RCA
Solid State
Division

Power Transistors

Application Note
AN-6145

A Test Set for Nondestructive Safe-Area Measurements Under High-Voltage, High-Current Conditions

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Techniques for determining the safe operating area of power transistors at moderate voltages, currents, and dc conditions have been available for some time. Circuitry for accomplishing this task nondestructively has also been available. A more difficult task has been to test devices nondestructively at high voltage/ampere products under pulsed and repetitive-pulsed conditions which more closely simulate the electrical environment in an actual equipment. The usual rnethod has been to use a statisticaliy significant sample and to test the devices to destruction to produce a rating curve. Then, by comparing the point of failure of the sampled units to the results of the dc tests, the pulse rating of the units is correlated • to the dc tests. Because this procedure is obviously rather imprecise, users needing devices with high levels of reliability frequently require that devices be 100-per-cent tested to specific voltage, current, time, and duty-cycle conditions. This testing may be performed in a "sudden death" circuit where inadequate units are destroyed. However, this Situation is unsatisfactory,both analytically and economicaily.

This Note describes a test equipment designed to perform the tests described above, for the most part, nondestructively. A photograph of the interior of the equipment and the control panel is shown in Fig. 1; an enlargement of this photograph is shown in Fig. 9, page 7. The equipment has a current range of 200 mitliamperes to 20 amperes, a voltage range of 10 volts to 350 volts, a pulse width of 10 microseconds to two seconds, and a pulse repetition rate limited only by external equipment restrictions.

System Philosophy

As shown in the block diagram of Fig. 2, the transistor under test, TUT, is connected in a common-base configuration modified by a series base diode. *VCC* is applied,and the TUT emitter is then driven by a constant-current source which is

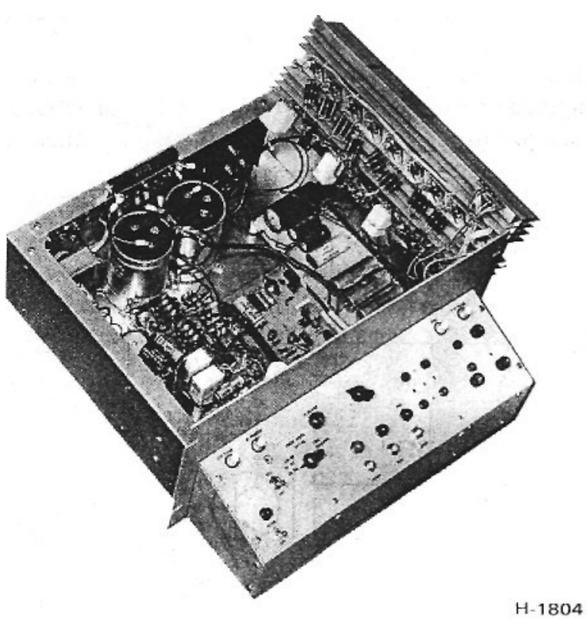

Fig. 1— Interior and control panel of test equipment.
(See Fig. 9, page 7, for enlarged photograph.!

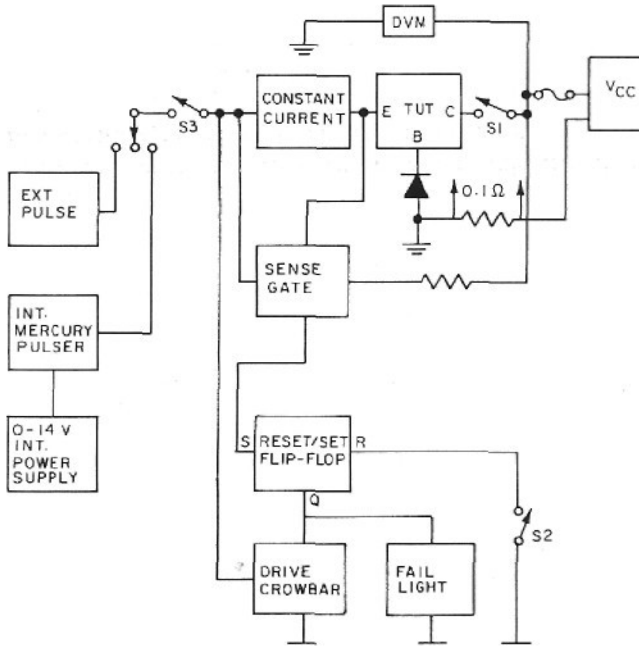

Fig. 2- Block diagram of test equipment.

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driven, in turn, by a large-signal pulse generator, such as an HP214A, or a meicury-wetted relay pulser. Voltage at the TUT emitter is monitored by a sensing network and a high-speed, bistable flip-flop. The coilector of the TUT is tied to a Vcc supply appropriately filtered for high-current/fast-rise-time loads.

A device failure is observed as a sudden increase in voltage at the emitter of the TUT, which normally holds at a voltage, below ground, equivalent to twice the drop across the series base diode. A +3-volt, 50-nanosecond change is sufficient to switch the State of the flip-flop. The flip-flop then turns on a crowbar circuit which shorts out the voltage drive to the emitter current source. When the emitter current becomes less than the coilector current, the series base diode becomes back-biased and opens the base-collector loop. The total shutdown procedure takes less than 0.5 microseconds.

