IOT RF Power Sources for Pulsed and CW Linacs

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Linac RF source property requirements

(not necessarily in that order)

- High efficiency
- Reliability, ruggedness
- High long-term stability
- Low pushing factors (AM/AM and AM/PM)
- Long life
- A price that does not jeopardize the project

Klystrons have provided most of these properties, and they still do.

So, why and when use IOTs?

Comparison: IOT vs. klystron in linac operation

- **Efficiency**
- Reliability, ruggedness
- Long-term stability
- **Pushing factors (AM/AM and AM/PM)**
- Life
- **Price**

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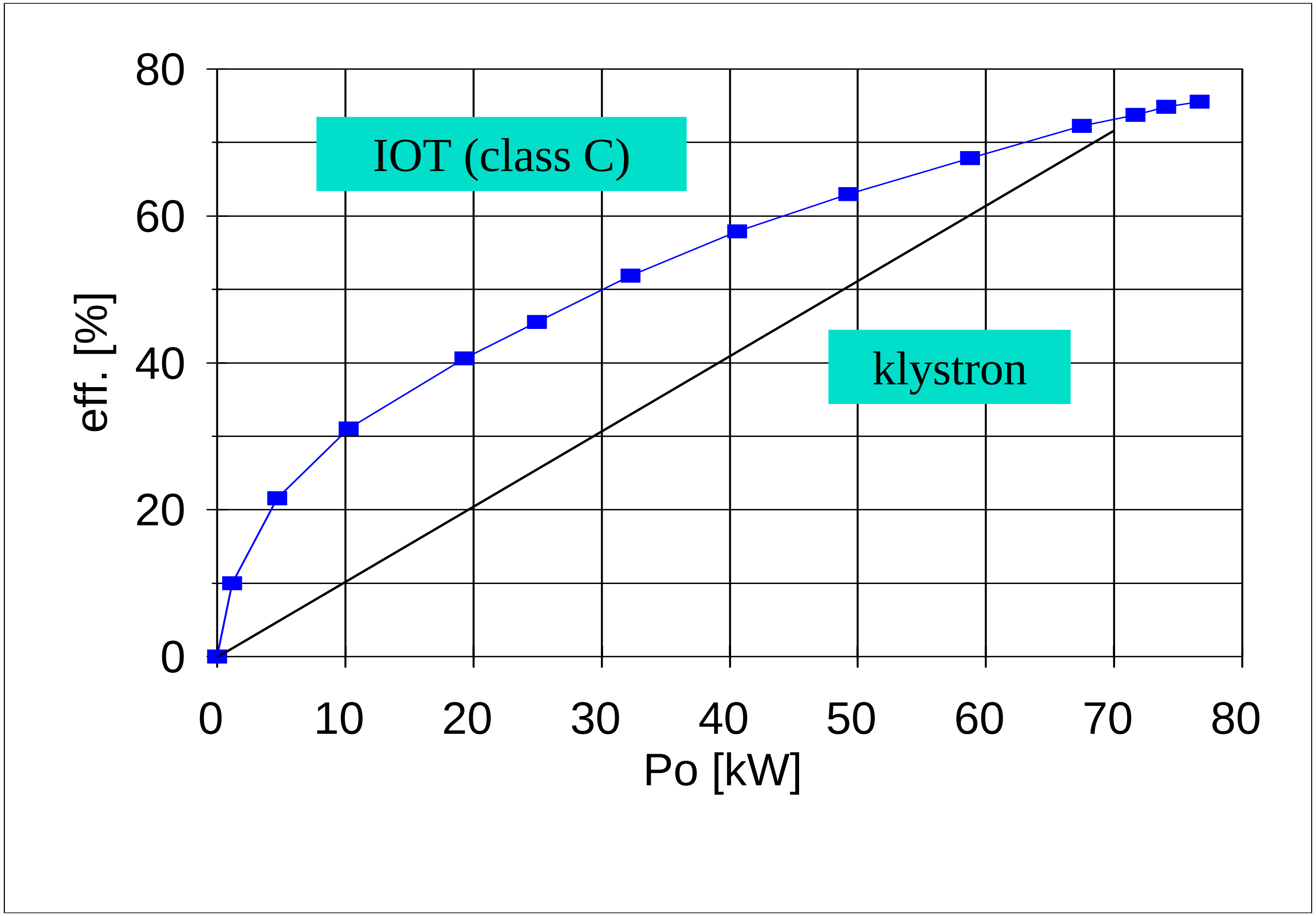
70 kW amplifier at 500 MHz
Efficiency vs. output power



