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NEW FIRING CIRCUITS FOR TRANSREX POWER SUPPLIES

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INTRODUCTION

In applications where firing circuit balance is critical, the original firing circuits in Transrex 0.5 and 0.25 MW power supplies at Fermilab do not perform adequately. The firing circuits introduce substantial sub-harmonic ripple at some, if not most, power supply output levels. Other disadvantages of the circuits include the necessity for frequent tuning and the fact that the individual firing circuits are not truly independent of each other. As the output of a power supply is slowly changed, sudden steps in the firing angle of one or more of the circuits in the supply can be observed. This makes sub-harmonic ripple reduction by voltage feedback techniques more difficult with these circuits.

To improve the power supply problems which have been described, a new set of firing circuits has been designed to replace the original circuits. The requirements for the new circuits included the following: 1) improved power supply performance, 2) no tuning or adjustments to be made at any time, 3) interchangeable with the original circuits to the point where no power supply rewiring is necessary, 4) auxiliary power supply requirements of the new circuits to be compatible with the capability of the existing Transrex auxiliary power supplies, 5) the analog control signal range to the new firing circuits should be essentially the same as with the original firing circuits, and 6) the firing circuits should not be frequency limited. In achieving the above requirements the approach taken was to use the existing 12 phase reference transformer (which was measured and found to be accurate to $\pm$ 0.5°) and package the new firing circuits for a power supply in four single-width NIM modules, each containing three firing circuits, as was done with the original circuits.

In the following pages the new firing circuits are described and it is shown that the firing circuits substantially improve the performance of a 0.5 MW Transrex power supply operating over a wide output range.

NEW FIRING CIRCUIT DESCRIPTION

A complete block diagram of the 12 new firing circuits for a Transrex power supply is shown in Fig. 1. To understand operation of the firing circuit system consider only the circuit to fire SCR 1. The $\phi 1$ AC reference signal at the input is derived from the 12 phase reference transformer. A precision passive filter is used to filter the AC reference and remove the effect of line harmonics on the performance of the firing circuits. The filter shifts the AC reference signal by -20° $\pm$ 0.2°. A zero crossing circuit converts the filtered reference to a square wave which controls a precision ramp generator. The ramp generator is an operational amplifier integrator with precision passive components and a CMOS switch across the integrating capacitor. When the zero crossing circuit output is high, the CMOS switch is open and a very linear ramp from approximately 0V to 12V is generated. The integrator in simplified form is also shown in

Fig. 1. Each firing circuit module has its own negative DC reference for the integrators. However, by tying the references together with front panel BNC cables, a common negative reference is provided to all four firing circuit modules, insuring that no ramp slope errors are caused by slightly different reference voltages. The output of the ramp generator is compared to the firing circuit control input signal. When the ramp signal exceeds the control signal, a high level signal is generated which triggers a one-shot circuit with a 0.7 msec output pulse. The one-shot drives a darlington transistor which drives a Transrex hardfire SCR gate circuit which generates the appropriate pulse to the gate of SCR1 to turn that SCR on. The above described sequence takes place for all 12 firing circuits and SCR's; the only difference is that there is a 30° phase shift between the input AC reference signals to each of the firing circuits. Typical waveforms for one firing circuit is shown in Fig. 2.

A few words should be said about the selection of components in the new firing circuits shown in Fig. 3. The critical parts in the new firing circuits have been selected to minimize the error in the theoretical firing angle. The errors are greatest at low power supply output levels (when firing near the end of the ramp) and least near maximum output. The input filter uses $\pm$ 0.5% components which results in a worst case phase shift error of $\pm$ 1% of -20° or $\pm$ 0.2°. The CMOS switches choosen have a low R_{on} to make negligible the variations in voltage across the switches when they are on and a high surge current capability to discharge the integrating capacitor. A $\pm$ 0.1% resistor and a $\pm$ 0.5% capacitor are used with the integrator circuits to keep the maximum error from these parts to

±1.08°. Offset voltage and bias current can also contribute to timing errors. An offset voltage tolerance of ± 5 mv can cause a ± 12.5 μs or ± 0.27° firing error and a 500 nA bias current can cause about the same error. The op amp chosen has a 2mv max V_{OS} and a 75 nA max I_{bias} resulting in a maximum firing angle error of ± 0.15°. The worst case error for all conditions is sum of the above errors or ± 1.43°. Under normal circumstances some of the errors would tend to cancel and the firing angle accuracy is probably ± 1° or better. Thus when testing these circuits, if a common AC reference is fed to all the firing circuits, the maximum difference seen between the pulses at the one-shot output should be less than ± 1.4° or ± 64 μsec. It should further be noted that all critical components have low temperature coefficients and the above tolerances should not change appreciably over reasonable temperature excursions.

