Note PS/LP 92-06

PS KLYSTRON-MODULATOR TECHNICAL MEETING

7th and 8th October 1991

edited by P. Pearce

PS Division

KLYSTRON-MODULATOR TECHNICAL MEETING

7th and 8th October 1991

in the PS Auditorium

Chairman: P. Pearce PS Div. CERN ext. 2992

Secretary : H. Guemara PS Div. CERN ext. 2399

CERN PS/LP
October 1991

KLYSTRON-MODULATOR TECHNICAL MEETING PROGRAMME

1st day

08.45	Welcoming address	K. Hübner
08.50	Opening session	J.P. Delahaye
09.00	High Power RF Transmitters at DESY	H. Schneemann
10.00	*Coffee*	
10.30	GENT University modulator systems	W. Mondelaers
11.15	LURE-NIL Modulator	D. Lagrange
12.15	*Lunch break*	
14.00	SLAC modulator reliability and operation	A. Donaldson
14.45	NIKHEF Modulator systems	P. Bruinsma
15.30	*Coffee*	
16.00	ESRF modulator system for the 200MeV preinjector	P. Berkvens
16.45	Visit to the CERN Microcosm	

2nd day

08.45	Improvements and new designs for SLAC klystron modulators	R. Cassels
09.30	LIL modulator systems	P. Pearce
10.15	*Coffee*	
10.45	Thyratron switches in modulator circuits	D. Fiander
11.30	CGR-MeV modulator design and construction	J.L.Pourre
12.15	Lunch in a regional Restaurant	
14.30	VALVO-PHILIPS high power klystrons	E.G. Schweppe
15.15	*Coffee*	
15.45	THOMSON high power klystrons	G.J. Faillon
16.30	Discussions and Questions	
	Chairmans closing remarks and tentative conclusions	P. Pearce

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October 1991

KLYSTRON-MODULATOR TECHNICAL MEETING TELEPHONE LIST

DESY, Hamburg. Group MIN	Mr. M. Bieler Mr. S. Choroba Mr. H. Schneemann	49-40-89980 ext 3805 49-40-89980 ext 3918 49-40-89980 ext 3630
TRIESTE, Italy	Mr. D'Auria	39-40-37581
LAL/LURE ORSAY, Paris	Mr L. Melard Mr Lagrange	33-1-64.46 83.00
NIKHEF Amsterdam	Mr. P. Bruinsma Mr. E. Heine	31-20-592.91.11
FRASCATI Italy	Dr. G. Vignola Mr. F. Sannibale Mr. M. Vescovi	39-6-940.31
ESRF, Grenoble France	Mr P. Berkvens Mr J.P. Perrine	3376.88.20.71
SLAC, Stanford USA	Mr. A. Donaldson Mr. W. Cassel	ARDAT@SLACVM Fax 001.415.926.3588
SERC, Daresbury England	Mr M. Dykes	44-925-60.31.42
GENT University Belgium	Mr. W. Mondelaers	91-64.65.33
Paul Scherer Institute (PSI) Villigen, Switzerland	Mr. P. Marchand	41.56.99.21.11
CGR-MeV BUC, France	Mr. Meyrand Mr. Malglaive Mr. Pourre	33-1-30.70.42.12 Fax 1-39.56.41.35
Thomson Tubes Velizy, France	Mr. G. J Faillon Mr. Ph. Guidee	33-1-30.70.24.37 33-1-49.09.28.28
EEV Ltd Chelmsford, UK	Mr. H. Menown Mr. P. Maggs	245-49.34.93
Valvo-Philips Hamburg	Mr. Neumann Mr. W. Matziol Dr. E.G Schweppe	40-32.96.641 40-56.13.30.29 and FAX 40-56.13.30.07
SCIE DIMES (ITT) France	Mr. Josefowicz	33-1-69.41.82.82

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LIST OF ABSTRACTS

H. Schneemann, DESY, Hamburg

"High Power RF-Transmitters at DESY"

A report will be given about a line type modulator with a peak power output of 62.5 MW. Fourteen modulators of the same type are working since 1970 at DESY. These modulators were built by VARIAN. The operating experience of just over one million high voltage working hours will be given and the influence of the lifetime of both the thyratrons and klystrons will be discussed, since these contribute to the major running costs of the installation.

W. Mondelaers, Nuclear Physics Laboratory, GENT, Belgium

"Gent University modulator systems"

The Gent State University disposes of two linear electron accelerator facilities:

- a 90 MeV low duty factor accelerator running with two line type klystron modulators and
- a 15 MeV medium duty factor linac operating with a hard-tube modulator.

In the first part of the presentation, a short description of the general set-up of the facilities will be given. The second part will be devoted to the pulse-line type modulator systems, with emphasis on long-term operational experience as well as thyratron and klystron performance.

The hard-tube modulator will be considered more in detail. The 15 MeV accelerator was designed to provide a high level of beam power over a wide range of energies with a high degree of stability. This imposes very stringent requirements upon the hard-tube modulator. Great flexibility and excellent pulse shape and stability specifications have been obtained. The methods for ensuring these performances will be described.

D. Lagrange, LURE, ORSAY, France

"The NIL modulator"

The New Injector Linac (NIL) modulator gives high voltage pulses: 5 ns or 20 ns width with an amplitude of up to 5 kV. The jitter being less than 1 ns. This modulator was realized with coaxial lines according to the Blumlien scheme. The power switch is made by an hydrogen thyratron with the two gates being pulsed by specific current and voltage amplifiers. As the modulator is connected to the -100 kV gun cathode voltage, commands and trigger use optical fiber transmission.

A. Donaldson, SLAC, USA

"SLAC modulator reliability and operation in the SLC Era"

The reliability and operation of the 245 modulators in the SLAC linac, with an emphasis on the past four years will be discussed. The linac modulators were designed and built in the 1960's, upgraded for the SLC in the mid 1980's, and despite their age are still reliable accelerator components. The modulator characteristics, improvements and component lifetimes will be presented.

P. Bruinsma, NIKHEF, Amsterdam, Holland.

"NIKHEF Modulator systems"

The all solid-state klystron modulators, in use with with the 900 MeV electron linac will be presented. The present system performance as well as some of the design details will be highlighted. In addition, new developments will be indicated and discussed.

P. Berkvens, ESRF, Grenoble, France

"ESRF modulator system for the reinjector electron accelerator"

The ESRF preinjector is a 200 MeV electron linear accelerator, consisting of two 100 MeV, 6 metre $2\pi/3$ sections plus a short standing wave buncher. They are powered via two klystron modulators using TH2100 klystrons. The triggering tubes are EEV CX1525A thyratrons. The characteristics of the two modulators are the following:

- Repetition frequency 10 Hz,
- Peak power 35 MW, pulse length appr. 5 μs

The first modulator powers both the first section and the buncher, plus the pre-buncher. The presentation will focus on the performance of the modulators and the linac beam characteristics.

R. Cassels, SLAC, USA

"Improvements and new designs for SLAC klystron modulators"

The talk will cover a number of improvement techniques for line type klystron modulators, some of which are operational at SLAC and others which are in the design or concept stages. The items that will be covered are the following:

- Primary SCR Phase control of the modulator power supply.
- Energy recovery deQuing for the resonant charging circuit.
- New command charging circuit, under development.
- Alternate PFN thyratron circuit and End of Line clipper considera tions.

In addition, the conceptual design of the proposed 600 kV, 1 μs, 200 ns rise time, klystron modulator for the Next Linear Collider X band klystron will be presented.

P. Pearce, PS Div. CERN

"LIL/PS modulator systems"

The long-term reliability of a pulsed modulator system depends heavily on the continued good performance of a number of active and passive high voltage components. The thyratron switches and klystron amplifiers are the most critical and usually the most expensive of these. Commissioning of the LIL machine with the modulators started in 1985, and the first electron beam was produced in June 1986. This talk discusses the problems that have occurred since then, the developments that have taken place, and the measures currently used to improve modulator performance without degrading system reliability.

D. Fiander, PS Div. CERN

"Thyratron switches in modulator circuits"

The commonly used switch in high voltage modulator circuits is the hydrogen thyratron. Performance in terms of reliability and lifetime varies considerably according to the modulator architecture. This talk will concentrate on the influence of impedance mis-matching between modulator and load on thyratron performance.

J.L. Pourre, GE-CGR MeV, BUC, France

"CGR MeV modulator design and construction"

The company CGR MeV will be presented and an overview of its activities in the industrial and scientific fields, worldwide, will be given. Typical modulator designs for medical, industrial and scientific areas, that have been installed and are in use, are to be described. The technical evolution of of these designs using the new solid state devices and high power thyratrons will also be presented.

E.G Schweppe, Valvo-Philips, Hamburg, Germany.

"Valvo-Philips high power klystrons"

In this paper an overview of Philips high power klystrons and gyrotrons for research is presented. To improve stability of klystrons with high efficiency, new tools for their simulation are supporting the development. Results from these simulations are reported together with the future activities of Philips HFPT.

G.J. Faillon, THOMSON TUBES, France.

"THOMSON high peak power klystrons"

For several years THOMSON TUBES ELECRONIQUES has been developing a new high peak power S-band klystron family. The peak power range spreads from 35 to 45 MW with typical 4.5 µs pulse lengths. The Th2094, which equips several sockets of the LIL at CERN is a good example of this type of klystron.

Because reliability became a critical issue for the operators of accelerator facilities, a strong and continuous development effort was performed. This is continuing to increase the klystron lifetime through technology improvement on built-in parts of the tube, such as cathodes, RF structures, windows, and also by taking care of external factors, like focussing , cooling, output matching and modulator interface.

KLYSTRON-MODULATOR TECHNICAL MEETING

OPENING SESSION ADDRESS

CERN, 7th October 1991

J.P Delahaye, PS Division, CERN

Why another Meeting ?

* Concentrate on the very particular field of " Modulators and Klystrons for Linear Accelerators "-

* Meeting of experts with operational experience in this field.

* Exchange of informations and practical experiences

Not a Conference :

Questions - Discussions

Richness of the field

* Large number of linacs in operation:
  - e^+/e^- colliders
  - Production of Positrons
  - Synchrotron Radiation Facilities
  - Free Electron Lasers
  - Photoinjectors
  - Medical or Industrial Applications

* Design and Construction of performant and powerful linacs for:
  - Φ, τ charm, Beauty Factories
  - Synchrotron Radiation Facilities

* Large scale of next generation of Linear Colliders -

  Reduce Cost Investment
  Exploitation load

  Increase Power Efficiency

  Replace Thyratron
  New ideas for Modulators
  Development of High Power Klystron (≥ 100

LIL experience
(3 years of operation)

* Design made in close collaboration with LAL/Orsay - Construction by Industry.

* Youth problems solved :
  - Weak elements replaced

* Overall Performance O.K.
  - Power delivery of ~ 100 MW in 6 stations (100H
  - 5000 to 6000 hours of operation per year
  - Pulse to Pulse Modulation (φ, E) between e+/e

* Unsufficient Reliability
  - 50% of LEP Injector down-time
    (~ 3% of 5000 h : 150 hours / year)
  - Large number of short stops

* Heavy maintenance load and exploitation budget.

Main Expectations from the Klystron - Modulator Meeting

- Exchange of Operational Experience
- Analysis / Status of present LIL system
  * Performance - Reliability - Lifetime
- Recommendations of possible improvement
  * The overall reliability
  * A preventive maintenance
  * The interlock system and faults recording
  * The procedure to adapt to ageing Klystrons and Thyratron.

HIGH POWER RF-TRANSMITTERS AT DESY, HAMBURG

H. Schneemann

CERN, 7th October 1991

High Power RF-Transmitter at DESY, Hamburg

The High Power RF-Transmitter (14 in all) is required to generate a pulse output power of 20 MW at 3 GHz for a period of 3.7 μsec. This power is supplied to a SLED-type cavity and further to a linear accelerator section by means of a rectangulare waveguide system. The waveguide system is evacuated. There is no window at the accelerator section.

The modulator output pulse has an effective length of 6 μsec. and is typically 250 KV at 250 A. (Figure 1)

The modulator consists of a High Voltage Power Supply which is derived in two stages. The main portion from a 75% fixed transformer and the remainder from a variable transformer followed by a fixed transformer, the percentage referring to the maximum output voltage attainable.

The Pulse-Forming Network (PFN) is resonantly charged by a 12 henry charging choke from the high voltage power supply and a 10 μF filter capacitor to nearly twice the HV power supply voltage. The charging period is nearly 8 msec; the peak current 3,5 A at 20 KV.
The PFN used in this modulator consist of 26 fixed-value capacitors (0.02 μF; 45 KV DC) and 26 individually slug-tuned inductors. Suitable adjustment of these inductors enables the top of the klystron pulse to be made flat to 0.25% bin (peak-to-peak ripple) over a period of 3,7 μsec.

Pulse-to-pulse stability of charging voltage to ± 0.1% is achieved by means of a resistive de-Quing system.
The HV power supply itself is stabilized to ± 1% by means of a voltage regulator associated with the variable transformer (25% portion).

After the PFN is fully charged, the modulator main switch tube, a ceramic thyratron, is triggered, discharging the PFN via the pulse transformer primary winding to produce a pulse voltage approx. equal to the high voltage DC level.

Klystron Oil Tank

The klystron oil tank is a portable oil-filled steel box which houses the pulse transformer, klystron filament transformer, voltage- and current monitor.
The klystron and its magnet are mounted on top of the tank together with a lead shielding. The klystron cathode end immersed in the oil.

The pulse transformer is required to generate the high voltage necessary for modulating the klystron and to match its impedance to that of the PFN.
The voltage delivered to the klystron can be adjusted about 11% by varying the pulse transformer secundary taps. Under these conditions, the klystron pulse current will cover a wide range.
The heat produced within the oil tank is removed by a water-cooled heat exchanger immersed in the oil at the top of the oil tank.
Klystron and magnet are water-cooled.
The klystron output window and the rectangular waveguide are pumped by means of getter ion vacuum pumps to a pressure of 10^{-9}mbar.

Protection of relevant modulator auxiliaries

I am not talking about fuses, signal lamps etc.
If an operating fault occurs associated with the modulator performance such as HVPS o/c or pulse o/v, shunt diode or VSWR the modulator trigger in the control rack will be gated off.
The fault protection is arranged to turn off the high voltage power supply only in the event of an overcurrent fault.
The mean overcurrent trip is set to about 2A and protects the modulator against multiple pulsing or shorts across the power supply.
The peak overcurrent trip is set to about 6 A and protects the power supply against continuous conduction of the thyratron or transitory arcing.
The pulse o/v-signal is taken directly from the cap-divider which measures the klystron pulse volts. At a preset level (270KV) the modulator trigger will be gated off.
The shunt diode circuit is used to remove negativ voltage from the thyratron anode during normal running and more particularly under fault conditions. Arcs in the klystron tank or the klystron result in a large inverse voltage appearing across the PFN. Should this voltage exeed a certain level, then the modulator trigger will be inhibited.
The normal shunt diode signal bears a ratio of 750:1 to the negative voltage or the PFN.
Each klystron is fitted with a directional coupler at its output in order to monitor forward and reverse power.The reverse power is detected by means of a diode and the vidio signal generated provides a measure of the voltage standing wave Ratio (VSWR) seen by the klystron.

The klystron filament and focus magnet setting are interlocked by means of meter relays that protect the filament and the magnet and prevent modulator operation at settings that deviate by more than ± 5% from their respective set points.
It should by noted that the filament isolation transformer is a high reactive type which limits the filament surge current to 8A.

There are five indicating circuits associated with the klystron tank. They indicate if the following are safe:
oil level, klystron body water, klystron magnet and tank water, klystron collector water and rectangular waveguide water.

During normal machine operation it is unavoidable that faults should occur on modulators from time to time.
A reset system is such that the reset time and number of resets within a given time can be adjusted. After a predetermined number of resets in a given time have been exeeded, the circuit locks itself out and the operator has to reset manually.
For o/c, S/D, o/v and vacuum the reset time is in the order of 5 seconds for the total of 3 times.

Performance and reliability

During the last 16 years each modulator has been working for at least 75000 high voltage hours, or, for the sum of 14 modulators just over one million hours.

During that time we have lost for example only two pulse capacitors out of 364. We had to replace sets of rectifiers because of low ratings and we had to replace the variable transformers for the power supply because we could not get any spare parts of the older type. Smaler items have been changed here and there.

We got a bigger problem with the high impedance klystron magnets. The occasions have been shorted turns and water leaks. We had to replace nine magnets out of 16.

The shaped magnetic field for the klystron is generated by an electromagnet with three main coils and one counter coil. The main coils are splitted in halfs and seven copper cans for cooling purpose are installed between the adjacent halfs. Bobbins and cans are assembled in a steel housing by means of epoxy casting.

In co-operation with a german factory we found a better solution of building the magnets. Bobbins and cans are single and they are bolted together inside the case. So it becomes very easy to change a faulty coil or can. Up to now we never had to change a coil or a can.

The real consumption parts of a modulator are thyratrons and klystrons and we have to spend a lot of money out of the budget. 1975 we payed for the main thyratron CX 1168 DM 6.000, at the present the price went up to DM 15.667 (increase 2.6 in 16 years). 1981 the price for a klystron was DM 80.926, today DM 99.612 (increase 1.2 in 10 years).

These figures point out, that we have to watch those parts very careful.

As <u>DeQ-thyratron</u> we use the EEV-type CX 1159 (33 KV_{max}, 1000 A_{max}). After about 20.000 working hours we stopped counting the elapsed time.

The <u>Main thyratron</u>, EEV-type CX 1168, is a deuterium-filled ceramic tetrode thyratron fitted with a gradient grid. The filament is supplied at 6.8 V and 22 A and the reservoir at the manufacturer's specified voltage and about 7 A. The tube is required under normal running conditions to switch peak currents of 4000 A. The peak forward voltage is 80 KV_{max}.

A positive bias is supplied to G1 and allows a current of 60 mA to pass through the G1 cathode region. The G1 to cathode voltage is typically 25 V. A negative 120 V-bias is applied to G2. A further feature is the provision of a gradient grid associated with a gradient grid resistor chain. This divides the thyratron anode voltage in half and ensures an even distribution of voltage gradient within the valve.

As with the DeQ thyratron a double trigger is required for the main thyratron. In this case the trigger spike from a main thyratron driver is fed via a pulse transformer to a small delay line. This provides a small time delay between the trigger for G1 and G2.

A capacitor provides D.C. isolation for the negative bias and an other capacitor decouples the anode grid voltage spike to ground.

The judgement, why thyratrons live for a longer or shorter time is very difficult. They are inserted in the same type of modulator, the thyratron switch circuit is the same, the supplier is the same, but the statistic points out, that there is a big difference. (Figure 2)

Note 1 , Fig.2

We noticed that the lifetime was decreasing.

To get a good statistic figure, say ten tubes, also with 14 sockets, it takes some time. To be sure one waits for the next ten tubes before going into details. The first answer from the supplier will be: " We have changed nothing", later one will learn from private communications that there have been changes.

Simultaneous we had changed the air cooling system for the modulator cabinets, so the ambient temperature was lower than before. A fan, located next to the thyratron did cool the envelope of the thyratron down to 30-40°C. This temperature is much to low. Changing the fan type and its position brought the temperature up to about 50-60°C. The reliability changed a lot.

Note 2,Fig.2

At this time we started the storage ring DORIS. For radiation reasons we run the modulators with a repetition rate of 25 Hz during the filling time and 3 Hz during standby, just to keep the acceletor guides warm. We got the following figures:

Fil. hours:	100%
25 Hz:	14%
3 Hz:	64%
off :	22%

The result of this mode of working was a decrease in lifetime due to the change of envelope temperature.

Note 3 ,Fig.2

For financial reasons we had to be very careful with the consumption of electrical energy, so modulators and big power consumers have been switched on only during the filling time of DORIS or PETRA. The heaters have been running the whole time.

The result again was an unusual decrease in lifetime.

The statistic brought the answer: We splitted the tubes Nr. 121-270 in groups of ten tubes, identified the average of filament and high voltage hours and put these values in relation. The result is shown in figure (3).

The interpretation has to be done very careful, because I think, that these results stay only for a special cycle of working time and time of rest. The result will be quite different if the heater of the thyratron runs for hours and the modulator will be triggert later and for a shorter time but continuous.
I think the short-term change of power consumption will shorten the life of a thyratron.

The klystron, Thomson-CSF-type TV 2002 DOD, is a high power, high gain, pulsed amplifier klystron. This five-cavity klystron delivers a minimum of 24 MW peak output power with a minimum average power of 7.5 KW..It is pretuned at the factory to a frequency of 2998 MHz. The RF input is made via a coaxial plug and the output through a SLAC type vacuum tight flange. The klystron is used with an evacuated output waveguide.
The TV 2002 DOD requires the use of an electromagnet for focusing. The waveguide and the body of the klystron are cooled by the same water flow.The collector is cooled by a distinct water circuit.
The klystron includes an active getter which insures a permanent high vacuum.
During the whole time we never run into problems, except a couple of years ago the supplier has had problems together with the ceramic window. We noticed an arcing on the window, and some windows have been punched. Sometimes we noticed a crack at the window after thousands of hours with the result of breakdowns in the klystron

or the waveguide. In both cases the klystron had to be changed. During the mean time there will be a change of perveance but a sleight will help: increase the heater voltage a little bit and another thousand hours will be yours.

Summarized one can say, that the average lifetime of the klystrons are in the order of more than 16.000 high voltage hours.

At least a few words about spare thyratrons and klystrons. The amount has to be choosen very careful, because one needs enough thyratrons and klystrons for replacement, but guarantee figures give also a bordering.

Together with a good up to date statistic a good balance for the number of spare tubes will be found.

(Figure 4, Figure 5)

Overall specifications of modulator (incl. pulse transformer)

Peak power output	62.5	MW
Average power output	19	KW
Output pulse voltage	250	KV
Output pulse current	250	A
Load impedance range	1000	ohms
Pulse length, eff.	6	µsec
Pulse length, flat top	3.7	µsec
Pulse repetition rate	50	pulses/sec
Pulse height deviation from flatness	0.25	%
Pulse amplitude drift :		
Short term	0.2	% (30 minutes)
Long term	1.0	% (24 hours)

High Voltage Power Supply
Pulse-Forming Network
De-Quing System
(CX 1159)
Main Switch Tube
(CX 1168)

Pulse Transformer
Kly.Fil.Transformer
Kly.Pulse Voltage Monitor
Kly.Pulse Current Monitor
Klystron Magnet
Klystron 2002 DOD
Water Cooling

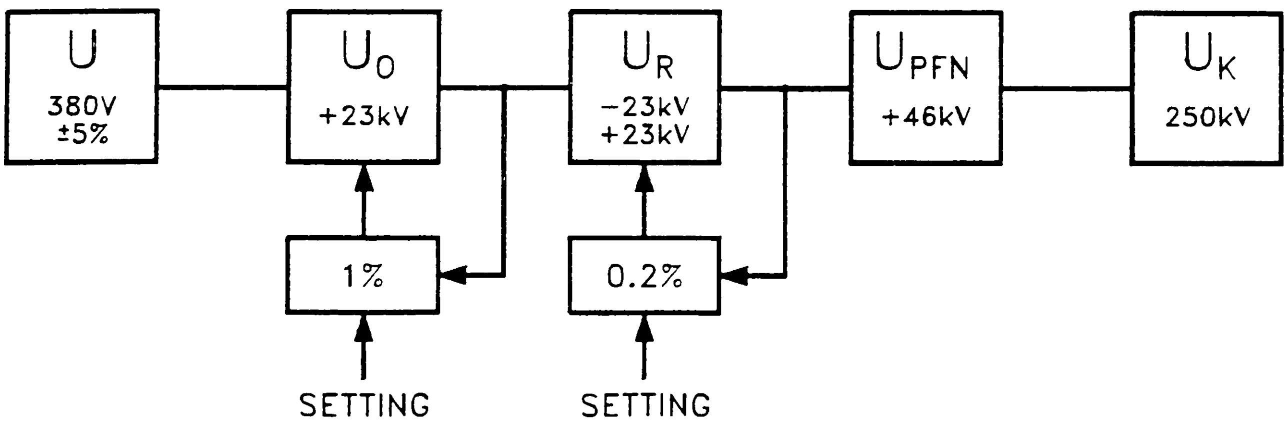


FIG. 1

Statistic of used Thyratrons since 1974

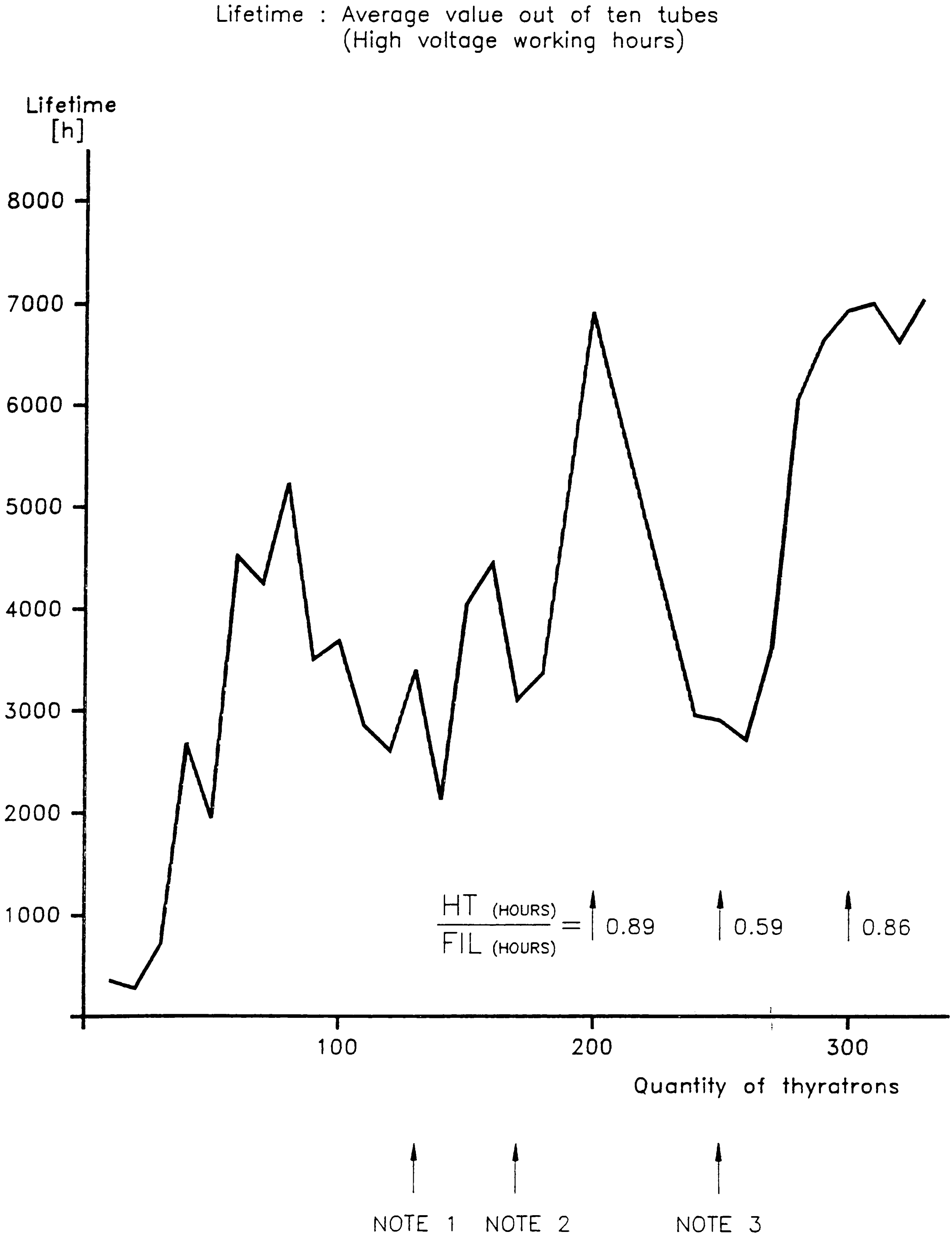
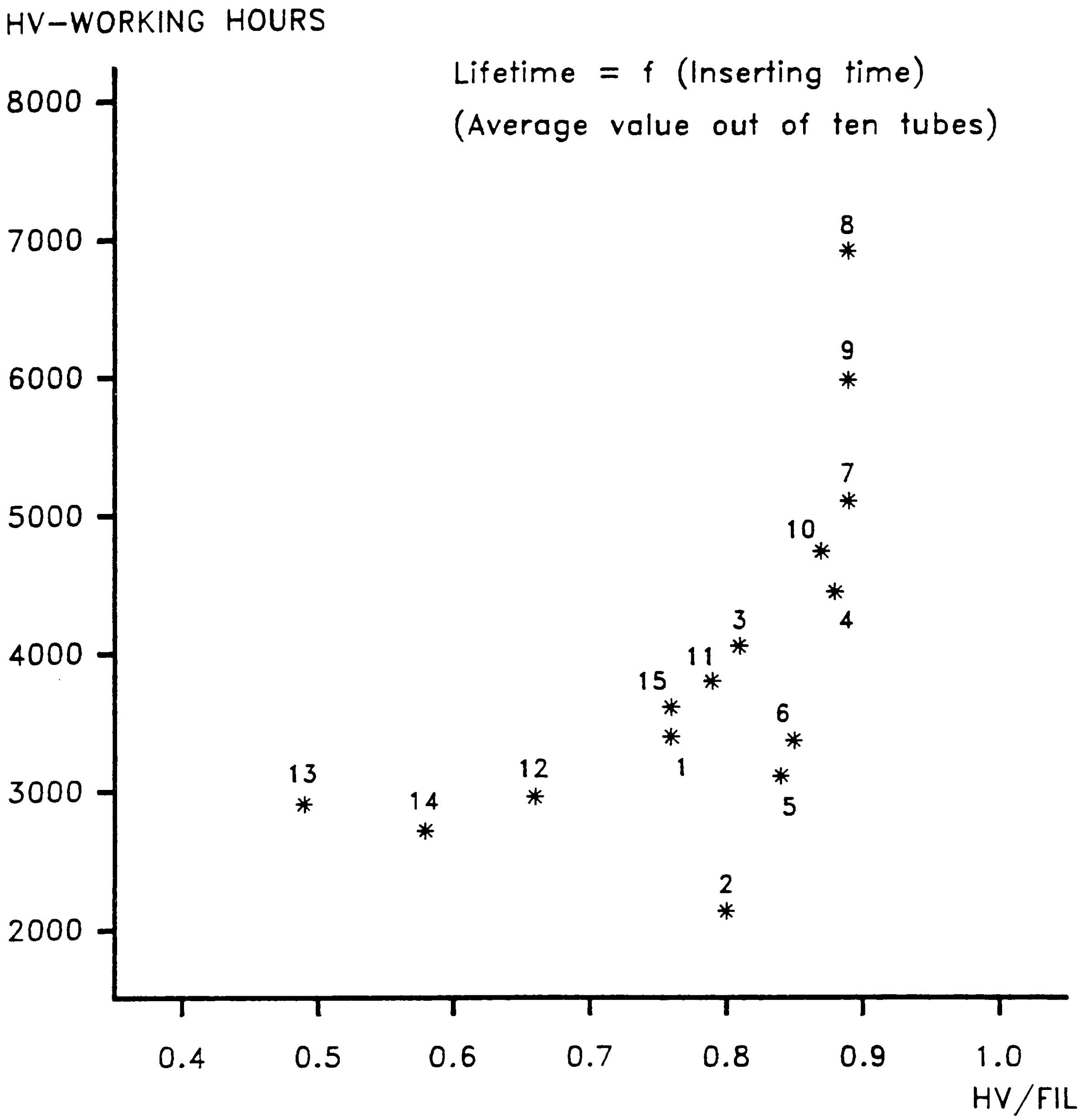
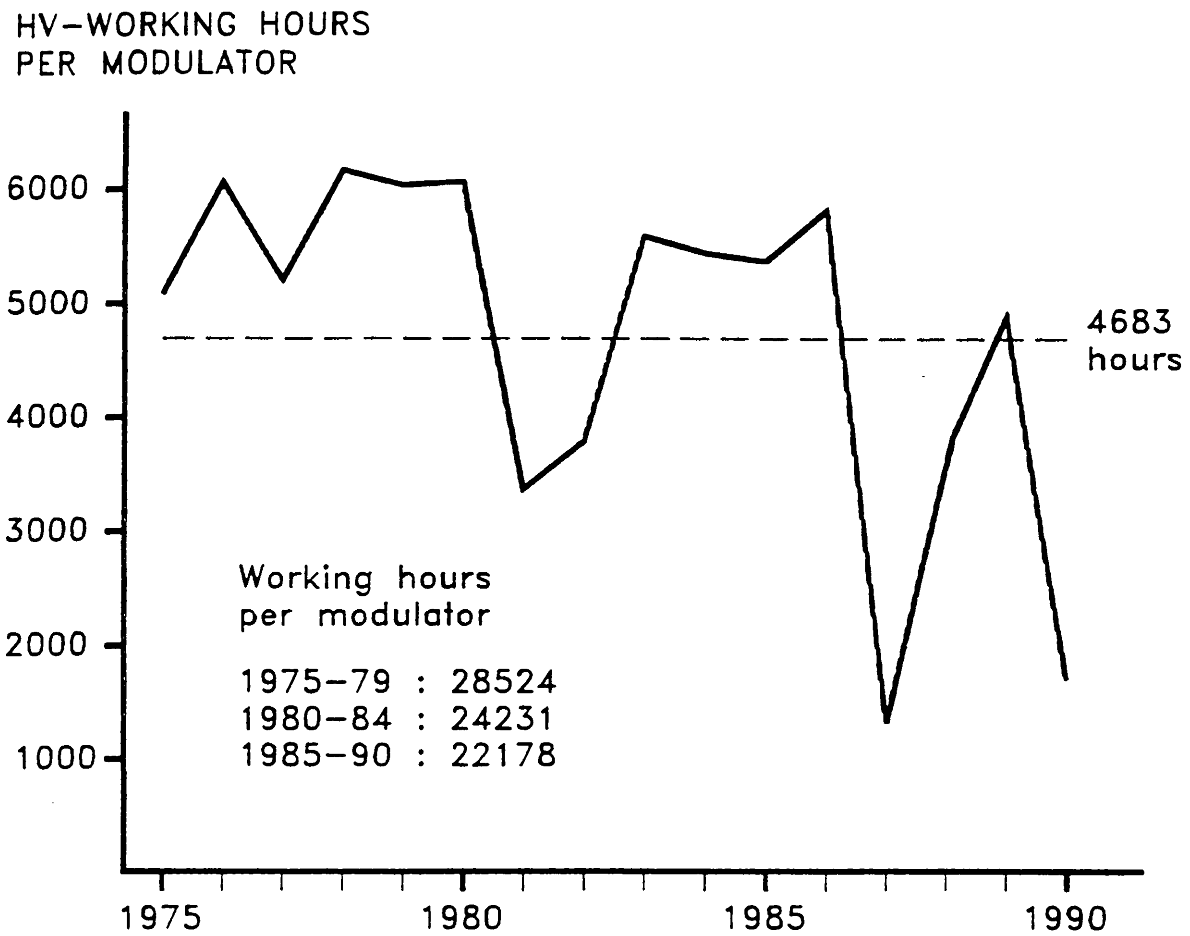


FIG 2



POINT	FIL	HT	HT/FIL	
1	4438	3395	0.76	NOTE 1, FIG. 2
2	2649	2131	0.80	
3	4996	4053	0.81	
4	5047	4444	0.88	
5	3708	3107	0.84	NOTE 2, FIG. 2
6	3962	3366	0.85	
7	5722	5102	0.89	
8	7745	6910	0.89	
9	6748	5977	0.89	
10	5439	4737	0.87	
11	4853	3797	0.79	NOTE 3, FIG2
12	4479	2957	0.66	
13	5940	2905	0.49	
14	4690	2712	0.58	
15	4741	3609	0.76	

Fig. 3


HV-WORKING HOURS
PER MODULATOR
6000
5000
4000
3000
2000
1000
4683
hours
Working hours
per modulator
1975-79 : 28524
1980-84 : 24231
1985-90 : 22178
1975
1980
1985
1990

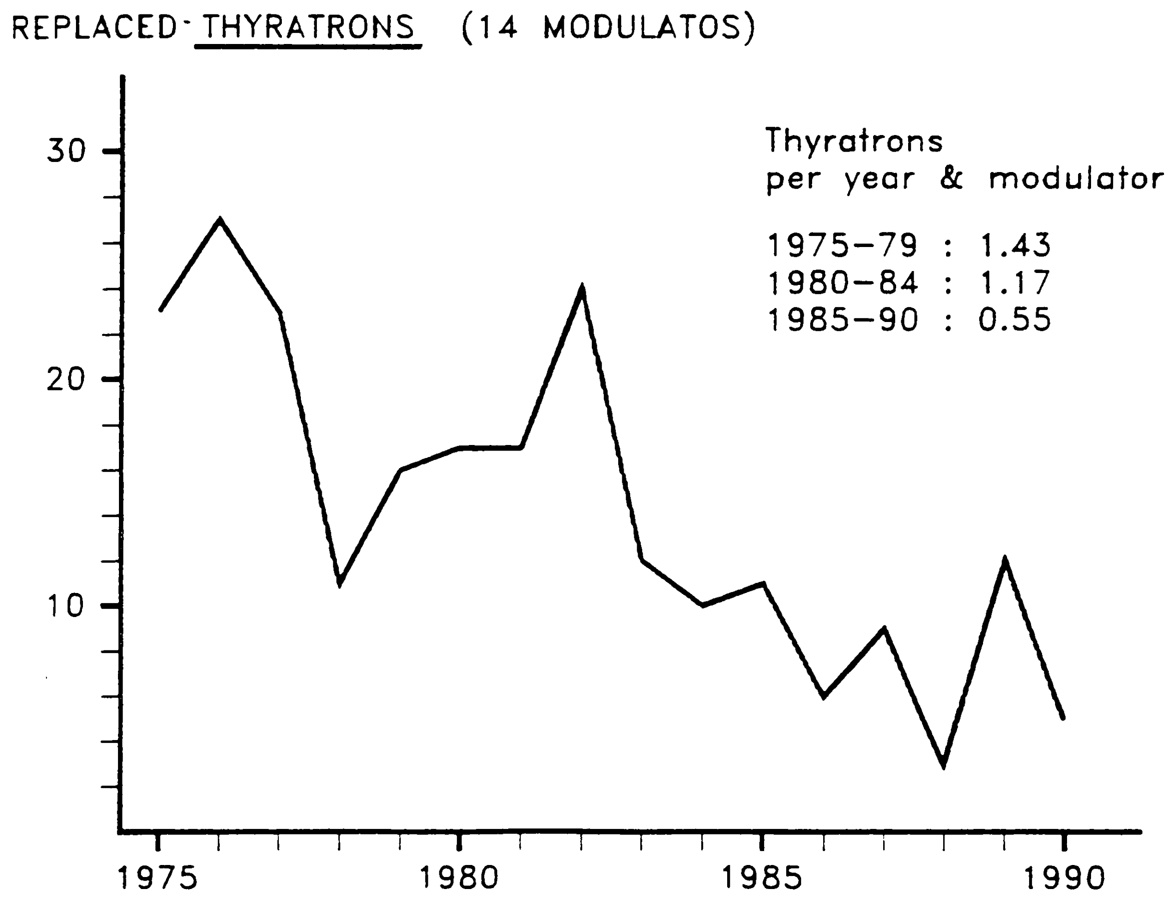
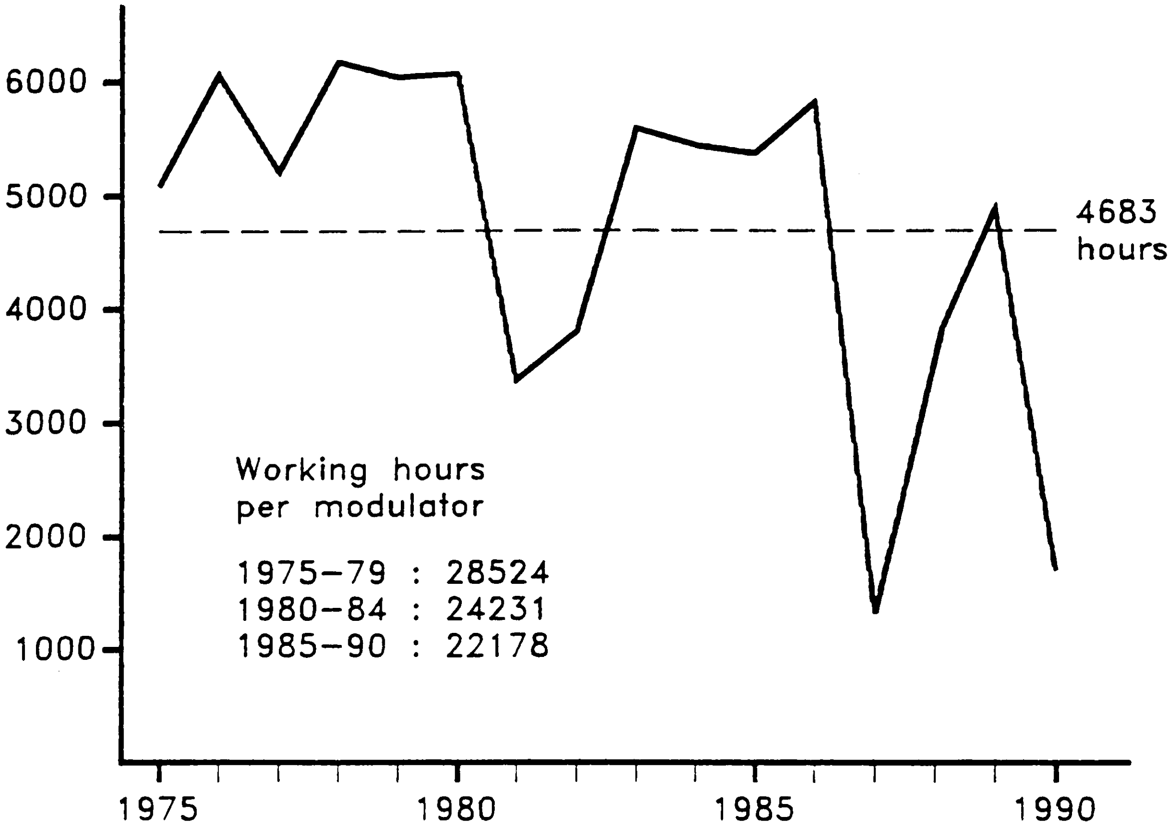

REPLACED THYRATRONS (14 MODULATOS)
30
20
10
Thyratrons
per year & modulator
1975-79 : 1.43
1980-84 : 1.17
1985-90 : 0.55
1975
1980
1985
1990

Fig. 4

HV–WORKING HOURS
PER MODULATOR



REPLACED KLYSTRONS (14 MODULATORS)

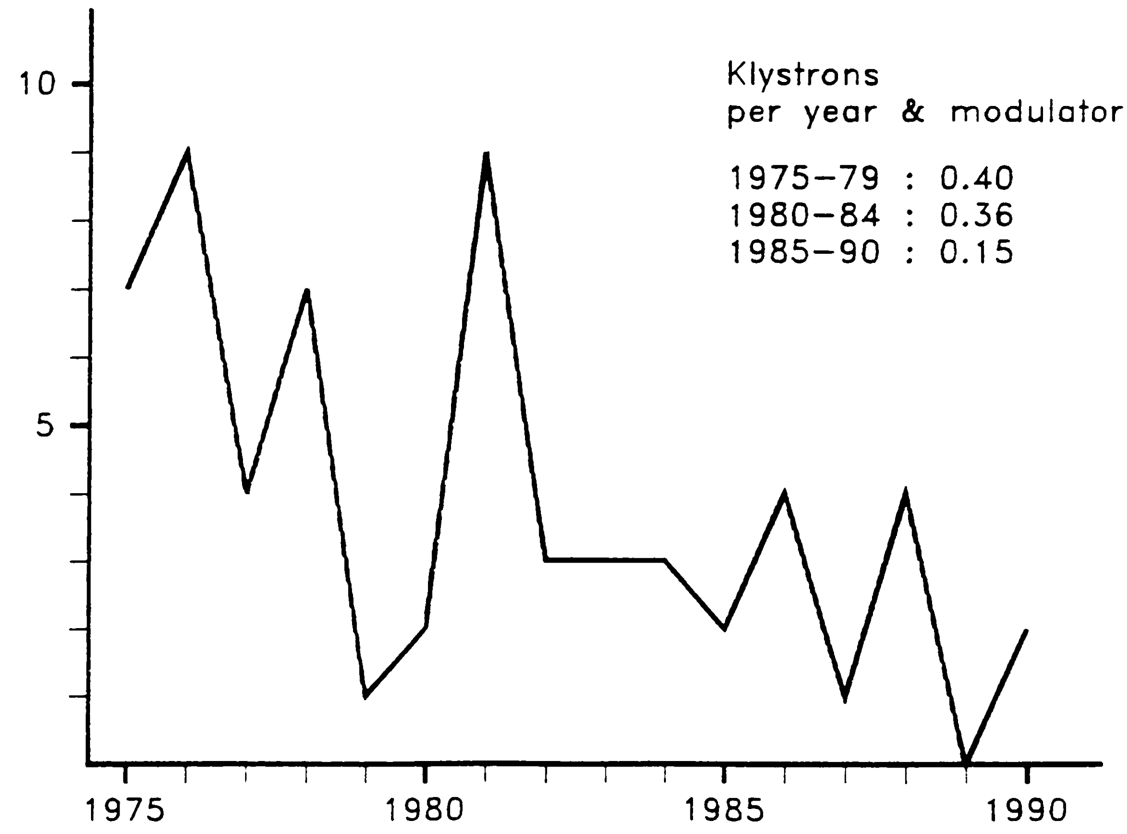


Fig 5

GENT UNIVERSITY KLYSTRON - MODULATOR SYSTEMS

W. Mondelaers

CERN, 7th October 1991

Gent University Klystron Modulator Systems

Nuclear Physics Laboratory

Gent, Belgium

1. General set-up of the accelerator facilities
2. Pulseline-type modulators

   design approach = conventional

   → - operational experience (> 50 000 hours)

   - thyratron and klystron performance
3. Hard-tube modulator

   major challenge = high quality specifications

   over a wide dynamic range

   → - specifications

   - regulation systems for improving performance
   - operational experience (> 22 000 hours)
   - hard tube and klystron performance

1953	first home-built accelerator
	4.3 MeV electron linac
1965	45 MeV linear electron accelerator
1975	90 MeV linear electron accelerator

e^- beam	:	0.07%	duty factor
		300 Hz	p.r.f.
		2.5 μ sec	pulselength
		100 μ A	average current
modulator	:	0.1%	duty factor

1984 15 MeV high intensity, medium duty factor

low energy electron accelerator

e^- beam	:	2%	duty factor
		5000 Hz	p.r.f.
		10 μ sec	pulselength
		2 mA	average current
modulator	:	2.8%	duty factor

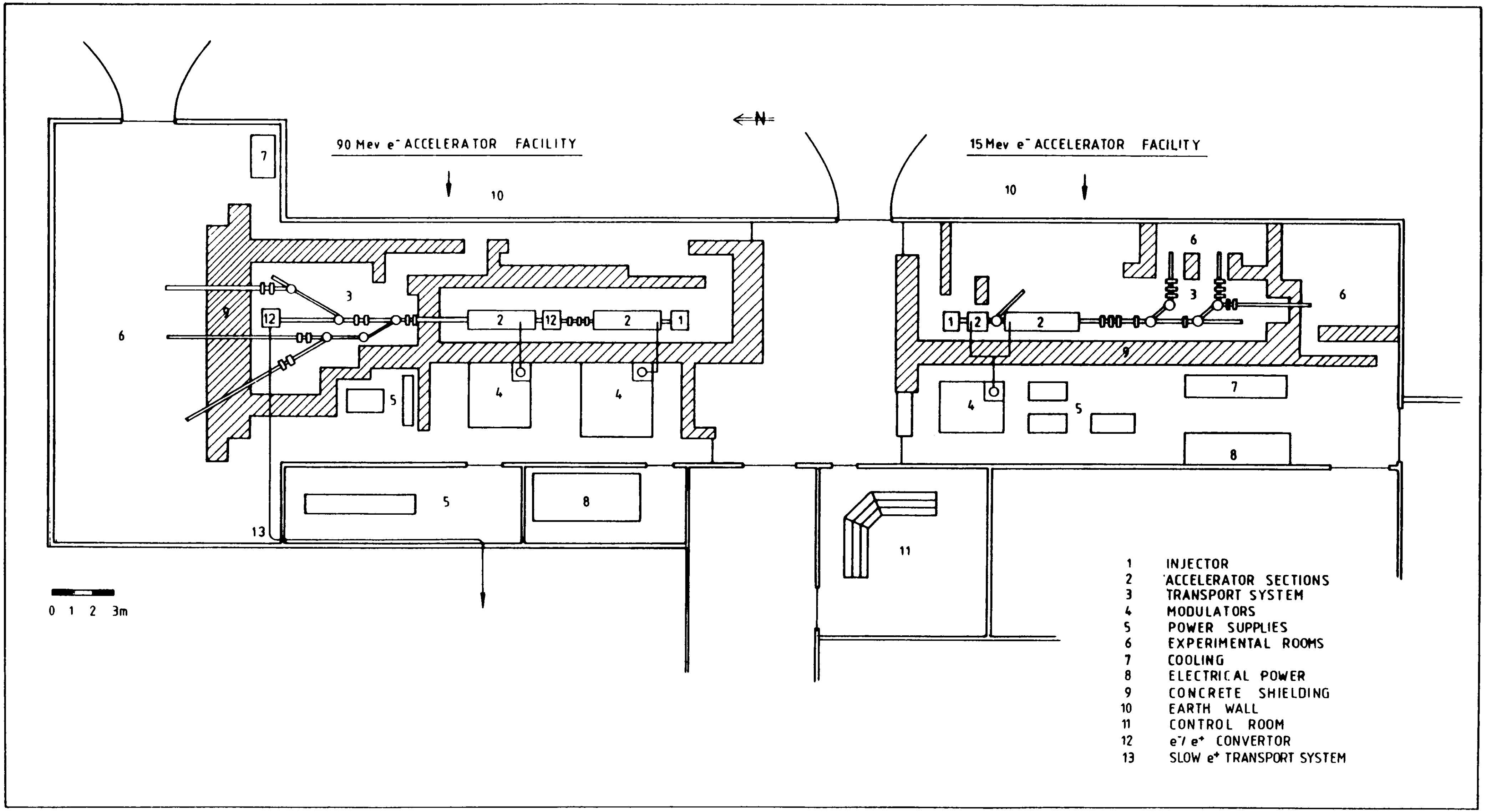
Both facilities are dedicated to the production of :

- **electron beams**
- **positron beams** – **fast** / **slow**
- **gamma beams** – **unpolarised** / **polarised**

Research :

- **low energy nuclear physics**
- **materials research**
- **radiation dosimetry**
- **radiation therapy**

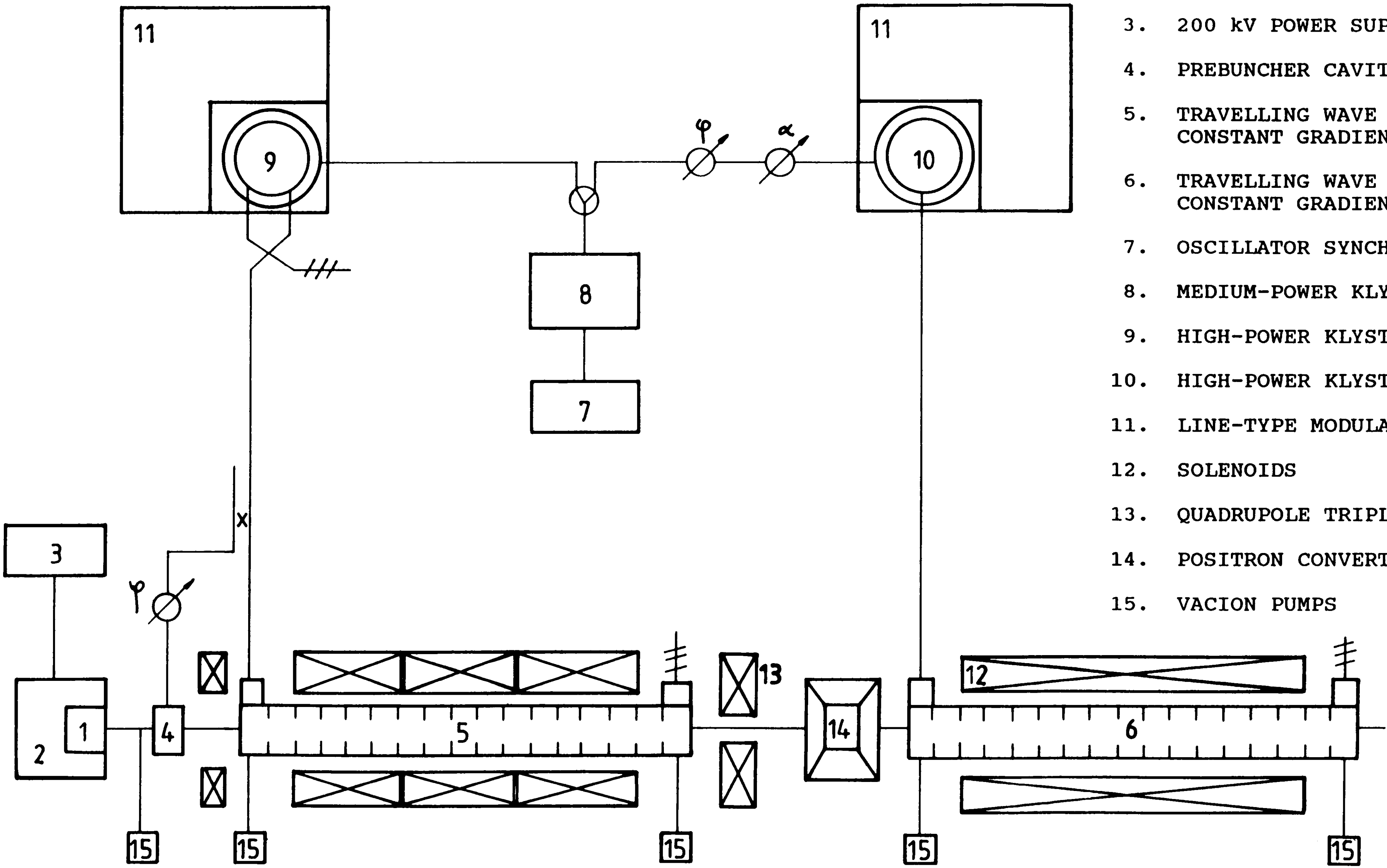
Running time per year : ≈ 4000 hours


90 Mev e⁻ ACCELERATOR FACILITY
15 Mev e⁻ ACCELERATOR FACILITY
N
0 1 2 3m
1 INJECTOR
2 ACCELERATOR SECTIONS
3 TRANSPORT SYSTEM
4 MODULATORS
5 POWER SUPPLIES
6 EXPERIMENTAL ROOMS
7 COOLING
8 ELECTRICAL POWER
9 CONCRETE SHIELDING
10 EARTH WALL
11 CONTROL ROOM
12 e⁻/e⁺ CONVERTOR
13 SLOW e⁺ TRANSPORT SYSTEM

90 MeV accelerator

	built by
injector	HRC
sections 1 modulator	GE/CGR-MeV
1 modulator beam transport system positron facilities peripheral equipment	NPL, Gent

90 MeV electron accelerator



1. 200 kV ELECTRON GUN
2. GUN MODULATOR
3. 200 kV POWER SUPPLY
4. PREBUNCHER CAVITY
5. TRAVELLING WAVE VARIABLE β CONSTANT GRADIENT SECTION
6. TRAVELLING WAVE CONSTANT β CONSTANT GRADIENT SECTION
7. OSCILLATOR SYNCHRONIZER
8. MEDIUM-POWER KLYSTRON TH204
9. HIGH-POWER KLYSTRON TV2015
10. HIGH-POWER KLYSTRON ITT8568
11. LINE-TYPE MODULATORS
12. SOLENOIDS
13. QUADRUPOLE TRIPLET
14. POSITRON CONVERTER ASSEMBLY
15. VACION PUMPS

15 MeV accelerator

	built by
injector sections modulator	GE/CGR-MeV
beam transport system high beam power handling equipment fast beam monitoring units beam quality regulation systems peripheral equipment	NPL, Gent

Major challenge

Production and transport of e^- beams :

- high average current
- low emittance
- continuous variable energy
- narrow energy spectrum
- stable : - during the pulse
  - from pulse-to-pulse
- variable pulselength
- variable pulse repetition frequency

e^- beam power density : up to 150 kW/cm^2

range in Al : only 2 cm

low accelerating field
high beam loading

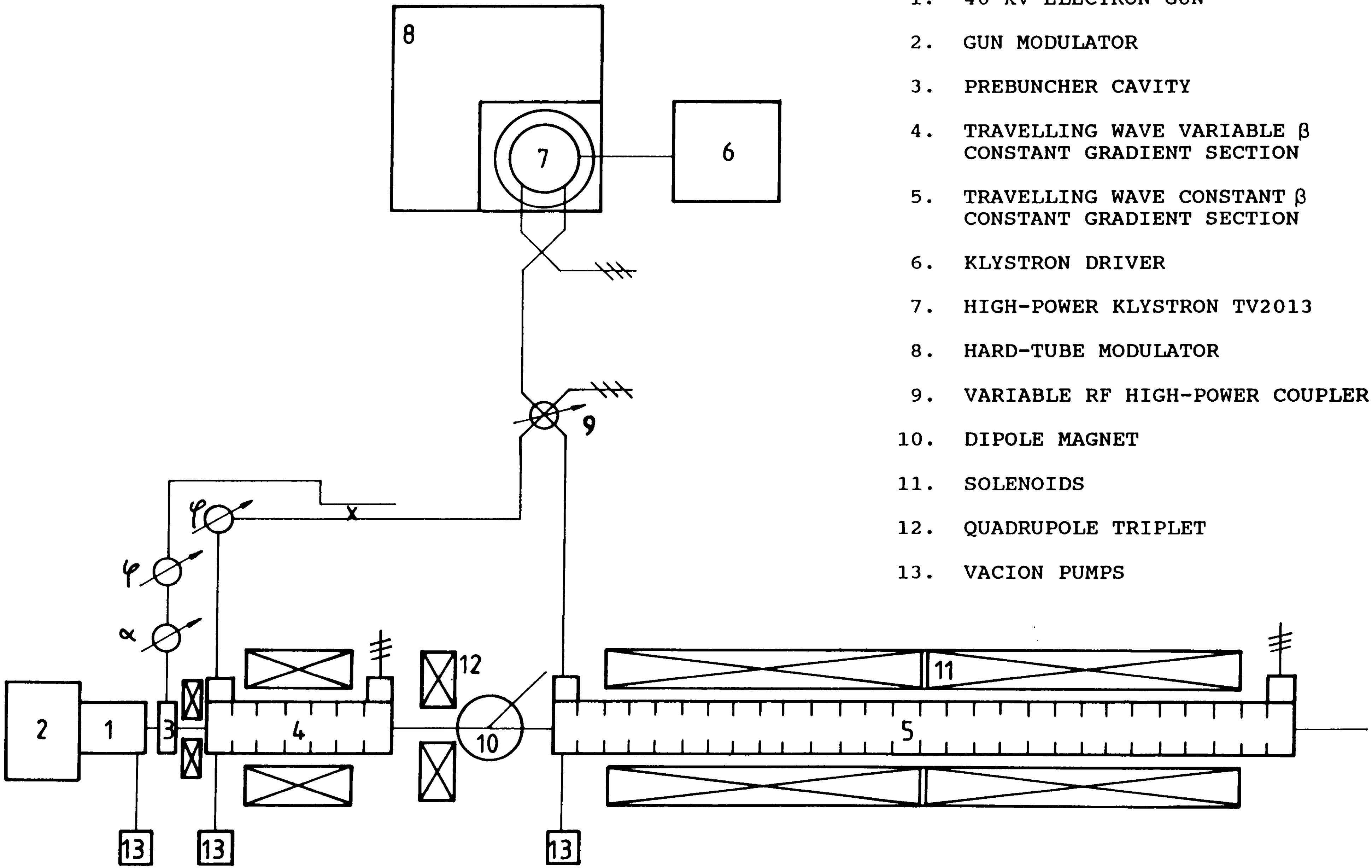
→ beam dynamics very sensitive to changes of :

- field amplitude
- phase

→ stringent requirements on klystron modulator specifications

	Design		Actual
Max. energy	10 MeV	→	15 MeV
Max. p.r.f.	2000 Hz	→	5000 Hz
Max. avg. current on target	0.5 mA	→	1.5 mA

15 MeV electron accelerator



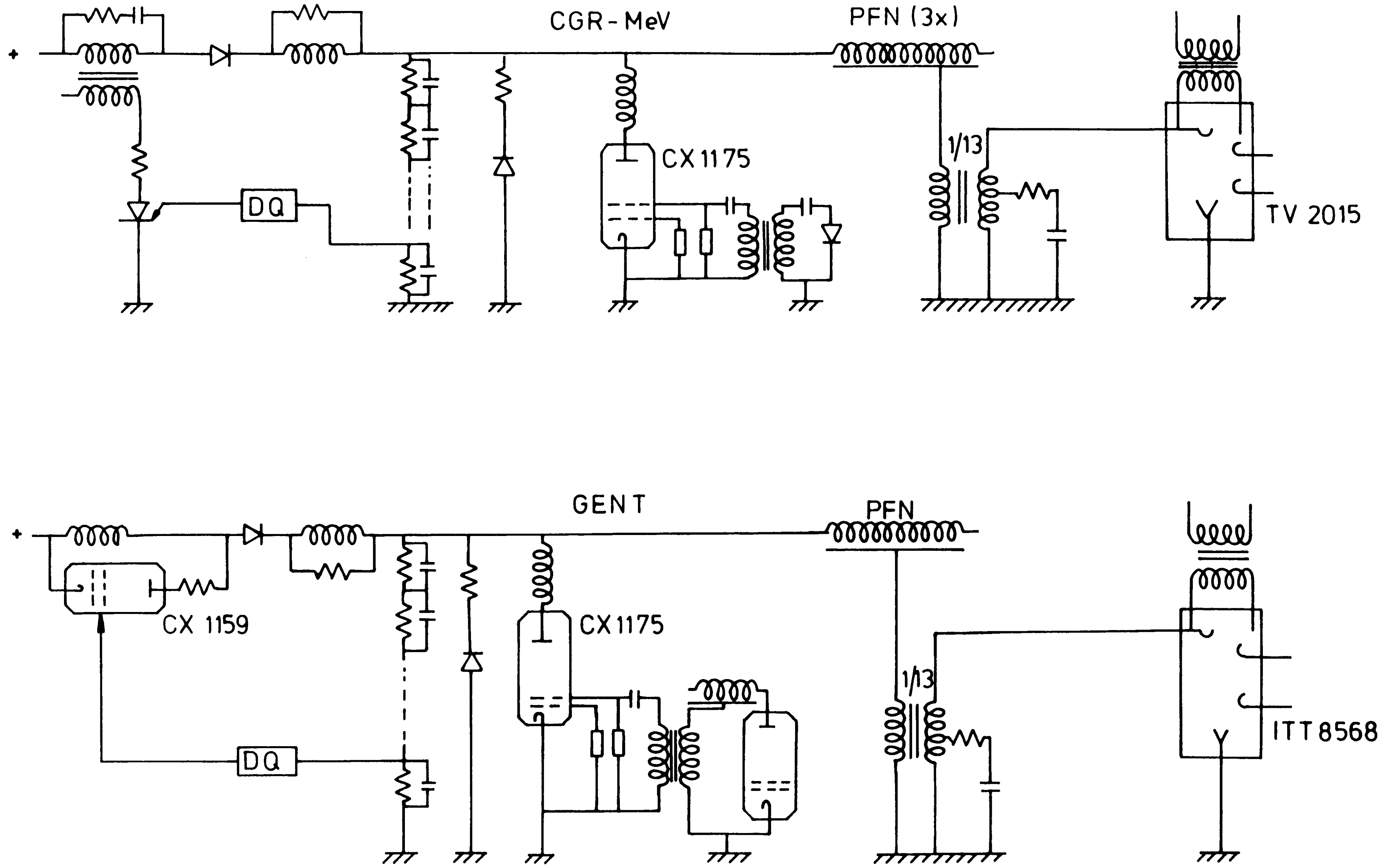
1. 40 kV ELECTRON GUN
2. GUN MODULATOR
3. PREBUNCHER CAVITY
4. TRAVELLING WAVE VARIABLE β CONSTANT GRADIENT SECTION
5. TRAVELLING WAVE CONSTANT β CONSTANT GRADIENT SECTION
6. KLYSTRON DRIVER
7. HIGH-POWER KLYSTRON TV2013
8. HARD-TUBE MODULATOR
9. VARIABLE RF HIGH-POWER COUPLER
10. DIPOLE MAGNET
11. SOLENOIDS
12. QUADRUPOLE TRIPLET
13. VACION PUMPS

ACCELERATOR SPECIFICATIONS	15 MeV LINAC	90 MeV LINAC
Beam energy range	1.75 - 15 MeV	10 - 90 MeV
Beam duty factor	2 %	0.07 %
Max. beam pulselength	10 μsec	2.5 μsec
Max. beam pulse repetition rate	5000 Hz	300 Hz
Max. average beam current	2 mA	100 μA
Max. average beam power	20 kW	6 kW
Accelerated current in 0.5% energy bin	Up to 80% of I_{max}	Up to 50% of I_{max}
Emittance	2.7 π mm mrad (9 MeV)	20 π mm mrad (25 MeV)
Electromagnetic frequency	2999 Mhz	2856 Mhz
Number of accelerating sections	2	2
RF source	1 klystron TV2013	1 klystron TV2015 1 klystron ITT8568
Sections per RF source	2	1
RF power per source	2 MW peak 56 kW mean	24 MW peak 24 kW mean
Klystron modulator type	hard tube	pulse line
Modulator duty factor	2.8 %	0.1 %

Pulseline-type modulator

Klystron specifications

		TV 2015	ITT 8568
Frequency		2856 MHz	2856 MHz
RF output power	peak	25 MW	25 MW
	avg.	25 kW	25 kW
RF input power	peak	180 W	150 W
Beam voltage	peak	245 kV	250 kV
Beam current	peak	252 A	250 A
Heater power		680 W	210 W
Microperveance		2.08	2.00
Efficiency		40%	40%
Impedance		970 Ω	1000 Ω
Gain		51.5 dB	53 dB
Output		2 windows	1 window
Focusing		electromagnet	electromagnet



PULSELINE MODUL^TORS

Main thyratron specifications

Deuterium-filled , two-gap , ceramic tetrode thyratron

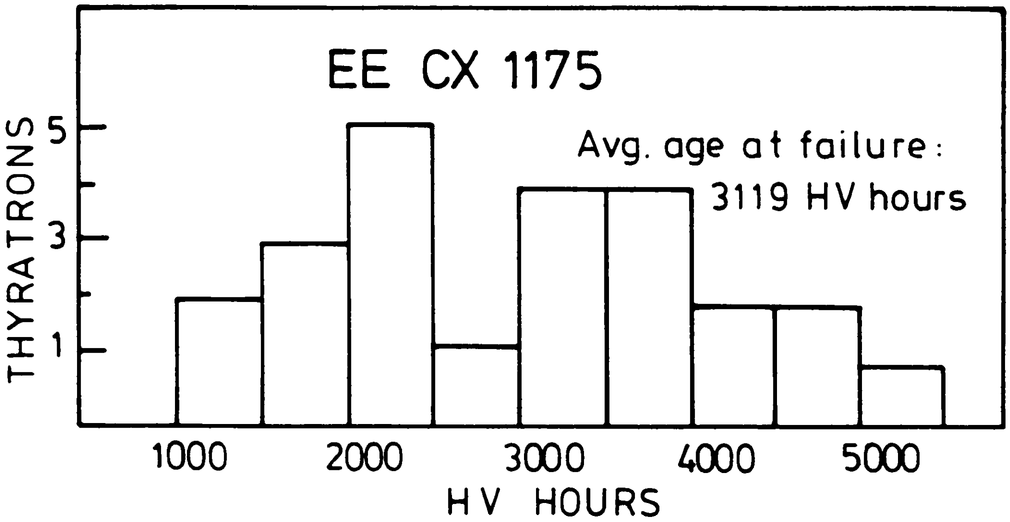
EE CX 1175

Peak forward anode voltage	80 kV max.
Peak anode current	6000 A max.
Average anode current	6 A max.
Anode heating factor	140.10^9 V.A.pps. max.
Cathode heater power	252 W
Reservoir heater power	50 W
Grid 2 drive pulse voltage	1200 V
Grid 1 DC priming voltage	150 V
Grid 2 bias voltage	-150 V

Pulseline modulator specifications

	max	min
RF peak power	25 MW	2.5 MW
Mod. peak power	65 MW	8 MW
Cathode voltage	250 kV	107 kV
Cathode current	250 A	75 A
Klystron impedance	970 Ω	1445 Ω
Repetition rate	300 Hz	50 Hz
Pulselength (flat top)	2.5 μsec	
Rise time	1 μsec	
Fall time	1.5 μsec	
Flat top ripple & droop Amplitude jitter	< 1%	
Number of PFN	3 in parallel (CGR) 1 (Gent)	
Number of cells/PFN	9	
Pulse transformer ratio	1:13	
Max primary pulse current	3250 A	
Max PFN voltage	45 kV	
HT power supply	25 kV/5 A	

Thyratron age at failure



Thyratron failure cause

– short circuit grid 1/ground	8 thyratrons
– filament failure	3
– reduced high voltage hold-off	7
– refusal of switching or instabilities during switching	6

Klystron failures

	Failure Cause	Age at failure
TV 2015	Vacuum	19 354 HV HOURS
	Arcing	7468
	Arcing	6563
	Perveance ↓	13 182
	Perveance ↓	2418
ITT 8568	Perveance ↓	14593

Hard-tube modulator

Energy range 1.75 - 15 MeV

Adjustable e^- beam energy :

1. Modulator working at fixed levels + phase shifting between sections

   but : - only 2 sections (first section : buncher)

   - spectrum requirements <—> optimum phase

2. Modulator with a wide dynamic range

   - continuous adjustable power level

   - high power variable waveguide coupler

First section	0.3 MW	peak HF power
Second section	0.3 - 1.7 MW	
Klystron	0.6 - 2.0 MW	

Other modulator requirements :

- flexibility (pulselength, p.r.f., ...)
- reliability
- stable pulse specifications over whole energy range

  └→ flat-top voltage droop & ripple (10 μsec) < 0.15%

  voltage amplitude jitter < 0.15%

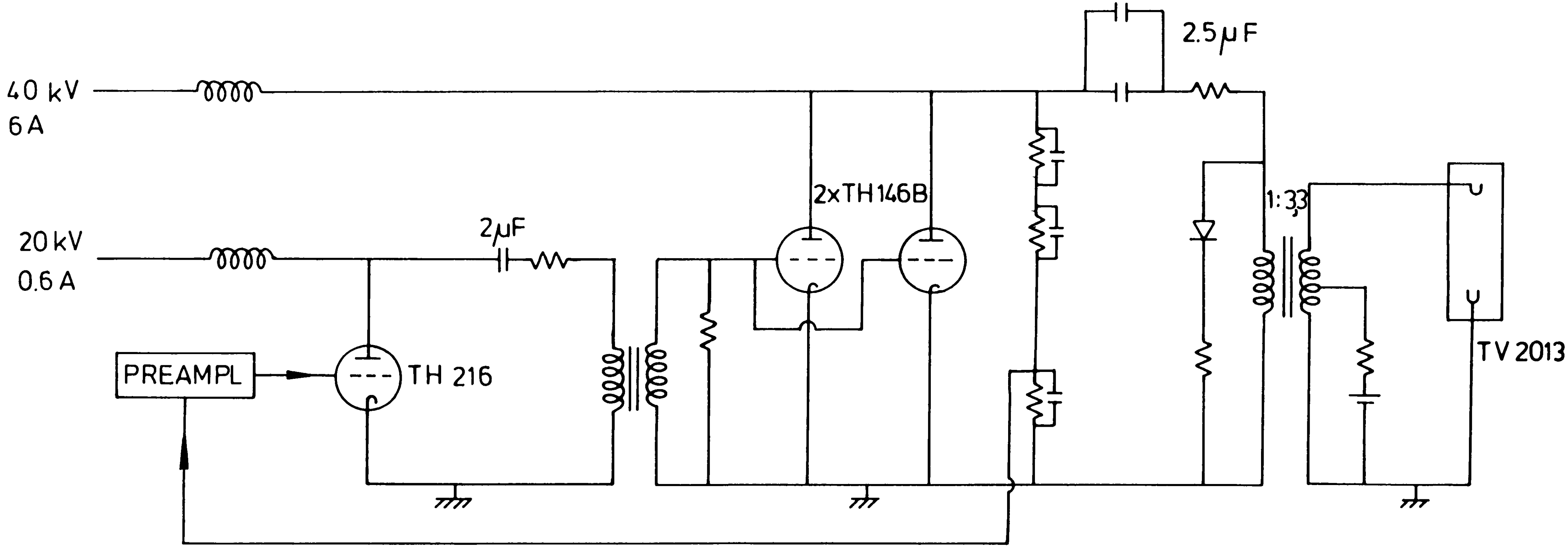
Hard-tube modulator

Klystron specifications

for typical operation		TV 2013	
Frequency		2999 MHz	
RF outpout power	peak	2 MW	(4 MW max.)
	avg.	56 kW	(60 kW max.)
RF input power	peak	90 W	
Beam voltage	peak	95 kV	(120 kV max.)
Beam current	peak	56 A	(80 A max.)
Heater power		450 W	
Microperveance		1.9	
Efficiency		40%	
Impedance		1700 Ω	
Gain		43.7 dB	
Output		2 windows	
Focusing		electromagnet	

Hard-tube modulator specifications

	max	min
RF peak power	2MW	0.6 MW
Mod peak power	5.4 MW	1.7 MW
Cathode voltage	95 kV	60 kV
Cathode current	56 A	28 A
Klystron impedance	1700 Ω	2150 Ω
Repetition rate	5000 Hz	500 Hz
Pulselength (flat top)	10 μsec	2 μsec
Rise time	< 4 μsec	
Fall time	< 4 μsec	
Voltage flat top ripple & droop	< 0.15%	
Voltage amplitude jitter	< 0.15%	
Storage capacitor	2x1.25 μF	
Stored energy	2000 joules	
Max. energy/pulse	75 joules	
Pulse transformer ratio	1:3.3	
Max.primary current	185 A	
HT power supply	40 kV/6 A	
	20 kV/0.6 A	



HARD-TUBE MODULATOR

Hard-tube modulator switching tubes

Main circuit

Klystron pulse	95 kV/58 A
Pulse transformer	1:3.3
Switch current (peak)	200 A
Storage capacitor voltage	40 kV

Max. switch anode dissipation

(at $V_{switch} = 2/3\ V_{load}$) 90 kW avg.