System Design

The System is made up of seven "building blocks":

1. The Vcc power supply and filters
2. The VEE power supply and filters
3. The pulse-timing block
4. The emitter-current-source block
5. The sense-gate, failure-detection, crowbar, and fail-light block
6. The TUT socketing and metering block
7. The relay-sequencing block

These circuits are shown interconnected in the System schematic diagram of Fig. 3. Fig. 4 shows the schematic diagram for the zero-to-20-volt drive power supply, VBB-

The Vcc supply must have adequate current capability to cover the intended spectrum of pulse widths and duty cycles. Its voltage regulation must be such that any spiking caused by stepped changes in load can be absorbed by reasonable filtering on the TUT test chassis. The filtering arrangement shown in Fig. 3 is adequate for the design current of 20 amperes. Whenever fast rise and fall times are a factor, Mylar[1] or the best quality paper capacitors must be used to Supplement the electrolytic capacitors. The filter capacitors must be chosen to act in the same manner as a storage battery for a length of time sufficient for the Vcc supply to recover from the load change.

The same comments apply to the -14-volt VEE supply, which must not only provide the power for the

[1] Trademark of E. I. duPont de Nemours & Co., Inc.

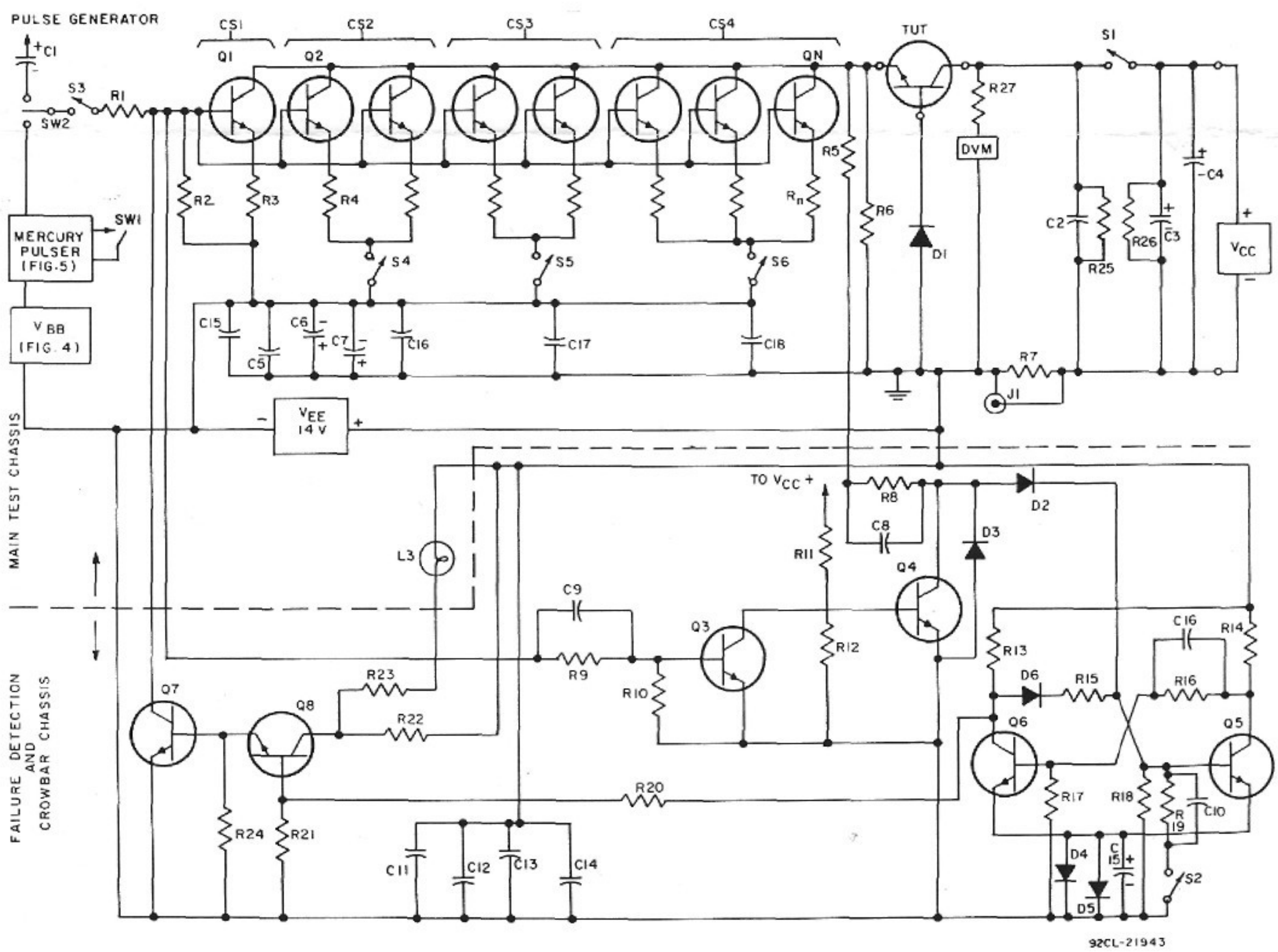

Fig. 3— Schematic diagram of main test Chassis (parts list on pages 6 and 8).

