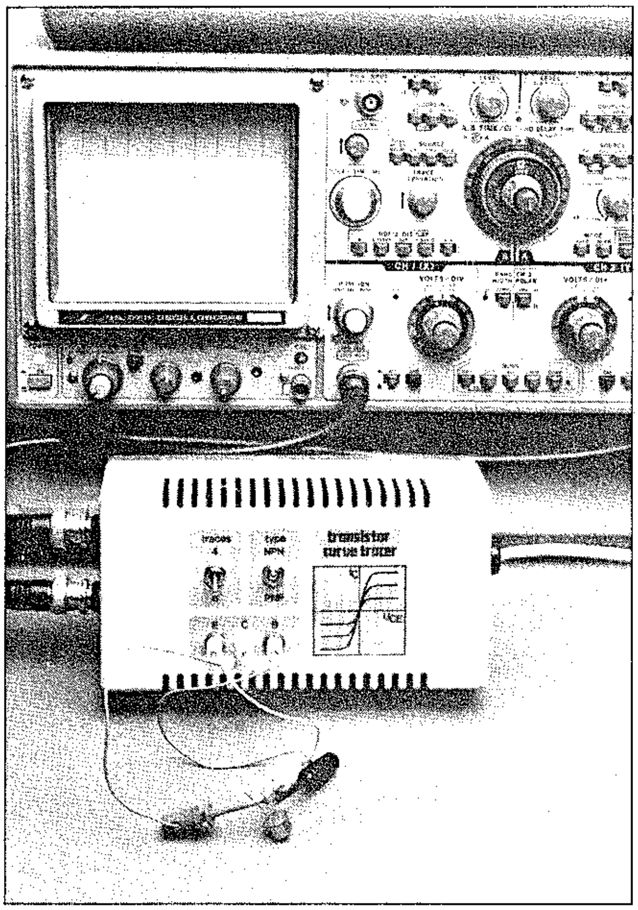
TRANSISTOR CURVE TRACER

T. Wigmore

With so many transistors used in today's equipment, a good tester for these devices is a must in every electronics workshop. And yet, most of us use a multimeter to check transistors. Although such a test is usually adequate for a quick o.k./faulty test, it fails to provide information on the characteristics of the device under test. The curve tracer presented here works in conjunction with an oscilloscope, and is capable of performing a stepped current amplification test on pnp as well as on npn transistors. The instrument so allows unknown or unmarked types to be matched to known ones, which is a frequent requirement in fault-finding and repair work.

The so-called output curve is among the most important transistor characteristics. The curve shows how the collector current (on the Y-axis) depends on the collector-emitter voltage (on the X-axis), with base current for the relevant bias setting as a parameter. By stepping up the base current within the permissible range, characteristic curves of different edge steepness are obtained on an oscilloscope or plotter. These curves indicate whether the transistor is good or faulty, and also allow its current amplification to be estimated. Furthermore, a useful indication is provided of the linearity and the resistance characteristic in the saturation range. Finally, since the tester can handle both npn and pnp transistors, the curves allow matching, complementary devices to be selected from available batches.



Digital and analogue

Two quite different test signals are required to write the output characteristic of a transistor: the base current must be switched in steps, while the collector voltage must have a continuous range of 0 V to the maximum value. Not surprisingly, therefore, the base current is controlled digitally, and the collector voltage by an analogue circuit. The latter also has a controlling function on the base current generator to prevent this stepping up or down while a curve is being written.

The collector voltage is supplied by a triangular generator consisting of a Schmitt-trigger and an integrator (see Fig. 1). The Schmitt-trigger is composed of a 1.45-times amplifier and a comparator. The amplifier supplies the reference level for the comparator. To ensure the required thresholds and hysteresis, the reference level, in turn, depends on the output level of the Schmitt-trigger. Diodes between the amplifier and the comparator allow the two switching thresholds of the Schmitt-trigger to be set to 0 V and 8 V, or 0 V and −8 V, as required for npn or pnp transistors respectively. The combination of the Schmitt-trigger and the integrator results in a triangular-wave generator whose output voltage varies between 0 V and 8 V, or 0 V and −8 V. This signal is used as the collector-emitter voltage for the transistor under test.

