

High Power Sources



HG2013

Trieste 3-6 June 2013

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FIRST KLYSTRON OPERATION AUGUST 21, 1937



Russell (front) and
Sigurd Varian
Ansel Adams photo

- CPI, former Microwave Tube Division of Varian Associates, continues the microwave tube business that was originally founded by the Varian brothers in 1948.
- Privately held
Principal Owner: Veritas Capital
- Worldwide Sales and Service Organization with 1,650 Employees
- Business Volume: \$400M



- The scientific community is an important segment of CPI markets
 - Its demands push the technology envelope and lead to desirable innovation
 - CPI invests in design tools and manufacturing equipment
 - Product development leads to increasing CPI capability

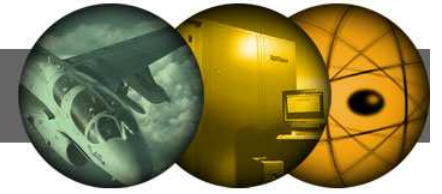


Active Vacuum Electronic Devices (VEDs)

- Gridded Tubes
- Klystrons
- Travelling-Wave Tubes
- Inductive Output Tubes (IOTs)
- Sheet-Beam Devices
- Gyrotrons
- Repair and Rebuilds



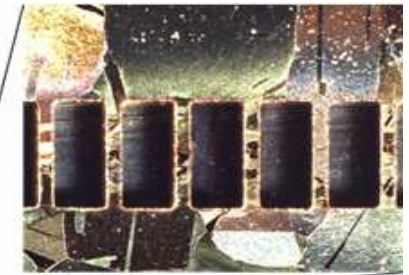
Capabilities and Experiences



3 MW peak,
325 MHz
Klystron



THz ladder circuit,
relative size to a
US penny



Actual Size
Comparison



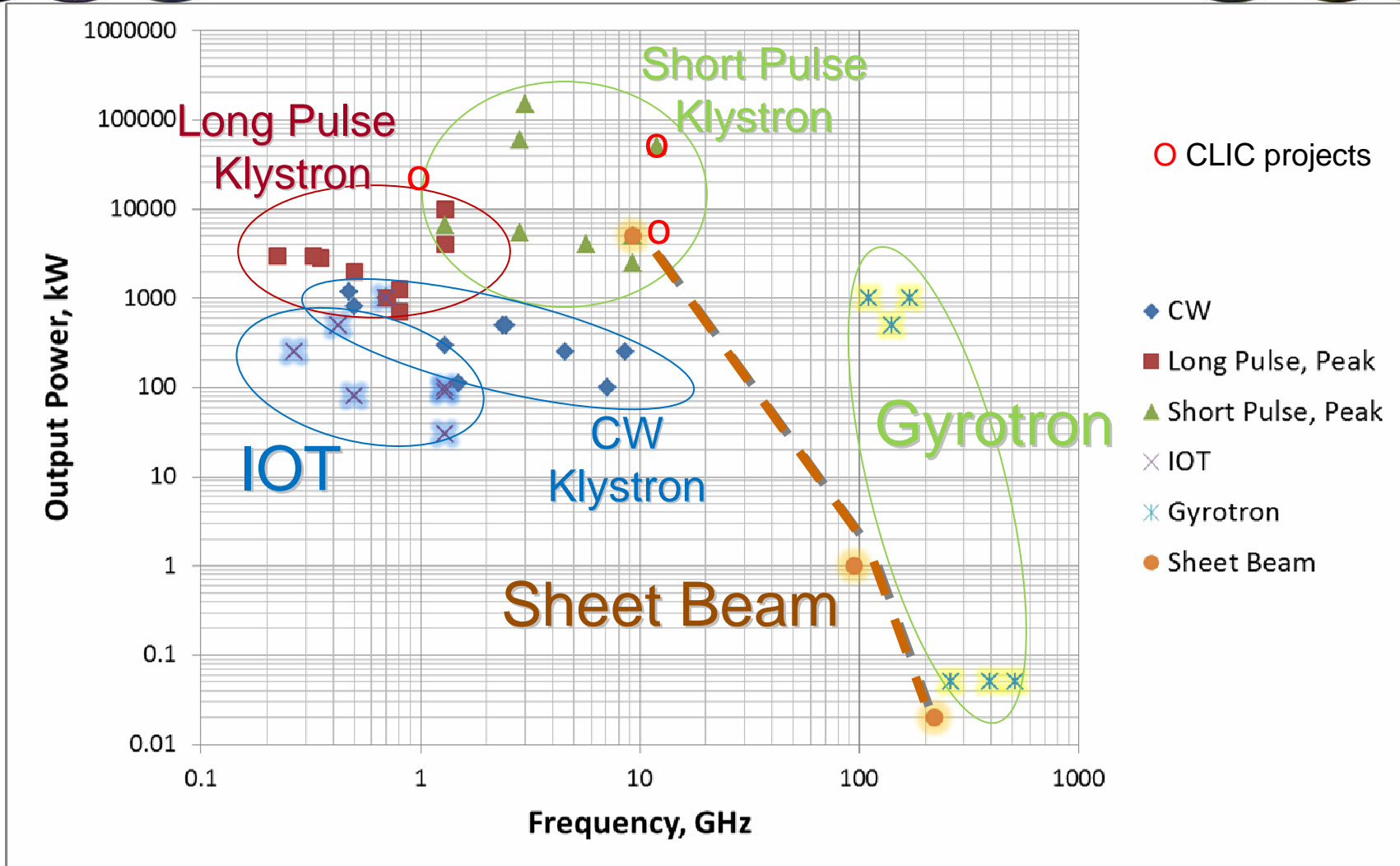
Capabilities and Experiences



- At the present stage of the project, desired RF power units for CLIC are understood to be:
 - 12 GHz, 50 MW short-pulse, or alternatively
 - 12 GHz, 6 MW short-pulse, and
 - 1 GHz, 20 MW long pulse



