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Deutsches Elektronen-Synchrotron DESY
MHF Group
Katrin Lando
Notkestraße 85
Postfach
22603 Hamburg
FRG

Phone: (0049/40) 8998 3339
Fax: (0049/40) 8994 4302
Bitnet: MHFLAN@DHHDESY3
Telex: 2 15 124 desy d

THE TESLA MODULATOR

H. PFEFFER
C. JENSEN
S. HAYS
L. BARTELSON

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INTRODUCTION

Fermilab has designed a modulator for use in a test stand that will be used for RF system testing at DESY in 1993. The modulator will power a Klystron which will be an upgrade of the Thompson TH2104A.

The EE Support group at Fermilab is at the stage of assembling the modulator and awaiting the delivery of a few key components. Our goal is to test the modulator at Fermilab in August and September, and to set up the operating system in DESY in December.

MODULATOR SPECIFICATION

The modulator output pulse is designed to meet the following specifications:

OUTPUT VOLTAGE	133 KV	
OUTPUT CURRENT	94 AMPS	
PULSE LENGTH	2.3 m.s.	(90% to 90%)
FLATNESS	+/-.5 %	(for 2 m.s.)
REGULATION	+/-.5 %	
PRR	10 Hz	
RISE TIME	100 u.s.	

MODULATOR OPERATION

Figure 1 shows the modulator circuit. In operation, the DC power supply keeps capacitor C1 charged to a 10 kV level. The output pulse is started by turning ON GTO switch S1, which connects C1 to the pulse transformer primary. The pulse is terminated after 2.3 m.s. by turning the GTO OFF. The primary pulse level is 9.6 kV / 1.14 kA, and is stepped up to the Klystron operating level by a 13:1 pulse transformer.

THE BOUNCER CIRCUIT

During the pulse, capacitor C1 discharges by 20% of its initial voltage, putting a 20% slope on the output pulse. To decrease the slope without resorting to a 20 mF capacitor in the C1 location, we correct the slope with a "bouncer" circuit.

The "bouncer" circuit, conceived by Quentin Kerns, is a resonant LC circuit that creates a single cycle sine wave with a 7 m.s. period. The bouncer is triggered slightly before the main pulse so that the linear, bipolar portion of the cycle is playing during the main pulse. The "bouncer" waveform cancels out the 20% slope from C1, and reduces it to less than a 1% level.

Since the bouncer capacitor voltage is ramping between -1 kV and +1 kV as the main primary current passes through it, the circuit loses no net energy other than that due to its own dissipation factor. This can be kept small so that only a low power supply is required to top up C2's voltage after charge recovery. The conduction of the main primary current through the bouncer circuit does reduce the natural slope of the bouncer waveform, but this is compensated for by increasing the initial voltage on the bouncer capacitor. The bouncer operation has been verified with a model circuit operating at the 500 W peak power level. Figures 2 and 3 show the bouncer waveforms and the output pulse voltage as modelled in SPICE.

KLYSTRON SPARK PROTECTION

In the event of a Klystron gun spark, we must keep the energy deposited in the spark below 20 Joules to avoid damage to the gun.

Our response to a spark will be to immediately open Switch S1, and to allow the stored energy in the transformer leakage inductance to be dissipated in the 80 Ohm resistor across the transformer primary. The 100 u.F. capacitor in parallel to this resistor limits the peak inverse voltage at the primary to 800 volts when S1 is opened. The undershoot voltage for a normal pulse is shown in Fig. 4.

Should the S1 switch fail to open due to either a circuit failure or a spark occurring during the first 100 u.s. of the pulse when the switch cannot be turned back off, we have a backup system to protect the Klystron.

The backup action will be to crowbar the main power supply and Bouncer circuit capacitor banks and to open GTO switches S2 and S3. The crowbars reduce the system voltage to the point that S2 and S3 can be single 4.5 kV GTO's. The two switches are used for redundancy and the crowbars are also redundant. Sparks are detected in three different ways to contribute to a fully redundant protection system.

THE GTO SWITCH

We are using a series string of six GTO's for the modulator switching element because the GTO's began to look more attractive than the forced commutated SCR switch that we had originally planned to use. The original plan is shown in Fig. 5. The advantages of the GTO's are:

1. Pulse Rise Time-- We reduced the output pulse rise time from 96 u.s. to 36 u.s. by removing the 500 uH choke that was part of the forced commutation scheme.