The triangular signal is fairly simple to convert into a rectangular one, which is used to clock the digital part of the circuit. As the collector-emitter voltage starts to rise (from 0 V with npn transistors, and from −8 V with pnp types), a counter, and with it the base current, is incremented by one step. The counter drives a discrete digital-to-analogue (D-A) converter that translates the 3-bit counter value into base current steps of 25 µA. Switch S_2 allows the D-A converter to be driven by two instead of three bits to select between four or eight displayed characteristic curves.

Although in theory not quite correct for the relevant test on the transistor, an emitter resistor is used to translate current into voltage. This arrangement was preferred over a collector resistor because most oscilloscope inputs have one grounded terminal.

Finally, a current limiter has been added on the integrator output stage to eliminate the risk of the test circuit being overloaded by a faulty transistor.

Detailed operation

The power supply — see the circuit diagram of Fig. 2 — inclusive of the mains transformer is accommodated on the printed-circuit board. The secondary transformer voltage is rectified to give a symmetrical direct voltage. Under no-load conditions, there is about 14 V on C_2 and C_3. Since single-phase rectification is used, the supply voltage has a relatively high ripple, and falls a few volts when a good transistor with high current amplification is being tested. Under this condi-

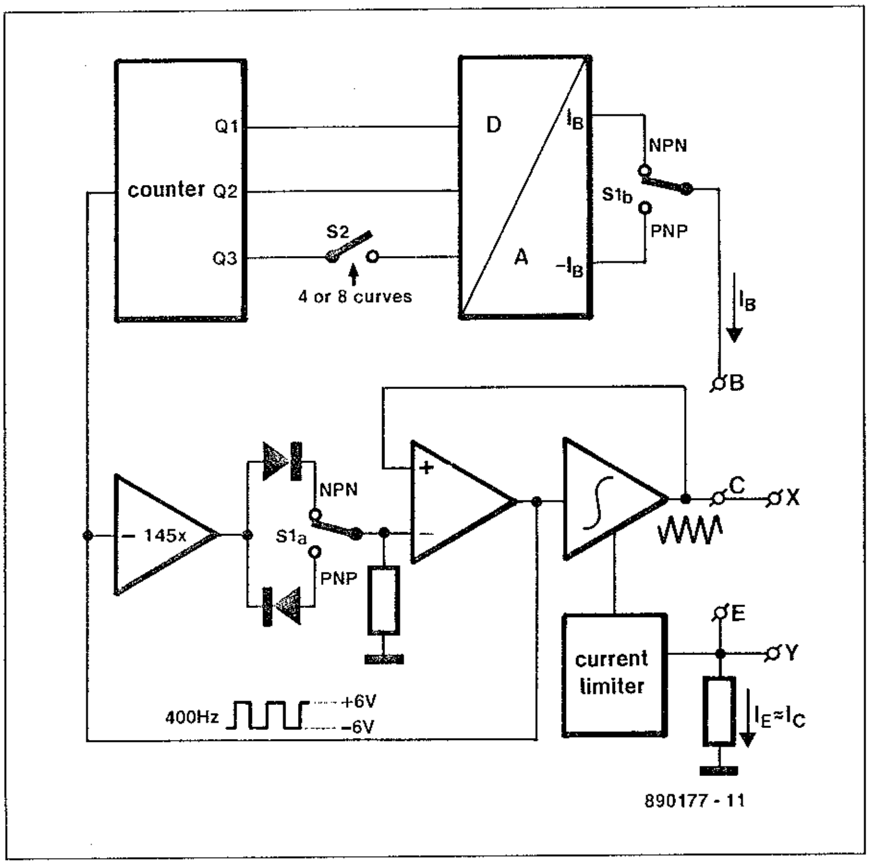


Fig. 1. Block diagram of the transistor curve tracer.

counter state	4 curves		8 curves	
	pnp	npn	pnp	npn
000	−75	0	−175	0
001	−50	25	−150	25
010	−25	50	−125	50
011	0	75	−100	75
100	−75	0	−75	100
101	−50	25	−50	125
110	−25	50	−25	150
111	0	75	0	175
	base current I_B (μA)			

Table 1. Digital current control

tion, the transformer's secondary voltage will also drop to its nominal (loaded secondary) value. The unregulated supply voltage is used to power the analogue part of the circuit. This voltage is too high to power counter IC1. Also, the supply voltage of the counter must be regulated because it determines the base current for the transistor under test. Zener diodes are, therefore, used to stabilize the IC supply voltage at ±5.6 V. The symmetrical supply enables the counter outputs to switch between positive and negative voltages relative to ground, corresponding to a logic 1 and a logic 0 respectively. These