Capabilities and Experiences





Capabilities and Experiences



CW Klystron Products

Model	Frequency	Power	User (Program)
VKP-7951A	476 MHz	1,200	SLAC (B-Factory)
VKP-7953B	500 MHz	100 kW	Commercial
VKP-7957A	500 MHz	800 kW	Cornell University (CESR)
VKP-7958A	500 MHz	800 kW	DESY, Hamburg (HERA)
VKP-7952A	700 MHz	1,000 kW	LANL (APT)
VKP-7952B	704 MHz	1,000 kW	BNL (ERL)
VKL-7966A	1,497 MHz	100 kW	TJNAF (ERL)
VKS-8269/70	2.38/2.45 GHz	500 kW	Arecibo
VKC-7849	4.6 GHz	250 kW	MIT (Alcator) & IPP
VKX-7864B	8.56 GHz	250 kW	JPL (Deep Space Network)



Capabilities and Experiences



- VKP-7952B for Brookhaven National Lab, US
 - 1 MW CW at 703.75 MHz for ERL
- VKP-7952C for CEA Saclay, France
 - 1 MW pulsed, 2 msec, at 704.4 MHz



Collector used
as Beam Dump
for BNL



Capabilities and Experiences



- VKL-7967A for HZB and TRIUMF
- 1.3 GHz
- 300 kW CW
- Prototype in Test





Capabilities and Experiences

Pulsed Klystron Products



Long
Pulse

Model	Frequency	Peak Power	User (Program)
VKP-7952C	704 MHz	1 MW	CEA Saclay
VA-862A1	805 MHz	1.25 MW	LANL (LANSCE)
VKP-8290A	805 MHz	550 kW	ORNL (SNS)
VKP-8291A	805 MHz	2.5 MW	ORNL (SNS)
VKL-8301A/B	1300 MHz	10 MW	DESY, FNAL
VKL-7796	1325 MHz	4 MW	USAF
VA-938	2.856 GHz	5.5 MW	MIT Bates
VKS-8262	2.856 GHz	7.5 MW	Commercial
VKS-8262	2.9985 GHz	7.5 MW	Commercial
VKS-8333	2.9985 GHz	120 MW	DESY (SBLC)
VKX-8253	9.3 GHz	6 MW	Commercial
VKX-8311A	12 GHz	50 MW	CERN (CLIC)