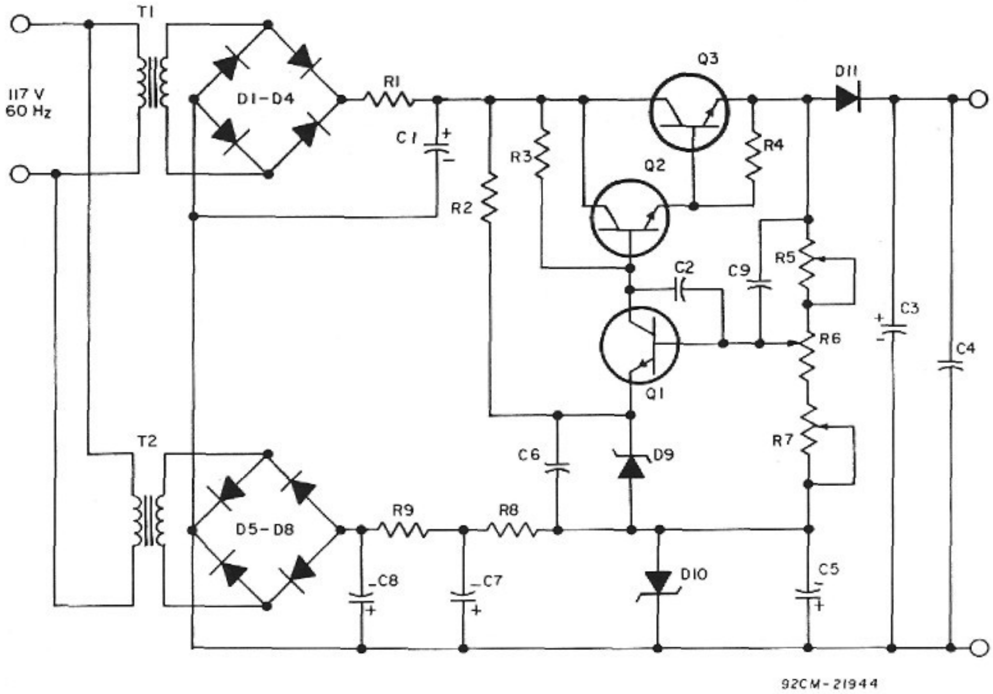

Fig. 4- Schematic diagram of zero-to-20-votl, drive power-supply, VBB (parts list on page 8).

constant-current supply, but must also operate the relay System, the pane) lights, and the failure-detection circuitry.

The pulse-timing block, shown in detail in Fig. 5, consists of an HP214A pulse generator, a mercury-wetted-relay pulse timer, a small zero-to-20-volt power supply, and a selector switch. The HP generator is used for single or multiple pulse testing where the pulse widths are 10 milliseconds or less.

To accomodate the design curient of 20 amperes, the current source consists of eight 2N5240 transistors, *Q1* through Qn with bases and collectors in parallel and with the emitters connected through 4-ohm ballasting resistors R2 through RN. The 2N5240 was chosen for its high voltage breakdown, fast fall time, and good current-handltng characteristics.

To achieve the wide current range desired, a current-source selector switch is used which, by means of relays, either adds or subtracts current-source drivers to fit the requirements of the desired test. Fig. 6 shows this arrangernent. Each driver can provide 2.5 amperes to the load. Hence, referring to the top of the circuit diagram of Fig. 3 and to Fig. 6:

For 0.2 A to 2.5 A use CSl only
For 2.0 A to 7.5 A use CS1 and CS2
For 6.0A to 12.5 A use CS1, CS2, and CS3
For 8 A to 20 A use CS 1, CS2, CS3, and CS4

The sensing circuit monitors the voltage at the emitter of the TUT. The existence of a positive-going pulse of 3 volts for a minimum of 50 nanoseconds is sufficient to trip the flip-flop (Q5 and Q6). The sense line must be gated so that the emitter of the TUT is sensed only during the power pulse. The gate is made up of Q3 and Q4, and is actuated through an RC combination (R9, C9) from the base of the current source. The gate is necessary to prevent turn-off transients from falsely firing the flip-flop. The turn-off transient comes from the sweep-out current of the disconnect diode, D1, and the stored Charge in the TUT. The sense-line coupling capacitor, *C8,* is paralleled by a 20,000-ohm bleeder resistor, R8, which assures that the 0.05-microfarad capacitor, C8, is discharged between test periods; R8 also provides direct coupling to the flip-flop if the failure of the TUT is of a gradual nature, in which case the 0.05-capacitor, C8, would be insufficient. The flip-flop drives the crowbar transistor, Q7, which, when triggered, shorts out the current-source drive to the -14-volt supply, thus shutting off the power to the TUT emitter. The series-base diode, D1, disconnects the base of the TUT within 100 nanoseconds after the emitter current of the TUT falls below its collector current.

