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RADIATION EFFECTS ON MICROELECTRONIC CIRCUITS (SEMICONDUCTOR)

FIRST QUARTERLY REPORT

By

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NOVEMBER 1965

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For

U. S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N. J.

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SUMMARY

The objective of this program is to determine and analyze the effects of high intensity nuclear radiation (both transient and permanent) on semiconductor integrated microelectronic circuits in order to minimize or eliminate any intolerable effects in circuits designed for reliability in specified nuclear environments. This program is a part of the DASA Nuclear Weapons Effects Research Program, and as such is intended to provide an understanding of the effects of nuclear weapon radiation environments on military electronic systems using this type of microelectronic circuitry and thus to furnish engineering guidelines by which these systems may be hardened to these effects.

The program is planned to be conducted in three phases:

Phase 1: Evaluation of radiation effects in available circuits.

Phase 2: Diagnosis of these radiation effects by special tests.

Phase 3: Investigation of remedial action for reducing these effects.

The first quarter of the program has been devoted entirely to the preparation of devices and instrumentation for the radiation tests. The circuits have been procured and subjected to a thorough pre-irradiation test in the laboratory. This report describes the circuits chosen for study and the measurements made in the laboratory bench tests.

All of the instrumentation to be used in this program is described in detail in this report. This includes the instrumentation for (1) the laboratory bench tests, (2) the Linac transient radiation effects tests, and (3) the pulsed reactor permanent damage tests.

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1. INTRODUCTION

The objective of this program is to determine qualitatively and quantitatively the mechanism and extent of transient and permanent effects of high intensity nuclear radiation on semiconductor integrated microelectronic circuits with a view toward minimizing or eliminating any intolerable effects in circuits designed for reliability in specified nuclear environments.

A semiconductor integrated circuit is a monolithic structure consisting entirely of a semiconductor material, and it is these materials which are most susceptible to radiation effects. It is the role of minority carriers in devices made of these materials that makes them susceptible to radiation effects. Transient disturbances in the circuitry arise from transient increases in the concentrations of these carriers produced by the radiation. Permanent damage is also observed as a permanent decrease in the lifetime of these carriers.

The underlying feature of monolithic construction is the formation of all circuit components on a semiconductor substrate and isolation from it by means of a reverse-biased diode configuration. The primary photocurrents induced by radiation in junction diodes are one of the most significant manifestations of the transient radiation effects. The presence of the substrate diode in these circuits is, therefore, the over-riding problem in this regard.

The total picture of transient radiation effects in monolithic integrated circuits includes besides primary photocurrents, also secondary photocurrents which may arise from primary photocurrents in pnp or npn configurations within the circuit, transient conductivity effects in diffused resistors, secondary emission currents, and ionization leakage currents across the surface.

Permanent damage in these circuits is primarily the degradation of the constituent transistors. To a lesser degree there may also be an increase in the reverse-bias leakage current in the various junctions such as those with the substrate.

This program is concerned with determining the extent of these various effects, pinpointing the specific mechanisms and their location within the circuit, and, finally, prescribing means for minimizing these effects. In pursuit of these ends, the program is divided into three phases as follows:

Phase 1: Circuit Evaluation. An evaluation of presently available circuits for transient and permanent radiation effects.

Phase 2: Diagnostic Studies. Diagnosis of radiation effects in the circuits of Phase 1 by means of special tests including the use of specially constructed configurations, as dictated by the diagnosis.

Phase 3: Remedial Action. Preliminary remedial action by experiments with specially constructed circuits, introducing variations indicated as desirable by the diagnosis in Phase 2.

In the first quarter of the program, circuits of Phase 1 have been procured and checked-out in the laboratory and instrumentation designed and constructed for the radiation tests. This equipment will be described in detail only in this report. Later reports will include descriptions only of modifications of the instrumentation that may be found necessary during the program.

2. SELECTION OF CIRCUITS FOR TEST

2.1 Test Circuit Description

The circuits to be studied are limited to digital logic circuits with three different circuit configurations. The basic logic circuit categories of interest to this program are DTL, RTL and RCTL. These are defined as follows:

DTL: Diode-Transistor Logic. Inputs are coupled to the transistor logic circuit through diodes as shown for the simple gate circuit in Figure 2.1-1a. The number of inputs to the circuit is called the "fan in" and varies with the application. Each input is coupled by a separate diode to the transistor circuit. The transistor in the circuit of Figure 2.1-1a is conducting or "ON" as long as an input (positive voltage) is applied to each input diode so that each is reverse-biased. When any one input is brought to zero volts the diode becomes forward-biased and the transistor base voltage drops, cutting the transistor off.

RTL: Resistor-Transistor Logic. In this case each input is coupled to the transistor circuit through a resistor as shown in the RTL gate circuit of Figure 2.1-1b. Here, each input couples to a separate transistor.

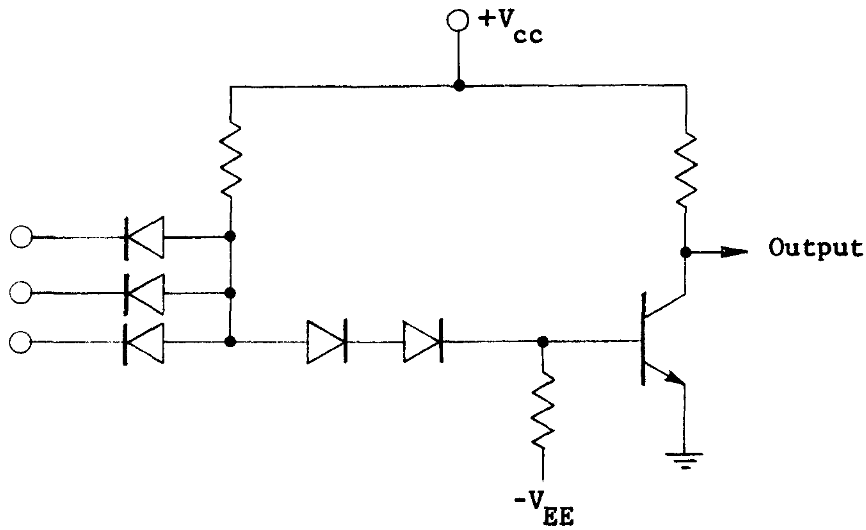
RCTL: Resistor-Capacitor-Transistor Logic. For this case each input is coupled to the transistor circuit through a resistor and a capacitor, as shown in Figure 2.1-1c. In all other respects, the RCTL gate circuit shown is like the RTL gate, as described above.

The gate circuits shown here are the simplest forms of digital-logic circuits for the three types. More complex functions are generally formed from these simple gates as building blocks.

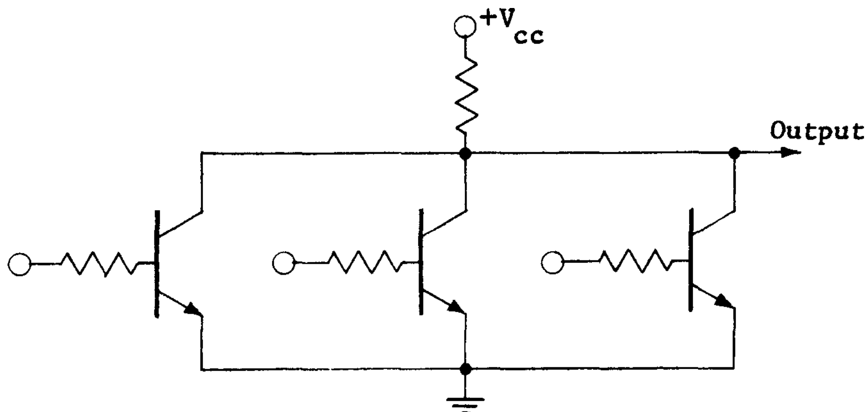
2.2 Commercial Circuits

The commercial circuits selected for study and evaluation include DTL, RTL, and RCTL digital logic circuits. The circuits include most of the major manufacturers in order to obtain a wide variety of manufacturing processes and circuit geometries. The circuits listed in Table 2.2-1 are the same as those originally proposed with the exception of the Signetics circuits. In this case the circuit types were changed at the request of the ECOM Contracting Officer's Designated representative.

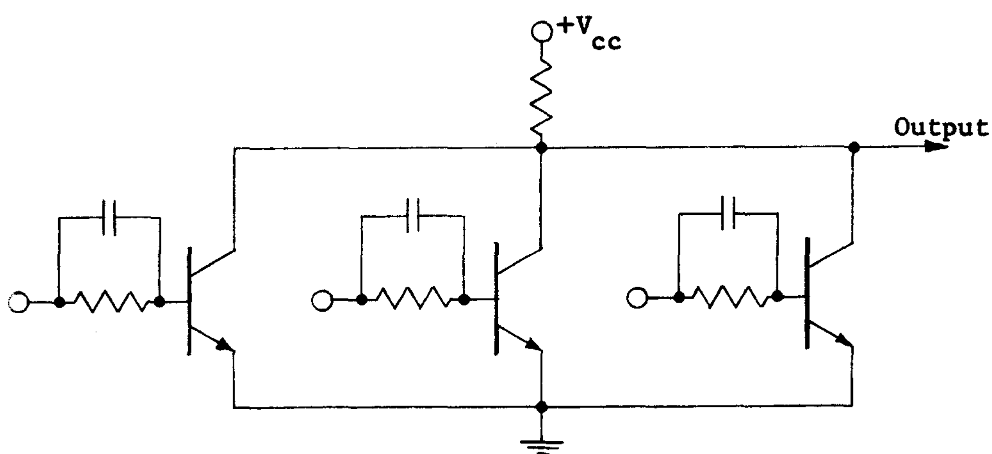
Multi-input and power gates, monostable and bistable multivibrators and both high and low speed circuits are being studied and evaluated. Table 2.2-1 summarizes the circuit types and manufacturers. Five samples of each of the thirty-four circuit types or a total quantity of 170 circuits are included in the evaluation.



(a) DTL GATE



(b) RTL GATE



(c) RCTL GATE

FIGURE 2.1-1 INTEGRATED CIRCUIT LOGIC

The manufacturing processes used include triple-diffusion, expitaxial-diffusion, n^+ pocket diffusions, and gold doping. Chip sizes vary from the 70 x 200 mil chip used in the Texas Instruments Series 51 circuits to the 40 x 40 mil chip used in the newest Fairchild, General Microelectronics, and Motorola integrated circuits.

Requests for complete manufacturing information have been sent to the manufacturers of all circuits used in these tests. The preliminary results of these requests are encouraging although they have not been completely successful. A number of circuit packages containing at least one sample of each circuit tested will therefore be opened and photographed. Photomicrographs of the circuit chips will be recorded when all circuit tests are completed.

The five specimens of each circuit type will be subjected to laboratory bench tests. At least one of the specimens for each circuit type will not be subjected to radiation tests but will instead be used as a control to determine if any changes occurred due to normal circuit operation.

2.3 Diagnostic Circuits

When the circuit-evaluation transient-radiation tests are completed, representative circuits of each logic type (DTL, RTL, and RCTL) will be selected for detailed circuit studies. The criteria for this selection will be:

- Amenability to analysis,
- Same electrical circuit produced by more than one process or manufacturer,
- Availability of process information from the manufacturer,
- Ease of accessibility to individual circuit components,
- Unusual performance noted during circuit evaluation tests.

In addition, DTL monolithic integrated circuits, produced by the Microelectronics Division of Hughes Aircraft, are being provided with special interconnection patterns for ease in evaluating specific circuit components. Complete manufacturing information for these circuits is available for use in circuit analysis and for radiation effects predictions. This particular DTL circuit is also produced by Motorola (MC202) so that variations in manufacturing techniques can also be considered.

DTL CIRCUITS

MANUFACTURER	MULTI-INPUT GATES		POWER GATES		BISTABLE MULTIVIBRATOR		MONOSTABLE MULTIVIBRATOR	
Fairchild	DTμL 930	5	DTμL 932	5	DTμL 931	5		
GME	254 G3	5	264P	5	264B	5		
Motorola	MC202G	5	MC204G	5	MC209G	5		
Signetics	D9004H	5	D9007H	5	D9006H	5	D9008H	5
Siliconix	A06A	5	A02A	5	A03A	5		
T.I.	SN341A	5	----		----			
Westinghouse	WM201T	5						
HUGHES	Special Fabrication	5						
Total No. of Circuits		40		25		25		5

TOTAL DTL CIRCUITS: 95

RTL CIRCUITS

MANUFACTURER	HI-SPEED GATES		LOW POWER GATES		POWER GATES		BISTABLE MULTIVIBRATOR		MONOSTABLE MULTIVIBRATOR	
Fairchild	FμL90329	5	FμL91029	5			FμL92329	5		
AMELCO	Type G	5			Type B	5	Type F	5		
GME	134D2	5			153D3	5	134D2	5	134D2	5
Total No. of Circuits		15		5		10		15		5

TOTAL RTL CIRCUITS: 50

RCTL CIRCUITS

MANUFACTURER	LOW-POWER GATES		BISTABLE MULTIVIBRATOR		MONOSTABLE MULTIVIBRATOR	
T. I.	SN512A	5	SN510A	5	SN518A	5
Sprague	US0104A	5	US0100A	5		
Total Number of Circuits		10		10		5

TOTAL RCTL CIRCUITS: 25

TABLE 2.2-1 INTEGRATED CIRCUITS PROPOSED FOR EVALUATION

A detailed description will now be given of the special DTL circuit module which is being supplied by the Hughes Microelectronics Division. Monolithic diode-transistor logic circuits are being used in the test module to investigate component and substrate interaction mechanisms. Three basic circuits have been included in the module design, all of which are constructed simultaneously on one silicon wafer. In this way, each of the three circuits can be subjected to exactly the same processing conditions so that a true comparison of performance, independent of process variations, may be obtained. The three circuit forms are:

a. Simple DTL configuration of Figure 2.3-1 with diffused passive elements. (Circuit "B" in Figure 2.3-3).

b. Simple DTL configuration of Figure 2.3-1 with vacuum deposited nichrome resistors. (Circuit "C" in Figure 2.3-3). Circuits "B" and "C" have identical component values and identical active elements. They differ only in the method of resistor construction and in their physical layout.

c. Modified DTL configuration of Figure 2.3-2 with diffused passive elements. (Circuit "A" in Figure 2.3-3).

Figure 2.3-3 shows the diffusion patterns for the three different circuits and identifies the components shown in Figures 2.3-1 and 2.3-2. Circuits "A" and "B", which are formed entirely by diffusion processes, will be evaluated and compared with the commercial circuits which are selected for diagnostic tests. The circuit containing thin-film resistors will be evaluated during remedial action tests.

In order to adapt the present circuit design to accommodate the required diagnostic and remedial action tests, it was necessary to design and construct three additional mask sets:

a. Two sets of interconnection masks to provide external contacts to all individual transistors, diodes, and resistors independent of other components.

b. One set of thin-film resistor masks. This set will be used in the thin-film investigations for remedial action.

This experimental design permits the different component interaction mechanisms to be isolated and controlled variables to be introduced.

