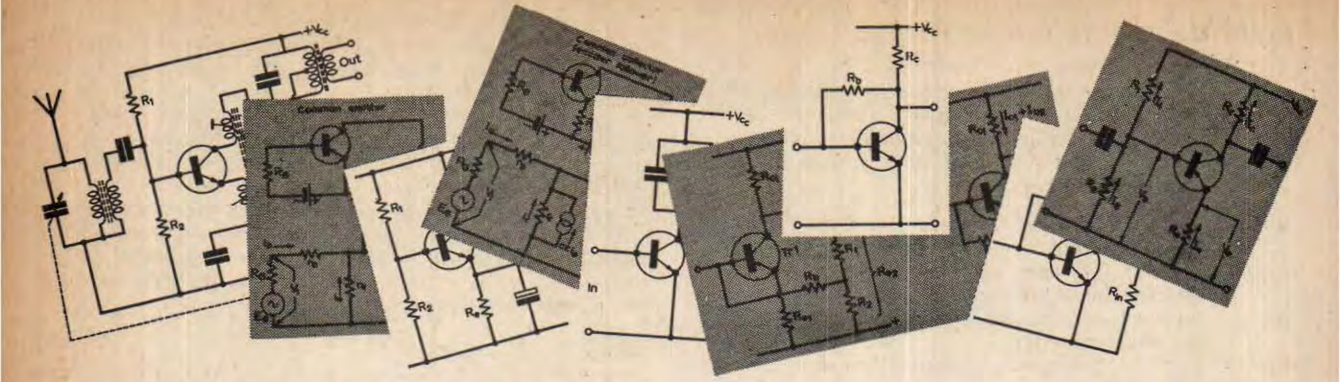

TRANSISTOR CIRCUITRY for beginners

PART 3

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Circuits and Parameters

That ugly word 'parameters' frightens many newcomers—and really, it need not, for it is only the guideline along which we can walk as we follow the curious path of transistor development. There have to be some hard-and-fast rules, and these are the parameters.

Transistors can be of p.n.p. or n.p.n configuration, the essential difference, in practice, being polarity of the supply voltage. The three basic modes are common-base, common emitter and common-collector. The last is more conveniently referred to as emitter follower, for reasons we shall explain. Some of our circuits show p.n.p. transistors, some n.p.n.—we must get it into our heads at the outset that the essential difference is polarity, and this makes it easy to combine the two types in one circuit.

The common-base circuit is a good introduction to transistor technology. Here, a small change in emitter current brings about a small change in collector current. The ratio between the two is the current transfer ratio, alpha (α).

In symbolic form: $\alpha = \dfrac{\delta I_C}{\delta I_E}$

where delta (δ) denotes change, in this case, increase. In some formulae, the symbol $\triangle$ may be used instead of δ.

Figures for alpha are very near, but not quite, unity. For a germanium device, typically 0·98.

Take Fig. 9, a proving circuit to demonstrate the above formula. Here we have a common-base transistor connected so that the emitter current flows, around 0·5mA. Voltage V_E establishes this. The emitter junction for an average transistor will be around 100 ohms. The collector current, I_C, flowing through the load R_L, will be slightly lower than the emitter current. Between base and emitter—the base being earthed, or common, a 1·5 volt battery biases the emitter positively.

The input voltage, V_{IN}, depends on the setting of the variable resistance, R_{IN}, which has a further 1·5 volt battery across it, again biasing the emitter positively. The proportion of voltage across the base/emitter junction aided by the position of R_{IN} in series with V_E represents the increase δI_E.

The emitter junction resistance of a typical small signal transistor is about 100 ohms, and let us suppose that the load resistor is 10000 ohms. Thus the change at the input is $10\mu A$ through a resistance of 100 ohms, but the change at the output is $9{\cdot}8\mu A$ through a resistor of 10000 ohms. The result, from Ohm's Law, is a voltage change across R_L of 98mV for a change in voltage at the input of 1mV. This gives us a voltage gain of 98 times in spite of a slight loss of current flowing out through the base contact.

Fig. 9: The common-base circuit arranged to demonstrate change in emitter current causing change in collector current.

With the more frequently used common-emitter circuit, the current transfer ratio is the ratio of current change at the base to current change at the collector, and is designated β (beta) (or sometimes α'). These parameters, β and α, are mathematically related, the relationships, for those wishing to look further into this being:

$$\beta = \frac{\alpha}{(1-\alpha)} \text{ and } \alpha = \frac{\beta}{(1+\beta)}$$

The figures quoted by manufacturers are for small-signal operation unless otherwise stated.

Another commonly seen transistor parameter is the transition frequency, designated f_T. This is the frequency at which the common-emitter current gain falls to unity, and gives an indication of the frequency limits of the transistor.

Hybrid Parameters

Hybrid parameters are widely used in the semiconductor industry to specify transistor characteristics. They are a set of resistance, admittance and voltage and current ratios for given conditions (hence the term hybrid). In the case of the common-emitter circuit these h parameters are:

h_{ie}:— input resistance, common emitter, output short-circuited.
h_{re}:— reverse voltage feedback ratio, common emitter, input open circuit.
h_{fe}:— forward current gain, common emitter, output short-circuited.
h_{oe}:— output admittance, common emitter, input open circuit.

