Fermilab

TM-627
2930.000

PULSED POWER SUPPLY INVERSION TESTS

Robert Trendler
November, 1975

GENERAL

A well known property of phase controlled rectifiers with pulsed inductive loads is the ability to advance firing angles from full rectification (positive voltage) to full inversion (negative voltage). Though these properties have been effectively used in the Main Ring power supplies, they have not been extensively utilized for beam line magnet power supplies. Tests were made in the Neutrino Department on three TransRex 500 KW power supplies, each with a separate magnet load: (1) 5D13 - two 3Q52's; (2) 1W01 - two M.R. Dipoles; (3) 1W02 - two M.R. Dipoles, and two Ling 55 KW power supplies (1) 7F00 - two 10' and one 5' EPB Quad; (2) 7D00 - two 10' and two 5' EPB Quads. The main objective of these tests was to permit a rapid field reduction in these loads, to permit use of the N1 and 15' Neutrino Beam Lines during the same accelerator flat top.

CIRCUIT MODIFICATIONS

Both power supplies have (fortunately) nominally 180^0 of firing angle control possible. Though complex schemes are possible, it appeared that only minor modifications would be required to affect adequate inversion. The free-wheeling diodes were removed and replaced with a single bypass SCR with trigger control. Figure 1 and 3 show

the general schematic with the bypass SCR and its trigger control for both the 500KW and the Ling. This circuit is necessary to protect the magnet and power supply in the eventuality of a emergency shutdown or power outage if fuses are open.

500KW CIRCUIT MODIFICATIONS

Two modifications to the regulator circuit were necessary to permit advancing the firing angle sufficiently for deep inversion and continued pulses. These changes are shown in Figure 2. Figures 2a and 2b show the diodes added to prevent the voltage loop from driving the firing angle towards rectification and, thereby, limiting the depth of inversion. Figure 2c shows the clamp circuit added to insure firing pulses during the inversion cycle. The normal 500KW firing circuit drive amplifier swings to far positive, and firing pulses subsequently disappear during the zero input voltage interval. This circuit permits adjustment of the firing circuit bias level to optimize the inversion voltage.

Several other component changes were made to improve the loop response, i.e., speed the rate at which the clamp is reached. R24 was changed to 680Ω and C2 was changed to 0.5μf.

Though not needed in the Neutrino application, it should be noted that additional inversion voltage can be obtained by rewiring the phase transformer T4 to phase shift the firing circuit phase voltages with respect to the line phase. Each tap change will slip the phase 30^0. Some loss in full rectify voltage will ensue, however, and the necessity of this procedure should be examined before it is attempted. Figure 5 shows (for a 100V tapped supply) 100V inversion for much of the inversion cycle.

LING CIRCUIT MODIFICATIONS

Figures 3 and 4 show the circuit modifications that will give adequate inversion for the Ling power supply. As in the 500KW, the bypass circuit is for protection and the regulator modification permits clamping at an adequate inversion level.

RESULTS

Figure 5 shows the output current and voltage for 5D13 (a 500KW) during the inversion period for several currents. Figure 6 demonstrates the improved fall time.

Figures 7 and 8 show the various current fall times for 1W01 and 1W02; this is also a 500KW power supply.

Figures 9 and 10 are the current and voltage wave forms for 7D00 and 7F00; these are Ling power supplies.

CONCLUSION

Reasonable inversion is possible for the power supplies tested for rather modest changes to the power supplies. The modified regulators will permit diode operation with virtually no circuit changes. As can be noted, in Figure 9 for the Ling, the depth of inversion is not as great as for the TransRex 500KW. If improved inversion is necessary, more extensive modifications to the firing circuit control will be necessary.

Though each of the loads tested were single power supplies, inversion of series connected power supplies should be a straight forward extension of these modifications.

ACKNOWLEDGEMENT

A note of appreciation to Gary Ross and Charles Worel of the Neutrino Section for assisting with and performing the tests, and in making the modifications to the power supplies.

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SUBJECT

FIGURE 1 (500KW)

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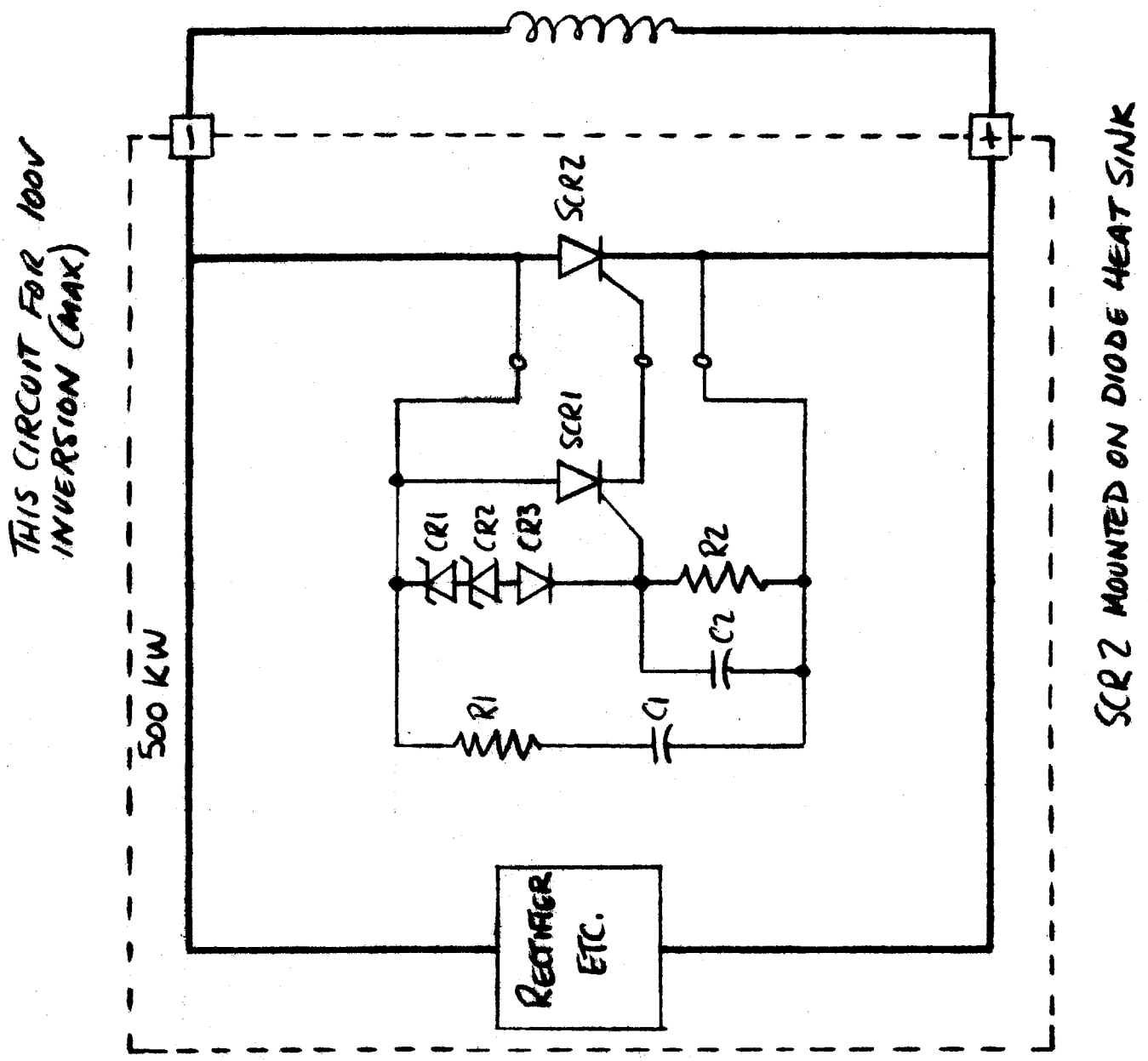

