LB-1025

EQUIPMENT FOR DISPLAYING TRANSISTOR CHARACTERISTICS

RADIO CORPORATION OF AMERICA
RCA LABORATORIES
INDUSTRY SERVICE LABORATORY

RADIO CORPORATION OF AMERICA

RCA LABORATORIES

INDUSTRY SERVICE LABORATORY

LB-1025

Equipment for Displaying Transistor Characteristics

Approved

Stuart W. Seeley

Equipment for Displaying Transistor Characteristics

This bulletin describes the principles of operation and the constructional details of equipment which provides an oscilloscope display of any of the following transistor characteristics: the output characteristic, the input characteristic, the forward transfer characteristic, and the current amplification factor. Output curves with base current as the parameter can be displayed as a family.

By using adapters, or auxiliar sweep facilities additional curves may be displayed, e.g., the current amplification curves of a pair of transistors.

Introduction

The equipment permits the display of the following four transistor characteristics:

(a) V_c vs. I_c, with I_b = *constant;* called the output characteristic and labeled R_o.

(b) F_b vs. I_b, with W_c = *constant;* called the input characteristic and labeled R_i.

(c) I_c vs. E_b, with V_c = *constant;* called the forward transfer characteristic and labeled G_m.

(d) I_c vs. I_b, with V_c = *constant,* called the current amplification characteristic and labeled β.

These relations all refer to the common emitter configuration. When the common base configuration is of interest, an adapter socket is used.

The basic circuits and means necessary to obtain the display of the above-specified transistor current-voltage relations on an oscilloscope are shown in Figs. 1a to 1d. A sweep of the proper amplitude and polarity is applied to the collector, as in case 1a, or to the base as shown in Figs. 1b to 1d. The output characteristic (Fig. 1a) is plotted with the base current I_b as the parameter. This requires a constant-base-current supply which is manually adjustable, or which automatically selects a number of predetermined constant-current values. Such an automatic arrangement allows the visual display of a family of output curves on an oscilloscope. The three basic circuits of Figs. 1b to 1d require a constant-voltage supply to feed the collector of the transistor.

Voltages and currents to be measured are taken from the appropriate branch of the transistor circuit and applied to the amplifiers of the oscilloscope. The voltage is taken directly from the pertinent transistor electrode while the current is measured by the voltage drop across a known resistor inserted in the circuit. A choice of current-sampling resistors is provided; a value should be employed which is high enough to yield sufficient deflection on the scope but low enough to cause a voltage drop that is negligible compared to the voltage measured at the same circuit branch. Reference potentials are provided for the calibration of the oscilloscope in terms of currents and voltages to be plotted on the screen.

Equipment

The complete equipment set-up is shown in Fig. 2. The large cabinet in the center of the figure contains the major portion of the equipment; the "basic unit" is mounted behind the upper front panel of this cabinet, while the "supply unit" is contained behind the lower front panel. At the right are two oscilloscopes, one of which serves as a monitor, while the second is employed in taking photographs of characteristic curves. On the left is a d-c power supply which provides biasing voltages and currents. Atop the power supply are two cabinets; the lower cabinet contains three transformers which are utilized to provide 60-cycle sweep voltages, while the upper cabinet houses an auxiliary circuit which permits the simultaneous display of the characteristics of two transistors.

Basic Unit

The basic unit contains the necessary switches for selecting the desired characteristic curve to be displayed, the necessary rectifiers, and the calibration means. Front and rear views of the basic unit are shown in Figs. 3 and 4. A schematic diagram of the unit appears in Fig. 5.

A variac, shown at the upper left in Fig. 5, serves as an amplitude control for the sweep; its output feeds the transformers of the main source. The secondary of

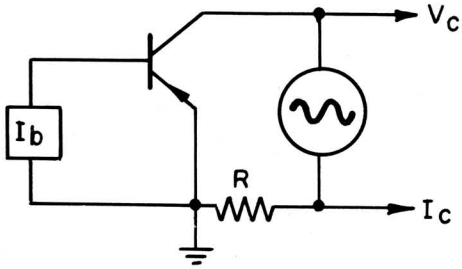

FIG. 1a

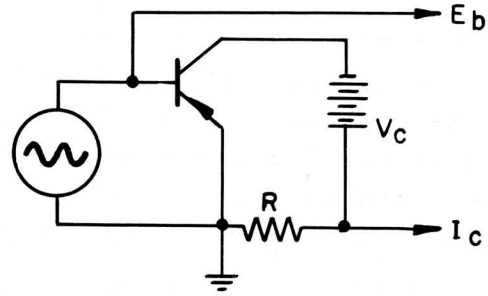

FIG. 1c

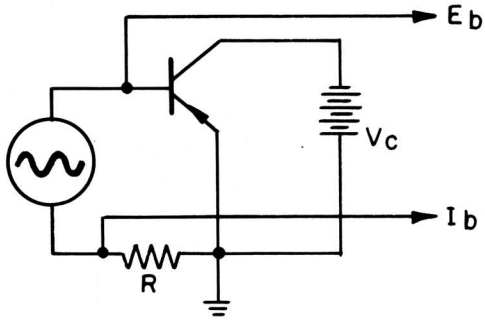

FIG. 1b

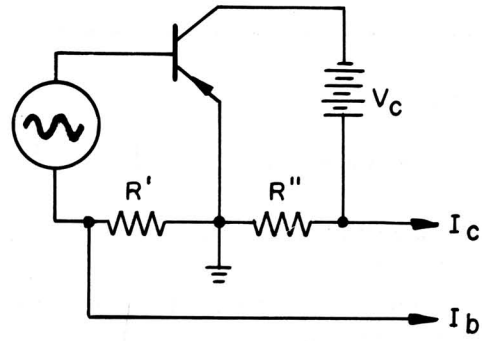

FIG. 1d

Fig. 1 – The four basic circuits for the display of: a. output characteristic (R_o), b. input characteristic (R_i), c. Forward transfer characteristic (G_m), d. current amplification curve (β).

