REPORT CTSL– **23**

MEASUREMENT OF SOME TRANSISTOR PARAMETERS

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MARCH 29, 1961

SYNCHROTRON LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA

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Synchrotron Laboratory
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Contents

Introduction

Design of transistor circuits, particularly those operating in the nanosecond time range necessitated the measurement of some transistor parameters usually not specified by the manufacturers.

Collector to base capacitance, gain-bandwidth product, beta and base spreading resistance of the transistors of Table 1 were measured.

I Collector to Base Capacitance

The collector to base capacitance has been measured as function of collector to base voltage at zero emitter current in the test set-up of Fig. 1.1. The results, plotted in Figs. 1.2 to 1.4, show qualitative agreement with the theory[1,2].

II Gain-bandwidth Product

Transient responses of the transistors were measured in a grounded emitter configuration at several operating points. The Laplace transform of the current transfer can be approximated as:[3]

$$L\left[\frac{i_c}{i_b}\right] \cong \frac{\beta}{1 + p\tau_o\beta}\, e^{-p\tau_d}$$

where $1/2\pi\ \tau_o$ is the gain-bandwidth product, exp $(-p\ \tau_d)$ corresponds to a constant delay.

The time constant of the exponential rise was measured in the arrangement of Fig. 2.1, beta was measured on a Type 575 transistor curve tracer. The pulse current was approximately one-third of the DC current

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1) Middlebrook: "Introduction to Junction Transistor Theory", Wiley and Sons, 1957.

2) Pritchard: "Transition Capacitance of PN Junctions", Semiconductor Products, August 1959.

3) Barna: "Some Transistor Equivalent Circuit Calculations", CTSL-22 (1961). (For symbols and equivalent circuits).

with a polarity to turn the transistor further on.

If the current measuring resistance in the collector circuit is R_c, the collector to base capacity C_{cb}, for a grounded emitter configuration the input capacitance can be written as

$$C_{in} \cong \frac{\tau_o}{r_e} + \left(\frac{R_c}{r_e} + 1\right) C_{cb} \cong \frac{\tau_o}{r_e} + \frac{R_c}{r_e} C_{cb}$$

Thus, the measured time constant of the exponential rise is

$$\tau_{\beta_{meas}} = \beta\, r_e\, C_{in} \cong \beta \left(\tau_o + R_c\, C_{cb}\right)$$

and

$$\tau_{o\ meas} = \frac{\tau_{\beta_{meas}}}{\beta} \cong \tau_o + R_c\, C_{cb}$$

and

$$\tau_o \cong \tau_{o\ meas} - R_c\, C_{cb}$$

Values of τ_o as function of collector voltage and collector current are plotted in Figs. 2.2 to 2.9.

III Beta as Function of Current

Small signal beta as function of collector current was measured on a Type 575 curve tracer. The results, plotted in Figs. 3.1 to 3.8, show the current limitations of the transistors.

IV Gain-bandwidth Product as Function of Beta

Values of τ_o as function of beta of the individual units at one operating point are plotted in Figs. 4.1 to 4.5. They show the expected behavior, higher beta, due to thinner base region, results in better gain-bandwidth product[1].

V Base Spreading Resistance

The current through the emitter to base junction was measured as function of the applied voltage with the collector open. The slope at sufficiently high voltages is constant and equal to $1/r_s$. The results are listed in Table 2.

TABLE 1

Transistors

Transistor		Number of Samples	Measured τ_o	Measured C_{cb}	Measured r_s
2N 167	NPN Ge	10		+	+
2N 301	PNP Ge	8			+
2N 326	NPN Ge	3			+
2N 336	NPN Si	8	+	+	+
2N 384	PNP Ge	10		+	+
2N 398	PNP Ge	10			+
2N 502A	PNP Ge	12	+	+	+
2N 527	PNP Ge	10		+	+
2N 585	NPN Ge	8		+	+
2N 599	PNP Ge	10			+
2N 636	NPN Ge	10			+
2N 636A	NPN Ge	5	+	+	+
2N 656	NPN Si	10		+	+
2N 699	NPN Si	10	+	+	+
2N 700	PNP Ge	5		+	+
2N 711	PNP Ge	5	+	+	+
2N 753	NPN Si	3	+	+	+
2N 1204	PNP Ge	6			+
2N 1500	PNP Ge	12	+	+	+
2N 1663	NPN Si	10	+	+	+
T 1832	PNP Ge			+	+
T 1943	PNP Ge			+	

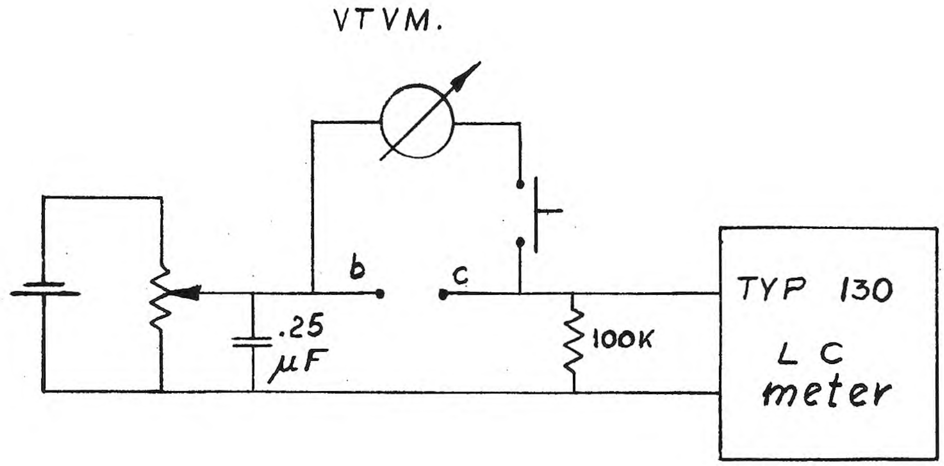


Fig. 1.1 Circuit for the Collector Capacitance Measurements

PNP Germanium Transistors

$I_e = 0$

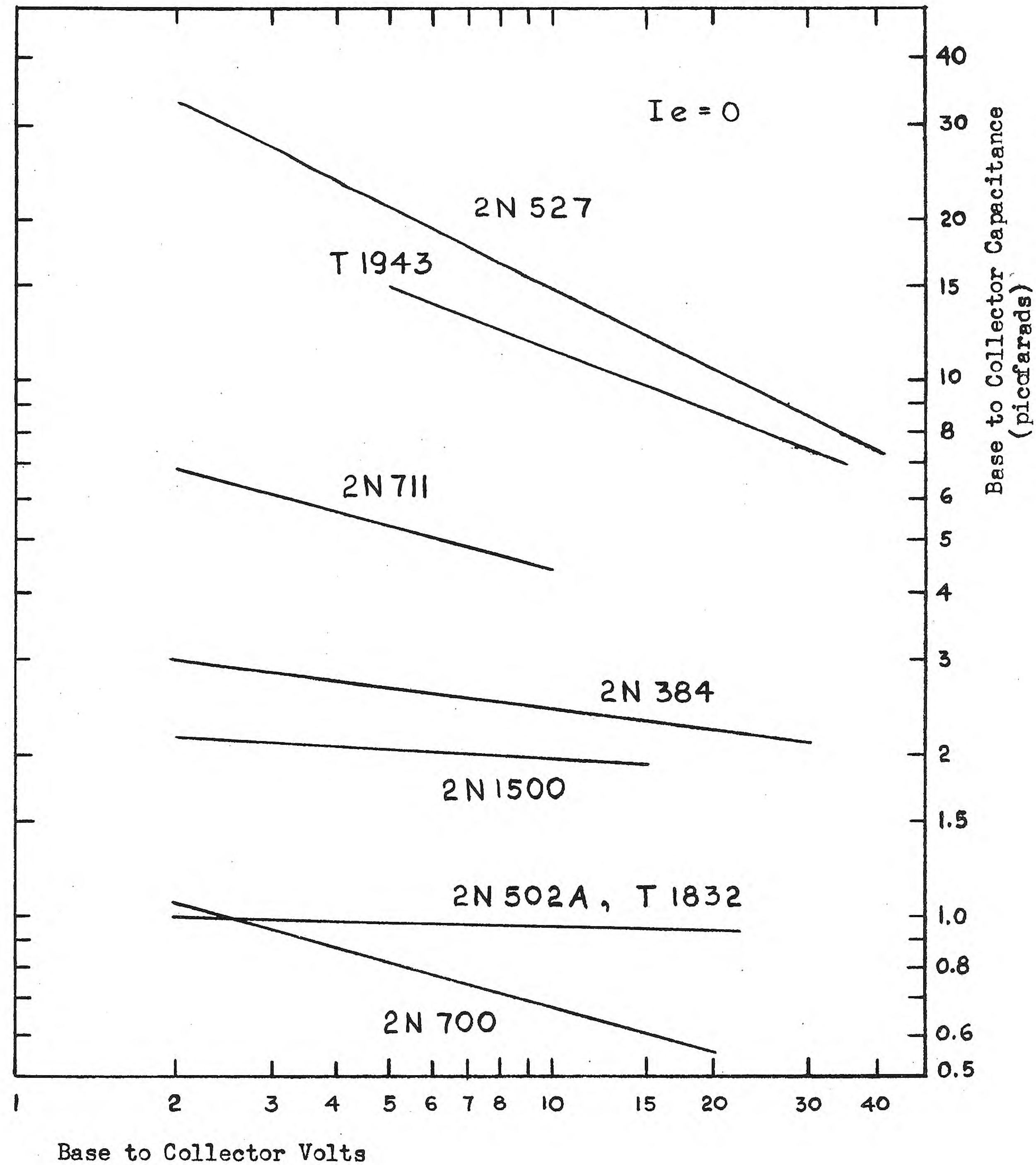


Fig. 1-2

NPN Germanium Transistors.

