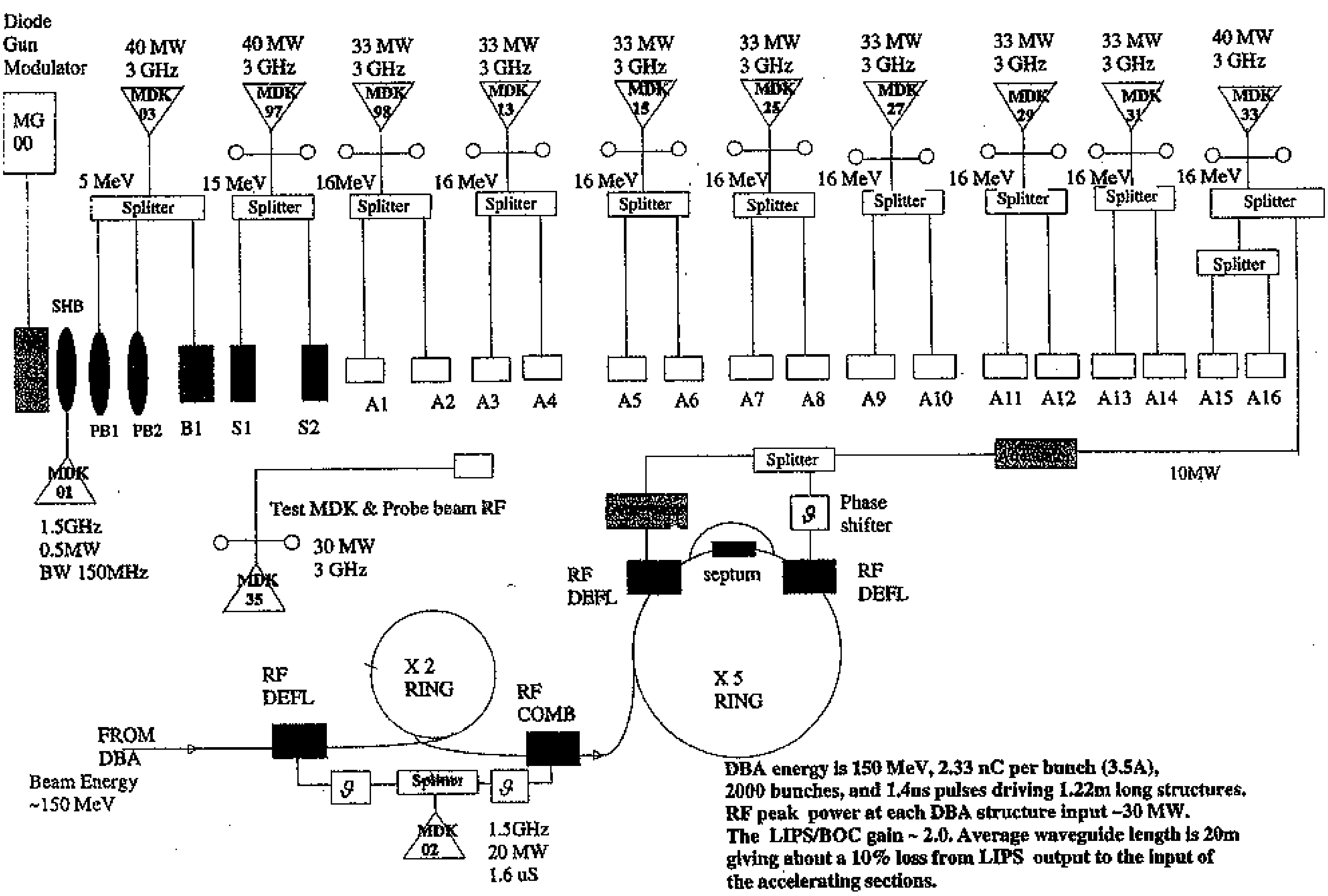
CTF3 Nominal Phase

Klystron-Modulators and other RF components

G.McMonagle

CTF3 Review 2nd October 2001



DBA energy is 150 MeV, 2.33 nC per bunch (3.5A), 2000 bunches, and 1.4us pulses driving 1.22m long structures. RF peak power at each DBA structure input ~30 MW. The LIPS/BOC gain ~ 2.0. Average waveguide length is 20m giving about a 10% loss from LIPS output to the input of the accelerating sections.