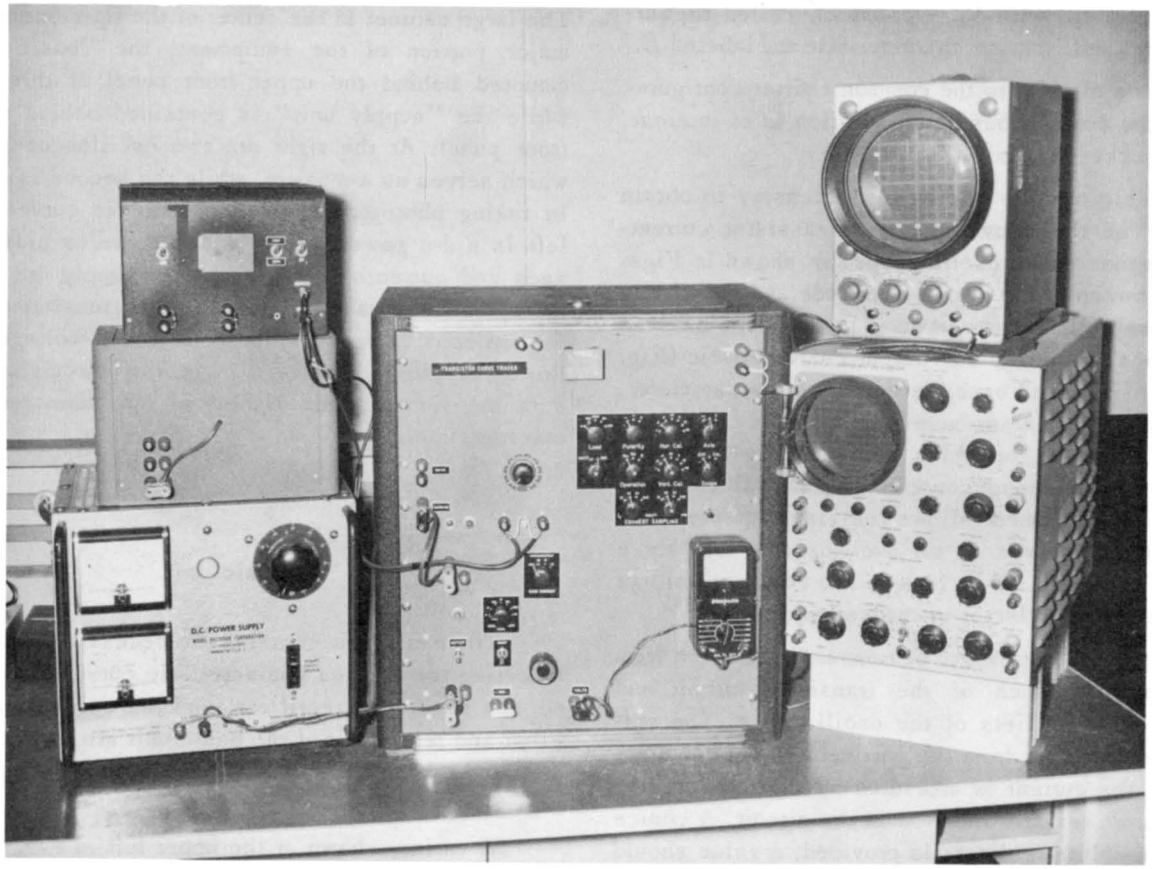

Fig. 2 – The curve tracing equipment and its accessories.

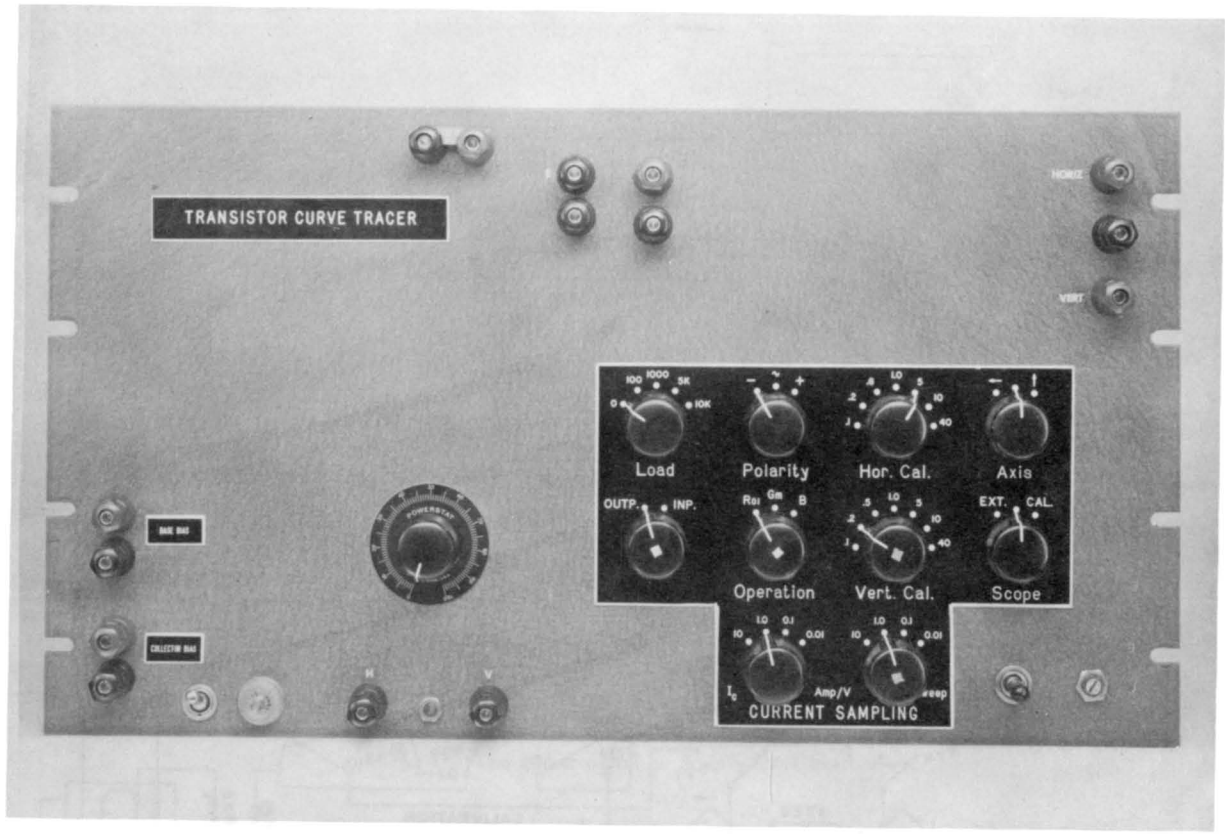

Fig. 3 – The upper panel or Basic Unit, front view.

