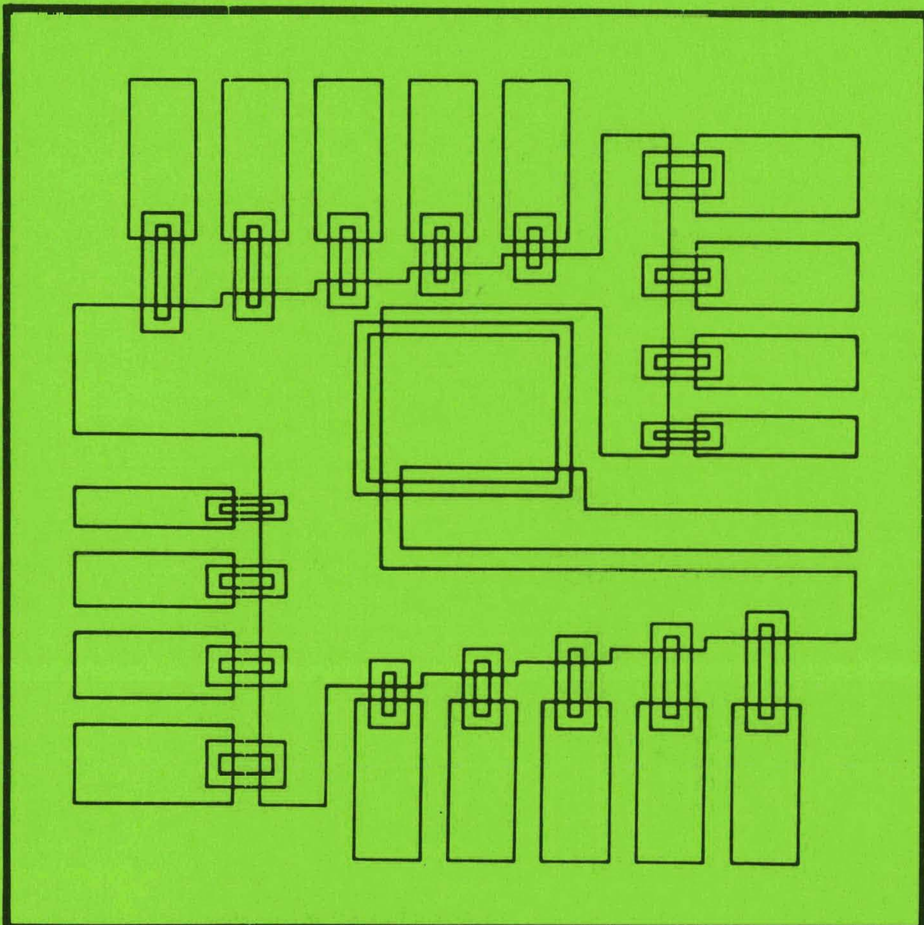
Junction Field Effect Transistor Degradation Caused by Electrostatic Discharge



BDX-613-815

December, 1972

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Prepared for the U. S. Atomic Energy Commission
Albuquerque Operations Office under Contract
Number AT(29-1)-613 USAEC.

Bendix Kansas City Division

DISCLAIMER

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Technical Communications

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JUNCTION FIELD EFFECT TRANSISTOR DEGRADATION CAUSED BY ELECTROSTATIC DISCHARGE

BDX-613-815, UNCLASSIFIED, Distributed December 1972

Prepared by W. J. Kirk, D/845

Electrostatic buildup of several hundred volts on the body of an operator is common in a low-humidity environment. This charge across measured 100- to 400-pF distributed capacitances of the human body may be discharged into a low-current FET, thereby degrading or destroying the gate-drain junction. Experiments have shown that static charges as low as 140 volts may damage JFET junctions and that normal body equivalent series resistance (less than 1000 ohms) does not limit the flow of current significantly. Safeguards against the effects of static discharge on JFET junctions during assembly and handling are therefore necessary.

THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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SUMMARY

A literature search and physical experiments were conducted to determine the effects of electrostatic discharge on four types of junction field effect transistors (JFET's) that are required in a new electronic assembly. These JFET's had not been used previously in a low-humidity manufacturing environment; therefore, preparations for production required that processes and facilities necessary to ensure product performance and reliability be evaluated. Common knowledge that the gate-drain junction of FET's is susceptible to damage from electrostatic discharge prompted special attention to this phase of the work.

