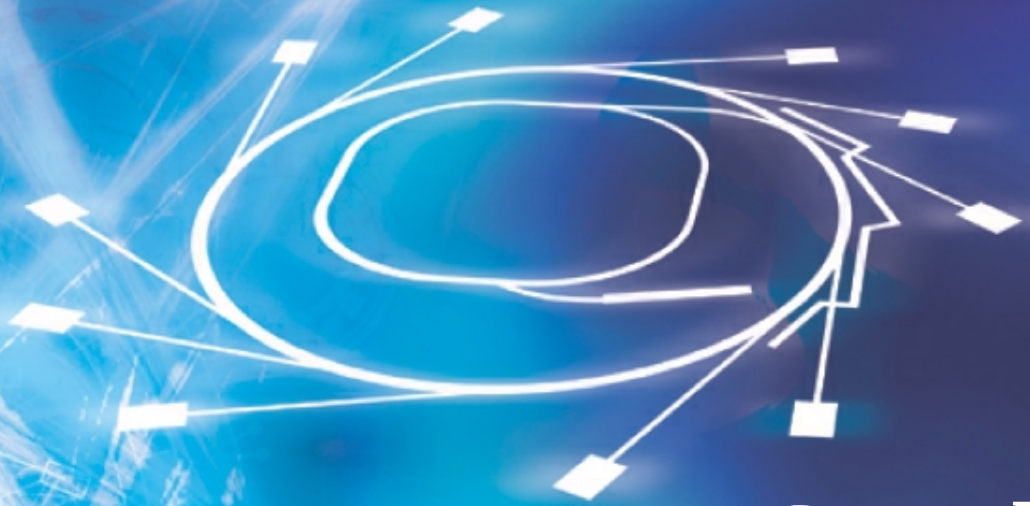
The Australian Synchrotron



Crowbar Less High Voltage Power Supplies (HVPS)

7th ESLS RF meeting, 16 - 17 Oct. 2003

Karl Zingre – RF Engineer

www.synchrotron.vic.gov.au

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Delivery schedule

2003	Construction works commence
Late 2004	Building complete
Early 2005	Injection system assembly commences
Late 2005	Injection system commissioned Storage ring assembly underway
Mid 2006	Storage ring commissioning and beamline installation commence
Early 2007	Machine and beamline commissioning complete
2007	Australian Synchrotron opens

Crowbar-less, SCR High Voltage Power Supplies for Klystron and inductive output tubes applications

Crowbar-less high voltage power supplies were introduced about 20 years ago (PSM modulators based on GTO technology for AM transmitters and tetrode applications). They are now standard for most high power tube applications!

Their highlights are :

- **High security (short circuit energy < 25 J)**
- **High reliability (MTBF 10-20'000 hrs)**
- **High quality (regulation, ripple, functionality)**
- **High efficiency (95 - 98 %)**
- **Low operating costs (no tubes to be replaced)**

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The following presentation should give you answers about :

- **What are the requirements ?**
- **Existing systems and designs**
- **What system meets the requirements best ?**

Requirements

Performance: Klystrons : 30 - 55 kV@ 2 - 10 A CW
IOT's : 15 - 36 kV@ 8 - 15 A CW

- ~ Regulation: < 0.5 %, voltage controlled, variable voltage adjustment 0.1 - 0.2 %
- ~ Ripple: < 0.5 %, no spurious emission nearby f (synchrotron) 2-20 kHz
- ~ Efficiency: > 96 %
- ~ MTBF: > 15 - 18 000 hrs, reliability
- ~ SC energy: < 15 Joules, response time < 5 µs

Environmental aspects:

- ~ Used space: small but easy for serviceability or MTTR
- ~ Mains Input: 12 pulse rectification, harmonic current components
  inrush current limitation
- ~ Cooling: preferable air cooling, low heat radiation
- ~ Integration: Integration to the master control system
- ~ No oil: transformers, capacitors
- ~ vibration: < .05 microns

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Reliability

Design aspects:

- ~ low switching frequency
- ~ allowed failure rate (modular design)
- ~ low voltages across single components
- ~ short circuit current limitation (di/dt)
- ~ proper damping circuits (parasitic oscillation, overshoot limitation)
- ~ safety margin for single components

Mechanical aspects:

- ~ low operating temperatures
- ~ air cooling
- ~ dust free (closed cabinets and cooling circuit)
- ~ enough isolation distance, corona protection

Short circuit energy

Criteria:

~ Low stored energy	$E = \frac{1}{2}(C \cdot U^2 + L \cdot I^2)$	**~10 J**
~ short HV cables to load	$E = \frac{1}{2}C' l \cdot U^2$	**~ 1 J every 10 m**
~ Fast switch off	$E = U \cdot I \cdot t_{off}$	**~ 3 J**

~ short circuit current limitation less than $2 \cdot I_0$

~ current slope $(\Delta i/\Delta t) < I_0 / t_{off)}$

Principal designs

Primary switched

SCR at low level (400 V).