2. Power Savings-- We eliminated the 15 kW losses in the 15 Ohm resistor that was part of the original forced commutation circuit.

3. Non-Turn Off Window.-- The GTO can be turned off within 100 u.s. of its initial turn-on. The SCR switch can be turned off after 1 m.s. This means that in the case of most Gun sparks we will be able to turn off the switch and not crowbar the capacitor bank. With the SCR approach, a crowbar would be much more likely.

4. Simpler Circuit-- The forced commutation circuit is more complicated than the straightforward idea of a switch that you just turn on and off.

The disadvantages of the GTO switch are our lack of experience using GTO's and the relatively sparse literature on the use of GTO strings. Also, the comparativelty small capacitance in parallel to the GTO switch (1 u.F vs. 30 u.F. for the SCR's) leads to a requirement of low stray inductance in the pulse circuit in order to avoid large overshoot voltages across the switch when it opens. Figure 6 shows the calculated voltage across the first GTO in the string to open at the end of the pulse. The overshoot is due to the 2 uH stray inductance that we are trying to maintain in our modulator construction. The GTO's are rated at 4.5 kV, so this transient voltage looks comfortable.

The low-inductance constraint also means that we must have a free wheeling diode across the 50 uH choke (L4) that we have added to protect the switch from the effects of a breakdown in the primary circuit.