Electrical models of the human body were devised and tests were conducted to determine approximate values of capacitance and equivalent series body resistance that can be expected at typical work stations, the electrostatic potentials that can be expected on the bodies of operators, and the effects of discharging electrostatic energy into the high-impedance low-current JFET's that are to be used in this assembly.

Tests to determine the effects of electrostatic discharge on the JFET's resulted in several significant findings:

- A 2N4118A, the most susceptible of the four types tested, was degraded by a static discharge from the body of an operator charged to only 140 volts. This energy level is about 1/100 of that required to detonate an explosive hydrocarbon gas.[14]

- Many samples of the four types of JFET's were degraded by static voltage, but remained functional in assemblies. This posed a potential reliability problem which was solved by including an additional test to the in-process inspection procedure.

- Measured operator body capacitances of 90 to 405 pF were much more significant than measured equivalent body series resistances of 87 to 190 ohms when considering the JFET static damage potential.

Study and evaluation of static prevention methods will be continued to determine the most effective means of preventing JFET junction damage in production assemblies. Humidity control, operator clothing, fixturing, and grounding techniques such as conductive floors and work surfaces are some of the aspects to be considered.

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DISCUSSION

SCOPE AND PURPOSE

This work was conducted as a part of preparations for manufacturing an electronic assembly that contains four junction field effect transistors (JFET's) which had not been used previously in a low-humidity production environment. Common knowledge that FET's are susceptible to junction damage caused by electrostatic discharge prompted this investigation to determine the problems that might be encountered and the safeguards necessary to ensure product reliability.

The electrostatic-control work includes

- Determining the effects of various static voltages on the JFET's,
- Establishing the maximum allowable value of static voltage for each of the four JFET types, and
- Developing procedures to ensure that allowable static voltage values are not exceeded in environments of 5- to 50-percent rh.

When the necessary static-control techniques have been developed, they will be applied to

- JFET lead forming and pretinning,
- Fixturing and assembly operations,
- JFET and assembly testing, and
- Special JFET packaging, both in and out of assemblies.

ACTIVITY

JFET Static Damage

The four JFET types were tested to determine which is the most susceptible to damage from static electricity. A capacitor was charged to a known voltage, then discharged through the gate-drain junction of the JFET, as shown in Figure 1. The results of those tests (Table 1) show that the 2N4118A is the most susceptible of the four types to static discharge and that all of the four types are more sensitive to reverse breakdown polarity than to forward conducting polarity.

Table 1. Effects of Capacitance and Voltage Polarity on Static Catastropic Failure of JFET's

JFET Type	2N2608 (P Channel)				2N3112 (P Channel)				2N3971 (N Channel)				2N4118A (N Channel)			
Voltage Polarity	Reverse Breakdown		Forward Conducting		Reverse Breakdown		Forward Conducting		Reverse Breakdown		Forward Conducting		Reverse Breakdown		Forward Conducting	
Capacitance (pF)	218	425	218	425	218	425	218	425	218	425	218	425	218	425	218	425
Test Voltage																
170														C		
255													CC			
340									CX	X						
425										C						
510										C						
595		C														C
680																C
765									X						C	
850		X						C								
935																
1020					X											
1105																
1190																
1275					C											
1360								C								
1445			C				C									
1530	PP	PP	PP	PP		P	P	P			PP	P				

Procedure:
The gates received one discharge pulse at each test voltage in sequence (starting at 170 volts) until failure occurred (see Figures 1, 2A and 2B. No series resistance was used in the tests.

Key:
C = Catastrophic failure
X = Catastrophic failure after passing 1530 v reverse polarity
P = Passed
Each letter represents one data point.

