Review of Available Power Sources

Mike Dykes

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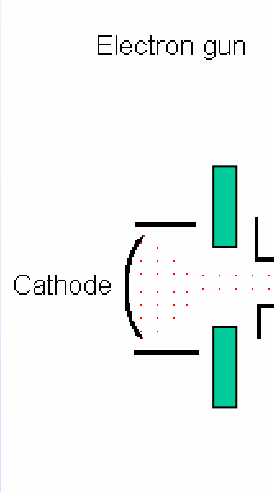
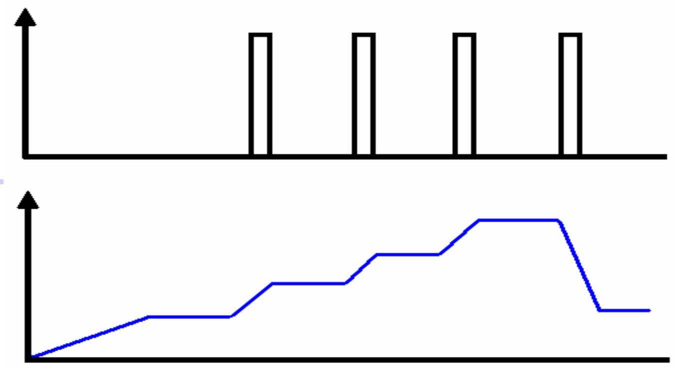
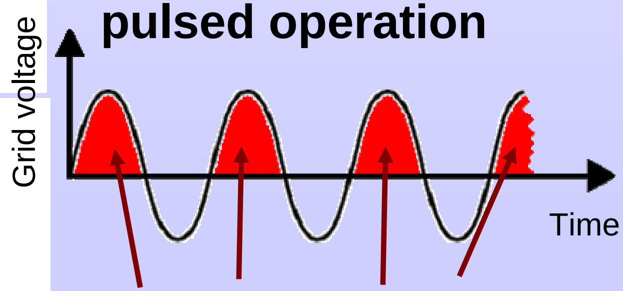
- Klystron
- IOT (Inductive Output Tube)
- Comparison
- CPI
- e2v
- Thales
- Solid State

Klystron

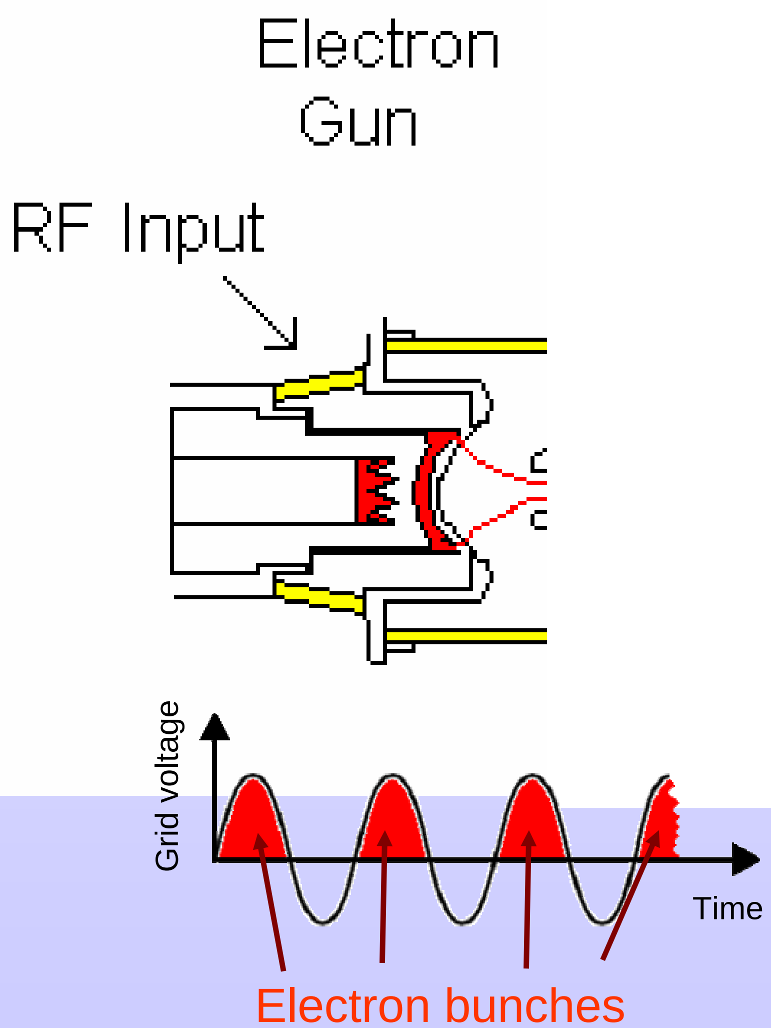




A Modulating anode can be applied to the gun for pulsed operation

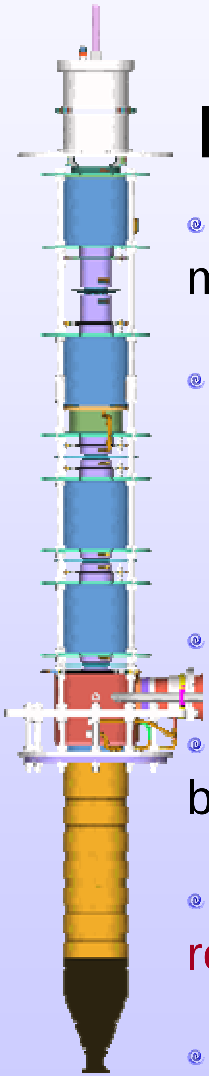


IOT



Density Modulation

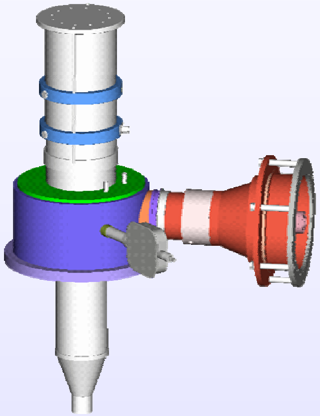
Comparison of Klystron and IOT



Klystron

- Electron Bunches formed by density modulation from the cavities.
- Several bunching cavities
  - High Gain
  - Long Device
  - Expensive
- Considerable velocity spread
- Maximum gap voltage determined by the slower electrons
- Rapid reduction in efficiency for reduced output power
- High Gain

IOT



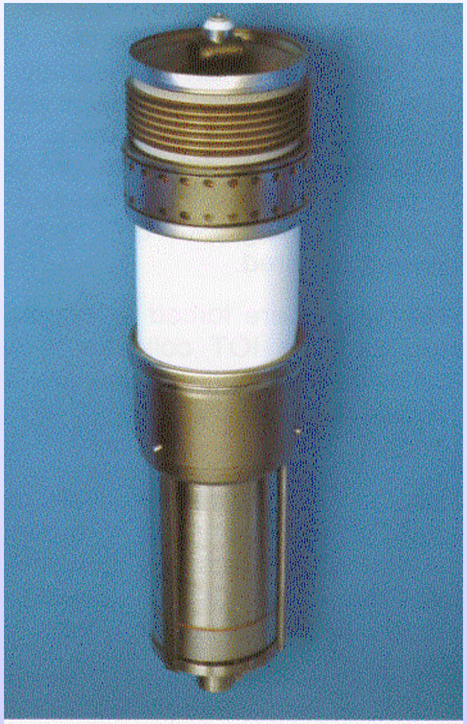
- Velocity modulation direct from the cathode
- Little velocity spread
- Higher gap voltage
  - Increased output power
  - Higher efficiency
- Efficiency is approximately constant for reduced output power
- Low Gain
- Grid geometry will not permit IOTs to operate at high frequencies like Klystrons.