The new interconnection masks make it possible to obtain access to each individual component for all three DTL circuits. The twelve pin header on the TO-5 can, however, limits the number of components on any one chip which can be tested. Figures 2.3-4, -5, and -6 show the interconnection points which will be monitored during the diagnostic tests. Representatives of each type of component (transistors, diodes, and diffused resistors) have been selected, with particular attention given

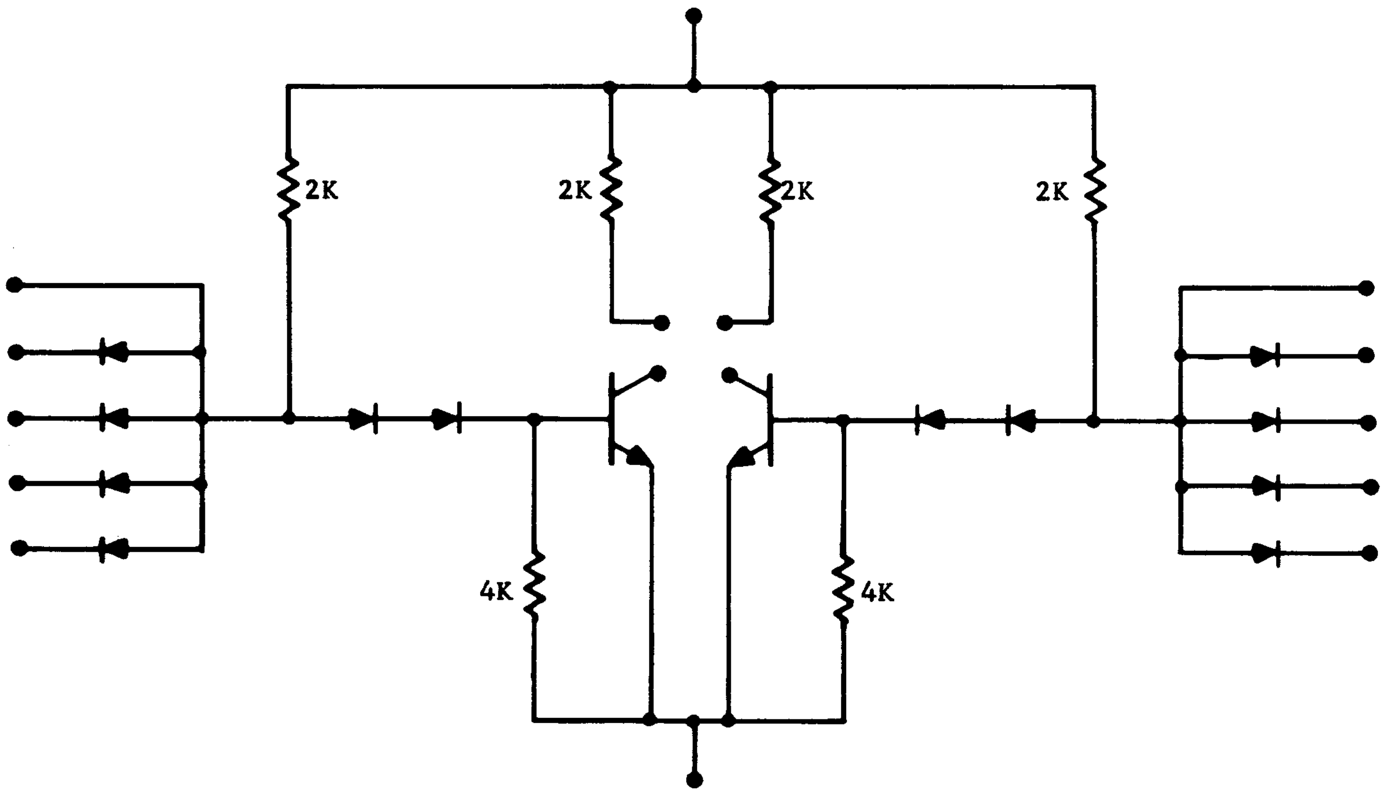


FIGURE 2.3-1 SIMPLE DTL TEST CIRCUIT

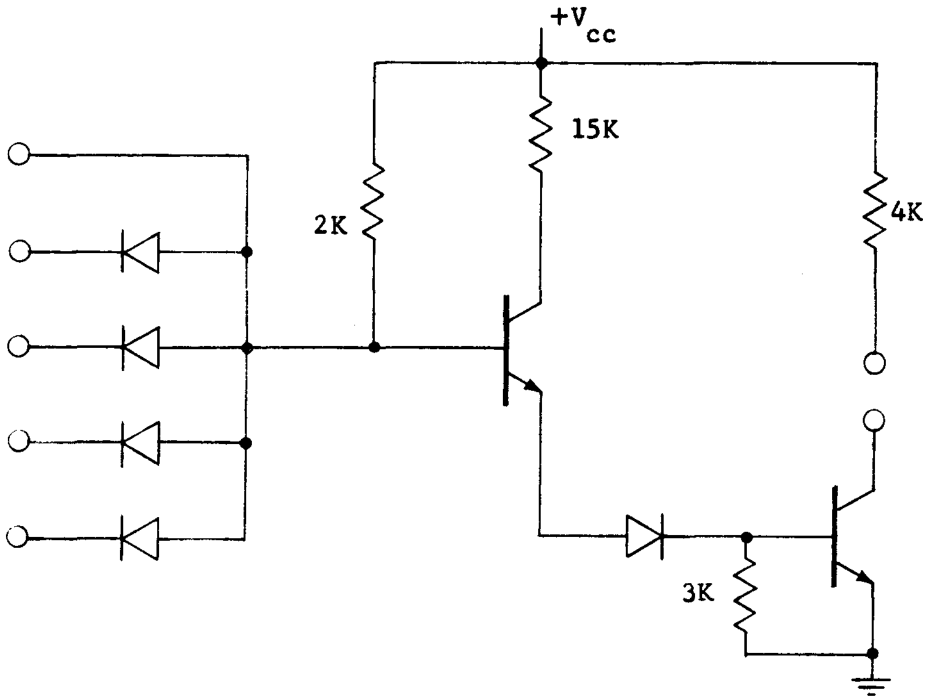


FIGURE 2.3-2 MODIFIED DTL CIRCUIT

to different geometries and relative physical locations.

The circuits for the diagnostic studies and the components which are directly accessible are summarized as follows:

DIAGNOSTIC CIRCUIT	TRANSISTORS	DIODES	RESISTORS
A (Modified)	2	2	4
B (Simple)	1	2	3
C (Thin-Film)	1	2	3
Total Of Different Geometries Available	2	3	7 Diffused 3 Thin Film

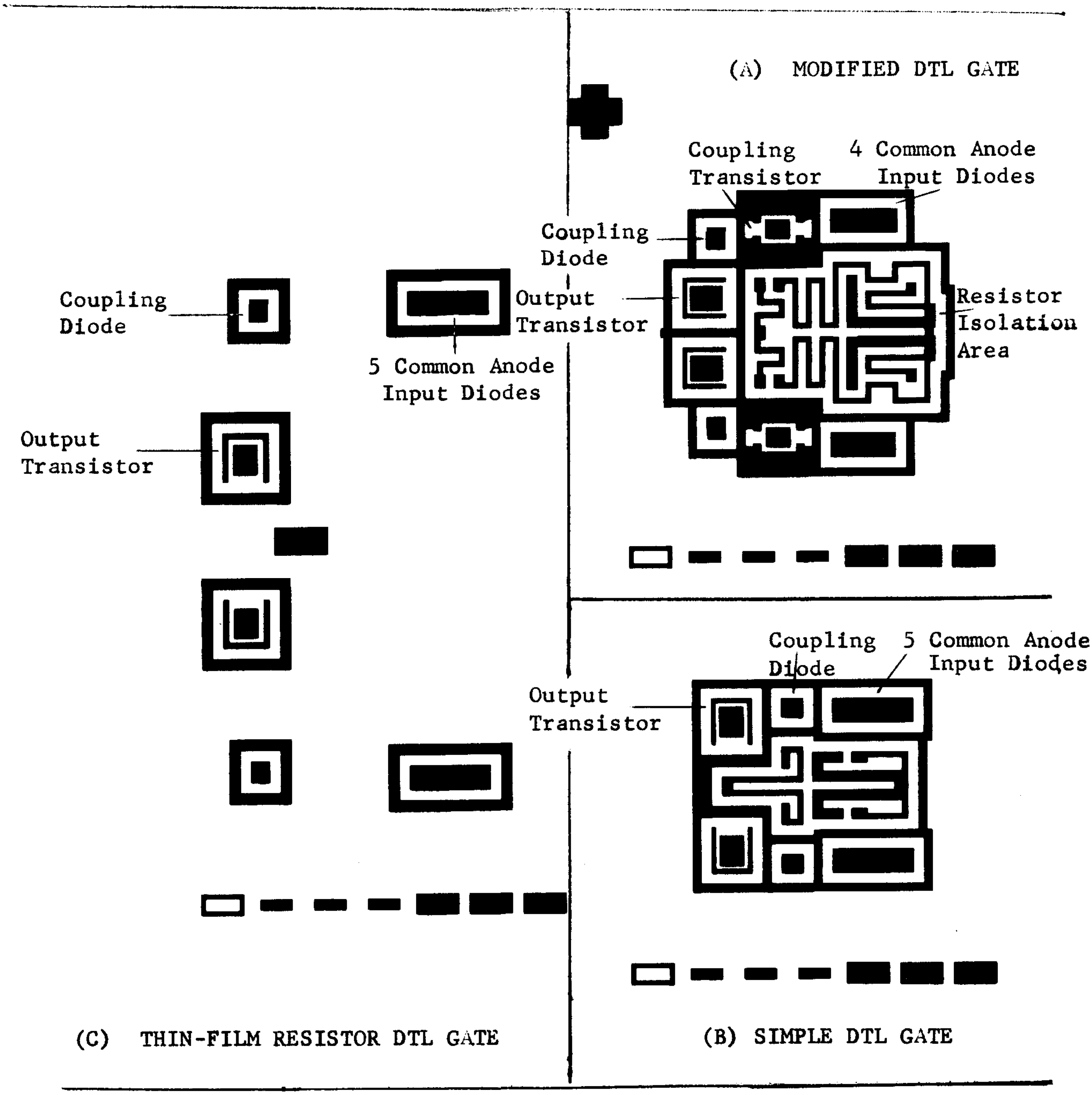


FIGURE 2.3-3 DIFFUSION PATTERNS FOR DIAGNOSTIC CIRCUITS

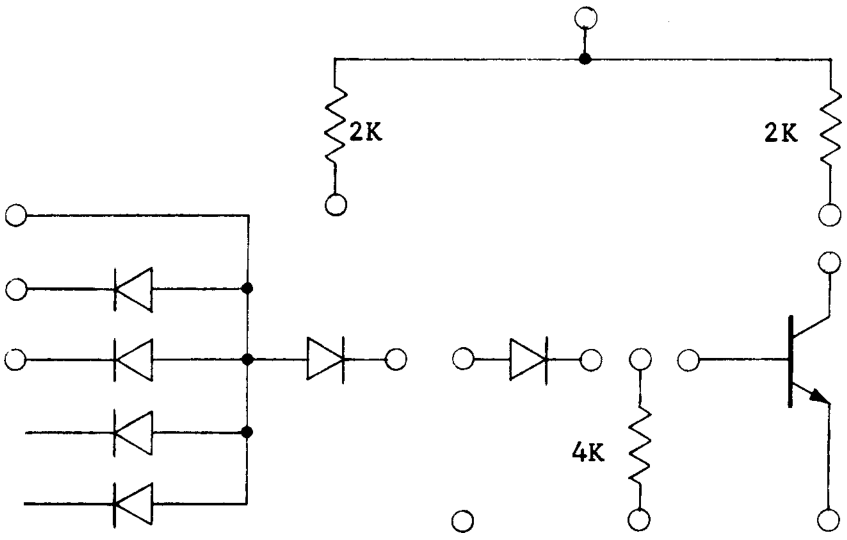


FIGURE 2.3-4 DIAGNOSTIC EVALUATION COMPONENTS FOR SIMPLE DTL CIRCUIT

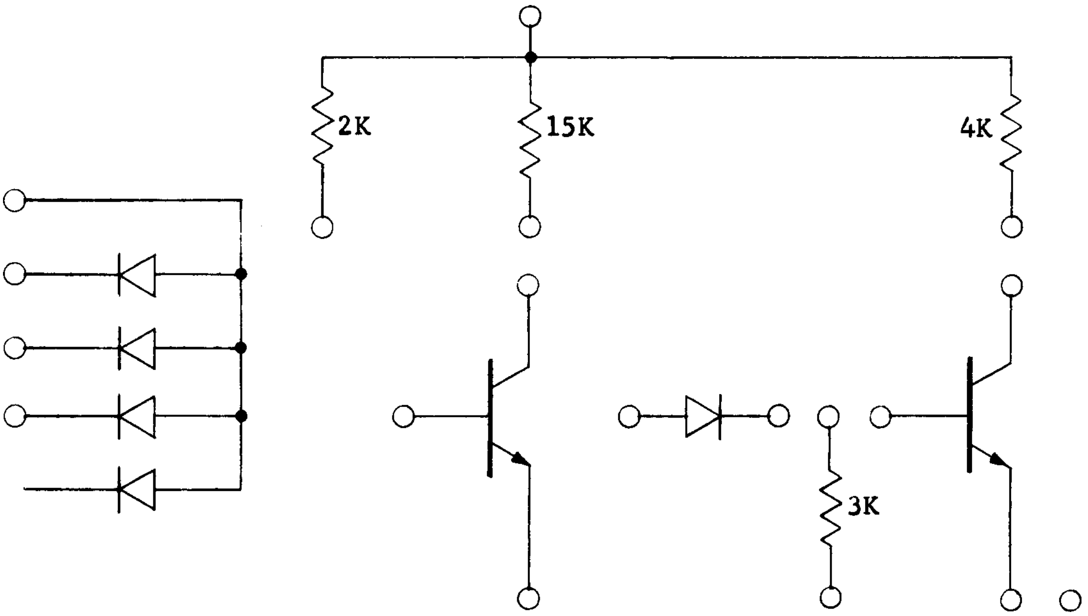


FIGURE 2.3-5 DIAGNOSTIC EVALUATION COMPONENTS FOR MODIFIED DTL CIRCUIT

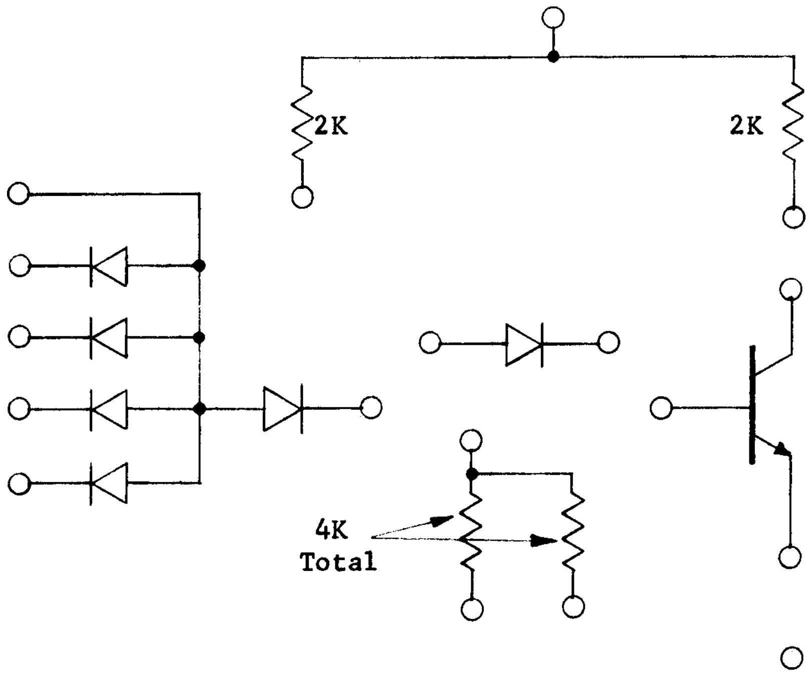


FIGURE 2.3-6 DIAGNOSTIC EVALUATION COMPONENTS FOR THIN FILM DTL CIRCUIT

3. MEASUREMENTS TO BE MADE

3.1 Definitions of Circuit Failure

The transient and permanent effects of high intensity nuclear radiation on digital circuits can best be related to digital circuit malfunction or failure as defined in terms of the output voltage vs input voltage transfer characteristics. This transfer characteristics is shown in Figure 3.1-1. The various parameters shown in the figure are defined as follows:

$V_o(OFF)$ = circuit output voltage when turned off

$V_o(ON)$ = circuit output voltage when turned on

$V_i(OFF)$ = normal input voltage when circuit is off,

$V_i(ON)$ = normal input voltage when circuit is on,

$V_i^{max}(OFF)$ = maximum input voltage which will maintain circuit completely off.

$V_i^{min}(ON)$ = minimum input voltage which will maintain circuit completely on.