LIPS Peak Power versus Klystron Pulse Length

Limitations of Klystron Pulse Length

- Saturation of HV Pulse Transformer, $\Phi = \int U \cdot dt < \Phi_{sat}$
  $\Phi<1.68$Vs for trafo of TH2094, can be changed by other trafo $\Phi<2.25$Vs of TH2132.

- Cathode High Voltage Breakdowns
  It is very difficult to condition the gun of an old klystron for longer pulses (TTE).

- RF Losses of RF Windows
  Klystron TH2094 (LIL): 35MW x 4.5μs or 31MW x 5.0μs.
  Klystron TH2100 (CTF3): 38MW x 5.0μs, to be tested.

LIPS Compression Gain G versus Klystron Pulse Length T

Flat top of LIPS pulse: T2=1.4μs, $\Delta P/P<\pm 1\%$, $\Delta\varphi<\pm 6$deg.
Duration of pulse compression: T3=1.6μs, $t_r = t_f = 0.1$μs.

T =	4.5μs	5.0μs	5.5μs	6.0μs	
G(T)=	1.90	2.04	2.12	2.16	
η(T)=	59%	57%	54%	50%	$\eta = G \cdot T2 / T$

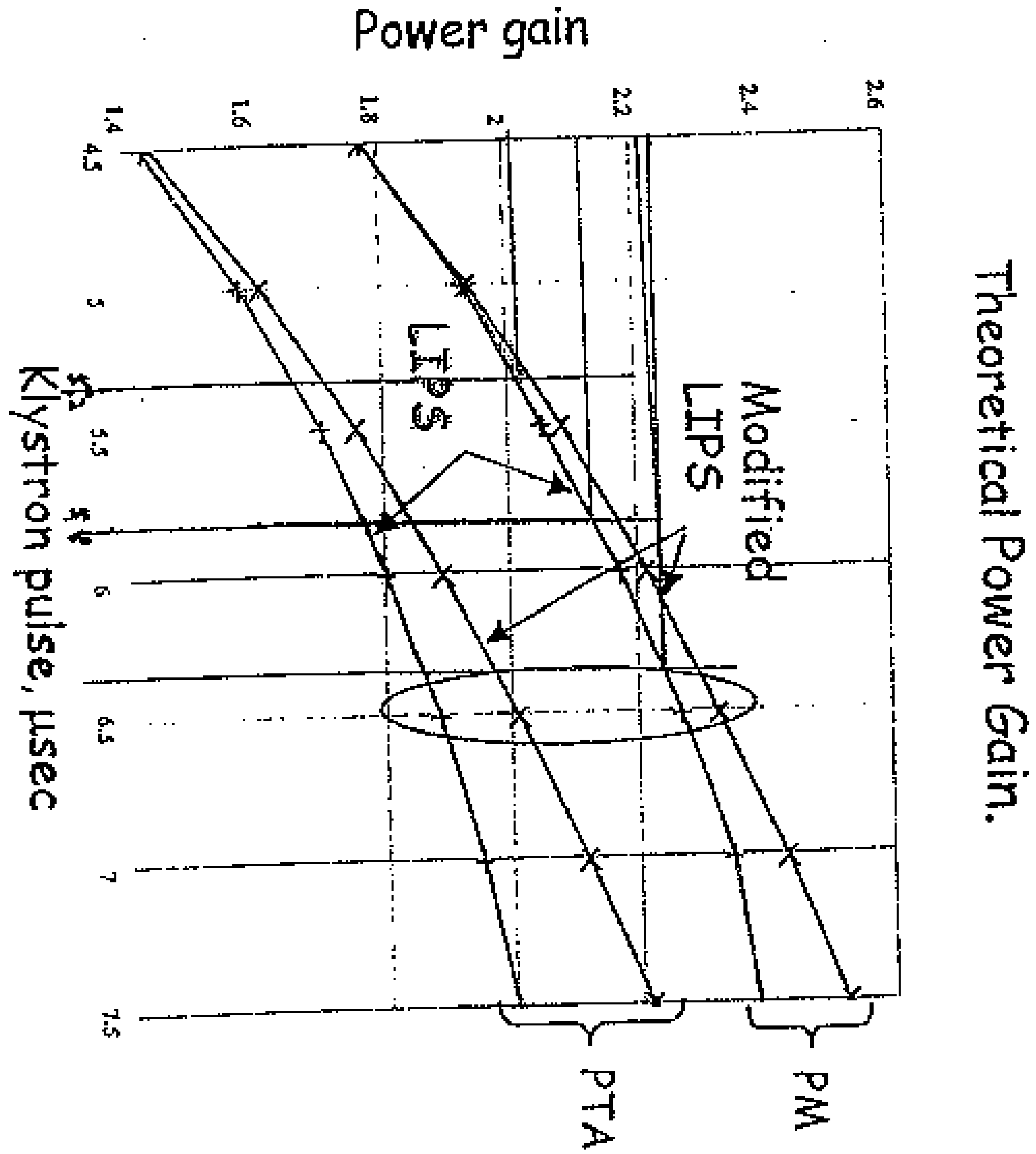
LIPS Peak Power P_L for TH2094, $P_L = G \cdot P_K$