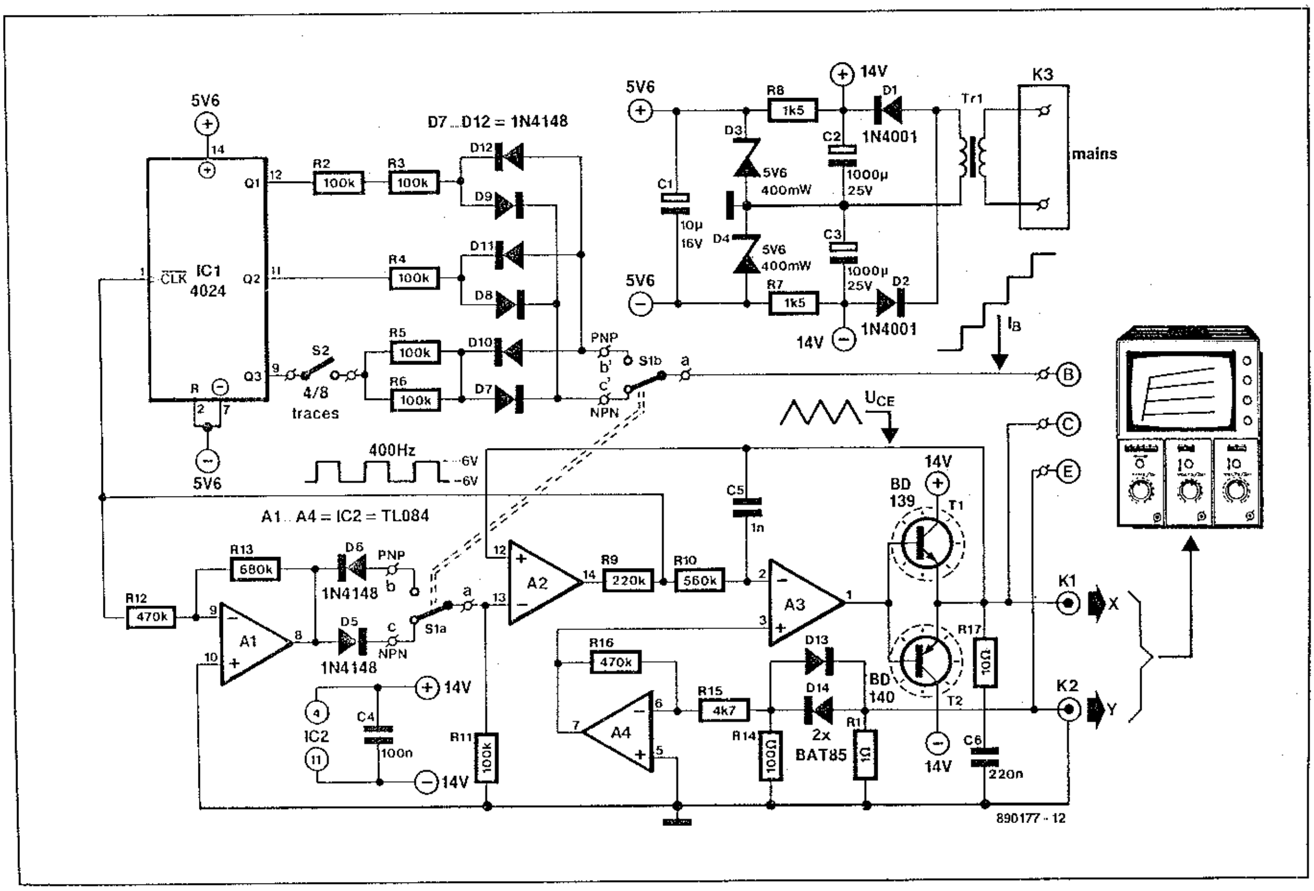


Fig. 2. Circuit diagram of the curve tracer, which is a combination of analogue and digital electronics.