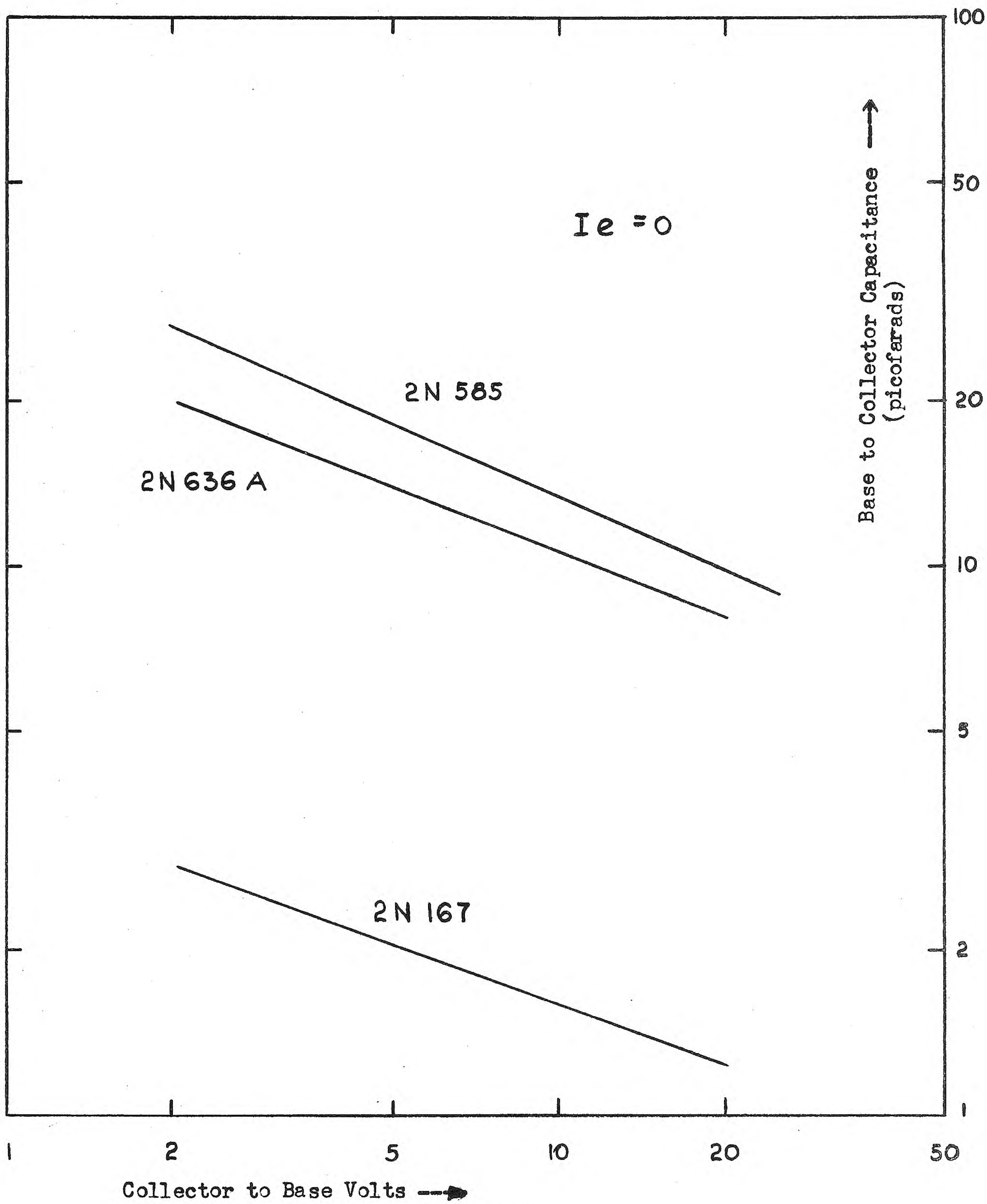


Fig. 1-3

NPN Silicon Transistors

$I_e = 0$

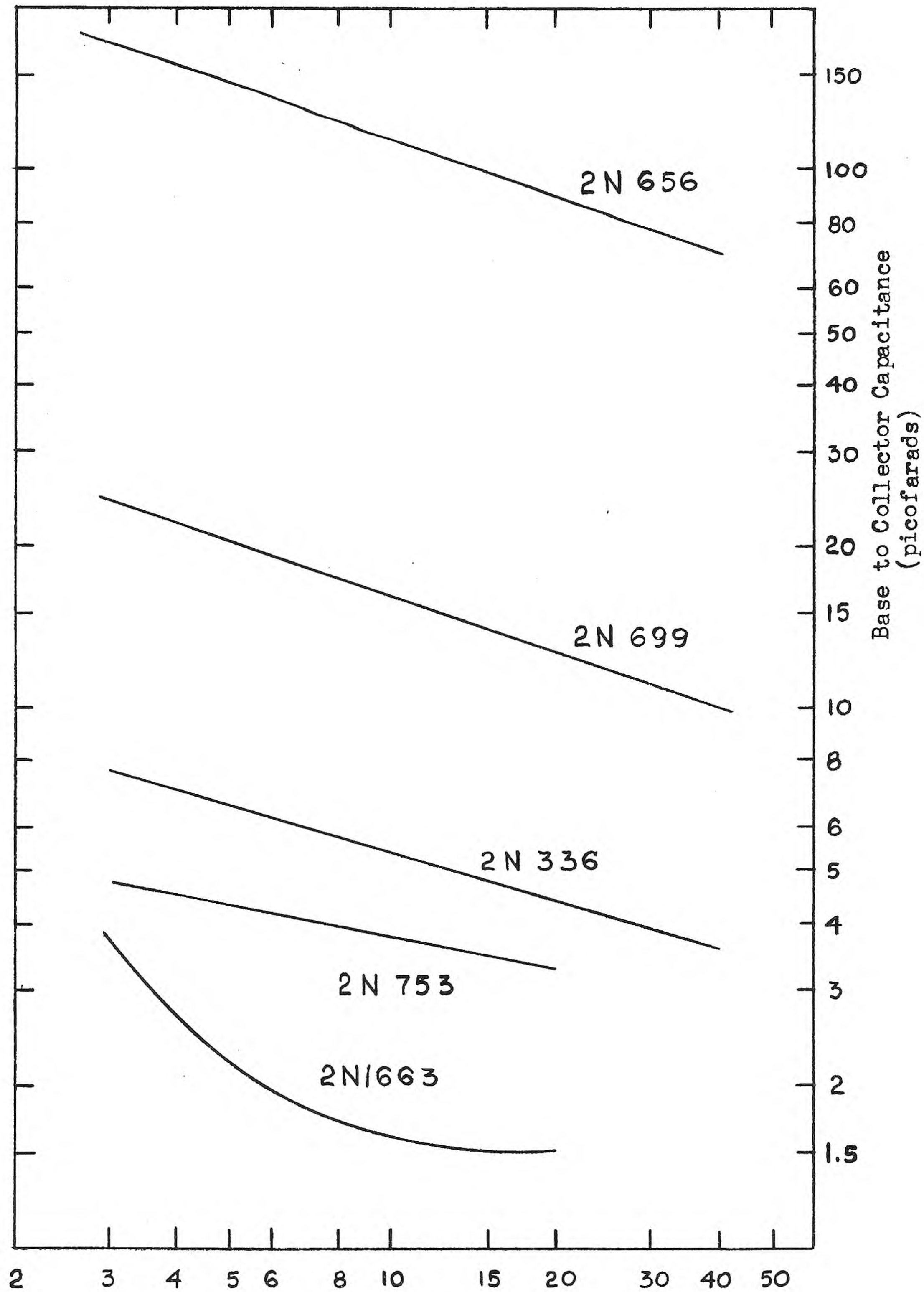


Fig. 1-4

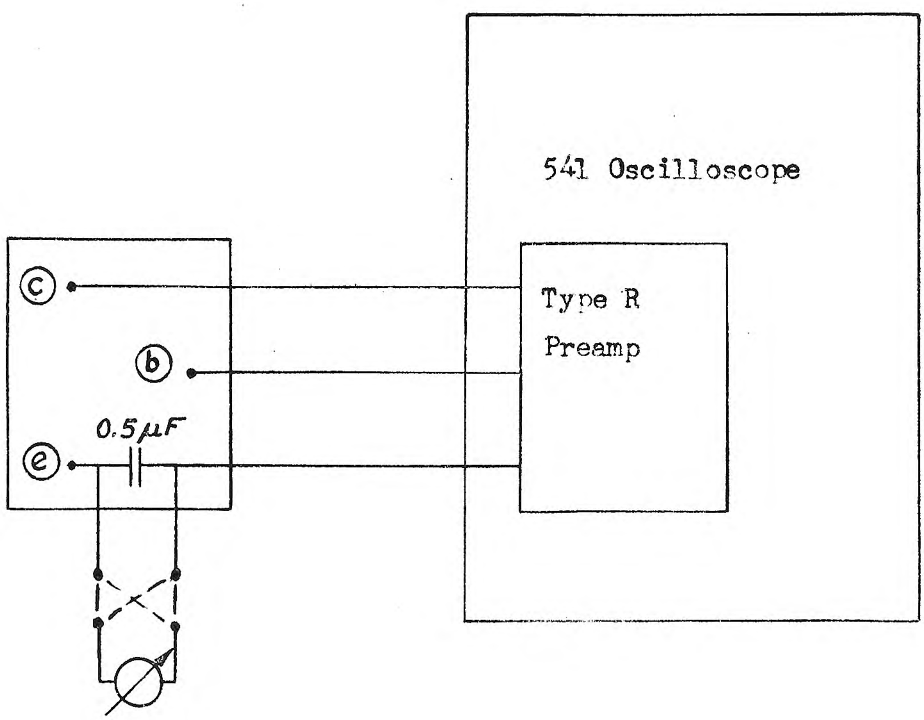


Fig. 2.1 Circuit for the gain bandwidth product measurements