- $T = 4.5\mu s$: $P_K = 35MW$, $G = 1.90$, $P_L = 66MW$
- $T = 5.0\mu s$: $P_K = 31MW$, $G = 2.04$, $P_L = 63MW$

For constant dielectric losses of the RF windows, $P_K \cdot T$=const, a short pulse length 4.5μs provides a higher LIPS peak power P_L, since the RF losses in the LIPS cavities are less.

Conclusion

If the klystron RF power is limited by the dielectric losses of the RF window, it is recommended to use the klystron at the highest nominal power which the klystron is built for, because it provides the best pulse response and the best LIPS pulse compression gain at this working point.



LIPS modification is mainly the adjusting of the cavity coupling.

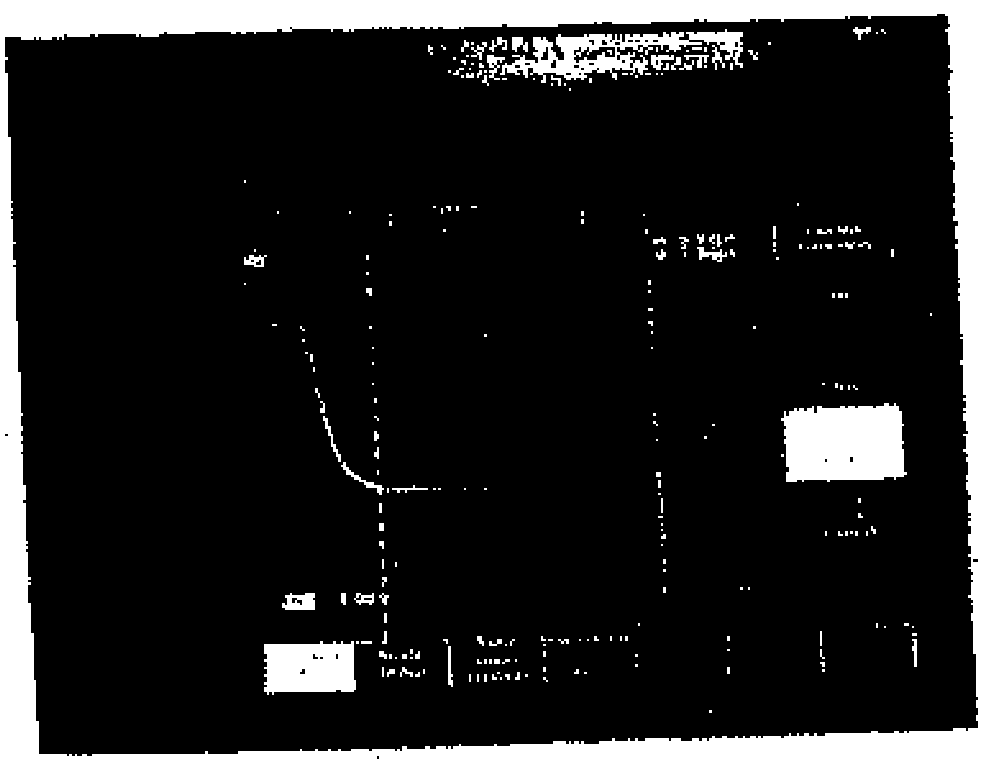
Klystron-Modulator peak operating parameters

Parameters	35 MW klystron-modulator	45 MW klystron-modulator	Units
RF Frequency	2998.55	2998.55	MHz
RF Peak output	35 (37)	45	MW
RF average power	17.5 (18.5)	20	kW
RF power gain	53	54	dB
Klystron efficiency	45	44	%
Rf pulse length	4.5	4.5	µs
Klystron voltage	273	305	kV
Klystron current	285	335	A
PFN impedance	5.5	4.4	Ω
Pulse transformer ratio	1:13	1:14.85	
Pulse voltage ripple	±0.15	±0.15	%
Pulse stability	±0.1	±0.1	%