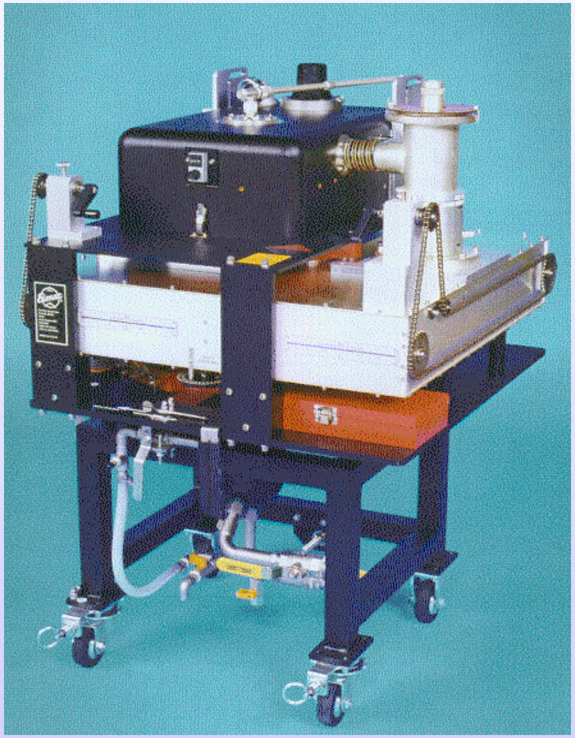
Development of a 1.3 GHz Inductive Output Tube for Particle Accelerators

H. Bohlen, Y. Li, Bob Tornoe

Communications & Power Industries

Eimac Division, San Carlos, CA, USA





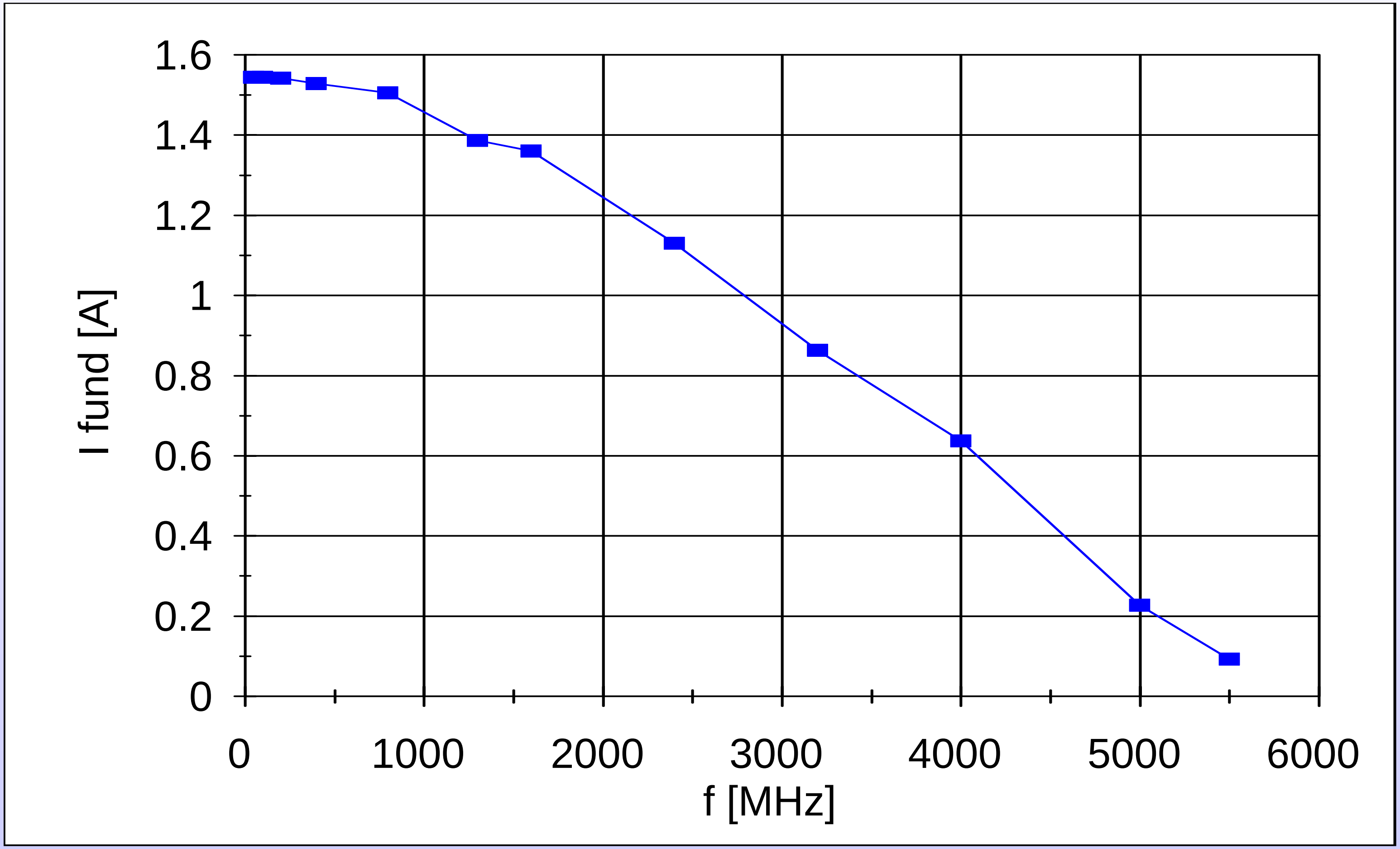
Typical UHF-Band IOT and Hardware
(Eimac K2 Series)

1.3 GHz IOT for Particle Accelerators

- 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?