R1	15Ω 2W
R2	270Ω 2W
C1	0.22μf 400V
C2	0.22μf 400V
CR1	IN2984
CR2	IN3005
CR3	IN4005
SCR1	C107A1
SCR2	PSI H1400-5 OR EQUIV.

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FIGURE 2 (500KW) Reference Drawing #2816-EC-38519	R. Trendler	
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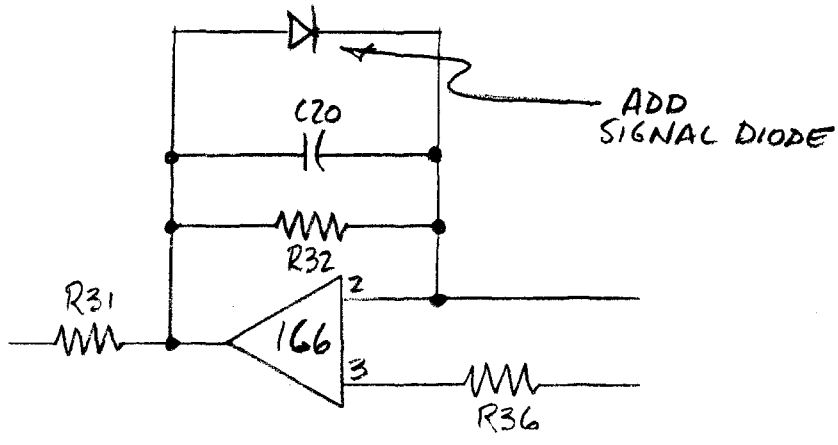
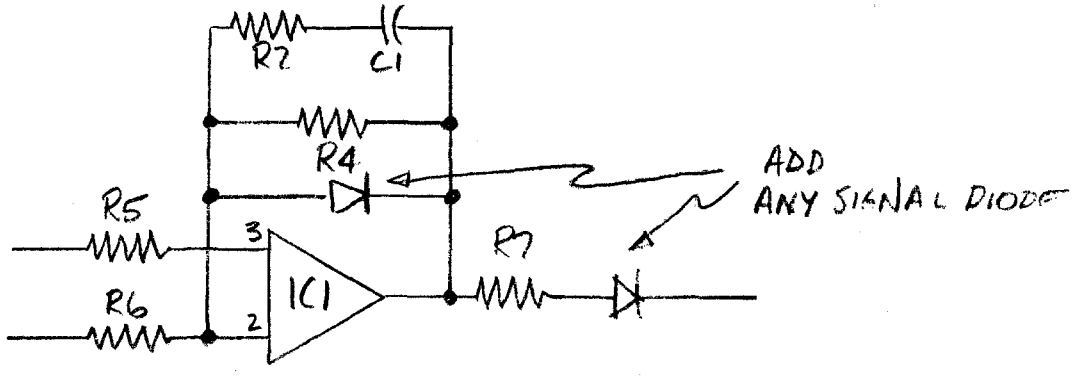
A)



B)



C)

