



Fermi National Accelerator Laboratory

FERMILAB-TM-1718

Transrex 500 kW Power Supply Transducer Upgrades

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Cat #2080.000

TRANSREX 500 kW
POWER SUPPLY TRANSDUCTOR
UPGRADES

1. SUMMARY

This paper describes various upgrades and tests done at the Research Division 500 kW Transrex power supply dc current transducers and chassis. The results of all modifications were measured on the same test setup with the same transducer head and chassis. The setup used for the measurements is shown in Fig. 1. Field testing of over one-hundred power supplies indicated that the results given in this paper are similar to the signals observed in the field within a factor of + or - two. The dc transducers yield 10Vdc burden resistor voltage at 5000 A load current.

2. DESCRIPTION OF TESTS AND CIRCUIT CHANGES

Reference

The transducer head and chassis as built by Transrex was studied at 3 operating points which were: zero Amp, 500 Amp, and 2000 Amp dc current. The original Transrex schematic is shown in Fig. 3. The voltage ripple across the burden resistor at these 3 points is shown in Figs. 2A, 2B, and 2C. The spectrum analysis of this voltage at 2000 Amp, which results in 4 Vdc burden resistor voltage shows the burden voltage to contain the following components:

60.0 Hz	at	6370.0	μV_{RMS}
15.0 Hz	at	22.4	μV_{RMS}
9.2 Hz	at	8.2	μV_{RMS}
4.6 Hz	at	5.0	μV_{RMS}

There was additional harmonic noise above 60 Hz, in the burden voltage, however these harmonics have little effect on the actual beamline operation of these power supplies. This data is therefore not presented in this report.

Change #1

The first change in the chassis was a change of R41 and R42 (Fig. 3) in the sense winding bridge from 1k Ω , 1%, 10W to 75 Ω 1% 10W. The result of this was a factor of 2 reduction in the peak to peak ripple of the voltage signal seen on the

burden resistor. This is shown in Figs. 4A, 4B and 4C. At 2000 Amp and 4.0 Vdc burden voltage the ripple was:

16.0 Hz	at	2290.0	μV_{rms}
15.0 Hz	at	100.0	μV_{rms}
9.2 Hz	at	62.6	μV_{rms}
4.6 Hz	at	33.7	μV_{rms}

Change #1 and #2

The next upgrade was the replacement of the original amplifier board by a new amplifier board, shown in Fig. 5. The original boards were in poor electrical and mechanical condition due to corrosion and aging. The original board needed to be replaced. At this time it was noticed that there were also certain low frequency noise components in the burden resistor signal when the booster was running, in particular a 15 Hz component. These low frequency components were not present in the power supply current when the same power supply was run in a voltage regulated mode. These low frequency components resulted in a modulation of the power supply output current with 15 Hz, 9.2 Hz and 4.6 Hz in the current regulated mode. It was decided to sacrifice a percentage of the 60 Hz noise reduction gained in change #1 in order to reduce the low frequency noise of 15 Hz and lower by adjusting the break frequency of the A.C. feedback of the amplifier card. These low frequencies would be more evident in the magnetic field of beamline magnets driven by these power supplies. A gain of -10 to -12 dB was realized at 4.6 to 15 Hz. The 60 Hz component was still -3 dB less than it was in the original chassis. Figures 6A, 6B and 6C show the resulting ripple on the burden voltage. At 2000 Amp, and 4 Vdc burden voltage the ripple was:

60.0 Hz	at	4800.0	μV_{rms}
15.0 Hz	at	30.4	μV_{rms}
9.2 Hz	at	11.5	μV_{rms}
4.6 Hz	at	7.8	μV_{rms}

Change #1, #2 and #3

With the use of the new and faster A to D's in Research Division controls systems, there was renewed interest in getting cleaner signals from the transducer

chassis. It was found that by using single phase excitation on the head as shown in Fig. 5., rather than 3 phase excitation as built by Transrex, the peak to peak ripple was reduced by a factor of 2 to 2.5 on any given head and chassis. A side benefit of this change was that the power dissipation in the heads sense windings was reduced by 1/3. Also, because of reduced loading on the chassis' power transformer, the feed back power supply is stiffer, enabling the different interconnected head and chassis to operate up to 6K amps ramped. The chassis still retains its 3 phase power supplies for various D.C. voltages. The resulting ripple wave shapes are shown on Fig. 7A, 7B and 7C. Single phase excitation reduces the 60 Hz component in the ripple by 12 dB and increases the 4.6 to 15 Hz components by 1 to 3 dB. With these changes at 2000 Amp and 4 Vdc burden voltage the ripple was:

60.0 Hz	at	1140.0	μV_{rms}
15.0 Hz	at	43.6	μV_{rms}
9.2 Hz	at	18.9	μV_{rms}
4.6 Hz	at	8.7	μV_{rms}

At this point a frequency response test of the transducer head and electronics was run comparing the as built by Transrex head and chassis to a head and chassis with changes #1, #2 and #3. The test set up involved running current through the head from a Kepco bipolar op-amp power supply at the equivalent of 1000 Amps D.C. with a modulation of 50 Amps random noise on top of the D.C. component. For all practical purposes the frequency response was identical with the exception that the chassis with changes #1, #2 and #3 was 1 DB flatter between 5 Hz to 500 Hz.