Simplifies design.

Secondary switched

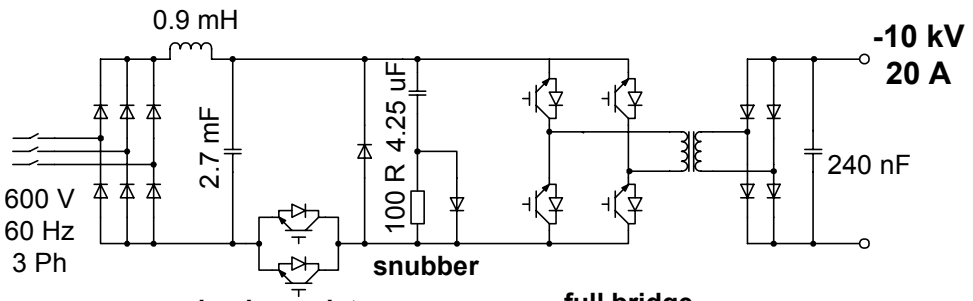
SCR at HV side of the transformer.

HV design required

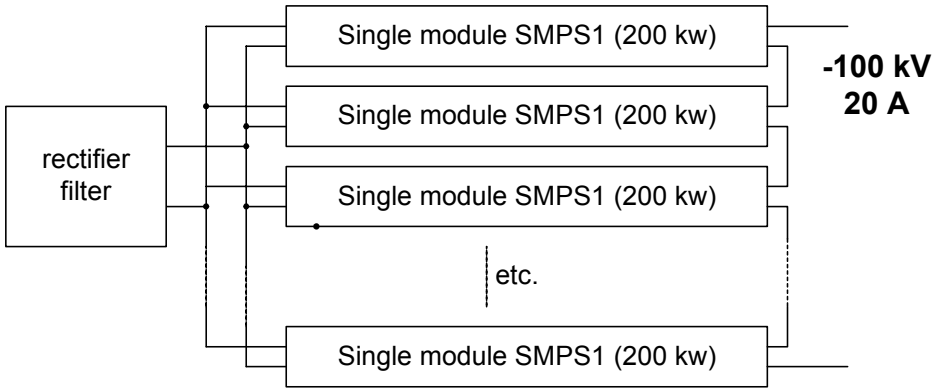
Modular or single design

Klystron Power supply for KOMAC (Korea)

Switch Mode Power Supply (SMPS)



module connection concept



Actual situation

project not realised
crowbar solution !!!

Proceedings of EPAC 2002,
Paris, France

Parameter	value	comment
Power	2 MW	
output voltage	100 kV	
Power/module	200 kW	10 modules
Voltage/module	10 kV	series connection
voltage ripple	< 2%	peak to peak
stored energy	<25 J	
efficiency	> 90 %	
MTBF	?	