- **Simulation results for second-harmonic IOTs are not devastating, but not really convincing either.**
- **So, what about fundamental-frequency operation without sacrificing the reliability of the existing gridded-gun structure?**
- **How does this structure actually behave at frequencies exceeding the UHF range, if taking the cathode-grid transit time effects into account?**

1.3 GHz IOT for Particle Accelerators



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

Comparison of simulated results

(1.3 GHz, 24 kV, Class B)

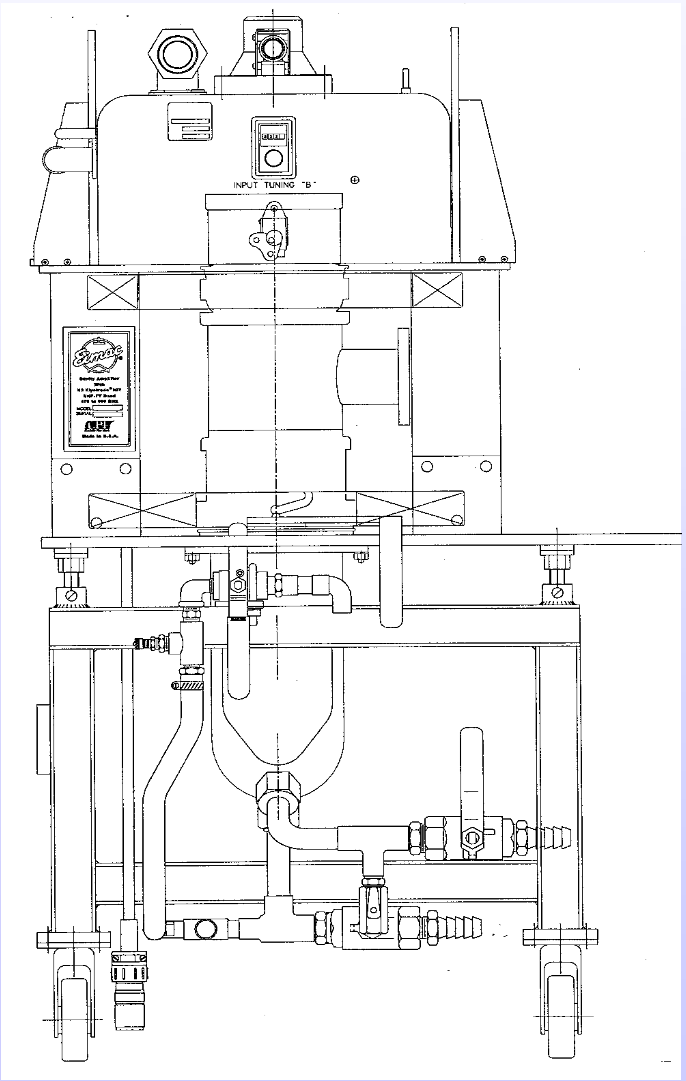
Principle	Fundamental	Second harmonic
Output power	18.0 kW	11.4 kW
Gain	23.7 dB	22.3 dB
Efficiency	66.5 %	43.1 %

1.3 GHz IOT for Particle Accelerators

UHF version

L-band version

1.3 GHz IOT for Particle Accelerators



Outline of a
15 - 25 kW CW
L-Band IOT
in hardware set

1.3 GHz IOT for Particle Accelerators

Prototype test results

Device	Beam voltage	Beam current	CW output power	Gain	Efficiency
Alpha-1	30 kV	1.23 A	20.1 kW	21.1 dB	54.4 %
Alpha-1	34 kV	1.58 A	29.5 kW	22.5 dB	54.9 %
Alpha-2	30 kV	1.44 A	26.0 kW	22.4 dB	54.7 %

Next steps

- Closer approach to theoretical efficiency (> 60 %)
- Manufacture 1.5 GHz version
- Design 300 kW peak, 1.3 GHz long-pulse IOT