Change #1, #2, #3 and #4

With further testing it was found that the source of ripple below 60 Hz was due to ripple in the chassis feed back power supply voltage. For a test the 1300 μF filter capacitor was increased to 10,000 μF . With this configuration at 2000 Amp and 4.0 Vdc burden voltage we find:

60.0 Hz	at	1300.0	μV_{rms}
15.0 Hz	at	7.1	μV_{rms}
9.2 Hz	at	3.4	μV_{rms}
4.6 Hz	at	6.5	μV_{rms}

This test indicated that with this current transducer the operation can be improved by using a well filtered and regulated feed back power supply. At this time there is no plan to use 10,000 μF capacitors in the Research Division transducer chassis because of physical size limitations; or to regulate the feed back power supply because of the cost and man hours involved.

The 240kW Transrex and 150, 250, 500 kW PEI power supplies do not appear to have this problem, probably because of different head design and/or the fact that the transducer chassis is fed from a constant voltage transformer reducing the 15 Hz and lower burden ripple.

Change #1, #2, #3, #4 and #5

Another area of the transducer chassis that was investigated was the silicon diodes used in the sense winding bridge rectifier. It was thought that by using an active rectifier that the forward voltage drop variation of the diodes would be eliminated. The circuit used is shown in Fig. 8. Upon testing it was found that there was a 40% reduction in the peak to peak ripple on the burden resistor at 500 Amp and 2000 Amp as shown in Figs. 9A, 9B, and 9C. A spectrum analysis of the ripple showed a 12 dB reduction in the 60 Hz component at 2000 Amp and 4.0 Vdc burden voltage. The ripple at that point was:

60.0 Hz	at	277.3	μV_{rms}
15.0 Hz	at	104.0	μV_{rms}
9.2 Hz	at	47.1	μV_{rms}
4.6 Hz	at	30.0	μV_{rms}

At the same operating point with a 10,000 μF filter capacitor on the feed back power supply the burden ripple was:

60.0 Hz	at	364.0	μV_{rms}
15.0 Hz	at	10.5	μV_{rms}
9.2 Hz	at	6.7	μV_{rms}
4.6 Hz	at	14.0	μV_{rms}

Again, the cost of rebuilding the 500 kW Transrex transducer chassis using an active rectifier in the sense winding bridge is prohibitive. It is suspected that some of the residual ripple across the burden resistor (especially at zero Amp) is common mode noise. This is due to the fact that the sense windings are at a different potential than the burden resistor and that the heads were built without electrostatic shielding between the windings. Several shorted transducer heads have been dissected and no evidence of any shielding was found.

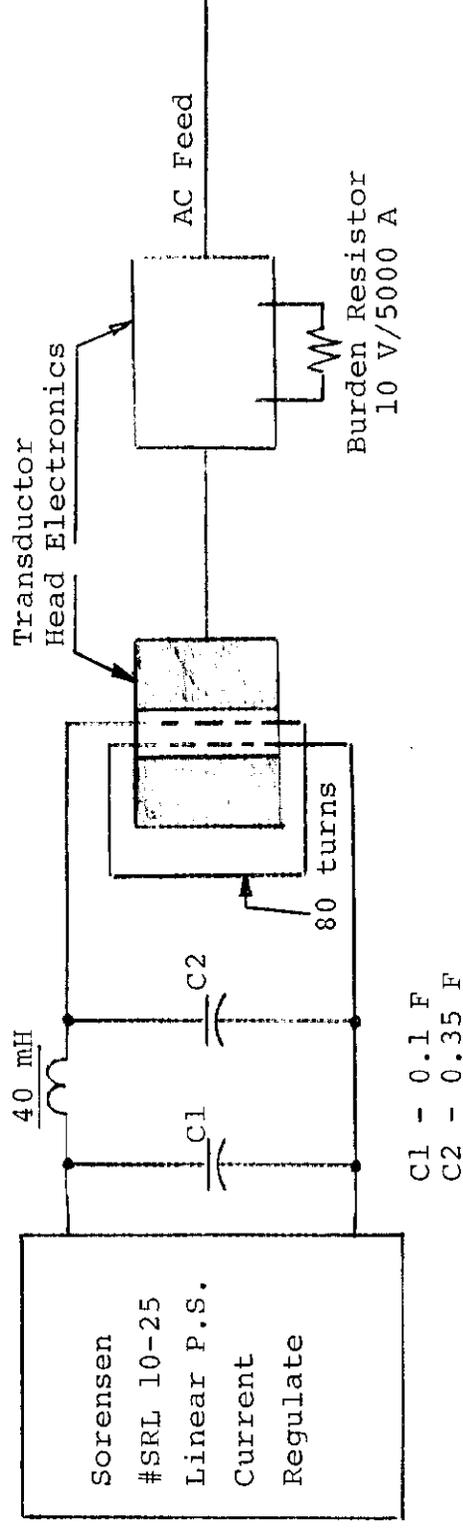
Future current transducer heads and chassis could incorporate a regulated feed back P.S., an active rectifier on the sense winding bridge and electrostatic shielding between windings for improved performance.