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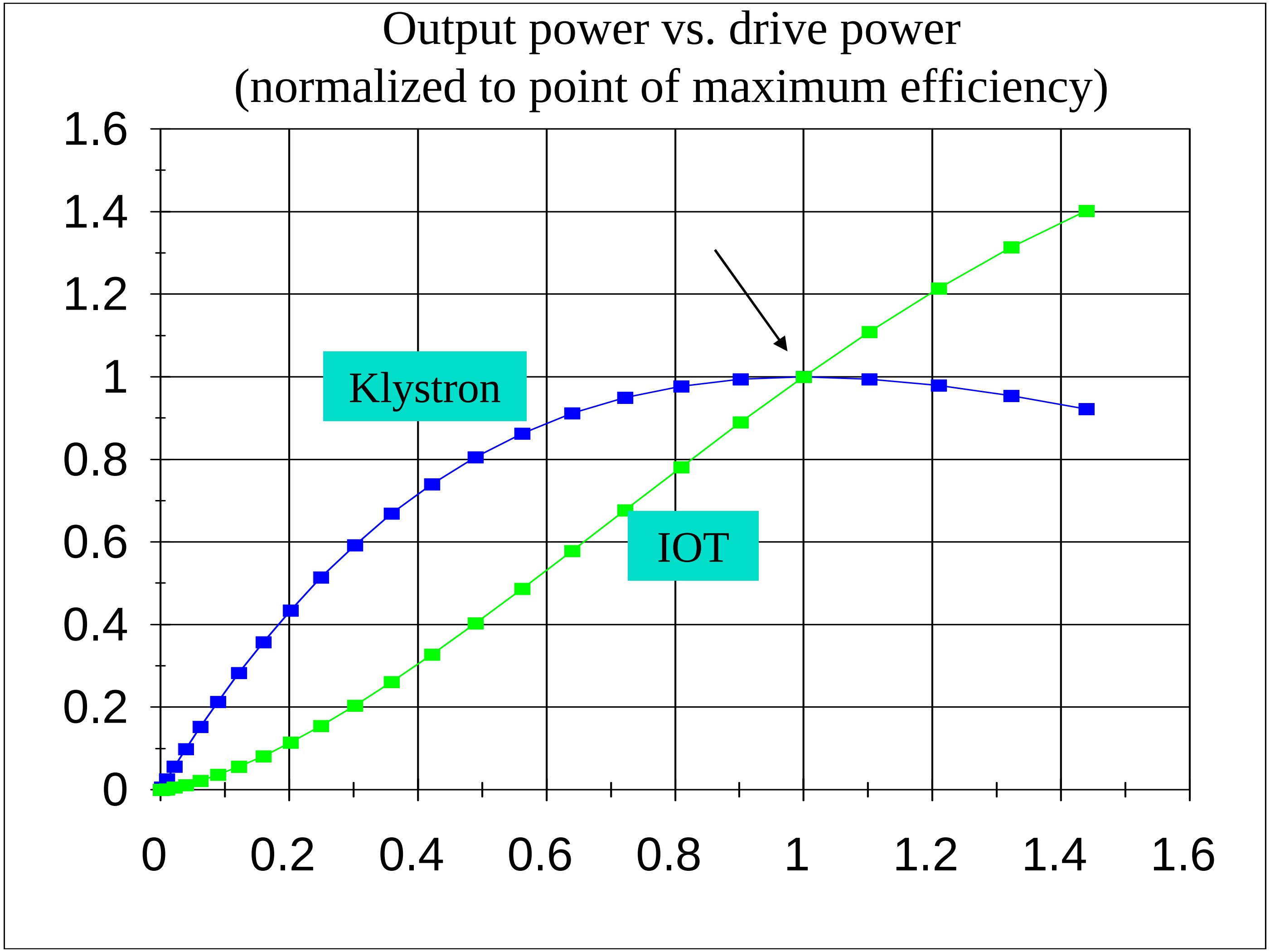