High Frequency IOT Development Project IOT116LS

Alan Wheelhouse & Steve Aitken

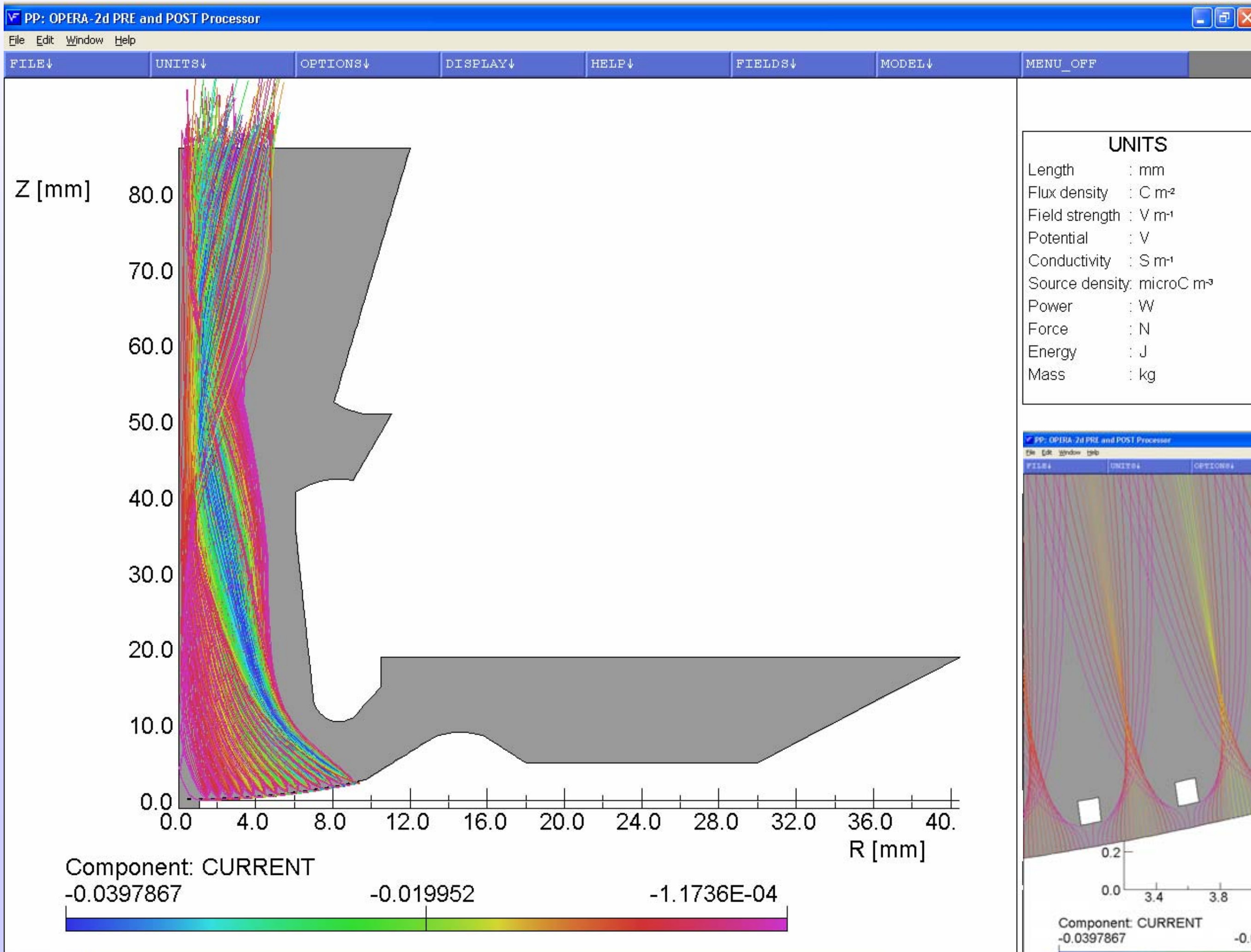
Project Scope

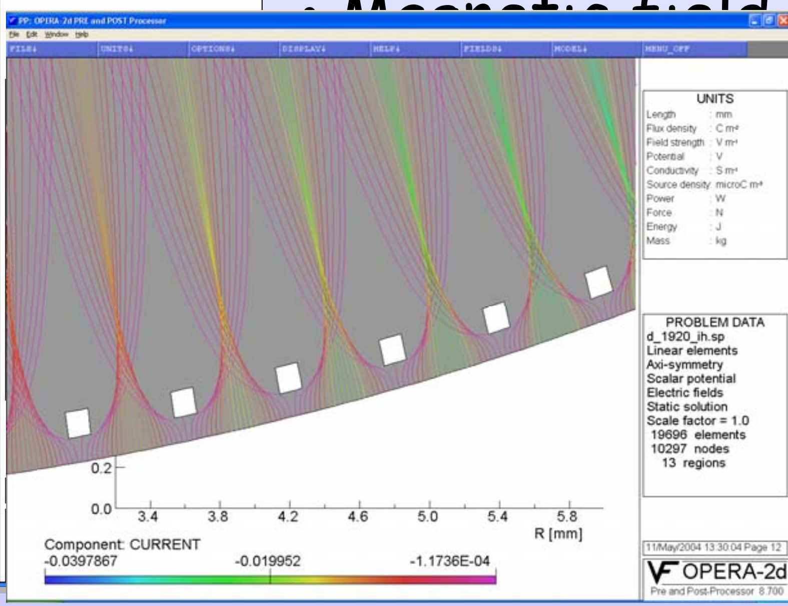
- PVR&D project to develop a 1.3GHz CW IOT
  - Output power - 16kW
  - Efficiency > 60%
  - Gain > 20dB
- Project is scoped out to develop the tube with input from potential customers
- Project will deliver 8 prototype tubes and associated circuit assemblies.
  - 5 customer evaluation samples
  - 3 in-house evaluation samples

Specification

• Frequency	1.3GHz
• Bandwidth at 1dB	>2MHz
• Bandwidth at 3dB	>4MHz
• Beam Voltage	25kV
• Beam Current	1A
• Bias Voltage	100V
• Output Power	16kW
• Efficiency	>60%
• Drive Power	<160W
• Gain	>20dB

Beam Profile

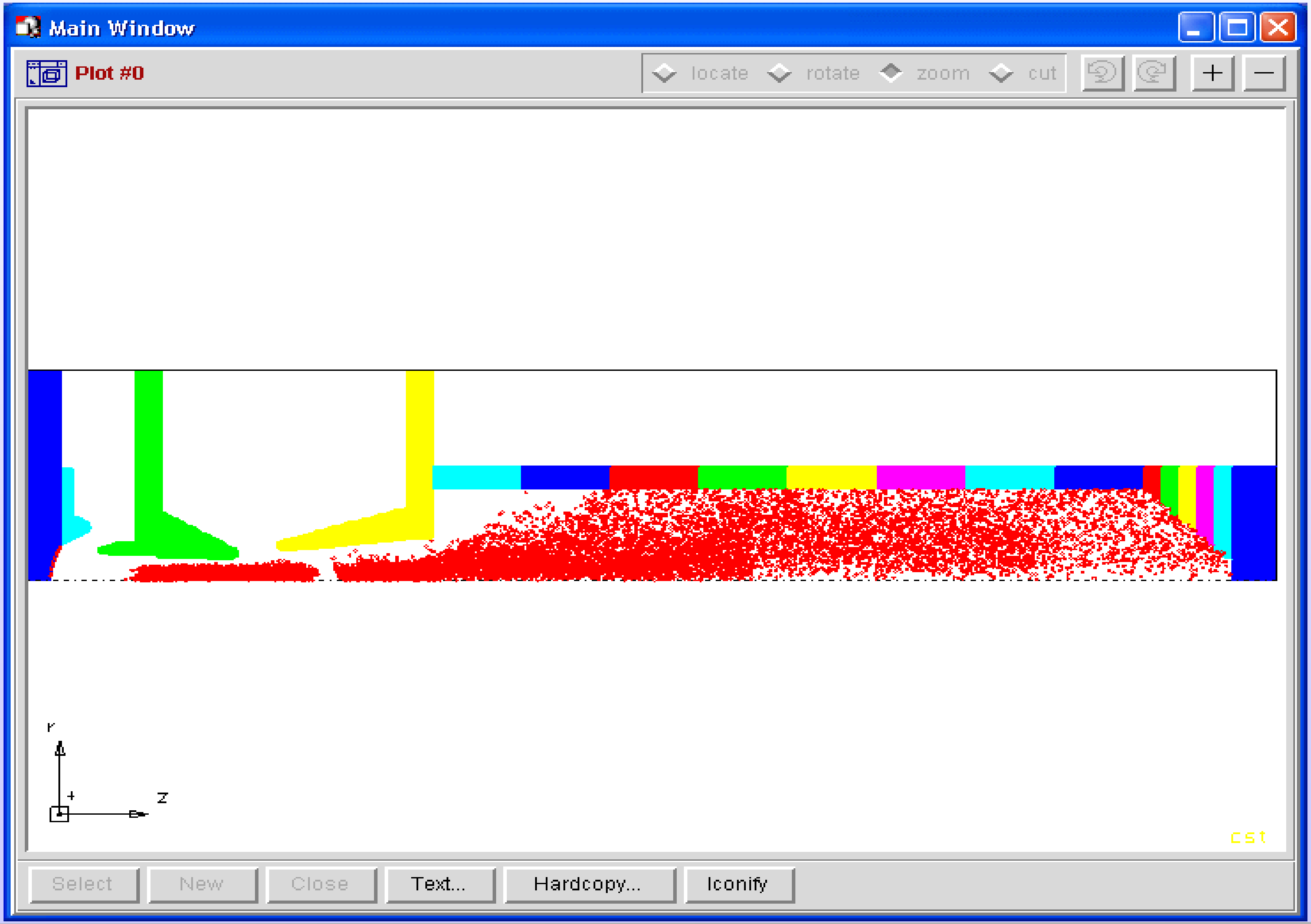




OPERA 2D Model

- Beam Voltage 25kV dc
- Magnetic field

RF Model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IOT116LS Test Results