Rise time 10 - 90% ~ 740 ns 24/9/99
Fall time 90 - 10% ≈ 1.5 µs
Flat top ~ 5.5 µs
Pulse width at 75% = 7 µs
Pulse width (Rise time + flat top) ≈ 6.3 µs

Measured with PFN impedance ~ 4.4 ohms
and pulse transformer ratio 1:14.8 and klystron TH2132

Measured on MDK97



	MDK	Nominal Peak Power Output MW			Maximum peak power available from klystron with security margin MW			Peak power available available at each of the two accelerating sections, two per klystron (1) (2) MW			Peak power available at accelerating section using 800nS rise time of klystron voltage, two per klystron (2) (4) MW		
Klystron voltage flat top legnth		4.5μS	5.0μS	5.5μS	4.5μS	5.0μS	5.5μS	4.5μS	5.0μS	5.5μS	4.5μS	5μS	5.5μS
	03	45	43	41*	43	41	39						
	13	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	15	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	25	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	27	45	43	41*	43	41	39	35.3	35.5	35.6	39.2	39.2	40
	29	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	31	45	43	41*	43	41	39	35.3	35.5	35.6	39.2	39.2	40
	33 (3)	45	43	41*	43	41	39	30.2	30.5	30.5	33.6	34.3	37.6
	35	35	35	35	33	33	33						
	97	37	37	37	35	35	35	28.7	30.3	31.9	31.9	33.5	35.9
	98	37	37	37	35	35	35	28.7	30.3	31.9	31.9	33.5	35.9
Total peak power available to accelerating sections with a pulse width of 1.6μS (MW) (Nominal 540 MW)								532	553	571	591	612	643

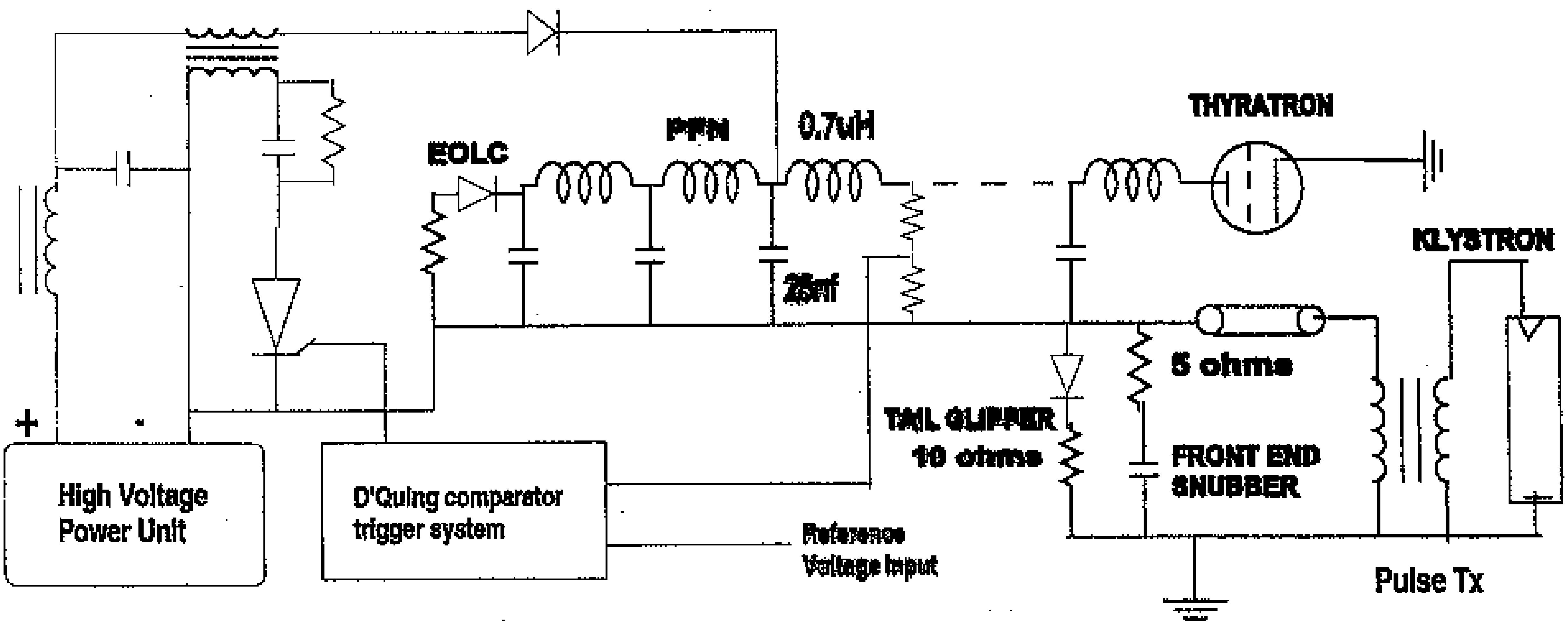
(1) Communication of LIPS gain from R. Bossart (LIPS Gain 1.8 at 4.5μS, 1.9 at 5μS, 2 at 5.5μS)
(2) 0.4dB power loss in waveguides
(3) Three way split of RF power after LIPS, first split 6:1
(4) Communication I.Syratchev
* increase in pulse width → lower maximum voltage applied to klystron → lower peak power out (THALES)