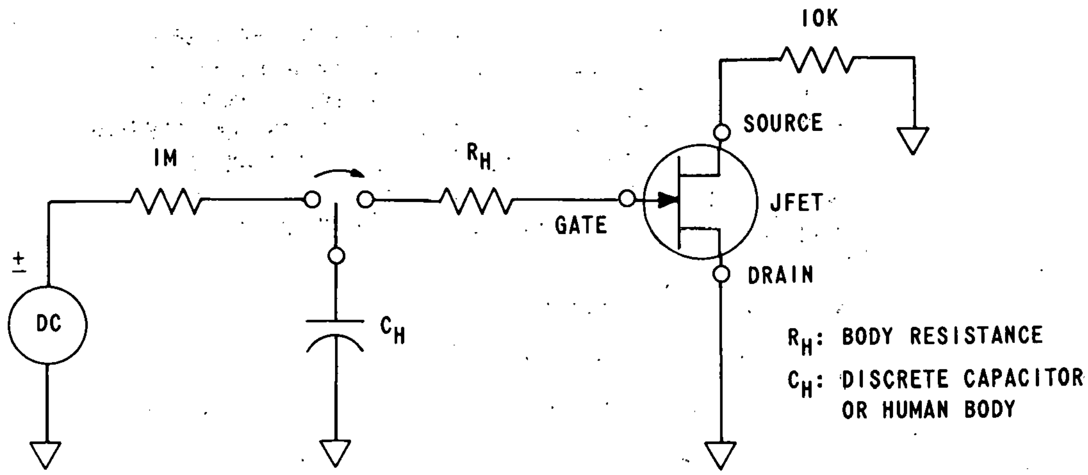


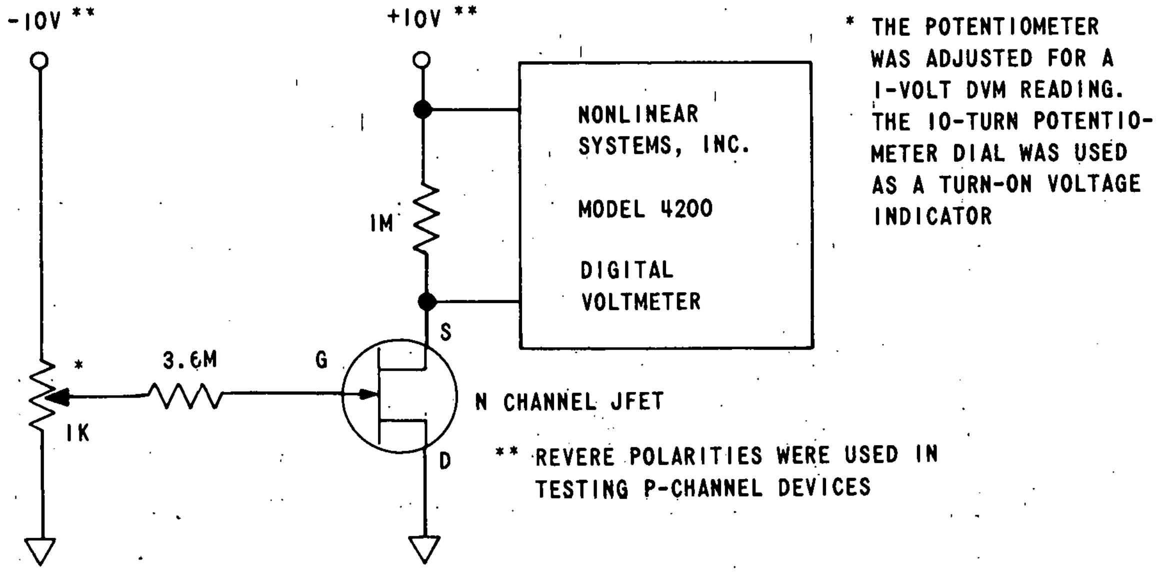
Figure 1. Static Discharge Test Circuit

The failure criterion for these first tests was a change in either turn-on voltage (gate-drain) or saturated source current. The test circuits are shown in Figure 2.