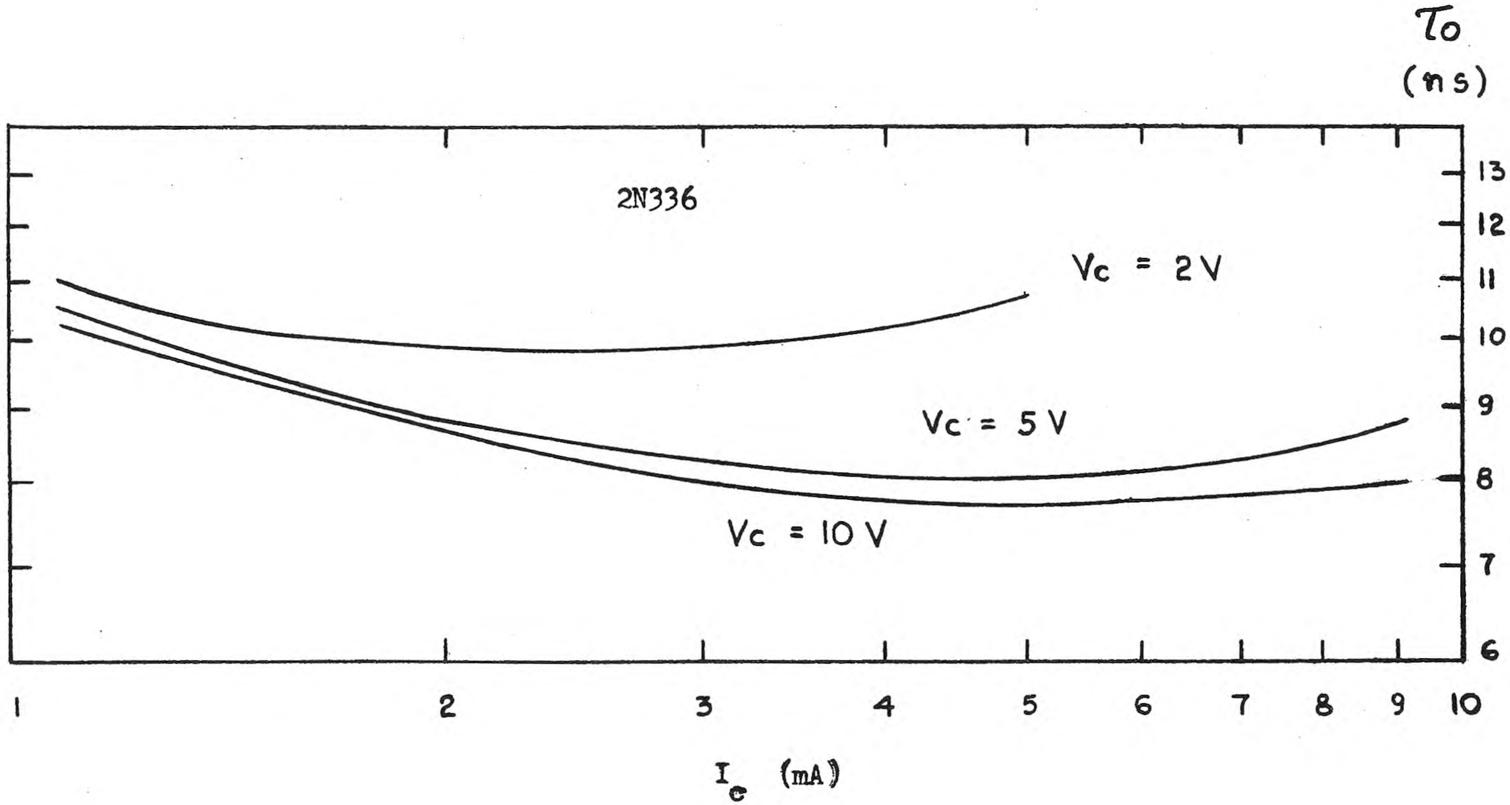


Fig. 2-2

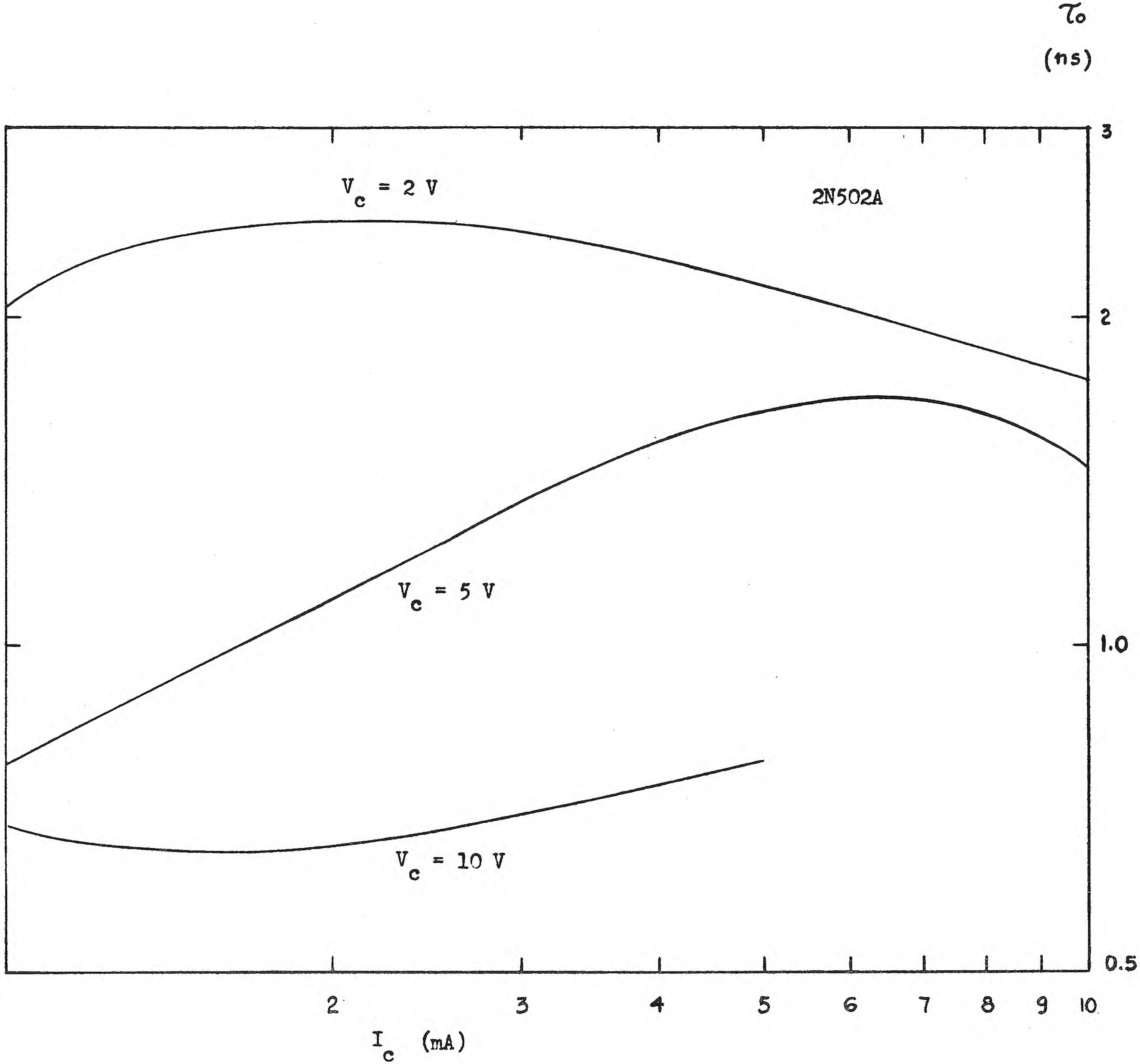


Fig. 2-3

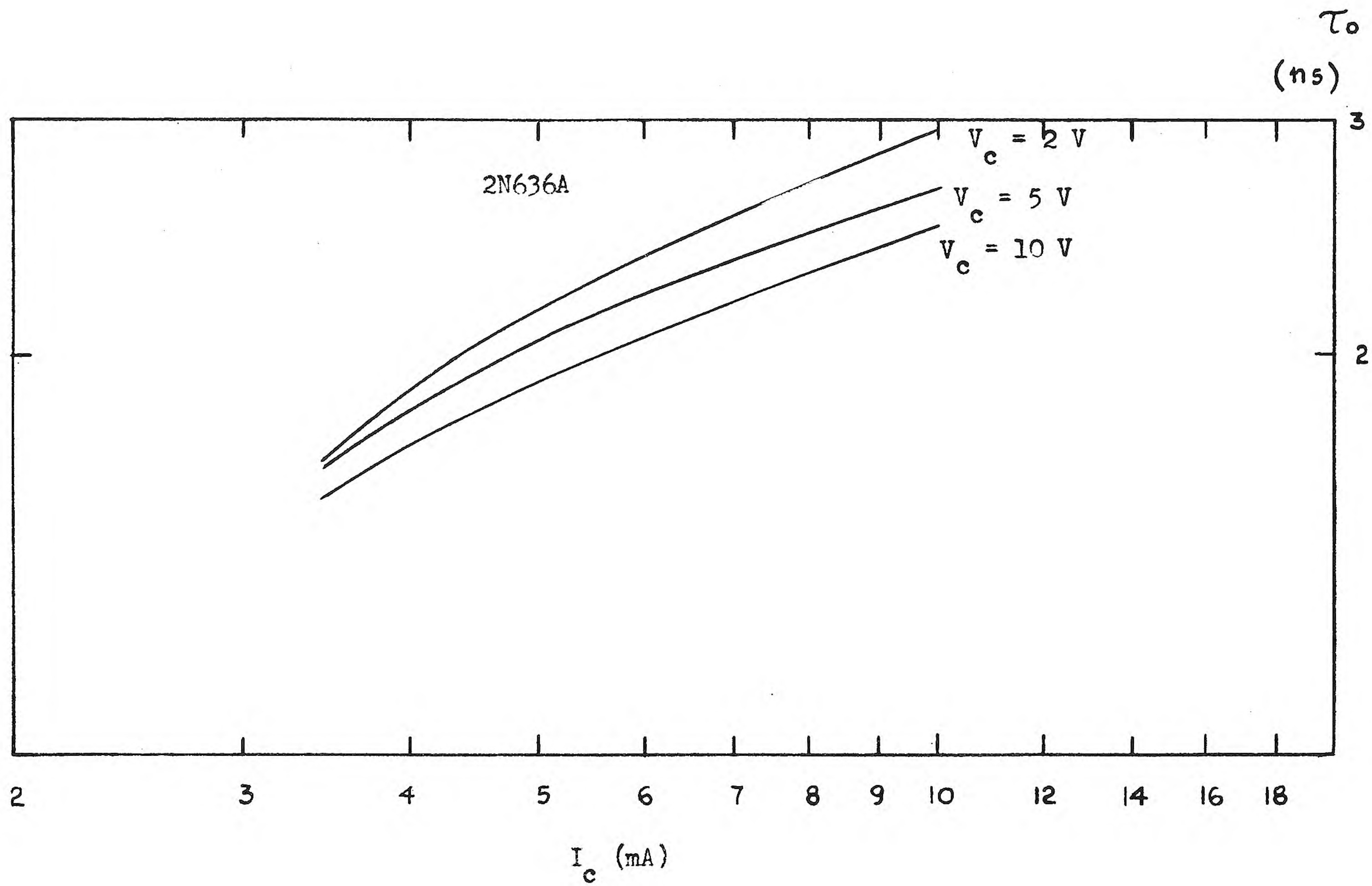


Fig. 2-4

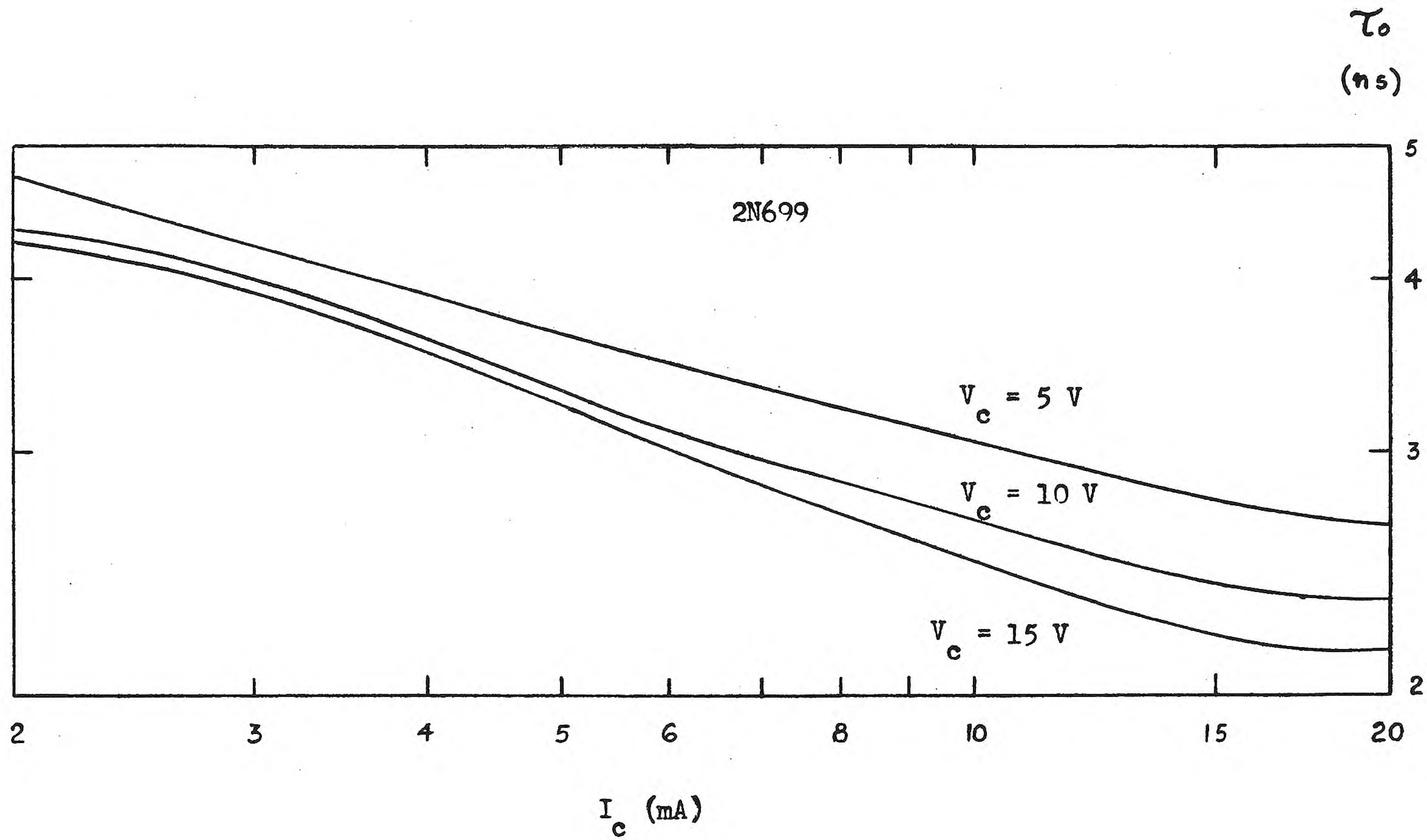


Fig. 2-5

