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A PROPOSED LINAC CAVITY RF DRIVE SYSTEM FOR THE LOS ALAMOS EXTREME ULTRAVIOLET FREE-ELECTRON LASER*

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Abstract

Since 1979, scientists and engineers at the Los Alamos National Laboratory have designed, constructed, and operated a radio-frequency (RF) linac free-electron laser (FEL) at wavelengths from 9 to 45 μm. Coupled with the success of other research centers investigating wavelengths from the visible to far-infrared, Los Alamos is now proposing a vacuum-ultraviolet and soft x-ray [referred to henceforth as extreme ultraviolet, (XUV)] FEL oscillator/Self-Amplified Spontaneous Emission amplifier with beam energies ranging from 100 MeV to 1 GeV.

This paper will focus on the first milestone of the proposed Los Alamos XUV project, i.e., a 250-MeV linac with approximately 50 mA of average current, producing photons with wavelengths below 1000 Å.

1. RF drive system power considerations

The first phase of the Los Alamos XUV project requires a total energy of 250 MeV and an average current of 50 mA. The workhorse for this first phase will be a

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side-coupled cavity linac, similar in design to one currently being used in present experiments [1], and a photoinjector [2]. The electron-beam power is given by

$$P_B = V_o I_b \ .$$

where V_o is the total accelerator voltage and I_b is the beam average current; this results in $P_B = 12.5$ MW. The structure copper power loss is

$$P_{cu} = \frac{V_o^2}{RL} \ ,$$

where R is the shunt impedance figure-of-merit for accelerators and L is the total accelerator length. With a peak on-axis gradient of 10 MV/m, the copper power is 50 MW. A near ideal matched condition will exist for the klystrons during beam loading in order to minimize reflected power. Additionally, approximately 20% of the klystron power is necessary to maintain a control margin and have good regulation. The total RF power is then 78 MW. Recently, a 7.5-MW modulating-anode klystron has been developed for the accelerator community. With this type of klystron, total of 11 RF stations are necessary.

2. Modulator design

In a previous paper [3], the present modulators have been described. The XUV modulators will utilize a modulating-anode-type switch tube common to four klystrons. The current switch tube has a grid to turn the device on and off. This would present problems at the higher duty cycle envisioned for the XUV because of high grid dissipation.

The 40-MeV high-brightness accelerator free-electron laser (HIBAF), now under construction at Los Alamos, will be a testing facility for XUV RF systems. A two-klystron per one-grided switch-tube system has been developed. A photograph of this modulator is shown in fig. 1. Lead glass windows were installed to facilitate high-voltage arc location. Note the symmetry in mechanical design, this same basic symmetry would be preserved for the four klystron modulator, see fig. 2. An electronic schematic is depicted in fig. 3. With the particular type of klystrons we use, it is extremely important that energy dissipation during an arc be kept to a minimum. The manufacturer recommends less than 10 J; however, we have found that less than 5 J is necessary to continue operation after a high-voltage arc. When two or more klystrons are placed in close proximity, enabling a common high-voltage electronic circuit, not only must you protect the klystrons from the large energy storage of the capacitor bank, but also you must protect them from each other. This mutual protection is necessitated by the internal capacitances of the nonarcing klystron discharging into the arcing klystron. Referring to fig. 3, resistors R2, R5, R6, and R13 protect against modulating-anode to cathode discharges and R2 & R13 protect against modulating-anode to ground discharges. Resistors R1 and R14 dissipate any residual energy stored in the high-voltage coaxial cables after the crowbar has been fired.

Finally, one common klystron filament transformer was used, i.e., one input, three secondary outputs — all on a common iron core. This design presents another difficulty; when one tube arcs, there is a large potential difference between the three secondaries. Although it is not shown in the schematic, miniature spark gaps ($\sim$2.5 kV) were placed across all transformer outputs, thereby minimizing the differences and protecting the transformer. For the XUV FEL, the klystron filament transformer shall be redesigned so that each secondary will be physically separated from the other by insulating oil.

