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PARAMETERS OF BIPOLAR, FIELD EFFECT, AND UNIJUNCTION TRANSISTOR LARGE SIGNAL MODELS FOR USE IN TRANSIENT RADIATION EFFECTS ANALYSIS

Jerry L. Hill

TECHNICAL REPORT NO. AFWL-TR-66-25

March 1966

AIR FORCE WEAPONS LABORATORY
Research and Technology Division
Air Force Systems Command
Kirtland Air Force Base
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FOREWORD

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This technical report has been reviewed and is approved.

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ABSTRACT

The purpose of this study was to measure the large signal equivalent circuit parameters and transient radiation response of selected semiconductor components. These measurements are to be used by the personnel of the Instrumentation Laboratories, Massachusetts Institute of Technology, to select components in the development of the SABRE guidance system. The devices measured include three types: bipolar, field effect, and unijunction transistors. The difficulties experienced in the study were due to the lack of acceptable equivalent circuit models and measurement techniques. These difficulties were overcome by the development of both acceptable models and measurement techniques. The models derived and parameter measurements are presented in this report. The data presented are only to be considered as representative because of the small sample of components measured. The study is being continued as an in-house research effort in an attempt to verify the validity of the models derived and to improve the model parameter measurements.

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GLOSSARY

A	=	Junction area
C_c	=	Collector junction capacitance
C_E	=	Emitter junction capacitance
$C_{E'}$	=	Emitter junction capacitance of unijunction
C_{gD}	=	Gate to drain capacitance
C_{gs}	=	Gate to source capacitance
C_{OC}	=	Collector capacitance proportionality constant
C_{OD}	=	Drain capacitance proportionality constant
C_{OE}	=	Emitter capacitance proportionality constant
$C_{OE'}$	=	Emitter capacitance proportionality constant of unijunction
C_{os}	=	Source capacitance proportionality constant
C_{SC}	=	Stray capacitance of base and collector leads
C_{SE}	=	Stray capacitance of base and emitter leads
g	=	Generation rate
g_m	=	Transconductance
I_c	=	Collector current
I_{co}	=	Collector junction saturation current
I_E	=	Emitter current
I_{EO}	=	Emitter junction saturation current
$I_{E'O}$	=	Emitter junction saturation current of unijunction
I_{ppD}	=	Drain junction primary photocurrent
$I_{pp}(t)$	=	Primary photocurrent
K_{CD}	=	Collector junction diffusion capacitance coefficient

K_{ED}	=	Emitter junction diffusion capacitance coefficient
Kg	=	Ionization constant
$n_{E'}$	=	Emitter junction grading constant of unijunction
n_p	=	Drain junction grading constant
n_s	=	Source junction grading constant
q	=	Electron charge
R_B	=	Base resistance
R_{b1}	=	Resistance of B_1 region
R_{b2}	=	Resistance of B_2 region
R_{b2b1}	=	Total interbase resistance
R_c	=	Collector resistance
R_{DS}	=	Drain to source resistance
Rg	=	Gate resistance
$\phi(t)$	=	Radiation dose
T_c	=	Minority carrier lifetime in collector
T_n	=	Electron lifetime in "P" region
T_p	=	Hole lifetime in "N" region
u(t)	=	Unit step function
V_d	=	Built-in diode voltage
wt	=	Depletion width
$\dot{\phi}$	=	Peak radiation dose rate
θ_c	=	Collector Boltzmann term
θ_E	=	Emitter Boltzmann term
$\theta_E 1$	=	Emitter Boltzmann term of unijunction

ϕ_C = Built-in collector junction voltage

ϕ_E = Built-in emitter junction voltage

ϕ_D = Built-in drain junction voltage

ϕ_S = Built-in source junction voltage

α_i = Inverted short circuit current-transfer ratio

α_n = Normal short circuit current-transfer ratio

β = Current gain of common emitter

β_u = Current gain of unijunction transistor

SECTION I

INTRODUCTION

This report presents the techniques and methods involved in the characterization of semiconductor electronic components for large signal circuit analysis. Included are equivalent circuit models, model parameter evaluations, and a tabulation of these parameters. These models are necessary to the transient analysis of electronic circuits. The components characterized include selected Bipolar, Field Effect and Unijunction transistors. These components were selected as being typical of the types of devices presently being manufactured for use in aero-space systems.

The study was accomplished through the selection or development of an acceptable large signal equivalent model, theoretical evaluation of the model parameters, laboratory measurement of available component parameters, and utilization of these component parameters to evaluate the model parameters. Following these measurements, the response of the components to transient gamma radiation up to 10^{10} rads silicon/sec were measured at the AFWL Flash X-ray and the White Sands LINAC Facilities. Transient neutron radiation responses were not measured due to nonavailability of a suitable source during this period.

SECTION II

BASIC MODEL DEVELOPMENT

To develop a large signal equivalent circuit model, one must begin with the basic geometry of the device being considered. The geometry can be obtained either from the manufacturer or by disassembling the unit and determining the construction through the use of stereo microscopes and lapping or grinding techniques. Once the construction has been determined, a thorough knowledge of the physics of the electrical operating characteristics must be obtained. Discussions of the device's operation can be found in text books, manufacturers data sheets and application notes, and in technical journals. It is desirable to physically observe these characteristics in a laboratory after a well founded knowledge of the device's operation has been obtained through a study of the aforementioned literature.

Understanding both the geometry and the device operation, one can determine all the equivalent circuit parameters, including bulk resistances; stray, depletion, and diffusion capacitances; leakage resistances; conductivity modulated resistances; transconductances; and current and voltage gains. Having determined these parameters, one must then recognize the nodes within the geometry that he desires to describe with his equivalent model. For measurement purposes the only existent nodes are those which are external to the device being characterized. All other nodes introduced complicate the evaluation of the model parameters and in some cases make it impossible. Once the component nodes have been established, the equivalent model components and the equivalent current and voltage generators which have been determined to exist must be placed between proper nodes of the model. The tasks remaining are the verification of the model and the evaluation of the model parameters through laboratory measurements.

The verification of the model normally requires considerable laboratory effort. However, if one has access to an automatic circuit analysis computer program such as the IBM PREDICT I, the problem is reduced to observing the response in a laboratory of some circuit utilizing the component in a large signal mode of operation and then verifying this operation with the computer using the model derived. The remainder of this report will be devoted to model derivation and description of the model parameter evaluations.

SECTION III

BIPOLAR TRANSISTOR

The discussion of the Bipolar Transistor will primarily be limited to a presentation of the Modified Ebers-Moll equivalent circuit of an NPN transistor (Fig. 1). A discussion of the theoretical derivation of this model can be found in Reference 1.

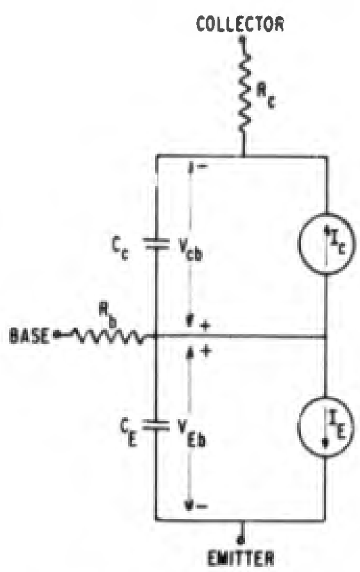


FIGURE 1: Modified Ebers-Moll Equivalent Circuit for an NPN Transistor

The following equations describe the modified Ebers-Moll equivalent circuit shown in figure 1:

$$I_c = I_{c_o}\,[\exp(\theta_c V_{cb}) - 1] - \alpha_n I_{EO}[\exp(\theta_E V_{Eb}) - 1]$$

$$I_E = I_{EO}\,[\exp(\theta_E V_{Eb}) - 1] - \alpha_i I_{co}[\exp(\theta_c V_{cb}) - 1]$$

$$C_C = C_{SC} + C_{oc}/(\phi_c - V_{cb})^{n_c} + K_{cD} I_{CO} \exp(\theta_c V_{cb})$$

$$C_E = C_{SE} + C_{OE}/(\phi_E - V_{Eb})^{n_E} + K_{ED} I_{EO} \exp(\theta_E V_{Eb})$$

This model is well accepted and its mathematical basis lends well to analysis. Several other models exist. However, since they all result from a common mathematical basis, the parameters for one may be calculated from parameters of another. The choice of the Ebers-Moll is based upon its accuracy at high frequencies (approaching f_α), amenability to computer solution and validity in the regions of cutoff, normal active, saturation, and inverted operation.

Examining the current equations, one finds in the collector current (I_c) and emitter current (I_E) an equation of the form:

$I = I_o[\exp(\theta V) - 1]$ where I_o = junction saturation current.

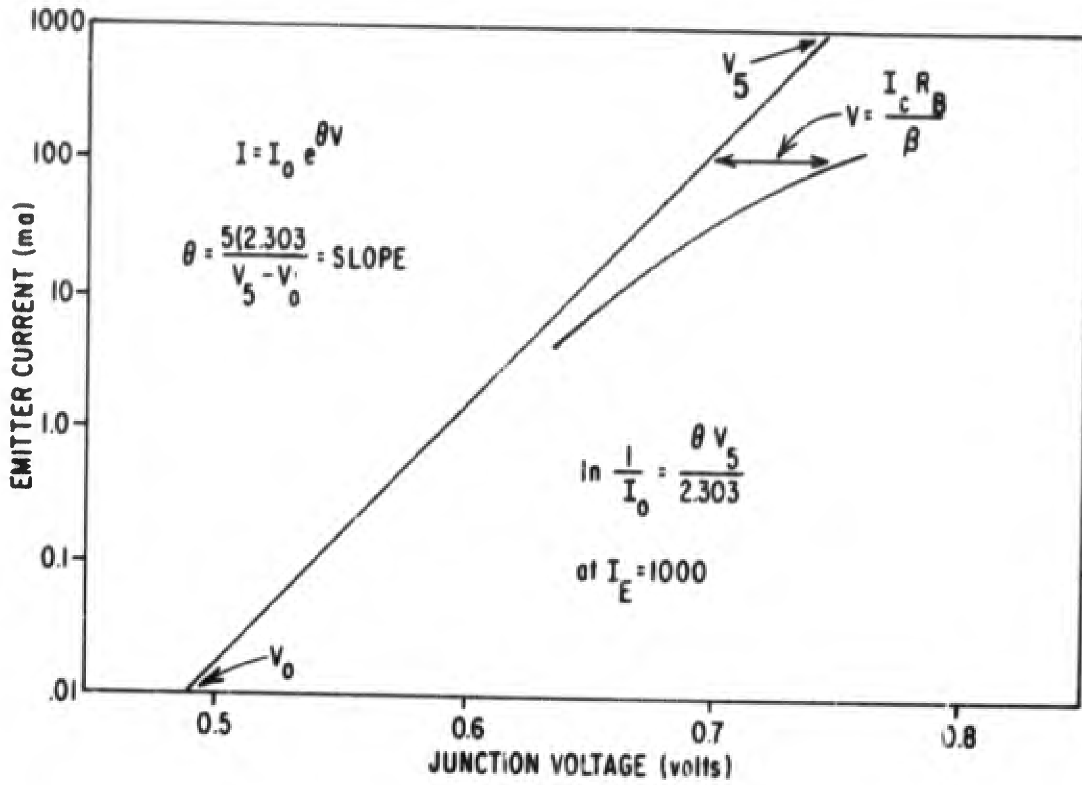
This equation comes from a theoretical description of the movement of carriers in a PN junction. Separating variables and taking the log

$$V = \ln(I/I_o - 1)/\theta$$

since we are considering forward bias conditions where I is always greater than 10^{-5} amps and I_o is always less than 10^{-6} amps this equation can be reduced to

$$V = \ln(I/I_o)/\theta$$

with no loss in accuracy in the model. Plotting the log of the junction current against the junction voltage with the other junction reverse biased, the parameters in the equation can readily be evaluated. (See figure 2.)



<u>FIGURE 2</u>: Plot of Junction Voltage Equation

In addition to the voltage equation parameters, this plot may also be utilized to evaluate the base resistance (R_B). The difference between the straight line theoretical curve and the experimental data curve is due to the potential dropped across the base resistor. This potential is given by:

$$V = I_b R_B$$

and since

$$I_b = I_c/\beta$$

$$R_B = \beta V/I_c$$

The junction capacitance equation:

$$C = C_S + C_o/(\phi - V)^n + K_D I_o \exp(\theta V)$$

where

C_S = stray capacitance between junction leads

$C_o/(\phi - V)^n$ = depletion capacitance

$K_D I_o \exp(\theta V)$ = diffusion capacitances

gives the total capacitance of any PN junction depending upon how the junction is operated. The depletion capacitance equation

$$C_{dep} = C_o/(\phi - V)^n$$

can be rearranged algebrically to the form

$$\log(\phi - V) = 1/n\,(\log C_o - \log C_{dep})$$

Plotting log (V) against log C_{dep} as shown in Figure 3. leads to the evaluation of n, ϕ, and C_o. The values of C_{dep} are obtained by measuring capacitance of the reverse biased junction with a suitable capacitance bridge.

The diffusion capacitance equation

$$C_{diff} = K_D I_o \exp(\theta V) = K_D I$$

shows the ease of evaluating K_D if the diffusion capacitance can be measured as a function of the junction current. In reference 2, Dr. Jonn Wirth describes a technique that uses recovery time wave forms to evaluate the total junction capacitance with forward bias conditions

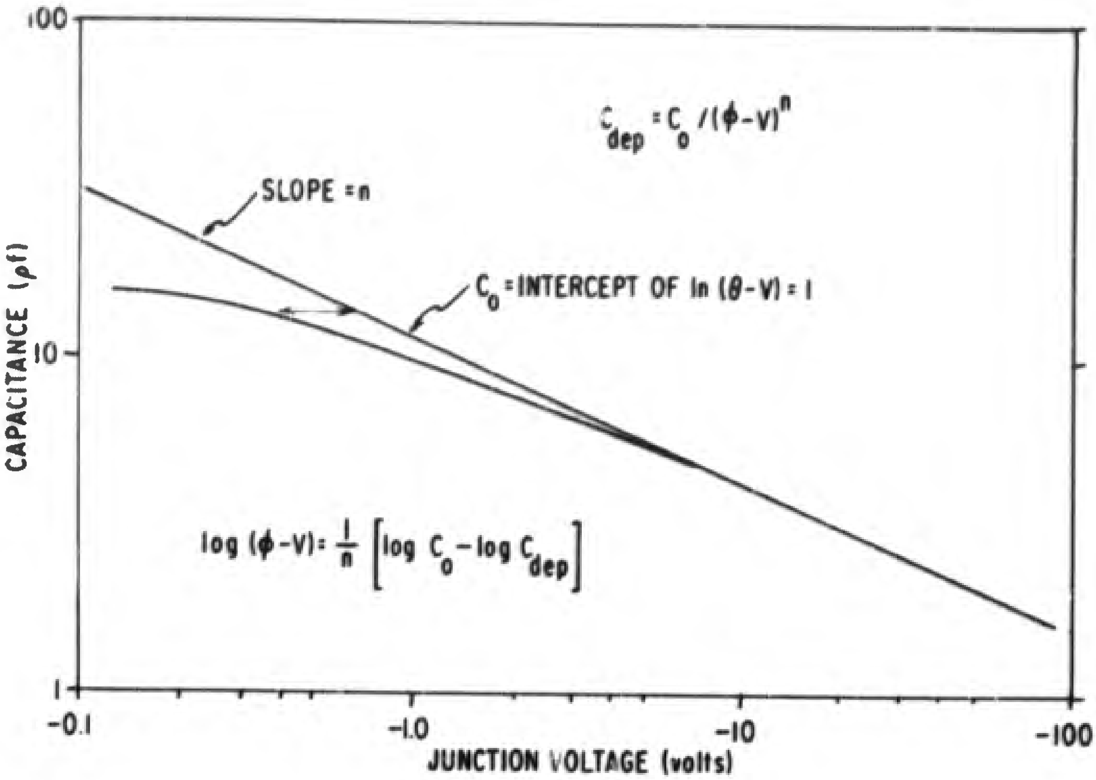


FIGURE 3: Depletion Capacitance Characteristic

leading to an evaluation of C_{diff} at a value of junction current. During recovery, the total junction capacitance:

$$C_T + C_{diff} + C_{dep} = I(v)\ dv/dt$$

where dv/dt is the slope of the recovery voltage wave for (Fig. 4). Evaluating dv/dt and I(V) at some point in time where the voltage wave form is linear K_D can be obtained by:

$$K_D = [I(V)/dv/dt - C_{dep}]/I$$

where I = magnitude of I(V) and C_{dep} is value at V taken from junction voltage characteristic at I = $|I(V)|$.

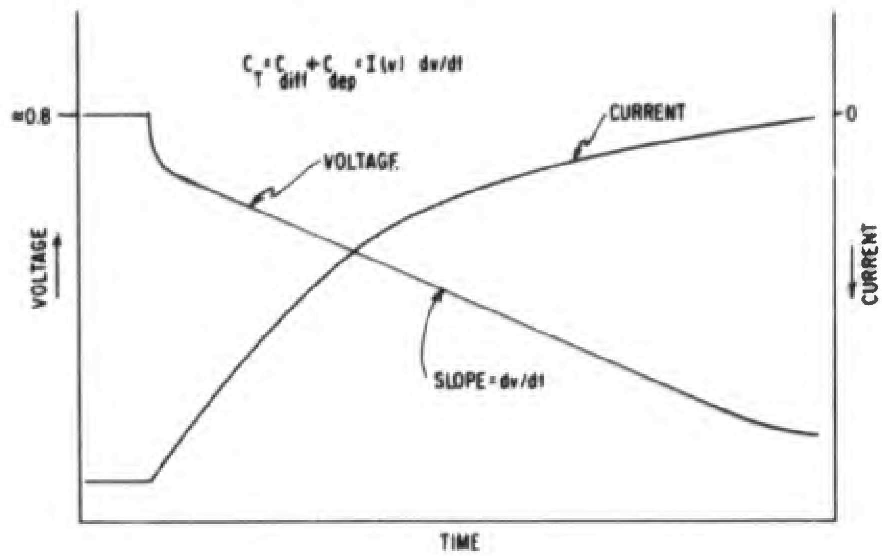


FIGURE 4: Recovery Wave Shapes

The parameters that remain to be evaluated are the normal and inverted current transfer ratios α_n and α_i and the collector resistance R_c. The current transfer ratios are evaluated by measuring the pulsed current gain (β) for normal and inverted operation and utilizing the relationship

$$\alpha = \beta/\beta+1$$

The collector resistance is evaluated from the slope of the collector saturation characteristic where

$$V_{Csat} = I_c R_c$$

Table 1 contains a tabulation of parameters for four types of bipolar transistors, the data from which these parameters were evaluated may be found in the appendix.

For transient radiation analysis, the circuit model is modified to include a primary photocurrent generator as shown in Figure 5. This photocurrent is produced in the reverse-biased

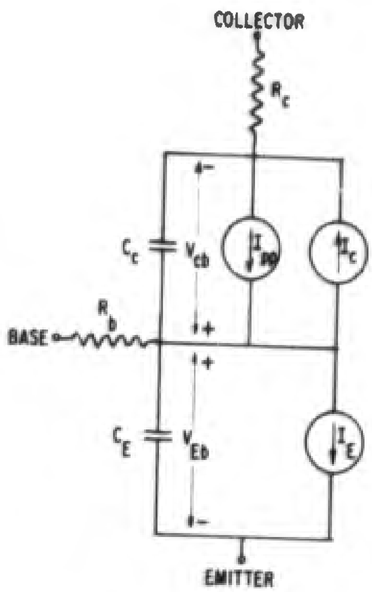


FIGURE 5: Ebers-Moll Circuit for NPN Transistor with Primary Photocurrent Generator

collector junction where the minority carrier density at the edge of the depletion layer is zero. The primary photocurrent for a rectangular radiation pulse defined by

$$\phi = \dot{\phi}\,[u(t) - u(t-tp)]$$

where $\dot{\phi}$ = peak radiation dose rate

is given by

$$Ipp(t) = Aqg\{w_t + L_n erf(t/Tn)^{1/2} - erf[t - tp/Tn]^{1/2}\} \qquad (1)$$

for $o < t < tp$

$$Ipp(t) = Aqg[L_n(erf(t/Tn)^{1/2} - erf(t-tp/Tn)^{1/2} + Lp(erf(t/Tp)^{1/2} - erf(t-tp/Tp)^{1/2}] \qquad (2)$$

for $t > tp$

Examining these equations from a viewpoint of their representing a physical rather than theoretical PN junction leads to the following equation:

$$Ipp(t) = Aqg\, L_c\, [u(t)\, erf(t/Tc)^{1/2} - u(t-tp)\, erf(t-tp/T_c)^{1/2}] \quad (3)$$

for all $t > o$

where L_c and T_c are associated with the minority carriers of the collecting region.

This simplification is based upon the fact that for most transistor (F_t < 500) junctions the diffusion length is much greater in the collecting region than in the base region. In addition, the depletion contribution to the photocurrent is much less than the diffusion contribution and can generally be neglected. Typical primary photocurrent is shown in figure 6.

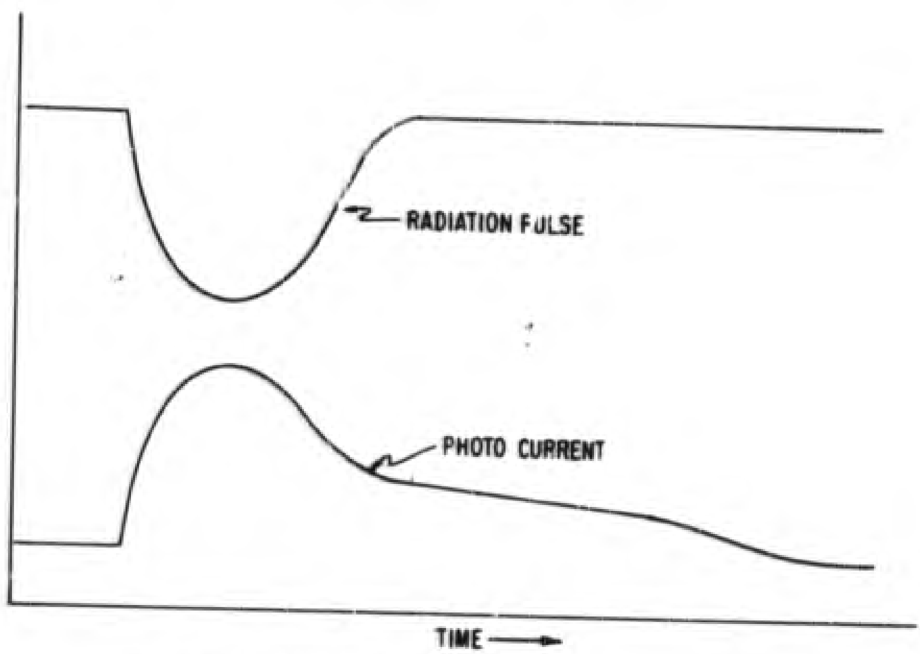


FIGURE 6: Typical Primary Photocurrent

TABLE I

BIPOLAR TRANSISTOR PARAMETERS

Component	I_{E_O}	I_{c_o}	θ_E	θ_C	C_{OE}	C_{OC}	ϕ_E	ϕ_C	n_E
	μ Amps	μ Amps			p farad	p farad			
FM709	10^{-10}	2.69×10^{-9}	42	37	1.3	2.2	0.8	0.82	0.2
FM915	1.7×10^{-9}	8.91×10^{-6}	42	28	5.4	4.6	0.82	0.75	0.46
2N2222A	1.32×10^{-8}	5.37×10^{-8}	41	40	19.0 17	12.2	0.8	0.8	0.40
2N3303	3.8×10^{-9}	5.9×10^{-6}	41.5	28	17.5	[illegible]	0.8	0.80	0.34

	n_C	K_{ED}	K_{CD}	t_r	t_f	t_s	t_{recE}	t_{recC}	Ipp at
		pf/ma	pf/ma	nsec	nsec	nsec	nsec	nsec	2×10^{10} r/sec
FM709	0.17	--	--	80	25	100	23	20	13 ma
FM915	0.5	17	--	55	60	1080	150	175	40 ma
2N2222A	0.41	--	--	50	25	1240	180	90	32 ma at 8×10^{9} r/sec
2N3303	0.21	2.5	--	5	20	20	20	20	12 ma at 7×10^{10} r/sec

SECTION IV

FIELD EFFECT TRANSISTOR

The field effect transistor (FET) is a semiconductor device whose operation is based upon the conductivity modulation of a P or N-type bar of silicon called the channel, by depletion regions which reach into the channel. A cross-section of such a device is shown in Figure 7.

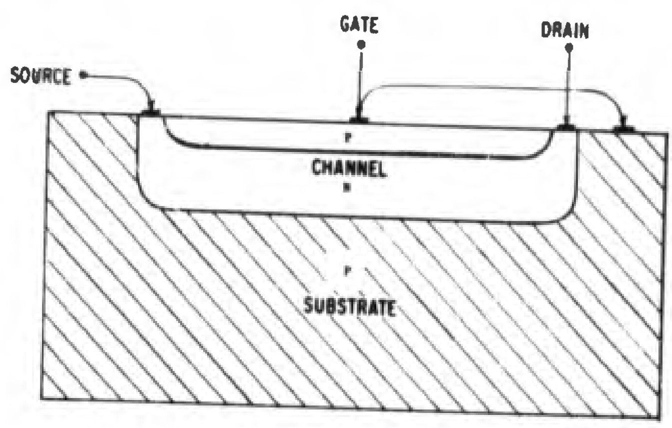


FIGURE 7: Cross Section of N-channel FET

In making such a device, one begins with a slice of P-type silicon. Into this is diffused a strip of N-type material, then a P-type material is diffused into the N-type, creating the N channel between two P-type materials. The original substrate of P-type material is connected to the diffused strip of P-type material and forms what is known as the gate, one end of the N-channel is called the drain and the other the source.

The operation of field effect transistor can best be explained by using the characteristics shown in Figure 8. From the drain

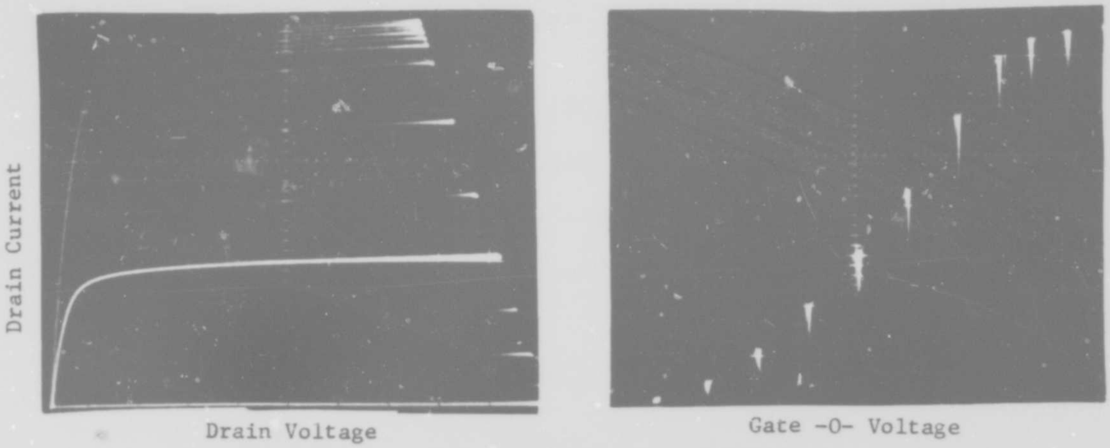


FIGURE 8: Typical (a) drain characteristic and (b) transfer characteristic of FET.

characteristic, it can be seen that the drain current is dependent upon the drain to source (V_{DS}) and the gate to source (V_{gs}) voltages. The dependence upon gate to source voltage is better demonstrated by the transfer characteristic. It can be seen that for a give V_{DS} there is a negative gate to source voltage at which drain current ceases to flow. This voltage is known as the "pinch off" voltage. This voltage corresponds to a fully depleted channel, that is when the depletion regions from both sides of the gate meet and "pinch-off" the drain current. As the gate to source voltage is increased above this voltage, the depletion regions retract, returning more and more of the channel to conduction. This process continues until the depletion regions become nonexistent, approximately 0.8 volts forward bias. At this point the drain current saturates due to the extremely high gate resistance which prevents any conductivity modulation due to injected carriers.

From this discussion, an important consideration can be deduced for a depletion type device. In normal FET operation the two PN junctions are always operated in the depletion region, at no time are the junctions allowed to be forward biased. Should this occur, the device ceases to be a FET and the model fails.