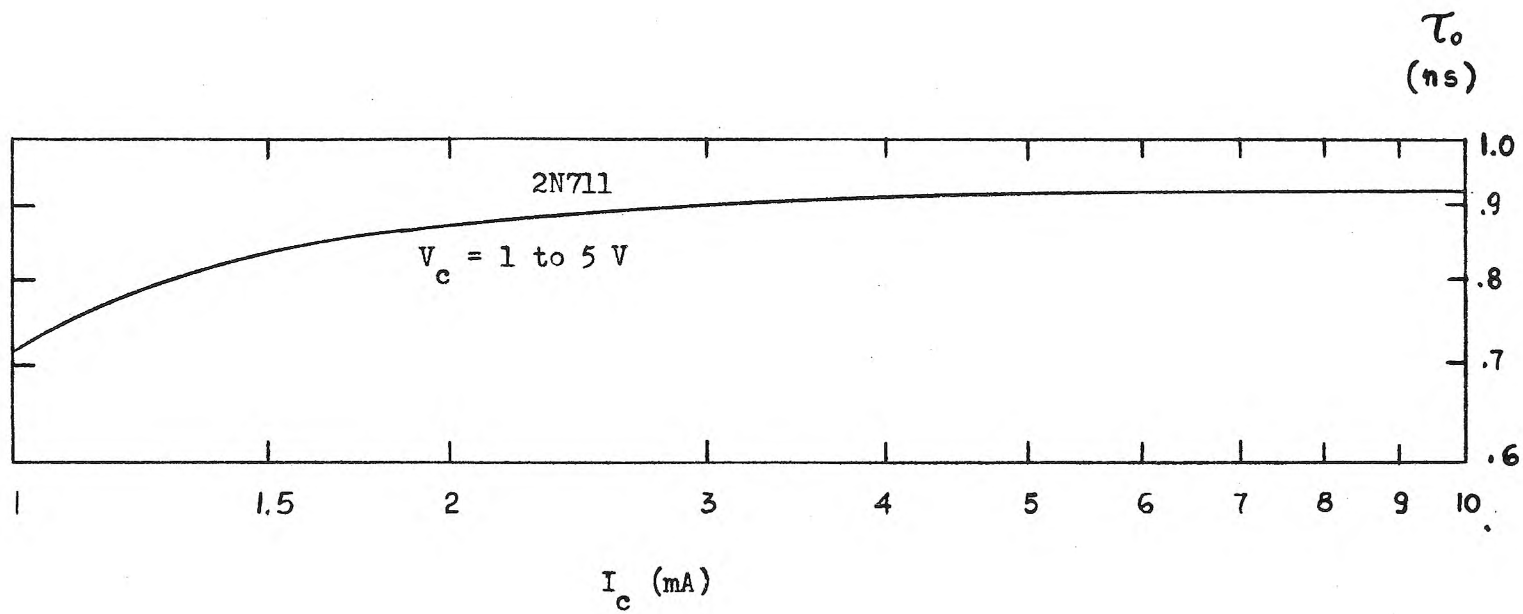


Fig. 2-6

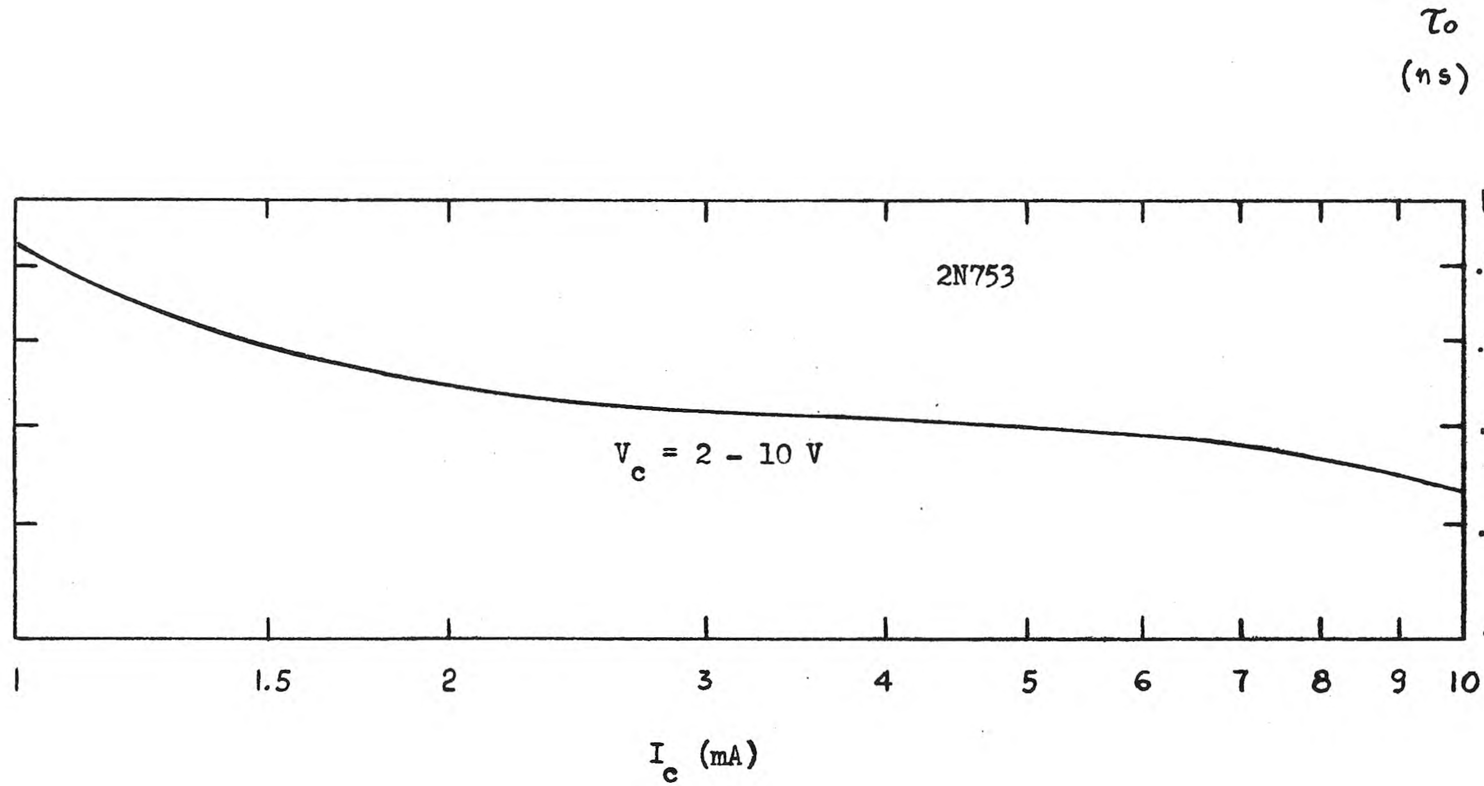
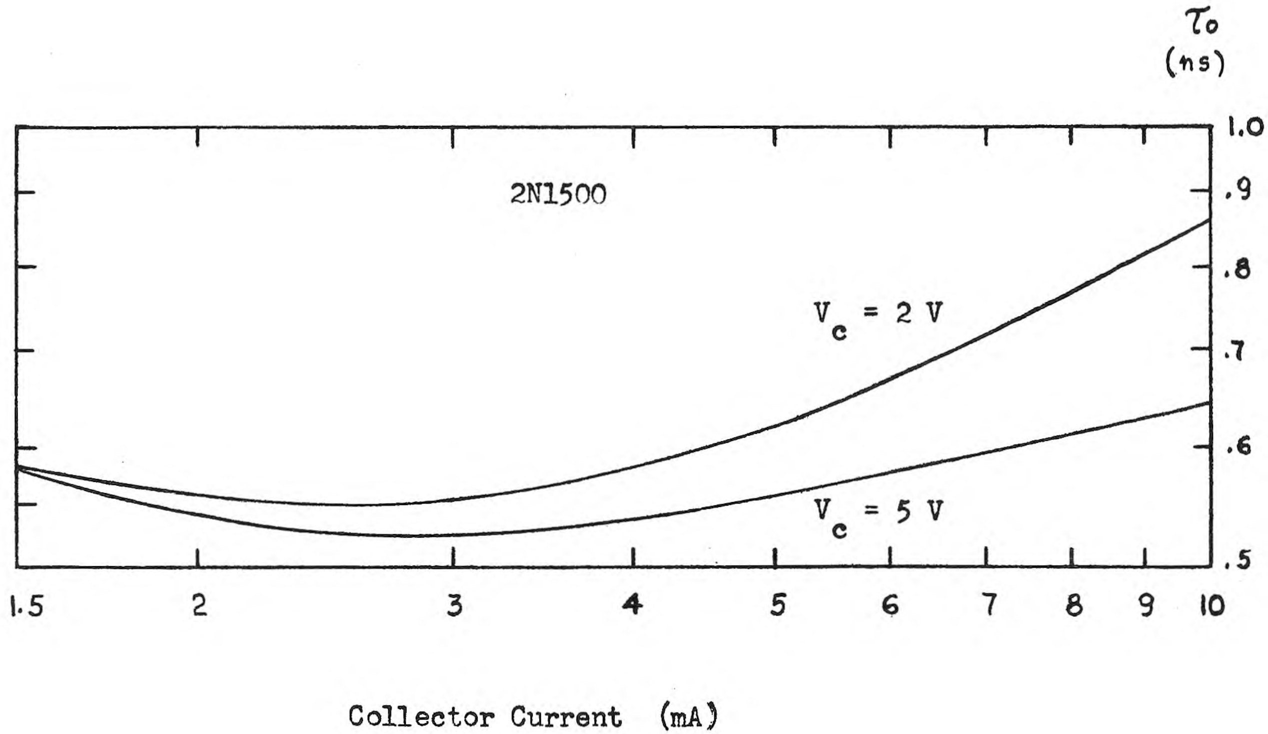


Fig. 2-7



τo
(ns)
1.0
.9
.8
.7
.6
.5
2N1500
Vc = 2 V
Vc = 5 V
1.5
2
3
4
5
6
7
8
9
10
Collector Current (mA)

