A NEW GENERATION OF GRIDDED TUBES FOR HIGHER POWER AND HIGHER FREQUENCIES

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1 INTRODUCTION

Until recently, triodes and conventional tetrodes have satisfied most of the requirements in accelerators applications. The present and future physicists specifications in this field, calling for increased duty factor, peak power, pulse length and reliability, reach or exceed the possibilities of such components. Power grid tubes technology must evolve to answer these demands.

2 LIMITATIONS

2.1 Triodes

Triodes can reach very high peak power (3 to 5 MW). But for these ratings, the control grid current is very high and the dissipating power capability of the grid only authorizes very short pulse duration (≈ 1 ms) and very low duty factor (≈ 1/100).

<u>Operational examples :</u>

TH 116:	2.2	MW	3/100	700 ms	200 MHz
7835:	4	MW	6/100	2000 ms	250 MHz

2.2 Tetrodes

Tetrodes do not have the problem of excessive control grid current. Because of the positive screen grid voltage, high output power can be reached with a very low control grid current. With the other advantage of good efficiency, tetrodes have been developed for high average or cw power.

<u>Operational examples:</u>

TH 526 / TH 525
VSWR _ 1.5 / 2 MW / 30s / 12.5% duty factor up to 80MHz
VSWR _ 1.1 / 1.5 MW CW up to 60 MHz
TH 781
VSWR _ 1.1 / 200 kW / 200 MHz / CW
VSWR _ 1.1 / 300 kW / 110 MHz / CW
VSWR _ 1.1 / 400 kW / 200 MHz /1.4 ms / 120 Hz
TH 681
VSWR _ 1.1 / 130 kW / 200 MHz / CW
VSWR _ 1.1 / 200 kW / 110 MHz / CW

The TH 525 / TH 526 are operational in accelerators and fusion applications. The TH 681 and TH 781 are in use in industrial accelerators or for cavities testing.

2.2.1 Limitations with the conventional tetrodes

Tetrode in an amplifier is a part of the one quarter or three quarters wavelength resonant circuit. Also its geometrical dimensions act on and dictate the RF voltages and currents (left hand side of fig. 2). The power delivered by tetrodes is the product of the plate RF voltage by the fundamental anodic current. As explained below, the RF voltage is necessarily limited to 30 kV maximum; therefore, reaching high performances requires a large cathode area. This increase of the cathode area can be achieved in two ways:

<u>Cathode diameter</u>

Cathode diameter increase has two effects on the electrical parameters:

- a lowering of the TE11 resonance mode frequency. If this frequency is too close to the nominal frequency or to the first harmonic, it will be difficult, if not impossible, to damp parasitic oscillations.
- an increase of the tube end stray capacitance.

<u>Cathode height</u>

The rule of experience adopted by the tubes' manufacturers is: never exceed 1/16 of wavelength for the height of the cathode at the highest operation frequency when the tube works at high duty cycle. For example, at 80 MHz the maximum height would be 234 mm.

This rule has to be interpreted and is dictated by the RF losses generated on the tube electrodes, in particular on the screen grid mesh.

In the output circuit, in the space between screen-grid and anode, RF voltages and currents can be represented by these two equations:

$$V(x) = Vmax \,.\cos \beta x = \sqrt{Pout \,.\, RL} \,.\cos \beta x$$

$$I(x) = J\,\frac{Vmax}{Zc}\sin \beta x \qquad with: \beta = \frac{2\pi}{\lambda}$$

X = distance from the top of the tube
RL = load impedance applied on the tube
Vmax = voltage on the axis (at x = 0)
Zc = characteristic impedance of the anode-screen grid space.

In the last cm of the screen-grid mesh, if R is the resistance of the screen-grid taking into consideration the skin effect, the RF losses P will be:

$$P = R \cdot \left(\frac{Vmax}{Zc}\sin \beta l\right)^2 \qquad \text{If } l = \lambda/16,\ \ \beta l = 22.5°$$

Example: Vmax = 20 kV
Zc = 8 Ω
R = 1 mΩ
P(at x = λ/16) = 915 W
P(at x = λ/32) = 238 W (see fig. 1)

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Losses being proportional to the maximum anode voltage, this voltage must be relatively low, depending on the frequency, and in all cases not higher than 30 kV.

These V(x) and I(x) equations clearly show that the distribution of voltage and current along the screen-grid to anode space is not uniform. Consequently, the power distribution is also not uniform, and power is higher at the top than at the bottom. We can see also that the power capability of the tube is depending on the frequency of operation. After analysis of these physical realities, THOMSON TUBES ELECTRONIQUES has developed the Diacrode to overcome the conventional tetrode limits.

The Diacrode design combines in a tetrode the capabilities and advantages of an up-to-date technology with the concept which had been implemented by RCA long time ago in their very high peak power double ended triodes.