Short
Pulse



Capabilities and Experiences



- ✦ VA-862A
 - ✦ 1.25 MW Peak, 150 kW Ave at **805 MHz**
 - ✦ Originally built in **1970's**
 - - 44 sockets for LANSCE (LANL) (800 MeV Proton Accelerator)
 - - Average life of installed tubes >100,000 filament hours
 - - Several tubes exceed 200,000 hours
 - ✦ At present building 45 more new tubes to the original design





Capabilities and Experiences



- ✦ **805 MHz**, 1 msec pulsed klystron
- ✦ Built for Spallation Neutron Source (SNS) at Oak Ridge National Lab
- ✦ VKP-8291A
 - ❑ 550 kW
 - ❑ 81 delivered
- ✦ VKP-8291B
 - ❑ 700 kW
 - ❑ 38 delivered

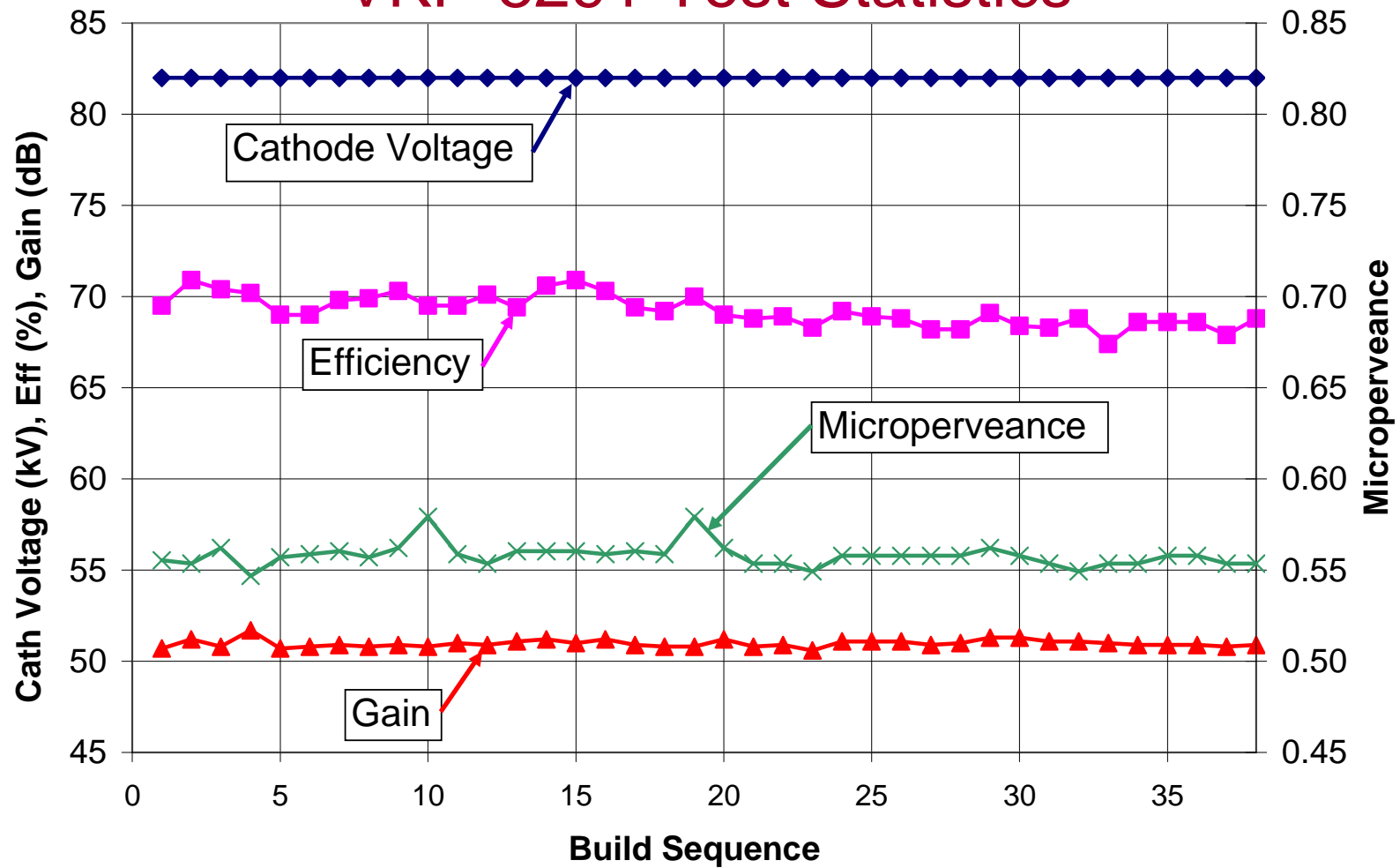




Capabilities and Experiences



VKP-8291 Test Statistics





Capabilities and Experiences



- ✦ VKP-8325A
 - ✦ Recent development for Tsinghua University

- ✦ Parameters
 - ✦ **325 MHz**
 - ✦ 3 MW
 - ✦ 3.3% Duty
 - ✦ Solenoid Focused
 - ✦ 1 unit shipped

- ✦ Order Placed 1/6/2010
- ✦ Shipped July 7/30/2011



Just received order for 4 units
for IHEP (Beijing) for CSNS

- Tune to 324 MHz



Capabilities and Experiences



- Customers
 - ❖ CERN (Linac4)
 - ❖ ESS Bilbao
- Parameters
 - ❖ **352.2 MHz**
 - ❖ 2.8 MW Peak Power
 - ❖ 10-126 kW Average
 - ❖ 230 kW Average Power with Optional Upgrade
 - ❖ 109 kV Beam Voltage, Peak
 - ❖ 46.8 A Beam Current, Peak
- 8 units ordered June 2010
- 5 units shipped to date



VKP-8253A/B



Capabilities and Experiences



- Multiple Beam Klystron VKL-8301A/B
 - ❖ Pulsed klystron
 - **1.3 GHz**
 - 10 MW peak
 - 150 kW average
 - 1.5 ms pulse length
 - ❖ Horizontal version delivered to:
 - DESY (Euro-XFEL)
 - Fermi Lab
 - ❖ **Would be baseline for 1 GHz,
20 MW source for CLIC Drive Beam**
- MBK advantages
 - Reduced operating voltages (typically 50% to 80%)
 - Leads to shorter circuit lengths (typically 30% to 60%)
 - Lower X-ray generation





Challenges