The previous paragraph states that power is shut off to the EMITTER of the TUT. The series base diode effects the disconnection of the collector power to the TUT. The selection of the proper diode for this function is critical. It must have a reverse recovery time that is comparable to the shutdown time of the flip-flop "crowbar" current-source combination. However, it must have a breakdown voltage greater than the highest-rated test voltage of the equipment. R7 is a 0.1-ohm, non-inductive, precision resistor used in the observation and setting of the current in the collector loop.

The TUT socketing block is arranged to accommodate, on banana plugs spaced three-quarters of an inch apart, both the six-pin, Kelvin, heavy-duty sockets used for production work and the Tektronix[1] sockets. This arrangement offers some interesting possibilities, such as testing of the $I_{s/b}$ capability of paired devices. The banana plugs also provide external access for the application of base-emitter terminations, such as Rbe

[1]Trademark of Tektronix, Inc.

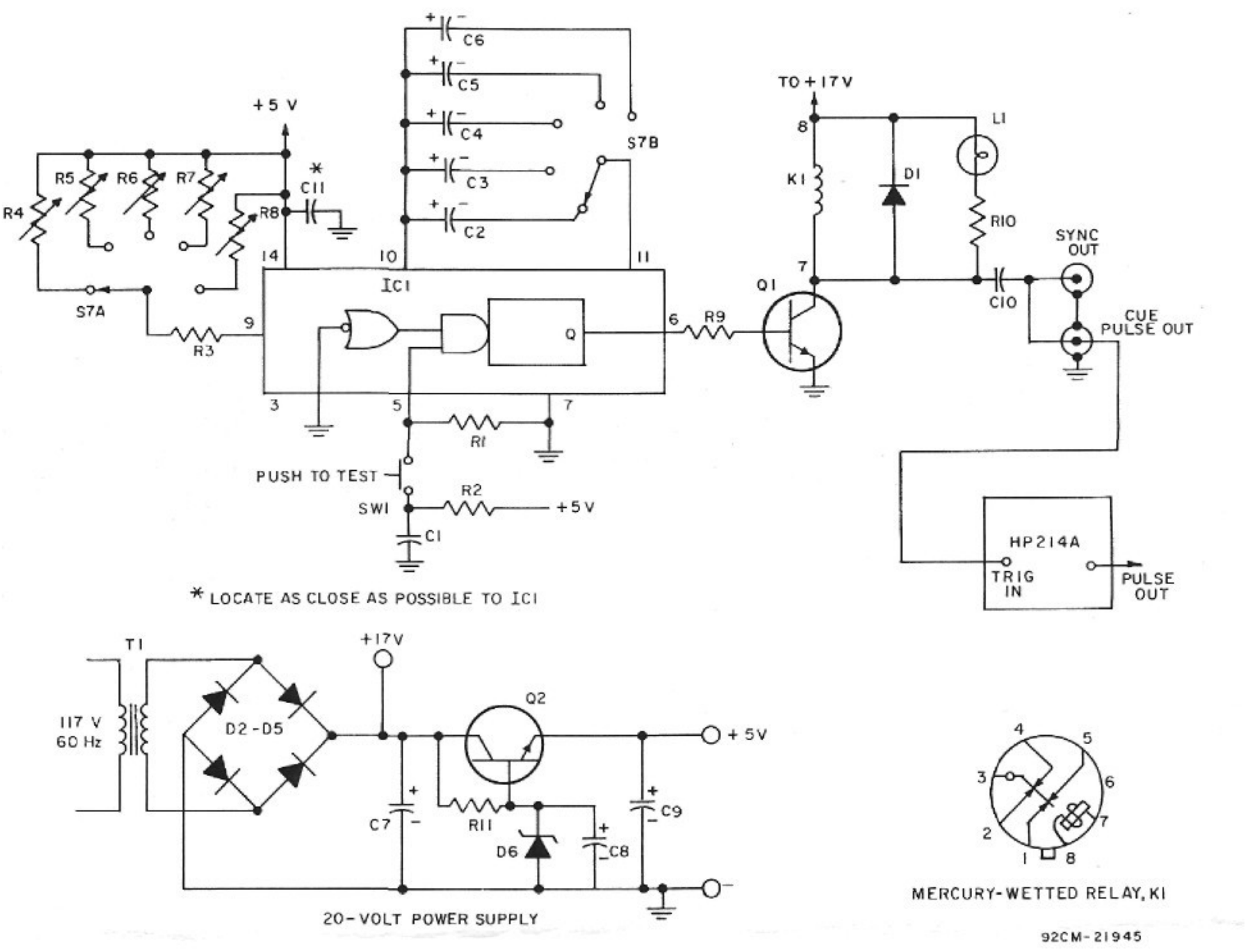

Fig. 5—Schematic diagram of pulse-timing-block components (parts /ist on page 81.

and VEB. R5 and *R6* are connected directly to the emitter terminals, and D1 is connected directly to the base terminal.

The sequencing relay circuit, Fig. 7, is arranged so that the sequence of switching events shown betow occurs when the Start button is depressed at the initiation of a test:

1. S1 closes, applies VCC to the TUT, and lights the Start light.
2. S2 closes momentarily and resets the flip-flop.
3. S3 closes and connects the pulse source to the current drivers.