FIG 1

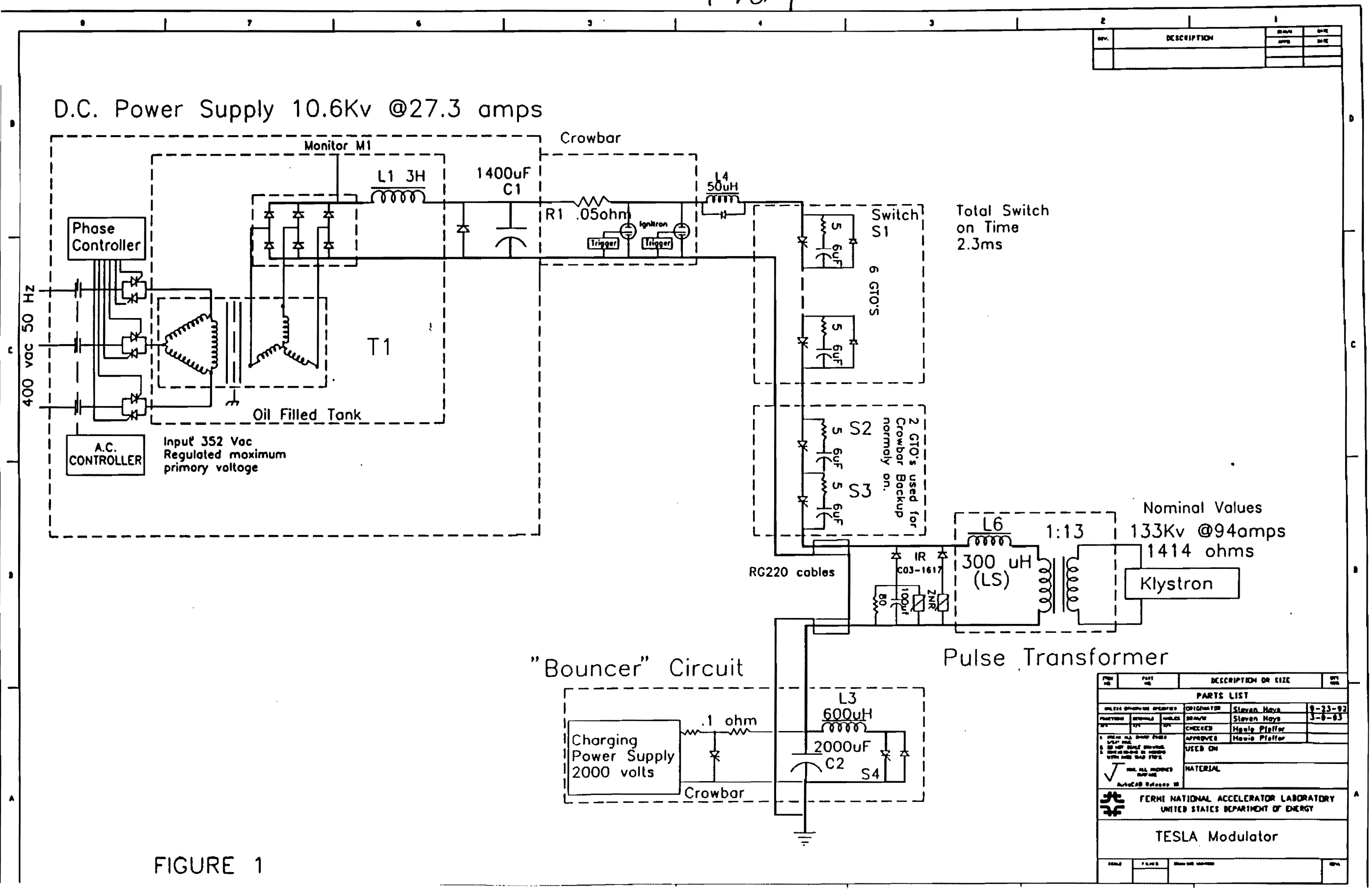
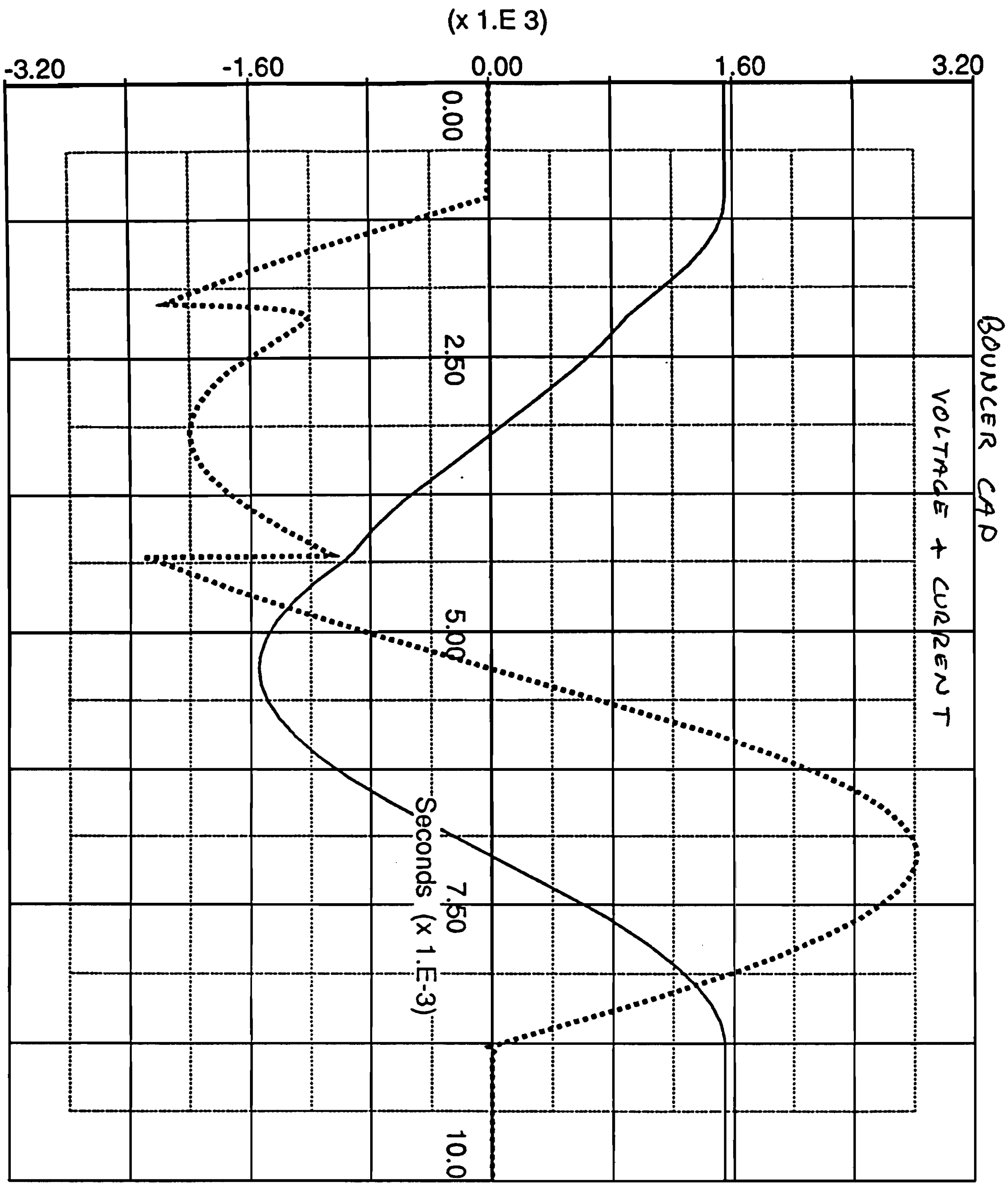