Fig. 2-8

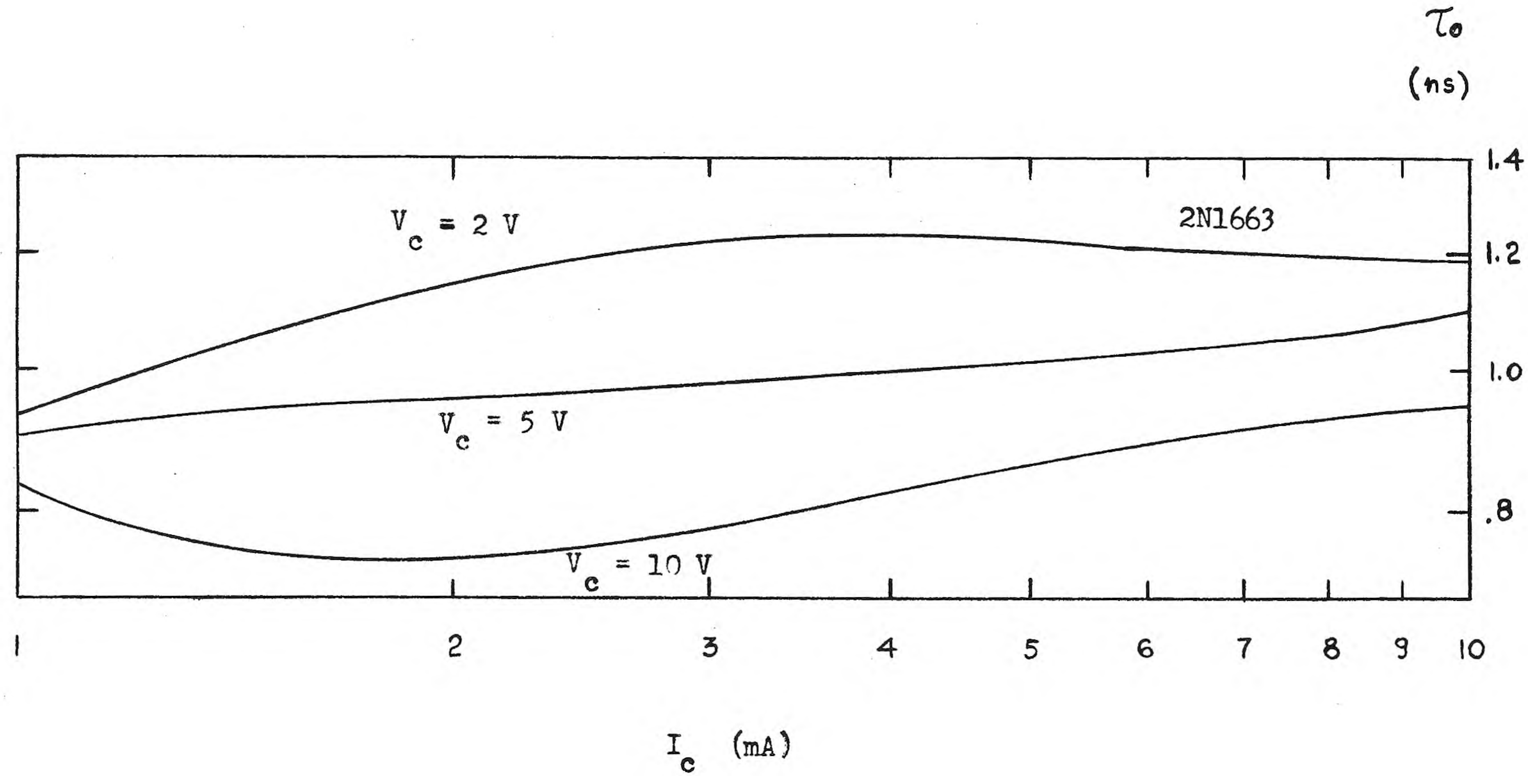


Fig. 2-9

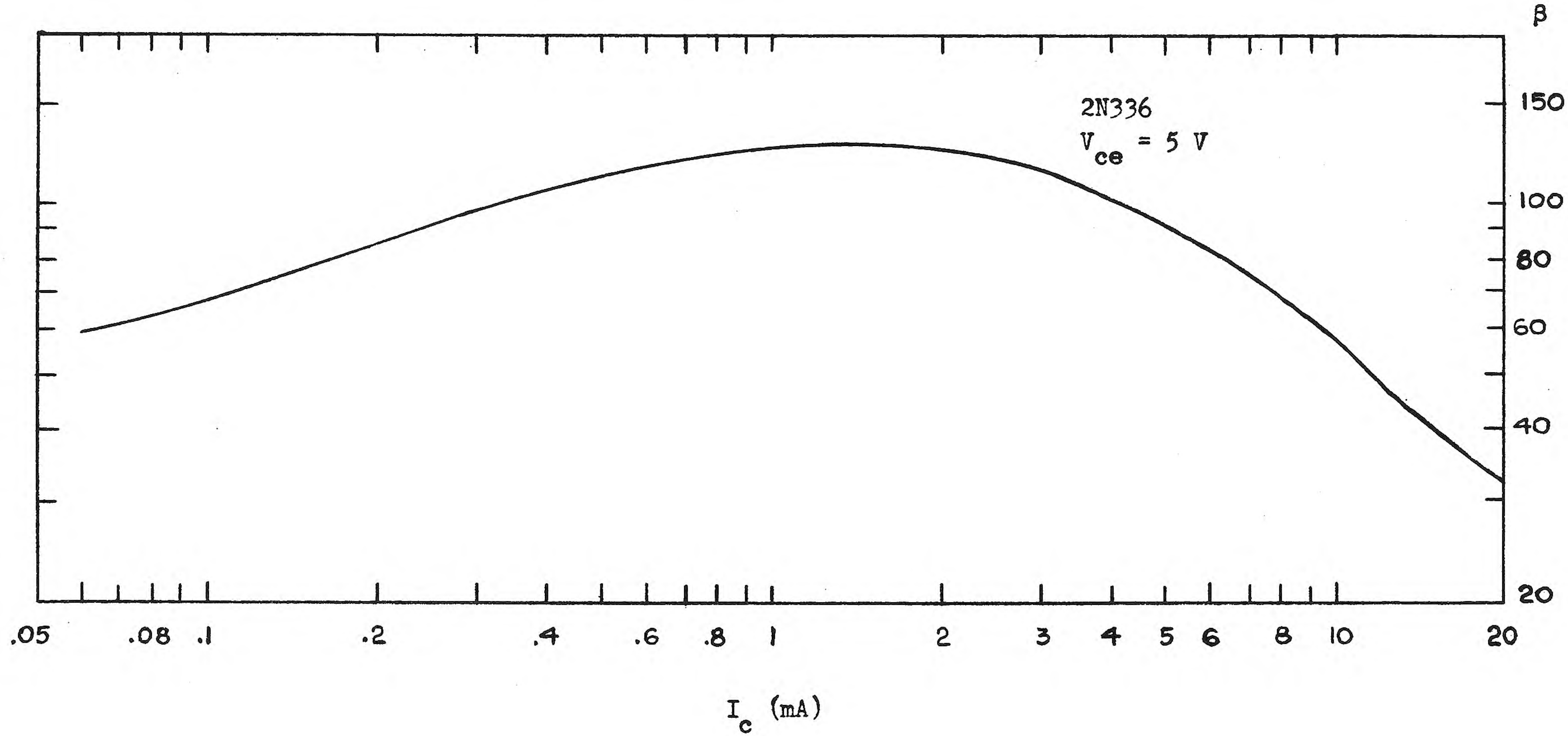


Fig. 3-1

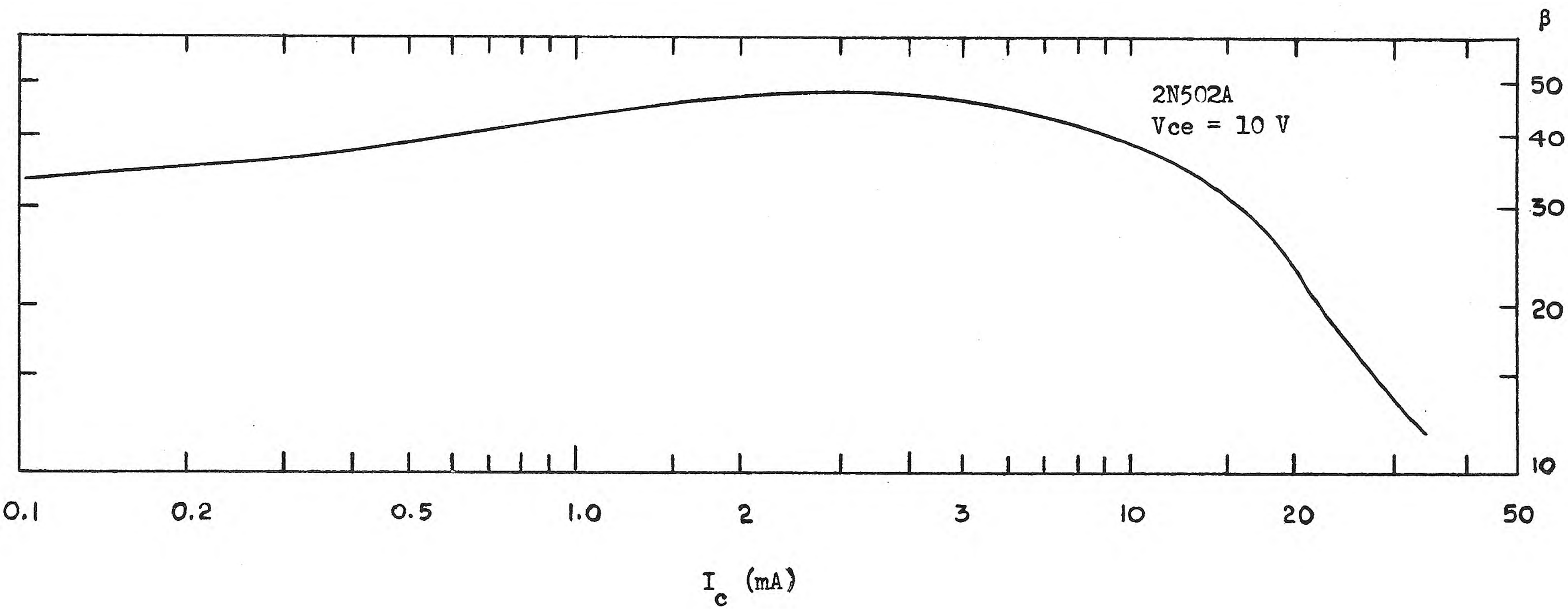


Fig. 3-2

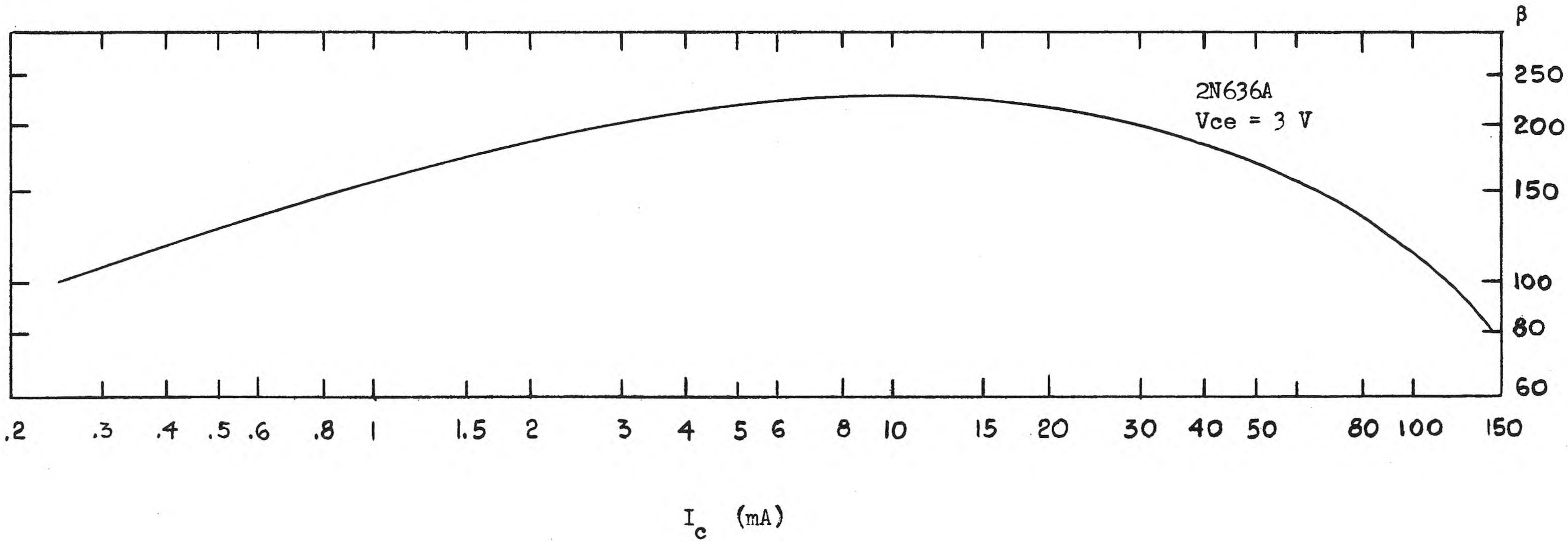

β
250
200
150
100
80
60
2N636A
Vce = 3 V
.2
.3
.4
.5
.6
.8
1
1.5
2
3
4
5
6
8
10
15
20
30
40
50
80
100
150
I
c
(mA)

Fig. 3-3

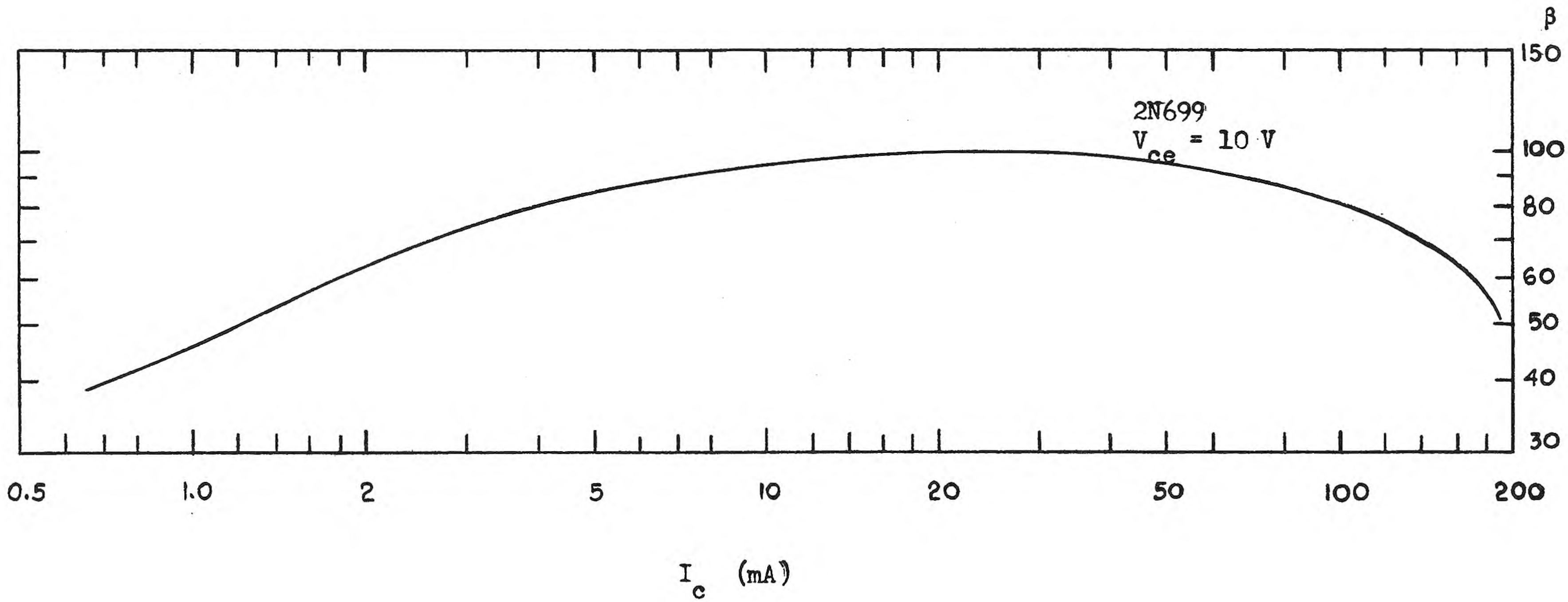

β
150
100
80
60
50
40
30
2N699
V_{ce} = 10 V
0.5
1.0
2
5
10
20
50
100
200
I_c (mA)