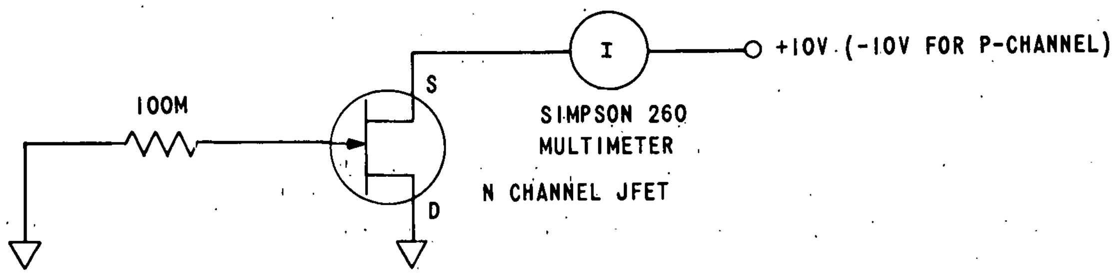
The results of this catastrophic test were so inconsistent and the voltages were so high that the validity of the test method was reviewed. Although the method simulated the product usage, it did not indicate the point of first transistor degradation. Therefore, four 2N2608 transistors that still passed the catastrophic failure test after stressing to ±1500 volts were subjected to complete electrical tests which revealed that the gate reverse breakdown voltage was grossly reduced. Postmortems of these units revealed dark brown burn paths between the gate and the drain elements, as shown in Figure 3.

The test circuit was modified as shown in Figure 2C to use gate breakdown voltage as the test criterion. This part of the work showed that it is possible that a degraded JFET in an assembly might not be detected by the present product test procedure. Since long-term product reliability is a paramount requirement, these tests emphasized the need for static protection.

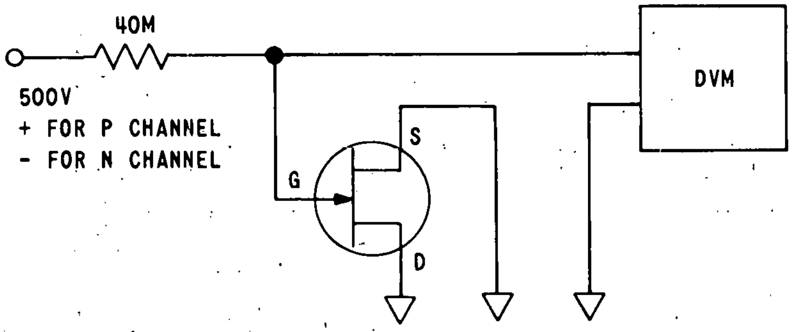
Sensitivity to reverse breakdown voltage was used as the criterion to obtain the refined data of the effects of static voltage shown in Table 2. Most of the data points represent less-than- catastrophic degradation.



A. TURN-ON VOLTAGE FOR 1-MICROAMPERE SOURCE CURRENT



B. SATURATED SOURCE CURRENT



C. REVERSE BREAKDOWN VOLTAGE

Figure 2. JFET Test Circuits

Table 2. Effects of Capacitance and Voltage on JFET Degradation

JFET Type	2N2608			2N3112			2N3971			2N4118A						
													Charge on Body of Operator			
													Standing		Sitting	
													Power Supply Charge	Static Movement Charge	Power Supply Charge	Static Movement Charge
Capacitance (pF)	97	218	425	97	218	425	97	218	425	97	218	425	190	118	110	99
Test Voltage																
70																
85																
100												C				
120																
140											CCD	C	DD	C		DC
160								D		D			C	D		
190												D				
230													C		C	D
270	D									D						
320		D							C	D					D	
380			DDD						C					D		
450															D	
530		D			D	D	DD									
620		D						D	D							
730						DD										
860	X			D	D			D								
1000				D			D									
1105	D															
1190																
1275																
1360																
1445					C											
1530				P												

Procedure:
Each FET gate received one discharge pulse at each test voltage in sequence (starting with 70 volts) until the gate-drain breakdown voltage at 5 microamperes decreased significantly (Figures 1 and 2C). No series resistance was used in the tests.

Key:
D = Degraded
C = Catastrophic, reverse breakdown <3 volts
X = Degraded after passing 1530 volts reverse polarity
P = Passed
Each letter represents one data point.