FIGURE 1



PLOT DATA FROM FILE : 28-May-93 09.52.11 - NODE NAMES & PLOT POINT SUMMARIES FOLLOW:

——— BC3 BCOM 178 POINTS (2 %) USED --------- BC3 BCOM 135 POINTS (1 %) USED

FIG 2

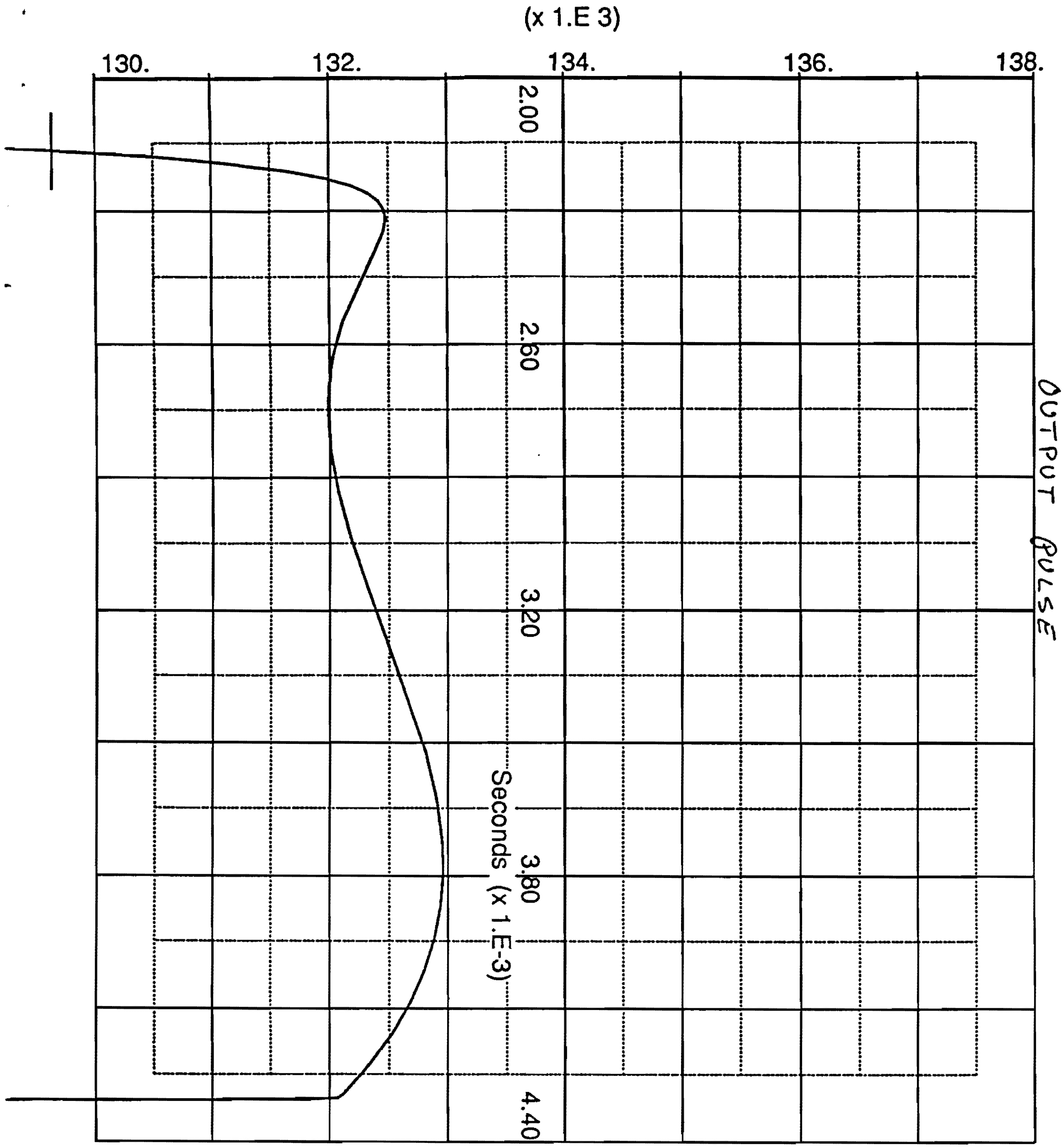


FIG 3

PLOT DATA FROM FILE : 28-May-93 09.52.11 - NODE NAMES & PLOT POINT SUMMARIES FOLLOW:

——— RLOAD 49 POINTS (2 %) USED

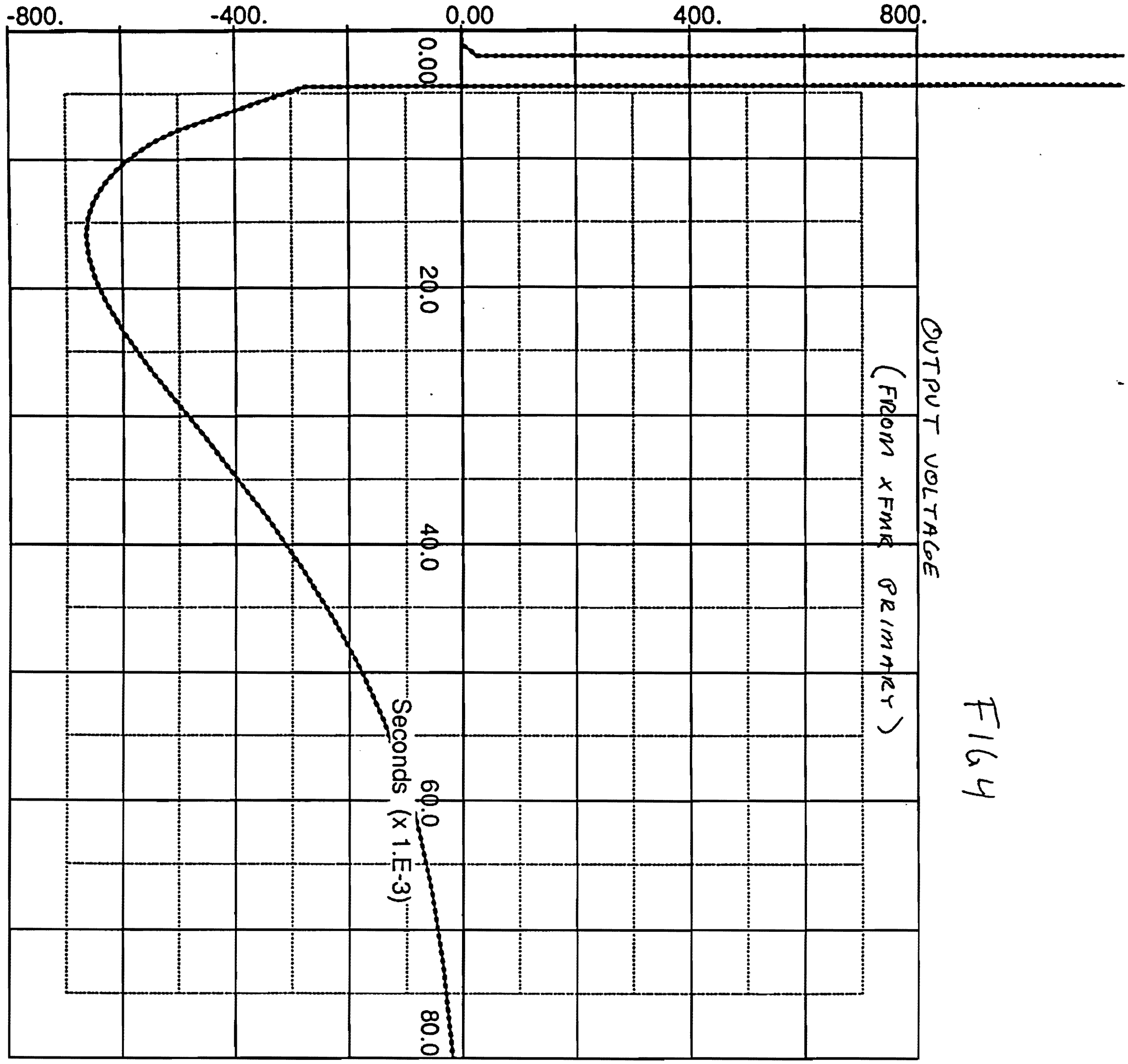


FIG 4

PLOT DATA FROM FILE : 28-May-93 09.56.30 - NODE NAMES & PLOT POINT SUMMARIES FOLLOW:
——— TFMR TXLOW 87 POINTS (0 %) USED --------- RXFMR TXLOW 124 POINTS (0 %) USED

