Communications & Power Industries

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Workshop on High Power RF

Vacuum Electron Device Limitations for High-Power RF Sources

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Devices discussed in this presentation:

<u>CW and High Average Power Amplifiers</u>

- Single-Beam Klystrons
- Multi-Beam Klystrons (MBK)
- Single-Beam Inductive Output Tubes (IOT)
- Higher-Order-Mode IOT (HOM-IOT)

CW and High Average Power Devices not (yet) considered here:

- Sheet Beam Klystrons (early state of development)
- Coaxial IOT (early state of development)
- Gyrotrons
- Traveling Wave Tubes

Warning:

- Numerous papers on this subject have been written already.
- Device limitations are shifting with time and effort.
- "Absolute" limits have been proven wrong, again and again.

Thus:

- In the limited time frame available, just expect a chat about <u>some</u> of the borderlines that are presently under siege.

Limitations discussed in the following

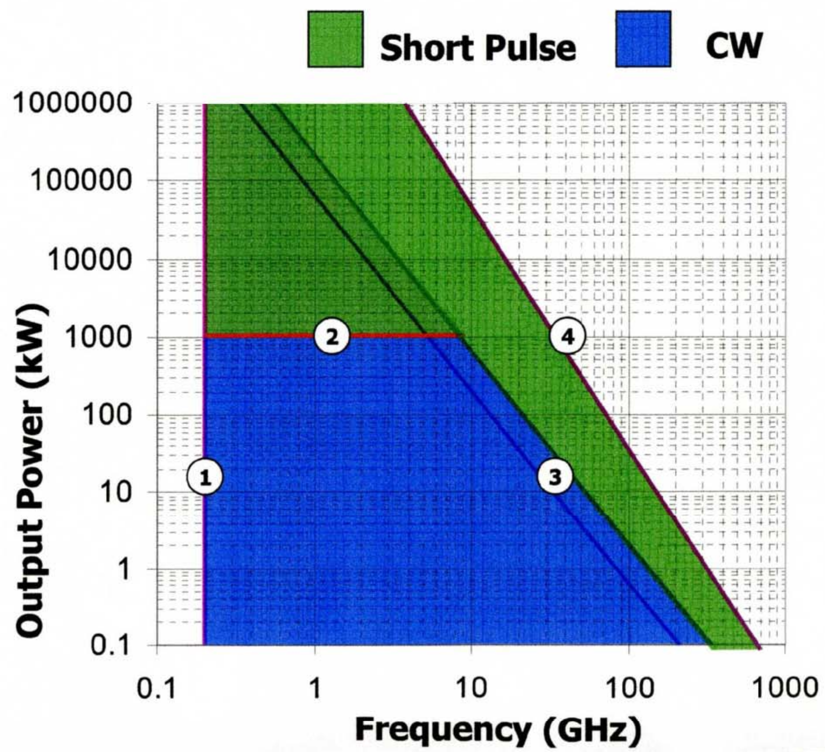
VED technology related
- Size
- Output window capability
- Output cavity capability
- HV breakdown in electron guns
- Cathode emission limitations

Other reasons
- Manufacturing capacity
- Reproducibility
- Demand
- "Blinkers"

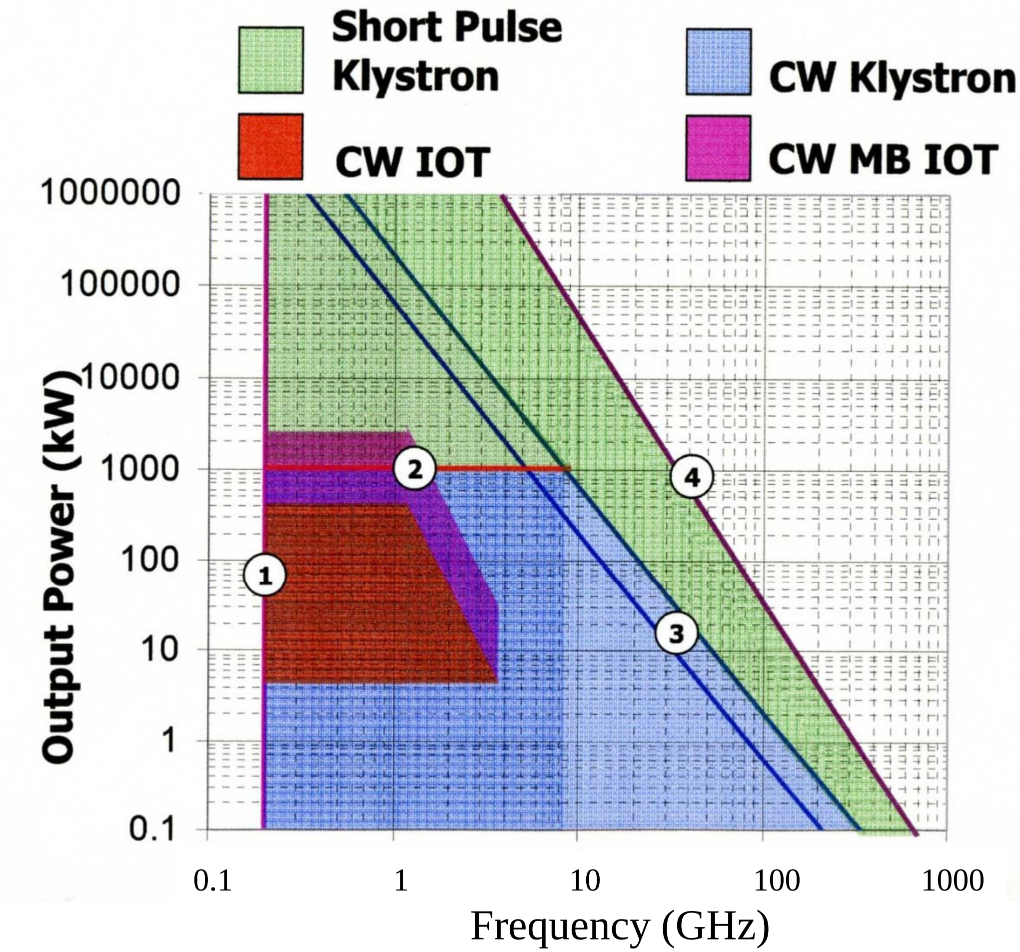
Klystron technology limitations (debated)

- Plot showing the PF spectrum for klystrons, both short pulse and CW
- Approximate limitations

(1)	Size	(CW & Pulsed)
(2)	Window	(CW)
(3)	O/P Cavity Power Density / Cyclical Fatigue	(CW)
(4)	RF Breakdown	(Pulsed)



Considerable part of former klystron domain claimed by IOTs



Why?