3. High-voltage system

The four klystrons will be powered by one high-voltage system. This system (power supply, transformer, crowbar, capacitor bank, energy detector, and high-voltage transport) is also being tested on the HIBAF facility. Because physical space and reliability is a premium, the capacitor bank will be fabricated with 200-kV, 0.5-μF capacitors whose total volume will be 8.9 ft. long by 10 ft. wide by 4.5 ft. high when two rows of 16 capacitors in each row are placed next to each other.

4. Control system

Currently there are two competing theories being explored for controlling the XUV RF system. One is based on full-state feedback and the other on the more traditional input/output feedback. Both have relative merits, although the former is more insensitive to system perturbations than the latter. Experimental verification is incomplete as of the date of these proceedings. However, because the beam input into the accelerator occurs on a time scale many times smaller (micropulse width ~10 ps, rep. rate 10 MHz) than the RF power input (cavity fill time ~2 μs), beam loading is a singular perturbation. Although both of these methods can control some low-frequency parameter perturbations, if these perturbations occur at the beam-loading rate, then neither controller configuration can recover. A mitigating effect does, however, occur because accelerators are operated in a stored-energy mode. If the cavity stored energy is many times greater than the removed micropulse beam energy, a small buffering effect will occur when there are small beam charge fluctuations. As a result, when it is necessary to have exceedingly tight beam specifications, as FELs require, it is absolutely necessary to control both accelerator inputs (beam and RF power).

Acknowledgments

I wish to acknowledge Brian Newnam for his helpful discussions about XUV FELs and William E. Stein for his collaboration with me on the HIBAF two-klystron modulator construction.

References

[1] W. E. Stein, et al., "The Accelerator for the Los Alamos Free-Electron Laser-IV," *IEEE Journal of Quantum Electronics*, 21, (7), July 1985.

[2] B. E. Carlsten, "New Photoelectric Injector Design for the Los Alamos National Laboratory XUV FEL Accelerator," Proc. 10th International Free-Electron Laser Conf., Jerusalem, Israel, August 1988, to be published.