→ 2 triodes TH 146B in parallel

Driver circuit

TH 146B grid polarisation	-1.5 kV
Driver pulse	2.5 kV/40 A
Pulse transformer	4:1
Switch current (peak)	10 A
Storage capacitor voltage	20 kV

→ 1 triode TH 216

Switch life times > 21 000 hours

Hard-tube specifications

	TH 146B	TH216
Anode voltage continuous	45 kV	30 kV
Peak voltage across switch (typ.)	8 kV	5 kV
DC grid polarisation voltage	-1.5 kV	-1.5 kV
Peak grid voltage	1 kV	1.2 kV
Peak anode current (max.)	400 A	150 A
Anode dissipation (max.)	45 kW	15 kW
Grid dissipation (max.)	1.8 kW	0.5 kW
Filament voltage	13 V	8 V
Filament current	500 A	320 A
Filament power	6.5 kW	2.6 kW

Pulse shape distortion due to – pulsetransformer

– parasitic circuit elements

- Rise & fall time (≅ 4 μsec)

  ~ stray capacitance C_S

  leakage inductance L_L

  C_S (hard-tube) > C_S (pulseline)

  └→ - storage capacitor

  - hard-tubes

- Pulse droop (≈ 2% pulsetransformer; ≈ 3% capacitor droop)

  ~ shunt inductance L_S

  generator resistance // load resitance R

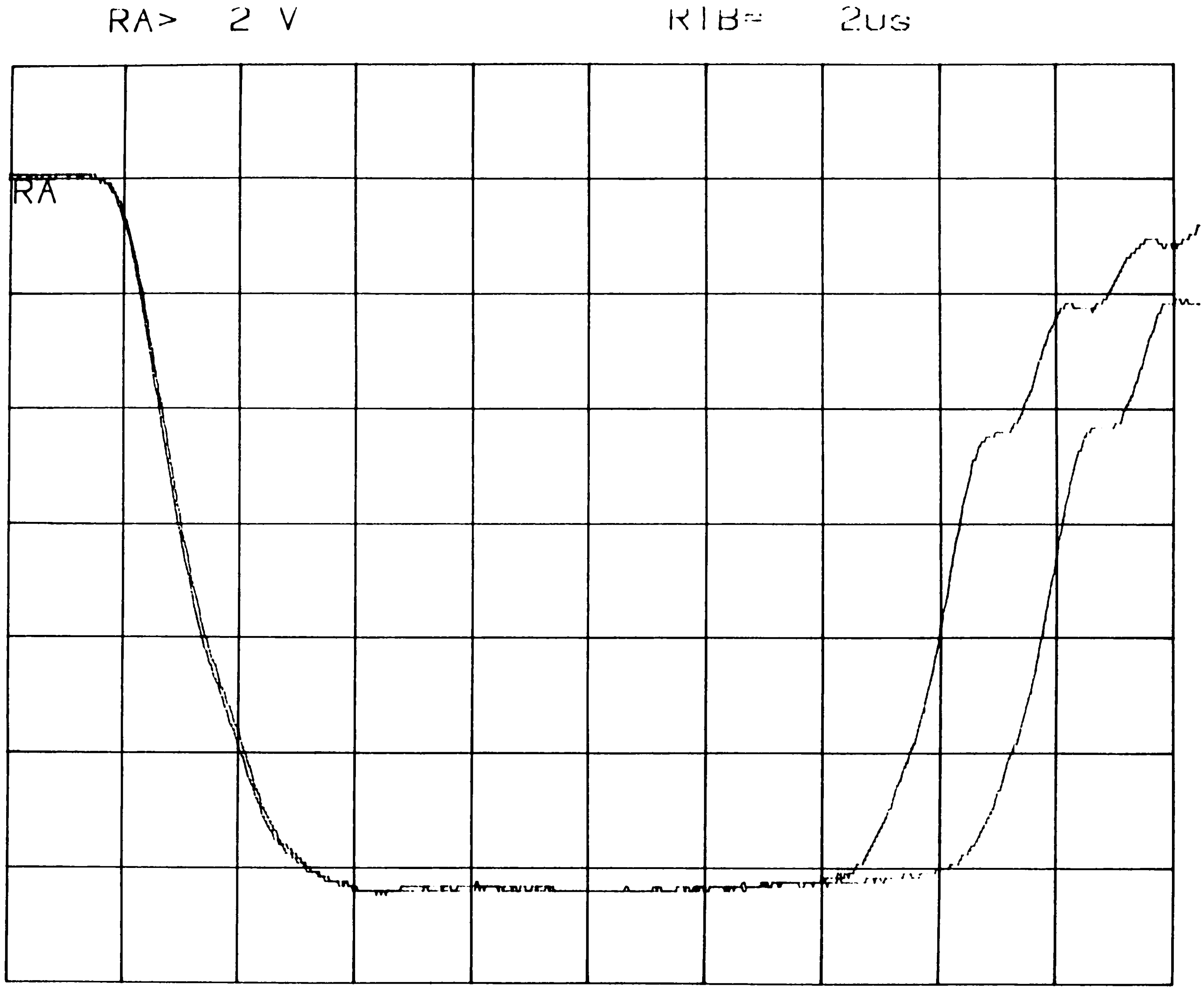
  R (hard tube) > R (pulseline)

but : droop compensation

Versatility of hard-tube modulator

- changing pulseamplitude
- pulselength
- droop compensation
- pulse shaping
- feedback regulation

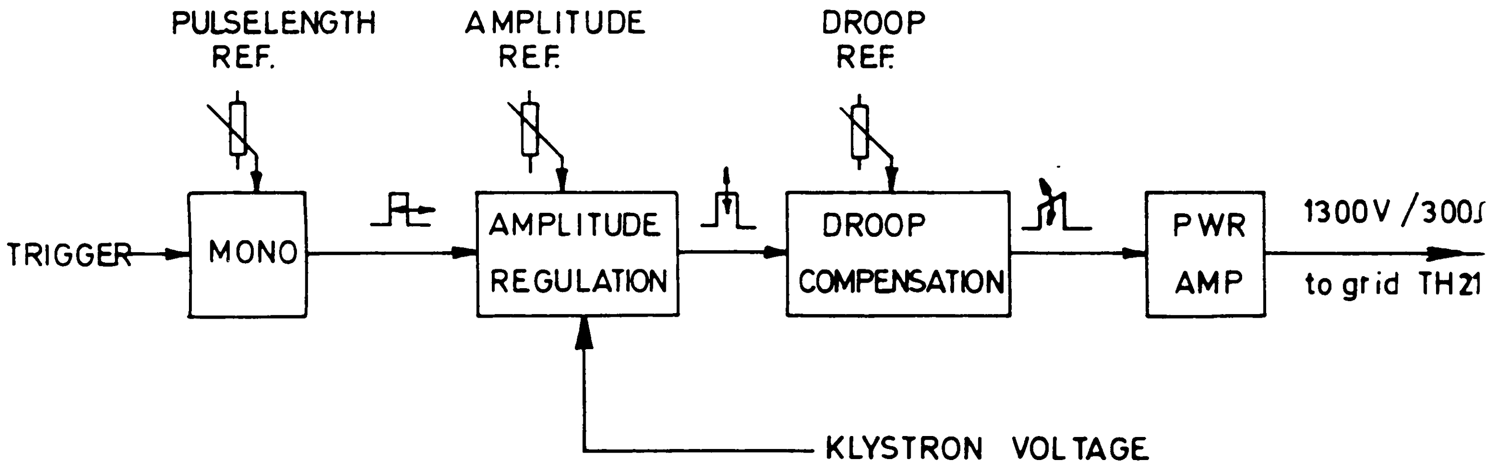
} at low voltage level

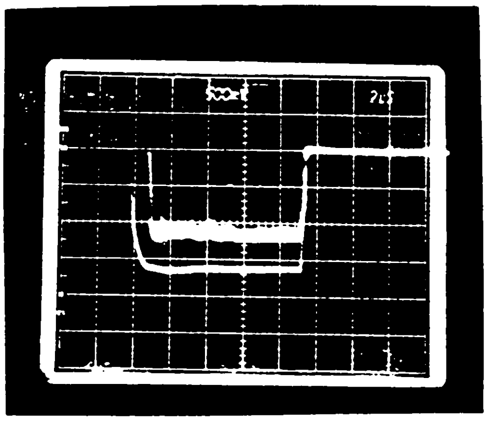


Klystron HV pulses

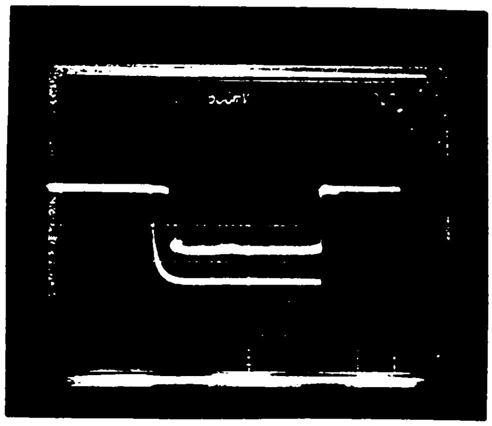
with different pulselengths

KLYSTRON VOLTAGE REGULATION & STABILISATION SYSTEM



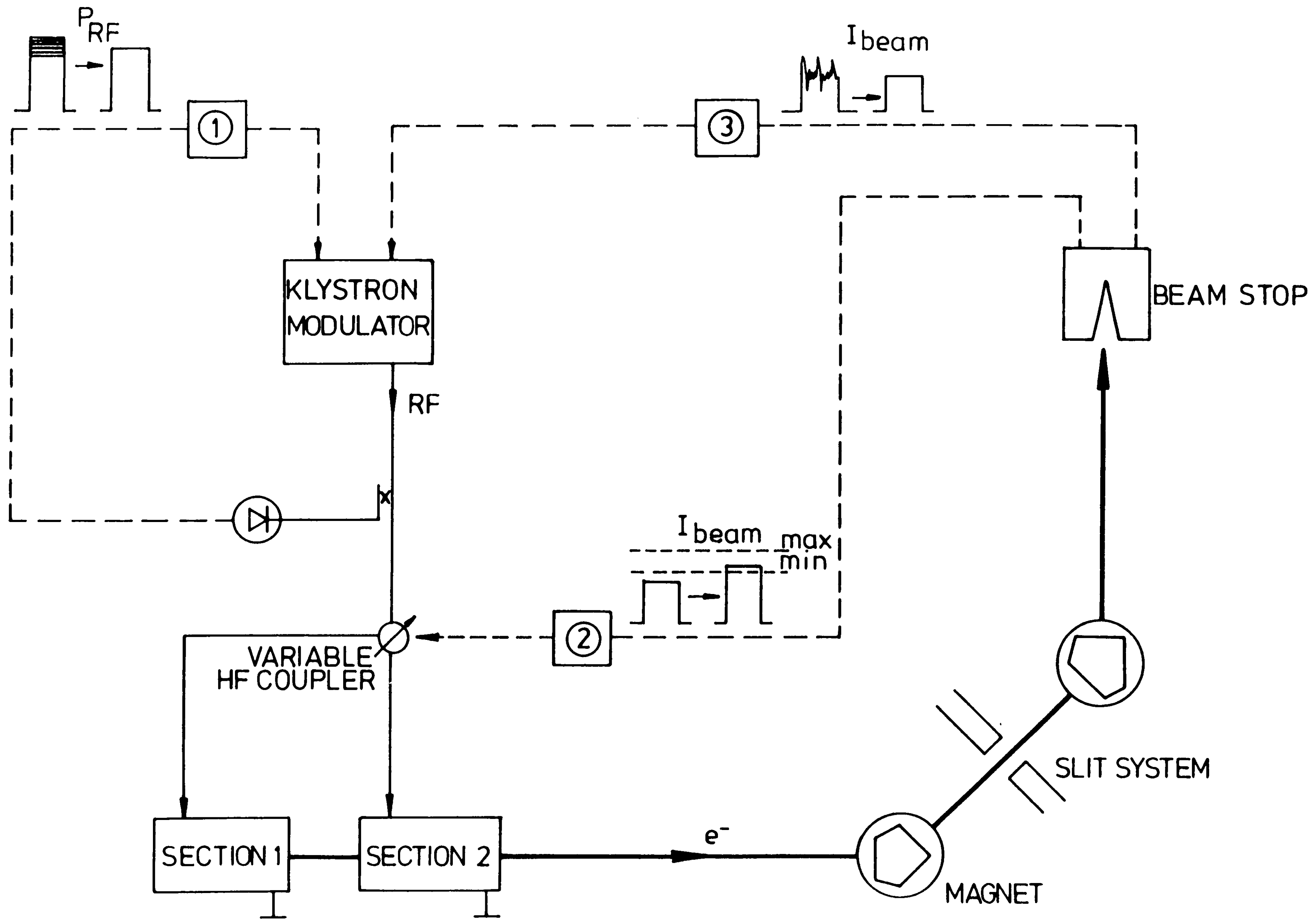


4 MeV

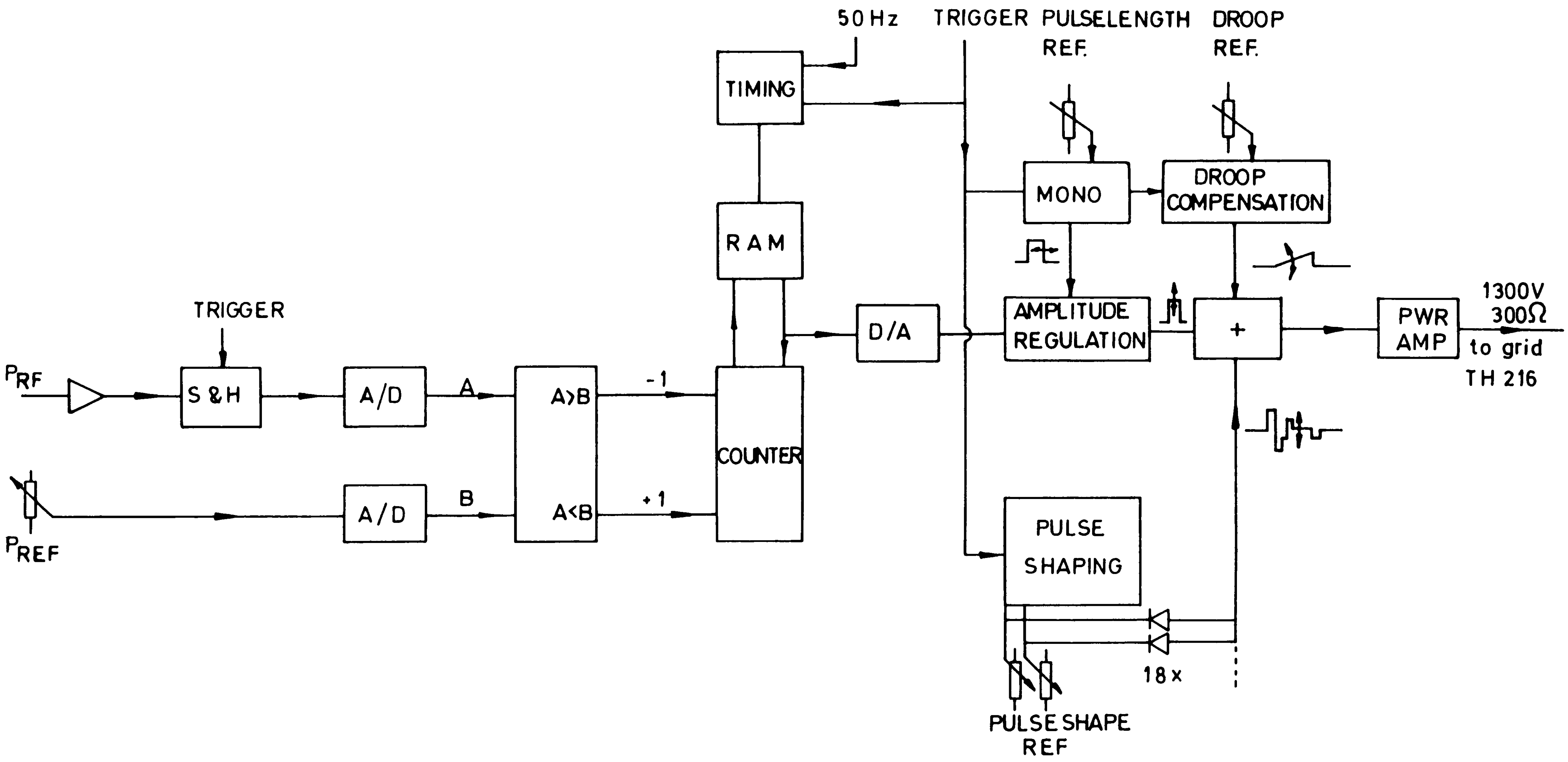


10 MeV

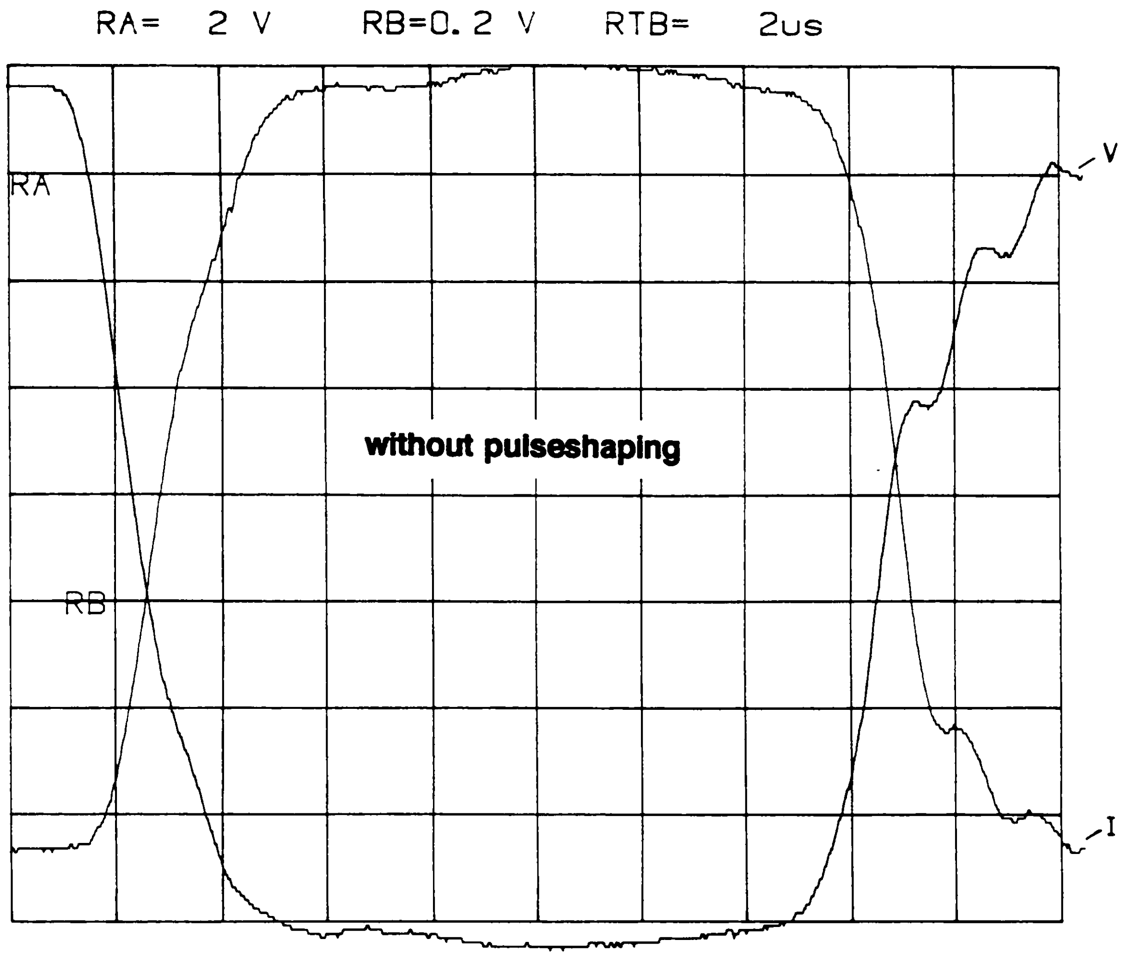
Beam pulses before and after energy analysis

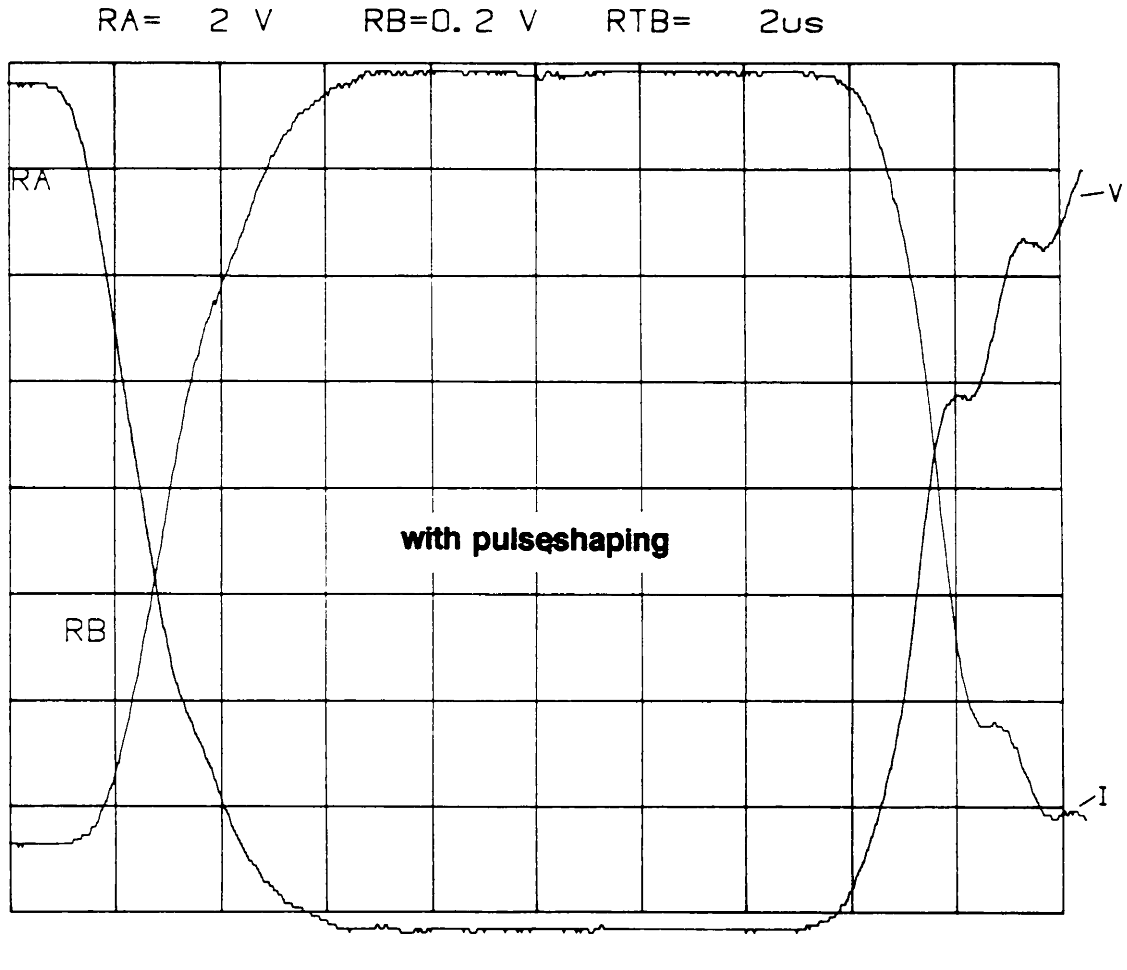


Feedback systems to improve beam quality



RF POWER STABILISATION & PULSESHAPING SYSTEM

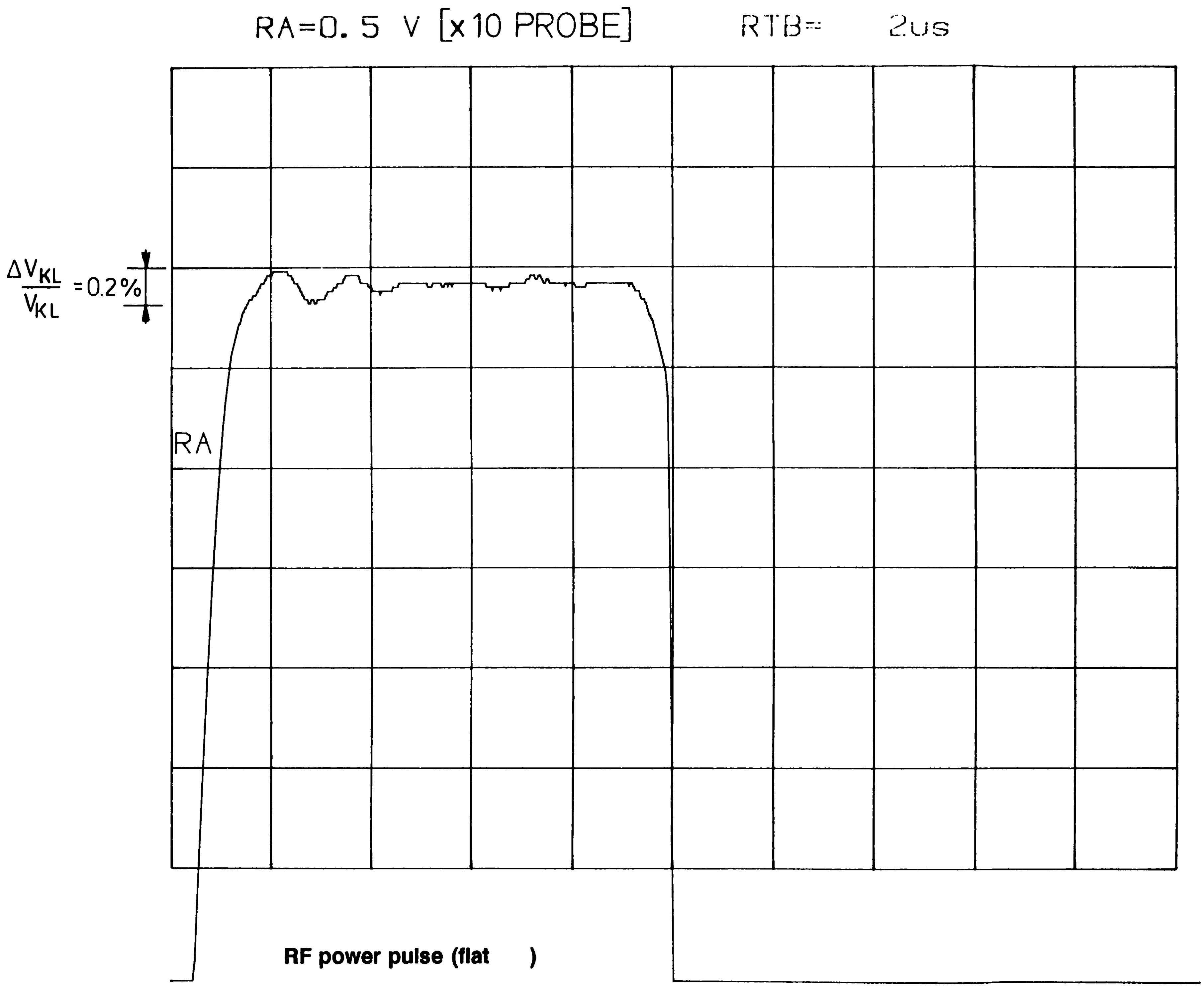




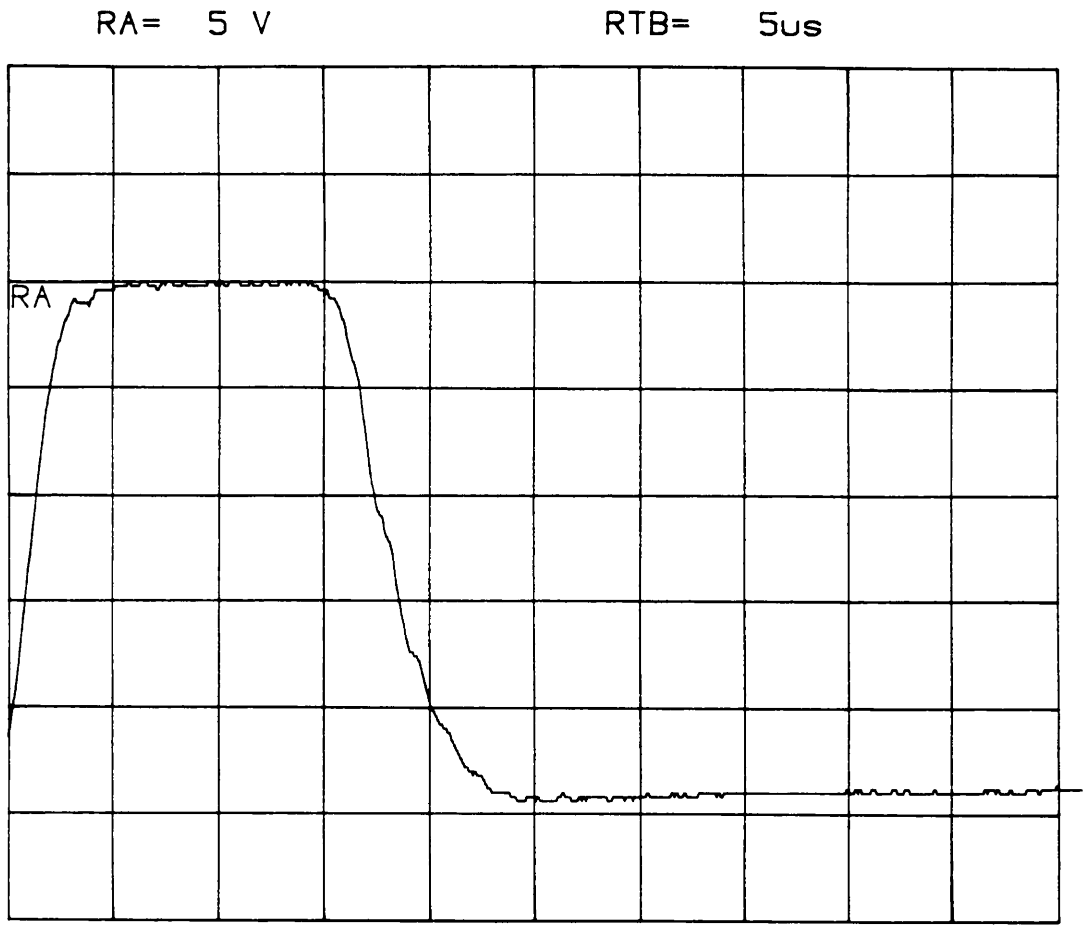
Klystron voltage and current pulse

V_{KL} = 75.8 kV peak

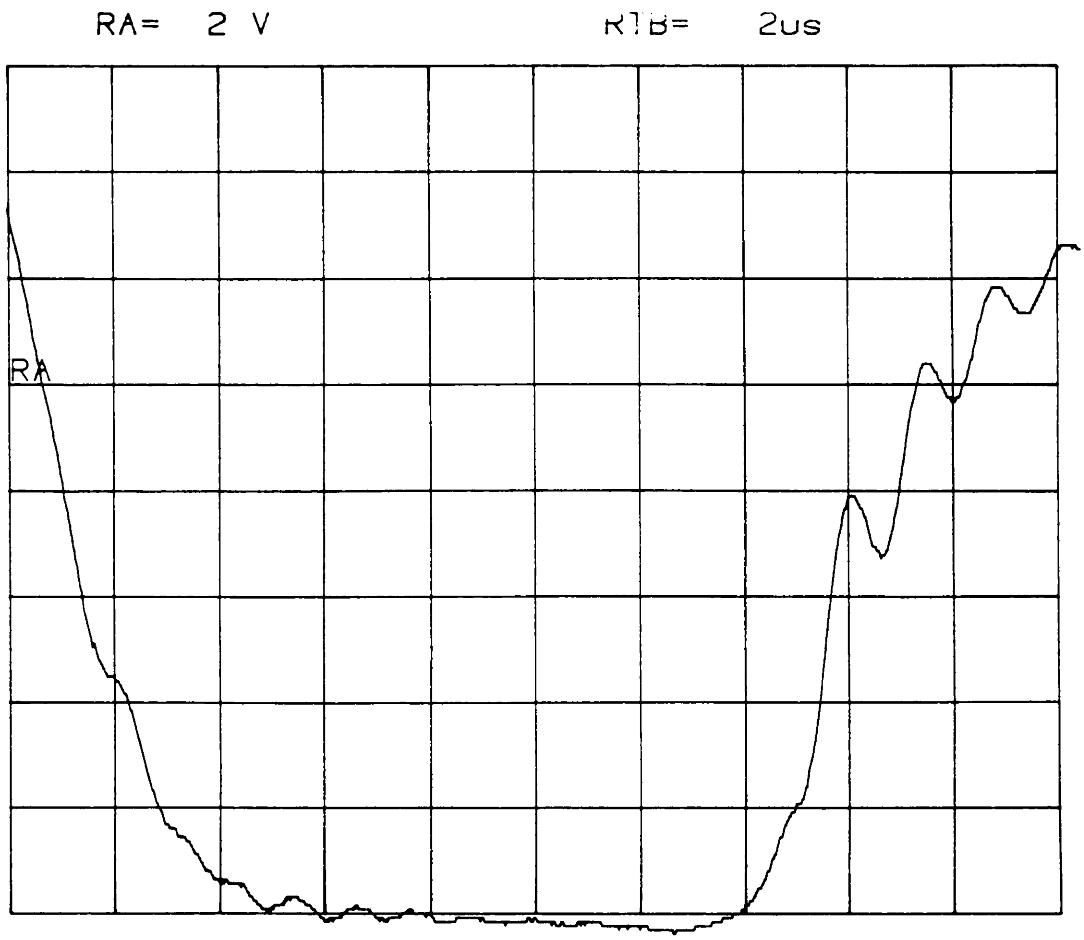
I_{KL} = 41.7 A peak



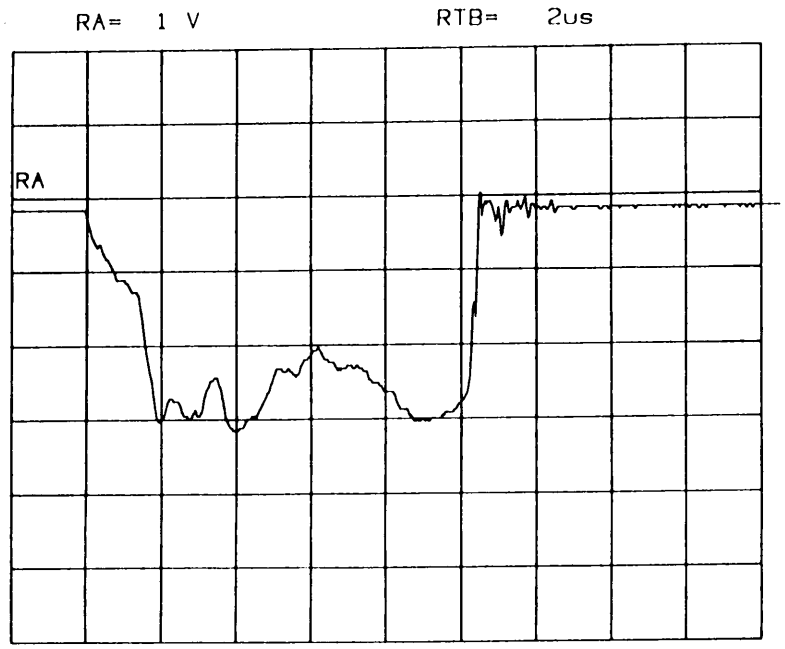
RF power pulse (flat)



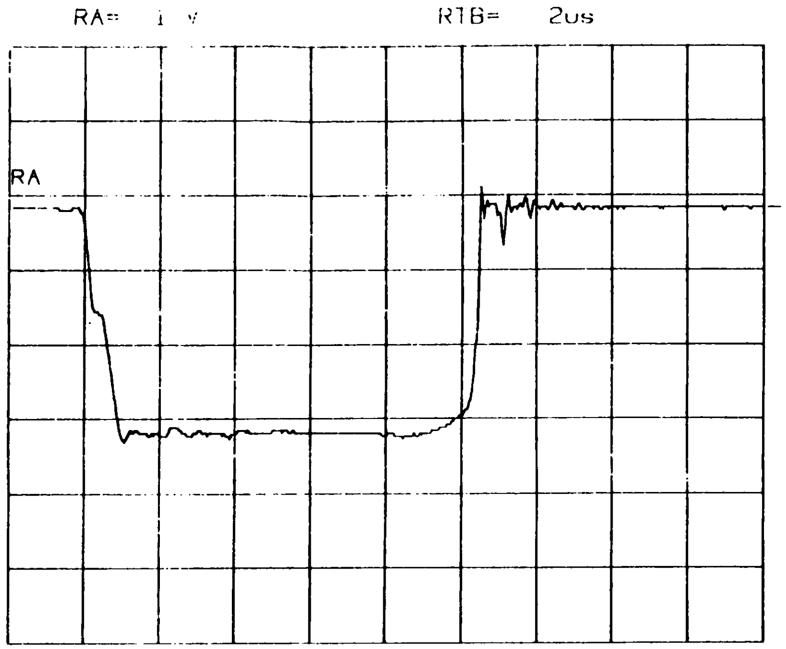
TH 146 driver pulse



TH 146 plate voltage



without pulseshaping

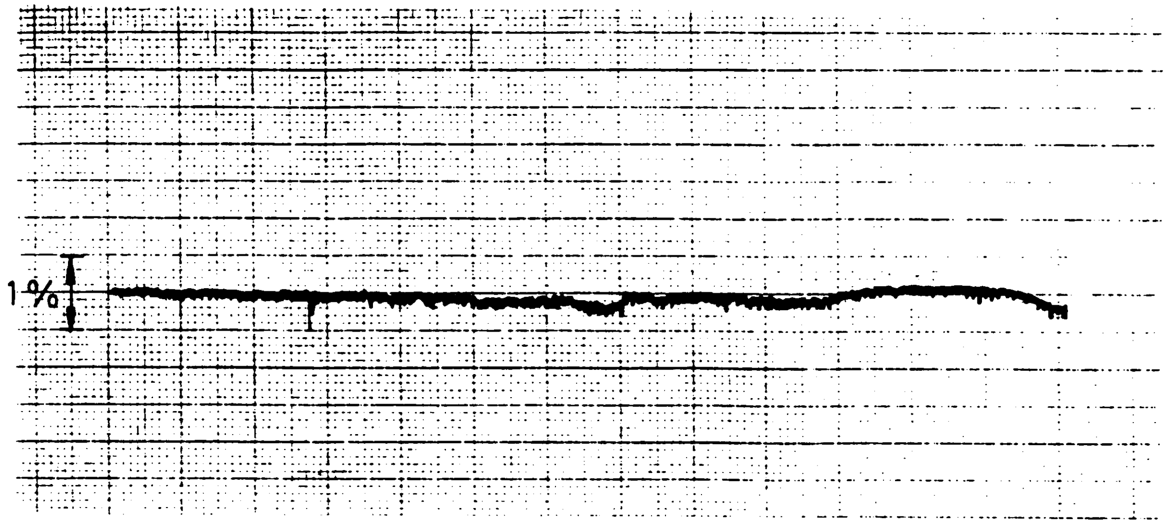


with pulseshaping

Energy-analysed beam pulse on target

Electron beam

Energy :	6.5 MeV
Average beam current:	
with system [3] ON	1.25 mA
with sustem [3] OFF	0.92 mA
Peak beam current :	60 mA
Pulse length :	10 μ sec
Repetition rate :	2000 Hz
Spectrum width :	0.5%



Electron beam

Energy :	7.0 MeV
Average beam current :	1.5 mA
Peak beam current :	75 mA
Pulse length :	10 μ sec
Repetition rate :	2000 Hz
Spectrum width :	0.5%

Long-term stability of energy-analysed electron beam intensity on target, the accelerator running automatically without any operator interventions. (recording time: 1h)

THE NEW INJECTOR LINAC MODULATOR FOR THE LURE - ORSAY ELECTRON GUN

D. Lagrange

CERN, 7th October 1991

N. I. L.

The NIL (New Injector for Linac) modulator gives high voltage pulses : 5ns or 20ns width, 0 to 5kV, the jitter being less than 1ns.

This was realized with coaxial lines according to the Blumlein scheme. The power switch is made by an hydrogen thyratron, the two gates are pulsed by specific current and voltage amplifiers.

As the modulator is connected to the -100 kV gun cathode voltage, commands and trigger use optical fibers.

D.LAGRANGE
LURE ORSAY

NEW

INJECTOR

FOR

LINAC

LURE - ORSAY

SPECIFICATIONS

	ELECTRON GUN	MODULATOR
CURRENT :	15 A Max 30	~1 kV 3 kV
WIDTH :	< 7 ns or 20 ns	5 ns/20 ns
JITTER :	< 1 ns	< 1 ns
FREQUENCY :	50 Hz	50 Hz
VOLTAGE REFERENCE :...	Anode to ground	- 100 kV

65

TRIODE ELECTRON GUN
FROM CGR-MEV

ANODE-CATHODE VOLTAGE : .... 100 kV

PIC CURRENT : .... 30 A

BIAS VOLTAGE : .... 700 V to 2 kV

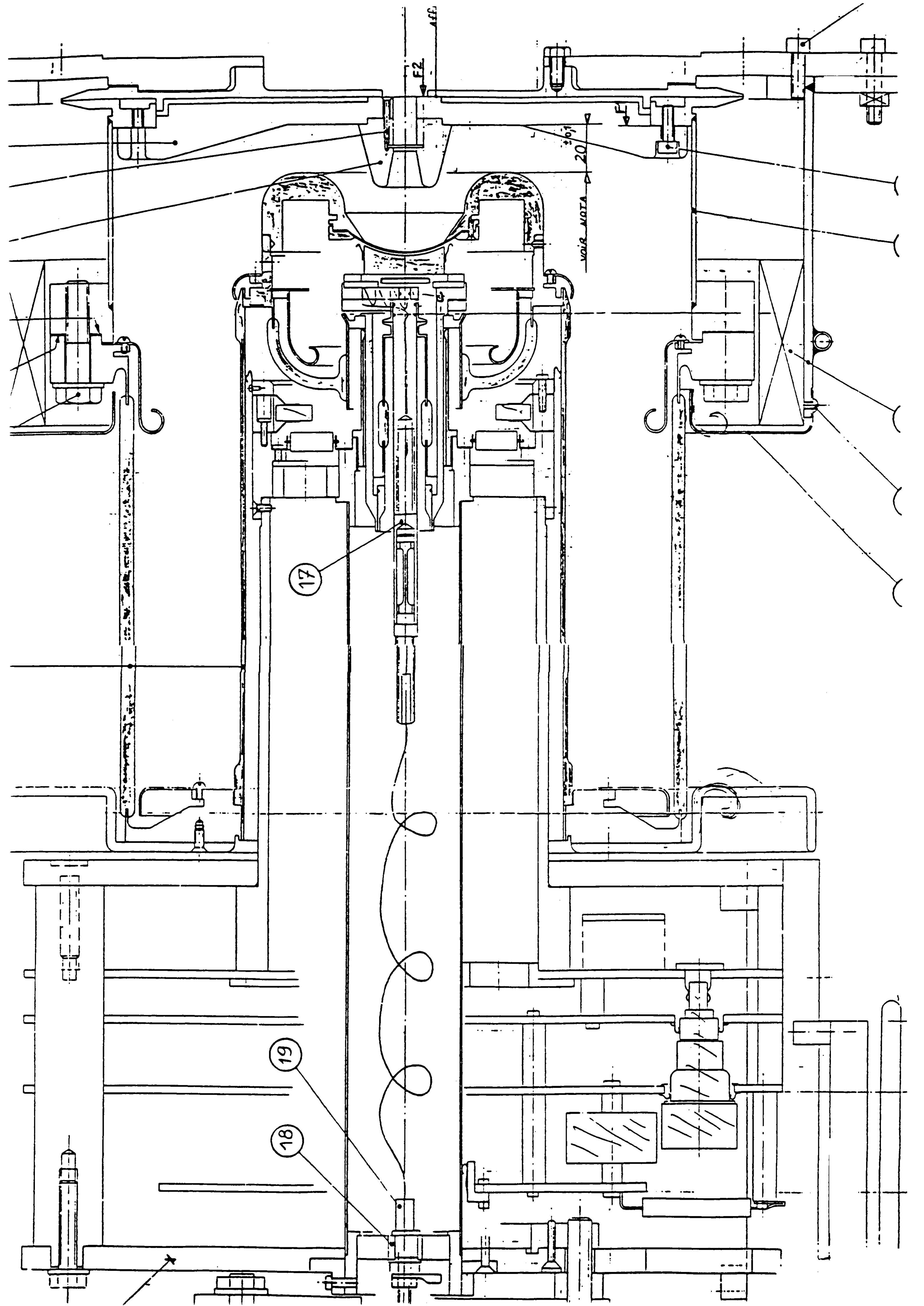
HEATING CURRENT : .... 20 A

CAPACITY GRID-CATHODE :................ 5 pF

IMPEDANCE CATHODE-GRID : .... ∞ for 0 A
109 Ω for 16 A

TEST LIL : 15 A transmitted with :

* High voltage = - 100 kV
* Heating current = 19 A
* Bias voltage = - 750 V
* Pulse voltage on cathode = - 2,5 kV



Aff
F2
F
20
VOIR NOTA
17
19
18

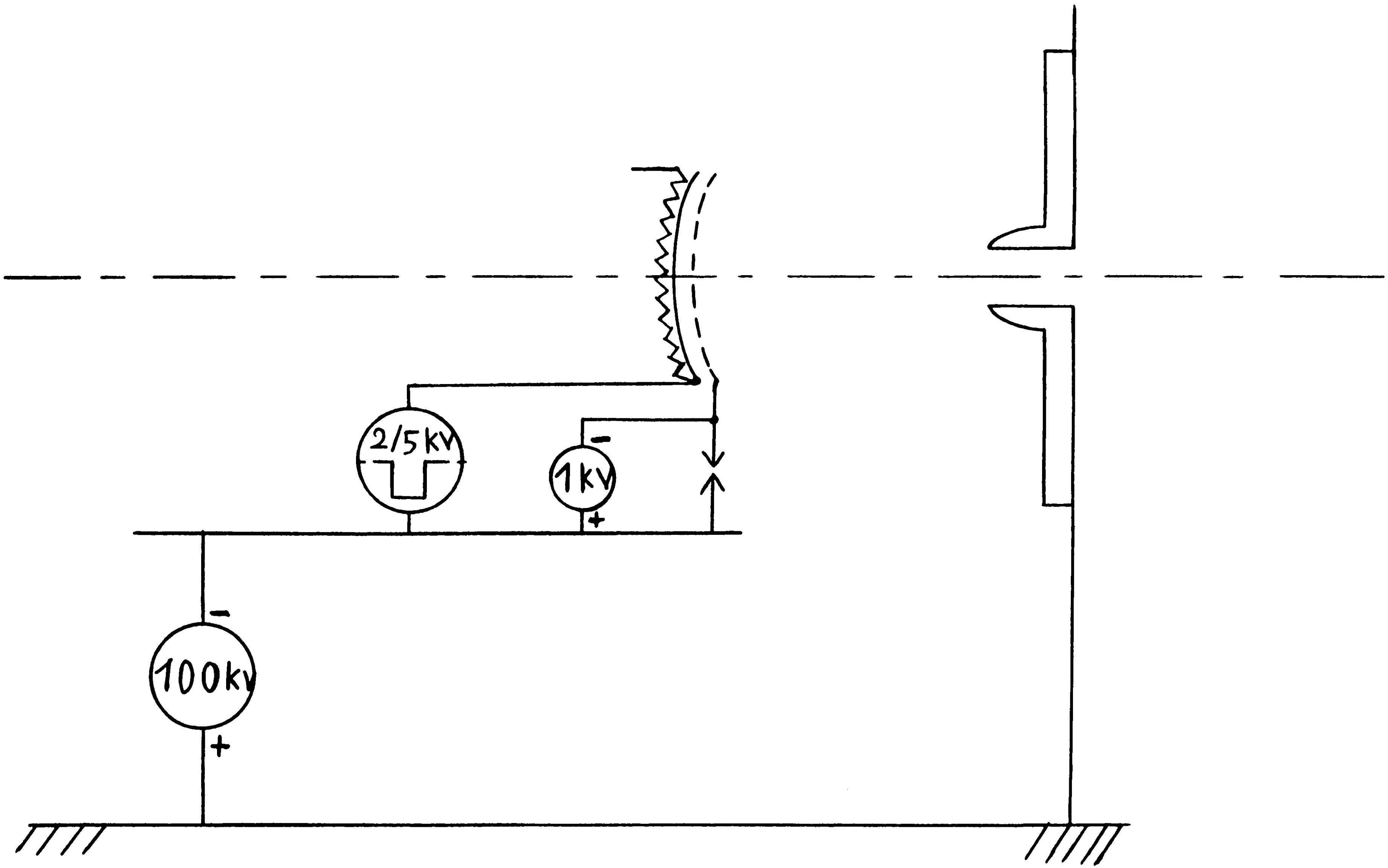
MAIN CHOICES

TRIGGER :

* CATHODE TRIGGERING.
* PULSE GENERATOR WITH COAXIAL LINES.
* BLUMLEIN SCHEM FOR SHORT PULSES.
* TWO PULSE GENERATORS CONNECTED AT A TIME.

COMMAND :

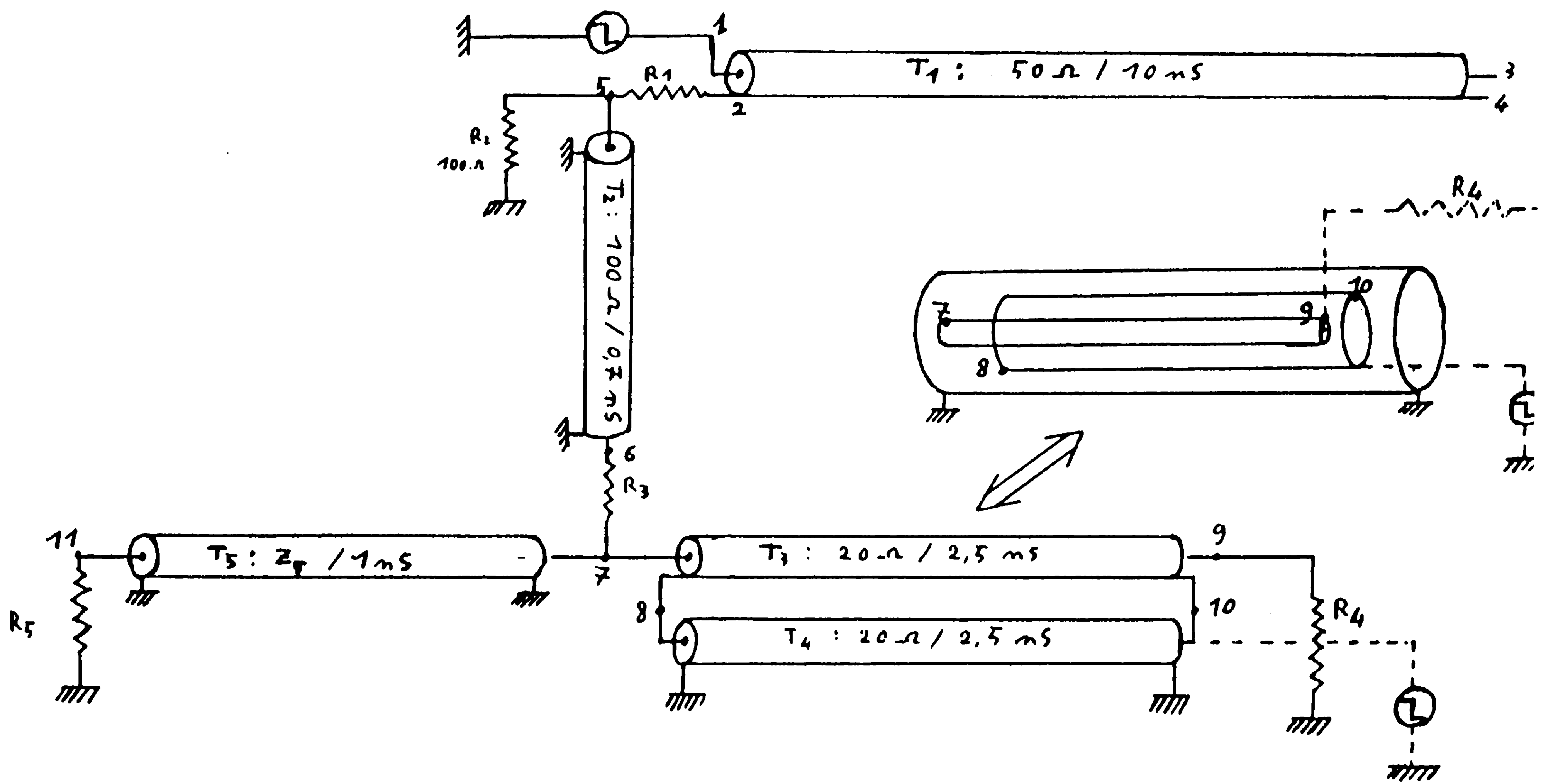
* PULSE TRIGGER WITH FAST OPTICAL FIBER.
* HARDWARE SECURITY ON BOARD.
* COMMAND BY VME SYSTEM.
* COMMUNICATION BY RS 232 IN OPTICAL FIBER.



2/5kV
1kV
100kV

FORMEUR CANON NIL

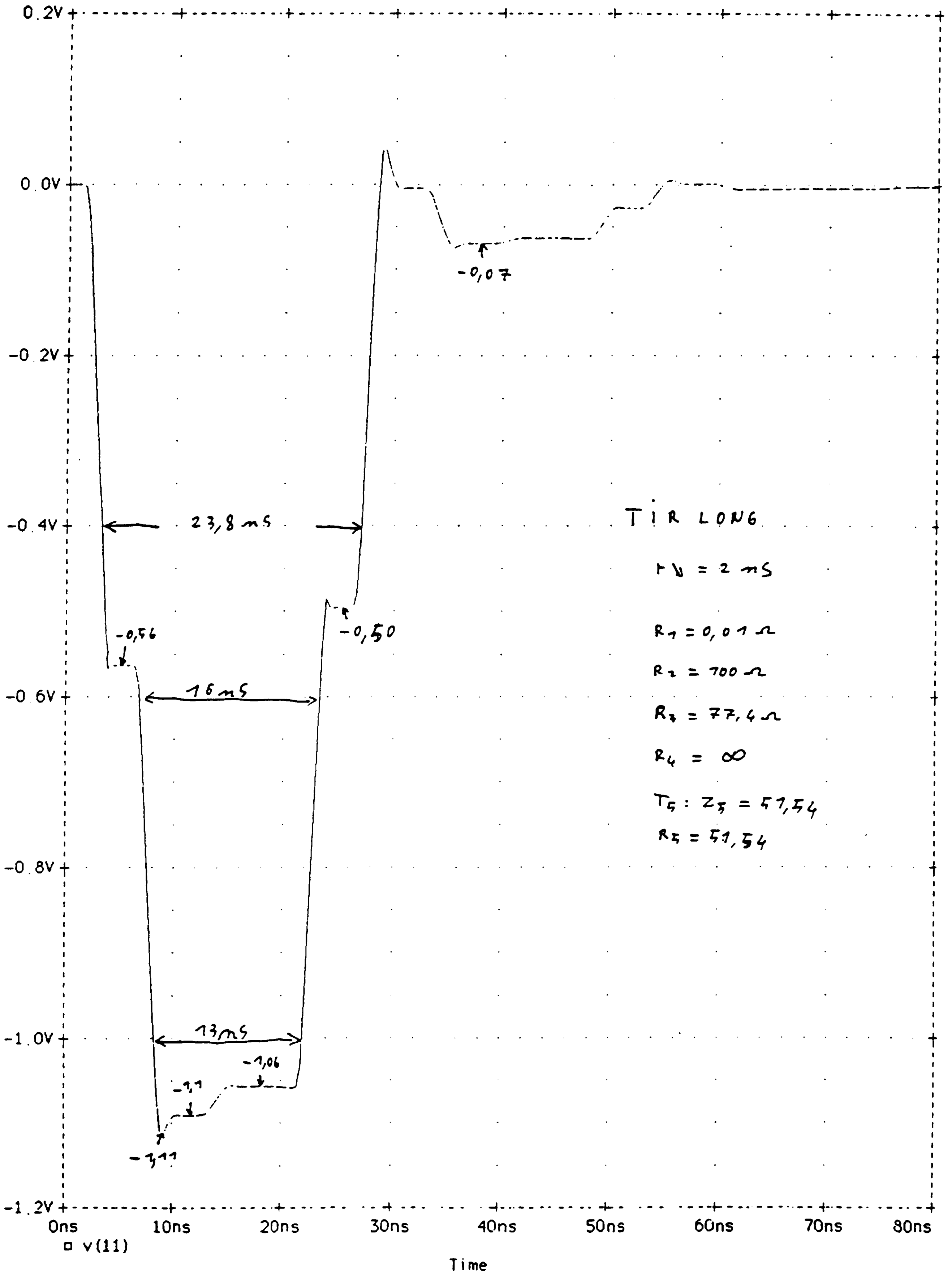
MODELISATION

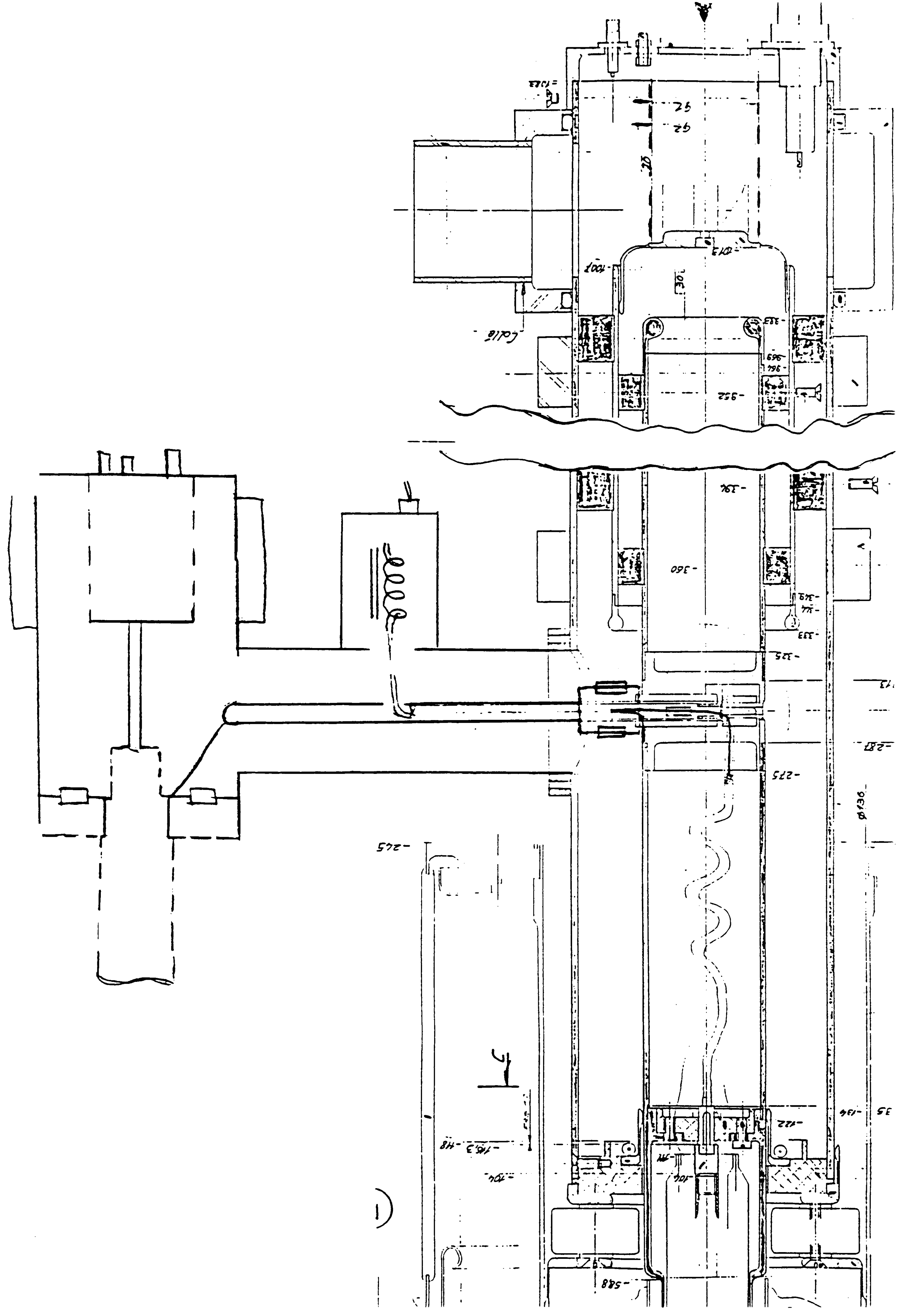


* Noeud intermédiaire pour Self Série : N° Noeud + 100
* R Terminaison de ... (1E6) : N° Noeud + 200
* ...

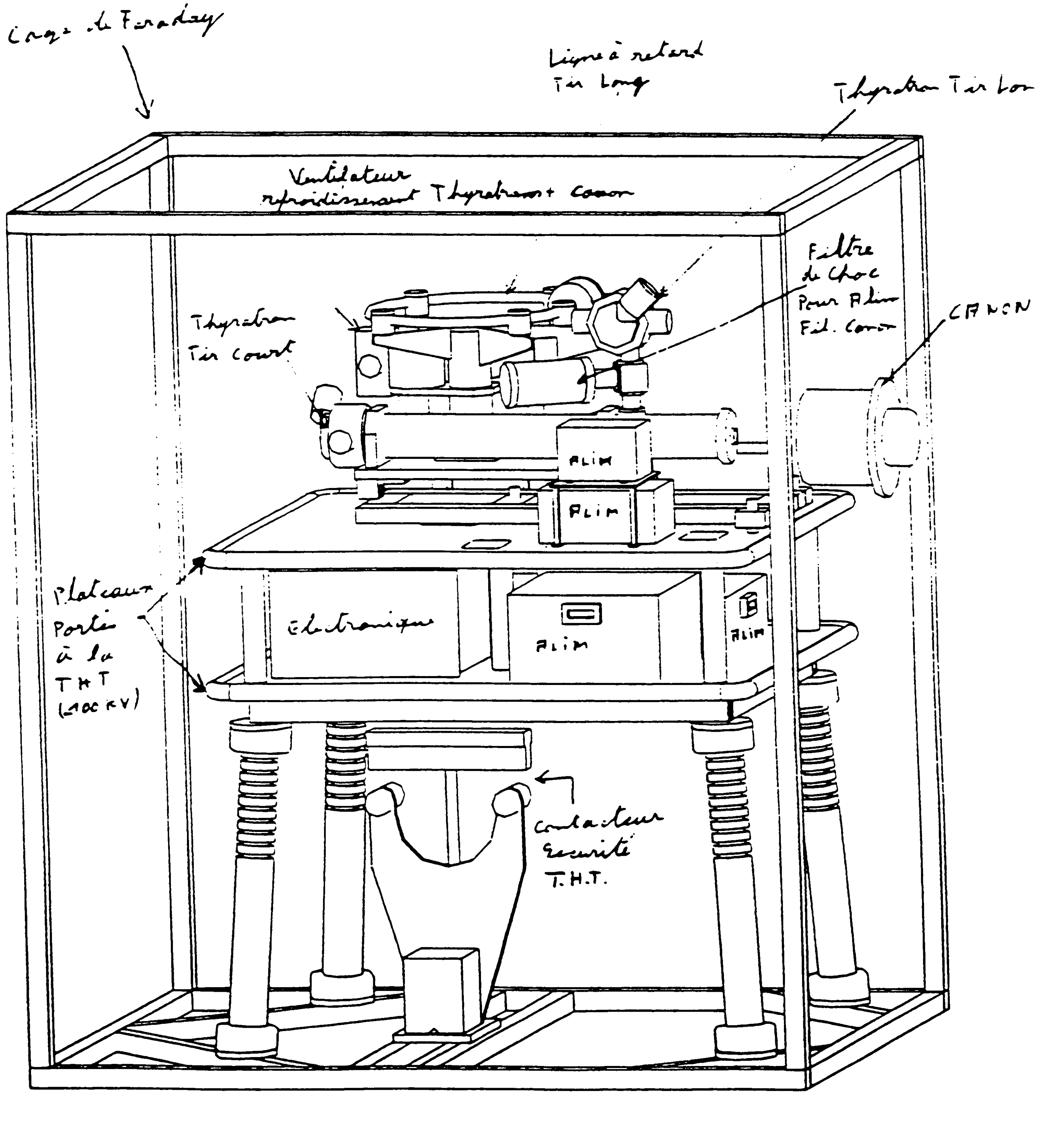
ESSAI canon DL-CANO.cir

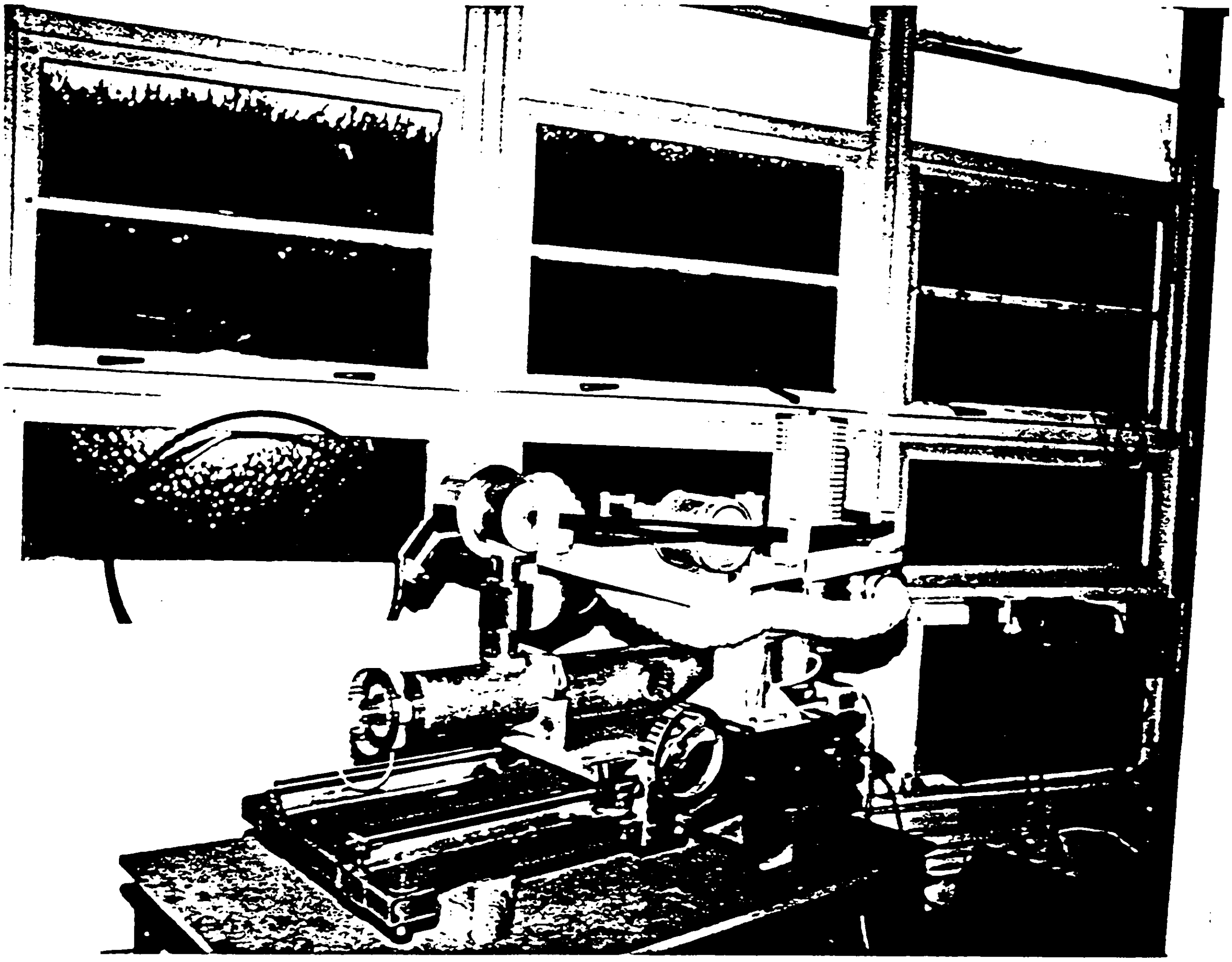
Date/Time run: 12/14/89 10:16:14 Temperature: 27.0

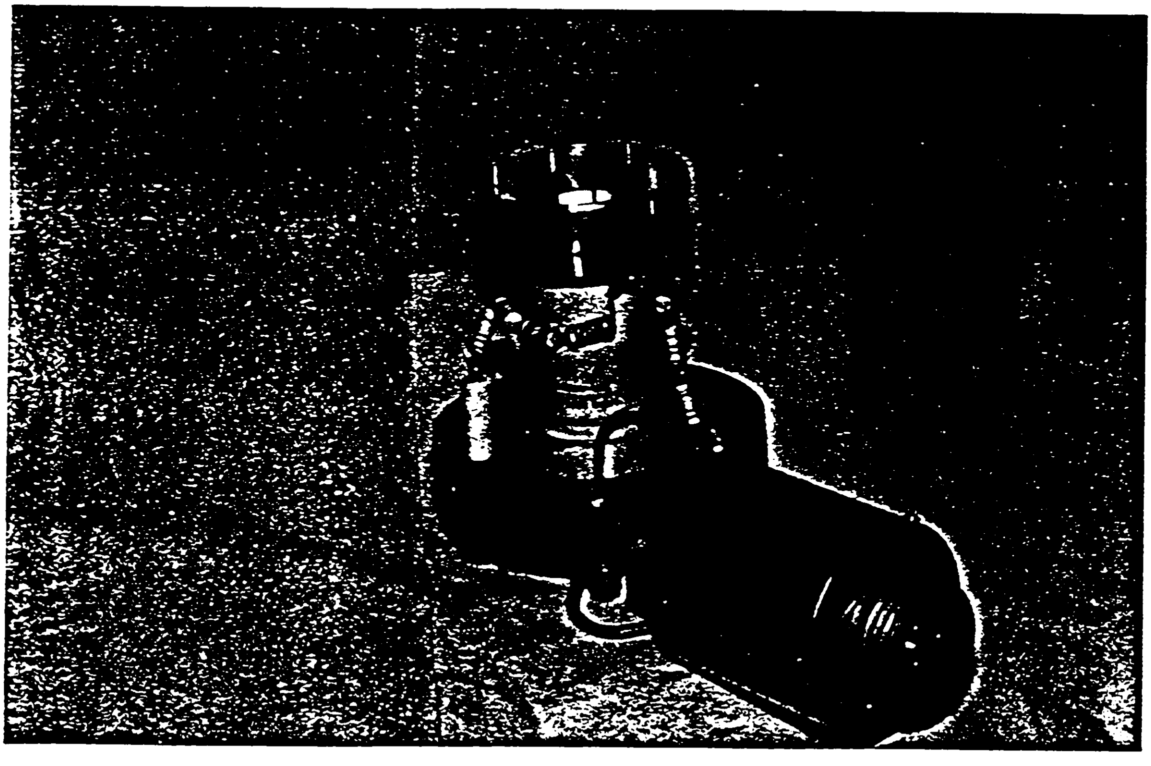




FERMEUR NIL


Cage de Faraday
Ligne à retard
Tir Long
Thyratron Tir Lon
Ventilateur
refroidissement Thyratrons + Canon
Filtre
de Choc
Pour Alim
Fil. Canon
CANON
Thyratron
Tir court
ALIM
ALIM
Plateaux
Portés
à la
THT
(100 KV)
Electronique
ALIM
ALIM
Contacteur
Sécurité
T.H.T.





THYRATRONS

	SHORT PULSES	LONG PULSES
	CX 1599 EEV	CX 1588 EEV
PEAK VOLTAGE :	12,5 kV	25 kV
PEAK CURRENT :	1 000 A	1 000 A
dI/dT :	100 kA/µs	100 kA/µs
DELAI TIME :	0,03 µs	0,03 µs
JITTER :	0,2 ns	0,2 ns

PULSED :

GRID 1 :	500 V 2/50 A	500 V 2/50 A
GRID 2 :	500 V	500 V
BIAS VOLTAGE :	-25v/-200	-25v/-200

IMPULSION DE COURANT

CAHIER DES CHARGES

AMPLITUDE : 10 A - 20 A

LARGEUR : 1 µs - 10 µs

TEMPS MONTE: le + rapide possible

FREQUENCE : 50 Hz

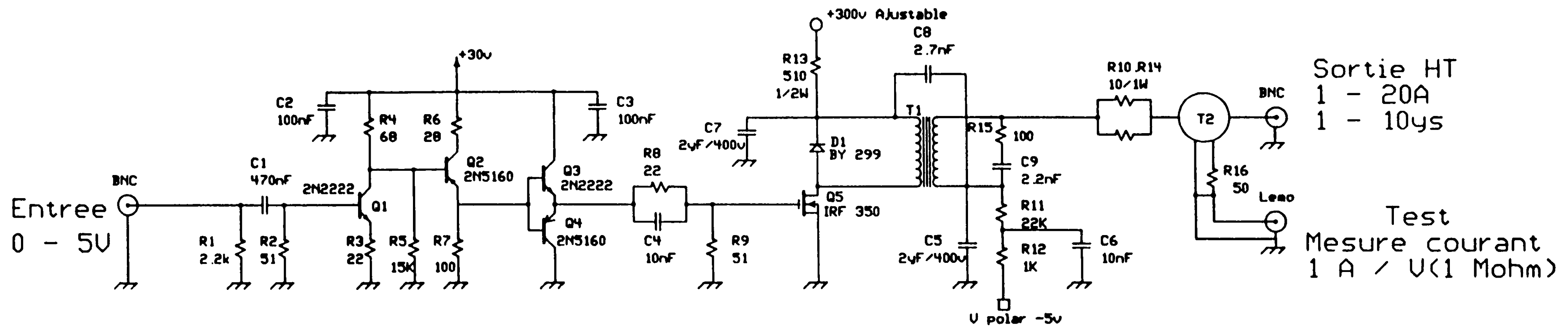
POLARISATION NEGATIVE : - 5 V

SOLUTION ADOPTEE :

Sur la base de l'ampli utilisé pour le feed-back bétatron :

- Ampli d'impulsion (réglage d'amplitude par l'alim.)
- Transistor MOS IRF 350
- Sortie Basse Impédance

  (Transformateur "quasi" coaxial)
- Test par transformateur de courant.



T1 -> 50 spires de 4 cables bifilaires 50 ohms en // sur 2 tores 36*23*10

T2 -> 1/50 spires mesure de courant

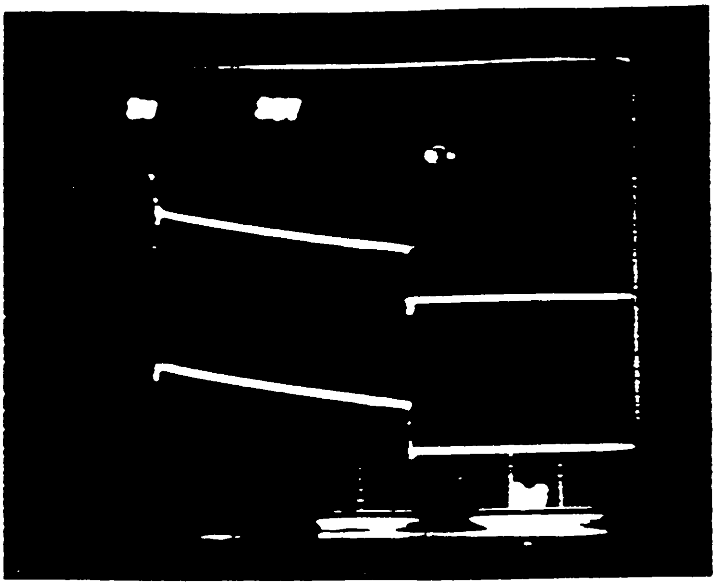
Masse -> 3,6,9,12,15,18,21,AC32

+30V -> C3

V polar -5V -> C22

+300V Ajustable -> C28 ou C30 (selon position inter)

3013	D.LAGRANGE
Generateur de courant	



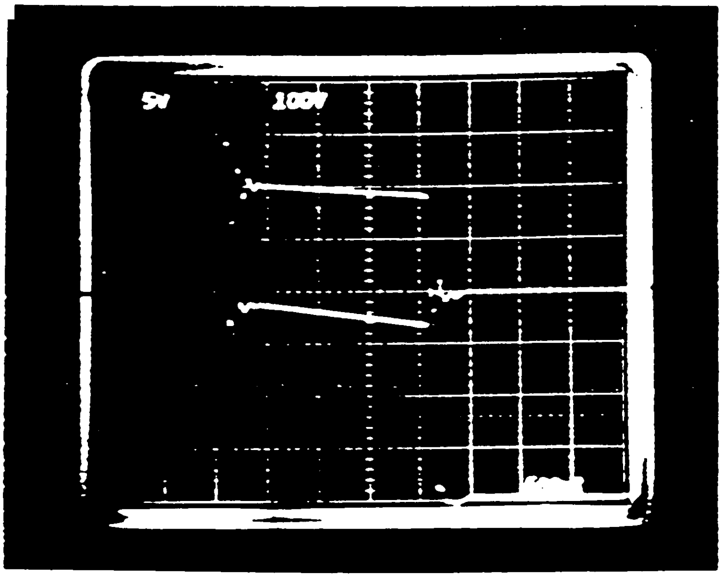
6/ Formes d'Ondes :

V sortie sur 11 Ohms (20 V/C)

I # 2 A

I test (2 V/C)

2 µS/C T= 10 µS

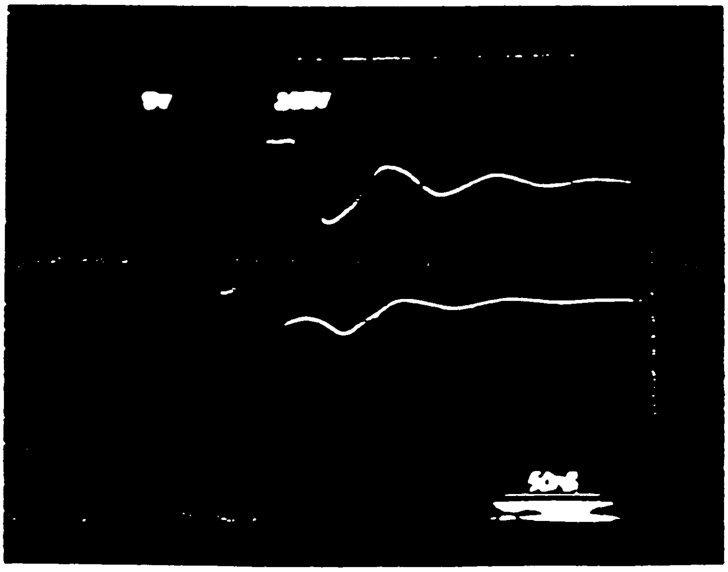


V sortie sur 11 Ohms (100 V/C)

I # 20 A

I test (5 V/C)

500 nS/C



V sortie sur 11 Ohms (100 V/C)

I # 20 A

I test (5 V/C)

50 nS/C

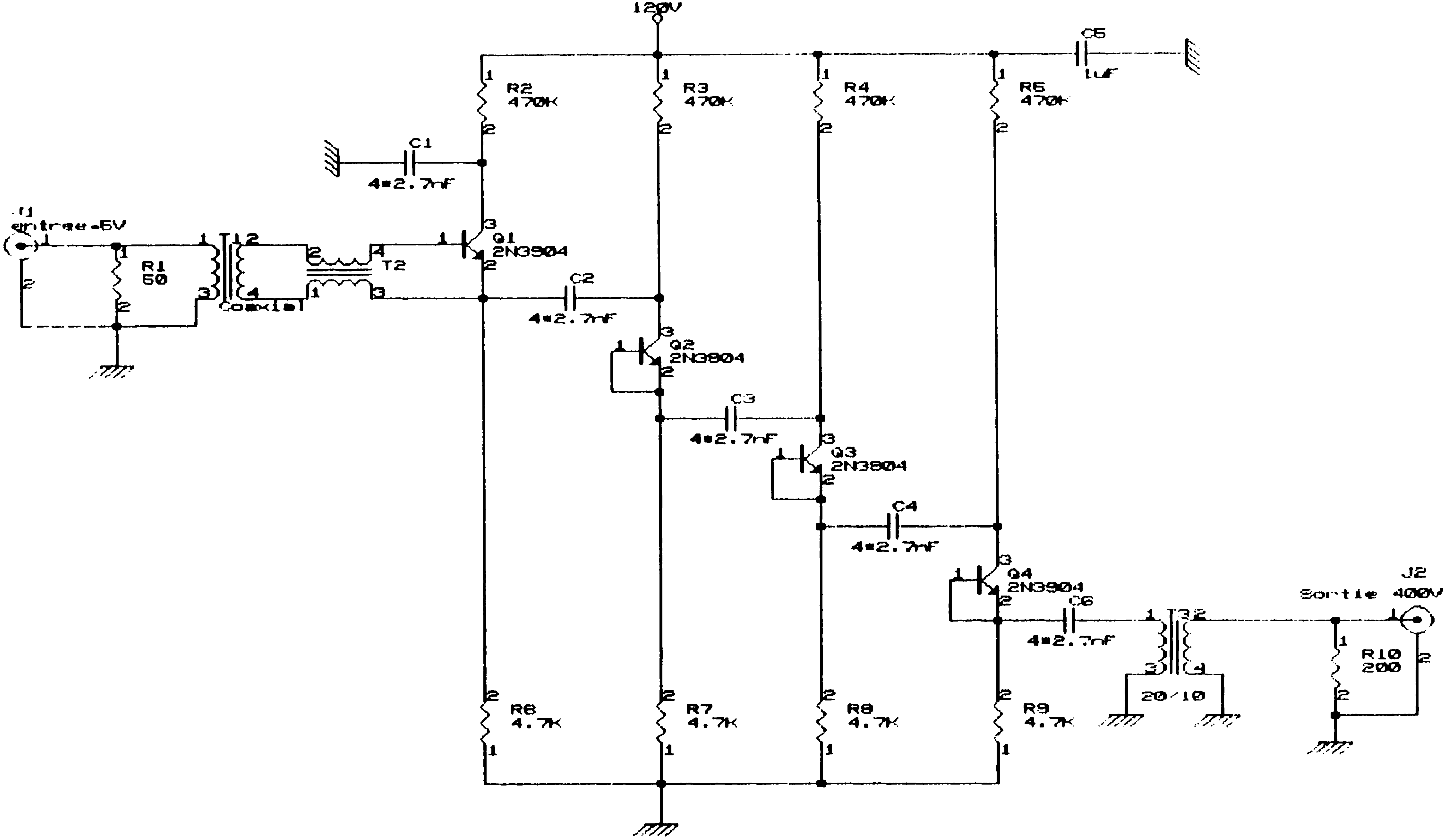
IMPULSION DE TENSION

CAHIER DES CHARGES :

Amplitude :	> 150 V stable
Largeur :	~ 100 ns
Temps Montée :	~ 1 ns
Polarisation Négative :	- 50 V
Jitter :	< 200 ps
Fréquence :	50 Hz

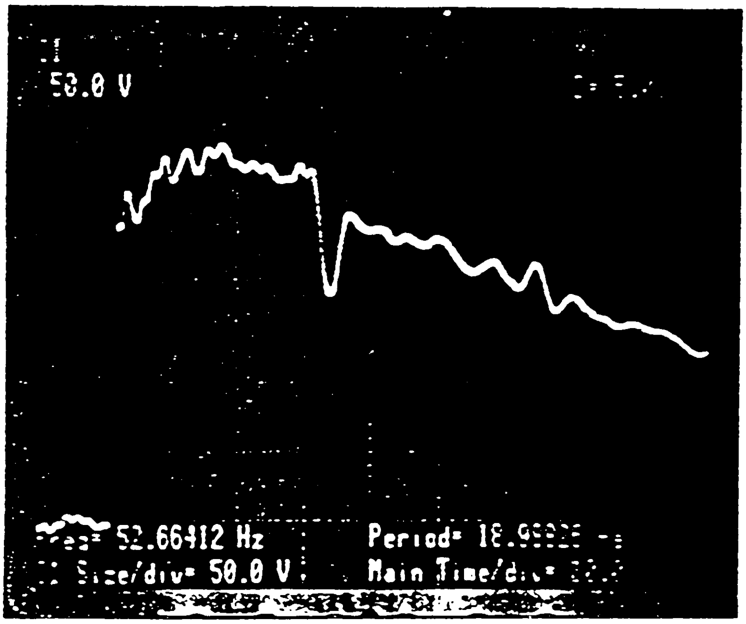
SOLUTION ADOPTEE :

- Générateur avalance
- Montage Marx (4 étages)
- Transfo élévateur en sortie



Size	Document Number	
A	GENERATEUR AVALANCHE	
Date: February 27, 1990	Sheet	1 of

VOLTAGE GENERATOR

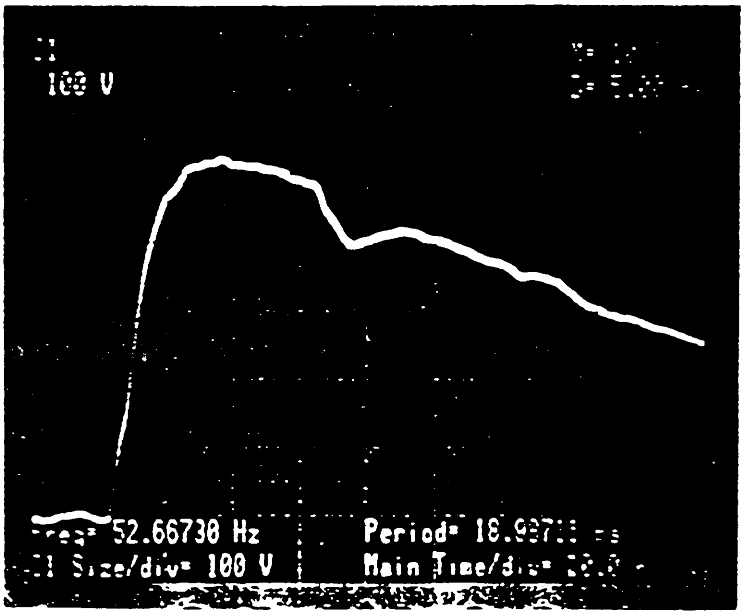


Without transformer

Zs = 50 Ω

Vs = 220 V

tm = 2 ns

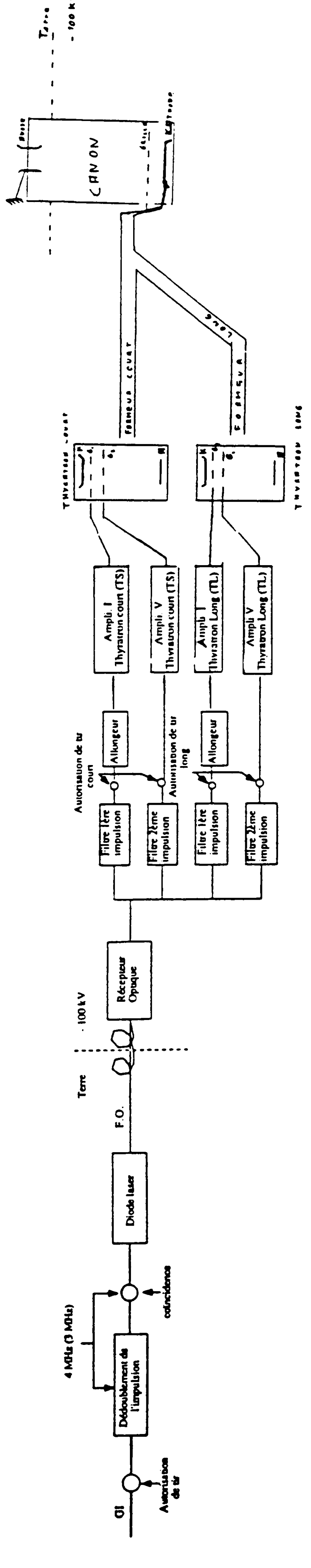


After transformer

Zs = 200 Ω

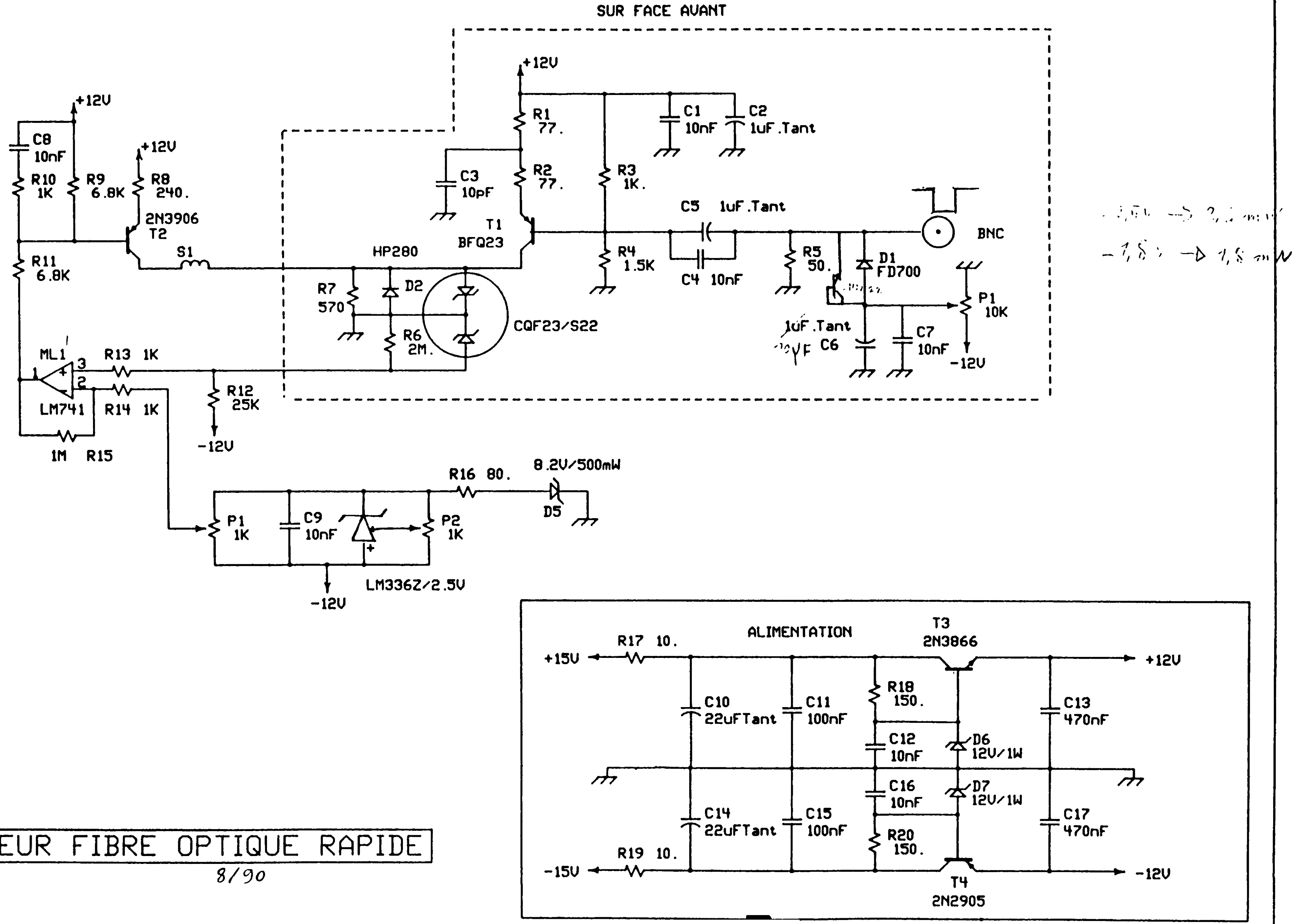
Vs = 450 V

tm = 7 ns



ANNEXE I

SYNOPTIQUE DE DECLENCHE



EMETTEUR FIBRE OPTIQUE RAPIDE

8/90

R:1/8W sauf specifie

L1:6 spires sur tube 4F . T1:2*1 spire dans section 4F e=3mm

L2:3 spires a air diametre 4mm . T2:2*1 spire dans section 4F e=3mm

L3:5spires sur tube 4F . T3:2*3 spires dans section 4F e=3mm

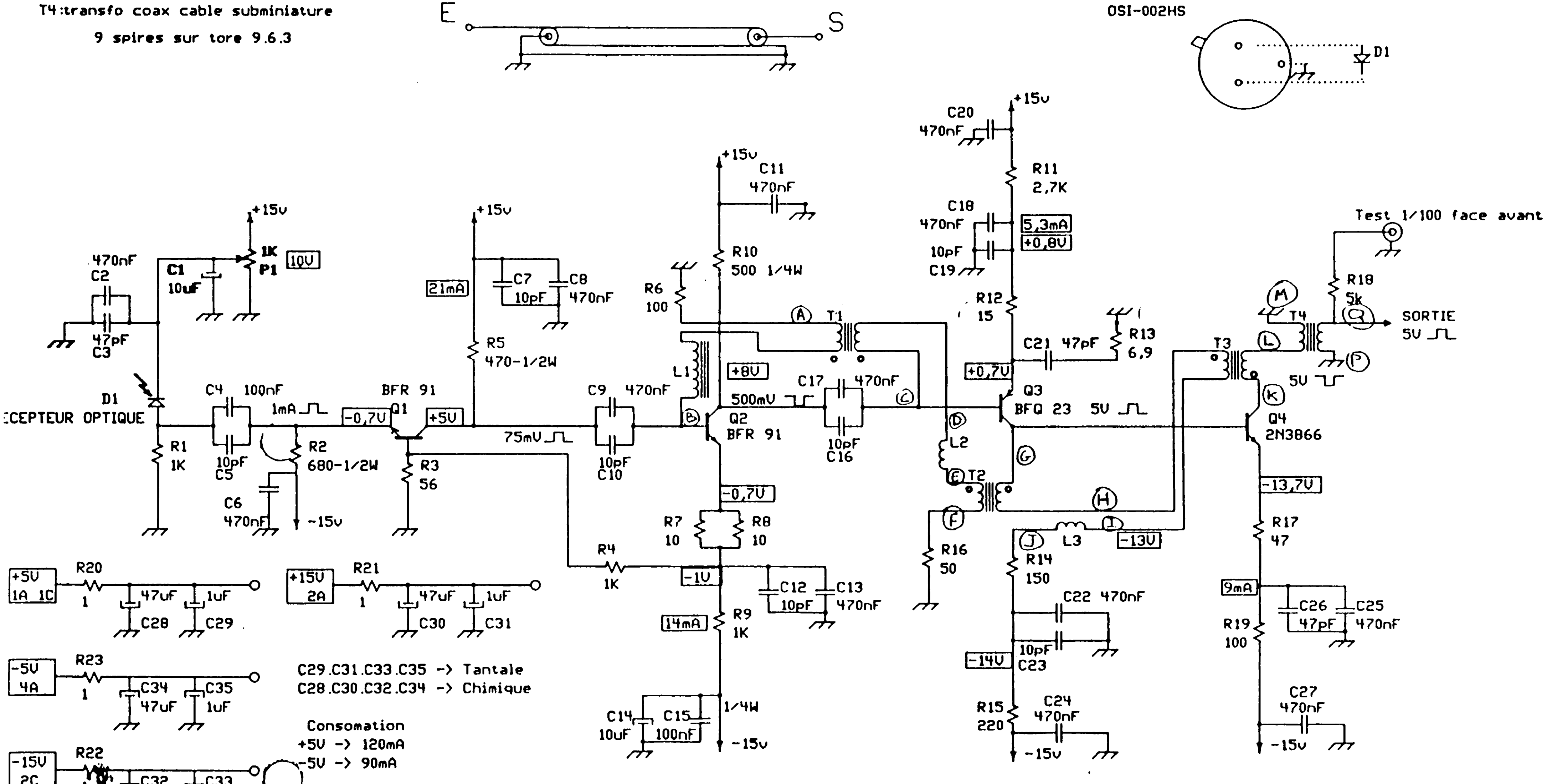
T4:transfo coax cable subminiature

9 spires sur tore 9.6.3

⚠ Pas de plan de masse sous les transistors

D1 vue de dessous

OSI-002HS

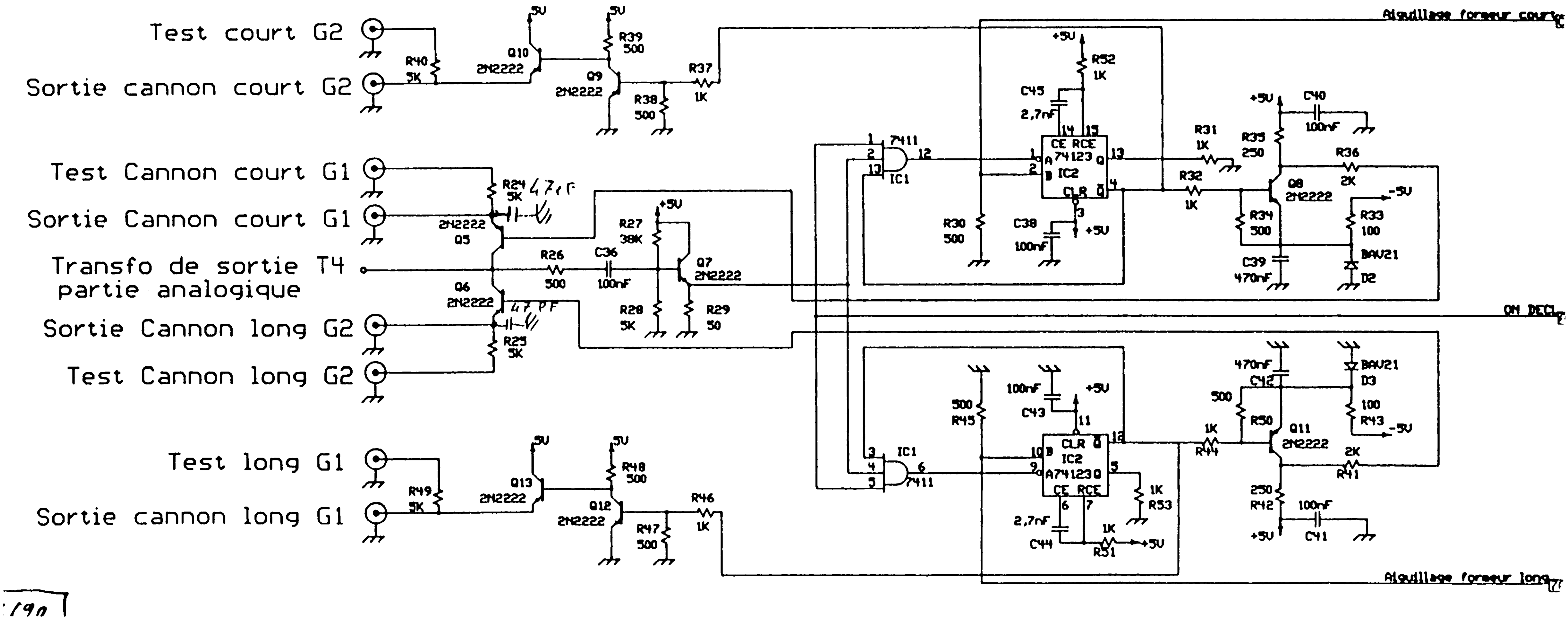


C29.C31.C33.C35 -> Tantale
C28.C30.C32.C34 -> Chimique

Consomation
+5V -> 120mA
-5V -> 90mA

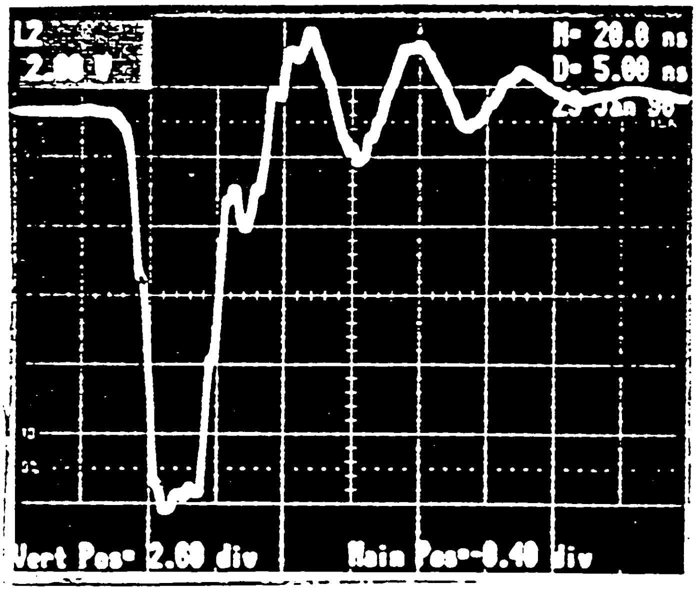
A 3.6.9.12.15.18.21.32.32C -> ⏚

3015	D.LAGRANGE	6/90



Test court G2
Sortie cannon court G2
Test Cannon court G1
Sortie Cannon court G1
Transfo de sortie T4
partie analogique
Sortie Cannon long G2
Test Cannon long G2
Test long G1
Sortie cannon long G1
Aiguillage formeur court
ON DECL
Aiguillage formeur long