- With present day means, scaling VKL-8301 to 1 GHz and 20 MW long-pulse (down in frequency, up in power) would be a major task, but not a technological challenge.
- The challenge for the CLIC drive beam klystron is rather a logistical one.
- Diligent choice of suppliers, a timely development start and careful compromises between manufacturing capacities and delivery schedules will be necessary to meet this challenge.



Capabilities and Experiences



Medical and Industrial Accelerator Klystrons for S-Band and X-Band

	VKS-8252	VKX-8253
Frequency	2856 MHz	9300 MHz
Peak Power	5.5 Mw	5.5 Mw
Average Power	5.7 kW	18 kW
Gain	40 dB	53 dB
Efficiency	47 %	44 %



CERN considering 6 MW, 12 GHz klystron for test stand.
VKX-8253 would be the baseline for a straight-forward
development well within the state of the art.



VKX-8253 Features



VKX-8253A Features

- ✓ Water cooled 6-Cavity RF Body
- ✓ Single Output Alumina Window
- ✓ Single-Section Electromagnet
 - Runs on a Single Supply
- ✓ Grounded Collector
- ✓ Proven S-band Gun Design
- ✓ Low Cost, High Volume Manufacturing Design
- ✓ Typical Life Expectancy in excess of 80,000 Hours



VKX-8253A Standalone



VKX-8253A in the Magnet



Data details of VKX-8253



Parameter	Spec.	Units
RF Operating Frequency	9.3	GHz
Bandwidth, -1 dB	+/-15	MHz
Peak Output Power	5	MW
Average Output Power	20	KW
RF Pulse Width	2.5	μsec
RF Duty Factor	0.4	%
RF Drive Power	20	W
Beam Voltage	135	kV
Beam Current	95	A
Perveance	1.85 - 2.1	uP
VSWR Tolerance	1.2:1	N/A
Solenoid Major Diameter	18	Inch
Cathode type	Oxide	N/A



2.7 MW Pulsed VKX-7993 at 9.3 GHz

Typical Operating Parameters

• Frequency	9.3	GHz
• Peak Power	2.7	MW
• Peak Power (goal)	5.5	MW
• Pulse Width	7	μs
• Saturated Gain	52	dB
• Bandwidth (-1 dB)	65	MHz
• Efficiency	43	%
• Beam Voltage	120	kV
• Beam Current	52	A

Need for lightweight source led
to **PPM focused** klystron.





