A frequency choice for the SPL machine:

Impact on hardware

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General considerations:

Nb. of SC cavities:	234
Power per cavity:	1MW (high β region)
RF pulse length:	1.55ms / 50Hz - 40mA (HPSPL)
	1.90ms / 2Hz - 20mA (LPSPL)

Remark:

- low β region: less power per cavity required → more cavities per klystron

- HPSPL vs LPSPL: 1MW, 1.5ms pulse, 50Hz instead of 500kW , 1.9ms, 2Hz per cavity → much higher average power + power distribution scheme affected

Klystrons:

704MHz	1.4GHz

5MW option: 4 (or 8) cavities per klystron

- 805MHz SNS klystron (TH2168)
  - Ucat/ Icat : 140kV/88A
  - duty cycle: 1.5ms / 60Hz
  - gain / η: 50dB / 50%
  - av. Power 450kW
- Cost estimate: 290kEuros/tube
- Modulator: SNS HVCM

- 1.3GHz ILC – FNAL-KEK (TH2104)
  - Ucat/ Icat : 128kV/88A
  - duty cycle: 2ms / 10Hz
  - gain / η: 50dB / 45%
  - av. Power 100kW
- Cost estimate: 240kEuros/tube
- Modulator: similar to SNS

P_{av} ~450kW feasible???

10MW option: 8 (or 16) cavities per klystron

- 10MW 704MHz mutli-beam klystron

FEASIBLE???

- 10MW 1.3GHz MBK – FLASH/XFEL
  - Ucat/ Icat : 140kV/155A
  - duty cycle: 1.5ms / 10Hz
  - gain / η: 50dB / 50%
  - av. Power 150kW
- Price estimation: 400kEuros/tube
- Modulator: new development at 10Hz for XFEL

P_{av} ~450kW feasible???

Development cost for new design 1MEuros/vendor and takes 1-2 years (applies to all options)

Klystrons – some considerations:

- Electron gun design:
  - cathode-to-beam convergence factor increases with frequencies
  - not a problem with MBKs (lower gun perveance)

Higher power levels @ lower frequencies

- Beam perveance:
  - klystrons efficiency increases with lower perveance
  - i.e.: lower charge density = easier bunching ➔ better energy transfer from DC to AC.

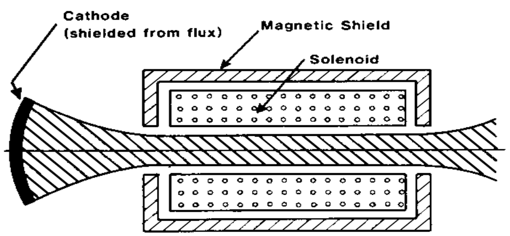
Advantage of the MBK

- Output window:
  - peak power limitation – doesn't seem to be a issue in our case. MBKs have two windows.

- Collector:
  - most effective design take advantage of the latent heat of water evaporation by allowing boiling at the collector surface (hypervapotron), can absorb: ~3kW/cm^2

→ maximizing the wetted area
→ optimizing the spread of the focused beam on the collector surface

Higher power levels @ lower frequencies



Modulators

<u>5MW klystrons</u>

- SNS HVCM (Los Alamos)
  - Rectangular HV pulses 140kV @ 90A, 60Hz
  - 11MW peak power, 1MW average
  - 8% max duty cycle
  - trise – tfall: 100µs
  - ripple ~0.1%
  - modularity for different klystron configuration
- 15 HVCM installed
- Cost estimate: ?

More info on real tests needed

<u>10MW klystrons</u>

- Bouncer modulator for XFEL & FLASH
  - Rectangular HV pulses 120kV @ 140A, 10Hz
- 3 systems supplied by FNAL for TESLA (now in operation at FLASH)
- 8 systems made in cooperation with industry.
- New development by industry for XFEL: bouncer type + pulse step – to be tested in 2008
- Cost estimate:?

Will this work @ 50Hz? (XFEL will push the rep rate to 30Hz – but reduce pulse length to keep av. power < 250kW)

For the modulators power is important, not frequency

RF distribution:

<u>Examples with 5MW klystrons feeding 8 cavities (LPSPL) or 4 cavities (HPSPL)</u>