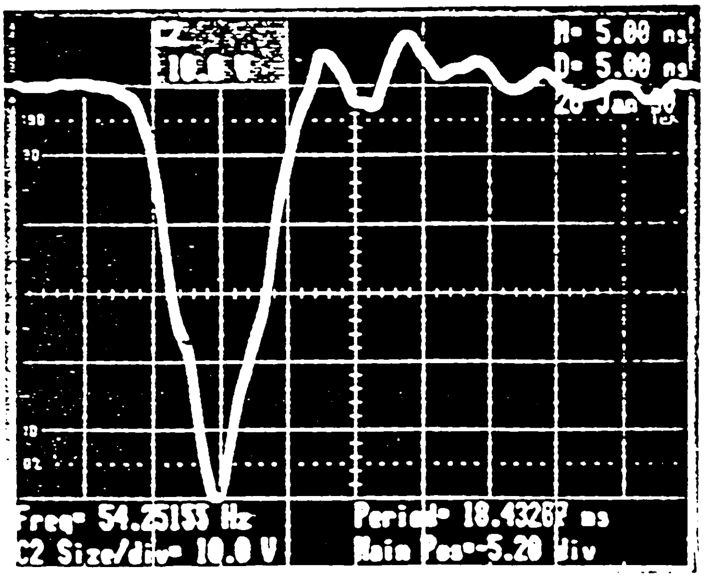
Long Pulse



HT = 5 kV

Vs = 900 V

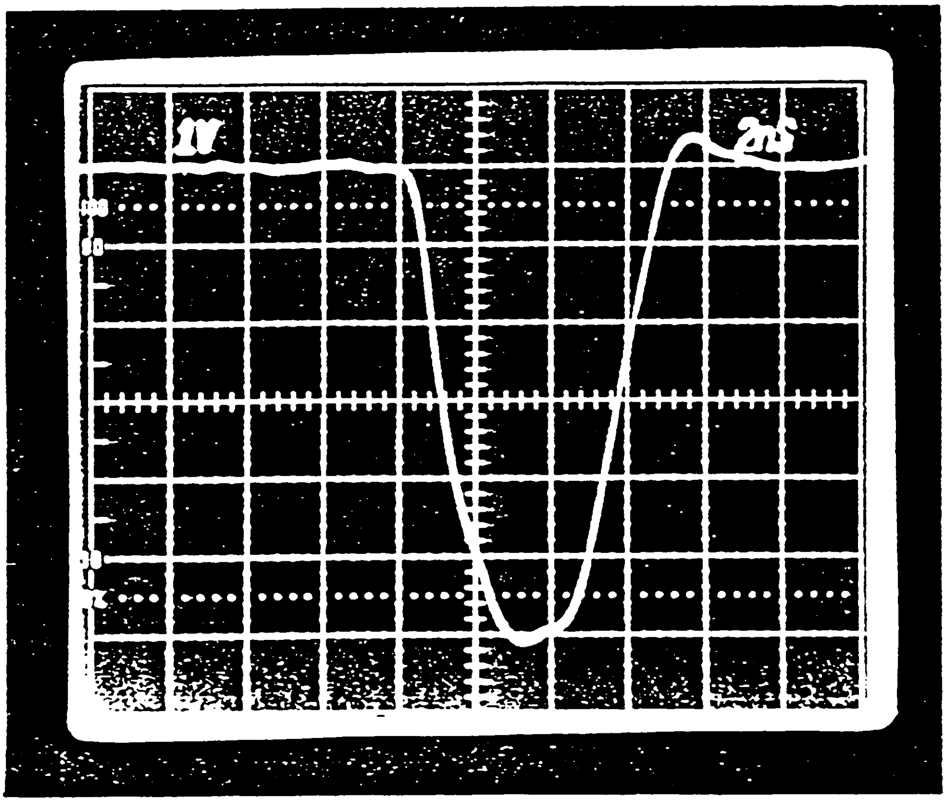
Short Pulse



HT = 5 kV

Vs = 4,8 kV

CURRENT PULSE
OUT OF THE
ELECTRON GUN



Ie = 24,4 A

$t_{1/2}$ = 4,6 ns

for :

Heating current = 17,5 A

Bias voltage = 1,4 kV

Thyratron voltage = 2 kV

High voltage = - 100 kV

SLAC MODULATOR OPERATION AND RELIABILITY IN THE SLC ERA (*)

A.R Donaldson, C.W Allen, J.R Ashton

Stanford Linear Accelerator Center

Stanford University, Stanford, CA 94309

7th October 1991, CERN Presentation by A.R Donaldson

* Work supported by the U.S. Dept. of Energy, Contract number DE-AC03-76SF00515

KLYSTRON NO-LOAD ENERGY GAINS

SECTOR	UNIT ENERGY (MeV)								SECTOR TOTAL (MeV)	RUNNING TOTAL (GeV)	KLYS COUNT
LI00	39	42	47	51	29				208	0.21	5
LI01	193	226	213	210	277				1118	1.33	10
LI02	0	230	232	222	237	229	231	234	1615	2.94	17
LI03	231	244	234	239	231	238	228	243	1890	4.83	25
LI04	230	247	240	224	269	292	237	259	1997	6.83	33
LI05	257	280	250	237	253	255	256	250	2039	8.87	41
LI06	253	235	218	236	248	227	247	199	1861	10.73	49
LI07	250	253	247	254	254	231	255	252	1997	12.72	57
LI08	253	224	248	250	248	236	242	217	1918	14.64	65
LI09	242	234	253	246	271	230	219	235	1929	16.57	73
LI10	173	191	240	235	262	259	241	244	1845	18.42	81
LI11	203	268	0	0	252	226	218	227			
	276								1668	20.09	88
LI12	210	253	217	221	212	233	252	211	1808	21.89	96
LI13	225	248	231	238	218	250	265	204	1879	23.77	104
LI14	242	237	237	244	226	227	242	205	1859	25.63	112
LI15	246	264	243	237	224	220	210	210	1854	27.49	120
LI16	223	212	181	235	240	223	229	190	1731	29.22	128
LI17	236	236	236	220	198	223	214	232	1795	31.01	136
LI18	242	261	214	221	265	255	249	228	1935	32.95	144
LI19	252	228	248	225	212	244	253		1660	34.61	151
LI20	250	223	249	242	272	230	204		1670	36.28	158
LI21	206	215	234	218	193	235	209	221	1731	38.01	166
LI22	221	262	234	206	228	249	203	190	1794	39.80	174
LI23	230	210	240	204	241	229	245	322	1921	41.73	182
LI24	254	250	245	229	264	223	256	272	1994	43.72	190
LI25	163	142	150	164	159	148	164	229	1320	45.04	198
LI26	138	152	146	158	165	115	168	167	1210	46.25	206
LI27	182	155	142	133	143	159	167	157	1239	47.49	214
LI28	112	156	175	167	153	226	164	366	1519	49.01	222
LI29	129	165	154	139	121	152	132	163	1153	50.16	230
LI30	134	143	110	150	140	143	151	132	1102	51.26	238

NPI MODE
Nuclear Physics Injector & Five sectors of Acceleration

TOTAL ENERGY = 51.26 GeV

30-SEP-91 16:54:25

SLAC Accelerator Energy Display #1 ARD

LINAC 5045 KLYSTRON DEPLOYMENT

TOTAL QUANTITY 243

LOCATION	NUMBER OF KLYSTRONS	ENERGY	
INJECTOR STATIONS	5	200	Mev
SECTOR 1 STATIONS	5	1.15	Gev
N & S DAMPING RINGS			
IN/OUT RING ENERGY		1.15	Gev
*NRTL COMPRESSOR	1		
*SLTR COMPRESSOR	1		
*SRTL COMPRESSOR	1		
SECTOR 2 STATIONS	7	^2.80	Gev
SECTOR 3 TO 18	127	^32.77	Gev
SECTOR 19	7	^34.43	Gev
POSITRON SOURCE			
e^- ON POSITRON TARGET		30.5-31.5	Gev
e^+ ACCELERATED	2	200	Mev
SECTOR 20	7	^36.01	Gev
SECTOR 21 TO 30	80	^54.96	Gev
INTO ARCS		47	Gev
INTO DETECTOR		46	Gev
TOTAL COUNT	243		

^ INDICATES MAX POSSIBLE ENERGY (PHASE ALIGNED) AND DOES NOT INCLUDE LOSSES DUE TO:

15 DEGREE OFFSET BNS DAMPING
OVERHEAD FOR ENERGY FEEDBACK LOOPS
MODULATORS DOWN FOR MAINTENANCE
KLYSTRONS DOWN FOR MAINTENANCE

* STATIONS COMPRESS THE BEAM AND ADD NO ENERGY GAIN TO THE BEAM

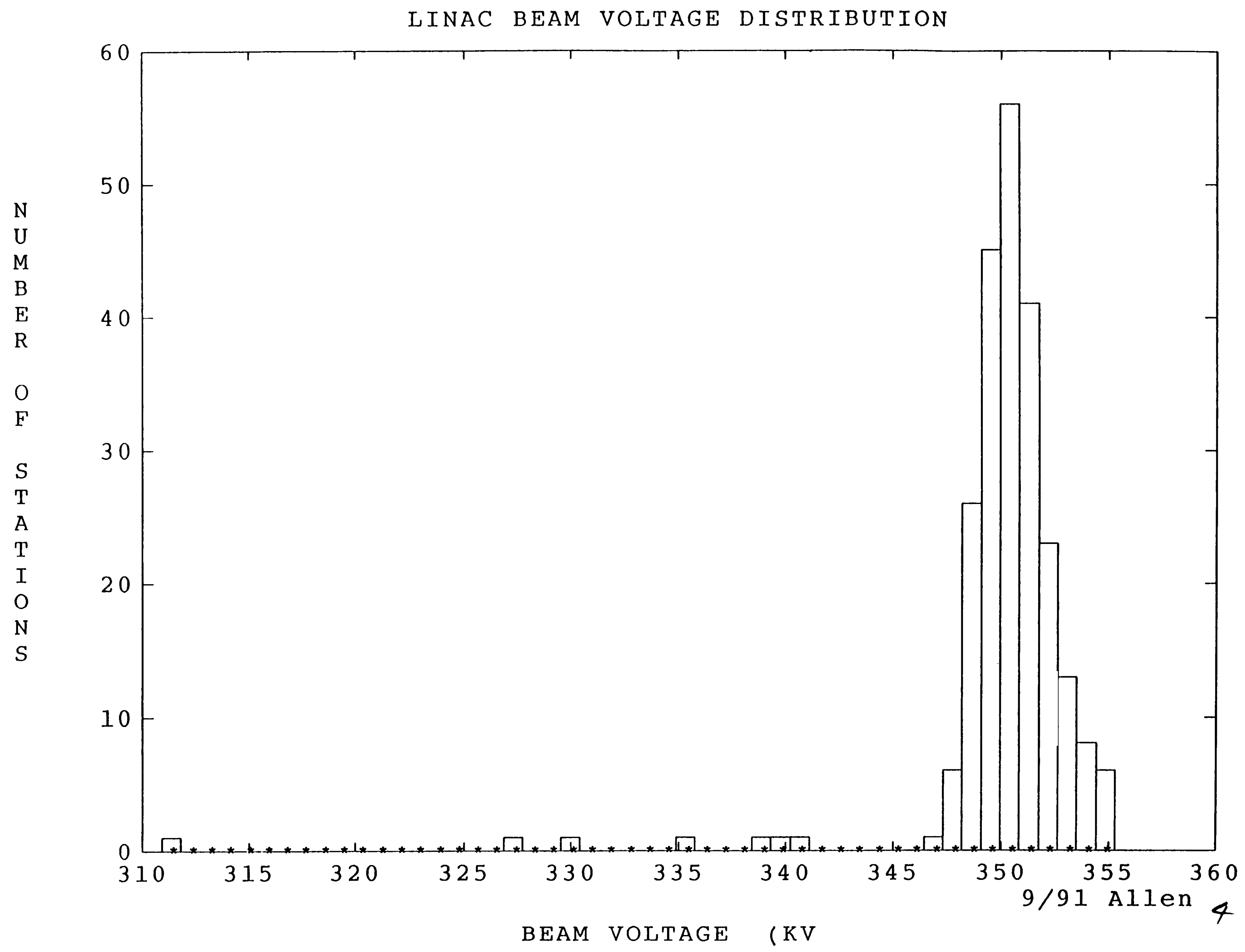
#2 ARD

5045 KLYSTRON DATA *LT~ 36→40kHr.*		
Klystron Frequency	2856	MHz
Klystron Beam Voltage	350	kV
Klystron Beam Current	414	A
Microperveance	2	
Peak Power Out	67	MW
Peak Input Power	500	W
Power Gain	50	dB (minimum)
RF Pulse Width	3.5	μs

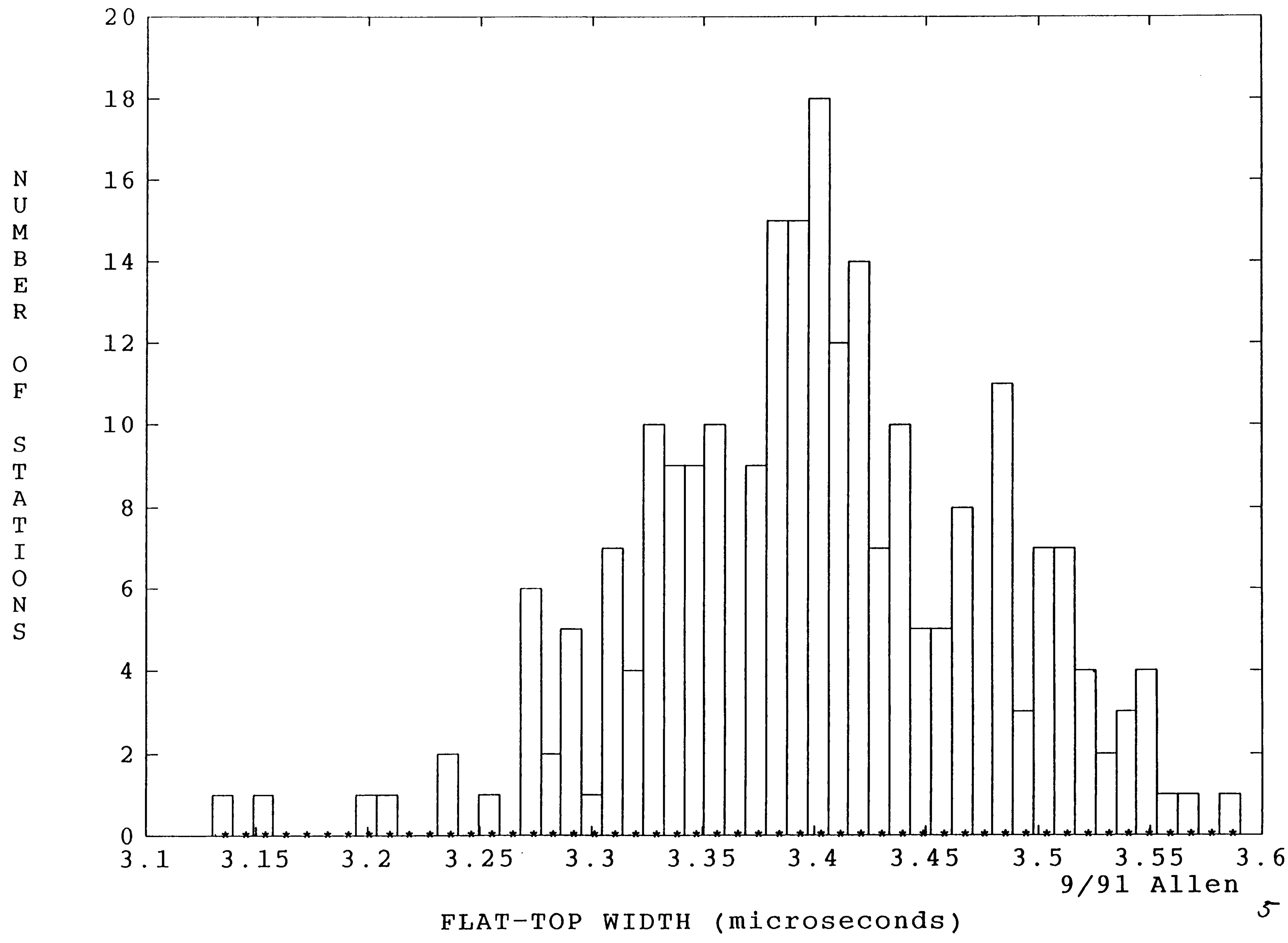
Modulator klystrons (243) operation ~ 6x10⁶ Hrs.

150 MW MODULATOR DATA		
Repetition Rate	120	Hz (maximum)
Thyratron Anode Voltage	46.7	kV
Thyratron Anode Current	6225	A
Pulse Transformer Ratio	1:15	
Voltage Pulse Width	5.0	μs
Pulse Rise Time	0.8	μs
Pulse Fall Time	1.8	μs
Pulse Flattop Ripple	± 0.25	%
Nominal PFN Impedance	4	Ω
Total PFN Capacitance	0.70	μF
Charging Inductance	2.4	H
PFN Charging Time	4.1	ms
Peak Charging Current	12.7	A

#3ARD

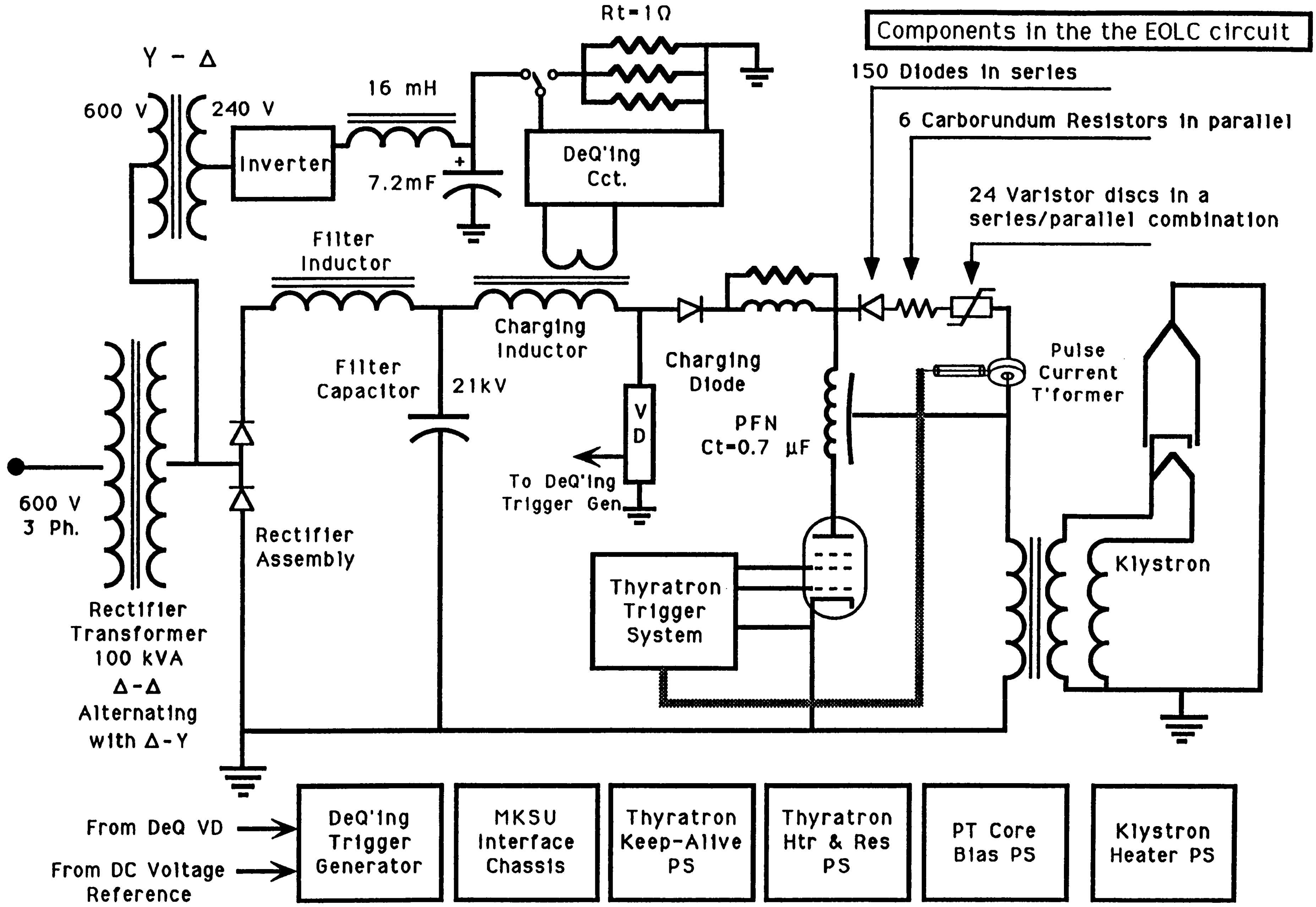

LINAC BEAM VOLTAGE DISTRIBUTION
NUMBER OF STATIONS
60
50
40
30
20
10
0
310
315
320
325
330
335
340
345
350
355
360
9/91 Allen
BEAM VOLTAGE (KV
4

LINAC BEAM VOLTAGE FLAT-TOP DISTRIBUTION



5

SLAC MODULATOR DIAGRAM with Energy Recovery DeQ'ing



A.R. Donaldson SLAC PCD
September 28, 1991

	0	1	S	N	2	3	4	5	6	7	8	9	10	11	12	13	14
S																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	

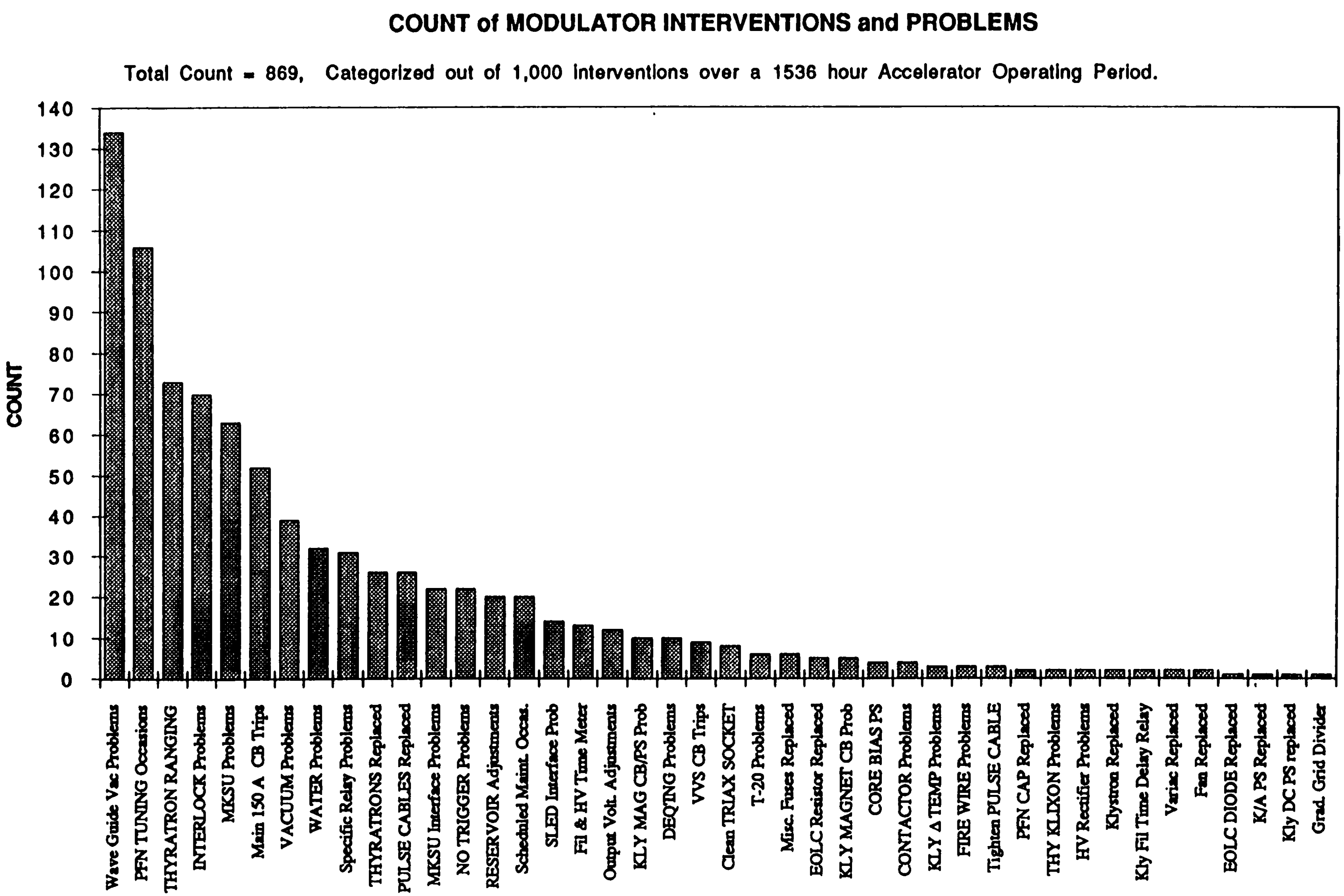
Accelerator Modulator Status Display
with only 5 sectors of accelerator
in operation for Fixed Tgt Experiments

	15	16	17	18	19	20	E+	21	22	23	24	25	26	27	28	29	30
S												—	—	—	TRG	—	—
1												$\overline{PHM}$	—	ACC	ACC	—	—
2												—	—	ACC	ACC	ACC	—
3												ACC	—	ACC	ACC	—	PHM
4												—	—	ACC	ACC	—	$\overline{PHM}$
5												—	—	$\overline{AMM}$	ACC	—	MNT
6												—	—	ACC	MNT	—	—
7												—	—	ACC	ACC	—	ACC
8												—	—	ACC	ACC	—	PHJ

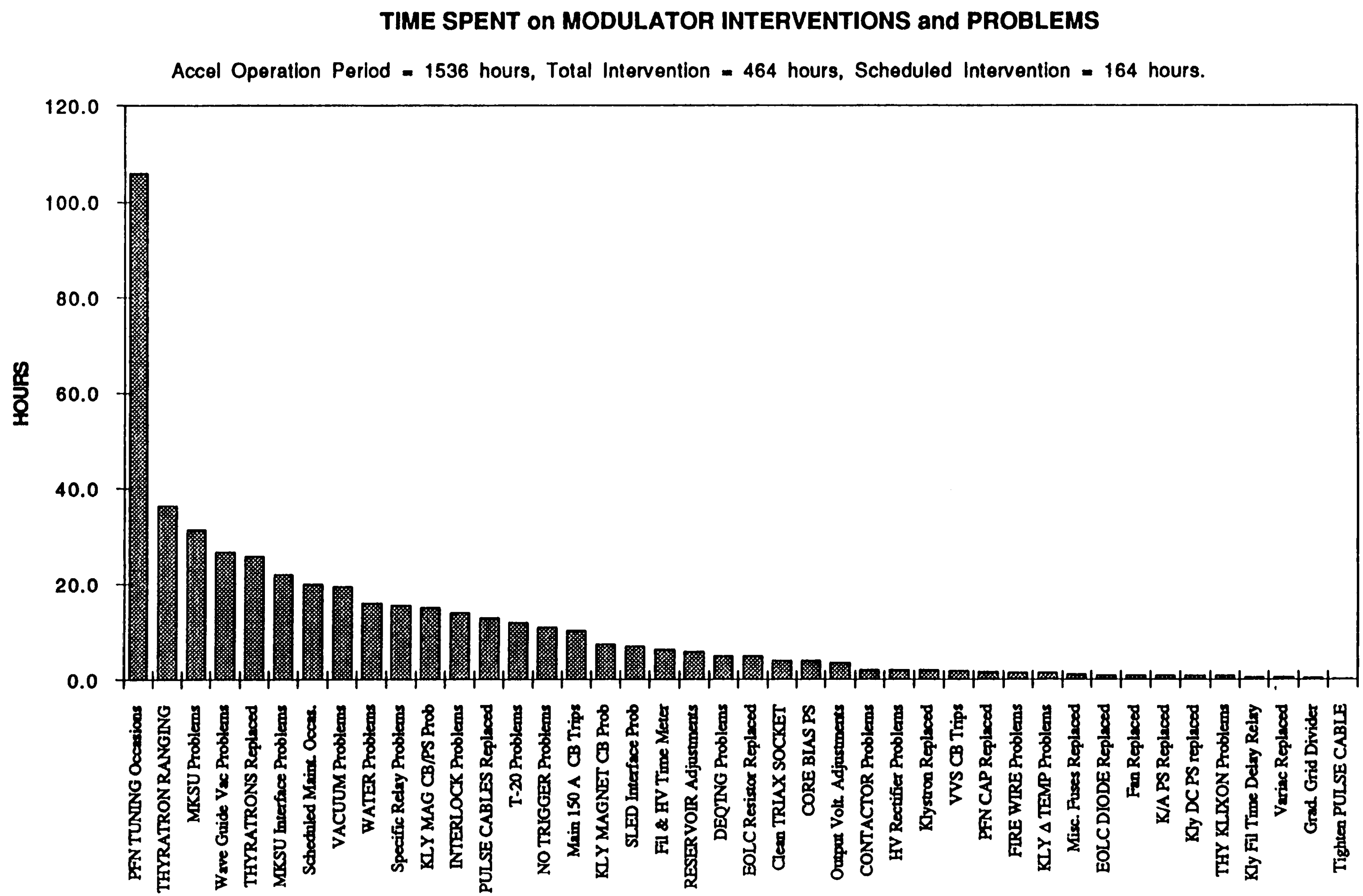
—	ACC	MNT	☐	OFF	⌈W⌉	W	ANA	☐
ON A BEAM	STANDBY	MAIN-TENANCE	HW/FAULT STATUS	OFF-LINE	RECENT FAULT	OLD FAULT	MISC/DB STATUS	NO RESPONSE

KLYSTRON STATUS DISPLAY

30-SEP-91 16:36:49

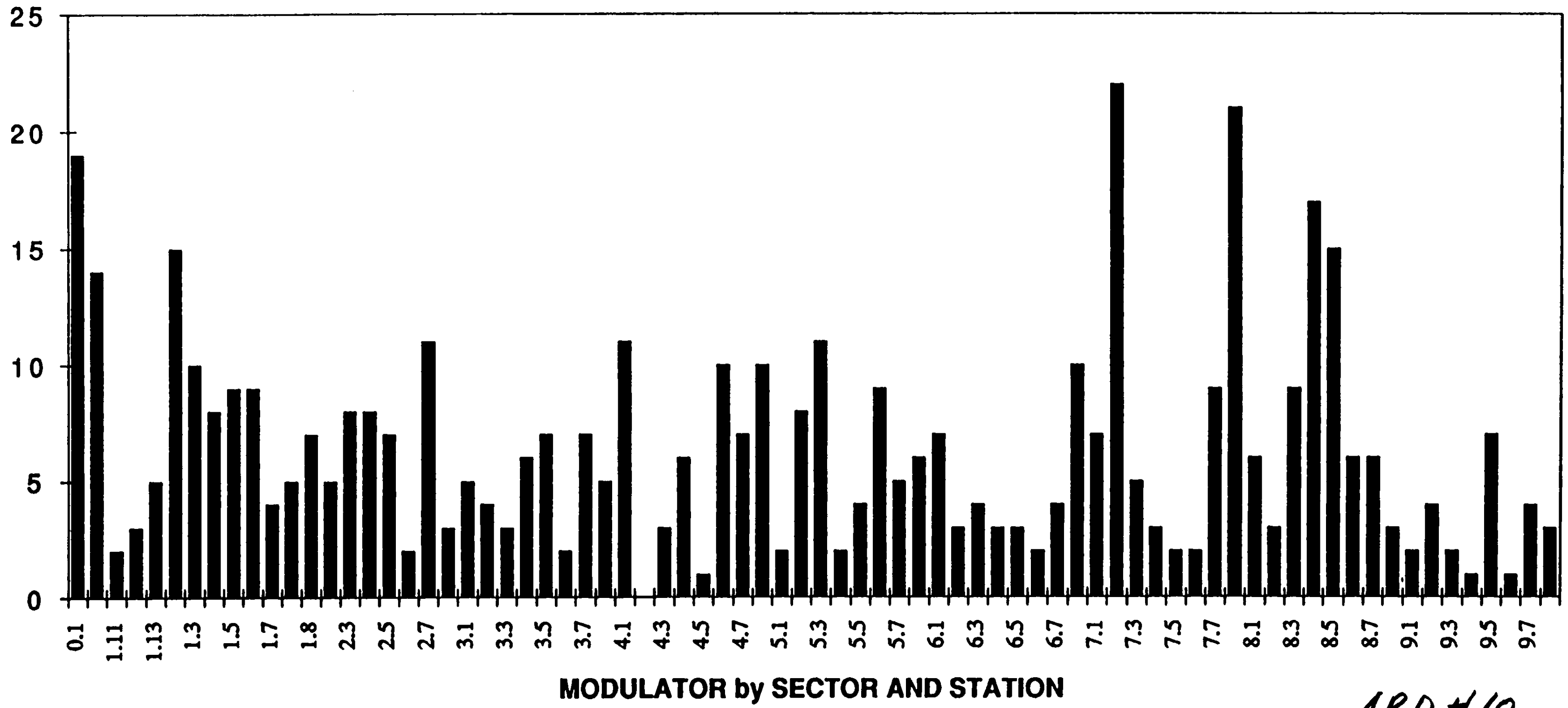

COUNT of MODULATOR INTERVENTIONS and PROBLEMS
Total Count = 869, Categorized out of 1,000 Interventions over a 1536 hour Accelerator Operating Period.
COUNT
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Wave Guide Vac Problems
PFN TUNING Occasions
THYRATRON RANGING
INTERLOCK Problems
MKSU Problems
Main 150 A CB Trips
VACUUM Problems
WATER Problems
Specific Relay Problems
THYRATRONS Replaced
PULSE CABLES Replaced
MKSU Interface Problems
NO TRIGGER Problems
RESERVOIR Adjustments
Scheduled Maint. Occas.
SLED Interface Prob
Fil & HV Time Meter
Output Volt. Adjustments
KLY MAG CB/PS Prob
DEQING Problems
VVS CB Trips
Clean TRIAX SOCKET
T-20 Problems
Misc. Fuses Replaced
EOLC Resistor Replaced
KLY MAGNET CB Prob
CORE BIAS PS
CONTACTOR Problems
KLY Δ TEMP Problems
FIRE WIRE Problems
Tighten PULSE CABLE
PFN CAP Replaced
THY KLIXON Problems
HV Rectifier Problems
Klystron Replaced
Kly Fil Time Delay Relay
Variac Replaced
Fan Replaced
EOLC DIODE Replaced
K/A PS Replaced
Kly DC PS replaced
Grad. Grid Divider

ARD #8


TIME SPENT on MODULATOR INTERVENTIONS and PROBLEMS
Accel Operation Period = 1536 hours, Total Intervention = 464 hours, Scheduled Intervention = 164 hours.
HOURS
120.0
100.0
80.0
60.0
40.0
20.0
0.0
PFN TUNING Occasions
THYRATRON RANGING
MKSU Problems
Wave Guide Vac Problems
THYRATRONS Replaced
MKSU Interface Problems
Scheduled Maint. Occas.
VACUUM Problems
WATER Problems
Specific Relay Problems
KLY MAG CB/PS Prob
INTERLOCK Problems
PULSE CABLES Replaced
T-20 Problems
NO TRIGGER Problems
Main 150 A CB Trips
KLY MAGNET CB Prob
SLED Interface Prob
Fil & HV Time Meter
RESERVOIR Adjustments
DEQING Problems
EOLC Resistor Replaced
Clean TRIAX SOCKET
CORE BIAS PS
Output Volt. Adjustments
CONTACTOR Problems
HV Rectifier Problems
Klystron Replaced
VVS CB Trips
PFN CAP Replaced
FIRE WIRE Problems
KLY Δ TEMP Problems
Misc. Fuses Replaced
EOLC DIODE Replaced
Fan Replaced
K/A PS Replaced
Kly DC PS replaced
THY KLIXON Problems
Kly Fil Time Delay Relay
Variac Replaced
Grad. Grid Divider
Tighten PULSE CABLE

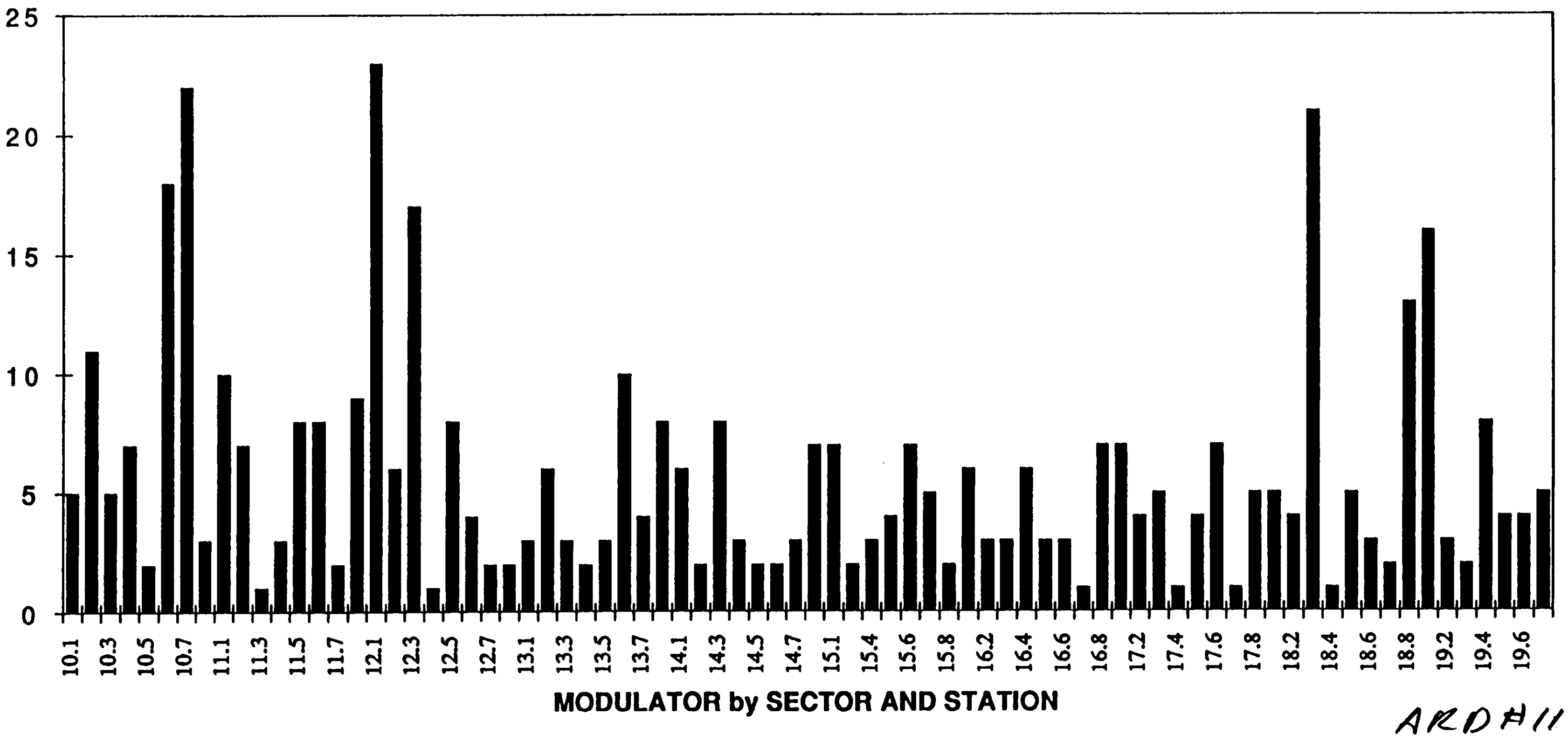
#9; ARD

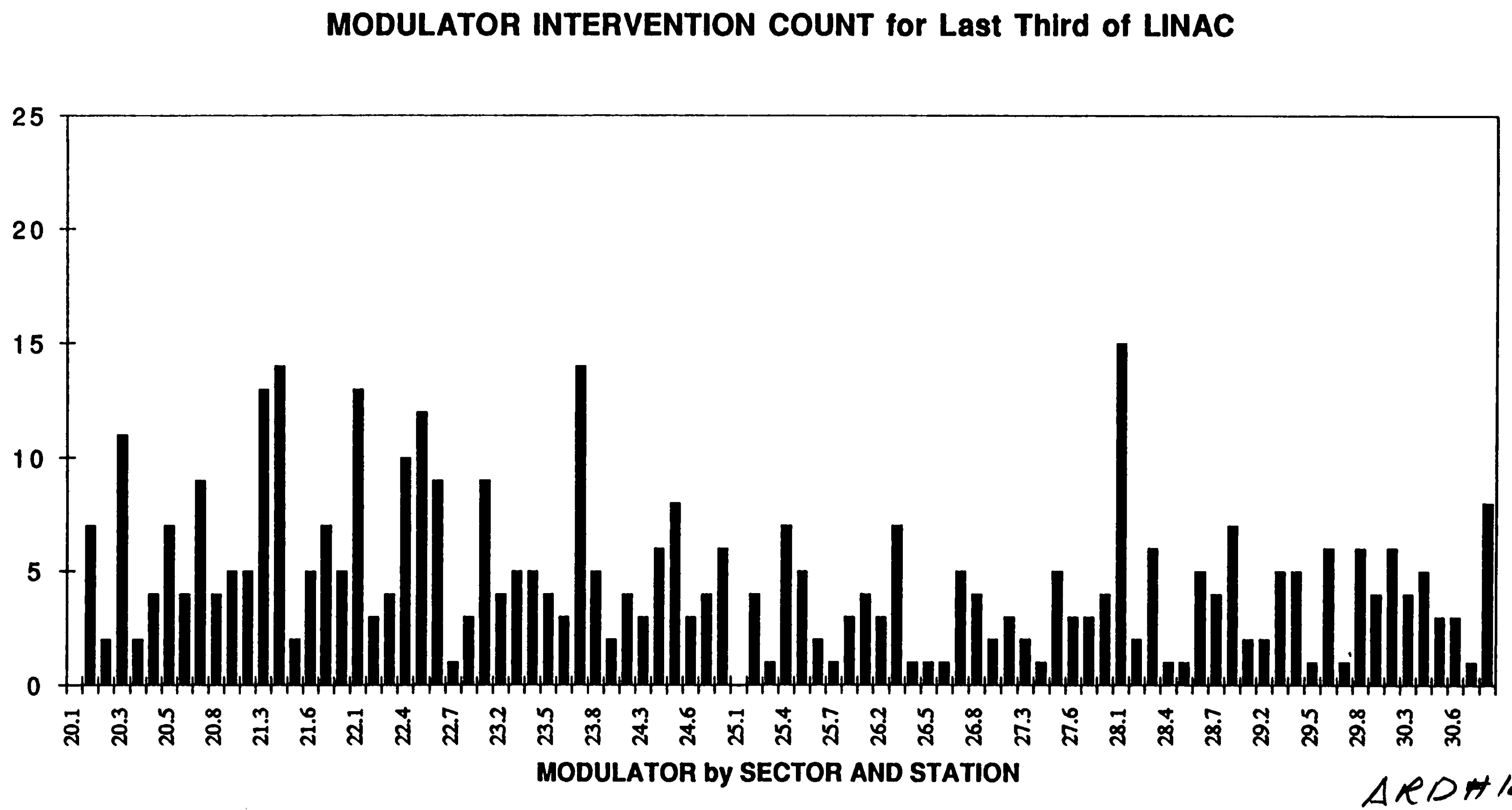
MODULATOR INTERVENTION COUNT for First Third of LINAC



ARD #10

MODULATOR INTERVENTION COUNT for Middle Third of LINAC




MODULATOR INTERVENTION COUNT for Last Third of LINAC
25
20
15
10
5
0
20.1
20.3
20.5
20.8
21.3
21.6
22.1
22.4
22.7
23.2
23.5
23.8
24.3
24.6
25.1
25.4
25.7
26.2
26.5
26.8
27.3
27.6
28.1
28.4
28.7
29.2
29.5
29.8
30.3
30.6
MODULATOR by SECTOR AND STATION

ARD#12

THYRATRON DATA

Repetition Rate	120	Hz (maximum)
Thyratron Anode Voltage	46.7	kV
Thyratron Anode Current	6225	A
Voltage Pulse Width	5.0	μs
Pulse Rise Time	0.8	μs
Pulse Fall Time	1.8	μs

THYRATRON LIFETIME DATA

<u>from the beginning</u>

Based on thyratron retesting & reuse.

	AVE	MAX
Present Overall Average	21 kHr	
Wagner CH1191	63 kHr	94 kHr
ITT F-143	45 kHr	56 kHr
ITT F-241	16 kHr	25 kHr
Omniwave 1002	5 kHr	34 kHr

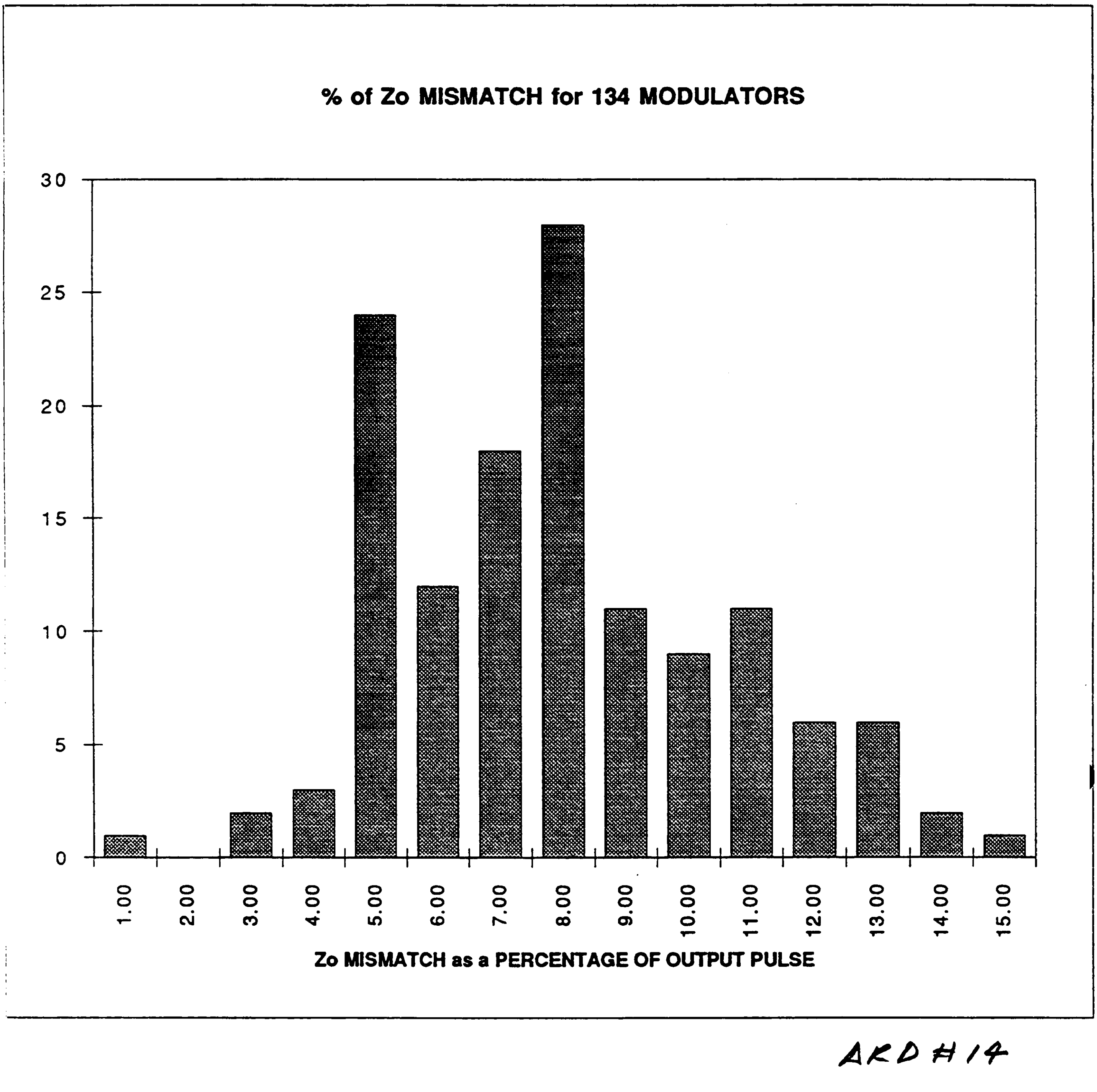
THYRATRON LIFETIME DATA

for the 90 and 91 SLC Runs

Based on thyratron replacement rate.

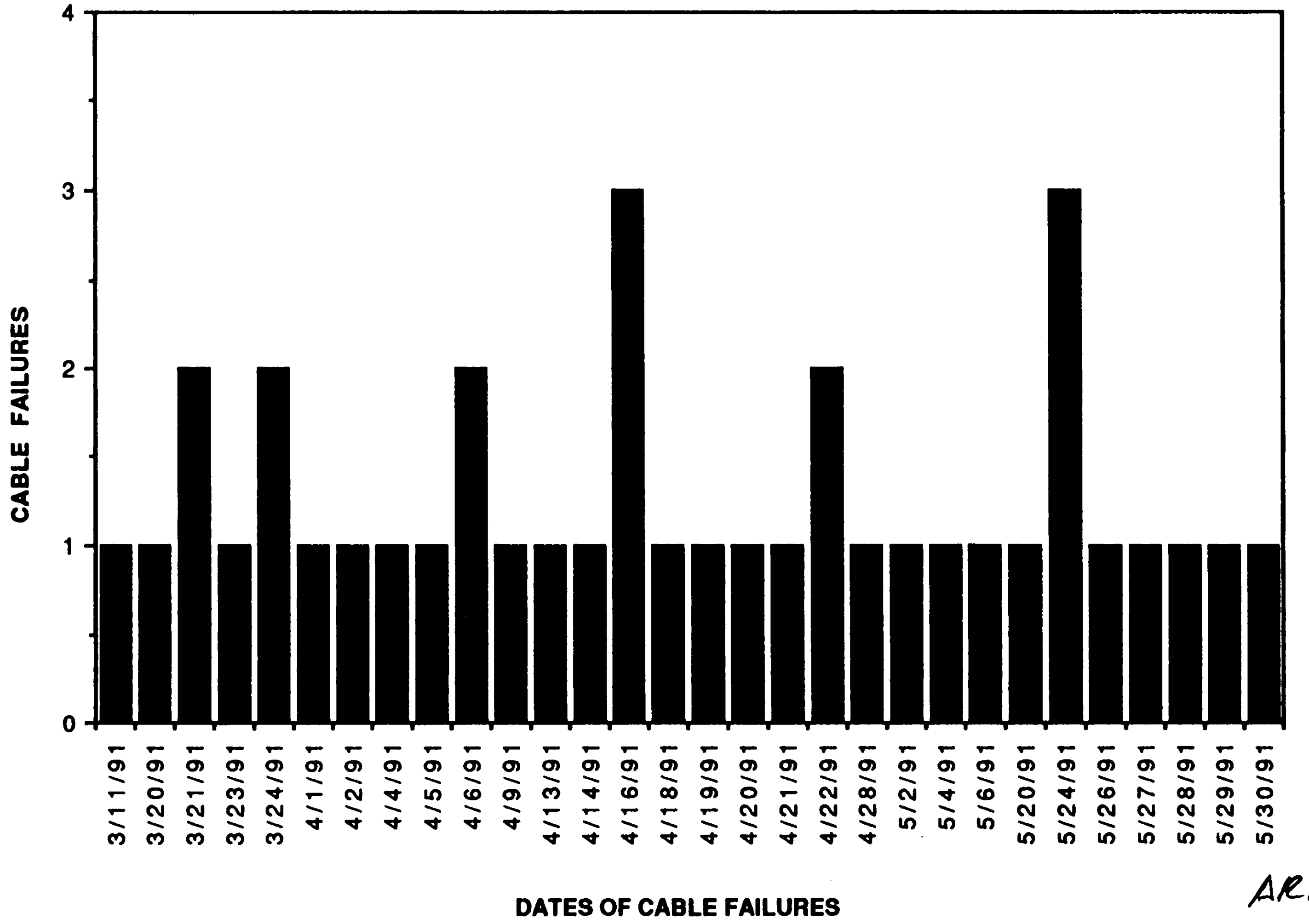
Overall Average for 91 Run	16 kHr	120 Hz for ≈ 4 weeks 60 Hz for 20 weeks
Overall Average for 90 Run	15 kHr	30 weeks
Average for 90 Run at 120 Hz	13 kHr	20 weeks
Average for 90 Run at 60 Hz	22 kHr	10 weeks

AR D #13


% of Zo MISMATCH for 134 MODULATORS
30
25
20
15
10
5
0
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
Zo MISMATCH as a PERCENTAGE OF OUTPUT PULSE

AKD #14

CABLE FAILURES BY DATE



ARD#15

PULSE CABLE (TRIAX) LIFETIME

During the first nine weeks of the 91 SLC Run 26 cables were replaced.
At this period in the run there were a few weeks of operation at 120 Hz.
The period involved 1500 hours with 243 cables in use
for a total of 364,500 cable-hours, the replacement rate was

364,500 cable-hours/26 cables ≈ 14 kHr

When the next month of the run is included which was at only 60 Hz
with 33 total cable failures
for a 2100 Hr period of operation, the replacement rate inproved to

515160 cable-hours/33 cables ≈15.6 kHr

The majority of the failures occur at the PFN end of the cable
not at the triaxial socket or PT end.

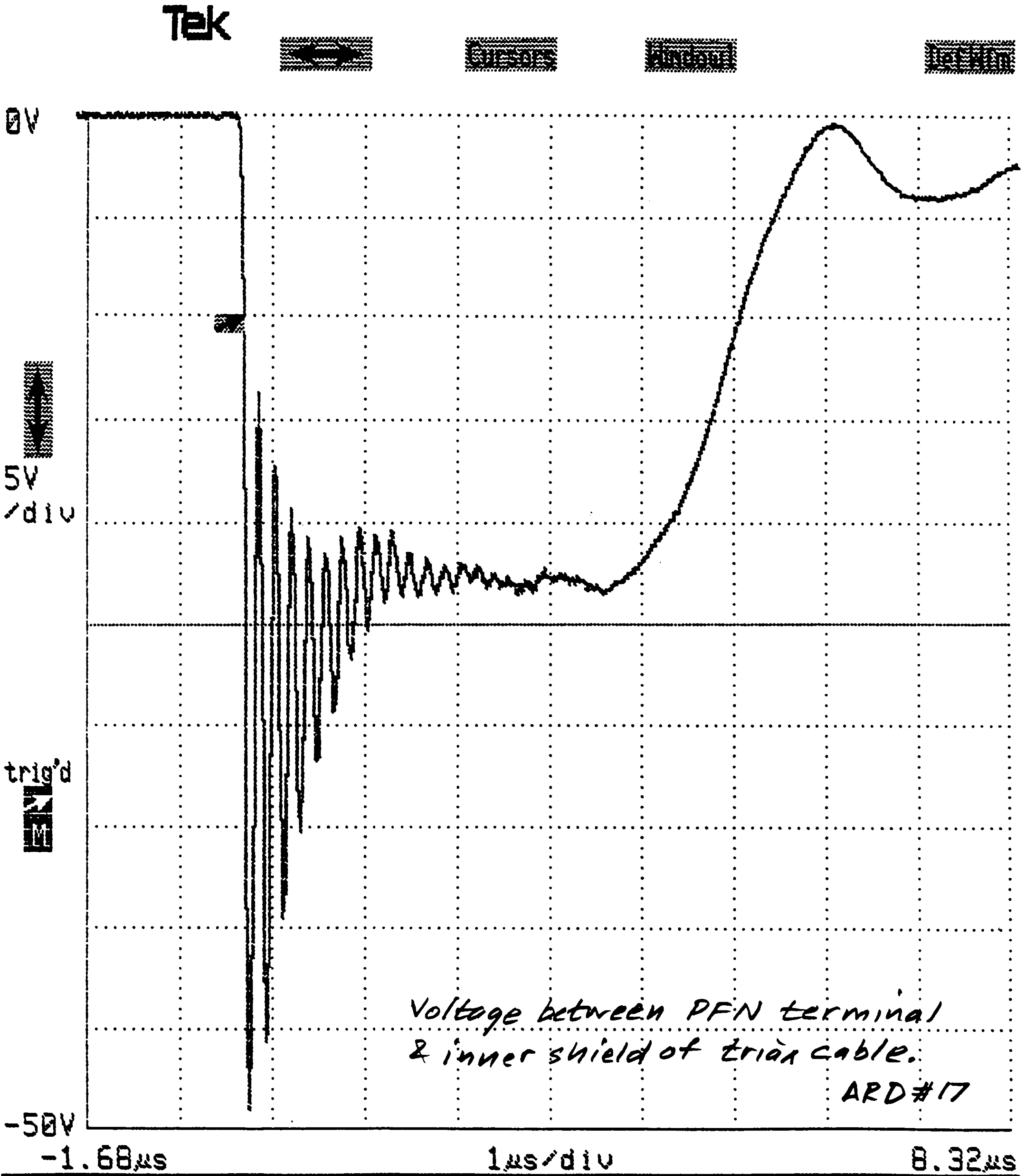
Possible reasons for the cable failures

1) Higher average current, the manufacturers claim
2) Higher peak voltage than the dielectric can withstand
3) Cable dielectric deformation,
   a result of the technique used for inner shield termination
4) A combination of the above

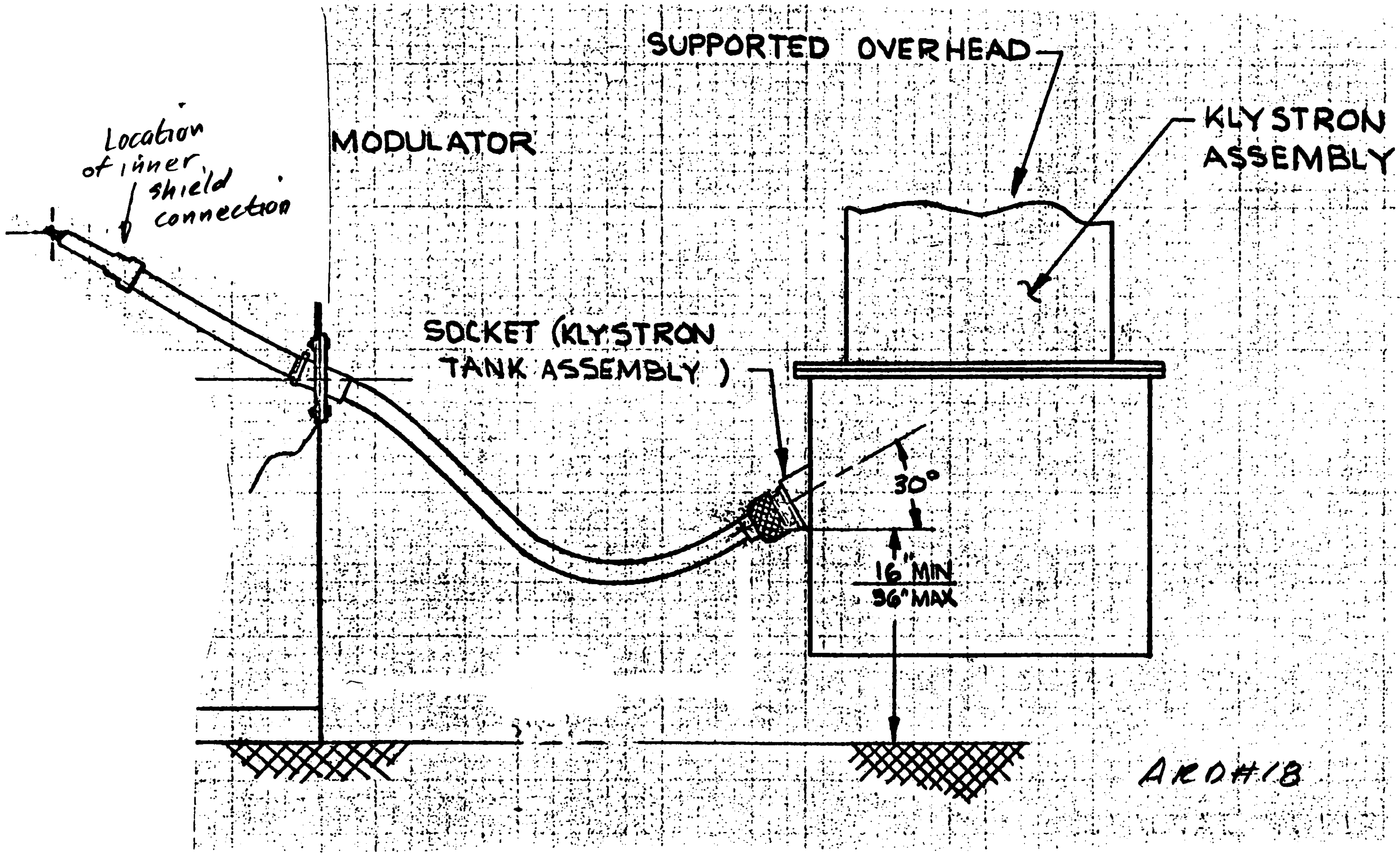
ARD #16

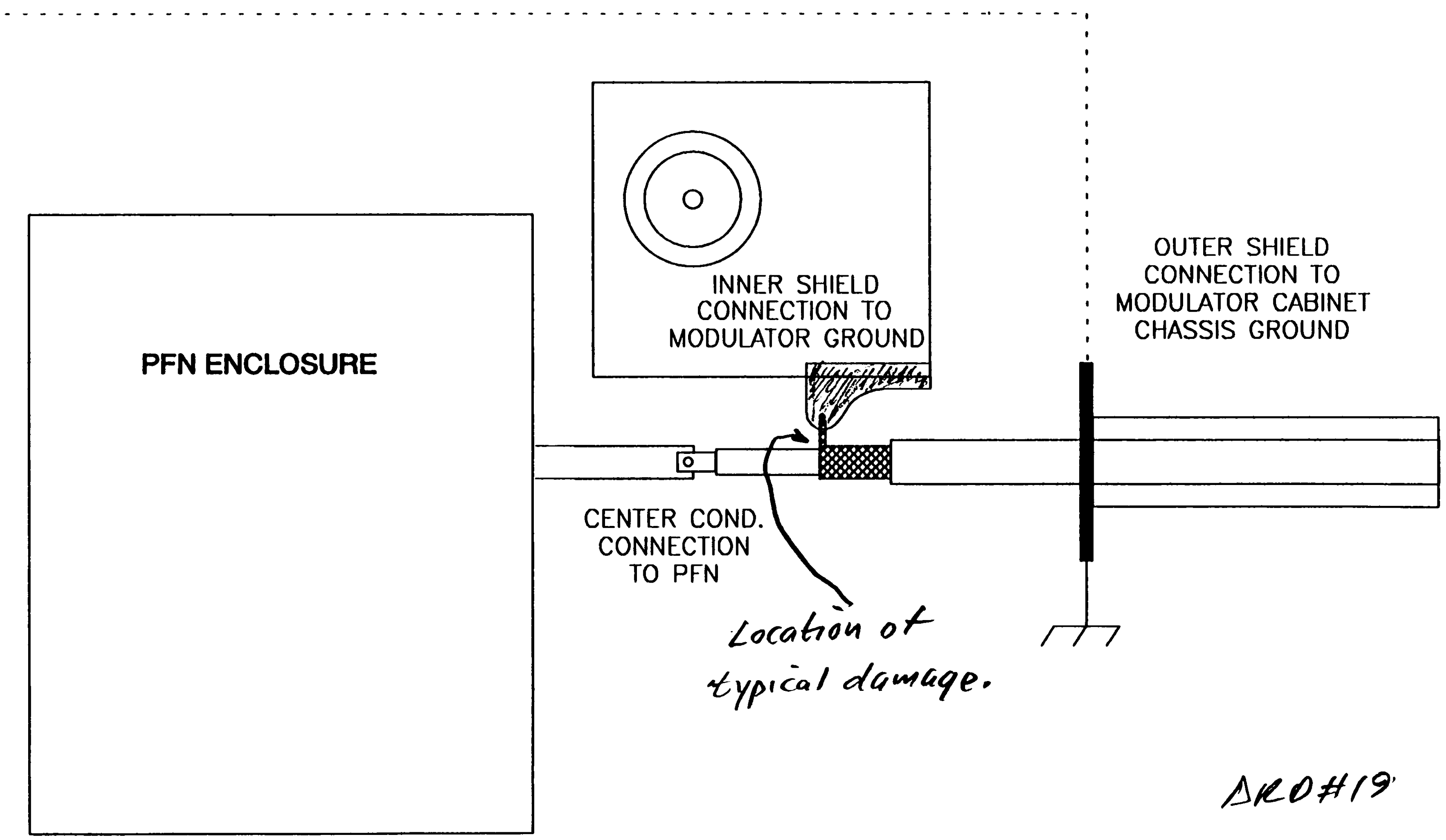
11402 DIGITIZING OSCILLOSCOPE
date: 1-OCT-91 time: 14:05:59

{exp:3.8,dig:3.91,dsy:3.3}
Instrument ID# B021366

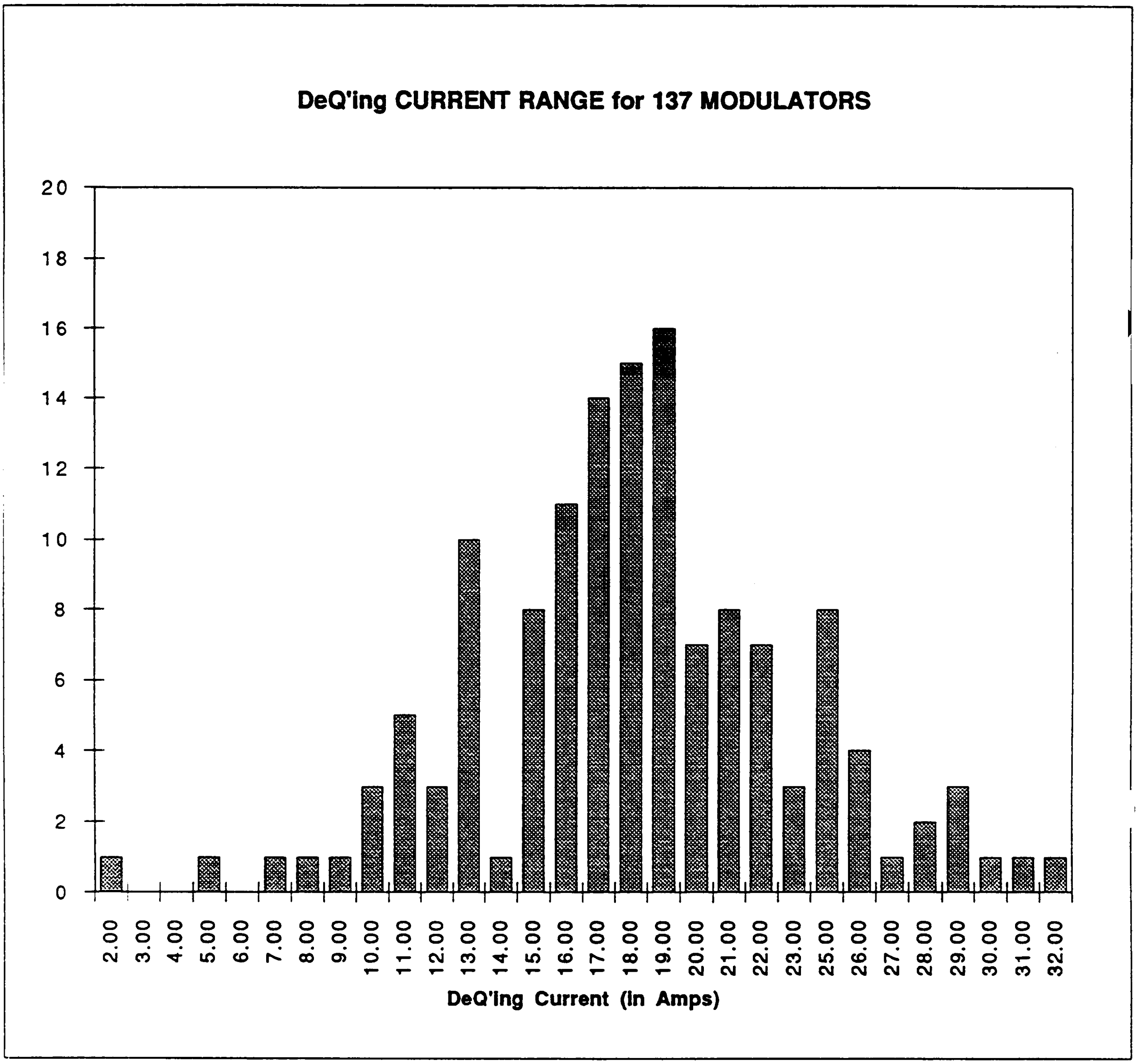


Trigger Select	Source Desc	Level	Time Holdoff	Trig Level: M
				-10V
Main	C1	-10V	490ns	Time Holdoff: M
				490ns
Mode	Coupling	Slope	Window Holdoff Md	Remove Wfm 1	Main Trig
Auto	DC	-	HO: none Trig: Main	C1 Main	


SUPPORTED OVERHEAD
KLYSTRON ASSEMBLY
MODULATOR
Location of inner shield connection
SOCKET (KLYSTRON TANK ASSEMBLY)
30°
16" MIN
96" MAX
ARD#18

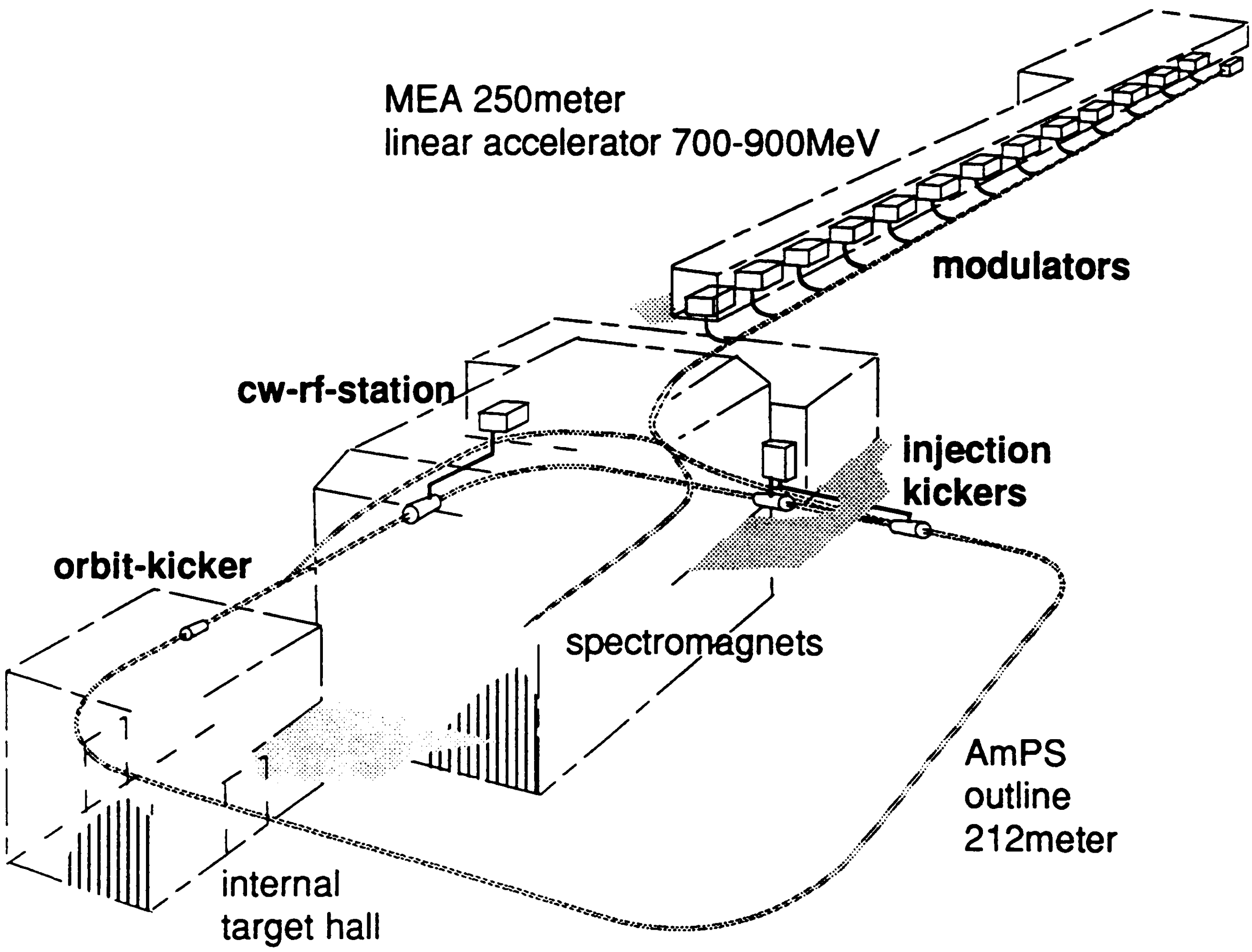

PFN ENCLOSURE
INNER SHIELD CONNECTION TO MODULATOR GROUND
OUTER SHIELD CONNECTION TO MODULATOR CABINET CHASSIS GROUND
CENTER COND. CONNECTION TO PFN
Location of typical damage.