Returning to Figure 7, we first establish the nodes we wish to recognize in the model. We begin with the three nodes defined by the external leads, namely drain, gate, and source. We now attempt to recognize the parameters between these nodes. Stray capacitances (C_s) exist between the gate and drain, gate, and source, and drain and source, see Figure 9. In addition, there are leakage resistances (R_l) between all three terminals. From the preceding discussion of operation, we recognize depletion capacitances between the gate to drain (C_{gd}) and gate to source (C_{gs}). In series with these capacitances are bulk resistances due to the channel that exists between the drain and source contacts. In addition there exists a very high input resistance R_d in the gate and a channel resistance R_{ds} between the drain and source. Finally there is a current generator that exists between the drain and source that is due to the depletion conductivity modulation of the channel by the gate voltage. This current, in addition to the current due to the channel resistance flows in the drain and is defined by $g_m e_g$ where g_m is the transconductance defined by the transfer characteristic.

Analyzing the equivalent circuit, it is recognized that certain parameters are of questionable value. The stray capacitances are typically of 0.5 to 1.5 pf in magnitude; however when the device is

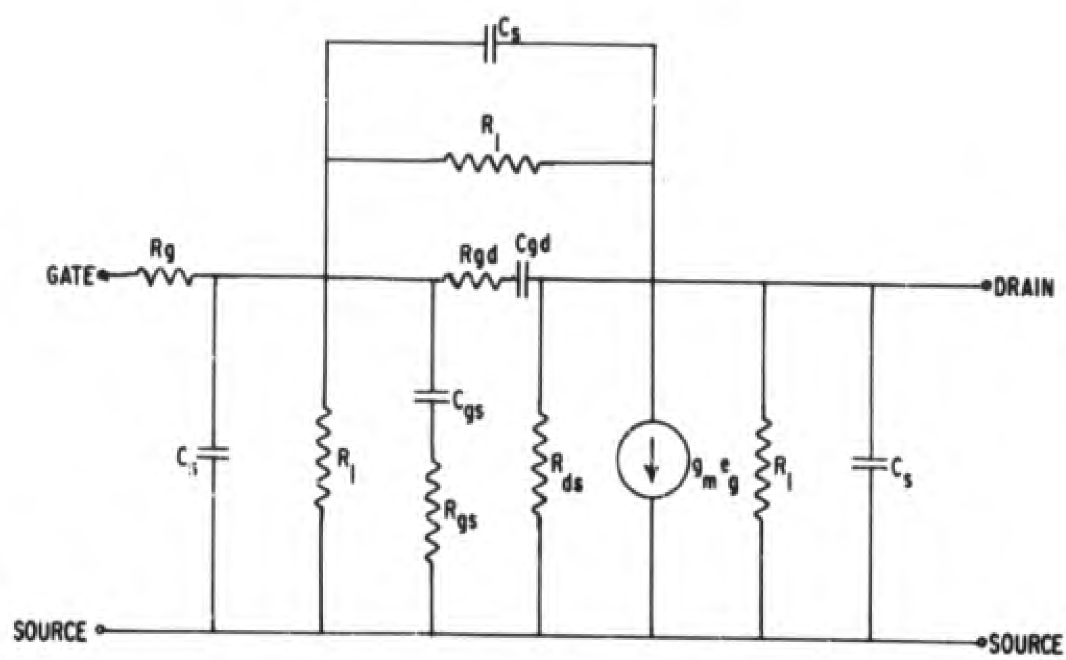


FIGURE 9: Equivalent Circuit of FET

utilized in a circuit, these capacitances are much less than the inter-wiring capacitance and hence can be neglected in the model. The leakage resistances are much greater than the channel resistance and can also be neglected. Our next step is to consider the bulk resistance in series with the junction capacitances. At this point, we are faced with attempting to eliminate two internal unapproachable nodes. Since these resistances allow no d-c to flow and are only active when there is charge transfer through the depletion capacitances, we assume that they will be effective in the value obtained in the measurement of these capacitances. Hence, upon eliminating these resistances, it is felt that no significant error will be introduced. The equivalent model that results is shown in Figure 10. This greatly simplified model can easily be characterized.

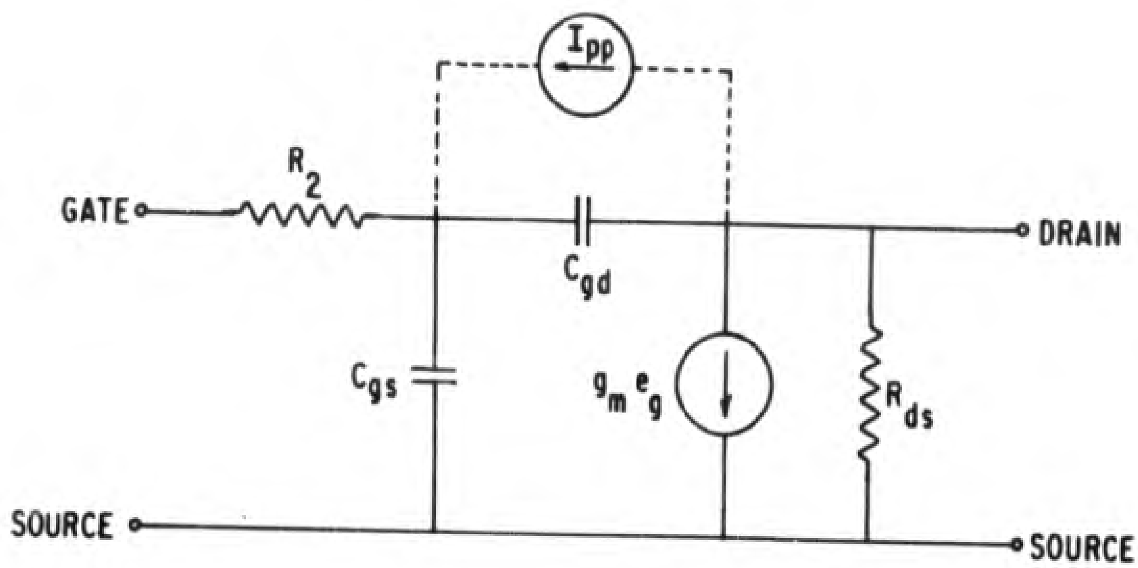


FIGURE 10: Simplified Equivalent Circuit for FET

The characterization begins with measuring C_{gs} and C_{gd} in identically the same manner as that previously discussed for the depletion capacitance of bipolar transistor junctions. R_{ds} is considered to be the slope of the $V_g = 0$ drain characteristic curve beyond drain voltage saturation. R_g is so large that in most cases it is neglected and the input impedance considered to be determined by the junction capacitances as a function of frequency. This transconductance, g_m is defined by the transfer characteristic.

For transient radiation analysis, a primary photocurrent generator is added to the model as shown by the dotted lines in Figure 10. This photocurrent is produced in the reverse biased drain junction. The photocurrent produced in the source junction is neglected due to its inability to produce a change in the drain potential. A typical photocurrent wave form for a FET is shown in Figure 11.

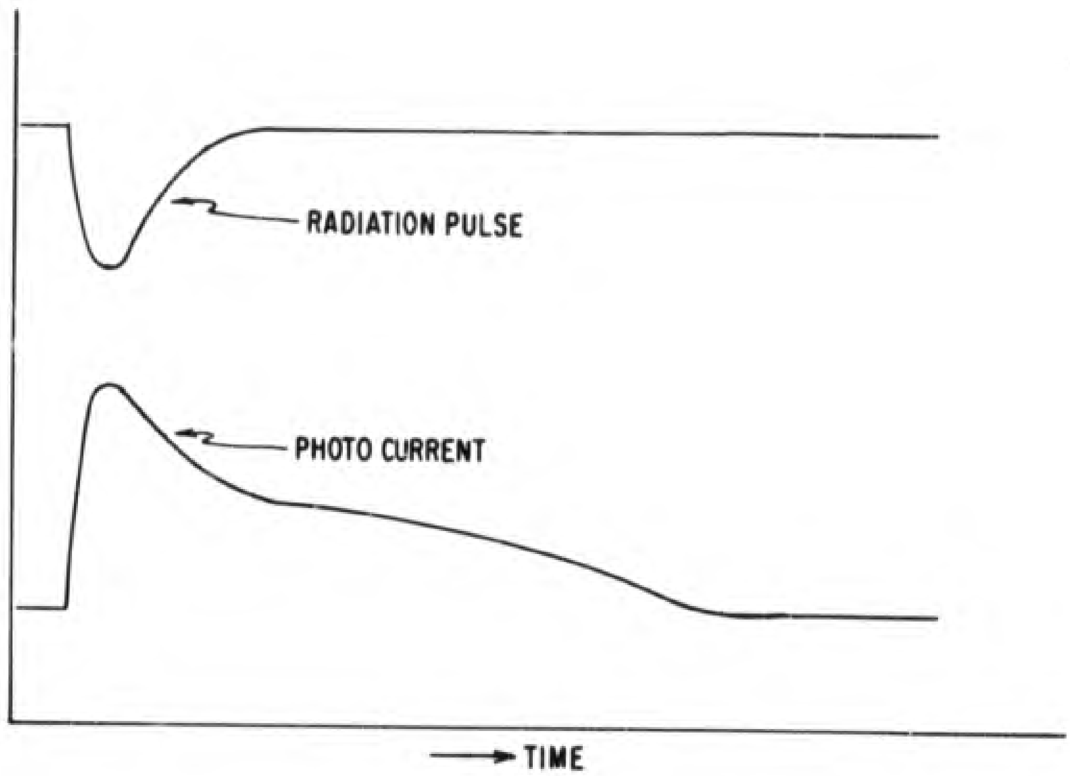


FIGURE 11: Primary Photocurrent of FET

Table 2 contains a tabulation of parameters for three types of FET's. The data from which these parameters were evaluated may be found in the appendix.

TABLE II

FIELD EFFECT TRANSISTOR PARAMETERS

Component	C_{OD} pf	C_{os} pf	ϕ_D	ϕ_S	n_D	n_S	R_{ds} Kohm	Ipp_D	Cm µmhos at VG=0
U1323	7.6 for V<20vdc	7.0 for V<10vdc	0.8	0.8	0.44 for V<20vdc	0.45 for V<10vdc	40	24 ma at $2x10^{10}$ r/sec	6000
	3.4 for V≥20vdc	4.5 for V≥10vdc			0.19 for V≥20vdc	0.24 for V≥10vdc			
U1324	6.2 for V<20vdc	6.6 for V<2vdc	0.8	0.8	0.86 for V<2vdc	0.8 for V<2vdc	100	24 ma at $2x10^{10}$ r/sec	4000
	3.7 for V≥2vdc	3.7 for V≥2vdc			0.20 for V≥2vdc	0.16 for V≥2vdc			
SU2002 Unit A	20.0 for V<5vdc	20.0 for V≤5vdc	0.8	0.8	0.78 for V<5vdc	0.8 for V<5vdc	80	144 ma at $2.1x10^{10}$ r/sec	7000
	7.5 for V≥5vdc	8.6 for V≥5vdc			0.24 for V≥5vdc	0.27 for V≥5vdc			
SU2002 Unit B	20.0 for V<4vdc	20.5 for V<10vdc	0.8	0.8	0.9 for V<4vdc	0.67 for V<10vdc	100	100 ma at $2.5x10^{10}$ r/sec	7000
	9.0 for V≥4vdc	7.4 for V≥10vdc			0.32 for V≥4vdc	0.23 for V≥10vdc			

SECTION V

UNIJUNCTION

The unijunction transistor (sometimes referred to as a double-based diode) is a semiconductor device whose operation is based upon the conductivity modulation of a bar of N-type silicon by a junction formed by diffusing a P-type layer into the bar. A cross-section of such a device is shown in Figure 12. The end of the bar closest to the junction is called base two (b_2) and the other is base one (b_1). The P-type layer is called the emitter since it emits carriers into the bar.

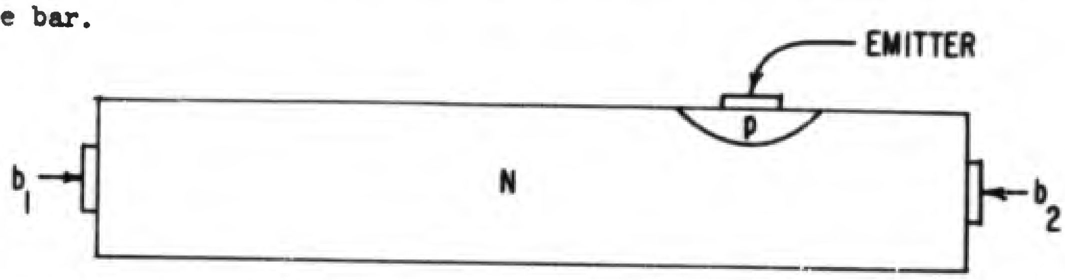
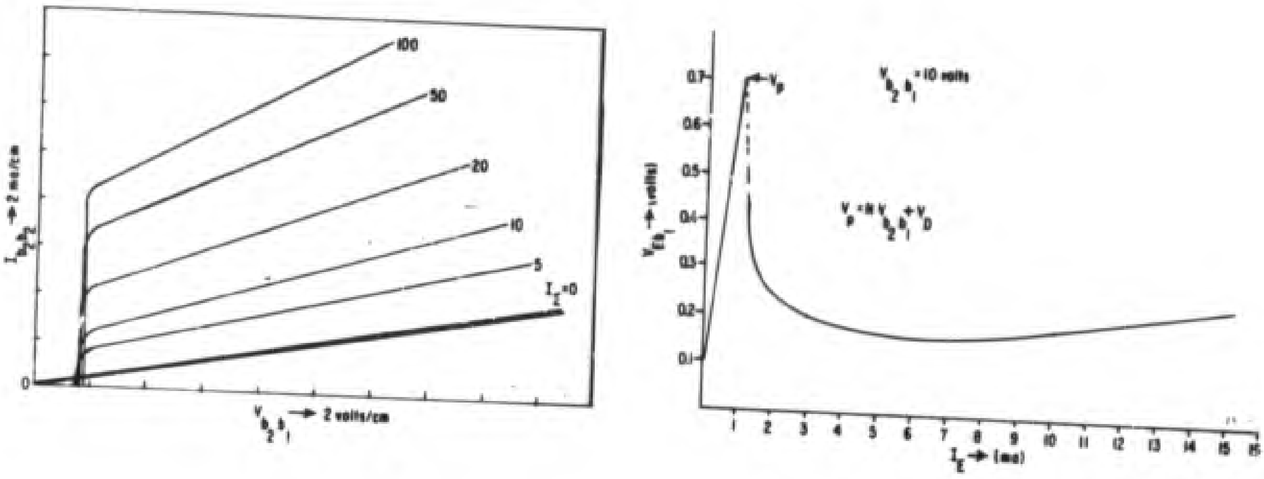


FIGURE 12. Cross Section of Unijunction Transistor

The operation of the device is best illustrated by the characteristics shown in Figure 13. With positive voltage applied across the N-type region from b_2 to b_1, a current flows through the device causing the potential to be distributed across the resistance of the silicon.

It is this distributed potential that produces the internal voltage (Vp) at the emitter junction which must be overcome by the external emitter voltage. As long as the emitter voltage is less than Vp the input and interbase resistances are high as shown in Figure 13. Increasing



(a)

(b)

FIGURE 13: Typical (a) Interbase Characteristic and (b) Input Characteristic of Unijunction Transistor

the emitter potential beyond the peak voltage which is determined from

$$Vp = NV_{b_2b_1} + V_D \qquad (4)$$

allows current to flow into the emitter junction. This durrent corresponds to the injection of holes into the N region. These holes are swept toward b_1 by the interbase potential causing the conductivity of the b_1 region to increase while the conductivity of the b_2 region remains constant. This drop in resistance allows more emitter current to flow and the process regenerates causing the negative resistance characteristic. Once the device has switched from the "off" to "on" state, the unijunction acts as an ordinary transistor with a very poor collector efficiency and the interbase current is controlled by the magnitude of the emitter current. One should note that the gain is less than one in this process and hence the emitter current is much larger than the interbase current. As the emitter current increases, the interbase current increases in corresponding steps.

Beginning with the three external leads as nodes and noting that an additional node exists at the interface of the emitter junction and the silicon slab, see Figure 14 we define the model. The total interbase resistance $R_{b_2b_1}$ at $I_E = 0$ is divided into two parts by the node at the emitter junction. This resistance is divided according to the intrinsic stand off ratio as shown below:

at $V_E = V_P$

$$V_P = NV_{b_2b_1} + V_D$$

since $V_E = V_P$, $V_D = 0$

under these conditions,

$$I_{b_2b_1}R_{b_1} = NI_{b_2b_1}R_{b_2b_1} \qquad (5)$$

and $R_{b_1} = NR_{b_2b_1}$ and $R_{b_2} = R_{b_2b_1} - R_{b_1}$

Having established the values for R_{b_2} and R_{b_1} at $I_E = 0$, we continue by assuming that R_{b_2} is a constant since all injected carriers are immediately swept in the R_{b_1} by the interbase potential making R_{b_1} a varing resistance. Next we include the current generator $\beta_u I_E$.

We now recognize the usual stray capacitances (C_S) and leakage resistances (R_1) between the external leads. In addition, we recognize the diode parameters of the emitter junction, R_E, C_E, and the current generator I_E completing the model.

Examining the complete model, we can simplify it considerably by again recognizing that the leakage resistances are very high and hence can be neglected and that the stray lead capacitances are much less than

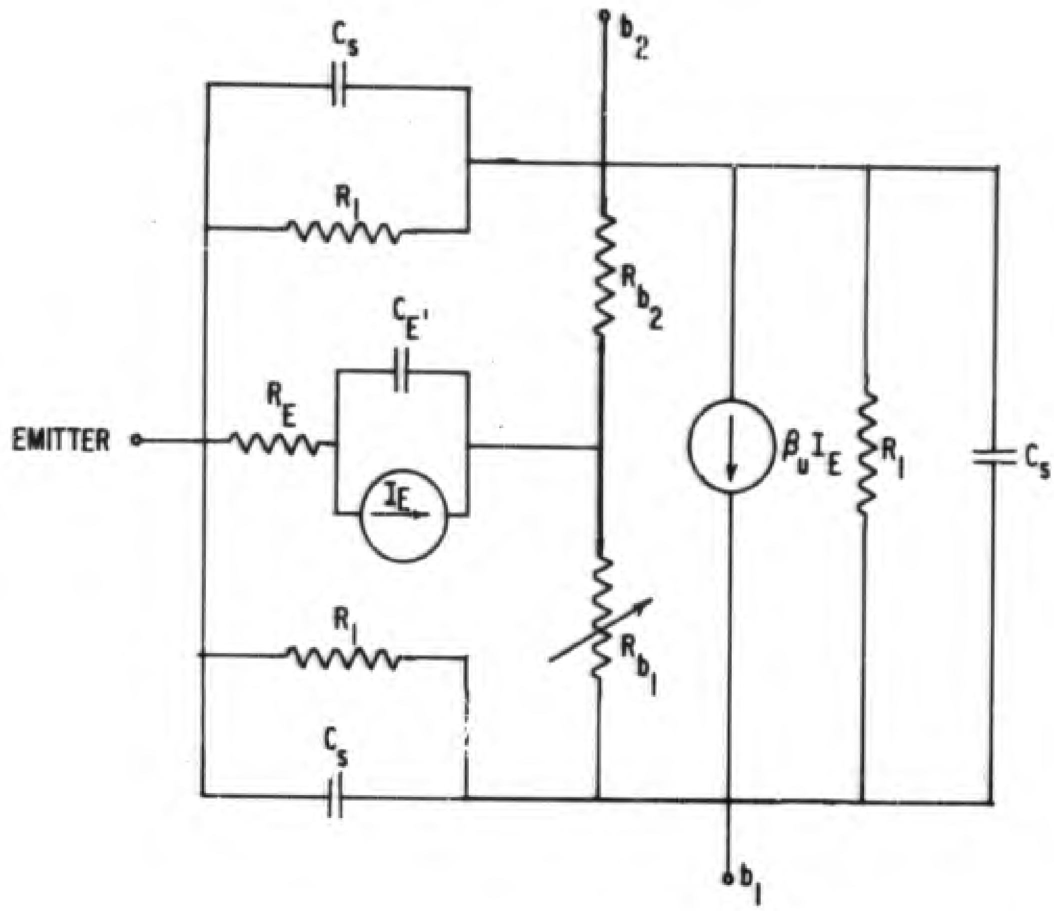


FIGURE 14: Equivalent Circuit of Unijunction Transistor

the circuit interwiring capacitances and can also be neglected. The emitter current generator I_E and R_E are combined into one and are defined by the input characteristic. These combine to result in the simplified model shown in Figure 15.

The value of R_{b_2} is determine as previously discussed. The emitter capacitance is determined by measuring the junction capacitance with forward and reverse voltages applied. This capacitance varies as shown in Figure 16. The variation of R_{b_1} and β are determined from the interbase $I_{b_2b_1}$ vs $V_{b_2b_1}$ characteristic.

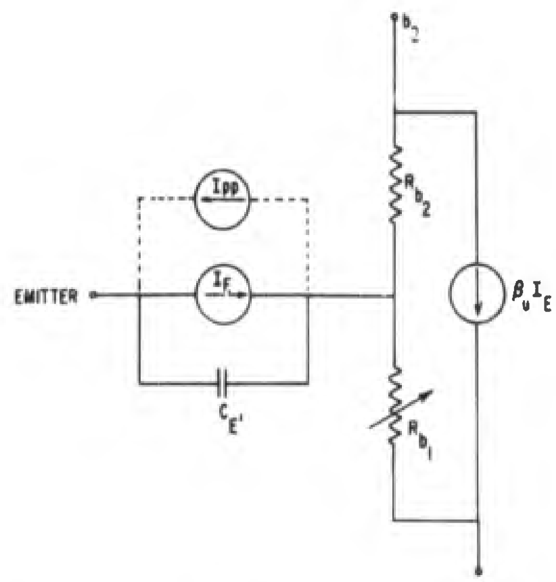


FIGURE 15: Simplified Equivalent Circuit of Unijunction Transistor

Transient radiation analysis is accomplished by adding a primary photocurrent generator to the model as shown by the dotted lines in Figure 15.

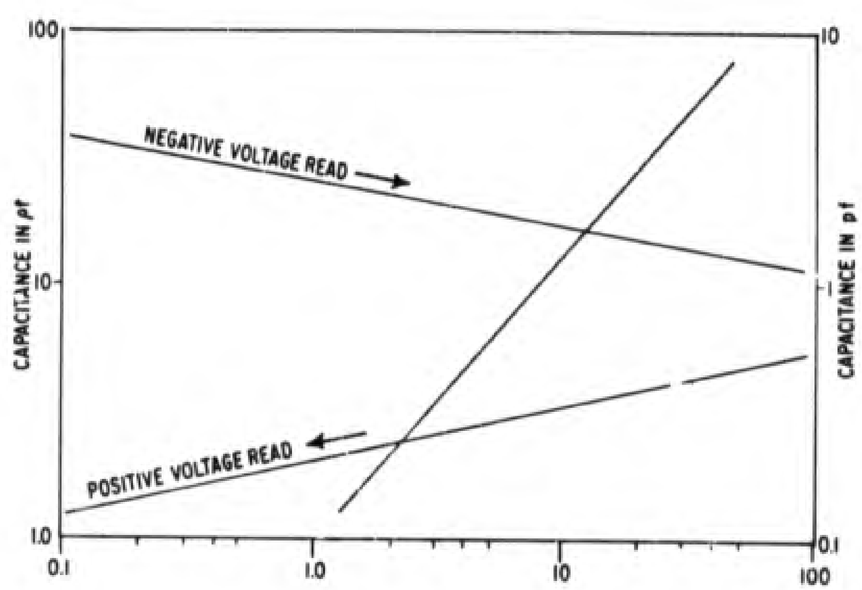


FIGURE 16: Typical Junction Capacitance of Unijunction Transistor

This photocurrent is defined as discussed for the bipolar transistor and is produced in the reverse biased E junction which acts as a collector. A typical photocurrent wave form due to a short burst of ionizing radiation is shown in Figure 17.

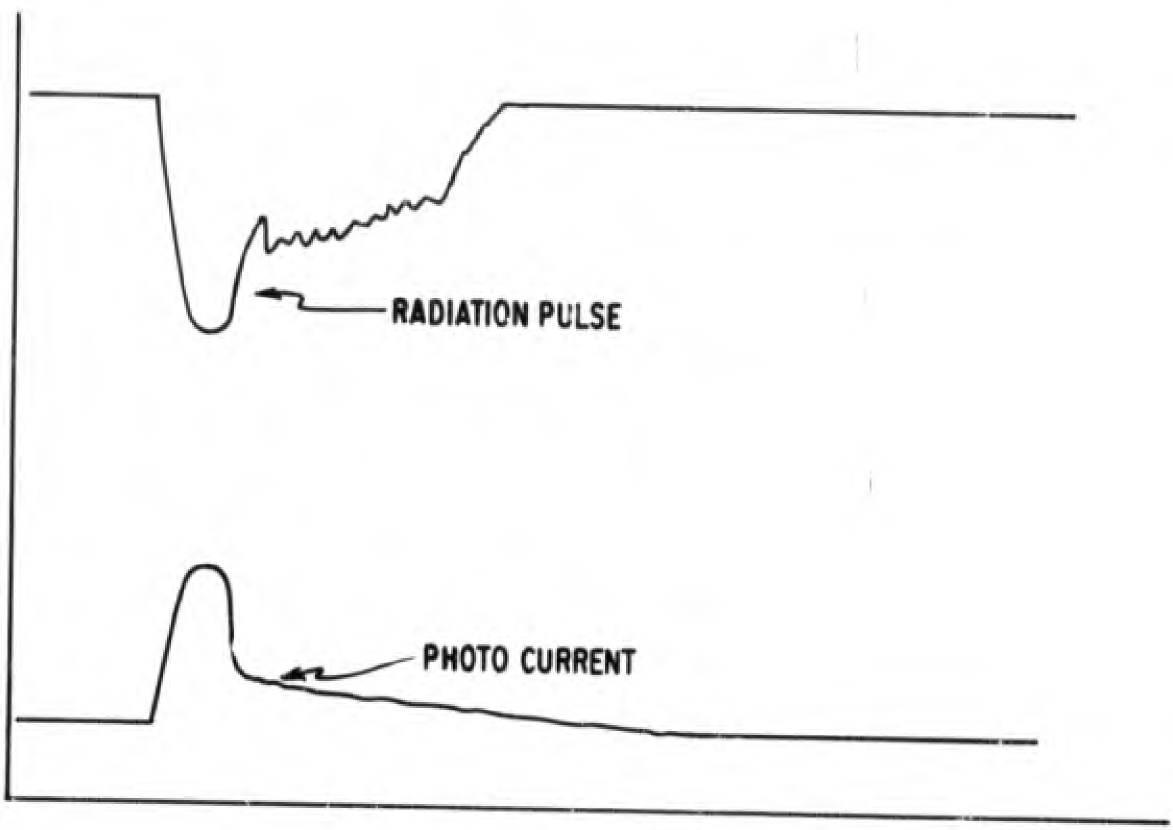


FIGURE 17: Primary Photocurrent of Unijunction Transistor

A tabulation of model parameters for two types of unijunction may be found in Table 3 and the data from which they were evaluated can be found in the appendix.

TABLE III

UNIJUNCTION TRANSISTOR PARAMETERS

Component	$R_{b_2b_1}$	N	R_{b_2}	V_P	$C_{OE'}$	η_E	$\theta_{E'}$	$I_{E'O}$	Ipp
	$I_E = 0$		$I_E = 0$		Pf			Amps	ma
2N2414	6.3 Kohms	0.58	2.63 Kohms	6.2 Volts	$\frac{1.95}{\text{for } V<1.5\text{vdc}}$ $\frac{2.6}{\text{for } V\geq1.5\text{vdc}}$	$\frac{0.07}{\text{for } V<1.5\text{vdc}}$ $\frac{0.49}{\text{for } V\geq1.5\text{vdc}}$	15.6	1.62×10^{-8}	25 at 2.5×10^{10} r/sec
2N2420	6 Kohms	0.63	2.22 Kohms	6.6 Volts	$\frac{1.85}{\text{for } V<1.5\text{vdc}}$ $\frac{2.5}{\text{for } V\geq1.5\text{vdc}}$	$\frac{0.075}{\text{for } V<1.5\text{vdc}}$ $\frac{0.495}{V\geq1.5\text{vdc}}$	15.2	1.62×10^{-8}	22 at 2.2×10^{10} r/sec

SECTION VI

CONCLUSION

This paper presents the method followed by the author in developing large signal equivalent circuit models for transient analysis. The method consists of (1) possessing a knowledge of the construction of the device being modeled, (2) a knowledge of the physics of the electrical operating characteristics of the device, (3) a knowledge of the existing equivalent lumped circuit parameters within the device, (4) recognizing the electrical nodes that must exist to accommodate the above, (5) assembling these into a model that properly describes the device, and (6) simplifying this model by removing all negligible or inoperative parameters. Having accomplished these tasks, the remaining parameters must be evaluated by recognizing their relationship to operating characteristics that may be measured at the external approachable nodes. The measurement of these operating characteristics often requires special instrumentation, however, no appreciable difficulty should be anticipated in attempting these measurements. This effort is continuing through computer model verification development of an automatic computer component parameter evaluation system.

