# HIGH POWER L-BAND KLYSTRONS FOR LINEAR ACCELERATOR

G. Faillon - E. Boghossian - Ph. Guidée

THOMSON-CSF Division Tubes Electroniques
38 rue Vauthier BP 305
92102 Boulogne-Billancourt Cedex, France

ABSTRACT

The use of L-band Linear Accelerators for a large range of applications has become very widespread during the past years ; these Linacs operate at 1.3 GHz, usually in a medium energy range, which allows to drive a high electron beam for appropriate industrial applications, such as irradiation, sterilisation and hardening of solid state devices.

In addition to these still-active application areas, a renewal of the L-band Linacs has arisen lately with the fast growth of the Free Electron lasers.

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Usually the RF sources are multimegawatt pulsed klystrons. The characteristics of these high power tubes are basically the same, that means they work at a fixed frequency of 1.3 GHz with a 1 % (-1 dB) bandwidth and a peak output power in the order of several MW peak up to 30 or 40 MW peak. But because each accelerator has its own pecularities as regards the required average power, pulsed lengths, maximum available high voltages ... it appeared very soon that the klystrons had to be optimized for each user and at the same time to keep the advantages of an important number of similar klystrons already built and to be built.

These ascertainments have led Thomson-CSF to design the L-band klystrons in a modular structure. To define a tube, the designer has the following basic subassemblies available :

- Three guns : the first one is cathode pulsed, with a perveance adjustable between 1.7 μperv. and 2.4 μperv. The high voltage capabilities are 320 kV - 7 μs with a cathode load of 12 A/cm$^2$ max.

  The second gun differs from the previous one, just by the ceramic insulator which is larger, in order to increase the pulse length capabilities (300 μs - 10 MW peak).

  The third gun has a modulating anode and two diameter ceramic insulators. The perveance is 2.5 μperv. when the anode is grounded. The characteristics of this gun are 135 kV DC/1.7 μperv. - 2.5 μperv. with a cathode load not greater than 4 A/cm$^2$ on the edge (see figure 1). Pulses of ms duration can be delivered easily.

- The cavities are parallelepipedic and made of copper. Their lengths are chosen in order to resonate at the design frequencies. However each has a standardized inductive tuning system to adjust the frequency on the field. All the klystrons have five cavities, including the output circuit.

The cathodes are made of impregnated tungsten with an osmium coating (M-type) for the third gun model. The figure 2 gives examples of normal and M cathode thermoemission curves :

- The total length of the body between the two polepieces is always the same. The cavities can be placed within this length. The drift tubes lengths can be chosen according the small and large signal calculations.

- The distance between the pole pieces being always the same, we don't need many electromagnets. Only two are manufactured : the TH 20100 with a small internal diameter, designed for the TV 2022 which is equipped with the first gun type, and the TH 20277 with a larger internal diameter fitted to the 2$^{nd}$ and the 3$^{rd}$ gun types. Usually a cathode trim coil allows to adjust the electrode beam transmission and thus the gain and the efficiency.

- The output cavities differ from one another by the coupling iris and the cooling circuits. Especially for the TH 2104U which delivers 250 kW average, the cooling subassemblies are critical parts.

- The output waveguide WR650 is horizontal and two pill box type windows are available, one with an AL300 Ø 19 cm usual ceramic and a second one with a low loss and same diameter AL995 ceramic. These windows can also be used for the accelerator itself (TH 20141).

- Four collectors are available, depending on the average power and the electrons energies. The dimensions are given on Figure 3. All of them are cooled by the hypervapotron(R) technique, allowing low water flow and low pressure drop. The total beam power (without any RF signal) can be accepted in any case by the collectors. The design has also taken into account reflected and secondary electrons originating in the collector region, which could give oscillations and instabilities problems.

Special features and characteristics which have been illustrated on the attached drawings need some comments :

- The large size third gun type with a modulating anode is mounted on the klystron TH 2095A used on a FEL injector. The dimensions and the design are chosen in such a way that everywhere the pulsed and DC electric fields on the dielectric and metallic surface are never greater than 10 kV/mm at 130 kV (figure 1) ; also a M-type low temperature cathode also prevents any contamination of the electrode and allows a good vacuum. During this process the Fowler-Nordheim diagram is drawn and the operating voltage is increased to stay in the transition region between the conduction and the field emission regions (figure 4).

- According our 1 and 2D large signal codes the efficiencies are always greater than 55 %, even with a 2.4 μperv. beam. Figure 5 gives examples of such calculations.