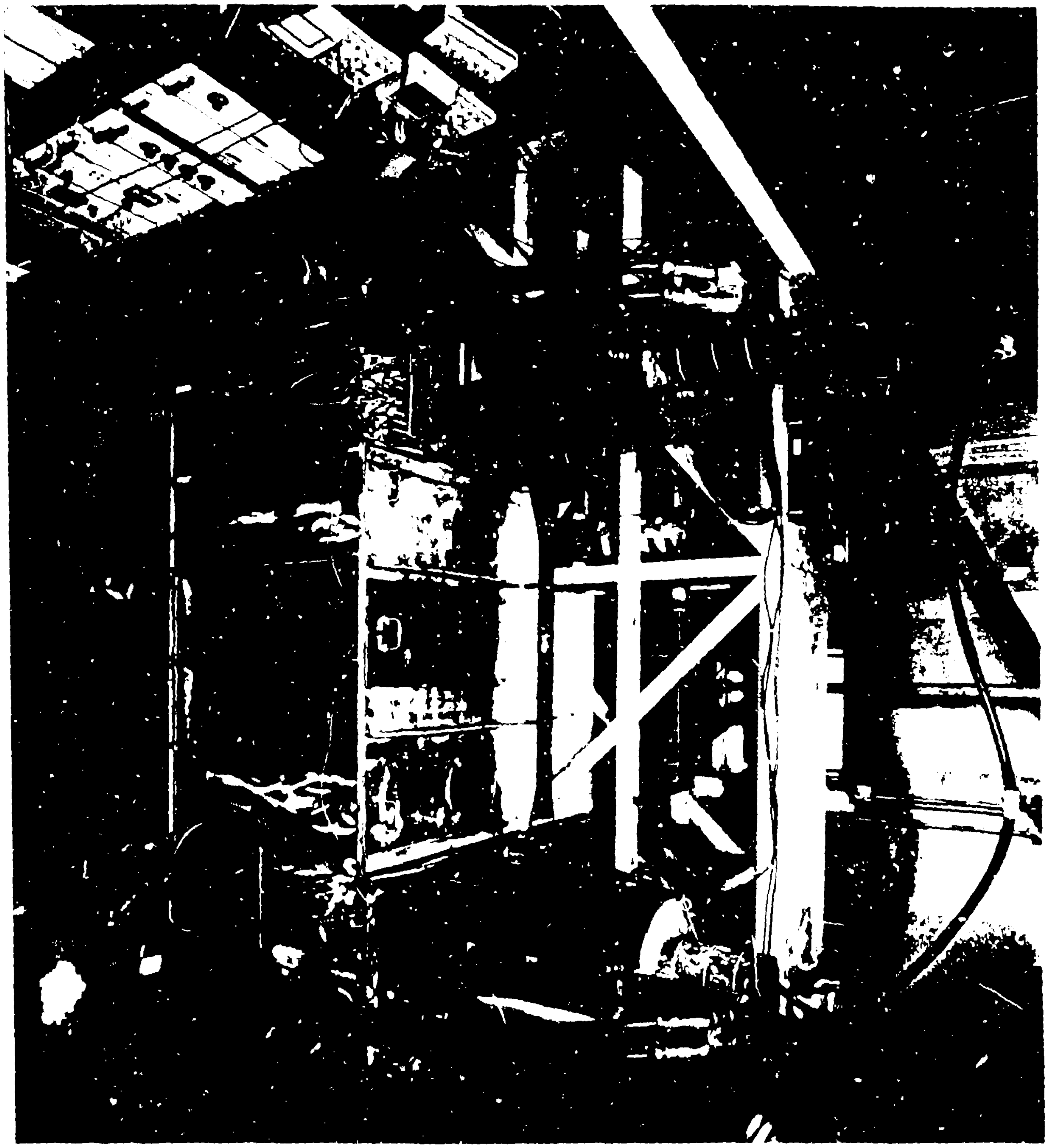
[3] W. J. D. Johnson, et al., "High-Power RF-Pulsed Modulators for the Los Alamos Free-Electron Laser," Proc. 1987 FEL Conf., *Nucl. Instr. and Meth.* A272 (1988) 232.