Comparison of amplifier characteristics: IOT vs. klystron

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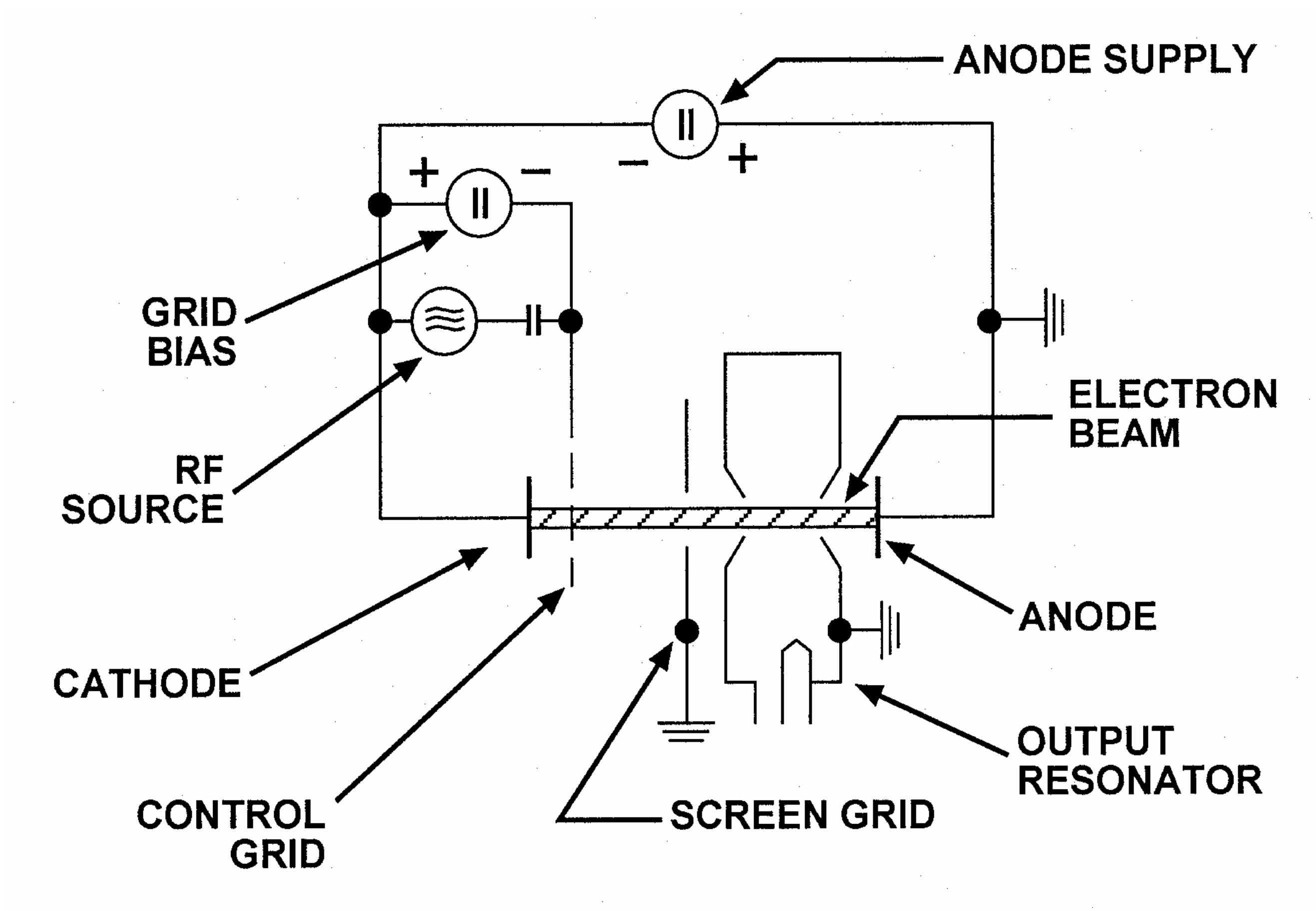

An IOT is a simple device

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What about applications in particle accelerators?

Aided by intensified cooling (water-cooled anodes and output cavities, improved air-cooling of the output window) IOTs like this CPI/EIMAC K2H80W are able to provide CW output power up to 80 kW at efficiencies between 70 and 76 %.

Of special importance for their use in particle accelerators is the fact that their output still rises vs. the input monotonously at the point of maximum efficiency. No back-off is needed for fast feed-back.

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Next to water-cooling and intensified air-cooling for stable operation at high CW output power, the double-tuned output circuit provides another feature:

The almost flat top of the frequency-response curve permits an offset between operating and central frequency, which leads to a further increase in efficiency.