Test Results

Frequency	1.2986	1.2986	1.2986	**GHz**
Beam Voltage	24.9	24.9	27.7	**kV**
Beam Current	0.91	0.84	1.1	**A**
Grid Voltage	-104	-122	-109	**V**
Drive Power	220	260	260	**W**
Output Power	12.4	12.4	16.3	**kW**
-1dB bandwidth	2.4	2.4	3.6	**MHz**
-3dB bandwidth	4.4	4.8	5.7	**MHz**
Efficiency	54.7	59.3	53.5	**%**
Gain	17.5	16.8	18.0	**dB**

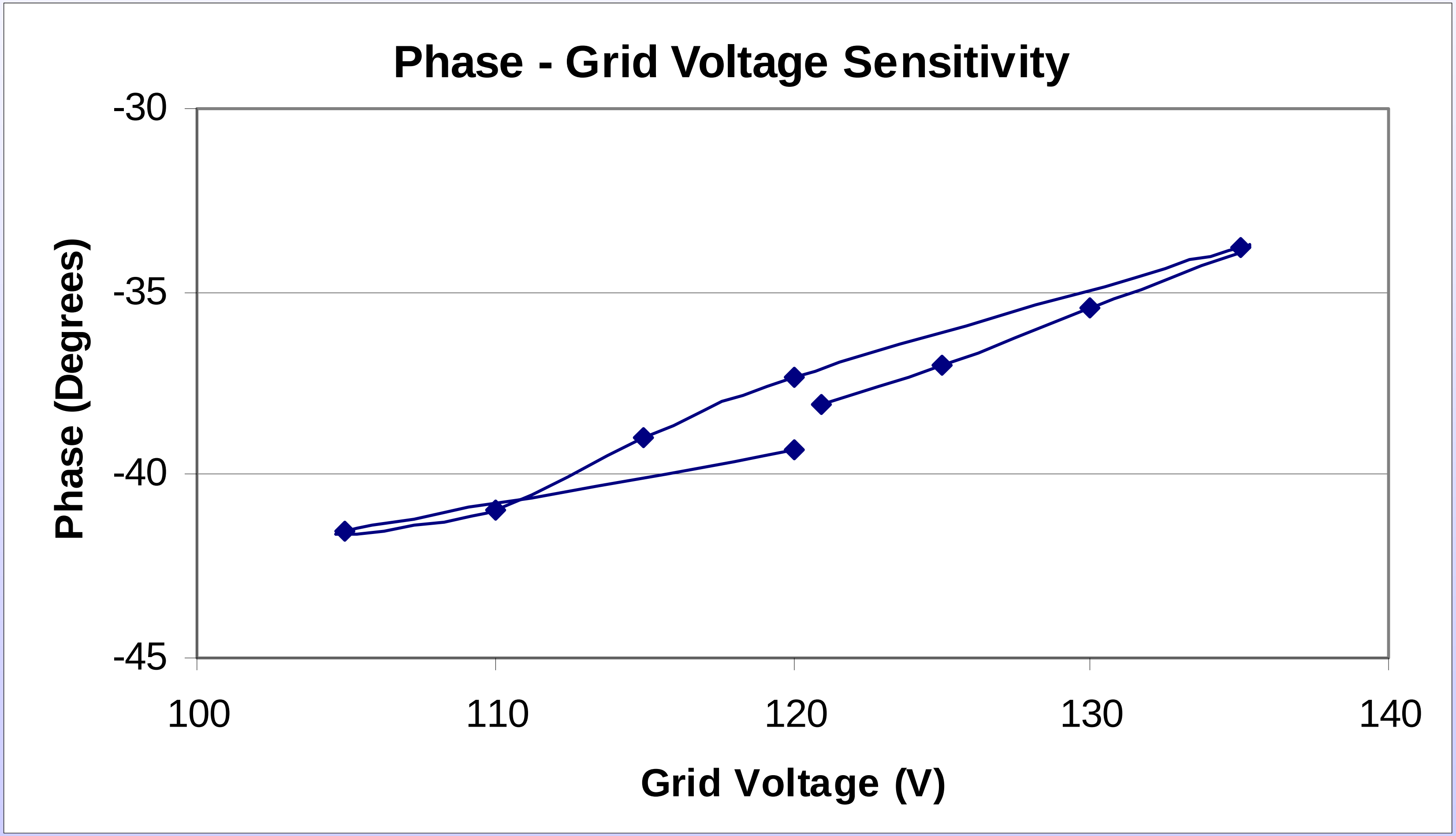
IOT116LS Test Results

Test Results

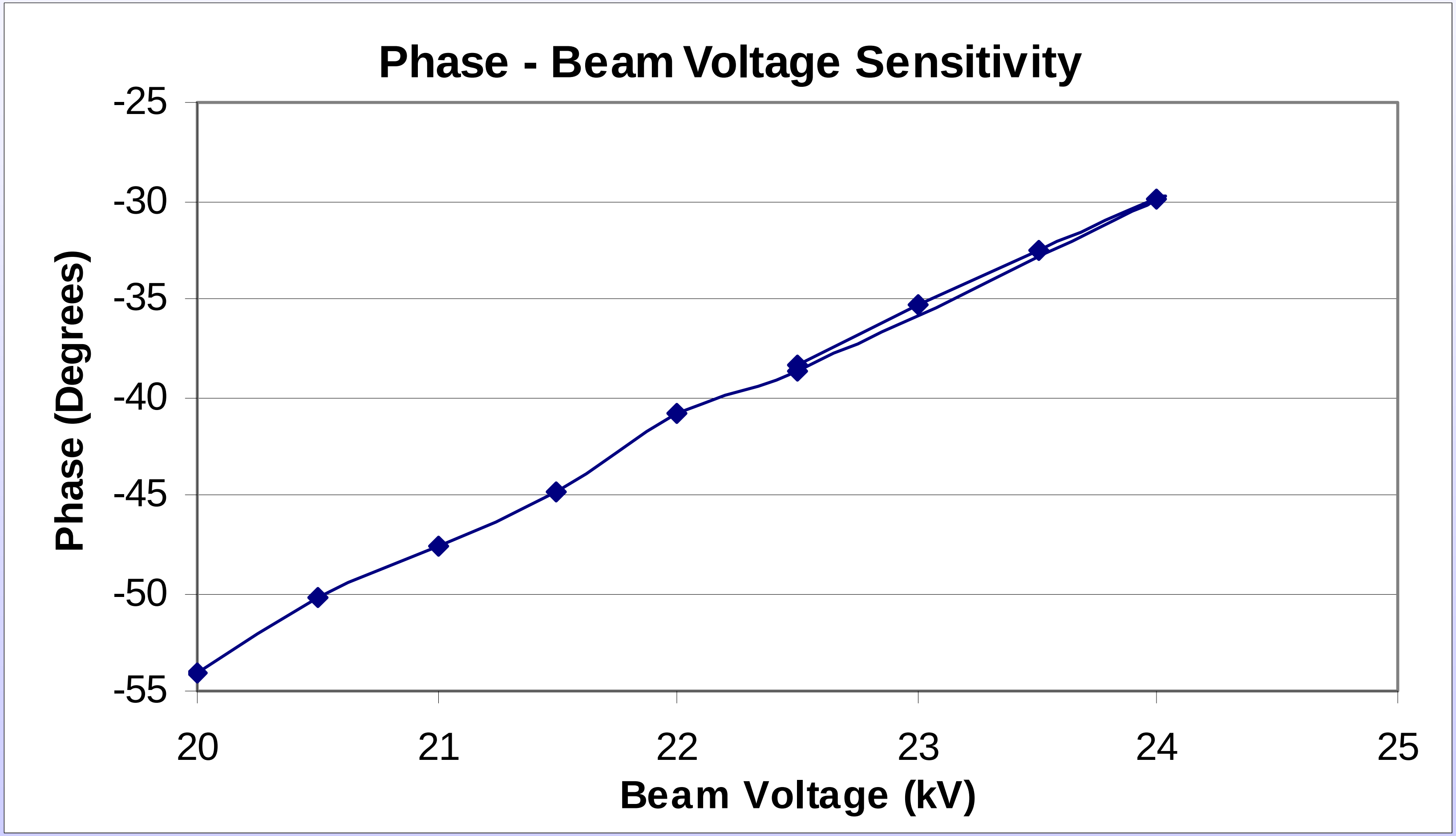
Frequency	1.3	1.3	1.3	GHz
Beam Voltage	25	25	25	kV
Beam Current	1.13	1.47	1.05	A
Grid Voltage	70	71	95	V
Drive Power	113	200	200	W
Output Power	14	19.8	14.9	kW
Efficiency	49.6	53.9	56.8	%
Gain	20.9	20.0	18.7	dB