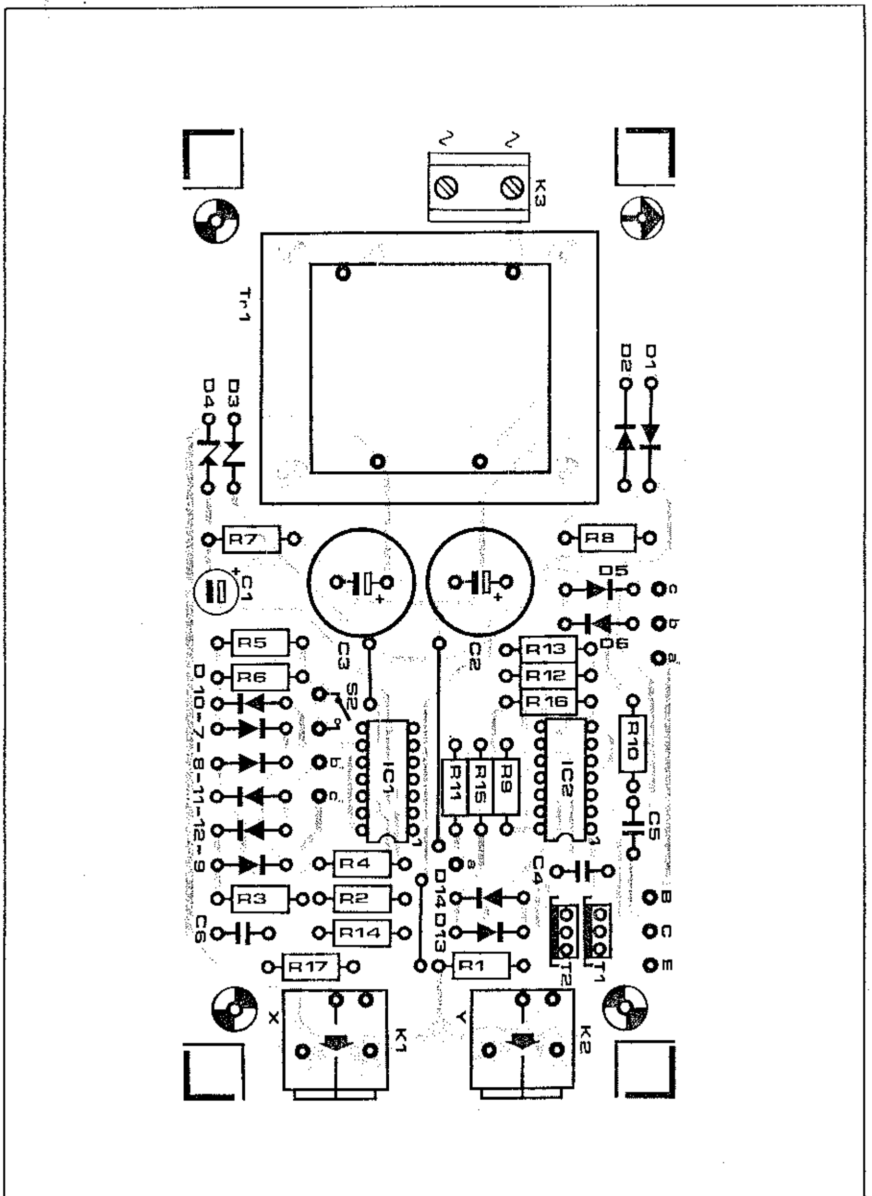


Fig. 3. Component mounting plan of the single-sided printed-circuit board for the transistor curve tracer.

Parts list

Resistors:
R_1 = 1Ω0
R_2 – R_6;R_{11} = 100k
R_7;R_8 = 1k5
R_9 = 220k
R_{10} = 560k
R_{12};R_{16} = 470k
R_{13} = 680k
R_{14} = 100Ω
R_{15} = 4k7
R_{17} = 10Ω

Capacitors:
C_1 = 10μ; 16 V; radial
C_2;C_3 = 1000μ; 25 V; radial
C_4 = 100n
C_5 = 1n0
C_6 = 220n

Semiconductors:
D_1;D_2 = 1N4001
D_3;D_4= zener diode 5V6; 400 mW
D_5 – D_{12} = 1N4148
D_{13};D_{14} = BAT85
T_1 = BD139
T_2 = BD140
IC_1 = 4024
IC_2 = TL084

Miscellaneous:
S_1 = miniature double-pole toggle (DPDT) switch
S_2 = miniature on/off (SPST) switch
Tr_1 = PCB mount transformer 9 V @ 7.5VA
K_1;K_2 = BNC socket (e.g. PCB-mount type UG-1094/UP from Monacor).
K_3 = 2-way screw terminal block, pitch 10 mm
Heat-sinks for T_1 and T_2
Enclosure 150×80×50 mm, e.g. Bopla type E440VL.
PCB Type 890177 (see Readers Services page)

levels enable the D-A converter to be kept simple but still capable of generating the required positive and negative base currents.