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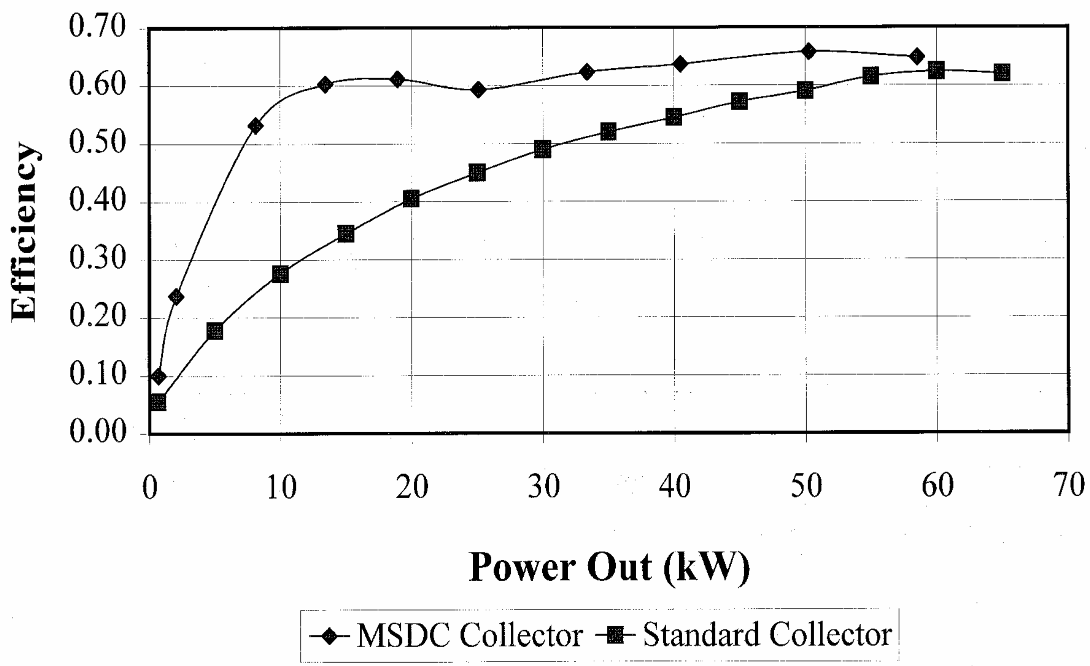

The improvement in efficiency due to collector depression is high at lower output power levels. For tubes that operate in the CW mode at high output power it becomes insignificant, on the other hand, as shown in this graph.

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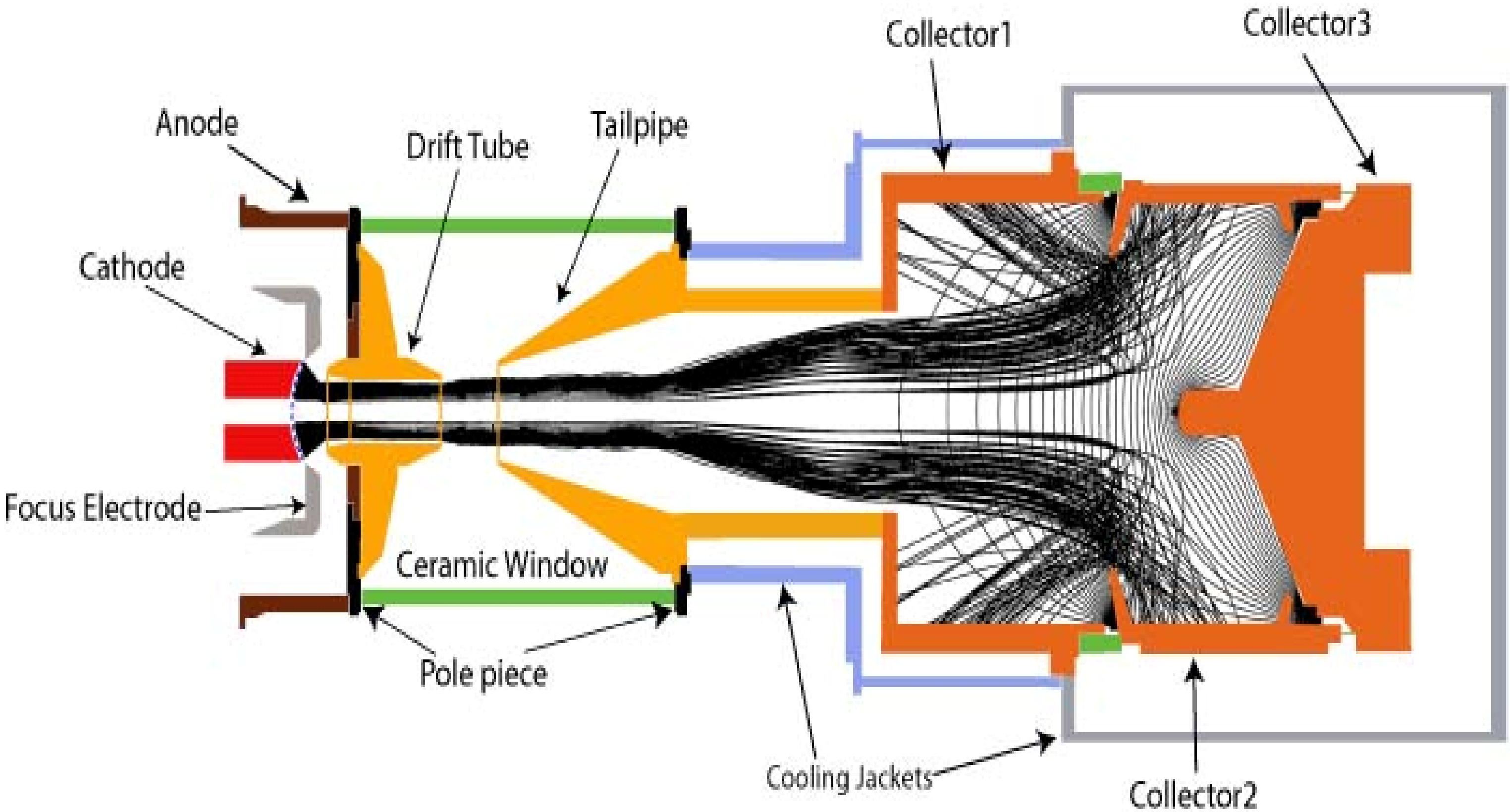
This computer graph shows the equipotential lines inside the collector assembly and the resulting distribution of the spent electron beam.