V_{th} = the intersection of the transfer characteristic and a line drawn through the worst case operating points.

The transient effects of radiation generally result in a pulse in the output of the circuit. In a system, these pulses are passed from one circuit to the next, being amplified in each successive amplifier stage, triggering flip-flops, and producing effects in the output that may or may not be significant, depending on the system. These transient pulses can be considered as a form of noise. In a system, the permissible noise in the output is defined in terms of the noise margin of each circuit in which the noise may originate.

The noise margins of a circuit are defined as the difference between a threshold voltage and either of the stable output voltages (see Figure 3.1-1). The two noise margins are usually different in magnitude and are defined as follows:

$$N.M.(+) = V_{th} - V_i(OFF)$$

$$N.M.(-) = V_i(ON) - V_{th}$$

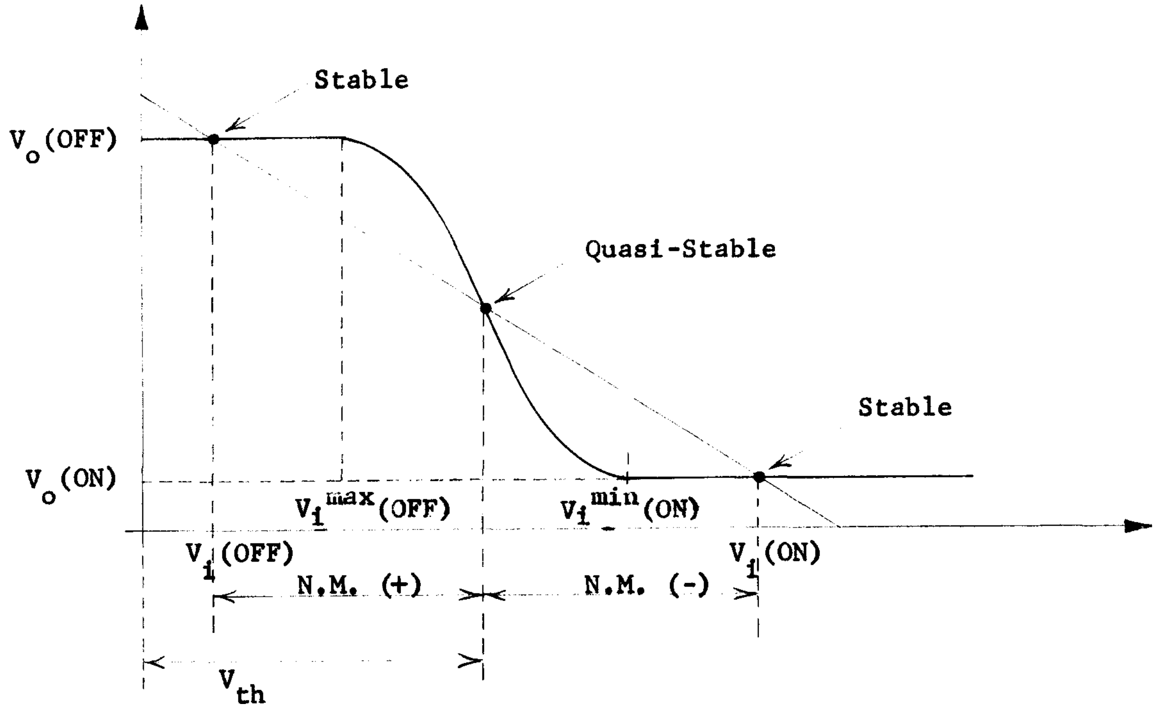


FIGURE 3.1-1 INPUT VOLTAGE vs OUTPUT VOLTAGE TRANSFER CHARACTERISTIC

It is difficult to compare the noise margins of different types of circuits because of differences in the logic voltage swing. However, different types of circuits can be compared in terms of <u>noise immunity</u>. <u>Noise immunity</u> (N.I.) is defined as follows:

$$\text{N.I.} = \frac{\text{Noise Margin}}{\text{Logical Voltage Swing (Worst Case)}} \times 100$$

$$\text{N.I.}(+) = \frac{V_{th} - V_i\,(\text{OFF})}{V_o\,(\text{OFF}) - V_o(\text{ON})} \times 100$$

$$\text{N.I.}(-) = \frac{V_{th} - V_i\,(\text{ON})}{V_o\,(\text{OFF}) - V_o(\text{ON})} \times 100$$

The noise margin and noise immunity of a digital circuit are of particular significance in the transient radiation environment because the typical effect of transient radiation is to create noise pulses in a system. Circuits can turn partially ON or OFF for short periods of time, but if the loading circuits (fan-out) are not affected then as far as the system is concerned no false information is injected into the system, and no loss of information results. Circuit failure during transient radiation therefore occurs when the radiation induced circuit output voltage exceeds the noise margin of those circuits which act as loads for the circuit under test.

The width of the noise pulse is also of considerable significance because the noise voltage amplitude at the input of a circuit required to cause a change in the output is a function of the duration of the noise pulse, as well as its amplitude. However, most of the available digital integrated circuits have turn-off and turn-on transition times which are less than typical transient radiation pulse widths so that the amplitude of the radiation effect is the only important factor in most cases.

The effect of permanent radiation damage to circuits is to decrease h_{FE}, increase leakage currents, reduce diode minority carrier lifetimes and possibly change component values. The predominant effect will, however, be to decrease h_{FE}. As h_{FE} is decreased, the available circuit output-current decreases, output voltages in the ON state increase and the circuit eventually ceases to function properly, particularly if fully loaded.

Circuit failure during neutron irradiation therefore occurs when the output voltage, $V_o(ON)$, rises sufficiently to reduce the noise margin below a minimum acceptable value or when the circuit transistor can no longer supply the load current required for a specified load.

If circuit loading and noise margin specifications are reduced to a minimum, it is possible that leakage currents and component changes could eventually result in circuit failure, but this prospect is considered highly unlikely at the neutron doses of interest.

3.2 Laboratory Bench Tests

3.2.1 Introduction

Laboratory bench tests are made in the laboratory prior to and immediately after each radiation test series. The purpose of these tests is to provide a comprehensive historical record of the important electrical characteristics of the test circuits. This record will serve as a reference for transient effects and will be used to determine the extent of any permanent change in circuit characteristics caused by radiation (Linac or pulsed reactor). It will also provide an additional tool for the diagnosis of radiation effects mechanisms. Control circuits, that is, circuits which are not subjected to radiation, will be used to determine the extent of circuit parameter changes due to normal circuit operation and shelf life. This procedure will allow such variations to be eliminated from the radiation test results.

One of the main objectives of the circuit evaluation phase of this program will be to define the nature of circuit failures or malfunctions caused by radiation, in terms of the circuit parameters which are used by circuit and system design engineers when designing electronic equipment. The circuits to be studied in this program are all digital logic circuits and are therefore normally specified in terms of the following d.c. parameters. These can be classified as follows:

(1) Terminal Current Parameters

a. Maximum output load current, I_L } Used to determine maximum fan-out

b. Input load current, I_{EL} } Used to determine maximum fan-out

c. Input leakage current, I_{EO}

d. Output leakage current, I_{OL}

(2) Power Drain, P_d

(3) Terminal Voltage Parameters (Section 3.1)

a. V_o(ON)

b. V_o(OFF)

c. V_i^{min}(ON)

d. V_i^{max}(OFF)

e. N.M.

(a–e: Determined from voltage Transfer Characteristic)

In addition, the switching characteristics of a digital circuit are normally specified in terms of the following switching parameters:

(a) Delay time, t_d

(b) Storage time, t_s

(c) Rise time, t_r

(d) Fall time, t_f

(e) Maximum operating frequency (bistable circuits only)

D-c parameters and switching parameters are normally specified for certain worst case conditions such as temperature, loading, supply voltage variation, etc. Consideration of all such variables is beyond the scope of this program. The measurements to be described will be made under the following condition:

- Manufacturer's recommended operating voltage
- Maximum and minimum specified loading
- Room temperature ($25 \pm 5^{o}C$)

The following paragraphs present a detailed description of the parameter measurements listed previously and a discussion of their significance. Since the integrated circuits to be studied include DTL, RTL and RCTL circuits, the same measurement techniques cannot be used on every circuit type. The parameter measurements for bistable and monostable elements are the same as for the corresponding gate wherever possible.

3.2.2 Terminal Current Measurements

(a) Maximum Output Load Current, I_L

In an RTL or an RCTL gate circuit, the output load current is determined by the applied circuit voltage and the circuit output load resistor when the transistors in the circuit are OFF. (See Figure 3.2-1). Radiation is not likely to affect this parameter significantly unless the load resistor changes value due to permanent radiation damage. This is not likely for the neutron doses of interest to this program (10^{13} $N_f vt$).

This measurement is much more significant in the case of the DTL circuit since the load current is supplied when the circuit transistors are ON. (See Figure 3.2-2). Degradation of h_{FE} due to radiation damage effects will decrease the load current the circuit transistor is able to supply. As the collector current decreases, the circuit output voltage, V_O, will increase positively and will eventually exceed the maximum allowable value of V_O. The maximum allowable value of V_O is usually limited by the minimum noise margin which can be tolerated. The output load current for a specified maximum value of V_O will therefore be measured for all DTL gate circuits during permanent damage tests.

(b) Input Load Current, I_{EL}

The input load current is the forward current through the input diode when the input is being held in the "zero" or low state. (See Figure 3.2-2). Typically it is about 1.5 ma for the DTL gate. As shown in Figure 3.2-2 the input load current is related to the output load current of the preceding gate.. Any change in this current will therefore affect the fan-out of the preceding gate. For RTL and RCTL circuits, I_{EL} flows in the opposite direction as shown in Figure 3.2-1.

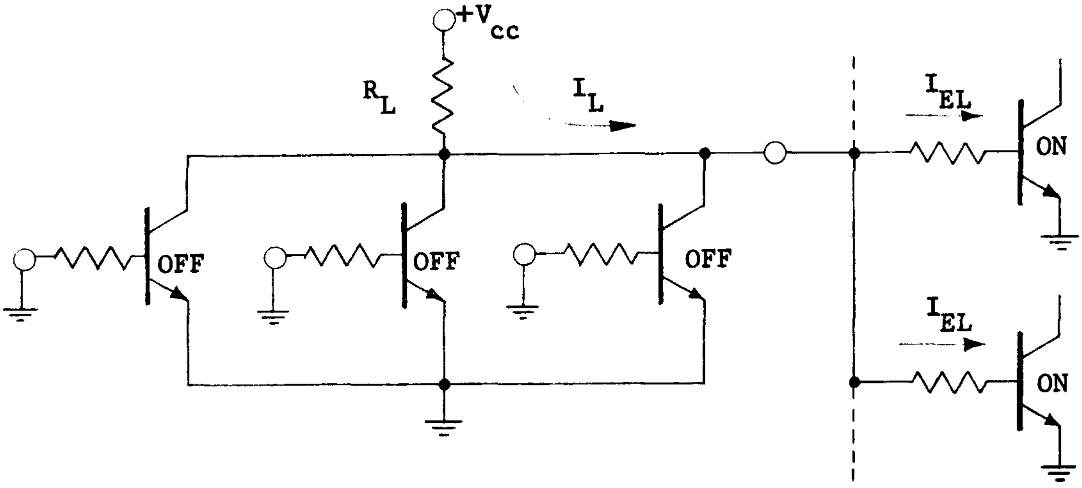


FIGURE 3.2-1 INPUT AND OUTPUT LOAD CURRENT FOR RTL AND RCTL CIRCUITS

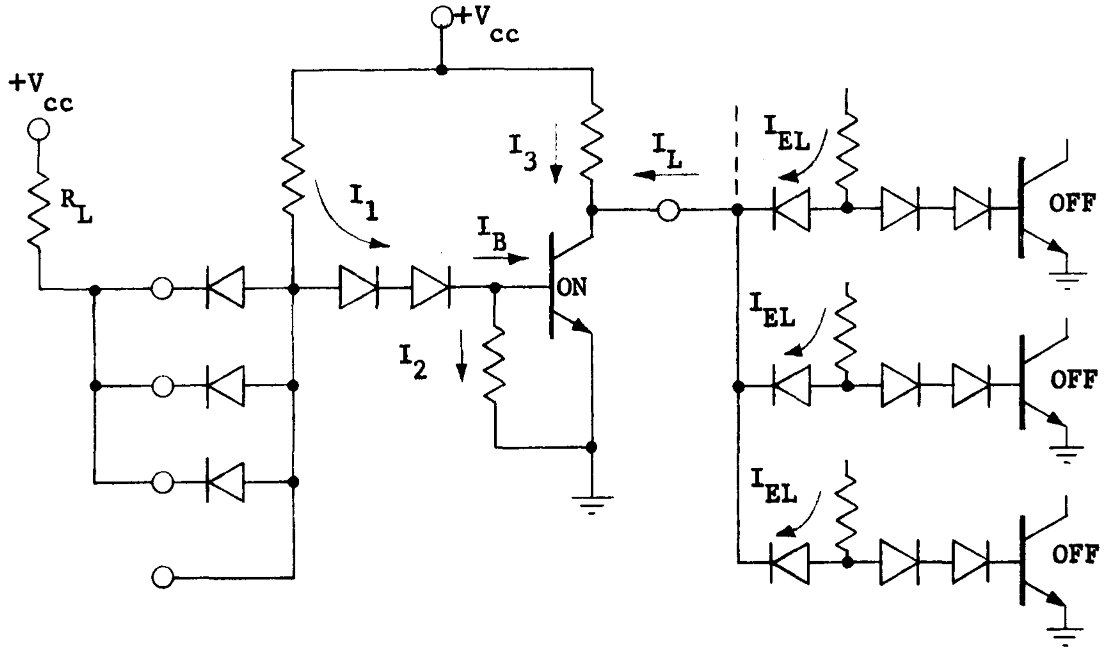


FIGURE 3.2-2 INPUT AND OUTPUT LOAD CURRENT FOR DTL CIRCUITS

The magnitude of I_{EL} for both circuits is related to resistor values and diode forward voltage drops. Any changes in I_{EL} due to permanent radiation damage are expected to be small at the neutron doses of interest.

(c) Input Leakage Current, I_{EO}

In a DTL gate, it is necessary that the input logic diodes exhibit low values of reverse leakage current. This is, therefore, an important parameter for measurement. It is measured at the same point as is I_{EL} but under conditions which reverse-bias one input diode. This is shown in Figure 3.2-3. The preceding gate must be OFF, while the test gate itself is OFF. In addition, the other input diodes are grounded in order to simulate ON transistor outputs since this is the worst case condition for I_{EO}. In the bench tests each input diode will be sequentially reverse-biased and the individual leakage currents measured.

In the case of RTL and RCTL circuits, I_{EO} is again measured at the same point as is I_{EL} but under reverse-biased conditions. These conditions are illustrated in Figure 3.2-4. In this case, the gate transistor under test is OFF and the preceding gate is ON. I_{EO} is just equal to the collector-base leakage current, I_{CO}, of the OFF transistor under test. Leakage currents through the substrate diode associated with R_1 can also contribute to I_{EO}.

In the laboratory bench tests, I_{EO} will be measured for each input transistor by sequentially placing each under reverse-bias conditions.

The magnitude of I_{EO} for both circuits would have to increase by at least one order of magnitude before circuit operation was seriously affected. This current represents the diode reverse leakage-current of a planar passivated silicon diode and is not expected to change appreciably at the neutron doses of interest.

(d) Output Leakage Current, I_{OL}

In most of the DTL circuits I_{OL} is equal to the collector-emitter diode reverse leakage current, I_{CER}, of the output transistor plus the reverse leakage current through the parasitic substrate diode as shown in Figure 3.2-5.

In the RTL and RCTL circuits, I_{OL} is the sum of the I_{CER}'s of all output transistors plus the reverse leakage current through the parasitic substrate diode, because the transistor collectors and emitters are connected together. The load resistor in both circuits also has a parasitic substrate diode associated with it which will contribute to the leakage current.