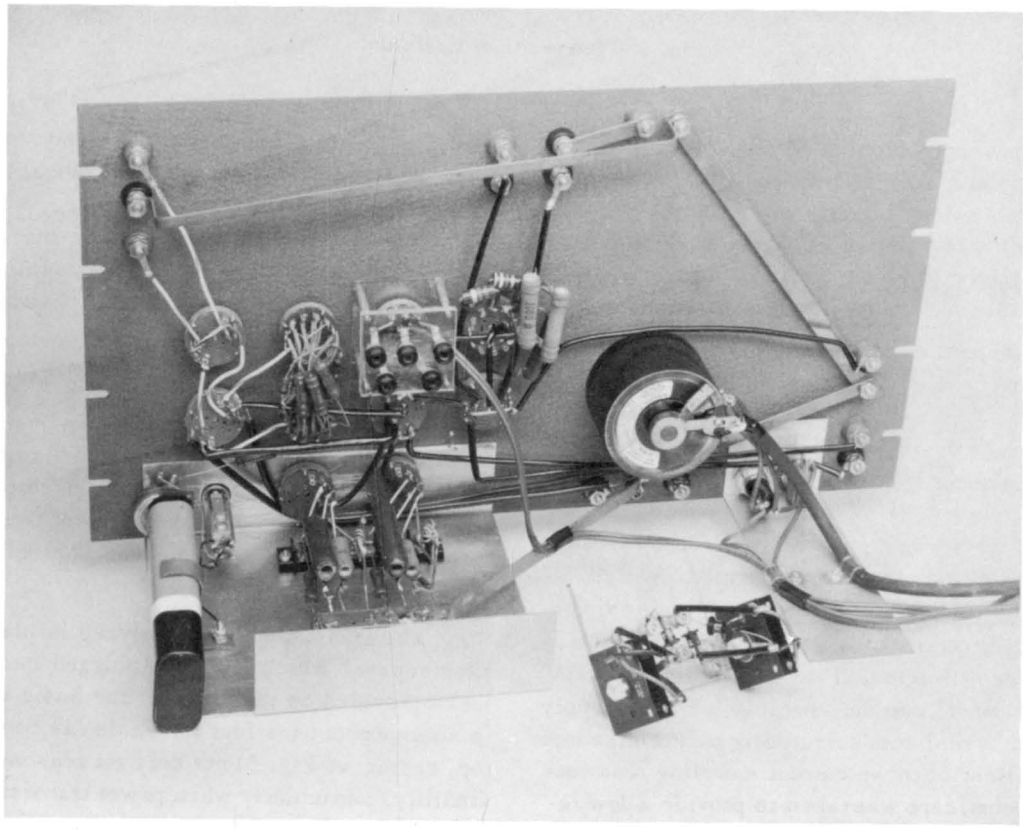

Fig. 4 – Rear view of Basic Unit.