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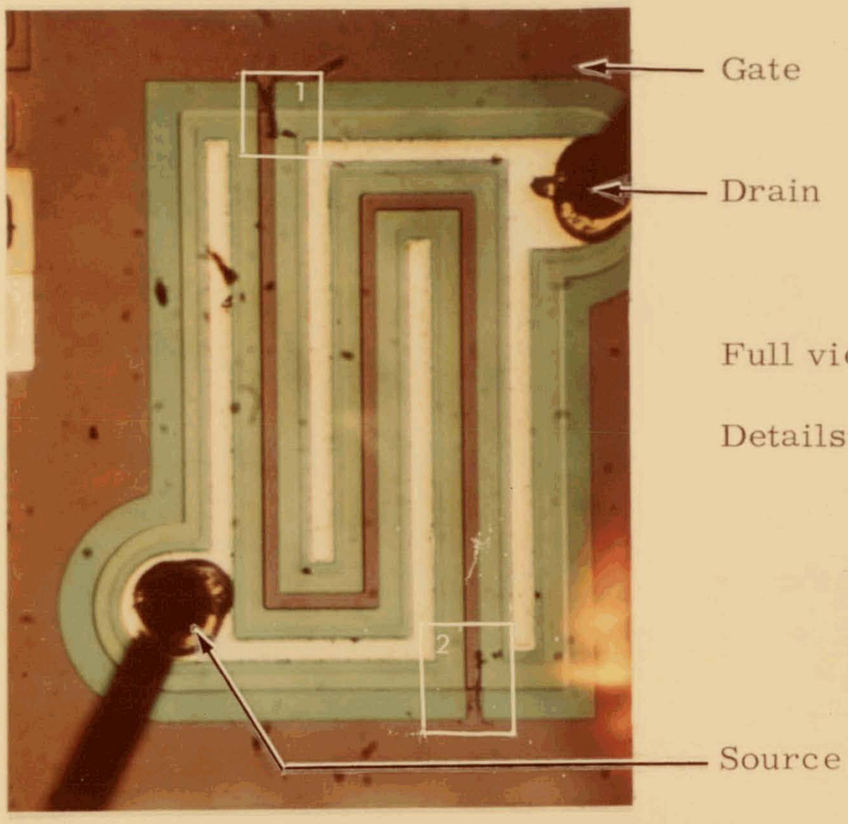