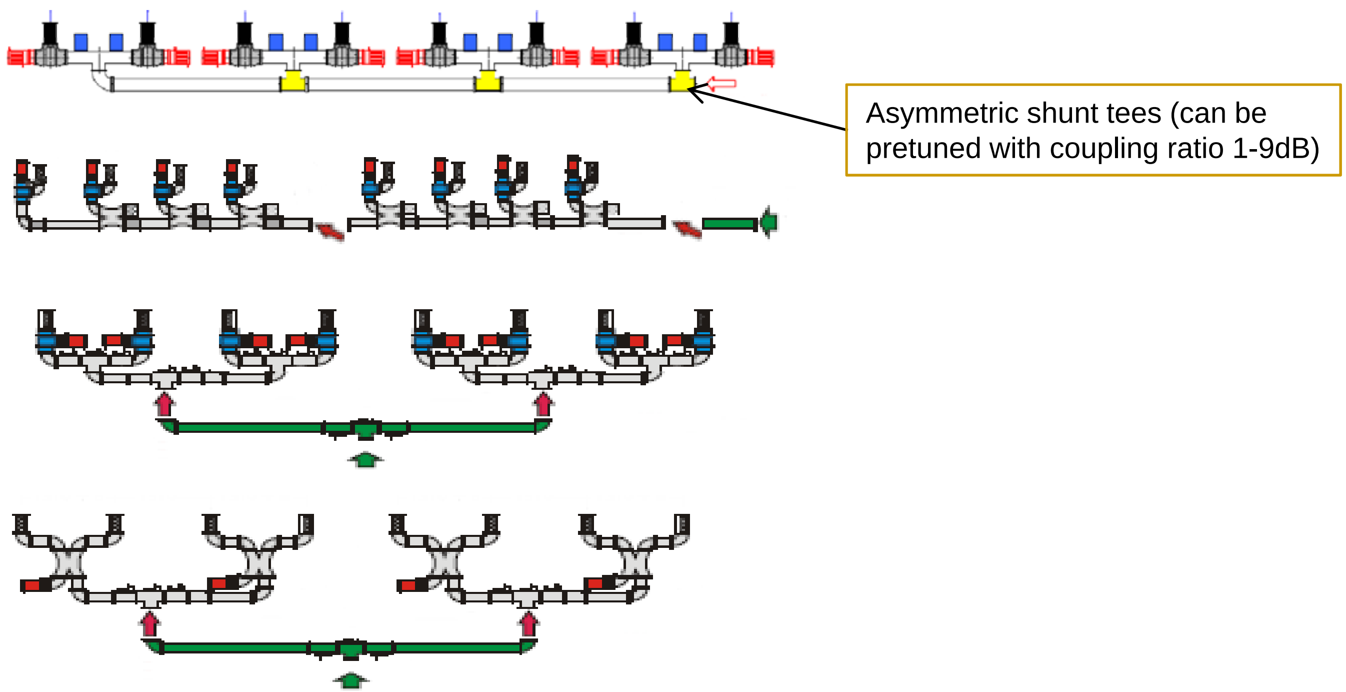
<u>(10MW klystrons would feed respectively 16 or 8 cavities)</u>

XFEL linear distribution

TTF/FLASH/ILC linear distribution

Tree like distribution with circulators

Tree like distribution without circulators



- Shopping list:
  - WR1150 or WR650
  - 1 circulator, RF loads per cavity
  - 1vector modulator or 1 phase shifter + Q_{ext} transformer per cavity
  - Big 5MW circulators & loads if tree like distribution with big protecting circulators and magic T's envisaged (MBKs: 2 output windows)

RF components:

- Power requirements:
  - LPSPL: 0.5MW/cavity, 1.9ms RF pulse, 2Hz → P_{av} ~2kW
  - HPSPL: 1MW/cavity, 1.5ms RF pulse, 50Hz → P_{av} ~75kW

704MHz

- WG losses lower for the larger WR 1150 WG (or WR1500??)
- SF6
- 5MW circulators & RF (water) loads exist (SNS)
- 1MW circulators & RF ferrite loads exist (APT)
- 1 MW vector modulator easier to built @ 704MHz?
- 75kW average power ferrite load – looks feasible
  - length ~1500mm

- WG components do NOT all exist yet
- Different RF distribution scheme can be envisaged

1.4GHz

- Smaller WG components cost less
- SF6
- New and sophisticated WR650 WG components developed for TTF, ILC, XFEL (e.g. circulators, loads, tuners, couplers,…)
  howev … W average
- RF loads:
  - A … dth 14cm)!!
    … ion is an
  - Wa … s 1.3GHz)
- Existing c…
  - ILC…
  - 20kW CW (Cornell)
  - 5MW, 50kW average (huge/expensive device)

Not realistic

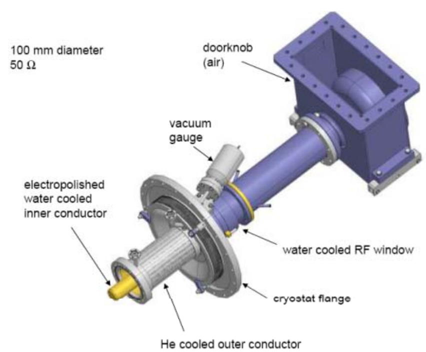
RF power couplers:

- Power requirements:
  - LPSPL: 0.5MW/cavity, 1.9ms RF pulse, 2Hz → P_{av} ~2kW
  - HPSPL: 1MW/cavity, 1.5ms RF pulse, 50Hz → P_{av} ~75kW

704MHz

- HIPPI 1MW power coupler
  - 1MW peak, 10% duty cycle
  - KEK/SNS type:
    - Coaxial warm window
    - He cooled coaxial lower part
    - No bellows
    - $Q_{ext} = 10^6$

tests to be completed soon



1.4GHz

- Examples of existing couplers:
  - XFEL power coupler: ~280kW, 10Hz
  - ERL: 1.5GHz ~35kW CW (tested up 50kW)

- From Sergey Belomestnykh we learned that "their modified TTF coupler is capable of handling up to 75 kW CW (they were tested up to 61 kW and should support up to 75). Since no major design change was done, the original peak power of 1.5 MW should still be valid“ (SPL Steering group minutes 7.12.08)

- …does not seem to be a unanimous agreement

more info and/or R&D needed

Some personal conclusions:

704MHz

- Pros:
  - Potentially higher klystrons peak &average power levels
    - Reduced number of power stations
  - Average power availability of passive components
  - More robust, less sensitive and less challenging

- Cons:
  - Reduced size of waveguides, cavities
  - Availability of components on the market
  - Expertise around the world

1.4GHz

- Pros:
  - Reduced size of waveguides, cavities
  - Availability of components on the market
  - Expertise around the world

- Cons:
  - Limited average power level &Extreme high power density
    - Trade off between peak power levels and duty cycle
  - Same arguments –to a lower extend- apply for LPSPL