Smaller firing angle errors can be achieved by using even closer tolerance components than specified herein. However, the greater expense does not seem warrented. Firing angle errors on the order of ± 1° should be acceptable up to the point where one becomes concerned about the 720 HZ ripple in the load. Furthermore, beyond this accuracy level, a better approach is to use negative feedback techniques to remove any remaining sub-harmonic ripple. This will be discussed in a later Technical Memo.

FIRING CIRCUIT PERFORMANCE

Several tests have been run to compare the performance of the new firing circuits to the original Transrex firing circuits. Fig. 4 shows the results of one test run on the Meson Lab 6SASAI power supply with a four bend magnet load. The Transrex circuits were tuned to provide a balanced output at 60VDC. Then pictures of magnet field ripple and power supply output voltage were taken at 10, 20, 40, 60, 80, and 100VDC as shown in Figure 4. The worst sub-harmonic ripple in the load over the power supply operating range was found to be about 10 Gauss peak-to-peak at 60 Hz. Running the same test with the new firing circuits resulted in a maximum sub-harmonic ripple of about 1 Gauss peak-to-peak as also shown in Figure 4 -- a substantial improvement.

One point which was checked was whether simply adding a filter, with a 20° phase shift, to the input of the Transrex firing circuits would improve the balance of the Transrex circuits. The test described above was run again with filtered-input Transrex circuits and very little if any improvement was noticed. Nevertheless, it is felt that the filters are necessary to remove harmonics and voltage notches on the incoming AC reference lines. The author has observed 12% voltage notches and even multiple zero crossings on the unfiltered reference lines.

CONCLUSION

A set of new firing circuits for Transrex power supplies has been described both in terms of their operation and performance. It should be pointed out that while other types of firing circuit schemes can be used with Transrex supplies, the approach presented here is direct and satisfies all the requirements which were outlined. On the other hand, this approach may not be the best for other applications. One change which surely should be considered in other applications is replacing the 12 ϕ transformer (which is quite costly) with a phase locked loop 12 ϕ generator.

The printed circuit artwork and front panel artwork and silk-screens have been made by the Research Services Electronic Development Group and are available for use by other Fermilab groups wishing to improve their Transrex supplies. The parts cost, including the printed circuit board is about $80 per firing circuit module, based on about a 30 module production run.

As a final remark, the main advantages of the new firing circuits are again noted: First, the new circuits provide a substantial improvement in power supply balance over a very wide power supply range. Second, the new circuits require no tuning and in fact require no adjustments at any time.