Vacuum Electron Device Limitations for High-Power RF Sources

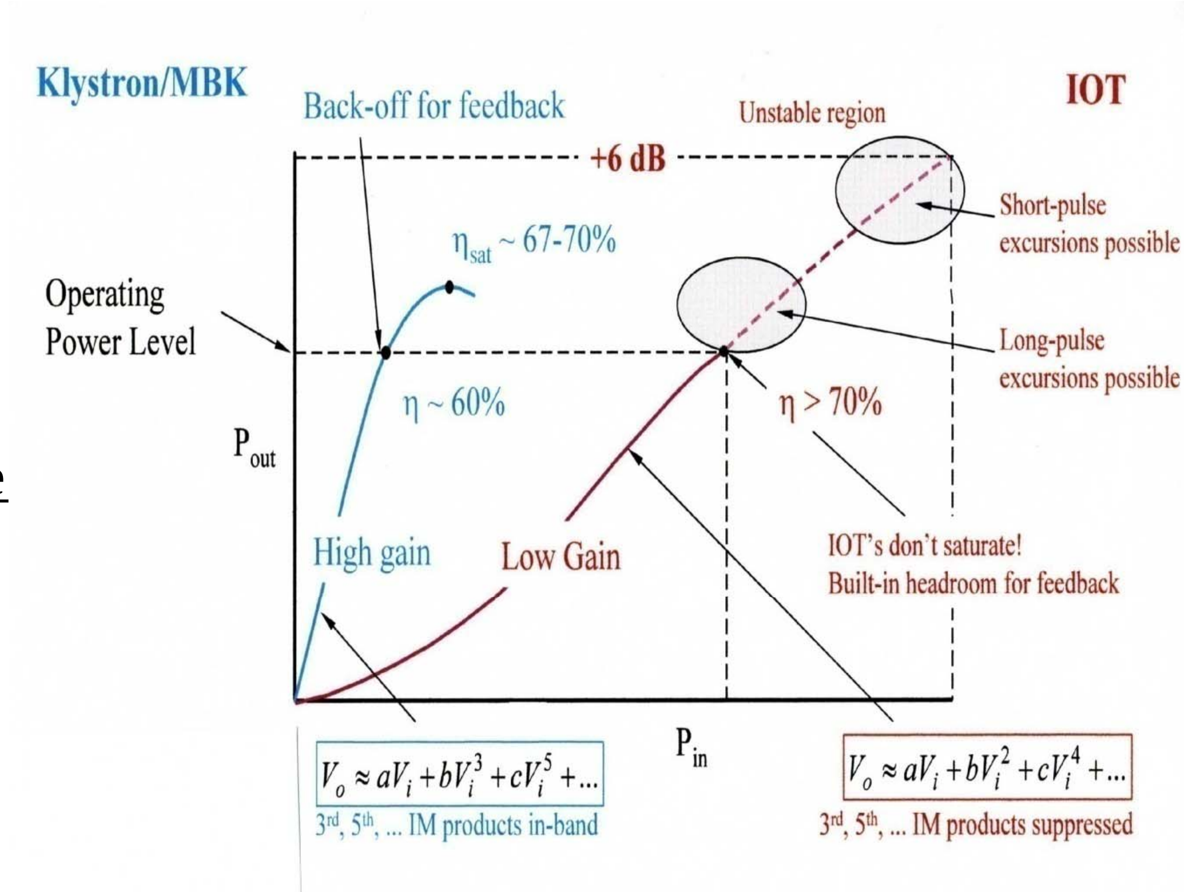
IOTs have operational advantages…

- Efficiency
- Absence of saturation
- Pulse-able via RF
- Small size
- High linearity

…and they are less expensive

Disadvantage:

- Low gain (± 22 dB)



Thus IOTs have replaced klystrons in a growing number of applications.