Proposed 6 MW/12 GHz klystron



Parameter	Spec.	Units
RF Operating Frequency	11,9942	GHz
Bandwidth, -1 dB	+/-15	MHz
Peak Output Power	6	MW
Average Output Power	12	KW
RF Pulse Width	5	μ sec
PRF	400	Hz
Gain	49	dB
Beam Voltage	155	kV
Beam Current	115	A
Perveance	1,8	μ P
VSWR Tolerance	1.2:1	N/A
Electronic Efficiency	40	%
Cathode type	Oxide	N/A



High Peak Power Klystron VKS-8333A

Electron Gun



- ✦ **150 MW peak (nominal)
at 2.9985 GHz**
- ✦ **Beam Voltage – 535 kV**
- ✦ **Beam Current – 700 A**
- ✦ **RF Pulse Length – 3 μ s**
- ✦ Klystron designed at SLAC for the S-Band Linear Collider (SBLC) at DESY
 - ▣ Extended from SLAC 65 MW pulsed klystron (5045) that fills 240 sockets at SLAC
- ✦ CPI awarded contract to make production version
 - ▣ Mechanical redesign performed to fit CPI production philosophy
- ✦ Prototype built and tested
 - ▣ Achieved >120 MW peak



Vacuum Envelope



Capabilities and Experiences



- **50 MW peak klystron VKX-8311A at 12 GHz for CLIC**
 - Based on SLAC XL5
 - SLAC provided print package and Technical support
 - Maintained electrical design
 - Changed mechanical design to better fit our assembly philosophy
 - 1st unit being rebuilt (suffered from accidental contamination)
 - Will be tested at SLAC



SLAC XL4, courtesy of SLAC website

Challenges

- **50 MW peak klystron VKX-8311A at 12 GHz for CLIC**
 - ❑ This device is a typical example for a technological challenge.
 - ❑ It is borderline state-of-the-art, unforgiving even in the case of minor negligence.



SLAC XL4, courtesy of SLAC website



XL5, Results achieved by SLAC



Parameter	Value	Units
Frequency	11.994	GHz
Output Power	52	MW
Gain	49	dB
Efficiency	40	%
-3 dB Bandwidth	>50	MHz
Beam Interception	0.8	%
Beam Voltage	400	kV
Beam Current	321	A
Perveance	1.27	$\mu\text{A}/\text{V}^{3/2}$
RF Pulse Length	1.5	μsec
Video Pulse Length	3.5	μsec
Rep Rate	60	Hz



Collaboration with SLAC



- ❖ CPI and SLAC have a long history of collaborating
 - ❖ B-Factory Klystron (1.2 MW CW at 476 MHz)
 - ❖ 150 MW peak, S-Band klystron for SBLC at DESY
 - ❖ NLC klystron components (75 MW, x-band)
- ❖ CPI and SLAC have entered a collaborative agreement to expand existing technology into new power and frequency operating regimes, and the commercialization of high power devices. Current initiatives include:
 - ❖ Commercial version of SLAC XL5 (50 MW peak at 12 GHz)
 - Designated CPI model VKX-8311A
 - 2 units being built for CERN for CLIC
 - Both units will be tested at SLAC
 - ❖ Building of the 5045 60 MW S-Band klystron at CPI
 - ❖ Discussing the co-development of a 30-MW peak, C-Band klystron



VKX-8311A Objectives



Develop an industrial version of the SLAC XL5 klystron

- produces 50 MW at 11.994 GHz

- preserve electrical and magnetic design

 - conduct basic simulations to fully understand design

- utilize Design for Assembly / Design for Manufacture (DFA / DFM) techniques to mechanically simplify design