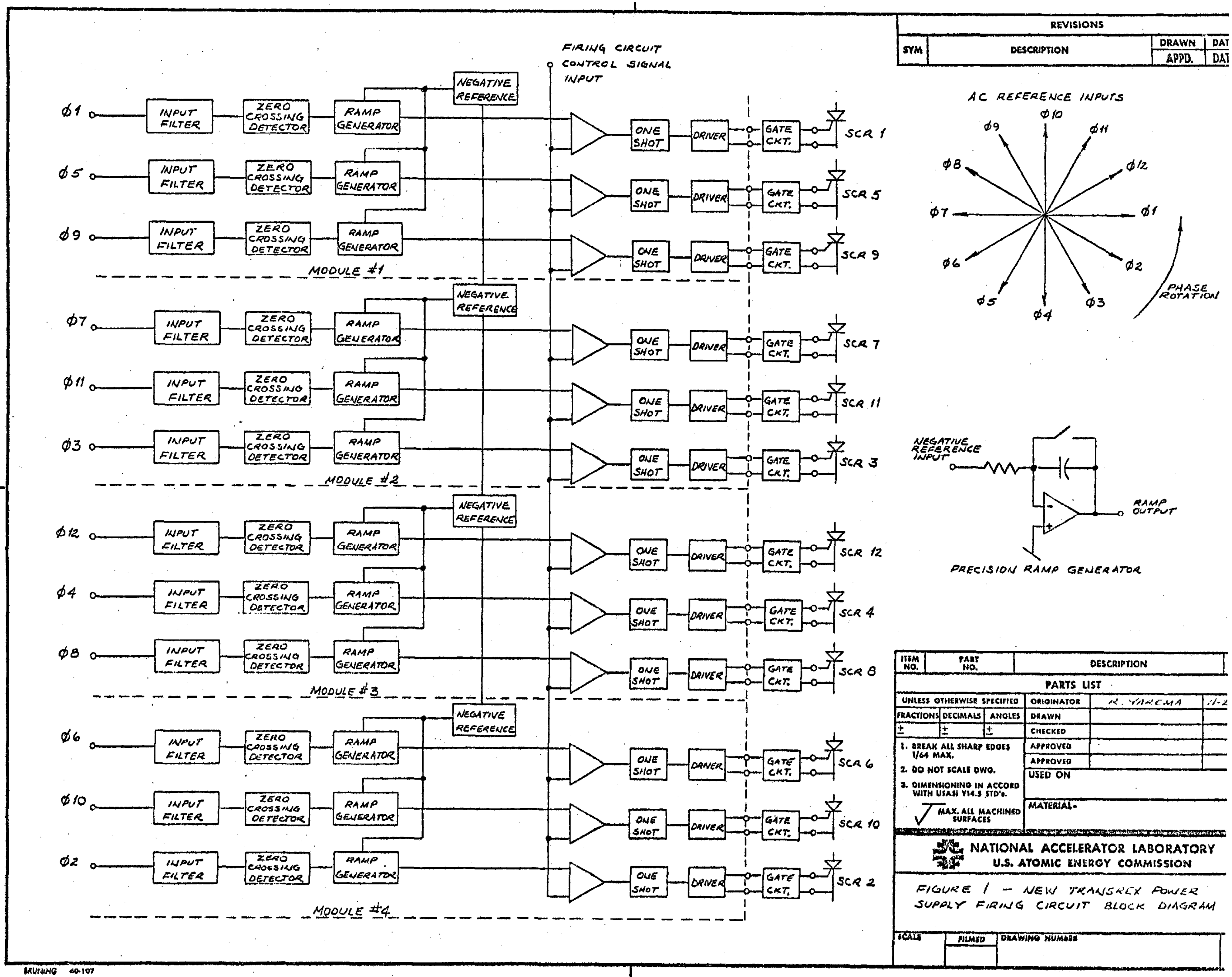


FIGURE 1 – NEW TRANSREX POWER SUPPLY FIRING CIRCUIT BLOCK DIAGRAM

TM-755

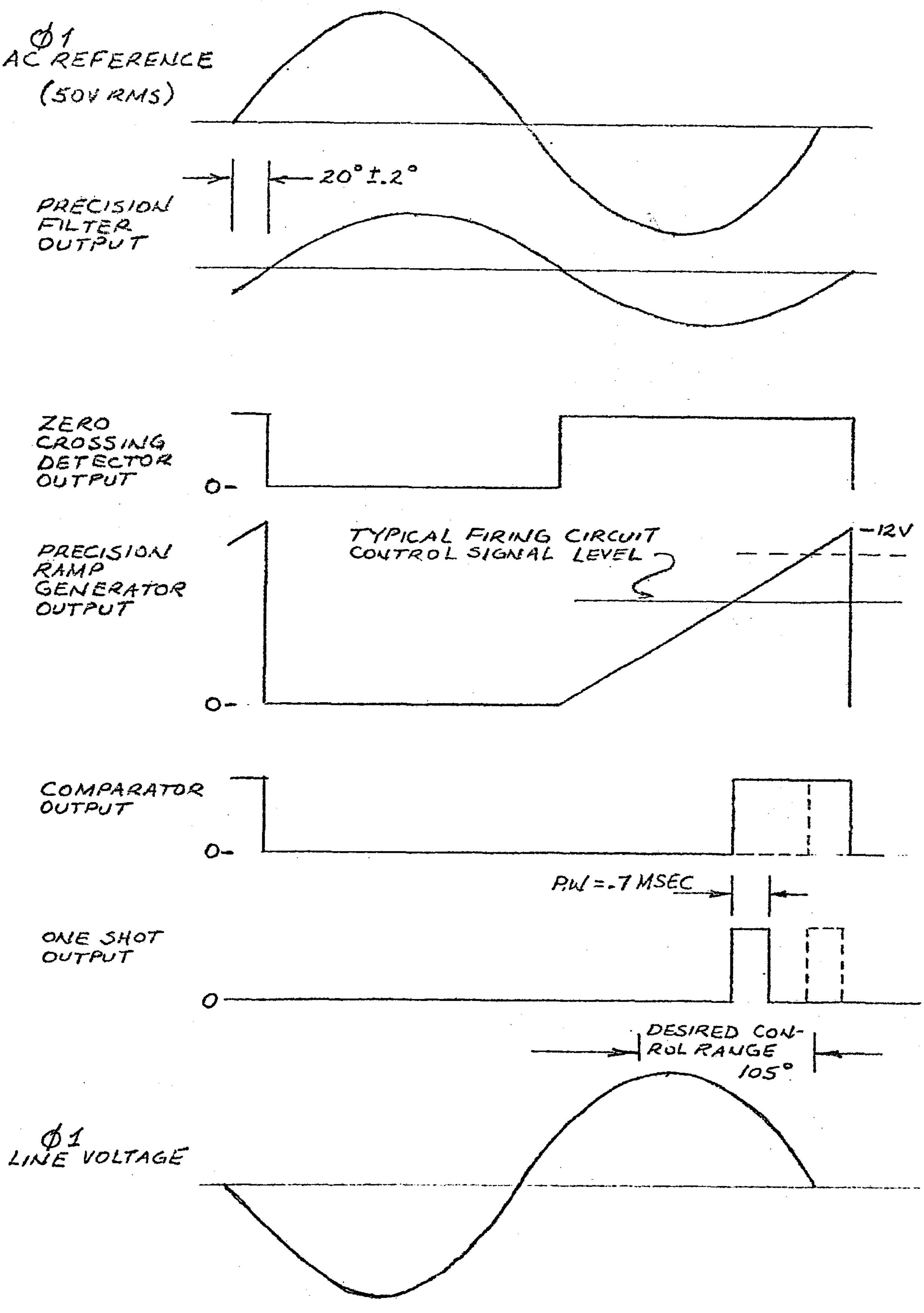
ENGINEERING NOTE

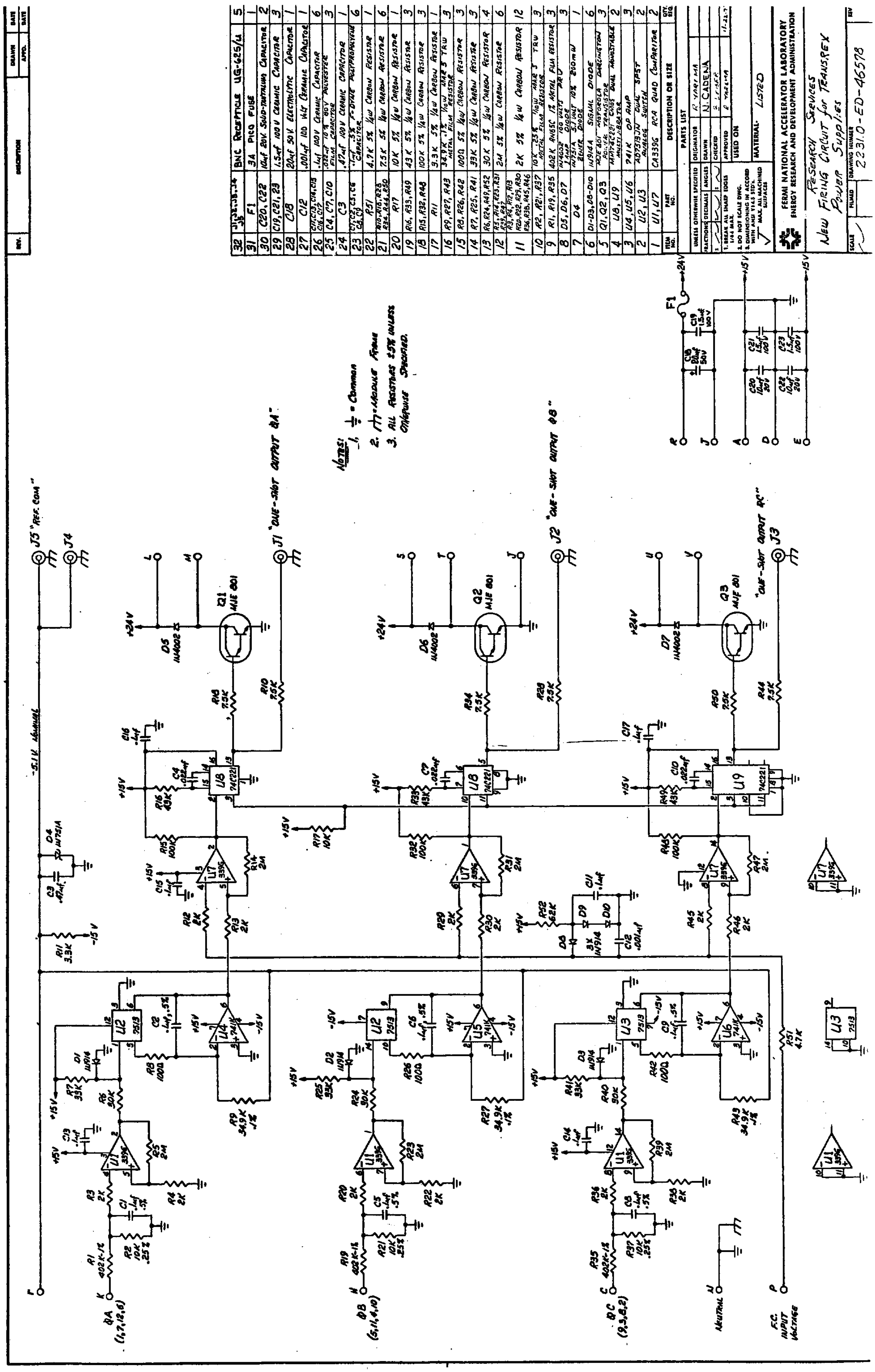
SUBJECT: FIGURE 2 - NEW TRANSREX FIRING CIRCUIT TYPICAL WAVEFORMS

NAME: R. YAREMA

DATE: 11-4-77

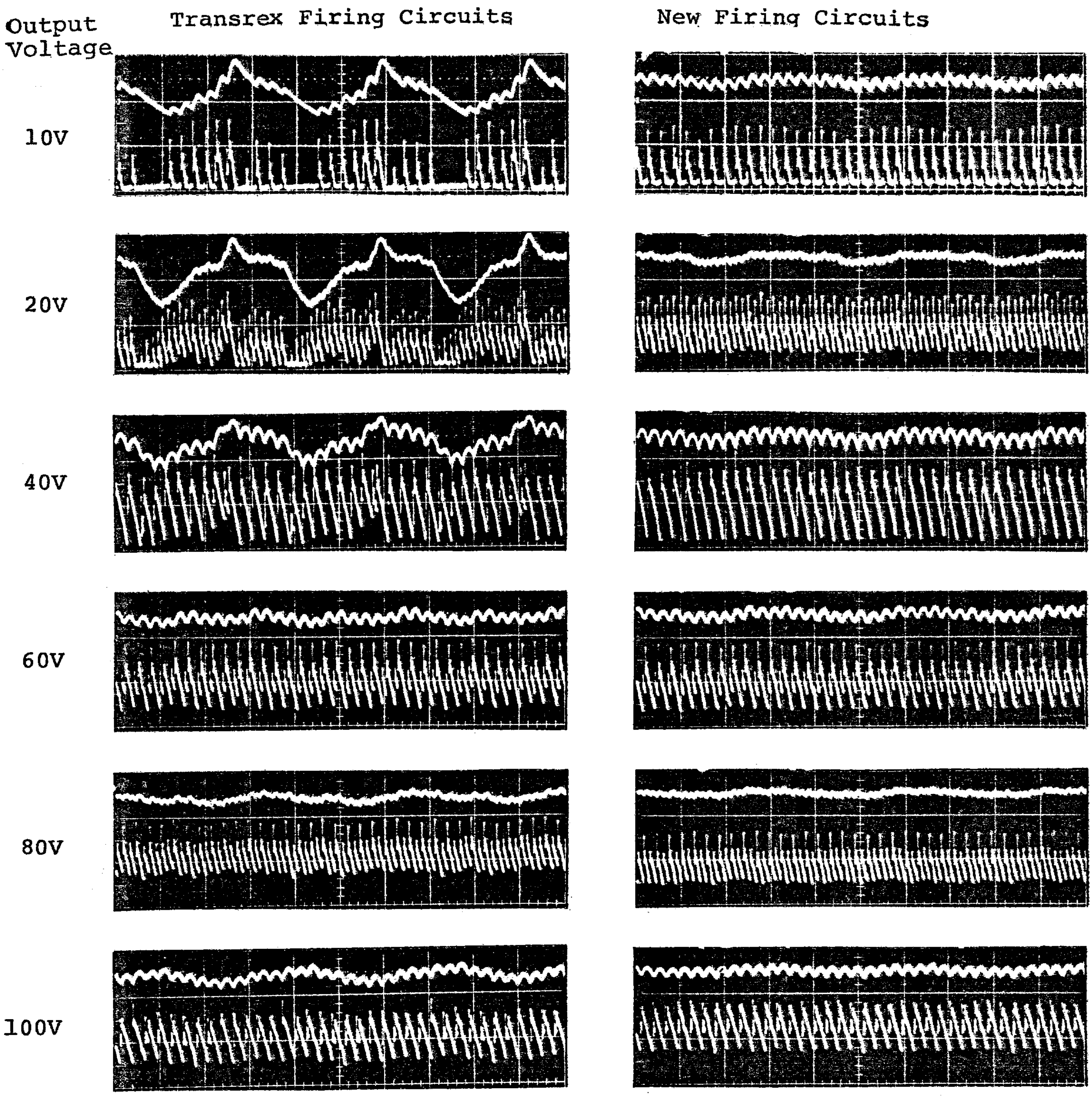
REVISION DATE





PARTS LIST

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
32	J1,J2,J3,J4,J5	BNC RECEPTICLE UG-625/U	5
31	F1	3A PICO FUSE	1
30	C20, C22	10uf 20V SOLID-TANTALUM CAPACITOR	2
29	C19, C21, 23	1.5uf 100V CERAMIC CAPACITOR	3