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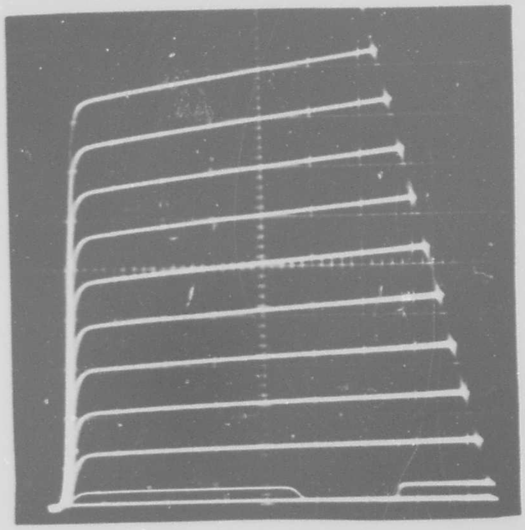
APPENDIX

TITLE V_c - I_c characteristic of FM 709 showing β linearity



HORIZONTAL

Quantity V_c

Sensitivity 0.5 v /cm

VERTICAL

Upper Trace

Quantity I_c

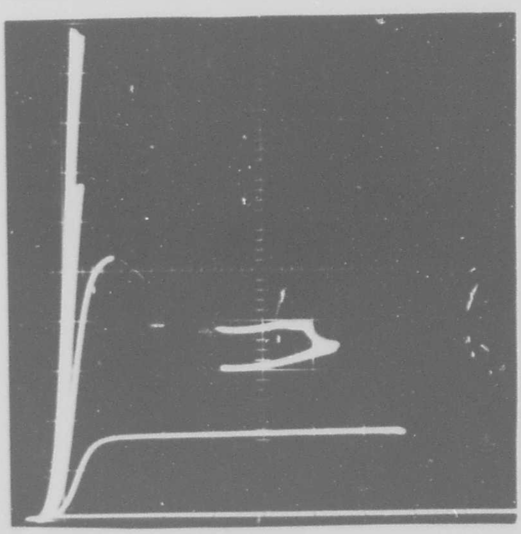
Sensitivity 0.1 ma /cm

Lower Trace

Quantity I_b = .001 ma/step

Sensitivity - /cm

TITLE V_c - I_c characteristic of FM 709 showing V_c sat



HORIZONTAL

Quantity V_c

Sensitivity 0.2 v /cm

VERTICAL

Upper Trace

Quantity I_c

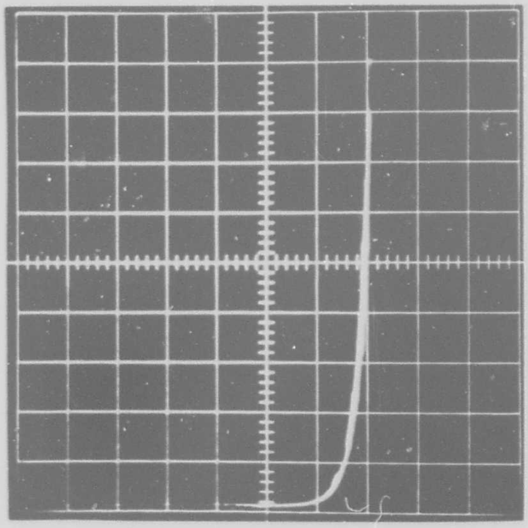
Sensitivity 0.5 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE I_c - V_{BE} characteristic of FM 709 showing base conduction



HORIZONTAL

Quantity V_{BE}

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

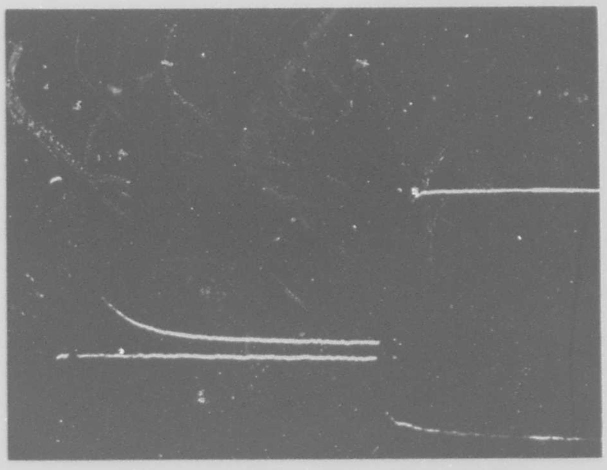
Sensitivity 0.1 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of FM 709 showing rise and fall time



HORIZONTAL

Quantity time

Sensitivity 50 nsec /cm

VERTICAL

Upper Trace

Quantity V_c

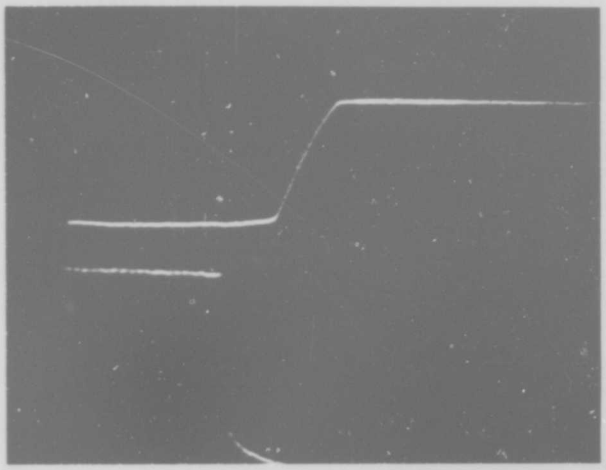
Sensitivity 50 mv /cm

Lower Trace

Quantity V_{BE}

Sensitivity 20 mv /cm

TITLE Switching characteristic of FM 709 showing storage time



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity V_C

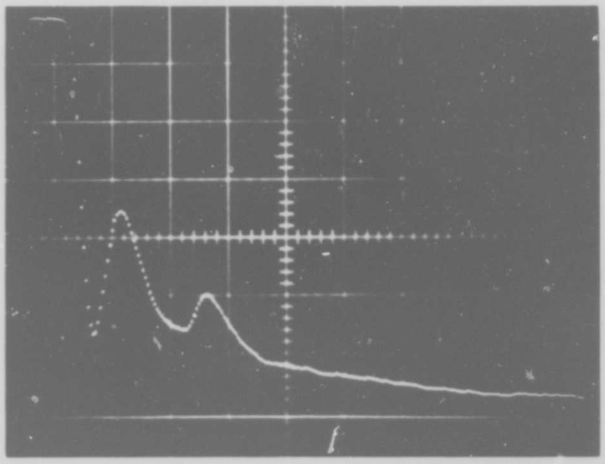
Sensitivity 100 mv /cm

Lower Trace

Quantity V_B

Sensitivity 100 mv /cm

TITLE Switching characteristic of FM 709 showing base emitter recovery



HORIZONTAL

Quantity time

Sensitivity 5 nsec /cm

VERTICAL

Upper Trace

Quantity V_{BE}

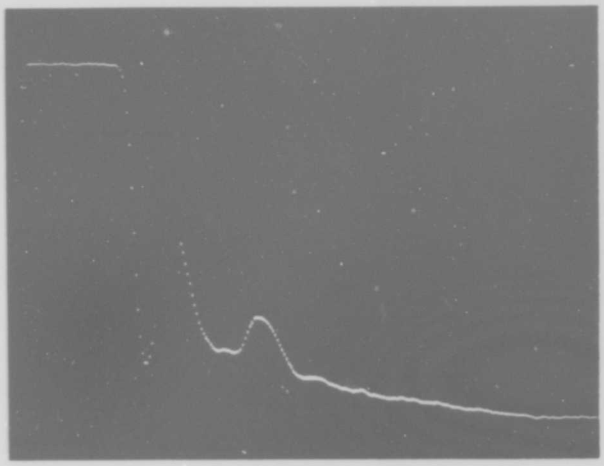
Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of FM 709 showing base collector recovery time



HORIZONTAL

Quantity time

Sensitivity 5 nsec /cm

VERTICAL

Upper Trace

Quantity V_{cE}

Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE ________

HORIZONTAL

Quantity ________

Sensitivity ________ /cm

VERTICAL

Upper Trace

Quantity ________

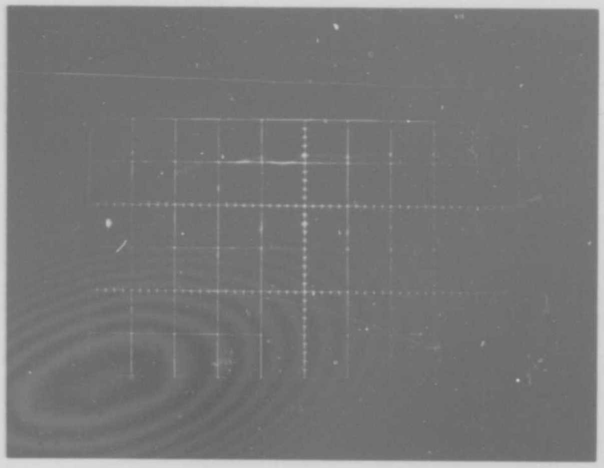
Sensitivity ________ /cm

Lower Trace

Quantity ________

Sensitivity ________ /cm

TITLE Primary photocurrent of FM 709 subjected to 5 x 10^6 r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity X-ray pulse

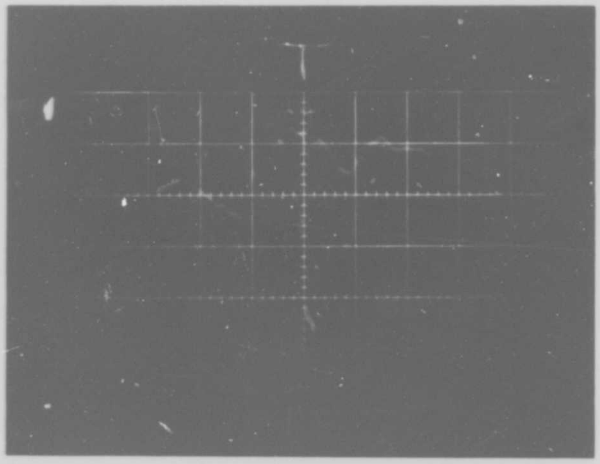
Sensitivity 0.5 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.0002v /cm

TITLE Primary photocurrent of FM 709 subjected to 2 x 10^{10} r/sec with V_{cc} = 30 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

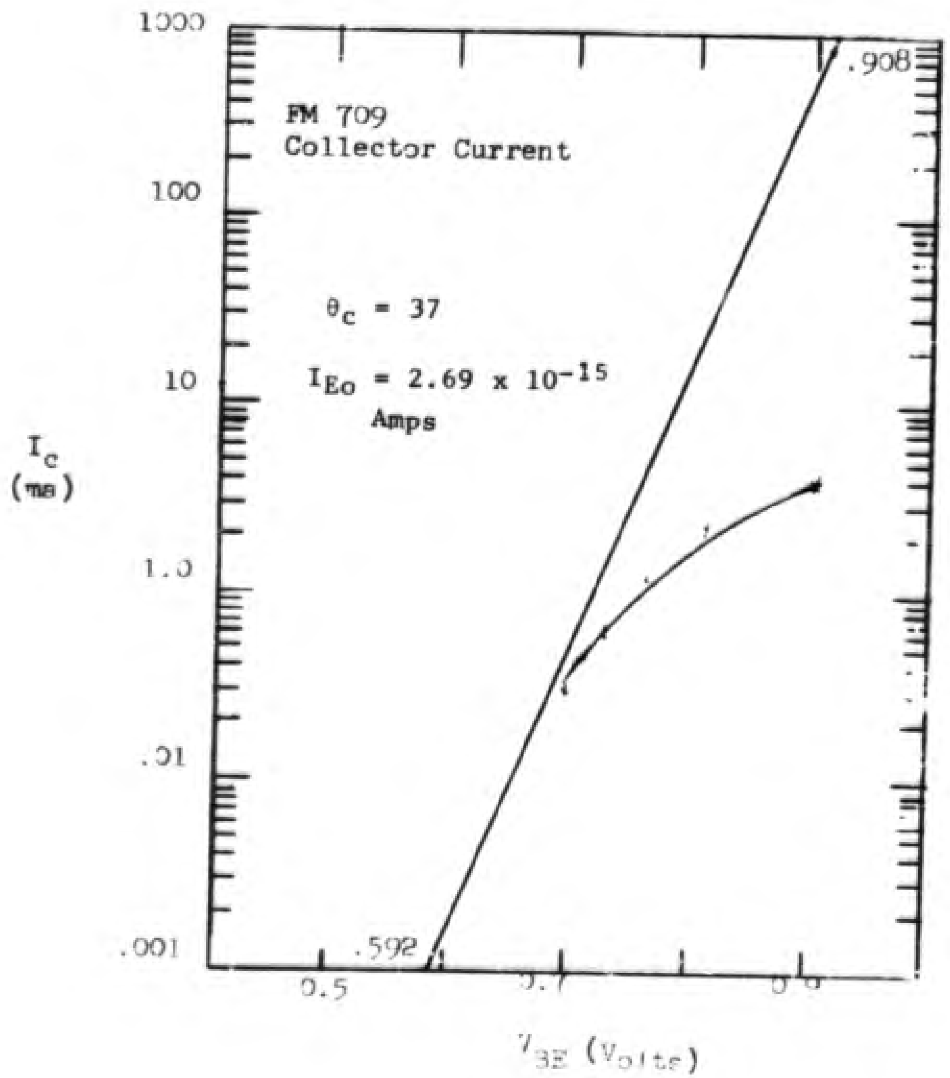
Quantity Linac pulse

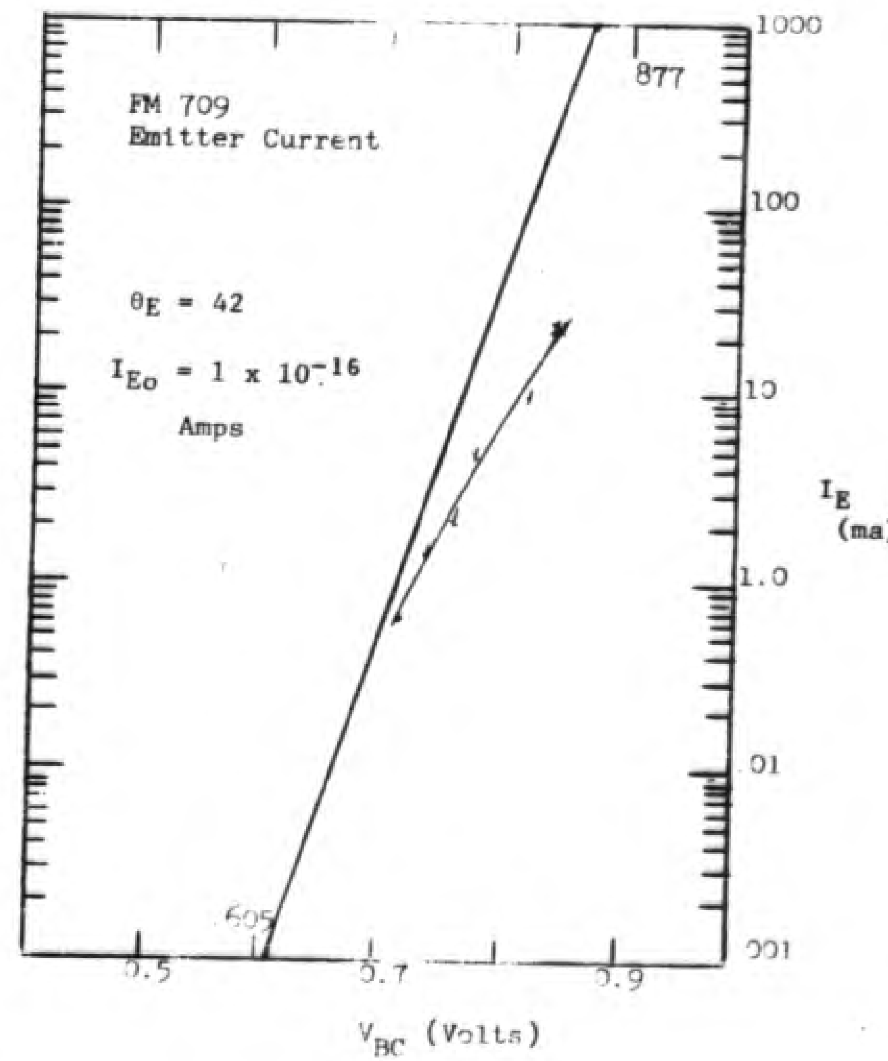
Sensitivity 0.1 v /cm

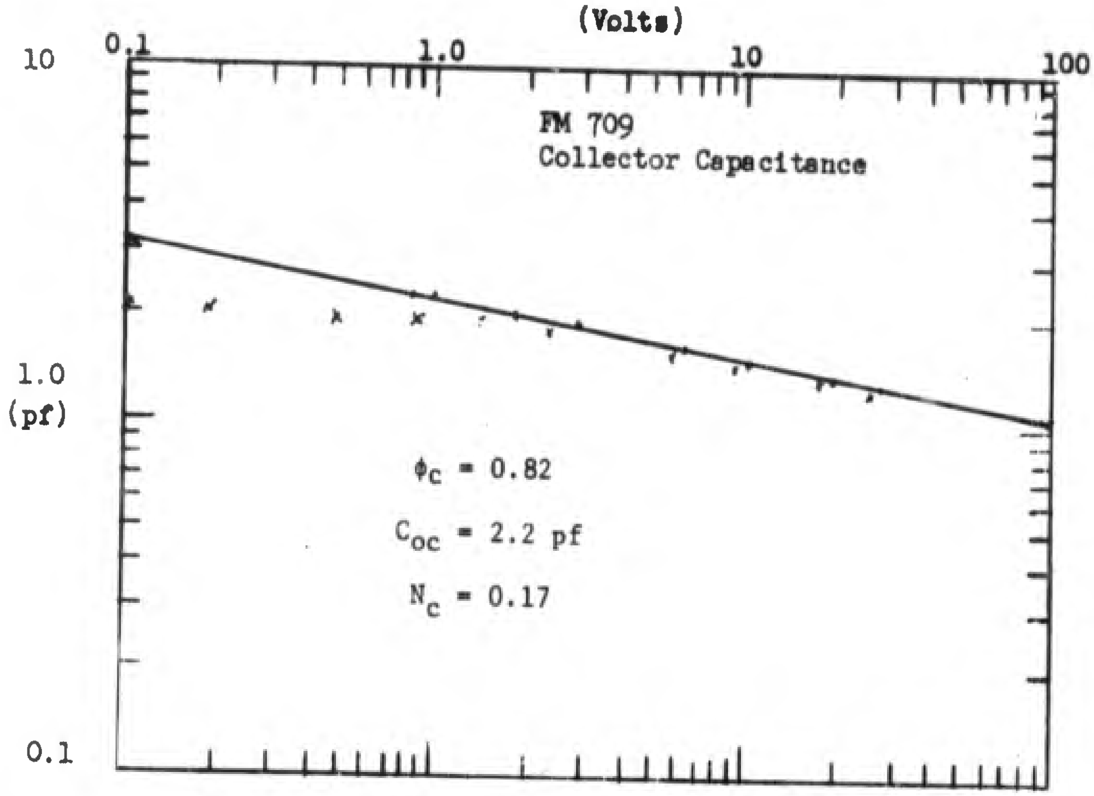
Lower Trace

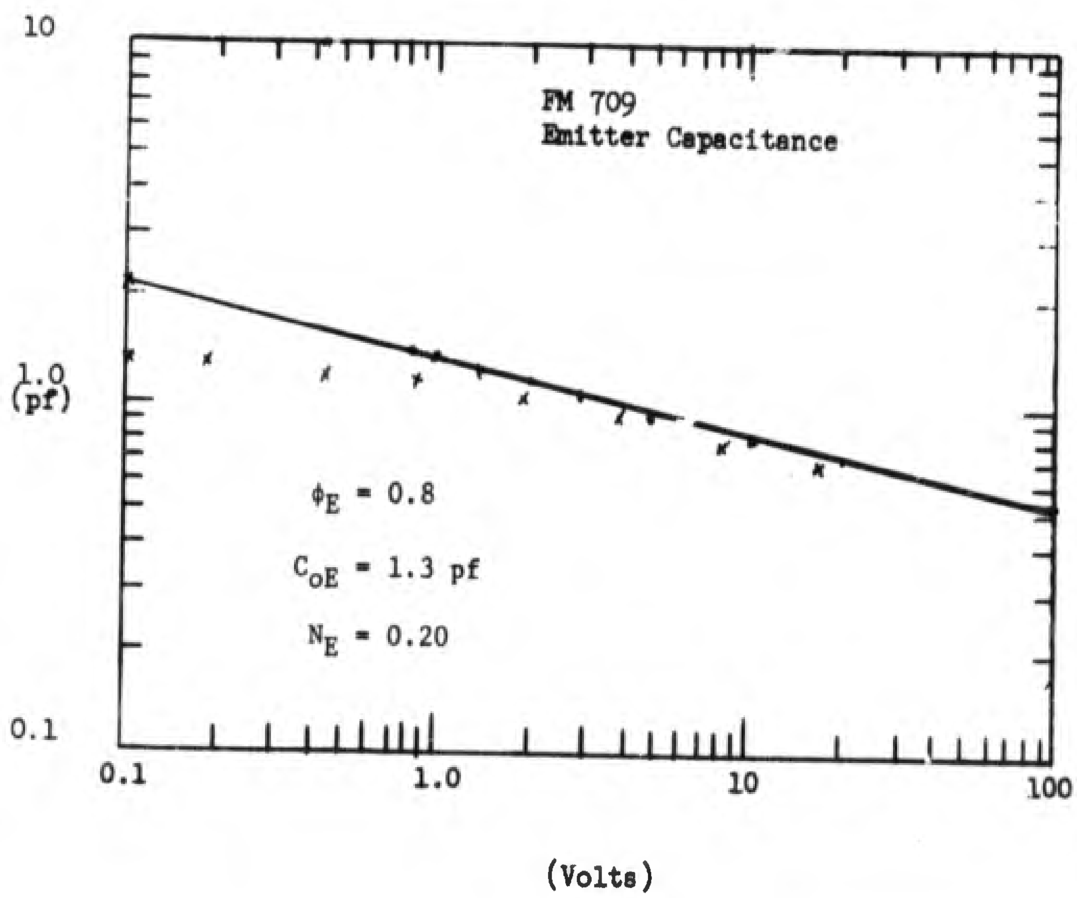
Quantity I_{pp}

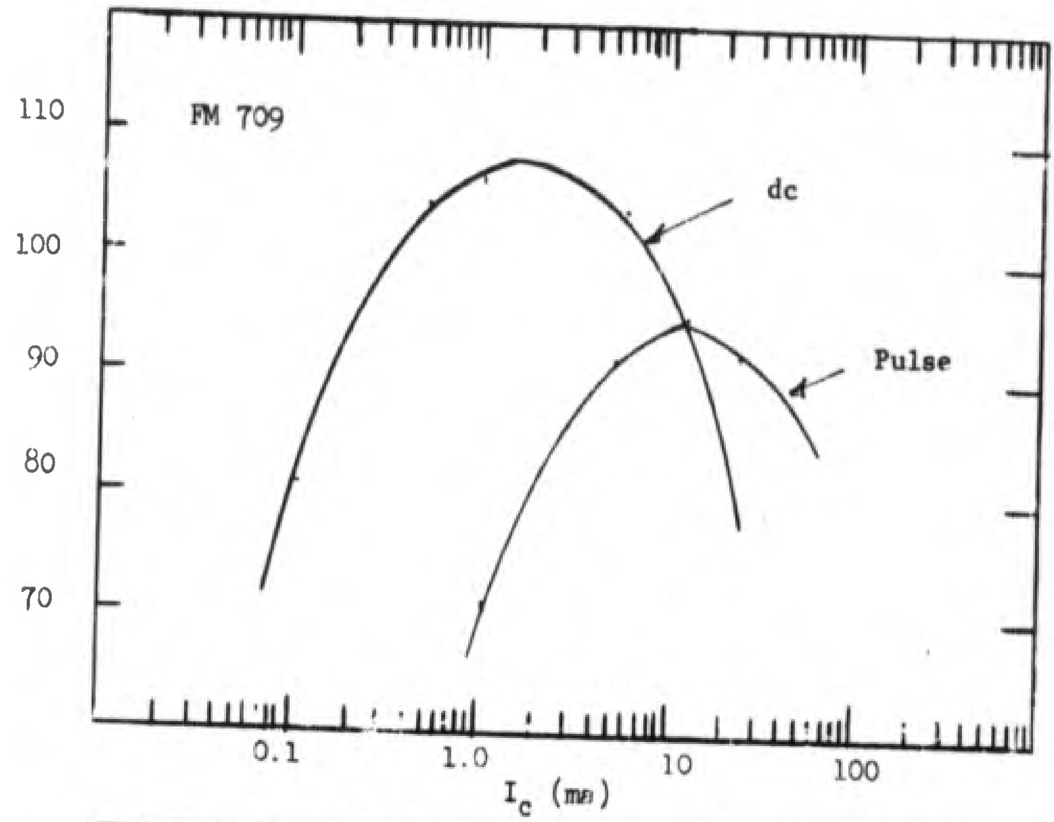
Sensitivity 0.2 v /cm

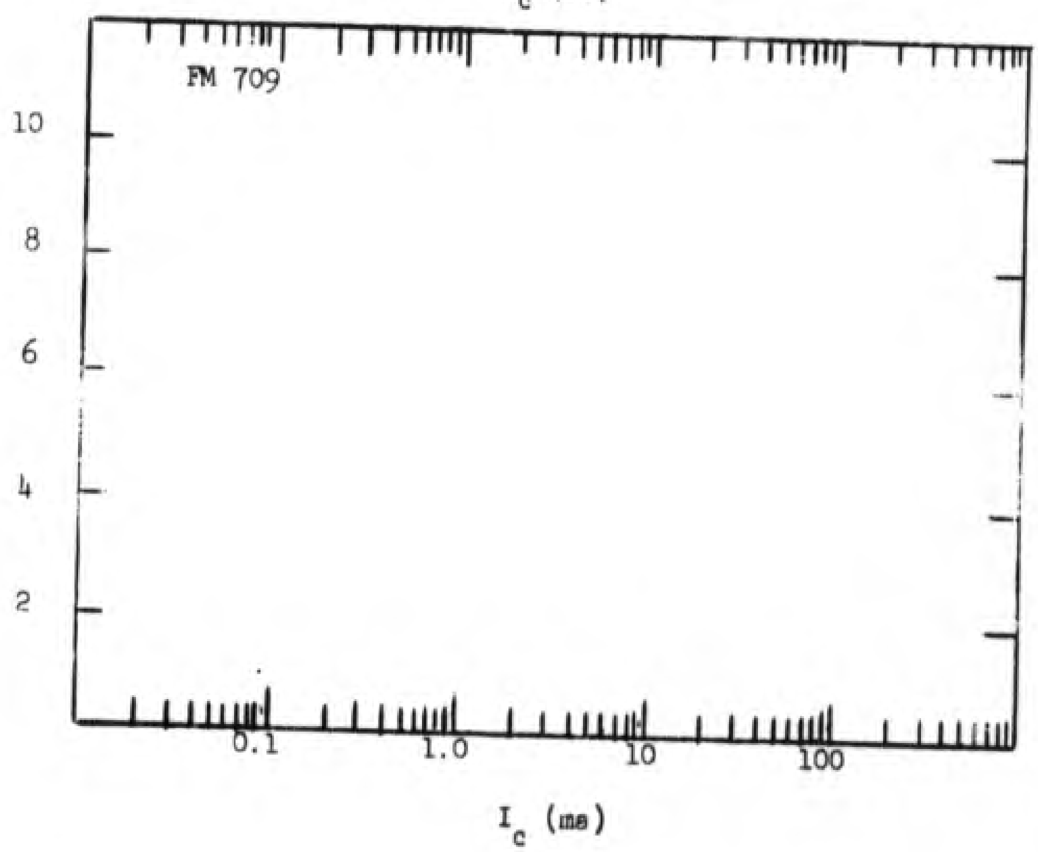

FM 709
Collector Current
θc = 37
IEo = 2.69 x 10-15
Amps
1000
100
10
1.0
.01
.001
.908
.592
0.5
VBE (Volts)
Ic
(ma)


FM 709
Emitter Current
θE = 42
IEo = 1 x 10-16
Amps
877
605
0.5
0.7
0.9
VBC (Volts)
1000
100
10
1.0
.01
.001
IE
(ma)