Example:
External cavity IOTs

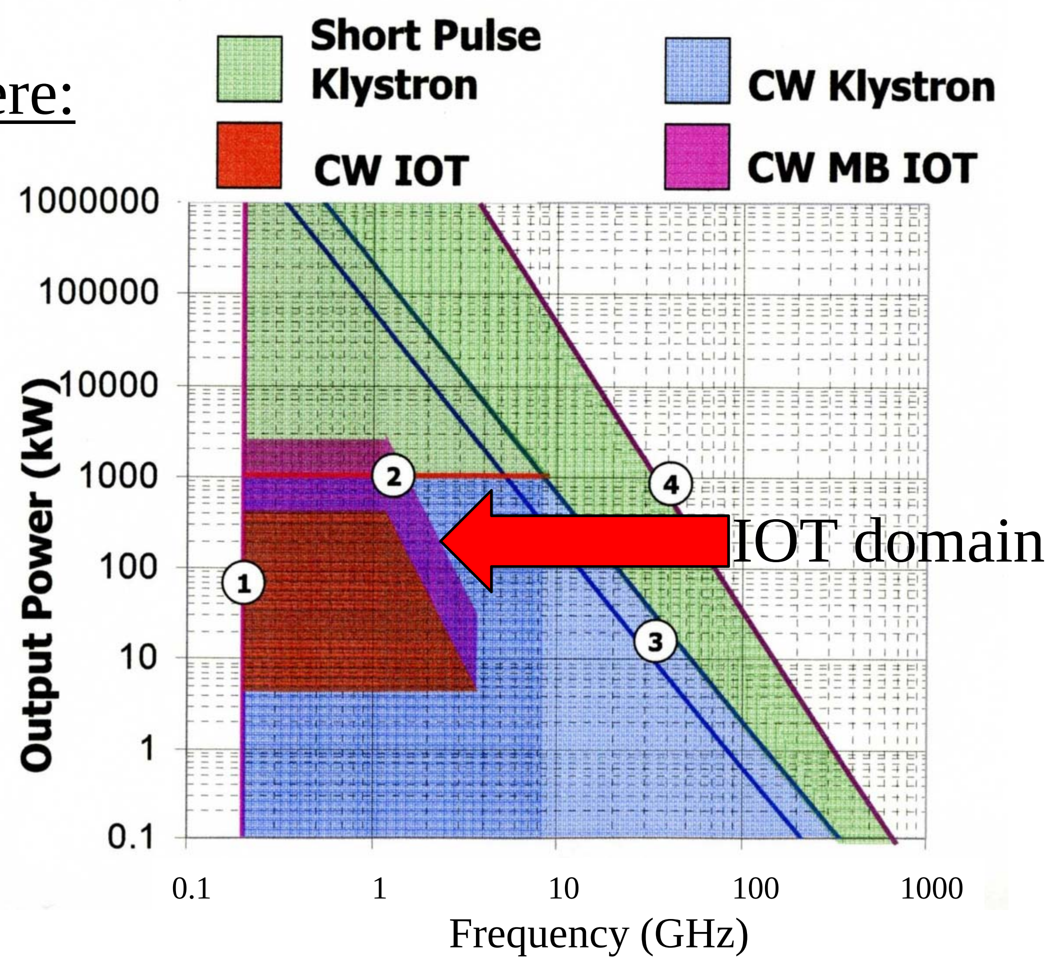
Here: CHK2800W

- tunable 470 – 860 MHz
- 130 kW in digital TV
- 80 kW CW at 500 MHz

Vacuum Electron Device Limitations for High-Power RF Sources

IOT limitations discussed here:

- Size
- Average output power
- Operational frequency



Linear-beam IOTs feature a size limitation at frequencies lower than ~ 200 MHz, due to their waveguide-type output cavities.

Example here:

"Chalk River" IOT
250 kW CW at 267 MHz
73 % efficiency

Coaxial IOTs do not suffer from that restriction!

Vacuum Electron Device Limitations for High-Power RF Sources

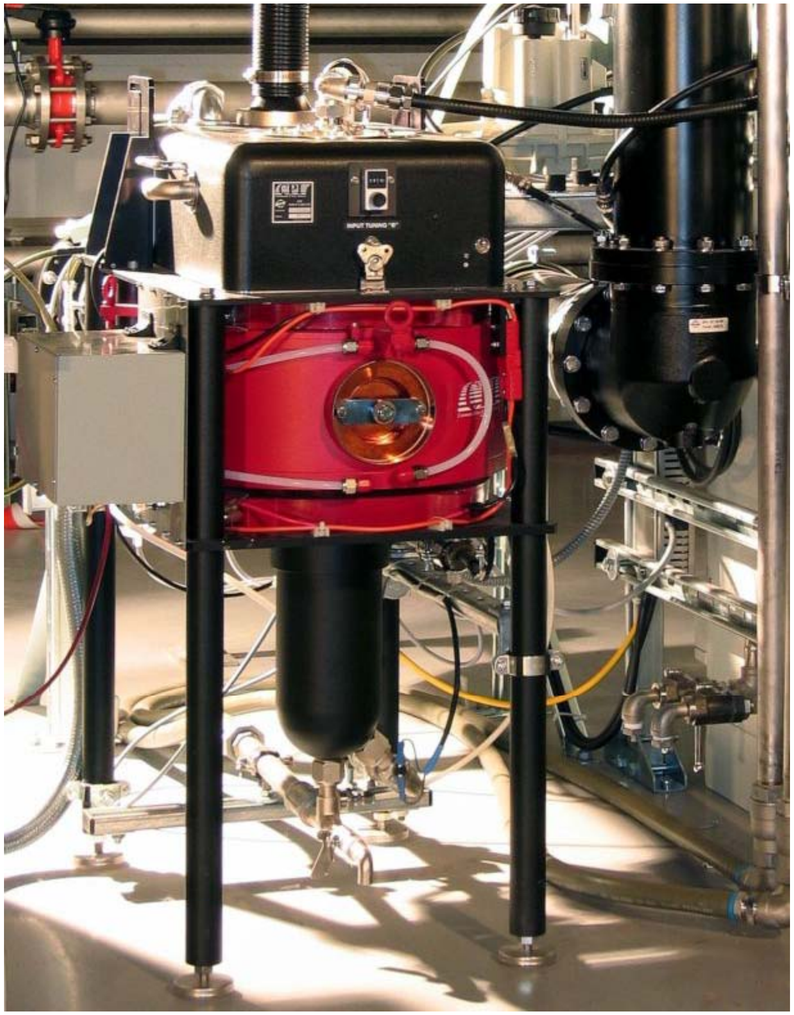
Safe operation of external cavities is limited to ~ 80 kW.

Beyond that level integrated cavities become necessary.

This example:

500 MHz / 90 KW CW
IOT K5H90W

(here at BESSY/PTB, Berlin)



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- IOT devices in the MW range therefore require different approaches.

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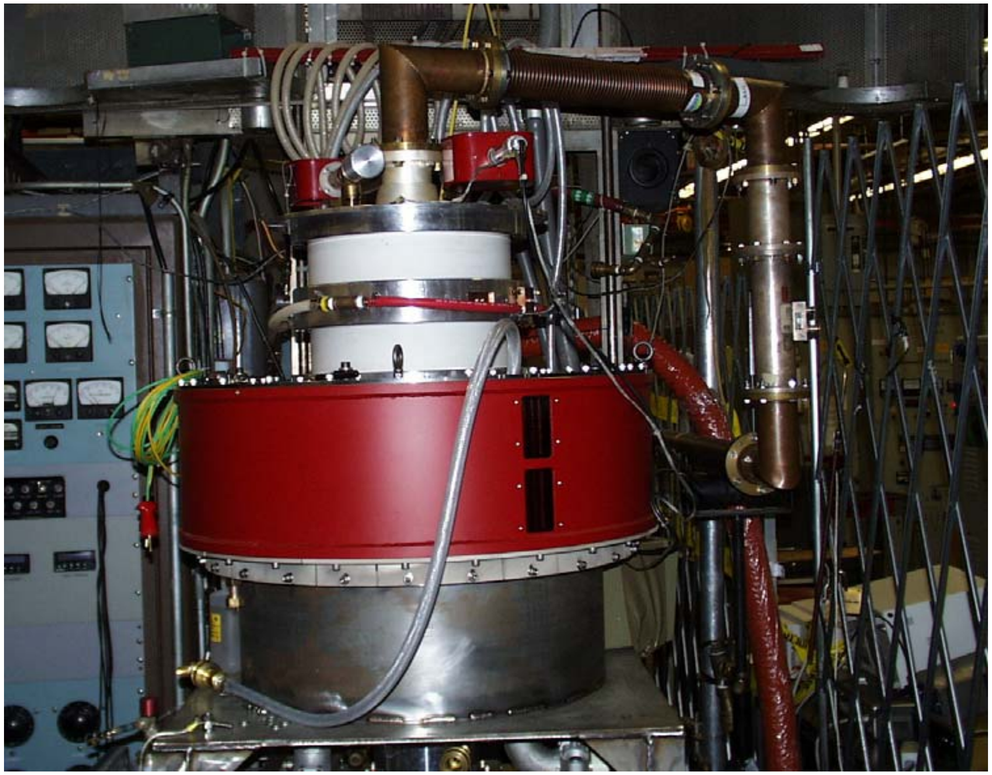


