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Klystron Modulators for 1) – the LP-SPL and for 2) – the HP-SPL

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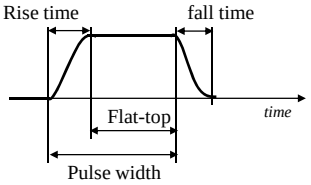
Summary

1. Modulators for the LP-SPL
Main parameters

Cathode power supply

- Pulse width:	2.3 ms
- Flat-top duration	2 ms
- Precision at flat-top:	< 1%
- HF ripple at flat-top:	< 0.1%
- Repetition rate:	2 Hz
- Nominal voltage:	110 kV *(*)*
- Nominal current:	91 A *(*)*
- Nominal power (peak):	10 MW *(*)*
- Rise/fall times (99% / 1%):	300µs
- Cooling:	Air (natural or forced)
- Maximum energy in case of arc:	< 20 J

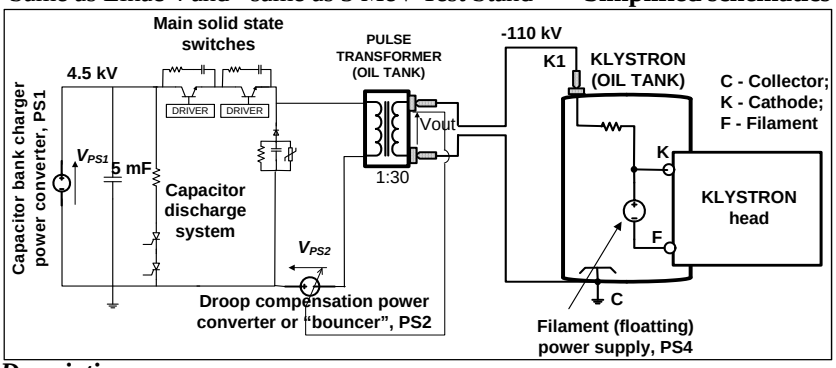


(*) to be confirmed, taking the new klystrons design into consideration

No Anode Mode terminal

1. Modulators for the LP-SPL
Selected topology.

Same as Linac 4 and ~same as 3 MeV Test Stand **Simplified schematics**



Description

- Capacitor bank charged via a standard commercial power converter, *PS1;*
- Pulses formed by solid state medium-voltage switches;
- Step-up pulse transformer with oil insulation;
- Droop compensation system, *PS2;*
- Commercial filament power converters, *PS4;*
- No CROWBAR needed in the HV line for klystron arc protection

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Prototype for the 3 MeV Test Stand.

Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

Flat-top width: 30% of the LP-SPL;

Peak power: 20% of the LP-SPL;

Average power: 16 % of the LP-SPL;

A global klystron supply solution:
(Cathode, Anode, Filament power supplies in one system)

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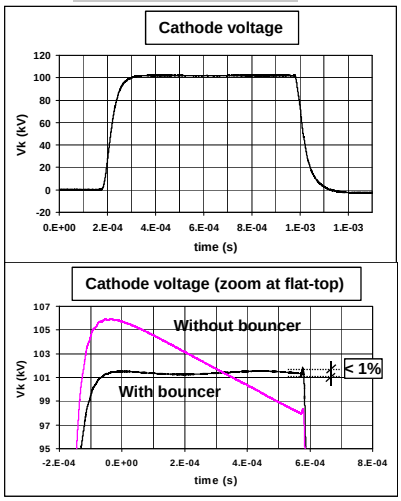
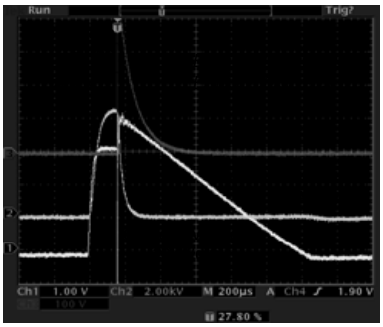
Test of the prototype in a dummy load

Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

Normal Operation



Arc protection (short circuit with Thyratron)