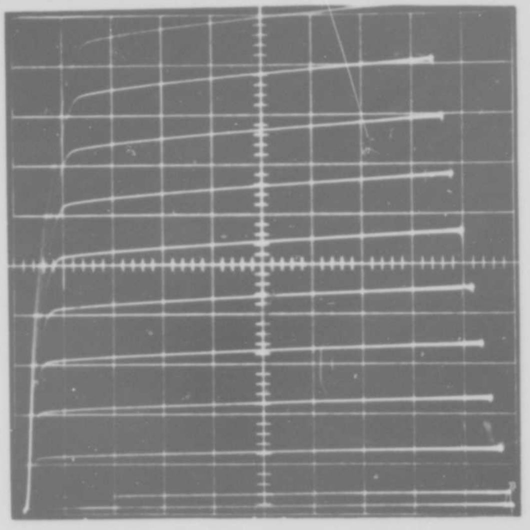

(Volts)
0.1
1.0
10
100
10
1.0
(pf)
0.1
FM 709
Collector Capacitance
ϕc = 0.82
Coc = 2.2 pf
Nc = 0.17


10
1.0
(pf)
0.1
FM 709
Emitter Capacitance
ϕE = 0.8
CoE = 1.3 pf
NE = 0.20
0.1
1.0
10
100
(Volts)


110
100
90
80
70
FM 709
dc
Pulse
0.1
1.0
10
100
I_c (ma)


10
8
6
4
2
FM 709
0.1
1.0
10
100
I_c (ma)

TITLE V_c - I_c characteristic of FM 915 showing β linearity



HORIZONTAL

Quantity V_c

Sensitivity 1 v /cm

VERTICAL

Upper Trace

Quantity I_c

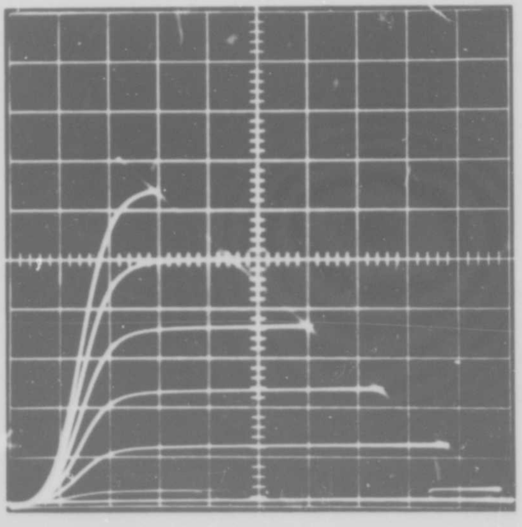
Sensitivity 0.5 ma /cm

Lower Trace

Quantity I_b = 0.005 ma/step

Sensitivity - /cm

TITLE V_c - I_c characteristic of FM 915 showing V_c sat



HORIZONTAL

Quantity V_c

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

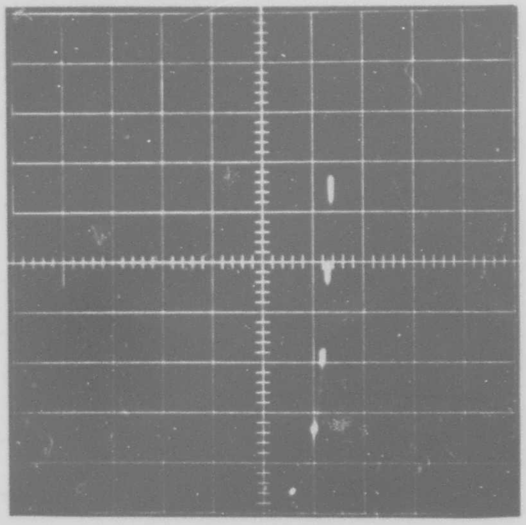
Sensitivity 0.02 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE I_c - V_{BE} characteristic of FM 915 showing base conduction



HORIZONTAL

Quantity V_{BE}

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

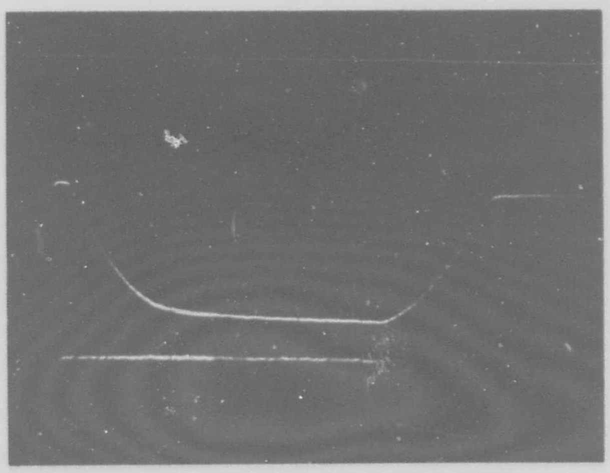
Sensitivity 0.1 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of FM 915 showing rise and fall time



HORIZONTAL

Quantity time

Sensitivity 50 nsec /cm

VERTICAL

Upper Trace

Quantity V_e

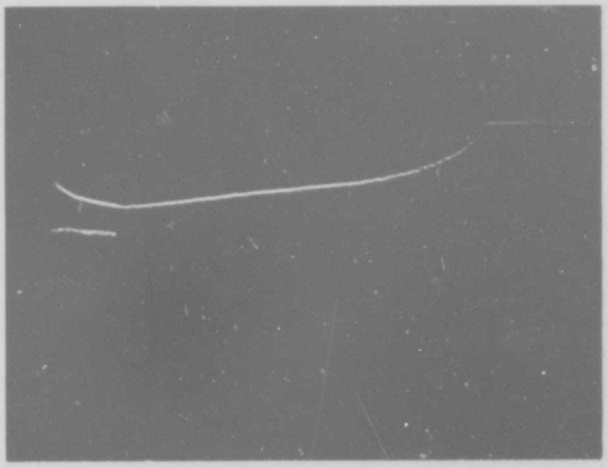
Sensitivity 50 mv /cm

Lower Trace

Quantity V_B

Sensitivity 20 mv /cm

TITLE Switching characteristic of FM 915 showing storage time



HORIZONTAL

Quantity time

Sensitivity 200 nsec /cm

VERTICAL

Upper Trace

Quantity V_C

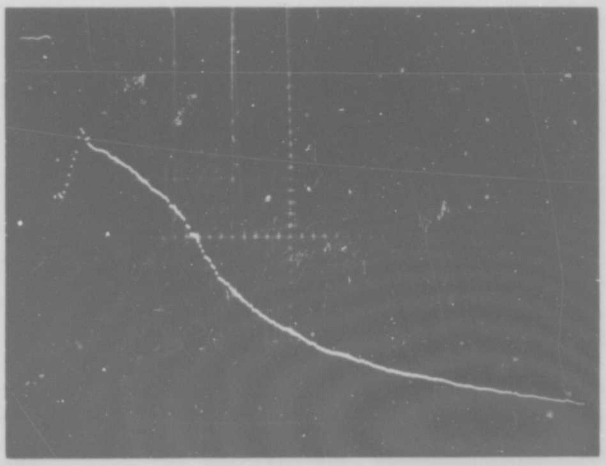
Sensitivity 100 mv /cm

Lower Trace

Quantity V_B

Sensitivity 100 mv /cm

TITLE Switching characteristic of FM 915 showing base emitter recovery time



HORIZONTAL

Quantity time

Sensitivity 25 nsec /cm

VERTICAL

Upper Trace

Quantity V_{BE}

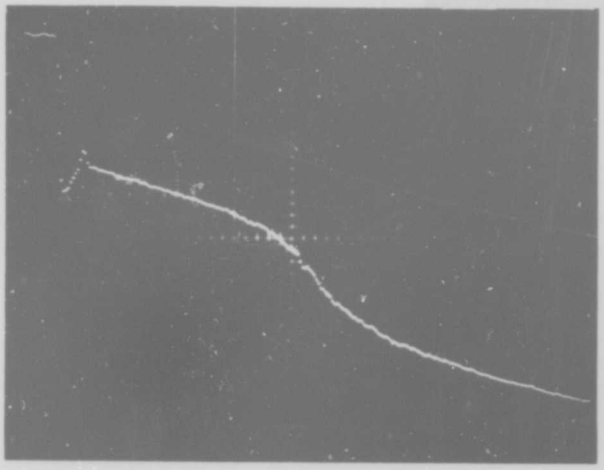
Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of FM 915 showing base collector recovery time



HORIZONTAL

Quantity time

Sensitivity 25 nsec /cm

VERTICAL

Upper Trace

Quantity V_{CB}

Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE

HORIZONTAL

Quantity

Sensitivity /cm

VERTICAL

Upper Trace

Quantity

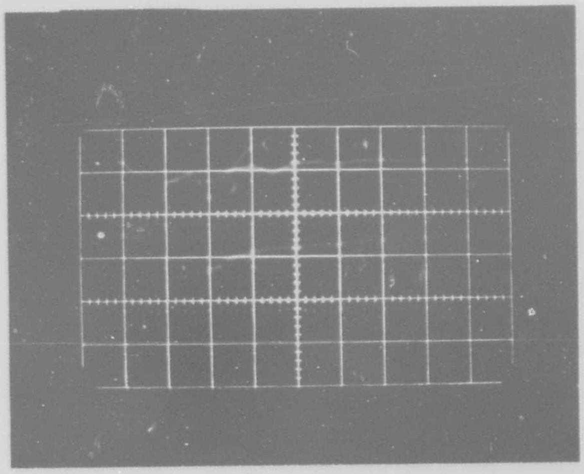
Sensitivity /cm

Lower Trace

Quantity

Sensitivity /cm

TITLE Primary photocurrent of FM 915 subjected to 6.5×10^6 r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity X-ray pulse

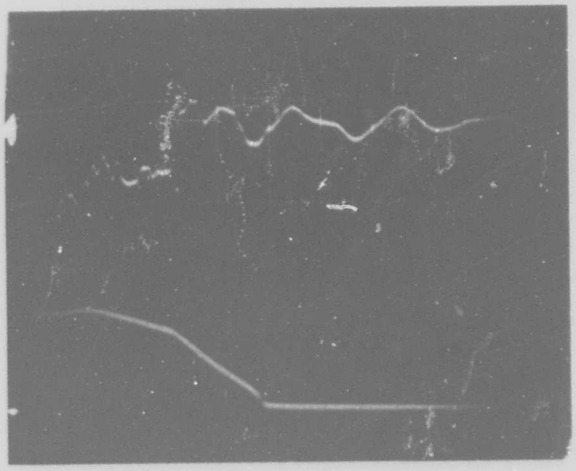
Sensitivity 0.5 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.001 v /cm

TITLE Primary photocurrent of FM 915 subjected to 2×10^{10} r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 200 nsec /cm

VERTICAL

Upper Trace

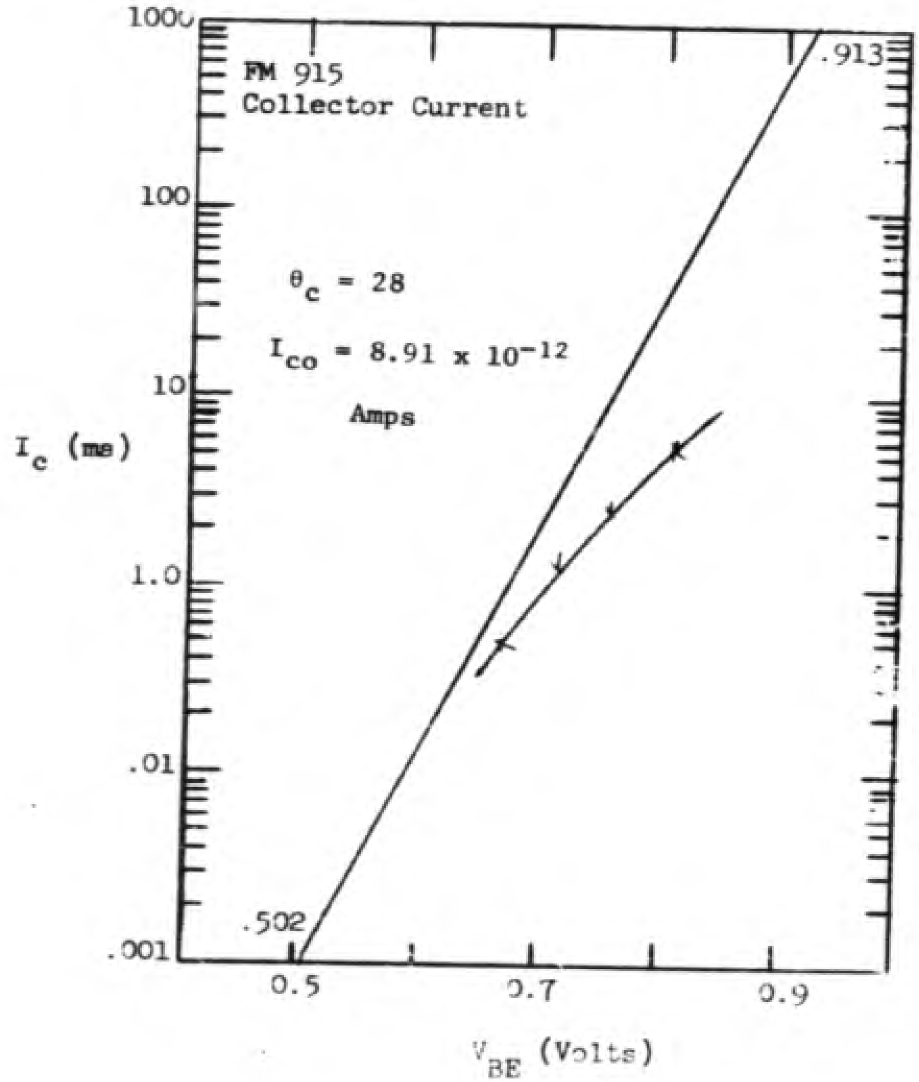
Quantity Linac pulse

Sensitivity 0.1 v /cm

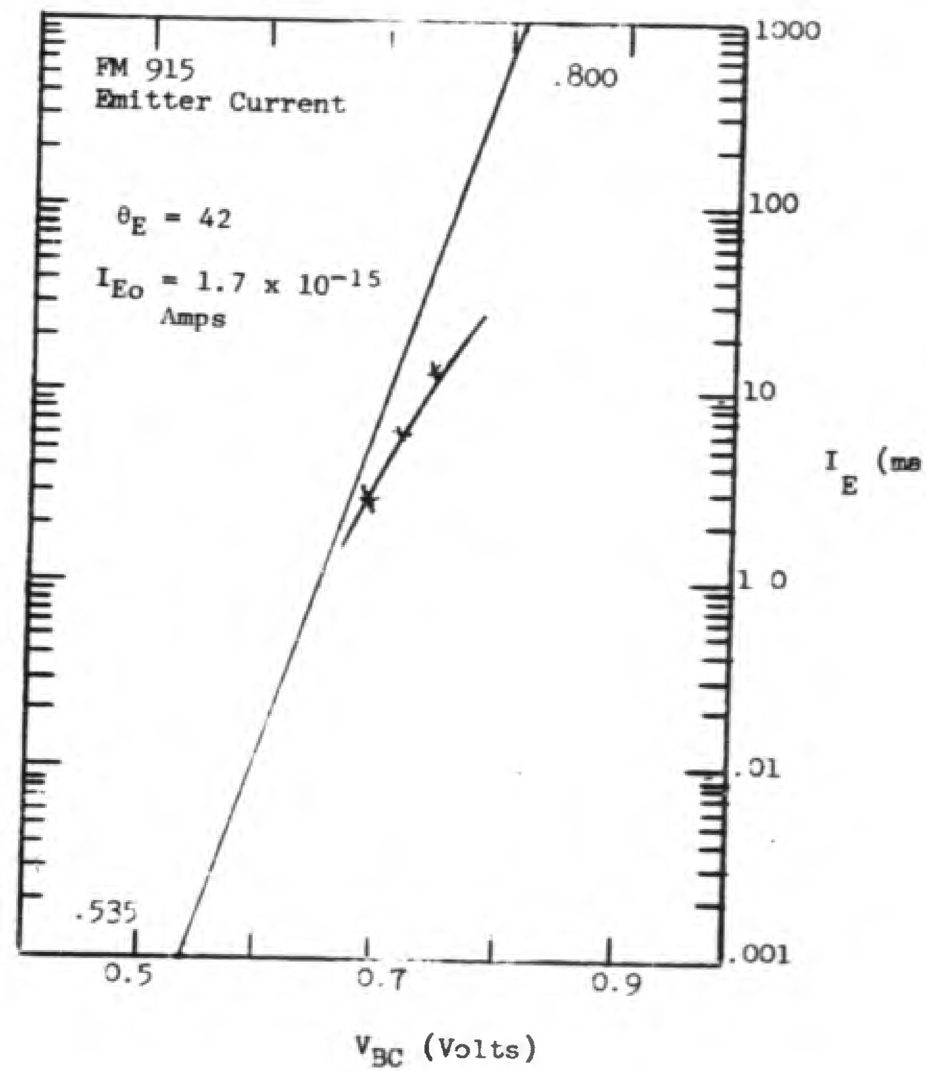
Lower Trace

Quantity I_{pp}

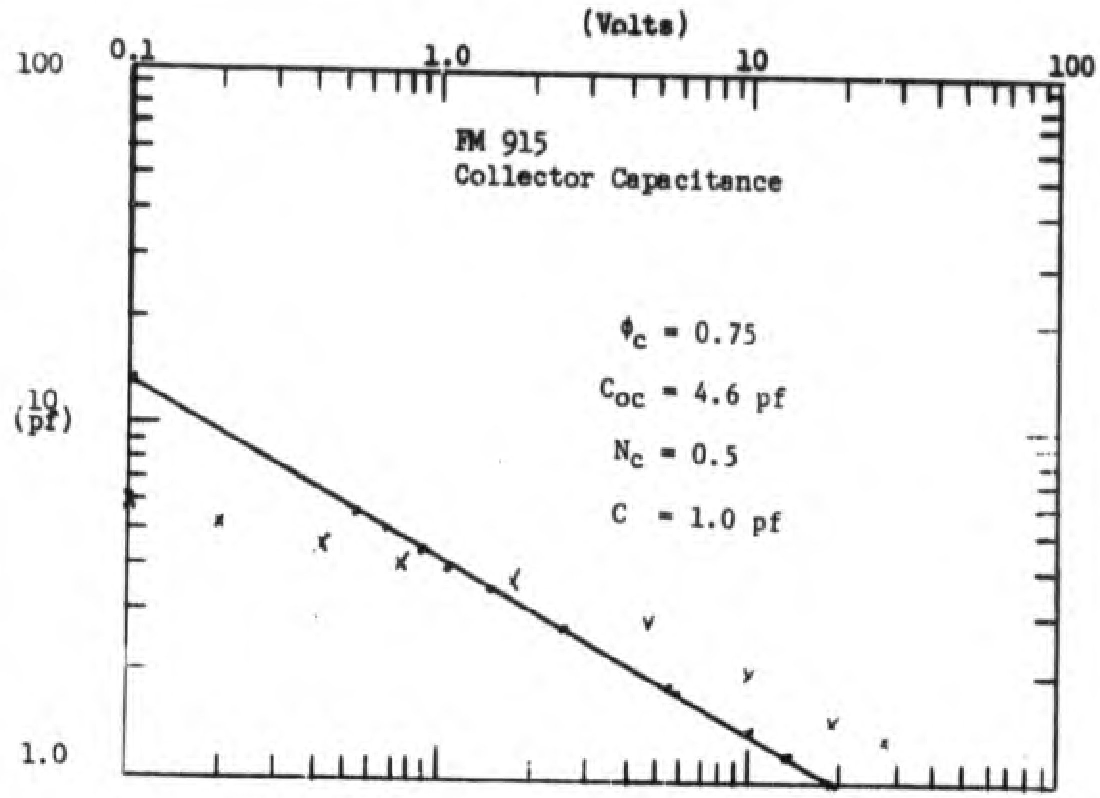
Sensitivity 1.0 v /cm



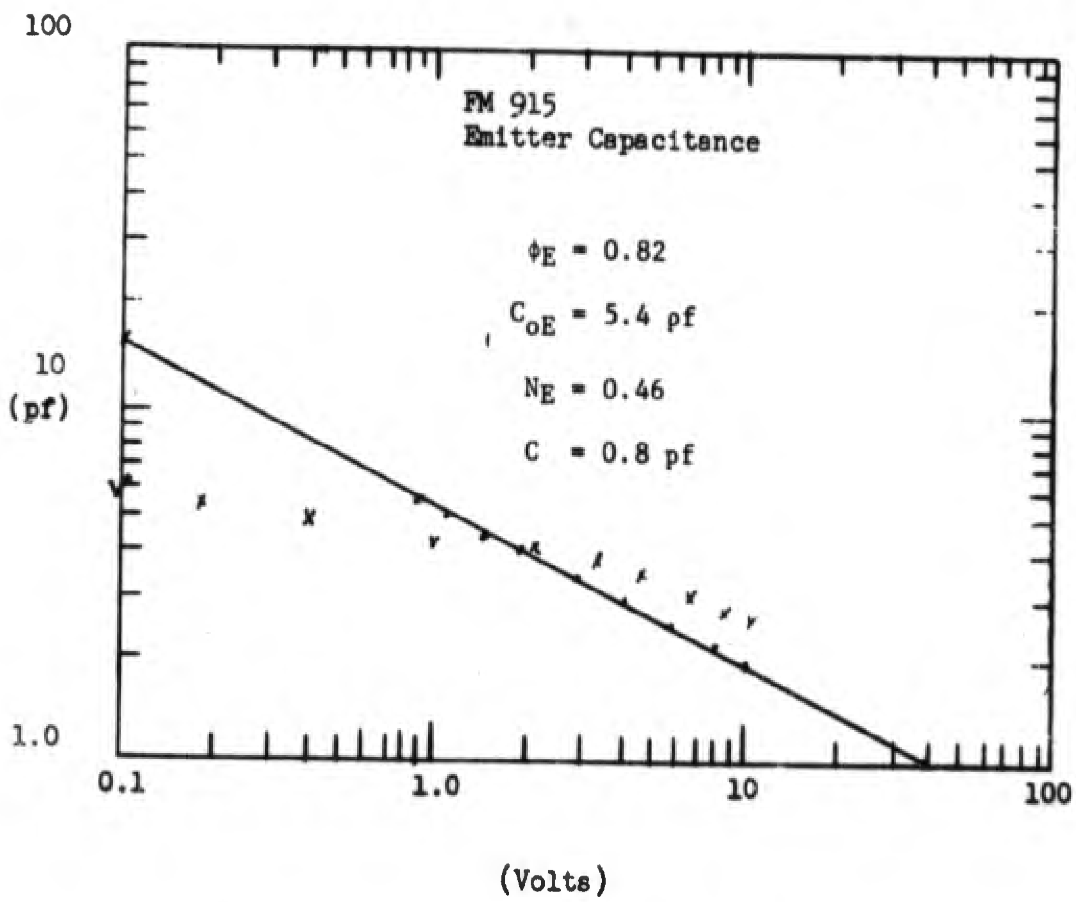
FM 915
Collector Current
θc = 28
Ico = 8.91 x 10^-12
Amps
.913
.502
1000
100
10
1.0
.01
.001
Ic (ma)
0.5
0.7
0.9
VBE (Volts)



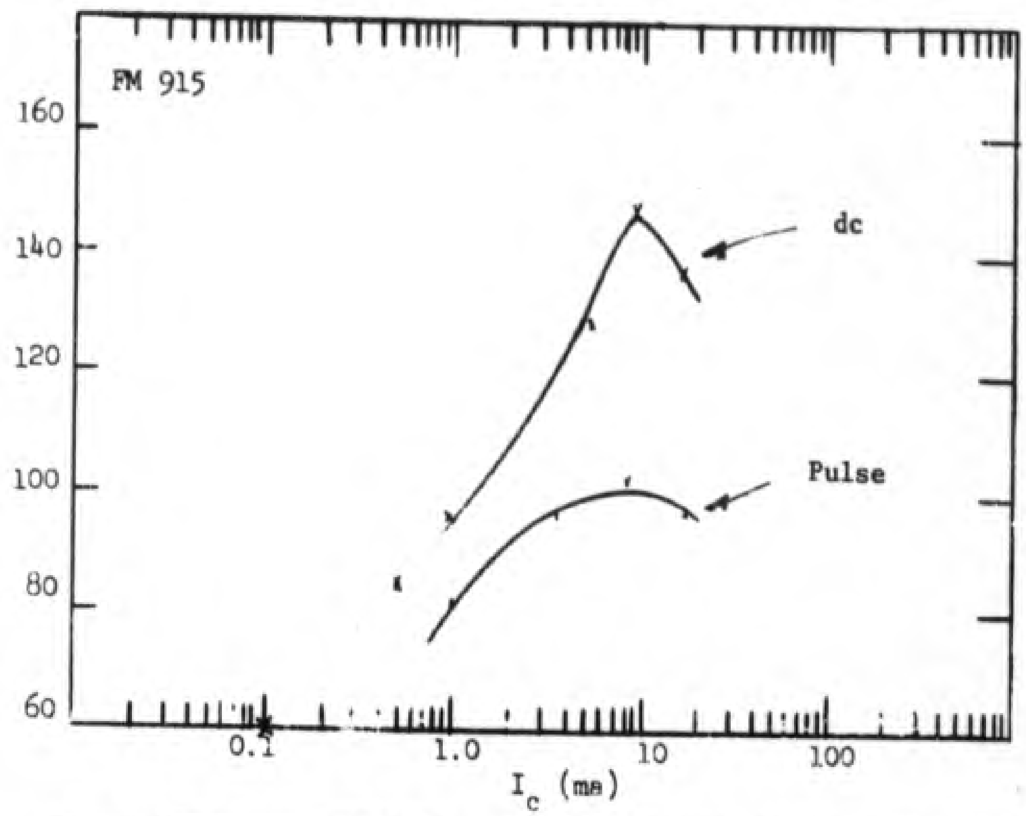
FM 915
Emitter Current
θE = 42
IEo = 1.7 x 10^-15
Amps
.800
.535
1000
100
10
1.0
.01
.001
IE (ma)
0.5
0.7
0.9
VBC (Volts)

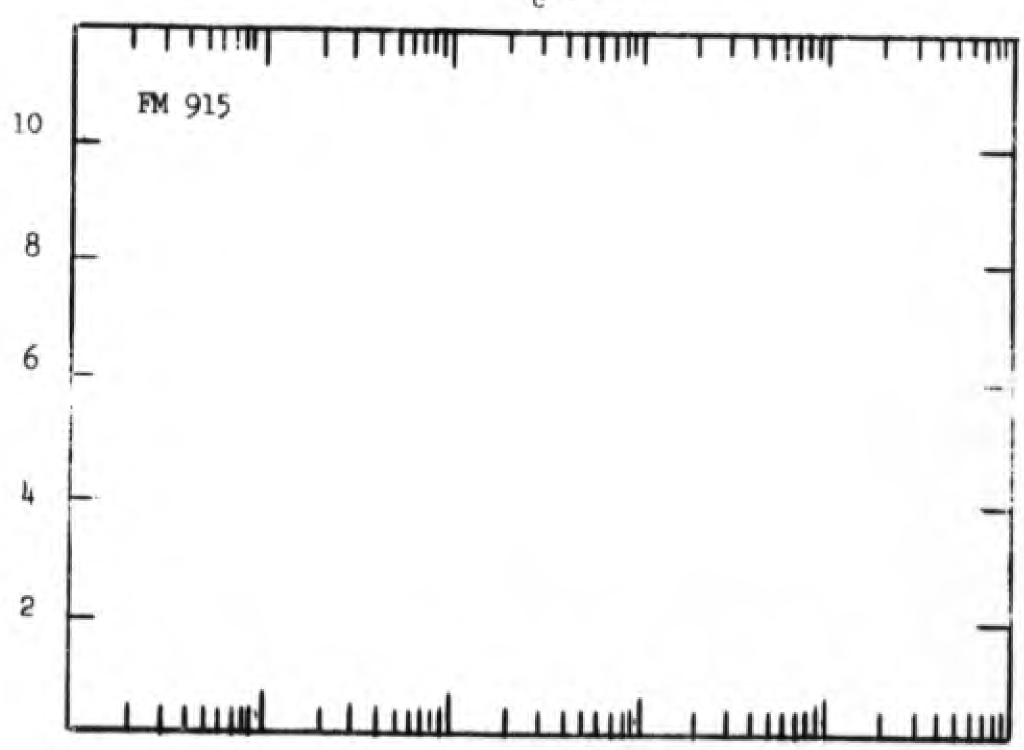


(Volts)
0.1
1.0
10
100
100
10
(pf)
1.0
FM 915
Collector Capacitance
ϕ_c = 0.75
C_{oc} = 4.6 pf
N_c = 0.5
C = 1.0 pf