3 GHz Klystron Modulator Status

- The klystrons and modulators can be used as they exist to produce the required power to the accelerating structures for the 150 MeV nominal phase
- Reserve klystrons can replace some lower power klystrons to increase available power
- There is the capability to increase the pulse width of the 35/37 MW systems for energy upgrade by modifying the pulse forming networks and pulse transformers if necessary

- **Reserve klystrons**
- 2 TH2100 37 MW
- 1 TH2100 45 MW (November 2001)
- 1 TH2132 45 MW (March 2002)
- 4 YK1600 35 MW (2 already mounted in HT tanks)

Modulator Schematic Diagram

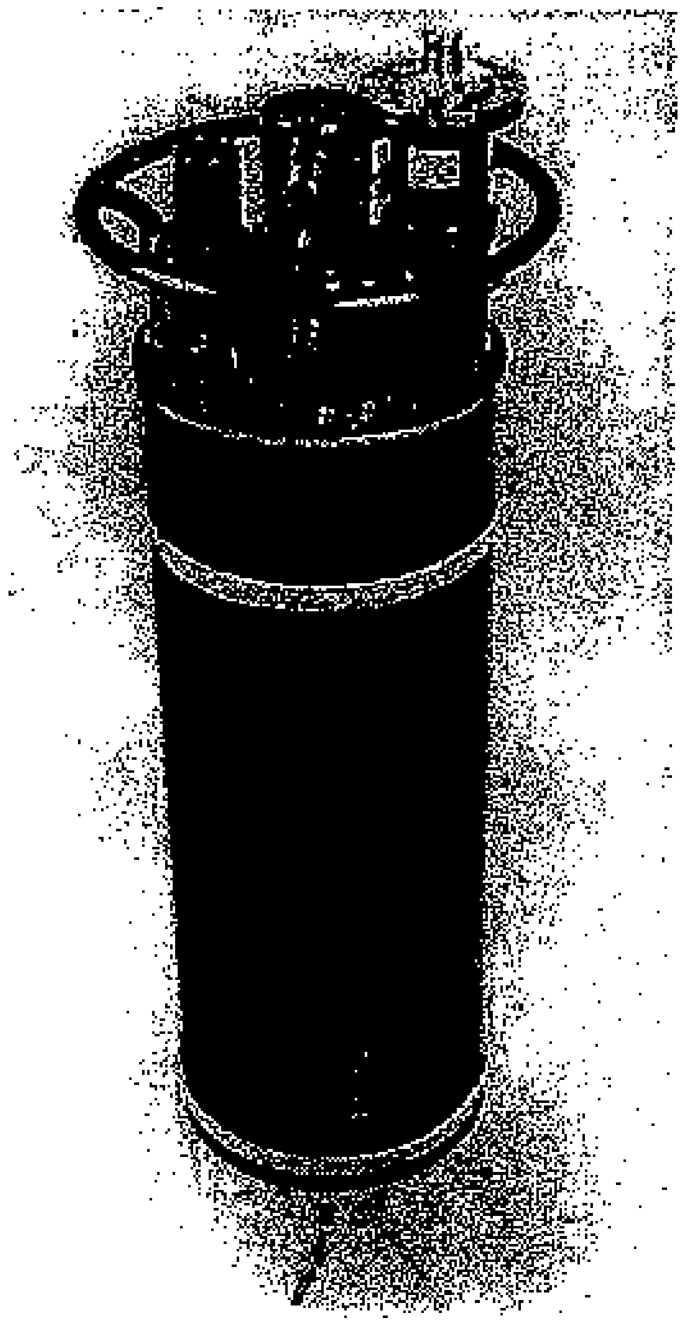


3 GHz Klystrons

	Valvo YK1600 35 MW	Thales TH2094 35 MW	Thales TH2100 37 MW	Thales TH2100 45 MW	Thales TH2132 45 MW
Klystron Voltage (kV)	270	270	280	305	305
Modulator PFN voltage (kV)	40	40	41	41	41
Pulse Transformer ratio (1: x)	1 : 13	1 : 13	1 : 13	1 : 14.8	1 : 14.8
PFN Impedance (ohms)	~ 5.0	~ 5.0	~ 5.0	~ 4.4	~ 4.4

PT6006
Pulsed Klystron Amplifier

The PT6006 is an 8 cavity, L-band tunable pulsed high power klystron which features an output section of the extended interaction type to optimise instantaneous bandwidth.



QUICK REFERENCE

Centre frequency
1.3 GHz
Instantaneous bandwidth
90 MHz
Peak output power (Nominal)
100 kW
Gain
25 dB

Cathode modulated
Solenoid focused
Liquid cooled

Input RF connector
TYPE N
Output RF connector
3 1/8"standard coaxial

TYPICAL OPERATION

Heater voltage
7 volts
Heater current
18 amps
Beam voltage (peak)
33 kV
Beam current (peak)
12.6 amps
Beam duty factor
0.05
Efficiency
25%

TYPICAL PERFORMANCE

Frequency range
1.25 -1.34 GHz
Peak output power
90 kW minimum
Bandwidth*
90 MHz
Saturated gain
25 dB
Beam pulse length
8.5 μs
Beam duty factor
0.05
Spurious output power level
-85 dB