Captions

Fig. 1. Two-klystron modulator

Fig. 2. Proposed four-klystron modulator configurations

Fig. 3. Two-klystron modulator electronic schematic



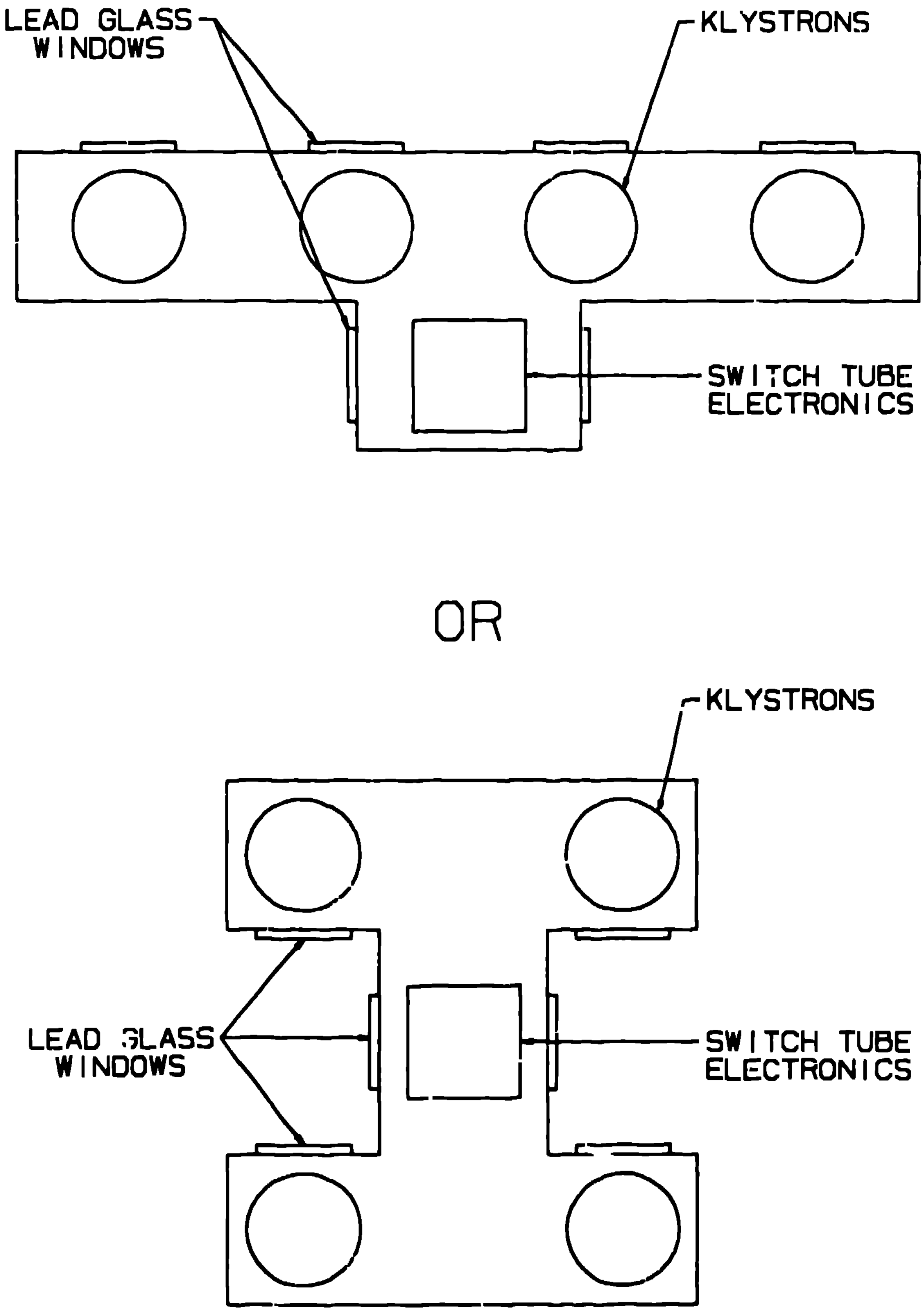
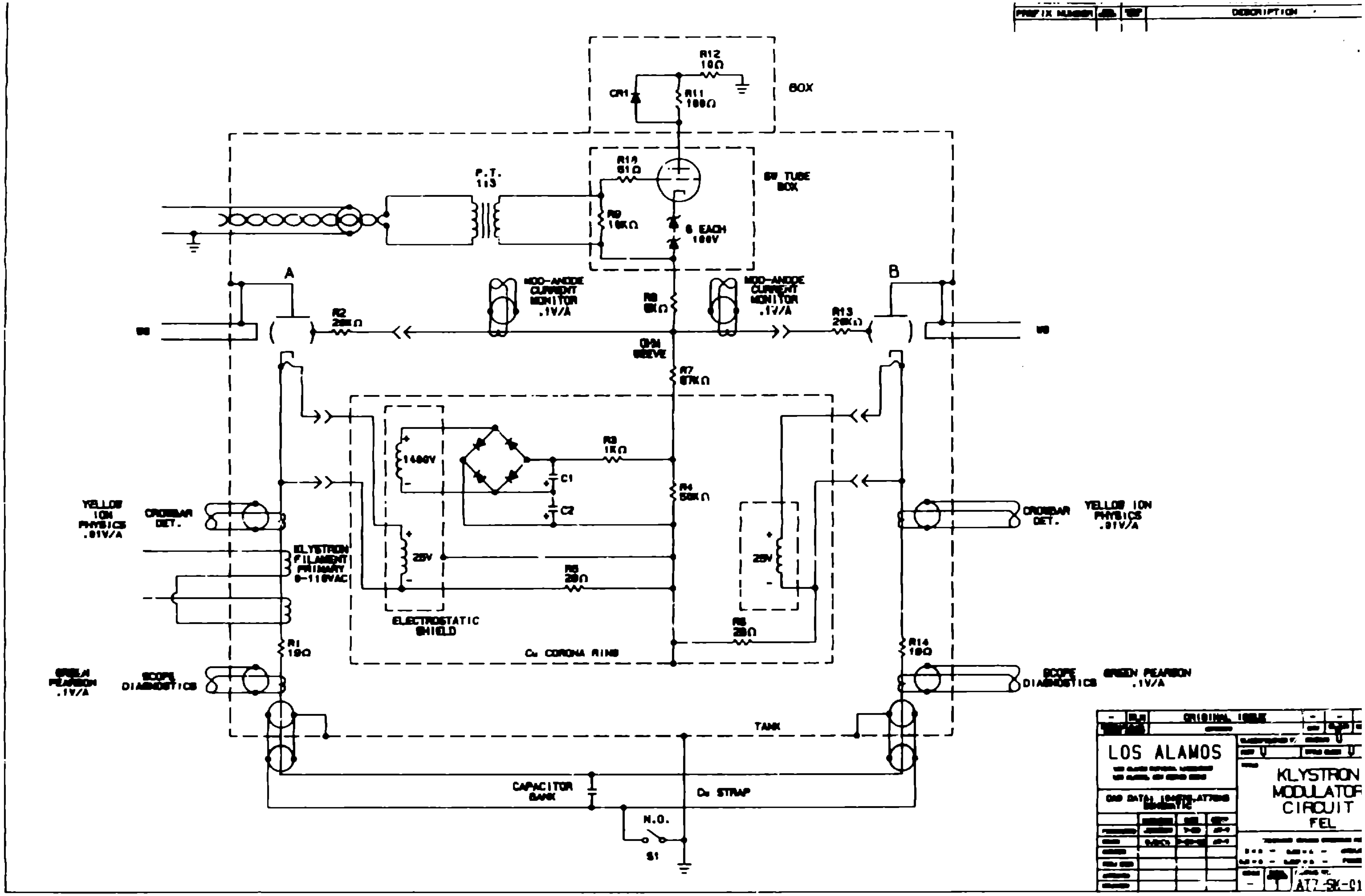