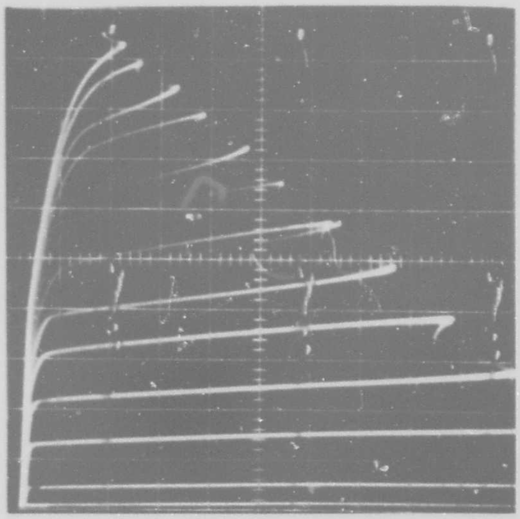


100
10
(pf)
1.0
0.1
1.0
10
100
FM 915
Emitter Capacitance
ϕ_E = 0.82
C_{oE} = 5.4 pf
N_E = 0.46
C = 0.8 pf
(Volts)


FM 915
160
140
120
100
80
60
dc
Pulse
0.1
1.0
10
100
I_c (ma)


FM 915
10
8
6
4
2

TITLE V_c - I_c characteristic of 2N2222A showing β linearity



HORIZONTAL

Quantity V_c

Sensitivity 5 v /cm

VERTICAL

Upper Trace

Quantity I_c

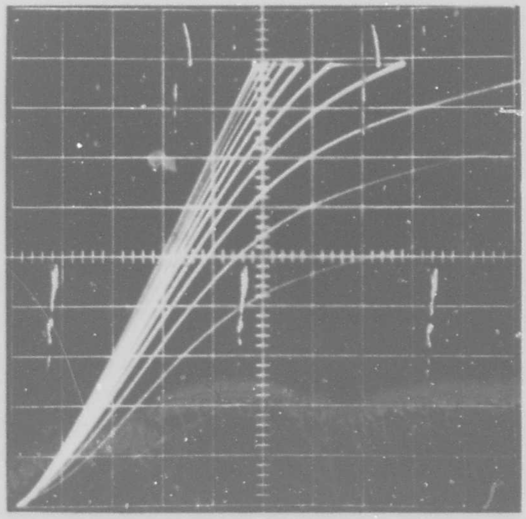
Sensitivity 20 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE V_c - I_c characteristic of 2N2222A showing V_c sat



HORIZONTAL

Quantity V_c

Sensitivity 0.05 v /cm

VERTICAL

Upper Trace

Quantity I_c

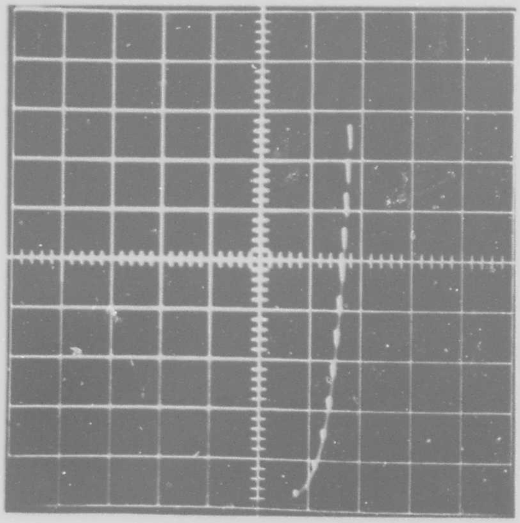
Sensitivity 20 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE I_c - V_{BE} characteristic of 2N2222A showing base conduction



HORIZONTAL

Quantity V_{BE}

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

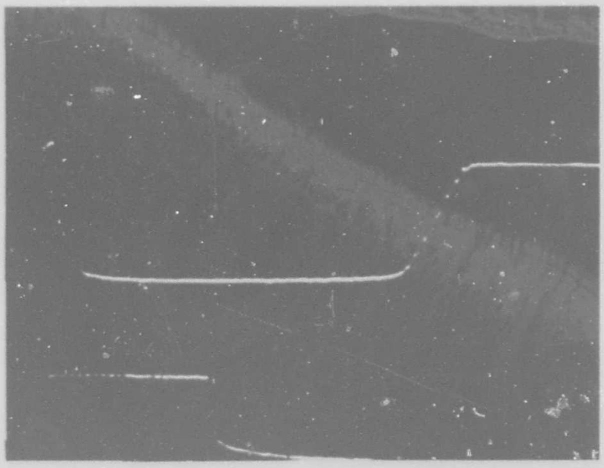
Sensitivity 2 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristics of 2N2222A showing rise and fall time



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity V_c

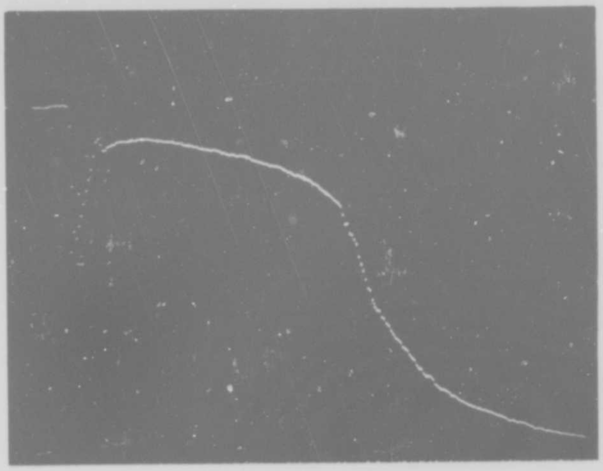
Sensitivity 100 mv /cm

Lower Trace

Quantity V_B

Sensitivity 100 mv /cm

TITLE Switching characteristic of 2N2222A showing collector base recovery time



HORIZONTAL

Quantity time

Sensitivity 25 nsec /cm

VERTICAL

Upper Trace

Quantity V_c

Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity- /cm

TITLE

HORIZONTAL

Quantity

Sensitivity /cm

VERTICAL

Upper Trace

Quantity

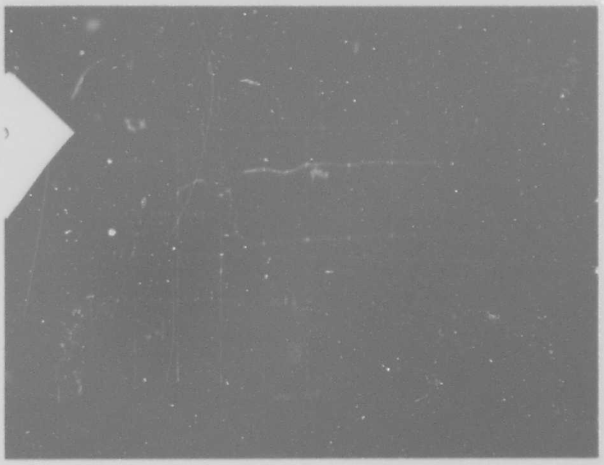
Sensitivity /cm

Lower Trace

Quantity

Sensitivity /cm

TITLE Primary Photocurrent of 2N2222A subjected to 6.0 x 10^6 r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity X-ray pulse

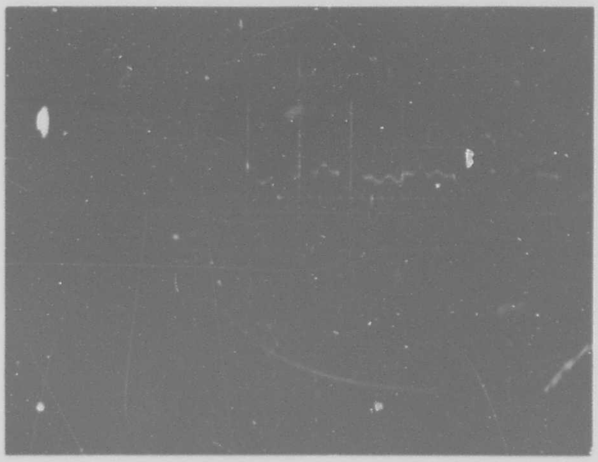
Sensitivity 0.5 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity .001 v /cm

TITLE Primary photocurrent of 2N2222A subjected to 8 x 10^9 r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

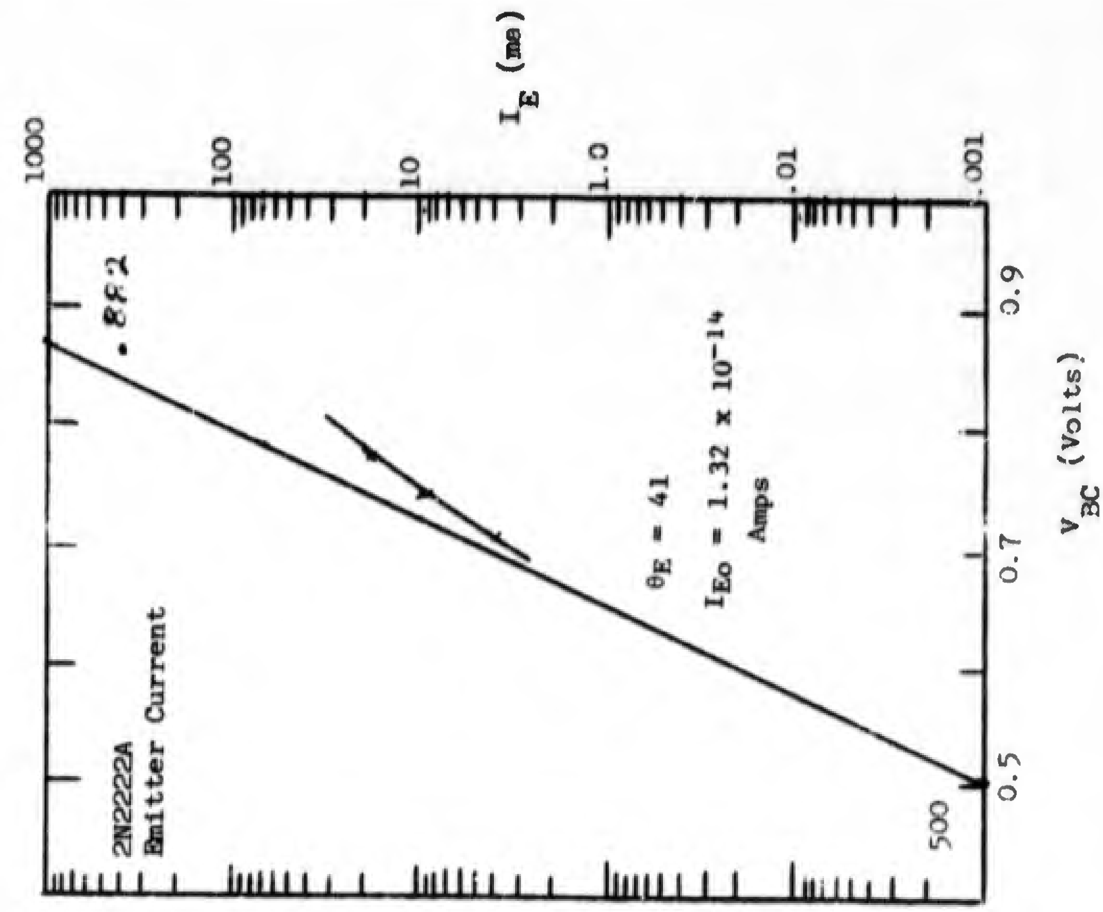
Quantity Linac pulse

Sensitivity 0.1 v /cm

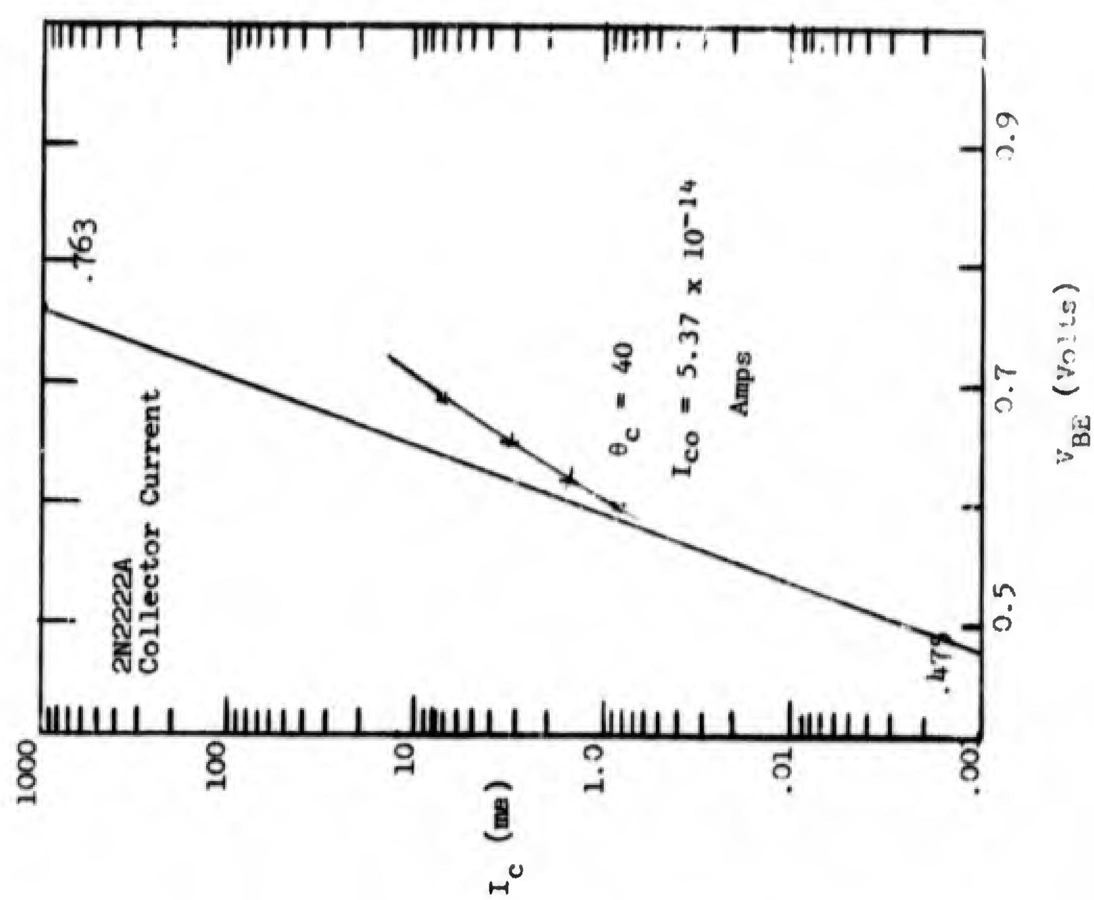
Lower Trace

Quantity I_{pp}

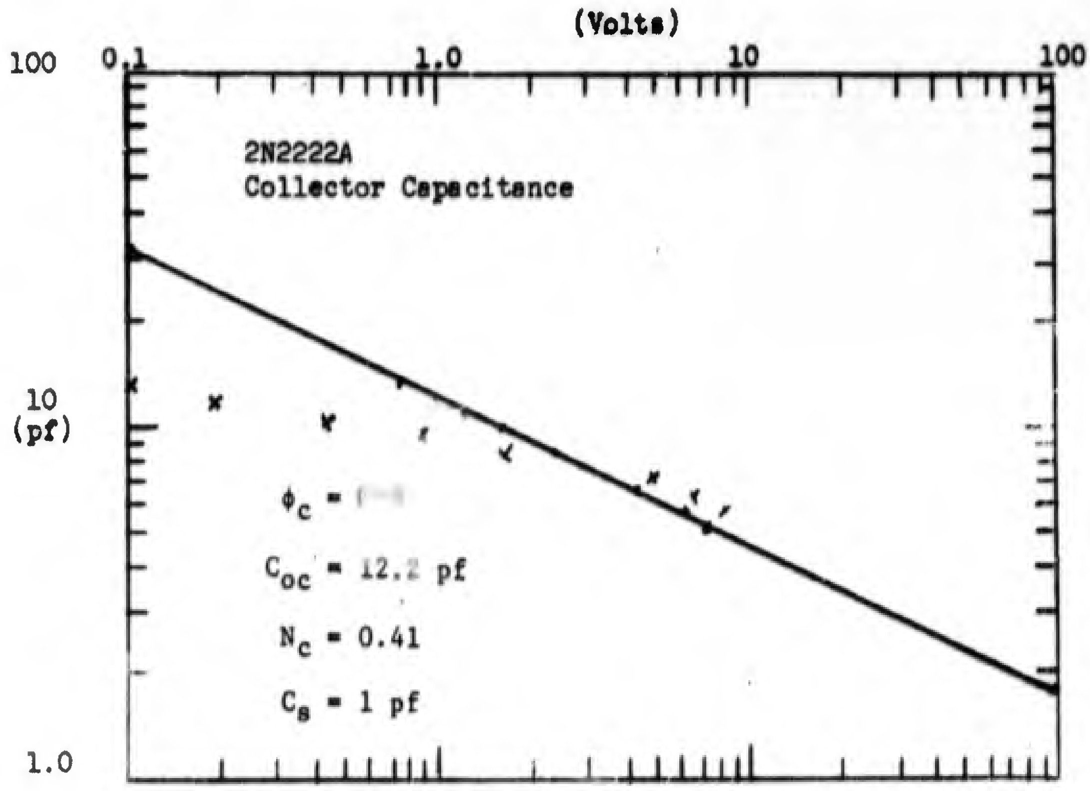
Sensitivity 0.5 v /cm

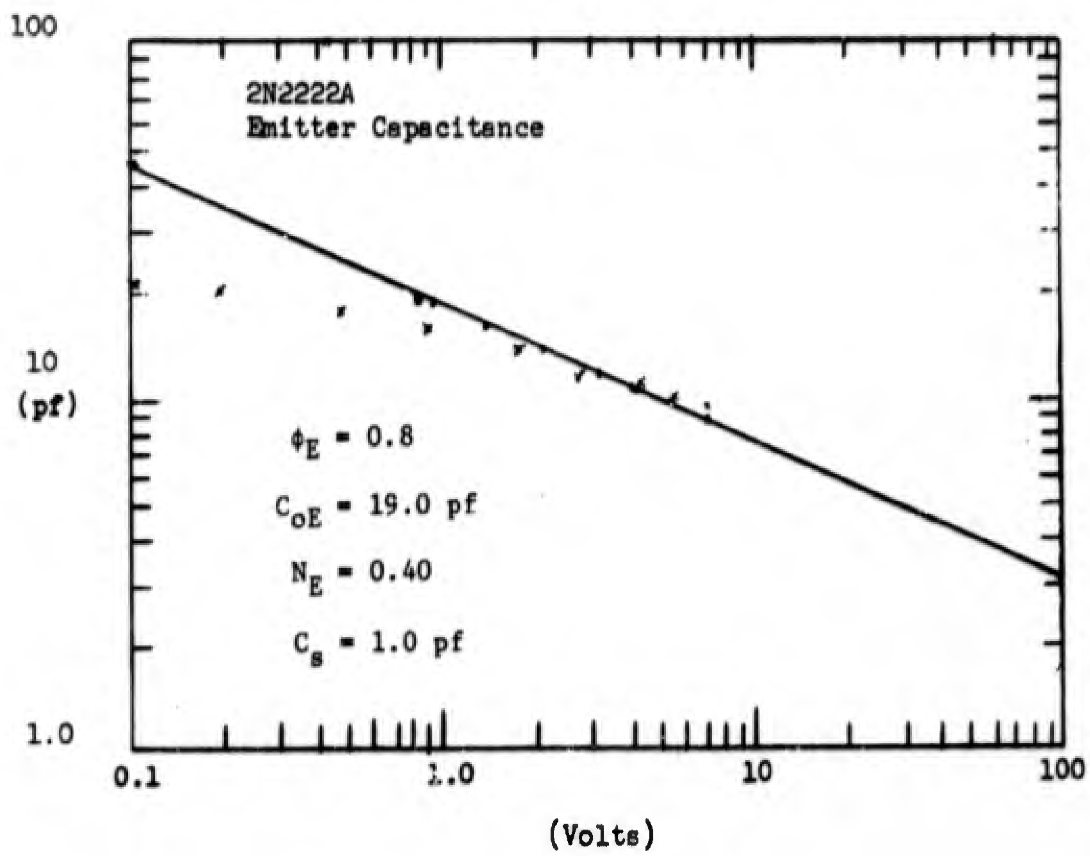


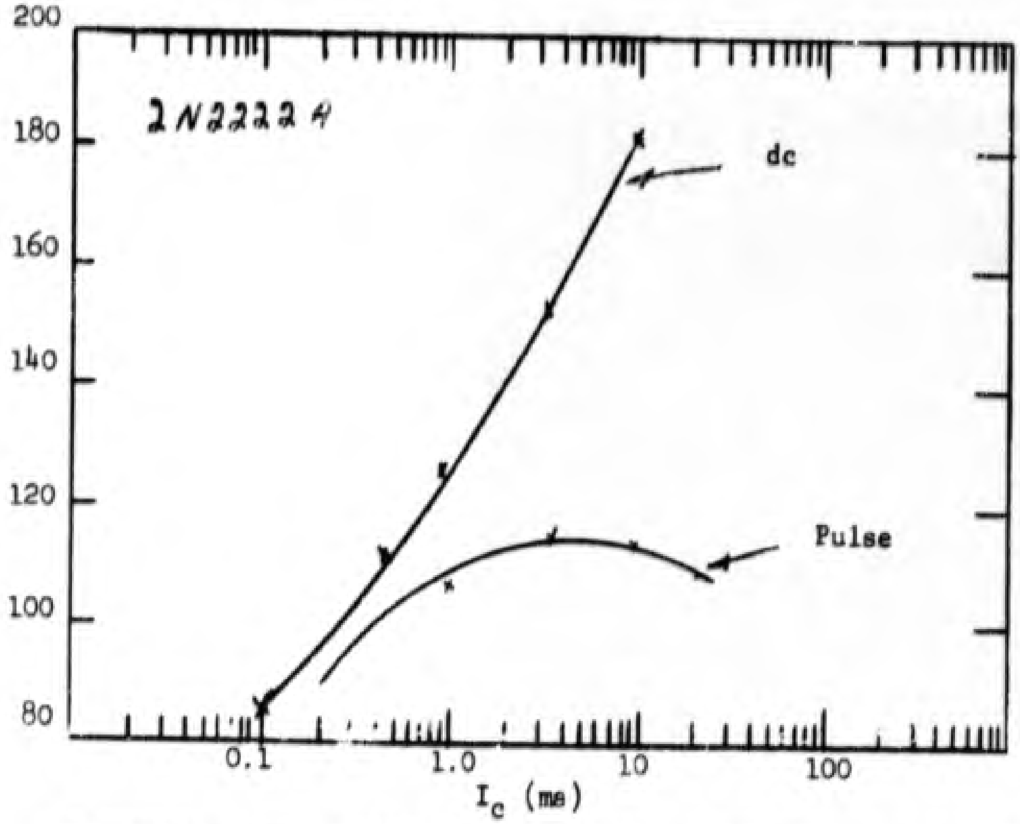
2N2222A
Emitter Current
θE = 41
IEo = 1.32 x 10^-14
Amps
VBC (Volts)
IE (ma)
1000
100
10
1.0
.01
.001
0.5
0.7
0.9
500
.882

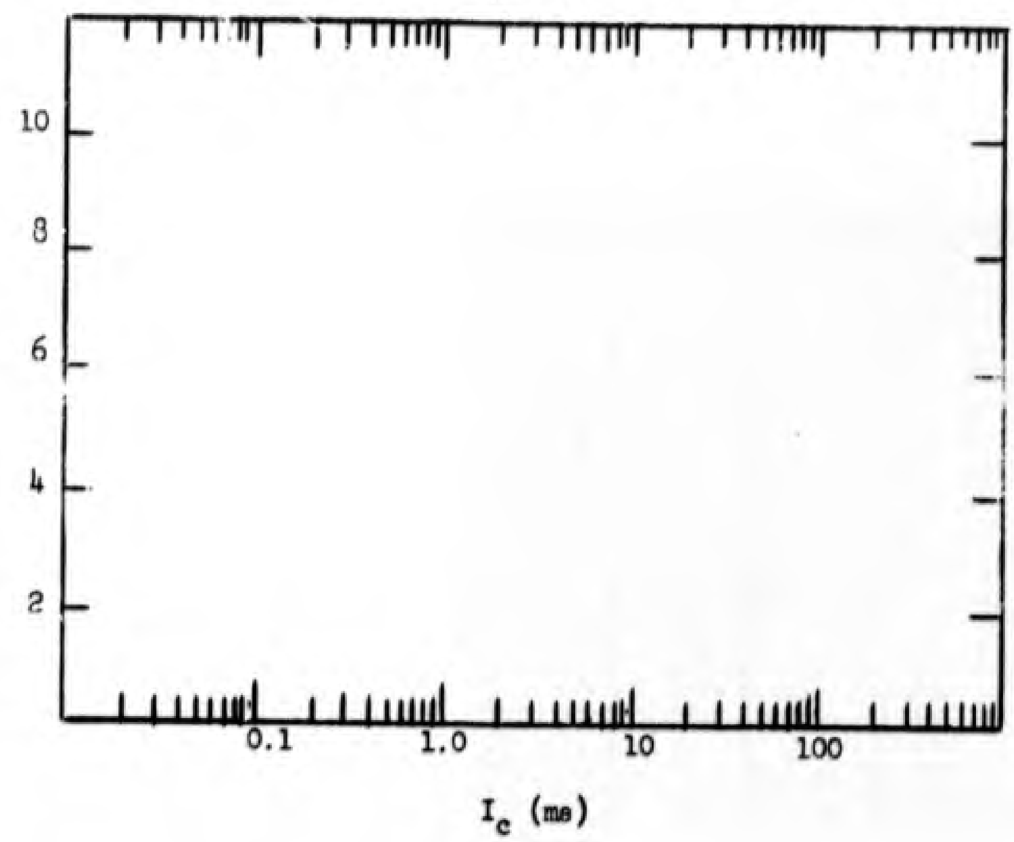


2N2222A
Collector Current
θc = 40
Ico = 5.37 x 10^-14
Amps
VBE (Volts)
Ic (ma)
1000
100
10
1.0
.01
.001
0.5
0.7
0.9
.763
.479

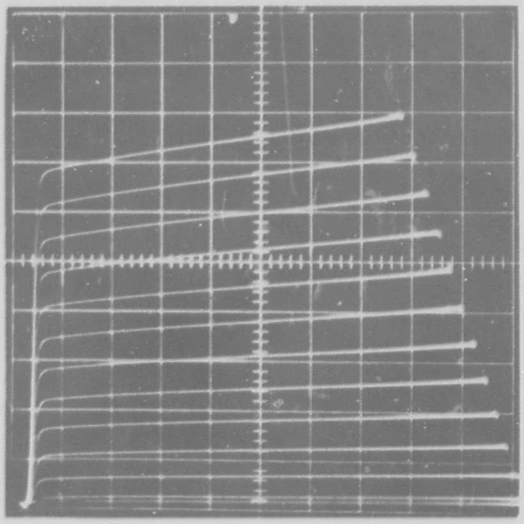

(Volts)
0.1
1.0
10
100
2N2222A
Collector Capacitance
(pf)
N_c = 0.41
C_s = 1 pf


100
2N2222A
Emitter Capacitance
10
(pf)
φ_E = 0.8
C_oE = 19.0 pf
N_E = 0.40
C_s = 1.0 pf
1.0
0.1
10
100
(Volts)


200
180
160
140
120
100
80
2N2222A
dc
Pulse
0.1
1.0
10
100
I_c (ma)


10
8
6
4
2
0.1
1.0
10
100
I_c (ma)