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Brand new:
The Multi-Stage Depressed Collector (MSDC) IOT

Adding 2 ore more collector stages that are operated at potentials lower than the tube’s body potential (with respect to the cathode) permits to slow down considerable parts of the spent beam before it hits a collector surface. This saves energy.

The IOT depicted here (CPI/EIMAC K3130WC) features 3 collector stages, with those at high voltage being oil-cooled.

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Depressed-collector assemblies are relatively bulky. To maintain the quick-change feature that is necessary in TV operation, the IOT is mounted collector-up in this case, with the input circuit at the bottom.

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For output power levels exceeding 80 kW, and for higher frequencies than UHF, internal cavities replace the external ones.

Shown in this picture the VARIAN/EIMAC 2KDW250PA, the so called “Chalk River Tube”, which provides 250 kW CW output power at 267 MHz with 73 % efficiency.

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An opportunity for super-power: The HOM-IOT

Higher-Order Mode IOTs use multiple beams or large electron beams with quasi-annular cross-sections that interact with the outer voltage maxima in TM_{0n0} cavities. The advantage: low beam voltages, low emission densities, low energy densities. The table compares the capabilities of an HOM-IOT and a klystron, both for 1 MW CW in UHF.

0	HOM-IOT	Klystron
Effective efficiency	73 %	60 %
Rel. power consumption	82 %	100 %
Assembly volume (approx.)	30 cbf	200 cbf
Assembly weight (approx.)	1,000 lbs	5,000 lbs
DC voltage	45 kV	90 kV

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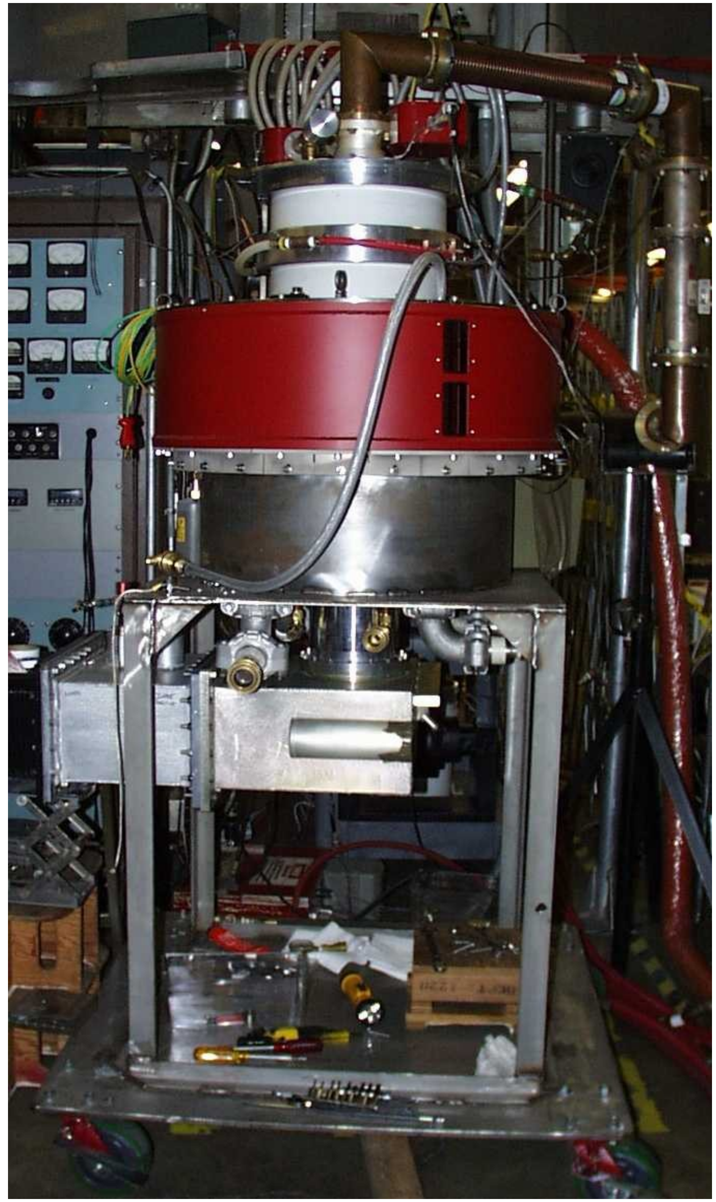
This picture shows the first (and so far only) HOM-IOT in test.
It has been developed by CPI for Los Alamos National Laboratories for their abandoned APT program, and was mothballed together with it.