LEAD GLASS
WINDOWS
KLYSTRONS
SWITCH TUBE
ELECTRONICS
OR
KLYSTRONS
LEAD GLASS
WINDOWS
SWITCH TUBE
ELECTRONICS

FIG. 2



R12
10Ω
CR1
R11
100Ω
BOX
R10
51Ω
P.T.
1:3
SW TUBE
BOX
R9
10KΩ
6 EACH
100V
A
B
MOD-ANODE
CURRENT
MONITOR
.1V/A
R8
6KΩ
R2
20KΩ
R13
20KΩ
CHM
SLEEVE
R7
67KΩ
R3
1KΩ
1400V
C1
C2
R4
56KΩ
YELLOW
ION
PHYSICS
.01V/A
CROWBAR
DET.
KLYSTRON
FILAMENT
PRIMARY
0-110VAC
25V
R5
20Ω
R6
20Ω
ELECTROSTATIC
SHIELD
Cu CORONA RING
R1
10Ω
R14
10Ω
GREEN
PEARSON
.1V/A
SCOPE
DIAGNOSTICS
TANK
CAPACITOR
BANK
Cu STRAP
N.O.
S1
DESCRIPTION
ORIGINAL ISSUE
LOS ALAMOS
KLYSTRON
MODULATOR
CIRCUIT
FEL