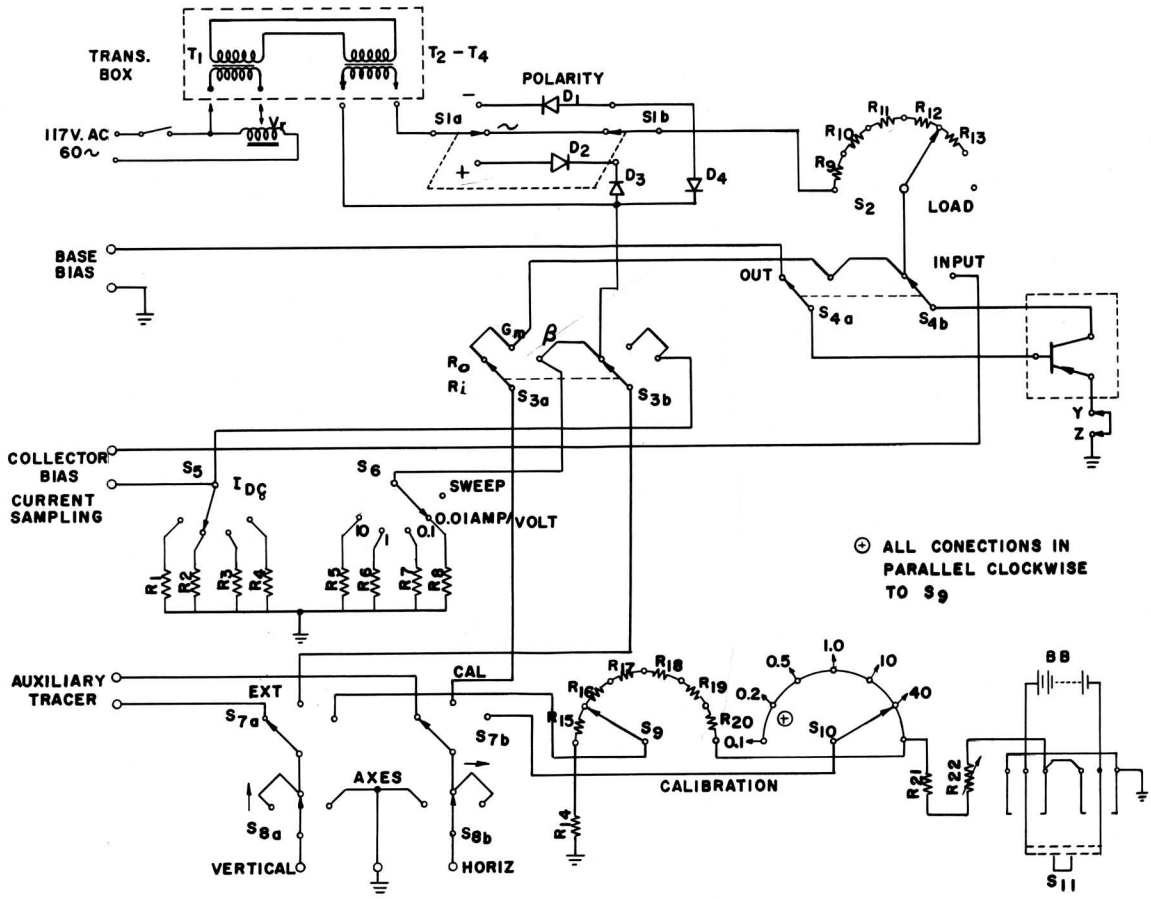

Fig. 5 – Schematic of Basic Unit.

the transformer chosen to provide the sweep voltage is connected to the polarity selector switch S_1. This switch may be employed to select either a 60-cycle per second sine wave or a half sine wave of either positive or negative polarity for sweep. Diodes are used to provide the half sine-waves, as can be seen in the schematic.

An appropriate load resistor, which is in series with the sweep current path, may be selected by means of switch S_2. Switches S_3 and S_4 are used for the selection of the current-voltage function which is to be displayed. In the position shown in Fig. 5 the output characteristic (R_o) would be displayed. If switch S_4 is rotated clockwise the input characteristic may be plotted. By means of S_3, the G_m and β curves ray be selected. Switch S_5 is used to select an appropriate current-sampling resistor for the current delivered from the collector supply which is connected between the terminal marked "collector bias" and the terminal marked "current sampling". Sweep supply current is sampled by resistors selected by means of switch S_6. Since the smallest of these current sampling resistors has a value of 0.1 ohm, care was taken to provide a low resistance return path to ground. Wherever possible heavy copper bars were used (these may be seen in Fig. 4).

The oscilloscope terminals may be switched, by means of S_7, to the sweep circuit, the calibration circuit, or the external auxilary sweep source. Switch S_8 is used during calibration and allows either the vertical amplifier input to be grounded or the horizontal amplifier input to be grounded. Its normal operating position is as shown in the schematic.

The calibration circuit consists of a voltage divider connected by means of switches S_9 and S_{10} to the corresponding horizontal and vertical amplifiers of the oscilloscope. This voltage divider is energized by a dry battery controlled by switch S_{11}. By means of this switch, either a plus or minus voltage may be applied to the voltage divider.

The transistor to be analyzed is placed on a small adapter panel, which in turn is plugged into corresponding jacks provided on the panel of the basic unit. This plug-in arrangement uses four terminals (as can be seen at the top, center, of Fig. 3) not only for reasons of mechanical stability, particularly when power transistors placed on a heat sink are analyzed, but also to accomodate the second base connection of tetrode transistors.

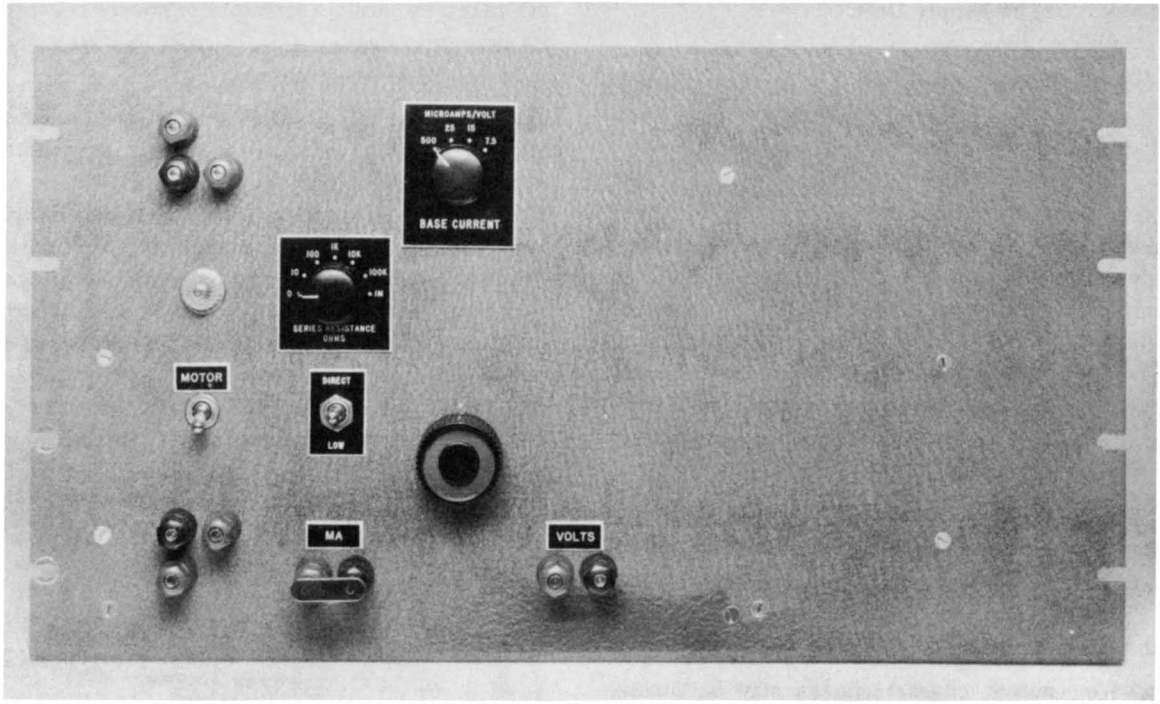

Fig. 6 – The lower panel or Supply Unit front view.