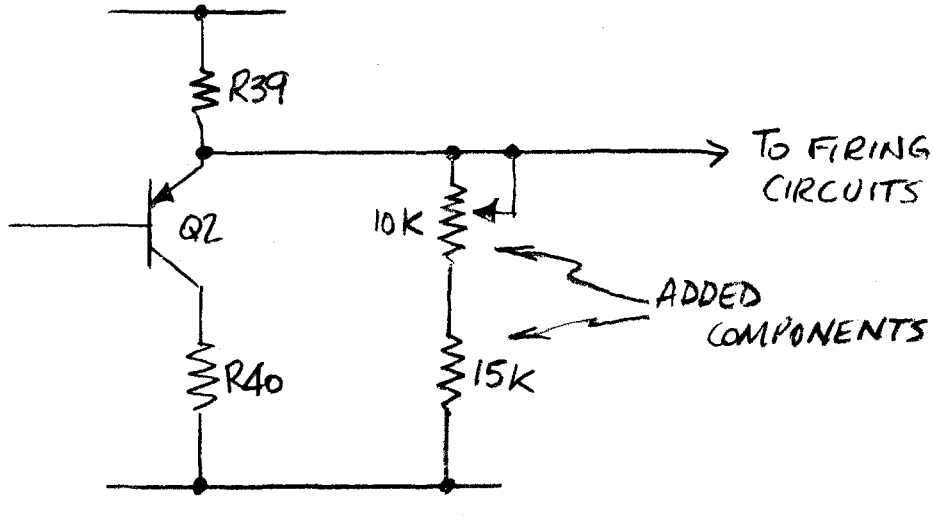


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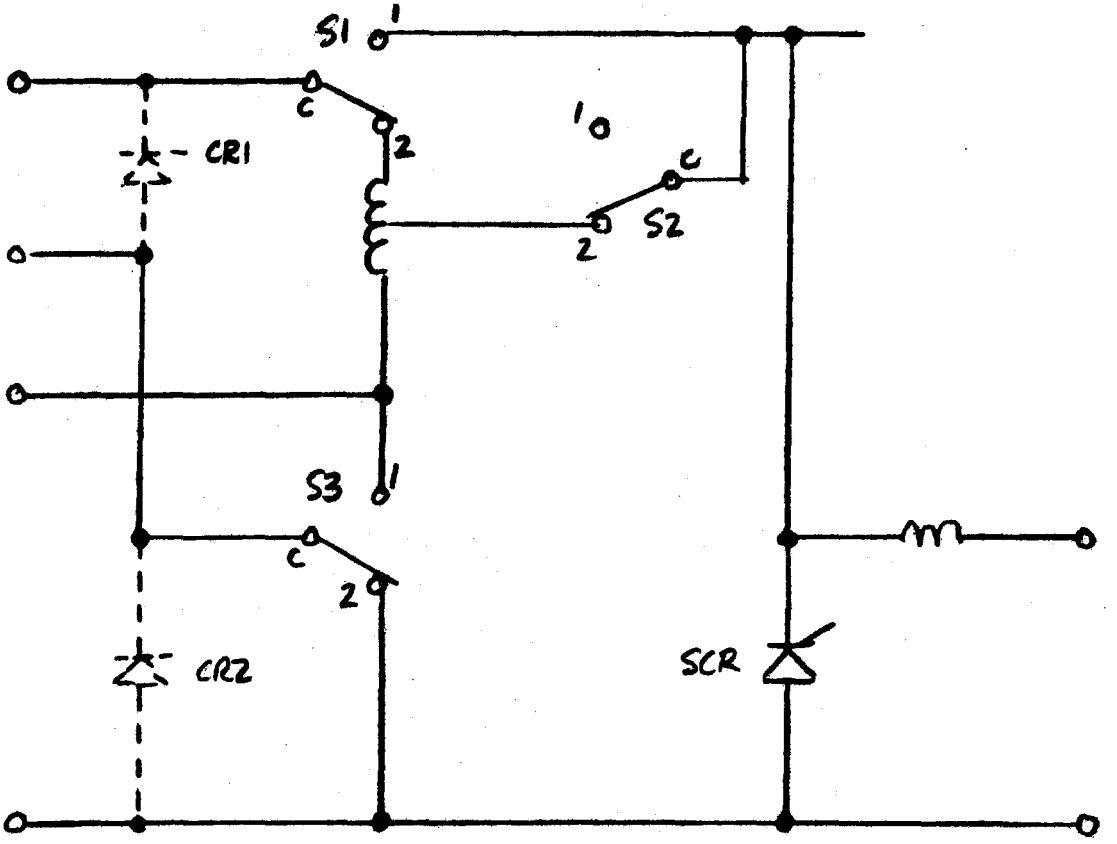
FIGURE 3 (Ling)	R. Trendler	
Reference Drawing #6008-ED-42714	DATE: Nov., 1975	REVISION BY:

A) BYPASS SCR LOCATION



B) FIRING CIRCUIT

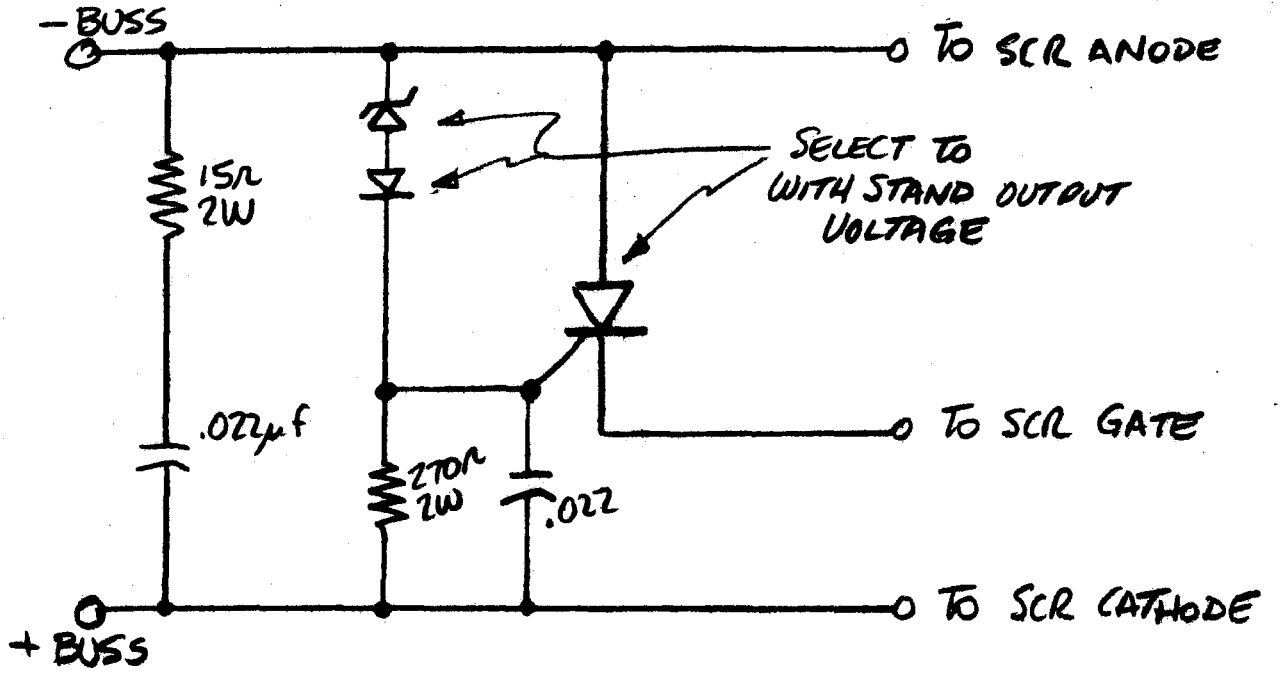


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FIGURE 4 (Ling) Reference Drawing #6008-ED-42726	R. Trendler
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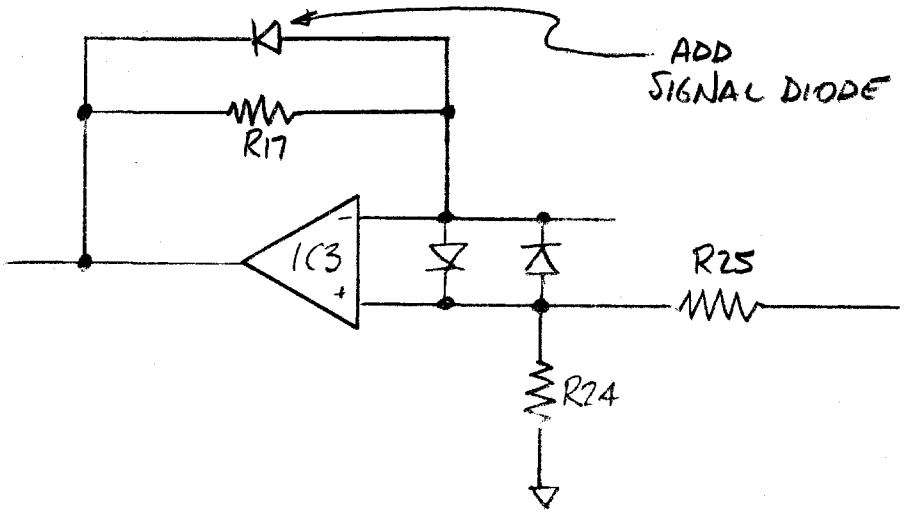
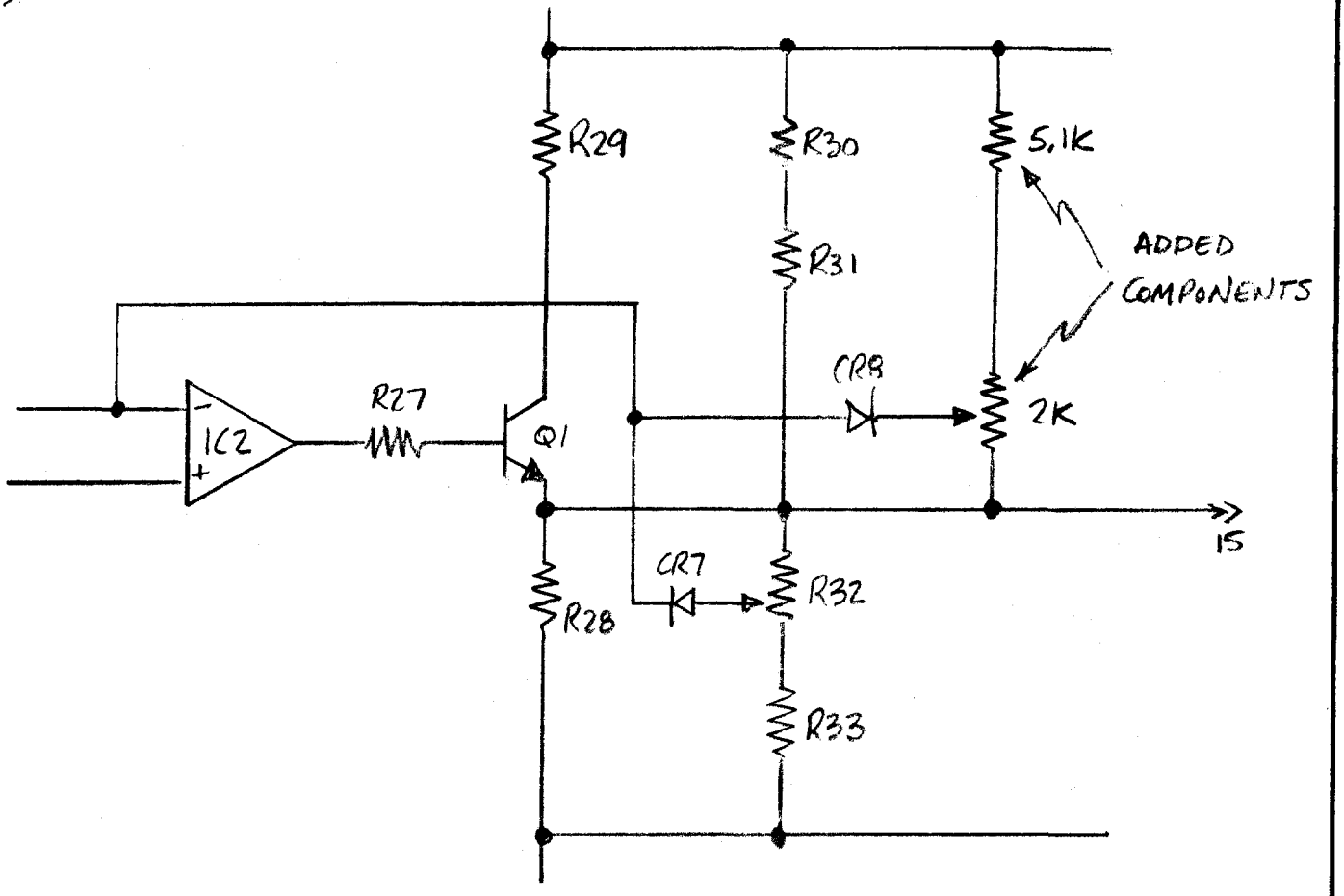
A)



B)