Its target specification:
1 MW CW at 700 MHz.

The coaxial feeder at the top (gun end) is the input; the output is the waveguide at the bottom below the collector. The red element is the focusing coil.



L-Band IOTs

- **The cathode/grid configuration of modern IOTs is well proven. There are scarcely any grid failures reported.**
- **Thus there are good reasons to maintain this configuration when designing an IOT for higher frequencies.**
- **Second-harmonic IOTs have been proposed for some time already. So why not maintain the input circuit tuned to a UHF frequency and just operate the output resonator in L- or even C-band?**

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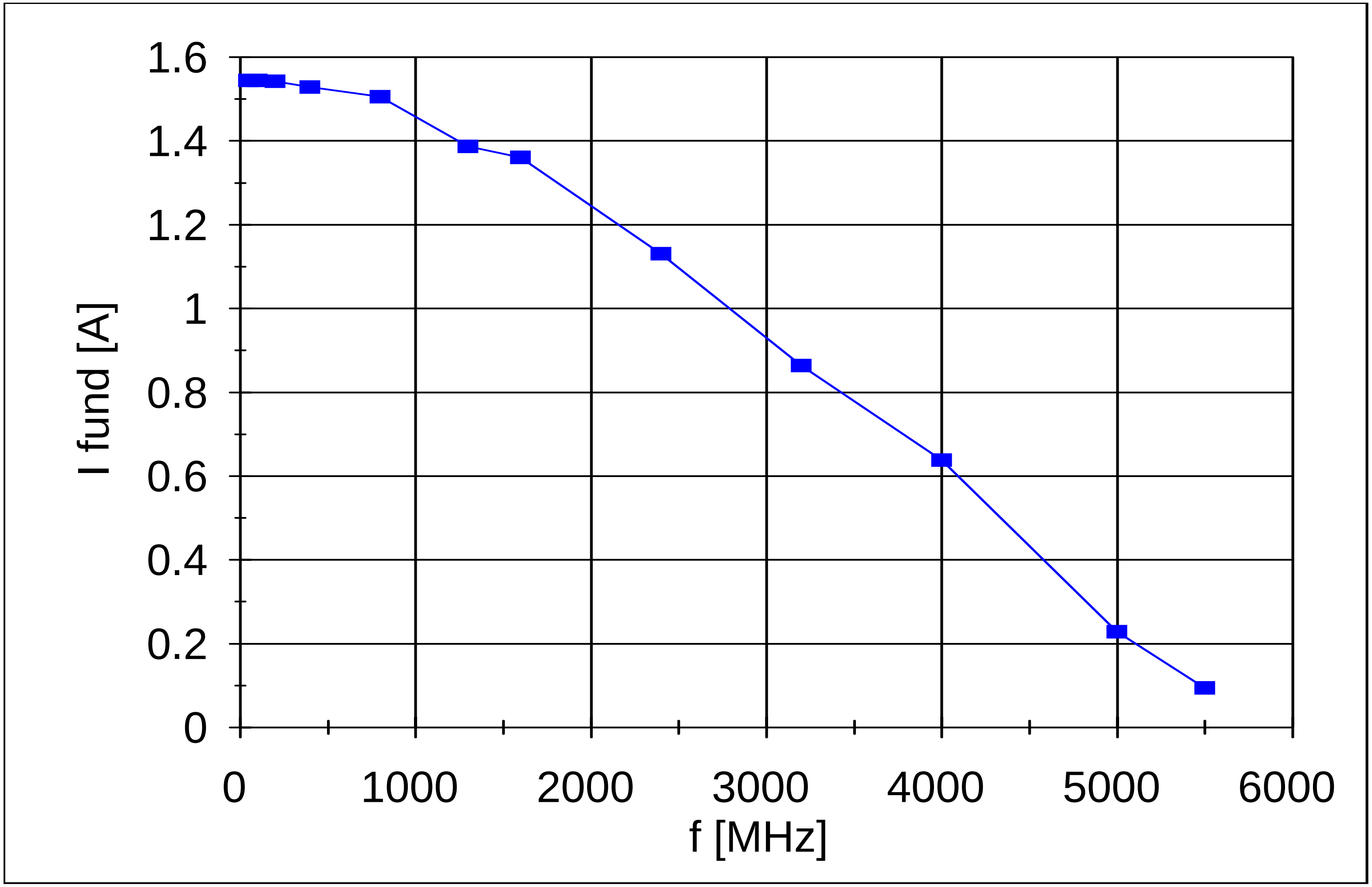