ARO#19


DeQ'ing CURRENT RANGE for 137 MODULATORS
20
18
16
14
12
10
8
6
4
2
0
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
25.00
26.00
27.00
28.00
29.00
30.00
31.00
32.00
DeQ'ing Current (In Amps)

ARD #20

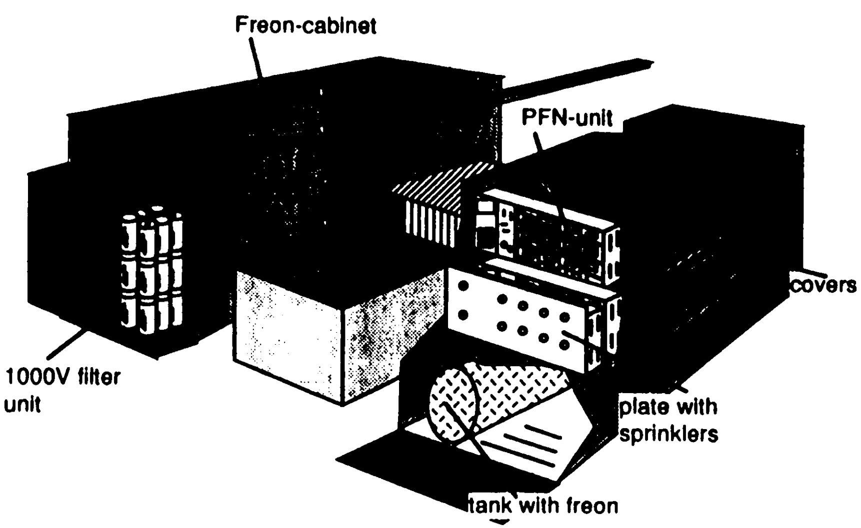
Pulse Power at the NIKHEF-site



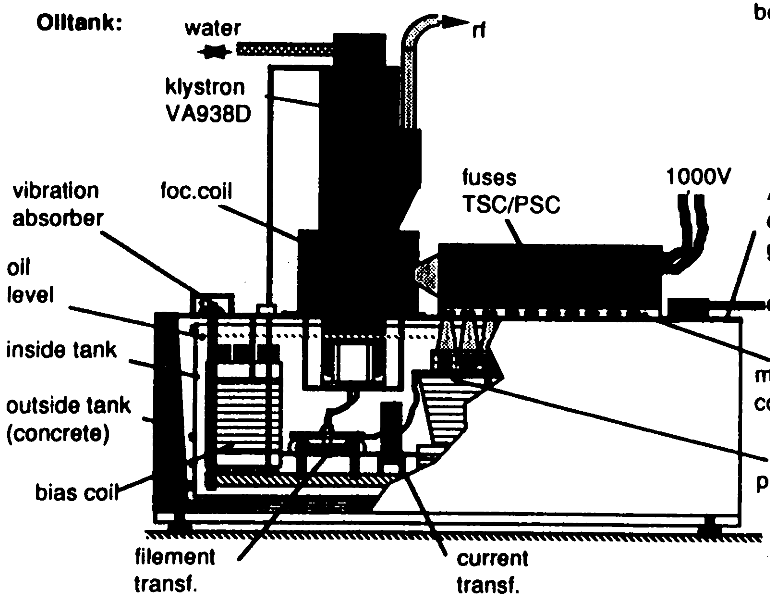
P.J.T. Bruinsma
E. Heine
7 October 1991

NIKHEF

Modulator physical lay-out

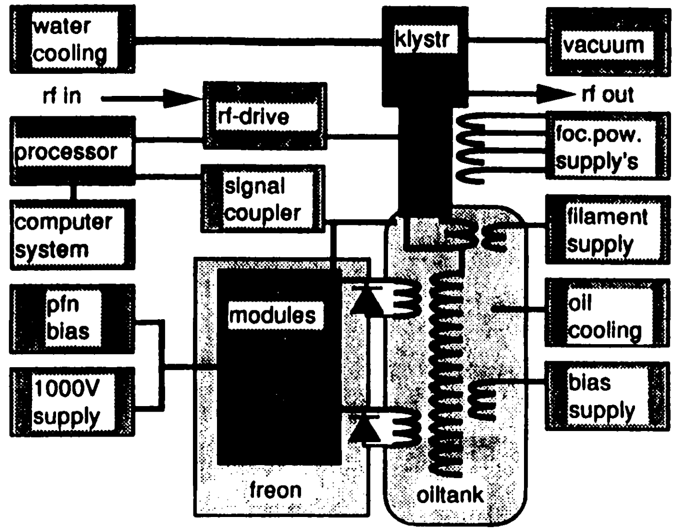


Oiltank:

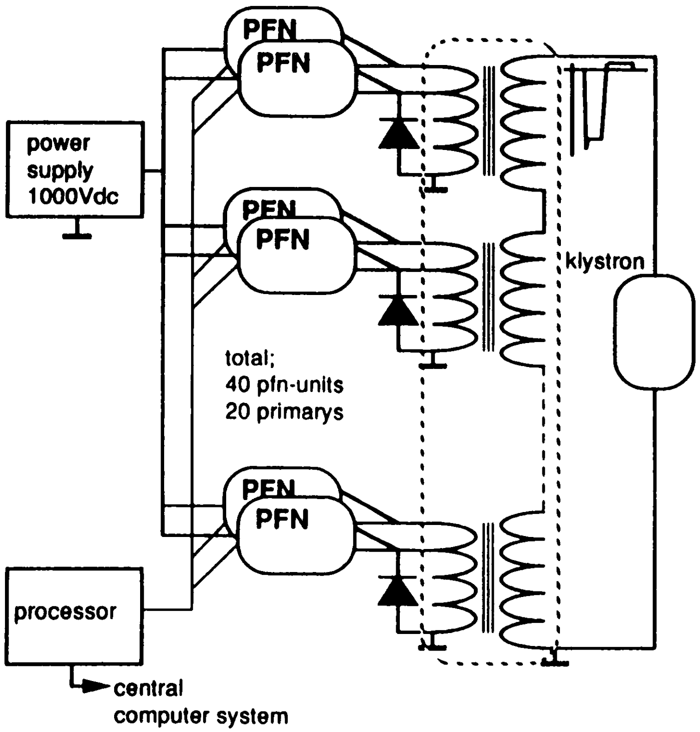


benefits;
fire-proof
noise reduction
long oil life

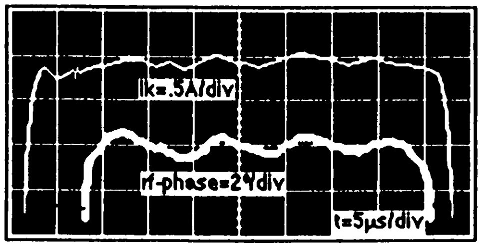
Modulator infra-structure



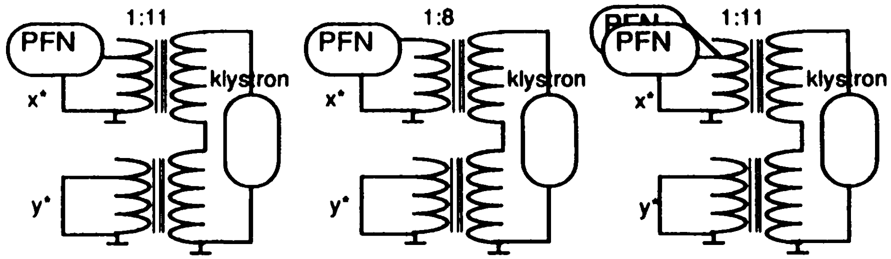
MEA modulator



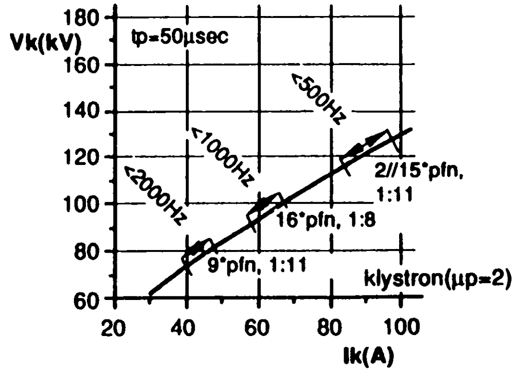
klystron pulse on 100kV-60A level



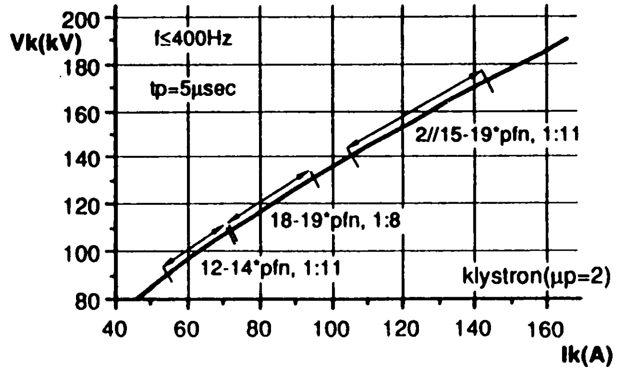
Klystron level modes:



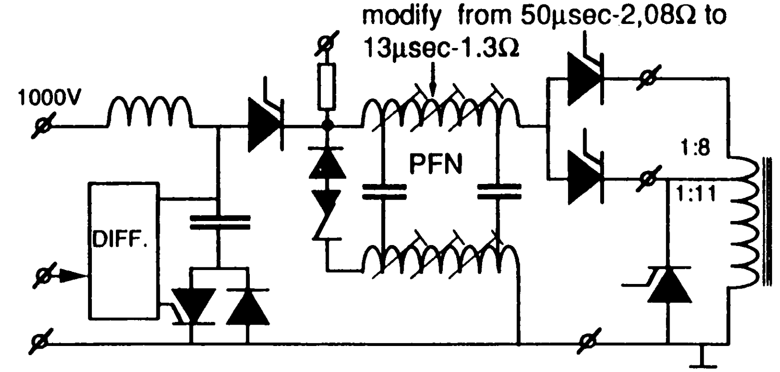
VA-938-D klyston from Varlan;

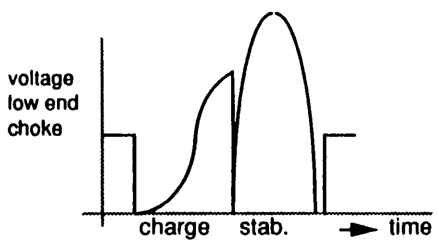


TH2129 klystron from Thomson-CSF;

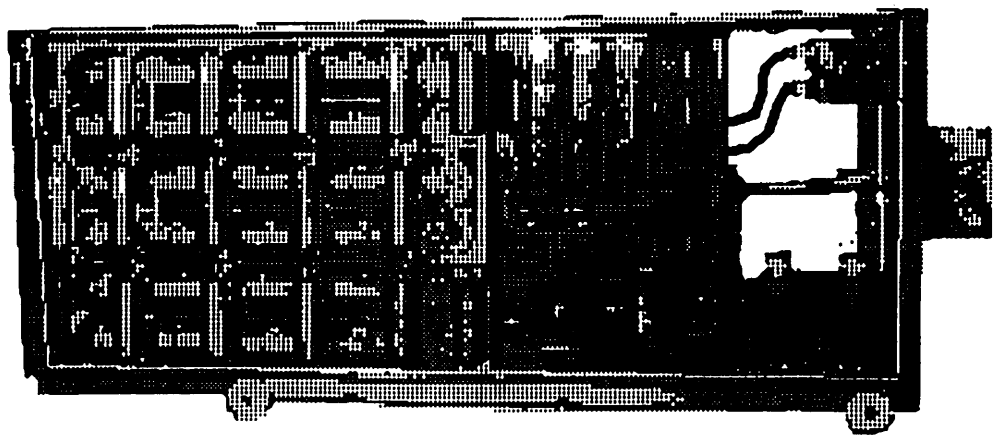


PFN-unit

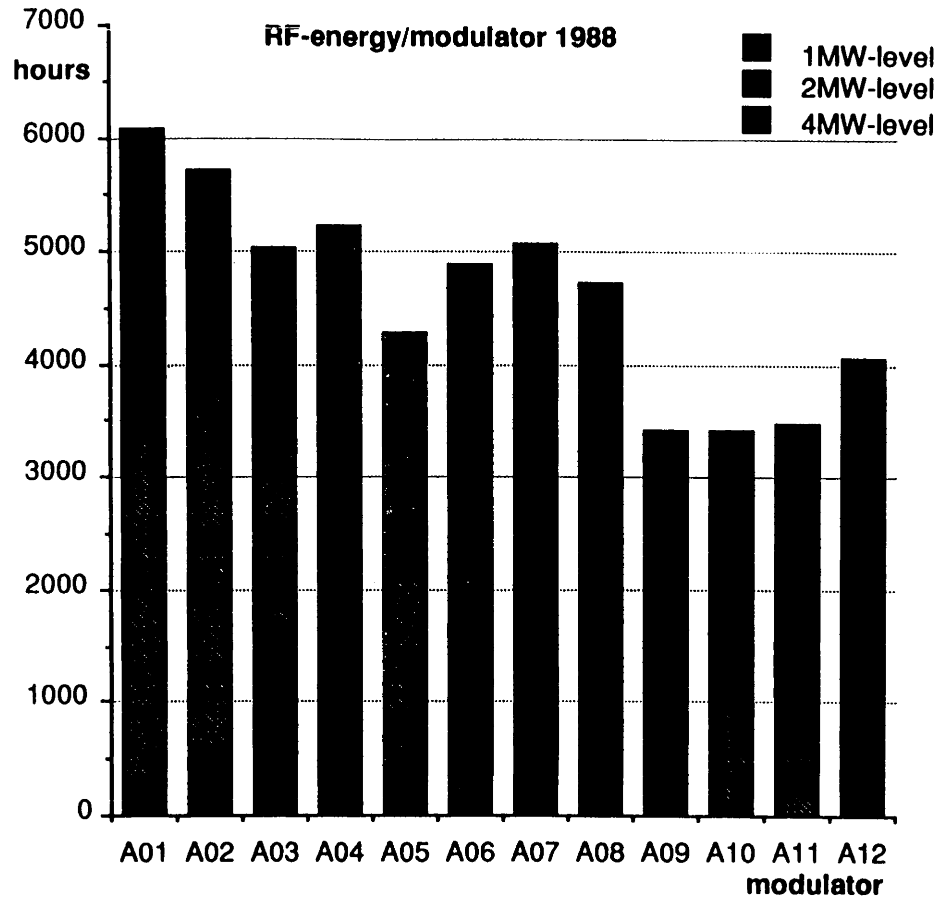


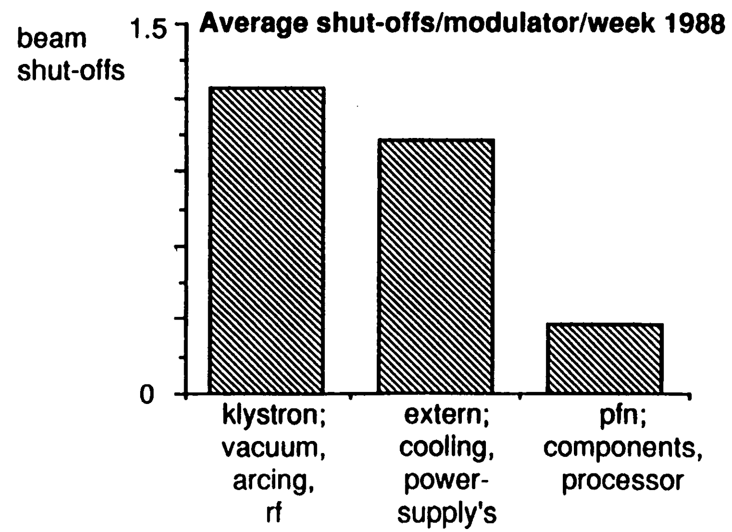


PFN-unit (1.3m * .5m * .2m, 45kg)

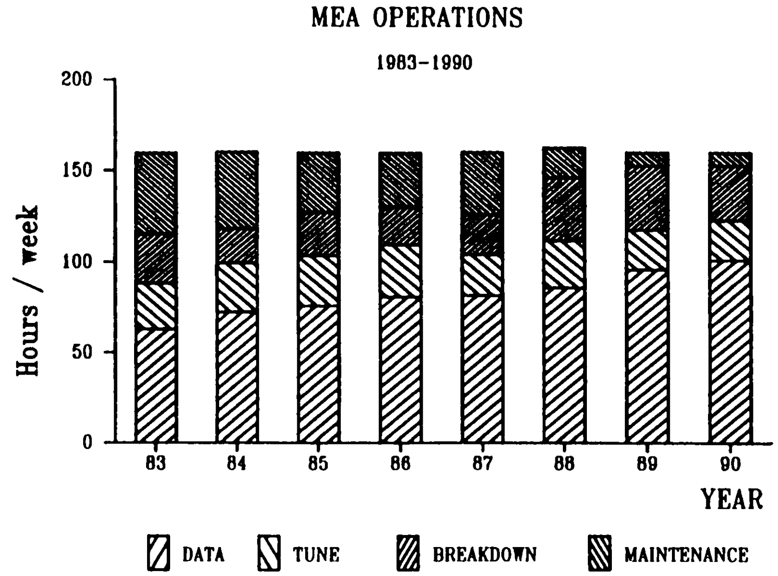


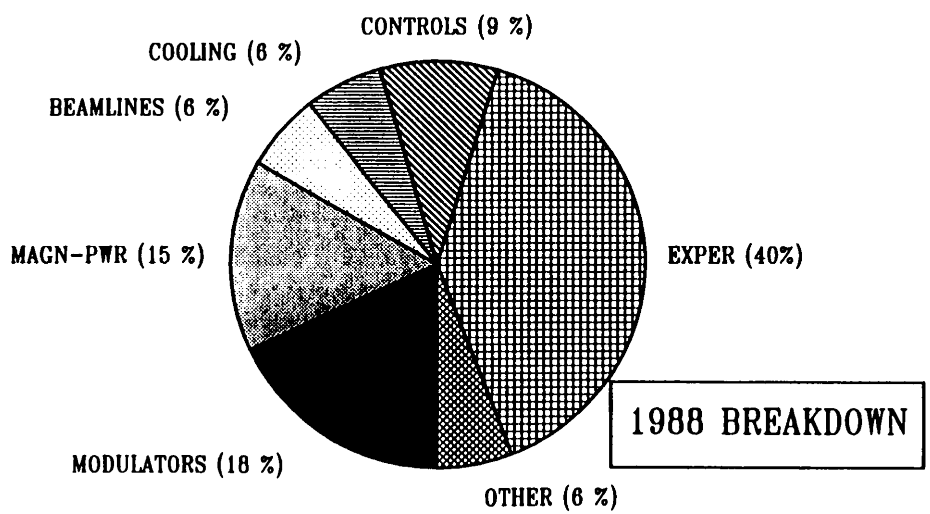
NIKHEF



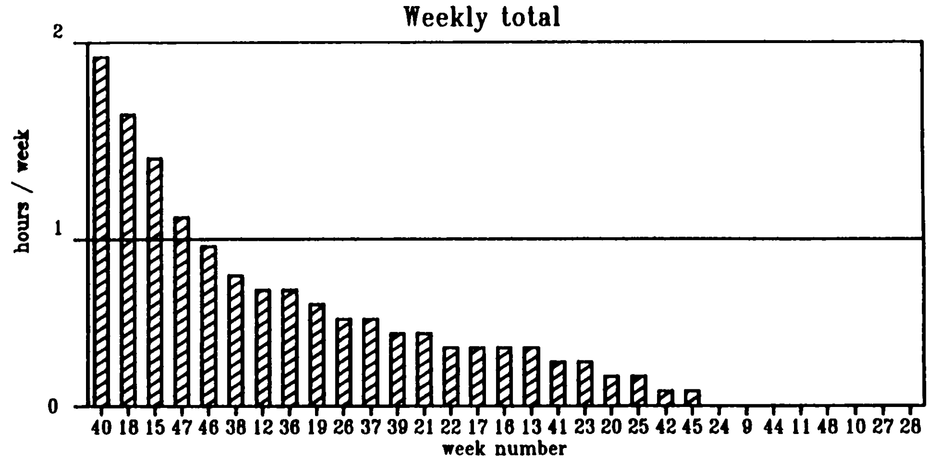


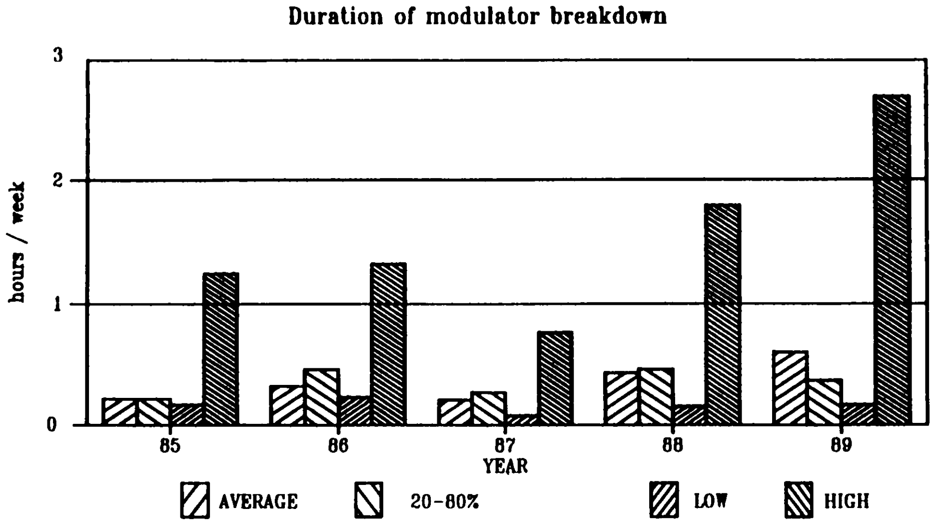
NIKHEF





MODULATOR BREAKDOWN in 1988





Cost breakdown

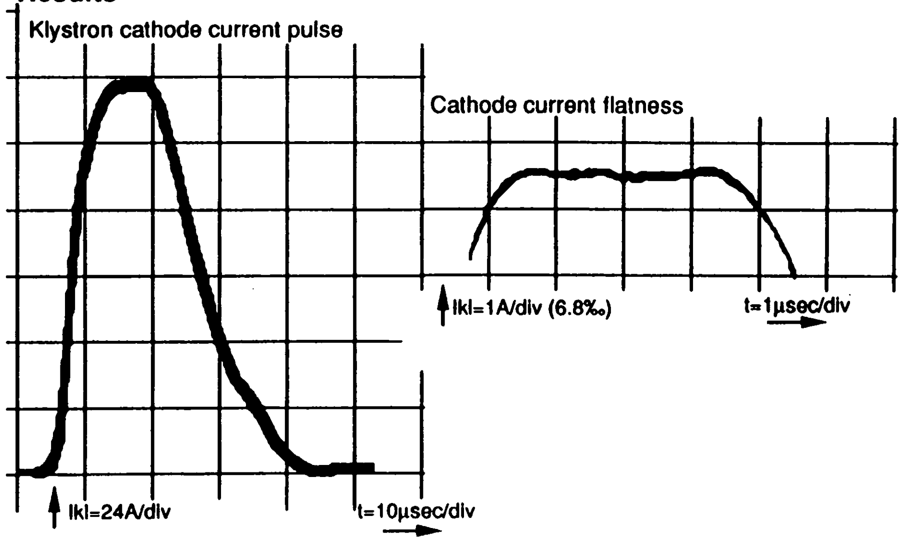
Mea high duty factor modulator
1-5MW peak RF-power
100kW average RF-power
2856MHz

Item	kECU
Pulsforming network	304
PFN's	
cabinet + cooling	
Pulse transformer	107
electronics	
pulse transformer	
tank	
Klystron	135
filament pwr supply	
focussing	
klystron	
DC power system	43
Controls	33
Installation	40
Operation (14 years);	
manpower	140
components	157
elec.pwr [0.05ecu/kWh]	539
klystrons	147
project cost	1645

Data klystrons;

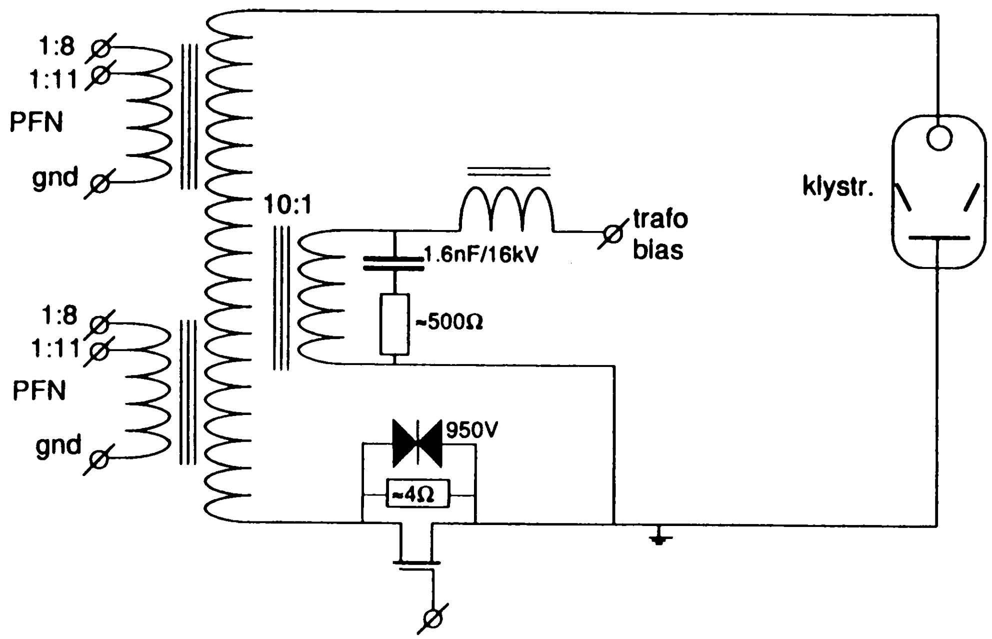
parameters	**unit**	**VA-938-D**	**TH2129**
peak output power	MW	1-5	10-15
drive peak power	W	<120	<100
bw (-.5dB)	MHz	20	10
efficiency	%	43	43
repetition rate	Hz	2000-500	400
RF pulse duration	μsec	40	4
Video pulse duration	μsec	50	13
collector dissipation	kW	350	100
peak beam voltage	kV	80-135	170-200
peak beam current	A	40-100	140-180
filament voltage	V	<20	<30
filament current	A	<66	<28
e.magnet voltage	V	<220	<250
e.magnet current	A	<8	<10
number of coils		4	3
vacuumpump voltage	kV	3.5kV	5kV
vacuumpump curr.	μA	<20	<20

Results



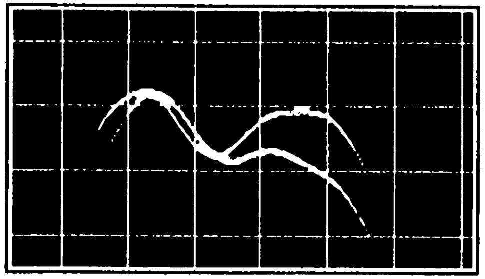
Pulse measured on a TH2129 klystron at the "10MW" discharge scheme (18//2units).

Pulse regulation



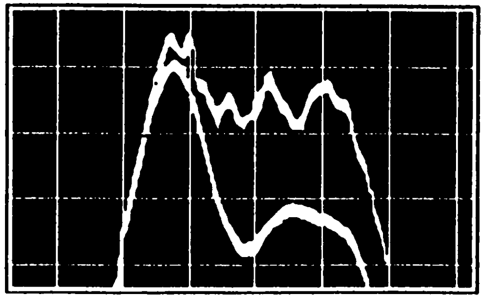
Filter effect

Iklystron=140A
i=500mA/div (4‰)
t=1µs/div
Cfilter=1600pF
Rfilter=1350Ω
Rfilter=900Ω

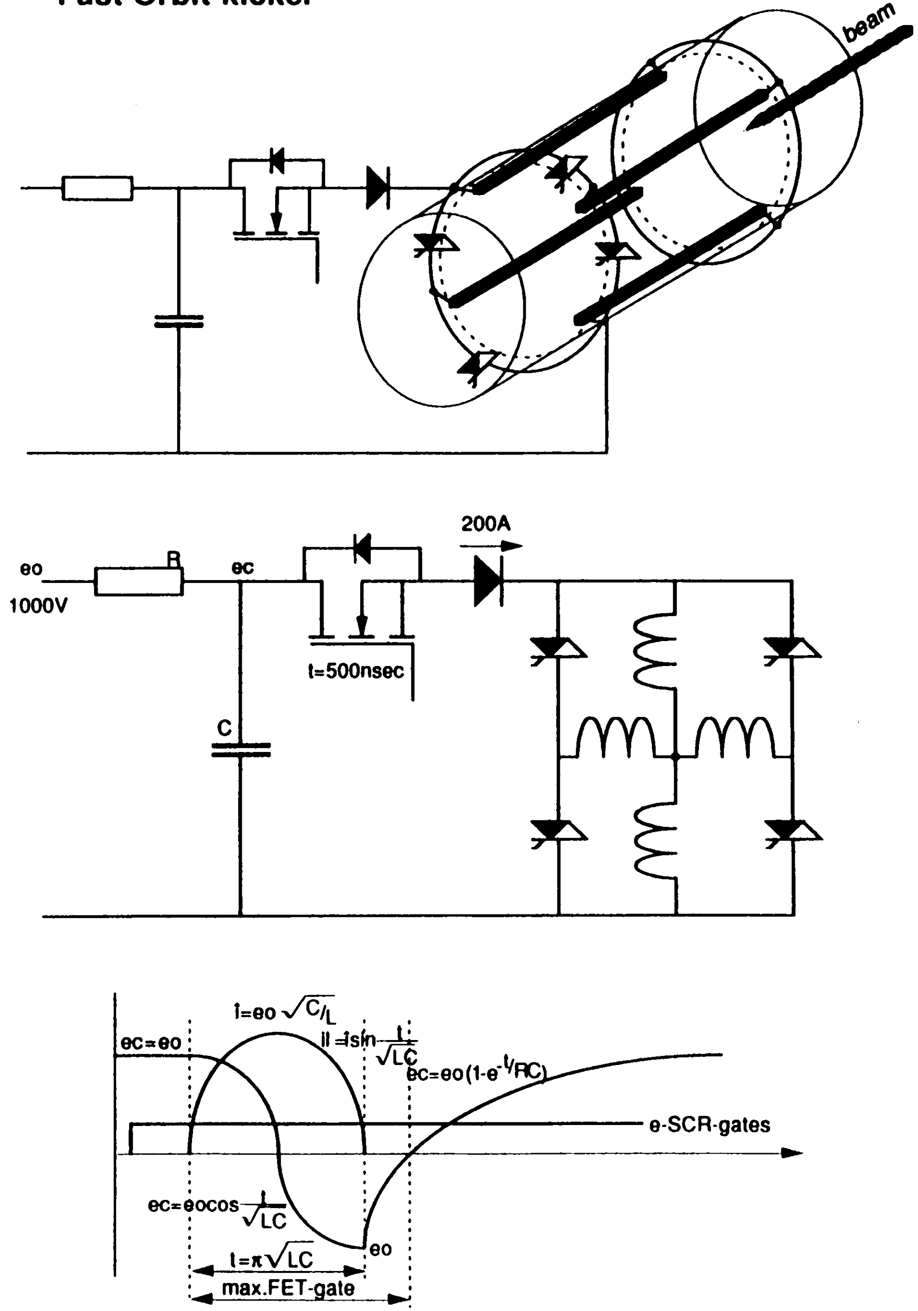


Regulator effect

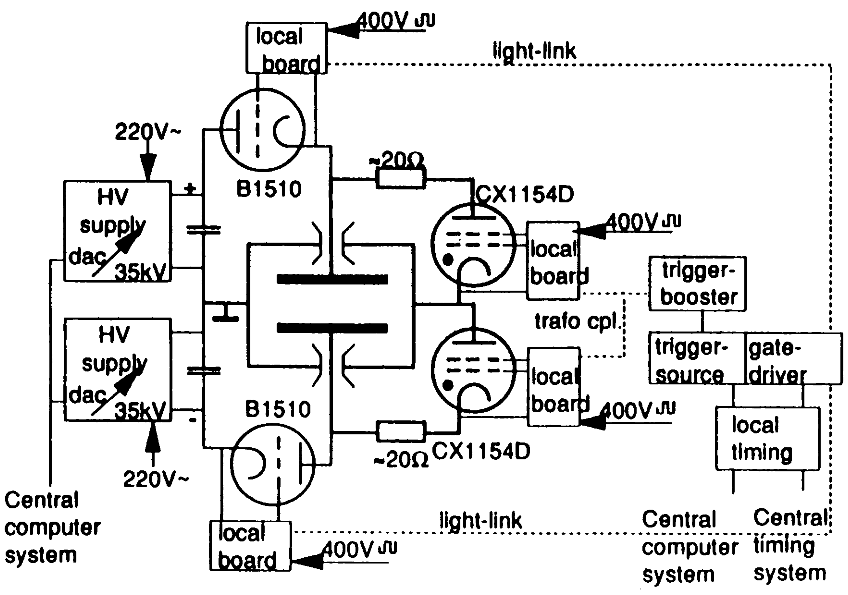
Iklystron=140A
i=200mA/div (1.5‰)
t=1µs/div



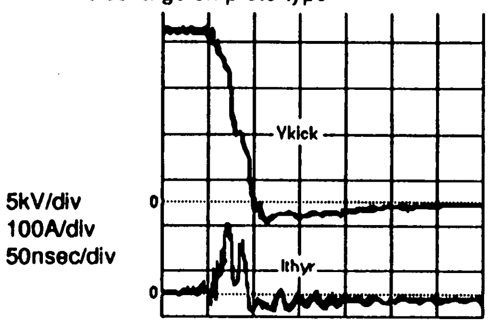
Fast Orbit-kicker



Injection Kicker Power-supply Set-up



status
-construction of mechanical design
-testing and evaluation electric design



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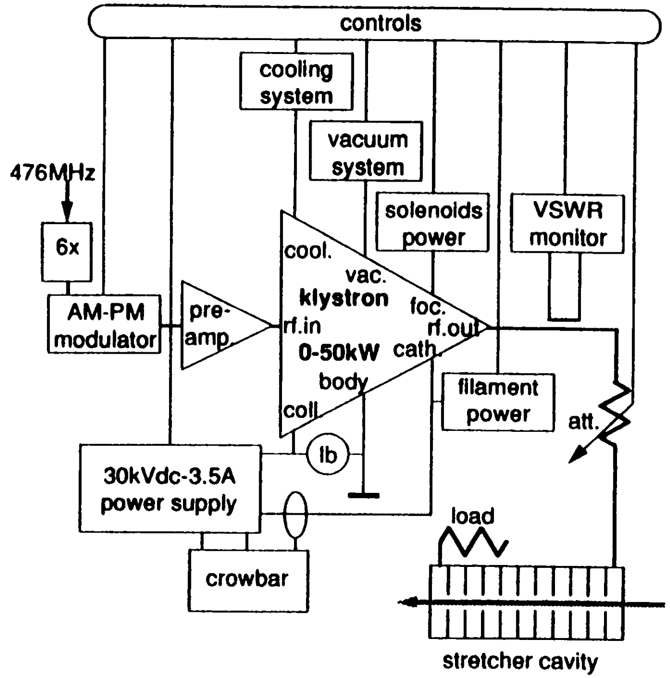
CW-RF STATION



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Related publications;

P.J.T.Bruinsma, E.Heine, e.a.,
"An all solid-state line-type modulator for 10% duty factor",
IEEE Trans. on Nuclear Science, vol. NS-20 1973
J.G.Noomen, e.a.,
"A modular cooling system for the MEA high duty factor electron linac",
IEEE Trans. on Nuclear Science, vol. NS-28, No.3, June 1981
F.B.Kroes, E.Heine, T.Sluijk,
"A fast amplitude and phase modulated RF-source for AmPS",
IEEE Part.Acc.Conf., San Fransisco 1990

to be published at EPAC 1992;

E.Heine, A.vd.Linden, P.J.T.Bruinsma, e.a.,
"The synchronously Discharged Fast Electrostatic Kickers of AmPS"

A.vd.Linden, P.J.T.Bruinsma, E.Heine, e.a.,
"The AmPS 80kV electrostatic septum withe .65 wire spacing"

contact persons;

accelerator department;	P.J.T.Bruinsma
rf-systems;	F.B.Kroes
pulse power;	E.Heine

This work is part of the research program of the Nuclear Physics section of the National Institute for Nuclear Physics and High-Energy Physics (NIKHEF-K), made possible by financial support from the Foundation for Fundamental Research on Matter (FOM) and the Nteherlands Foundation for Science Research (NWO).

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NIKHEF

CERN Modulator Technical Meeting 7-8/10/91

EUROPEAN SYNCHROTRON RADIATION FACILITY

P.Berkvens - ESRF

The ESRF, at present under construction at Grenoble, France is funded by different European countries.

The accelerator facility includes:

- PREINJECTOR:
  200 MeV linear electron accelerator

- full cycling BOOSTER SYNCHROTRON:
  200 MEV -> 6 GeV
  5 mA
  10 Hz repetition frequency
  352 MHz

- STORAGE RING:
  6 GeV
  100 mA
  352 MHz
  multibunch mode or single bunch mode

30 ESRF insertion device beamlines will be installed.
External beamlines will be installed on dipole magnets (CRG's).

Time schedule:

Preinjector:

commissioning: May - June '91, January - February '92

Booster:

- commissioning: September - December '91

Storage Ring:

- commisioning: from March '92 onwards

Beginning '92: installation of first beamlines

PREINJECTOR

- beam characteristics:

  - repetition frequency: 10 Hz

  - RF frequency : 2.998 GHz

    booster + storage ring RF not subharmonic from preinjector frequency

  - beampulse length:

    1. multibunch operation
       - booster length: 1 μs
       - transient beamloading

    --> 2 μs

    2. single bunch operation

       storage ring period: 2.8 ns

       --> 2 ns

    peak current:

    multibunch e^- : 25 mA

    single bunch e^-: 250 mA

    single bunch e^+: 2.5 A

Modulator characteristics:

Figure 1 shows the general layout of the linac setup. There are 2 identical modulators. The first modulator feeds the first 6 meter section, the buncher and the prebuncher cavity.

pulse repetition frequency:
The modulators run at a fixed pulse repetition frequency of 10 Hz. The electron beam can be set at 10, 5 , 2 or 1 Hz (plus single shot) by yes or no putting the RF pulse and the gun puls together.

pulse length:
The pulse length is 5 µs: the filling time of the 6 meter sections is 1.5 µs. Therefore in order to get a 2 µs beampulse at least 3.5 µs flat top of the RF modulator pulse is required.

peak power:
In order to get 200 MeV, 50 mA peak current 35 MW peak power per modulator is required.

Figure 2 shows the schematic diagram of the modulator.
The modulators are of a standard design, made by CGR MeV. They use TH2100 Thomson klystrons, and CX1525A EEV thyratrons. The PFN is made of 19 cells. Charging time of the PFN is about 10 ms. Low voltage deQing is foreseen.
The modulators run with a negative mismatching (appr. 6 %)

Modulator driving system:
At present a problem with the modulator driving system is observed. The phase shift between the RF of the 2 modulators is obtained at very low power via an electronic phase shifter. This phase shifter introduces an important phase shifting during the RF pulse between the two signals. This can be observed on the energy analyzed beam behaviour when displacing the 10 µs input power pulse relative to the modulator (and beam) pulse. This is shown on figure 3. A direct measure of this phase shift is shown in figure 4.

Operation schedule:

- routine operation:
  3 filling cycles / 24 h
  per filling cycle : a few minutes beam
- --> linac normally fully shut down between filling cycles

Possible positron operation:

to increase storage ring beam lifetime
project under study
--> design proposal beginning '92
decision course '92

400 MeV e^+ linac or alternative design
--> at least 1 other modulator

in house development

Klystron failure:

After appr. 500 hours of operation one of the TH2100 klystrons failed: one of the filaments failed.

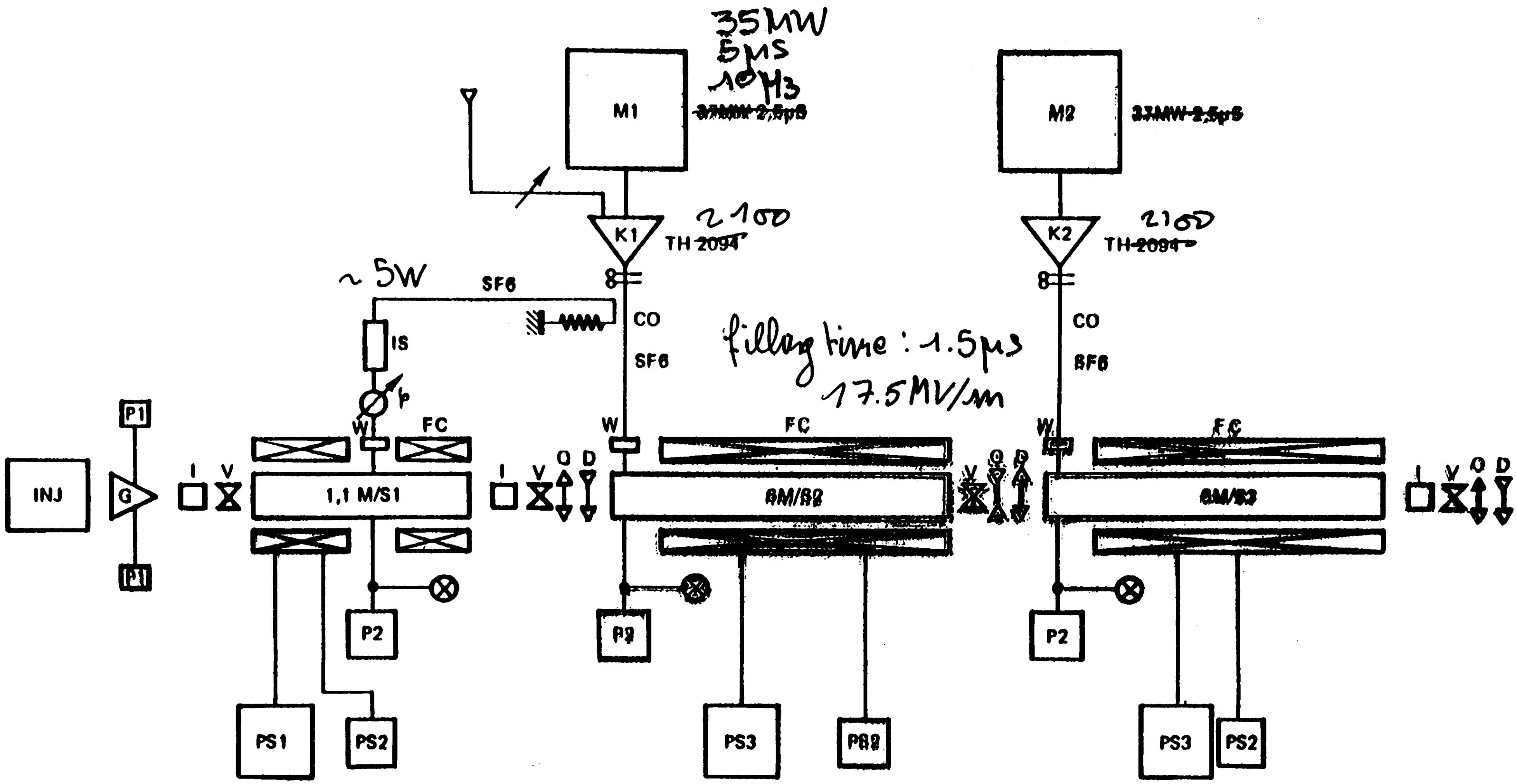
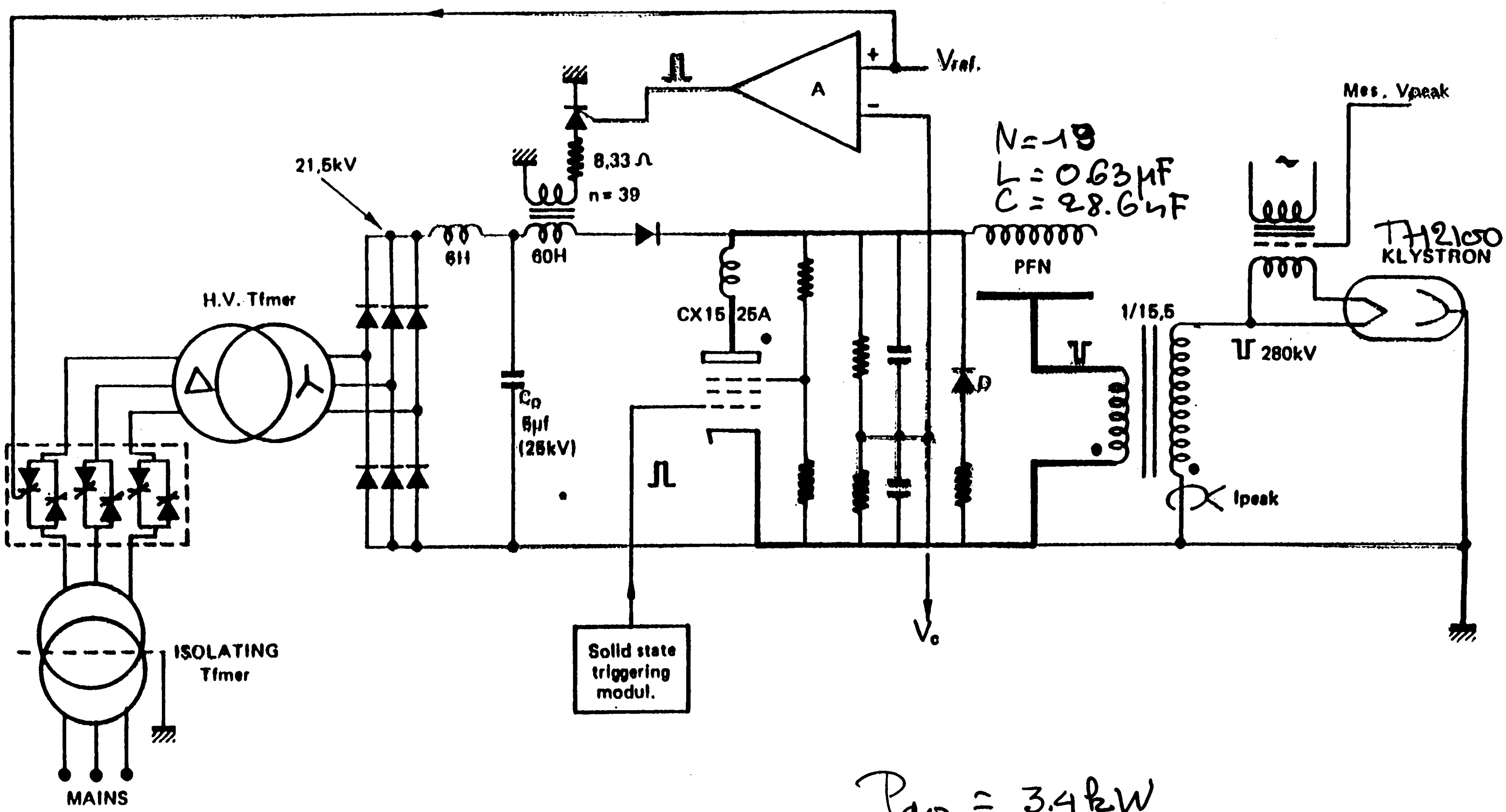
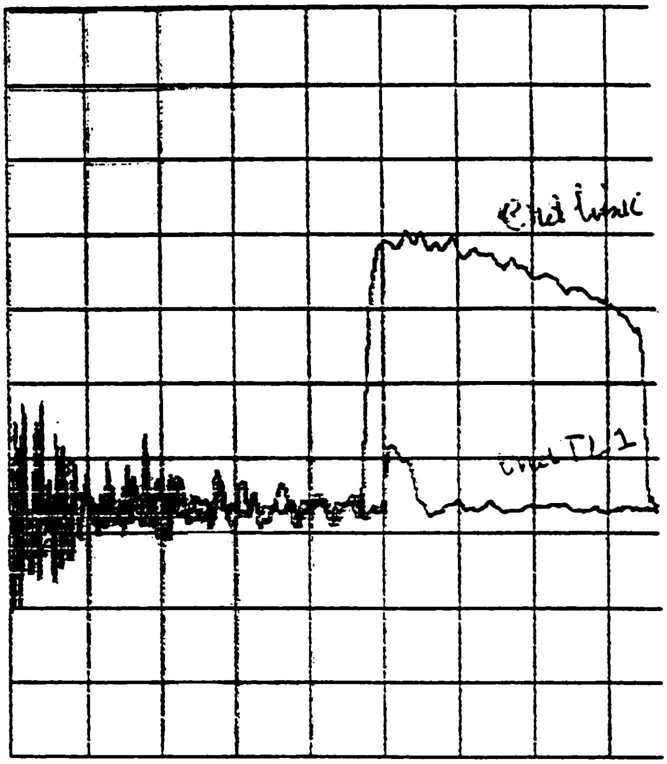


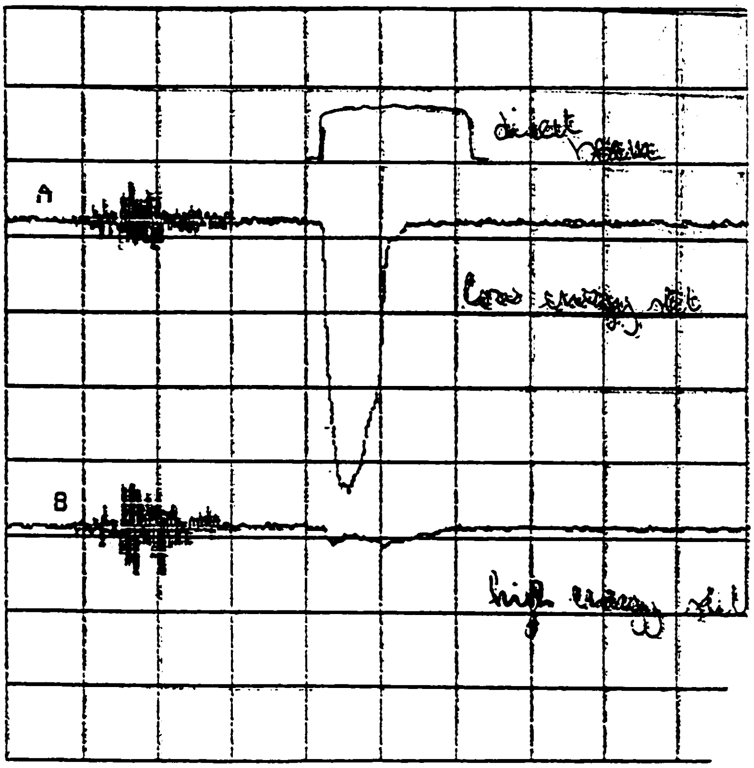
FIG : 1
200Mev PREINJECTOR SYNOPTIC FOR E.S.R.F GRENOBLE



Pao. = 3.4kW

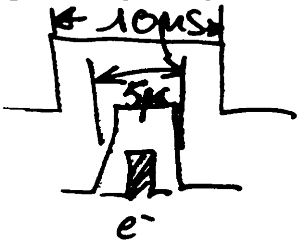
fig. 2



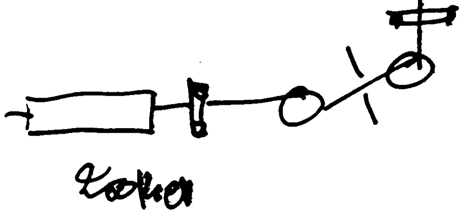


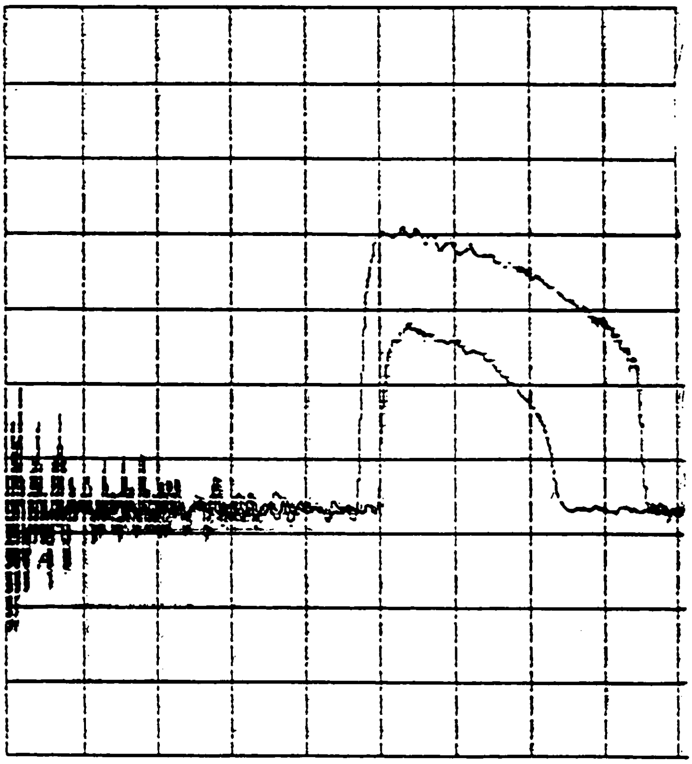
REGØ A: 100mV + 0mV T: 500ns SNG
BW B: 100mV + 0mV D:+ 1DIV

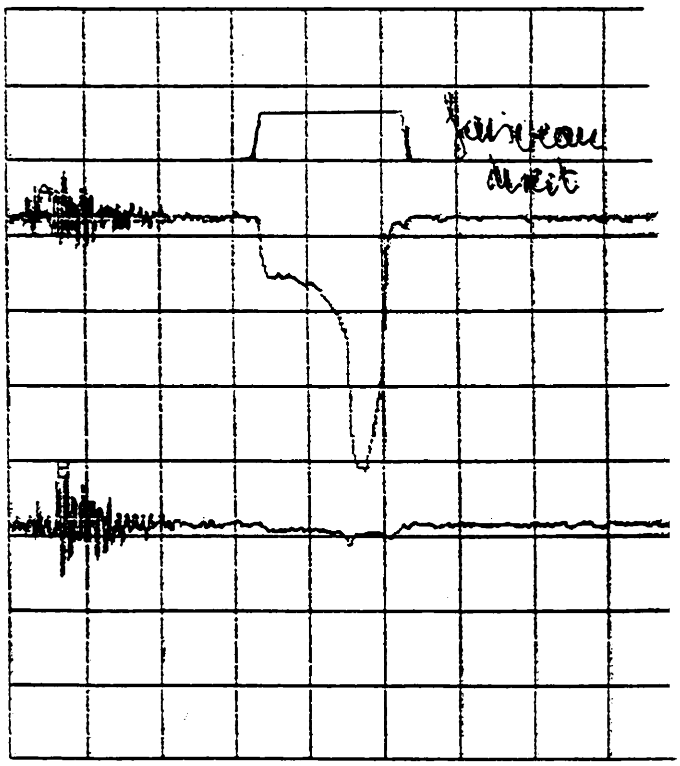
REGØ A: 50mV + 0mV T: 1us SNG DC
BW B: 50mV + 0mV D:- 5DIV / A



r f delay = 10 µs





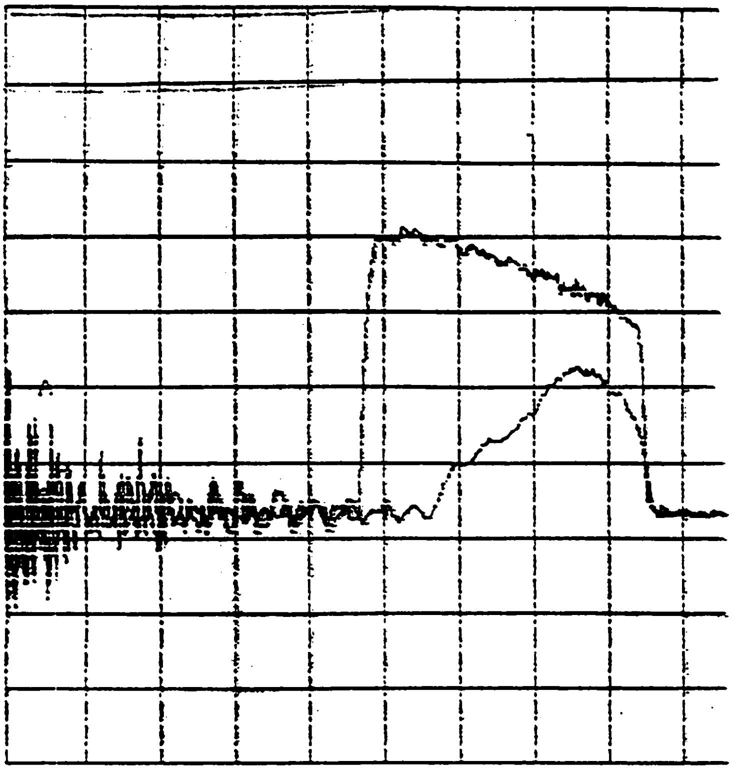


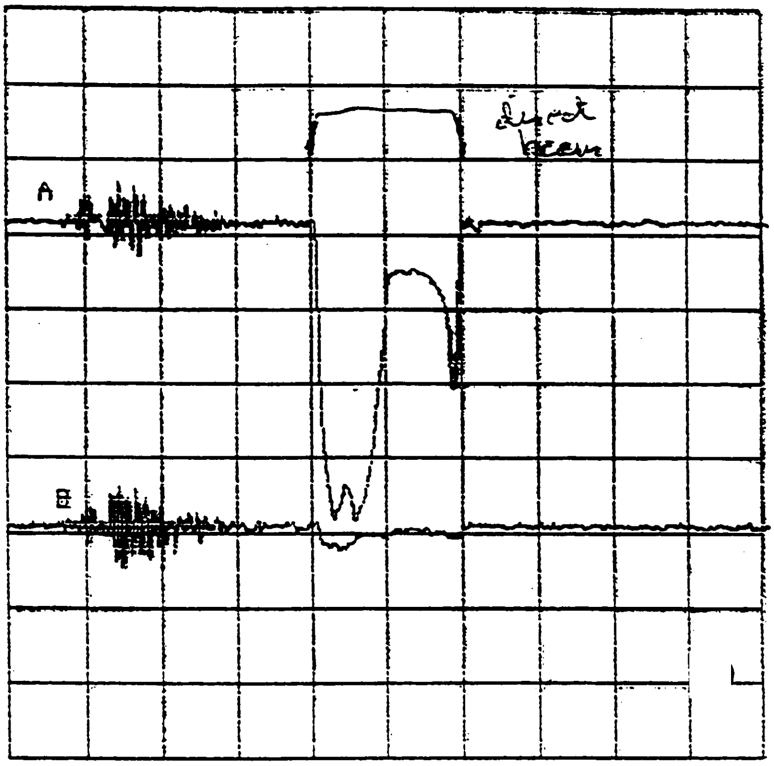
REGØ A: 100mV + 0mV T: 500ns SNG DC
BW B: 100mV + 0mV D:+ 1DIV / /

REGØ A: 50mV + 0mV T: 1us SNG
BW B: 50mV + 0mV D:- 5DIV /

r f delay = 11 µs

fig 3/a

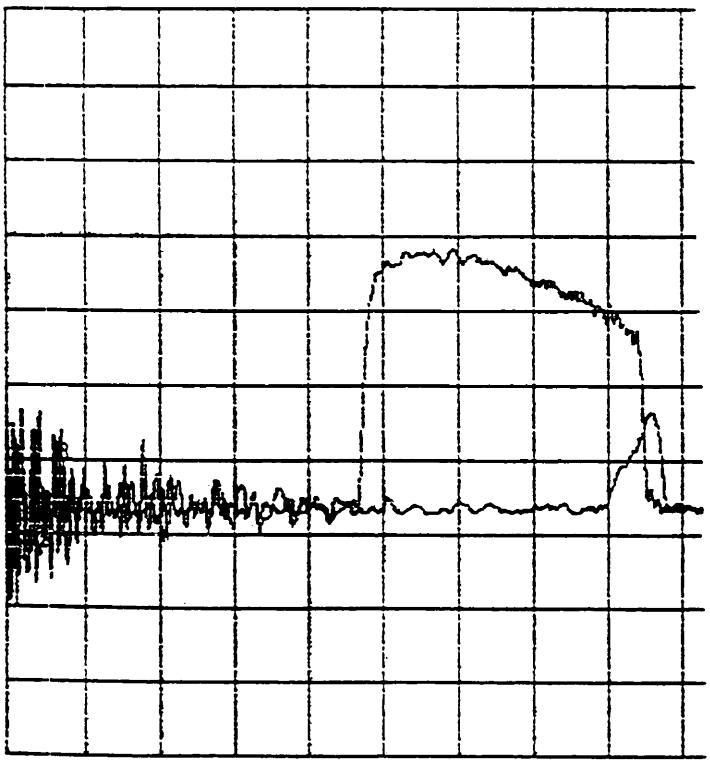


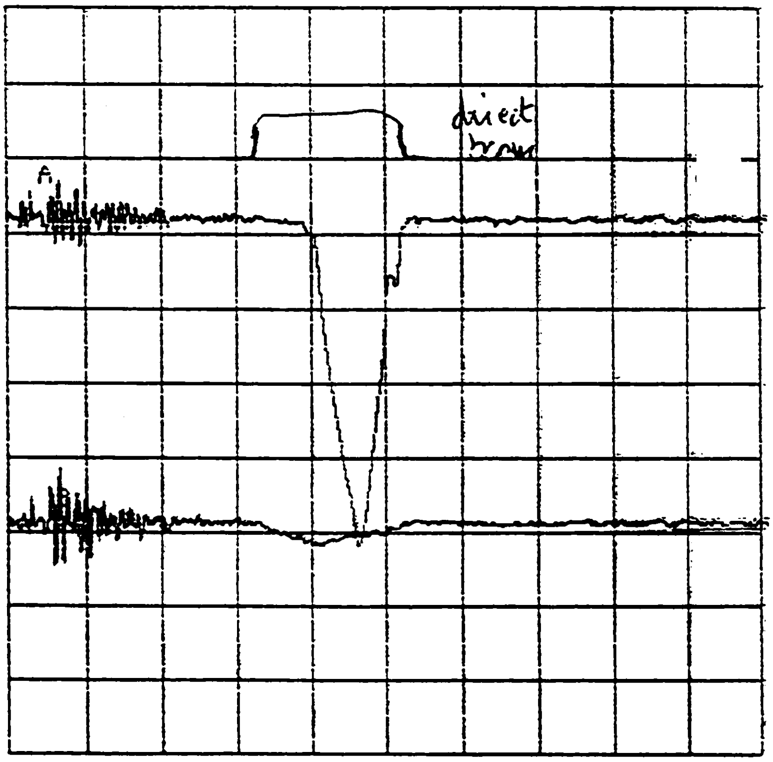


RE60 A: 100mV + 0mV T: 500ns SN6 DC
BW B: 100mV + 0mV D:+ 1DIV / A

RE60 A: 50mV + 0mV T: 1us SN6 DC
BW B: 50mV + 0mV D:- 5DIV / A

rf delay = 12 µs



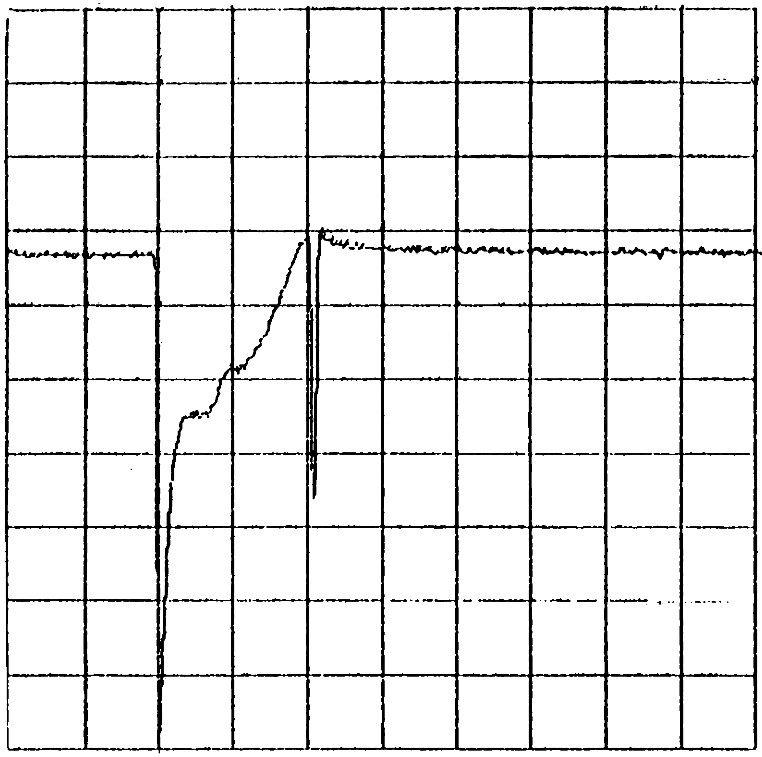


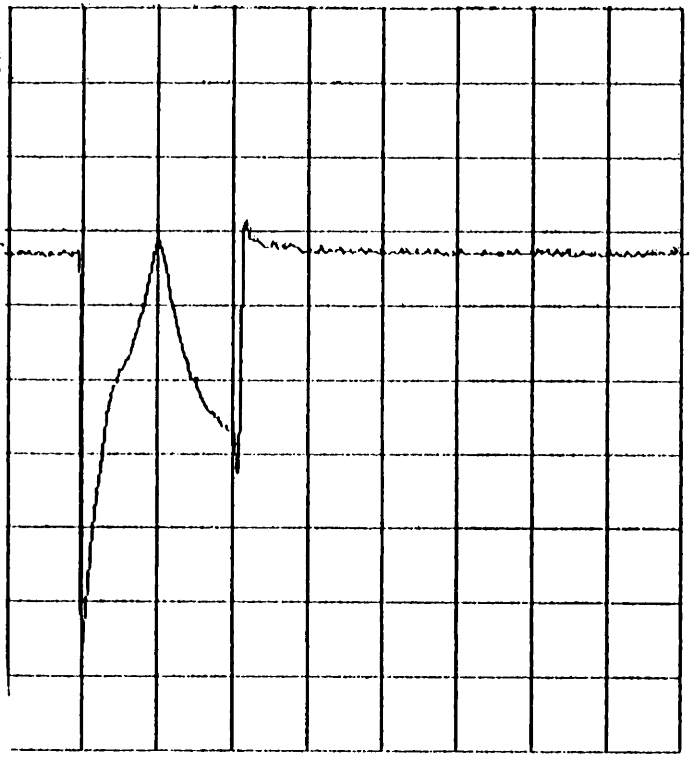
RE60 A: 100mV + 0mV T: 500ns SN6 DC
BW B: 100mV + 0mV D:+ 1DIV / A

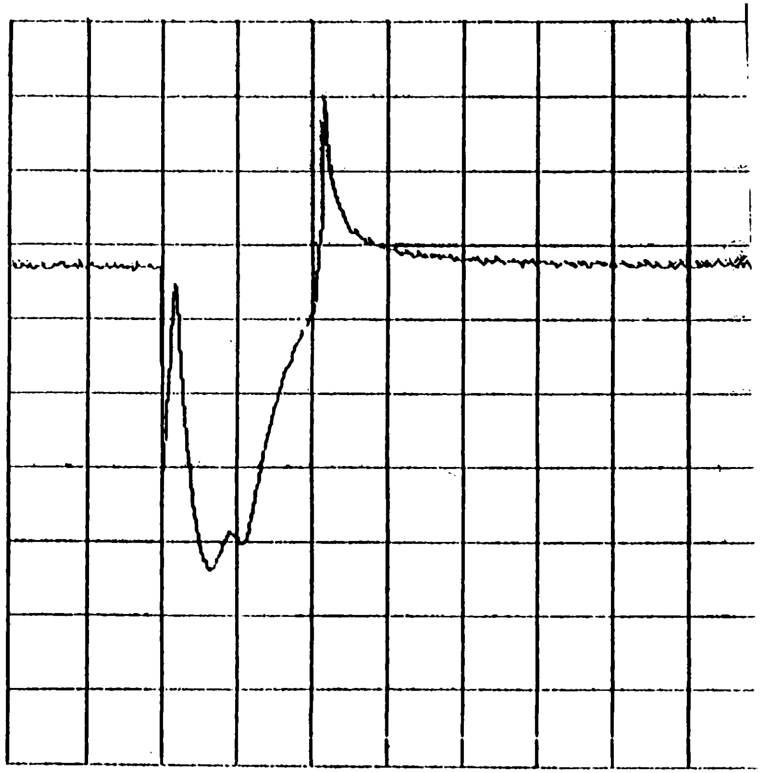
RE60 A: 50mV + 0mV T: 1us SN6 DC
BW B: 50mV + 0mV D:- 5DIV / A

rf delay = 13 µs

fig 3/b







REGI A: 100mV + 0mV T: 5us REC DC
B: 200mV + 0mV D:- 2DIV \ A

$\phi_{rel} = 180°$ $\phi_{rel} = 120°$ $\phi_{rel} = 30°$

→ 150°/10µs

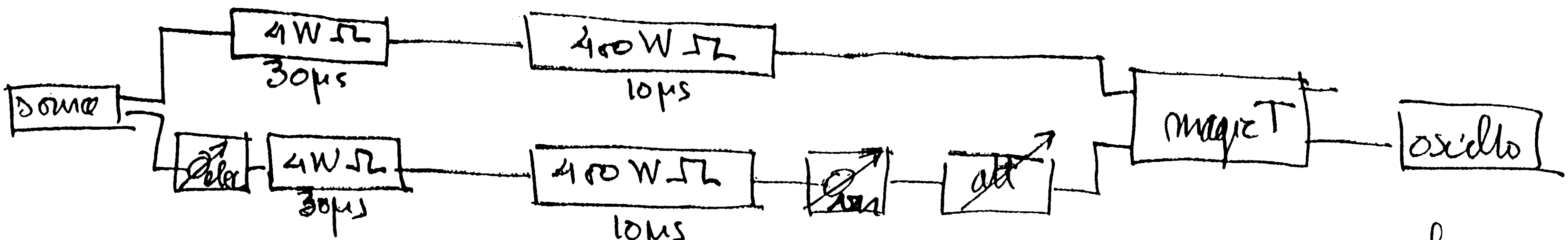
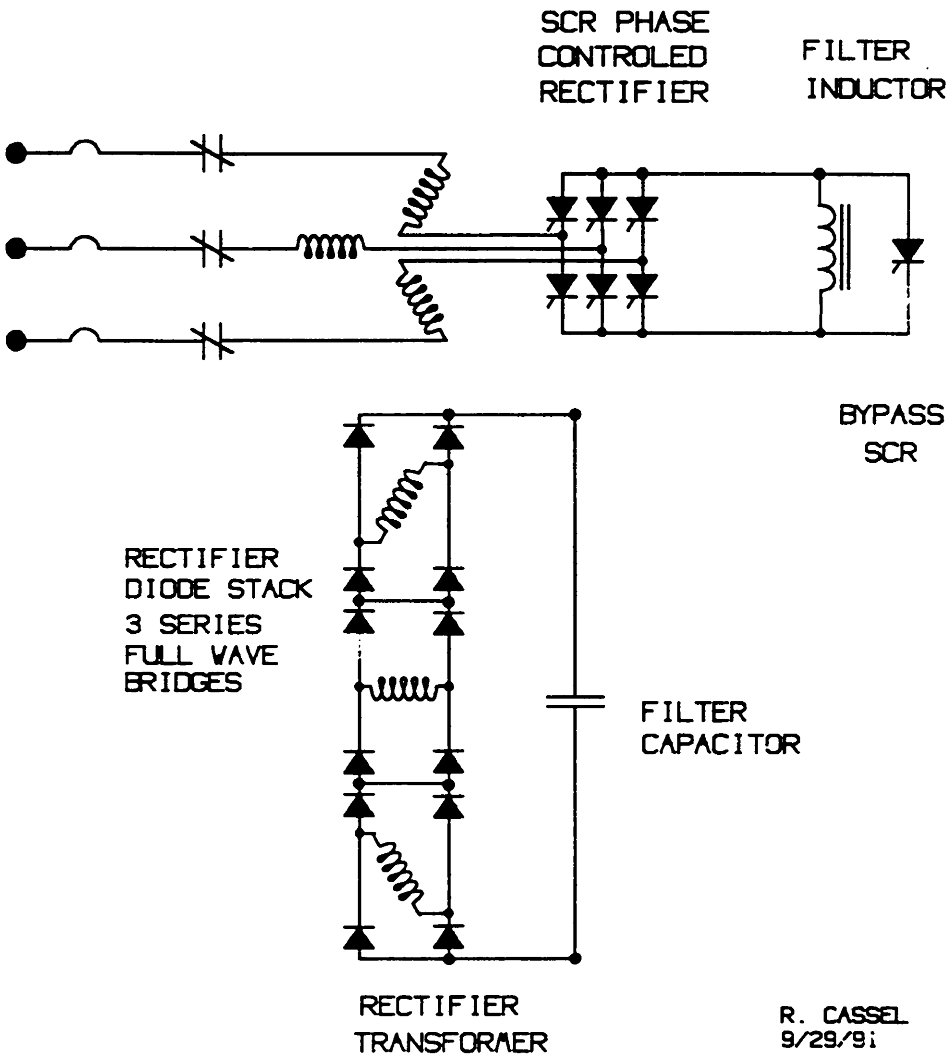
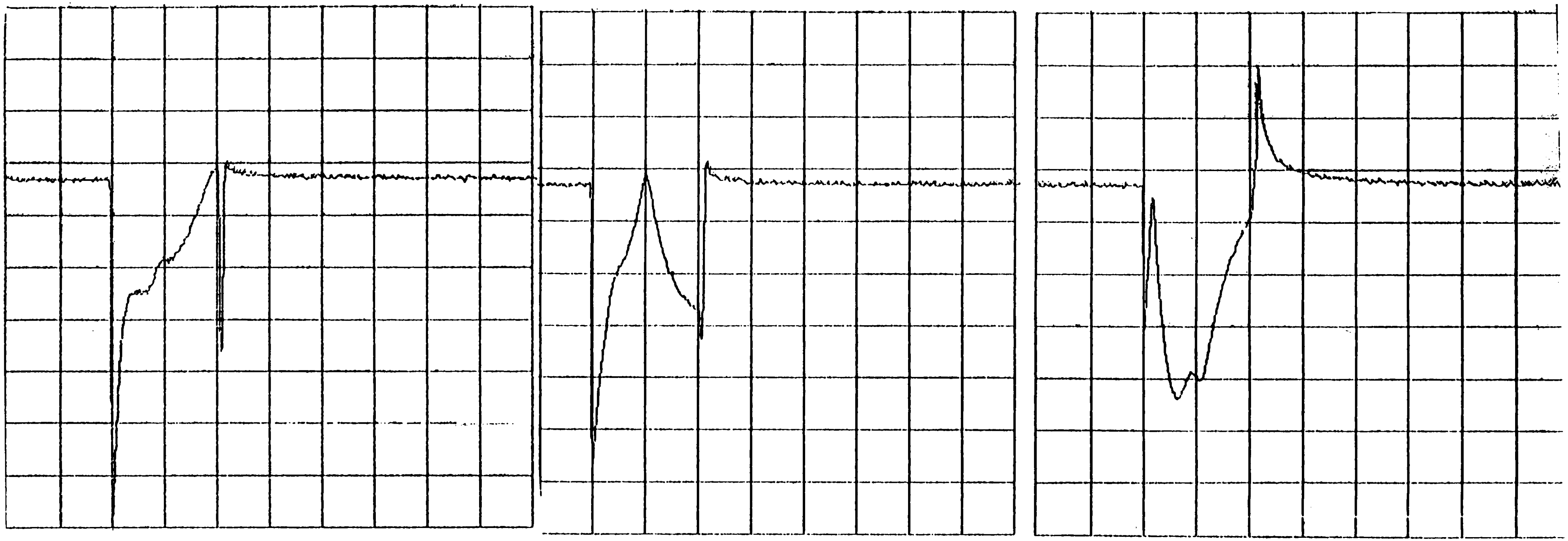


fig 4.b

PRIMARY CONTROL PS





REGI A: 100mV + 0mV T: 5us REC DC
B: 200mV + 0mV D:- 2DIV \ A

$\phi_{rel} = 180°$ $\phi_{rel} = 120°$ $\phi_{rel} = 30°$

→ 150°/10µs

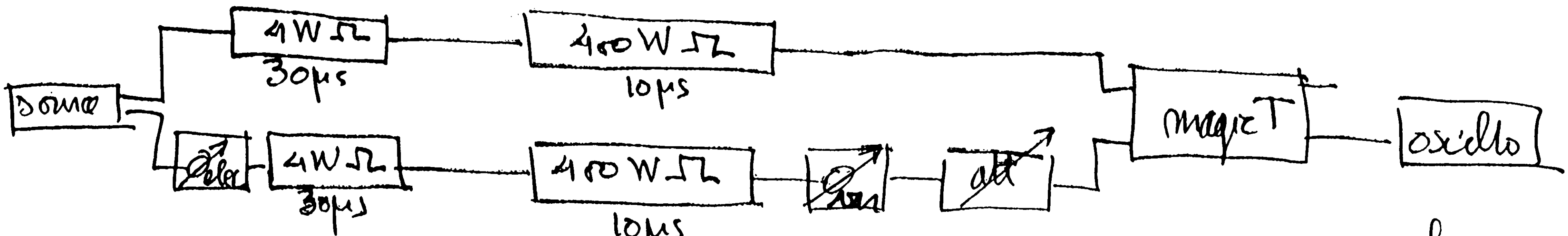


fig 4.b

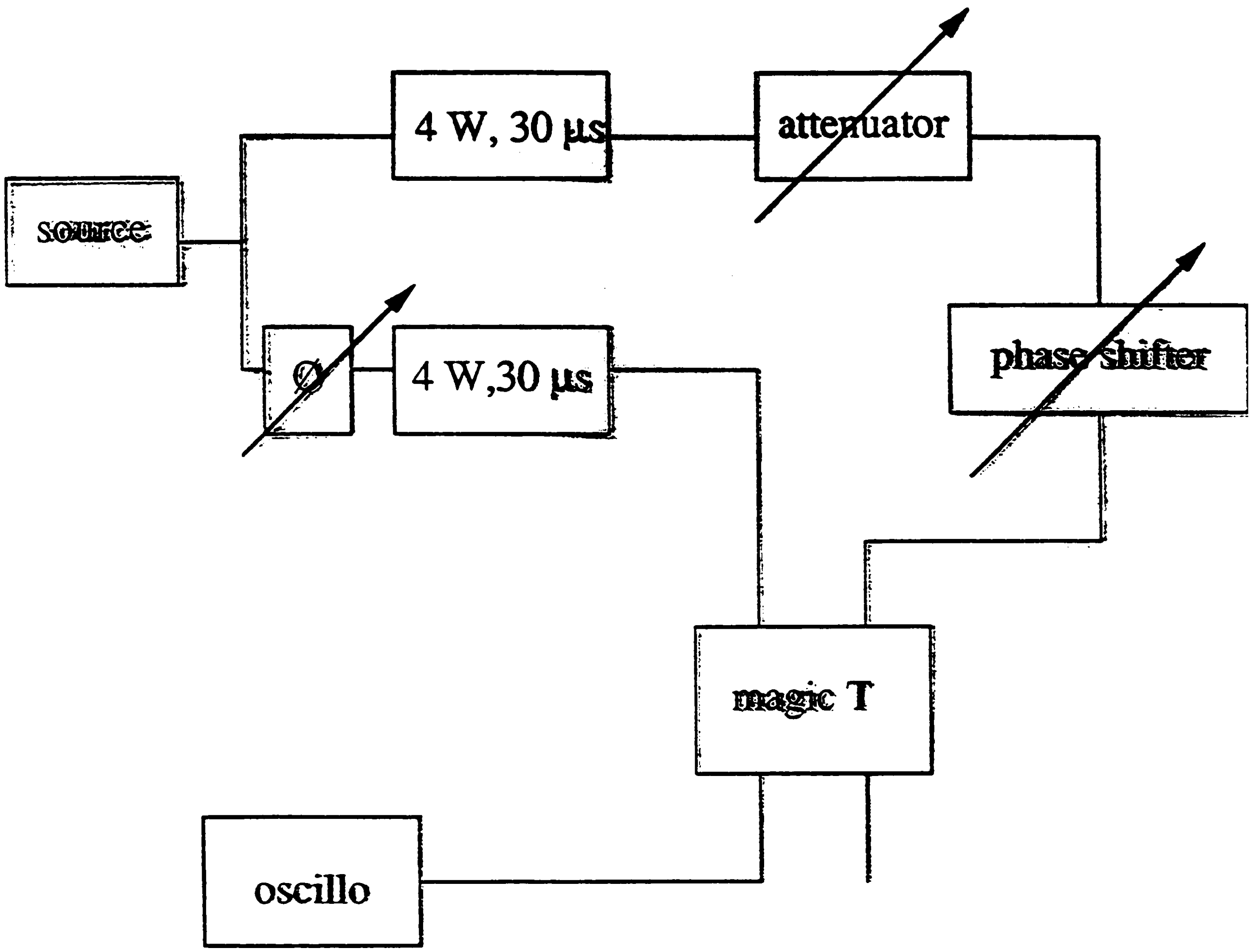

4 W, 30 µs
attenuator
source
Ø
4 W,30 µs
phase shifter
magic T
oscillo

fig. 4/a

KLYSTRON-MODULATOR TECHNICAL MEETING

R. Cassel
10/1/91

Improvements and new designs for SLAC Klystron Modulators

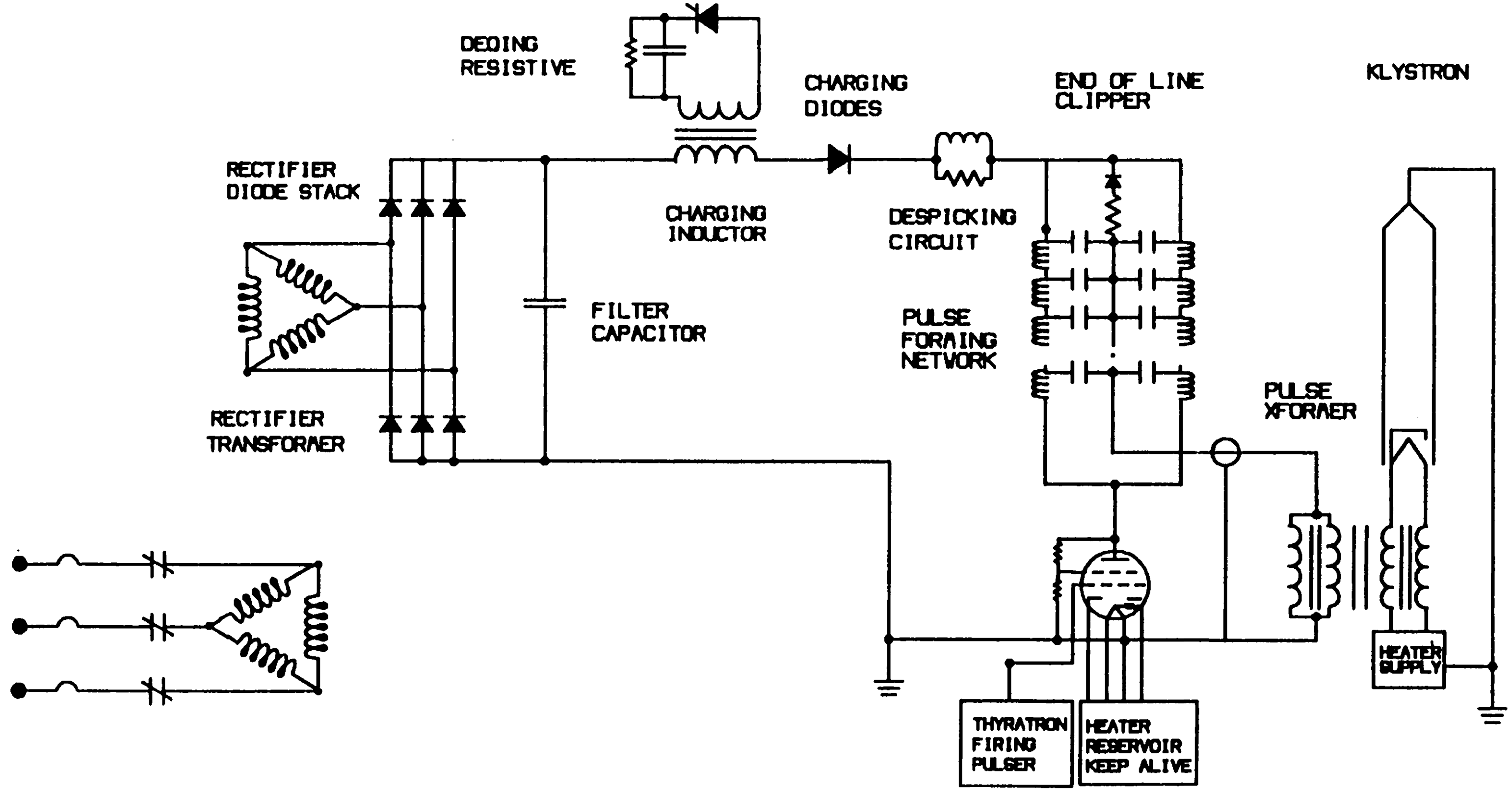
Stanford Linear Accelerator Center

ITEMS TO BE COVERED

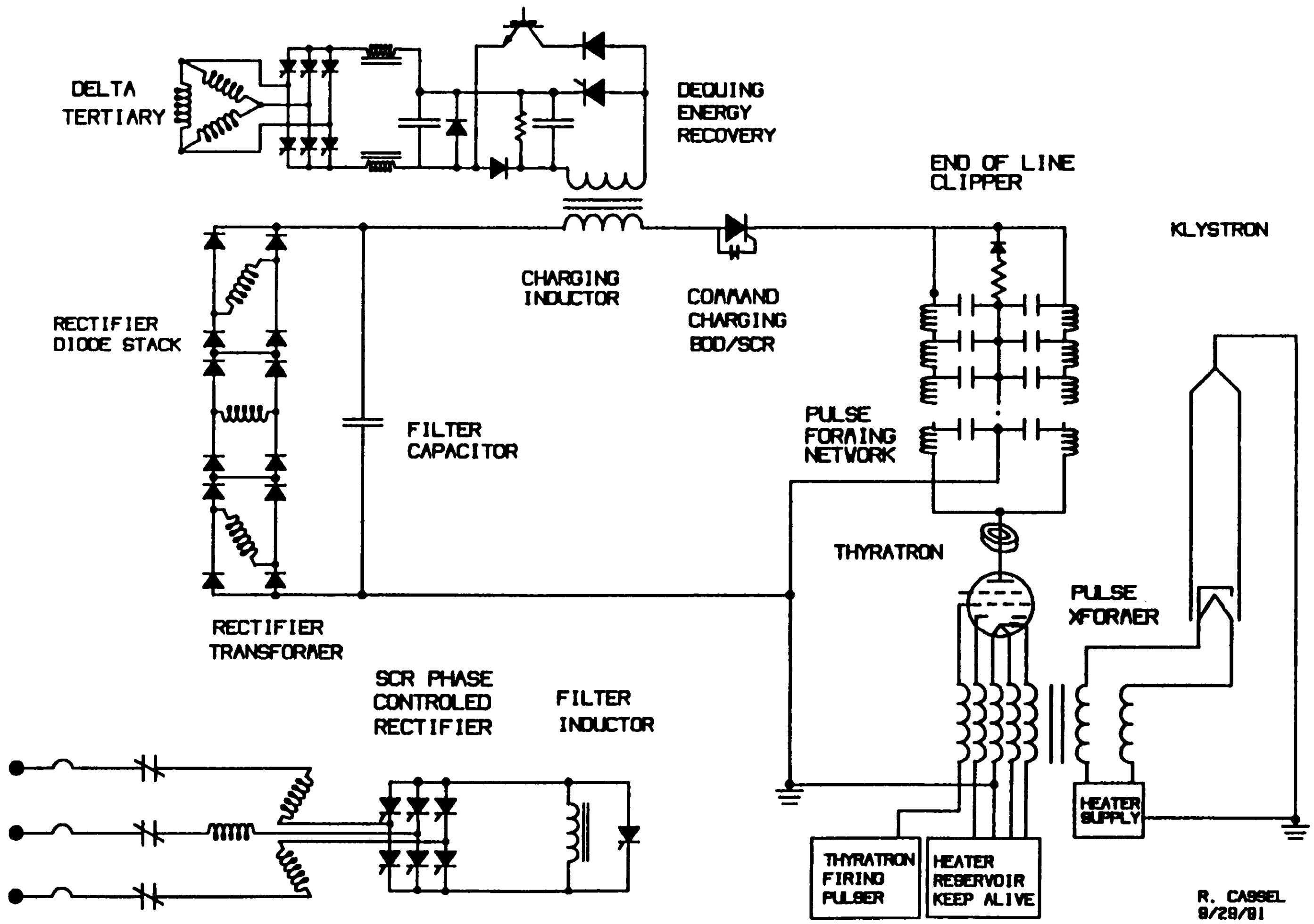
R. Cassel
10/1/91

* PRIMARY SCR PHASE BACK CONTROL POWER SUPPLY
* FULL WAVE BRIDGE RECTIFIER CONFIGURATION
* PULSED CHARGING
* ENERGY RECOVERY DeQING
* COMMAND CHARGING
* GROUNDED PFN AND TRANSFORMER
* END OF LINE CLIPPER VS FRONT OF LINE CLIPPER
* RECTIFIED KLYSTRON HEATER POWER SUPPLY
* NLCTA MODULATOR RISE TIME
* CUMULATIVE WAVE LINE DESIGNS
* 440KV / 480KV XBAND KLYSTRON MODULATOR
* 600KV NLCTA XBAND KLYSTRON MODULATOR

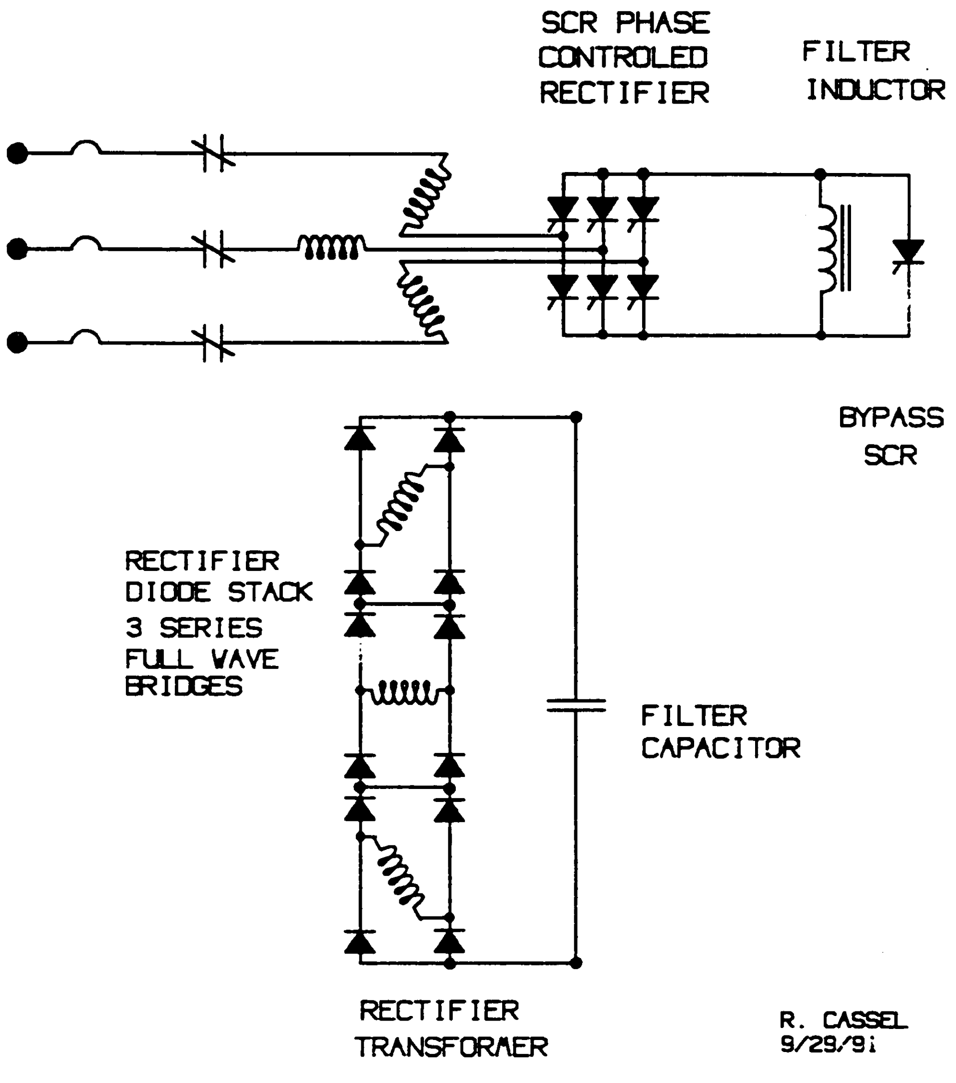
SLAC KLYSTRON MODULATOR



KLYSTRON MODULATOR



PRIMARY CONTROL PS



R. CASSEL
9/29/91

MODULATOR PRIMARY CONTROL
OPEN WYE SCR WITH FILTER INDUCTOR

R. CASSEL
10/1/91

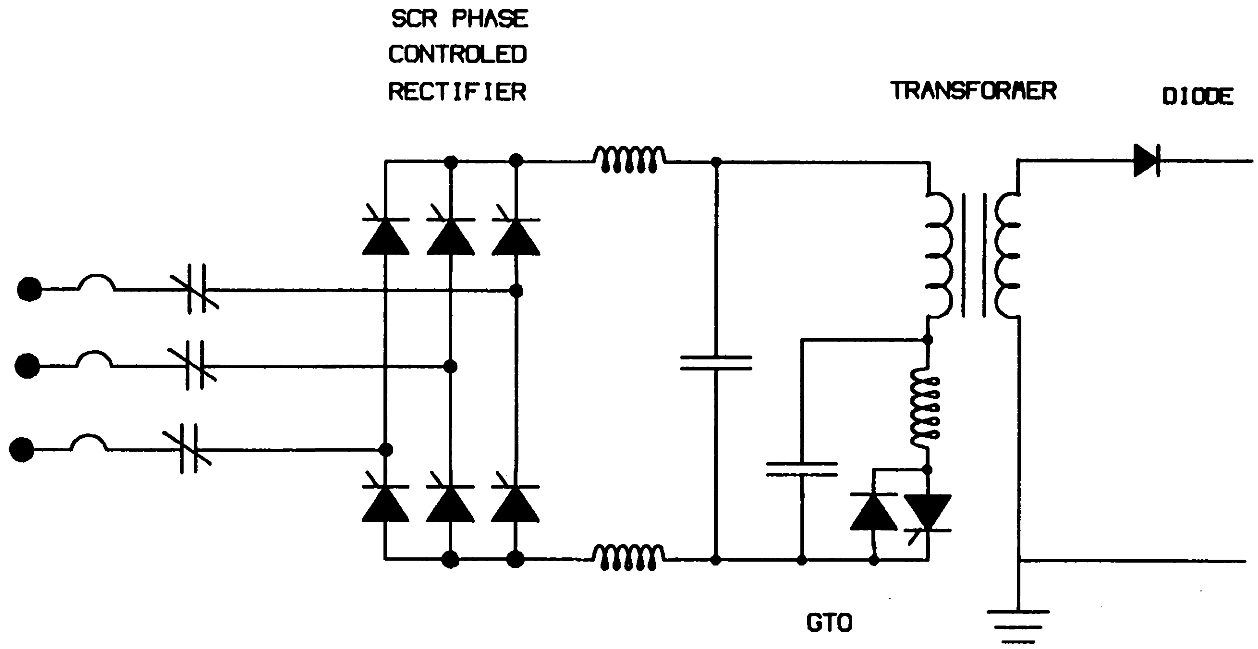
ADVANTAGES

* VOLTAGE CONTROL RANGE 10%-100%
* VOLTAGE REGULATION BETTER THAN 1%
* FILTER INDUCTOR AT LOW VOLTAGE
* REDUCED SHORT CIRCUIT CURRENTS