TITLE V_c - I_c characteristic of 2N3303 showing β linearity



HORIZONTAL

Quantity V_c

Sensitivity 1 v /cm

VERTICAL

Upper Trace

Quantity I_c

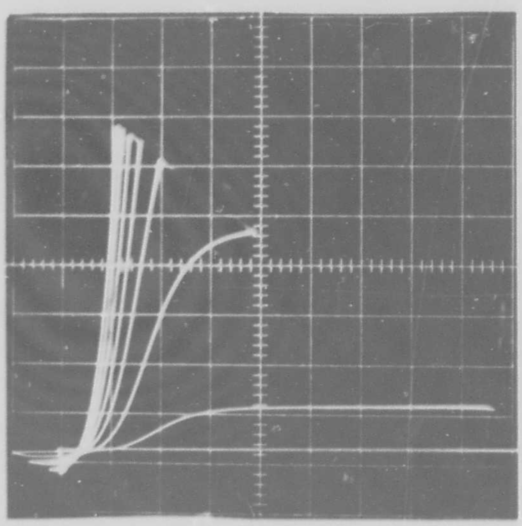
Sensitivity 2 ma /cm

Lower Trace

Quantity I_b 0.2 ma/step

Sensitivity - /cm

TITLE V_c - I_c characteristic of 2N3303 showing V_c sat



HORIZONTAL

Quantity V_c

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

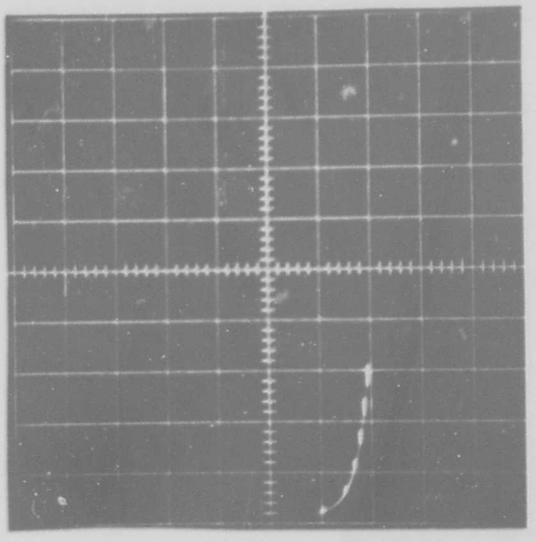
Sensitivity 0.2 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE I_c - V_{BE} characteristic of 2N3303 showing base conduction



HORIZONTAL

Quantity V_{BE}

Sensitivity 0.1 v /cm

VERTICAL

Upper Trace

Quantity I_c

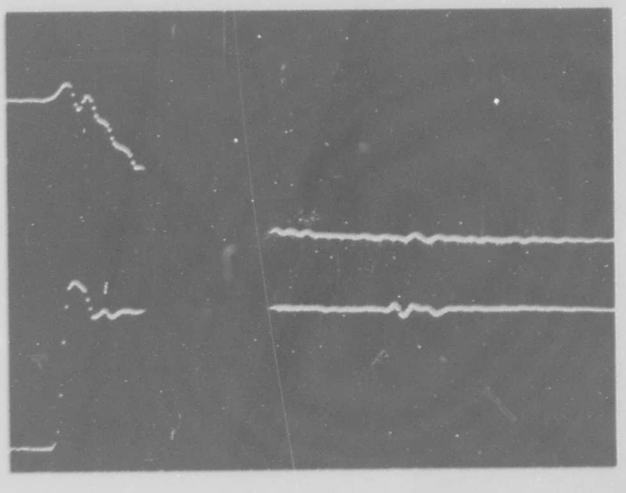
Sensitivity 2 ma /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of 2N3303 showing rise time



HORIZONTAL

Quantity time

Sensitivity 2.5 nsec /cm

VERTICAL

Upper Trace

Quantity V_c

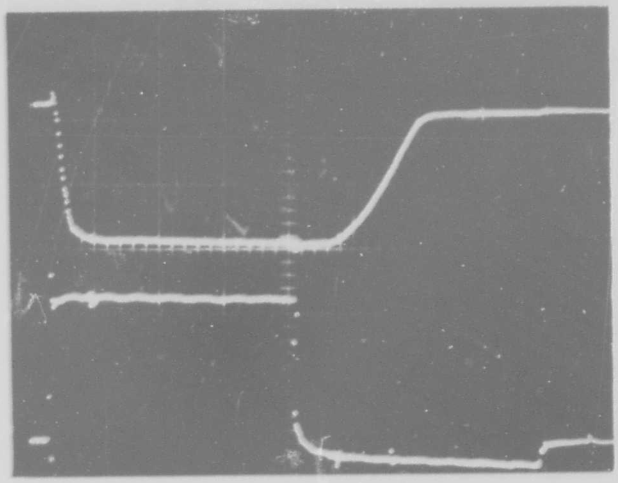
Sensitivity 100 mv /cm

Lower Trace

Quantity V_B

Sensitivity 200 mv /cm

TITLE Switching characteristic of 2N3303 showing storage and fall time



HORIZONTAL

Quantity time

Sensitivity 20 nsec /cm

VERTICAL

Upper Trace

Quantity V_c

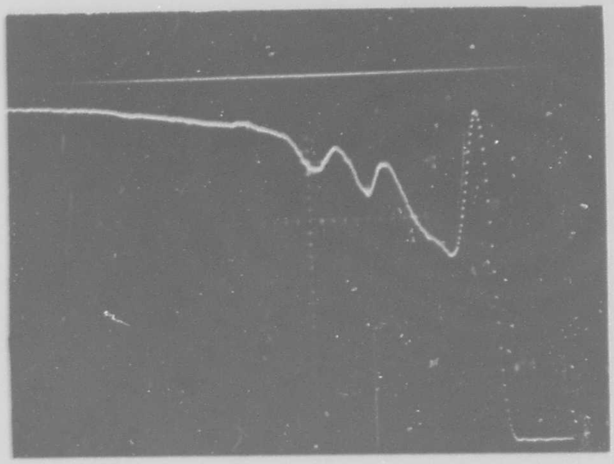
Sensitivity 100 mv /cm

Lower Trace

Quantity V_B

Sensitivity 200 mv /cm

TITLE Switching characteristic of 2N3303 showing base emitter recovery time



HORIZONTAL

Quantity time

Sensitivity 5 nsec /cm

VERTICAL

Upper Trace

Quantity V_{BE}

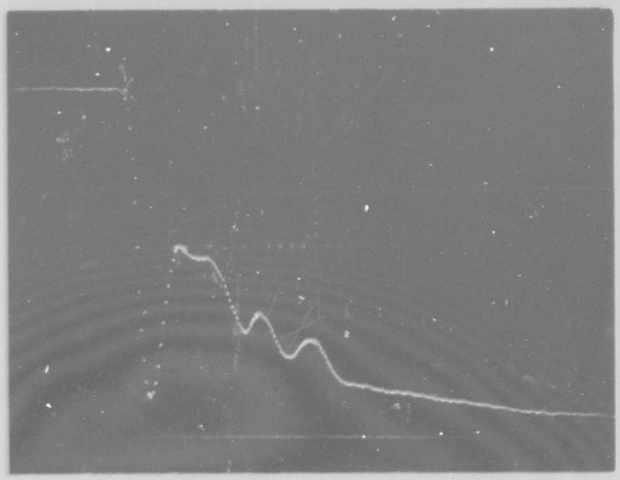
Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE Switching characteristic of 2N3303 showing base collector recovery time



HORIZONTAL

Quantity time

Sensitivity 5 nsec /cm

VERTICAL

Upper Trace

Quantity V_{Bc}

Sensitivity 150 mv /cm

Lower Trace

Quantity -

Sensitivity - /cm

TITLE

HORIZONTAL

Quantity

Sensitivity /cm

VERTICAL

Upper Trace

Quantity

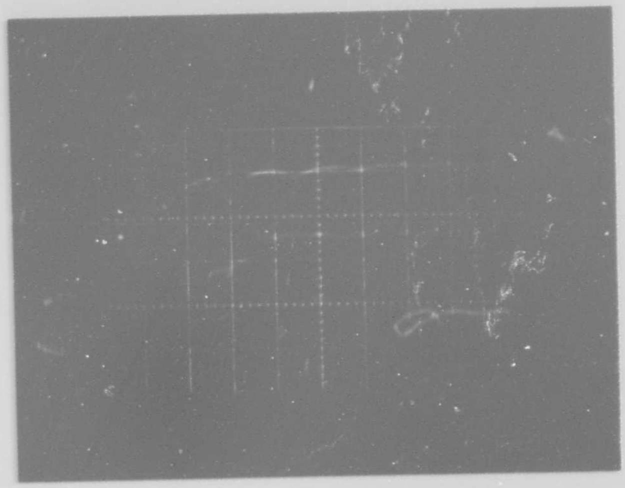
Sensitivity /cm

Lower Trace

Quantity

Sensitivity /cm

TITLE Primary photocurrent of 2N3303 subjected to 7 x 10^6 r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity X-ray pulse

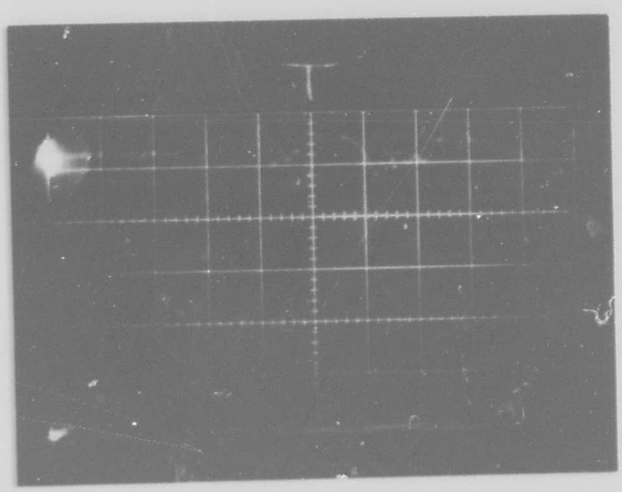
Sensitivity 0.5 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 mv /cm

TITLE Primary photocurrent of 2N3303 subjected to 7 x 10^{10} r/sec with V_c = 10 volts



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

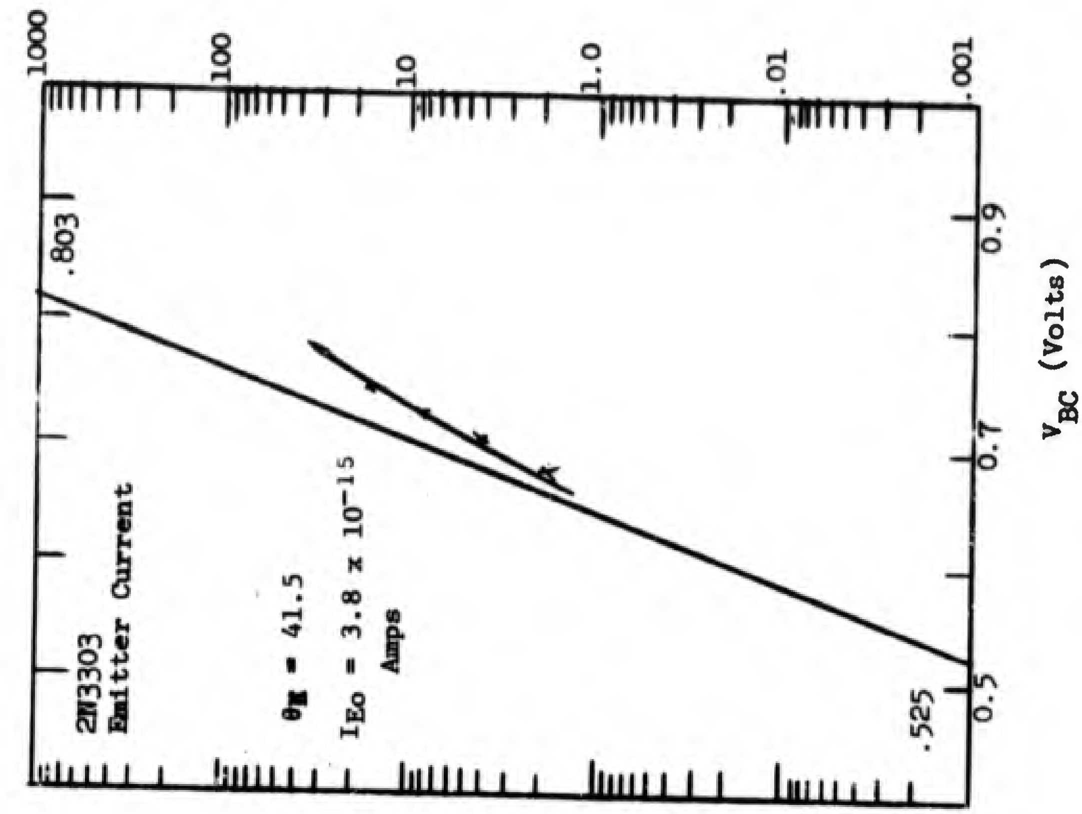
Quantity Linac pulse

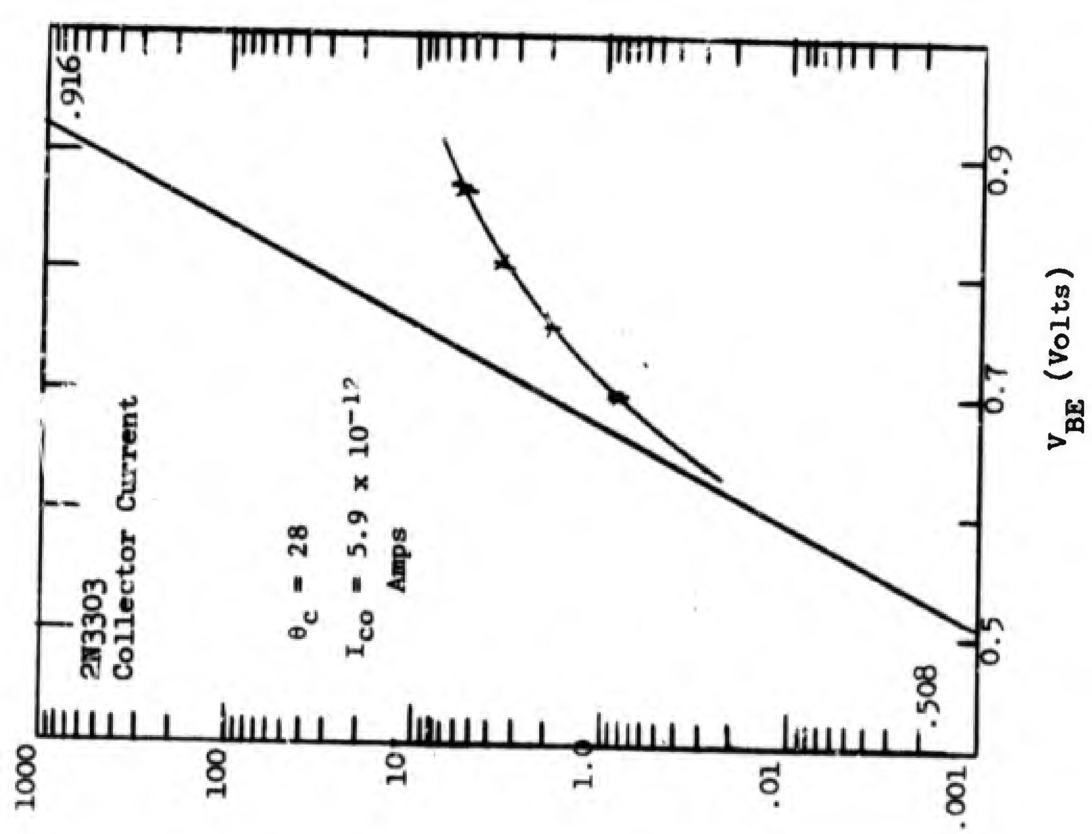
Sensitivity 0.1 v /cm

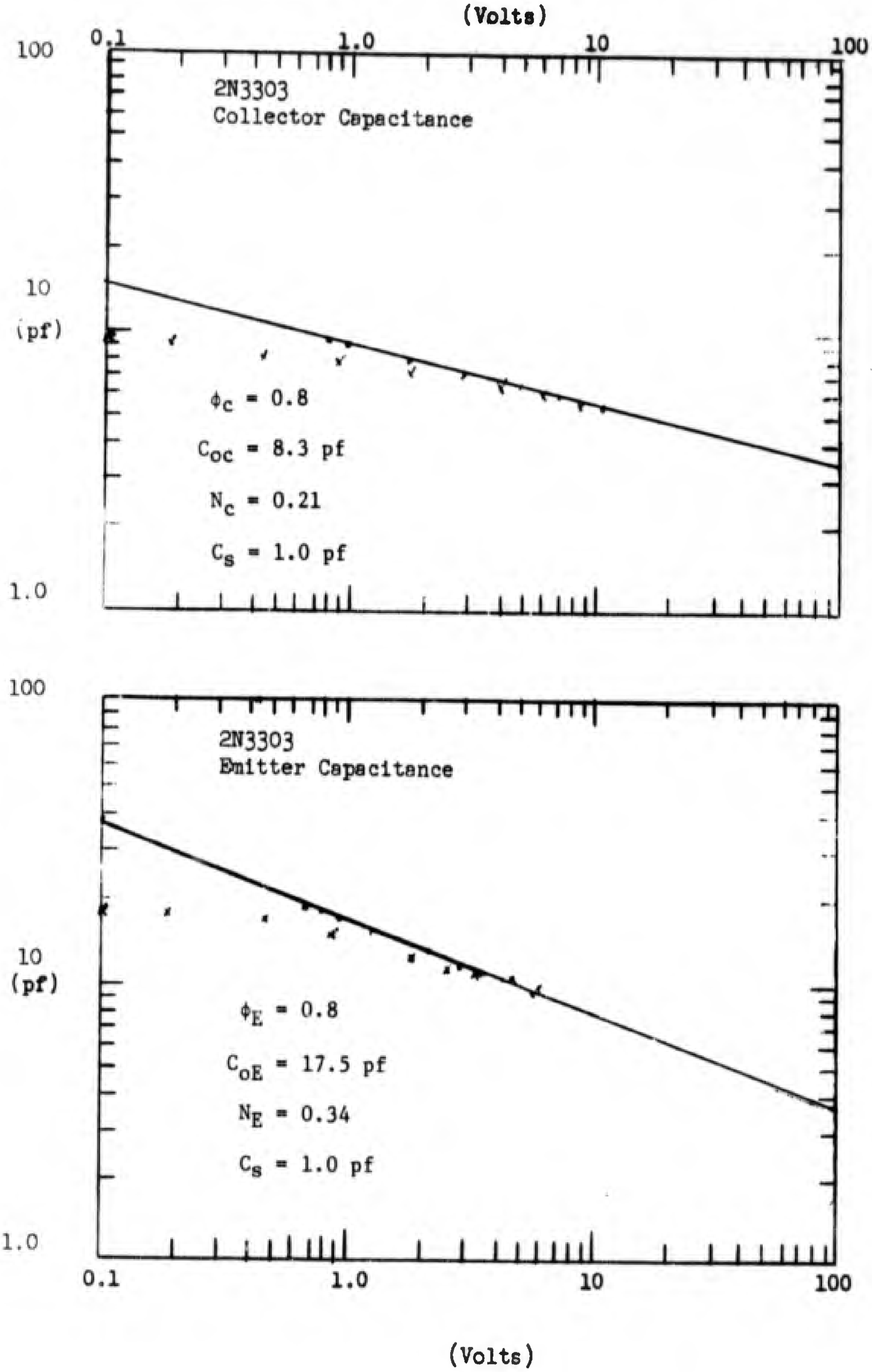
Lower Trace

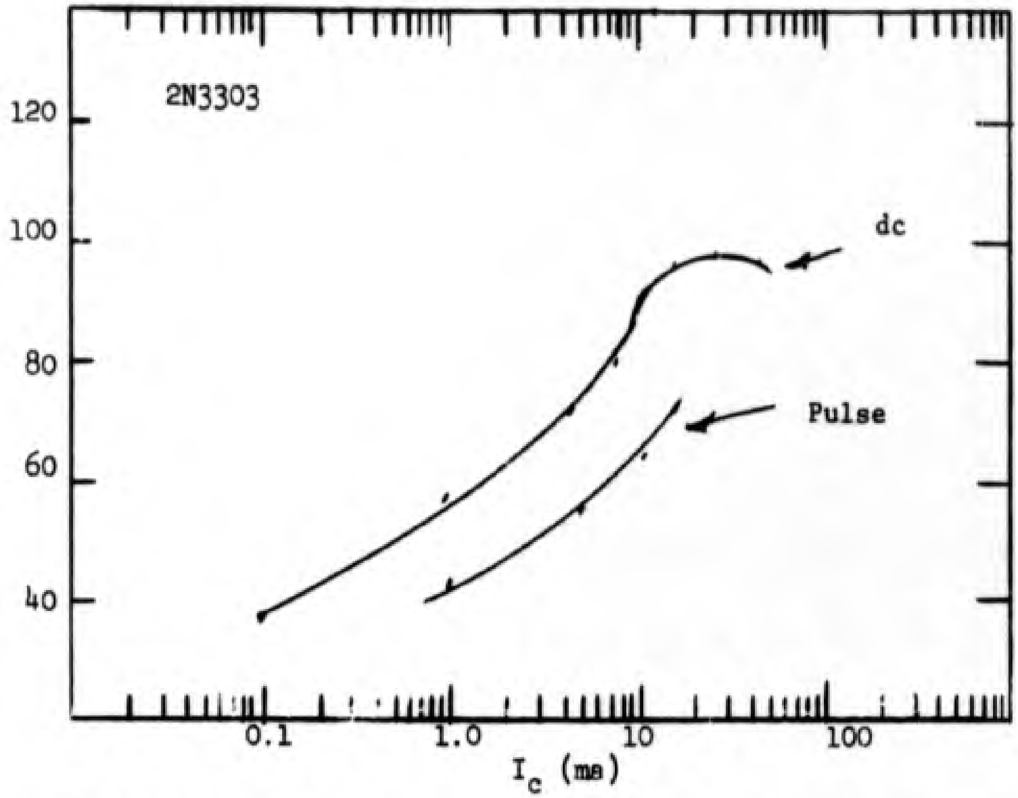
Quantity I_{pp}

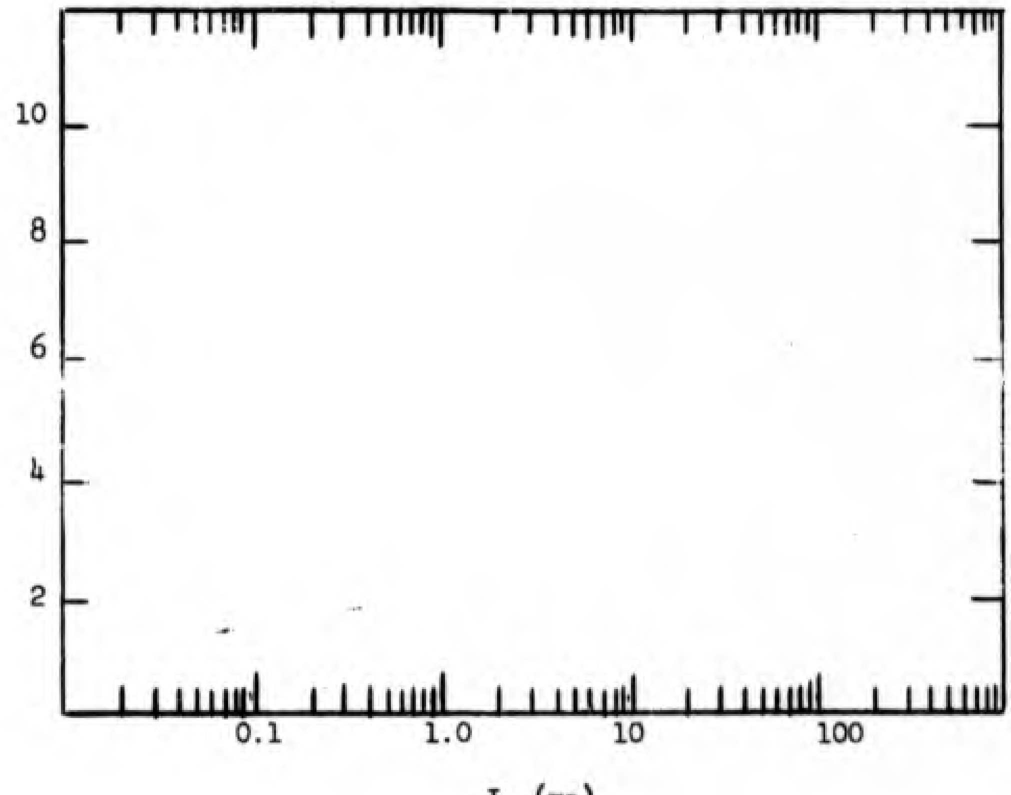
Sensitivity 0.2 v /cm


2N3303
Emitter Current
θE = 41.5
IEo = 3.8 x 10^-15
Amps
1000
100
10
1.0
.01
.001
.803
.525
0.5
0.7
0.9
VBC (Volts)

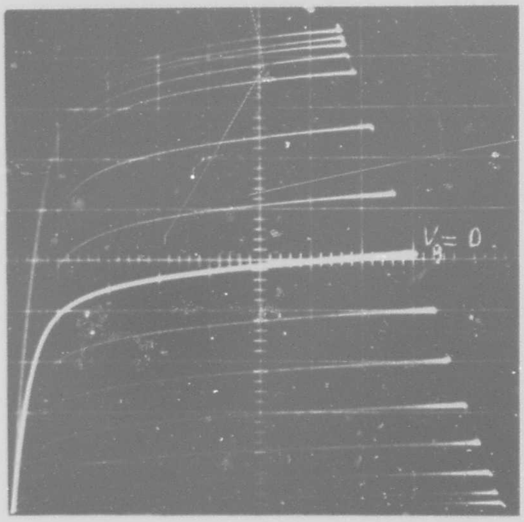

2N3303
Collector Current
θc = 28
Ico = 5.9 x 10^-12
Amps
1000
100
10
1.0
.01
.001
.916
.508
0.5
0.7
0.9
VBE (Volts)


(Volts)
100
0.1
1.0
10
100
2N3303
Collector Capacitance
10
(pf)
ϕc = 0.8
Coc = 8.3 pf
Nc = 0.21
Cs = 1.0 pf
1.0
100
2N3303
Emitter Capacitance
10
(pf)
ϕE = 0.8
CoE = 17.5 pf
NE = 0.34
Cs = 1.0 pf
1.0
0.1
1.0
10
100
(Volts)


2N3303
120
100
80
60
40
dc
Pulse
0.1
1.0
10
100
I_c (ma)


10
8
6
4
2
0.1
1.0
10
100
I_c (ma)

TITLE I_p - V_{ps} characteristic of U 1323 FET showing linearity of g_m



HORIZONTAL

Quantity V_{es}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_p

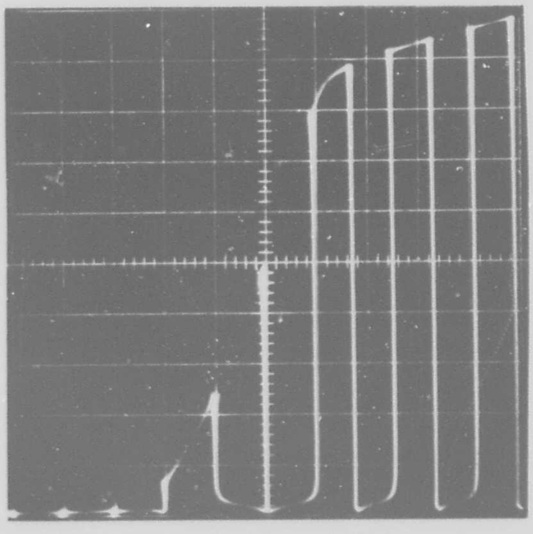
Sensitivity 0.5 ma /cm

Lower Trace

Quantity V_{gs} = 0.2 v/step

Sensitivity - /cm

TITLE Transfer characteristic of U 1323 showing variation of gm and V pinch-off



HORIZONTAL

Quantity V_{GS}

Sensitivity 0.5 v /cm

VERTICAL

Upper Trace

Quantity I_p

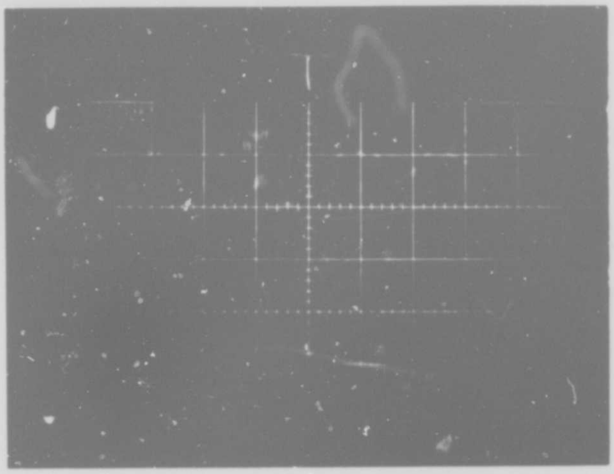
Sensitivity 0.5 ma /cm

Lower Trace

Quantity gm = 3000 mhos at V_{gs} = 0

Sensitivity - /cm

TITLE Primary photocurrent of drain to gate junction of U 1323 subjected to 2×10^{10} r/sec, V_{DS} = 20 volts



HORIZONTAL

Quantity time

Sensitivity 100 sec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

Sensitivity 0.1 volt /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE ____________________

