic tees or 3dB couplers. This has the advantage of bandwidth, but requires space, extra load resistors and is costly

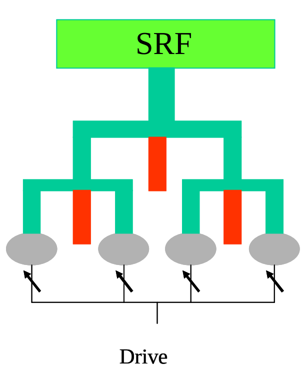

Figure 3: 4 IOTs combined using magic tees

Figure 3 is a representation of combining 4 IOTs with magic tees.

4.2 Single Output Cavity with a Common Combing Cavity

As the particle accelerator application requires a bandwidth of 1 – 2 MHz, Marconi Applied Technologies have tested their IOT 8585[1] with a single output cavity to improve the efficiency. The results of some of the tests are shown in Table 1.

These show that high efficiencies can be achieved, and that by changing the beam voltage that the IOTs can operate at much reduced output power with similar efficiencies.

However, simulations show that it is difficult to combine a number of these IOTs in a common combining cavity.

Table 1. Test Results on Marconi Applied Technologies IOT 8505

	Test 1	Test 2	Test3
Beam Voltage (kV)	35	35	25
Beam Current (A)	2.38	1.58	1.77
Grid Voltage (V)	108	108	74
Body current (mA)	54	12	7
Input Power (W)	250	140	140
Output Power (kW)	60.0	30.0	29.9
Efficiency (%)	72.0	54	67.6

Heinz Bolen, using CPI proprietary one-dimensional computer code MSDC-IOT, showed that when using a single cavity output and a TM_{020} combining cavity, it was difficult to find an adequate impedance on the steep slope of the frequency response curve, see figure 4.

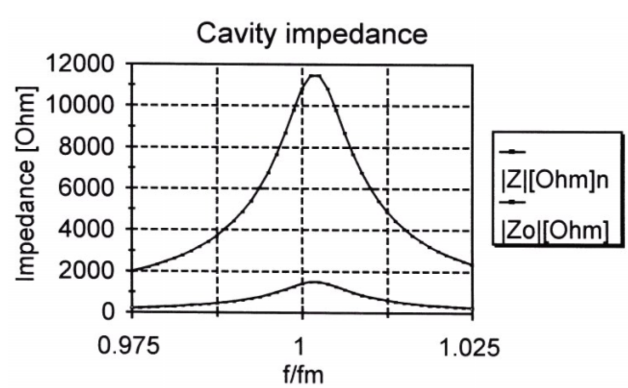

Figure 4: Frequency response single cavity

4.3 Double Output Cavity with a Common Combing Cavity

If, however, the standard double cavity system is used it is easy to find an operating point on the gentle slope of the frequency response. Figure 5 shows the curve and table 2 the results of combining 6 IOTs in a common TM_{020} cavity.

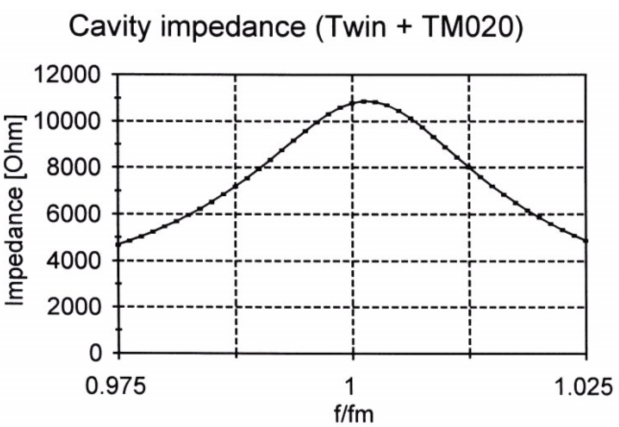

Figure 5: Frequency Response Curve for Double Cavity

Table 2.Six IOTs combined with a Combining Cavity

Frequency (MHz)	500
Beam Voltage (kV)	34
Grid Bias Voltage (V)	-75
Gain (dB)	25.1
Efficiency (%)	72.6
Output Power (kW)	306.4

Figure 6 shows what happens if one tube fails. As can be seen the degradation is graceful, and it is possible to compensate for the failure of one tube by increasing the drive to the other tubes.

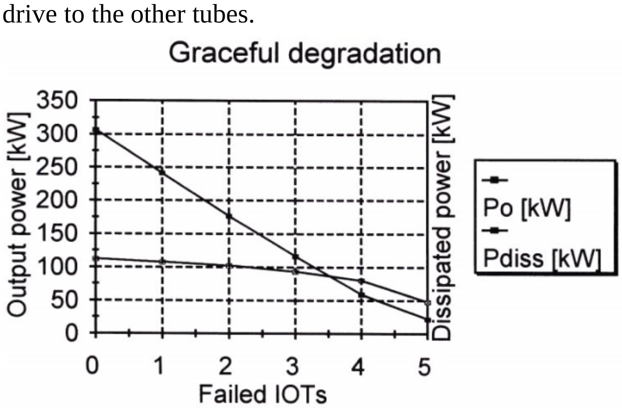

Figure 6: Power degradation as IOTs fail.

Figure 7 is a representation of 6 IOT's combined.

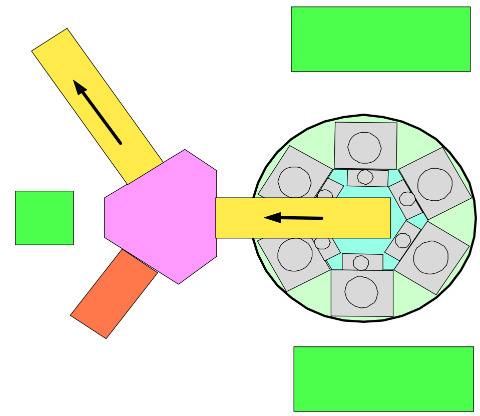

Figure 7: Representation of 6 IOT's combined

5 SUMMARY

It is possible to combine television IOTs using magic tees to obtain economically power levels up to 300 kW for use in particle accelerators. However, simulations show that using a combining TM_{020} cavity is more elegant and space saving, and will be cheaper to produce.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] http://www.marconitech.com/iot/products.php