FULL WAVE BRIDGE RECTIFIER CONFIGURATION

* REDUCED VOLTAGE ON WINDINGS
* FEWER NUMBER OF DIODES NEEDED

PULSE CHARGING



RLCassel 7/29/91

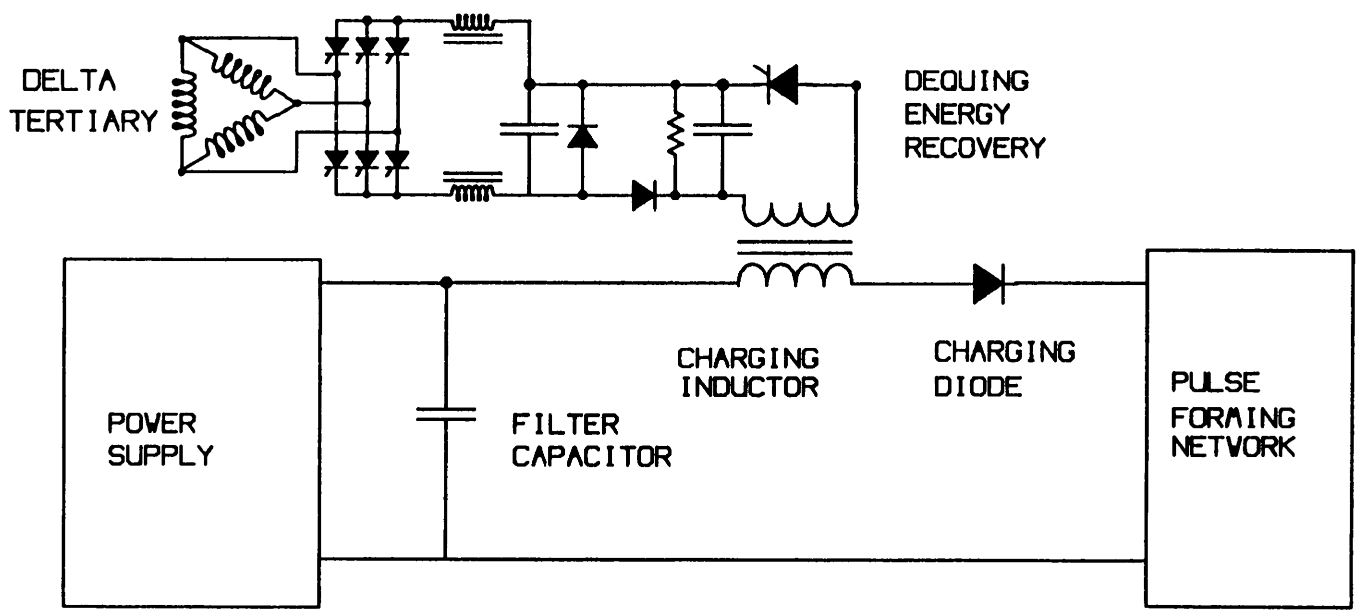
MODULATOR PULSE CHARGING
FOR USE AT LOW AVERAGE POWER

R. CASSEL
10/1/91

ADVANTAGES

* VOLTAGE REGULATION BETTER THAN 0.1%
* CHARGE PFN ON COMMAND
* NO LOW FREQUENCY TRANSFORMER

ENERGY RECOVERY DEQING



R. CASSEL
9/29/91

ENERGY RECOVER DeQing

R. Cassel
10/1/91

* Wide DeQing range > 20% voltage range

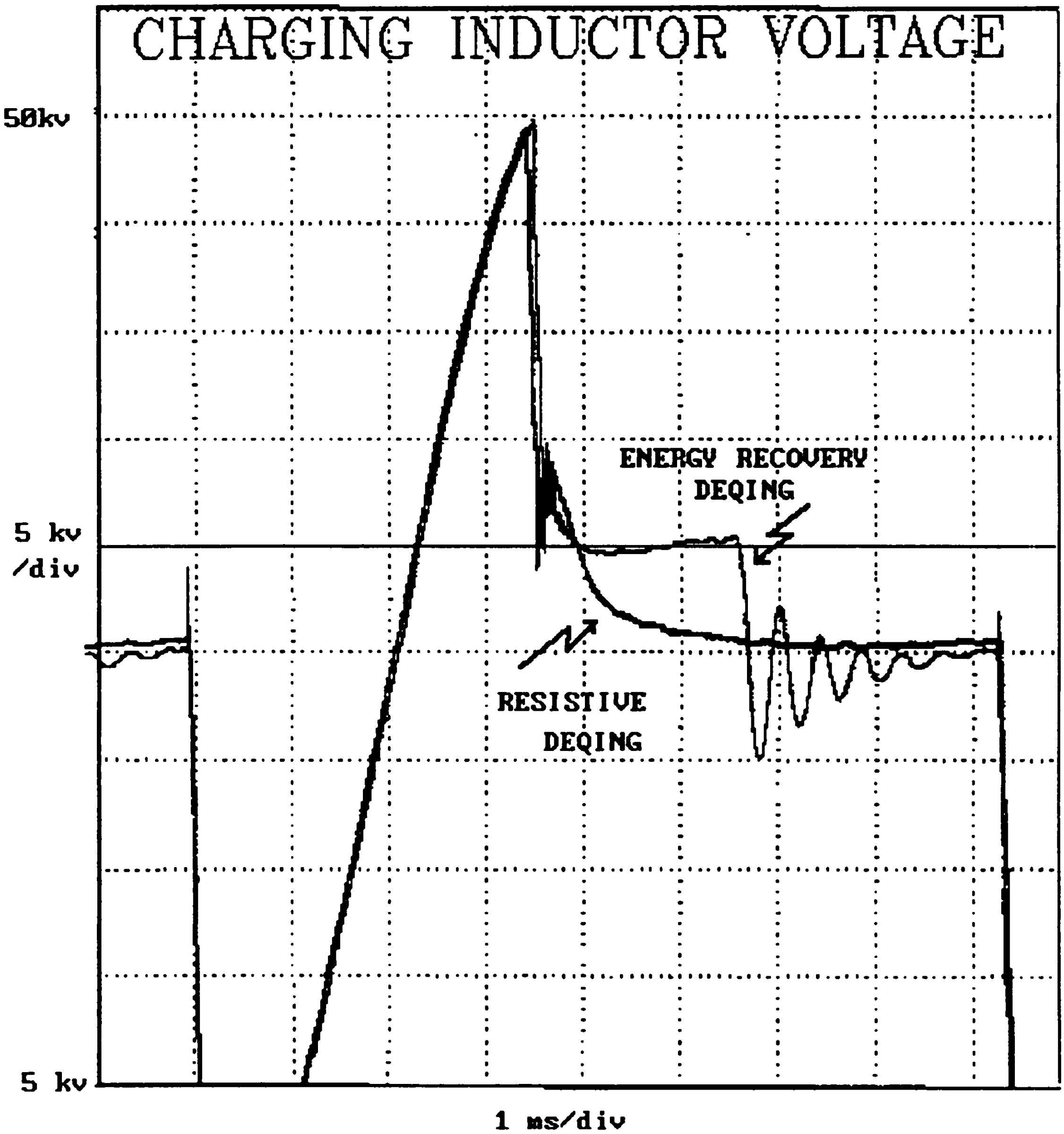
* High efficiency modulator, good regulation

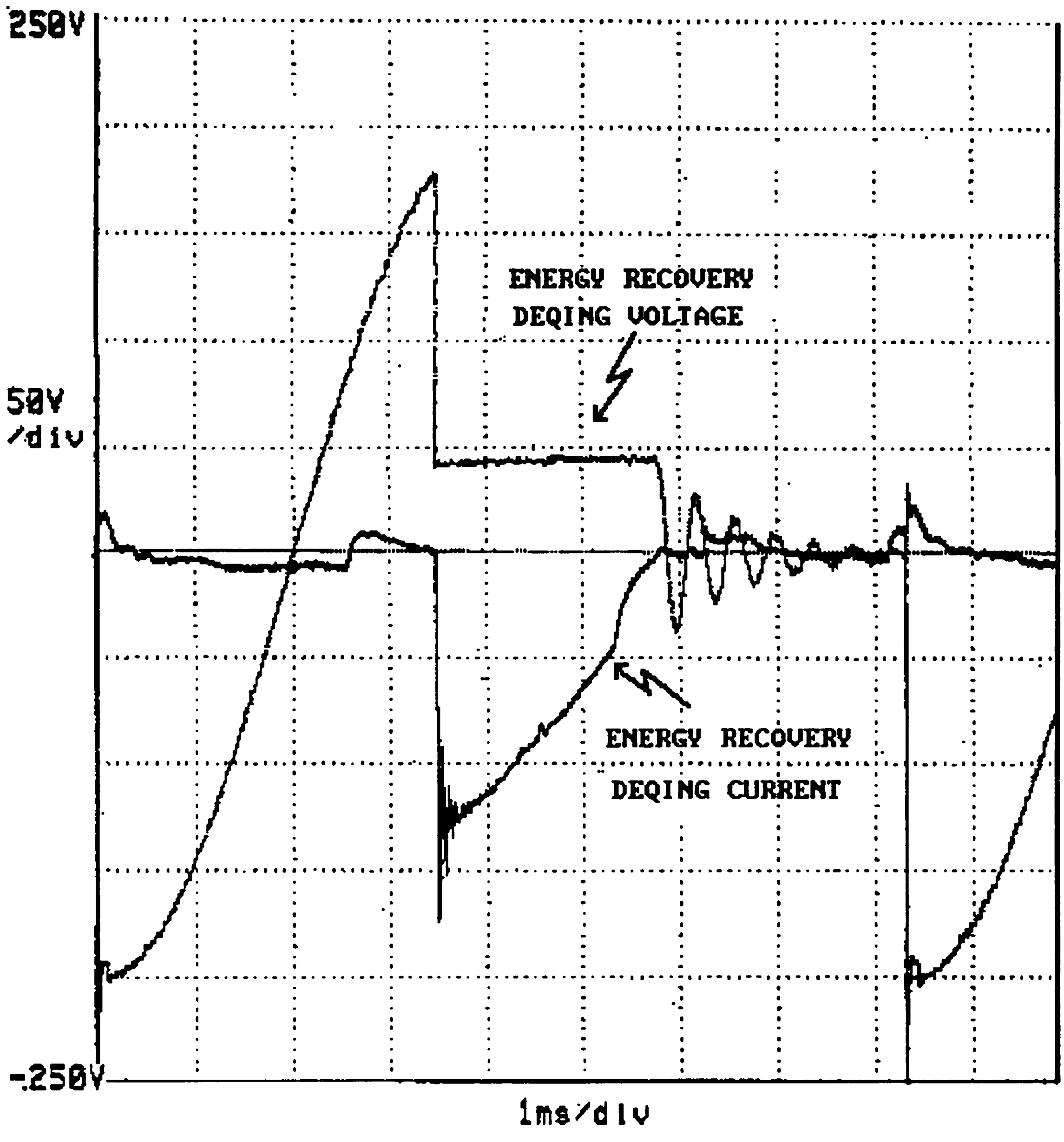
* No residual DeQing current independent of rate

Stanford Linear Accelerator Center

27-SEP-90

SLAC ENERGY RECOVERY DEQING





250V
50V
/div
-250V
ENERGY RECOVERY
DEQING VOLTAGE
ENERGY RECOVERY
DEQING CURRENT
1ms/div

COMMAND CHARGING

R. Cassel
10/1/91

* PFN Voltage independent of repetition rate

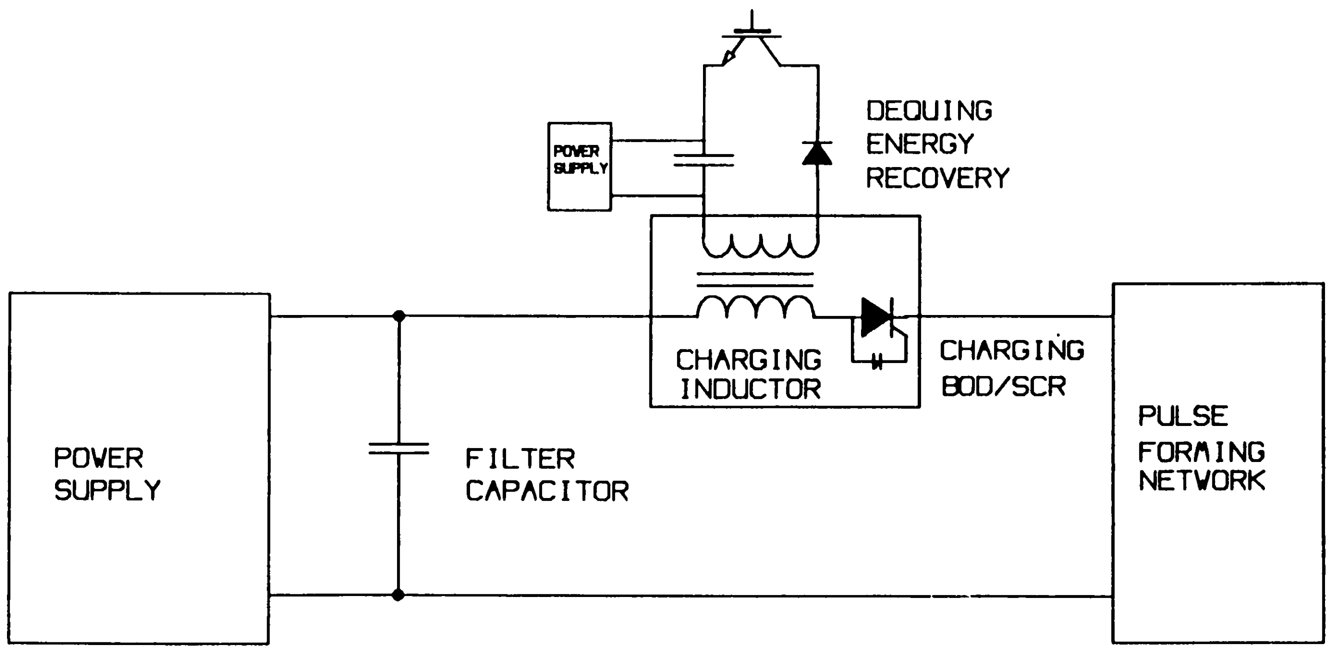
* Thyratron has a long deionization time.

* Additional method to stop pulsing under klystron fault

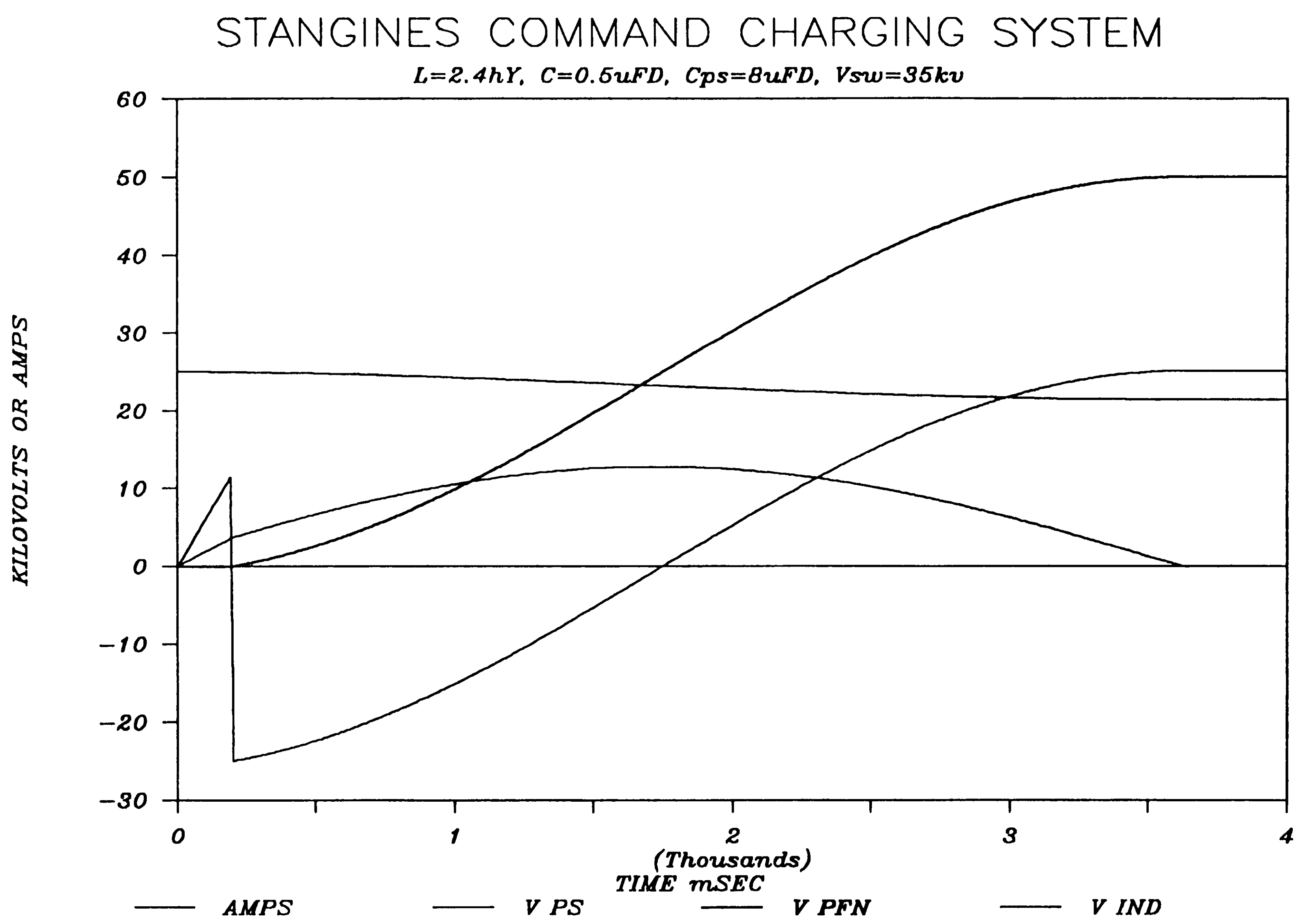
Stanford Linear Accelerator Center

COMMAND CHARGING

Stangenes Industries Inc.



R. CASSEL
9/29/91


STANGINES COMMAND CHARGING SYSTEM
L=2.4hY, C=0.5uFD, Cps=8uFD, Vsw=35kv
60
50
40
30
20
10
0
−10
−20
−30
KILOVOLTS OR AMPS
0
1
2
3
4
(Thousands)
TIME mSEC
AMPS
V PS
V PFN
V IND

GROUNDED PFN/TRANSFORMER

R. Cassel
10/1/91

* Reduce inductance from PFN to pulse transformer

* Reduce stray capacity discharge from PFN

* Reduce space for PFN

Stanford Linear Accelerator Center

END OF LINE CLIPPER

R. Cassel
10/1/91

* Absorbs energy for klystron short no thyrtron reverse current

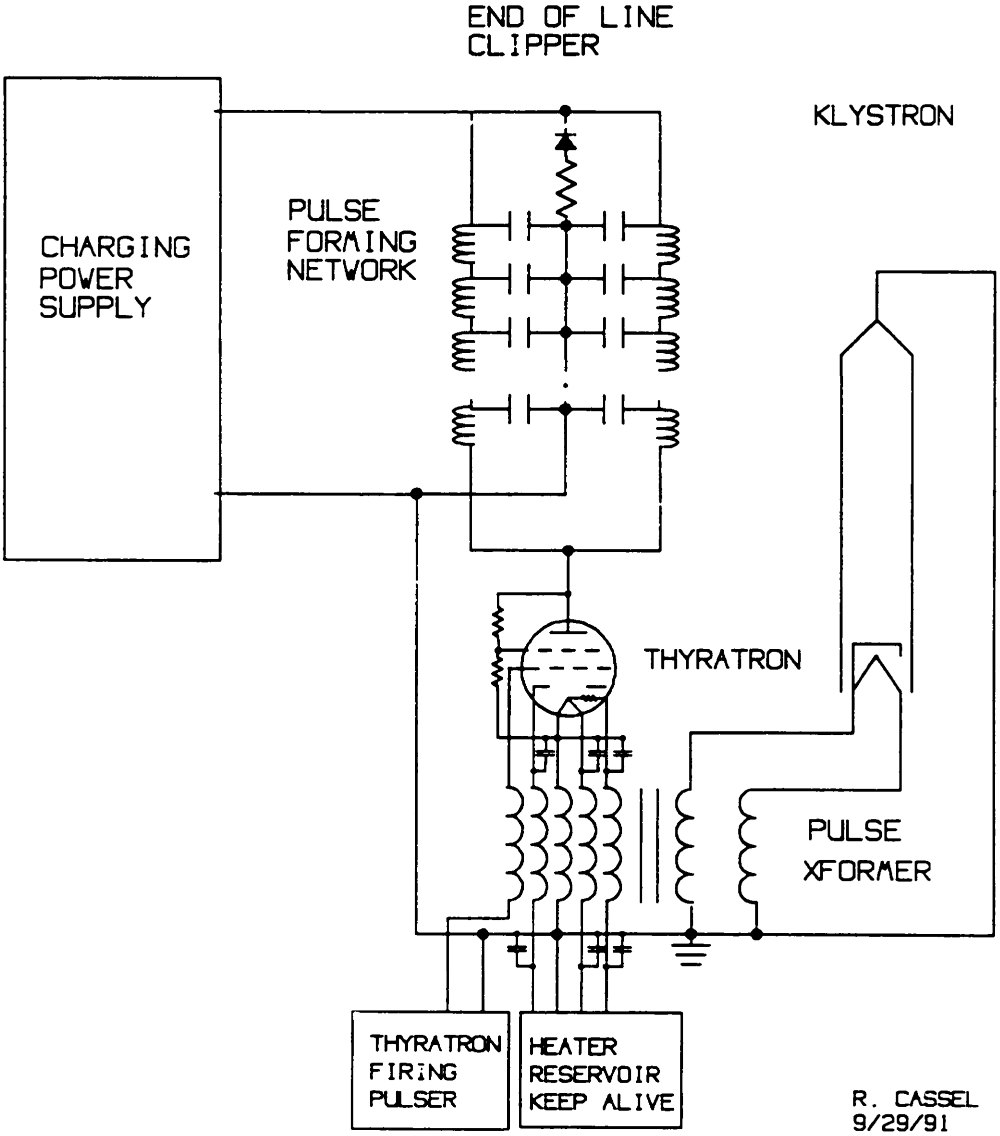
* Prevents reverse voltage due to magnetizing inductance

* Indicate klystron arcing

* Reduce klystron reverse voltage

Stanford Linear Accelerator Center

GROUNDED PFN/TRANSFORMER



R. CASSEL
9/29/91

RECTIFIED KLYSTRON HEATER POWER SUPPLY

R. Cassel
10/1/91

* Reduce phase changes in klystron due to heater current

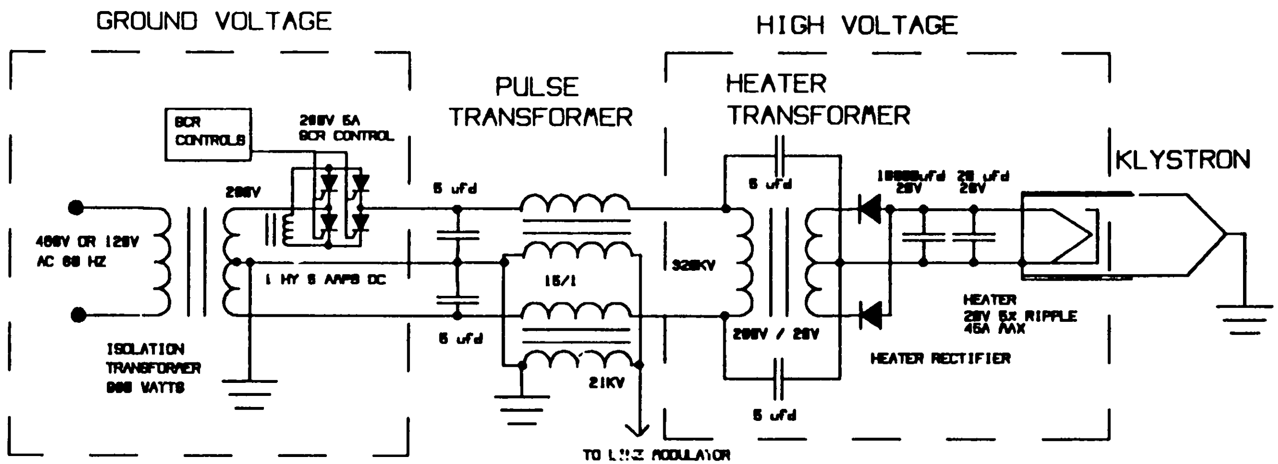
* Power / temperature regulation of Klystron heater

* Reduce size of pulse transformer due to heater current

* Reduce heater current inrush during cooled start up

Stanford Linear Accelerator Center

KLYSTRON HEATER POWER SUPPLY
200 TO 900 WATTS



R. CASSEL
3/22/90

NLCTA Klystron
Modulator rise time problems:

Rise time
goal 100 nsec

1) Thyratron rise time

* Thyratron inductance from 200 to 300 nhy
  (impedance must be greater than 3 ohms)

2) Klystron capacitance

* klystron impedance greater than 1000 ohms
  (klystron capacitance <100 pfd)

3) Pulse transformer inductance

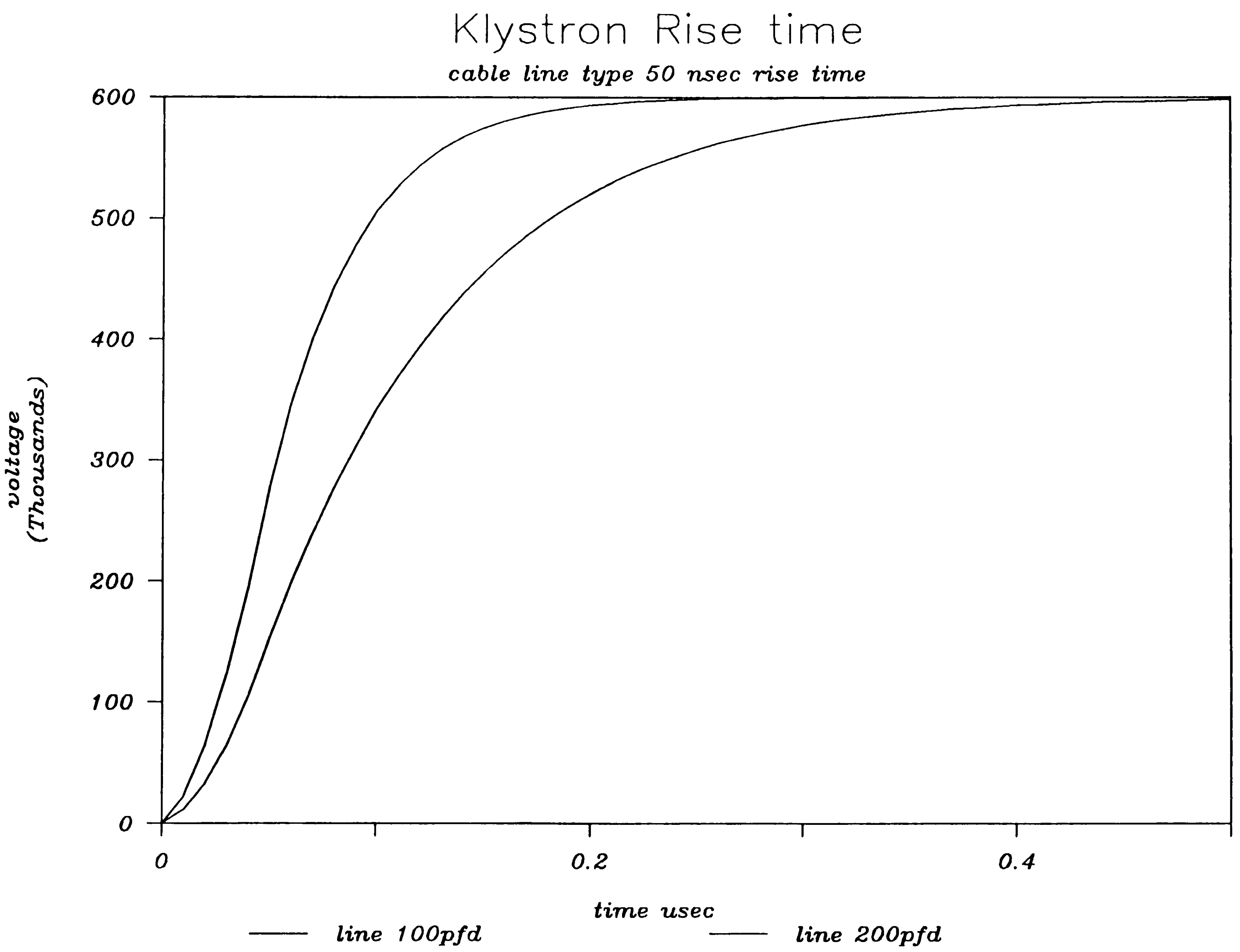
* klystron impedance 1000 ohms
  (leakage inductance secondary <100 uhy)

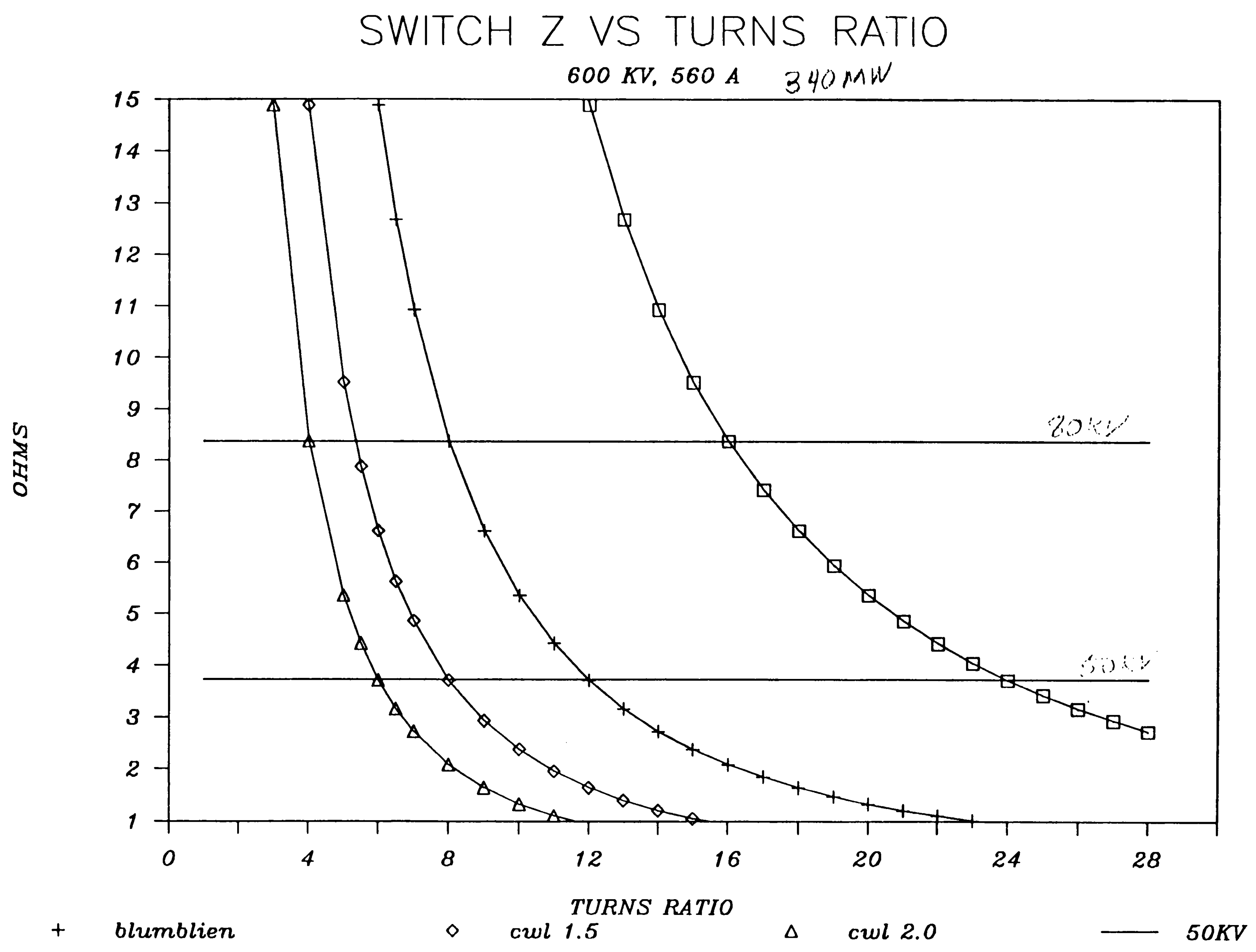
4) Number of PFN sections

* rise time approx (pulse length)/(number of PFN sections)
  (number of section greater than 10)
  (cable rise time <30 nsec)

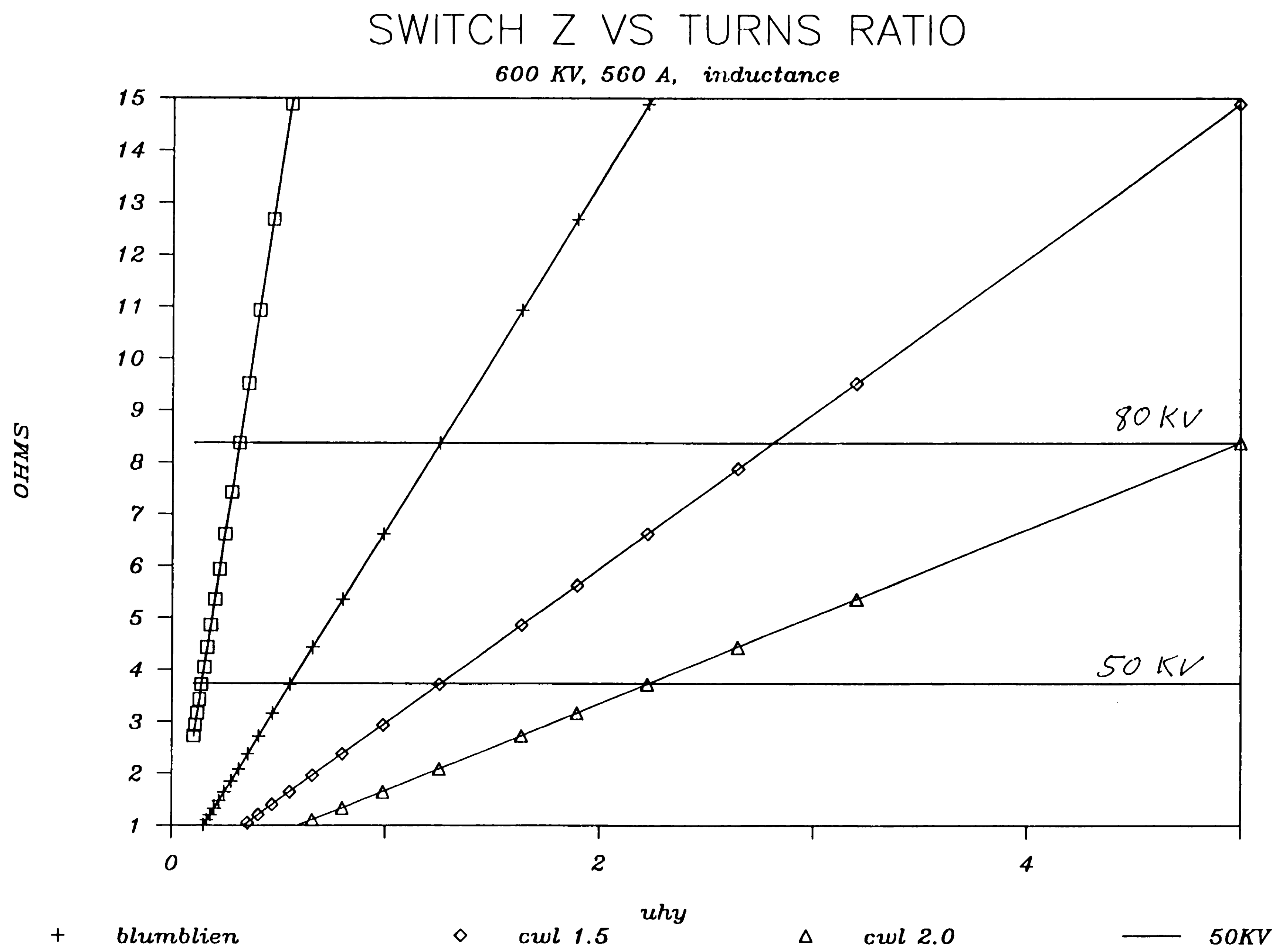
4) Stray inductance/ capacitance

* impedance less than equivalent PFN, transformer, thyratron
  (depends on type of system used)


Klystron Rise time
cable line type 50 nsec rise time
voltage
(Thousands)
600
500
400
300
200
100
0
0
0.2
0.4
time usec
line 100pfd
line 200pfd

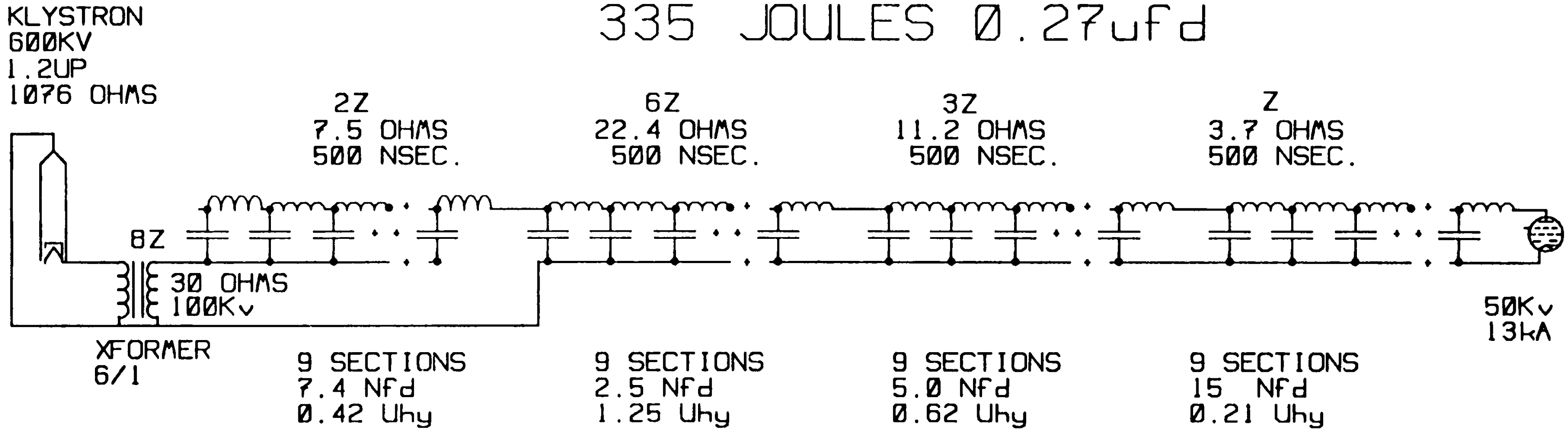


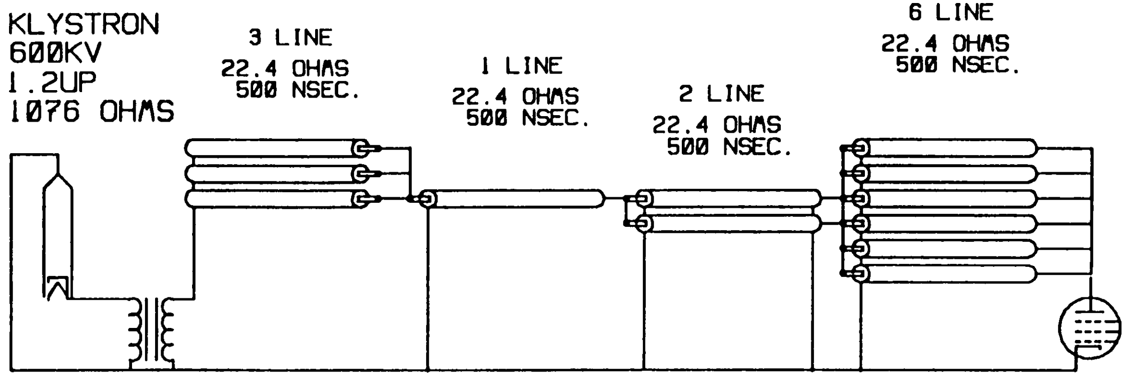
SWITCH Z VS TURNS RATIO
600 KV, 560 A
340 MW
OHMS
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
4
8
12
16
20
24
28
TURNS RATIO
+ blumblien
◇ cwl 1.5
△ cwl 2.0
50KV


SWITCH Z VS TURNS RATIO
600 KV, 560 A, inductance
OHMS
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2
4
uhy
80 KV
50 KV
+ blumblien
◇ cwl 1.5
△ cwl 2.0
— 50KV

KLYSTRON TEST STAND

335 JOULES Ø.27ufd

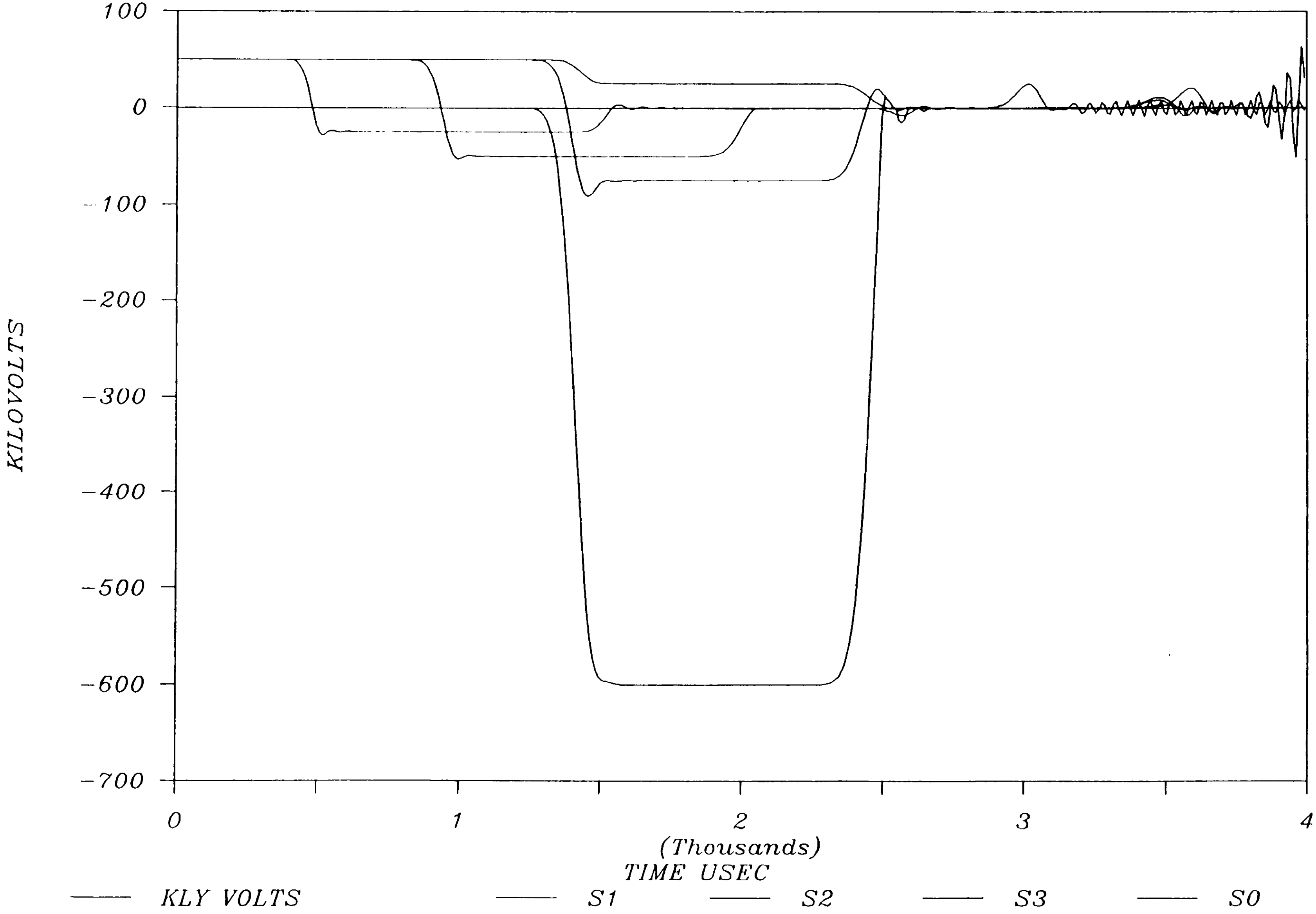




R. CASSEL
6/6/91

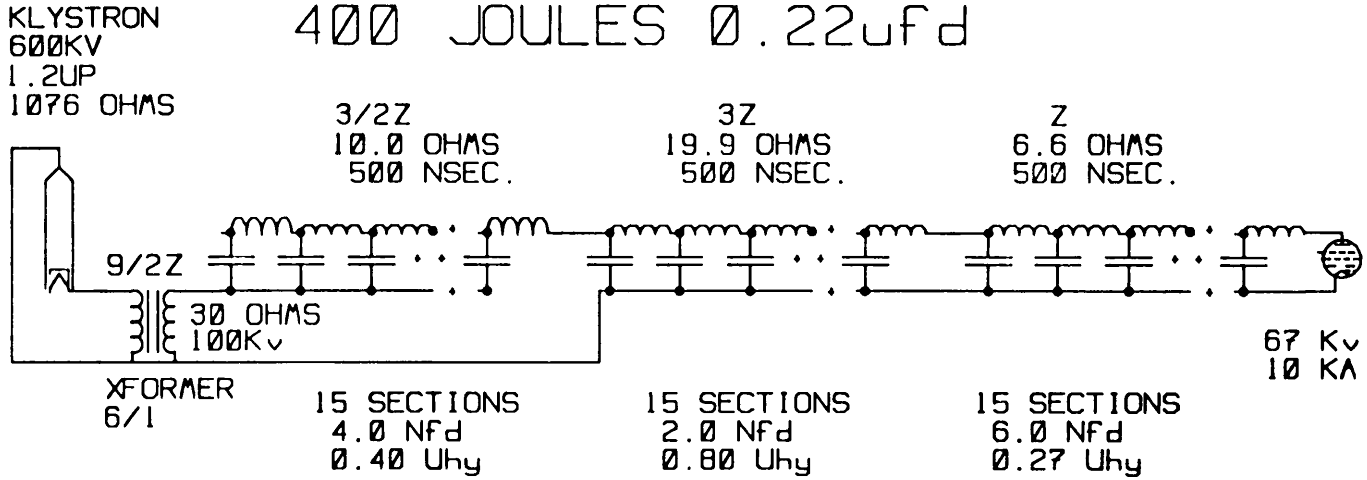
CWL KLYTRON MODULATOR

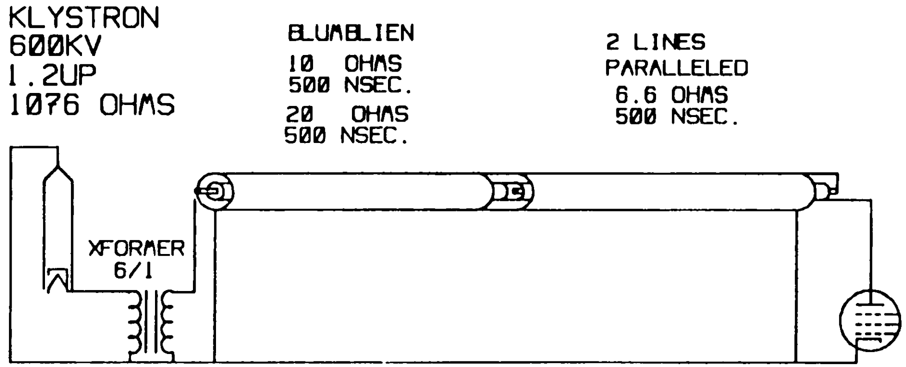
1.2 uP 3 STAGE 1 USEC 10 SECT 6/1



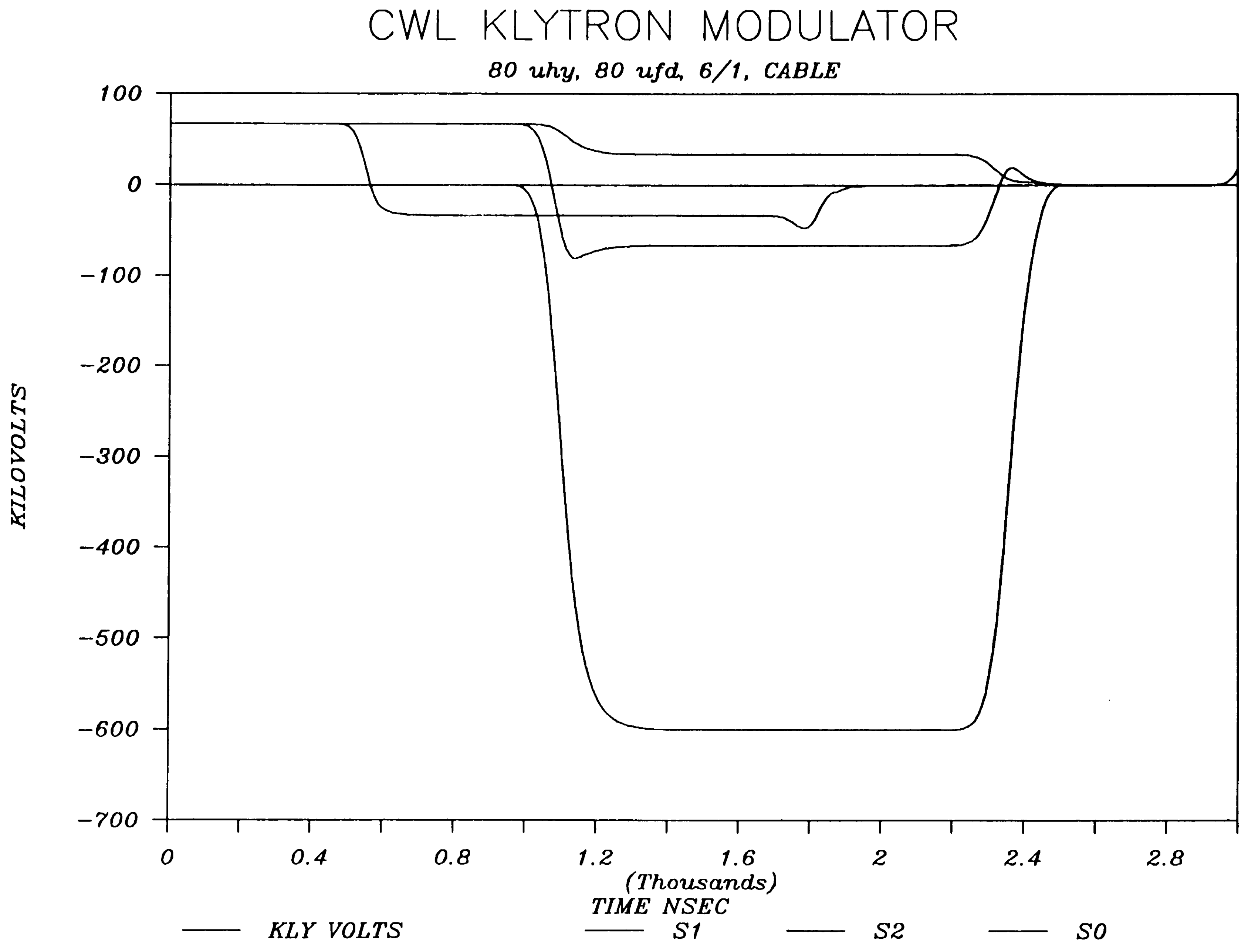
KLYSTRON TEST STAND

400 JOULES Ø.22ufd

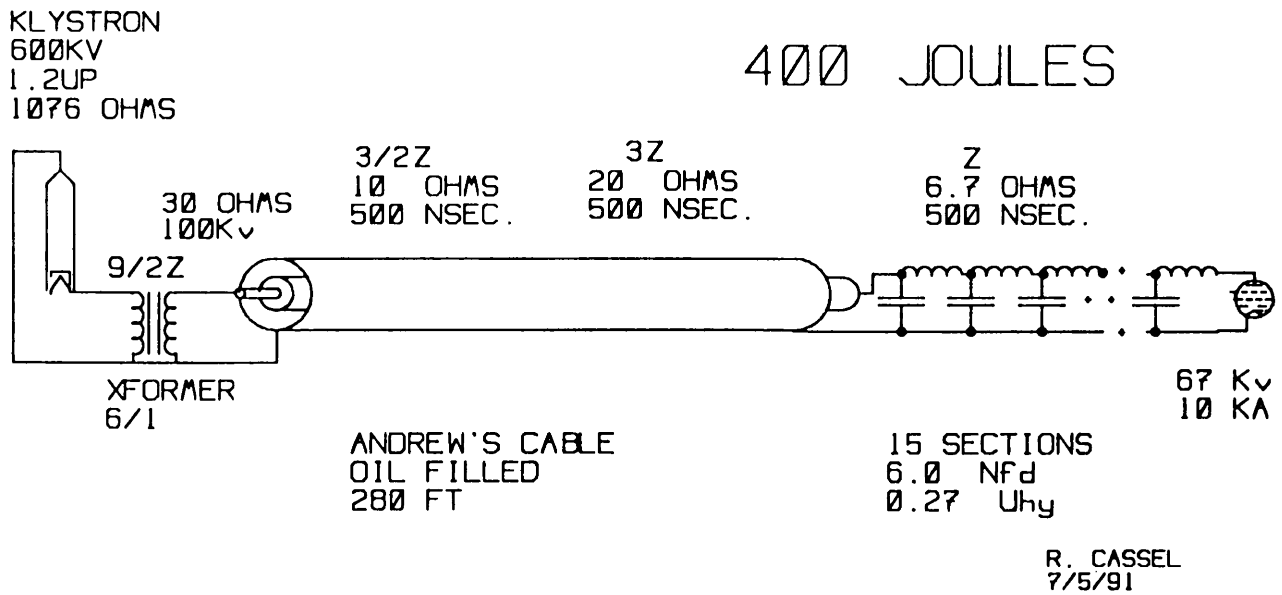




R. CASSEL
7/5/91

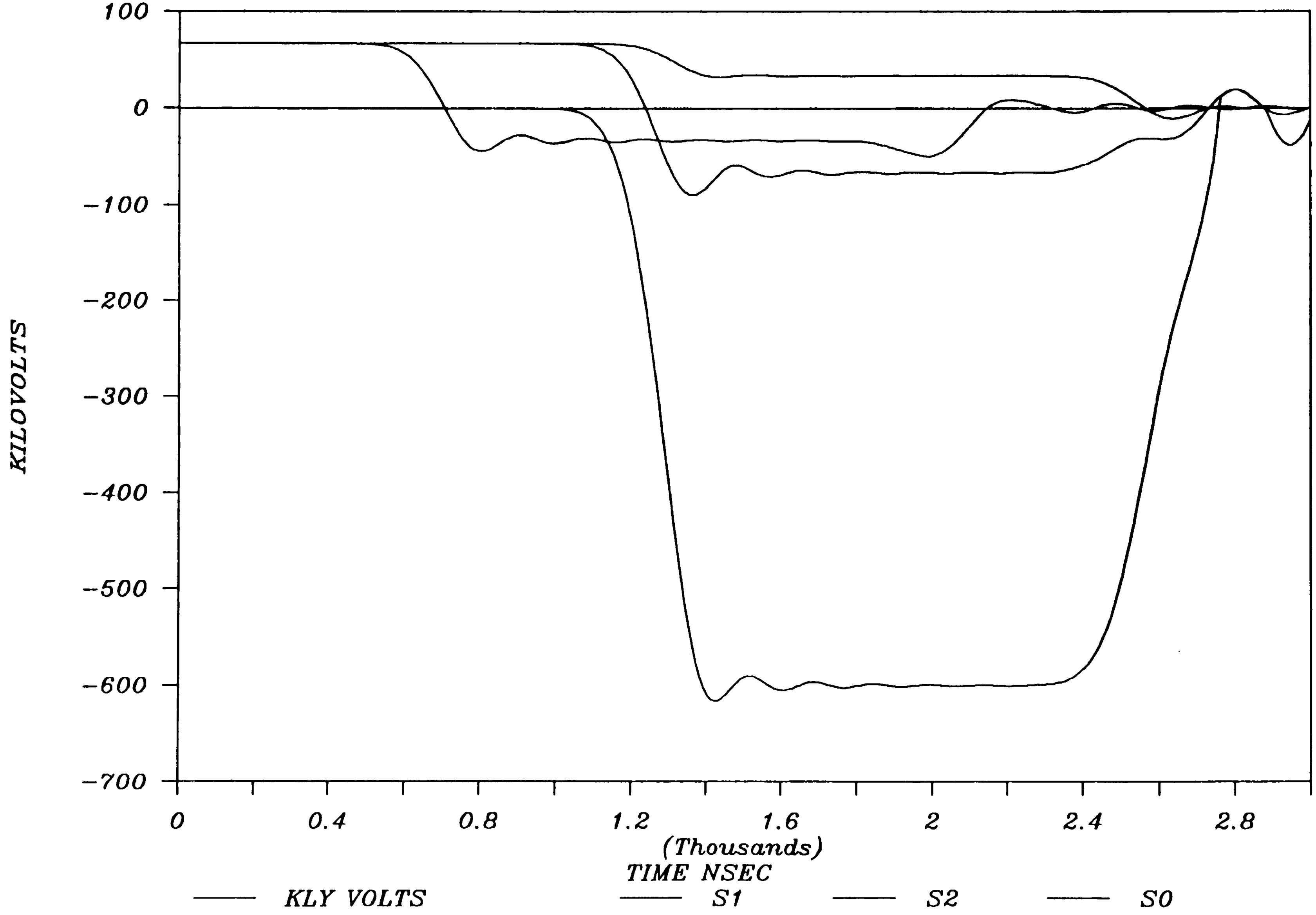

CWL KLYTRON MODULATOR
80 uhy, 80 ufd, 6/1, CABLE
KILOVOLTS
100
0
-100
-200
-300
-400
-500
-600
-700
0
0.4
0.8
1.2
1.6
2
2.4
2.8
(Thousands)
TIME NSEC
KLY VOLTS
S1
S2
S0

KLYSTRON TEST STAND

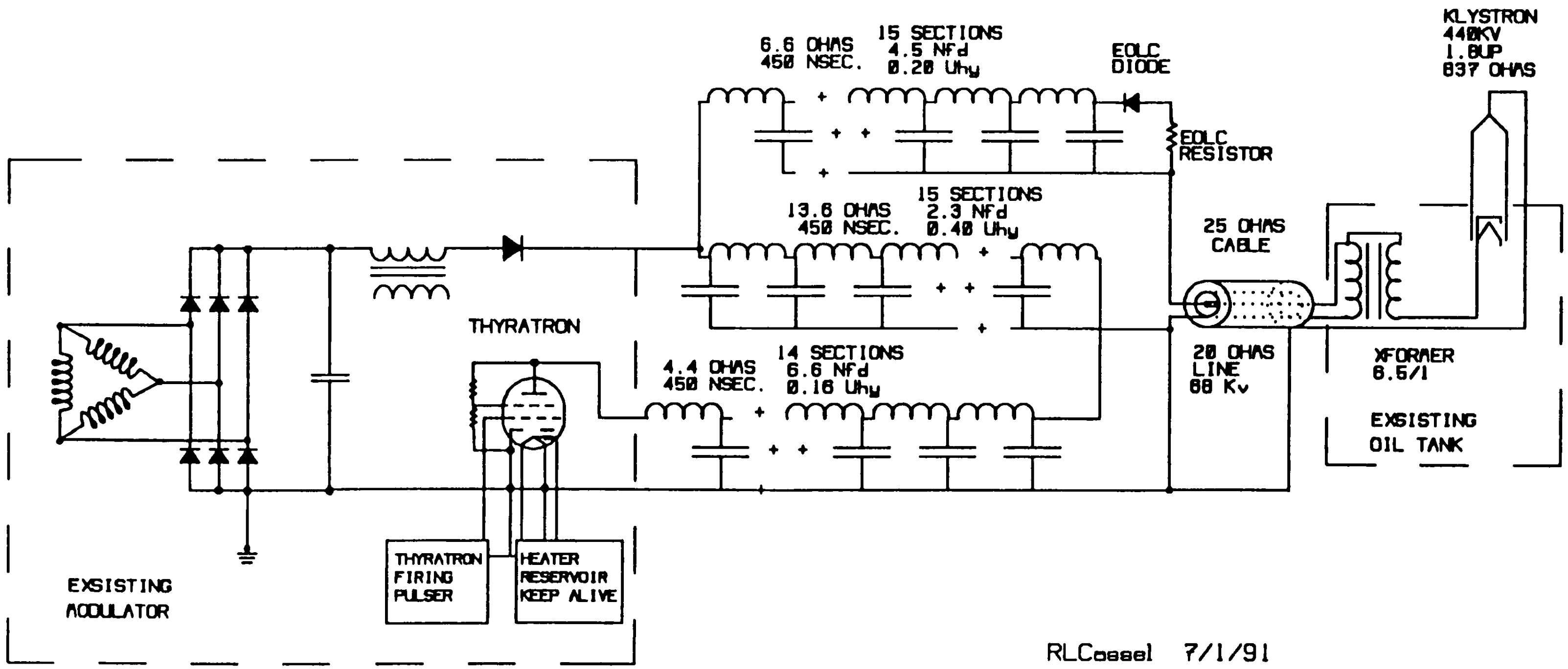


CWL KLYTRON MODULATOR

80 uhy, 220 ufd, 6/1, 15 SEC + CABLE



440KV TEST STAND MODULATOR PROPOSAL 1.8 μP 0.8 μSEC



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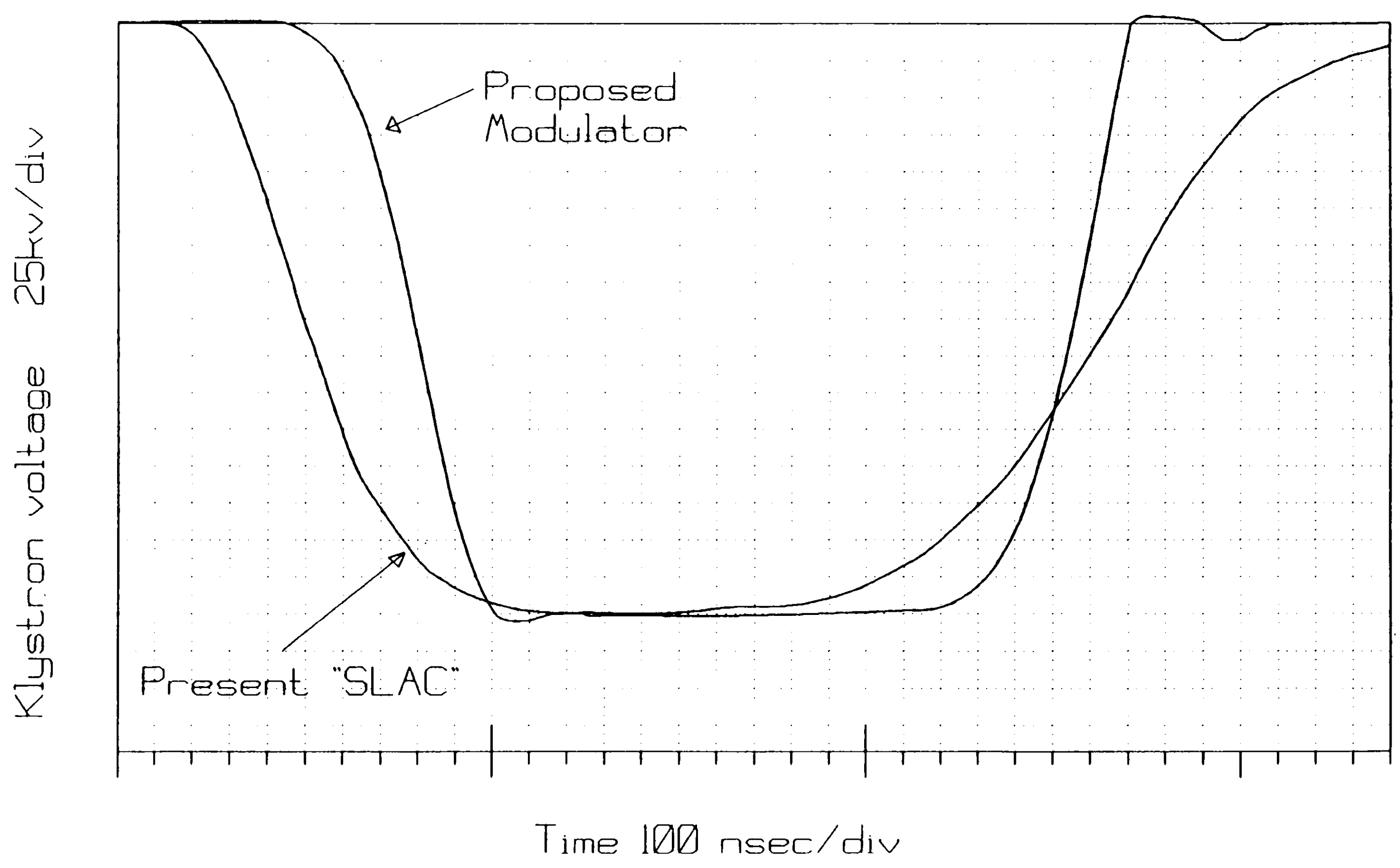
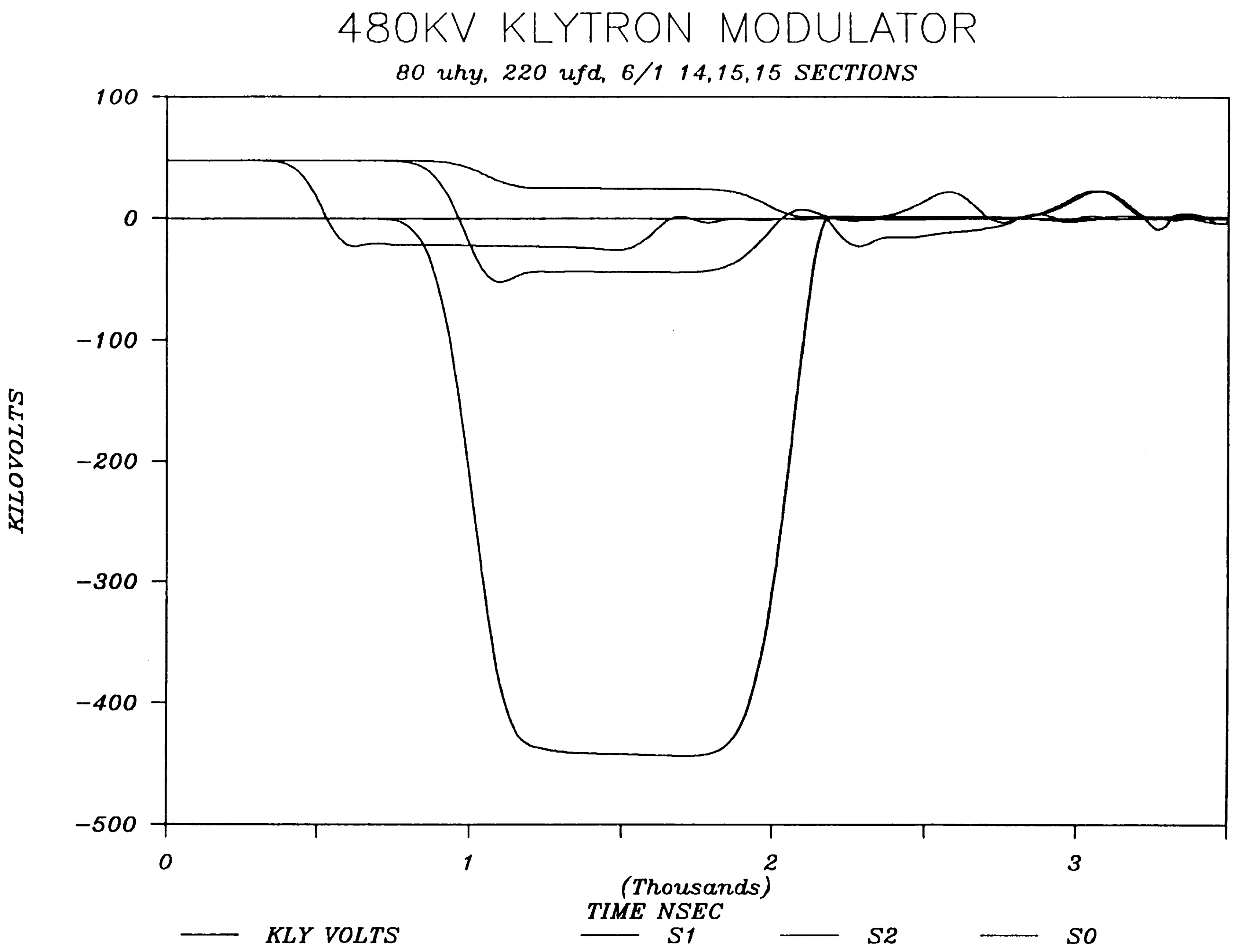
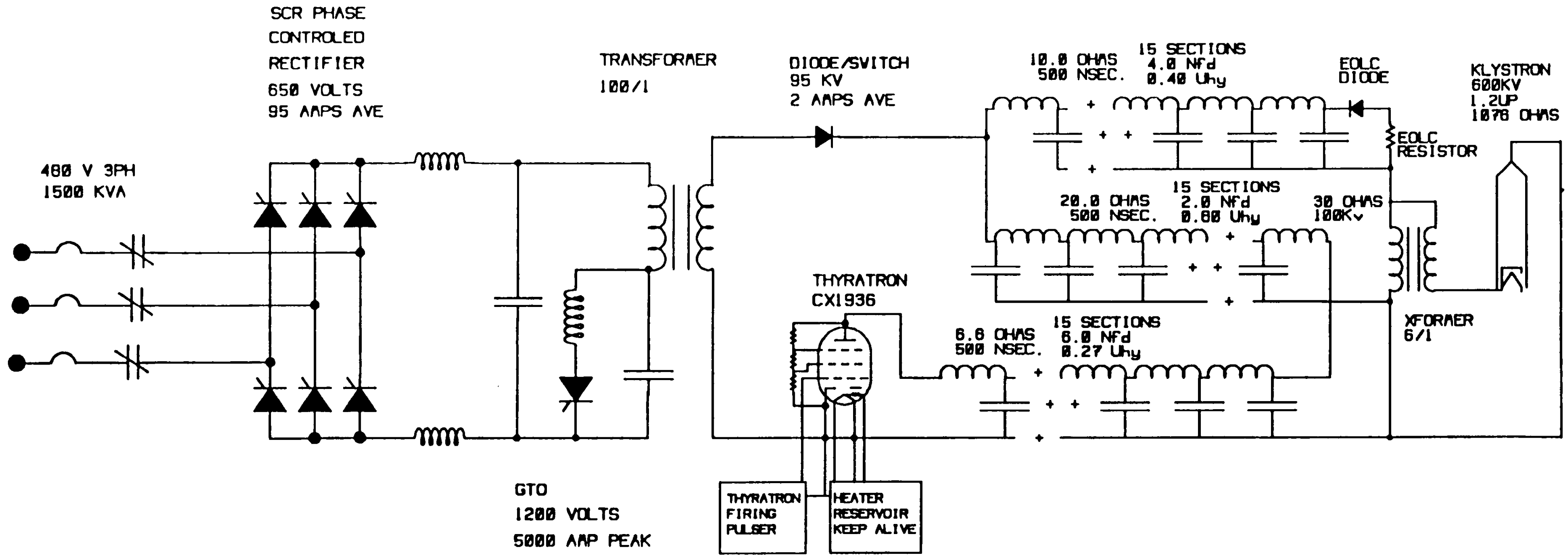
KLYSTRON MODULATOR VOLTAGE WAVEFORM



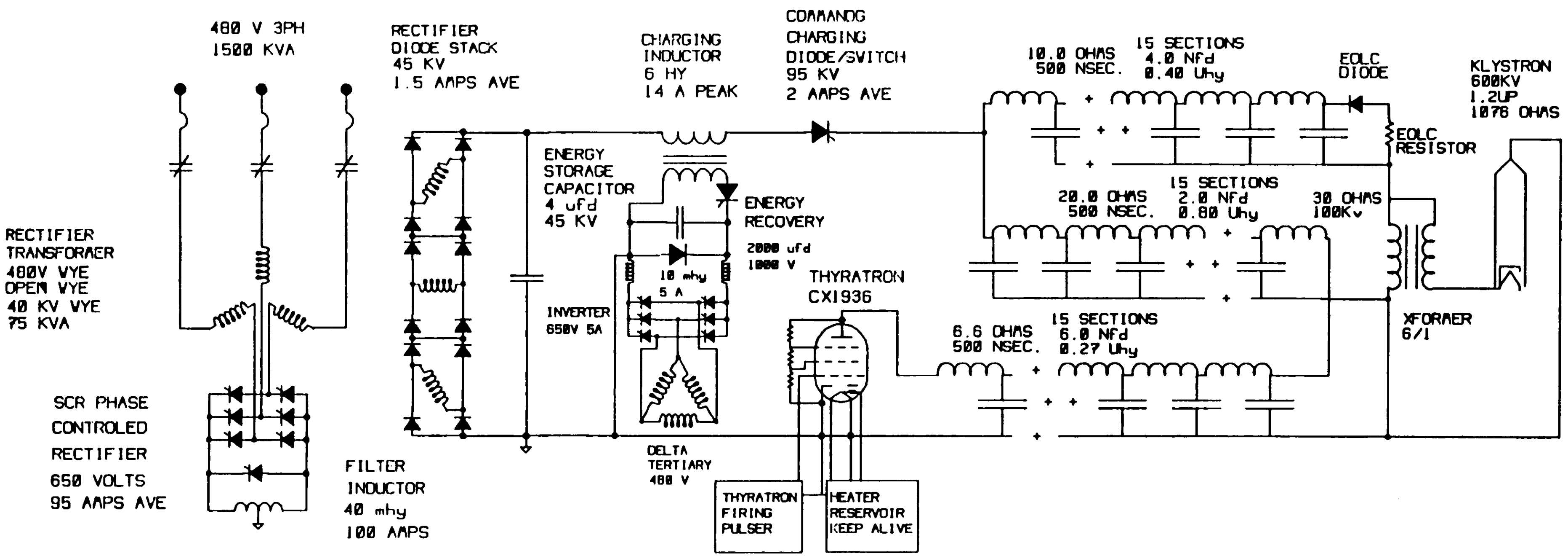

480KV KLYTRON MODULATOR
80 uhy, 220 ufd, 6/1 14,15,15 SECTIONS
100
0
-100
-200
-300
-400
-500
KILOVOLTS
0
1
2
3
(Thousands)
TIME NSEC
KLY VOLTS
S1
S2
S0

NLC MODULATOR



RLCassel 7/29/91

NLC TEST STAND MODULATOR



RLCassel 6/23/91

LIL Modulator Systems

P.D Pearce, PS Division, CERN

1) Introduction

The LIL machine produces sequentially, beam pulses of e- and e+ at a repetition rate of 100Hz. These pulses are accumulated in 4 or 8 bunches in the EPA ring and then ejected to the PS machine. This 530MeV beam is then accelerated to 3.5GeV before ejection to the SPS, where it is further accelerated to about 20GeV before being sent to the LEP. The PS machine complex with the location of the LEP Injector Linac (LIL), is shown in Figure 1.

2) LIL machine configuration

There are six modulator stations in the present LIL machine that are used for beam acceleration. A seventh modulator is a spare parts device, but is used also for CTF experiments. A dedicated test modulator is in the process of being constructed. This will be used for conditioning new klystrons and thyratrons, testing repaired controls and interlock equipment, developing new components or configurations and for developing technicians maintenance procedures and skills. This modulator will be commissioned and be ready for use as a test facility in June 1992.

The present machine LIL configuration is as shown in Figure 2 (A). The thermionic gun works at around 80 to 90kV with a perveance of about 0.8x E-6. The peak cathode current is of the order of 9A, from a cathode area of about 10 cm2. The electron beam is bunched by the 15 mm long prebuncher placed at a distance of 100mm from the buncher. The buncher is a triperiodic structure and is located inside a solenoidal field of 0.2T and works in standing wave mode. The 4MeV beam produced out of the buncher is accelerated by each of the 4.5 metre linac structures as shown. The RF power needed for the newly installed buncher and pre buncher, is 2.8MW . This means that the klystron used in this position has an easy life compared to the others in the machine. The first four acceleration sections are powered from one klystron running at 24.5MW and fitted with a pulse compressor. The acceleration per section used is about 55MeV per section and the voltage gradient is 12.5MV/m. The electron beam energy striking the converter target for producing positrons is around 220MeV. The RF power provided by the klystron modulators accelerates the beam up to 530MeV for injection into the EPA storage ring. The acceleration per section in the LIL W part of the machine is around 44MeV.

A possible future machine layout, when an improved positron production rate could be required is shown in Figure 2 (B). This configuration change would probably have to be done in stages in order to keep the machine operational as much as possible between modifications. The first step in this direction to test out a small part of the basic arrangement will start in early 1992. A pulse compressor (LIPS), will be fitted to the last modulator station (MDK35) to provide RF power, at a high gradient, for these last two accelerator sections. Following good results here the next stage for conversion could be modulator station MDK25, just after the converter target, to improve collection efficiency. The moving of the converter target further downstream would require significant changes to the machine layout, as will introducing further modulators, and will require careful planning and installation.

3) Operating parameters

The modulator and LIL parameters are shown in Figure 3. The klystron voltages and currents are those of a new device operating at the maximum of 35MW. However the klystrons do not at present need to have the output power increased above 25MW . The future layout will require that all stations run at between 17 and 30MW. The typical peak thyratron anode voltage used today is between 32 and36kV.

4) Output power

In the present machine setup the RF power profile produced from the klystrons, down the linac , is as shown in Figure 4. This also shows the reduction of power requirements for the first station (MDK03). This reduction in RF power is the result of installing a new pre-buncher /buncher in the machine during the 1990/91 winter shutdown. This means that there is one position in the machine where old, low perveance klystrons could be fitted to obtain maximum lifetime from them. This however is not a long term solution that can be used instead of a klystron replacement planning programme.

5) The modulator basic circuit

The basic circuit diagram of the LIL modulators is shown in Figure 5. These modulators were constructed for CERN under a collaboration with LAL Orsay laboratory, using the well tried SLAC layout. The circuit analysis and detailed electrical design was made in CERN as part of the collaboration. The RF pulse compressors shown earlier also originate from a SLAC design , and are more commonly known as SLED devices.

The modulator has a primary 3 phase charging system with the charging choke feeding a 6 microfarad storage capacitor. The stability of the voltage on the PFN is assured by the D'quing system which operates basically when the measured voltage equals the required reference voltage. The voltage stability obtained at the PFN is of the order of 0.1%.

The PFN is a lumped component assembly with 25 capacitors of each 25nF. The inductors are slug tuned with a minimum inductance (slug fully in) of about 0.7 microH. As a klystron gets older and the perveance decreases, its dynamic impedance increases. This means that to maintain the 10% positive klystron load mismatch, used to create a long period of relatively low inverse voltage on the thyratron to help its recovery, the PFN inductors need frequent re-adjustment by means of the tuning slugs. Figure 6 shows the range of adjustment possible on the lowest curve. The higher curve is what is possible in order to match the klystron over most of its lifetime with the coil compressed. Future coils will have an extra turn to make this adjustment easier, and not have to compromise between flat top quality and mismatch.

The HV filter or de-spiker circuit between the charging power supply and the PFN/thyratron assembly was one of the components to fail early in the life of these modulators. This has been redesigned (two versions exist) which use commercially available components rather than the homemade capacitor using two concentric copper tubes and polypropelene waste water pipe as the dielectric. The latter regularly broke down after a 100 hours or so. Nylon fire wires were installed on the filter resistors, connected to the interlock system, after one of these burnt up inside the faraday cage causing some damage.

The end of line clipper circuit was redesigned to use more robust diodes, capacitors and resisitor assemblies. Very few problems have been experienced with the klystron tank components, like the pulse transformer and chokes. The triaxial high voltage cable that connects the PFN voltage pulse to the tank has also been reliable, after the initial development of getting the earth connections in the correct place. Figure 7 shows the components inside of the high voltage klystron tank.

The capacitive divider used for high voltage measurement of the 270kV on the klystron cathode has a ratio of 30,000:1 and the top end is 0.7picoFarad. This capacitive divider uses the tank oil as its dielectric. The high ratio value enables a small 10 volt analogue signal to be produced for the electronics but reduces the measurement precision. Also, as the oil degrades the division ratio changes and so does the read-out voltage value. Since the klystron perveance is also changing during its active life this signal cannot be used exclusively as an accurate means to recalibrate the readout or calculate the perveance values with. The PFN charging voltage and mismatch must be accurately measured, enabling the high voltage value and perveance to be calculated from the results.

6) Running data

Most of our present problems revolve around the running and adjustments of the thyratrons and klystrons, and in obtaining a reasonable lifetime from them. The six modulators are equiped with klystrons from Thomson (type Th2094) or Valvo (type YK1600). Figure 8 shows the operating parameters of MDK27 taken recently. This modulator has a Thomson klystron which has run for nearly 15,000 heater hours with 14,000 high voltage hours, and now has a perveance of 1.85 E-6. The starting value was about 1.95 E-6.

The thyratron used in all modulators at present is the ITT KU275C . The number of klystron and thyratron tubes that have been replaced in the total system, with the range of lifetimes obtained are shown in Figure 9.

7) Thyratron management

Figure 10 shows the regular reservoir voltage adjustments needed with the KU275C thyratrons in order to compensate for the gas clean-up and loss of pressure with lifetime. When the tube is new these adjustments are made at about 2000 hour intervals, and as the tube gets older this becomes every 500 hours or less. At this moment the faulty shot rate and the subsequent modulator downtime increases. The thyratron must then be replaced. Older tubes that function with a high reservoir voltage and low fault rate recover their performance after a machine stop of a week or so, and require a lower reservoir voltage to start-up with. Then after a period of two days the reservoir voltage has to be increased again to the previous value to maintain modulator performance. When this stage is reached the tube must be replaced rapidly or suffer a period of repeated modulator stops due to thyratron current extinguishing during the pulse. The effects of this is shown in Figure 11, where the low gas pressure in the thyratron tube causes it to extinguish towards the end of the current pulse. This photo shows this effect as seen on the applied klystron voltage pulse at its cathode.