I_{OL} is measured at the circuit output with the output transistors OFF, as shown in Figures 3.2-6 and 3.2-7. The output load resistor is open circuited, if possible, and the V_{cc} terminal is left open during this measurement.

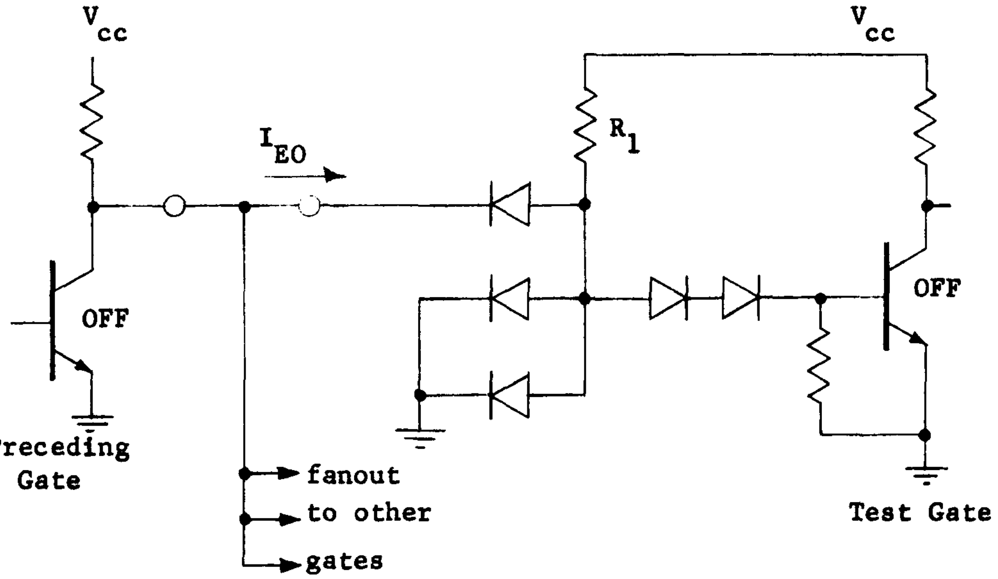
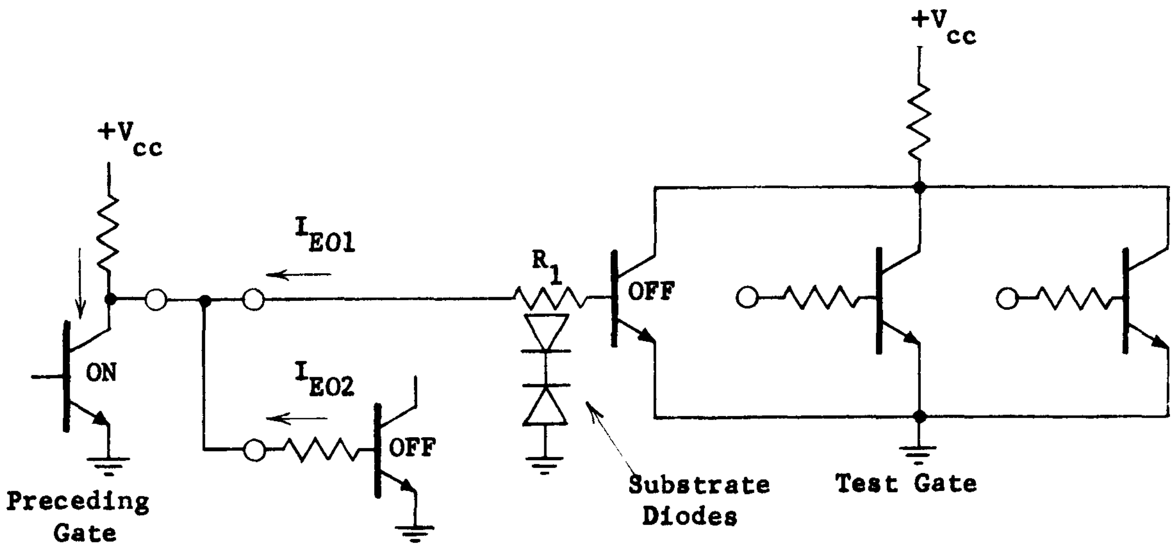


FIGURE 3.2-3 INPUT LEAKAGE CURRENT, I_{EO}, FOR DTL CIRCUIT



3.2-4 INPUT LEAKAGE CURRENT, I_{EO}, FOR RTL AND RCTL CIRCUITS

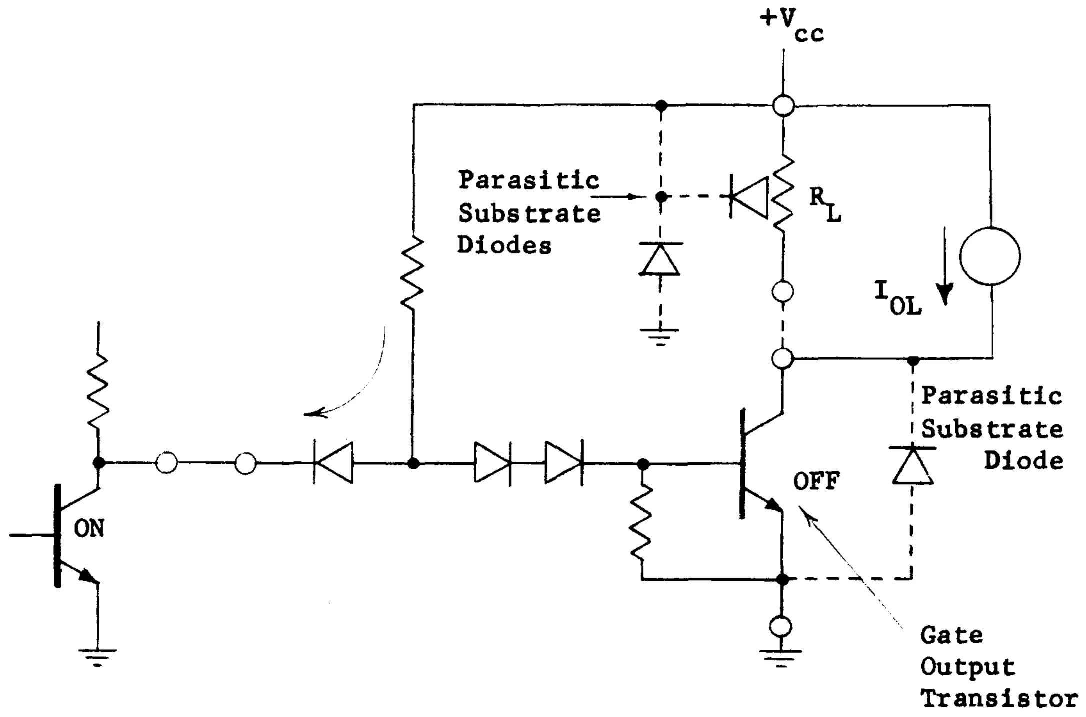


FIGURE 3.2-5 OUTPUT LEAKAGE CURRENT, I_{OL}, FOR THE DTL CIRCUIT

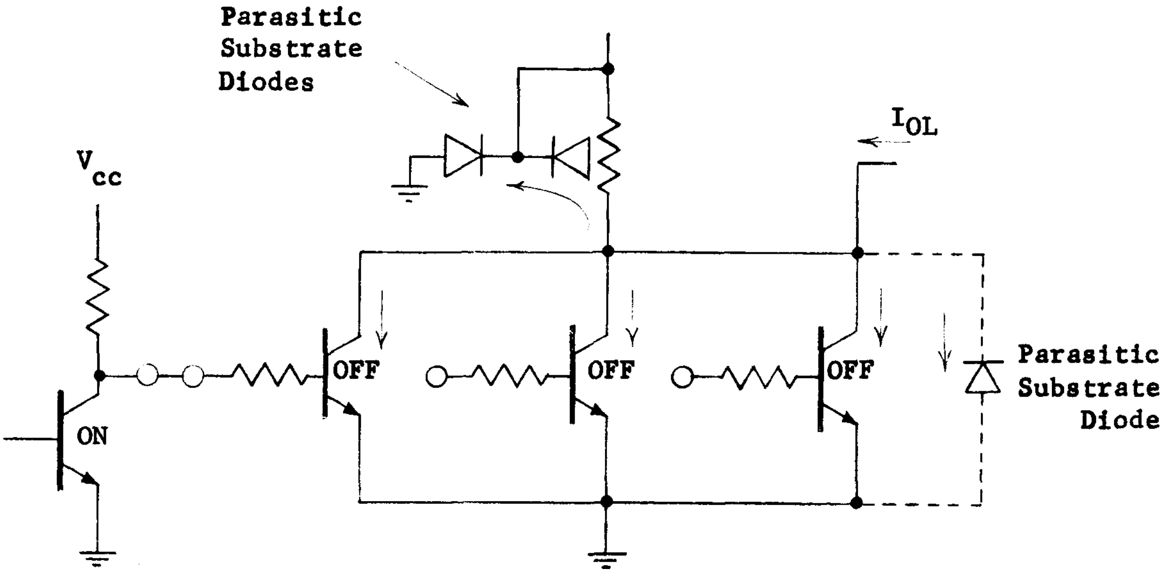


FIGURE 3.2-6 OUTPUT LEAKAGE CURRENT, I_{OL}, FOR THE RTL AND RCTL CIRCUITS

In the event that I_{OL} should become excessively large due to radiation damage, the circuit noise margin in the OFF state would decrease and the circuit would become inoperable. It is difficult to predict the effect of radiation damage on this parameter due to the presence of the large area substrate diodes. This parameter will therefore be measured carefully before and after the neutron damage tests.

3.2.3 Power Drain Measurements

The power supply current drawn by the bistable and monostable multivibrator circuits is measured in both operating states. Gate circuits are measured in both the ON and the OFF states.

The power drain is calculated as follows:

$$P_d\ (ON) = I_{ON}\ V_{cc}$$

$$P_d\ (OFF) = I_{OFF}\ V_{cc}$$

$$P_d\ (AVE) = \frac{P_d(ON) + P_d(OFF)}{2}$$

The power supply current drain is related to resistor values and the output saturation voltage of transistors. Since h_{FE} determines the saturation voltage, decreases in h_{FE} due to neutron damage should result in a decrease in the power supply current when the test circuit is in the ON state.

3.2.4 Terminal Voltage Measurements

The following d.c. parameters can be determined from the input voltage-output voltage transfer characteristic which was discussed previously in section 3.1 and defined in Figure 3.1-1:

(a) $V_O(ON)$

(b) $V_O(OFF)$

(c) $V_i^{min}(ON)$

(d) $V_i^{max}(OFF)$

(e) N.M.

The voltage transfer characteristic of each circuit will be displayed on an oscilloscope and photographed under maximum loading conditions. The ON and OFF operating points V_O (OFF) and V_O(ON) will be located on the photograph and a straight line will be drawn between the operating points. The intersection of this line with the transfer characteristic (the threshold voltage) will be measured from the photograph.

The five terminal voltage measurements can now be made from the photograph as illustrated in Figure 3.1-1.

(a) V_0(ON) (Read directly on vertical voltage scale)

(b) V_0(OFF) (Read directly on vertical voltage scale)

(c) V_i^{min}(ON) (Read directly on horizontal voltage scale)

(d) V_i^{max}(OFF) (Read directly on horizontal voltage scale)

(e) Noise Margins (Calculated from V_{th}, $V_i(\overline{ON})$, and $V_i(\overline{OFF})$)

It is difficult, however, to make an accurate measurement of V_0(ON) from the transfer characteristic, therefore separate measurement of this parameter will be made as described in the following paragraphs using a d.c. parameter tester.

V_0(ON) is measured with the gate subjected to maximum d.c. loading conditions as shown in Figure 3.2-7.

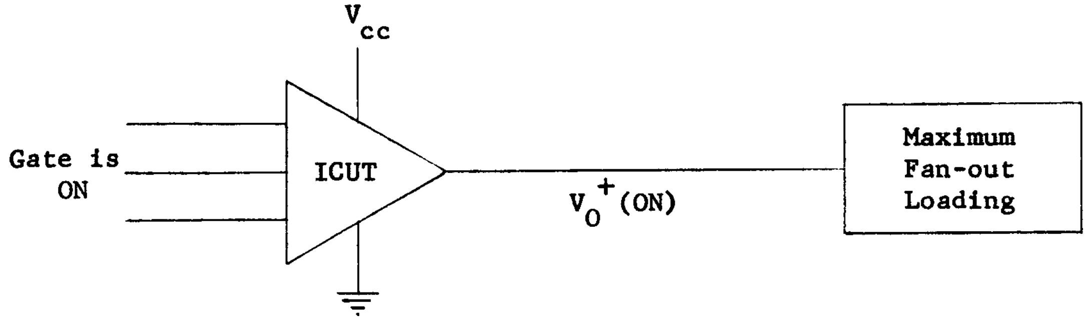


FIGURE 3.2-7 MEASUREMENT OF V_0(ON)

ICUT = Integrated Circuit Under Test

Since the output transistor is ON, this test is actually a measurement of the collector-emitter saturation voltage, V_{CE}(sat), for the output transistor. Degradation of h_{FE} due to permanent radiation damage increases V_0(ON), thus reducing the noise margin and eventually causing circuit failure.

3.2.5 Switching Parameter Measurements

(a) Turn On Delay Time

This test is an a.c. switching measurement of the time required to turn a circuit ON. It is measured between the +1.5 volt levels of the input and output voltage waveforms for DTL circuits as shown in Figure 3.2-8. The corresponding voltage levels of RTL and RCTL circuits are

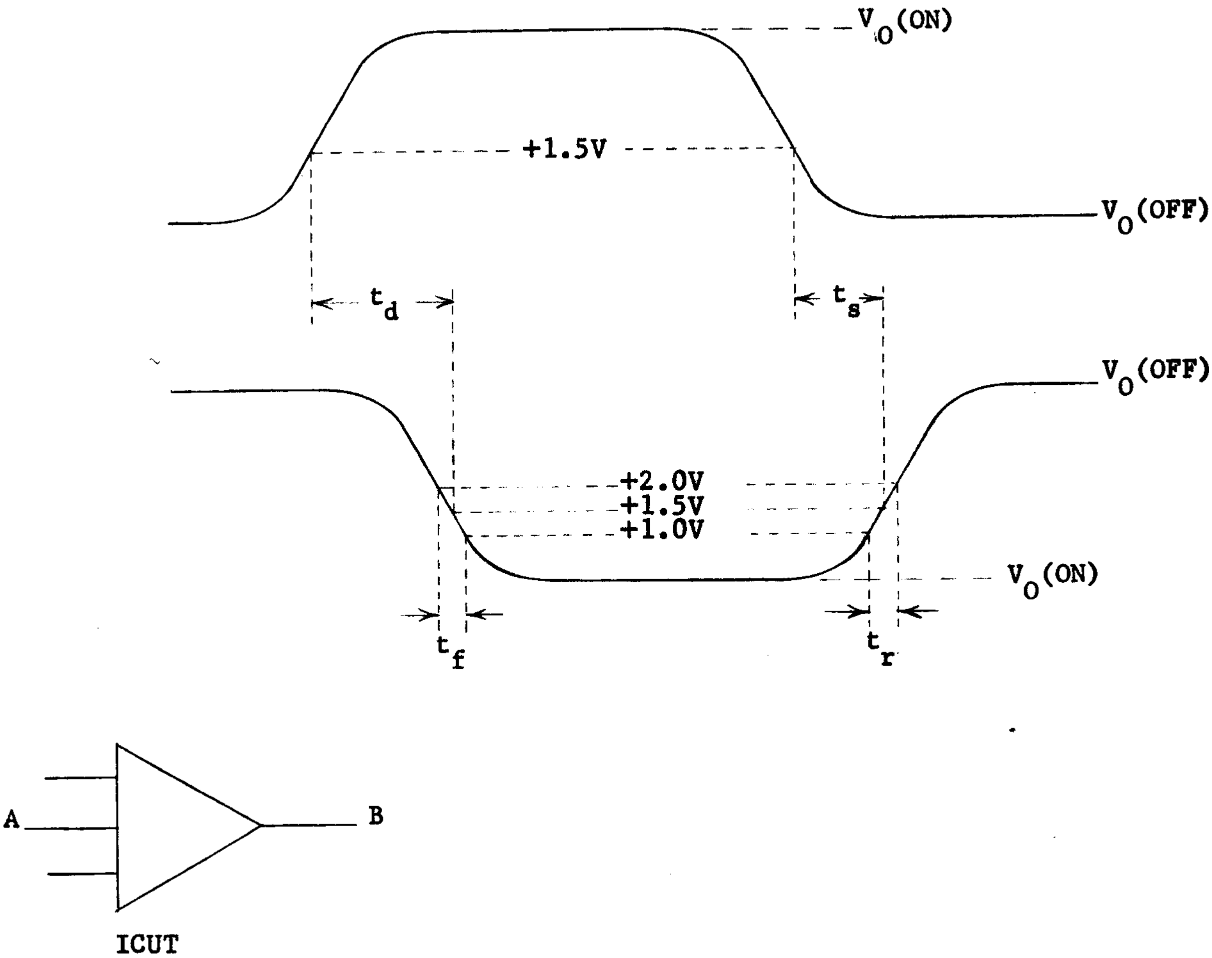


FIGURE 3.2-8 A-C PARAMETER MEASUREMENT

smaller (0.75 volts) due to their smaller logic voltage swings. Turn on delay is related to h_{FE} and the gain-bandwidth product, f_t, of the output transistor. Since this parameter is related to h_{FE}, it can be expected to change in a radiation environment that produces permanent damage.