3. INSTALLED FIELD CHANGES

Only changes 1, 2 and 3 have been installed in all Research Division Transrex 500 kW magnet power supplies.

4. ACKNOWLEDGEMENT

These transducer upgrades would not have been possible without Age Visser's tutoring in magnetics over the years and his encouragement for me to write this paper.



- Spectrum analyzer was a H.P. 3561A Serial No. 2549A03152.
- Transducer chassis was 500 kW Transrex Serial No. 73-099-9.
- Transducer head was 500 kW Transrex Serial No. 71-104-14. Scale factor for head and chassis is 10.0 Volts at 5000 Amp.
- Scope measurements done with Tex. type 7633 with 7A22 diff. plug in and matched Tek P6055 probes.
- All tests done with booster running but over a 2 month period. Booster creates 15 Hz disturbance in ac feed.
- The measured voltage ripple across the 80 turn winding at 20.0 Adc was 60 Hz = 2 ppm, 15 Hz = 0.12 ppm, 9.2 Hz = 0.15 ppm, 4.6 Hz = 0.09 ppm.

FIGURE 1
TEST SET UP FOR NOISE MEASUREMENTS



SUBJECT

TM 1718 XDTR BURDEN VOLTAGE

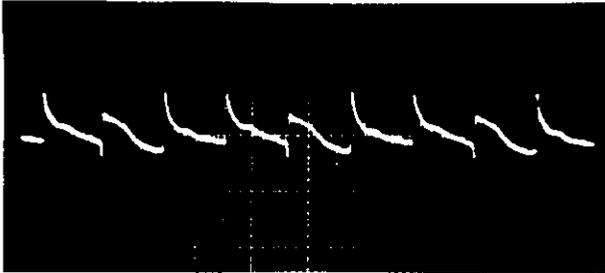
NAME

W. F. JASKIERNY

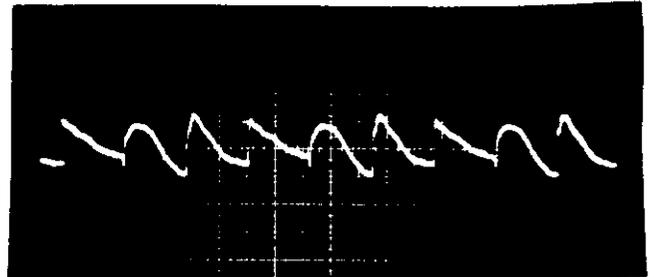
DATE

3/91

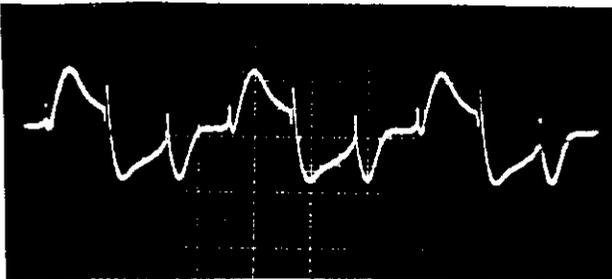
REVISION DATE



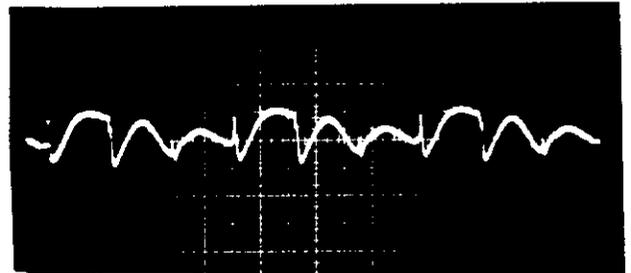
2A ORIGINAL AT 0A



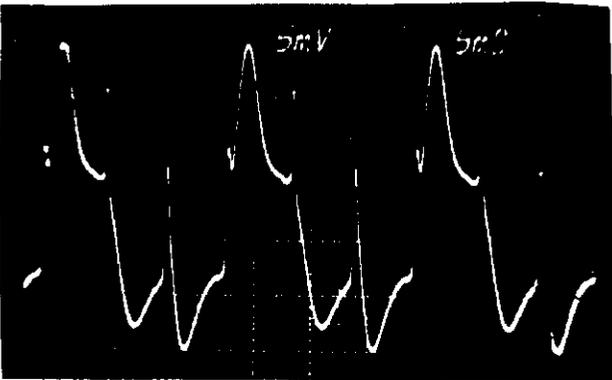
4A CHANGE 1 AT 0A



2B ORIGINAL AT 500A



4B CHANGE 1 AT 500A



2C ORIGINAL AT 2000A



4C CHANGE 1 AT 2000A

ALL FIG 5mV/DIV
5ms/DIV ?



SUBJECT

TM1718 XDTR BURDEN VOLTAGE

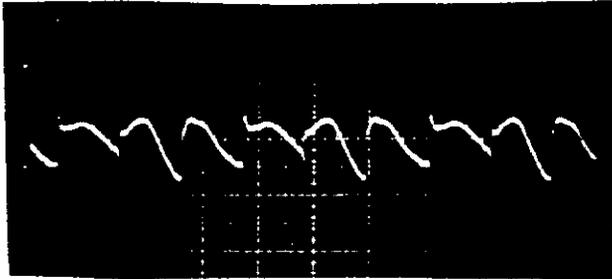
NAME

W. F. JASKIERNY

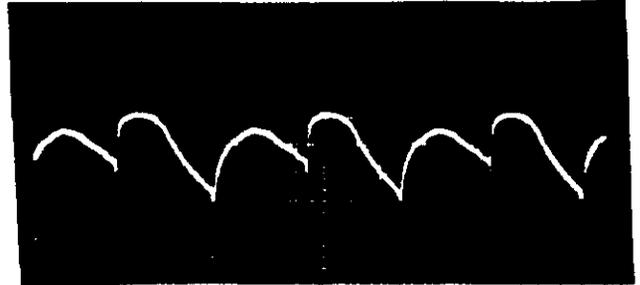
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3/91