* for peak power output of 90 kW minimum

TMD

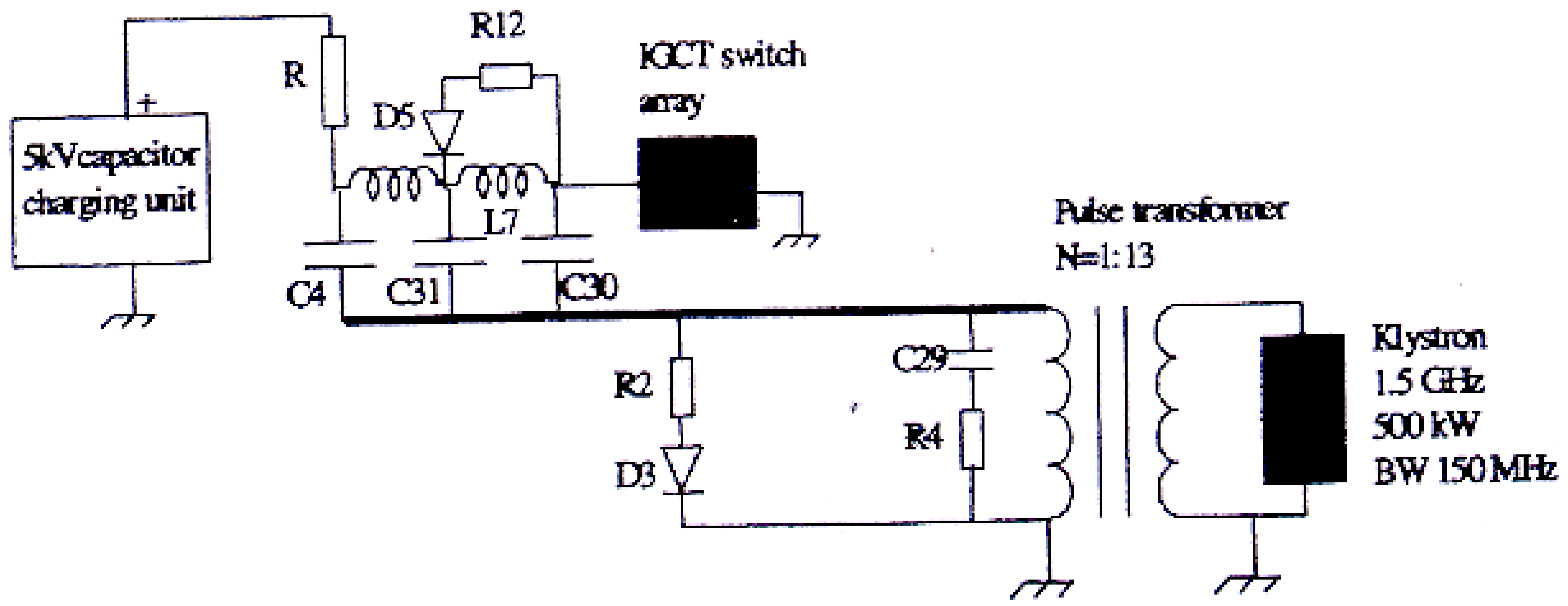
1.5 GHz klystrons and modulators

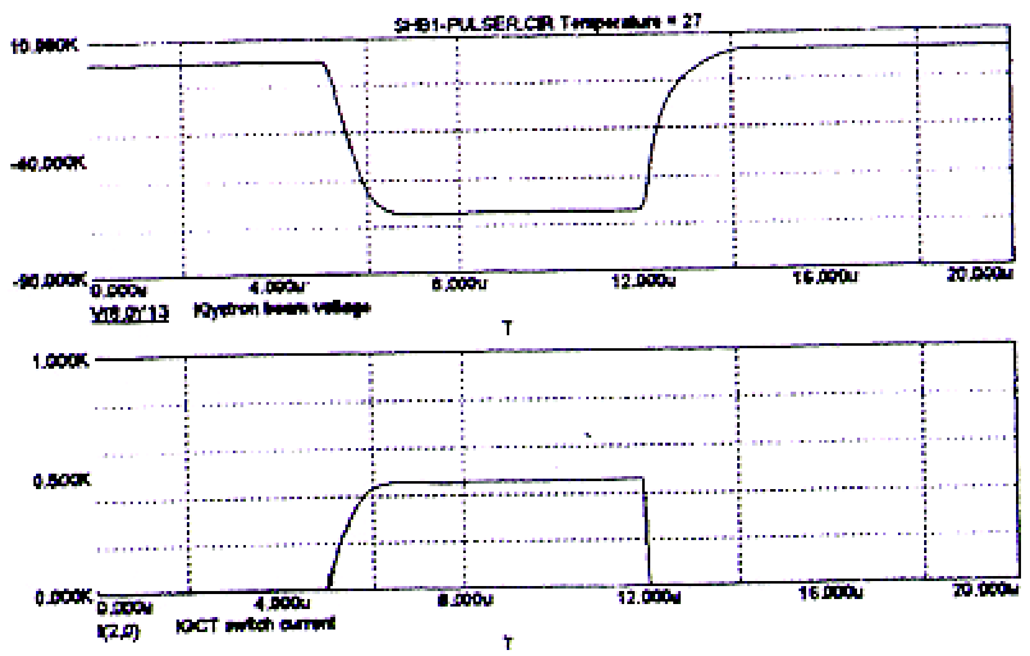
- 0.5 MW Broadband 150 MHz klystron feasibility study completed, call for tender to manufacture being processed
- Modulator for broadband klystron being manufactured and developed in CERN using existing equipment apart from the solid state switch (delivery December 2001)
- narrow band 20 MW 1.6μS klystron on order from Thales
- modulator based on existing 3 GHz systems to be constructed in 2002/2003
- specifications for 1.5 GHz waveguides, phasors attenuators, splitters, couplers etc. in preparation for price enquiry next year

- 760 -

SHB modulator main parameters

Parameter	Value	Units
Primary capacitor voltage	5	kV
Peak IGCT pulse current	450	A
Pulse voltage rise time(10-90%)	800	ns
Flat top voltage deviation over 2 μs pulse width	0.3	%
IGCT DC voltage for 100 FIT failure rate	2800	V





It is also possible to mount the tube horizontally but in that case it would be difficult to use transformer oil because of the problems in sealing the gun region of the tube when the tube is removed from the socket.

A self-connecting plug has been fitted to the end of the gun which will work immersed in transformer oil. The action of lowering the tube into the solenoid will automatically make the cathode, heater and grid connections.

A cut-away drawing of the tube with overall dimensions is shown in Figure 14.

5. CONCLUSIONS AND RECOMMENDATIONS OF THE STUDY

The main conclusions of the feasibility programme are:-

i) The calculations show that the PT6006 klystron can be scaled to give the required output power over the correct bandwidth at the higher frequency required.

ii) The same number of buncher cavities will be needed as in the standard design but a longer body stack will be required because of the higher power operation. The latter means operating at a higher EHT voltage which increases the interaction length.