(b) Fall Time

Fall time is a measurement of the time required for the circuit output to change from the OFF state to the ON state. It is related to the h_{FE} and f_t of the output transistor and is measured at the +2.0 and +1.0 voltage levels for the DTL circuits as shown in Figure 3.2-8. The corresponding voltage levels for the RTL and RCTL circuits are 0.5 and 1.0 volts.

Since this parameter is related to h_{FE}, it can be expected to change in a radiation environment that produces permanent damage.

(c) Storage Time

Storage time is a switching time measurement of the time required to turn a gate OFF. It is measured at the same voltage levels as turn-on delay time, but is instead measured on the trailing edges of the input and output voltage waveforms as shown in Figure 3.2-8. It is related to h_{FE} and f_t of the output transistor.

Since this parameter is related to h_{FE}, it can be expected to change in a radiation environment that produces permanent damage.

(d) Rise Time

Rise time is the time required for a circuit output to change from the OFF to the ON state. The rise time is measured between the +1.0 and +2.0 voltage levels at the output of DTL circuits as shown in Figure 3.2-8. Again the output levels for RTL and RCTL circuit measurements are lower, (0.5 to 1.0 volts).

Rise time is primarily related to the value of the output load resistor in most of the circuits which are being studied. For this reason it should not be affected appreciably by neutron radiation.

(e) Maximum Operating Frequency For Bistable Multivibrators

The maximum operating frequency of a bistable multivibrator (flip-flop) is a parameter which describes the ultimate capability of the circuit. Many factors determine the maximum operating frequency such as transistor h_{FE}, transistor f_t, base current overdrive, and the R-C time constant of the load resistor and the capacitance associated with the output of the circuit.

This frequency can be determined by routing alternate trigger pulses to the opposite inputs of the circuit and increasing the pulse frequency until failure occurs. Since output loading affects the maximum operating frequency, these tests will be made with normal circuit loading.

The decrease in h_{FE} due to neutron damage is expected to lower the maximum frequency if the frequency is primarily determined by transistor parameters. If it is determined by the R-C time constant of the output circuit, however, then little change is anticipated.

3.3 Transient Radiation Tests

Transient radiation tests will be performed in the environment produced by the Hughes Linear Electron Accelerator (Linac) at dose rates up to 1×10^9 rads/sec.

The measurements of radiation-induced output voltages and circuit failure-threshold levels will be related to the electrical device parameters, noise margin, noise immunity, fan-in and fan-out.

3.3.1 Commercial Circuit Evaluation Tests

A series of tests will be performed on each circuit in order to determine the mode of circuit failure and to determine quantitatively the mechanism involved in this failure. These tests are summarized in Table 3.3-1 and will be discussed in detail in the following paragraphs.

(a) Circuit Failure Threshold Level

The circuit failure threshold level measurement determines the radiation dose rate at which the radiation-induced output voltage pulse from a digital circuit exceeds the level required to cause a loading circuit to change state or propagate the pulse to other circuits. The test circuit for this measurement is shown in Figure 3.3-1. Only the circuit under test is exposed to radiation. The radiation dose rate is increased and when a pulse occurs at the output of the loading circuit, the circuit failure threshold level for transient radiation is determined. This threshold will be measured in both the ON and OFF states of the circuit under test.

(b) Effects of Fan-In and Fan-Out on Failure Threshold

The initial circuit failure threshold level measurements will be made with a fan-in of 1 and a fan-out of 1. After these measurements are completed, the fan-in and fan-out will be increased to the maximum allowable values and the new circuit failure threshold levels will be determined. The magnitude of the voltage response of the circuit under test will be recorded photographically at the same time that the dose rate causing circuit failure is recorded.

TYPE OF MEASUREMENT	TEST CONDITIONS				
	NUMBER OF FAN-OUTS	NUMBER OF FAN-INS	NUMBER OF DOSE RATES	CIRCUIT OPERATING STATES	TOTAL NUMBER OF TESTS
Transient Effect Dose Rate Threshold	1	1	1	2	2
Transient Effect vs. Dose Rate	1	1	3	2	6
Transient Effect vs. Fan-In	1	2	1	2	4
Transient Effect vs. Fan-Out	2	1	1	2	4
NUMBER OF TESTS PER CIRCUIT					16

TABLE 3.3-1 SUMMARY OF TRANSIENT RADIATION TESTS TO BE PERFORMED ON EACH CIRCUIT

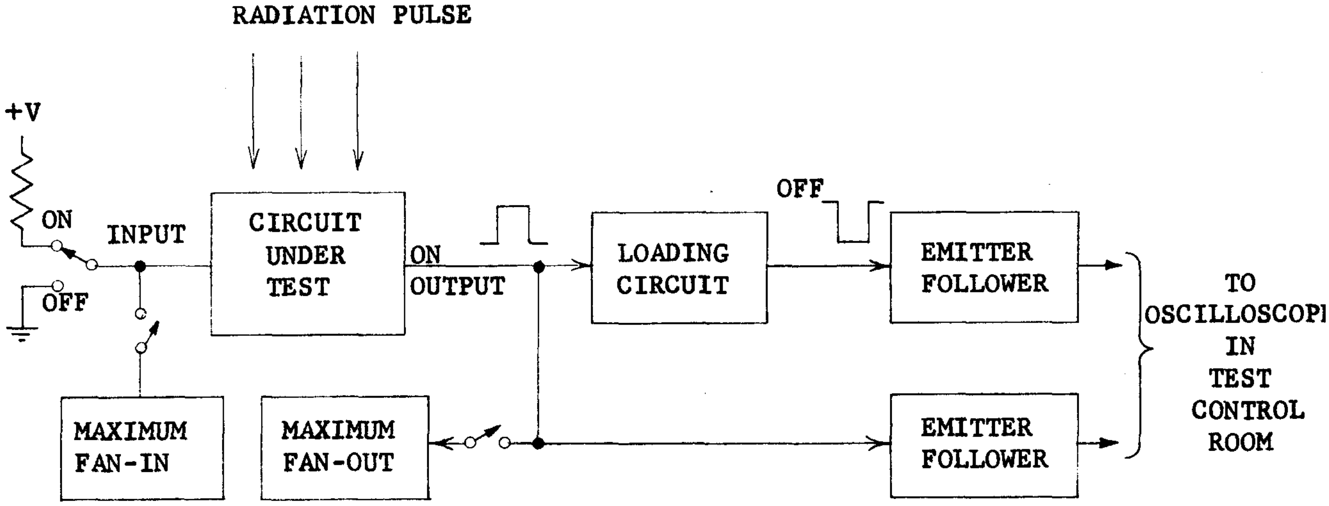


FIGURE 3.3-1 TRANSIENT RADIATION MEASUREMENTS

The fan-in and fan-out performance of a circuit will be investigated because increased fan-in and fan-out will change the circuits' operating points (See Figure 3.1-1), so as to reduce the noise margins. The magnitude of the effect of changes in fan-out and fan-in on the noise margins of a circuit can be determined by performing a d-c analysis for a particular circuit, or by measuring the input voltage vs output voltage transfer characteristic for various values of fan-in and fan-out.

In many cases the change in noise margin caused by changes in fan-in and fan-out is insignificant when related to the very small change in radiation dose rate required to produce a corresponding change in the noise level. For example, fan-out may reduce the noise margin from 0.7 to 0.5 volts. The corresponding change in the dose rates required to produce noise voltages of 0.7 and 0.5 volts may be from 5×10^7 rads/sec to 4×10^7 rads/sec. Larger radiation response variations than this are commonly experienced between two different circuits of the same type under identical loading conditions.

(c) Transient Radiation Effect vs Dose Rate

The magnitude of the transient radiation effect will be recorded for the three different dose rates as follows:

- Circuit failure threshold level when both ON and OFF.
- Dose rate for circuit output change from OFF to ON.
- Dose rate for circuit output change from ON to OFF.
- Dose rate for circuit output change barely visible for both the ON and OFF states.

If circuit output responses are not observed in the ON state for the maximum dose rate obtainable, some of the measurements, of course, will be impossible.

(d) Circuit Failure Threshold Level for Bistable Circuits

Past experience in transient radiation testing has shown that transient radiation-induced output-voltage responses of sufficient amplitude to trigger other loading circuits, such as gates, can be generated without causing a permanent change in state of the bistable circuit. Two modes of failure can therefore be defined for bistable circuits. The test circuit shown in Figure 3.3-1 will determine either mode of failure, and photographs of the output response of the circuit under test will record the mode of failure.

3.3.2 Diagnostic Transient Radiation Tests

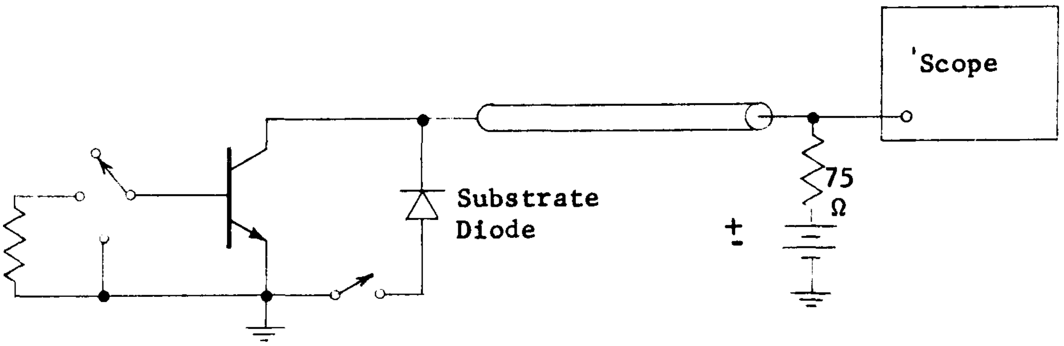
The objective of diagnostic tests will be to qualitatively determine the basic transient radiation effects mechanisms in specially selected and constructed integrated circuits.

Selection of circuit responses to be measured will be based on a preliminary computation of circuit and component responses. This analysis will identify the circuit parameters and components affected by radiation and provide estimates of the response magnitudes and durations.

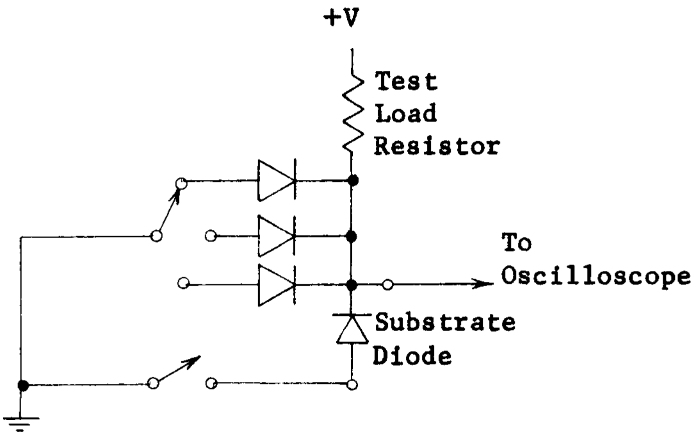
The transient radiation tests will begin with the measurement of individual component photocurrent responses for the specially constructed diagnostic circuits. The basic component radiation photocurrent response will be separated from that due to its associated substrate diode in most cases. Resistors are expected to present problems in this respect, however, since they are all located in a common isolation area. Test circuits for measuring the various component responses are shown in Figure 3.3-2.

The sum of the individual component radiation responses will then be compared to the responses of complete circuits manufactured at the same time as the diagnostic components.

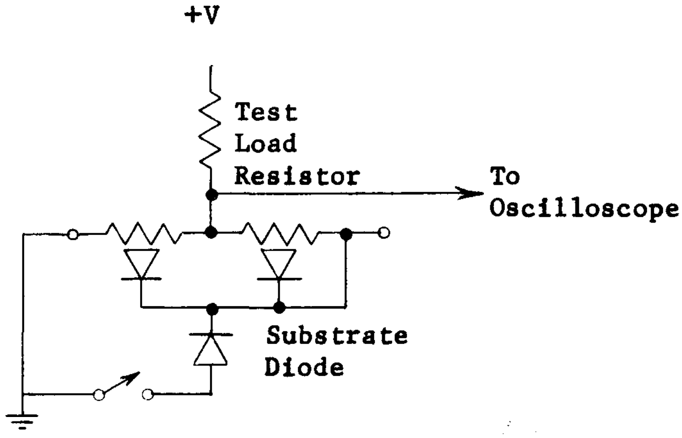
The commercial circuits which are selected for diagnostic studies will be studied in as much detail as possible consistent with the external



TRANSISTOR STRUCTURE



MULTIPLE DIODE STRUCTURE



MULTIPLE RESISTOR STRUCTURE

FIGURE 3.3-2 PHOTOCURRENT MEASUREMENTS FOR DIAGNOSTIC COMPONENTS circuit connections which are available. Individual component photocurrents will be measured whenever possible. Input and output nodes which have external connections will also be monitored for voltage pulse responses.

Component responses will be interpreted in terms of photocurrent rather than noise level because photocurrent is the parameter which can analytically be correlated with circuit geometries. The data obtained will be analyzed and recommendations for remedial action will be made.

3.4 Pulsed Reactor Tests

3.4.1 Introduction

Radiation damage tests will be performed on selected monolithic integrated circuits in the fast neutron environment provided by the White Sands Pulsed Reactor (WSPR). Automated test equipment will be used in order to perform a series of tests on each circuit. The tests are designed to determine the degradation in circuit performance due to neutron damage and will therefore be made after each reactor burst with normal circuit voltages applied.

The circuits will be subjected to a series of reactor bursts until a total dose of at least 1×10^{13} $N_f vt$ is accumulated. By recording data after each burst, a series of measurements will be obtained which will enable parameter degradation as a function of total dose to be plotted. The most important damage mechanism for integrated circuits will be the degradation of transistor current gain, h_{FE}.

Circuit tests to be performed between bursts at the WSPR will, therefore,be designed to determine the extent of h_{FE} degradation and to determine the total permanent damage effect on circuit performance. In the diagnostic tests h_{FE} degradation will be measured. Degradation in other components such as diodes and resistors will be carefully evaluated.

3.4.2 Commercial Circuit Evaluation Tests

(a) Gate Circuit Tests

The degradation of transistor current gain, h_{FE}, as neutron dose is increased will be determined in several different ways. For RTL and RCTL gate circuits, which have accessible transistors in the circuit, h_{FE} will be measured by injecting base current directly into the base resistor as shown in Figure 3.4-1.