Full view at left is at 150X

Details below are at 1200X

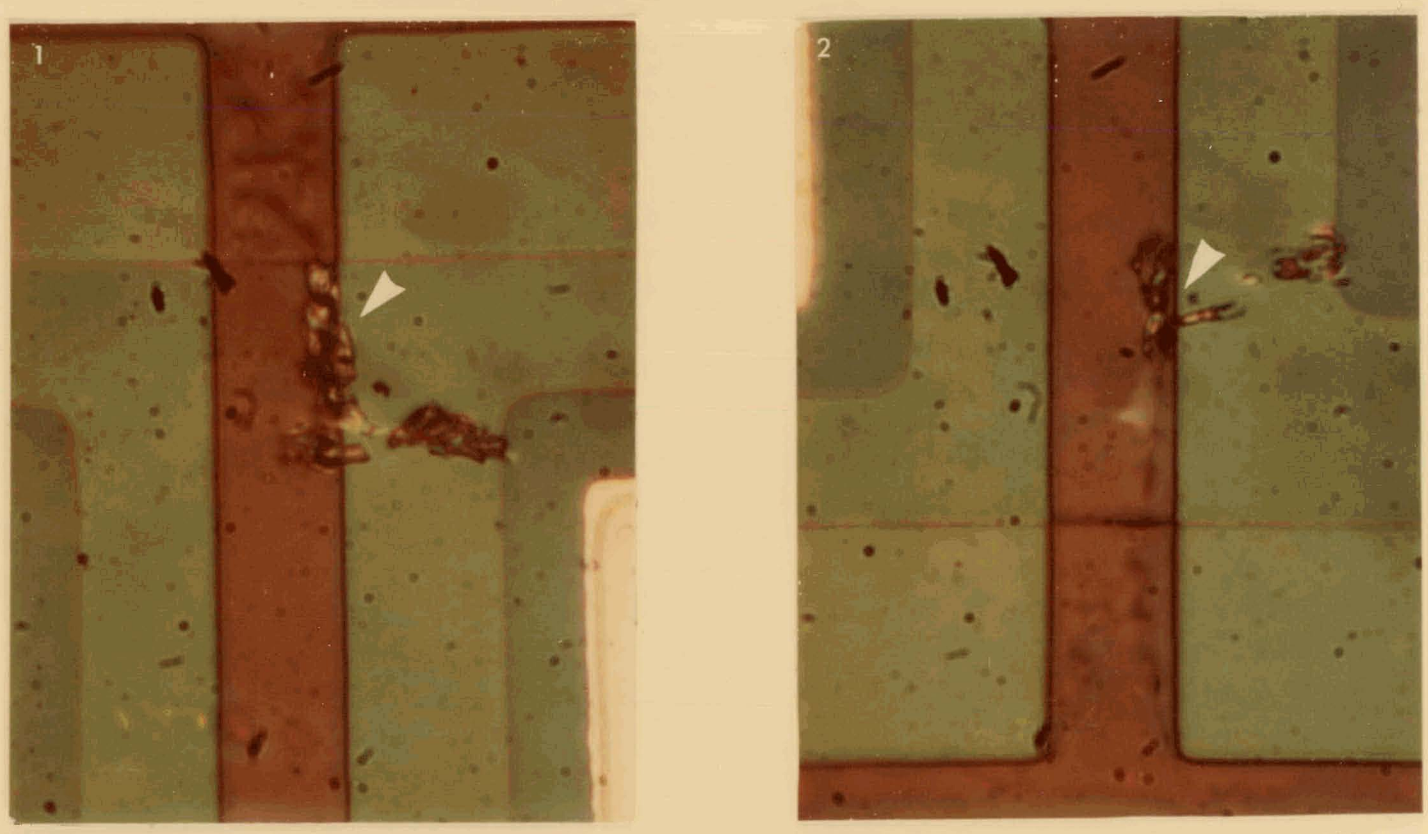

Figure 3. Degraded 2N2608 FET

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In the first Bendix controlled-condition experiments a discharge from a standing operator charged to 140 volts degraded a 2N41184 JFET. The energy discharge from a 218 pF capacitor charged to 140 volts is 2.1 microjoules, about 1/100 of that required to detonate an explosive hydrocarbon gas.[14]

The effect of the static discharge from the measured 190-pF distributed capacitance of a standing person on 2N4118A degradation was essentially the same as that from a 218-pF discrete capacitor. The effect of the measured 110-pF capacitance of an operator in sitting position was comparable to that of a 97-pF discrete capacitor. Since these capacitance values are not identical and body equivalent series resistance was not considered, the comparisons are only approximate. Exact values of body capacitance and voltage charge vary between individuals and depend on such factors as clothing, movement, proximity to surrounding objects, and moisture content in the atmosphere.

Energy Storage on the Human Body

A reasonably accurate energy-storage model of the human body must be used to obtain conclusive results of the effects of static energy on JFET's. A review of published literature revealed that a rather wide range of body capacitance and resistance values have been used by others.[1-14] These published values are listed in Table 3. Equivalent body resistance was reported to be a function of voltage,[3,5] but most models ignored that consideration.

Several different test methods were used to measure body capacitance under a variety of conditions. The results, shown in Tables 4 and 5, indicate that measured values are dependent on the test location and the test method used; however, the values obtained were in general agreement with the values given in the literature. Capacitances of 97, 218, and 425 pF used to obtain the data in Table 2 appear representative of the values expected at a typical work station.

The RC discharge method used to measure apparent body resistance was prompted by Petrick,[8] although the technique was altered slightly, as shown in Figure 4. The test results shown in Table 5 are somewhat inaccurate because of the methods used, but are considered sufficiently accurate for use in static tests. The apparent body resistance of one person varied from 87 to 190 ohms, and did not appear significantly voltage sensitive. The data in Table 6 indicate that body resistances below at least 1000 ohms offer no significant FET protection. For that reason, the effects of body resistance will not be investigated further. A slightly conservative but realistic value of 100 ohms will be assumed for continued work on this project.

Text continues on page 26.