First approach to 1 MW:

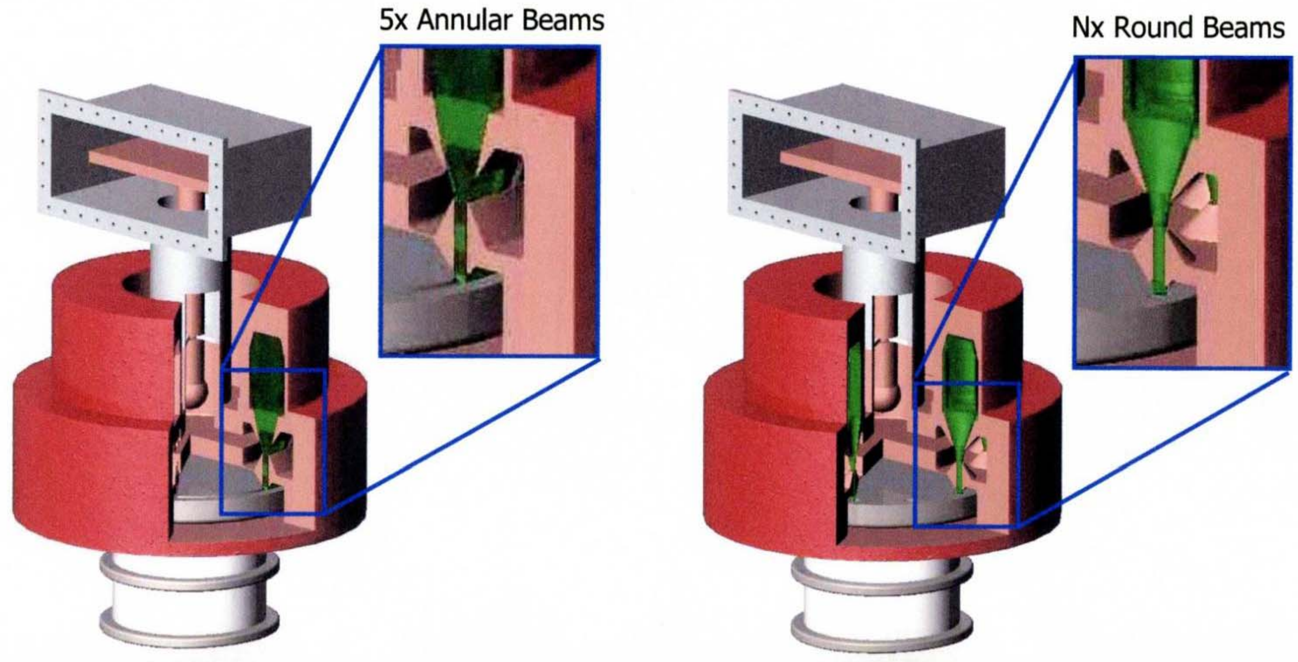
HOM-IOT with annular cathode and grid.

Development sponsored by LANL.

Proved the principle, but turned out to be too vulnarable.

Second approach to 1 MW level:

HOM-IOT with n single beams.



Presently under development:

- VHP-8330B – Round beam prototype

Typical Operating Parameters

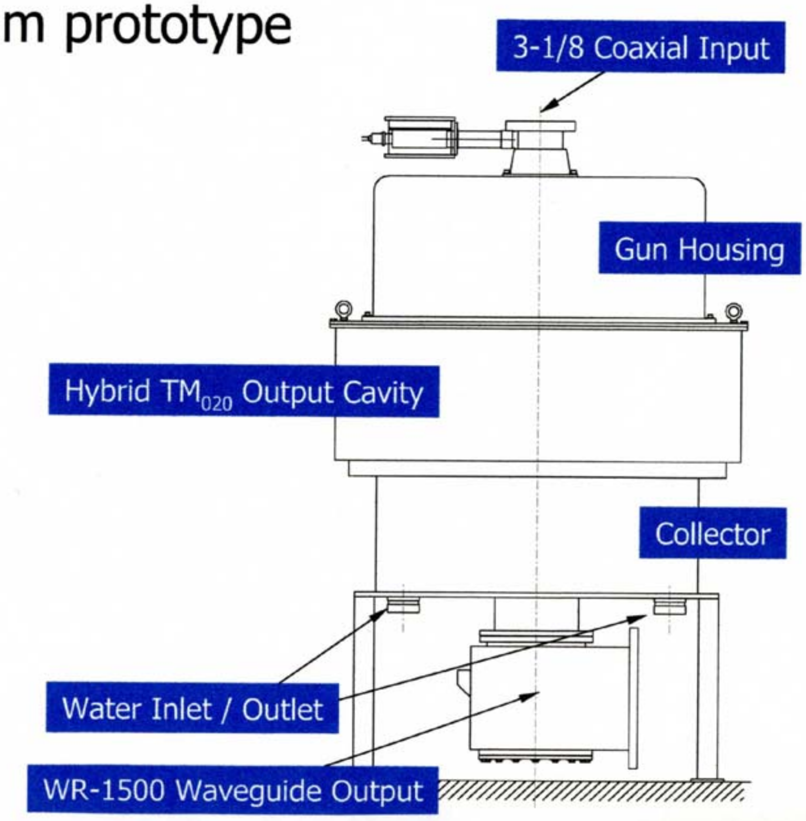
Power Output	1000	kW (min)
Beam Voltage	42	kV (nom)
Beam Current	33	A (nom)
Frequency	650-750	MHz
1dB Bandwidth	6	MHz (min)
Gain	25	dB (min)
Efficiency	71.5	% (min)
Cathode Loading	0.37	A/cm²