8) Klystron management

The variation of klystron perveance, up to the present, of some of those tubes used in the LIL machine are shown in Figure 12. We have noticed that those klystrons with a more peaky power curve are more likely to be those tubes that will have a rapid fall off in perveance between 10,000 and 15,000 heater hours.The klystrons with flatter power curves seem to decrease in perveance at a slower rate. The tube labelled No 2 is one of these, whilst No 5 is one of the first types. These observations, as well as those for the KU275C thyratrons should be treated with caution since they come from a very small statistical sample size with only seven modulators actually in use.

In order to improve the lifetime of our klystrons, which are not operating anyway at the peak output power specified by the manufacturers, we have adopted a number of procedures at the start of this years machine run. These are shown in Figure 13. The focal currents have been set for that used in operation at 270kV. The actual power and voltage needed for that tube being then set as needed. This means accepting a loss of gain and efficiency in exchange for some operator flexibility over the long term. The klystron voltages can then be increased by the operators to compensate for a power reduction of that station without having to re-adjust focal currents, which is a delicate operation. With new klystrons the heater voltages are reduced from the nominal by about 10% to decrease slightly the cathode temperature. The life of the cathode is a normally a function of heater power, and the temperature limits within which the cathode can work safely depends on the emission density drawn from the cathode. With too low a heater power, sparking occurs at the cathode surface, whilst with too high a level the increased cathode emission causes evaporation of the barium and thorium in the oxide structure and a subsequent reduction in tube lifetime. The Thomson cathodes are very insensitive to heater voltage variations, whilst the Valvo cathodes respond quite quickly.

Another method being used to try and increase lifetime is to reduce by about 40% the klystron heater voltage when the LIL beam is not required for operation. Since this situation may last several hours, when the tube would previously have been completely heated, just waiting, and using up its useful life without providing acceleration power. This new state is called the economy mode. This also means that sufficient heating time must be allowed after putting the modulator into a ready- for- pulsing state (Standby), before the high voltage is applied. In our case this heating-up time is about 7 minutes.

Typical power curves for one our klystrons are shown in Figures 14 and 15. The Figure 14 shows operation with focal currents adapted to each level of the klystron voltage and output power. Figure 15 shows how we are running at present with the focal currents set for the highest klystron voltage we want to use and the applied voltage adjusted for the required output power. It is evident that more input drive is needed to obtain the same output power under saturated conditions for this mode of operation.

9) Modulator faults

Figure 16 shows the relationship between output power level (high voltage on the klystron) and faults in the various modulators for the 1990 running period. It also shows the results of the breakdown voltage tests using the Bauer test procedure, performed on the insulating oil in the klystron high voltage tanks over the same period. In Figure 17 the breakdown voltage test results for both 1990 and 1991 are shown. The differences are seen as being a result of improvements made to the condensation problem in the tanks during the 1990/91 winter shutdown.The lower output power in the MDK03 position may also have had an effect on the oil quality, probably due to running at a much lower voltage. The changes in oil breakdown strength as obtained in 1991 have been plotted in the third graph as a function of klystron power. The have been normalised to the 70kV test level.

10) Improvements

Some of the improvements that need to be made in the system are considered to be the following:

* An interlock memorisation system/programme that will enable intermittent faults to be captured and stored over a period of time.

* Computer logging of klystron and thyratron data to permit perveance values and lifetime statistics to be easily available for decision taking when tubes may need to be changed.

* Improving control rack screening and eliminate spurious tripping due to electrical noise.

* Possibly more frequent changing of our old klystrons and thyratrons for new ones.

* A test facility that will enable off-line testing of all components before installation into the operational modulators.

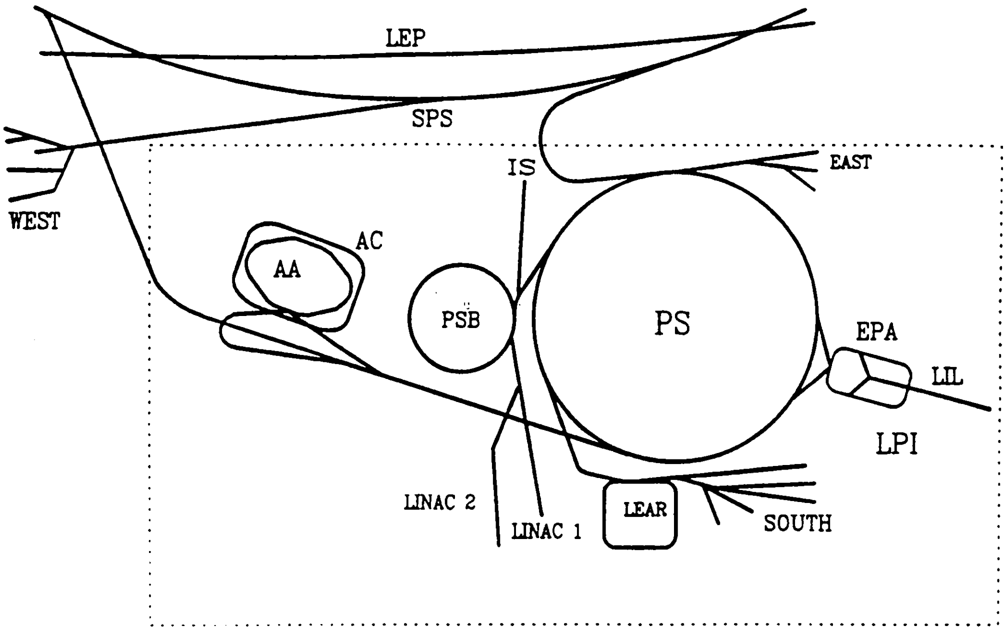


FIGURE 1.

LIL Modulator configurations

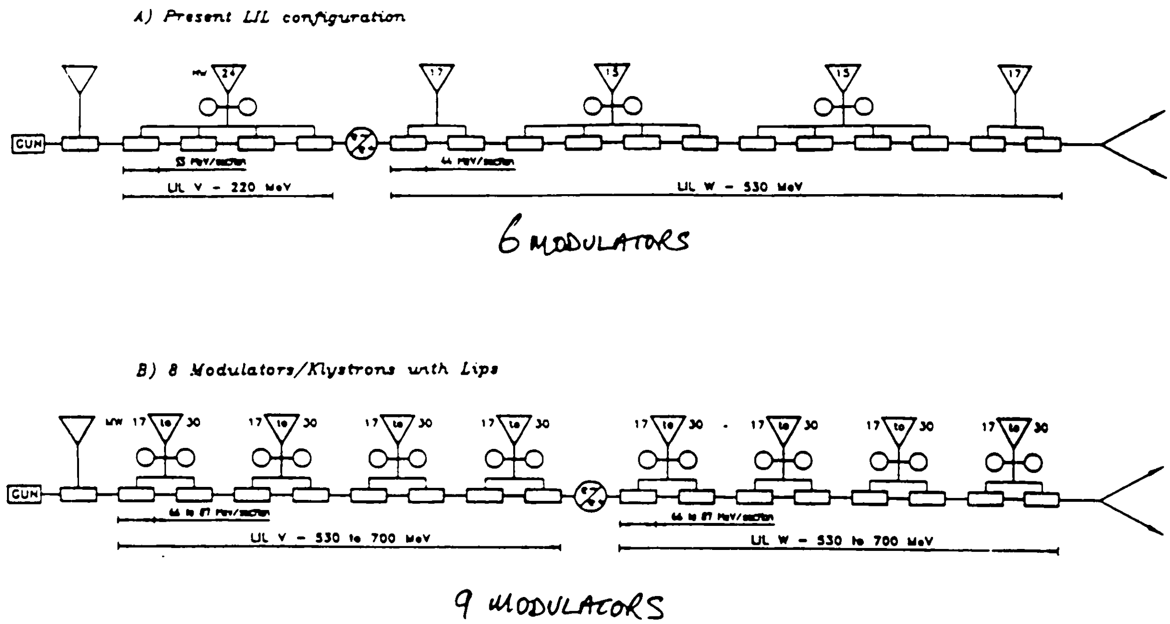
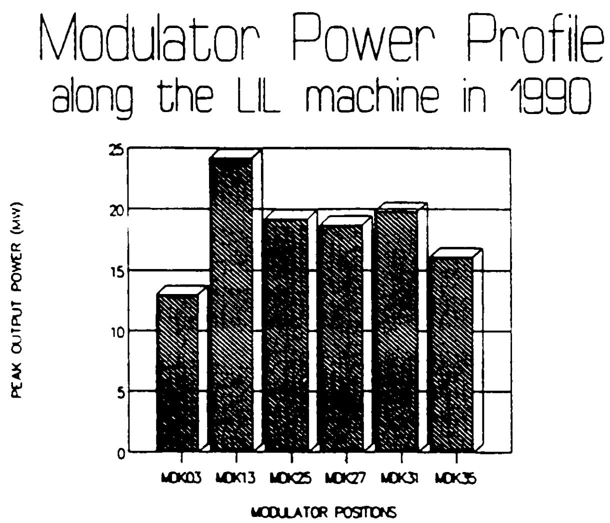


FIGURE 2.

Table 1: Present LIL Modulator Parameters

Accelerator Data:		
e+ production rate	4.8	10^{10} e^+/sec
Total No. LIL-V sections	4	
Electron beam hitting target	3.0	10^{11}
Electron beam energy	220	MeV
Klystron Data.		
Klystron frequency	2998.5	MHz.
Klystron voltage	275	kV
Klystron current	288	A
Microperveance	2.0	
- Peak output power	35.0	MW
- Peak input power	130	W
- Power gain	54	dB
- RF pulse width	4.5	μs
Modulator Data.		
Repetition rate	100	Hz
Thyratron anode voltage	42.0	kV
Thyratron anode current	3925	A
Pulse transformer ratio	1:13	
Voltage pulse width	6.5	μs
Nominal PFN impedance	5.0	ohms
Total PFN capacitance	0.625	μF
Peak charging current	7.7	A
PFN charging time	6.45	ms
Charging inductance	7.44	H

FIGURE 3



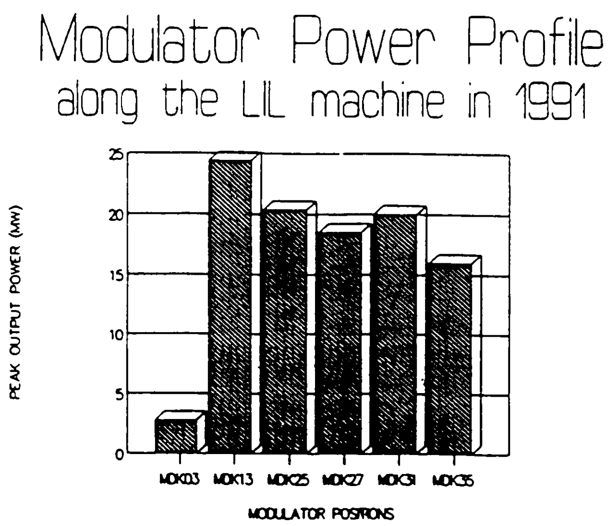
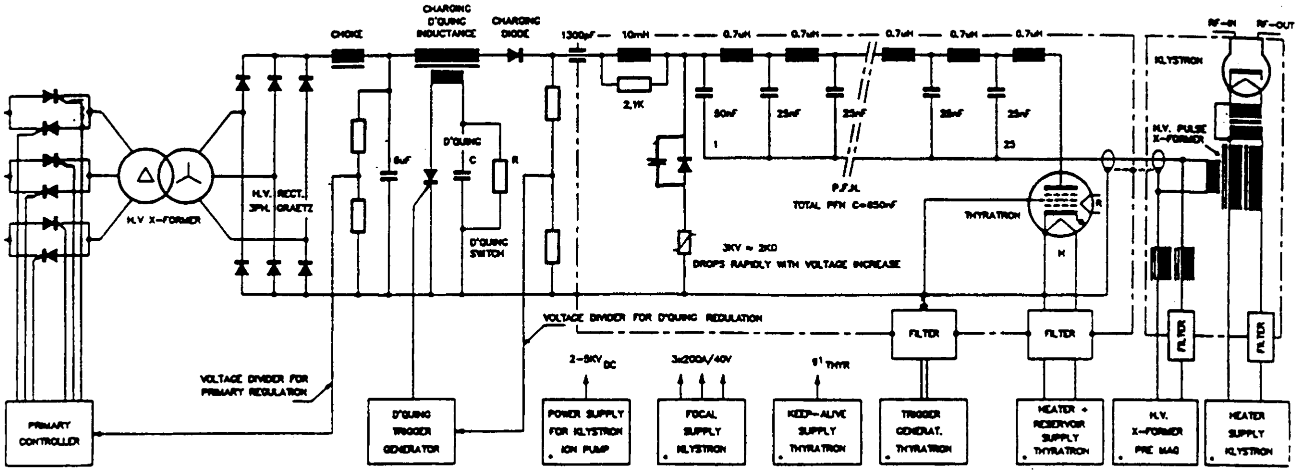


FIGURE 4.



- Low voltage SCR D'Quing
- 25 cell PFN
- ITT KU275C thyratron
- Pulse transformer ratio 1:13
- 10 – 15 % positive mismatch
- PFN voltage stability 0·1 %

- Klystrons are 35MW
Thomson Th2094
Valvo YK1600

FIGURE 5.

Klystron MDK PFN coil

variation with plunger position

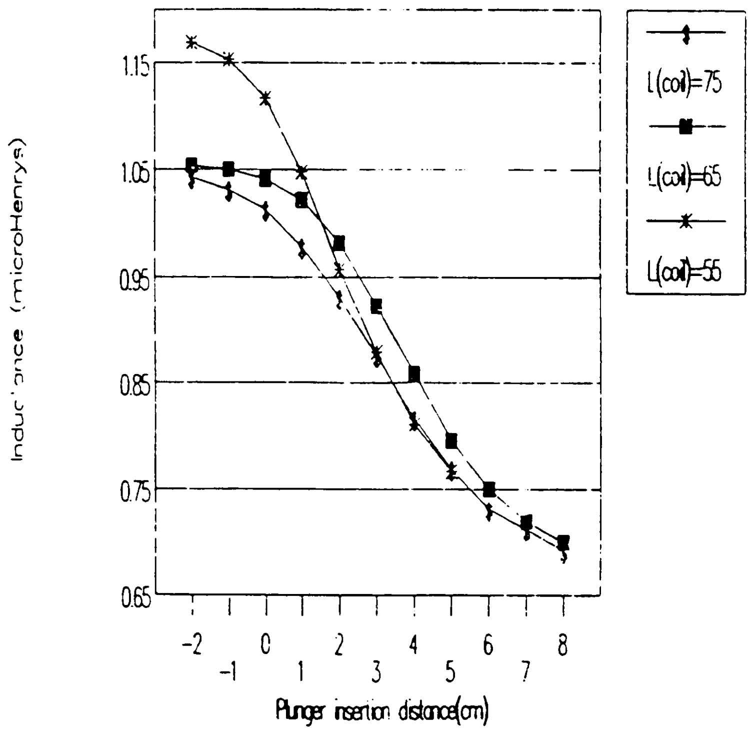


FIGURE 6.

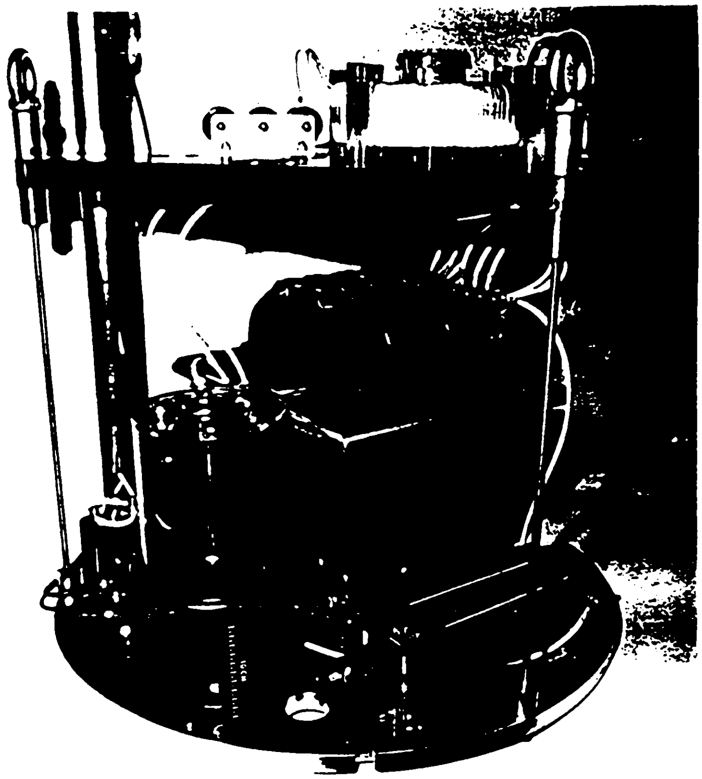


FIGURE 7.

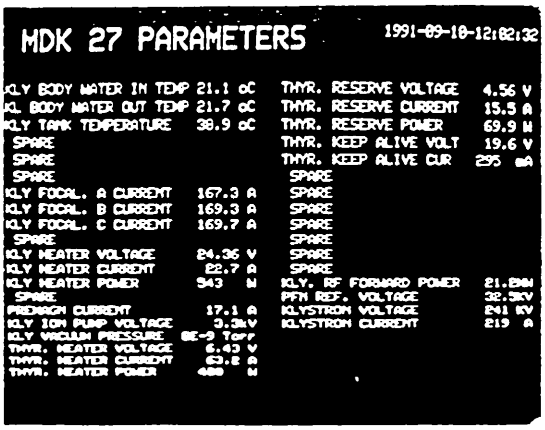


FIGURE 8.

TUBE LIFE TIMES

THYRATRONS KU275C — ITT.

- ALL TUBES HAVE BEEN REPLACED AT LEAST ONCE.
- LIFETIMES OBTAINED WITH:

  35 KV ANODE VOLTAGE

  3300 A PEAK CURRENT

  REPETITION RATE = 100 Hz

  PULSE WIDTH 6.25 μS

BETWEEN: 16000 AND 20 000 HOURS.

KLYSTRONS THOMSON Th 2094
VALVO YK 1600

4 TUBES HAVE BEEN REPLACED WITH ANOTHER ONE TO BE CHANGED VERY SOON.

$V_{KLY} \approx 270$ KV

$I_{KLY} \approx 250$ A

LIFETIMES BETWEEN 13000 AND 18 000 HEATER HOURS WITH THE LONGEST (STILL LIVING) TUBE LIFE = 22500 HOURS

FIGURE 9.

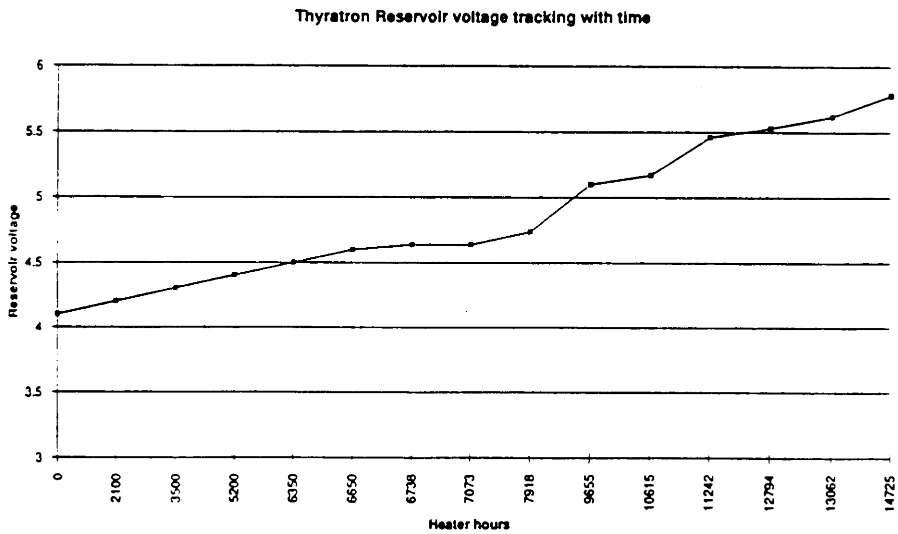


FIGURE 10.

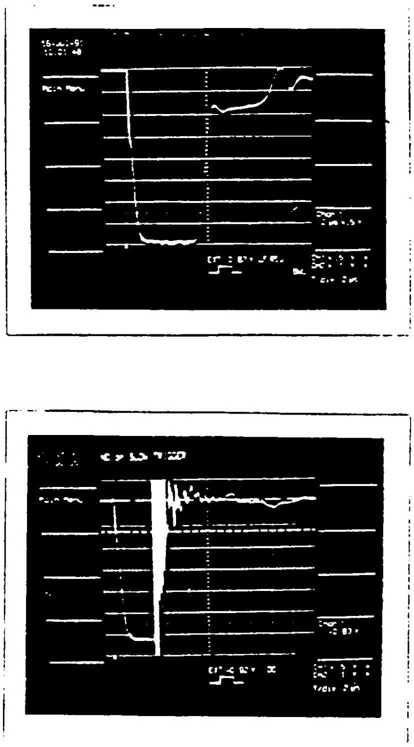


FIGURE 11.

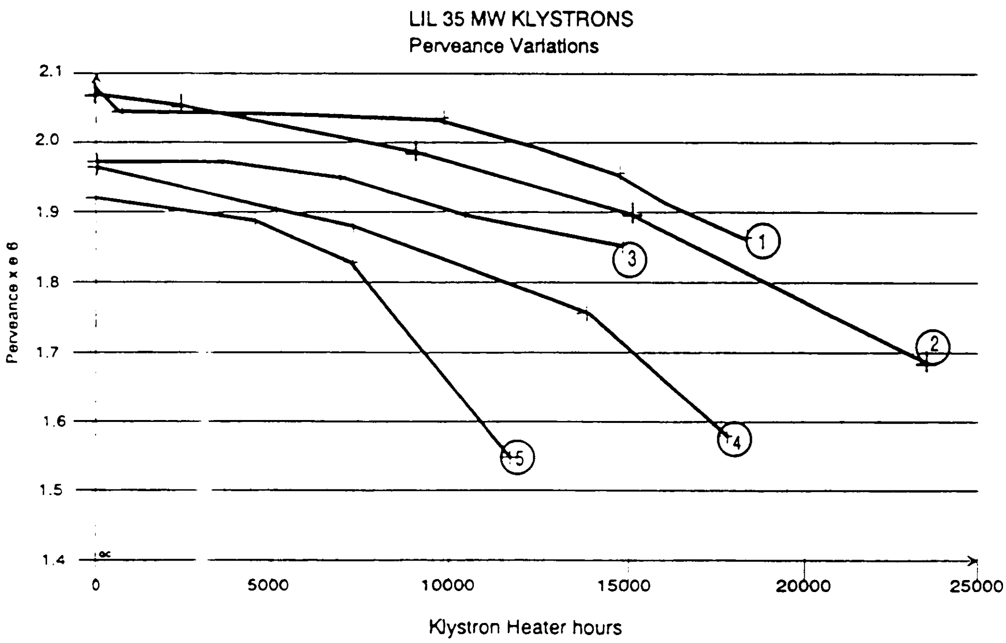


FIGURE 12.

MEASURES TO INCREASE KLYSTRON LIFETIMES

- SET FOCAL CURRENTS FOR 270KV OPERATION
- ADJUST KLYSTRON VOLTAGE FOR REQUIRED OUTPUT POWER
- SET INPUT POWER TO SATURATE THE KLYSTRON
- ADJUST NEW KLYSTRON HEATER VOLTAGES TO 5% (10% MAX) BELOW NOMINAL LEVEL FOR THE FIRST 5000 HOURS USE.
- REDUCE HEATER POWER IN STANDBY (ECONOMY) MODE

- AS TUBES DEGRADE IN PERFORMANCE, FIRST INCREASE KLYSTRON VOLTAGE TO GET BACK THE LOST POWER. MAKE SURE KLYSTRON IS SATURATED.
- ONCE 270KV HAS BEEN REACHED, TRY INCREASING HEATER VOLTAGE BY UP TO 10% ABOVE NOMINAL
- OPTIMISE FOCAL CURRENTS AS LAST EFFORT BEFORE CHANGING KLYSTRON.

FIGURE 13.

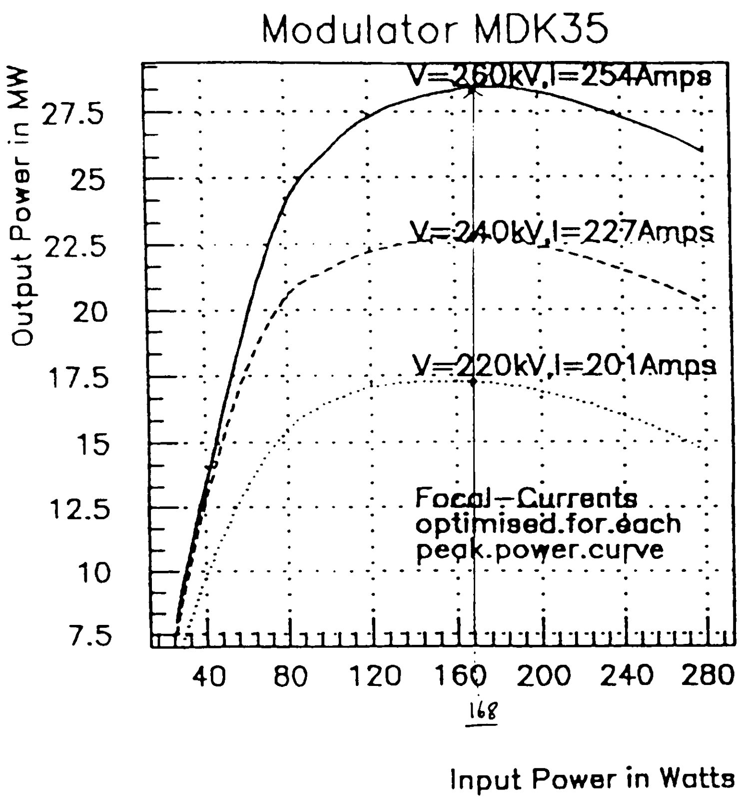


FIGURE 14.

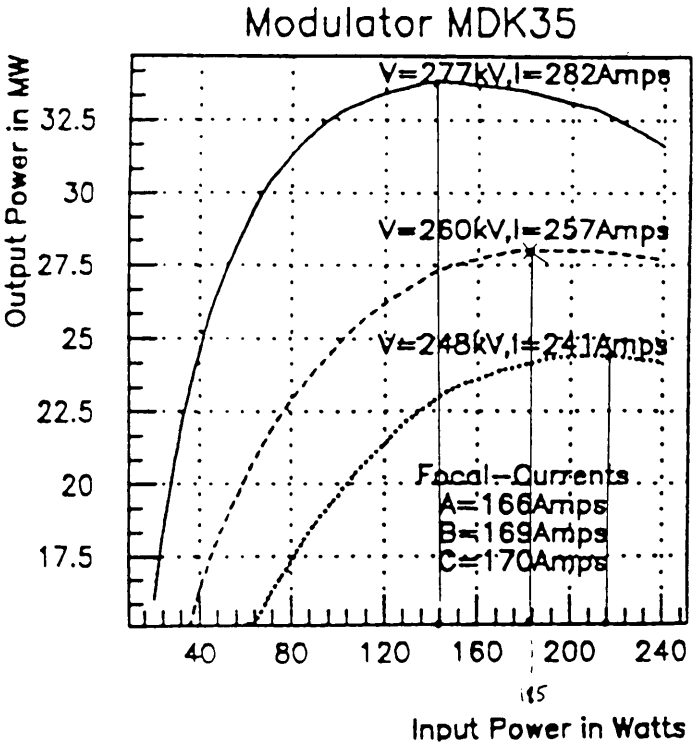


FIGURE 15.

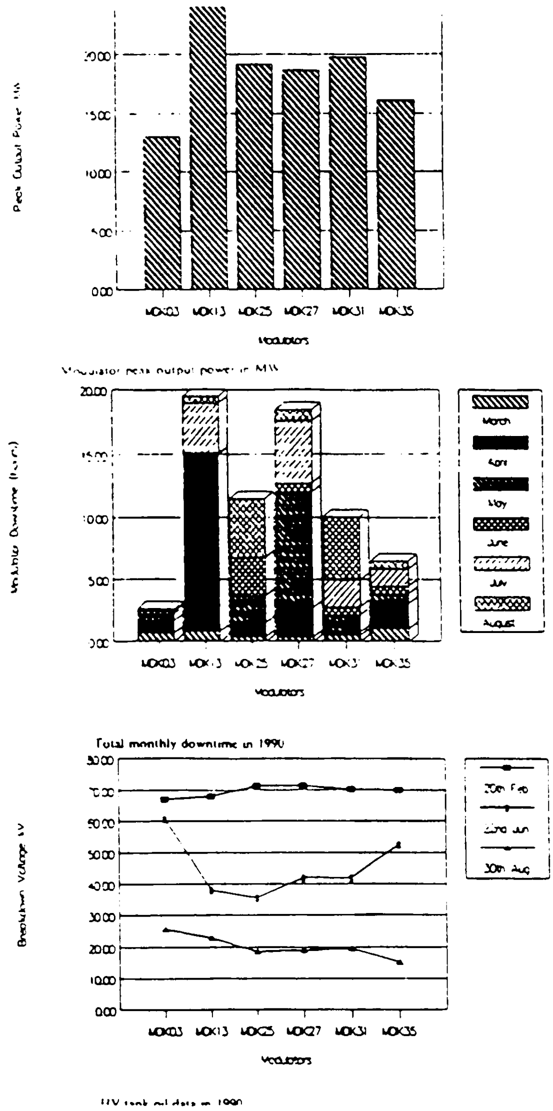
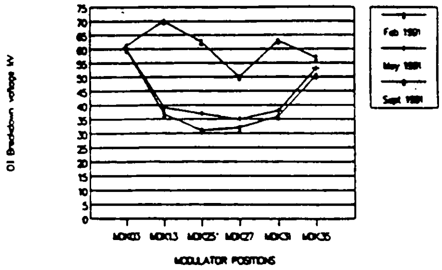


FIGURE 16.

Klystron HV tank Oil data in 1991

Test breakdown voltages



Change in Klystron tank Oil

strength with Peak Power

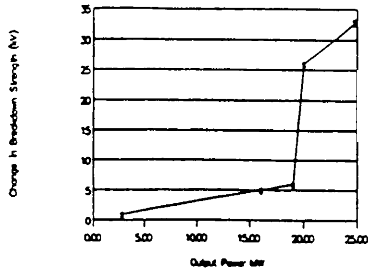


FIGURE 17.

THYRATRON SWITCHES IN MODULATOR CIRCUITS

D. C . Fiander, PS Division, CERN

7th October 1991

IMPEDANCE MATCHING OF MODULATORS

1. MATCHED
2. POSITIVE MISMATCH $R_L > Z_{o\,PFN}$
3. NEGATIVE MISMATCH $R_L < Z_{o\,PFN}$

CASE 1. ZERO POST-PULSE SWITCH CURRENT

CASE 2. CONTINUING POSITIVE SWITCH CURRENT

CASE 3. INVERSE CURRENT (OR VOLTAGE) AT SWITCH

THYRATRONS

1. "Turn-on" only device
2. Uni-directional — damaged by reverse current.

3. Finite recovery time — influenced by previous history.

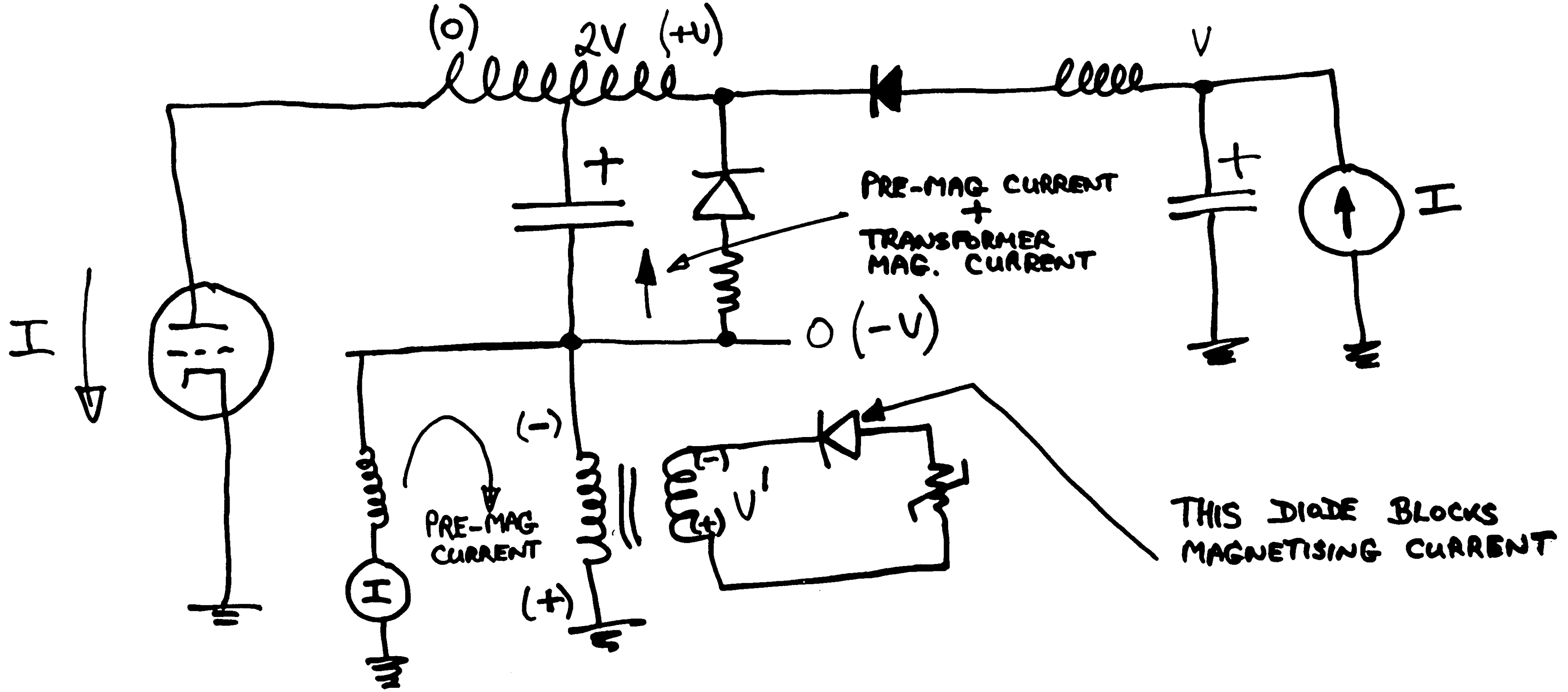
↓

low fwd $\frac{dI}{dt}$

limited voltage in recovery period

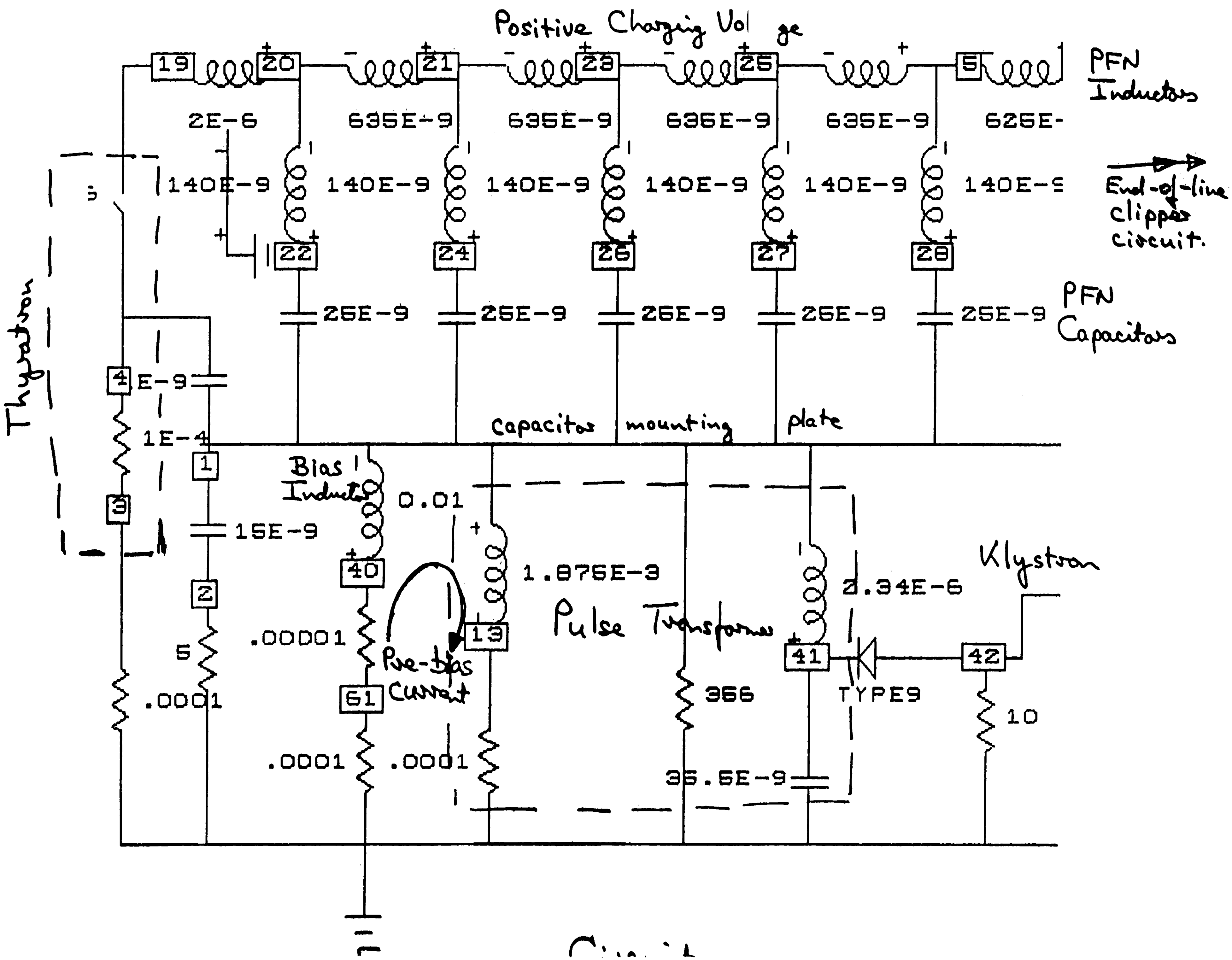
polarity of voltage in recovery period.

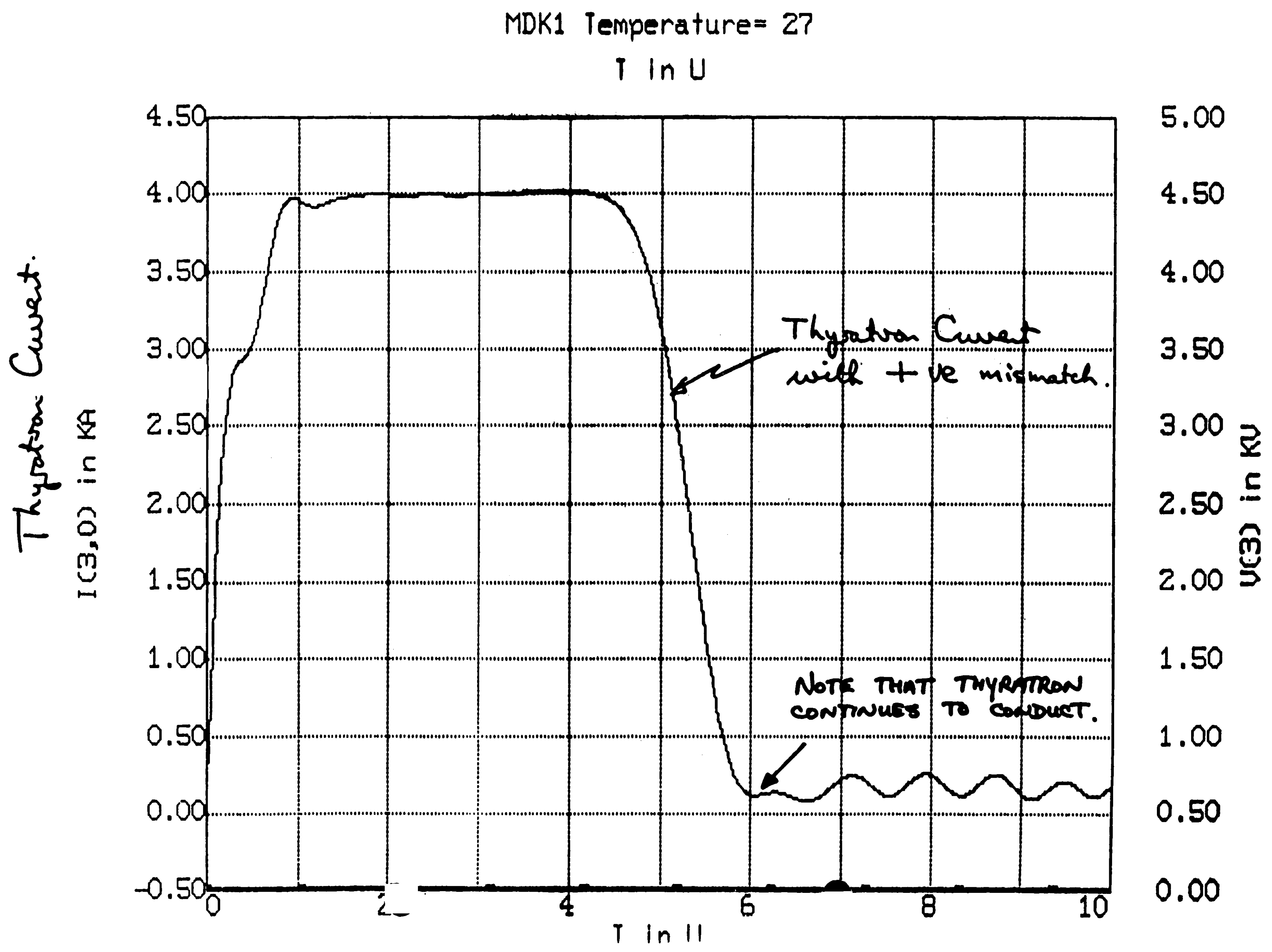
SIMPLIFIED MODULATOR CIRCUIT

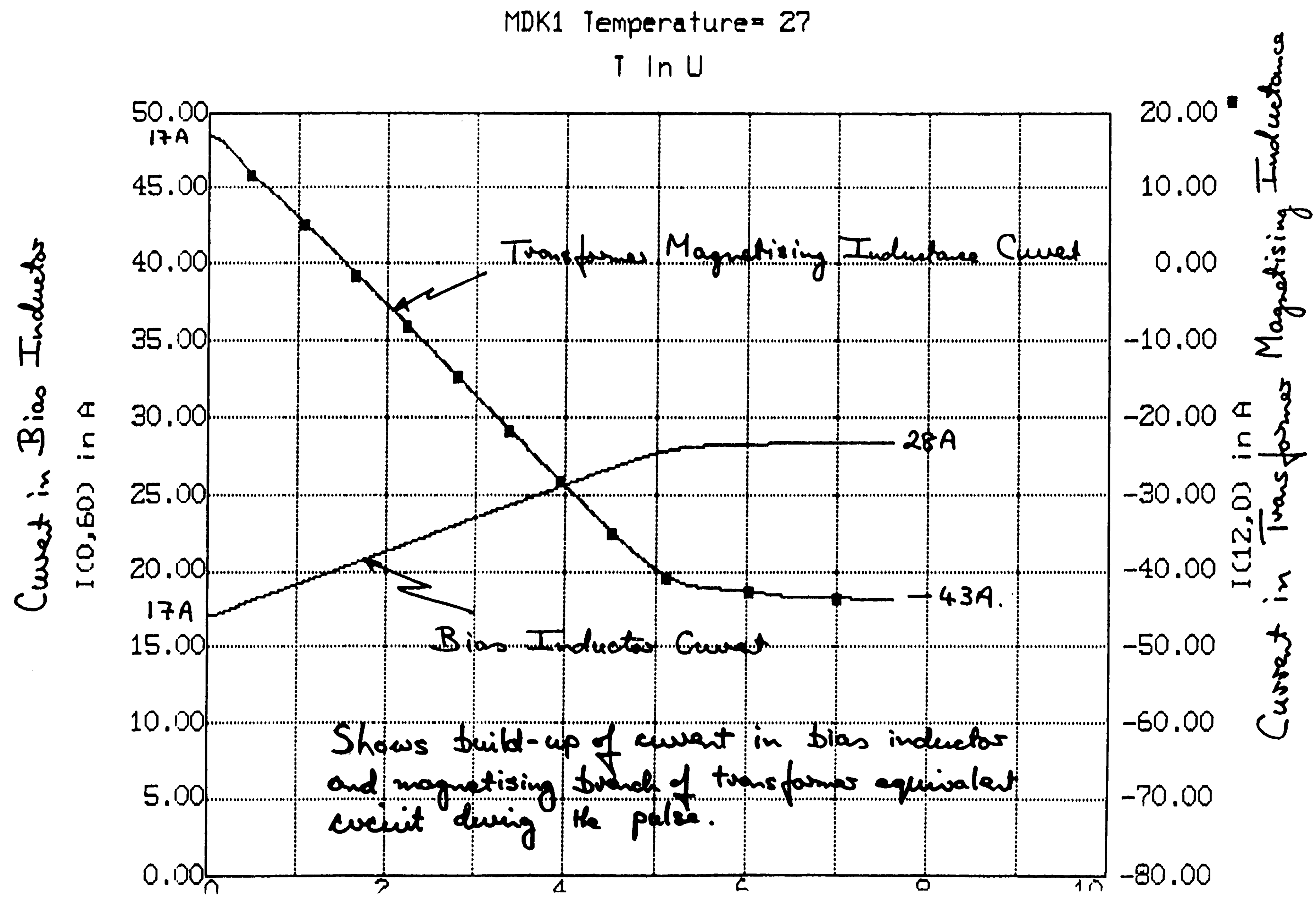


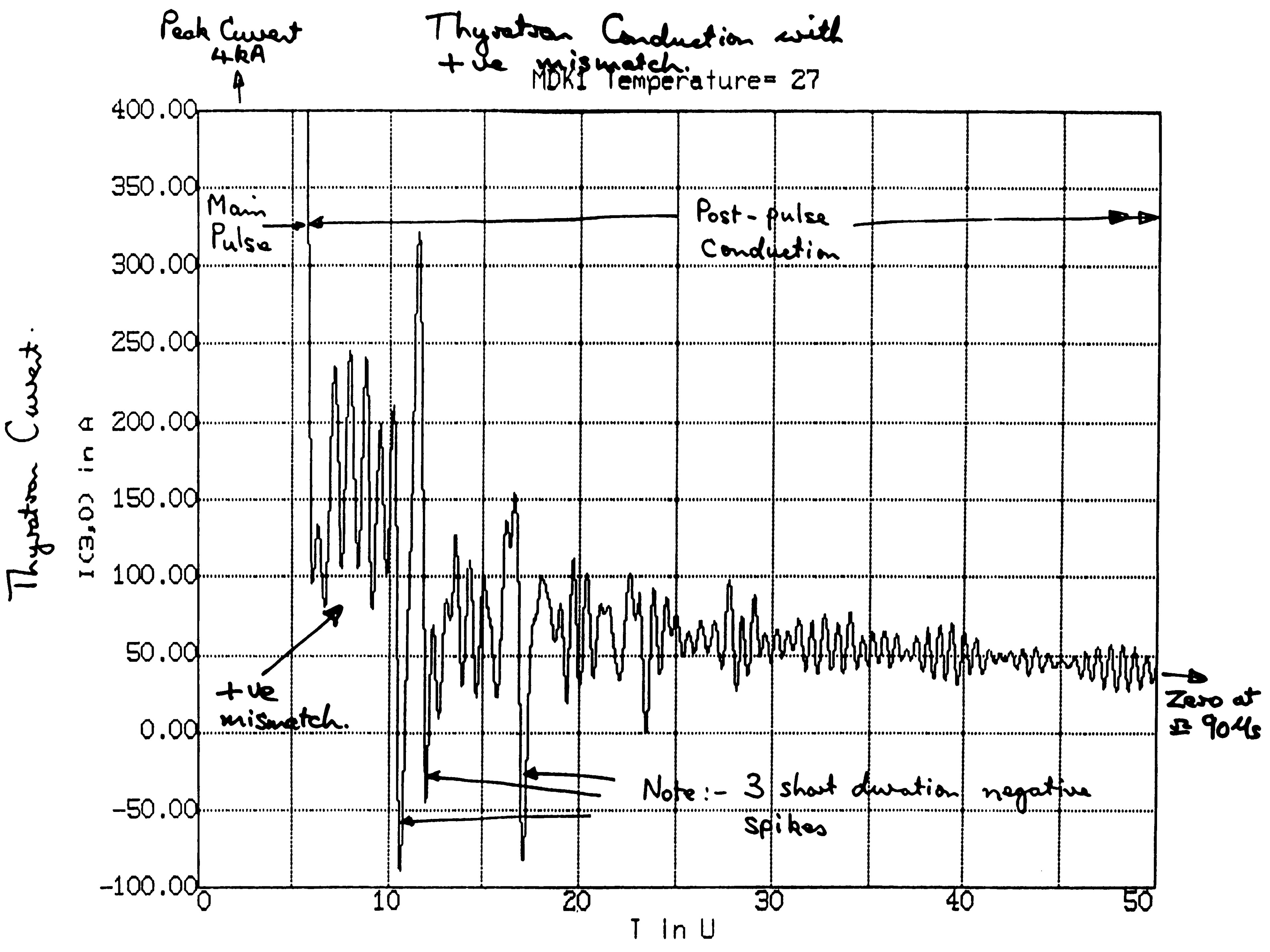
RED – CIRCUIT CONDITION PRIOR TO SWITCHING

GREEN – CONDITIONS DURING / AFTER SWITCHING


Positive Charging Vol ge
PFN Inductors
19
20
21
23
25
5
2E-6
635E-9
635E-9
636E-9
635E-9
626E-
140E-9
140E-9
140E-9
140E-9
140E-9
140E-9
End-of-line clipper circuit.
22
24
26
27
28
26E-9
25E-9
26E-9
26E-9
25E-9
PFN Capacitors
Thyratron
4
E-9
1E-4
3
capacitor mounting plate
1
Bias Inductor
0.01
15E-9
2
5
.0001
40
.00001
Pre-bias current
61
.0001
.0001
13
1.876E-3
Pulse Transformer
366
35.6E-9
2.34E-6
41
TYPE9
42
10
Klystron

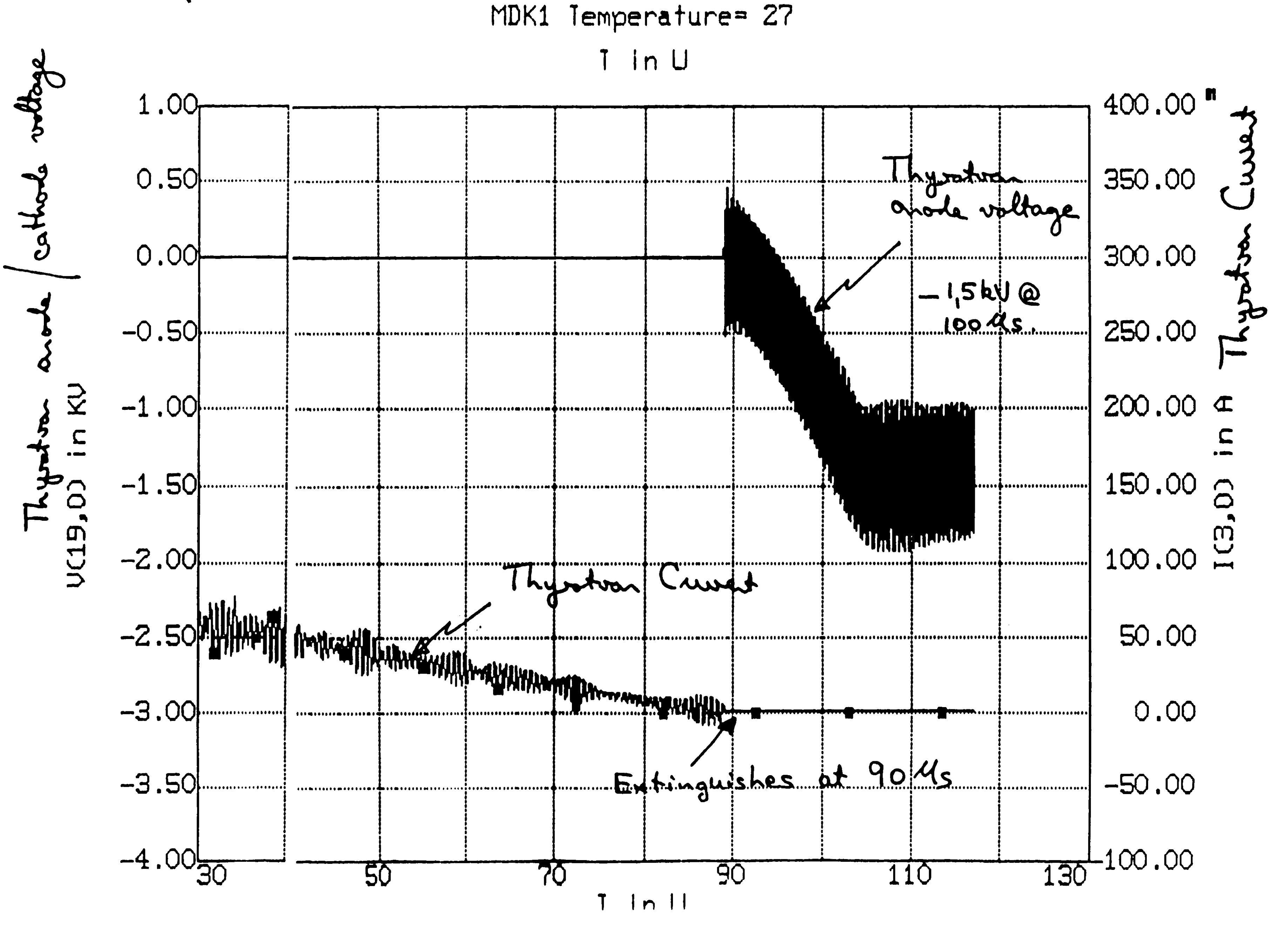

MDK1 Temperature= 27
T in U
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
I(3,0) in KA
Thyratron Current.
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
V(3) in KV
0
4
6
8
10
T in U
Thyratron Current with +ve mismatch.
NOTE THAT THYRATRON CONTINUES TO CONDUCT.


MDK1 Temperature= 27
T In U
Current in Bias Inductor
I(0,60) in A
I(12,0) in A
Current in Transformer Magnetising Inductance
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
0
2
4
6
8
10
17A
17A
28A
43A.
Transformer Magnetising Inductance Current
Bias Inductor Current
Shows build-up of current in bias inductor and magnetising branch of transformer equivalent circuit during the pulse.



Peak Current 4kA
Thyratron Conduction with +ve mismatch.
MDKI Temperature= 27
Main Pulse
Post-pulse Conduction
+ve mismatch.
Note:- 3 short duration negative spikes
Zero at ≅ 90μs
Thyratron Current.
I(3,0) in A
T In U
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
-100.00
0
10
20
30
40
50

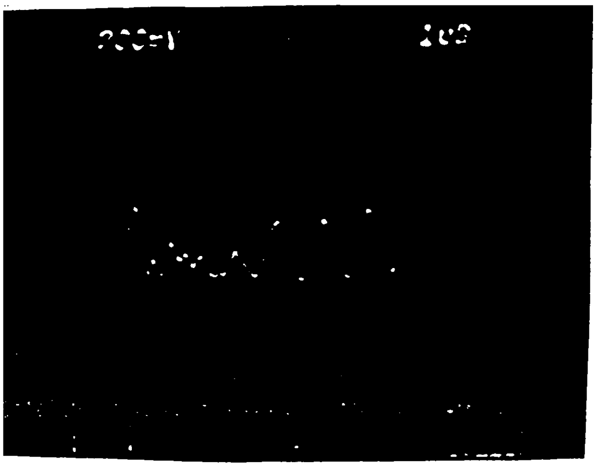
Final phase of thyratron conduction and application of inverse anode / cathode voltage. (LEP pre-injector modulator simulation)



Modulator acceptance tests at Orsay April [illegible] 1988

(All tests performed at 100Hz)

Photo 1.



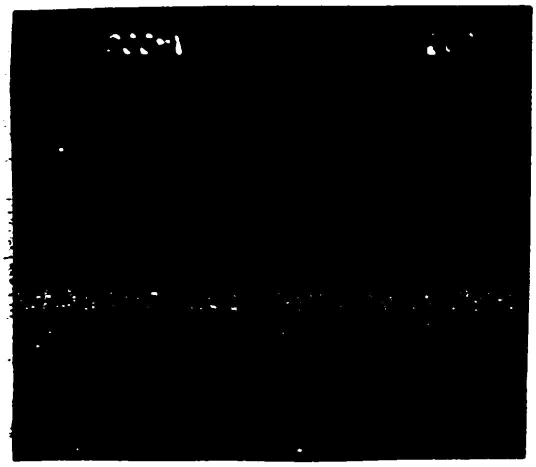
Klystron Voltage (285kV)
(Stangenes 10000/1 voltage divider)

Access door to PFN open, measuring cable 1m too long.

1% ripple ≡ 1,6 major divisions.

Conclusions (i) Flat-top ripple ≅ 0,8% p-p. } i.e. within specification
(ii) Pulse flat-top ≥ 5µs. }

Photo 2.

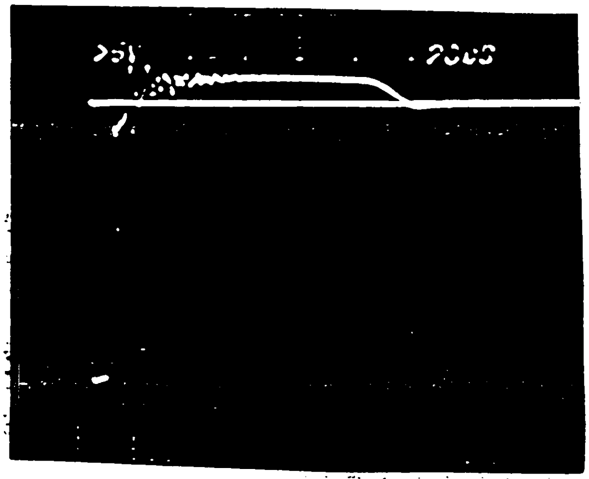


Ditto but access door to PFN closed, measuring-cable correct length.

Conclusion result sensibly unchanged w.r.t. Photo 1.

Comment concerning flat-top ripple – the movable inductance slugs permit easy and rapid adjustment of flat-top ripple, but the results of photos 1 and 2 represent the best result which can be obtained.

Photo 3

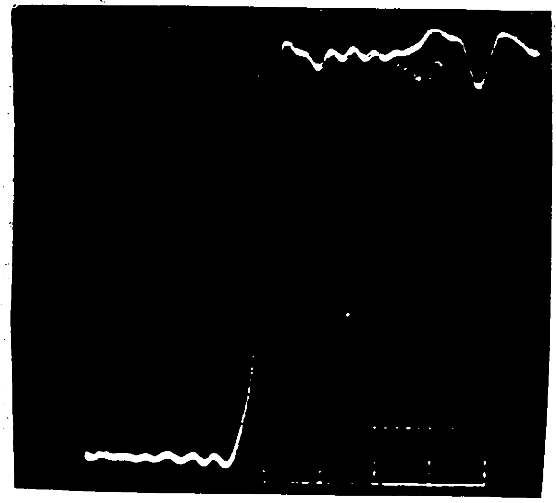


Ditto, extended time scale, showing inverse.

	Measured	ECAP
Peak inverse V	9%	9,8%
Duration of inverse V	112µs	104µs

Conclusion Good agreement on inverse voltage conditions for klystron

Photo 13



Thyratron current, with Pearson 110 CT on anode connection. CT terminated in 50Ω at scope.

Calibration 500A/div Flat top = 3800A

Corresponding klystron voltage for this photo was 270kV (reduced because of klystron arcing).

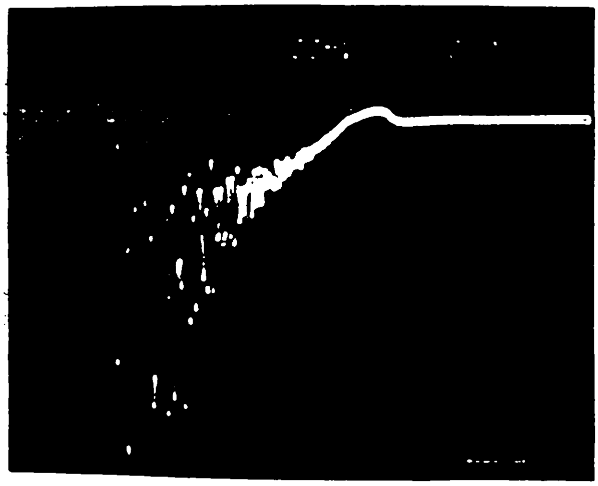
	Measured	ECAP
Positive post-pulse spike	≃ 13%	9.7%

ECAP value is too low for same reason as given for Photo 11.

Conclusion: Thyratron current waveform is healthy. Absence of inverse current and of prolonged periods of zero current (implying inverse voltages).

Note that the thyratron current could not be measured satisfactorily at the cathode because of multiple current paths to the cathode via the middle and screen conductors of the triaxial cable. The triaxial connections need to be restudied.

Photo 14.

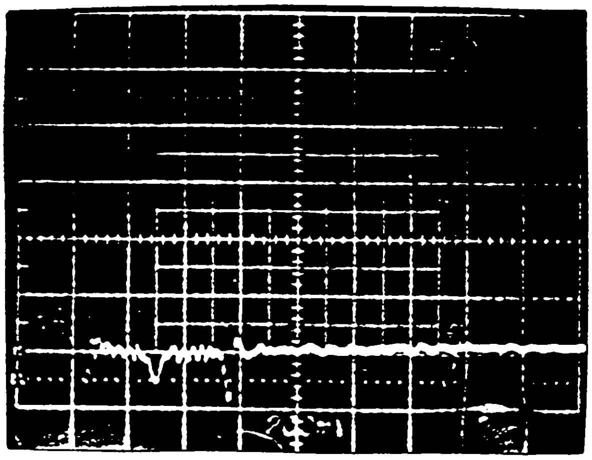


As photo 13, extended time scale, 20A/div

	Measured	ECAP
Total thyratron conduction period	≃ 90μs	88μs
Current at 60μs	≃ 30A	35A

Conclusion: Good agreement between measurements and ECAP for thyratron conduction due to resonance of pulse transformer magnetising inductance with PFN capacitors.

Photo 15.



Thyratron anode/cathode voltage during post-pulse period.
Measurement with Tektronix H.V. probe

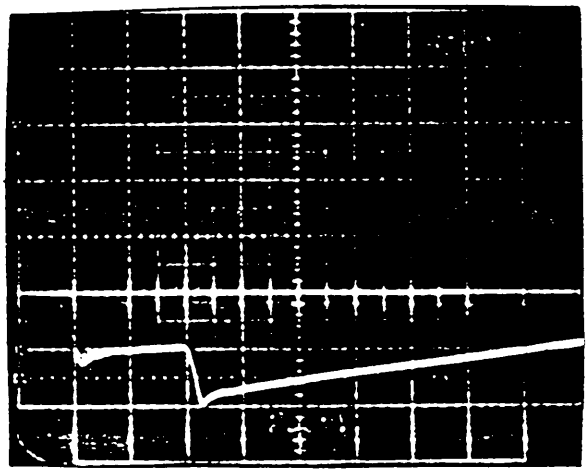
2 kV/div, 5 µs/div.

Note inverse voltage spikes at 7 µs and 14 µs (respectively 1 kV and 1,8 kV).

ECAP predicted 0,4 kV @ 7 µs
2,0 kV @ 12 µs
0,9 kV @ 14 µs

Conclusion: Thyratron inverse voltages in immediate post main pulse period are close to predictions and are acceptably low.

Photo 16.



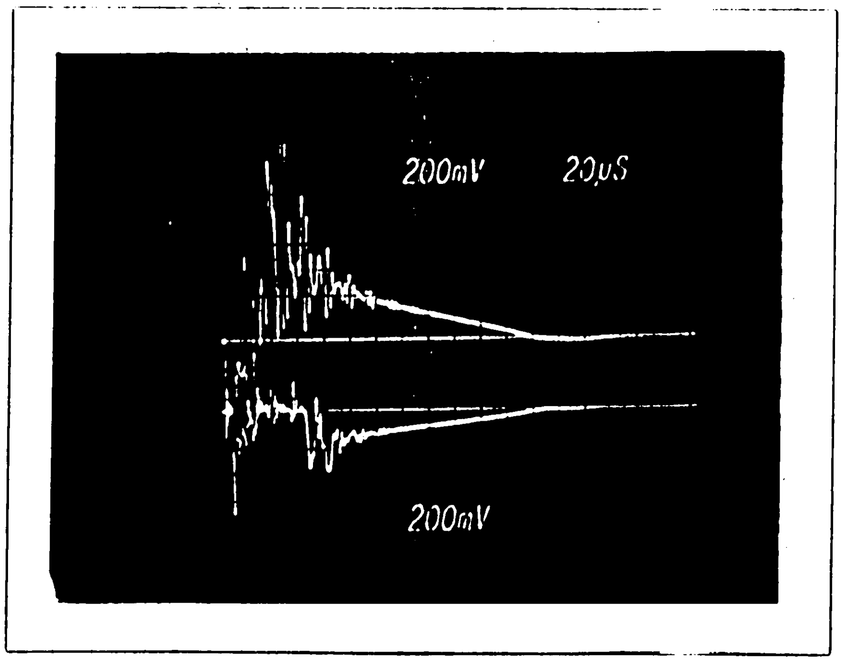
As photo 15, but extended time scale

	Measured	ECAP
Thyratron conduction duration	≃ 100 µs	88 µs
Peak inverse voltage.	2 kV	2,2 kV
Crossover to +ve voltage	≃ 400 µs	≃ 700 µs

Conclusion: Thyratron conduction period and peak inverse voltage are as predicted, crossover to +ve voltage occurs much sooner than predicted (a question of the representation of the power supply and the EOLC NLR in ECAP). Measured period of controlled inverse voltage is more than adequate for thyratron recovery.

General Note: All photographs of this test report are presented in the order in which they were taken.

J. P. Perrine LAL
D. Fiander CERN.



Thyratron Current

End-of-line Clipper Current.

(Note - conduction takes place only when voltage is high enough to overcome diode forward drop)

Conduction period $\simeq$ 120 μs

Taken in LPI Klystron Gallery, October 1991

CONCLUSIONS

POSITIVE MISMATCH HAS THE ADVANTAGES OF:-

1. NOT EXTINGUISHING THE THYRATRON WITH PULSE CURRENT. HENCE NO INVERSE VOLTAGE APPEARS IMMEDIATELY AFTER FULL FORWARD CONDUCTION.

2. THYRATRON CONDUCTION IS PROLONGED BY A RESONANCE OF THE PFN CAPACITORS WITH THE BIAS INDUCTOR AND TRANSFORMER MAGNETISING INDUCTANCE. THIS IS A LOW FREQUENCY HIGH IMPEDANCE RESONANCE WITH LOW THYRATRON dI/dt.

3. INVERSE VOLTAGE BUILDS UP ON THE PFN DURING THE RESONANCE. AT THYRATRON EXTINCTION THIS INVERSE VOLTAGE IS APPLIED ACROSS THE THYRATRON.

4. THYRATRON RECOVERY IS ASSURED BY THE LOW FINAL dI/dt AND THE MODEST AND CONTROLLED APPLICATION OF INVERSE VOLTAGE.

5. NO ADDITIONAL CIRCUIT COMPONENTS ARE REQUIRED TO BRING ABOUT THIS FAVOURABLE SITUATION.

WARNING

THE ABOVE APPLIES TO DIODE-TYPE LOADS ONLY. TESTING WITH WATER LOADS MODIFIES (UNFAVOURABLY) THYRATRON RECOVERY.

CGR MeV

Jean-Louis Pourre
Technical Department

Subsidiary of General Electric CGR
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Tél.: (1) 30 70 46 08. Tx: 695 277 F. Fx: (1) 39 56 41 35
DIALCOMM: 86 44 46 08. Fax: 86 44 41 35

Buc, Sept. 1991

GENERAL-ELECTRIC CGR MeV

****

Some history...

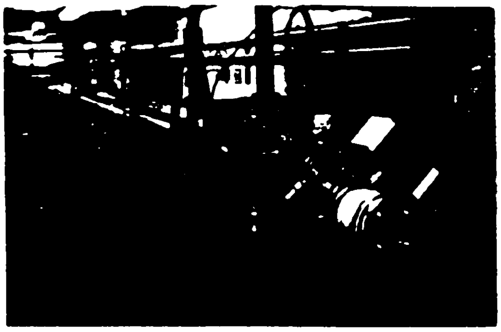
Started in 1955 as a CSF "High Energy Department", then Thomson-CSF "Departement Accélérateur" in 1967, the Society merged to Thomson-CGR group in 1972, under the name CGR MeV.
The factory is located in Buc, near Paris, and today attached to General-Electric Company (merging in 1987).

Involved at first in rather low energy electron accelerators, (5 MeV), CGR MeV was then involved in big Linear Accelerators for Physics (ENS Orsay, ALS Saclay), various medical linacs, and Cyclotron business.

Today, GE CGR MeV, with a staff of 300 people, is involved in three fields : **Medical, Industrial, and Scientific Accelerators**, delivered worldwide.

The highly professional solution ...

For more than 30 years, CGR MeV has been a world's leading developer of electron linear accelerators for a wide range of applications. With more than 300 experts in disciplines ranging from research and development to marketing and manufacturing, we are ideally positioned to meet your accelerator requirements.
We are centrally located near Paris, close to the National Laboratories, State Universities, and Grandes Ecoles – one of the world's leading centers for advanced engineering, research and development.

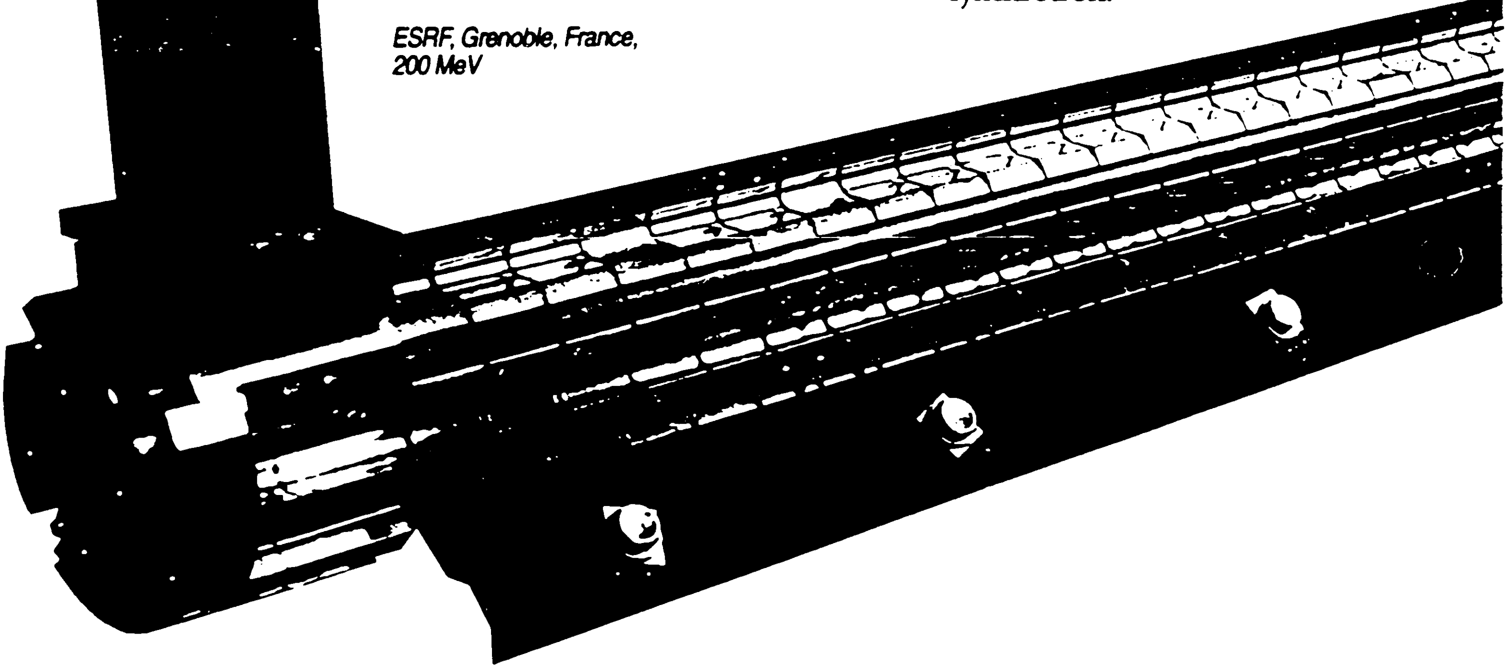


ESRF, Grenoble, France, 200 MeV

A wealth of experience

Our track record is your best assurance of receiving the right solution for the challenges facing your organization. Recently, for instance, we provided:

- IBM in the United States with a 200 MeV injector for the Oxford Instruments compact synchrotron Helios. This has been installed at the IBM wafer fabrication facility at East Fishkill, New York, USA.
- European Synchrotron Radiation Facility in Grenoble, France, with a 200 MeV pre-injector for the ESRF synchrotron.
- Maxwell Laboratories, Inc., Brobeck Division with a 200 MeV injector for a synchrotron light source they are installing at the Center for Advanced Microstructures and Devices (CAMD) at Louisiana State University in Baton Rouge, USA.
- Synchrotrone Trieste, Italy, with a 1500 MeV injector for Elettra synchrotron.



200 cells result in 6 m length accelerating section

GENERAL-ELECTRIC CGR MeV

TYPICAL DESIGN AND REALIZATION
IN MEDICAL, INDUSTRIAL, AND SCIENTIFIC AREA.

****

1/. MEDICAL

SATURNE Modulator

τ = 5 µsec
fr= 200pps
P_{RF} = 2 to 6 MW
P_{RF}(Ave)= 2 to 6 kW
RF tube : Klystron TH2074
Switch tube : Thyr. CX 1528

2/. INDUSTRIAL

CIRCE Modulator

τ = 15 µsec
fr= 700 pps
P_{RF} = 5.5 MW
P_{RF}(Ave)= 50 kW
RF tube : Klystron TH 2108
Switch tube : Thyr. CX 1536X
or F 241 (ITT)

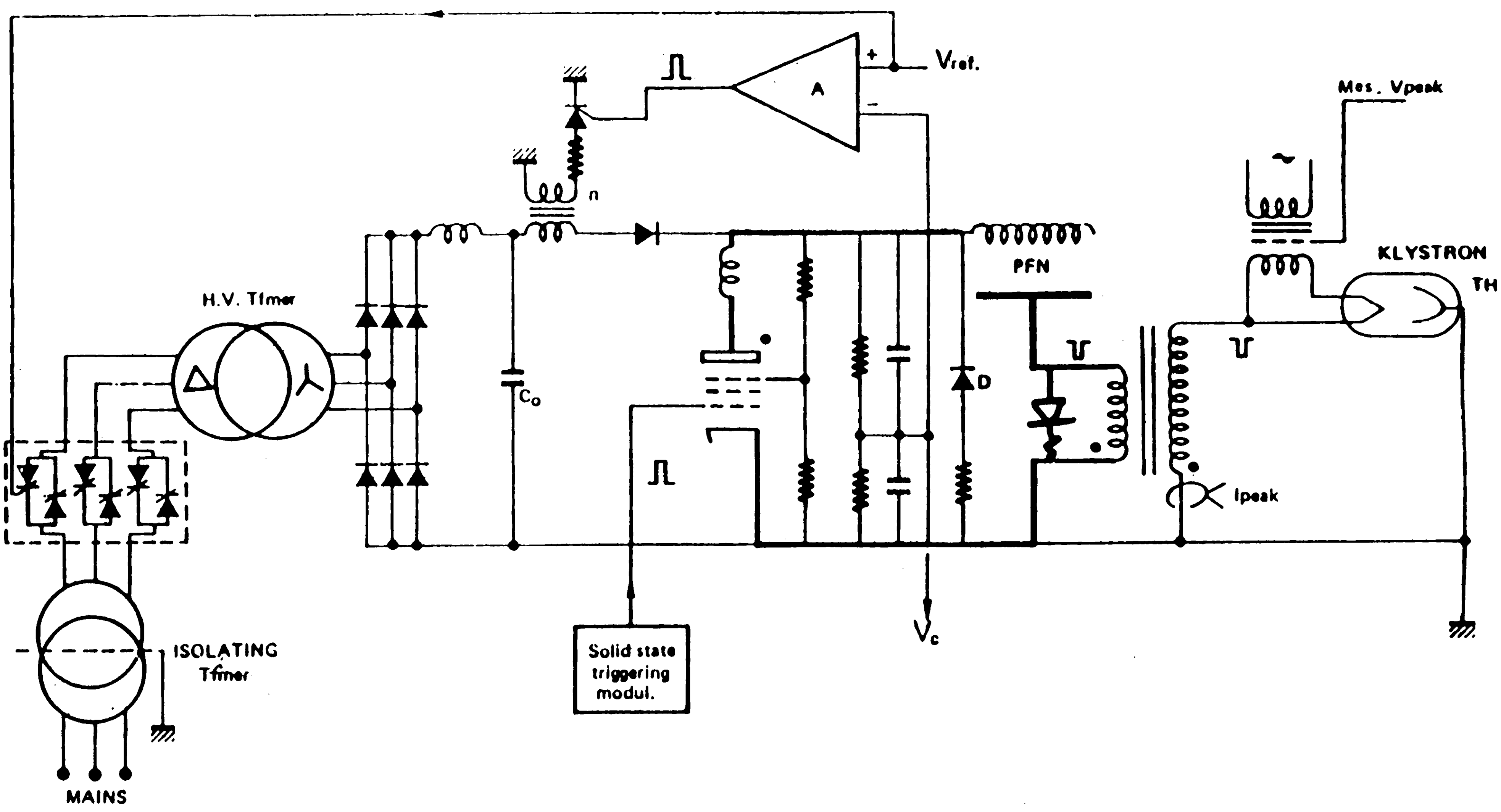
3/. SCIENTIFIC

ELETTRA Modulators (Trieste)

		Short	Long Pulse
τ (RF)	=	1.5	11 µsec
τ (Mod)	=	4.5	16 µsec
fr	=	10	10 pps
V_K	=	310	250 kV
I_K	=	340	250 kV
P_{RF}	=	45	25 MW
P_{RF}(Ave)	=	2	3.5 kW

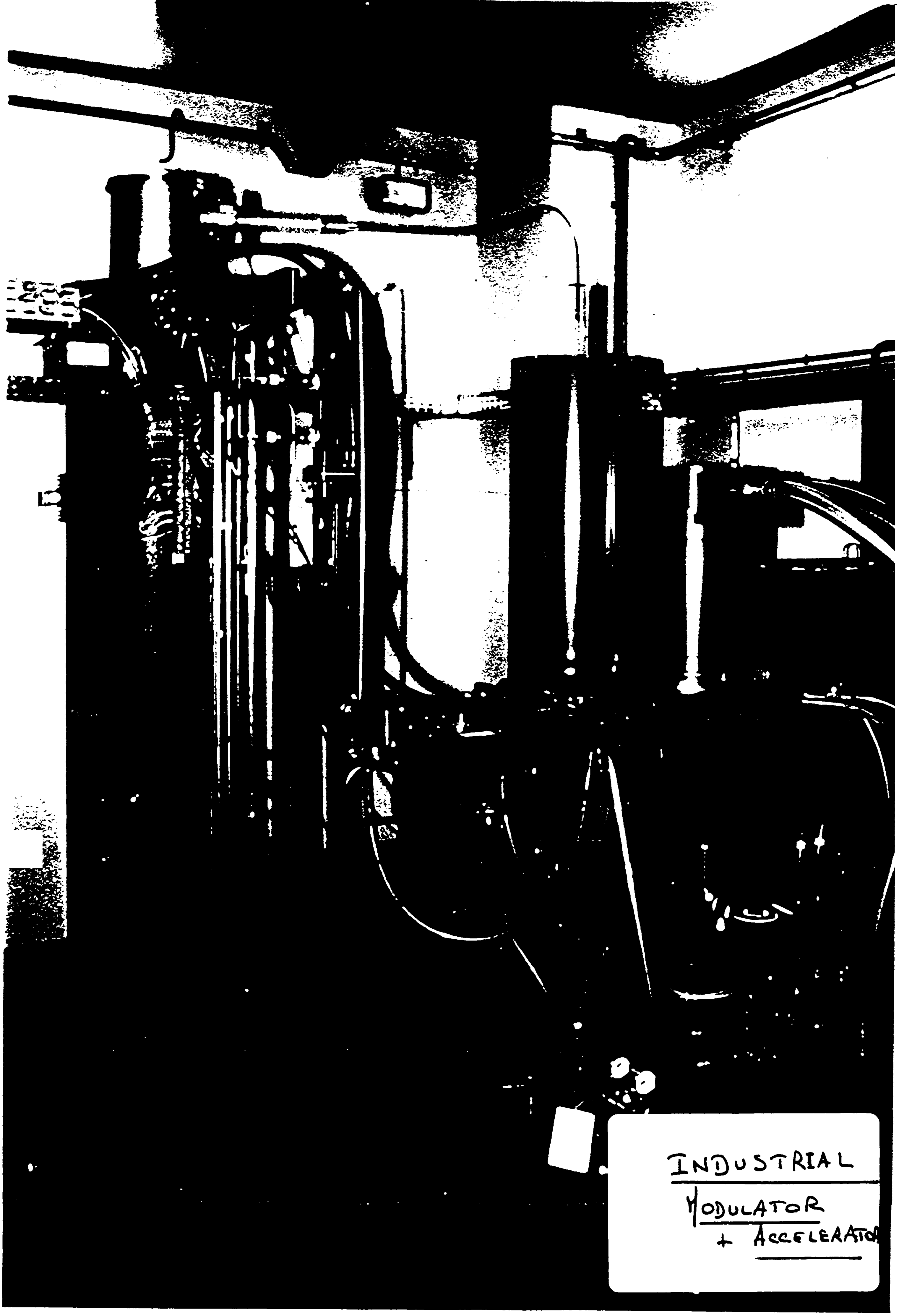
RF tube : Klystron TH 2132
Switch tube: Thyr. CX 1536X

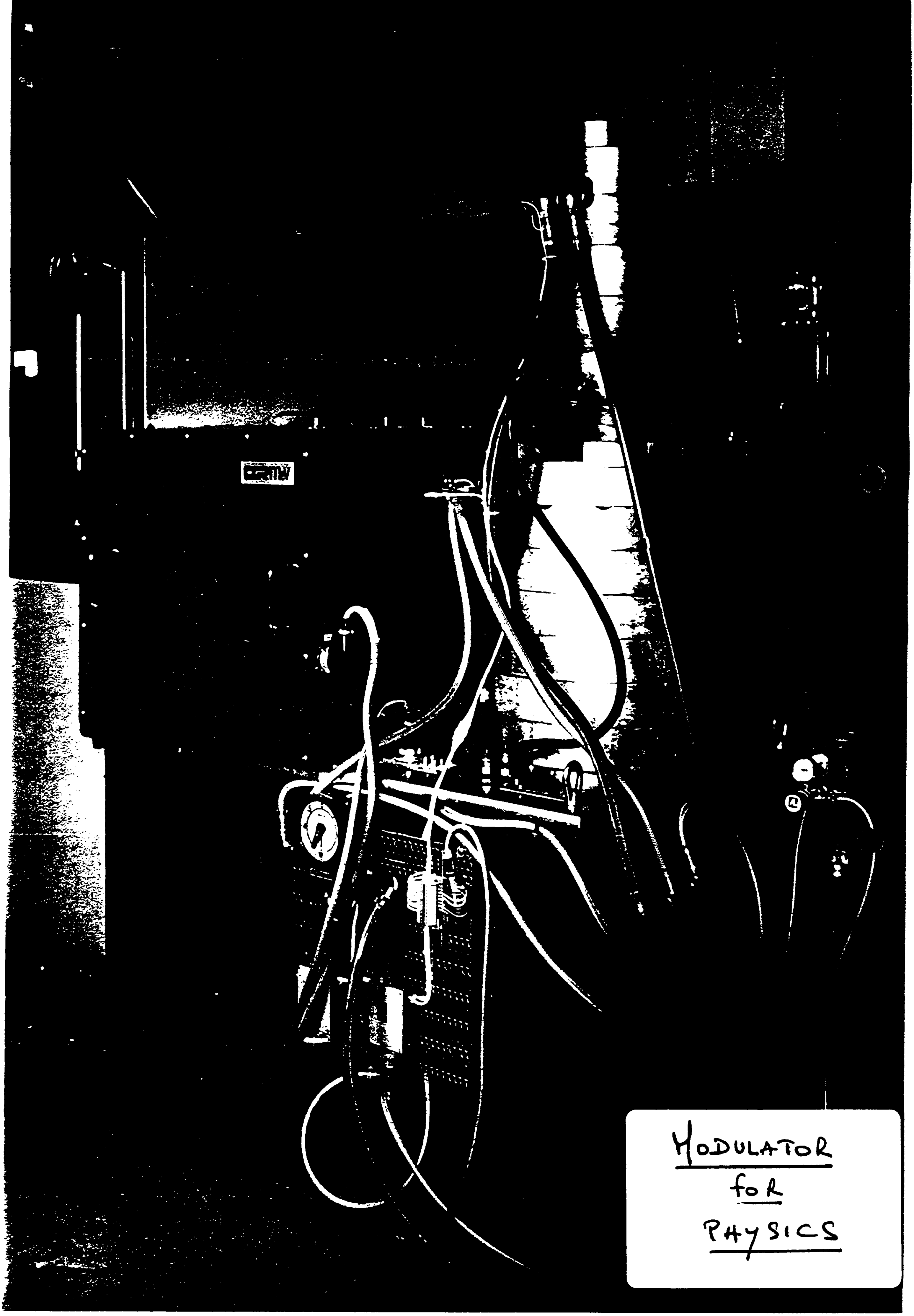
+ (CIDRE)
Energy Doubler



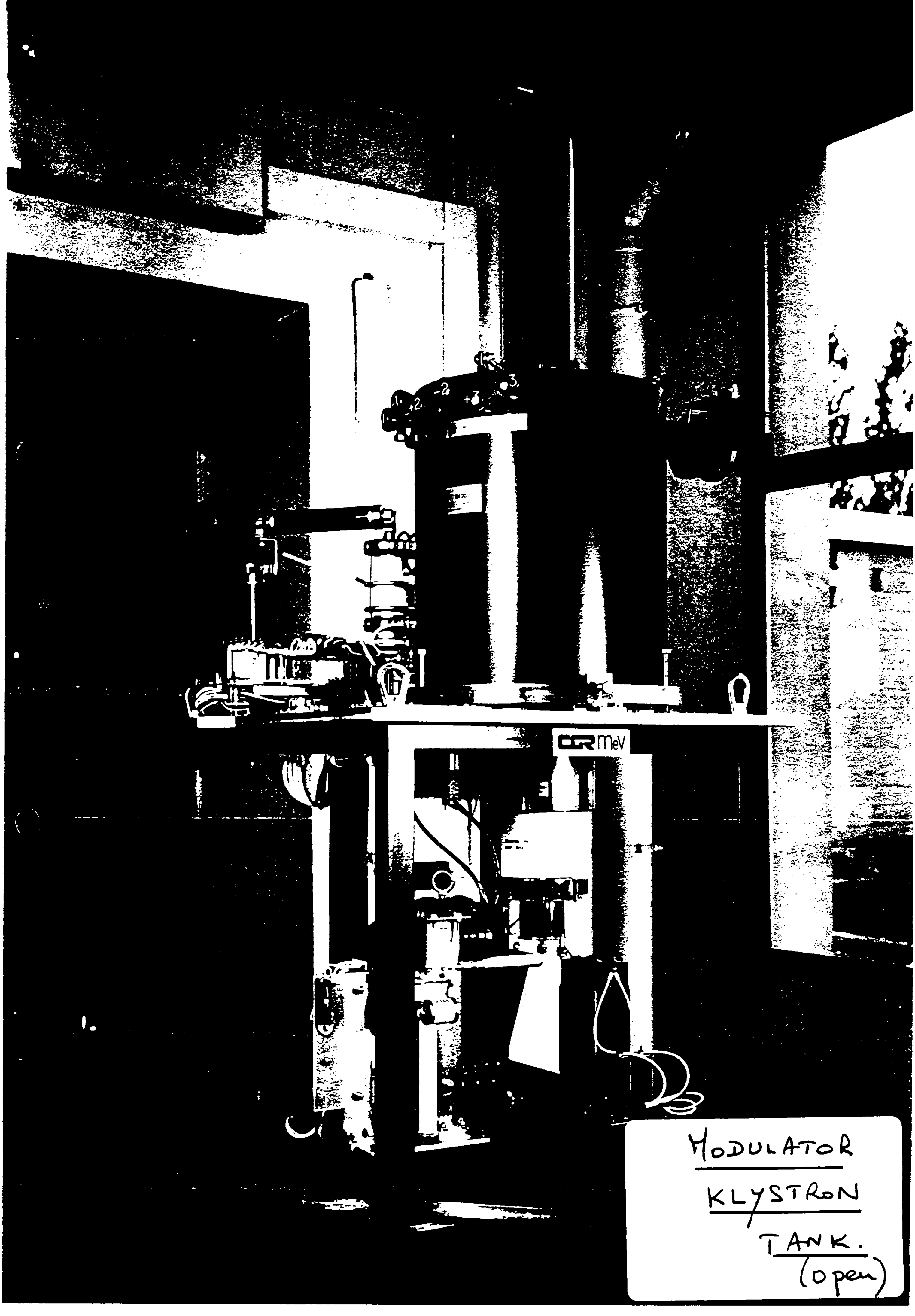
V_{ref.}
A
+
−
Mes. Vpeak
n
KLYSTRON
TH
H.V. Tfmer
PFN
C_o
D
Ipeak
Solid state triggering modul.
V_c
ISOLATING Tfmer
MAINS

MOD.