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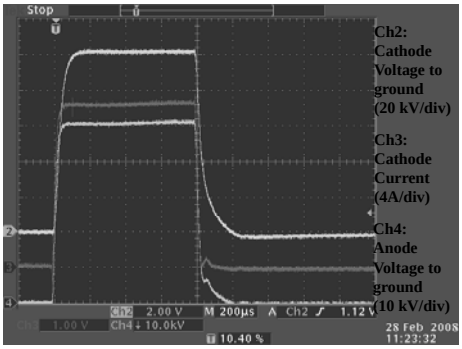
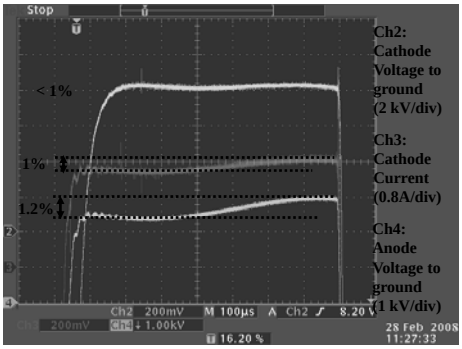
Test of the prototype with the LEP klystron

Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

Normal Operation at nominal



Zoom at flat-tops



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1. Modulators for the LP-SPL Advantages of this topology.

Advantages

- Simple and reliable;
- All active electronic components on transformer primary side (medium voltage);
- Easy to control and interlock;
- Straightforward path from design to practical results;

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2. Modulators for the HP-SPL
Why not the same topology as LP-SPL?

Cathode power supply	**LP-SPL**	**HP-SPL**
- Pulse width: ……	2.3 ms ……	2.3 ms
- Flat-top duration ……	2 ms ……	2 ms
- Precision at flat-top: ……	< 1% ……	< 1%
- HF ripple at flat-top: ……	< 0.1% ……	< 0.1%
- **Repetition rate: ……**	**2 Hz ……**	**50 Hz**
- Nominal voltage: ……	110 kV ……	110 kV
- Nominal current: ……	91 A ……	91 A
- Nominal peak power: ……	10 MW ……	10 MW
- **Nominal average power: ……**	**46 kW ……**	**1.15 MW**
- Rise/fall times (99% / 1%): ……	300µs ……	300µs
- **Cooling: ……**	**Air (natural or forced) ……**	**Water**
- Maximum energy in case of arc: ..	< 20 J ……	< 20 J

Practical limitations of the LP-SPL topology

- Relies on two SPECIAL components (solid state HV switch and pulse transformer);
- The whole power has to pass through these two crucial components;
  - A pulse transformer for 1.2 MW average power, 50Hz, has never been built: - demagnetization of the core during "off-time" requires high negative voltages;
  - A HV solid state switch for 1.2 MW average power has never been built;
- A modular approach, by placing several LP-SPL systems in parallel to increase power is possible, however very expensive and less reliable for klystron protection in case of arc;

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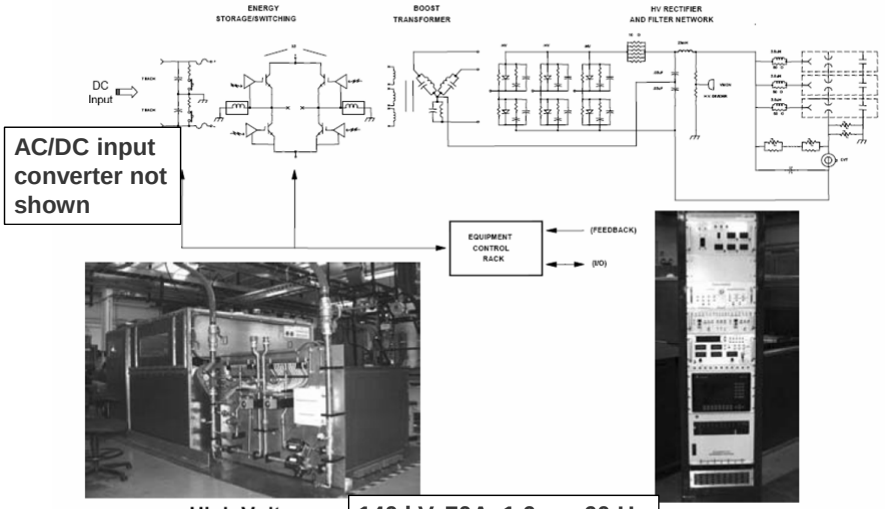
The SNS modulator, by LANL

The *Oak Ridge Nat Lab (SNS)* type modulator, *Bill Reass and Al.* Los Alamos Lab



The SNS modulator, by LANL
Advantages

Advantages

- All active electronic components on transformer primary side (medium voltage);
- Semiconductor switches of standard commercial types (multisource);
- Transformers are not of “pulsed type”. Traditional High Frequency transformer design and construction techniques can be applied;
- Flat-top closed loop regulation through the IGBT controls;
- Intrinsic voltage shut-down in case of klystron arc, due to the resonance technique (De-Qing);