- We can obtain in any case a -1 dB bandwidth around 12 MHz - 15 MHz. The 2$^{nd}$ harmonic level is low, but can increase strongly if a resonance at such frequencies is presented to the klystron output with a defined phase. For example a circulator must be matched not only at 1.3 GHz (< 1.3:1) but also at 2.6 GHz perhaps within more flexible constraints (VSWR ⩽ 2:1). Also it is the same thing to say that the maximum acceptable VSWR all phases is 1.5:1, or to say that 4 % of reflected power is allowable. At a lower output power, the reflected power can be the same - at least- and therefore the acceptable VSWR be greater.

The sensitivities of the output power and of the phase variation as regards the cathode voltage (V) and the anode ($V_A$) are roughly given by :

- pulsed cathode : $\Delta P/\Delta V \simeq 3P/V$ and $\Delta\phi/\Delta V \simeq 1000\ °/V$
- modulating anode : $\Delta P/\Delta V \simeq P/V$ and $\Delta\phi/\Delta V \simeq 1000\ °/V$

$$\Delta P/\Delta V_A \simeq 1.5\ P/V_A \text{ and } \Delta\phi/\Delta V_A \simeq 172\ °/V_A$$

- The X rays radiation pattern is needed to evaluate the shielding or the protection inside the building (figure 6). Because the X rays are mainly created in the collector, it can be strange to observe a larger amount when the power in the collector becomes smaller by turning on the RF. This can be explained by some very high velocity electrons entering the collector when the RF is on.

Obviously in all cases the gain is high and around 50 dB. Taking into account usual RF losses between the driver and the high power klystron, the driver must be able to deliver at least 500 W peak. The medium power permanent magnet klystrons TH 2437 and TH 2437A have been designed for this purpose : 1 kW CW and 10 kW pulsed - 1.3 GHz.

The characteristics of all klystrons of this L-band family are summarized in Table I.

Beside the klystrons we have also presented, the TH 2086A is a totally different tube, specially designed for plasma heating and fusion experiment. Its main characteristics are the pulse length and the close CW operation around 1 MW. At the same time, the frequency can be adjusted by the user between 1.25 GHz and 1.35 GHz.

Other klystrons exist around 1.3 GHz ; however they are radar klystrons where the instantaneous -1 dB bandwidths and the frequency tuning capabilities are of special importance.

Usually the noise figure, related mainly to the current is around 60 dB, according to measurements on similar beam radar tubes. Therefore the signal to noise ratio is about 110 dB/kHz. But in some cases, spurious emerge from this low level 1/f noise. Such spurious can be explained by electrons oscillating within a gap or accross the tube between two cavities or the first one and the collector. Low frequency oscillations are sometimes related to a mismatch on the output side or to a feedback loop through external leakage. The multipactoring effects are sometimes involved in these parasitic phenomena.

In conclusion, we have described the present 1.3 GHz klystrons family of Thomson-CSF, designed for scientific and especially for accelerators applications. The modular technology is very flexible and quite adapted to many users, whose requirements differ slightly from one another. Special care is taken to eliminate any defect on all the character-istics curves, and any parasitic oscillation. At the same time, because of the growing number of sockets, the reliability is improved.

