10.8.5.2 Transistors

With transistors, we need to distinguish between two crystal types (Ge, Si) and two types of doping (PNP, NPN). Strongly simplified, the main differences♣ are: NPN-transistors require (in common-emitter configuration) a positive operating voltage, and PNP-transistors require a negative one. The typical base-emitter-voltage is 0.1 V for a Ge-transistor and 0.6 V for a Si-transistor. There is a vast multitude of the most different transistors – and among them a surprising number of compatible equivalents. PNP vs. NPN is, however, incompatible, as is Ge vs. Si, even though there may be instances where the latter swap will work. An OC44 may be exchanged for an AC151 without any problem, but an AC187 is incompatible with an AC188. For not too old specimen of Europe-built transistors, the first letter in the designation specifies the crystal-type: A for Germanium, B for Silicon. The second letter stands for the recommended usage: C for audio frequency preamplifiers, D for audio frequency power amps, F for RF-amplifiers, S for switching stages. The American (2N) and Japanese (2S) designations do not allow for such a distinction.

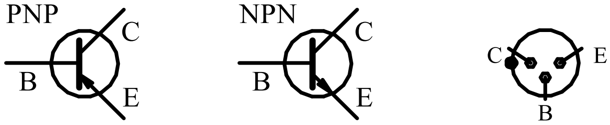

Fig. 10.8.28: Transistor-schematics, connections.

Fig. 10.8.28 shows the circuit diagram for transistors, and the connector-pin assignment (seen from below). Not all transistors have this assignment – in case of doubt the data sheets of the manufacturers help. For an **NPN-transistor**, the current flows into the base, out of the emitter and into the collector (the technical direction of the current-flow), and for the **PNP-transistor** out of the base, into the emitter and out of the collector. The usual collector-current values in distortion devices are smaller than 1 mA; the base current is about 1% of the collector current. The quotient of collector current and base current, i.e. the **current gain** B, is strongly dependent on the manufacturing process and the temperature. For commonly used transistors, B is about 40 … 300. It is therefore possible that the behavior of a circuit changes if one transistor is swapped for another (of the same type!).

In the idle state (i.e. without input signal) the collector current is about 0.1…1 mA. This of course depends on the specific circuit – as example we assume it to be 0,2 mA. For $B = 100$ the base current will amount to 2 µA. The input, i.e. the “gate” between base and emitter, is best described as a diode operated in the forward-direction – a Si-diode for the Si-Transistor, and a Ge-diode for the Ge-transistor. A forward-current of 2 µA yields a forward-voltage of about 0.1 V for the Ge-diode and of about 0.5 V for the Si-diode. Again, this is a first point of reference – depending on the manufacturing process these values may vary. If the base-voltage for an NPN-Transistor is more than 1 V larger than the emitter-voltage, that transistor is shot. If U_{BE} is negative for an NPN-transistor, the transistor will be in blocking mode, and the collector-current will be approximately zero. The same correspondingly holds for a PNP-transistor and negative base-emitter-voltages. The collector-current will, however, not be exactly zero since a **reverse current** will still flow – in Ge-transistors this can reach sizeable values. For example, the Siemens data-book specifies a reverse current of max. 200 µA for the AC188 (for the emitter-diode in blocked state) – corresponding to the current in the operating point for the above example! In addition, the reverse current has the unpleasant characteristic of exponentially growing with increasing temperature. All this has created in particular for Ge-transistors the image that they are solitary, hard-to-handle lone wolves.

♣ For practice-oriented details see e.g. Tietze/Schenk: Electronic Circuits – Handbook for Design and Application; Springer.

In **Fig. 10.8.29** a PNP-transistor is operated in common-emitter configuration, i.e. with the emitter connected to ground. If the transistor is in blocking mode, there will be (almost) no collector current and the collector voltage will be -9 V (left picture). If the transistor is fully on, there will be only a small voltage left at the collector of e.g. -0.2 V. As a first approach, an operating point in the middle of the characteristic curve would be selected; the collector voltage would be set to -4.6 V. From this, we obtain a voltage across the collector resistor of 4.4 V resulting in a collector current of -0.44 mA for a resistance of 10 kΩ♣. The base voltage would be -0.1 mV in this example.

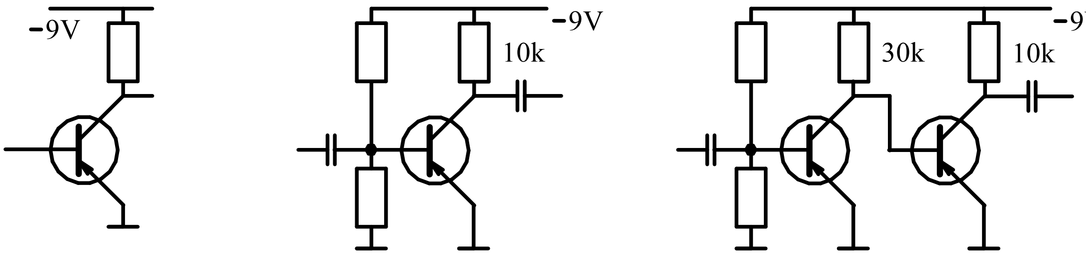

Fig. 10.8.29: Transistor in common-emitter circuit.

Both base and collector are not at 0 V without signal input, and a coupling capacitor each is necessary for connection to the dc-free outside world. The base voltage required for the operating point is set via the voltage divider at the base (middle picture). This circuit would not support a stable operation, however, even if the operating point would be set individually for each transistor specimen. With just a few degrees of temperature drift, the operating point would shift, and the sound would change. The means of choice countering thermal drift is **negative** (i.e. inverse-phase) **feedback**. This is implemented either via an emitter-resistor (increasing the input impedance), or via a resistor from the output back to the base (lowering the input impedance), or via other measures too extensive to be covered in the present context [see e.g. Fliege]. The following pages will show examples of transistor-circuits employing negative feedback – see e.g. chapter 10.8.5.3. Only with purposeful negative feedback, multistage amplifiers such as the one in the above right-hand picture can be put together. In the version shown, the first transistor would have to operate with too small a collector voltage: since the base voltage of the second transistor can not grow above about 0.2 V, the collector voltage of the first transistor is subject to the same limitation. This is why a resistor (of e.g. 1 kΩ) is introduced into the emitter branch of the second transistor; this resistor increases the input impedance and the input voltage.

Negative feedback decreases the gain but also stabilizes it, i.e. it becomes less sensitive to fluctuations in temperature or due to manufacture. Circuits that need not operate down to a frequency of 0 Hz allow for a separation of AC- and DC-negative-feedback. A strong negative feedback for DC will stabilize the operating point, while at the same time a weaker negative feedback for AC will ensure that the gain does not drop too far. One thing that needs to be considered for all amplifiers is the phase-shift that occurs at high frequencies: it can turn negative feedback into a positive one: the circuit may start to oscillate and inadvertently become an RF-generator.

♣ The in fact quite important area of reference arrows and algebraic signs will not be elaborated upon in this context – reference is made to literature, e.g. [20].

 Translated into English by Tilmann Zwicker