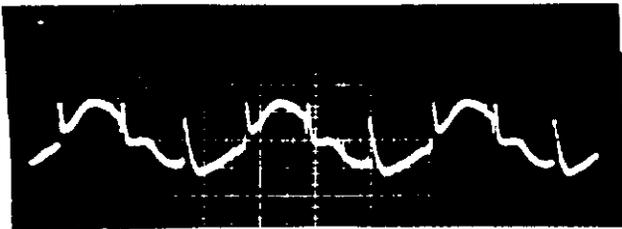
REVISION DATE



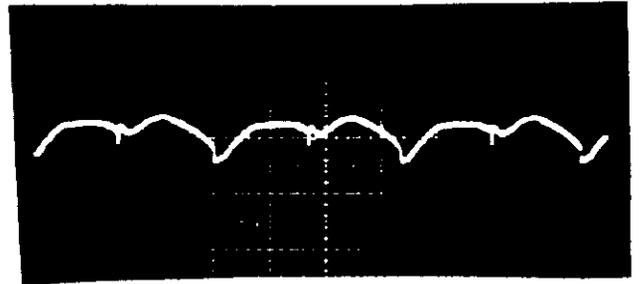
6A CHANGE 1,2 AT 0A



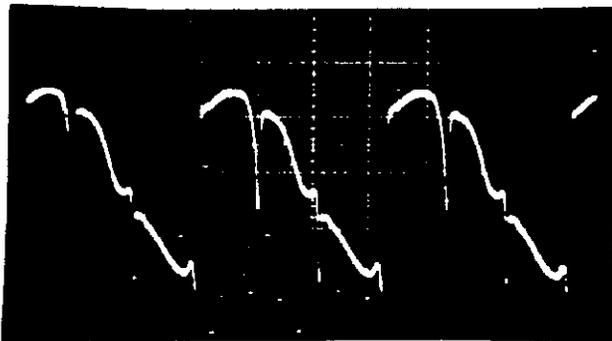
7A CHANGE 1,2,3 AT 0A



6B CHANGE 1,2 AT 500A



7B CHANGE 1,2,3 AT 500A



6C CHANGE 1,2 AT 2000A



7C CHANGE 1,2,3 AT 2000A

ALL FIG 5 mV/DIV
5 ms/DIV



SUBJECT

TM1718 XDTR BURDEN VOLTAGE

NAME

W.F. JASKIERNY