For DTL gate circuits h_{FE} degradation will be determined indirectly by testing the circuit as shown in Figure 3.4-2. This method of measurement allows the circuit to operate in its normal ON state. A fixed base current is supplied by the circuit's input voltage divider and the output current I_L is measured. The battery voltage, V, is made equal to the maximum allowable output ON voltage, $V_0^{max}(ON)$. I_L will then be determined by the transistor current gain, h_{FE}.

$$I_L = h_{FE}\ I_B - \left[\frac{V_{cc} - V_0(ON)}{R_3}\right] \qquad (3.4\text{-}1)$$

As h_{FE} decreases, I_L will decrease and $V_0(ON)$ will increase until $V_0(ON) = V_0^{max}(ON)$ at which time I_L will be zero. This condition represents complete circuit failure since the circuit can no longer supply any load current and still maintain the required output voltage for the ON state, $V_0^{max}(ON)$.

The output ON voltage, $V_0(ON)$, will also be measured after each reactor burst for all gate circuits. This measurement was described in section 3.2.4 (g) and will be made with maximum fan-out. This measurement together with a measurement of h_{FE} degradation will determine the point of circuit failure, whether due to a failure to meet noise margin specifications or due to circuit inability to supply the required load current. These measurements will be made on specially developed Hughes semi-automatic data recording equipment which will be described in Section 4.

(b) Multivibrator Tests

Multivibrator circuits are usually operated under dynamic conditions in any system application. The trigger inputs to most of the multivibrator circuits to be tested in this program are capacitively coupled. These two factors make it desirable to perform dynamic operating tests on these circuits between reactor bursts since failures due to the degradation of dynamic characteristics may occur before failure due to the degradation of d.c. parameters such as h_{FE} and V_0 (ON).

Trigger level sensitivity at the circuit input is one of the most important dynamic characteristics of a bistable or monostable multivibrator. A constant output pulse width is also extremely important in the performance of a monostable multivibrator. For these reasons the multivibrator circuits will be tested dynamically after each reactor burst. The circuit input pulse will be automatically varied in amplitude, and the circuit input and output will be displayed simultaneously on a dual beam oscilloscope. In this way the trigger sensitivity of the circuit will be measured. The presentation will be photographed under varying load conditions on a semi-automatic data recording camera.

As h_{FE} of the individual transistors in the circuit decreases, the allowable fan-out will decrease. Data will therefore be recorded for two different simulated fan-outs during each circuit test. Approximate values of $V_0(ON)$ and $V_0(OFF)$ can be obtained from the photographs of circuit outputs.

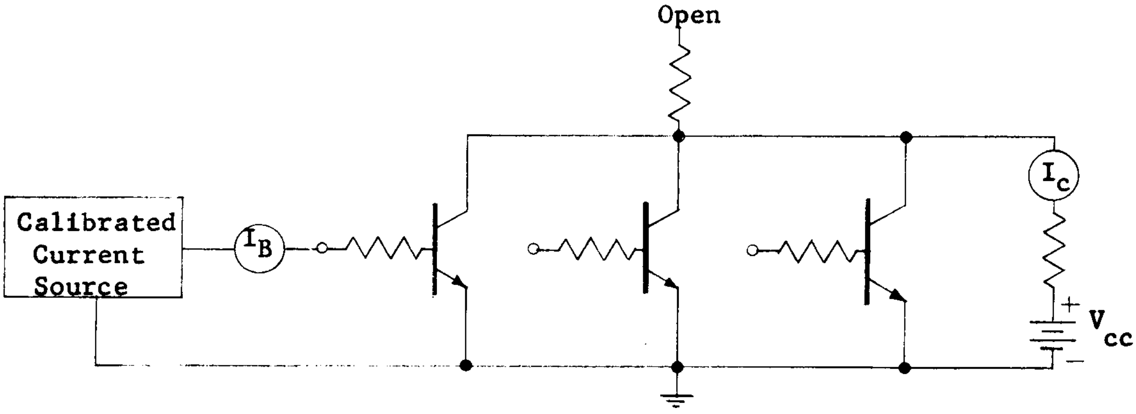


FIGURE 3.4-1 h_{FE} MEASUREMENT FOR RTL CIRCUIT

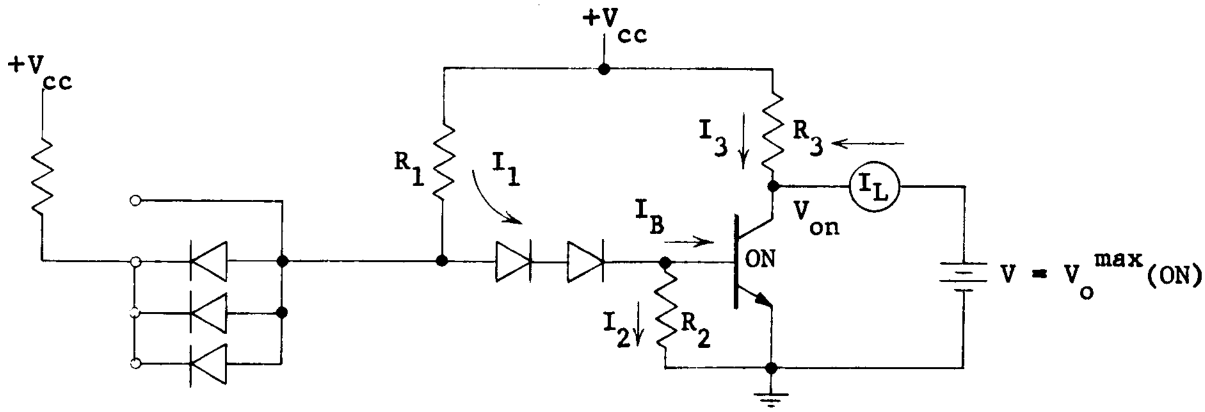


FIGURE 3.4-2 MEASUREMENT OF LOAD CURRENT FOR DTL CIRCUIT

(c) Summary of Tests

The data to be recorded after each reactor burst are summarized in Table 3.4-1 for the various types of circuits discussed.

	DTL	RTL	RCTL
GATES	I_L V_O(ON)	h_{FE} V_{SAT}	h_{FE} V_{SAT}
MULTIVIBRATORS	Trigger Sensitivity V_O(ON) V_O(OFF)	Trigger Sensitivity V_O(ON) V_O(OFF)	Trigger Sensitivity V_O(ON) V_O(OFF)

TABLE 3.4-1 EVALUATION TESTS FOR COMMERCIAL CIRCUITS

The measurement of the d.c. and switching parameters discussed in section 3.2 before and after the complete reactor test series will provide additional degradation data for all circuits.

3.4.3 Diagnostic Circuit Tests

The diagnostic permanent damage tests will be performed on special circuits, described in Section 2.3, which provide access to the individual components. Although damage effects are expected to affect only transistors and diodes at doses up to 10^{13} $N_f$vt, the other circuit components will be studied carefully for damage effects.

The specific components available in the three types of circuits to be fabricated are transistors, diodes, and resistors. Each component will be studied for changes in its electrical parameters.

For the transistors, measurements will be made of the degradation of h_{FE} since this is the major damage effect in transistors. For additional information, changes in V_{SAT} will also be measured. h_{FE} will be measured at three different transistor emitter current values: 5, 10, and 15 ma. These measurements will be accomplished by fixing the emitter current of the transistor and measuring the resultant base current. The collector saturation voltage, V_{SAT}, will be measured by fixing the base current at a value large enough to ensure saturation of the transistor at the lowest expected value of transistor beta, and measuring the collector voltage, V_{SAT}.

A constant forward current of 2 milliamperes will be impressed on each diode and the forward voltage drop measured.

Resistors will be investigated for change in resistance due to radiation. A constant voltage will be applied across the series combination of test resistor and a load resistor. The voltage at the intersection of the two resistors will be monitored. Since the load resistor will remain fixed, any change in monitored voltage will be proportional to a change in resistance of the test resistor.

4. INSTRUMENTATION

4.1 Introduction

The instrumentation requirements of this study program are divided into three major instrumentation systems. The first system was designed to measure the a-c and d-c parameters of the integrated circuits listed previously. Special equipment for measuring d-c parameters has been modified to meet the specific requirements of this program.

The second system was designed to measure the transient radiation response of circuits by semi-automatic test methods. The basic system was developed under a previous DASA sponsored program at Hughes. Modifications have been made under this contract to adapt the system to integrated circuits.

The third system is designed to measure the parameter degradation of a large number of integrated circuits as a function of absorbed radiation dose. The system to be used has been employed by Hughes to measure the parameters of a large number of transistors and diodes during the time periods between pulsed reactor bursts. The system is now being modified to accommodate integrated circuits. The original system measured only d-c paramters. A test circuit programmer and an automatic 35 mm data recording camera have been added to the system in order to record the dynamic performance of the multivibrator circuits. This camera will also be used to record the voltage transfer characteristics of the various circuits before and after radiation tests.

A detailed description of each instrumentation system follows.

4.2 Laboratory Bench-Test Instrumentation

4.2.1 Introduction

In order to measure several a-c and d-c parameters for a large number of integrated circuits of various types, it is necessary to develop an instrumentation system that will enable the test operator to perform the tests rapidly and accurately.

The system to be described is divided into three sub-systems:

(a) d-c Parameter Tester -- measures d-c currents and voltages.

(b) a-c Parameter Tester -- displays circuit switching characteristics on an oscilloscope. Switching times are read from the oscilloscope presentation and manually recorded.

(c) Voltage Transfer Characteristic Recorder -- displays input voltage vs output voltage transfer characteristic on an oscilloscope. This presentation is photographed and the required data are later read from the photograph.

These three sub-systems will now be described in detail.

4.2-2 D-C Parameter Tester

The d-c parameter tests on integrated circuits require precision voltage and current measurements. The system shown in the block diagram of Figure 4.2-1 performs these measurements and the test results are read out on a Keithley 150A millivoltmeter as the test selector switches are manually stepped through the test sequence for a particular circuit.

The following sequence illustrates the normal test procedure for a typical integrated circuit test.

(a) Place circuit in test socket.

(b) Adjust 10 x 10 crossbar switch to adapt test circuit lead configuration to that required for a particular test.

(c) Turn test selector switch to desired test.

(d) Diode relay control matrix then selects the proper relay from a group of 31 relays. The relays in turn select the proper test voltages and currents and connect the Keithley 150A millivoltmeter to the proper test circuit configuration for the test selected.

Voltages are measured directly on the Keithley 150A millivoltmeter. Current measurements are made by measuring the voltage drop across a "small" sampling resistor placed in series with the current path. The term "small" resistor means that its value is negligible compared with the circuit resistance in series with it, and the voltage developed across it is negligible compared with the voltage applied to the circuit being tested. This measurement is indicated in Figure 4.2-2.

4.2.3 A-C Parameter Tester

The a-c parameter tests for integrated circuits require precision time measurements. The system shown in Figure 4.2-3 will perform these measurements with the required accuracy.

These a-c measurements require a pulse generator (Rutherford B-2A), an oscilloscope with a good frequency response (Tektronix 585), and a crossbar switch for adapting the various lead configurations of integrated circuits to the test circuit.

The output voltage response of the integrated circuit under test is observed simultaneously with the pulse input to the test circuit. The switching times are then measured and recorded under typical loading conditions.

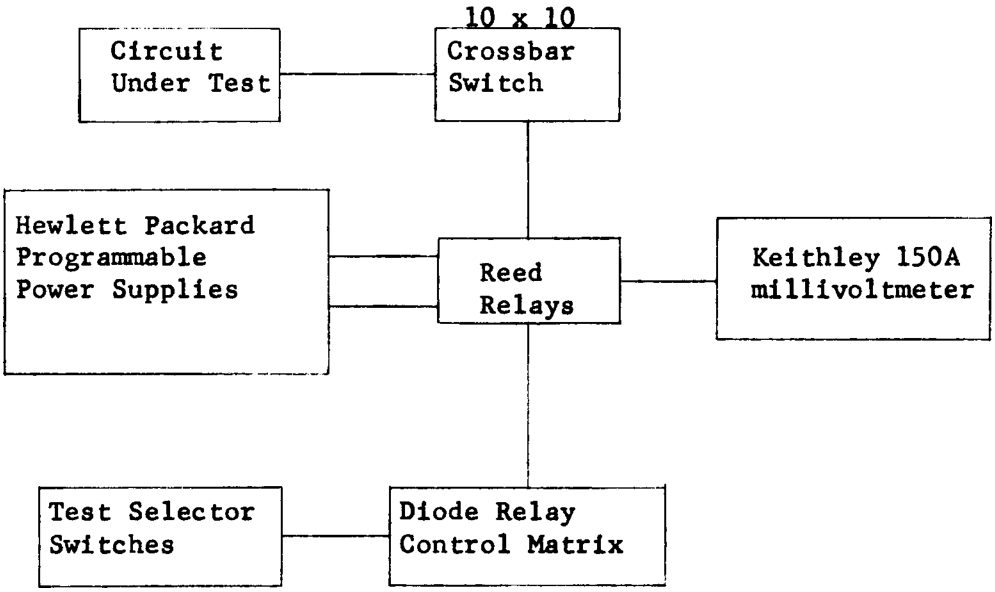


FIGURE 4.2-1 BLOCK DIAGRAM OF D.C. PARAMETER TESTER

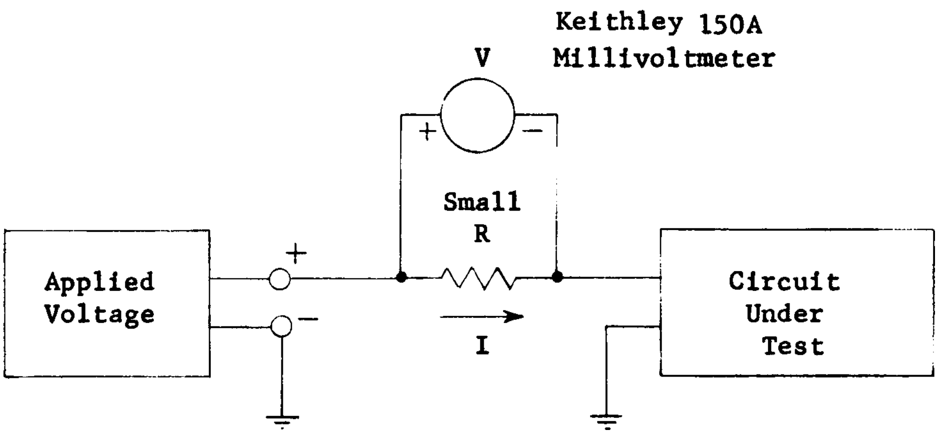


FIGURE 4.2-2 CURRENT MEASUREMENTS

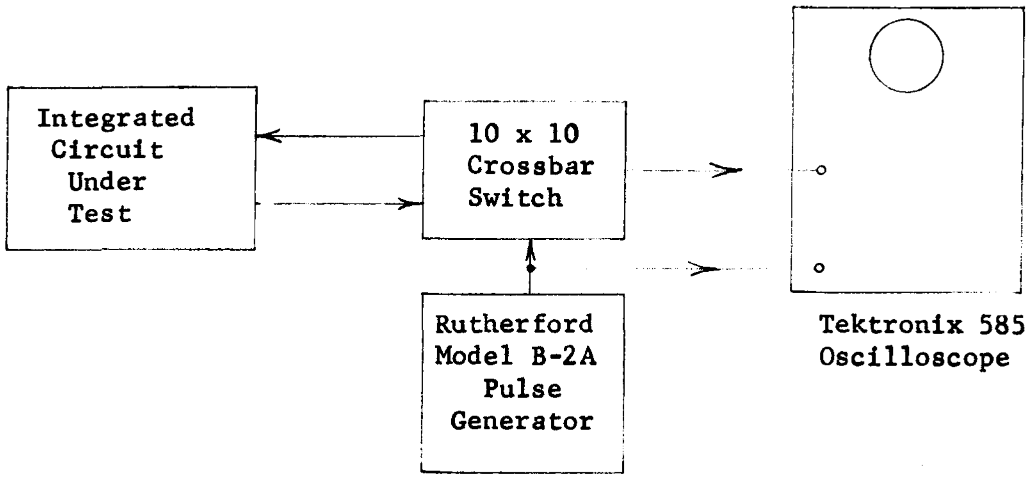


FIGURE 4.2-3 A-C PARAMETER TESTER

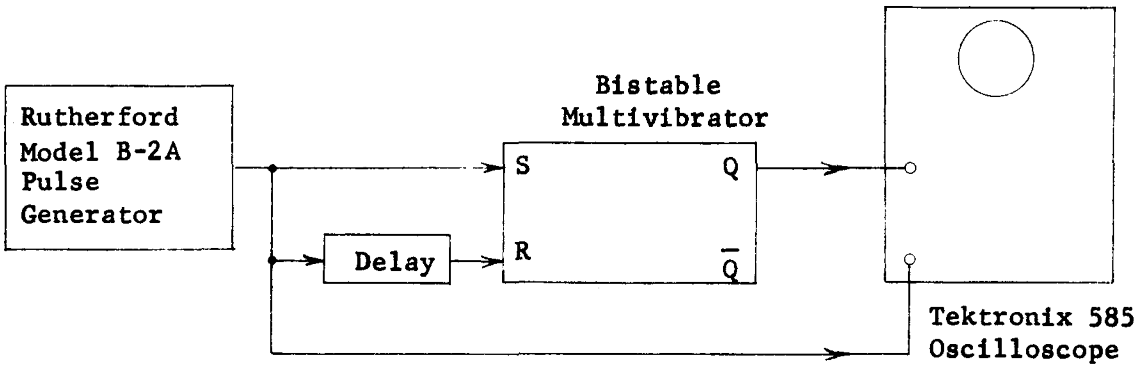


FIGURE 4.2-4 MEASUREMENT OF MAXIMUM FREQUENCY OF OPERATION

To measure the maximum frequency of operation for bistable multivibrators (flip-flops) the measurement system shown in Figure 4.2-4 is used. This circuit includes a delay so that out-of-phase pulse inputs can be applied to the set and reset inputs of the flip-flop. Increasing the frequency of the pulse generator output until the test circuit fails determines the maximum frequency of operation. Although it is not shown the crossbar switch is still employed to adapt various test circuit pin configurations to the test circuit.