The D-A converter consists of resistors R_2–R_6 and diodes D_7–D_{12}. The latter parts separate the positive and negative half periods of the currents that may be carried by the resistors. The value and direction (sign) of the currents depend on the counter value, and the positions of S_1 and S_2, which are in accordance with the transistor type. Table 1 summarizes all conditions that apply when a transistor is connected for testing.

The analogue part of the circuit closely follows the block diagram. What is not so apparent, however, is how the operation of the analogue circuit remains largely unaffected by the unregulated supply voltage. For opamp A_1, this is relatively easy to understand because the output voltage of this amplifier simply follows the input voltage with practically no effect of the supply voltage. This is not so with comparator A_2, since here the input voltage determines how the output voltage shifts as far as possible towards one of the supply voltages, which are subject to considerable variation. Clearly, if a fluctuating input voltage were applied to the integrator around A_3, the circuit would be incapable of generating a well-defined triangular output voltage. Note that this, in principle, need not be a problem: the only requirement is that the output voltage swings between two extremes.

The comparator, however, serves to clock the counter, which has a lower supply voltage. Clamping diodes are connected to the clock input of the counter as a protection against too high voltages. Together with current limiter R_9, the diodes ensure a stable rectangular voltage of about 6 V_{pp} at the input of the counter and, therefore, at the input of the integrator. The result of the clamping and regulation circuit is a triangular output voltage whose rate of rise is practically independent of the supply voltage.

The stabilized rectangular voltage also enables A_1 to supply a reference level for comparator A_2 that is hardly affected by the supply voltage. Hence the inflection points of the triangular voltage occur at accurately defined and stable voltage levels.

In order to be able to test medium- and high-power transistors also, the integrator opamp is followed by two transistors that are protected against short-circuits by the circuit around D_{13}, D_{14} and A_4. The two Schottky diodes type BAT85 have a threshold voltage of about 0.4 V. They conduct when the voltage on R_1 (I_c>400 mA) exceeds the threshold, and cause A_4 to shift the voltage at the + input of integrator A_3 to a level where the integration operation stops. The + input is

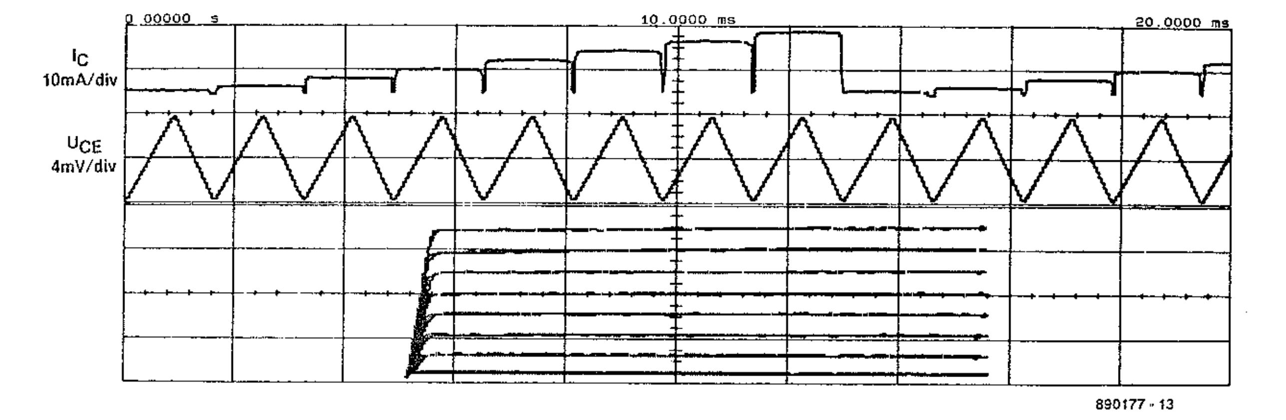


Fig. 4. Screendump provided by a Hewlett-Packard digital oscilloscope to illustrate the operation of the transistor curve tracer.

normally at 0 V. When actuated, the protection circuit causes the oscilloscope to show only a fixed bright spot instead of four or eight traces.