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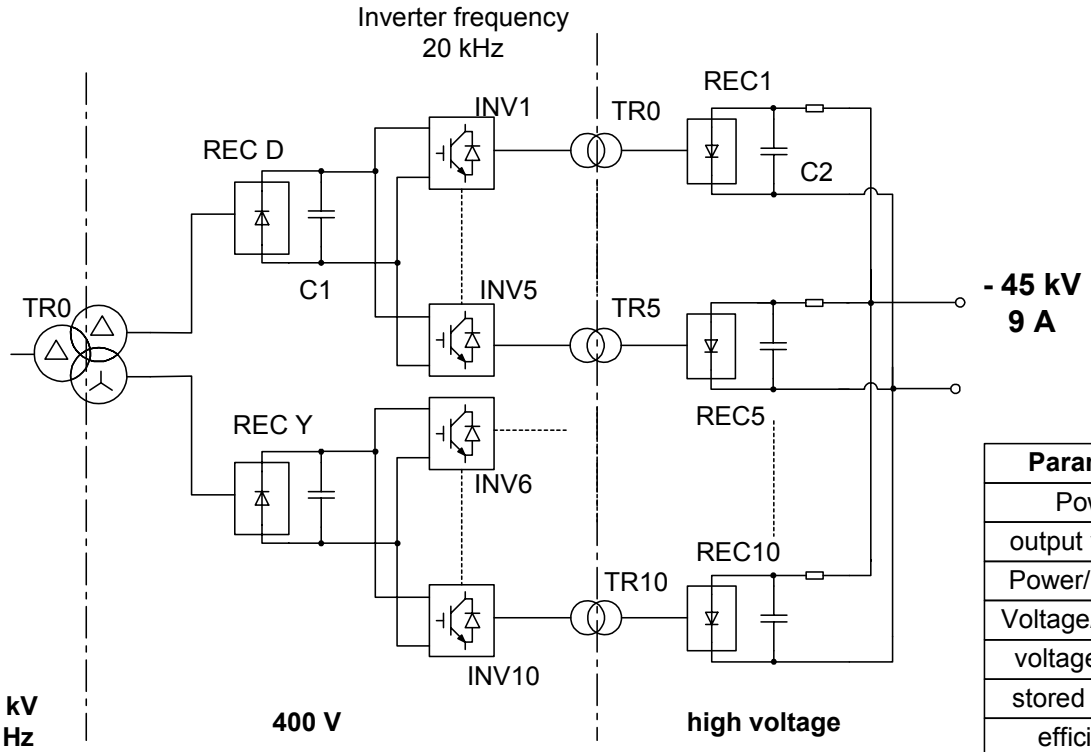
Klystron Power supply for New Subaru (Toshiba)



Parameter	value	comment
Power	405 kW	
output voltage	45 kV	45kV@9A
Power/module	40.5 kW	10 modules
Voltage/module	45 kV	// connection
voltage ripple	< 0.2%	1-10 kHz
stored energy	< 24 J	
efficiency	?	
MTBF	?	

Conversion: AC : DC : AC : DC

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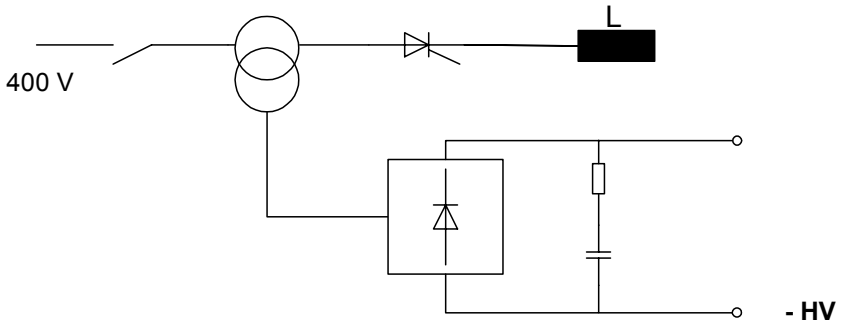
Klystron Power supply for ANKA (Jaeger)

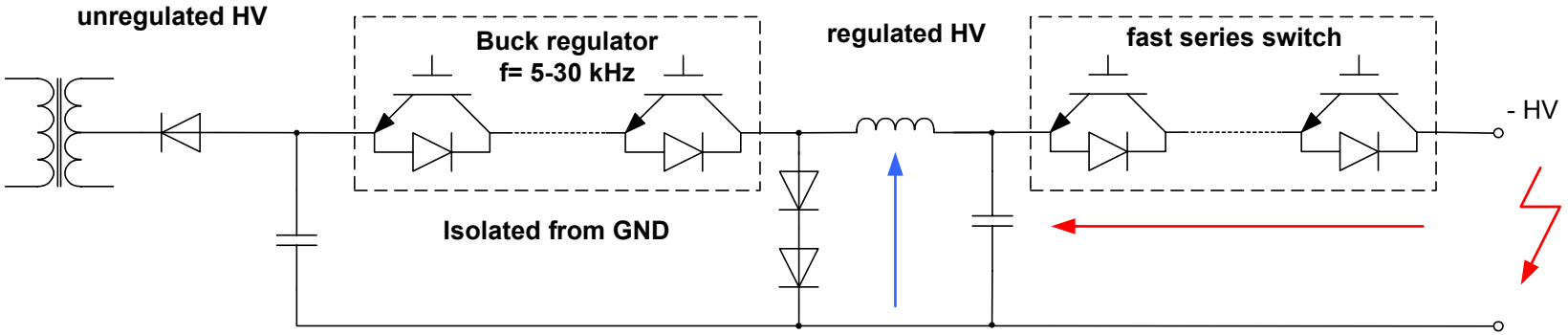


Primary switched system:

The High voltage power supply will be controlled by a thyristor converter on the low voltage side of the transformer where also the choke is located. (simplifies design)
Any fast current rise is limited by the output inductivity.