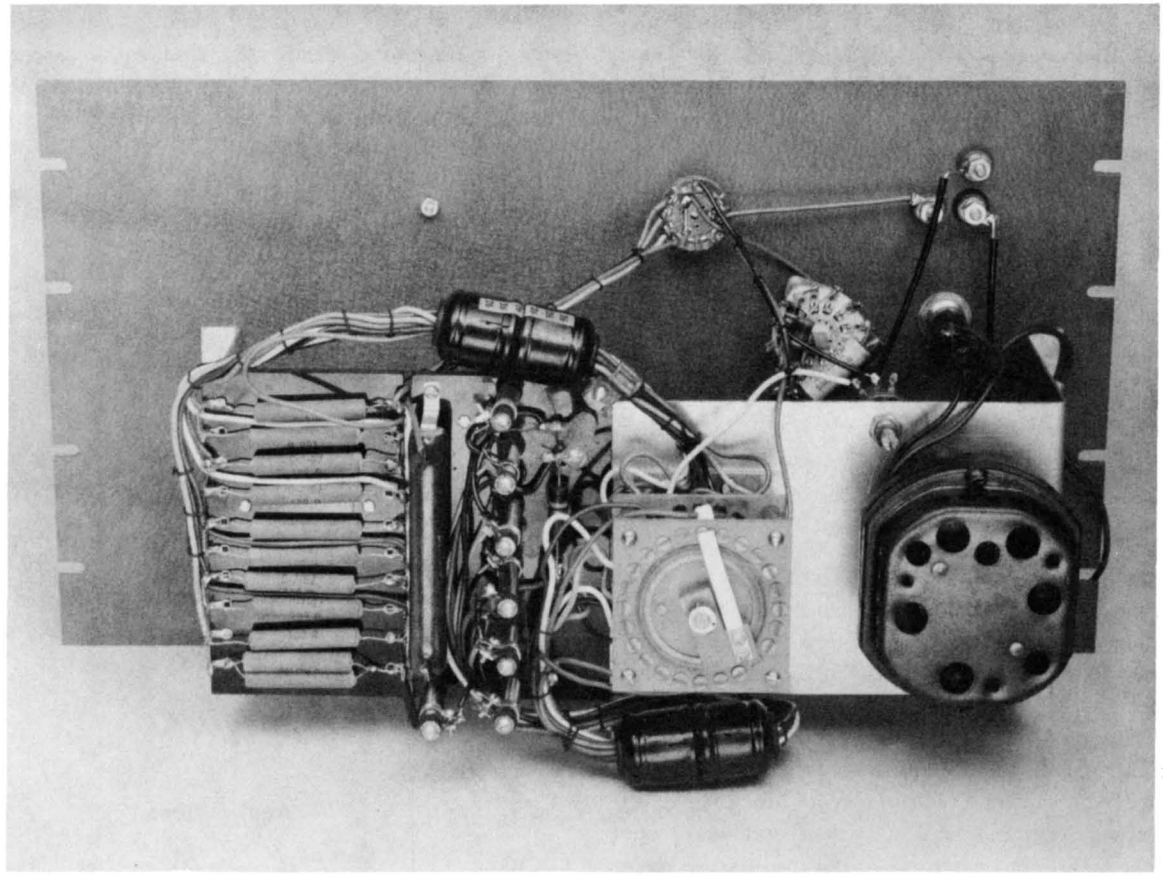

Fig. 7 – Rear view of Supply Unit.

The Supply Unit

The front and rear views of the supply unit are shown in Figs. 6 and 7. This unit contains a motor-driven switch and some of the circuitry relating to input-circuit biasing. The schematic diagram of this unit is given in Fig. 8. For manual operation, the "Base Bias" terminals of the Basic Unit are connected to terminals 4-6 of the Supply Unit. Base current for the transistor under test flows through a current meter, which must be connected to terminals "I", and through an appropriate resistor selected by switch $S14$. A low impedance source of constant voltage is available by means of the bleeder resistor R_{46}. This source is useful for applying a constant voltage to the base of the transistor, or the collector when G_m or β curves are desired.

In operation, the desired base current is selected by adjustment of the power supply, this current being read on the current meter. A single curve will then be displayed on the oscilloscope.

A family of output characteristics may be simultaneously displayed by using the base bias stepping arrangement shown schematically in the upper half of Fig. 8. Non-shorting, motor-driven switch S_{15} provides 10 consecutive steps of current. This switch is driven at 150 rpm by an 1800 rpm motor and 12:1 reducing pully arrangement. Each trace is thereby displayed for about 16 milliseconds corresponding to 1 cycle of the sweep frequency. The shaft of switch S_{15} is extended to the panel so that it may be positioned to any desired step manually. Switch S_{12} selects any one of four current ranges available. This switch is calibrated in microamperes per volt, i.e., the maximum available base current will be determined by the position of S_{12} times the voltage applied at terminals 1 and 3.

Oscilloscope

Any d-c oscilloscope having a horizontal and vertical deflection sensitivity of 30 millivolts per inch or better can be used with this equipment. A flat surface screen on the cathode ray tube used in the oscilloscope is very desirable to obtain linearity on the screen and to insure proper camera focus when taking photographs. For the direct viewing of a family of curves a tube with a long persistance (P7) screen is desirable but care must be taken with a phosphor of this type since it is extremely easy to burn the screen with a stationary spot such as might be present when changing transistors under test. For general use, a medium persistance (P4) screen on the tube is suitable. Photographs of families of curves are taken by using a multiple exposure technique when a P4 screen is used.

The particular oscilloscopes used with this equipment are an RCA type WO-56-A and a Tektronix type 504-D. A four position, four circuit, non-shorting switch is mounted directly on the RCA oscilloscope as is shown in Fig. 9. This switch allows the deflection plates to be connected such that the curves can be displayed in any desired quadrant. Fig. 10 is a circuit diagram of this switching arrangement. The RCA oscilloscope is used both as a monitor and a driver for the Tektronix oscilloscope. The deflection plates of both cathode ray tubes are connected in parallel. A camera can be mounted on the Tektronix instrument. An 8 by 8 cm graticule is placed in front of the oscilloscope screen. This particular size of graticule yields a full size picture when a Fairchild-Polariod Camera type F296 is used.