 - lower cost

 - faster build time

 - potential increase in reliability through reduction of number of joints

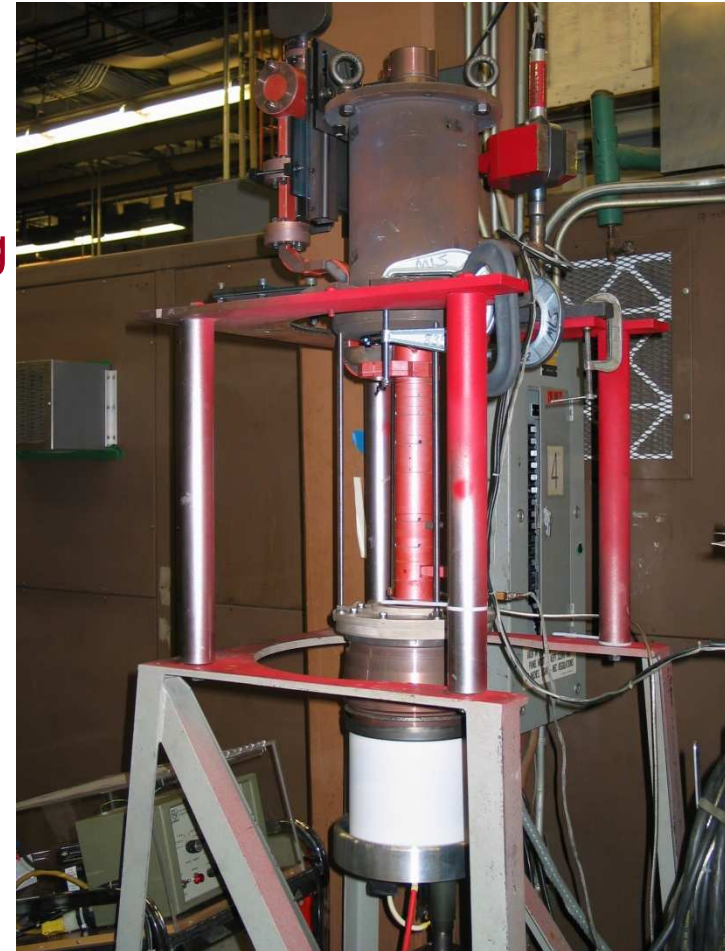
Manufacture two klystrons for CERN



VKX-8311A Status



First unit rebuilt after accidental contamination problem.
Unit exhausted successfully and being dressed-up for transfer to SLAC for testing.
Availability for CSI expected mid July 2013.
Scheduled to ship to CERN August 2013.
2nd unit scheduled to be build early 2014





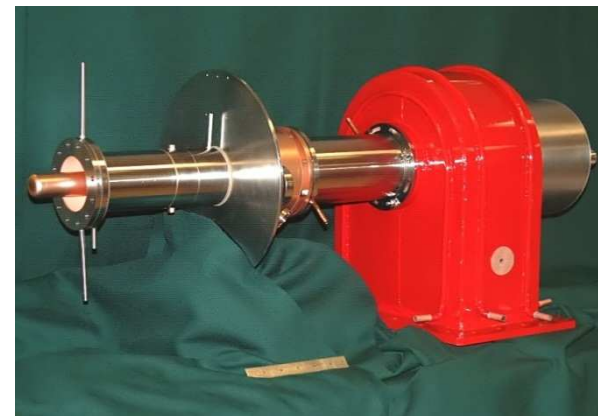
VED Technology Spin-Offs

- Technologies and tools necessary to design and manufacture VEDs are also used successfully to provide industry and the accelerator community with a range of different components:
 - RF Windows
 - RF Couplers
 - Beam Dumps
 - Electron Guns



Power Couplers

- Power couplers are key components in superconducting accelerators
 - ❖ Used to transfer high power microwaves into superconducting accelerator cavities
- Over 150 power couplers built in the last ten years
 - ❖ Frequency range 175 MHz to 5.8 GHz
 - ❖ Peak power up to 1 MW
 - ❖ Average power range 5 kW to 500 kW





Summary



- Vacuum electron devices continue to provide the RF power needed for today's advanced accelerators
- Continual improvement of the technology will provide systems with better products
- HF through S-Band - Mature
- Recent explosion of UHF and L-band applications will see benefit from IOT and Multiple Beam technology