The SNS modulator, by LANL
Design keypoints

Hard points

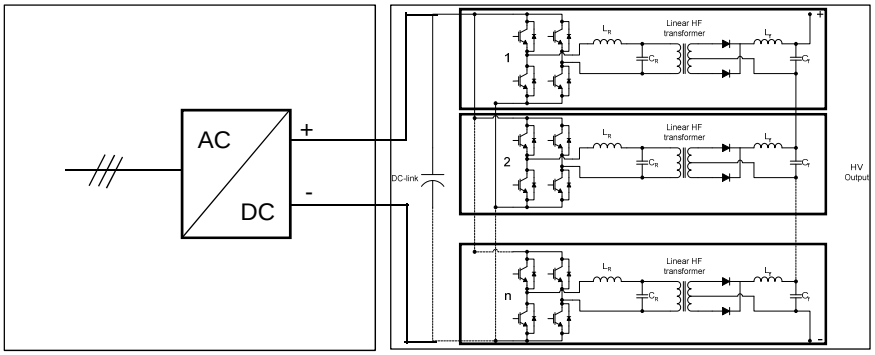
- Construction of the HF transformers:
  - Mechanical stress due to pulsed operation;
  - High Frequency (20 kHz) bandwidth with High Voltage insulation (110 kV at worst point);
- Assure “soft-switching” of the IGBT’s in all operating points -> safe interlocking if not;
- Thermal management;
- Mechanical layout (reliability);

2. Proposed topology for the HP-SPL

110 kV, 91A, 2.3ms, 50 Hz (10 MWpk, 1.15 MWav)

Capacitor charger: In surface building

Pulse former: In the tunnel

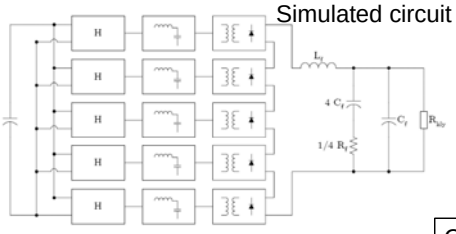


Pulse former:

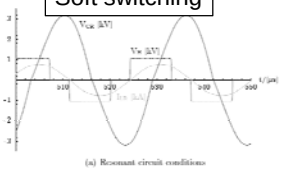
- Modular topology (4 or 5 independent modules in parallel/series);
- Easier imposition of "soft switching" in all operating points (no coupling between modules);
- However, former hard points related to the transformers, thermal management and mechanical layout remain.

Studies based on simulation
(Jonas BAKKEN, Tech. Univ. Trondheim, NO)

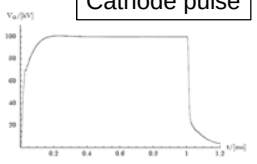
Simulated circuit

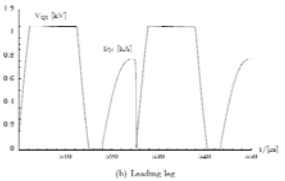


Soft switching

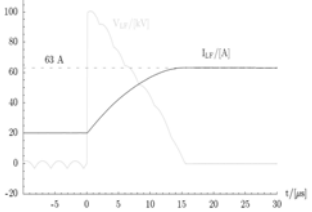


Cathode pulse

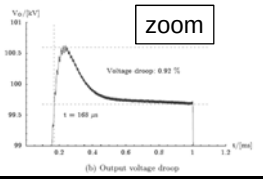


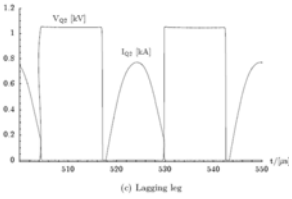


Intrinsic current limitation in case of arc



zoom





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Conclusions

- The acronym SPL is meaningless for modulator discussions. Always specify: **LP**-SPL or **HP**-SPL;
- The LP-SPL topology will be the same as the Linac 4 one. New design and prototyping needed for higher ratings (longer flat-top and peak power);
- The HP-SPL modulator project will be **a unique project in this domain, at the ultimate technology frontier**:
  - Only one (known) realization in solid state was done worldwide;
  - Several difficulties to get it working at nominal ratings;
- A new topology has been studied (simulation), based on a modular approach. It solves some of the former difficulties but others remain;
- A prototype construction and validation at CERN **is possible in the medium term only and requires advanced preparation**.