DATE

3/91

REVISION DATE

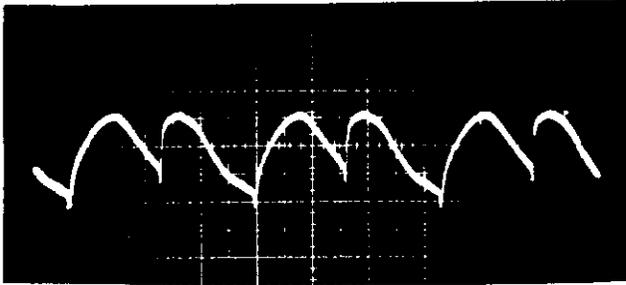


FIG 9A CHANGE 1,2,3,4,5 AT 0 A

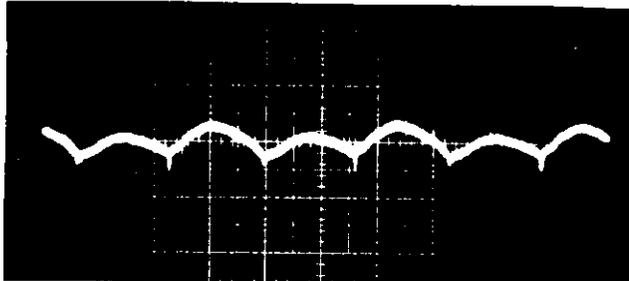


FIG 9B CHANGE 1,2,3,4,5 AT 500 A

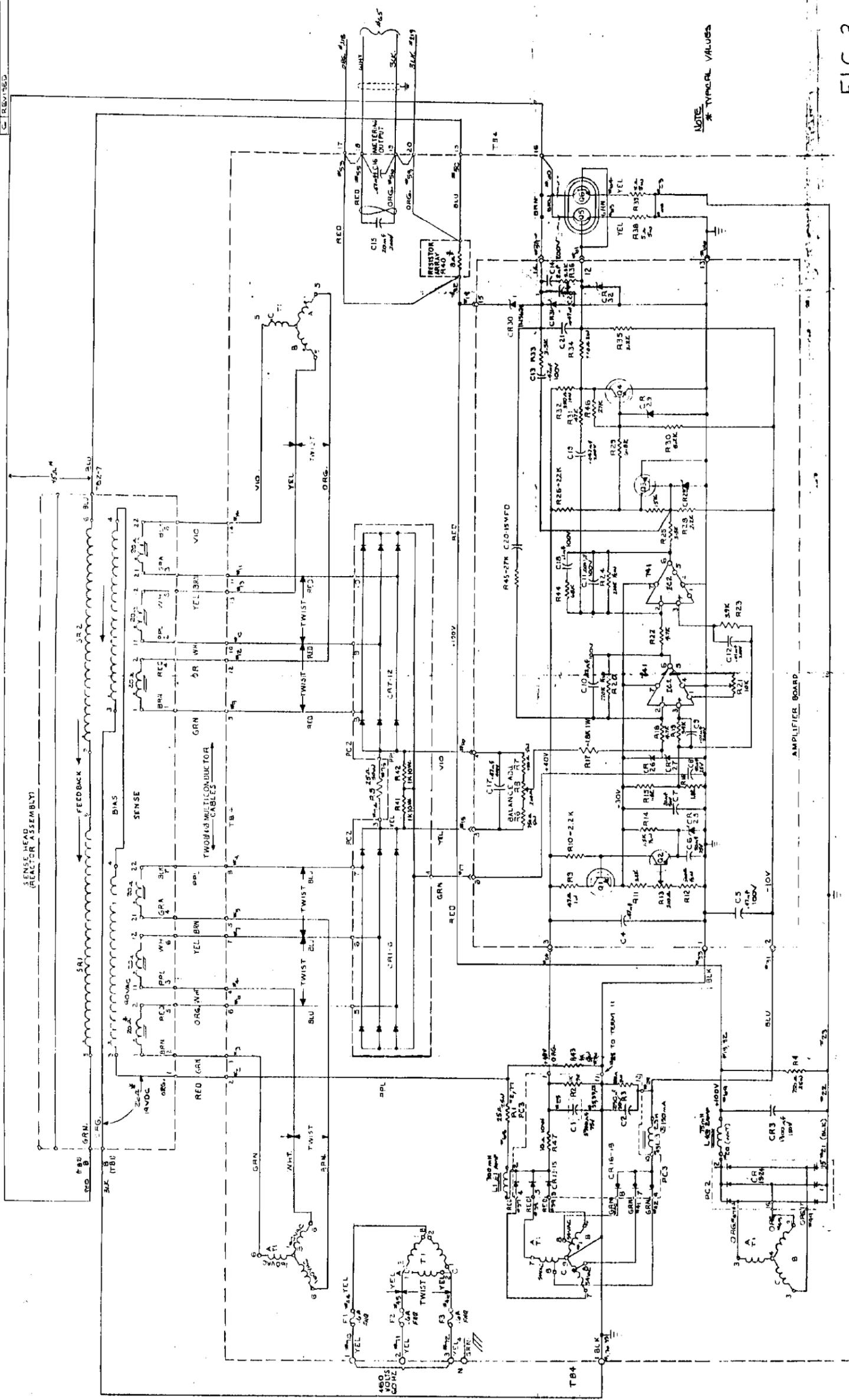


FIG 9C CHANGE 1,2,3,4,5 AT 2000 A

ALL FIG 5 mV/DIV

5 ms/DIV

REV	DESCRIPTION	DATE
A	TYPICAL VALUES ADDED	1/6/64
B	REVISED	1/27/64
C	REVISED	N.C. 1/27/64