Electromagnet

Main Coil Current	18	A
Main Coil Voltage	49	V

Size

Diameter	30/76	in / cm
Height	51/130	in / cm
Weight	1000 / 450	lbs / kg



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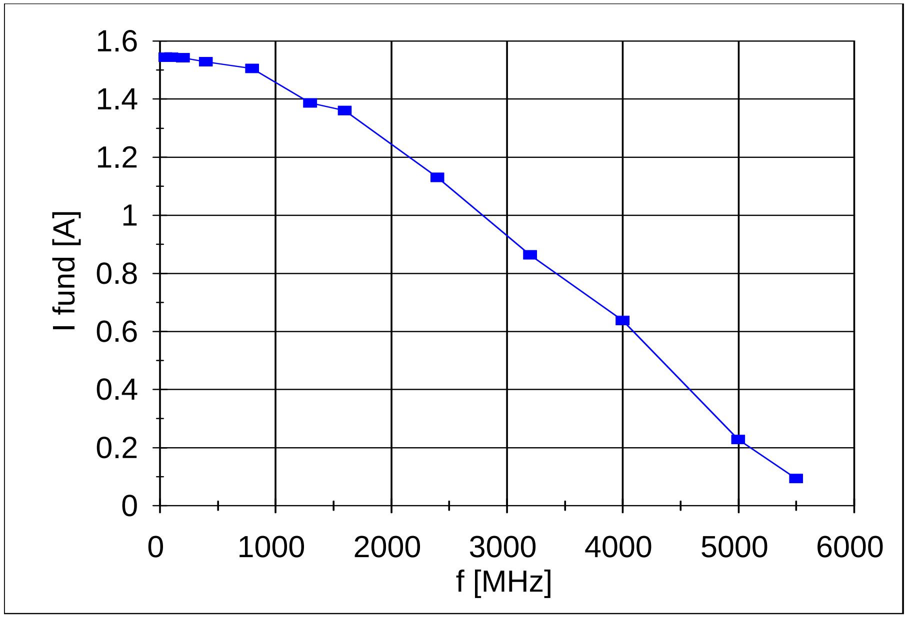
Simulated example:



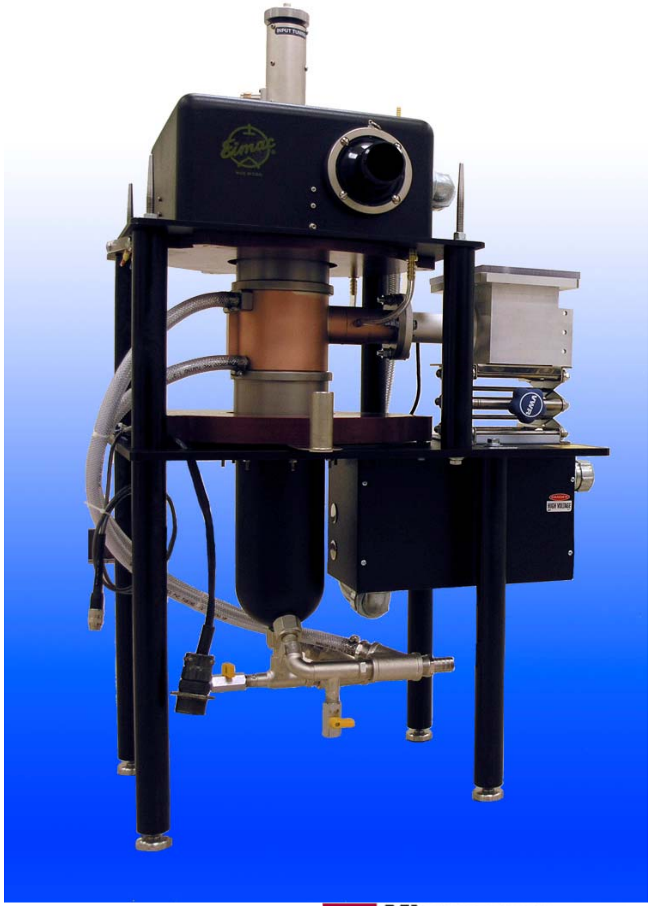
Frequencies up to 2 GHz still easily viable with existing technology

Example:

1.3 GHz IOT

30 kW CW

22 dB gain



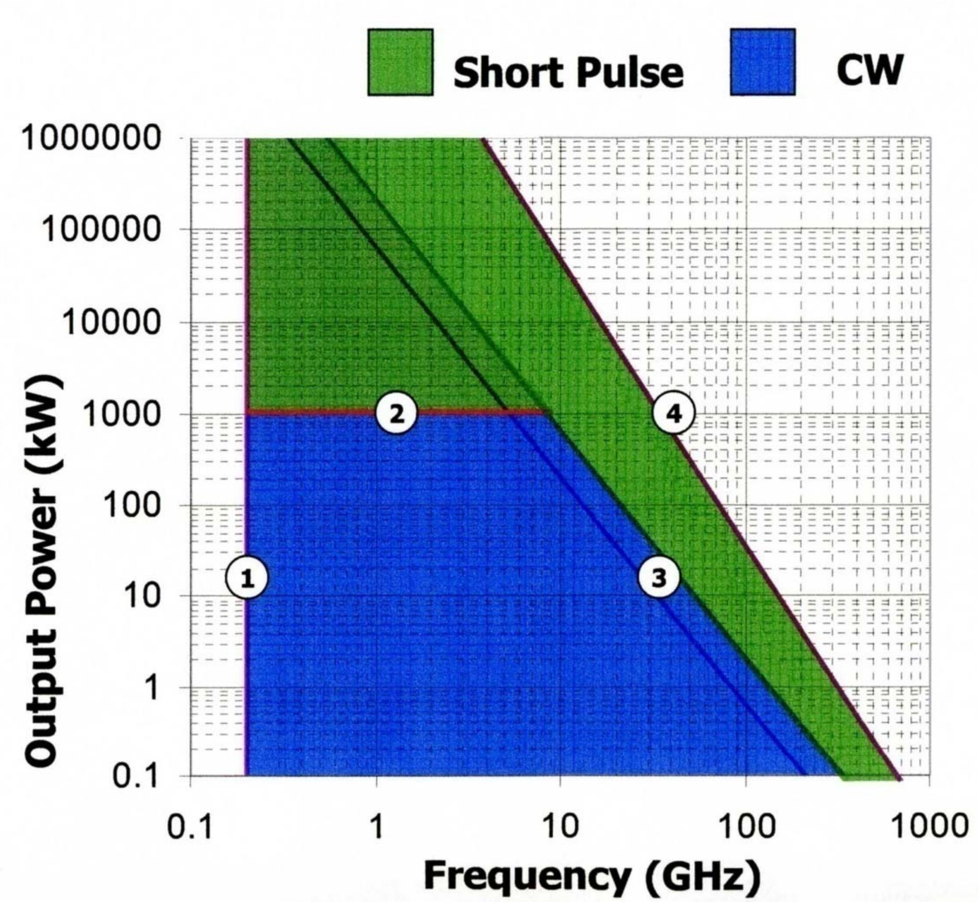
Under development:

1.3 GHz High-Power IOT

60 – 120 kW CW

(Development sponsored by DESY)

Back to device limitations in the klystron sector:



Size (1) is much more an issue here than in the IOT domain.