Sweep Source

The sweep source consists of three transformers built into a separate cabinet as pictured at left center in Fig. 2. Transformers for this purpose should have low capacitance between their windings and cores because this capacitance effectively shunts the current sampling resistor and may cause a loop to appear in the displayed trace. The specific transformers used with this equipment are described in Table I.

For evaluating pairs of output transistors an auxiliary sweep source is used. This unit is pictured at the upper left in Fig. 2 and it's circuit is given in Fig. 11.

D-C Power Supply

The d-c power supply used with this equipment is a Model Rectifier Corporation type SP-30-24. This unit will supply 0-30 volts and 24 amperes. With this power supply and bleeder resistor R_{46}, 3 volts and 4 amperes are available from the low impedance tap. Any comparable power supply would be suitable.

Applications

Characteristic Curves

Typical characteristic curves obtainable with this equipment are illustrated in Fig. 12. This photograph

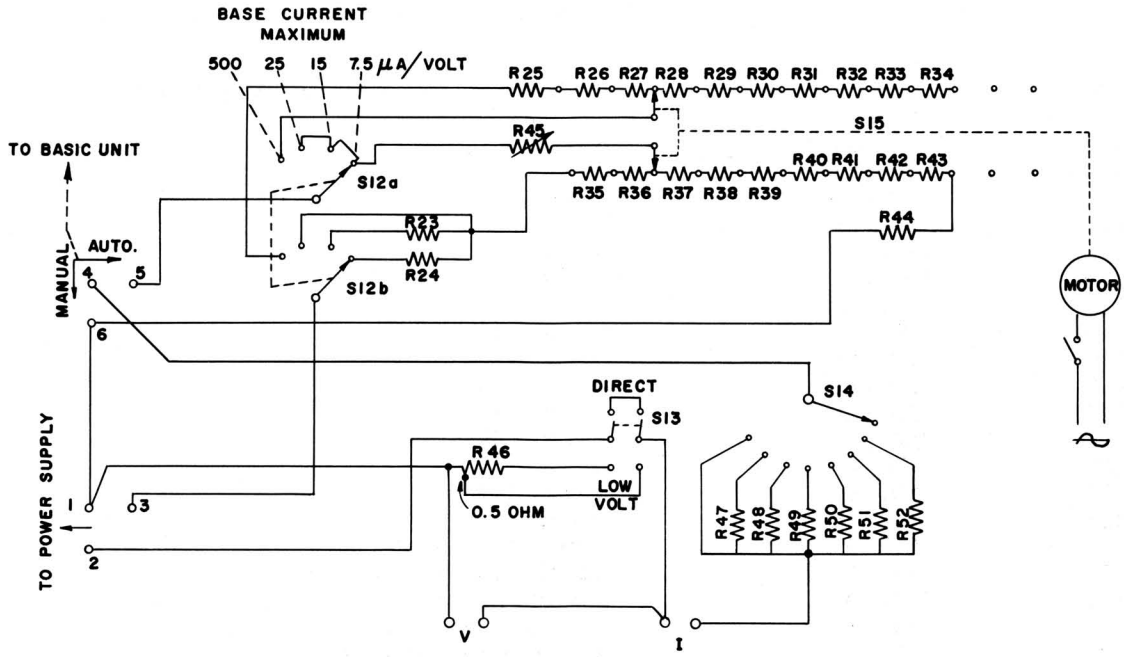

Fig. 8 – Schematic of Supply Unit.

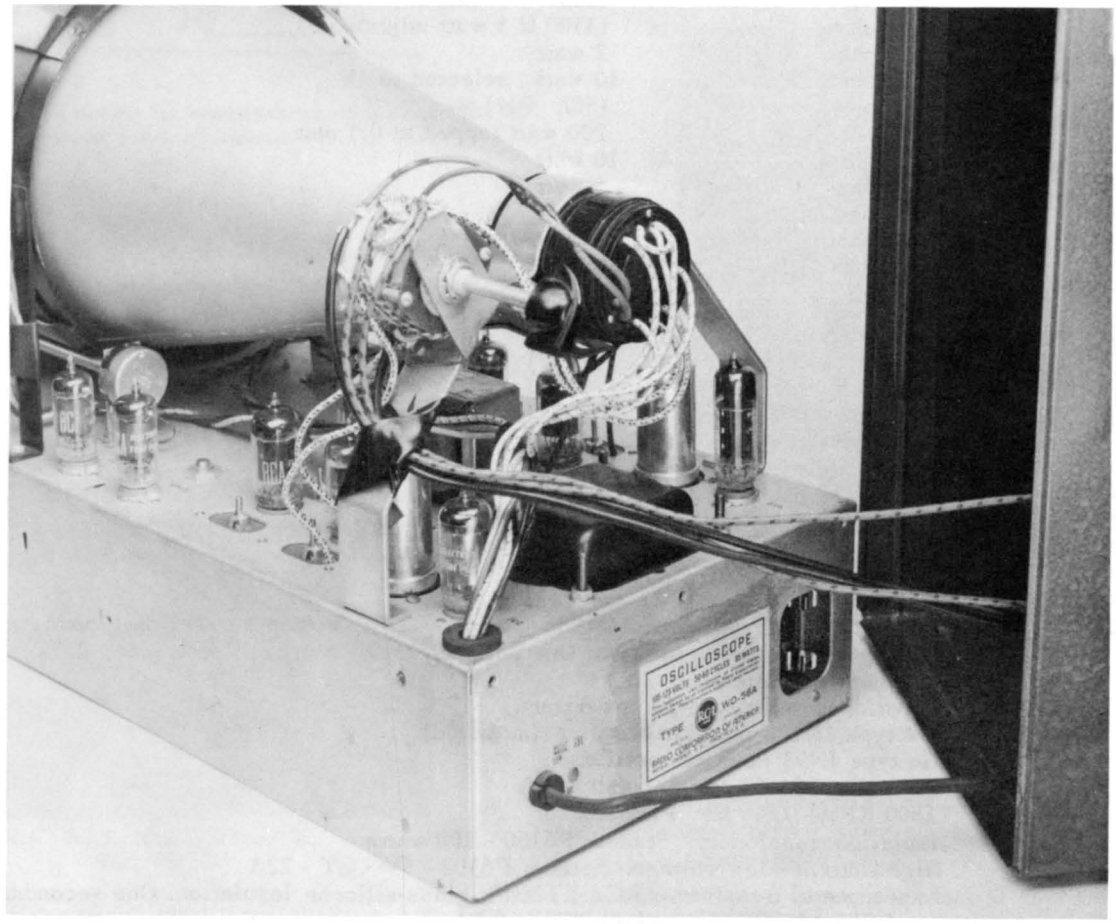

Fig. 9 – Quadrant switch mounted on RCA-WO-56-A oscilloscope.