INDUSTRIAL
MODULATOR
+ ACCELERATO



MODULATOR for PHYSICS



MODULATOR KLYSTRON TANK. (open)

Valvo-Philips high power klystrons

presented at Klystron Modulator Technical Meeting
7./8.10.91 at CERN
by Dr. E.- Günter Schweppe

During the past 35 years, nuclear physics and high energy research have stimulated the development of powerful and efficient microwave sources. Particular the employment of high power pulse klystrons in large linear accelerators has contributed to the progress of design concepts and the technology of klystrons.
Afterwards, the storage ring accelerator has been added for investigating still higer energy ranges. Its operation requires large amounts of cw microwave power at UHF frequencies.

500 Mhz/800 kW Klystron YK 1304

The YK 1304 is a full beam controlled 800kW cw klystron for DESY/HERA. It operates at 75 kV with an air cooled gun /water cooled collector in vertical position with an efficiency of more than 60%.

508 Mhz/1000 kW Klystron YK 1303

The YK 1303 operates at 90 kV with 1000 kW cw output at TRISTAN ring /KEK. With an efficiency of more than 60% and its vapour cooled collector it delivers the highest cw power in this frequency range.

352 Mhz/1000 kW Klystron YK 1350

Due to the low height in LEP tunnel / CERN the YK 1350 operates in horizontal position, delivering 1000 kW cw output power at 90 kV to the accelerating cavities. According to the low frequency and low perveance its 67% efficiency is the highest of Philips klystron family.

224 Mhz/3 MW Klyston YK 1320

For the research of the higher ionosphere the EISCAT Ass (European Ionosphere Scattering Experiment) at Kiruna (Sweden) has installed UHF and VHF high power transmitters at Tromsö (Norway). The YK 1320 is a long pulse klystron for lower frequencies, delivering a pulse power of 3 MW, at a pulse width of 0.01 ... 1ms and a duty cycle of up to 12%. The beam voltage amounts to 110 kV and efficiency being 55%.

2998.5 MHz/35 MW Pulse Klystron YK 1600

YK 1600 is a high gain high power pulse klystron designed for linear accelerator applications. It is equipped with five integral cavities, electromagnetic focusing, and water cooling for r.f. windows, collector and tube body. For handling the power of 35 MW, two parallel waveguide arms with r.f. windows are provided in order to reach high reliability and stability of the extremly loaded parts during operation, followed by a broadband power combiner. The klystron works at 270 kV/292 A to deliver 35 MW peak output power with an efficiency of 45 %.

UHF - TV YK 1265/YK 1285 PDC Klystron

Though this type of klystron with its mechanically tuned outer cavities was designed for TV application in the 470 to 860 Mhz range, it also can work for an r.f. source delivering 60 kW cw power to small and medium synchrotron sources. In combination with a multi stage depressed collector one can save dc power and special modulators when modulating or pulsing the klystron at the r.f.input.

Klystron instabilities

Long standing experience in klystron operation have shown two different sources of instabilities still appearing.

1. Backstreaming electrons

   In high efficient klystrons a slight mismatch of load can increase the gap voltage of the output cavity in such matter, that off phase electrons will be accelerated in opposite direction. This can lead to an increase in modulating anode current, a noisy r.f. signal and at least to sideband oscillations.
   To understand and analyze such a behavior the particle in cell simulation program FCI now plays a big role in Philips klystron development.

2. Barium evaporation

   During liftime of a klystron the cathode will evaporate Ba into gun and body section with a function of cathode temperature. This may cause unwanted electron emission of wehnelt cylinder, increase multipactor in 1. and 2. cavity and lead to h.v. instabilities in gun section due to Ba-flakes which falls on h.v. electrodes. In order to get rid of such problems Philips works on low temperatur cathodes such as Os/Ru and Scandat. Additionally a cathode pretreatment was investigated to evaporate the first Ba-cloud before mounting it to the tube.

Simulation of klystrons by FCI code

FCI-Field Charge Interaction code is a 2 1/2 dimensional particle-in-cell simulation program dedicated to analyse and design high power klystron amplifiers. The code simulates the electron beam motion with cylindrical symmetry, by taking into account the space-charge fields, RF-cavity and external focusing magnetic fields. The cavity voltages and the output power are determined by solving the circuit equations selfconsistently.

Since the entrance of digital computers in the 60'th a lot of computer codes for simulation of particle movements forced by static electric and magnetic fields have been developed and presented (SLACTRAY/EGUN, EBQ, INP, DEMEOS, TRACE, etc.). Later on computer codes using disc models have been introduced to calculate the interaction behavior of linear beam tubes (DISK, JPDISK, etc.). But these codes were restricted to small signal simulation, because they did not take into account radial forces of space charge due to bunching effects. The latest developments in computer simulation for particle accelerators lead to particle-in-cell codes where the forces and movement of so called "superparticles" are calculated. With these codes a large signal simulation of high power klystrons is possible today.

Taking the 6 cavity, 1.1 MW PHILIPS YK 1303 klystron as an example the power of the particle-in-cell code FCI developed by T.Shintake at KEK will be demonstrated.

The code's working area is restricted to the RF-section of a klystron. This area and the mesh size is defind by **MESH** routine. The **MAGNET** routine calculates the two-dimensional focusing field from on-axis measured or calculated (Poisson, PE2D) data. The cavity fields inside the drift-tube regions are determined by **CAVITY** routine from data as f_{drive}, gap position and size, and harmonic number.
From beam voltage and current, beam radius and slope (calculated by EGUN), drive frequency and power, and cavity parameters R/Q, Q_L and f_0 (calculated by Superfish) **BEAM** routine **MODE-1** determine the beam admittances Y_b seen by the cavities.

With these Y_b as input parameters **BEAM MODE-2** finally simulates the particle trajectories and calculates all cavity voltages and output power.

The program plots 4 "snap shots" of beam profile with time separation of one-quarter RF-cycles in which the bunching effect can be studied. From an energy distribution plot of the particles one can see the effect of backstreaming electrons caused by high gap voltage at the output cavity due to load mismatch.

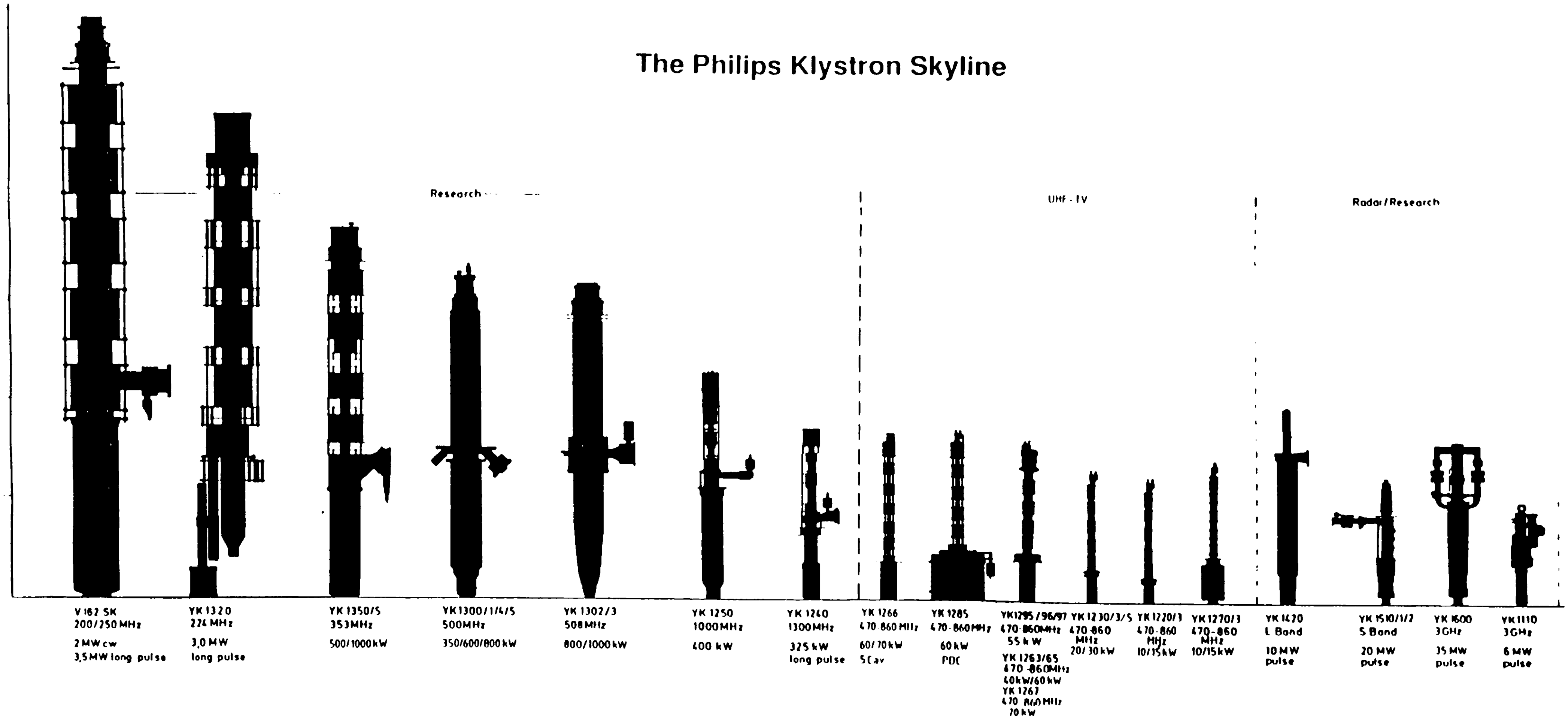
Some additional results in calculated output power of YK 1303 with respect to input power and tuning of harmonic cavity compared to measured values show good agreement.

CPU-time for executing CAVITY and BEAM MODE-2 routines takes about 1.5h on APOLLO 5500 work station.

Activities HFPT

Puls Klystrons	Military customers, Research
Power Klystrons	Research Application, CW only
TV-Klystrons	UHF Transmitters, External Cavities, Wideband
Transmitting-Tubes	TV Transmitters
Gyrotrons	Research, Fusion experiments
Circulators	Communication Industry, Professional equipment

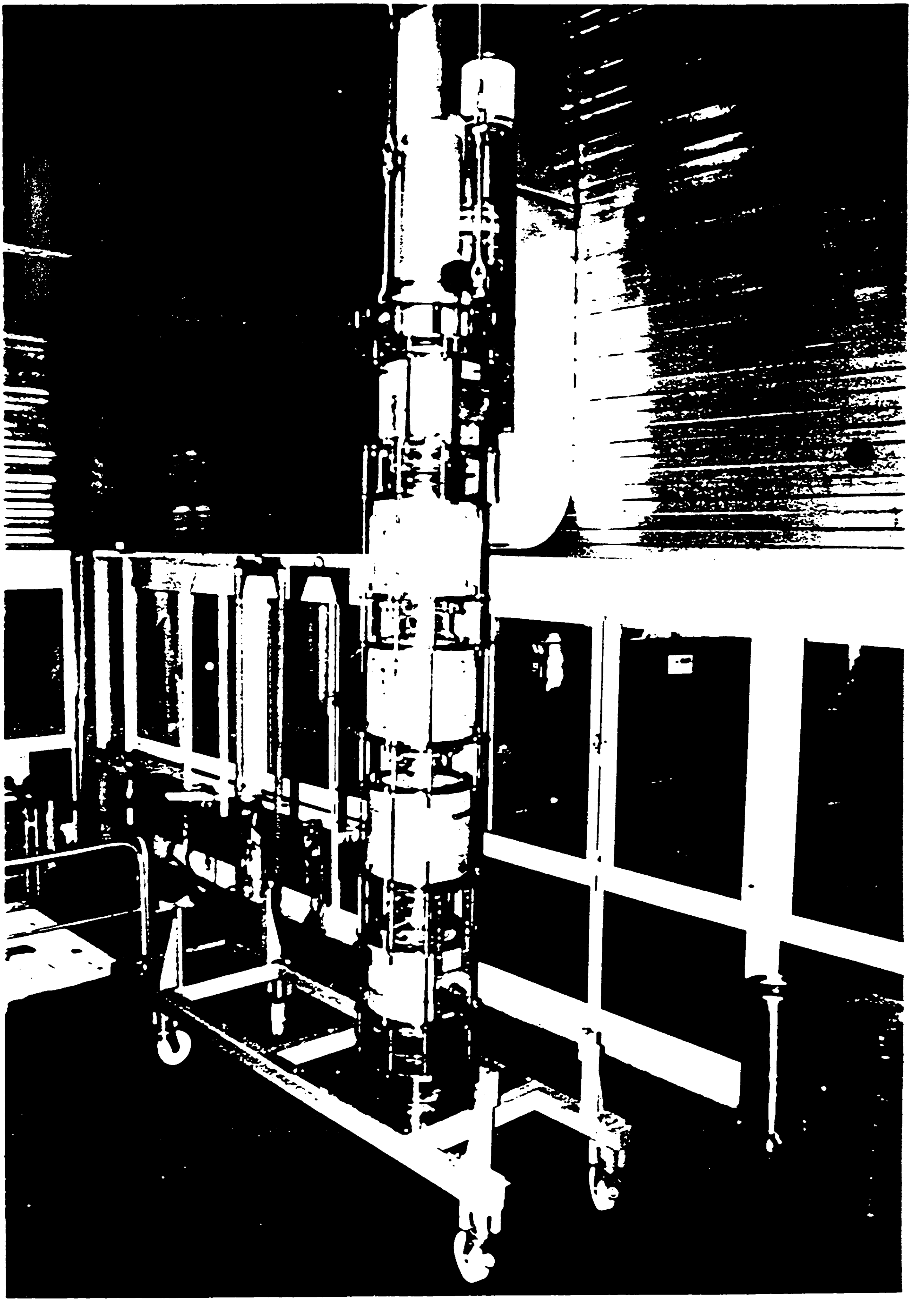
The Philips Klystron Skyline



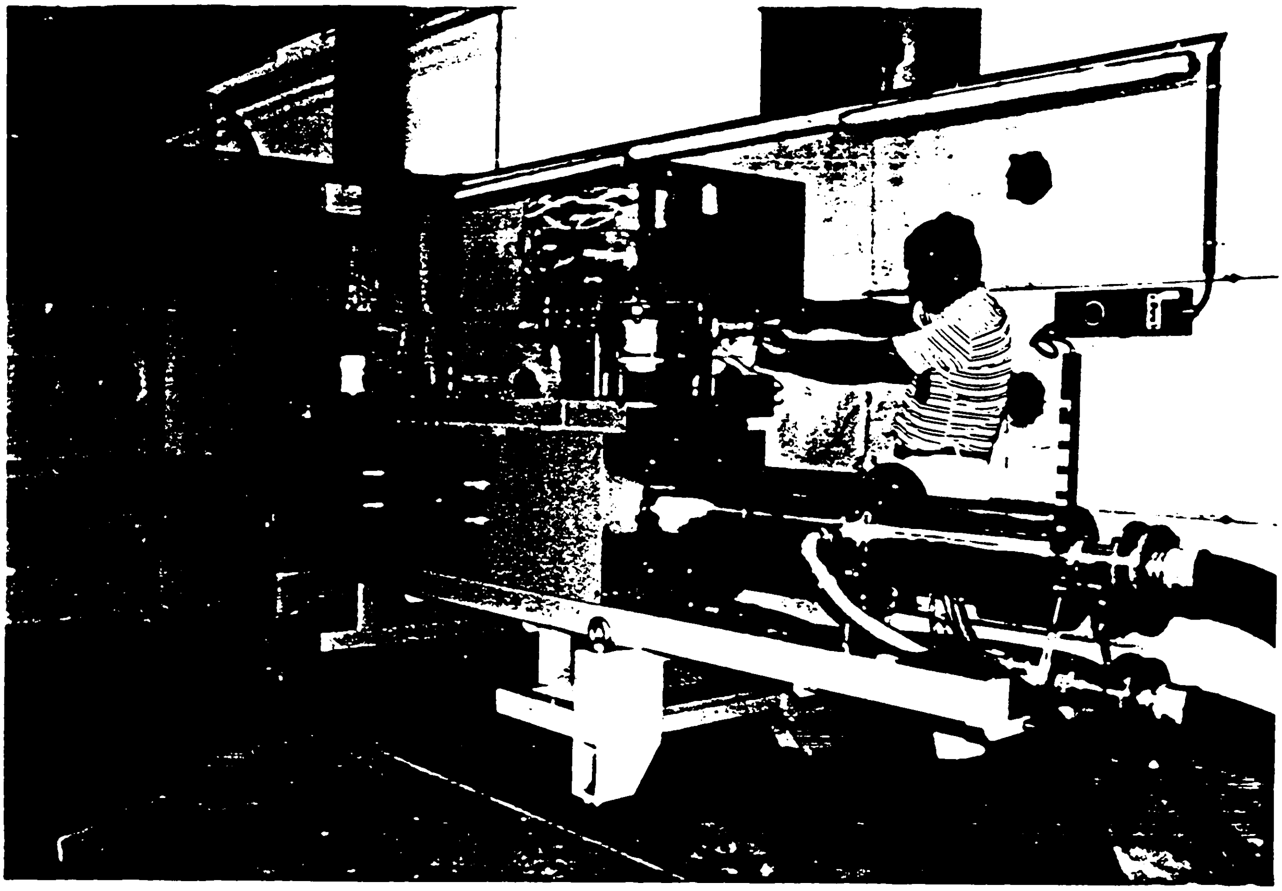
Philips Components

PHILIPS

PHILIPS



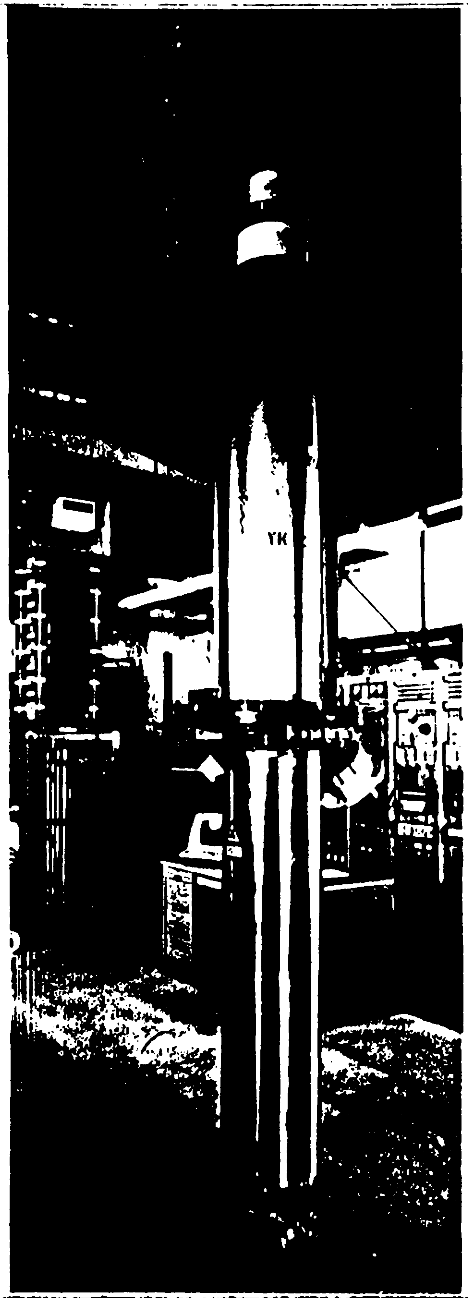
YK 1320 for EISCAT



PHILIPS

POWER KLYSTRON YK 1350
1,1MW 352MHz

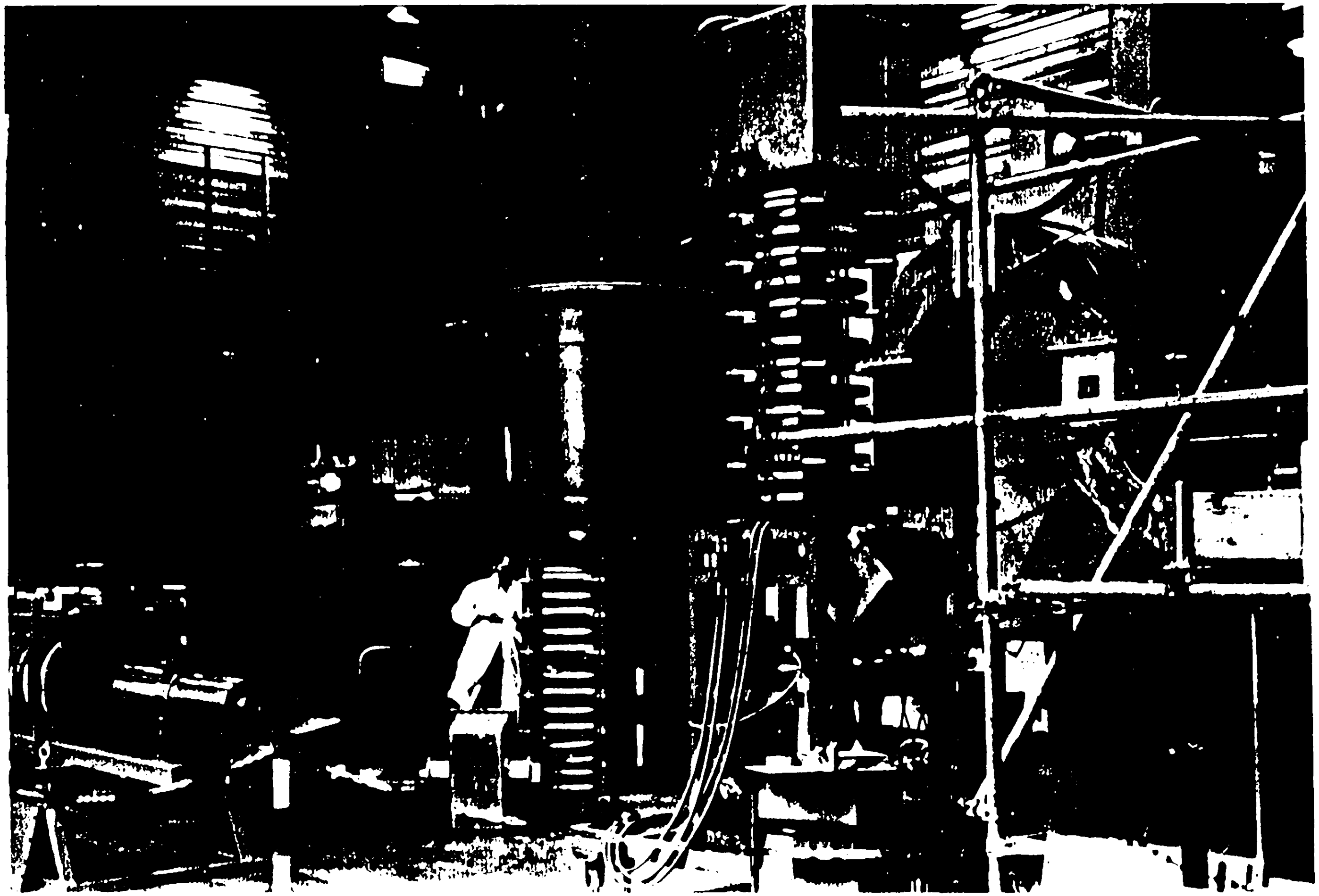
VALVO



PHILIPS

800KW-500MHz Klystron YK1300/01

VALVO



Power Klystron Testfield
(YK 1304 is installed)

Philips GmbH
Röhren- und Halbleiterwerke

YK 1600 pulsed power klystron

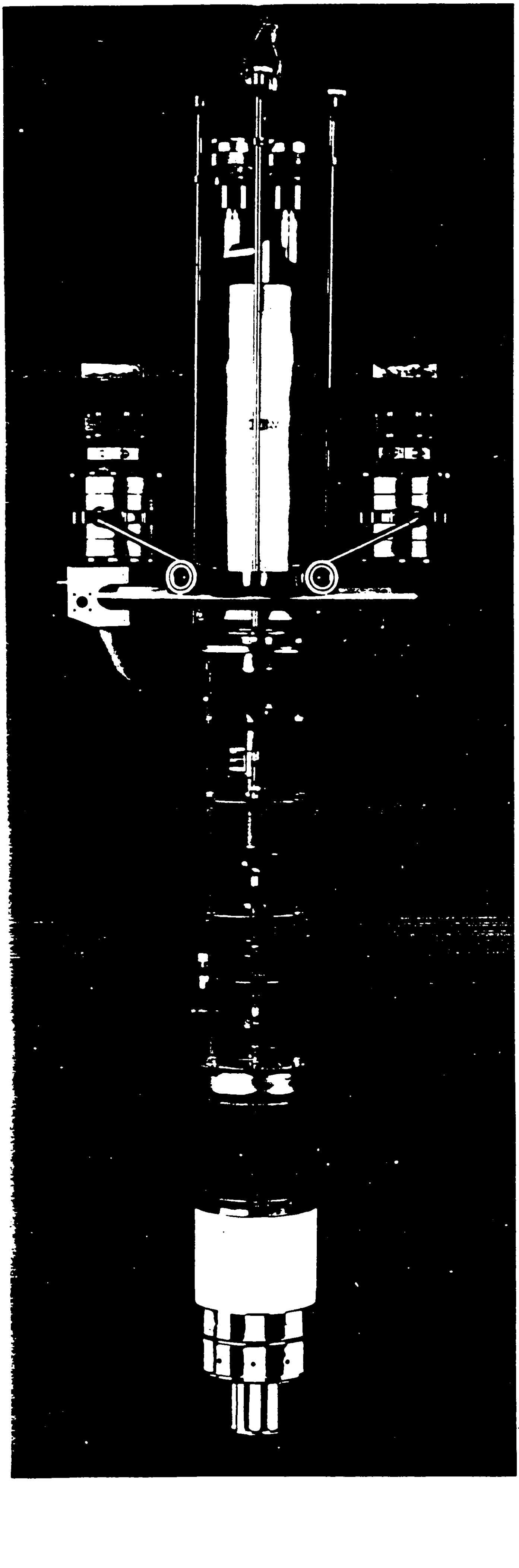
Frequency (fixed tuned)	2998.5 MHz
RF pulse width	4.5 μs
RF output power	
peak	35 MW
average	15.75 kW
Gain	52 dB
Efficiency	45 %

Features

- Double window
- extremly stable operation
- conservative design
- broadband design

Cathode	oxide type 5.6 A/cm² T ≈ 800°C
RF-System	5 internal cavities, broadband tuned
Window	double window, VSWR ≤ 1.01 ± 25 MHz
Combiner	broadband, VSWR ≤ 1.01 ± 75 MHz

YK 1600

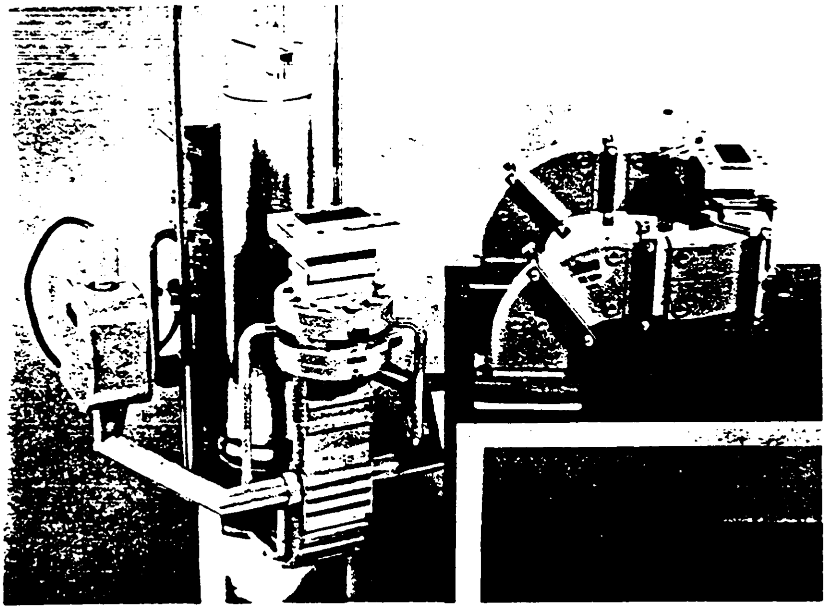


Pulse Klystrons for the Linear Accelerators of LEP/CERN

Completely installed klystron YK 1600 in LEP/CERN

In the previous chapter (pp. 12–13) the role of big klystrons YK 1350 for the acceleration of particles in the LEP storage ring has been described. The new 35 MW pulse klystrons YK 1600 are of similar importance to the operation of the pre-injector linacs providing the electrons and the positrons to be accelerated and stored in LEP. Both linacs are arranged in series and contain accelerating travelling wave structures operative in the S-band (2998.5 MHz). The first one (200 MeV) is an electron linac serving for the production of positrons, followed by the second linac (600 MeV) for electron and for positron acceleration. The overall length of both linacs is 100 m. The acceleration rate is constant and has a repetition frequency of 100 Hz; the duration of a beam pulse is 12 ns.

These linacs are operational since 1987, well before the commissioning of LEP.



RF output wave guide section and r.f. power combiner of YK 1600

Our most advanced TV Klystron Family

64 kW	45/58 kW	27/32 kW	11/16.5 kW	11/16.5 kW
YK 1265	**YK 1263**	**YK 1233**	**YK 1223**	**YK 1270**
				Air cooled

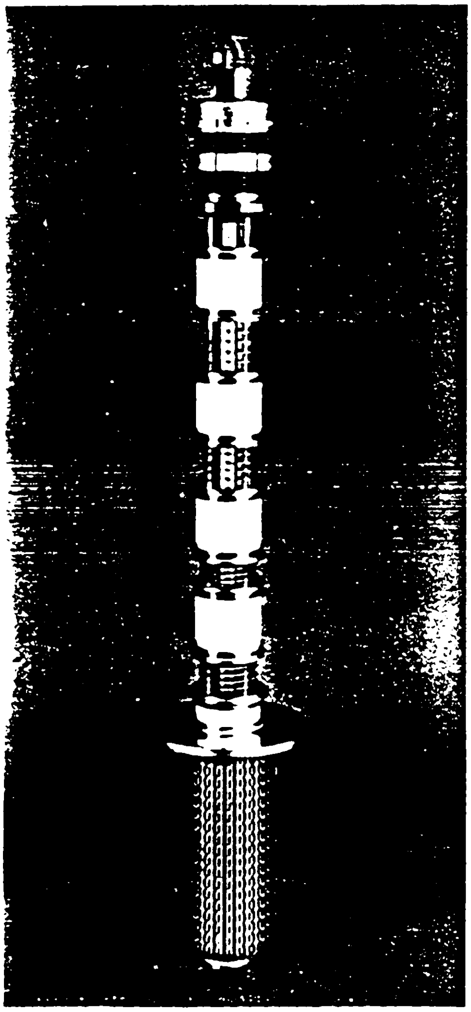
E-magnet
Water or Vapour cooled
Extremely high Efficiency
Very compact

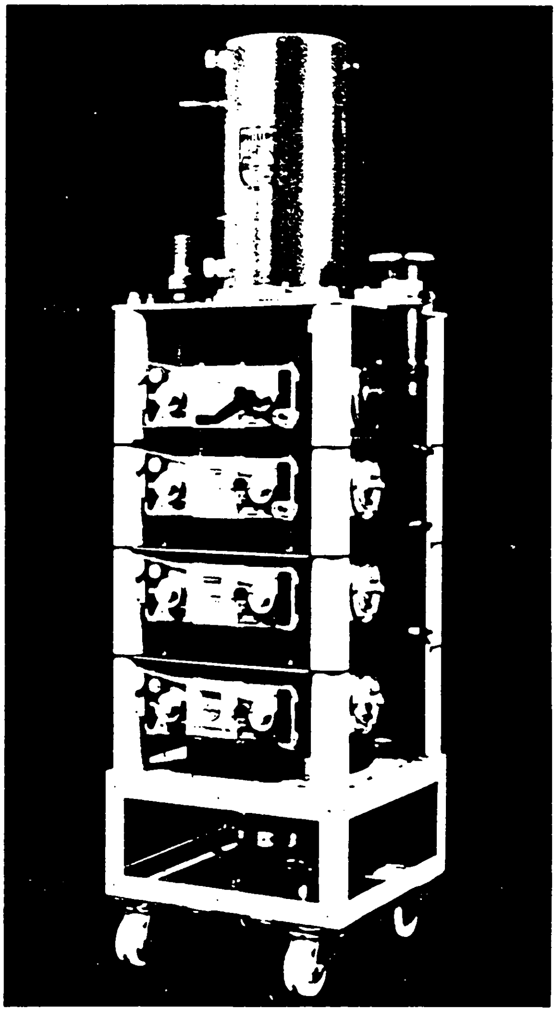
The klystron YK 1263 resp. YK 1265*) – to be seen on the photograph, on the right side completely assembled in its trolley – is the most powerful tube in the new range, with an extremely high efficiency of 65% if ABC sync. pulse switching is employed.

Features:

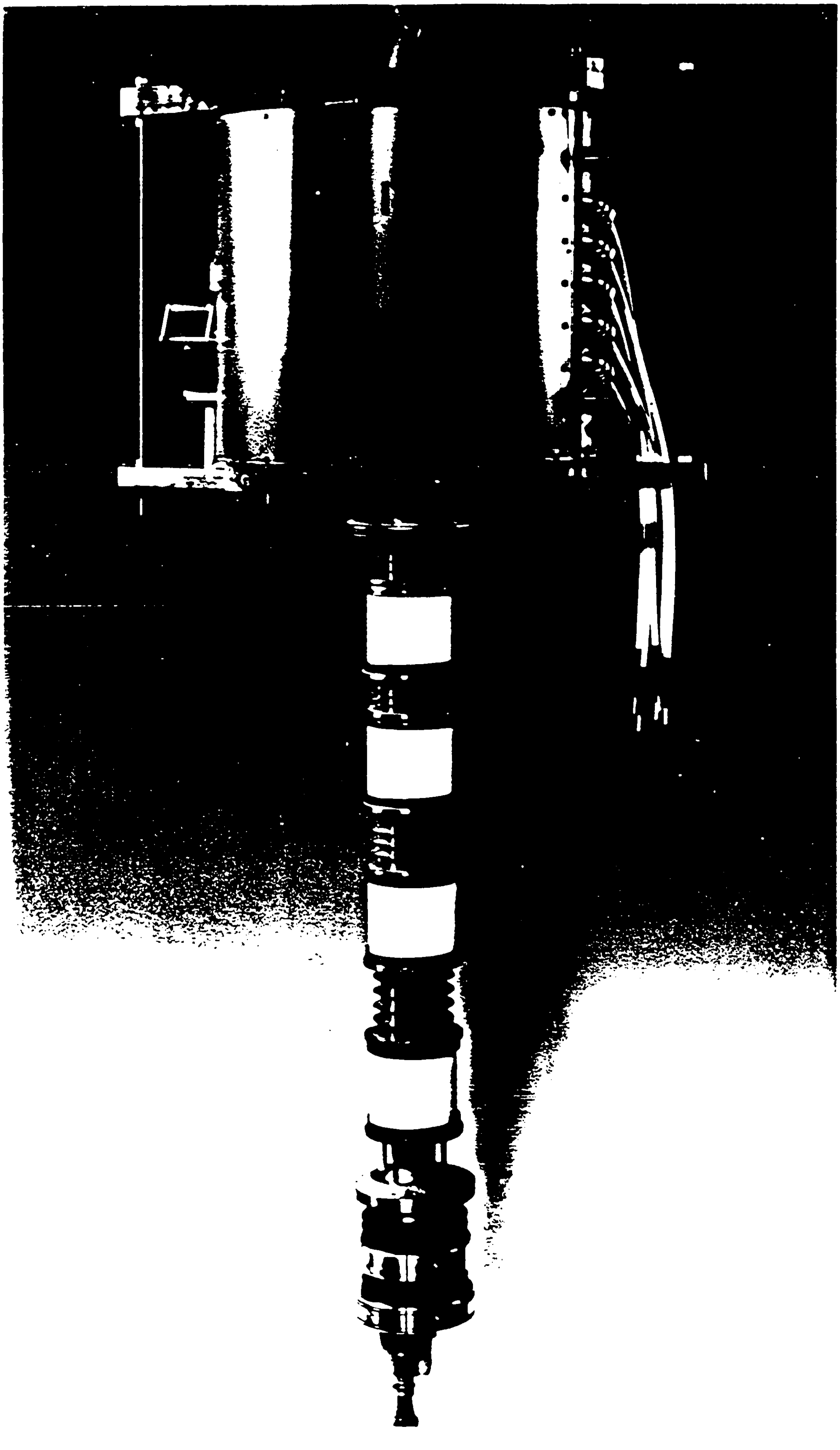
- Single tube advantage: planning, operating and purchasing made easier and more economical
- A single klystron now covers 470 to 860 MHz (types YK 1263 and YK 1265: 470 to 810 MHz)
- Continuously tunable cavities by crank or knob
- High basic efficiency
- Low-voltage beam modulation using the rugged ABC technique further improves efficiency (except YK 1270)
- Design and operating flexibility – choice of water, vapour condensation or vapour cooling with either tube (YK 1270 air cooled)
- Only non-beryllium oxide ceramics used
- Small size, compact units – for upgrading existing transmitters

  The area needed for 64 kW, YK 1265 is now 60 cm x 60 cm compared with 82 cm x 80 cm for YK 1195 (58 kW).



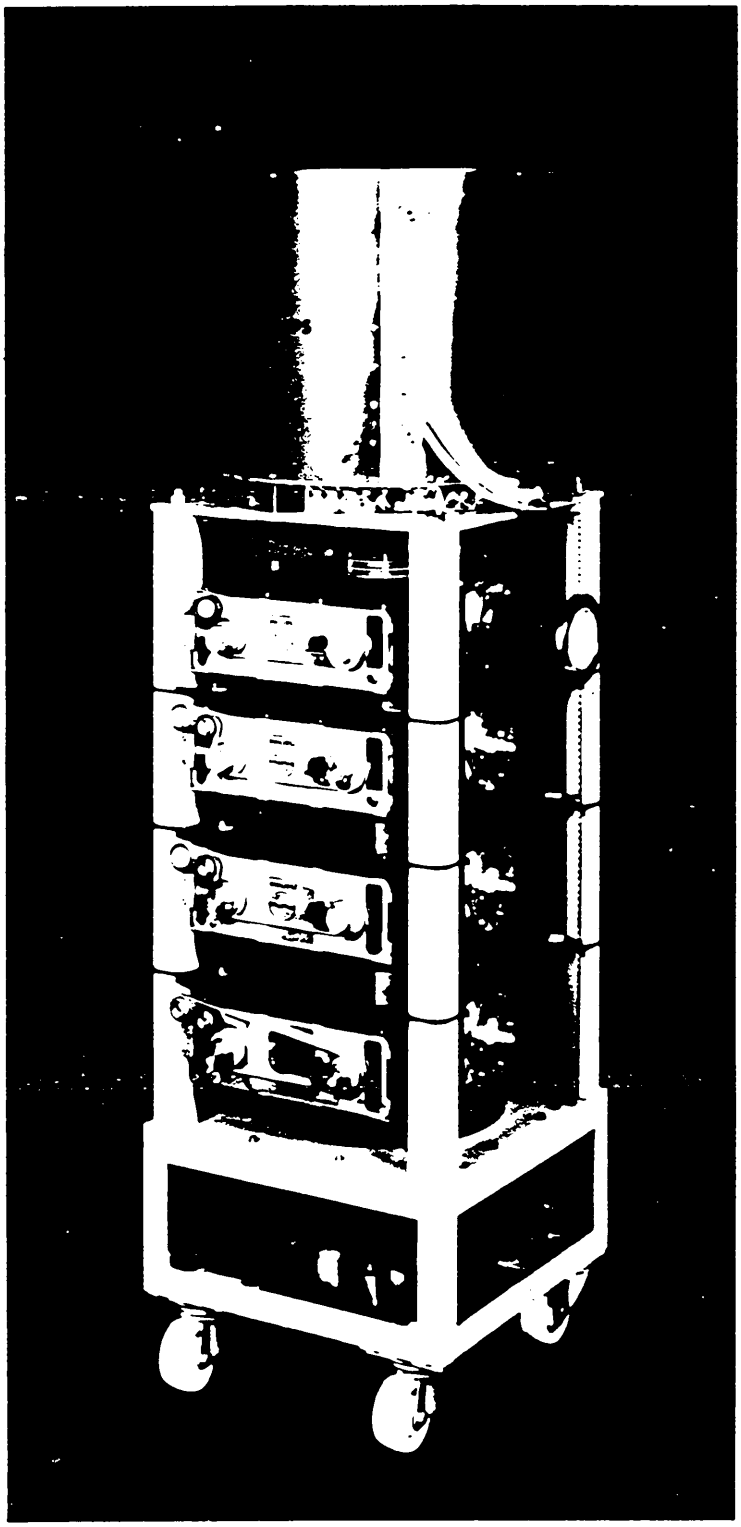


*) Klystron YK 1263/65, the collector shroud has been removed



Philips Components

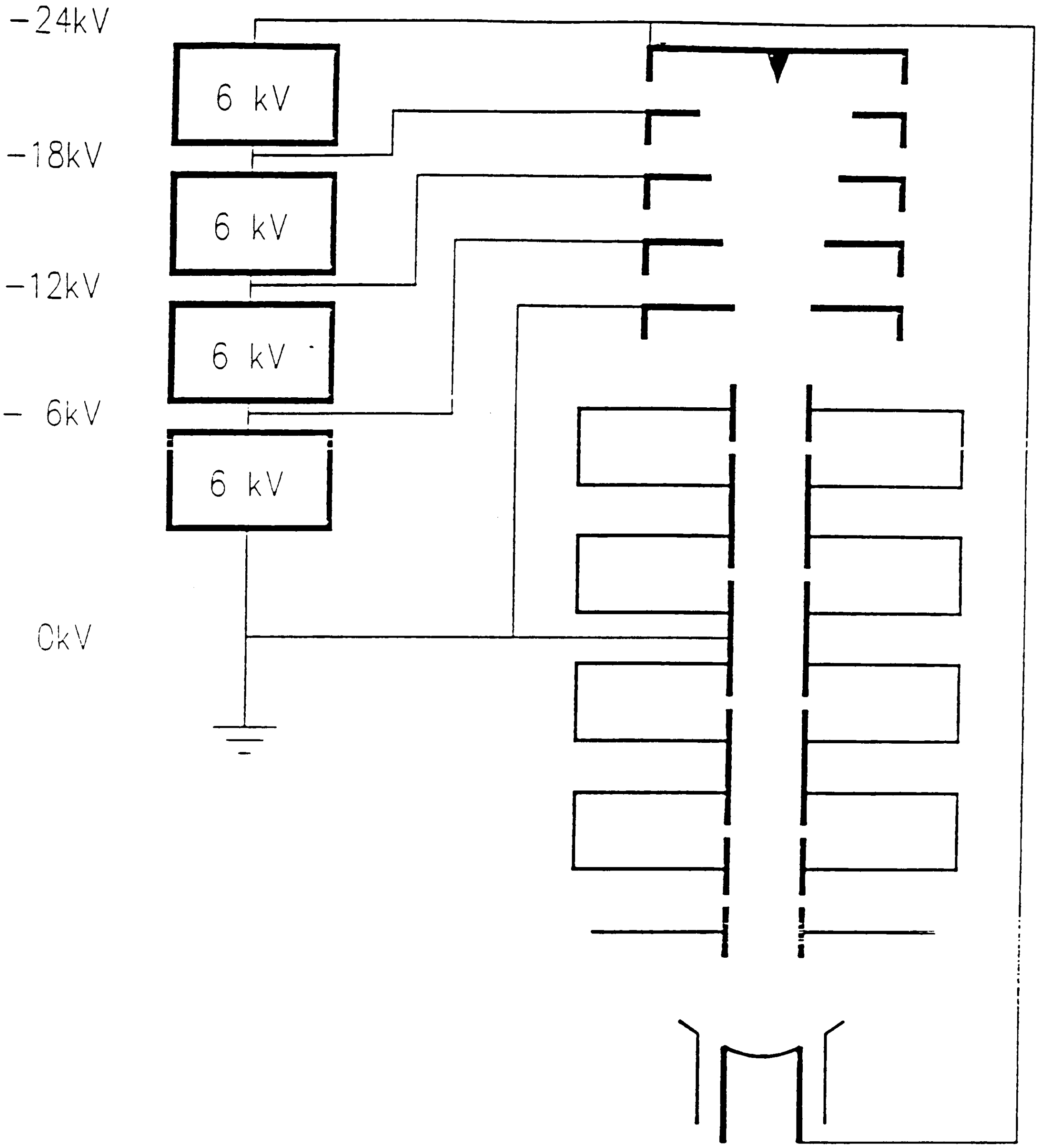
PHILIPS



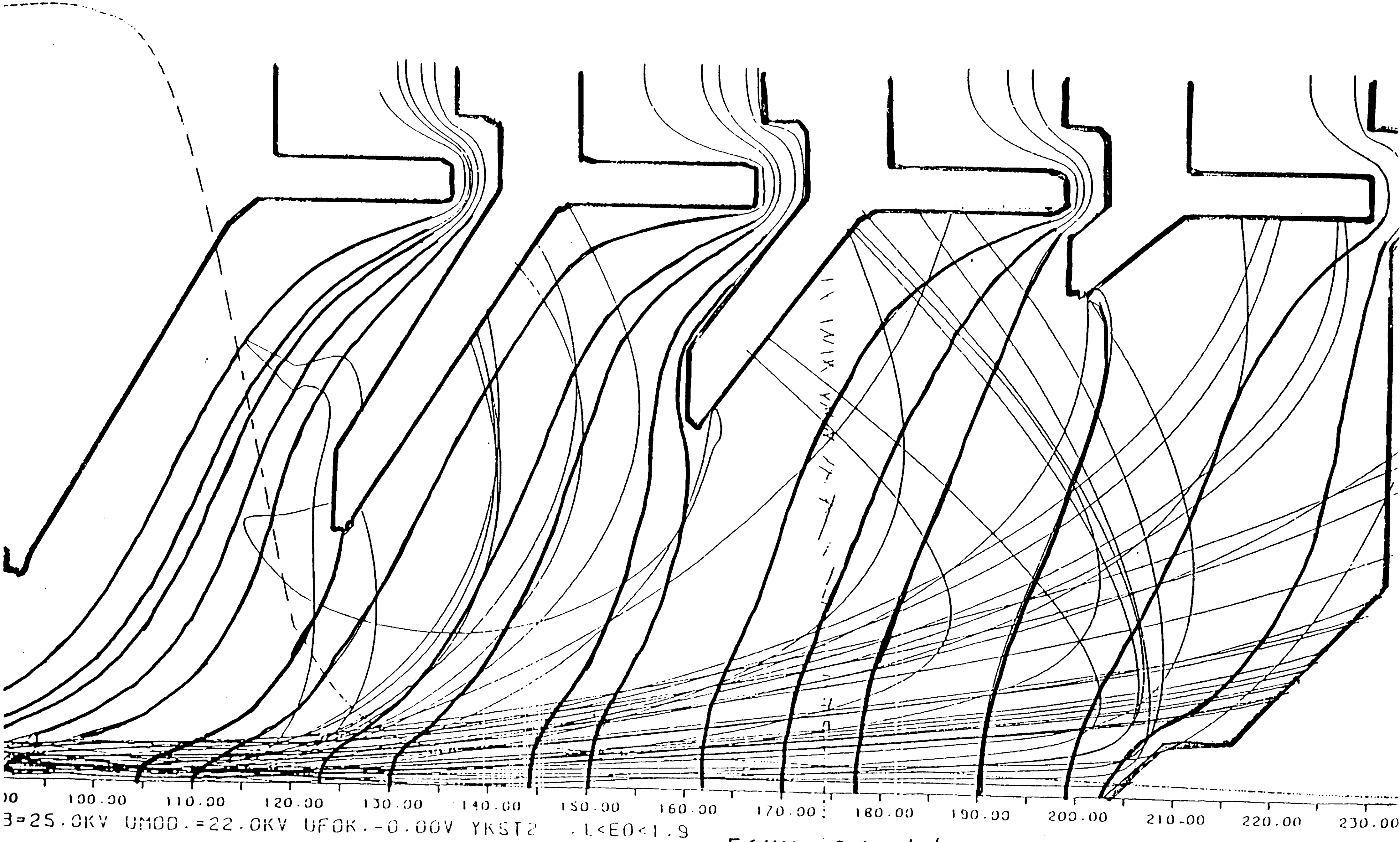
YK 1285 unit

60 kW, 5 stage depressed collector

PHILIPS



Design-Structure 60kW PDC Klystron YK 1285



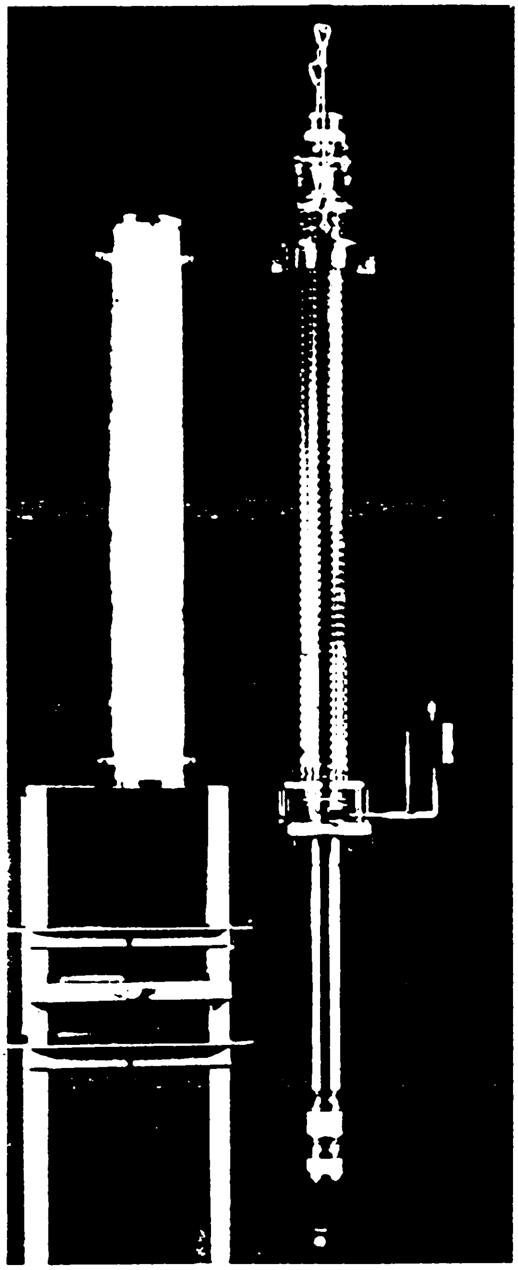
EGUN - Calculation YK 1285

Gyrotrons for Plasma Research made by Valvo

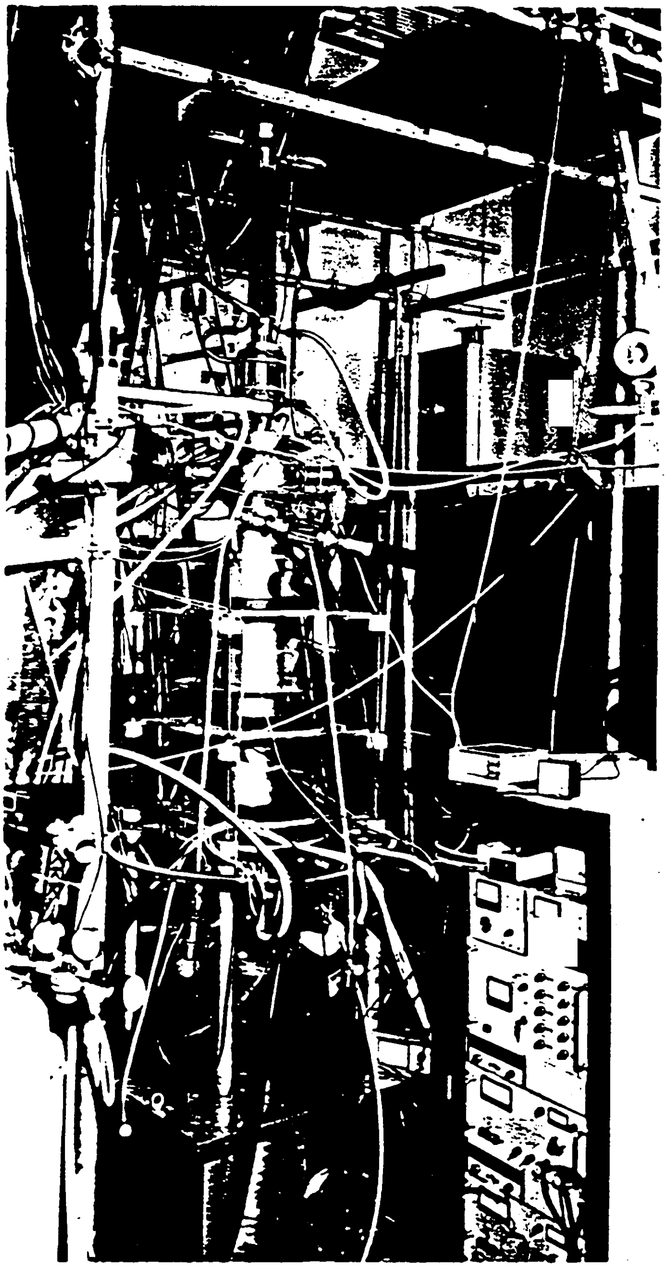
1984 Valvo started a development exercise on an innovative microwave power tube, the gyrotron. According to the diagram on p. 4, r.f. power levels of several 100 kW in the 100 GHz frequency range can effectively be generated by gyrotrons.

Valvo is developing a gyrotron prototype operating at 70 GHz with a long pulse output power in the range of 200 kW. The gyrotron is operated in the TE_{02} mode, the collector voltage being 80 kV at full power. The extremely high magnetic field for this tube will be generated by a helium cooled superconducting solenoid magnet made by Oxford Instruments.

In an advanced gyrotron design cooperation with KfK Karlsruhe, Valvo is responsible for the technological design and the manufacture of 140 GHz gyrotrons in the 200 kW range. The tubes will be used in the next generation of advanced H_2 fusion experiments.



70 GHz gyrotron prototype



Gyrotron under test.

Philips GmbH
Röhren- und Halbleiterwerke

V12SG

140 GHz gyrotron prototype

Development in cooperation with KFK

Preliminary data:

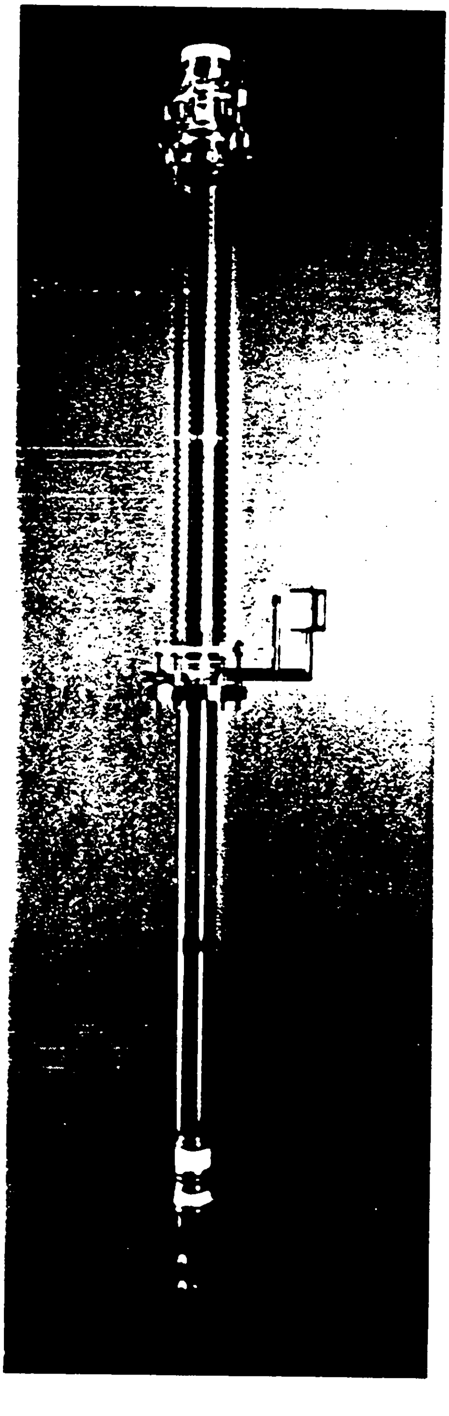
Frequency	140 GHz
Output power	120 kW
Pulse length	≤ 1s
Oscillation mode	TE 03
Beam voltage	68 kV
Beam current	8 A
Anode voltage	24 kV
Heater voltage	7 V
Heater current	6 A

Features

- tunable double disc window
- modulating capability by anode voltage

installed at plasma experiment W7AS in IPP Garching

Philips GmbH
Röhren- und Halbleiterwerke



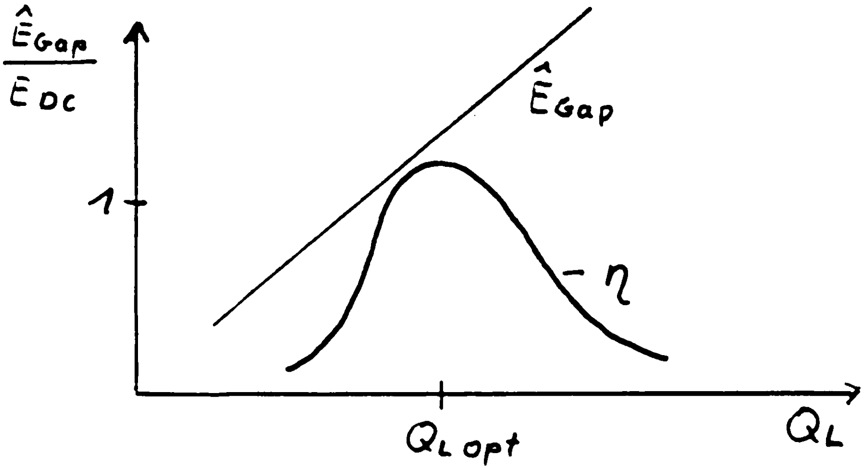
Philips Components

PHILIPS

Philips GmbH
Röhren- und Halbleiterwerke

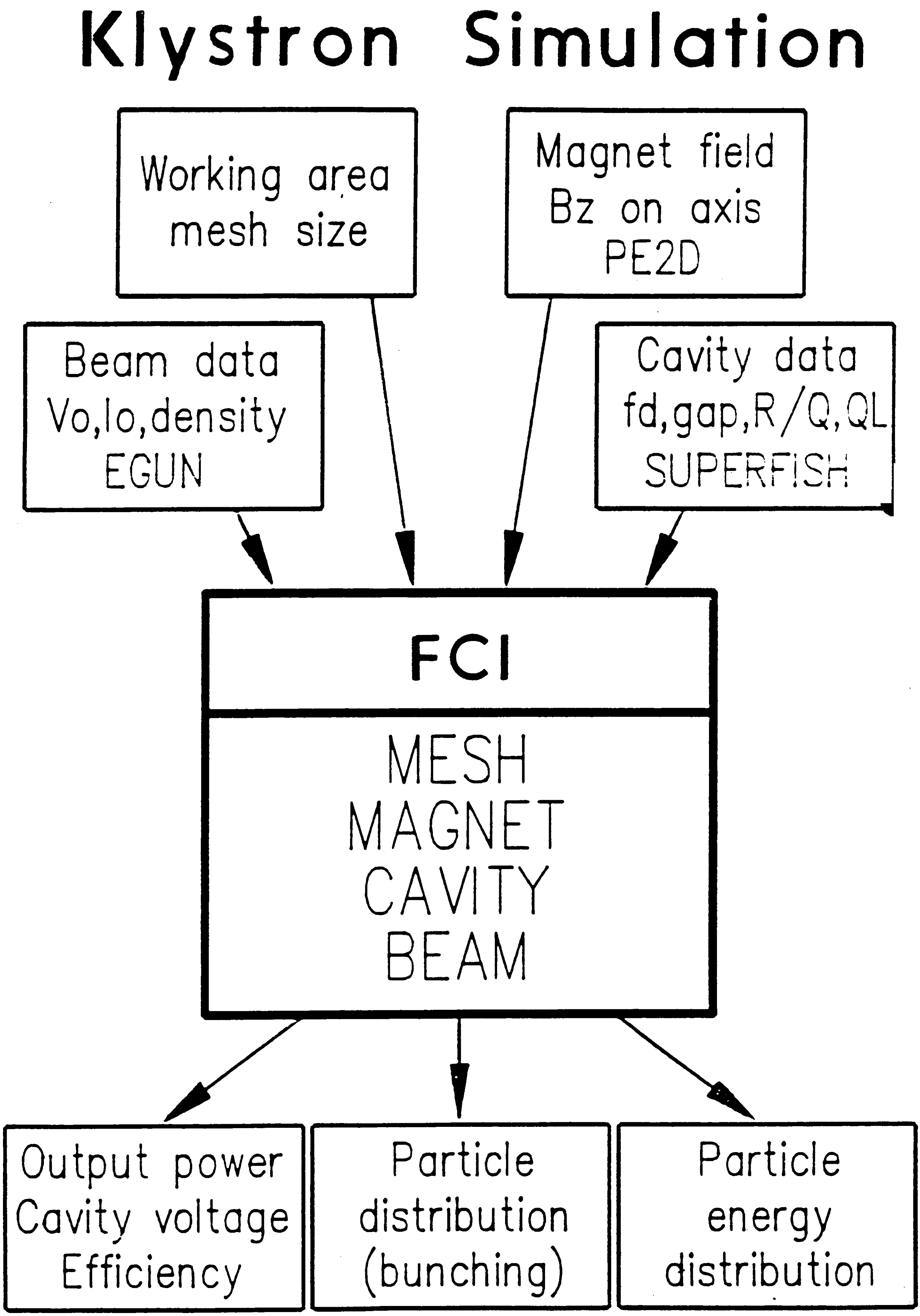
Klystron instabilities

1. Backstreaming electrons
   - noisy signal
   - increase in mod. anode current
   - side band oscillation



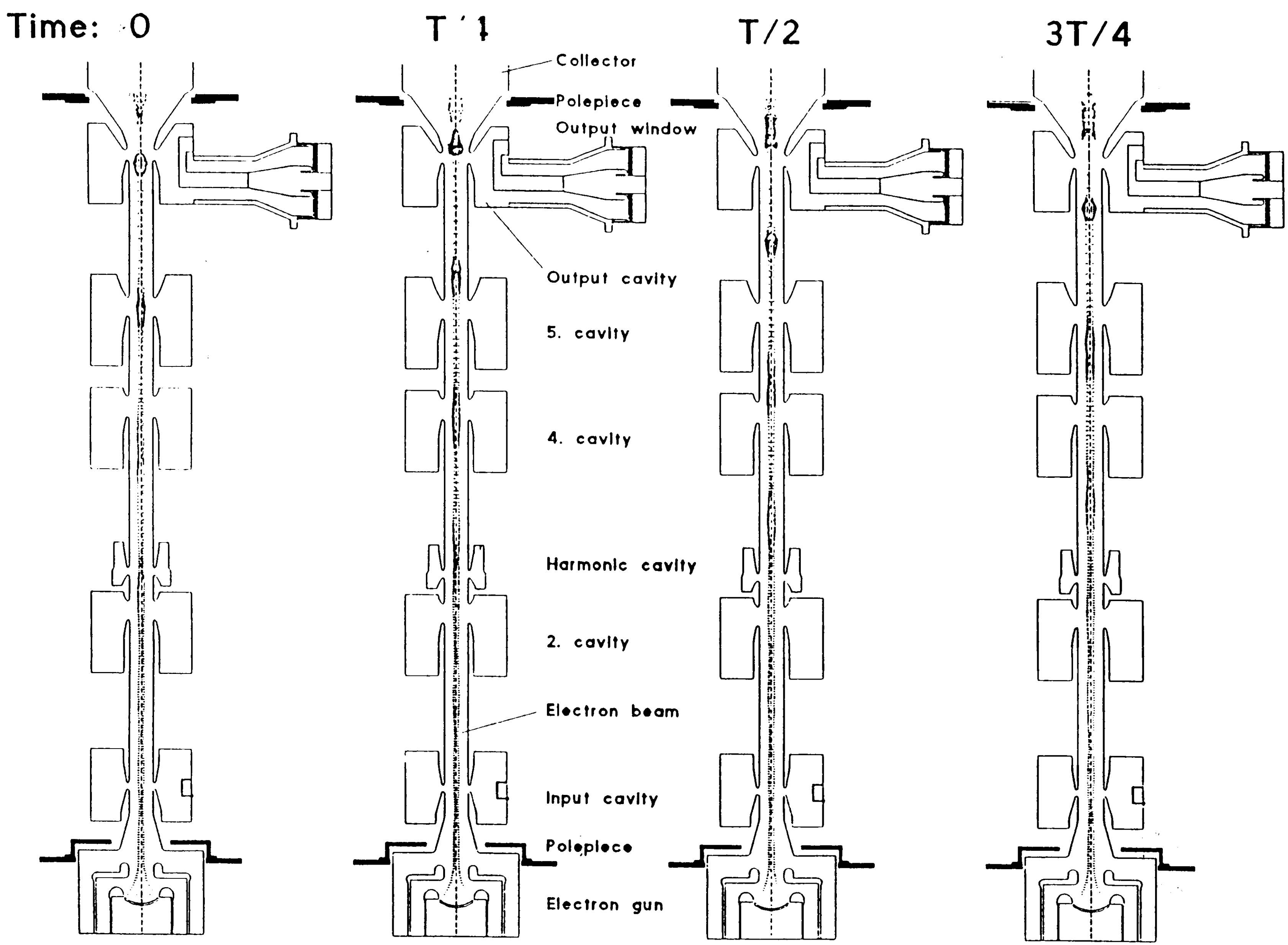
2. Ba. - evaporation (lifetime problem)
   - el. emission of hot electrodes (Wehnelt)
   - increase in multipactor (1. and 2. Gap)
   - decrease of HV - stability (Flakes)

   - low temperature cathodes (Os/Ru ; Scandat)
   - pretreatment

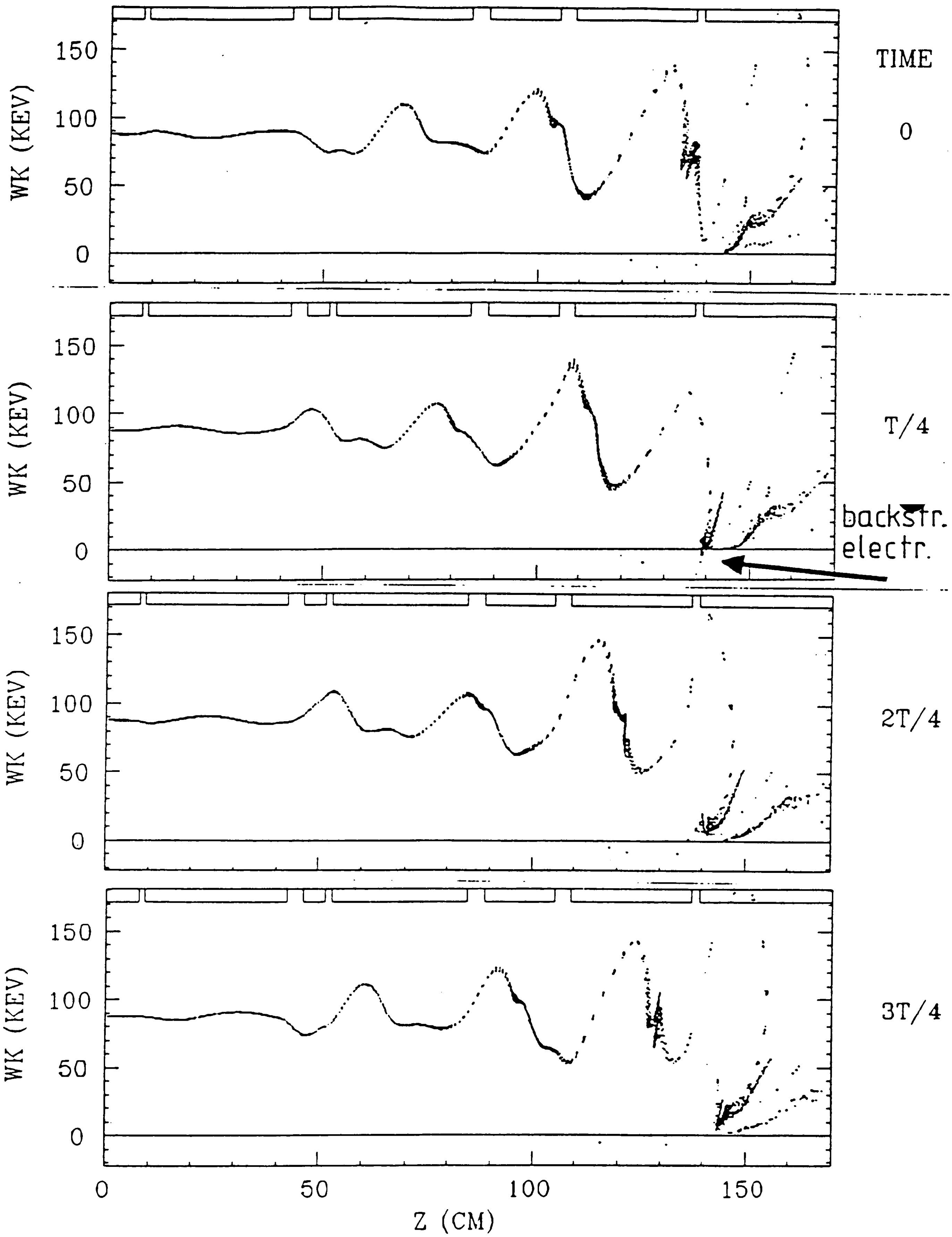


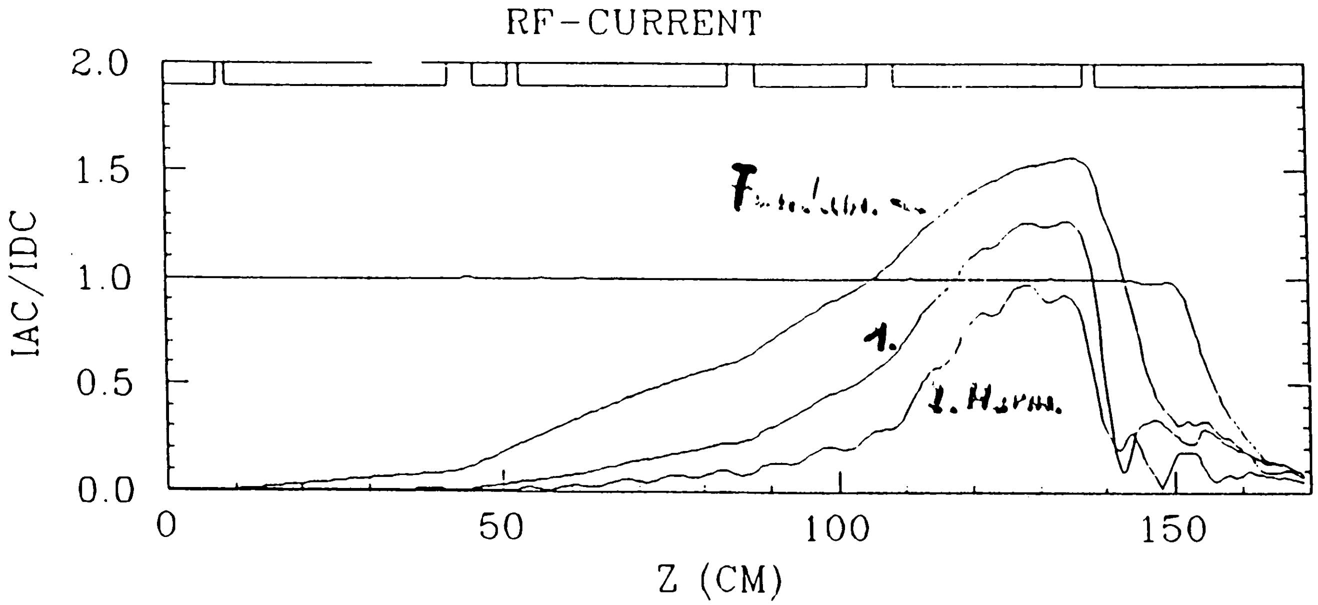
Klystron Simulation
Working area
mesh size
Magnet field
Bz on axis
PE2D
Beam data
Vo,Io,density
EGUN
Cavity data
fd,gap,R/Q,QL
SUPERFISH
FCI
MESH
MAGNET
CAVITY
BEAM
Output power
Cavity voltage
Efficiency
Particle
distribution
(bunching)
Particle
energy
distribution

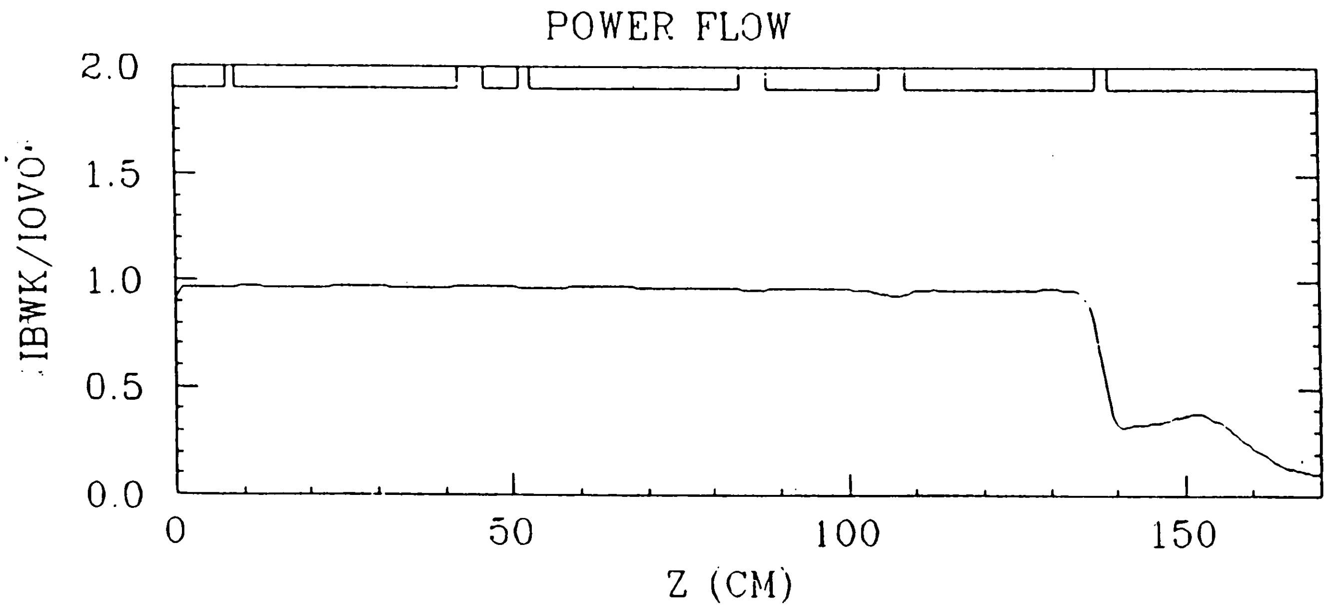
Fig. 1


Time: 0
T/4
T/2
3T/4
Collector
Polepiece
Output window
Output cavity
5. cavity
4. cavity
Harmonic cavity
2. cavity
Electron beam
Input cavity
Polepiece
Electron gun

YK 1303 ENERGY PROFILE $QL_6 = 50$




RF-CURRENT
IAC/IDC
2.0
1.5
1.0
0.5
0.0
0
50
100
150
Z (CM)
1.


POWER FLOW
IBWK/IOVO
2.0
1.5
1.0
0.5
0.0
0
50
100
150
Z (CM)

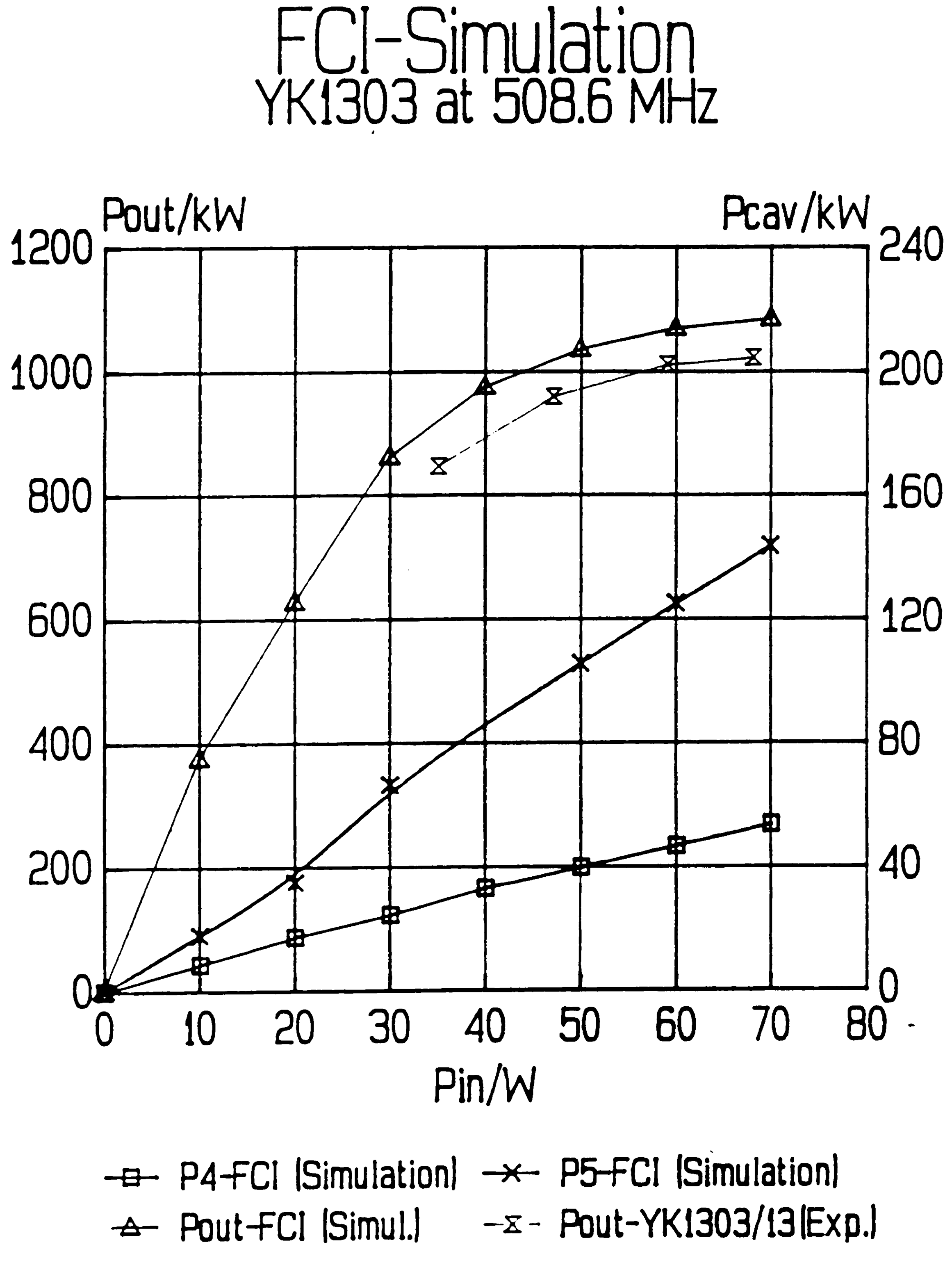

FCI-Simulation
YK1303 at 508.6 MHz
Pout/kW
Pcav/kW
1200
1000
800
600
400
200
0
240
200
160
120
80
40
0
0 10 20 30 40 50 60 70 80
Pin/W
P4-FCI (Simulation)
P5-FCI (Simulation)
Pout-FCI (Simul.)
Pout-YK1303/13 (Exp.)