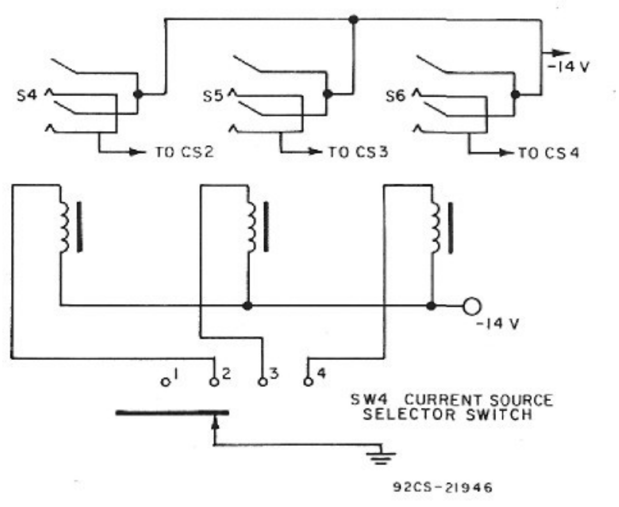

Fig. 6— Relay circuit for currentsource selection.

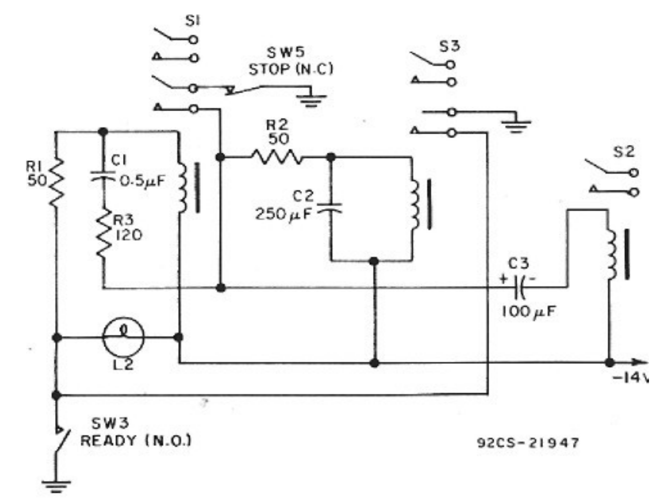

Fig. 7— Sequencing-relay circuit (parts list on page 8).

The sequence at the end of the fest when the Stop button is depressed is as follows:

1. S3 opens and disconnects the pulse drive.
2. S1 opens and removes Vcc, and the Start light goes out.

Construction

Lead dress is not criticat; however, there are some wiring restrictions that must be strictly observed:

1. Low-level signals and high-level Signals must not be carried in the same wires.
   a. The -14 volts for the flip-flop and gates must be carried on a separate bus which joins the -14-volt supply at the RI - RN bussing point.
   b. The common line for the flip-flop and gates must be a separate line and must meet the System common only at the indicated ground point.
   c. The sense line must connect directly to the emitter jack of the TUT socket.
   d. The pulse-gate drive line must connect through a separate wire to the bases of the current source.
   e. The collector of the crowbar transistor, Q7, must connect through its own wire to the bases of the current source.
   f. The disconnect diode, D1, must be connected directly to the base jack of the TUT socket, and its anode return must be carried on a separate wire to the ground bus.
   g. The IE and Ic lines are lengths of RG14 coaxial cable with shields tied to the ground bus at the TUT end.
2. Current-source and protection-circuit filtering functions for the -14-volt supply must be separated and located on appropriate sub-assemblies.
3. Multiple capacitors are used for two reasons:
   a. To minimize copper losses (IR drops) through leads and foil;
   b. To achieve complete bypassing and regulation regardiess of pulse rise time or duration.
4. Mylar capacitors are used wherever possible because of their higher Q and smaller size.

EXPLANATION OF CONTROLS AND ACCESS CONNECTIONS

Explanation of controls shown in Figs. 1 and 9:

AC On-Off - Operates main contactor to provide power for entire System.

Cue Pulse - Provides trigger pulse to external pulse generator when TEST button is pressed.

Ext.-Int. — Selects either internal mercury-relay timer or external pulse generator.

IC Monitor - Connects to vertical input of monitoring osciltoscope from 0.1-ohm, collector-current sensing resistor.

Mylar are Trademark of E. I. duPont de Nemours & Co., Inc.

Pulse Width - Sets the width of the desired test pulse on the internal timer.

IC Adjust - This control is used only with the internal mercury relay timer. It adjusts the voltage drive to the emitter current source.

Sync. - Provides sync pulse to monitoring oscilloscope,

Ready - Activates the sequencing relays and applies collector voltage to the TUT resets the failure-detection circuit, and connects the pulse drive circuits to the current source.

Test - Activates the internal timer or provides a cue pulse to the external pulse generator

Stop De-energizes the sequencing relays and disconnects the pulse source and the collector voltage.

Ext. Pulse - Receives drive pulse from external pulse generator.

Current Source Selector (Top middle of control panel) - Switches in additional current sources CS2 through CS4.