HORIZONTAL

Quantity ____________________

Sensitivity __________ /cm

VERTICAL

Upper Trace

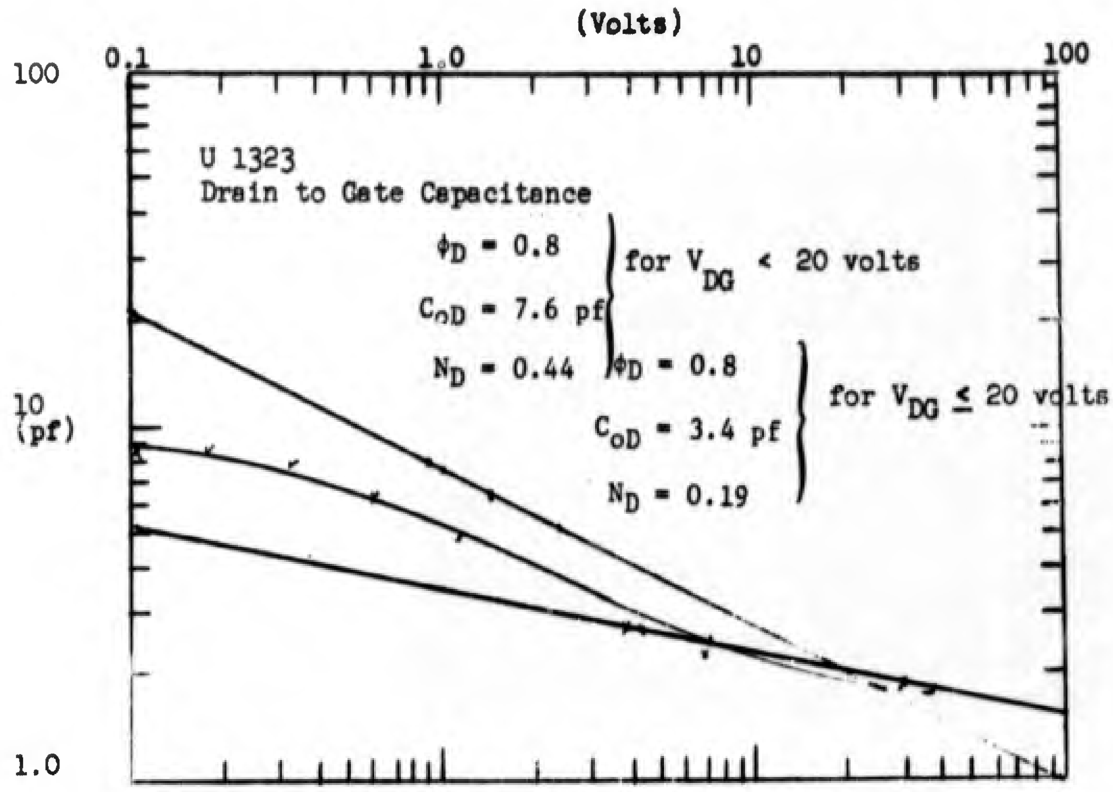
Quantity ____________________

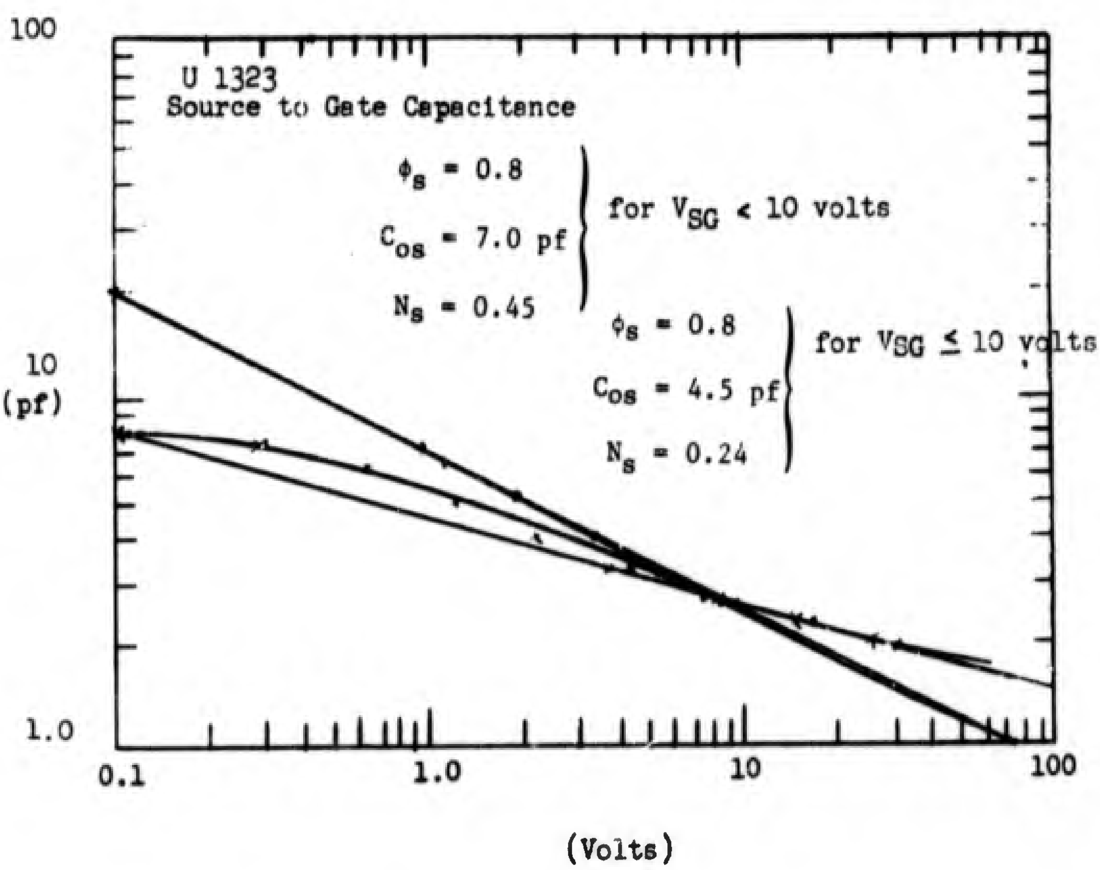
Sensitivity __________ /cm

Lower Trace

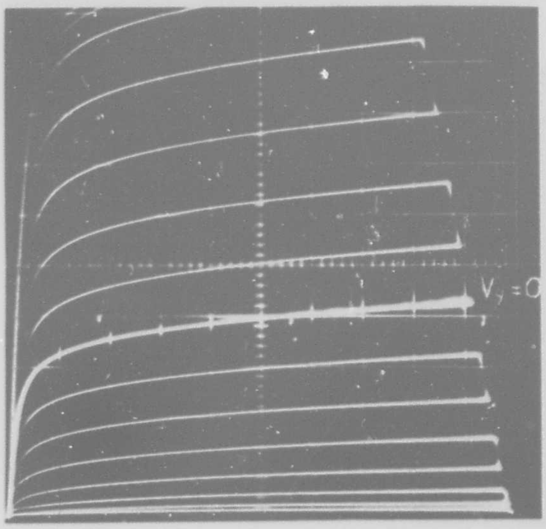
Quantity ____________________

Sensitivity __________ /cm


(Volts)
0.1
1.0
10
100
100
10
(pf)
1.0
U 1323
Drain to Gate Capacitance
ϕD = 0.8
CoD = 7.6 pf
ND = 0.44
for VDG < 20 volts
ϕD = 0.8
CoD = 3.4 pf
ND = 0.19
for VDG ≤ 20 volts


100
10
(pf)
1.0
0.1
1.0
10
100
(Volts)
U 1323
Source to Gate Capacitance
ϕs = 0.8
Cos = 7.0 pf
Ns = 0.45
for VSG < 10 volts
ϕs = 0.8
Cos = 4.5 pf
Ns = 0.24
for VSG ≤ 10 volts

TITLE I_D - V_{DS} characteristic of U 1324 FET showing linearity of g_m



HORIZONTAL

Quantity V_{DS}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_D

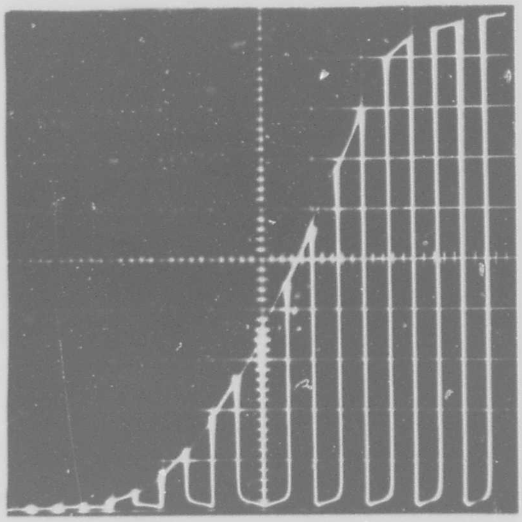
Sensitivity 0.2 ma /cm

Lower Trace

Quantity V_{gs} = 0.1 v/step

Sensitivity - /cm

TITLE Transfer characteristic of U 1324 FET showing variation of g_m and V pinch-off



HORIZONTAL

Quantity V_{GS}

Sensitivity 0.2 v /cm

VERTICAL

Upper Trace

Quantity I_D

Sensitivity 0.2 ma /cm

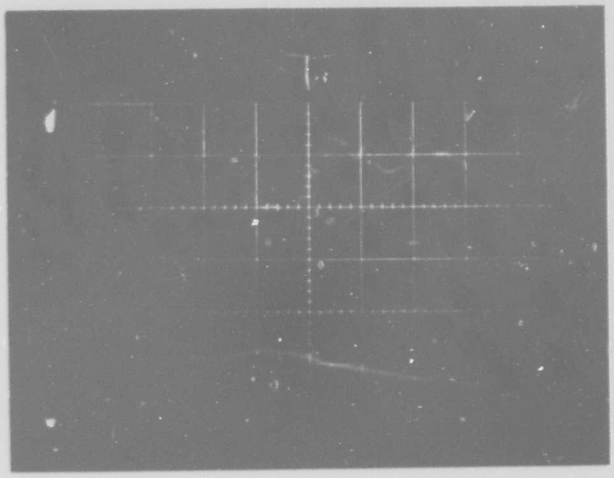
Lower Trace

Quantity g_m = 2000 mhos at V_{gs} = 0

Sensitivity - /cm

TITLE Primary photocurrent of drain to gate junction of U 1324

subjected to 2 x 10^{10} r/sec, V_{DS} - 30 volt



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE ______

______

HORIZONTAL

Quantity ______

Sensitivity ______ /cm

VERTICAL

Upper Trace

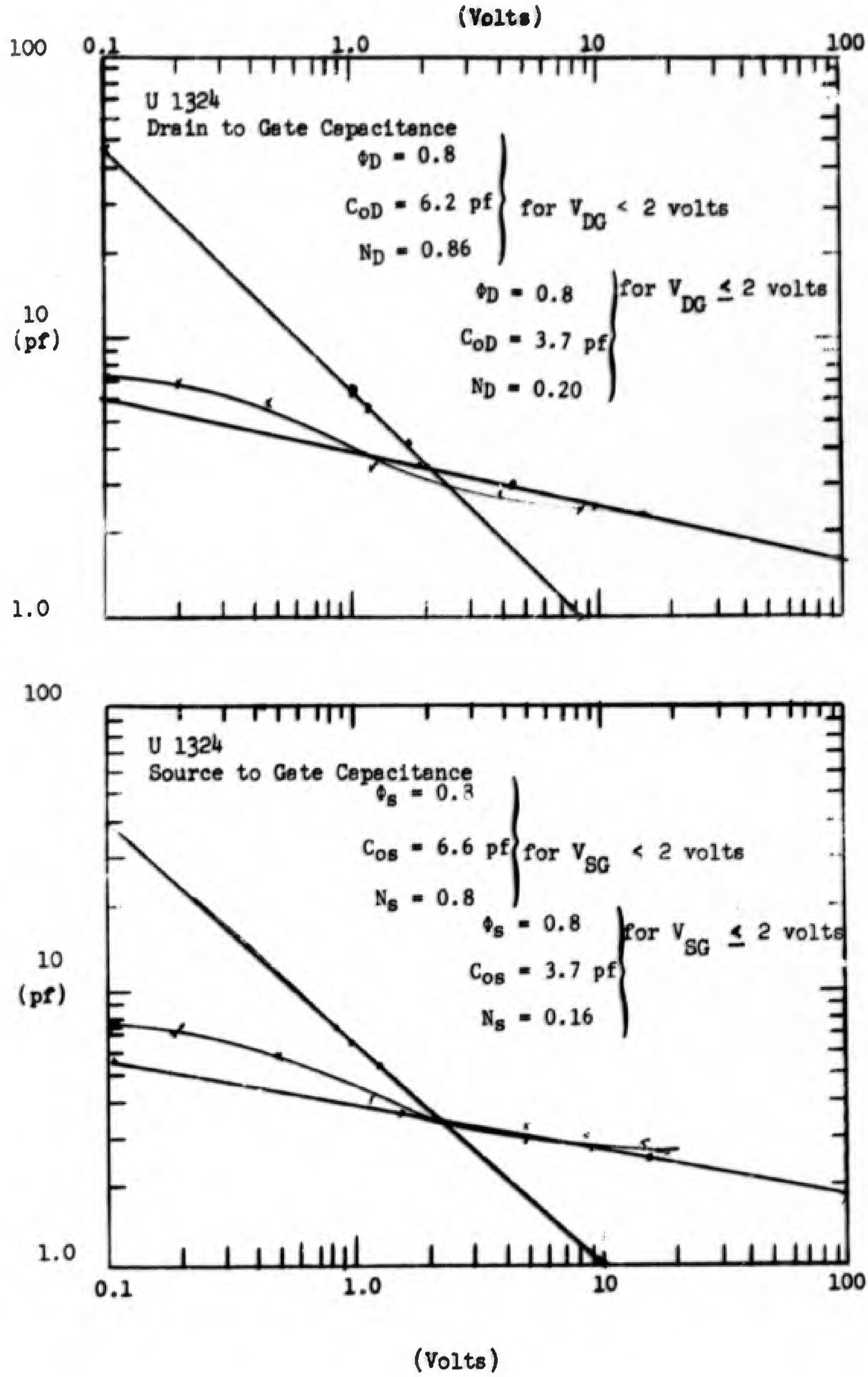
Quantity ______

Sensitivity ______ /cm

Lower Trace

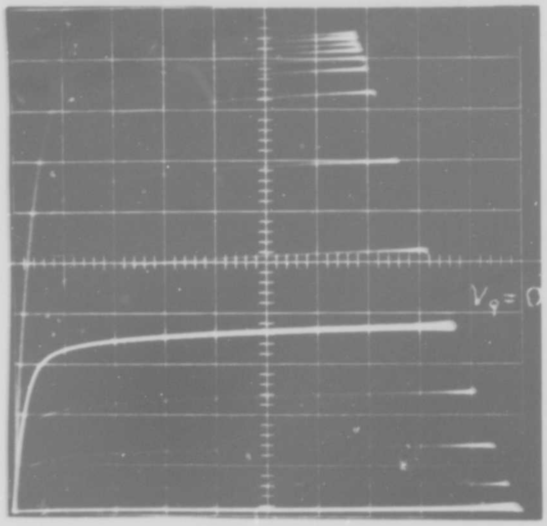
Quantity ______

Sensitivity ______ /cm


(Volts)
0.1
1.0
10
100
100
10
(pf)
1.0
U 1324
Drain to Gate Capacitance
ΦD = 0.8
CoD = 6.2 pf
ND = 0.86
for VDG < 2 volts
ΦD = 0.8
CoD = 3.7 pf
ND = 0.20
for VDG ≤ 2 volts
100
10
(pf)
1.0
U 1324
Source to Gate Capacitance
Φs = 0.8
Cos = 6.6 pf
Ns = 0.8
for VSG < 2 volts
Φs = 0.8
Cos = 3.7 pf
Ns = 0.16
for VSG ≤ 2 volts
0.1
1.0
10
100
(Volts)

TITLE I_D - V_{DS} characteristic of SU 2002 dual FET unit A

showing linearity of gm



HORIZONTAL

Quantity V_{DS}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_{DS}

Sensitivity 0.5 ma /cm

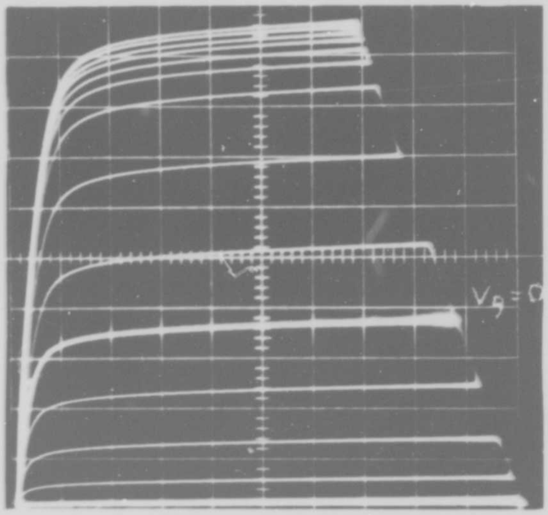
Lower Trace

Quantity V_{GS} = 0.2 v/step

Sensitivity - /cm

TITLE I_D - V_{DS} characteristic of SU 2002 Dual FET Unit A

showing linearity of gm



HORIZONTAL

Quantity V_{DS}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_D

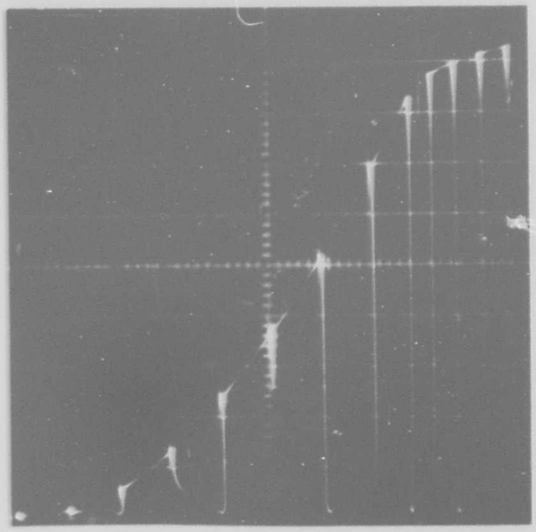
Sensitivity 0.5 ma /cm

Lower Trace

Quantity V_{GS} = 0.2 v/step

Sensitivity - /cm

TITLE Transfer characteristic of SU 2002 dual FET, Unit A showing variation of gm and V pinch-off



HORIZONTAL

Quantity V_{GS}

Sensitivity 0.2 v /cm

VERTICAL

Upper Trace

Quantity I_P

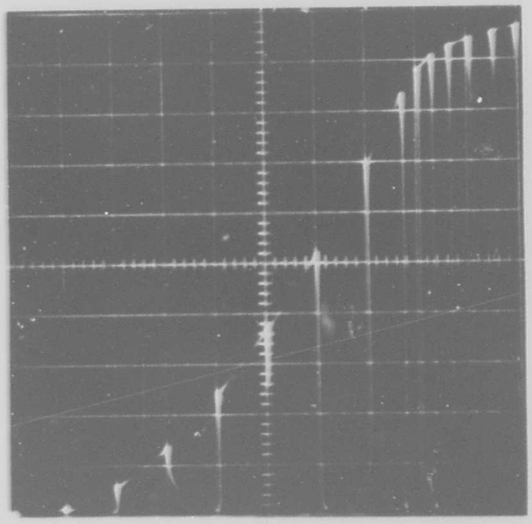
Sensitivity 0.5 ma /cm

Lower Trace

Quantity gm = 3500 mhos at $V_{GS} = 0$

Sensitivity - /cm

TITLE Transfer characteristic of SU 2002 Dual FETJnit B showing variation of gm and V pinch-off



HORIZONTAL

Quantity V_{GS}

Sensitivity 0.2 v /cm

VERTICAL

Upper Trace

Quantity I_p

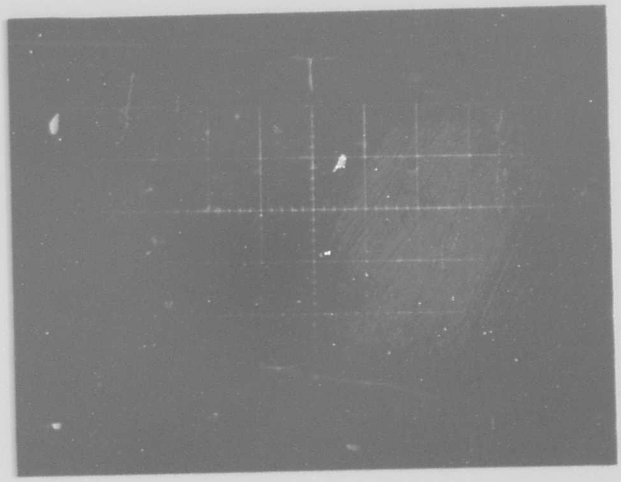
Sensitivity 0.5 ma /cm

Lower Trace

Quantity gm = 3500 mhos at $V_{gs} = 0$

Sensitivity - /cm

TITLE Primary photocurrent of drain to gate junction of SU 2002 Dual FET Unit A subjected to 2×10^{10} r/sec V_{ps} = 20 volt



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

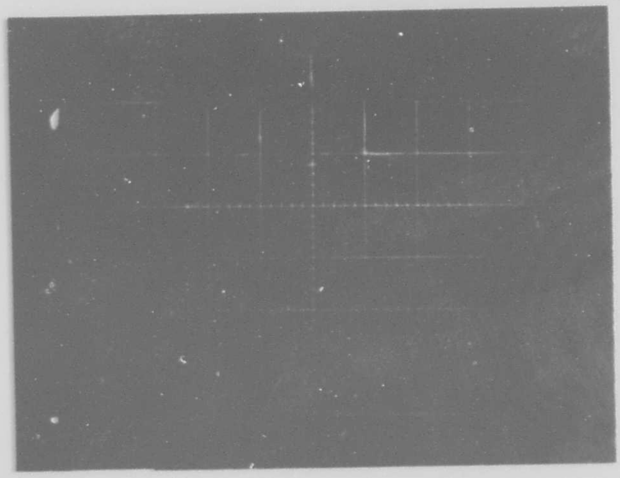
Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 2.0 v /cm

TITLE Primary photocurrent of drain to gate junction of SU 2002 Dual FET Unit B subjected to 2.5×10^{6} r/sec V_{ps} = 20 volt