Simulated fundamental-frequency current of existing IOT gun vs. frequency at 22 kV (Class B)

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UHF version

L-band version

Typical results of a Second-Harmonic IOT simulation
(Class B Operation)

Frequency:	**1.3 GHz**
Beam voltage:	**24 kV**
CW output power:	**11.4 kW**
Gain:	**22.3 dB**
Efficiency:	**43.1 %**

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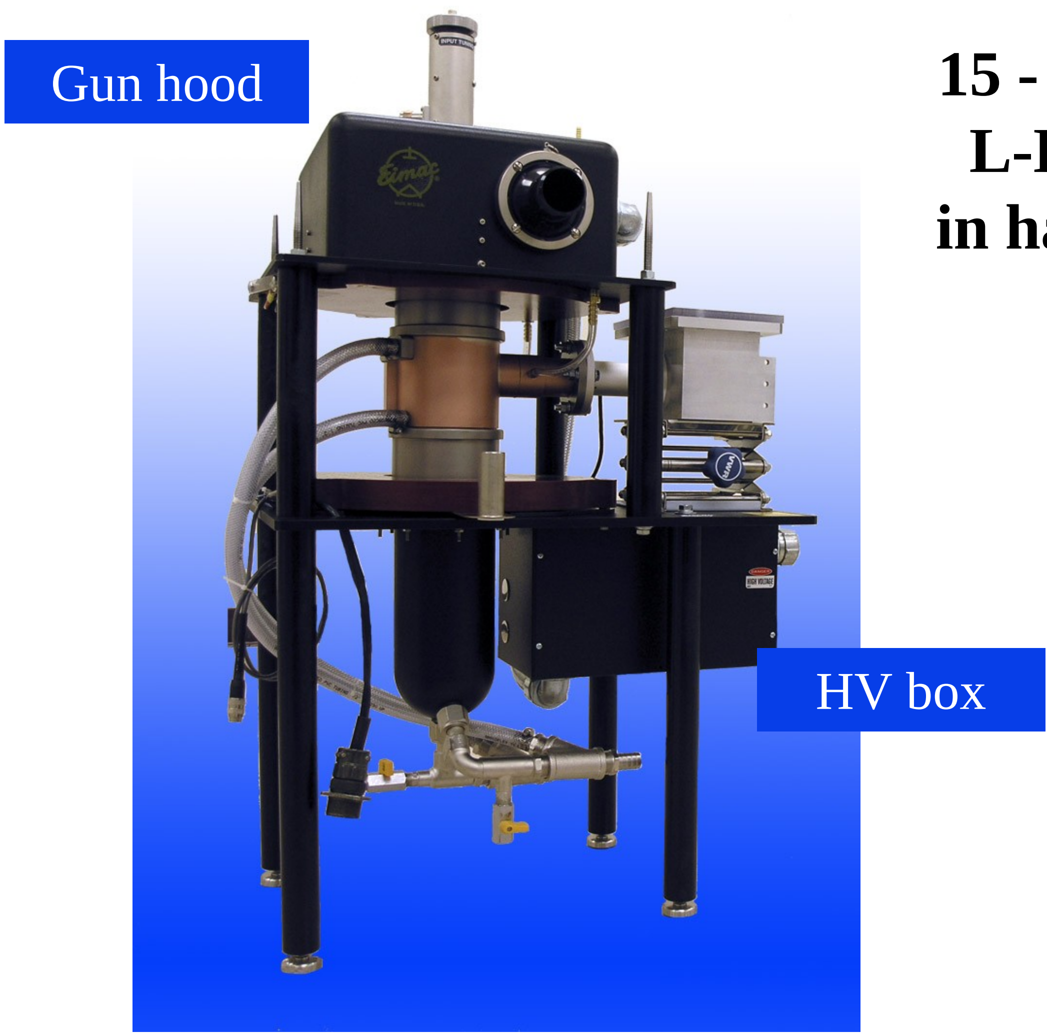