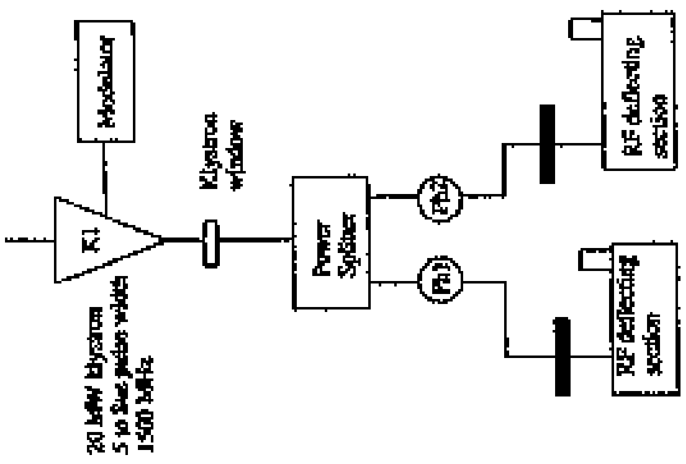
iii) The existing coaxial RF window used on the PT6006 will be adequate for use in the new design although it may need pressurised air or insulating gas to ensure arc-free operation.

iv) A larger 'pillbox' waveguide window can be provided if necessary.

v) It is recommended that a gridded gun is used on the tube as described in this report. This will give better RF pulse shaping and more flexibility with pulse length and timing. However a non-gridded version of the gun design can be produced if the equipment available makes it inconvenient to use the gridded technology.

vi) The mounting position of the tube can be vertical, with the gun downwards, or horizontal. In the former case, transformer oil insulation can be used around the gun for cooling and insulation. With horizontal mounting, the gun is best insulated with a gas such as SF6. The gun will operate in either of these environments.

vii) An insulated collector has been provided to allow for the possibility of collector depression to improve the overall efficiency of the tube.



General L-band klystron parameters

Parameters	Value	Units
Centre frequency	1500	MHz
Bandwidth (1 dB)	8.5 (min)	MHz
Peak Output Power	20 (min), 25 (max)	MW
Pulse width	5 max at 25 MW, 8 max at 20 MW	μs
Repetition frequency	100 (max)	Hz
Electronic efficiency	42	%
Klystron beam voltage	260 (max)	kV
Klystron beam current	250 (max)	A
Microperveance	1.9 (min) to 2.0 (max)	$\mu A/V^{3/2}$
Heater voltage	28 (max)	V
Heater current	28 (max)	A
Large signal gain	49.5	dB
SF6 pressure on RF window	1.5 (max)	bar
Focal coil voltage	180	V
Focal coil current	70	A
RF window flange	CPR 650F	-

RF deflector klystron-modulator parameters

Parameters	TW deflector MDK	SW deflector MDK	Units
Peak output power	25 (max)	20 (max)	MW
RF pulse width	5 (max)	8 (max)	μs
Repetition frequency (max)	100	50	Hz
Klystron perveance	1.9 [2.0]	1.9 [2.0]	$A/V^{3/2}$
Voltage pulse width	6	9	μs
Klystron beam voltage	250 [245]	230 [225]	kV
Klystron beam current	238 (243)	210 [213]	A
PFN impedance	4.5	4.75	Ω
Klystron to PFN mismatch	+5	+5	%
Number of PFN cells	25	25	-
Cell capacitance	32	42.5	nF
Cell inductance	0.7 [0.65]	1.0 [0.87]	μH
PFN operating voltage	34 [33]	31 [30.5]	kV
Pulse transformer ratio	1:14.85	1:14.85	-
Pulse transformer volt-seconds	1.76 [1.73]	2.3 [2.15]	VS
Thyratron peak current	3.67 [3.7]	3.29 [3.4]	kA
Thyratron average current	1.3	1.65	A
PFN charging power	30	30	kW
PFN charging time	15	18	ms

Conclusions

The existing 3GHz modulators and klystrons can all be used in the CTF3 Nominal phase.
They can eventually be upgraded to higher power operation with no technical difficulties if needed
The 1.5 GHz klystrons have positive feasibility reports, one is on order, a price enquiry for manufacture for the other is being prepared.
The associated modulators for the 1.5 GHz klystrons are being manufactured.
Specifications for 1.5 GHz passive components are being prepared for price enquiry next year