For save degassing VEDs need to be pumped at high temperatures in exhaust ovens. Their size limits the size of the klystrons.

A klystron at the very size limit:

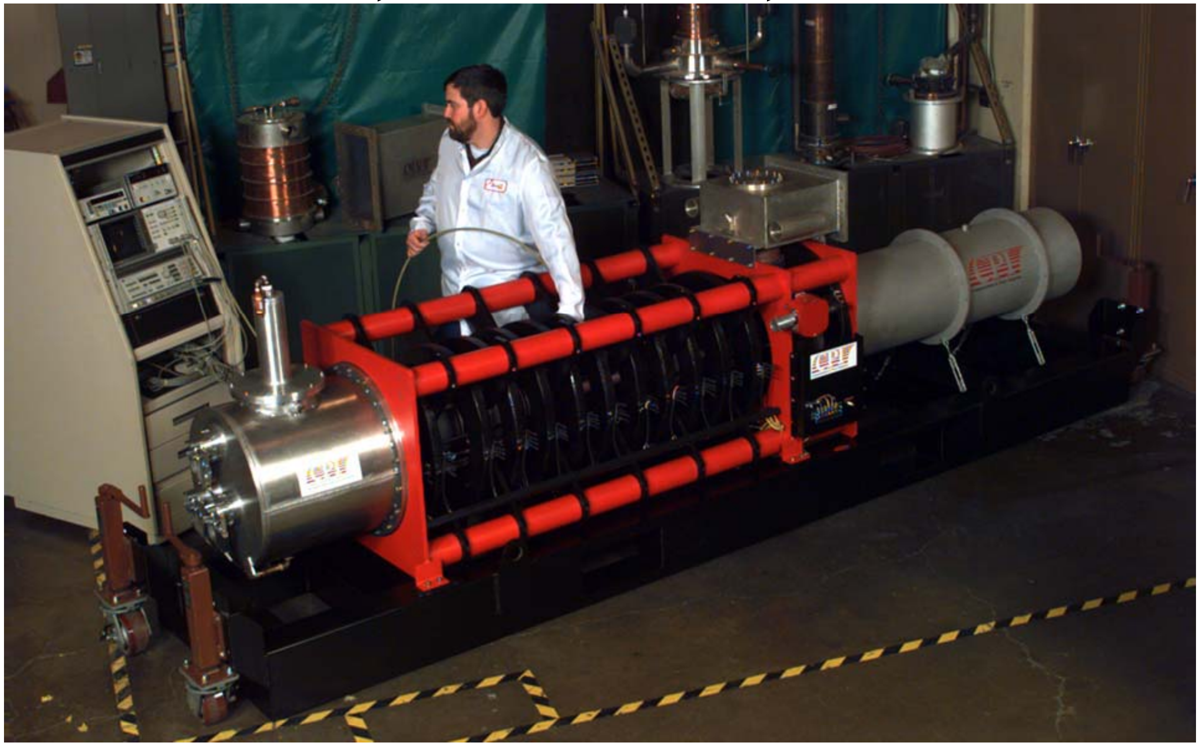
YK 1320, up to 3 MW long-pulse

Overall height: 5 m

(The engineer in the foreground is 1.84 m tall)

Still large, but easier to manufacture:

VKP-7952A/B, 700/704 MHz, 1 MW CW



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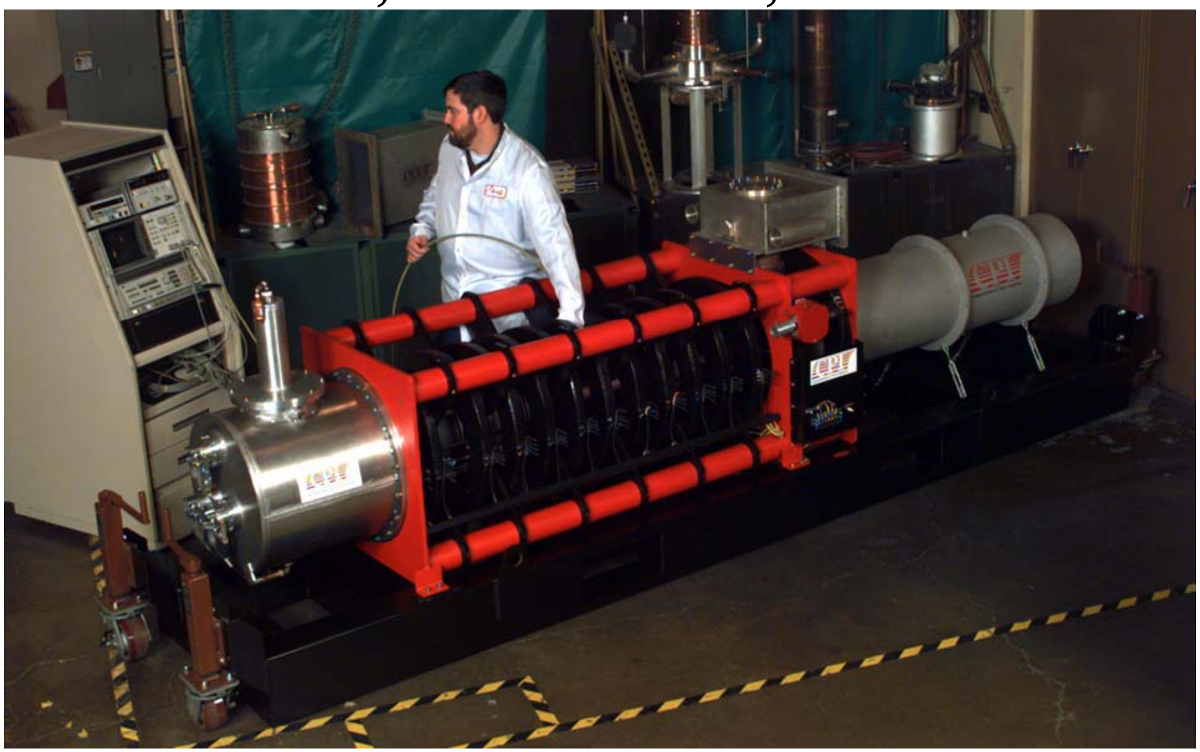
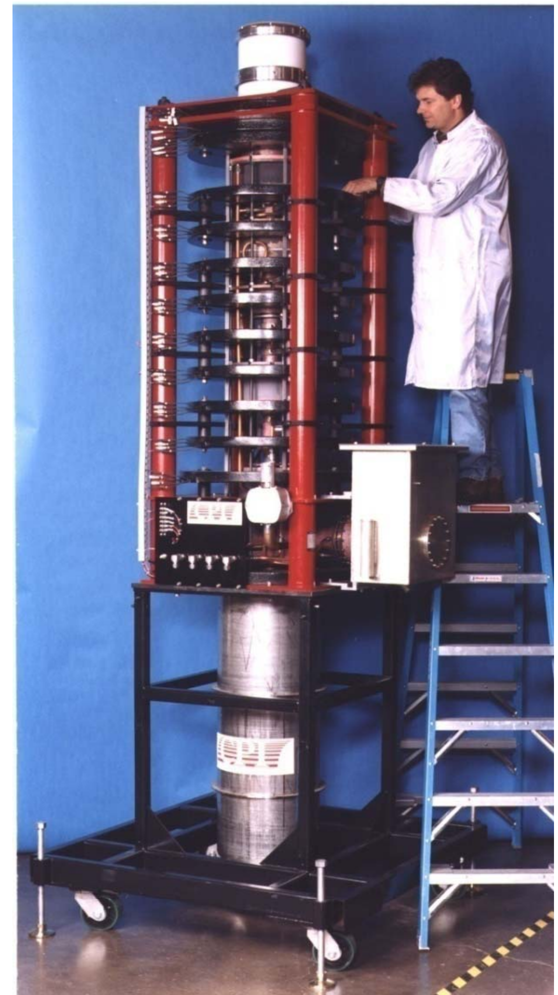


and VKP-7958A, 500 MHz, 800 kW CW



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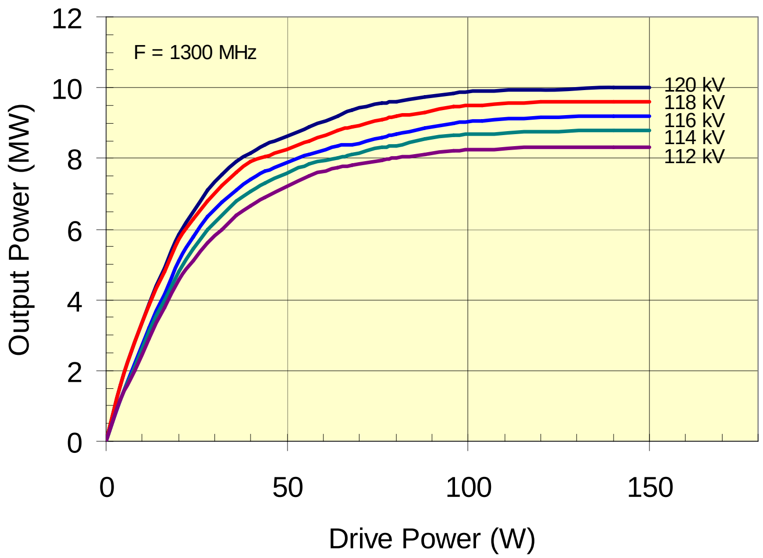
Example:

10 MW LP
150 kW average
1.3 GHz

(Development sponsored by DESY)



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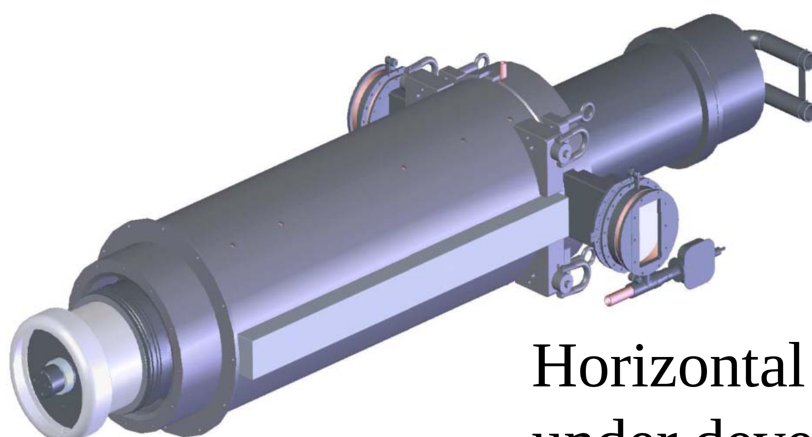


Horizontal version under development

Manufacturing Capacity and Reproducibility

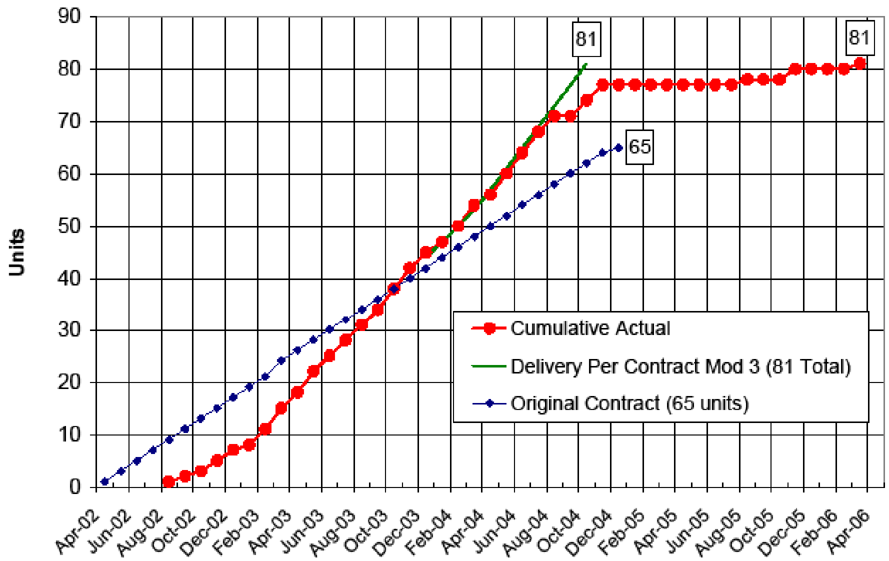
Example:

VKP-8291A/B series

805 MHz, 550/700 kW,
9 % duty cycle

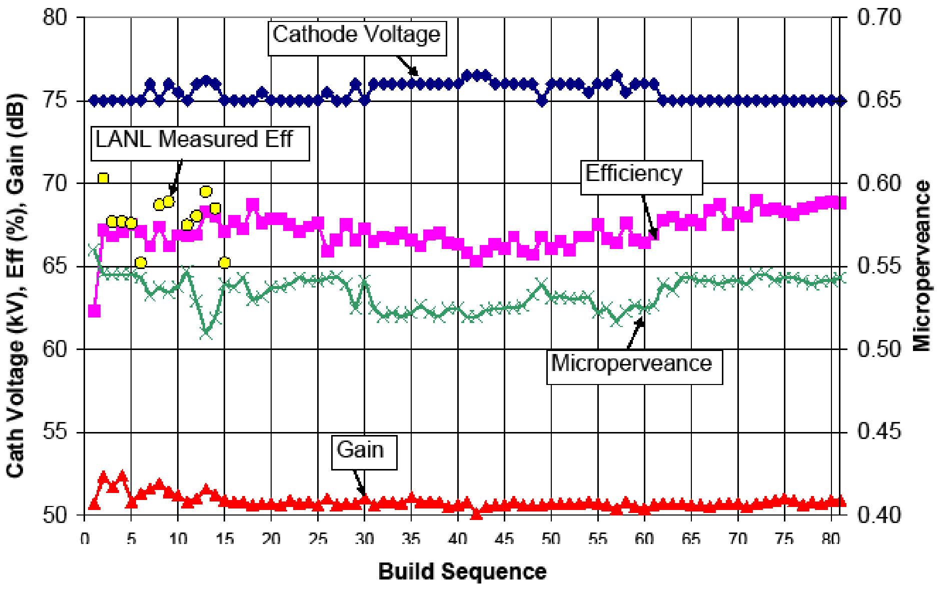
used in the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL)

Delivery Schedule of VKP-8291A



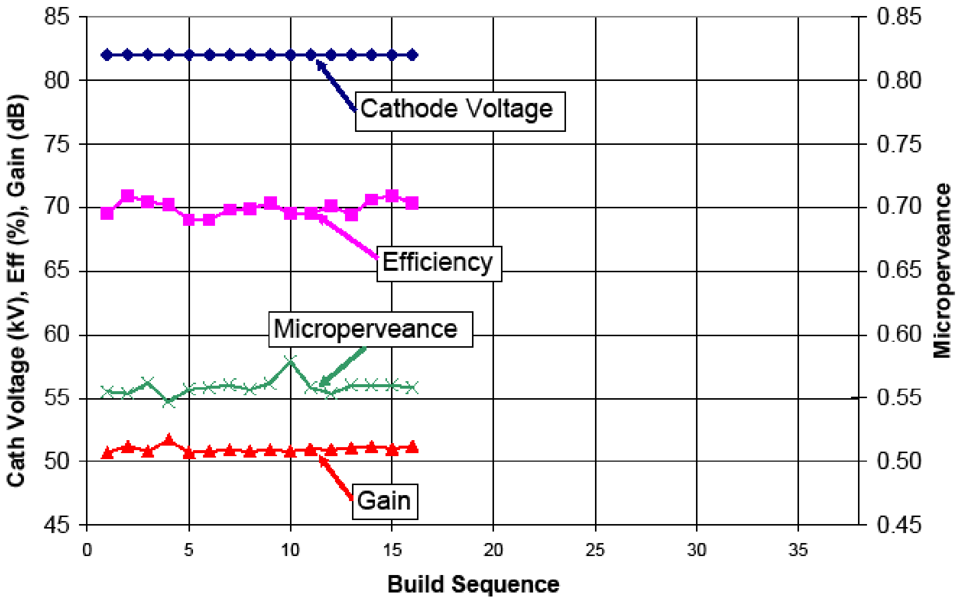
Delivery rate up to 3.3 units/month

Production Reproducibility of VKP-8291A



Production Reproducibility of VKP-8291B

(Delivery rate 4 units/month)



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R & **D**

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Typical case: At 352 MHz, the CW output power level of klystrons has been stagnating at 1.3 MW for more than two decades by now.
But this is not a limitation. It could be 2 MW, or 3?

Finally, let's not forget one more important limitation:
It's blinkers on the engineers' mind. We simply do not know which solution we just do not see.

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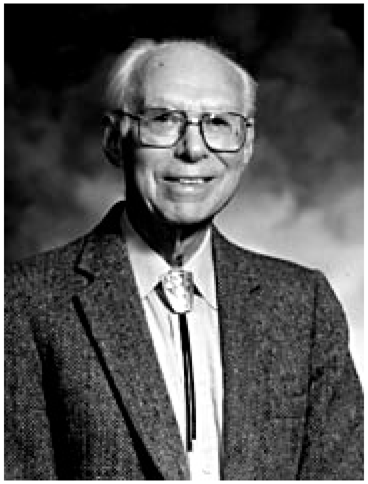

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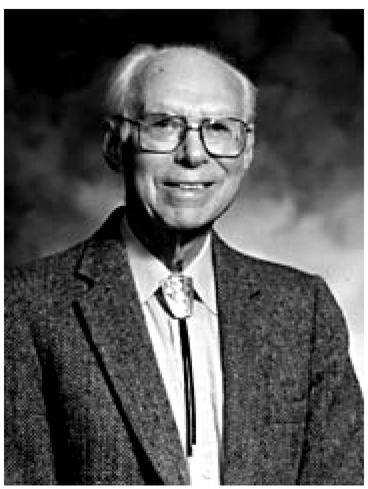

I thought about it the first time I saw it!