NOTE
* TYPICAL VALUES

FIG. 3

REV	DESCRIPTION	DATE
A	TYPICAL VALUES ADDED	1/6/64
B	REVISED	1/27/64
C	REVISED	N.C. 1/27/64

AMPLIFIER CHASSIS
EARLY VERSION CHASSIS MAY HAVE SOME DIFFERENT WIRE NUMBERS

CR 25 = 1U5234B - 2V
CR 26 = 2132L - 14
CR 30131 = 1U5624 - 28

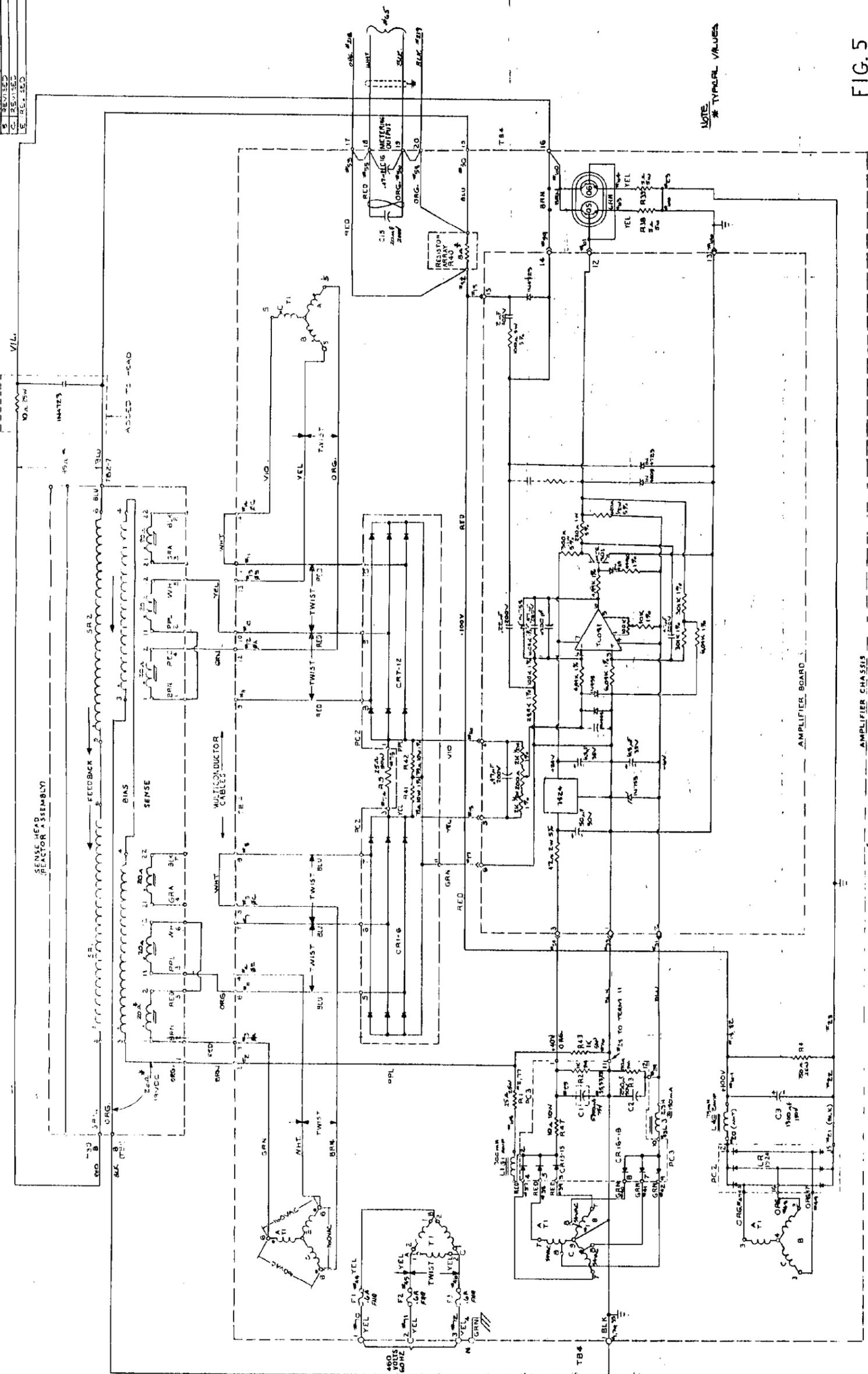
CR 25 = 1U5234B - 2V
CR 26 = 2132L - 14
CR 30131 = 1U5624 - 28