Building the tracer

The complete circuit is accommodated on the printed-circuit board shown in Fig. 3. Populating the board is straightforward and should not cause any difficulty.

The enclosure stated in the parts list requires the four squares at the corners of the PCB to be cut off. Great attention should be paid to safety as the mains voltage is applied direct to the board via a 2-way screw terminal block.

Although the board is designed to accommodate PCB-mount BNC sockets, standard types may also be used with short lengths of screened wire. Connect switch S_1 to terminals a, b, c, a', b' and c', which are at different locations on the board. Be sure not to mix up points a and a'.

Use short, flexible wires terminated in small crocodile clips to connect the transistor to the tester. Do not make these flying leads longer than about 10 cm on penalty of creating stray capacitance that may affect the test results.

Finally, insert a small rubber cabinet foot between the facing metal tabs of T_1 and T_2 to eliminate any risk of a short-circuit.

Using the curve tracer

Before discussing the practical use of the transistor curve tracer, it is worth while to have a look at Fig. 4. This shows the printout on paper (screendump) obtained with a Hewlett-Packard digital oscilloscope and associated plotter. The signals on the upper two traces, I_c and U_{ce}, are combined with the aid of the *X-Y* mode of the oscilloscope. The resulting graphs form the output characteristics of the transistor under test. It should be noted that each graph is written two times: first with U_{ce} rising, and then with U_{ce} falling. This results in the 'chopped' upper I_c curve. The output characteristics were obtained with a transistor Type BC141-10.

Connect the curve tracer to the oscilloscope via two short coax cables. Initially, set the scope to *X-Y* mode, 10 mV/div on the *Y* channel, and 1 V/div on the *X* channel. Since the collector current is measured via a 1 Ω resistor, the *Y*-axis indicates the voltage in volts and the current in ampères, obviating calculations. For pnp transistors, the characteristic must be inverted. This is achieved with the INVERT control provided on most oscilloscopes.

The photographs of Fig. 5 show a few transistor characteristics obtained with the curve tracer. Figure 5a shows the characteristic of a BC547A. By comparison, a BC547B (Fig. 5b) has a higher current amplification, but a quite different rate of rise of the top three curves. The curves in Fig. 5c belong to a BC550, and are even straighter than those in Fig. 5b, indicating better linearity than the previous two transistors. In addition, the BC550 has very little noise, which makes it eminent for application as and audio preamplifier.

Care should be taken when testing a high current gain transistor such as the BC550C (Fig. 5d). The current amplification is so high that there exists a real danger of the maximum permissible collector current or dissipation being exceeded (note that three of the eight curves run off the oscilloscope screen). If necessary, use S_2 to reduce the number of curves from eight to four. This setting also reduces the maximum base current from 175 μA to a safer 75 μA.

The curve tracer is also fine for selecting a replacement type for an unknown transistor that has been found to be faulty. Fortunately, much consumer equipment has a number of identical transistors. Remove one with the same type number as the faulty transistor, and connect it to the curve tracer. The resulting characteristic on the scope will, in many cases, enable you to find a near equivalent transistor of known type and make from an available lot.

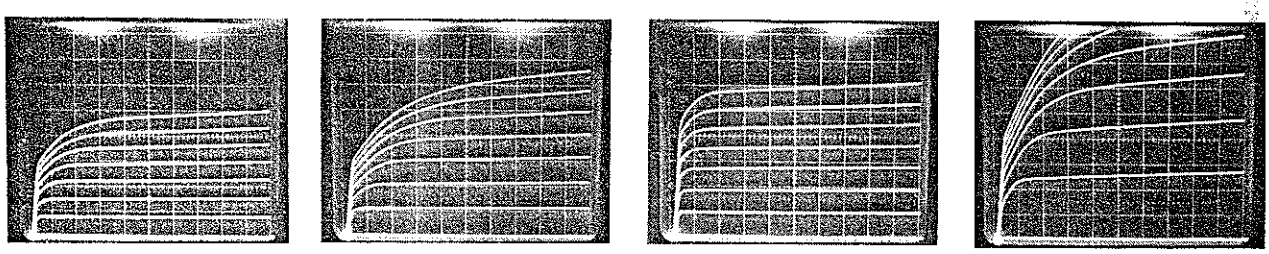


Fig. 5. Examples of curves obtained with some commonly used transistors. From the left to the right: BC547A, BC547B, BC550, BC550C.