4.2.4 Voltage Transfer Characteristic Recorder

The instrumentation required for measuring the voltage transfer characteristic is shown in Figure 4.2-5. This measurement requires a low frequency (100 cps)sine wave oscillator as an input voltage source and an oscilloscope with both X and Y amplifiers such as the Tektronix Type 536. This measurement is made for maximum loading conditions in order to minimize the noise margin. The oscilloscope display is photographed and the required data are measured from the photograph as described in section 3.2.4.

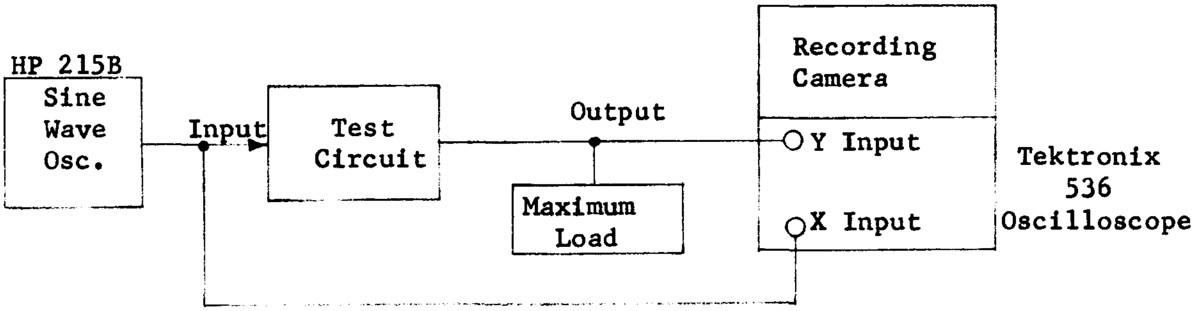


FIGURE 4.2-5 MEASUREMENT OF VOLTAGE TRANSFER CHARACTERISTIC

4.3 Transient Radiation Test Instrumentation

To maintain the statistical accuracy of a large number of circuit performance measurements in the transient radiation environment, it is necessary to insure that each circuit is tested under the same environmental conditions. To insure identical radiation environmental conditions, the following criteria must be met.

- Each circuit must be positioned to the same position in the radiation beam when under test.
- All circuits within any group whose radiation responses must be compared should be tested in the shortest time possible to eliminate radiation environment variations caused by long term changes in beam current and pulse shape.
- The same beam sensor should be used for establishing a radiation response standard for all test data which must be compared to insure identical radiation environments.

To meet these requirements Hughes has developed a remotely-controlled device positioner that will, upon command, automatically position several devices sequentially in the radiation beam to an accuracy of $\pm$ 0.01 inches in the x, y and z directions. This remote positioner has been modified for use with integrated circuits.

Figure 4.3-1 shows a diagram of the modified remote positioner. Thirteen sockets are mounted on a platform that moves to any pre-set position upon command. The sockets include six sockets for integrated circuits in multiple lead TO-5 cans, six sockets for integrated circuits in flat-packs, and one transistor socket for the beam sensor. The beam sensor is used to adjust the moveable platform in the radiation beam so that identical radiation environments can be maintained from one test series to the next.

As the socket platform moves the sockets sequentially into position, a set of gold plated contacts associated with that socket and mounted on the contact board beneath the sockets, moves to make contact with gold plated stationary contacts. The stationary contacts are connected to individual contacts on a 10 x 10 crossbar switch. The crossbar switch can be manually programmed to route any of the input, output or power supply lines to the required test circuit pins.

Beneath the crossbar switch, as shown in Figure 4.3-1, are several individual enclosures. These enclosures contain emitter followers, input and output load simulating circuits, batteries, and any other auxiliary equipment that might be required for a particular test.

A block diagram of the entire transient radiation test instrumentation system for integrated circuits is shown in Figure 4.3-2.

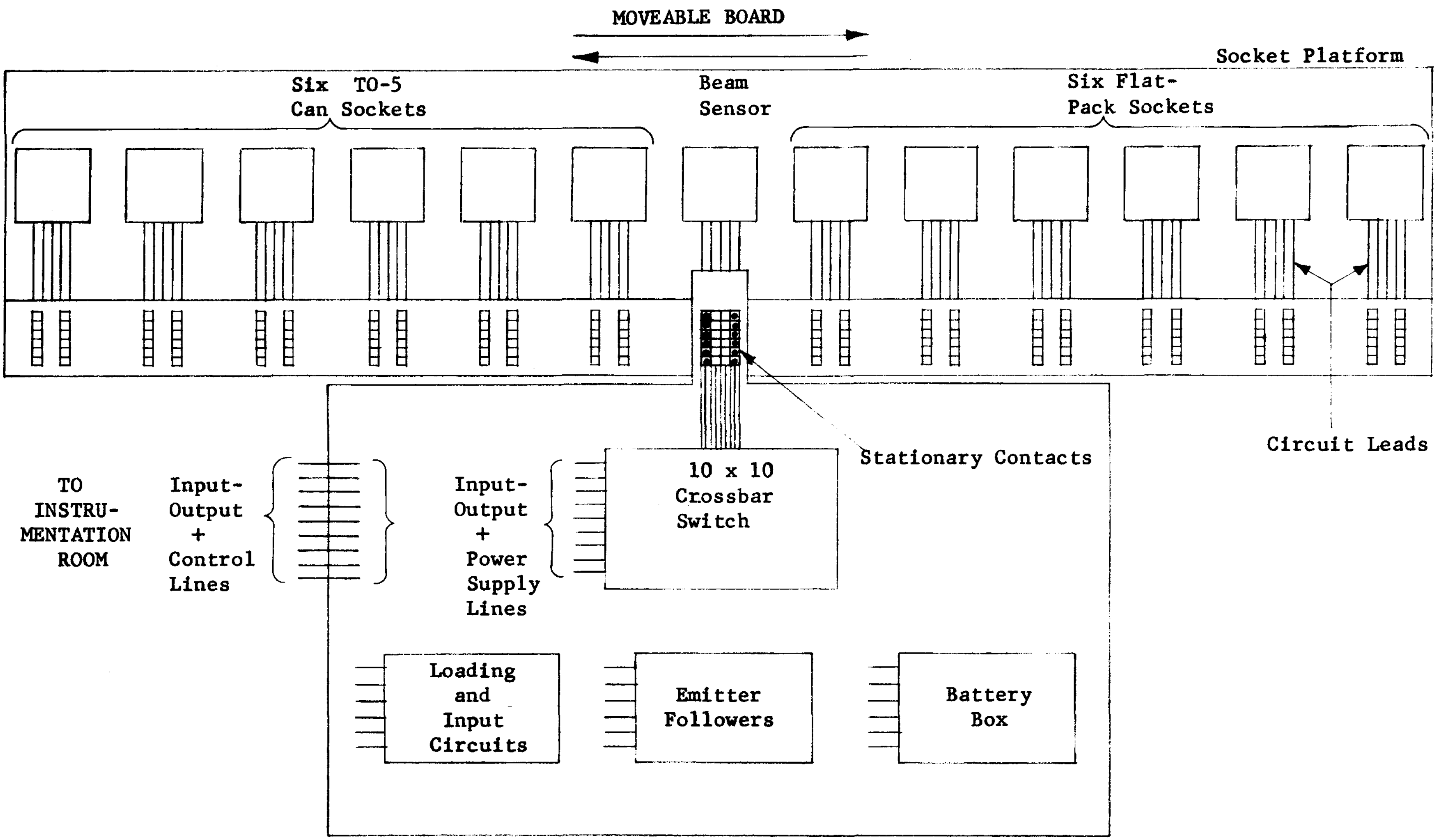


FIGURE 4.3-1 REMOTE POSITIONER FOR TESTING INTEGRATED CIRCUITS

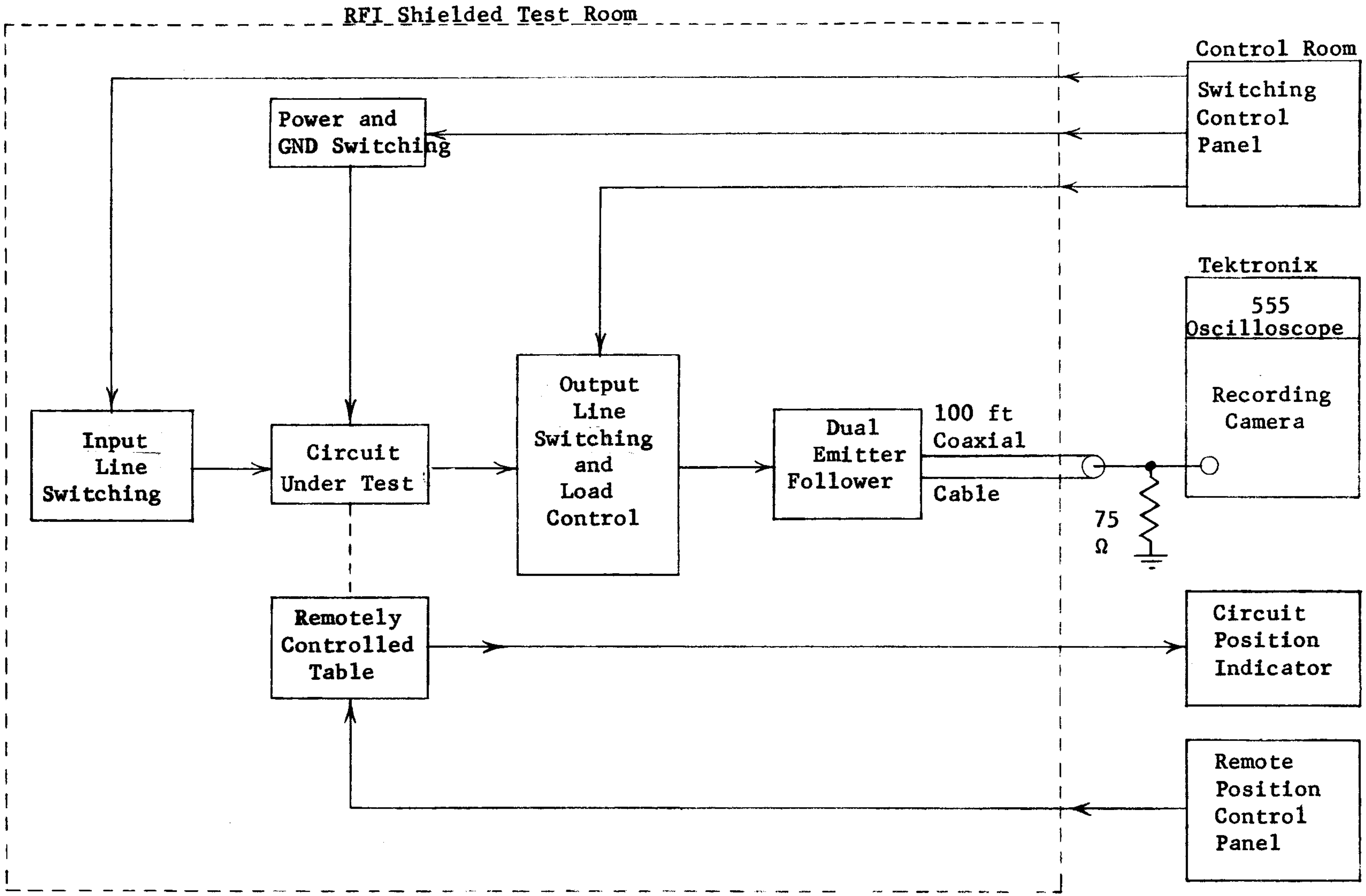


FIGURE 4.3-2 BLOCK DIAGRAM--TRANSIENT RADIATION TEST INSTRUMENTATION

This system allows a complete series of tests to be performed on a group of six identical test circuits without entering the radiation test area. The only need for entering the radiation test area is to change circuits and adjust and record their positions when located in the radiation beam. The switching control panel allows the test operator to remotely perform the following operations:

- Turn test circuit to OFF or ON state.
- Control circuit loading.
- Control emitter-follower inputs to monitor various circuit test points.
- Control circuit applied voltage.

All circuit transient radiation responses will be measured by means of emitter-follower probes. Emitter-follower probes are necessary because the integrated circuits to be tested must be monitored over long coaxial cables. These cables must be terminated in their characteristic impedance in order to preserve the rise and fall times of transient radiation responses, prevent reflections and minimize electromagnetic noise pick-up. The circuits to be tested cannot drive low impedance loads (< 100 ohms) and therefore an impedance matching device is required. Past Hughes experience has shown that the emitter-follower is an ideal device for this purpose.

The emitter-follower, the crossbar switch, and the function switching system will be shielded or located in a position where they are not affected by the transient radiation pulse. The radiation test area is enclosed by an RFI shielded room so that elaborate RFI shielding is not necessary.

A group of test circuits can be tested at several different dose rates in a very short time by this method of automated testing. This test set-up, developed by Hughes, has been employed on previous contracts and has proven very efficient in obtaining transient radiation effects data for a large number of test devices. This special testing capability makes it possible to perform the very large number of transient radiation response measurements required for this program.

4.4 Pulsed Reactor Test Instrumentation

4.4.1 Introduction

The circuits to be tested will be mounted on a curved board located at a fixed distance from the reactor, the distance being chosen to provide a specific dose per burst to each circuit. The total dose to be accumulated during these tests is to be 10^{13} $N_f vt$ at minimum.

The instrumentation for these tests will consist of two systems: one, for the gate circuits and the other, for the multivibrator circuits, since these require different kinds of measurements. The first system automatically records the d-c parameters in digital form for all gate circuits and for the diagnostic circuits. The second system automatically records photographs of input and output pulses for the multivibrator circuits.