Parameter	value	comment
Power	468 kW	one unit
output voltage	52 kV	52kV@9A
Power/module	-	
Voltage/module	-	
voltage ripple	< 0.4 %	
stored energy	<20 J	
efficiency	?	
MTBF	?	

Fast Solid State HV- Switch, (DESY, CERN, KEK) (DTI)



The higher the required voltage the more switches have to be in series, ~700 -1500 V / IGBT.

The current is limited by the IGBT.
Larger IGBT's or parallel design to increase the current.

Parameter	value	comment
Power	3 MW	one unit
output voltage	160 kV	5-100 kV
Power/module	-	
Voltage/module	-	
voltage ripple	< 1%	
stored energy	< 5 J	toff < 600 ns
efficiency	98%	according to DTI
MTBF	?	

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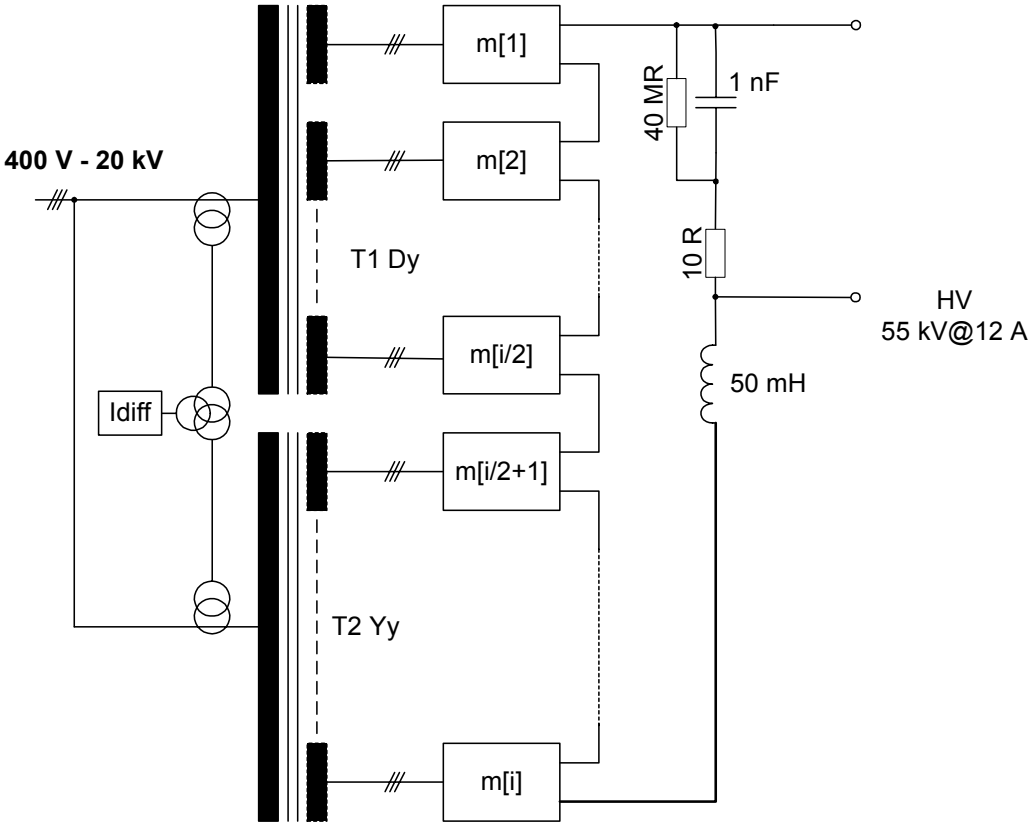
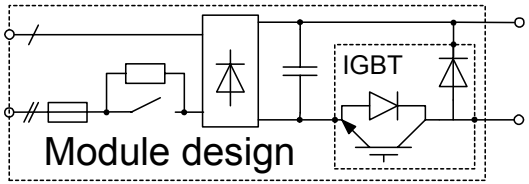
Pulse Step Modulation (PSM) (SLS,CLRC,CLS, SSRF)