5D13 500KW

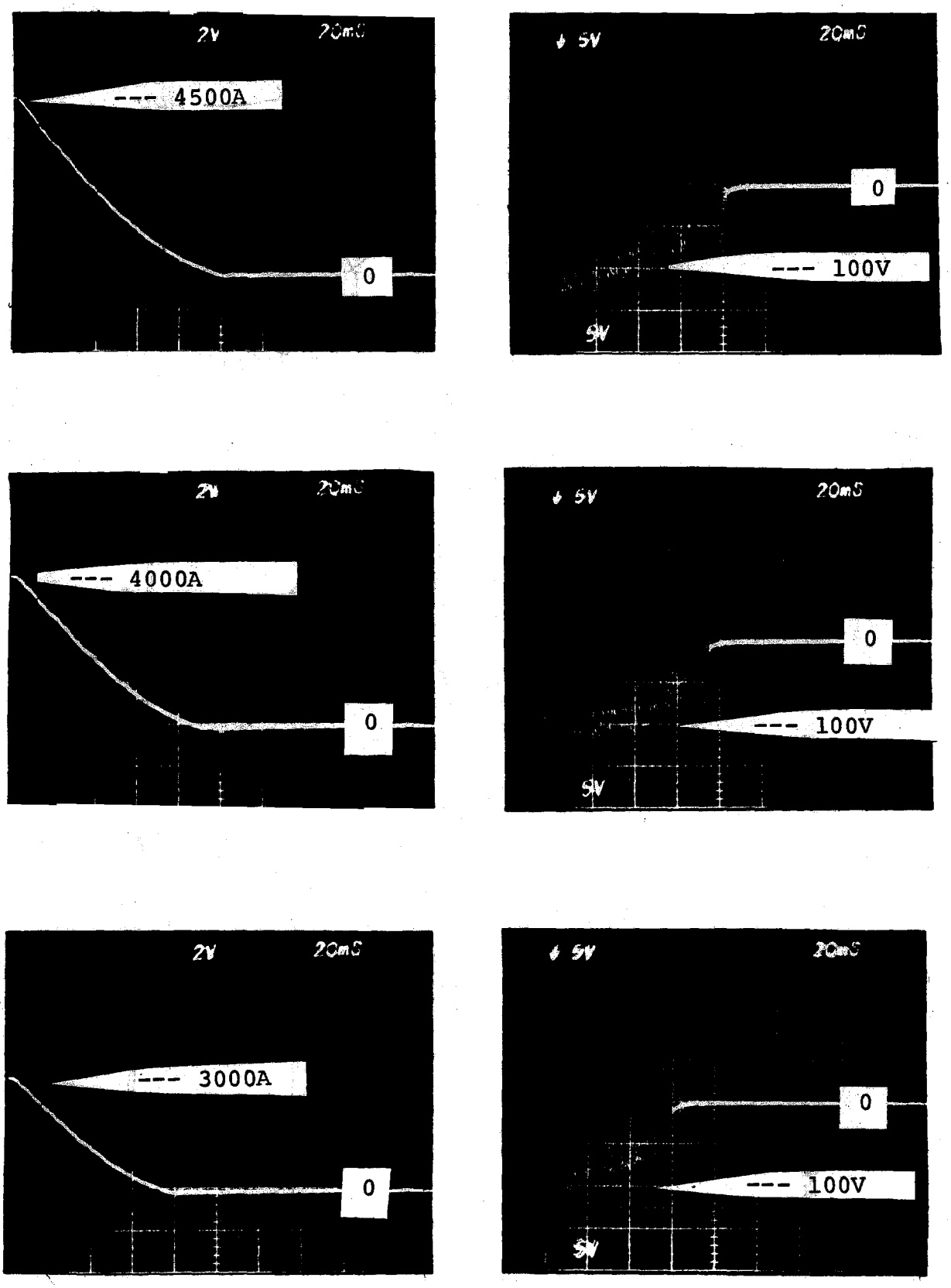


Figure 5

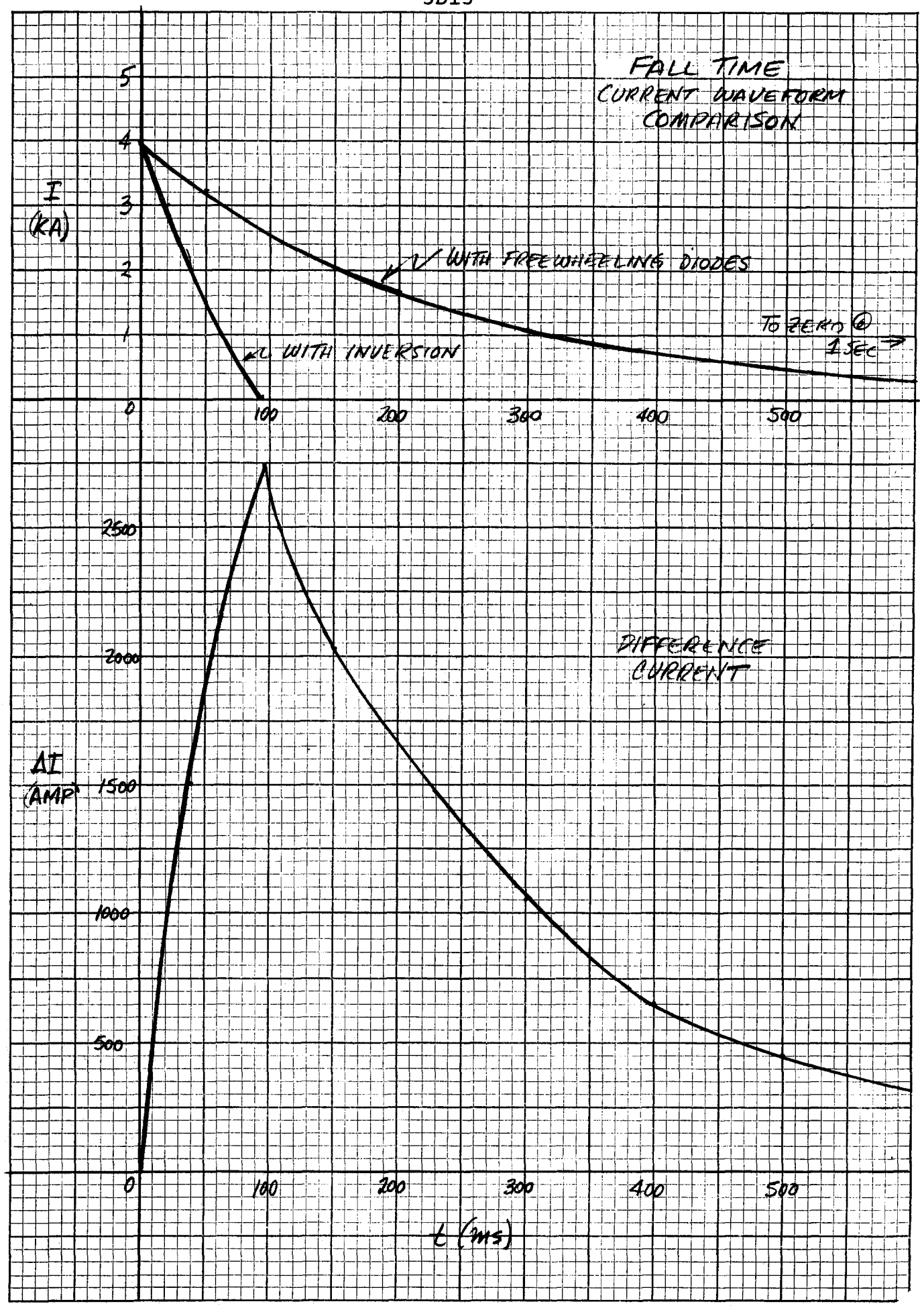

FALL TIME
CURRENT WAVEFORM
COMPARISON
I
(KA)
5
4
3
2
1
0
WITH FREEWHEELING DIODES
WITH INVERSION
TO ZERO @
1 SEC
100
200
300
400
500
2500
2000
1500
1000
500
ΔI
(AMP)
DIFFERENCE