FIG 5

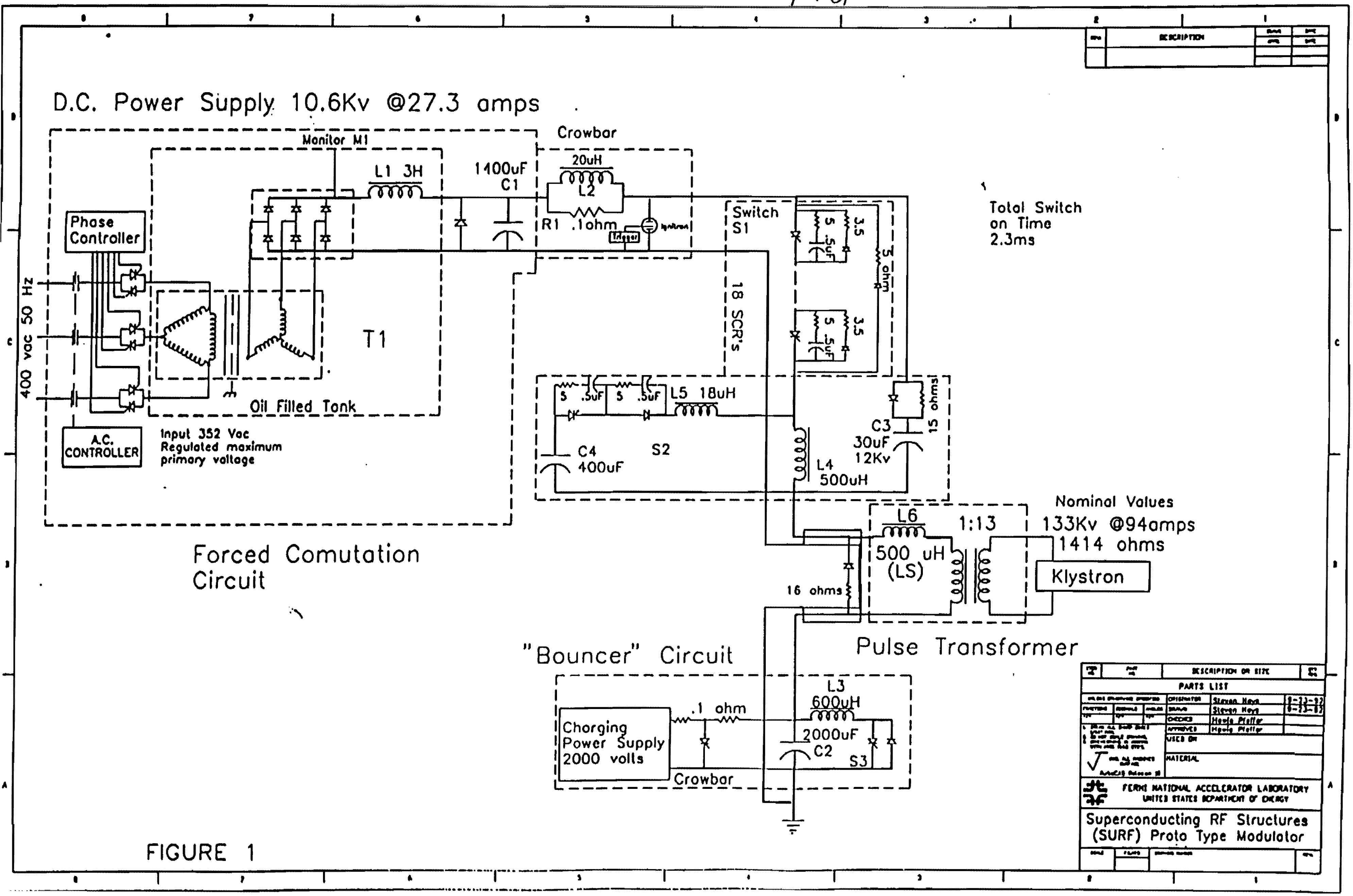
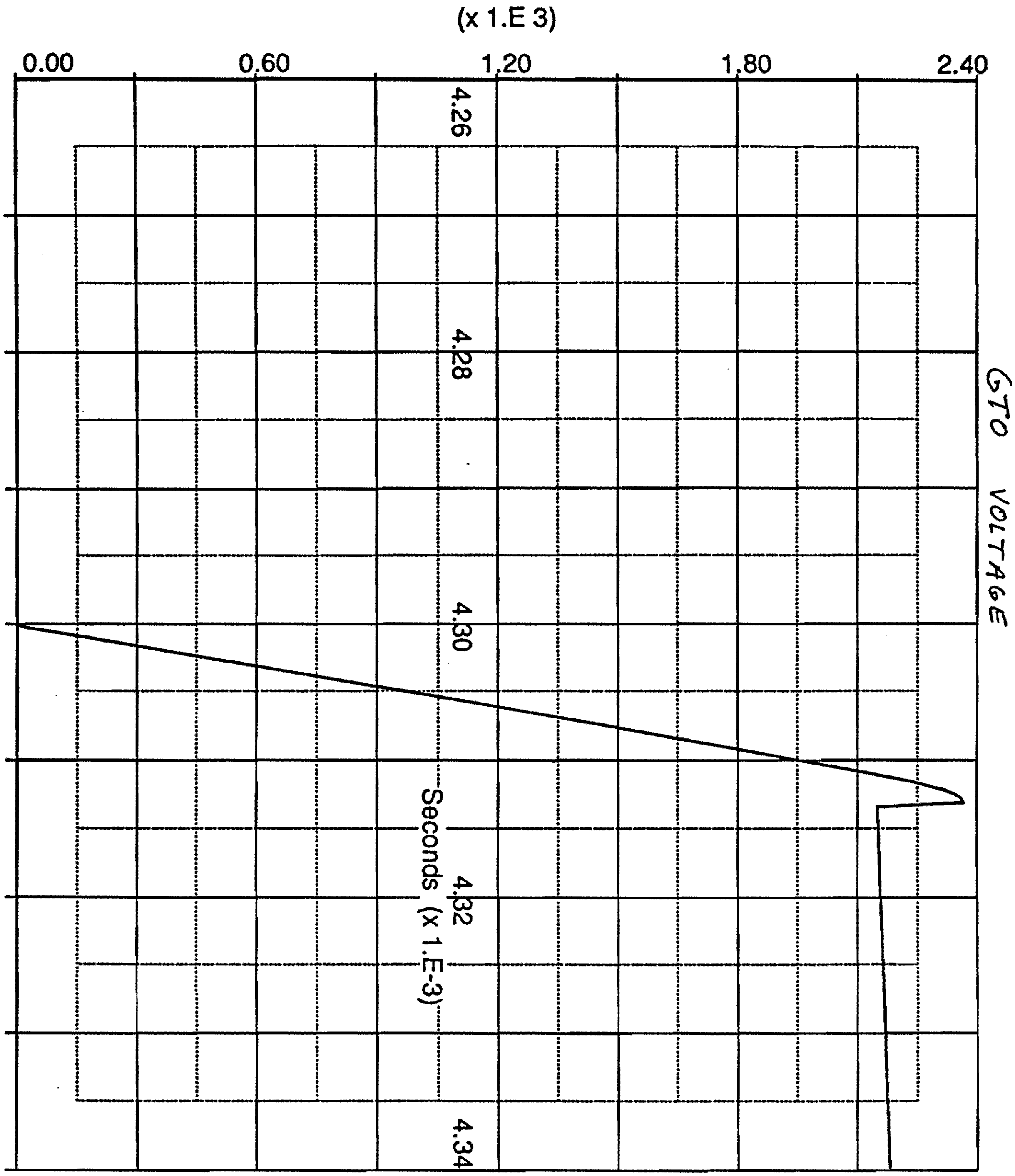


FIGURE 1



PLOT DATA FROM FILE : 28-May-93 09.33.15 - NODE NAMES & PLOT POINT SUMMARIES FOLLOW:

——— SWTCH SWT1 12 POINTS (4 %) USED

FIG 6