Fig. 5

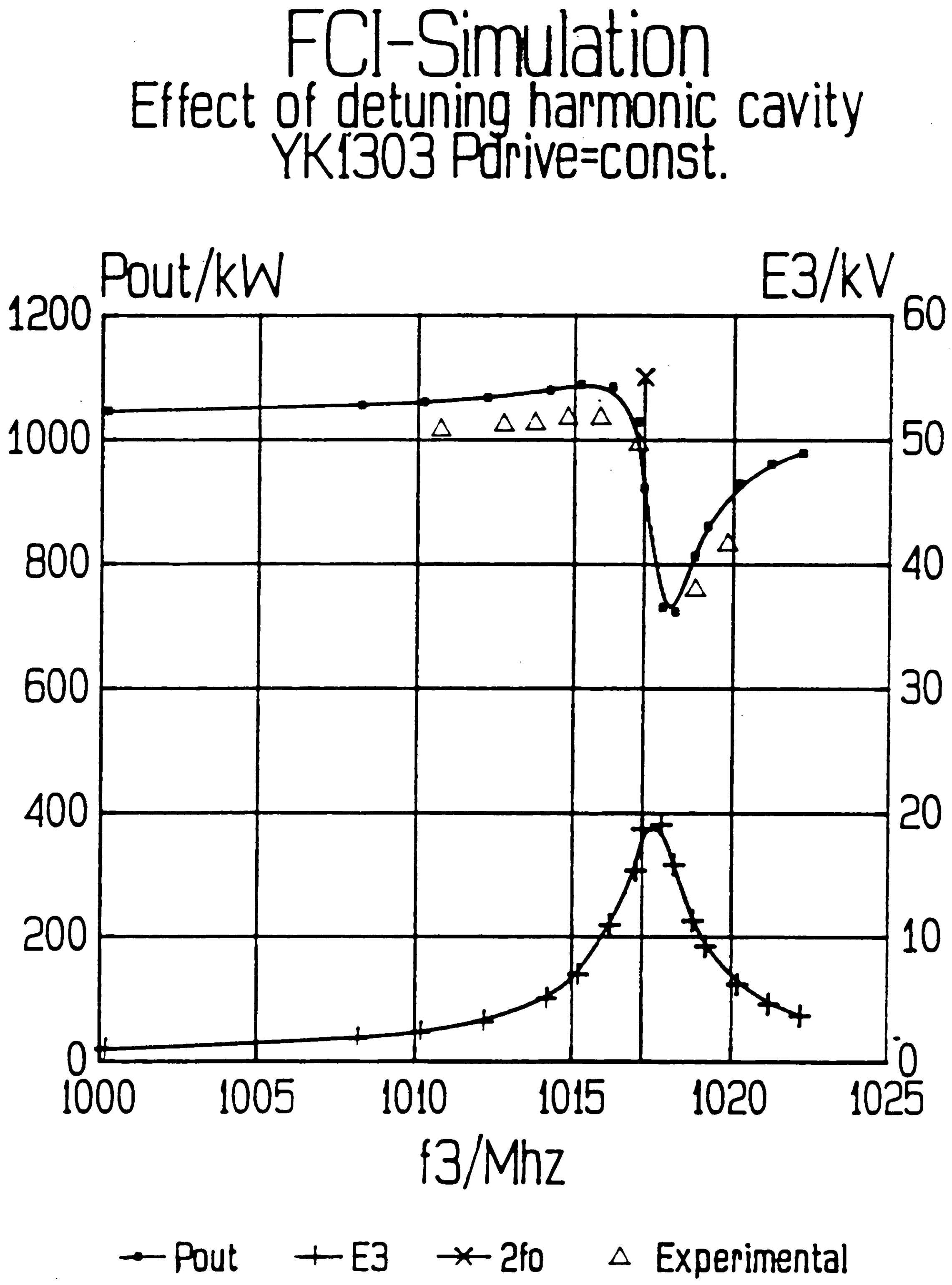

FCI-Simulation
Effect of detuning harmonic cavity
YK1303 Pdrive=const.
Pout/kW
E3/kV
1200
1000
800
600
400
200
0
60
50
40
30
20
10
0
1000
1005
1010
1015
1020
1025
f3/Mhz
Pout
E3
2fo
Experimental

Fig. 6

Development main activities

60 kW TV PDC - klystron

- air / water cooling
- coating

1.3 MW 352 Mhz power klystron CERN

- 100% beam controlled
- improved stability

Low temperature cathodes

- Os / Ru
- Scandat

PS KLYSTRON MODULATOR TECHNICAL MEETING
OCTOBER 7^{TH} AND 8^{TH} 1991 - CERN

THOMSON HIGH PEAK POWER KLYSTRONS

G. FAILLON

Abstract : For several years THOMSON TUBES ELECTRONIQUES has been developing a new high peak power S-band klystron family. The peak power range spreads from 35 to 45 MW with typical 4.5 μsec pulse length. So the TH 2094, which equips several sockets of the LIL at CERN, is a good example of this type of klystron.

Because the reliability became a critical issue for operators of accelerator facilities, a strong and continuous development effort was performed and is continuing to increase the klystron lifetime through technology improvement on built-in parts of the tube, such as cathodes, RF structure, windows, and also by taking care of external factors, like focusing, cooling, output matching and modulator interface.

For many years THOMSON has developed and manufactured high peak power klystrons for two types of applications :

- Radar and especially large instantaneous bandwidth transmitters

- Scientific and medical particle accelerators.

The characteristics of the tubes for these two types of applications are quite different. Nevertheless the powers are in the same range and after the choice of a modular technology many subassemblies have become identical, allowing a much better optimization.

The main features of these klystrons are the following :

. Cavities with high coupling and R/Q values. This comes from the requirement of klystrons, with large bandwidths to have a high gain times bandwidth product. Therefore higher gains and efficiencies of the accelerator tubes can be achieved.

. Mechanical frequency tuning system (5 to 7 %) and no parasitic mode in the harmonics bands.

.../...

. Mastery of the high voltage pulses in the modulators and in the electron guns, in several respects : design, manufacturing, processing.

. Capabilities to extend the pulse lengths, still with the same technology.

. Cooling especially of the collectors. The following examples can be given : TH 2108 (4 MW peak, 60 kW average), TH 2115 (2 MW, 150 kW, 1.5 ms), TH 2103 (650 kW, 10 sec, 3.7 GHz). But the thermal behaviour of the output circuit (cavity, drift tube, window) is also well mastered.

. Windows (conventional pill-box and thick windows).

. Cathodes : the oxide cathodes were replaced 20 years ago by metallic emitters and THOMSON continuously improves there cathodes.

And in 1982 a new advance has been made under the pressure of the CERN (LIL). The power range is no more 15 to 25 MW but 35 to 45 MW.

At the same time the new radar transmitter characteristics followed the exact opposite direction : smaller peak powers and still greater instantaneous bandwidths. Such performances are very severe : indeed on a klystron the bandwidth capability decreases when the peak power decreases, mainly because the cavities are less loaded by the beam resistance. On the other hand this difficulty has obliged THOMSON to develop or to improve computer codes, which have been immediately used to develop the 35 MW LIL TH 2094 and a new family of particle accelerators klystrons.

Thanks to these codes - especially 1D, but also 2D - we have been able to optimize the harmonics currents and the velocity dispersion and therefore the RF structure (drift tubes and cavities). Also with other codes, the electron trajectories are calculated taking into account the magnetic flux lines. And finally we continue to use improved thermal and mechanical codes.

Two of our transparencies show examples of Rieke diagrams which describe the klystron behaviour on matched and mismatched loads. Such diagrams approximately give an idea of the maximum admissible VSWR, and also the decrease of the efficiency with the load impedance.

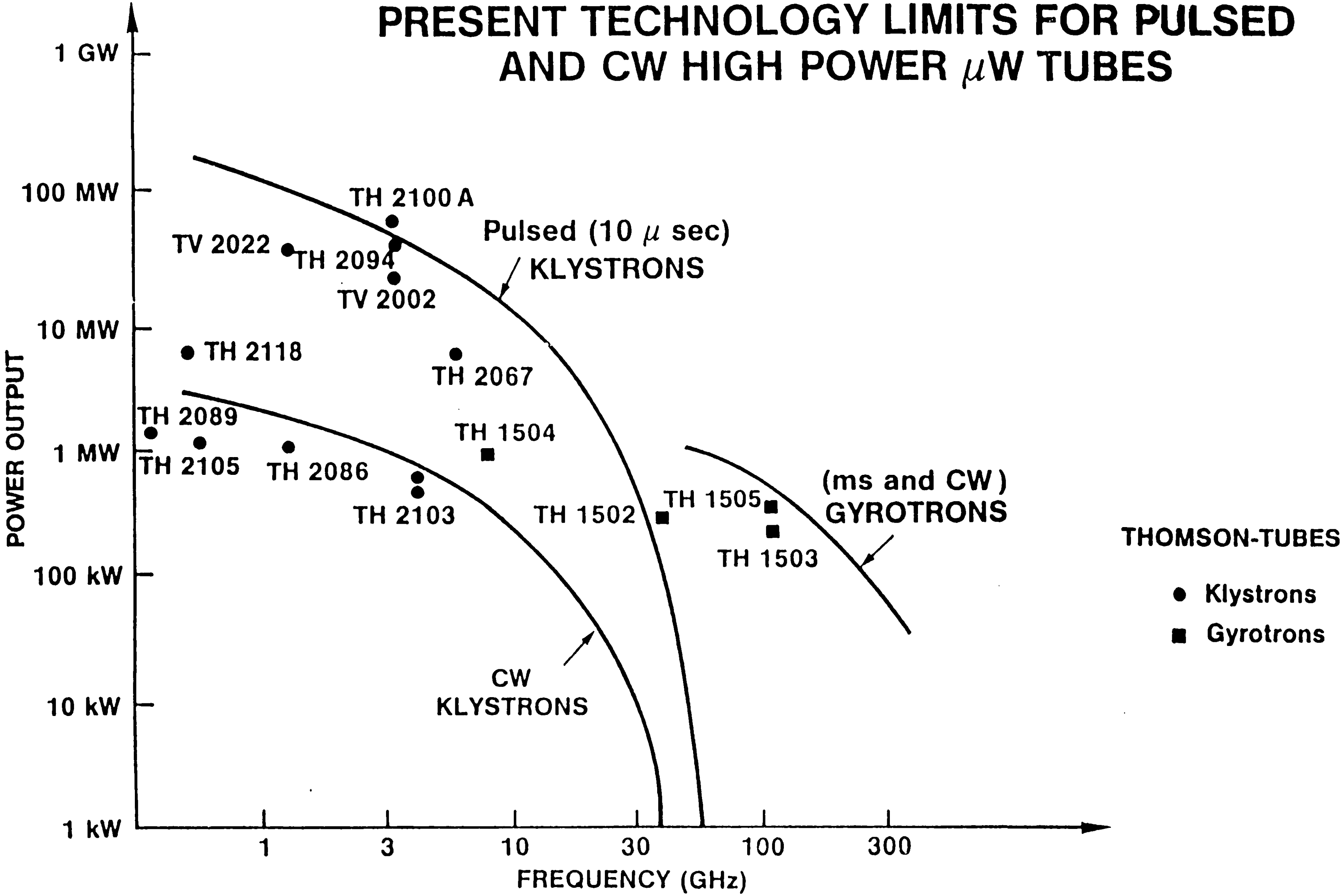
The TH 2094, which equips 3 sockets on the LIL, has the same modular technology as previously described and many parts and subassemblies are still used on other tubes. However it is longer just because of the higher voltage. The cathode is an impregnated S type cathode and from now on it will be coated in order to improve the lifetime : the temperature of the cathode itself, but also of all the parts of the gun, becomes

.../...

lower. The unique window is the most important part of the tube and takes time to be carefully manufactured. We have improved this window in order to present 45 MW, 4.5 μs/3 GHz and 2856 MHz tubes.
The external waveguide usually is under vacuum. The TH 2132 output power is also 45 MW peak, but the user requirement was for 2 arms. This tube is now under test with a pulse compressor device (CIDR) comparable to the one of the LIL, except that the expected power is greater.

We present in the following pages illustrations of the THOMSON technology and a table which describes the main characteristics of the THOMSON high peak power klystrons.

PRESENT TECHNOLOGY LIMITS FOR PULSED AND CW HIGH POWER μW TUBES

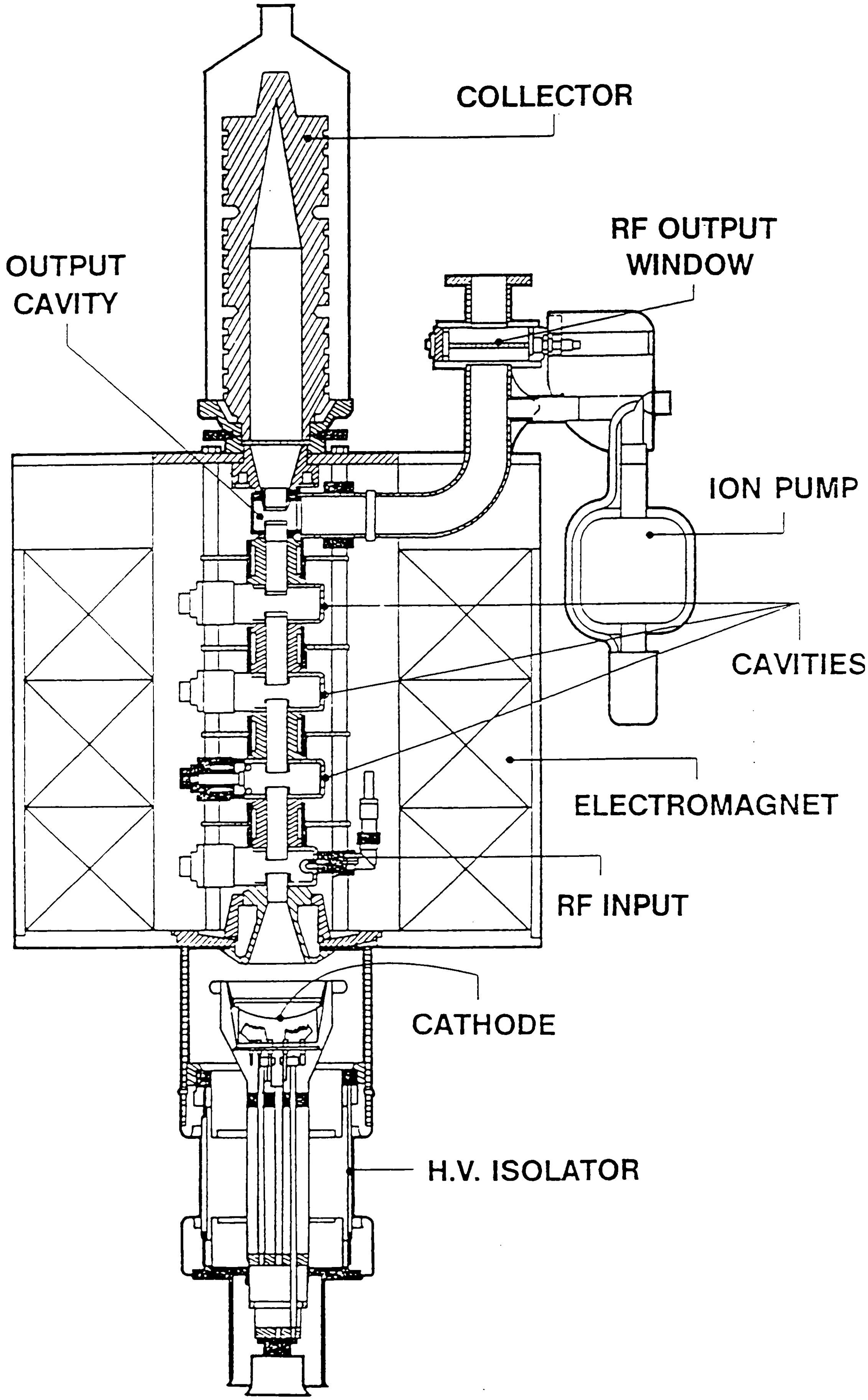


THOMSON TUBES ELECTRONIQUES

CERN 8/10/91

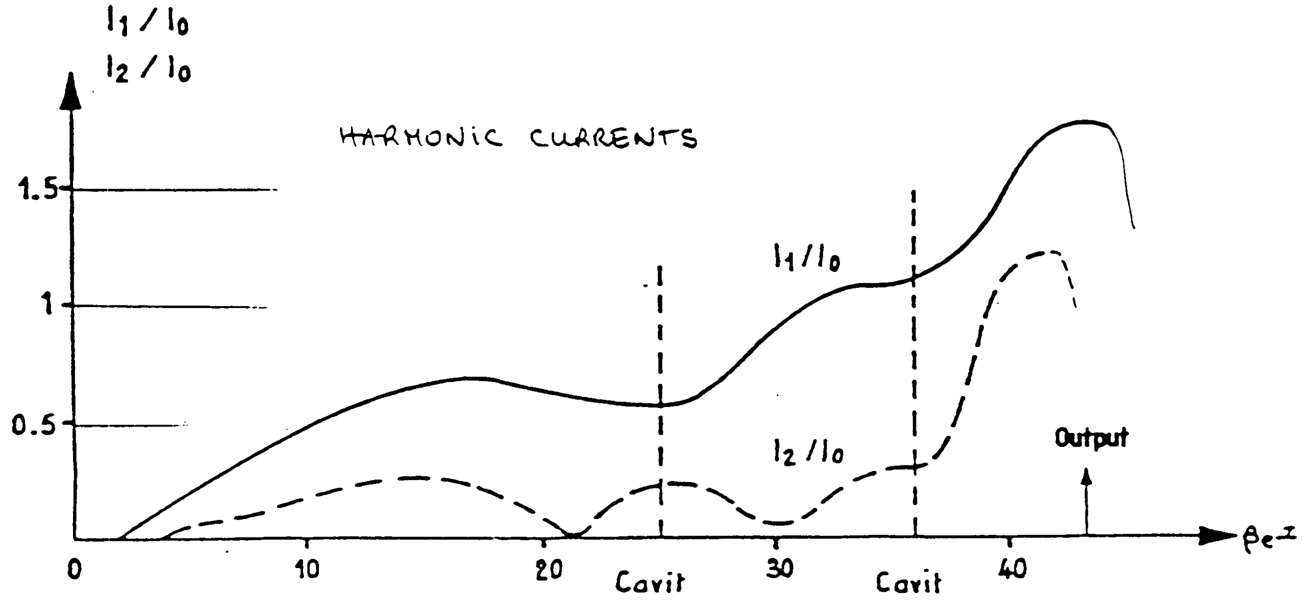
1

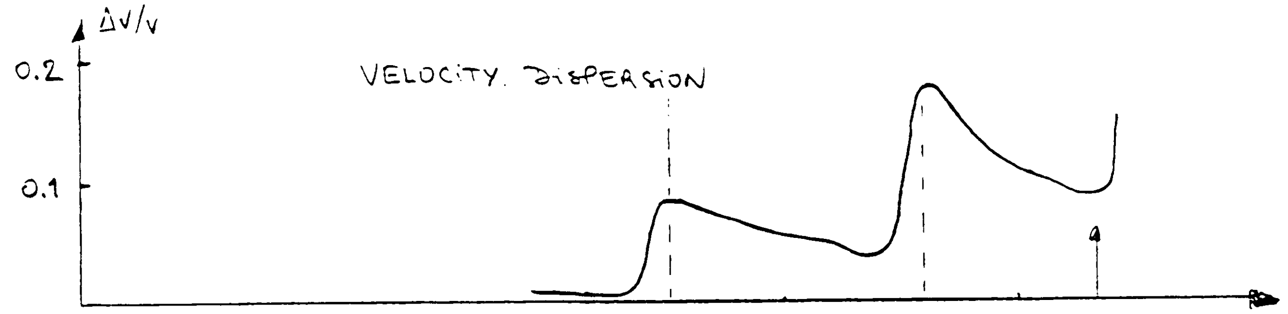
THOMSON TUBES ELECTRONIQUES

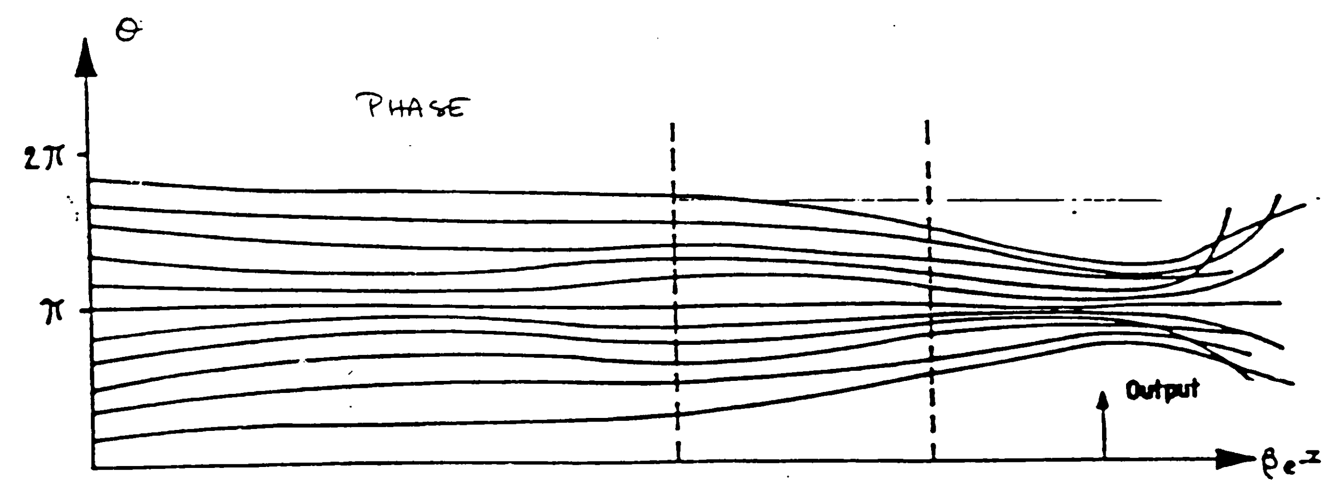


MULTI CAVITY KLYSTRON

CERN 8/10/91







CURRENTS, VELOCITY DISPERSION AND PHASES ALONG A KLYSTRON AXIS.

3

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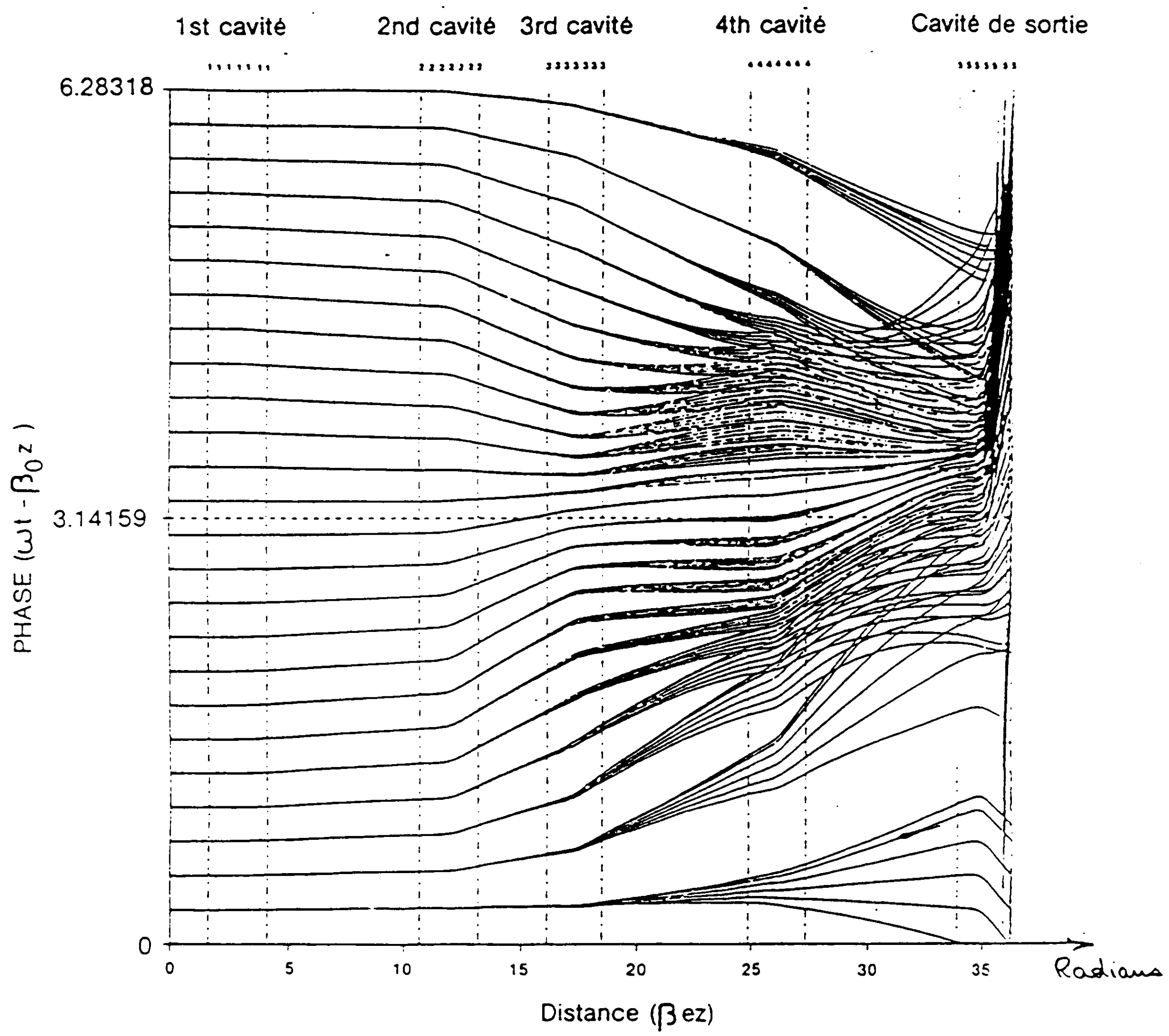

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DIAGRAMME D'APPLEGATE (PHASE FONCTION DE LA DISTANCE) OBTENU GRACE A UN CODE 2D (25 DISQUES - 6 ANNEAUX)

4

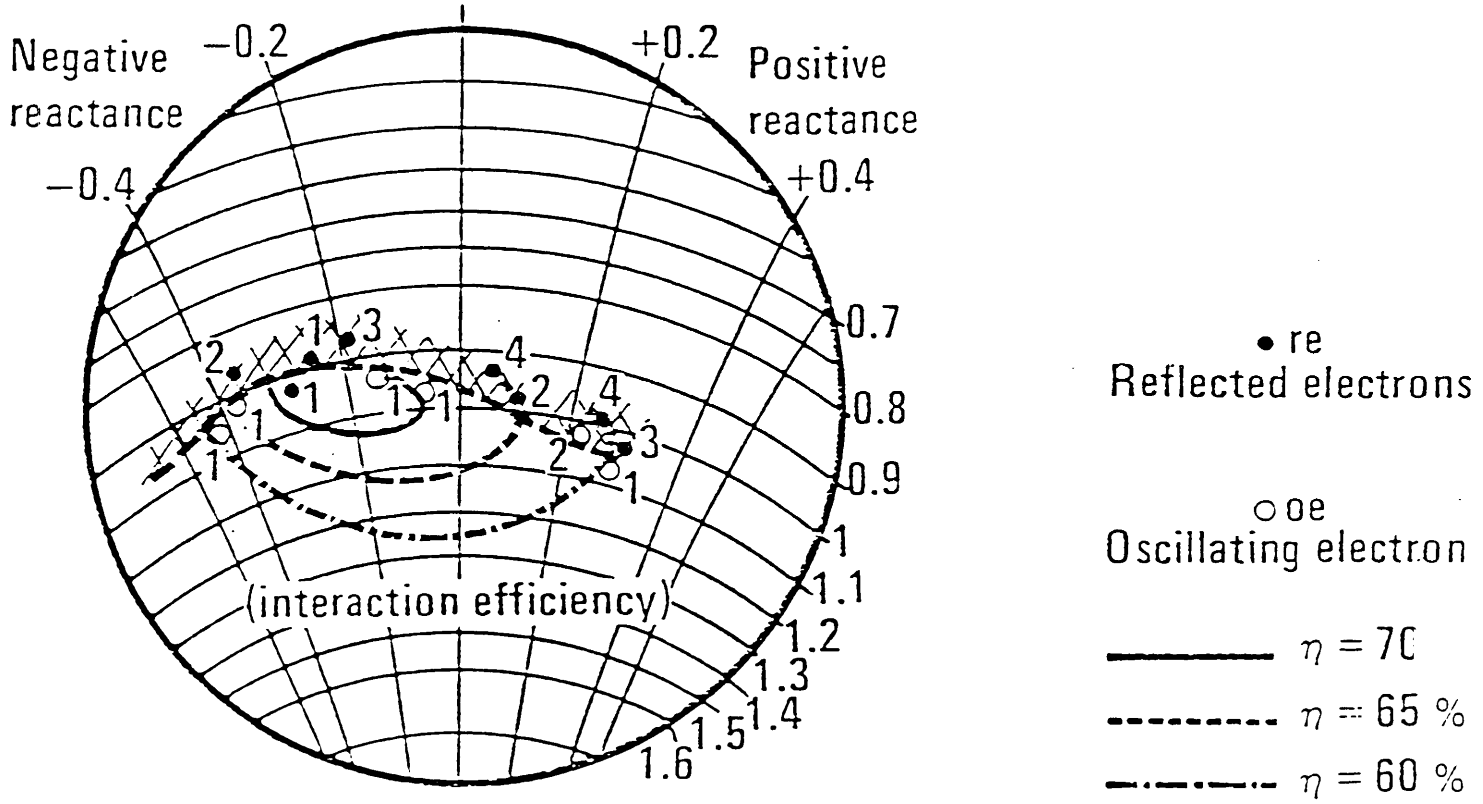
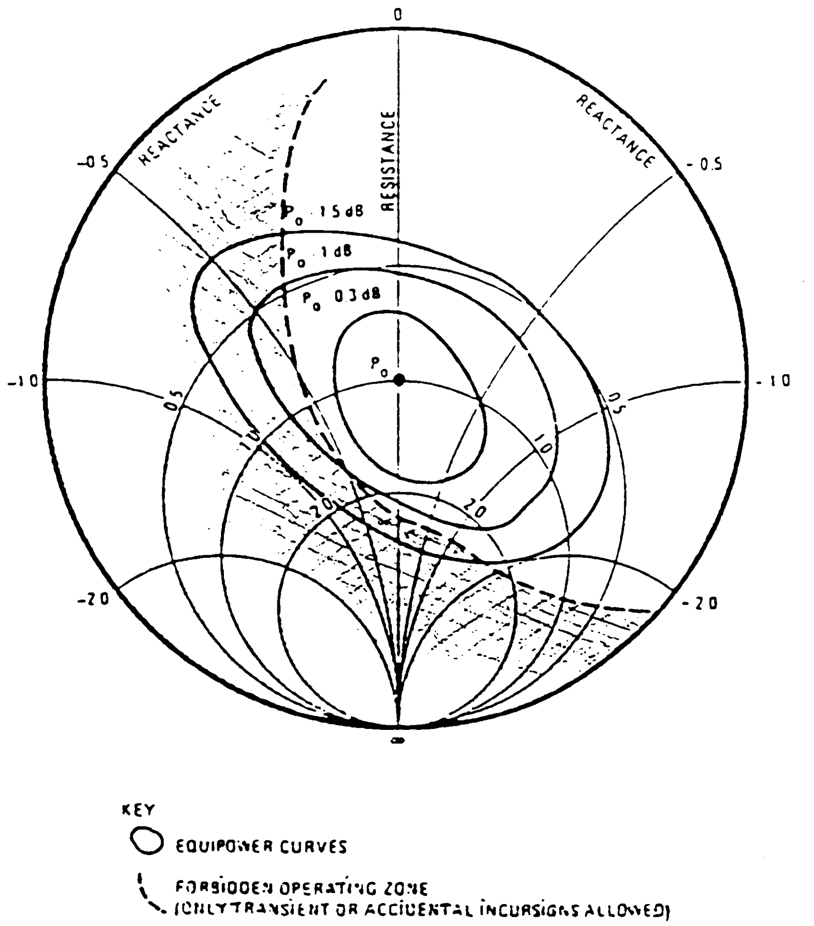


Figure 6 — Calculated Rieke diagram



Typical measured Rieke diagram

5

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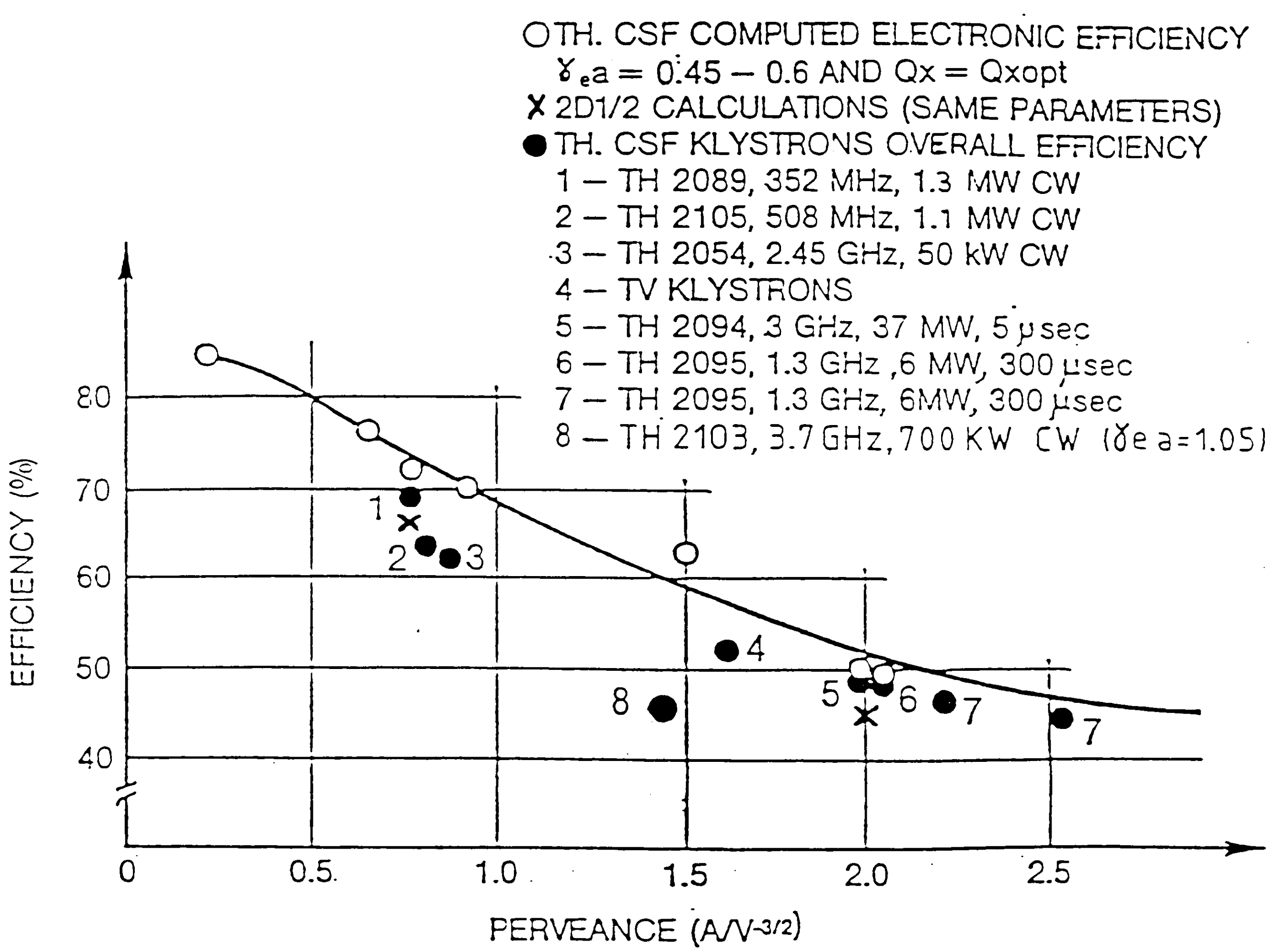
THOMSON TUBES ELECTRONIQUES



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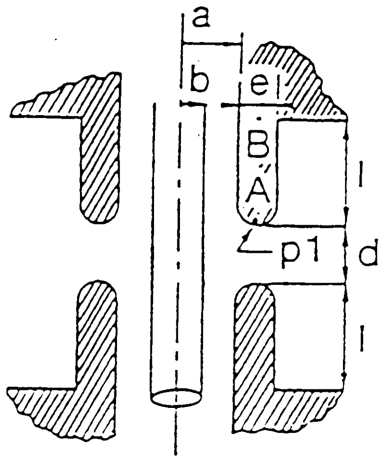
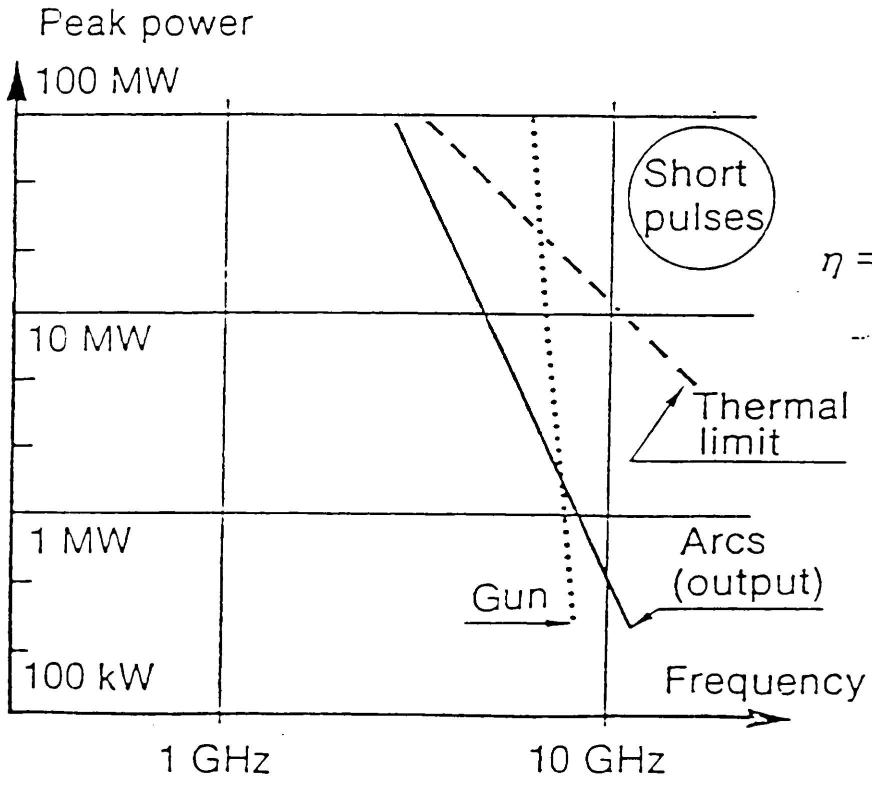
hauguel - 18382





$\eta = 45\,\%$ short pulses (μs)

$I_0 V_0^{-3/2} = 2 \times 10^{-6}$

$\gamma_e a = \beta_e d = 0.8$ rad

$\beta_e e = 0.3$ rad

$b/a = 0.5$

$\beta_e l = 1$ rad

$P_1 = 1\,\%\ V_0 I_0$

$T_A - T_B \leqslant 300\ °C$

$J_{cathode} \leqslant 10^A/cm^2$

$E = V_0/d \leqslant 300$ KV/cm

Power, frequency and computed limit diagrams (see hypotheses above) for klystron

11th European Con on Controlled Fusion a. PLA·
AACHEN - SEPT 83

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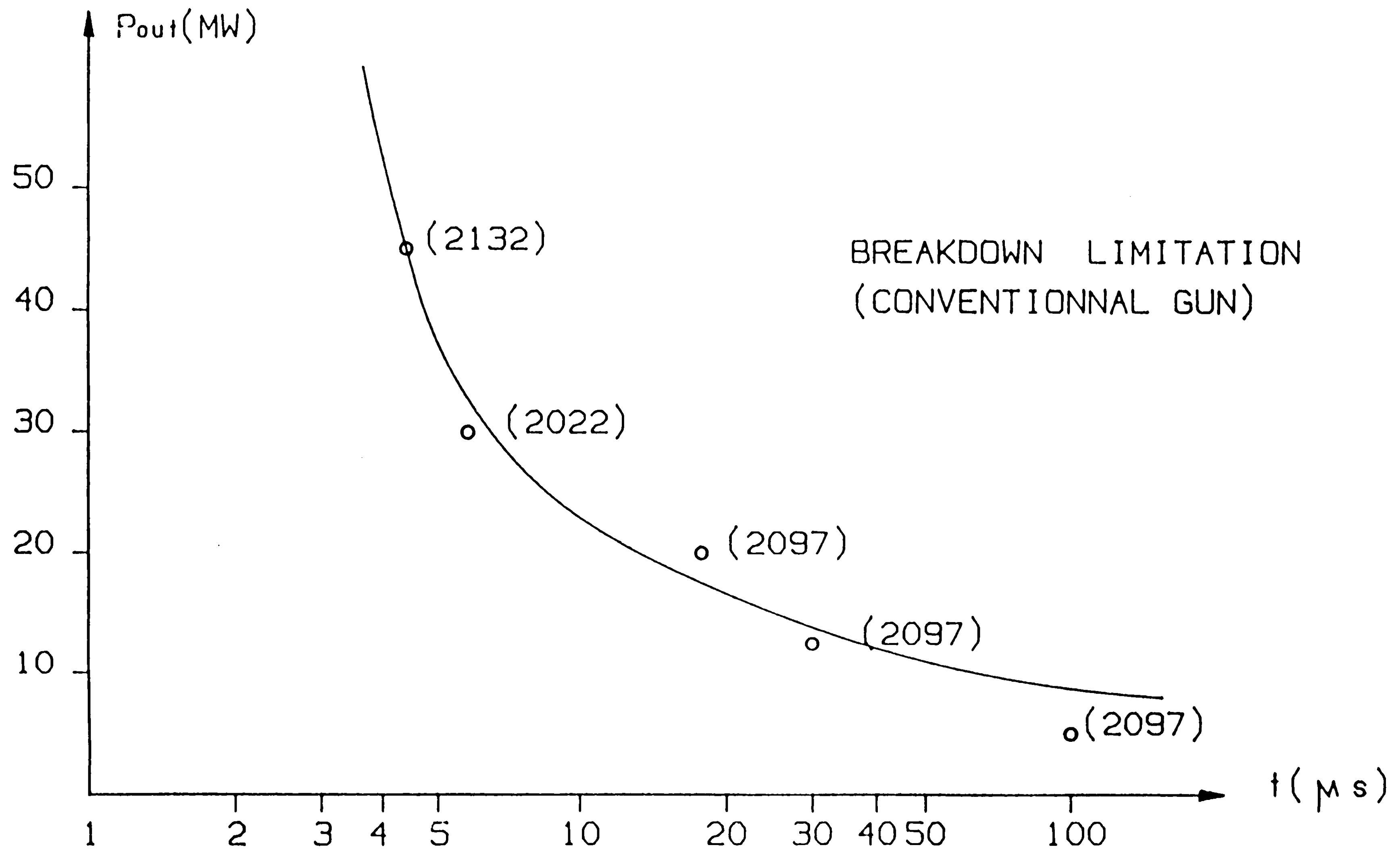
THOMSON TUBES ELECTRONIQUES



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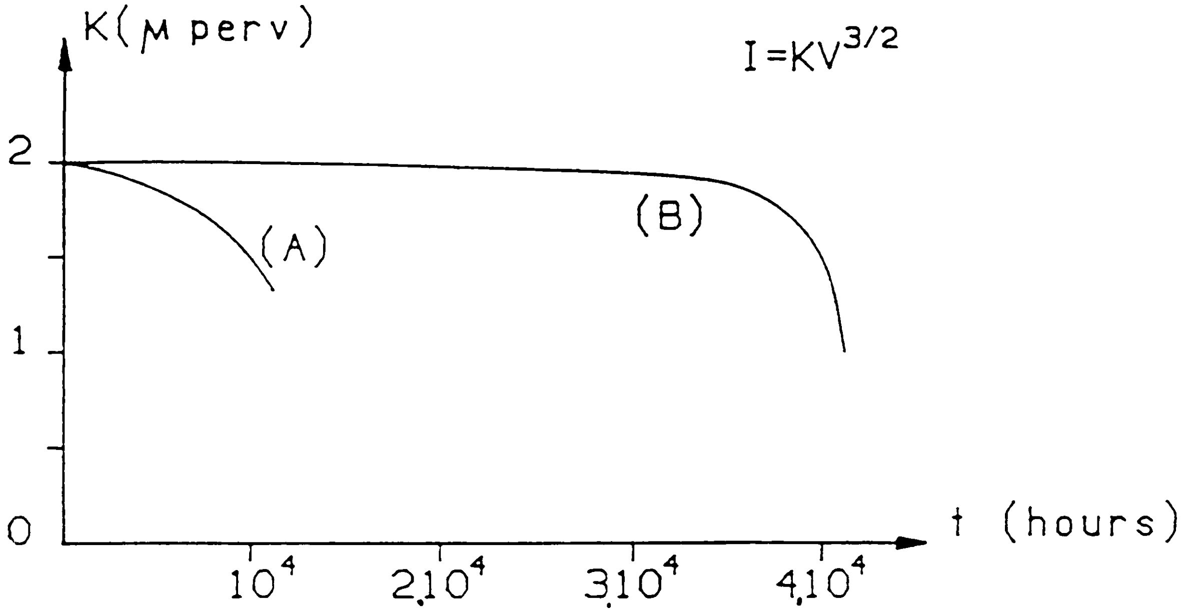
8

hauguet - 1627



CURRENT OR PERVEANCE DECREASING VERSUS TIME (TV2015 FRASCATI)

A) Oxide cathode

B) Dispenser cathode

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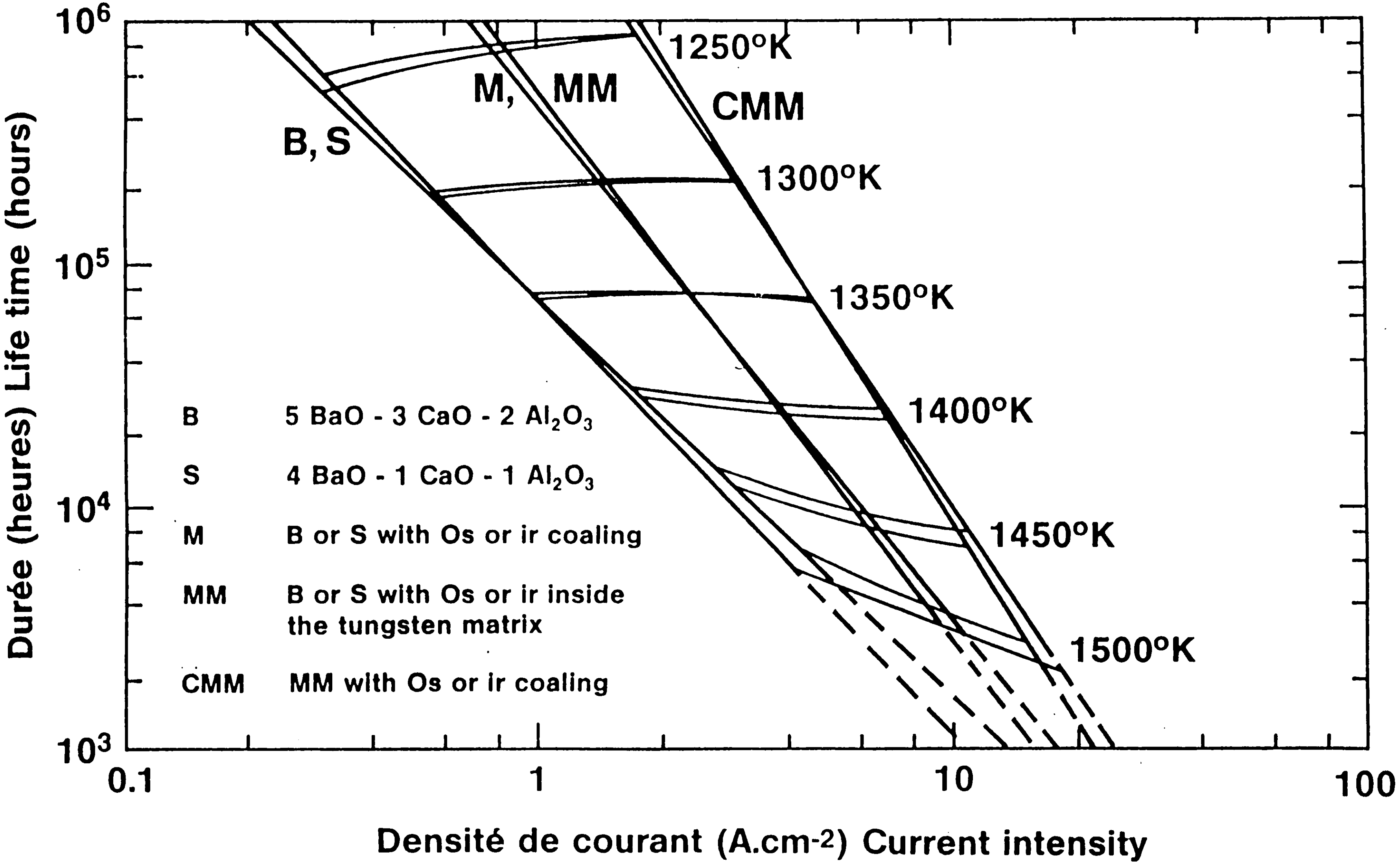

CATHODES IMPREGNEES IMPREGNATED CATHODES

THOMSON TUBES ELECTRONIQUES

(10)

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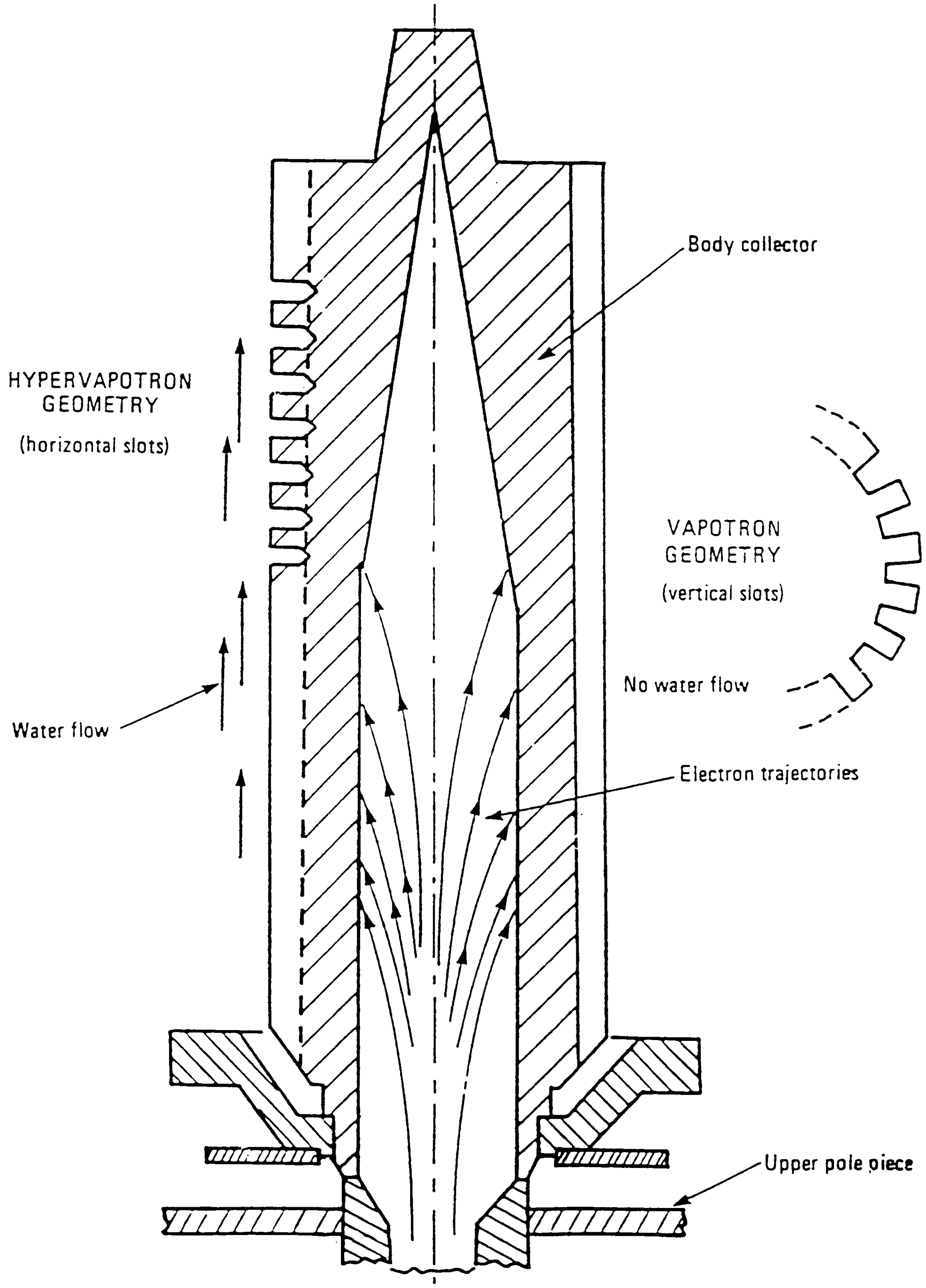

SCHEMATIC VIEW OF BEAM SPREADING IN A COLLECTOR AND OF THE COOLING SYSTEMS.

21

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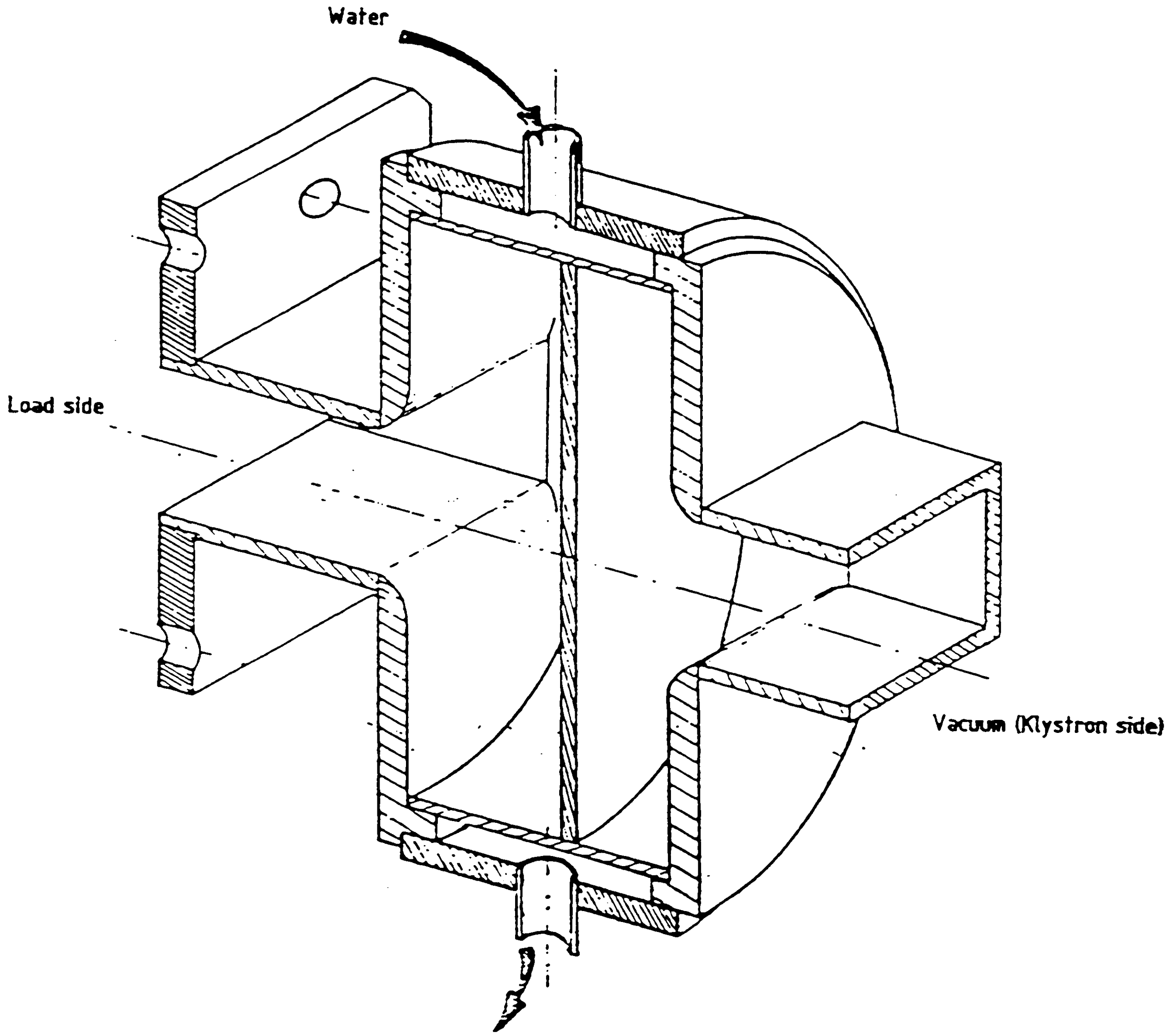
THOMSON TUBES ELECTRONIQUES



THIN PILL BOX WINDOW

12

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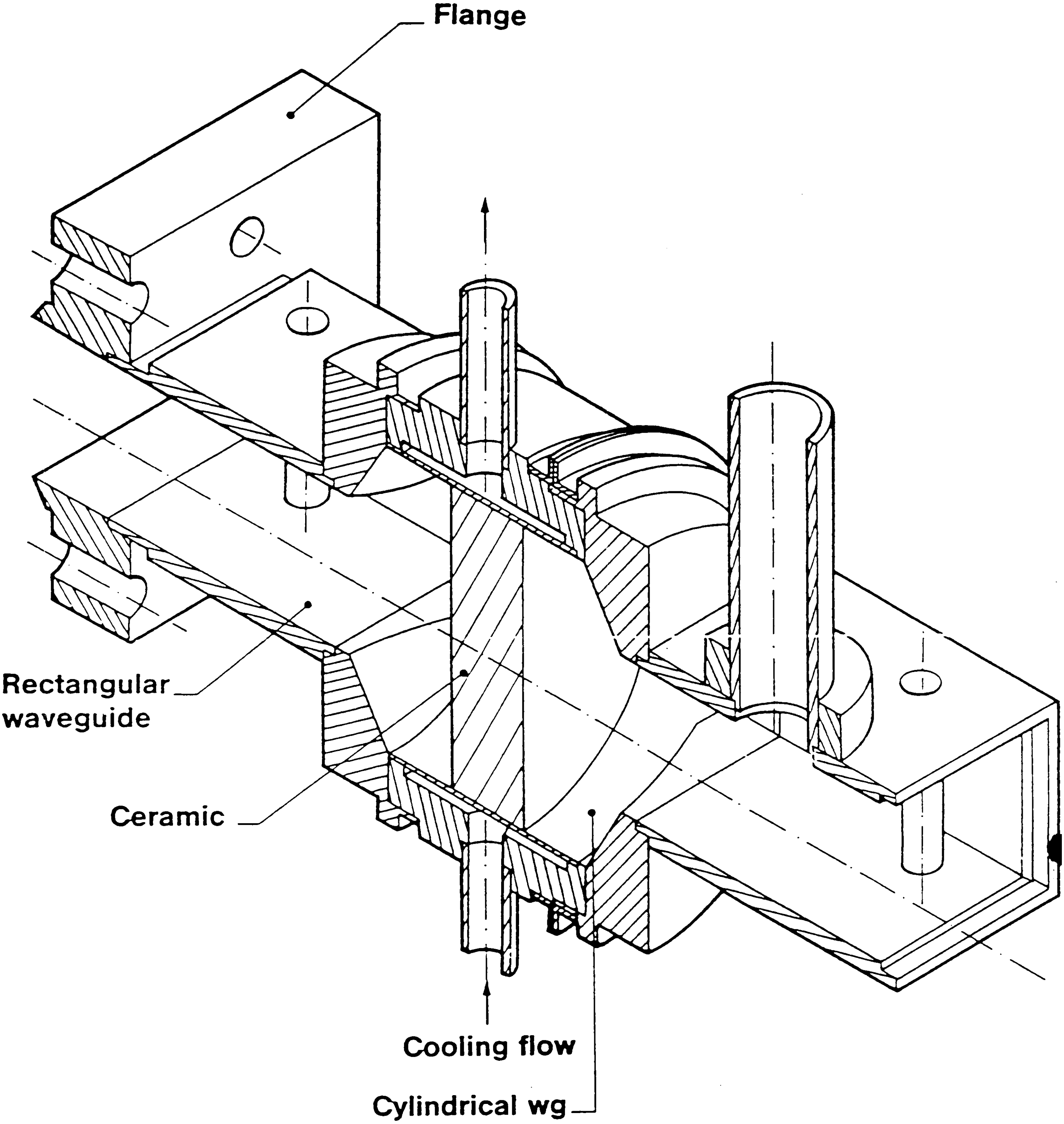
THOMSON TUBES ELECTRONIQUES



THICK PILL BOX WINDOW

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THOMSON VERY HIGH PEAK POWER PULSED KLYSTRONS

KLYSTRON	FREQUENCY	P_0 PEAK MW	P_0 AVE. kW	τ µs	V_0 kV x I A	η %	P_D W	OUTPUT
TH 2128	2856	37	20	5	275 x 280	48	180	1 VACUUM
TH 2128 A	2856	45	20	2 - 4.5	305 x 328	45	180	1 VACUUM
TH 2129	2856	20	30	4 - 5	228 x 212	41	90	1 SF6
F 2042	2998.5	41	12.5	6.5	303 x 324	42	240	2 SF6
TV 2002 D	2998.5	25	7.5	6	245 x 242	42	160	1 VACUUM
TH 2094	2998.5	35	20	4.5	275 x 280	45	180	1 SF6
TH 2100 A	2998.5	45	20	4.5	301 x 328	46	180	1 VACUUM
TH 2100	2998.5	37	17	4.5 - 5	275 x 280	48	180	1 SF6
TH 2130	2998.5	20	20	20	225 x 213	42	180	1 SF6
TH 2130 V	2998.5	20	20	20	225 x 213	42	180	1 VACUUM
TH 2132	2998.5	45	20	4.5	305 x 328	45	140	2 SF6
TH 2067	5712	6	6	10	135 x 105	42	80	1 SF6

THOMSON HIGH POWER KLYSTRONS

TECHNICAL FEATURES AND RELIABILITY POLICY

G. FAILLON and Ph. GUIDEE

The operation of large scientific facilities, such as particle accelerators, controlled fusion machines, free electron lasers or radiotelescopes requires not only very demanding technical performances, but also a level of fiability high enough to ensure that numerous research teams using the facility will be served in the conditions required by the experiments they are carrying out. Thus scientific applications are now taking into account the huge financial investment made in joint facilities and have to consider the profitability as it is obviously the case for industrial and medical applications.

This paper aims to show how the technical priorities in klystron design and manufacturing are supported by a continuous involvement in reliability analysis and efficient quality organization. A strong interaction between klystron manufacturer and user is necessary to obtain a quality improvement profitable to everybody.

TTE contribution to CERN Klystron Modulator technical meeting is divided in two parts :

- A technical survey of characteristics of high power klystrons for scientific applications. (presented by G. FAILLON).

- A presentation of the policy applied by TTE to improve the reliability of high power electron tubes in scientific facilities. (presented by Ph. GUIDEE).

CERN - PS KLYSTRON MODULATOR TECHNICAL MEETING

October 7 - 8 /1991

RELIABILITY OF THOMSON TUBES ELECTRONIQUES HIGH POWER KLYSTRONS

PH. GUIDEE

When compared to TV broadcasting or telecommunications applications of high power electron tubes, scientific applications are generally characterized by a large diversity of types of klystrons operated in various conditions by customers spread worldwide in numerous laboratories.

Two opposite cases could be examined for constructive comparison :

1) - SLAC case, where klystrons are designed, manufactured and operated by the same entity ; also another fact is that there is a single type of klystrons produced in large quantities for SLC equipment.

2) - TTE case, which produces a lot of various klystron types, operated in various conditions by different people in worldwide spreead laboraties.

The attached tables summarize the situation and explain what are the tools used by TTE to support its quality policy, which has internal features, such as technical design and manufacturing organization, as well as external aspects, i.e collection of operational data and strong interaction between customer and supplier.

THOMSON TUBES ELECTRONIQUES

CERN october 8, 1991

OUR SOLUTIONS

TO

IMPROVE THE RELIABILITY

----

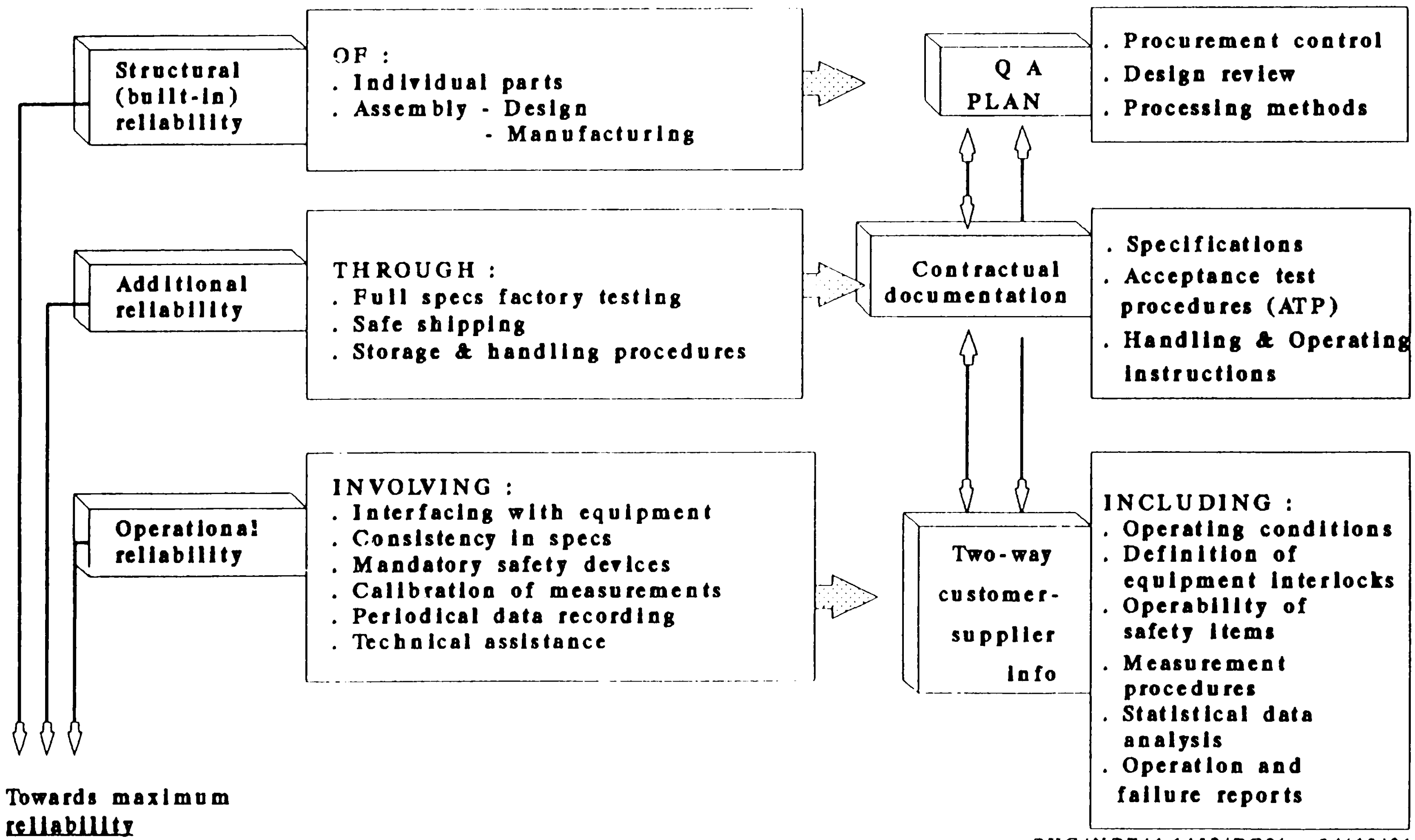
* Modular design

* Collection and analysis of operational data

* Customer - supplier interaction

* Application of manufacturing procedures through QA plan

KLYSTRON & MODULATOR TECHNICAL MEETING
CERN - 7,8 OCTOBER 1991
KLYSTRON RELIABILITY FLOW CHART



PHO/NDB/4.1459/DC91 - 04/10/91

THOMSON TUBES ELECTRONIQUES

CH1191 / F241 SPEC.

H.M.

TECHNICAL SPECIFICATION
PULSED MODULATOR HYDROGEN THYRATRON
PS-235-380-00-R4

Submitted ______________________ Klystron Department
D. Ficklin

Approved ______________________ Accelerator Department
R. Ecken

Approved ______________________ Klystron Department
R. Koontz

Approved ______________________ Klystron Department
M. A. Allen

Stanford Linear Accelerator Center
Stanford University, Stanford, California

Date: 3-7-89

SPECIFICATION

PULSE MODULATOR HYDROGEN THYRATRON

PS-235-380-00-R4

1.0 INTRODUCTION

The specified hydrogen thyratron will be used as a switch tube in a line type modulator.

The thyratron will discharge a pulse forming network, charged to approximately 850 joules, through a pulse transformer which drives a multi-megawatt klystron. See GP-237-380-01 for simplified schematic.

2.0 SCOPE OF WORK

The subcontractor shall design, develop, fabricate, manufacture, test and deliver hydrogen thyratrons in accordance with the following specifications. All SLAC drawings provided for this specification shall be of the latest revision.

3.0 ELECTRICAL SPECIFICATIONS

The thyratron shall meet the following specifications:

3.1 Pulsed Drive Conditions

3.1.1	Peak Anode Forward Voltage [i_b = 6300 Amps]	E_{py}	50 kV	max
3.1.2	Critical DC Anode Voltage for conduction		10 kV	min
3.1.3	Peak Reverse Voltage	E_{px}	5 kV or more	
3.1.4	Anode Pulse Current [E_{py} = 48 kV]	i_b	6500 A	max
3.1.5	Anode Average Current	I_b	7.0 A	max
3.1.6	Anode RMS Current	I_p	215 A	max
3.1.7	Current Equivalent Square Pulse Duration		5.9 μsec	min
3.1.8	Current Pulse Duration (at 70.7% height)	t_p	5.3 μsec	min

3.1.9	Pulse Repetition Rate	p_{rr}	10 pps	min
			180 pps	max
3.1.10	Anode Delay Time	t_{ad}	0.4 μsec	max
3.1.11	Anode Delay Time Drift	Δt_{ad}	0.02 μsec	max

Anode Delay Time Drift is defined as the change in time between the rise of the Control Grid pulse and the rise of current in the thyratron over an eight-hour time.

3.1.12	Anode Delay Time Jitter	t_j	0.01 μsec	max

Anode Delay Time Jitter is the pulse-to-puise variation in anode delay time.

3.1.13 Maximum number of faults — 3 per 24 hours

Faults are defined as one of the following conditions occurring:

(a) The thyratron continues to conduct current after a pulse causing the loss of pulses for the modulator.

(b) Conduction during the interpulse period without a proper Control Grid trigger.

(c) Lack of conduction in the presence of a rated Control Grid pulse at rated voltage.

3.2 Electrical Drive

3.2.1	Heater Voltage at 60 Hz	6.6 V RMS	max
3.2.2	Heater Current	150 A RMS	max

The subcontractor shall specify the heater voltage required for optimum life.

3.2.3	Reservoir Voltage, at 60 Hz	5.5 V RMS	max
		3.0 V RMS	min
3.2.4	Reservoir Current	40 A RMS	max

The subcontractor shall recommend an initial reservoir voltage for every tube. This specification shall be satisfied when the voltage is within ±5% of the recommended value.

3.2.5	Thyratron Heating Time	15 minutes	max

The cold start procedure and modulator interlocking shall insure that the heating time will apply to both the heater and reservoir.

3.2.6	Control Grid Bias	0 V	
3.2.7	Control Grid Drive into 25Ω	2 kV	max

The Control Grid drive pulse shall have a rise time measured between 10% and 90% of not less than 0.2 μsec nor greater than 0.3 μsec. The duration of the pulse at the 70.7% level shall be a maximum of 2.0 μsec.

3.2.8	Pretrigger Grid Voltage (open circuit)	250 V	max
3.2.9	Pretrigger Grid Current (short circuit)	350 ma	max

The pretrigger electrode (Keep-Alive) shall be driven from a DC supply which can satisfy the above requirements.

3.3 Life

3.3.1	Expected operating life	10,000 hours
3.3.2	Guaranteed operating life	5,000 hours
3.3.3	Replacement Warranty	500 hours
3.3.4	Shelf life	2 years

4.0 MECHANICAL

The thyratron shall meet the following requirements:

4.1 Workmanship

The thyratron shall be manufactured in a careful and workmanlike manner in accordance with good design and sound practice to assure that the unit meets the performance and life objective of this specification.

4.2 Mounting

4.2.1 The thyratron dimensions, mounting holes, leads and angular position of the Gradient Grid and Control Grid shall match the thyratron "Mounting Flange" drawing. The drawing labeled "MOUNTING FLANGE, THYRATRON TUBE, 50 MW MODULATOR" and numbered "PS-235-380-00, Size D" is included with this specification.

4.2.2 The thyratron leads shall be 10 inches minimum and 11 inches maximum in length.

4.2.3 The Keep-Alive lead must be terminated by a terminal lug having a full circle mounting hole for a No. 8 screw size. All other leads for the heater and the reservoir must be terminated by a terminal lug having a full circle hole for a 1/4-inch bolt size.

4.2.4 The thyratron shall be mounted vertically with cathode down.

4.2.5 The structural condition and operating performance of the unit shall not be impaired by normal shock and vibration incidental to normal personnel handling.

4.2.6 Outside dimension of all cooling fins shall be a maximum of 8-inches in diameter.

4.3 Cooling

4.3.1 The thyratron shall be forced air cooled from the bottom with a chimney (SLAC supplied) for directing air upward towards the anode.

4.3.2	Cooling air temperature	0°C	min
		55°C	max
4.3.3	Forced air available	500 CFM at 0.1-in. of water	
4.3.4	Inlet air humidity	50% at 55°C	min
		80% at 25°C	max

4.3.5 Anode cooling fins may extend into the vertical air stream to a maximum diameter of eight inches.

4.4 Nameplate

4.4.1 Nameplate information shall be provided on all thyratrons by permanently soldering, cementing a separate nameplate, or stamping directly on non-removable parts of the tube.

4.4.2 The nameplate shall contain the manufacturer's name, manufacturer's serial number, and the manufacturer's catalog number (if any), also heater voltage, if other than 6.3 VAC, and the tested reservoir voltage "set point" for proper operation.

5.0 TESTING

Each thyratron shall be installed in a line type test modulator similar in function to the modulator shown in the simplified schematic GP-237-380-01.

5.1 Measurement Definitions

5.1.1 The Peak Anode Forward Voltage (Section 3.1.1) shall be measured using a calibrated voltage divider. The anode voltage will be read 1 μsec prior to the Control Grid pulse. The measurement will be taken with the thyratron running at the specified anode load current.

5.1.2 The Anode Pulse Current (Section 3.1.4) shall be measured using the Pearson Electronics model 4191 current monitor or equivalent. The measurement will be taken with the thyratron running at the specified anode voltage.

5.1.3 The Pulse Duration (Section 3.1.8) shall be measured at the 70.7% point of the anode current pulse, by using a Pearson Electronics model 4191 current monitor or equivalent.

5.2 Subcontractor Tests

5.2.1 The subcontractor shall conduct routine factory tests on all thyratrons necessary to insure that every tube shipped complies with all of the specifications.

5.2.2 At a minimum the subcontractor shall test each tube for eight hours to the values specified in Section 3.1 with not more than one fault.

5.3 SLAC Acceptance Tests

SLAC shall perform acceptance tests on all thyratrons to insure compliance with this specification. SLAC reserves the right to reject any tube (without retesting) which fails any of the SLAC ACCEPTANCE TEST requirements.

5.3.1 Each tube shall be held non-operated for 96 hours. This is to allow any vacuum leaks or contamination that may occur after factory testing and conditioning to become apparent.

5.3.2 Each thyratron shall be installed in a test modulator similar to the linac gallery modulators but operating into a pulse transformer with dummy load resistors.

5.3.3 The heater and reservoir shall be adjusted to the manufacturer's suggested values, and allowed to warm up for a period not less than 15 minutes.

5.3.4 The modulator shall be turned on at 180 pps with a thyratron anode voltage of 20 kV. The resistance of the load shall be adjusted so as to produce the rated pulse condition of Section 3.1 when the supply voltage is increased.

5.3.5 The supply voltage shall be slowly increased to condition the thyratron until the rated pulse conditions are achieved. The thyratron shall be operated at rated pulse condition and 180 pps pulse rate for up to 24 hours. The thyratron shall have passed the 180 pps acceptance tests, if after 12 hours of operation the thyratron has failed not more than two times.

5.3.6 The thyratron turn on jitter shall be measured during the 180 pps operation by measuring the Control Grid pulse and comparing it in time with the Anode Current pulse. The jitter acceptance shall be passed if it is less than 0.01 μsec.

5.3.7 A "Snap-On" test shall be made as follows. When the tube has passed all previous and otherwise required tests and it is operating at 180 pps at 46 kV (Anode Voltage) the High Voltage will be turned off for a period of 10 minutes (–0 +5 minutes). When the High Voltage is turned back on at 46 kV, there shall not be more than one (1) High Voltage Over Current fault during the next 15 minutes of operation at rated load.

5.3.8 If the thyratron passed the 180 pps test, and the Snap-On test, the repetition rate shall be decreased to 60 pps. The thyratron will be operated at rated load conditions for a period of two hours, during which time there must not be more than two High Voltage Over Current faults. SLAC reserves the right to adjust the heater and/or the reservoir voltage by up to ±5% after which the thyratron should still meet all acceptance test specifications.

6.0 PREPARATION FOR DELIVERY

6.1 Preservation and Packaging

The tube shall be adequately protected against damage during shipping by common carrier.

6.2 Marking for Shipment

All exterior shipping containers shall be adequately and properly marked for identification. All packages shall include the following:

(a) Addressee

(b) Shipper

(c) University purchase order number and/or subcontract number.

(d) Tube model and serial number.

7.0 SPECIFICATION REVISION RECORD

7.1 **R0** - original

7.2 **R1** - (no date, no information)

7.3 **R2** - (no date)

(a) Added Table 1

(b) Upgraded operating levels in the text.

(c) Changed the simplified schematic from R1 to R2.

(d) Substituted drawing PF 238-277-01-R2 Universal Thyratron Flange.

7.4 **R3** - by R.R.H. released 2/18/87

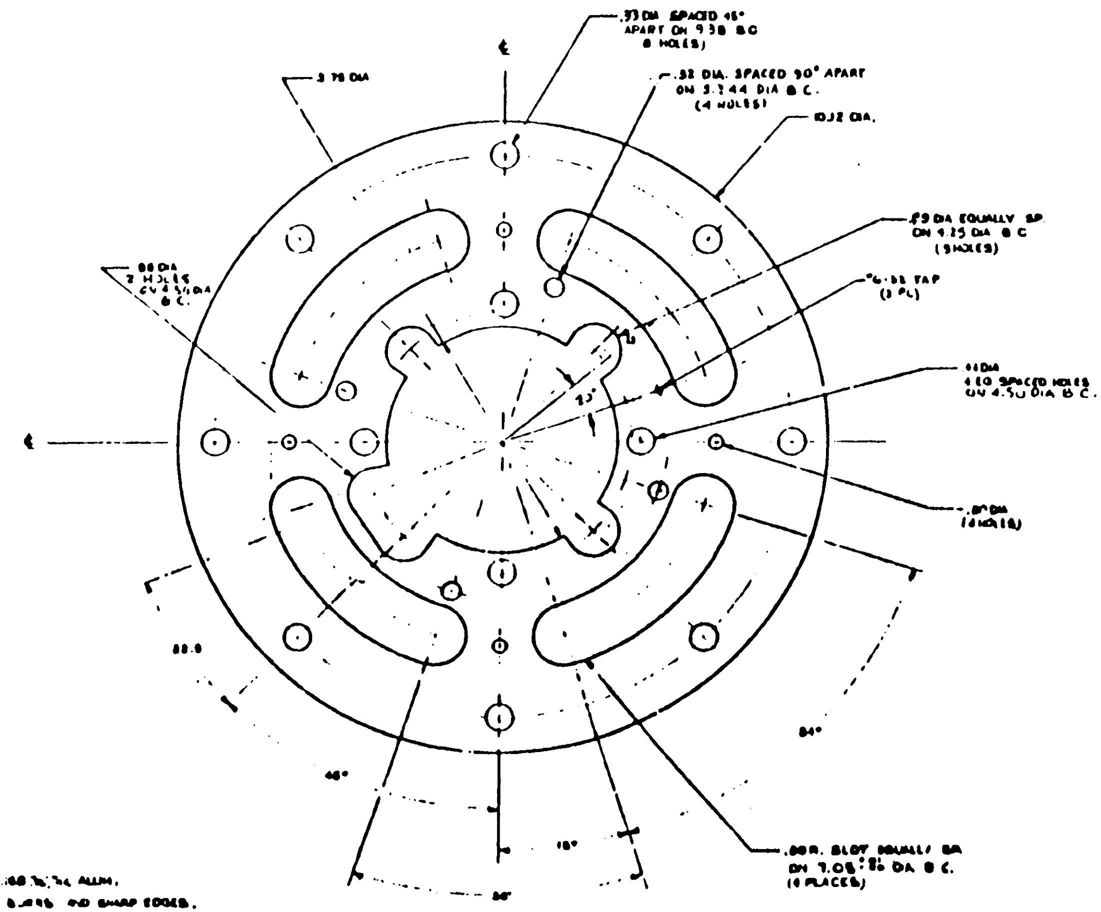
(a) Added subsection 5.2.8 "Snap-On" test.

(b) Changed the thyratron mounting flange to PS-235-380-00-R2 "Mounting Flange Sheet 11" showing the angular position for the gradient and control grids.

7.5 **R4** – by D.B.F. released March 1, 1989

(a) General Revisions

REV	DESCRIPTION				DATE
1	[illegible]				
2	B.C. ... SOR SLOT 4 PL WAS 7.00, IS 7.05				



NOTES:
1. MAKE FROM .68 THICK ALUM.
2. REMOVE ALL BURRS AND SHARP EDGES.
3. ALODINE FINISH NON-DIGING, (CONDUCTIVE) OR EQUIVALENT

SCALE NONE

DO NOT SCALE DRAWING

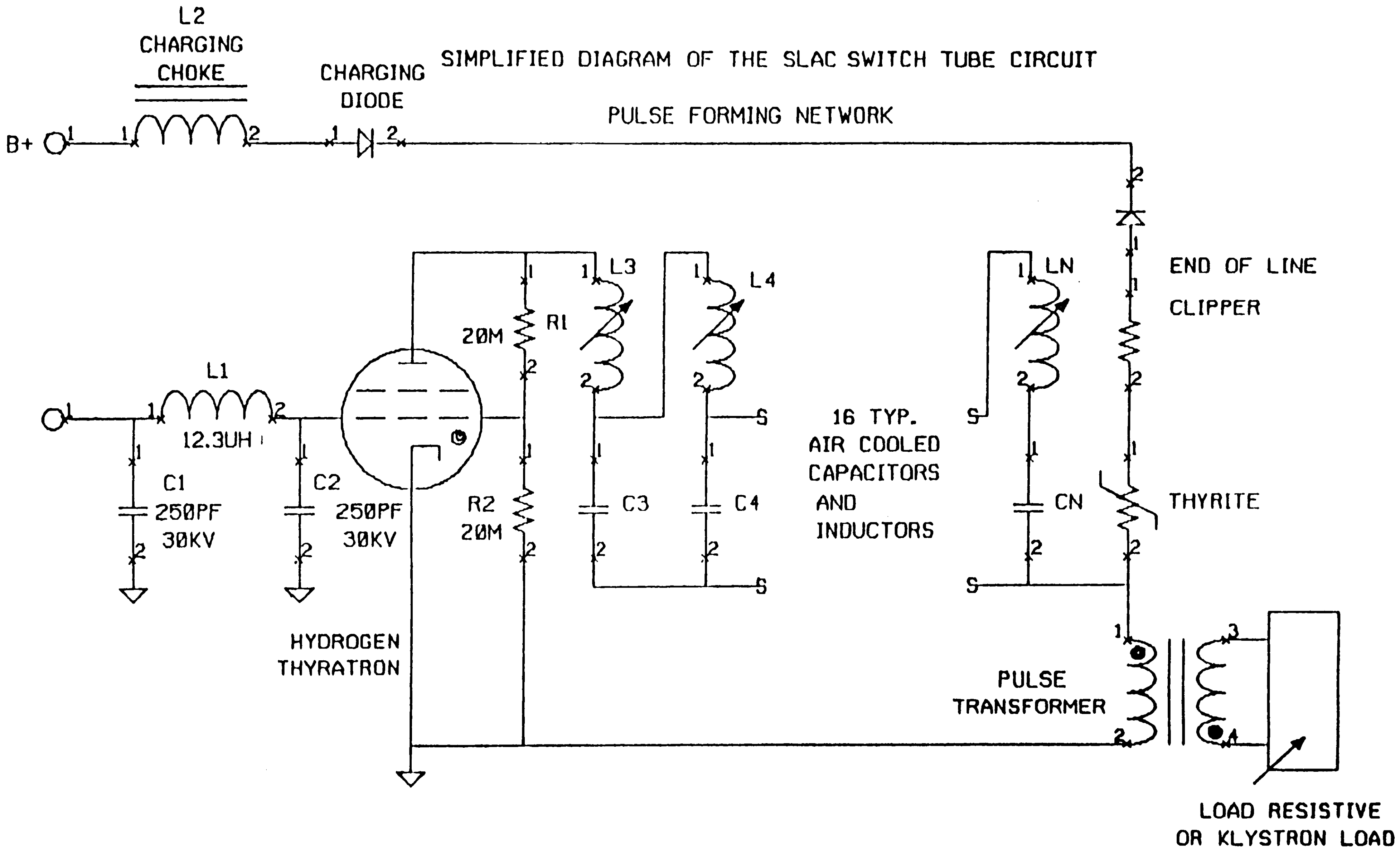
STANFORD LINEAR ACCELERATOR CENTER
U.S. DEPARTMENT OF ENERGY
STANFORD UNIVERSITY STANFORD CALIFORNIA

UNIVERSAL THYRATRON FLANGE
THYRATRON STAND ASSEMBLY
50 MW MODULATOR

PF 355-277-01-R2 D

SIMPLIFIED DIAGRAM OF THE SLAC SWITCH TUBE CIRCUIT

PULSE FORMING NETWORK



SCALE:

SHEET 1 OF 1

STANFORD LINEAR ACCELERATOR CENTER

STANFORD UNIVERSITY STANFORD, CALIFORNIA

DR. R. CASSEL

DR. J. YU 9-JAN-86

R. HANSELMAN

APPROVAL R. HANSELMAN

HYDROGEN THYRATRON
TYPICAL CONNECTION
PULSE MODULATOR

GP 237-380-01-R2 A