Table 3. Published Values of Body Capacitance and Resistance

Purpose / Reference	C_H (pF)	R_H (ohms) Value	R_H (ohms) Test Voltage
Electronic Circuit Protection:			
Lenzlinger[1]	100	1500	*
Protection From Electrocution:			
Morse[2]	- - -	4000 to 15,000	*
Lee[3]	- - -	200 to 1000	>600 ac
Hewlett-Packard[4]	- - -	1000	*
Molinski[5]	- - -	5000 to 18,000	50 ac
		800 to 1800	500 ac
		800 to 1800	1000 ac
Friedlander[6]	- - -	1000 to 1600	*
Protection From Explosion:			
Montesi[7]	10,000	100	*
Petrick[8]	100 to 4000	- - -	*
Silsbee[9]	110 to 273	- - -	*
Schroeder[10]	600	500	*
Eichel[11]	100 to 400	- - -	*
MIL-I-23659B	500	5000	*
Taylor[12]	150	0	*
Pitts[13]	500	600	*
NFPA[14]	200	- - -	

*Test voltage not stated

Table 4. Human Body Capacitance to Earth Ground or to Metal Plate

Operator Position	Floor Covering	Measured Capacitance (pF)			
		D/845 T Laboratory		D/48 D Laboratory (10% rh)	
		Tektronix 130 LC Meter	RC Discharge[b]	Tektronix 130 LC Meter	Charge Transfer[c]
Standing Shoes on	Bare concrete	120	150 to 177		
	Vinyl over concrete			190	610
	3/4-inch plywood			118	174
	Grounded metal plate	160		215	1400
	Guarded metal plate	70		103	
Standing Stockings only	Bare concrete	150			
	Vinyl over concrete			405[d]	860
	3/4-inch plywood			125	165
	Grounded metal plate[a]			1430[d]	3300
Sitting on chair Feet off floor	Bare concrete	90	132 to 141		
	Bare concrete with guarded chair	50			
	Vinyl over concrete			110	126
	Vinyl over concrete with guarded chair			57	
	3/4-inch plywood			99	117
	Grounded metal plate			125	182
Sitting on chair Shoes on floor	Bare concrete	140			
	Bare concrete with guarded chair	100			
	Vinyl over concrete			186	385
	Vinyl over concrete with guarded chair			150	
	3/4-inch plywood			131	171
	Grounded metal plate			225	610
Chair only No operator	Bare concrete	55			
	Guarded plate over bare concrete	40			

Notes:
a. Two 0.004-inch polyethylene sheets between feet and plate.
b. From Table 5.
c. Body of operator was charged to 200 volts, then discharged into 2100 pF. $C_H = (V_{final})(2100)/(200 - V_{final})$.
d. Values above 300 pF were measured with 260 pF in series with C_H. $C_H = (C_{mea})(260)/(260 - C_{mea})$.