Fig. 3-4

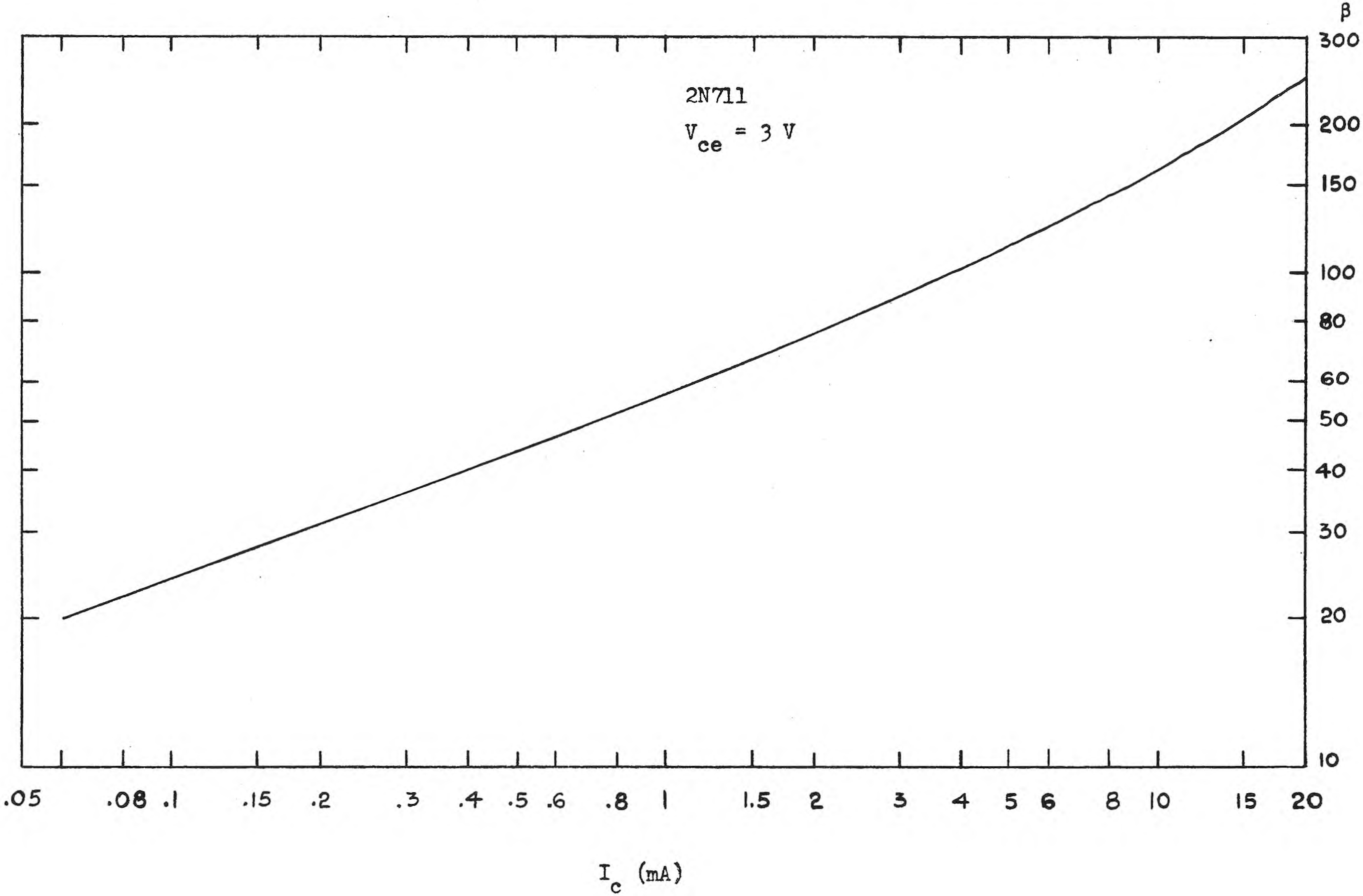

2N711
V_ce = 3 V
β
300
200
150
100
80
60
50
40
30
20
10
.05
.08
.1
.15
.2
.3
.4
.5
.6
.8
1
1.5
2
3
4
5
6
8
10
15
20
I_c (mA)

Fig. 3-5

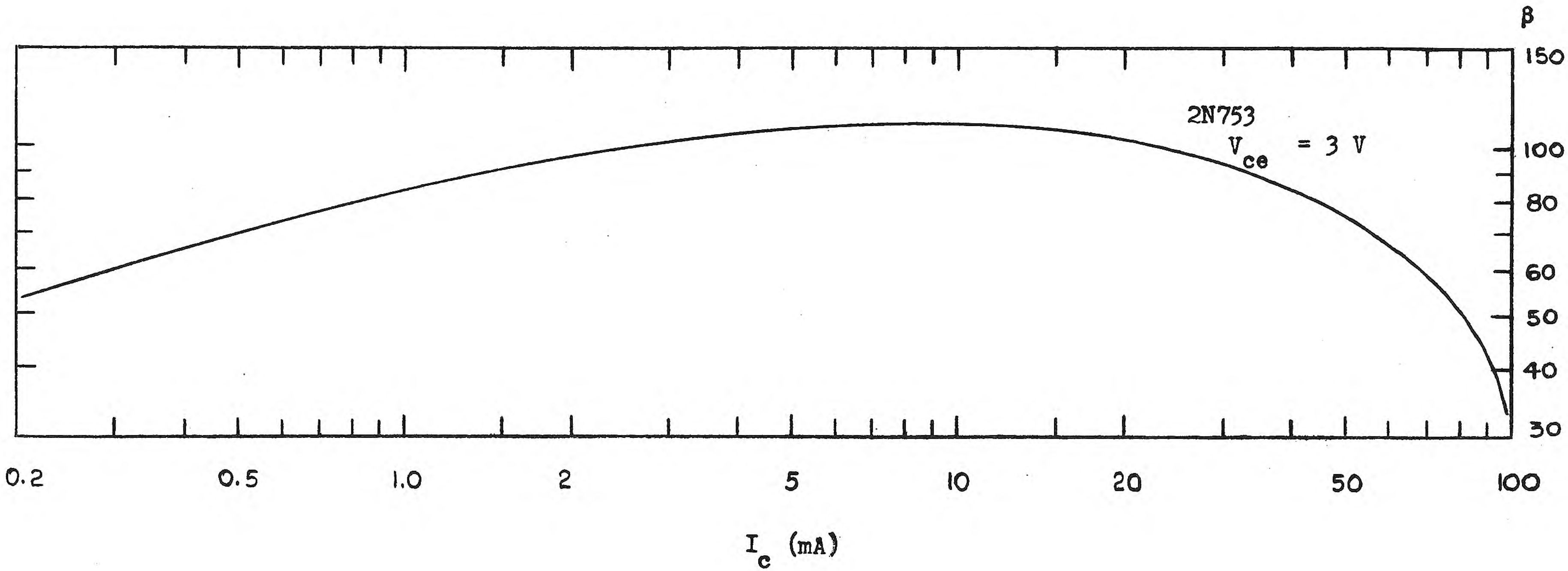


Fig. 3-6

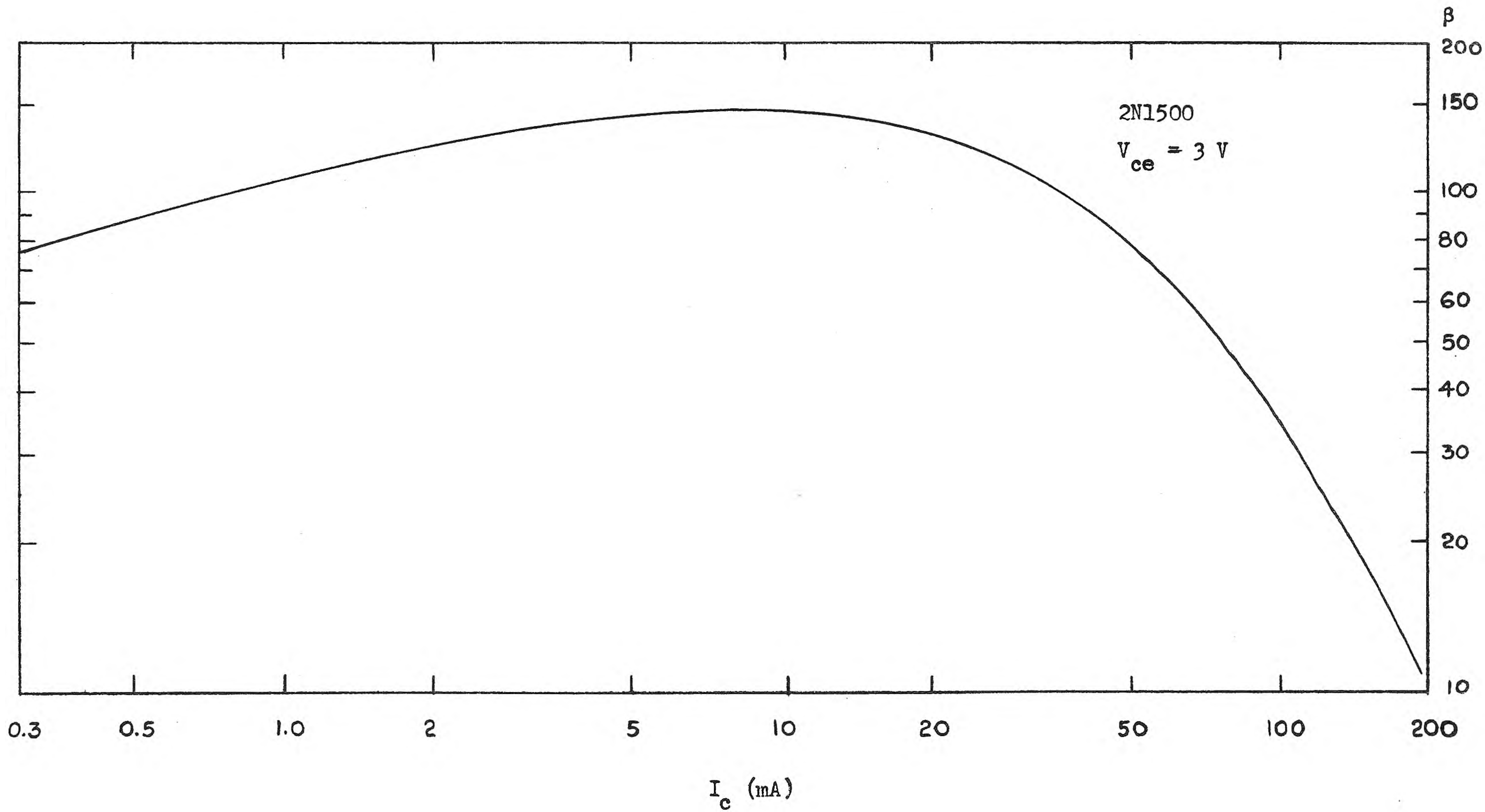

β
200
150
100
80
60
50
40
30
20
10
2N1500
V_{ce} = 3 V
0.3
0.5
1.0
2
5
10
20
50
100
200
I_c (mA)