If one group of parameters is known, for one circuit configuration, it is possible to work out the others. In practice, however, such information is more useful to the designer than to the engineer or constructor, who chooses replacement transistors on more empirical lines than a comparison of detailed parameters.

Characteristics of Basic Configurations

Approximate characteristics of the three basic circuit configurations are summarised in Table 1. These must be taken as a guide only, not as accurate conditions for a particular transistor. The table indicates the orders of magnitude of the main parameters with the three configurations: actual figures will of course vary considerably with different types of transistor.

TABLE 1 Features of Circuit Configurations for Comparison

Characteristic	Common Base	Common Emitter	Common Collector
Input to	Emitter	Base	Base
Output from	Collector	Collector	Emitter
Current Gain	Less than unity	About 50	About 50
Voltage Gain	High (approx. 250)	High (approx. 250)	Low (approx. 1)
Input Impedance	Low (200Ω)	Medium (1000Ω)	High (100kΩ)
Output Impedance	High (200kΩ)	Medium (40kΩ)	Low (1000Ω)
Power Gain	Medium (30dB)	High (40dB)	Low (16dB)
H.F. Response (Power ... 3dB down)	High (400kHz)	Low (12kHz)	Dependent on source and load resistances
Phase Shift	0°—Output and input in phase	180° (inverse)	0° (in phase)

It will be noted that the details given in Table 1 include power gain and phase shift, the latter stated to show the effect of the different configurations on the polarity of the signal. This last factor is too often overlooked when experiments are made. Another important factor, not given in the table, but necessary for the designer, is the comparison of collector leakage current with the three configurations: except in the common base configuration, this is dependent on the resistance in the base circuit.

Output Characteristics

As can be seen from the output characteristic set of curves of Fig. 10, circuit configuration makes quite a difference to collector voltage and current relationships (compare these characteristics with the basic pn junction characteristic shown in Fig. 6, Part 1). When considering the choice of a replacement transistor or working out a design it is necessary to take a set of output characteristics, i.e., a family of curves for different base currents—and plot a **load line** as shown in Fig. 11. It can be seen that with a common emitter circuit when the base current is zero the voltage between emitter and collector is almost the full supply volts, i.e. collector current is very small. (It is actually the reverse leakage current of the collector junction.)

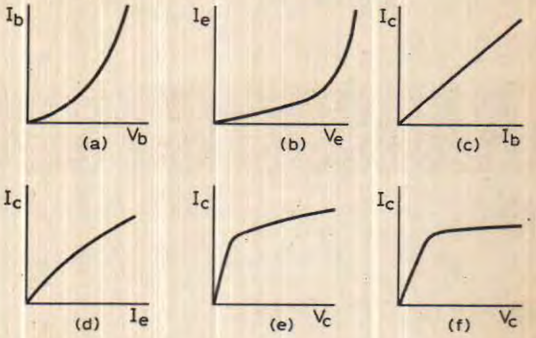

Fig. 10: Typical characteristics showing how circuit configuration drastically alters collector voltage and current relationships.

Increasing base current causes an increase of collector current; the voltage across the load resistance increases and the voltage across the transistor decreases. Eventually, as the base current is increased to a state when the collector current causes a voltage across the load almost equal to the supply voltage, the voltage across the transistor drops to practically zero. Any increase of base current beyond this point gives no further increase in collector current—the transistor is saturated. This, for a transistor of given characteristics, is at point B in Fig. 11. The load line, drawn through points X to Y passes through this point B. Point X is the maximum supply voltage and point Y the current resulting from dividing the supply voltage by the load resistance. In the example, a supply voltage of 12 volts and a load resistor of 6000 ohms gives a collector current at Y of 2 mA.

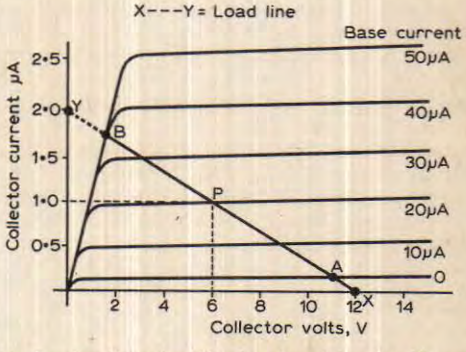

Fig. 11: Constructing a load line for a transistor gives its case history for design purposes.

From this load line, the transistor operating point can be chosen by adjusting the base current to a value between the two extremes of A and B. The best choice is midway along the load line, i.e. at P, where collector current is 1mA and collector volts 6. Since the current gain of our example is 50, the base current must be adjusted for $20\mu A$. This will allow an input signal for linear amplification to produce a base current variation of $\pm 20\mu A$, giving a collector current variation of almost $\pm 1mA$ between saturation and cut-off (at upper and lower ends of the curve respectively).