OPERATION

Operation at DC to 25 Milliseconds

The interconnection of the test equipment with the external units, the pulse generator and oscilloscope, is shown in Fig. 8

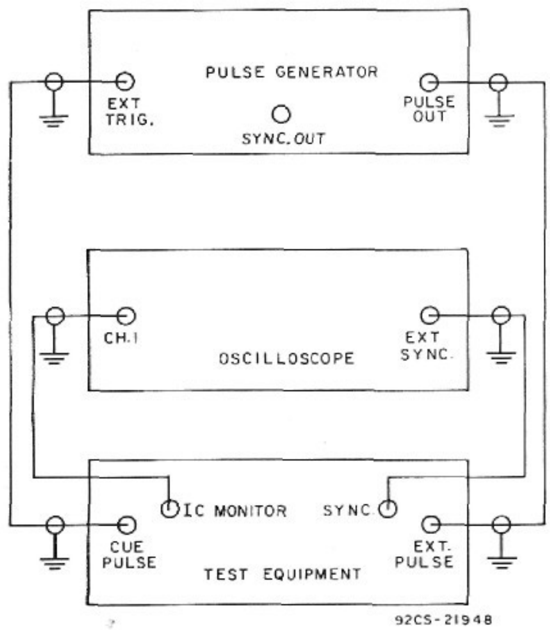

Fig. 8— Test-set interconnections.

The recommended sequence of Operation is as follows:

1. Turn all supplies on.
2. Set Ext. - Int. switch to INT.
3. Set Pulse Width switch to 50 milliseconds.

4. Set Vcc at 10 volts.
5. Set sweep rate on oscilloscope to 10 ms/div/ext/ + sync.
6. Set oscilloscope sensitivity to dc 0.1 V/div.
7. Turn IC Adjust full counter-clockwise.
8. Set Current-Source Selector switch to desired range.
9. lnsert a device into the test socket.
10. Push Ready button;green Start light will flash.
11. Push Test button; yellow test light will flash.
12. Adjust sync controls on oscilloscope to obtain a single trace each time Test button is pushed.
13. Turn IC-Adjust control clockwise to obtain negative vertical deflection indicative of desired test current (in this case, 1 division per ampere); for higher currents, change vertical sensitivity to 0.2 or 0.5 V/div. as needed.
14. Switch Pulse Width to that which is required, Change sweep rate on oscilloscope as well.
15. Set Vcc at desired test voltage.
16. Push Stop button. Remove set-up device.
17. lnsert device to be tested.
18. Push Ready.
19. Push Test; observe current trace on oscilloscope.
20. Push Stop and remove units.
21. If a unit fails the test, the red fail light will turn on.
22. The fail circuit and light will reset the next time the Ready button is pushed.
23. The failure-detection circuits may be checked at any time by switching the current-source switch to the next lower range. This action will produce a false failure Signal which will trip the protection circuit. Be sure to return the switch to its original position after the test.

Operation at 25 Milliseconds and Less

1. Turn all supplies on.
2. Set Ext.-Int. to Ext. This connects the external pulse generator to the test equipment.
3. Set Vcc at 10 volts.
4. Set sweep rate on oscilloscope to range of interest.
5. Set oscilloscope sensitivity to dc 0.1 V/div.
6. Set trigger selector on external generator to ext. Turn pulse amplitude controls to minimum.
7. Set Current-Source Selector switch to desired range.
8. lnsert a device into the test socket.
9. Push Ready button; green start light will flash.
10. Push Test button. Adjust synchronizing controls on oscilloscope to give a Single trace each time Test button is pushed.
11. Adjust pulse-amplitude control on generator to secure a usable vertical deflection while repeatedly pushing Test button. Then adjust Pulse-Width control to obtain desired current.
12. Re-adjust pulse-amplitude control to obtain desired current.
13. Set desired Vcc.
14. Push Stop. Remove set-up device.
15. lnsert device to be tested.
16. Push Ready.
17. Push Test.
18. Push Stop.

The remainder of the procedure is identical to that followed for Operation at dc to 25 milliseconds.

MAIN-TEST-CHASSIS PARTS LIST (Fig. 3)

C1 = 1000 microfarads, 60 volts, pulse-coupling capacitor
C2 = 3 microfarads, 600 volts, paper or Mylar
C3, C4 = 860 microfarads, 450 volts, electrolytic
C5 = 10 microfarads, 200 volts, Mylar
C6, C7 = 2000 microfarads, 50 volts, electrolytic
C15 - C17 = 0.05 microfarad, 200 volts, Mylar
R1 = 10 ohms, 2 watts, carbon
R2 = 100 ohms, 2 watts, carbon
R3, R4 - RN = 4 ohms, 6 watts, clusters of three 12-ohm, 2-watt carbon resistors
R5 = 0.1 kilohm, 1 watt
R6 = 8 kilohms, 1 watt
R7 = 0.1 ohm, non-induktive, 20 watts, with Kelvin connections
R25 = 250 kilohms, 2 watts
R26 = 8 kilohms, 50 watts, wire-wound
R27 = 1 kilohm, 1 watt
Q1, Q2, QN = transistor, type 2N5240
J1 = current-monitoring jack, BNC female
L3 = failure-indicator Lamp, 14 volts, 80 milliamperes
D1 = base-disconnect diode, GEA28D or TRWPD2708
S1 = collector-current relay, 2 Potter and Brumfield KA14DY,paralleled
S2 = flip-flop reset relay. Potter and Brumfield KHP 17D11, 12-volt coil
S3 = pulse-source relay. Potter and Brumfield KHP 17D11, 12-volt coil
S4 - S6 = current-source range relays. Potter and Brumfield KHP 17D11,12-volt coil
SW1 = test switch
SW2 = pulse-source selector switch
SW3 = Ready switch
SW4 = current-source selector switch
Vcc = 0-125 volt, 25-ampere power supply or 0-400 volt, 2-ampere power supply
VEE = 14-volt, 15-ampere power supply
VBB = 9-20-volt, 2-ampere, variable power supply