28	C18	20uf 50V ELECTROLYTIC CAPACITOR	1
27	C12	.001uf 100 Volt CERAMIC CAPACITOR	1
26	C11,C13,C14,C15,C16,C17	.1uf 100V CERAMIC CAPACITOR	6
25	C4, C7, C10	.022uf 10% 80V POLYESTER FILM CAPACITOR	3
24	C3	.47uf 100V CERAMIC CAPACITOR	1
23	C1,C2,C5,C6,C8,C9	.1uf .5% F-DYNE POLYPROPYLENE CAPACITOR	6
22	R51	4.7K 5% 1/4W CARBON RESISTOR	1
21	R10,R18,R28,R34,R44,R50	7.5K 5% 1/4W CARBON RESISTOR	6
20	R17	10K 5% 1/4W CARBON RESISTOR	1
19	R16, R33, R49	43K 5% 1/4W CARBON RESISTOR	3
18	R15, R32, R48	100K 5% 1/4W CARBON RESISTOR	3
17	R11	3.3K 5% 1/4W CARBON RESISTOR	1
16	R9, R27, R43	34.9K .1% 1/10W MAR 5 TRW METAL FILM RESISTOR	3
15	R8, R26, R42	100Ω 5% 1/4W CARBON RESISTOR	3
14	R7, R25, R41	33K 5% 1/4W CARBON RESISTOR	3
13	R6,R24,R40,R52	30K 5% 1/4W CARBON RESISTOR	4
12	R5,R14,R23,R31,R39,R47	2M 5% 1/4W CARBON RESISTOR	6
11	R3,R4,R12,R13,R20,R22,R29,R30,R36,R38,R45,R46	2K 5% 1/4W CARBON RESISTOR	12
10	R2, R21, R37	10K .25% 1/10W MAR 5 TRW METAL FILM RESISTOR	3
9	R1, R19, R35	402K RN65C 1% METAL FILM RESISTOR	3
8	D5, D6, D7	1N4002 100 VOLTS PRV 1 AMP DIODE	3
7	D4	1N751A 5.1 VOLT 10% 200mW ZENER DIODE	1
6	D1-D3, D8-D10	1N914A SIGNAL DIODE	6
5	Q1, Q2, Q3	MJE 801 MOTOROLA DARLINGTON POWER TRANSISTOR	3
4	U8, U9	MM74C221 CMOS DUAL MONOSTABLE MULTIVIBRATOR	2
3	U4, U5, U6	741K OP AMP	3
2	U2, U3	AD7513JN DUAL SPST ANALOG SWITCH	2
1	U1, U7	CA339G RCA QUAD COMPARITOR	2



Notes:
1. Top trace all photos - Field ripple - 6G/Div.
2. Bottom trace all photos - Output voltage ripple - 50V/Div.
3. Time scale all photos - 5 msec/Div.
4. Photos taken on 6SASAI power supply.
5. Transrex firing circuits balanced at 60 VDC.

Figure 4 - Comparison of new firing circuit to Transrex circuit performance at different output voltages.