- AMPLIFIER BOARD CONNECTIONS
BOARD NO. 1, 2, 3, 4, 5, 12, 13, 14, 15
WIRE NO. 31, 32, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
- TRANSDUCER AMPLIFIER BOARD TEST PROCEDURE (IN SUPPLY)
- 30 VDC ADJUSTMENT
 - NULL ADJUSTMENT
 - INSTABILITY ADJUSTMENT (FOR OSCILLATIONS)
 - ADJUST R1 AS REQUIRED TO STOP OSCILLATIONS
 - RECHECK STEP 2A THEN STEP 3A REQUIRED FOR STABILITY AND NULL

REF. DATA TRANSDUCER 3453B

NATIONAL ACCELERATOR LABORATORY
EXPERIMENTAL AREAS DEPT.
TRANSVERSE POWER SUPPLY
TRANSDUCER HEAD & CONTROL
1,000 AMPS - SCHEMATIC DIAGRAM
PA 2930-6-7-75

REV	DESCRIPTION	DATE	BY
A	TYPICAL VALUES & ADDED	6/61	GAH
B	REVISED	11/71	N.C.
C	REVISED	12/74	N.C.
E	REVISED	10/70	N.C.



NOTE
* TYPICAL VALUES

FIG. 5

REV	DATE	DESCRIPTION	BY
1	10/70	REVISION	GAH
2	11/71	REVISION	N.C.
3	12/74	REVISION	N.C.
4	10/70	REVISION	N.C.

NATIONAL ACCELERATOR LABORATORY
EXPERIMENTAL AREAS DEPT.
TRANSFORMER HEAD CONTROL
1500 AMPS SCHEMATIC DIAGRAM
23 80 4 1

REF DATA TRANSMUX 34515

EARLY VERSION CHASISSES AMPLIFIER CHASISSES

CSJ, Q6 = 2N3642 (PREFERRED REPLACEMENTS 2N4242, 2N 5740)