TABLE I

| TYPE | F (GHz) | Ppeak(MW) | Paverage | tp (µs) | BW(MHz)1dB | n(%) | Pd(W) | V (KV) | I (A) | SOL | Isol(A) | Vf(V)xIf(A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SCIENTIFIC | | | | | | | | | | | | |
| TV 2022 | 1.3 | 20 MW | 40 KW | 8 µs | 10 MHz | 44 % | 160 W | 235 KV | 194 A | TH 20100 | 53 | 28 V - 24 A |
| TV 2022A | 1.3 | 20 | 50 | 8 | 10 | 44 | 160 | 235 | 194 | TH 20100 | 57 | 28-24 |
| TV 2022B | 1.3 | 20 | 60 | 10 | 10 | 44 | 160 | 235 | 194 | TH 20100 | 59 | 28-24 |
| TV 2022C | 1.3 | 20 | 10 | 20 | 10 | 44 | 160 | 235 | 194 | TH 20100 | 59 | 28-24 |
| TV 2022D | 1.3 | 30 | 60 | 7 | 10 | 43 | 160 | 279 | 251 | TH 20100 | 69 | 28-24 |
| TH 2095 (2) | 1.3 | 6 | 45 | 275 | 10 | 46 | 150 | 126 | 97 | TH 20277 | 62 | 18-19 |
| TH 2095A(2) | 1.3 | 6.5 | 45 | 275 | 10 | 46 | 150 | 132 | 107 | TH 20277 | 66 | 18-19 |
| TH 2104 | 1.3 | 15 | 50 | 100 | 10 | 47 | 120 | 200 | 165 | TH 20277A | 61 | 21-21 |
| | 1.3 | 10 | 100 | 200 | 10 | 45 | 160 | 163 | 134 | TH 20277A | 54 | 21-21 |
| TH 2104A | 1.3 | 5 | 150 | 600 | 10 | 44 | 160 | 124 | 92 | TH 20277A | 48 | 21-21 |
| TH 2104U | 1.3 | 10 | 250 | 250 | 10 | 48 | 160 | 160 | 132 | TH 20277A | 51 | 21-21 |
| TH 2115 (2) | 1.3 | 2 | 150 | 1.1msec | 8 | 46 | 140 | 82 | 54 | TH 20277 | 59 | 20-20.5 |
| TH 2437 | 1.3 | - | 1 | CW | 1 | 30 | 0.1 | 6 | 0.55 | P.M. | - | 6-4.7 |
| TH 2437P | 1.3 | 10(KW) | 15(W) | 10 | 1 | 25 | 0.1 | 16 | 2.50 | P.M. | - | 6-4.7 |
| RADAR | | | | | | | | | | | | |
| TH 2068 (1) | 1.25-1.35 | 4.5 | 11 | 7 | 15 | 46 | 50 | 122 | 81 | TH 20108 | 16 | 12.5-21.5 |
| TH 2068A(1) | 1.25-1.35 | 4 | 8.5 | 7 | 15 | 46 | 30 | 116 | 75 | TH 20108 | 15 | 12.5-21.5 |
| TH 2068B(1) | 1.25-1.35 | 4 | 8.5 | 7 | 30 | 46 | 30 | 116 | 75 | TH 20108 | 15 | 12.5-21.5 |
| TH 2068S(1) | 1.25-1.35 | 1.5 | 2 | 4 | 40 | 35 | 50 | 87 | 49 | TH 20108 | 13 | 12.5-21.5 |
| FUSION | | | | | | | | | | | | |
| TH 2086 (1&3) | 1.25-1.35 | 1.5 | - | 100msec | 6 | 40 | 20 | 80 | 46 | TH 20108 | 13.5 | 18-21 |
| TH 2086A(1&3) | 1.25-1.35 | 1.0 | - | 250msec | 6 | 38 | 20 | 70 | 38 | TH 20108 | 12 | 18-21 |
| | 1.25-1.35 | 0.6 | - | 500msec | 6 | 35 | 20 | 58 | 30 | TH 20108 | 11 | 18-21 |

(1)= TUNABLE WITHIN THE INDICATED BANDWIDTH

(2)= WITH A MODULATION ANODE

(3)= TIME BETWEEN PULSES,20 sec min.