IOT116LS Test Results

Phase – Grid Voltage

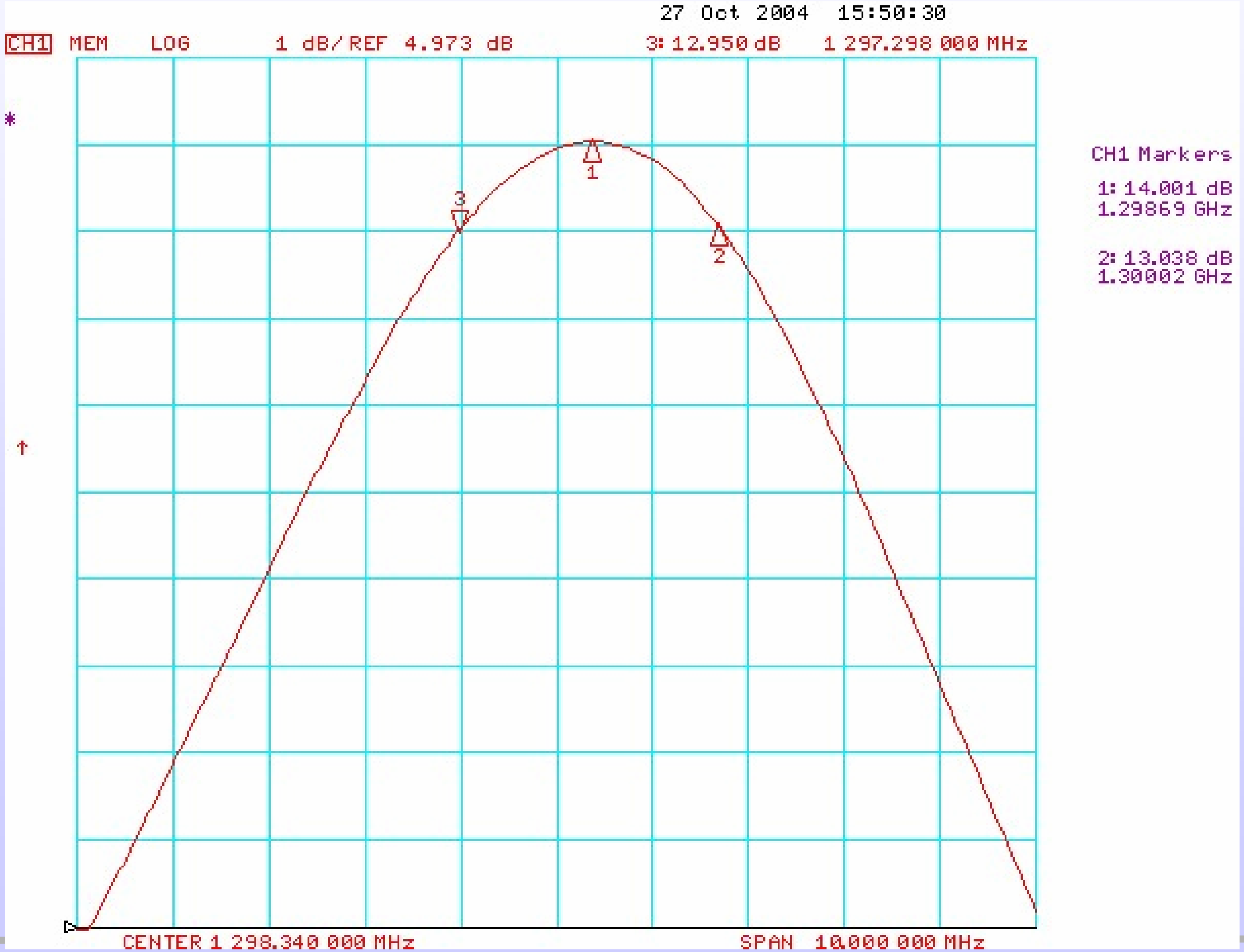


IOT116LS Test Results
Phase – Beam Voltage

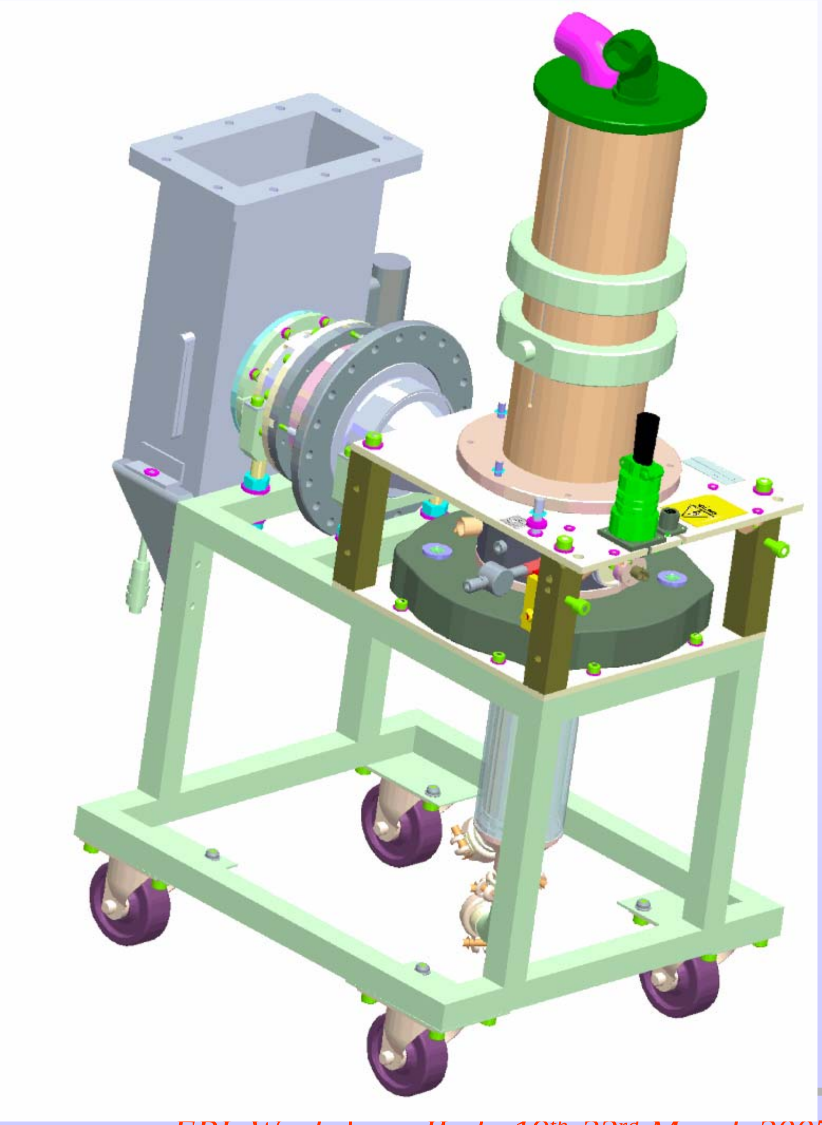


IOT116LS Test Results

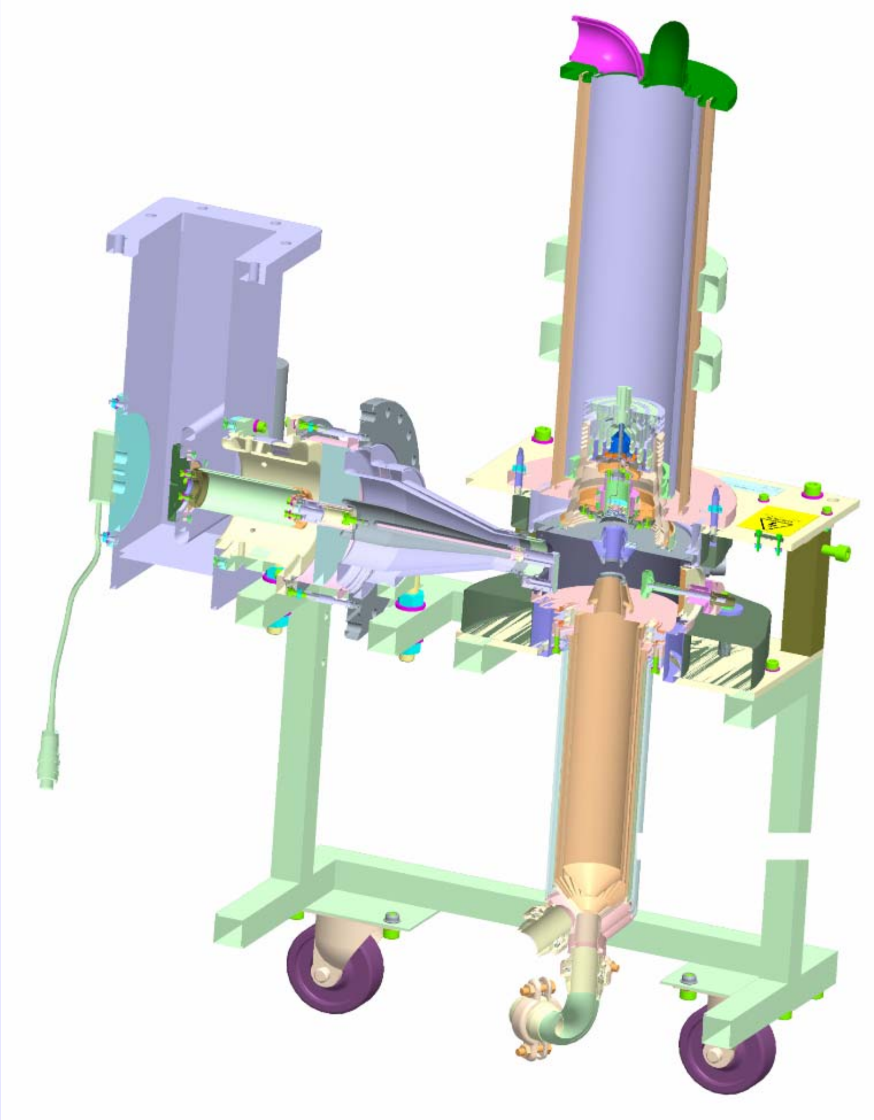
Bandwidth



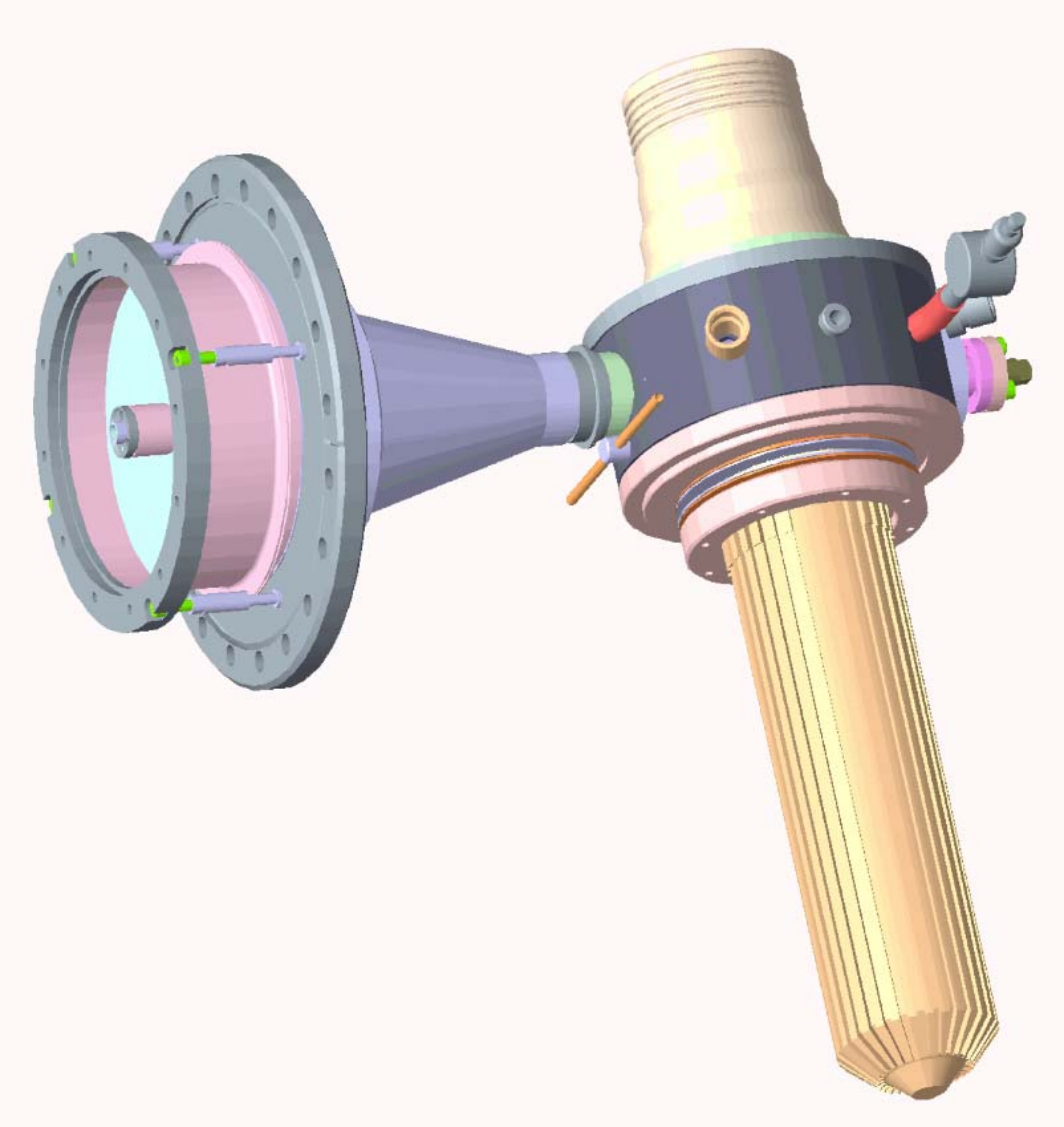
IOT116LS & Circuit



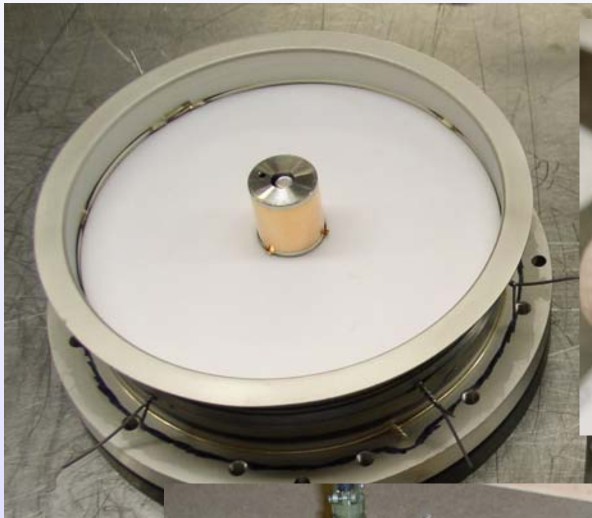
IOT116LS & Circuit – X Section

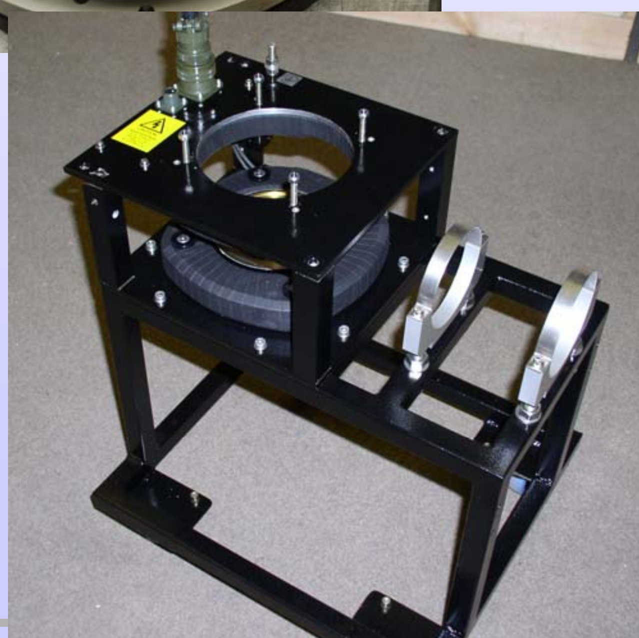


IOT116LS



IOT116LS Assembly & Parts





THALES TH713

- Pyrobloc® beam modulation grid,
- Pyrolytic graphite filament,
- Impregnated cathode with indirect heating,