HORIZONTAL

Quantity__________

Sensitivity__________/cm

VERTICAL

Upper Trace

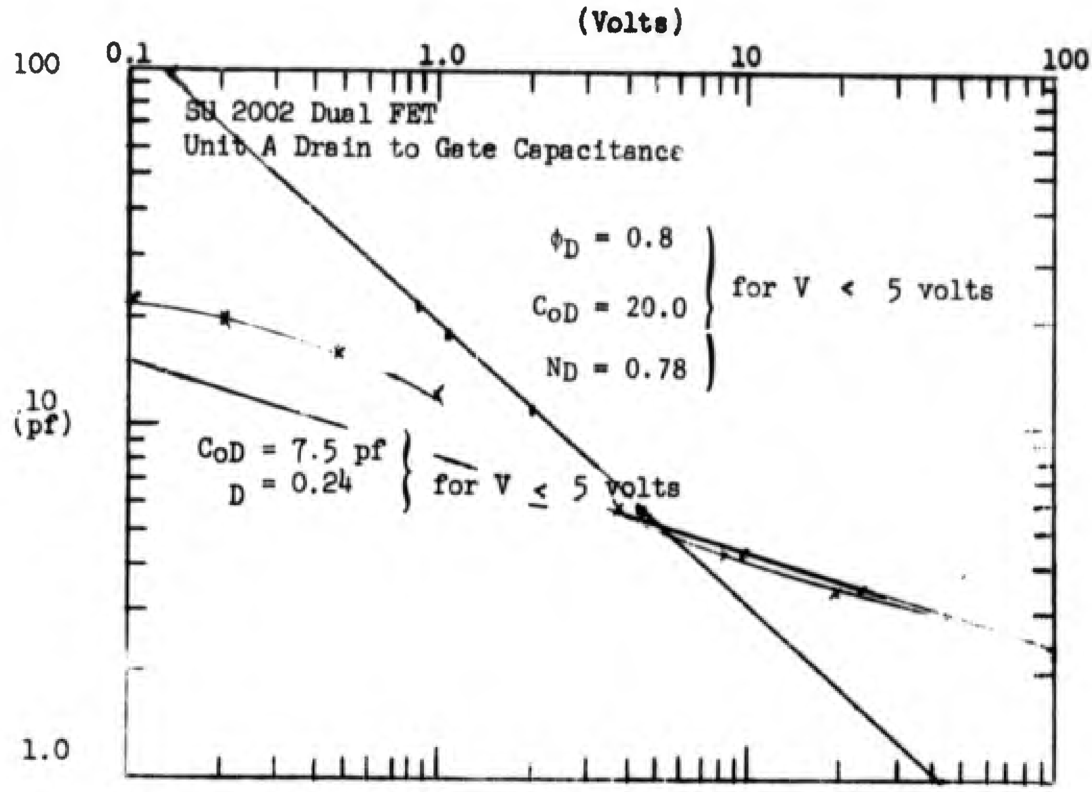
Quantity__________

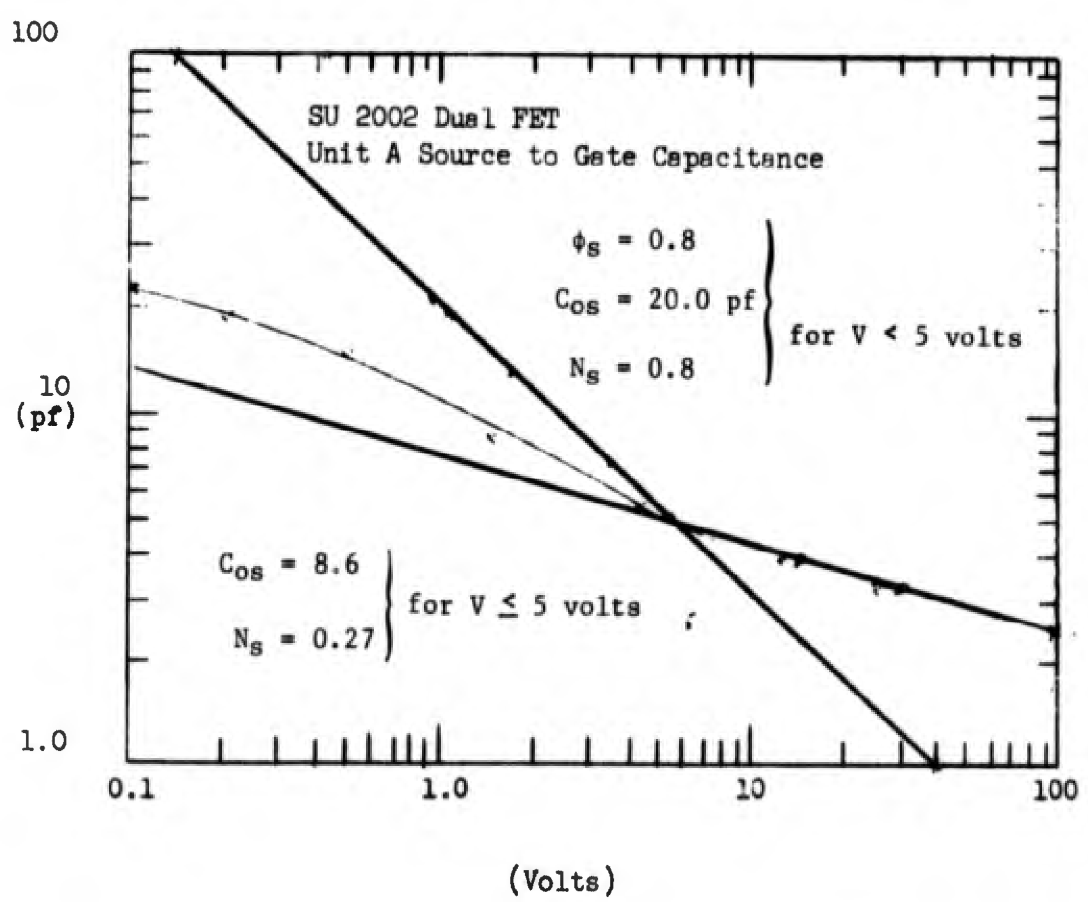
Sensitivity__________/cm

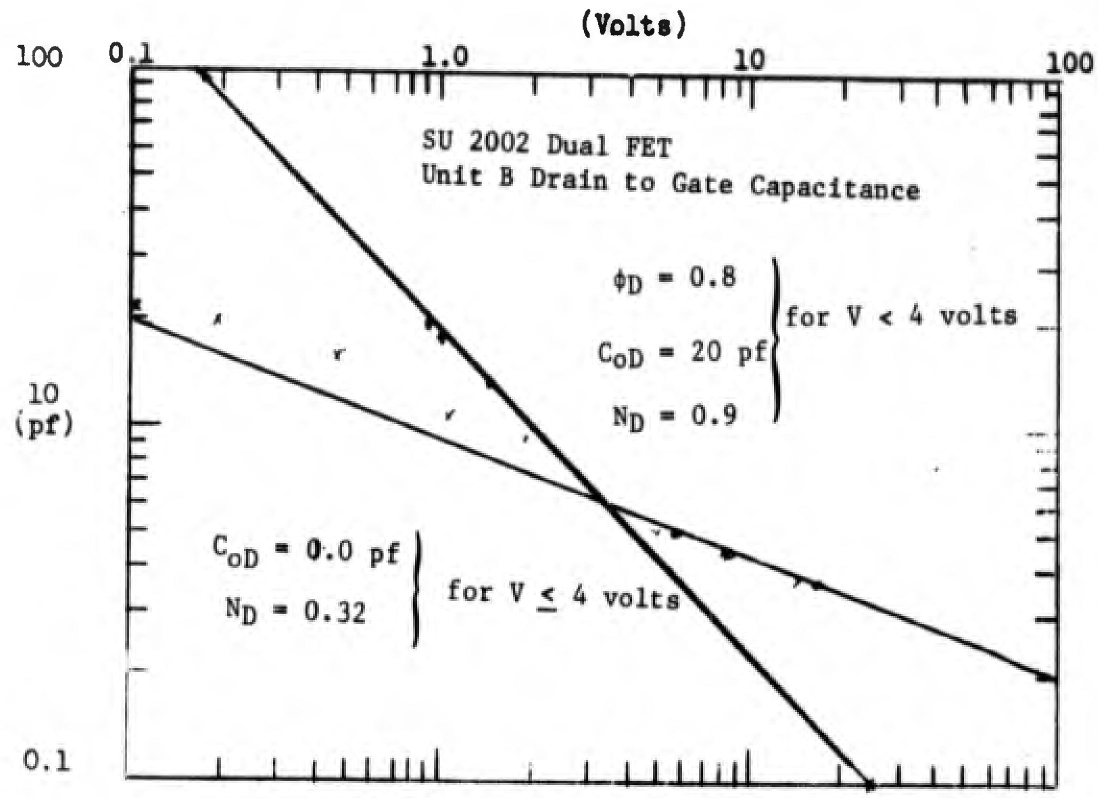
Lower Trace

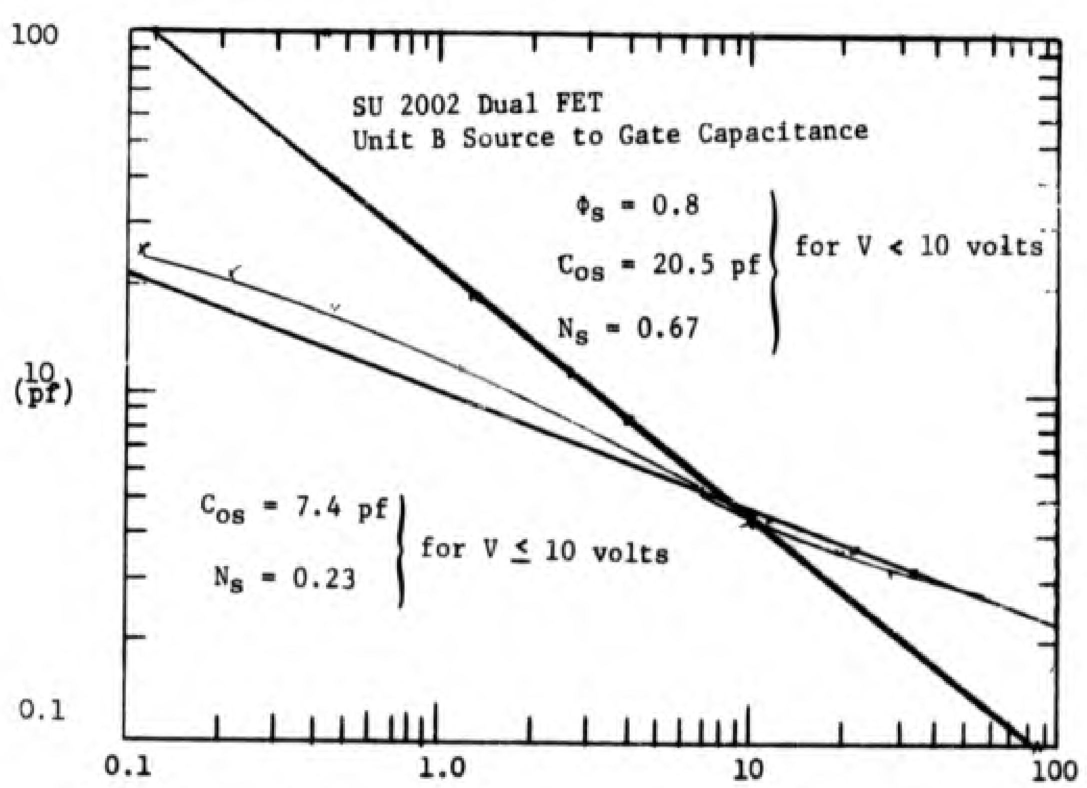
Quantity__________

Sensitivity__________/cm


(Volts)
0.1
1.0
10
100
100
10
(pf)
1.0
SU 2002 Dual FET
Unit A Drain to Gate Capacitance
ϕ_D = 0.8
C_{oD} = 20.0
N_D = 0.78
for V < 5 volts
C_{oD} = 7.5 pf
D = 0.24
for V ≤ 5 volts

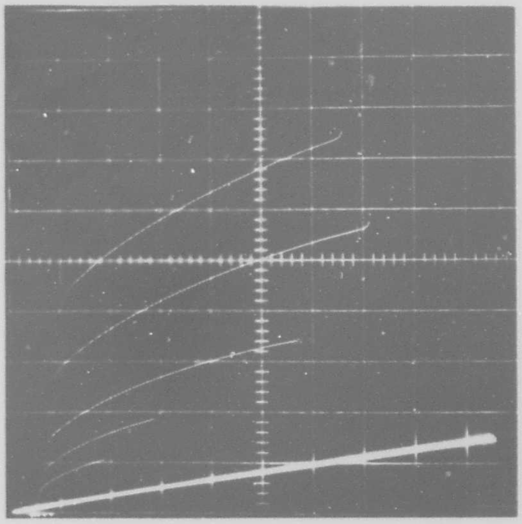

100
10
(pf)
1.0
SU 2002 Dual FET
Unit A Source to Gate Capacitance
ϕ_s = 0.8
C_{os} = 20.0 pf
N_s = 0.8
for V < 5 volts
C_{os} = 8.6
N_s = 0.27
for V ≤ 5 volts
0.1
1.0
10
100
(Volts)


(Volts)
100
0.1
1.0
10
100
SU 2002 Dual FET
Unit B Drain to Gate Capacitance
ϕD = 0.8
CoD = 20 pf
ND = 0.9
for V < 4 volts
10
(pf)
CoD = 0.0 pf
ND = 0.32
for V ≤ 4 volts
0.1


100
SU 2002 Dual FET
Unit B Source to Gate Capacitance
Φs = 0.8
Cos = 20.5 pf
Ns = 0.67
for V < 10 volts
10
(pf)
Cos = 7.4 pf
Ns = 0.23
for V ≤ 10 volts
0.1
0.1
1.0
10
100

(Volts)

TITLE I_{b2b1} - V_{b2b1} characteristic of 2N2417 unijunction transistor showing gain variation



100
50
20
10
5
I_E=0 ma

HORIZONTAL

Quantity V_{b2b1}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_{b2b1}

Sensitivity 2 ma /cm

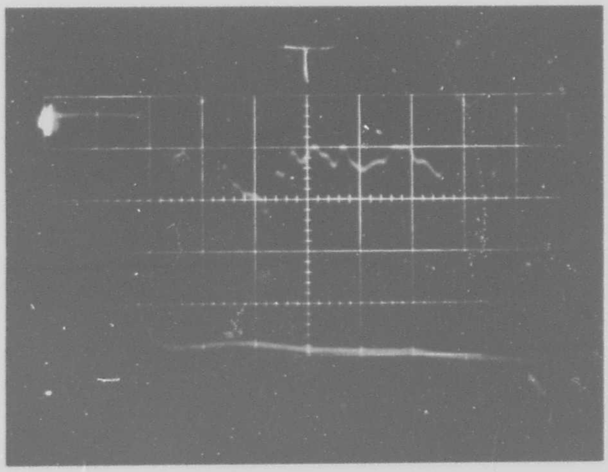
Lower Trace

Quantity R_{b2b1} = 6.3 Kohms

Sensitivity = 0.58 /

R_{b1} = 3.67K R_{b2} = 2.63K

TITLE Primary photocurrent of B_g-E junction of 2N2417 unijunction subjected to 2.5×10^{10} r/sec



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

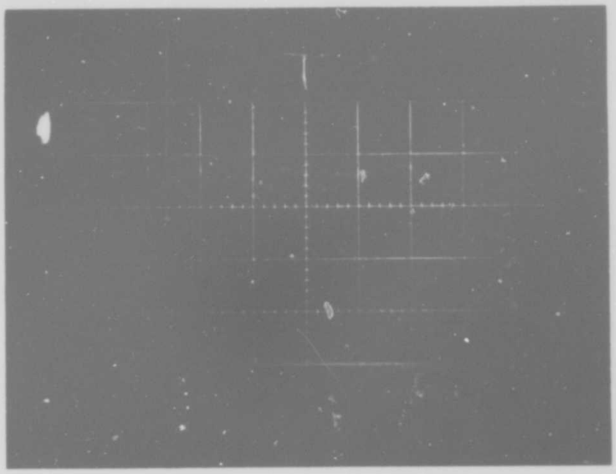
Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE Primary photocurrent of B_1-E junction of 2N2417 unijunction subjected to 3×10^{10} r/sec



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE ______

______

HORIZONTAL

Quantity ______

Sensitivity ______ /cm

VERTICAL

Upper Trace

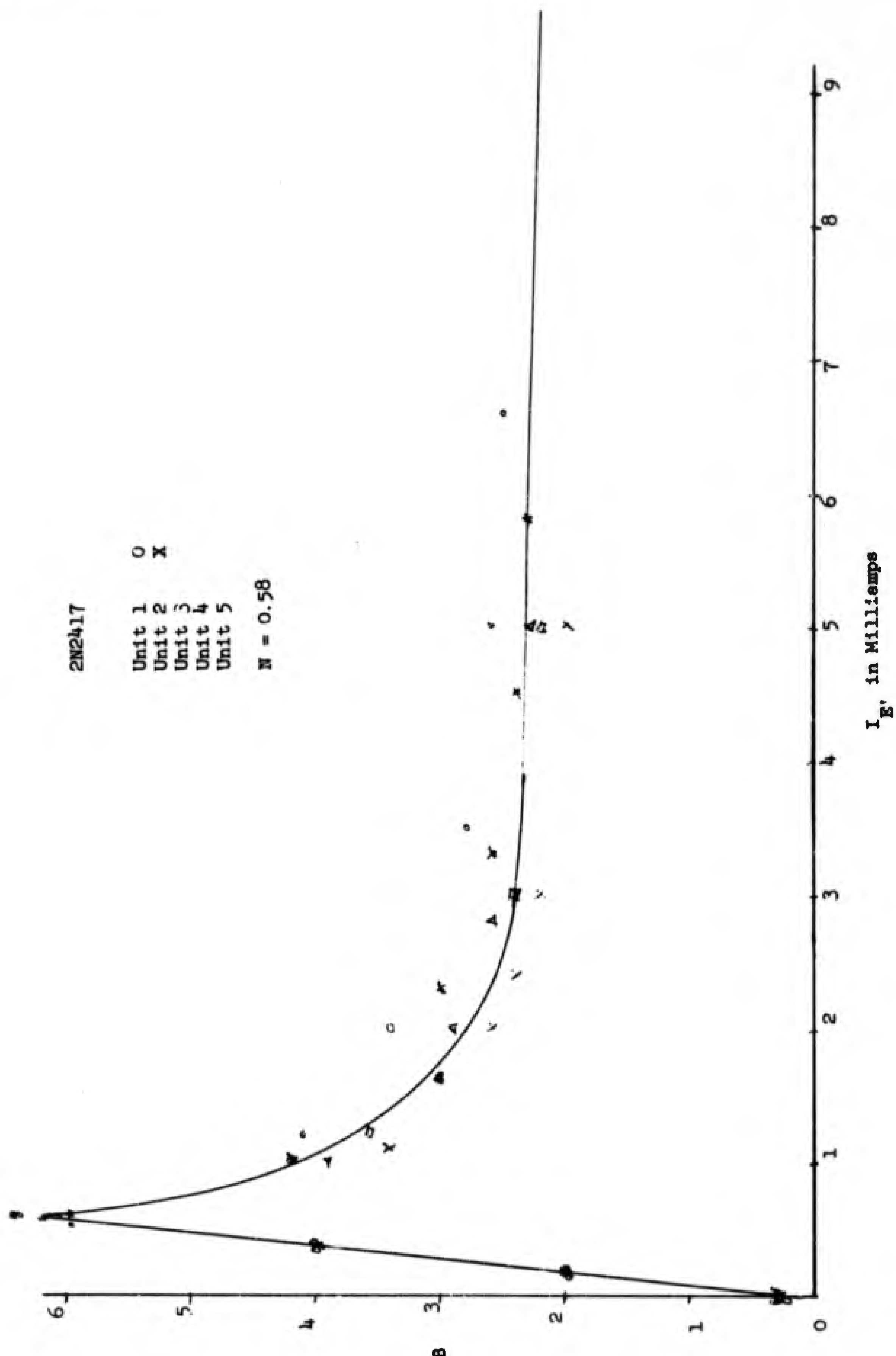
Quantity ______

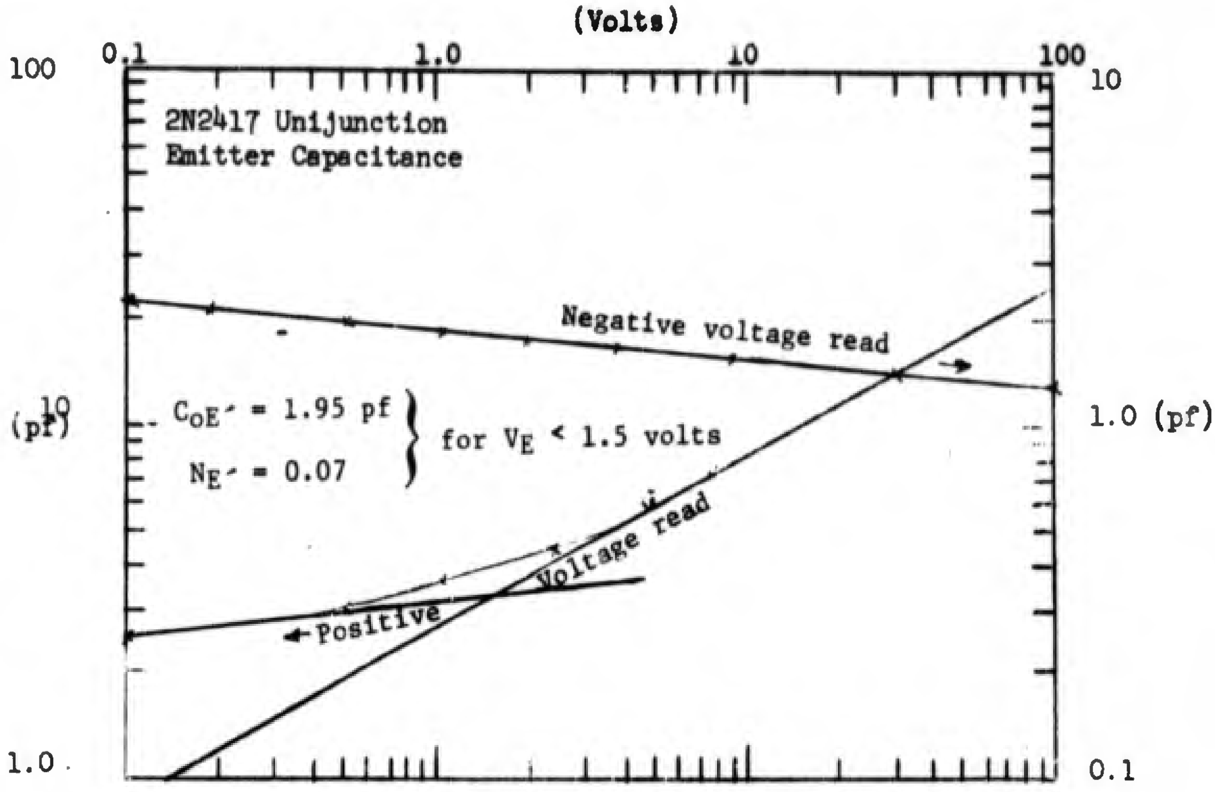
Sensitivity ______ /cm

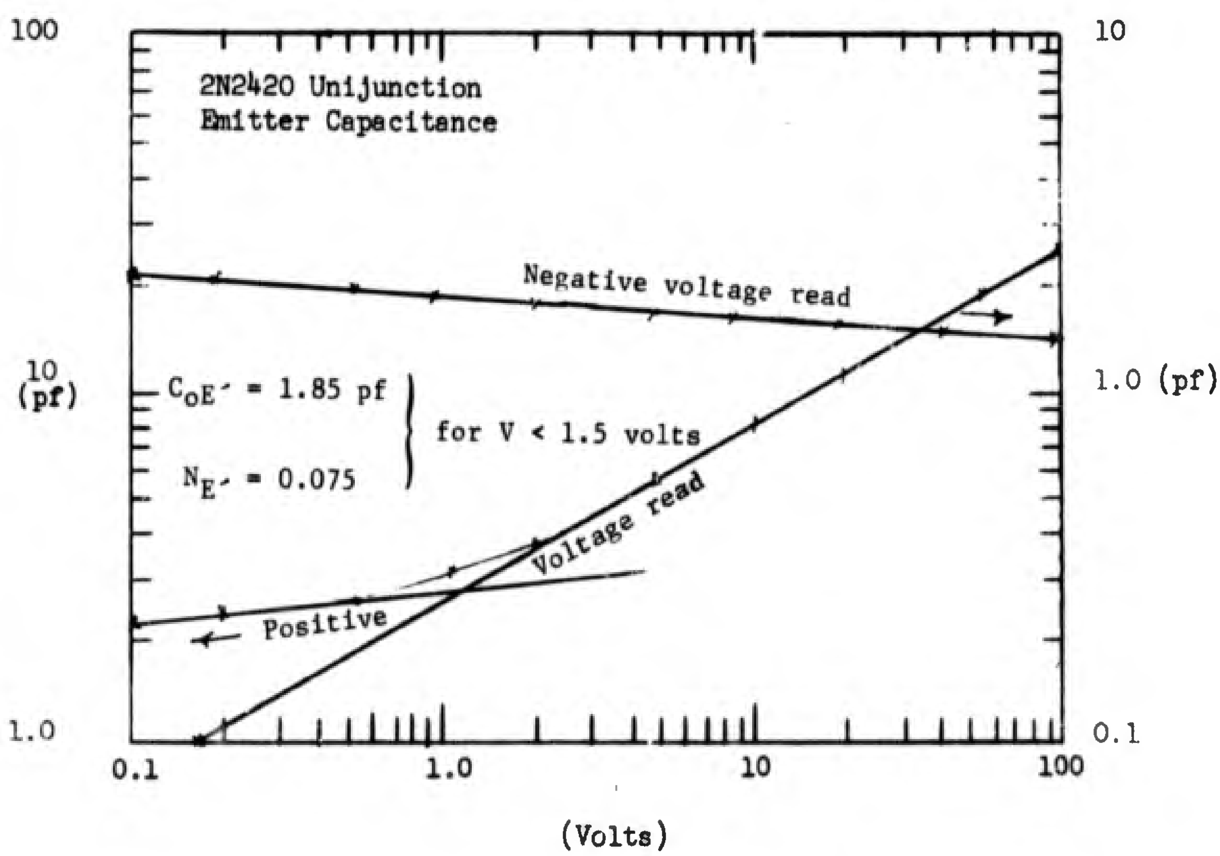
Lower Trace

Quantity ______

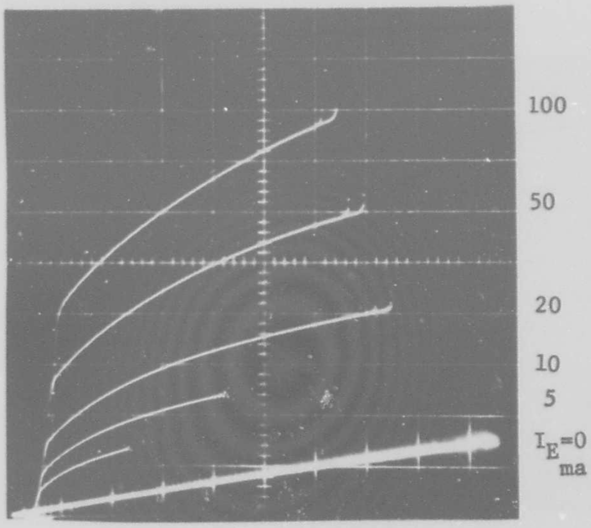
Sensitivity ______ /cm


2N2417
Unit 1 O
Unit 2 X
Unit 3
Unit 4
Unit 5
N = 0.58
V_{EB}
I_E, in Milliamps
0
1
2
3
4
5
6
7
8
9


(Volts)
0.1
1.0
10
100
100
10
1.0
10
(pf)
1.0 (pf)
0.1
2N2417 Unijunction
Emitter Capacitance
Negative voltage read
C_OE' = 1.95 pf
N_E' = 0.07
for V_E < 1.5 volts
Positive
Voltage read


100
10
2N2420 Unijunction
Emitter Capacitance
Negative voltage read
10
(pf)
1.0 (pf)
C_OE' = 1.85 pf
N_E' = 0.075
for V < 1.5 volts
Positive
Voltage read
1.0
0.1
0.1
1.0
10
100
(Volts)

TITLE I_{b2b1}-V_{b2b1} characteristic of 2N2420 unijunction transistor showing gain variation



HORIZONTAL

Quantity V_{b2b1}

Sensitivity 2 v /cm

VERTICAL

Upper Trace

Quantity I_{b2b1}

Sensitivity 2 ma /cm

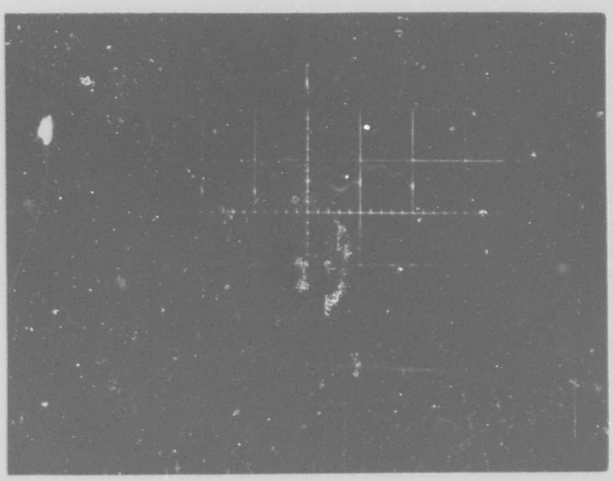
Lower Trace

Quantity R_{b2b1} = 6 Kohms

Sensitivity = 0.63 ~~xxx~~

R_{b1} = 3.78K, R_{b2} = 2.22K

TITLE Primary photocurrent of B_2E junction of 2N2420 unijunction subjected to 2 x 10^{10} r/sec



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

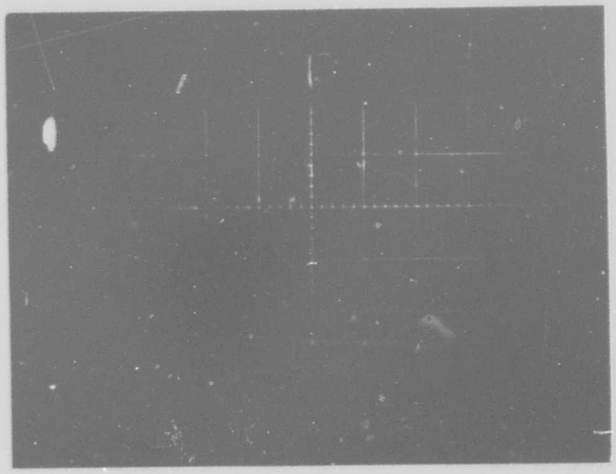
Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE Primary photocurrent of B_1-E junction of 2N2420 unijunction subjected to 2×10^{10} r/sec



HORIZONTAL

Quantity time

Sensitivity 100 nsec /cm

VERTICAL

Upper Trace

Quantity Linac pulse

Sensitivity 0.1 v /cm

Lower Trace

Quantity I_{pp}

Sensitivity 0.5 v /cm

TITLE ____________________

HORIZONTAL

Quantity ____________

Sensitivity ________ /cm

VERTICAL

Upper Trace

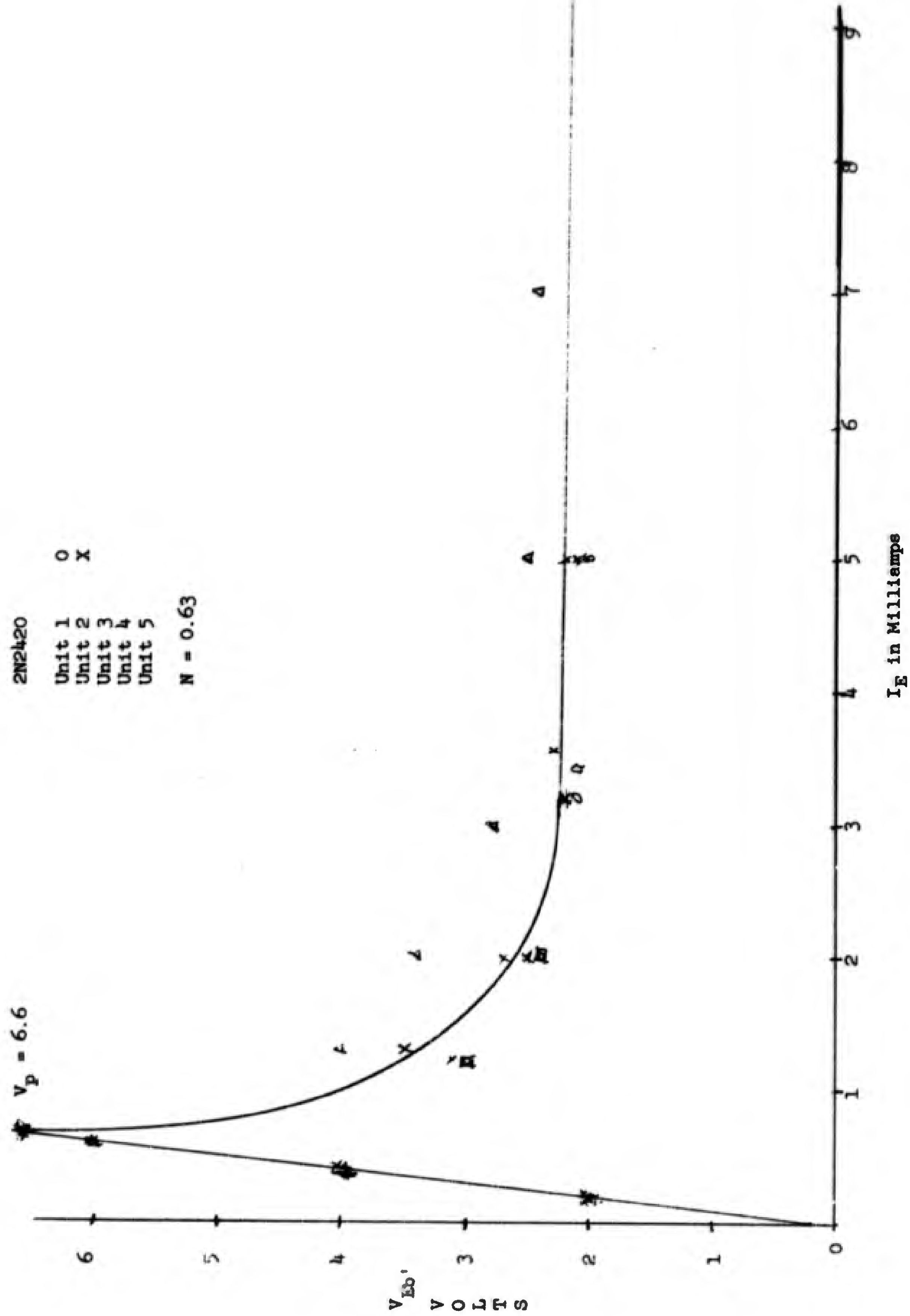
Quantity ____________

Sensitivity ________ /cm

Lower Trace

Quantity ____________

Sensitivity ________ /cm


2N2420
Unit 1 O
Unit 2 X
Unit 3
Unit 4
Unit 5
N = 0.63
V_p = 6.6
I_E in Milliamps
$V_{Eb'}$
VOLTS
0
1
2
3
4
5
6
7
8
9