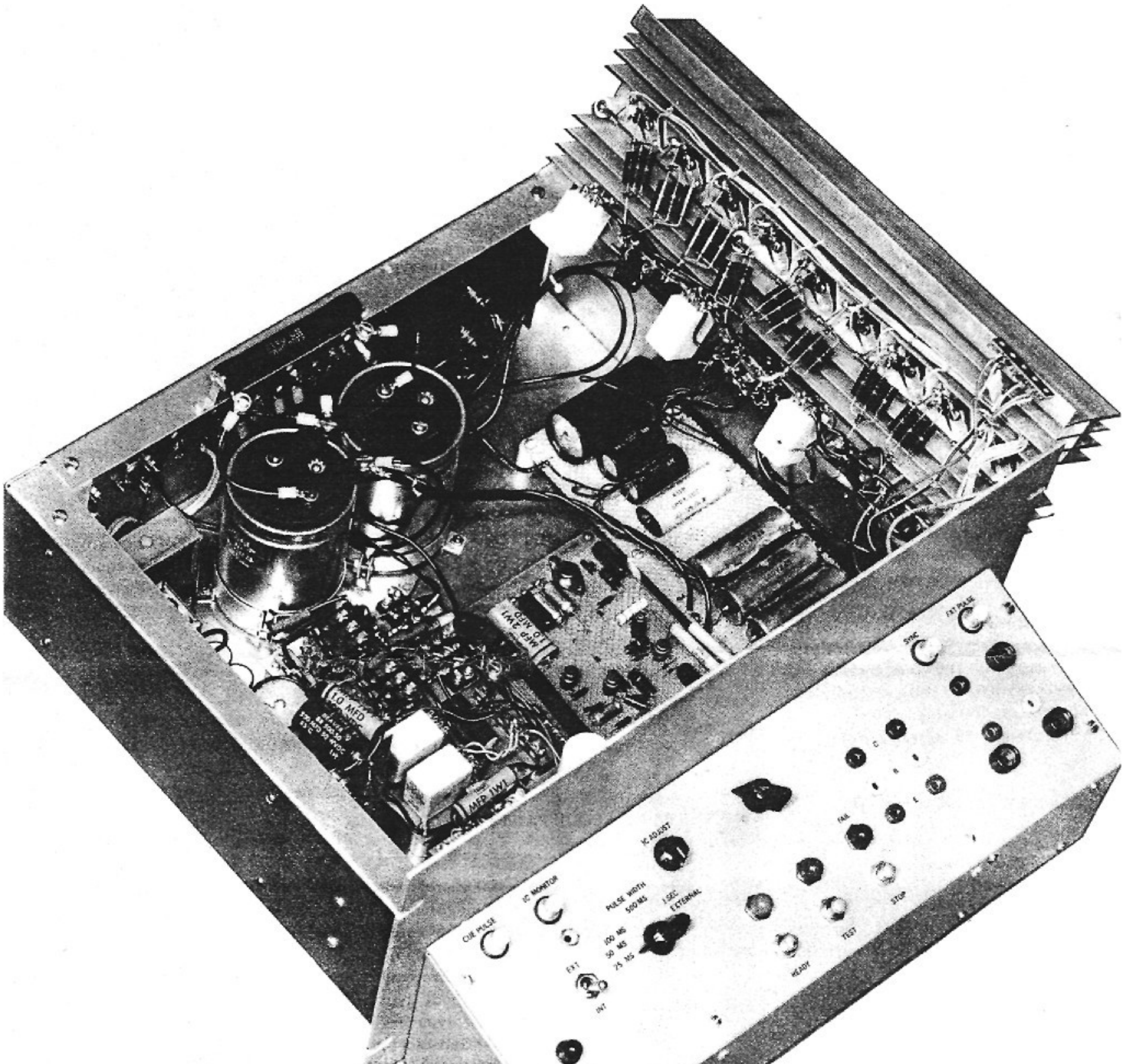

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Fig. I— Inferior and control panel of test equipment.