Fig. 3-7

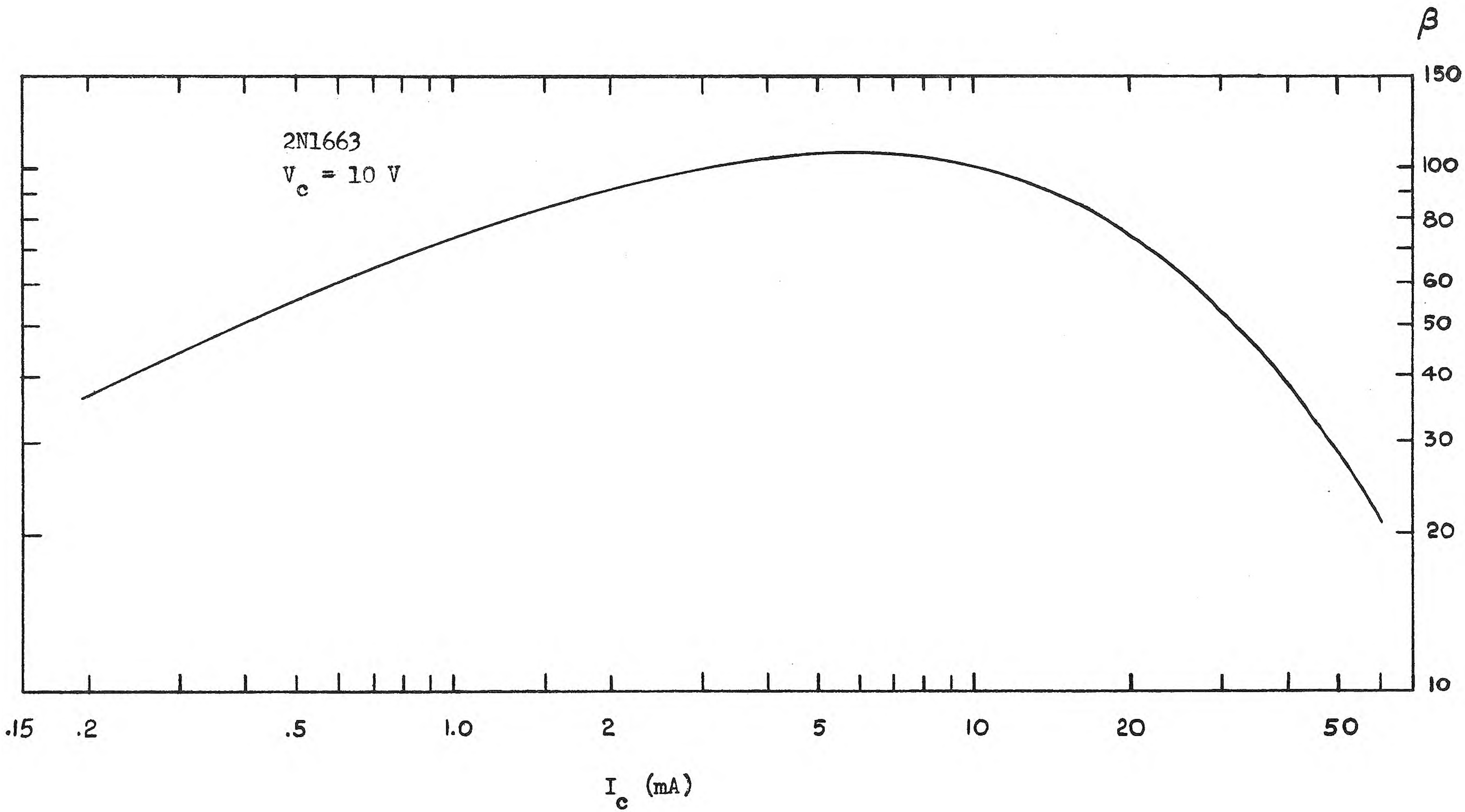

2N1663
Vc = 10 V
β
150
100
80
60
50
40
30
20
10
.15
.2
.5
1.0
2
5
10
20
50
Ic (mA)

