10.8.5.1 Diodes

In order to achieve non-linear distortion of a signal, at least one non-linear component is required. This may be a tube, a transistor, or – in the simplest case – a diode. In the following, the term diode is meant to refer to a **semiconductor diode** and not to a tube diode. The latter could also be used for distortion but this does not happen in practice. Simplified, diodes conduct current only in the forward-direction; with the reverse-polarity, the diode blocks. More accurate models consider that a few 100 mV are created across the diode in the forward-direction, and moreover include the reverse-current flowing for reverse polarity. Dynamic models add capacitances (possibly of non-linear nature) – a model for a diode can in fact get quite complicated. As a first approximation, the so-called Shockley-characteristic suffices:

$$I = I_S \cdot \left(\exp(U/U_T) - 1\right); \qquad U_T = 25.8\,\mathrm{mV}\ (300\,\mathrm{K}) \qquad \text{Shockley-equation}$$

The diode current I grows exponentially with the voltage across the diode in the forward-direction U which is referenced to the temperature-voltage U_T; I_S represents a theoretical reverse-current. Real diodes may strongly deviate from this idealization, and corrections and supplements are necessary. In particular, it is necessary to modify the temperature-voltage: for a real diode, measurements yield values for U_T of up to more than 60 mV; moreover a track-resistance in forward-direction needs to be considered. In the left section of **Fig. 10.8.25**, the forward characteristic of an 1N4148 diode is shown with linear scaling, the middle section shows the same characteristic but with log-scaling along the horizontal axis. The exponential function leads to a strong curvature for the linear scaling – this led to the term "threshold voltage"; for silicon diodes this is often specified at 0.7 V. A scaling for large currents indeed shows a sharp bend of the rounded characteristic at 0.7 V; a scaling for smaller current shifts the "kink" to 0.4 V or even smaller values. Do note: an exponential function does not have a kink – the value of the threshold is arbitrary!

Fig. 10.8.25: Pass-characteristic of a 1N4148 (data from Fairchild). The upper x-axis-scaling in the left picture holds for the dashed line, the lower scaling for the solid line. Right: AA113 (Siemens).

The right-hand picture shows the forward characteristic of a Germanium point-contact diode (AA113). In contrast to the silicon diode 1N4148, smaller voltage occur across the diode for small currents in the forward-direction. For currents above 3 mA, however, the voltage across the Ge-diode is higher than that across the Si-diode because spreading resistances make themselves felt more.

For all these characteristics, we need to bear in mind that there will be scattering due to temperature- and manufacturing-fluctuations. Increasing the temperature by 20°C may indeed double the forward-current, and exchanging a diode for another of the same type (!) may change the current flowing at a given voltage within a range of -70/+200%. It is therefore not purposeful to count on highly specific data from the data sheets.

Fig. 10.8.26 shows further forward-characteristics (from data sheets). All diodes marked AA are Ge-diodes, all others are SI-diodes.