PWM 100 kHz



switching frequency 1 kHz = PWM/i

current limitation (L)
fast switch off (3-5 µs)
up to four or more modules can be out of service at any time

Parameter	value	comment
Power	> 100 kW	100kW-20 MW
output voltage	> 10 kV	10-200 kV
Power/module	8 kW	86 modules
Voltage/module	730 V	700 - 800 V
voltage ripple	< 1%	<0.5%
stored energy	< 15 J	
efficiency	98%	
MTBF	18000 h	very high

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Weighted values

Parameter	weighted	Toshiba	Jaeger	DTI fast switch	PSM	Tube and Croowbar	Comments
Reliability	10	6	8	8	10	7	PSM: selected for APT 244 21@ 95 kV
Efficiency	9	7	8	9	10	3	PSM: higher efficiency due to lower switching losses
Ripple	8	6	7	4	5	8	DTI: higher smoothing capacitor but full PWM
SC energy	5	6	7	10	9	6	15-25 J is sufficient security for the loads
Space requirement	5	6	6	8	8	8	
MTTR	3	5	6	8	10	5	PSM, very simple, pluggable modules available
Price	4	6	8	6	7	5	
Pulse	1	2	2	10	8	9	DTI ideal, no problem with HV cable length
System limitations	2	4	8	8	8	5	PSM: Current, voltage for each module remains the same
System integration		-	-	-	-		
Total		**5.9**	**7.2**	**7.4**	**8.3**	**5.9**	

Summary:

- Crowbar-less SCR HVPS are very reliable and fulfil today's requirements.
- Most important are reliability and efficiency to reduce operating costs.
- Also important is the ripple.
- The selling price of a HVPS has minor priority compared to the operating costs.

Improvement:

- SCR especially PWM produces spurious emission and noise 0.5 – 1 %. This can interfere with the synchrotron frequency 2 – 20 kHz.
- An easy solution could be a linear amplifier 200 V @ 10A to reduce ripple down to a level of 0.1 %. The efficiency loss would be less than 0.5 %.

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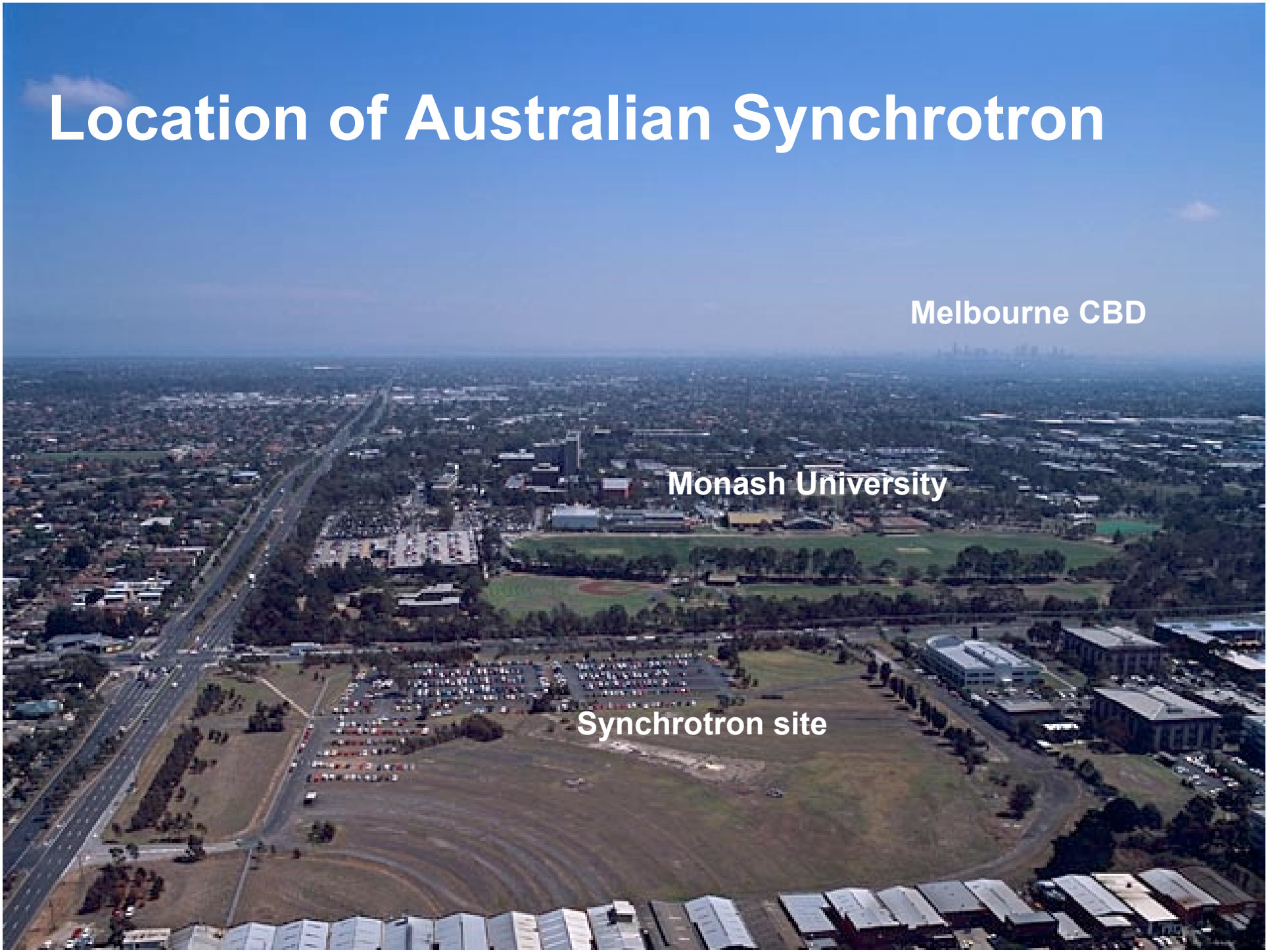
Location of Australian Synchrotron