15 - 25 kW CW L-Band IOT in hardware set

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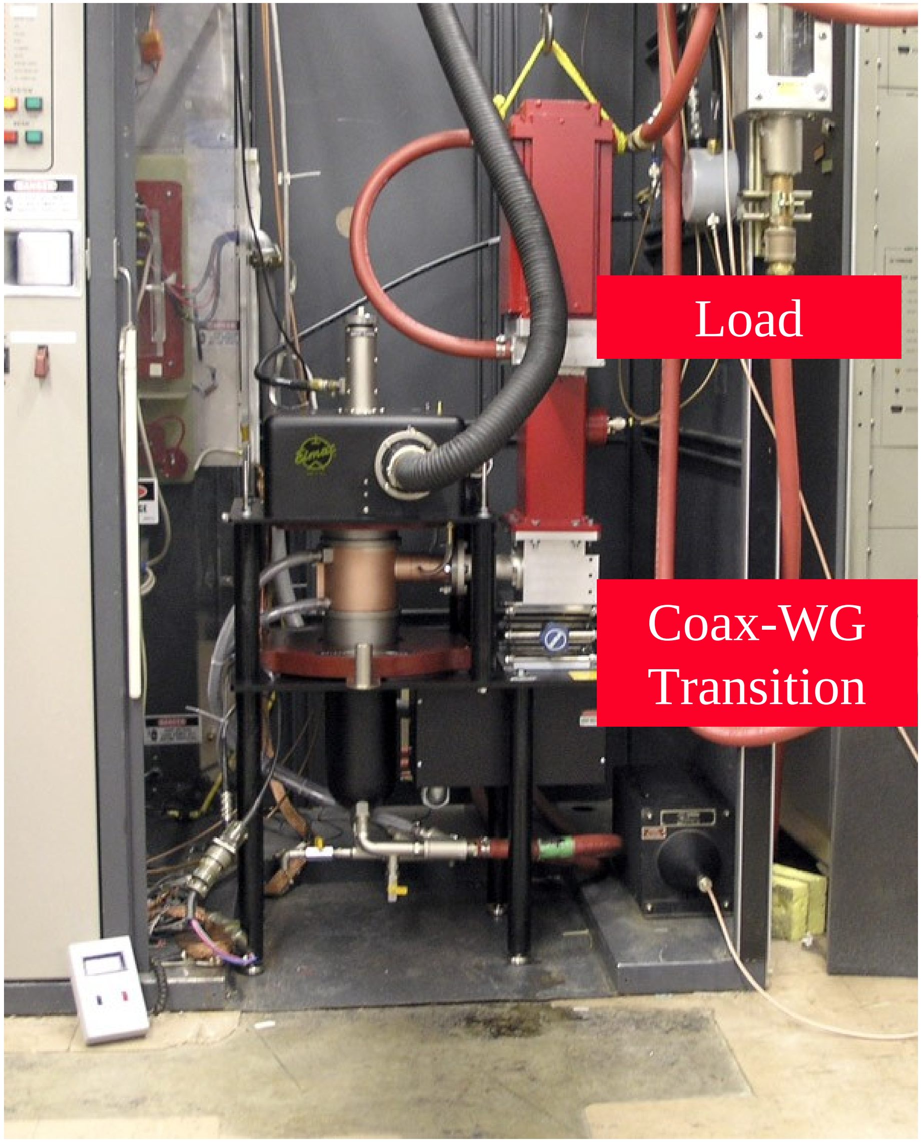

1.3 GHz IOT

under test

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3rd prototype test results

Voltage(kV)	Current(A)	Drive(W)	Output(kW)	Gain(dB)	Eff(%)
24	0.79	208	10.0	17	52.7
25	1.10	203	15.1	19	54.9
26	1.46	183	20.6	21	54.3
32	1.35	192	25.7	21	59.5
34	1.39	253	30.2	21	63.8

Next steps

- Manufacture 1.5 GHz version
- Design 300 kW peak, 1.3 GHz long-pulse IOT

Conclusion

Less than twenty years after the design of the first modern IOT the device has established itself as a reliable and very efficient amplifier for medium power levels in UHF, and it is on the verge to expand its area of use into the UHF super-power range and into medium power L-band applications, especially 4th-generation light sources.