TABLE I

R1 - R5	0.1 ohm	#18 Nichrone wire calibrated to less than 1%
R2 - R6	1.0 ohm	5 watt
R3 - R7	10 ohm	10 watt
R4 - R8	100 ohm	2 watt
R9	10 ohm	10 watt
R10	100 ohm	10 watt
R11	1000 ohm	10 watt
R12	3900 ohm	2 watt
R13	5600 ohm	2 watt
R14 - R15	50 ohm	1/2 watt 1%
R16	150 ohm	1 watt 1%
R17	250 ohm	1 watt 1%
R18	2000 ohm	1 watt 1%
R19	2500 ohm	1 watt 1%
R20	15K ohm	1 watt 1%
R21	10K ohm	1 watt 10%
R22	5K ohm	2 watt Pot.
R23	667 ohm	(750 Ω 20 watt adjustable)
R24	2333 ohm	(2500 Ω 20 watt adjustable)
R25	2000 ohm	40 watts
R26	222 ohm	(250 Ω 5 watt adjustable)
R27	278 ohm	(300 Ω 5 watt adjustable)
R28	357 ohm	(375 Ω 5 watt adjustable)
R29	476 ohm	(500 Ω 5 watt adjustable)
R30	667 ohm	(700 Ω 5 watt adjustable)
R31	1000 ohm	5 watt
R32	1667 ohm	(2000 Ω 5 watt adjustable)
R33	3333 ohm	(3500 Ω 5 watt adjustable)
R34	10K ohm	2 watt
R35 - R44	100 ohm	10 watt selected to 1%
R45	40K ohm	(50K Pot)
R46	5 ohm	200 watt tapped at 0.5 ohm
R47	10 ohm	10 watt
R48	100 ohm	5 watt
R49	1000 ohm	2 watt
R50	10K ohm	1 watt
R51	100K ohm	1/2 watt
R52	1Meg ohm	1/2 watt
S1	Mallory Switch	#3223J
S2	Mallory Switch	32112J
S3	Mallory Switch	3223J
S4	Mallory Switch	3222J
S5 - S6	Mallory Switch	3215J
S7 - S8	Mallory Switch	3223J
S9 - S10	Mallory Switch	32112J
S11	Switch Craft	#3037 Non-Locking - center position "OFF"
S12	Mallory Switch	3226J
S13	DPDT Toggle	
S14	Mallory Switch	32112J
S15	Daven Switch Type Special #4986 2 Pole - 12 Position per pole Non-shorting type - continuous rotation, One pole per deck - 2 decks. Deck size; 1.75 inches square	
VR	Superior electric type 10 powerstat	
D1 - D2	Ge type 1N158 junction rectifier (modified)	
D3 - D4	Ge type 1N93 junction rectifier	
BB	RCA VS 216 - 67 and 1/2 volt	
Motor	1800 RPM - 1/50 HP Phono motor	
T1	Isolation transformer: Stancor P6160 - 100 watts	
T2	High Current - low voltage: Stancor P6302 - 5V - CT - 22A	
T3 - T4	Experimental transformer RCA XT8648, glass-silicone insulation. One secondary 50V - 1A. One secondary 250V - 0.5A.	

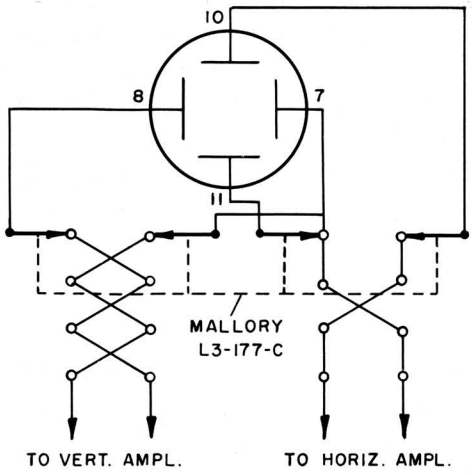

Fig. 10 – Schematic circuit diagram of quadrant switch.

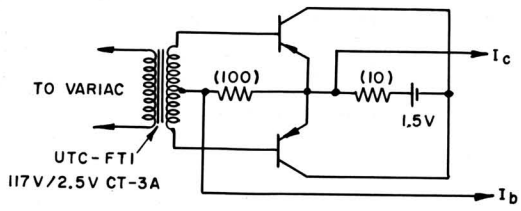

Fig. 11 – Simplified circuit for simultaneous display of "β" curves of a pair of transistors.

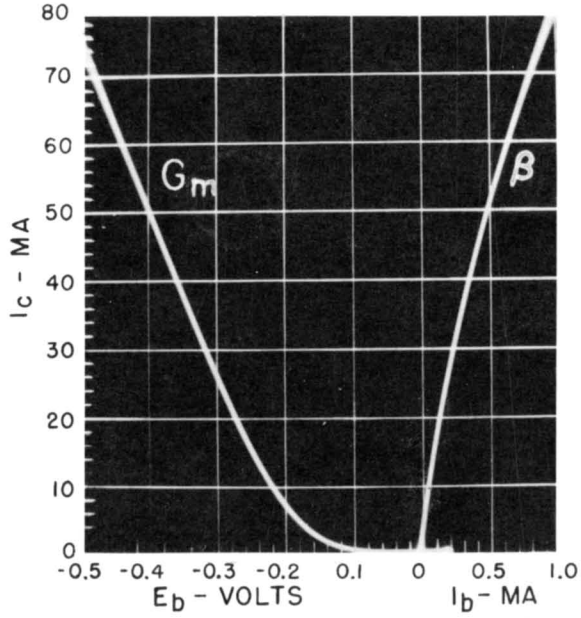

Fig. 12 – Forward transfer and current amplification characteristics (Exp: each trace 1/5 sec. F4).