4.4.2 Automatic D-C Data Recording System For Gate and Diagnostic Circuits

The efficient determination of parameter degradation for a large number of integrated circuits as a function of absorbed radiation dose requires an automatic means of measuring and recording of the parameters after each period of irradiation. Such a system has been used by Hughes to measure and record up to 2400 d-c parameters on transistors and diodes during a period of less than 40 minutes between bursts at a pulsed reactor. This same system will be adapted to the d-c parameter measurements required in this program for integrated circuits.

A block diagram of the present Hughes system is shown in Figure 4.4-1. Test circuits are selected sequentially by the test selector. The circuit test conditions are also sequentially controlled so that the proper inputs are connected to the test circuit at the proper time. The outputs of the test circuits are routed to either a d-c amplifier or an ac-dc converter depending on whether a 1KC a-c or a d-c measurement is being made. A voltage-to-frequency converter produces an output frequency proportional to the magnitude of the measured quantity. Settling time is required in the system to allow the frequency reading to stabilize. After this time has elapsed the sample gate is opened, the frequency is determined and the measurement is read out on printed paper tape. Auxilliary information is printed simultaneously with the data measurement and includes the circuit number, test number, and circuit group number.

The Test Selector in Figure 4.4-1 is located near the reactor with the circuits and will be wired to provide all the test conditions required for the measurements to be made on gates as described in Section 3.4. This includes also the circuit conditions for the measurement of the degradation of the components in the diagnostic circuits.

The remainder of the system is located in a van outside of the reactor room. From the van the testing sequence is initiated, and the data is processed and recorded automatically. Punched paper tape data readout and automatic sorting, processing, and plotting of the data is also available. The accuracy of the data system is $\pm 1\%$ of full scale.

4.4.3 Automatic Photographic Data Recording System For Multivibrator Circuits

A functional block diagram of the Photographic Data Recording System is shown in Figure 4.4-2.

After each reactor burst the automatic photographic data recording sequence will be initiated upon command from the instrumentation van.

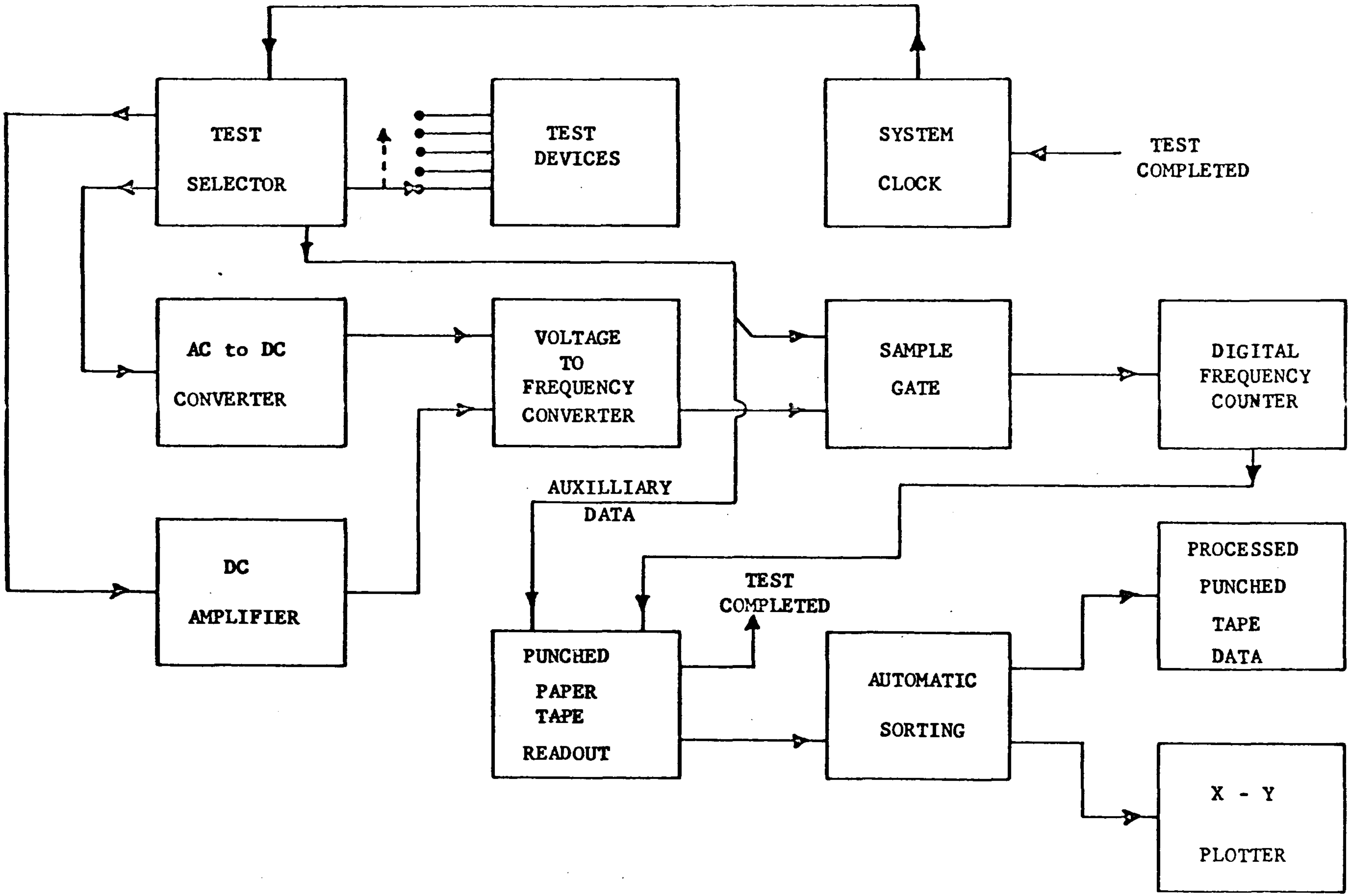


FIGURE 4.4.-1 AUTOMATED PARAMETER MEASUREMENT SYSTEM

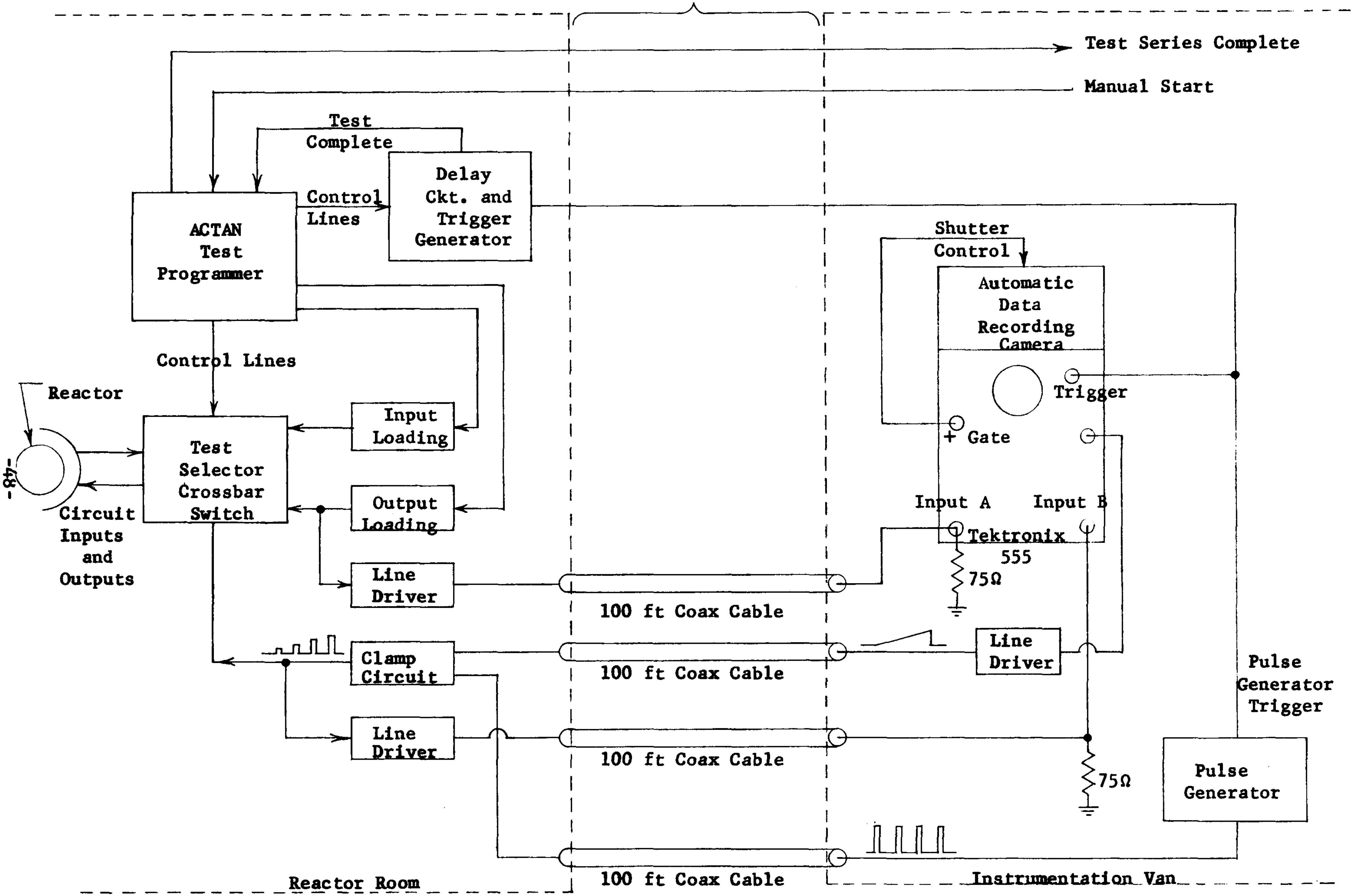


FIGURE 4.4-2 AUTOMATIC PHOTOGRAPHIC DATA RECORDING SYSTEM

The test programmer will then step through the required sequence of tests operating the test selector crossbar switch each time a new test begins. The test programmer also controls the fan-in and fan-out for the circuit under test. The test selector switch controls the input and output lines from the test circuits and sequentially routes them to the test equipment in the instrumentation van. The test circuit output line from the test selector switch goes to a line driver and through a coaxial cable to an oscilloscope in the instrumentation van where the circuit response is photographed. The test circuit trigger input line comes from a clamp circuit located in the reactor room.

The clamp circuit develops a variable amplitude pulse train which starts at zero amplitude and increases to a maximum value. At some intermediate amplitude the trigger threshold of the circuit is reached. The variable amplitude pulse train is derived from a pulse generator and the horizontal sweep output of the oscilloscope. The pulse train is connected to the oscilloscope B input where it is photographed along with the circuit output.

The test programmer also operates a delay circuit. This delay circuit produces an oscilloscope trigger pulse, and a "test-complete" pulse which have the timing sequence necessary to operate the system properly. The oscilloscope trigger pulse starts the oscilloscope sweep and triggers the pulse generator. The "test-complete" pulse causes the test programmer to step to the next test circuit.

Line drivers are required to drive the low impedance coaxial cables which connect the instrumentation van to the radiation test area.

A more detailed description of the important units of this system is presented in the following paragraphs.

(a) <u>Test Programmer</u>

An Actan drum programmer controls the crossbar switch and other required switching functions. This programmer consists of a cylindrical drum with program cams located on its circumference. The drum is sequentially stepped at predetermined times. At each step of the drum, selected contacts from a set of 38 contacts are operated by the program cams. The cams are manually inserted prior to the tests in such a way as to properly select the circuit input - output lines, loading, etc. for a series of 150 circuit tests. The programmer automatically steps through all circuit tests until the test series is completed.

(b) <u>Test Circuit Selector</u>

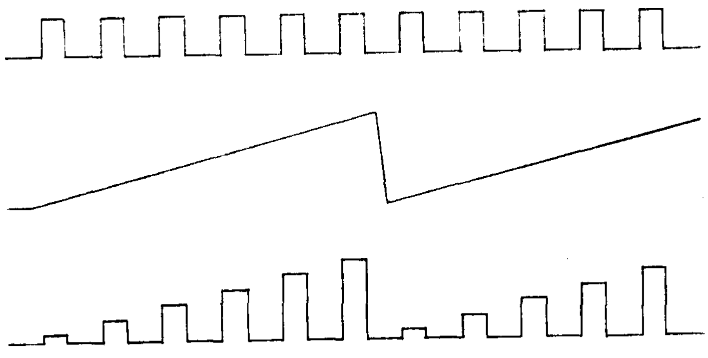
A 10 x 10 x 6 level crossbar switch provides the switch contacts necessary to control the inputs and outputs of 150 test circuits. Upon the command of the programmer, the crossbar switch operates and the input and output leads of the selected test circuit are connected to the voltage, current and loading conditions required for various multivibrator circuit tests described in Section 3.4.2. The crossbar switch has gold contacts which minimize contact resistance problems.

(c) Automatic Data Recording Camera and Oscilloscope

A pulse operated camera, which is controlled by the trigger generator, is mounted on an oscilloscope and records the input trigger level sensitivity and the output waveform for all multivibrator test circuits. This camera photographs oscilloscope patterns on 35 mm strip film and advances the frame upon remote command. The film is automatically processed within the camera and can be viewed 17 frames after exposure.

(d) Clamp Circuit

This circuit mixes the output of a pulse generator with the horizontal sweep output of the oscilloscope to provide a series of one microsecond pulses of varying amplitude as shown in Figure 4.4-3. These are used to trigger the flip-flop and give a measure of the trigger threshold at which the circuits operate.



Pulse Generator Output

Sawtooth Generator Output

Pulse Train Generator Output

FIGURE 4.4-3 PULSE TRAIN GENERATION

5. ACCOMPLISHMENTS

The program planning and instrumentation design have been completed for Phases 1 and 2 of the overall program. The specific achievements of the first quarter are as follows:

- All circuits have been obtained from the vendors with the exception of those from T.I. Early delivery of these circuits is assured. Manufacturing process information has been requested of each vendor but only Siliconix and Signetics have complied. The Microelectronics Division of Hughes Aircraft Company has provided the modified DTL circuits requested along with detailed manufacturing data on fence breakdown voltages, diffusion depths and profiles, resistivity of each diffusion, gold doping concentrations, transistor parameters, etc.

- The laboratory bench test instrumentation has been constructed, and the bench test measurements have been completed on all of the circuits received from the vendors.

- The instrumentation for the transient radiation effects measurements at the Hughes Research Linac has been constructed and is ready for the tests in September. These tests will provide detailed data on transient radiation effects in available commercial circuits and will, thus, provide an evaluation of the vulnerability of these circuits to transient disturbances in nuclear weapons environments.

6. PLANS FOR NEXT QUARTER

In the second quarter final preparations will be made for the Linac and pulsed reactor tests for Phases 1 and 2 of the program. Completion of the laboratory bench tests of the circuits will be necessary before the radiation tests begin.

The Linac tests are scheduled in September, and the instrumentation will require assembly and final check-out in position at the Linac. These tests will include both the circuit evaluation (Phase 1) and the diagnosis (Phase 2) of transient radiation effects in the circuits. The diagnosis will be aided by special circuits with access leads to various points of the circuit. These will be fabricated by the Microelectronics Division of Hughes during the second quarter in time for the diagnostic tests.

The pulsed reactor tests are scheduled in November at the White Sands Pulsed Reactor (WSPR). These tests will provide data on permanent damage to the circuits for both circuit evaluation (Phase 1) and diagnosis (Phase 2). Much of the second quarter will be devoted to the construction and assembly of the instrumentation for these tests.

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13. ABSTRACT

The first quarter of the program has been devoted entirely to the preparation of devices and instrumentation for the radiation tests. The circuits have been procured and subjected to a thorough pre-irradiation test in the laboratory. This report describes the circuits chosen for study and the measurements made in the laboratory bench tests.

All of the instrumentation to be used in this program is described in detail in this report. This includes the instrumentation for (1) the laboratory bench tests, (2) the Linac transient radiation effects tests, and (3) the pulsed reactor permanent damage tests.

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