Proposed beamlines

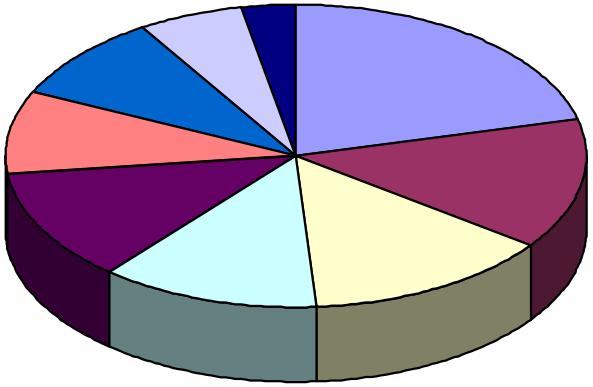
Beamline Description	Source	Energy Range
Protein Crystallography (MAD)	bending magnet	3 - 20 keV
Protein Crystallography (MAD) and Small Molecule	22 mm undulator	5.5 - 20 keV
Microfocus	22 mm undulator	5.5 - 25 keV
Powder X-ray Diffraction	bending magnet/ wiggler	4 - 60 keV
X-ray Absorption Spectroscopy	wiggler	4 - 65 keV
X-ray Imaging	wiggler	4 - 150 keV
SAXS and WAXS	22 mm undulator	5.5 - 25 keV
Visible Ultra Violet (VUV)	185 mm undulator	10 – 350 eV
Soft X-ray	55 mm undulator	200 - 3000 eV
Infrared	bending magnet	0.001 – 1 eV
General Purpose Microprobe	bending magnet	4 - 35 keV
LIGA	bending magnet	2 - 25 keV

Australian Synchrotron

Basic properties of the SR lattice

Energy	3.0 GeV	
Circumference	216 m	
Periodicity	14	
Number of straights	12	
Length of straights	5.397 m	
Current	200 mA	
Bend magnet field	1.300 T	
Critical energy	7.78 keV	
Betatron Tune – H	13.30	
Betatron Tune – V	5.20	
Dispersion (η)	0.0 m	0.24 m
Emittance	15.81 nm rad	6.98 nm rad
Beam size in straights (σ_H , σ_V)	389, 21 μm	340, 13 μm
Beam size in dipoles (σ_H , σ_V)	98, 72 μm	77, 48 μm

Research areas - current Australian usage of international synchrotrons (ASRP data)



- Materials research
- X-ray Physics
- Chemical Sciences
- Biotechnology
- Minerals and Mining
- IT applications
- Microbeam Applications
- Polymers/ Soft X-rays
- Environmental Science

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