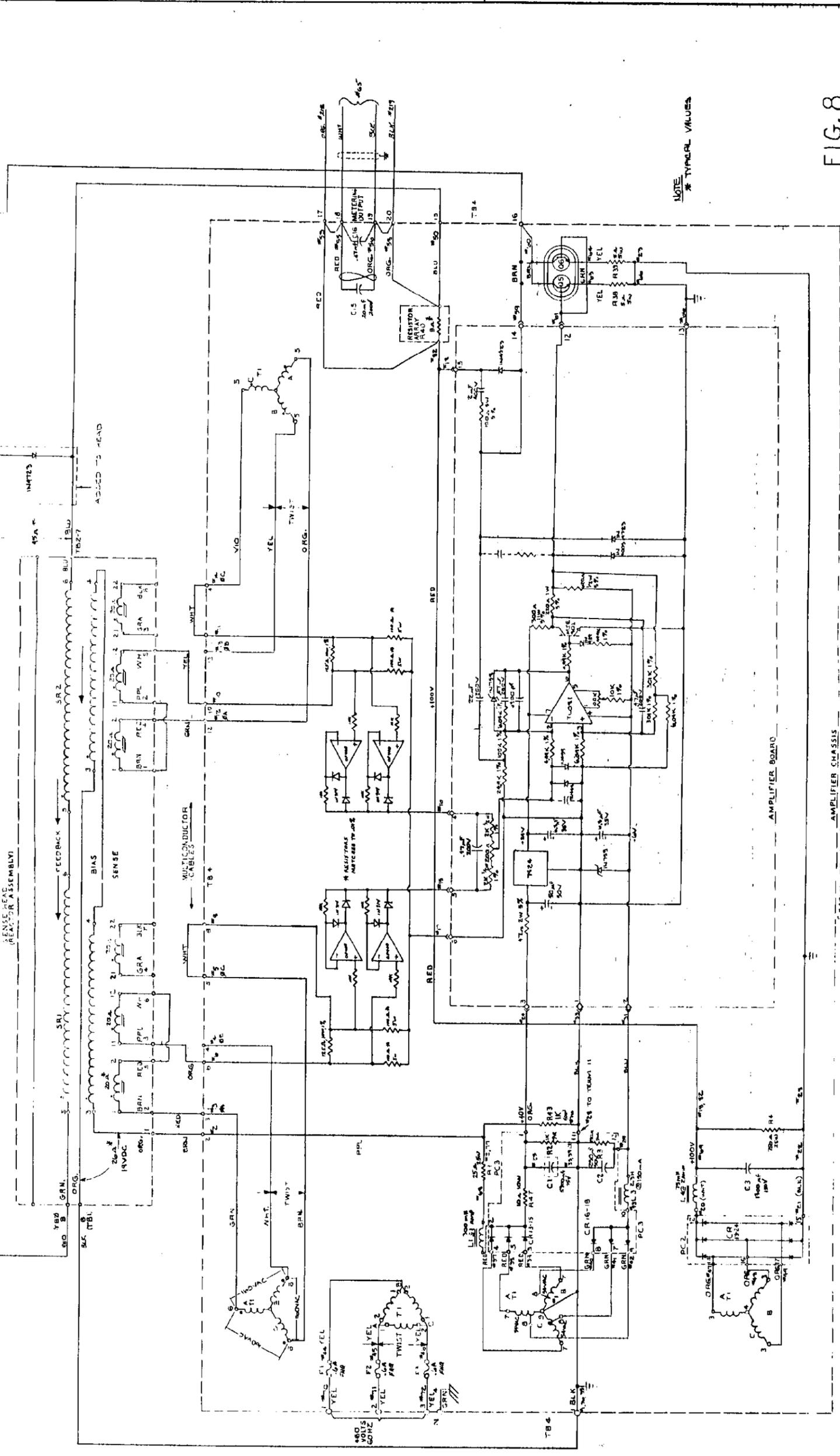
AMPLIFIER BOARD CONNECTIONS

BOARD NO	1	2	3	4	5	6	7	8	9	10	11	12	13
WIRE NO	33	31	28	25	15	10	10	10	10	10	10	10	10

TRANSDUCER AMPLIFIER BOARD TEST PROCEDURE (IN SUPPLY)

AC ON, POWER SUPPLY ON, OFF
READ THE VOLTAGE BETWEEN TERM #12 AND #13
OF AMPLIFIER BOARD, ADJUST 200A BALANCE
POT. SO THAT VOLTAGE IS SLIGHTLY
POSITIVE (25V) WITH LOAD ON 200A POT.
SO THAT CURRENT IS SLIGHTLY NEGATIVE
TO 25-30 VOLTS.

REV	DESCRIPTION	DATE	BY
A	TYPICAL VALUES ADDED	6/4/54	GM
B	REVISED	8/2/54	GM
C	REVISED	11/2/54	GM
D	REVISED	1/15/55	GM
E	REVISED	1/15/55	GM



NOTE: * TYPICAL VALUES

FIG. 8

REV	DESCRIPTION	DATE	BY
1	ISSUED	1/15/55	GM
2	REVISED	1/15/55	GM
3	REVISED	1/15/55	GM
4	REVISED	1/15/55	GM
5	REVISED	1/15/55	GM
6	REVISED	1/15/55	GM
7	REVISED	1/15/55	GM
8	REVISED	1/15/55	GM
9	REVISED	1/15/55	GM
10	REVISED	1/15/55	GM

REF. DATA TRANSMIT 34-536

05,06 - 243442 (PREPARED REPLACEMENTS 2N2624 & 2N5760)

AMPLIFIER CHASSIS
EARLY VERSION CHASSIS MAY HAVE SOME DIFFERENT WIRE NUMBERS

AMPLIFIER BOARD CONNECTIONS
BOARD NO. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100
WIRE NO. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100

TRANSDUCER AMPLIFIER BOARD TEST PROCEDURE (IN SUPPLY)
AC OR POWER SUPPLY DC OFF
READ THE VOLTAGE BETWEEN TERM. #12 AND #11
IF AMPLIFIER BOARD ADJUST 200A BALANCE
POT. SO THAT TERM. #12 DOES SLIGHTLY
POSITIVE (45V) THEN BACK UP 200A POT.
SO THAT TERM. #12 SLOWLY DRIFTS NEGATIVE
TO 20-30 VOLTS.

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
EXPERIMENTAL AREAS, DEPT.
TRANSREX 3000KW. POWER SUPPLY
TRANSDUCER HEAD CONTROL
3000 AMP. TRANSDUCER HEAD
SCHEMATIC DIAGRAM
FIG. 8
2930-EE-31575
E