- Water cooled body and collector,
- Air cooled electron gun and cavity,
- Plug-in IOT,
- Electromagnetical focusing.

Courtesy Eric Margoto

Characteristics

Characteristics	Measured value	Unit
Frequency	1.3	GHz
Bandwidth @ -1 dB	2.5	MHz
Power	16	kW
Gain	21	dB
Cathode voltage	28.5	kV
Cathode current	0.9	A
Grid voltage	- 110	V
Filament voltage	10 max	V
Filament current	25 max	A
Water cooling flow rate	30	l/min
Air cooling flow rate	1	m^3/min
TH713 collector diameter	160	mm
TH713 height	500	mm
TH713 weight	12	kg
TH18713 (TH713 cavity weight)	45	kg
RF input connector	N type	
RF output connector	Coaxial 3”1/8	

Data from different IOTs

First Test Results

TH 713 : Results

First Prototypes IOT 1.3 GHz

Parameters	*Typical value*	*Measurements*	
		Prototype 1	*Prototype 2*
RF ouput power	16 Kw	15 kW	16 kW
Frequency	1300 MHz	1300 MHz	1300 MHz
Gain	> 20 dB	22 dB	21,5 dB
Efficiency	> 60 %	59 %	61 %
Cathode voltage	23 to 25 kV	27,5 Kv	29 kV
RF input power	< 150 W	95 W	112 W

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THALES

Solid State

- Available at 1.3 GHz
- Low Power ~ 1kW
- Expensive (Drive amplifier ~ 1/3rd price of IOT)
- Need higher Q_O and Q_L