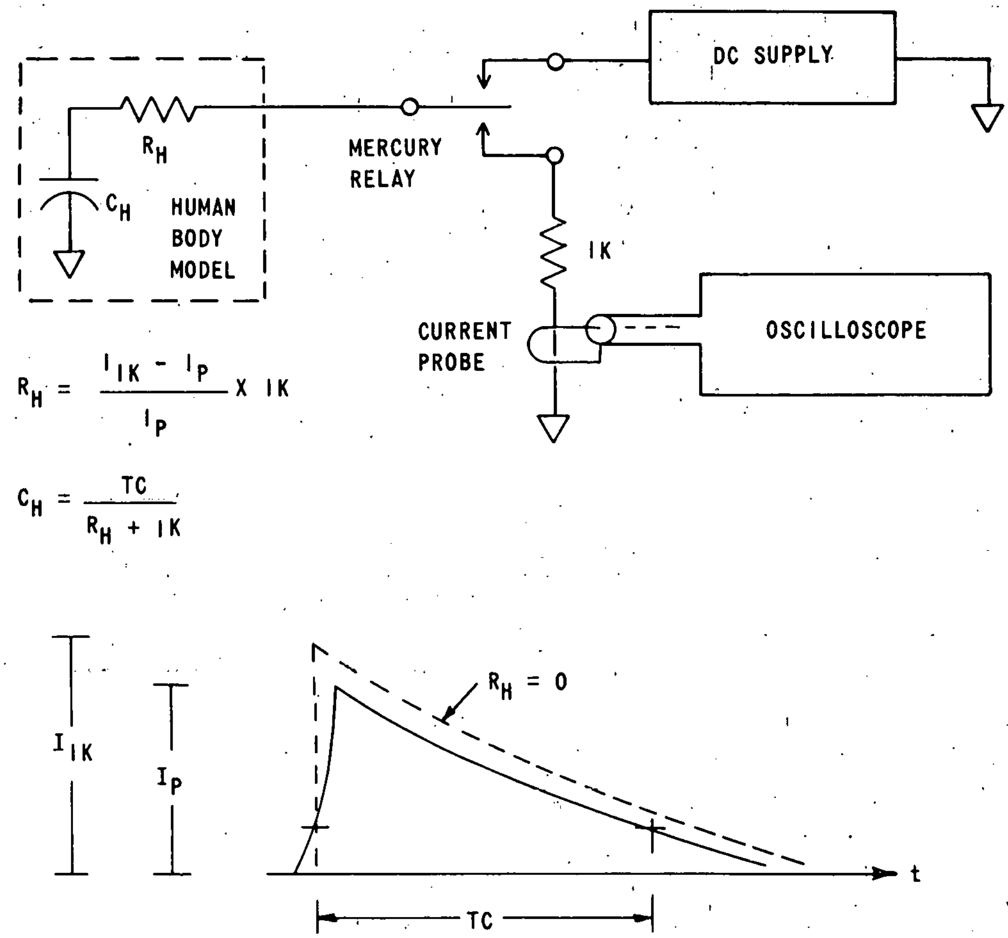

Figure 4. Method of Measuring Human Body Equivalent Series Resistance and Distributed Capacitance

Table 5. Body Distributed Capacitance and Equivalent Series Resistance

Test Condition	Voltage	I_{pk} (A)	Time Constant (microsec)	R_H (ohms)	C_H (pF)
Standing on bare concrete floor	200	0.18	0.18	110	162
	500	0.44	0.20	135	177
	1000	0.88	0.18	135	159
	2000	1.68	0.18	190	150
Sitting on chair on bare concrete feet off floor	200	0.176	0.16	135	141
	1000	0.88	0.15	135	132
	2000	0.92	0.15	87	138
Calibration:					
135 pF	500	0.48	0.16	40	135
270 pF	500	0.50	0.31	0	270

Measured by RC discharge method, as shown in Figure 4.

Table 6. Effects of Series Resistance and Inductance on 2N4118A JFET Static Degradation

Test Voltage	Series Resistance (ohms)			Inductance (uH)
	0	1000	50,000	5
170	D	D		C
255	D			D
340	D	D		
425		D		D
510				D
595				
680				
765			D	
850				C
935				
1020				
1105			C	
1190			D	

C Catastrophic failure (Capacitance 97 pF)
D Degraded
Test procedure as described in Table 2.

ACCOMPLISHMENTS

Evaluation of static damage in junction field effect transistors has yielded the following conclusions.

- The 2N4118A JFET's can be degraded by contact with the body of an operator charged to 140 volts.

- All of the four types of JFET's could have been significantly degraded before passing the catastropic failure tests or during the tests. Because this is a potential reliability problem, an additional test will be included in the product test procedure to detect a decrease in gate-drain reverse breakdown voltage.

- The 2N4118A is significantly more susceptible than the 2N2608, the 2N3112, or the 2N3971 to static damage from extraneous sources.

- The static energy required to degrade a 2N4118A JFET is approximately 1/100 of that required to detonate a sensitive explosive gas.

- The polarity of the static voltage applied to the gate-drain junction of the JFET is significant. The reverse (breakdown) polarity produces greater damage than the forward (conducting) polarity.

- Series resistances up to at least 1000 ohms, which encompass the range of apparent body resistance, have no appreciable effect on the value of static voltage required to degrade a JFET.

A series RC circuit was devised to approximate the discharge mechanism of the human body. Equivalent body resistance values of 87 to 190 ohms and body distributed capacitances of 90 to 405 pF were measured. These values are believed representative of those that can be expected at typical work stations.

FUTURE WORK

Additional 2N4118A JFET static degradation tests will be conducted to accumulate sufficient data to increase statistical confidence in the data listed in Tables 2 and 5, and the findings of this investigation will be applied to static control measures required to protect the JFET's from static damage during manufacturing operations.

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