FAILURE-DETECTION AND CROWBAR-ASSEMBLY PARTS LIST [Fig. 3)

C8 = 0.05 microfarad, 400 volts, Mylar
C9, C10 = 0.005 microfarad, 200 volts, Mylar
C11, C12 = 50 microfarads, 50 volts, electrolytic
C13 = 1 microfarad, 200 volts, Mylar or paper
C14 = 0.1 microfarad, 200 volts, Mylar or paper
C15 = 25 microfarads, 25 volts, electrolytic
C16 = 500 picofarads, 200 volts, ceramic
R8 = 20 kilohms. 1 watt
R9 = 1.5 kilohms, 1/2 watt
R10 = 15 kilohm, 1/2 watt
R11=5 kilohms, 20 watts, (two 10-kilohm, 10-watt, wire-wound, in paralle!}
R12, R14-R16 = 0.5 kilohm, 1 watt
R13 = 0.1 kilohm, 2 watts
R17 = 10 kilohms, 1/2 watt
R18 = 2.5 kilohms, 1/2 watt
R19 = 250 kilohms, 1/2 watt
R20, R21 = 0.1 kilohm, 1 watt
R22 = 73 ohms. (three 220-ohm, 2-watt, in parallell)
R23 = 22 ohms, 2 watts
R24 = 1 kilohm, 1 watt
D2 - D6 = diode, type 1N914A
Q3 = transistor, type 2N3261
Q4 - Q6, Q8 = transistor, type 2N5262
Q7 = transistor type 2N3878

ZERO-to-20 VOLT DRIVE POWER SUPPLY PARTS LIST (Fig. 4)

R1 = two 1.2-ohm, 2-watt, wire-wound resistors in parallel
R2 = 6.8 kilohms, 1/2 watt
R3 = 10 kilohms, 1/2 watt
R4 = 220 ohms, 1/2 watt
R5 = trimpot, 5 kilohms, 1/4 watt
R6 = Potentiometer, 5 kilohms, 2 watts
R7 = trimpot, 5 kilohms, 1/4 watt
R8 = 470 ohms, 1/2 watt
R9 = 220 ohms, 1/2 watt
C1 = 2000 microfarads, 50 volts, electrolytic
C2 = 0.01 microfarad, 100 volts, ceramic
C3 = 500 microfarads, 50 volts, electrolytic
C4 = 1 microfarad, 100 volts, Mylar[1]
C5 = 50 microfarads, 25 volts, electrolytic
C6 = 100 microfarads, 25 volts, electrolytic
C7 = 500 microfarads. 25 volts. electrolytic
C8 = 500 microfarads, 25 volts, electrolytic
C9 = 5 microfarads, 50 volts, electrolytic
D1 - D4 = 6 ampere bridge assembly, Varo VH247 or equivalent
D5 - D8 = 2-ampere bridge assembly, Varo VS247 or equivalent
D9 = zener, 6.8 volts, 1 watt
D10 = zener, 12 volts, 1 watt
D11 = diode, type 1N1206
Q1 = transistor, type 2N2102
Q2 = transistor, type 2N2102
Q3 = transistor, type 2N3772
T1 = transformer: 117-volts primary • 25.2-volt, 2.8-ampere secondary
T2 = transformer: 117-volt primary - 16.6 volt, 0.3-ampere secondary

PULSETIMING-BLOCK PARTS LIST (Fig. *5)*

R1 =820 ohms, 1/2 watt
R2 = 2,2 megohms, 1/2 watt
R3 = 2 kilohms
R4 - R8 = trimpots, 50 kilohms, 1/4 watt; Bourns 200P-1-503 or equivalent
R9 = 100 ohms
R10 = 47 ohms, 1 watt
R11 = 270 ohms, 1/2 watt
C1 = 0.01 microfarad, 80 volts, PACER
C2 = 5 microfarads, 50 volts, tantalum; Mallory CL65BJ050KPE
C3 = 22 microfarads, 25 volts, tantalum; Mallory CL65BG220KPE
C4 = 68 microfarads, 30 volts, tantalum; Mallory CL65BH681 KPE
C5, C6 = 100 microfarads, 25 volts, tantalum; Mallory CL65BG101 KPE
C7 = 100 microfarads, 25 volts, electrolytic
C8 = 10 mierofarads, 25 volts, electrolytic
C9 = 25 microfarads, 25 volts, electrolytic
C10 = 1 microfarad, 100 volts, Mylar
C11 = 0.1 microfarad, 100 volts, ceramic
D1 - D5 = diode, type 1N5395
D6 = zener, type 1N4734A, 5.6 volts, 1 watt
Q1, Q2 = transistor, type 2N5320
IC1 = integrated circuit, type SN74121N ISignetics)
K1 = mercury relay. Potter and Brumfield JM11211 or equivalent
L1 = lamp, No. 382; 14 volts, 0.08 amperes
S7A, S7B = wafer Switches, 2-pole, 5-position (matching contacts tied together to make each wafer a single-pole 5-posftion switch)

SEQUENCING RELAY-CIRCUIT PARTS LIST (Fig. 7)

S1 = collector power relay
S2 = flip-flop reset relay — See Main Test Chassis parts list, page 6
S3 = current-source drive relay
SW3 = Ready switch, normally open, push button
SW5 = Stop switch, normally closed, push button
R1, R2 = 50 ohms, 2 watts
R3 = 120 ohms, 1 watt
C1 = 0.5 microfarad, 200 volts
C2 = 250 microfarads, 50 volts
C3 = 100 microfarads, 50 volts
L2 - ready lamp, 80 milliamperes, 14 volts