Correct choice of operating point is important; input and output impedances of a common emitter amplifier stage vary with collector current and so performance depends on the value of the d.c. collector current.

Bias Stabilisation

To set the operating point, a simple method is to arrange that a d.c. base current flows which (when multiplied by the current gain of the particular transistor) gives the required value of collector current. A resistor from the negative supply to the base provides this, but is not really effective, because of collector leakage current and variation with temperature change. For stable operation, bias stabilisation is required, and the two circuits of Fig. 12 are methods of ensuring this.

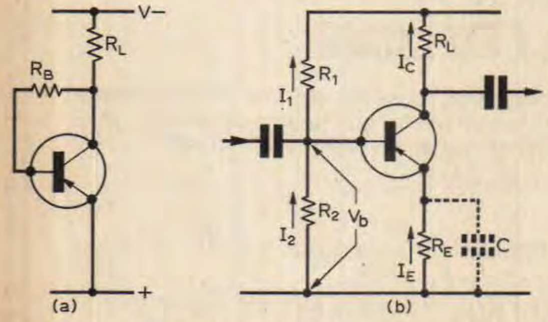

Fig. 12(a): Base bias current feedback and (b) voltage bias.

In Fig. 12(a) a resistor R_B is coupled back from collector to base so that if the collector current increases, collector voltage falls and this fall is reflected back to base via R_B, reducing base current. This tends to reduce collector current and oppose the change. However, this method does not allow control with zero base current and slight variations between transistors do not allow replacements to be made without reconsideration of the value of R_B. A further point is that a.c. negative feedback is introduced by this method, and this may not be wanted. Splitting the bias resistor and bypassing the centre point to chassis with a suitable capacitor can reduce this feedback.

A better method is shown in Fig. 12(b). The bias voltage V_b applied to the base is obtained from a potentiometer R1 and R2 across the supply. A further resistor R_E is put in the emitter circuit. The voltage across R_E is equal to V_b less the voltage dropped across the emitter-base junction of the transistor. If V_b is made large with respect to this junction voltage, the emitter current will depend only on V_b and R_E. Thus if V_b is held constant, I_E and therefore I_C will be independent of temperature and transistor gain.

A comparatively low value of R2 will not cause a significant change in V_b. Actual values can be seen in later circuits, and it will be noted that R1 is four or five times the value of R2. R_E depends on the transistor to be employed, and it will usually be bypassed by a large value capacitor (C, shown dotted) to avoid loss of gain with an a.c. signal.

Practical Circuits

Two low frequency amplifier circuits using this method of base bias stabilisation are depicted in Fig. 13. In the first, transformer coupling is used between stages, and in the second RC coupling is employed (note the polarity of the electrolytic coupling capacitors: in p.n.p. transistor circuits the succeeding base will generally be positive with respect to the preceding collector). Because a more precise impedance match between stages can be made with a transformer, and thus the greatest energy transfer effected, this type of coupling is widely used.

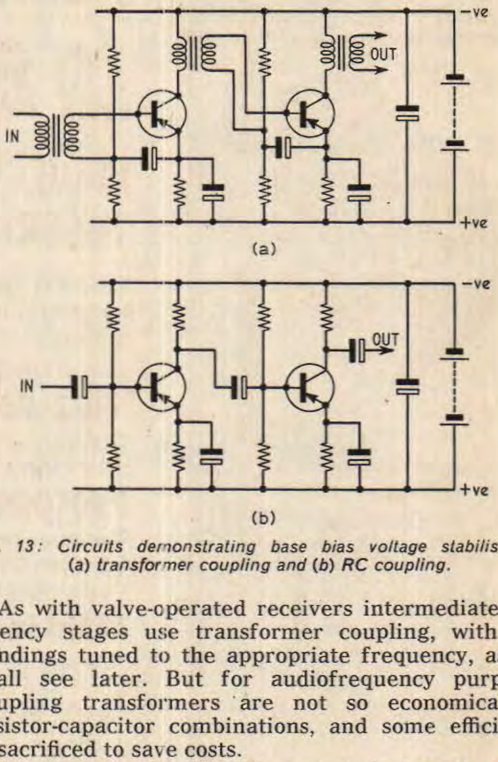

Fig. 13: Circuits demonstrating base bias voltage stabilisation, (a) transformer coupling and (b) RC coupling.

As with valve-operated receivers intermediate frequency stages use transformer coupling, with the windings tuned to the appropriate frequency, as we shall see later. But for audiofrequency purposes coupling transformers are not so economical as resistor-capacitor combinations, and some efficiency is sacrificed to save costs.

Having laid the ground and, it is hoped, taken some of the fearsomeness from formulae, we shall proceed to a breakdown of some of the circuitry likely to be met in radio and audio gear, with a few notes on constructing both the simple circuits themselves in practical form and test devices that can help us handle transistors with more confidence.

TO BE CONTINUED

We regret that, due to shortage of space, several regular features have had to be held over. These will be resumed as soon as possible.