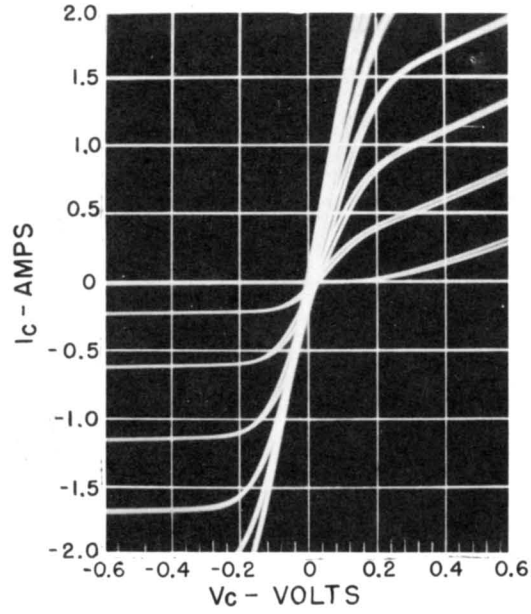

Fig. 13 – Output characteristic, A-C voltage applied to collector. Constant-base-voltage as parameter, $-E_b$ = 0, –0.5, –1.0, –1.5... 3.0 volts (Exp: each trace 1/5 sec. F4).

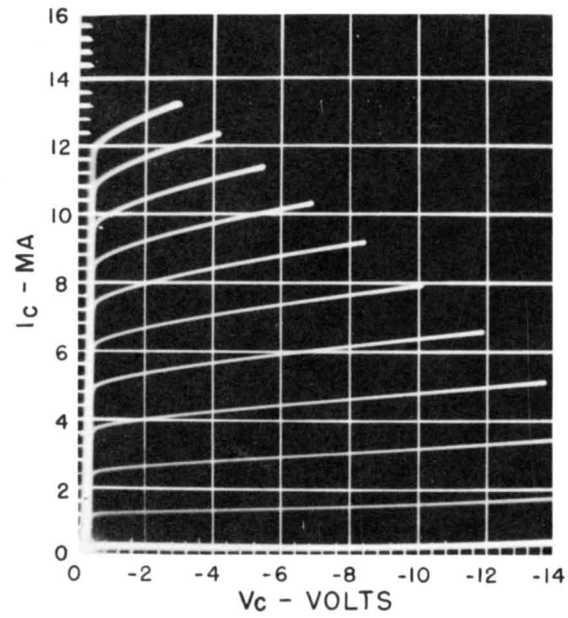

Fig. 14 – Family of output curves. Load 1000 ohms. Base current automatically stepped, 10 steps of 15 μamps each (Exp: 7 sec. F4).

shows both the current amplification and the forward transfer curves of the same transistor. The curves are displayed in the same quadrant for convenience. With these curves the d-c input resistance at any given collector or base current can be readily determined since $R_i = \beta/G_m$.

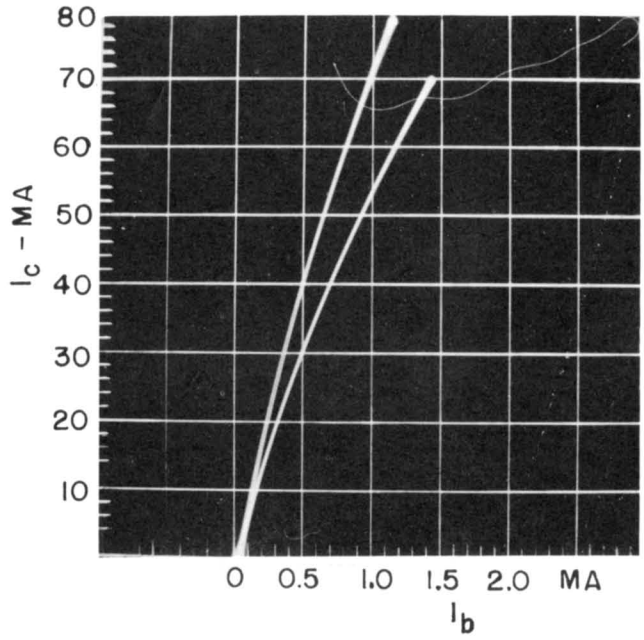

Fig. 15 – I_C versus I_b curves of a pair of output transistors.

Fig. 13 shows a family of output characteristics of a power transistor. All four quadrants are used in this case and the collector sweep is a full sine-wave. Constant base voltage is the adjusted parameter for this family of curves. This picture is an example of manual operation combined with multiple exposure. Exposure time for each trace was 1/5 second at F4, while for the graticule it was 4/5 second at F4.

The display of a family of output curves while using the automatic bias current stepping arrangement is illustrated by Fig. 14.

Evaluating Pairs of Output Transistors

The simultaneous display of the I_c versus I_b curves of a pair of transistors yields useful information as to the degree of their matching. For this application, the auxiliary sweep source is used. The circuit arrangement is illustrated by Fig. 11. The output terminals of this circuit are connected to the terminals labeled "Auxiliary Tracer" on the Basic Unit. The resistor values given in Fig. 11 are for collector currents of up to 500 ma. For larger currents, smaller resistors and higher voltages (not shown) are used. Fig. 15 is an example of the simultaneous display of the β curves of a pair of transistors. An unmatched pair of transistors was chosen intentionally to better illustrate the method.

Carlos F. Chong

Carlos F. Chong

Werner Hasenberg

Werner Hasenberg