CURRENT
0
100
200
300
400
500
t (ms)

FIGURE 6

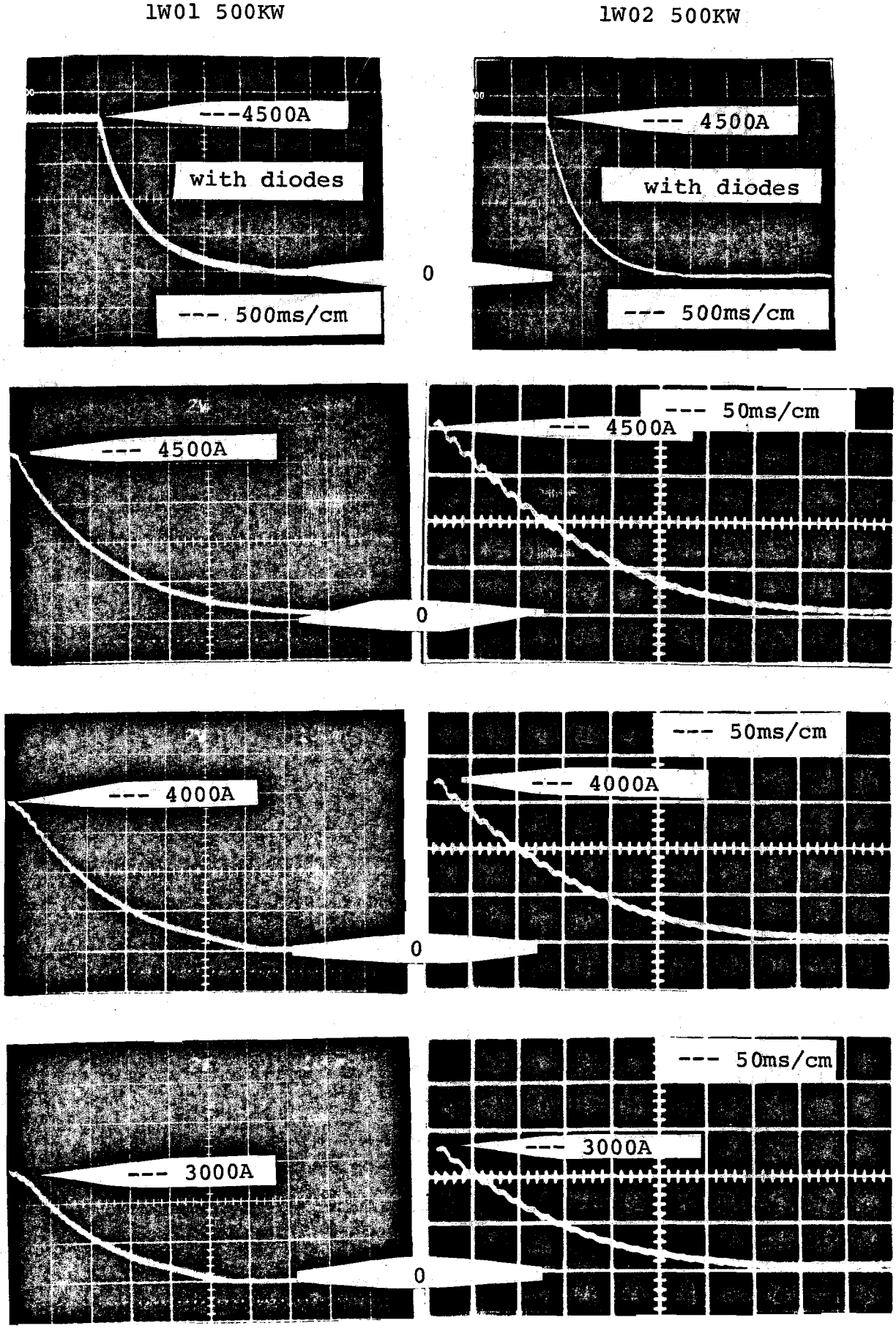

1W01 500KW
1W02 500KW
---4500A
with diodes
--- 500ms/cm
0
--- 4500A
with diodes
--- 500ms/cm
--- 4500A
--- 50ms/cm
--- 4500A
0
--- 4000A
--- 50ms/cm
--- 4000A
0
--- 3000A
--- 50ms/cm
--- 3000A
0