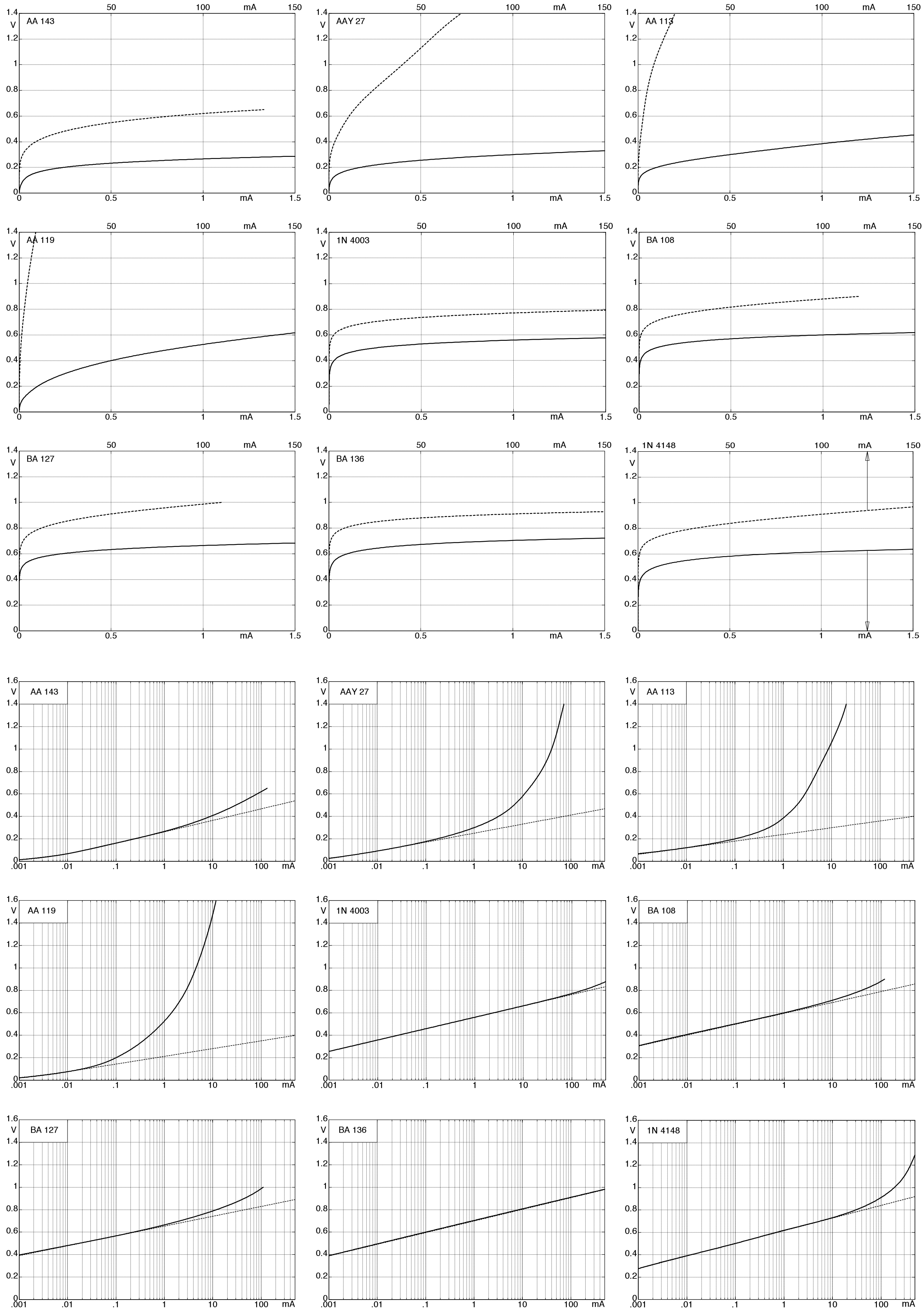

Fig. 10.8.26: Forward characteristics of various semiconductor diodes (data sheet specifications).

The diode currents flowing in typical circuits for distortion devices are small (max. about 1 mA). The characteristic curves (reaching over 100 mA in the data sheets) are therefore only relevant in the lower range – which is relatively well described via the Shockley-equation. To achieve a limitation of both sides of the signal, two diodes are interconnected in an anti-parallel fashion; this results in a zero-symmetrical (odd-order) characteristic. In theory, that is: manufacturing tolerances are felt considerably in real diodes. Driving the diode-pair by a stiff current source results in a signal rounded off at both sides, as depicted in **Fig. 10.8.27**). This ideal-current-source-drive is, however, not possible (and not necessary) in reality, since the impedance of the driving current source cannot become infinite. It is helpful to use, for the model, an ideal current source and extend the diode pair by a parallel resistor (left-hand picture) – this changes the behavior in particular at small drive-levels. In all 3 pictures we see the characteristics of two diode pairs: for the small-signal diode 1N4148, and for the power diode 1N4003.

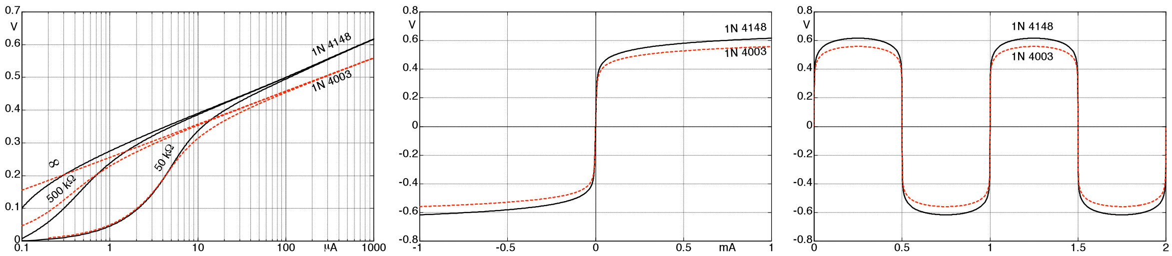

Fig. 10.8.27: *Left:* forward characteristics (half-log representation), diode with resistor in parallel. *Middle:* two anti-parallel diodes. *Right*: voltage limiting for sinusoidal current input.

Describing the diode characteristics with only the Shockley-model requires merely **two parameters**: the reverse current and the factor of the temperature-voltage (1…2). Both parameters can be seen as scaling factors for the current and the voltage, and consequently the following holds: within the framework of the Shockley-model all diodes show the same behavior as long as variable gain is available at both the distortion device input and the distortion device output. Working with this model does not require choosing a special diode because every diode allows for the same distortion characteristics. However, this does not tell us anything about the **dynamic** behavior, which is not described via a static characteristic curve. A diode will go into the blocking state only once "all" charges have left the barrier layer output, and this takes a moment: a relatively long moment for power diodes and a relatively very short moment for RF-diodes. Partnered up with the distortion-introducing diodes operating within the feedback branch of an operational amplifier, we often find an additional capacitor in parallel to the diodes; this leads to the conclusion that it is in fact not even desirable that the diodes act very quickly. In the **Tube-Screamer**, for example, there is a 50-pF-cap in parallel that will have an effect only in the highest frequency range – and only with the gain turned up. In the **Boss DS-1**, however, we find some quite respectable **10 nF** in parallel with the diodes! This rather huge capacitance pushes the switching behavior of the diode somewhat into the background. Moreover, we must not forget that even a capacitor of this size impresses a diode only as long as very small currents are flowing. At e.g. 2 mA (a current value that certainly may occur), the differential resistance of the diode is a mere 20 Ω, and compared to that even 10 nF are of relatively high impedance.

Different diodes are connected in an anti-parallel manner if a non-zero-symmetrical characteristic is desired – e.g. a Ge- and a Si-diode, or special parallel/serial-networks. The individual characteristic becomes more important in this scenario, because it is not possible to do an individual current/voltage-scaling anymore for each diode.

 Translated into English by Tilmann Zwicker