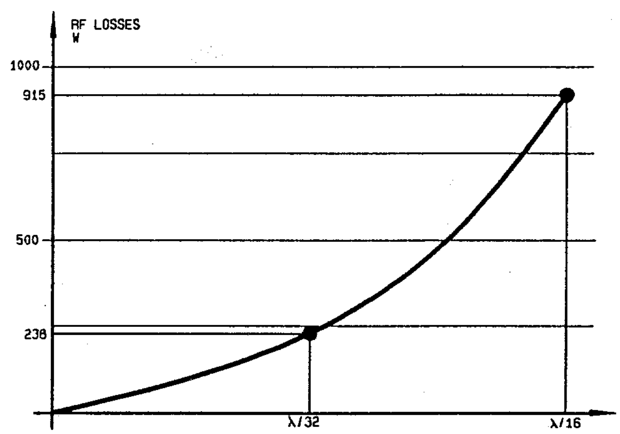

Fig. 1 RF losses versus screen grid length

3 THE DIACRODE

As discussed above, the tetrode main limitation is the length of the active part of the tube relative to the wavelength.

3.1 Diacrode or double ended tetrode

The losses variations are proportional to the square of the cathode height. So, the idea is to obtain the same equivalent height for the cathode by putting in parallel two half tetrodes. In this case, the connections are double and with a proper output circuit this device can be tuned in a half wavelength with the maximum anode voltage placed in the middle of the active part (fig. 2). With this conception, the voltage variation along the active part of the tube and the losses are minimized. So, with this kind of tube, the maximum acceptable length for the cathode is not l/16 but l/8 and the power can be double, provided that the operating point is carefully chosen.

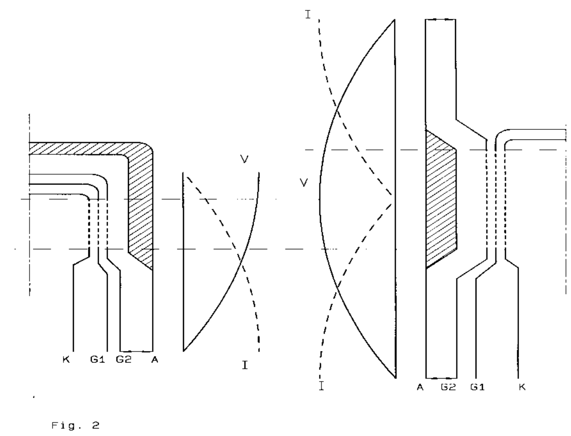

Fig. 2 Tetrode to diacrode evolution

3.2 Results

This principle has already been applied by THOMSON TUBES ELECTRONIQUES.

In UHF TV (470-860 MHz) the most powerful tetrode was the TH 563 which can deliver 30 kW in combined amplification of vision and sound.

The diacrode TH 680 with its double height cathode compared with the TH 563 can deliver 60 kW in combined amplification of vision and sound. A prototype of the diacrode TH 628 is now in testing phase. The measured results are compared below with those obtained with the tetrode TH 526 currently used in accelerators and in fusion Tokamaks.

TETRODE TH 526 / DIACRODE TH 628
- RESULTS AT 200 MHZ -

	PULSED OPERATION	
	TH 526	**TH 628**
Pulse duration (ms)	1.2	2.5
Peak output power (kW)	1600	3000
Average output power(kW)	240	600
Anode voltage (kV)	24	26
Screen-grid voltage (kV)	1.5	1.6
Control grid voltage (kV)	- 0.315	- 0.550
Anode current (A)	124	164
Screen-grid current (A)	3.6	5.1
Control grid current (A)	4.5	3.6
Peak input power (kW)	64.9	122.5
Gain (dB)	13.9	13.9

TETRODE TH 526 / DIACRODE TH 628
- RESULTS AT 200 MHZ -

	CW OPERATION	
	TH 526	**TH 628**
Output power (kW)	300	1000
Anode voltage (kV)	11.5	16
Screen-grid voltage (kV)	1.5	1.6
Control grid voltage (kV)	- 0.315	- 0.300
Anode current (A)	75	96
Screen-grid current (A)	0.8	2.97
Control grid current (A)	0.85	1.96
Input power (kW)	21	32
Gain (dB)	**11.5**	**15**

4 CONCLUSION

Power grid tubes need a large cathode area to cope with the limitation brought by the maximum allowed anode voltage. Cathode diameter increase is limited by the TE11 parasitic oscillation frequency. Cathode length increase is limited by a poor utilization of this cathode, and by the excessive RF losses on the screen-grid (in its lower part mainly), resulting in unacceptable high temperatures inside the tube. This problem shows that the tetrode has some limitations which can not be overcome with the conventional tetrode design. These limitations can be circumvented by the use of the diacrode concept. THOMSON TUBES ELECTRONIQUES has demonstrated the validity of the Diacrode principle and design first with its TH 680 UHF TV Diacrode now in operational service in a number of commercial TV transmitters. In another frequency and power range, tests have been effected with the TH 628 on our own high power test facility in THONON. The results which were expected have been measured and are now a fact. At 200 MHz, the targets of 1 MW CW and 3 MW pulsed with high duty cycle have been achieved. The knowledge acquired by TTE with its family of Diacrodes allows to go further. Then, the next step for TTE is to develop a new diacrode for fusion application. The performance target of 3 MW CW on VSWR £ 1.1 at 70 MHz can be considered as a realistic goal.

DIACRODE TH 628