Figure 7

1W01 and 1W02

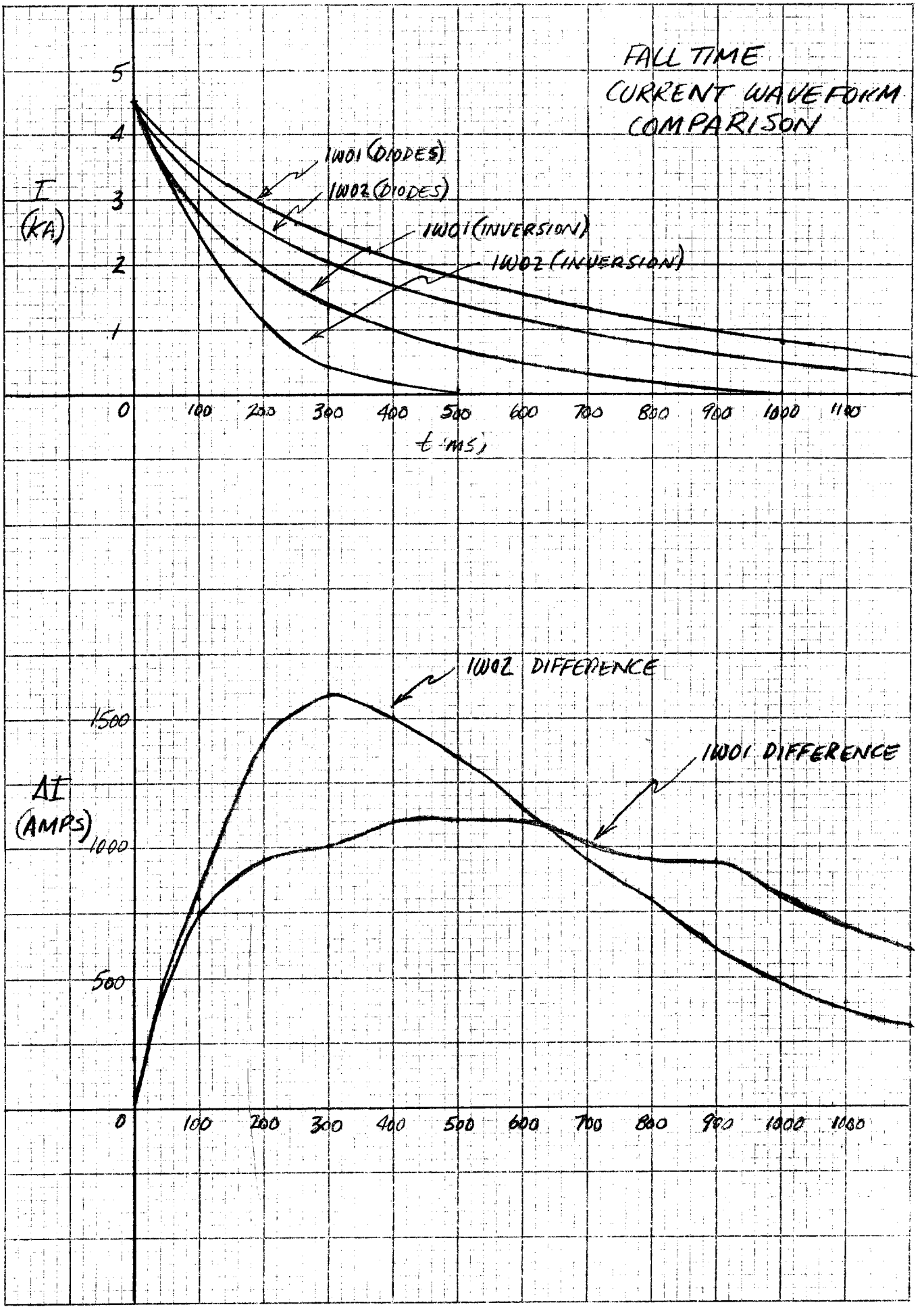


FIGURE 8

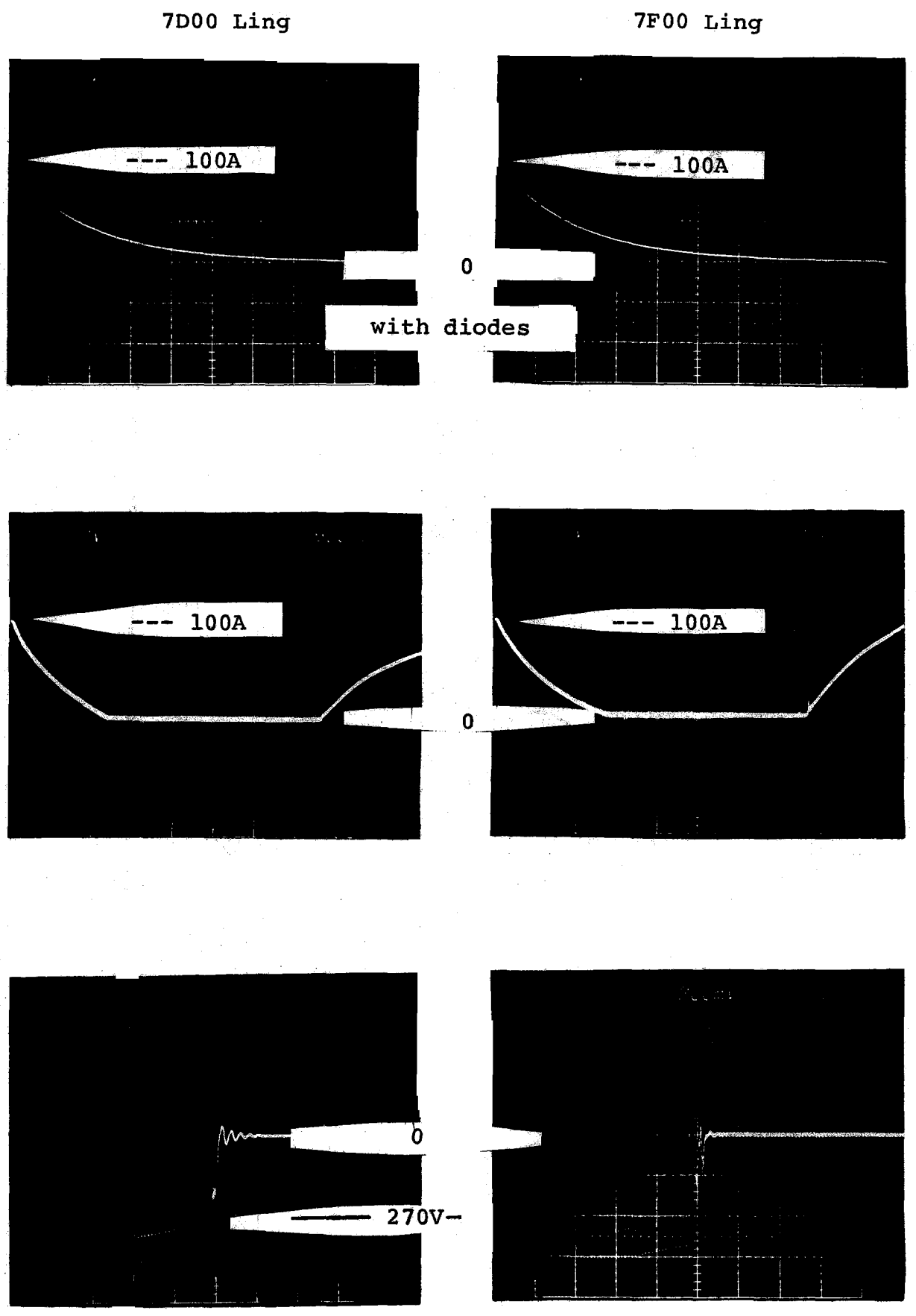


Figure 9

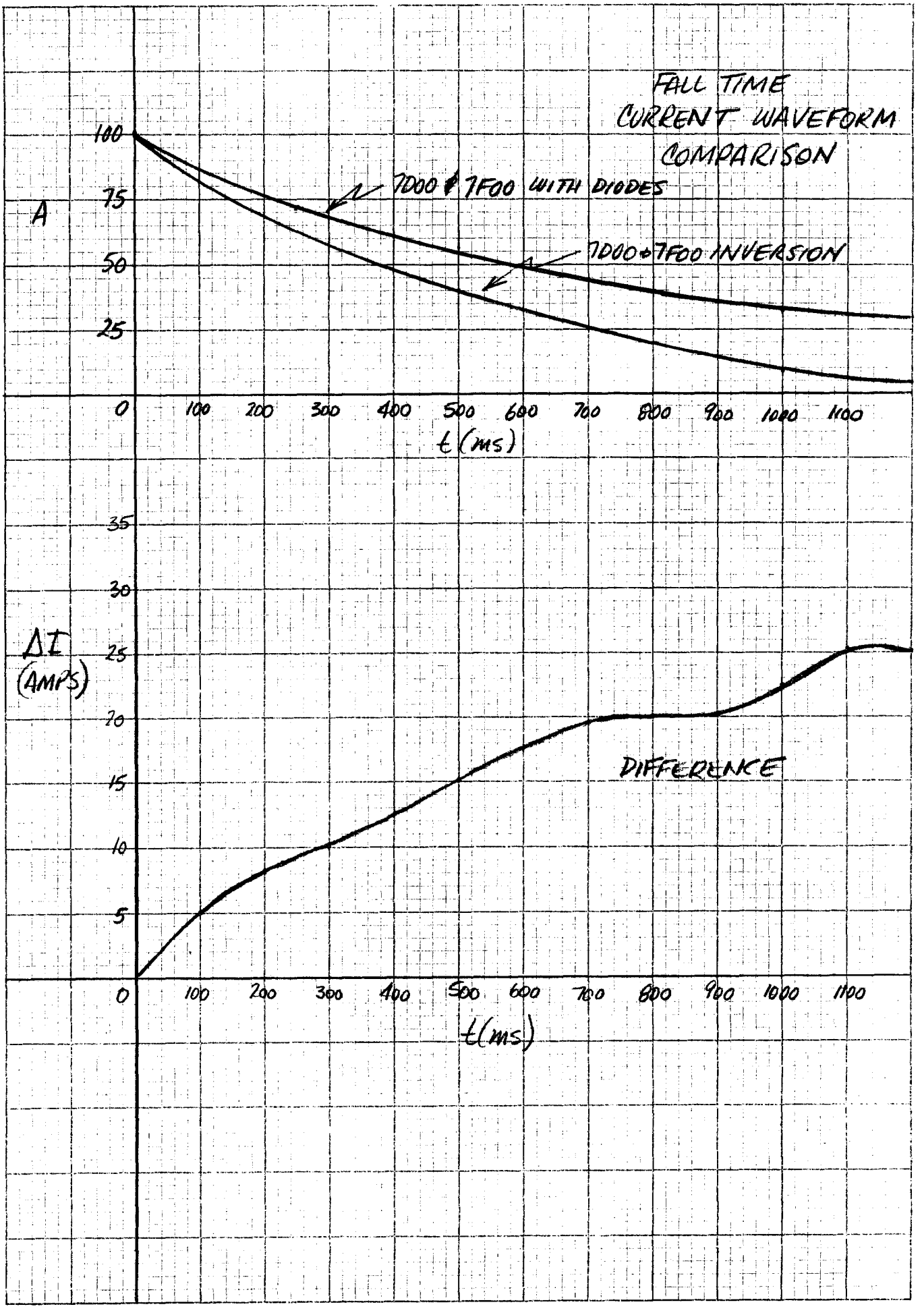

FALL TIME
CURRENT WAVEFORM
COMPARISON
7000 & 7F00 WITH DIODES
7000 & 7F00 INVERSION
A
100
75
50
25
0
100
200
300
400
500
600
700
800
900
1000
1100
t (ms)
ΔI
(AMPS)
35
30
25
20
15
10
5
0
DIFFERENCE
t (ms)

FIGURE 10

PROCEDURE FOR TRANSREX 500KW INVERSION

1. Operate power supply on normal load. Adjust phases for best tracking throughout current range. Replace any defective fuses or SCRs. Repair any defective circuits.
2. Remove all freewheeling diodes.
3. Install protection SCR and trigger circuit or equivalent in accordance to Figure 1. Circuit is for 100V max operation. Modify accordingly to permit higher voltage operation.
4. Retap power supply for 100V if 100V inversion is necessary. If lower taps are used, inversion voltage will be correspondingly lower. Modify voltage control card (A400), drawing #2816-EC-38519, as follows:
   a) Replace R24 (1500Ω) with a 6800Ω resistor.
   b) Install diodes as shown in Figures 2a & 2b.
   c) Install clamp circuit on IC1 as shown in Figure 2c.
   d) Replace C2 (6.8μf) with a 0.5μf capacitor.
5. Set up 150 module for maximum S6 slope (50000), and zero L6.
6. Operate power supply in ramped mode. Observing transductor output signal triggered from T6, adjust clamp potentiometer to minimize fall time.
7. If supply is to be operated at low currents (less than 400A), voltage ripple will be very large. If ripple is a problem, the freewheeling diodes may again be required with no inversion capability.

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