Fig. 3-8

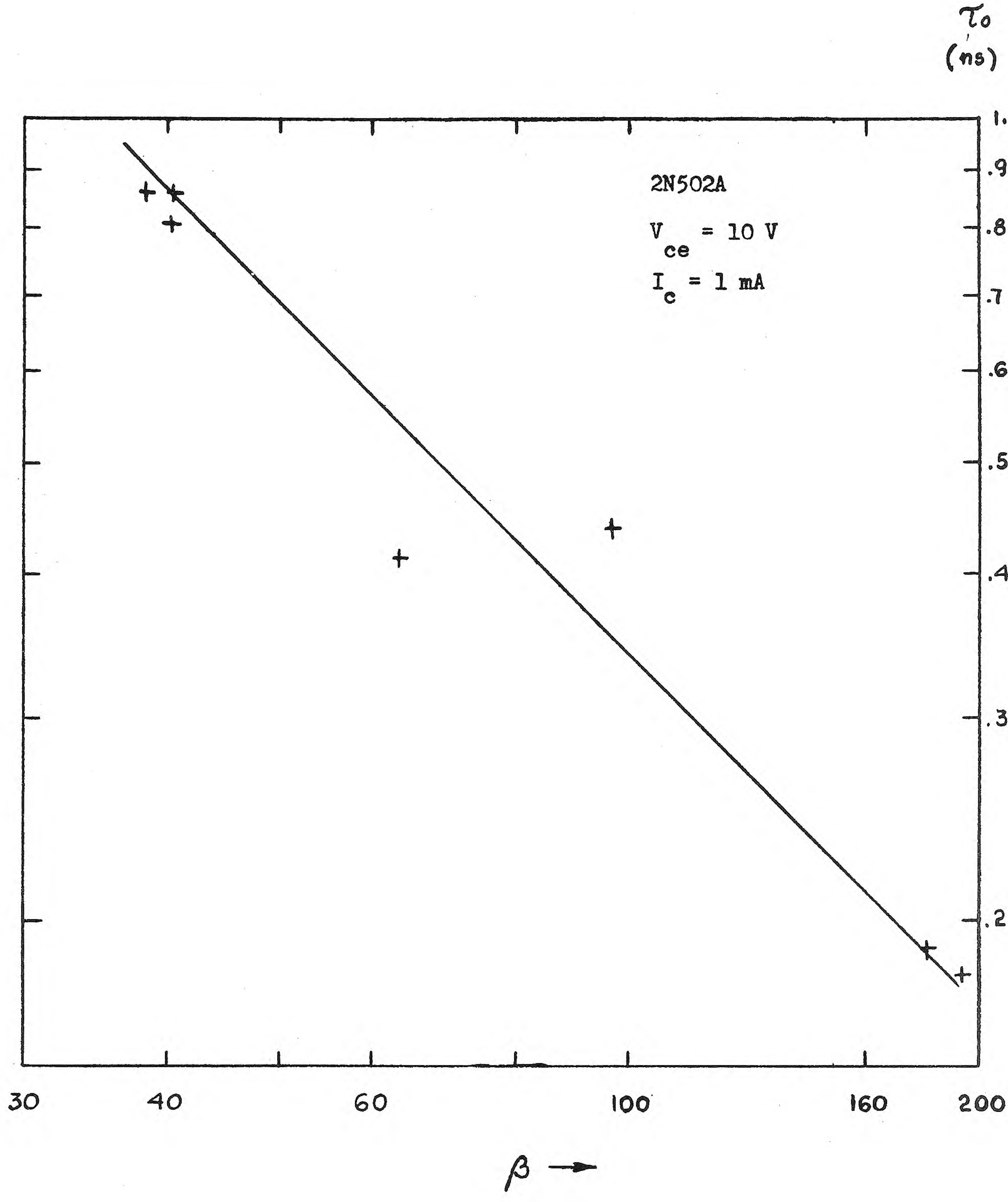


Fig. 4-1

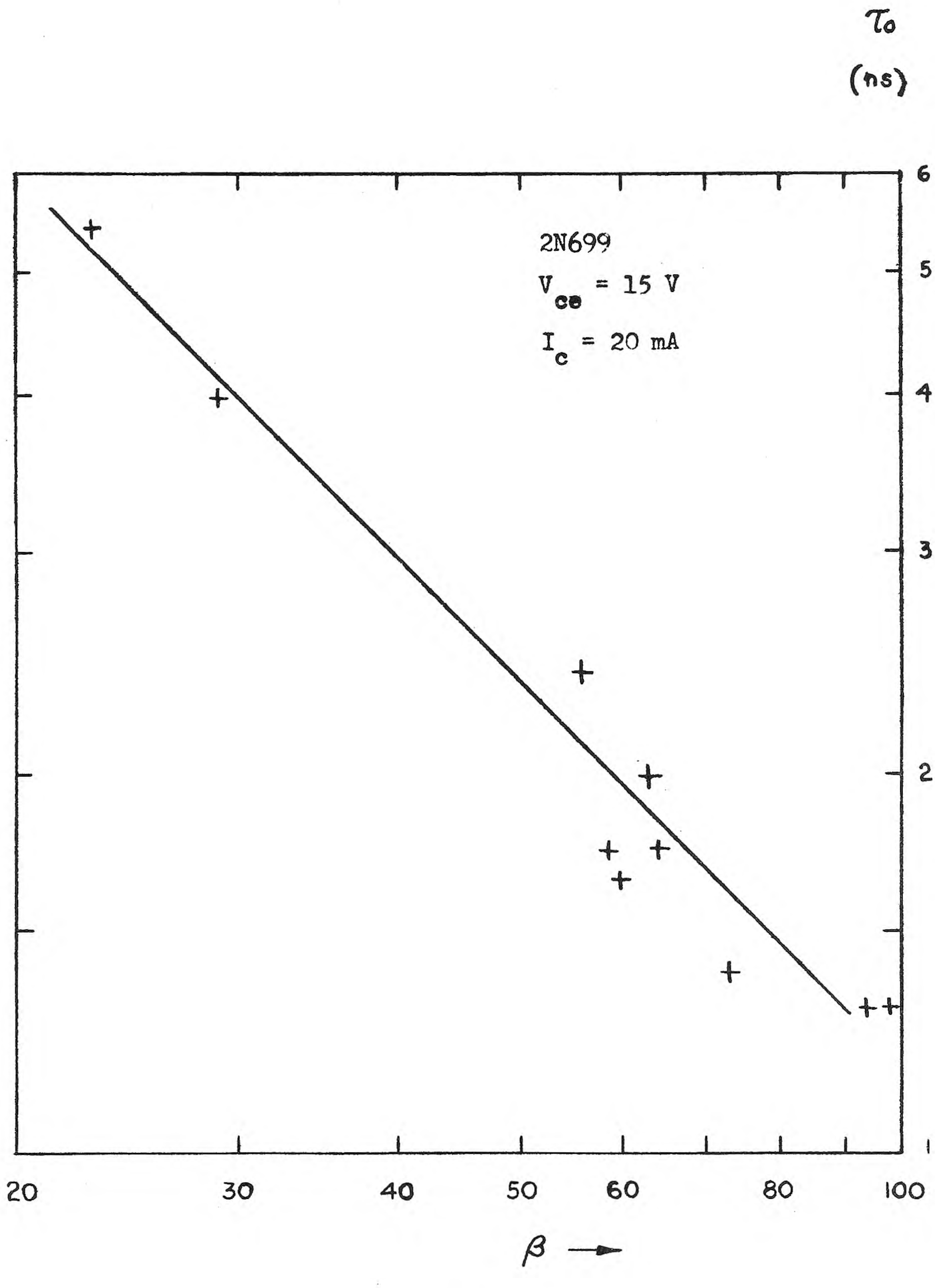


Fig. 4-2

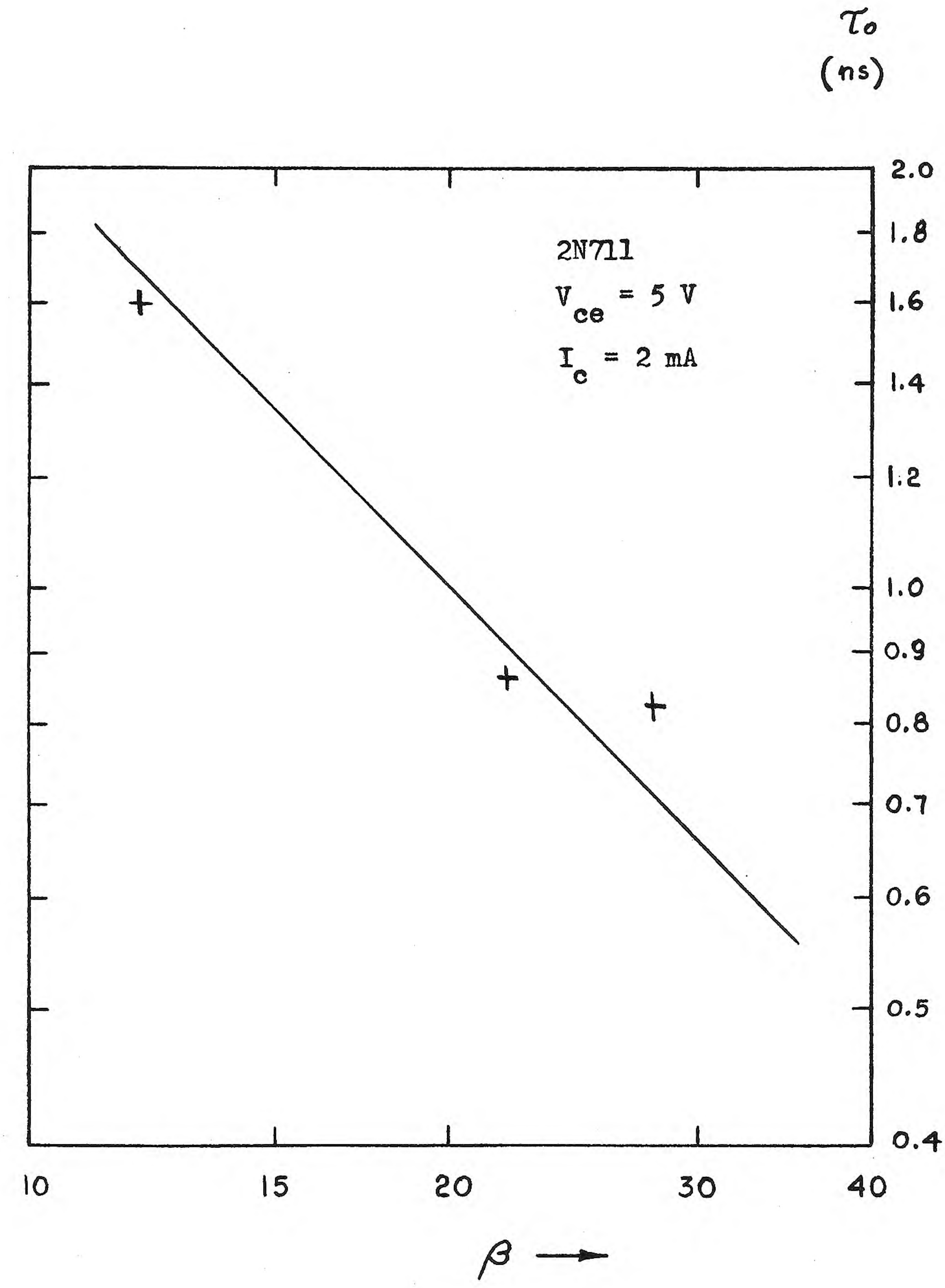
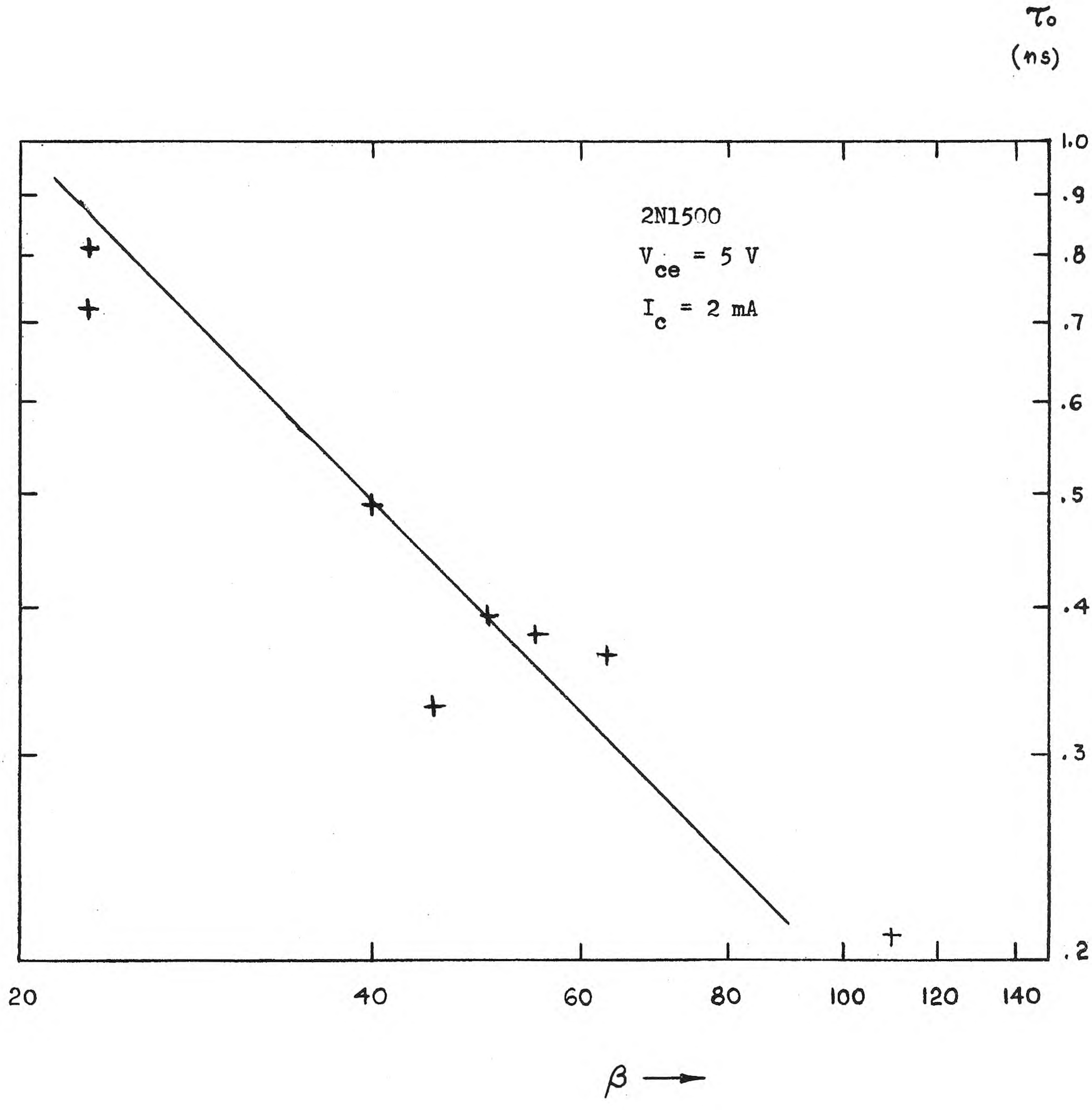

τo
(ns)
2N711
Vce = 5 V
Ic = 2 mA
2.0
1.8
1.6
1.4
1.2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
10
15
20
30
40
β

Fig. 4-3



τ_o
(ns)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
2N1500
V_{ce} = 5 V
I_c = 2 mA
20
40
60
80
100
120
140
β →

Fig. 4-4

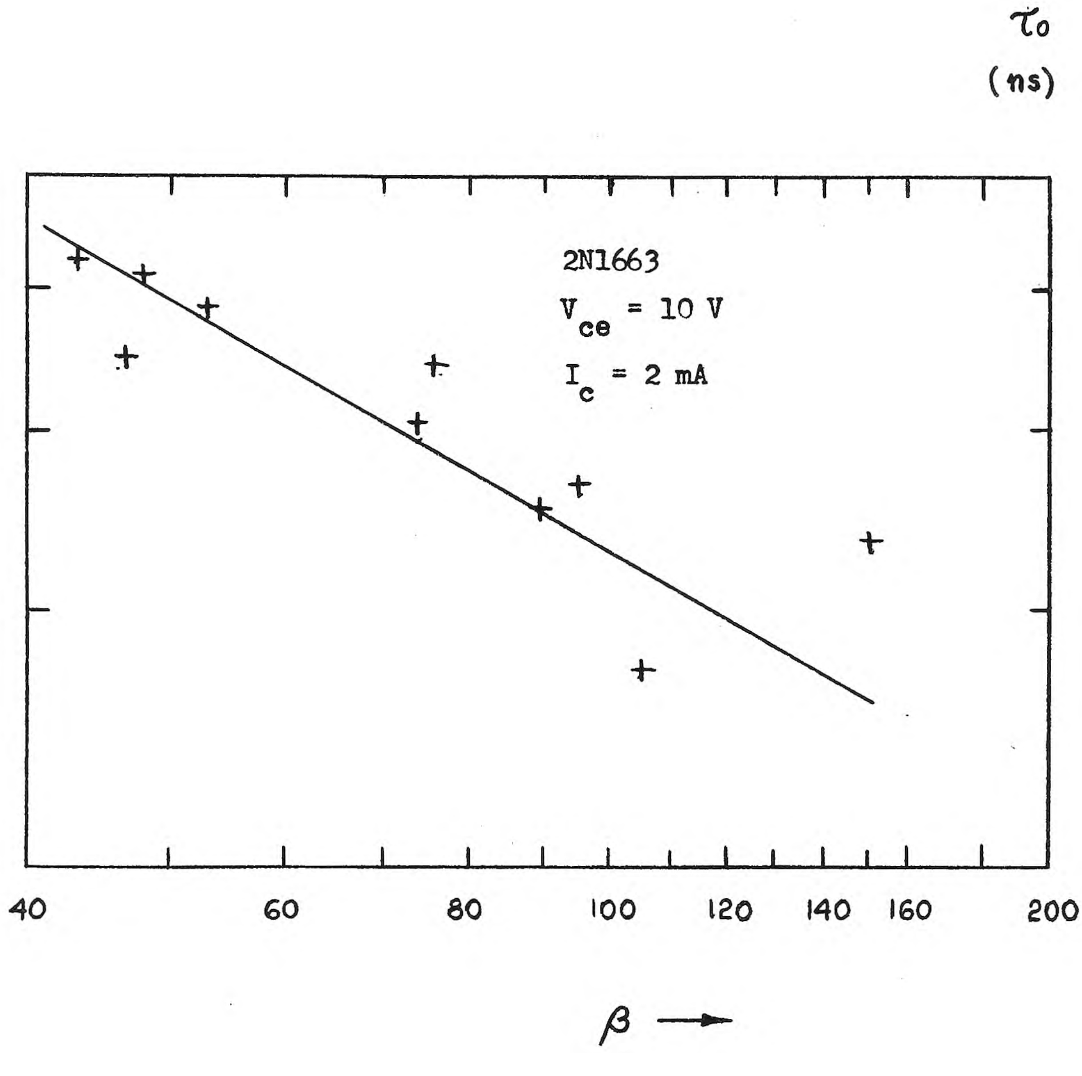


Fig. 4-5

TABLE 2

Measured Values of Base Spreading Resistances.

Transistor	Base spreading resistance r_s (ohms)		
	Min.	Avg.	Max.
2N 167	3.3	7.0	11.2
2N 301	0.36	0.38	0.40
2N 326	0.76	1.72	2.8
2N 336	3.2	4.6	5.8
2N 384	0.41	1.13	2.20
2N 398	0.66	2.30	4.35
2N 502A	3.5	4.6	6.2
2N 527	0.80	1.48	2.88
2N 585	1.92	6.78	13.2
2N 599	1.28	2.02	3.36
2N 636	31	37.4	44
2N 636A	6.8	7.6	9.2
2N 656	0.64	1.34	4.4
2N 699	0.7	0.86	1.25
2N 700	3.75	5.55	10.0
2N 711	1.6	2.45	3.0
2N 753	15.2	15.6	16
2N 1204	4.6	5.1	5.8
2N 1500	4.0	5.1	6.4
2N 1663	52	101	160
T 1832		2.0	