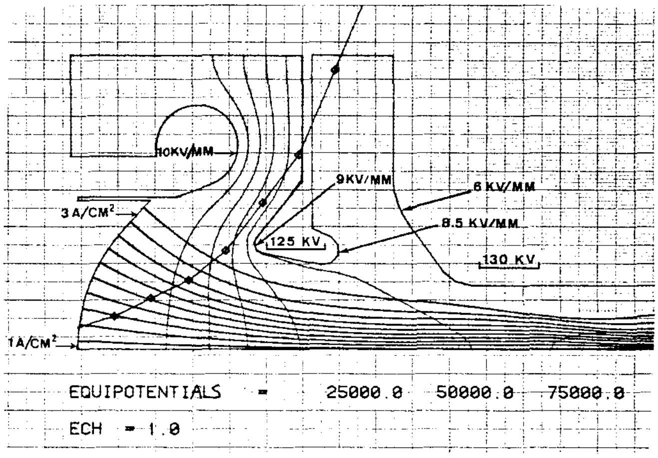


Figure 1 : TH 2095 computer calculations

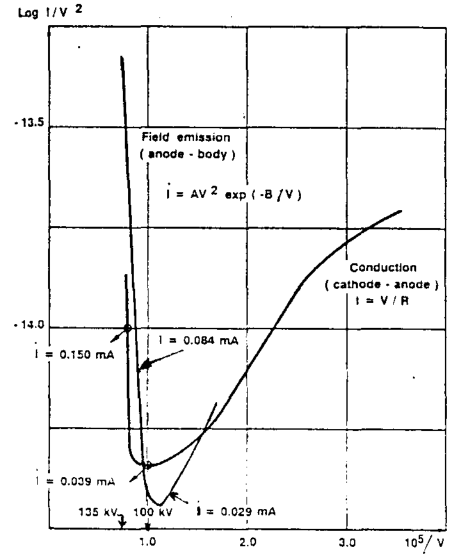


Figure 4 : TH 2095 Fowler-Nordheim diagram

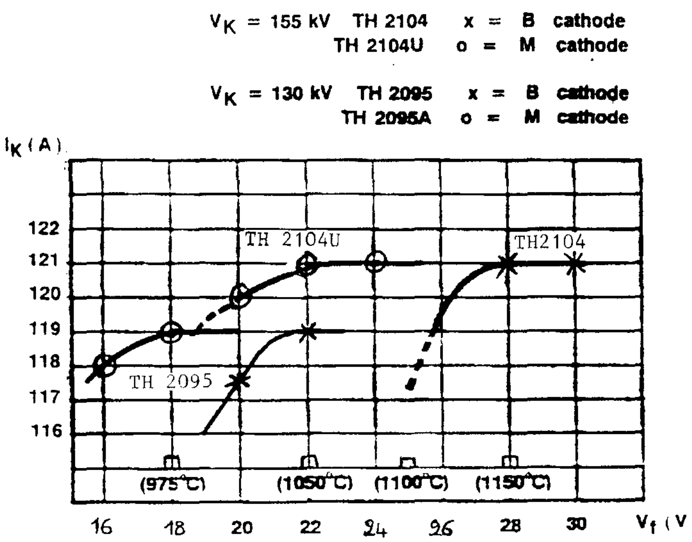


Figure 2 : Cathode behaviour curves

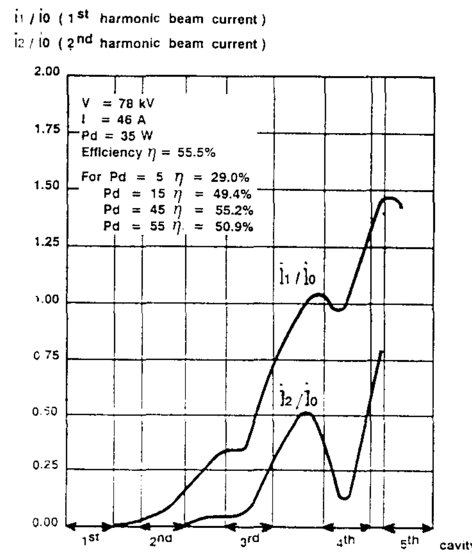


Figure 5 : TH 2115 efficiency calculation

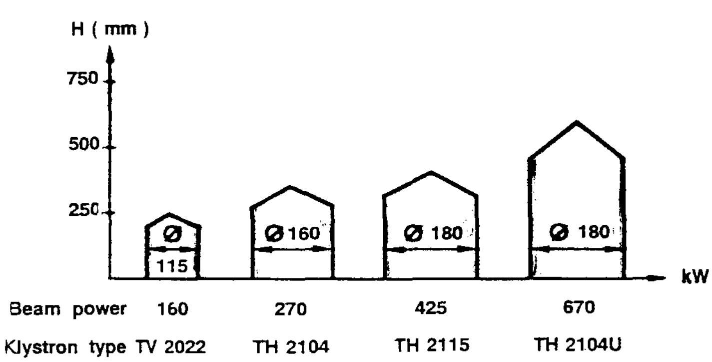


Figure 3 - L-band klystron collectors

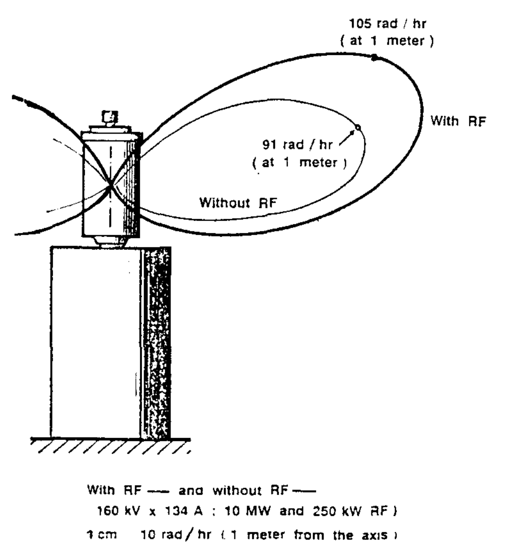


Figure 6 : TH 2104U X rays radiation pattern