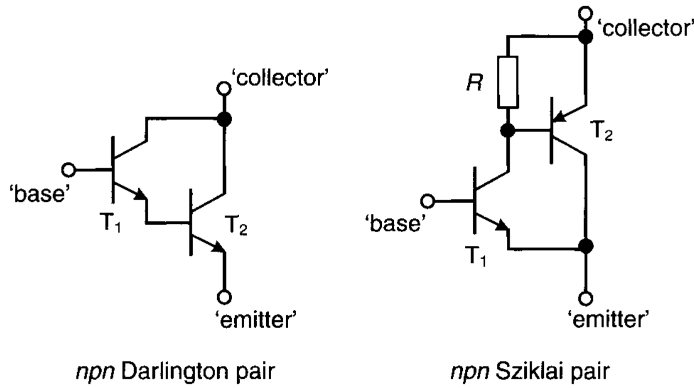

Fig. 8.11 The Darlington and Sziklai *npn* pairs.

8.5.1 The Darlington pair

As you can see, the Darlington is simply two emitter-followers cascaded together. The current gain of T_1 is $h_{fe1} + 1 \approx h_{fe1}$, and that of T_2 is $h_{fe2} + 1 \approx h_{fe2}$. The overall current gain is $h_{fe1}h_{fe2}$.

To find the output resistance, Thévenin's theorem is used. First, the short-circuit current: The input resistance of T_2, acting as a conventional emitter-follower, but with $R_L = 0$, is

$$r_{in2} \approx h_{fe2}r_{e2}$$

This is also the load r_L on T_1. The input resistance of T_1, and hence the overall input resistance, is

$$\begin{aligned} r_{in} &= h_{fe1}(r_{e1} + r_L) \\ &= h_{fe1}(r_{e1} + h_{fe2}r_{e2}) \end{aligned} \tag{8.3}$$

But the operating currents are related by

$$\begin{aligned} I_{o2} &= \beta_2 I_{B2} \\ &= \beta_2 I_{01} \\ &\approx h_{fe2} I_{01} \end{aligned}$$

so

$$r_{e1} \approx h_{fe2}r_{e2}$$

Substituting this in Eqn (8.3) gives

$$r_{in} \approx 2h_{fe1}h_{fe2}r_{e2}$$

So, the input current is

$$\begin{aligned} i_{in} &= \frac{v_{in}}{r_{in}} \\ &= \frac{v_{in}}{2h_{fe1}h_{fe2}r_{e2}} \end{aligned}$$

The short-circuit output current is

$$\begin{aligned} i_{sc} &= h_{fe1} h_{fe2} i_{in} \\ &= \frac{v_{in}}{2r_{e2}} \end{aligned}$$

Since the circuit acts as an emitter-follower, the open-circuit output voltage is

$$v_{oc} \approx v_{in}$$

Thus the output resistance is

$$\begin{aligned} r_{out} &= \frac{v_{oc}}{i_{sc}} \\ &= \frac{v_{in}}{i_{sc}} \\ &\approx 2r_{e2} \end{aligned} \tag{8.4}$$

So, the Darlington configuration has an output resistance which is twice that of a simple emitter-follower operating at the same quiescent current.

8.5.2 The Sziklai pair

The Sziklai configuration is shown in Figure 8.11. The quiescent current I_1 through T_1 is well-defined, and is set by the value of R

$$\begin{aligned} I_1 &= I_R + I_{B2} \\ &= \frac{V_{BE}}{R} + \frac{I_2}{\beta_2} \end{aligned}$$

I_1 is usually chosen to be about $0.1I_2$, so I_1 becomes

$$I_1 \approx \frac{V_{BE}}{R} + \frac{10I_1}{\beta_2}$$

If $\beta > 50$, say, then most of I_1 flows through R and

$$\begin{aligned} I_1 &\approx \frac{V_{BE}}{R} \\ R &\approx \frac{V_{BE}}{I_1} \\ &\approx \frac{10V_{BE}}{I_2} \\ &\approx \frac{6.5\,\text{V}}{I_2} \end{aligned}$$

Since the emitter of T_2 is 'grounded' for signals, T_2's input resistance is

$$\begin{aligned} r_{i2} &\approx h_{fe2} r_{e2} \\ &\approx \beta_2\left(\frac{25\,\text{mV}}{I_2}\right) \end{aligned}$$

For $\beta = 50$,

$$r_{i2} \approx 50\left(\frac{25\,\text{mV}}{I_2}\right) \approx \frac{(1.25\,\text{V})}{I_2}$$

So, the input resistance of T_2 is about one fifth of R, and most of the signal current from T_1 collector goes to T_2 base.

To find the output resistance of the Sziklai, first find the short-circuit current. With the output shorted to ground,

$$\begin{aligned} i_{c1} &= g_{m1}v_{in} \\ i_{sc} &\approx i_{c2} \\ &\approx h_{fe2}i_{c1} \\ &\approx h_{fe2}g_{m1}v_{in} \end{aligned}$$

With the output open-circuit, the Sziklai acts as a 'super' emitter-follower, and the open-circuit voltage is simply

$$v_{oc} \approx v_{in}$$

So, the output resistance is

$$\begin{aligned} r_o &\approx \frac{v_{oc}}{i_{sc}} \\ &\approx \frac{v_{in}}{h_{fe2}g_{m1}v_{in}} \\ &\approx \frac{r_{e1}}{h_{fe2}} \end{aligned}$$

For $\beta = 50$ and $I_2 = 10I_1$, we have

$$\begin{aligned} r_o &\approx \frac{10r_{e2}}{50} \\ &\approx 0.2r_{e2} \end{aligned}$$

So, under these conditions, the output resistance of a Sziklai is about **one-tenth** that of a Darlington with the same quiescent current. Since the Sziklai's output resistance is so much lower, one might expect that the **variations** in its output resistance would be much lower too, and that it would produce much less distortion than a Darlington with the same quiescent current. As with the double emitter-follower, for a given R_E there is an optimum I_Q which minimizes the THD.

Figure 8.12 shows the simulated output spectrum of the Sziklai output stage, with the same drive and load conditions as the double emitter-follower of Figure 8.7(b). Again, the emitter resistors are 175 mΩ. The optimum quiescent current is about 20 mA, and the THD about −61 dB or 0.00008%; about three times better than the double emitter-follower stage. Remember, these are **open-loop** values, with perfect drive and bias circuitry. Negative feedback will

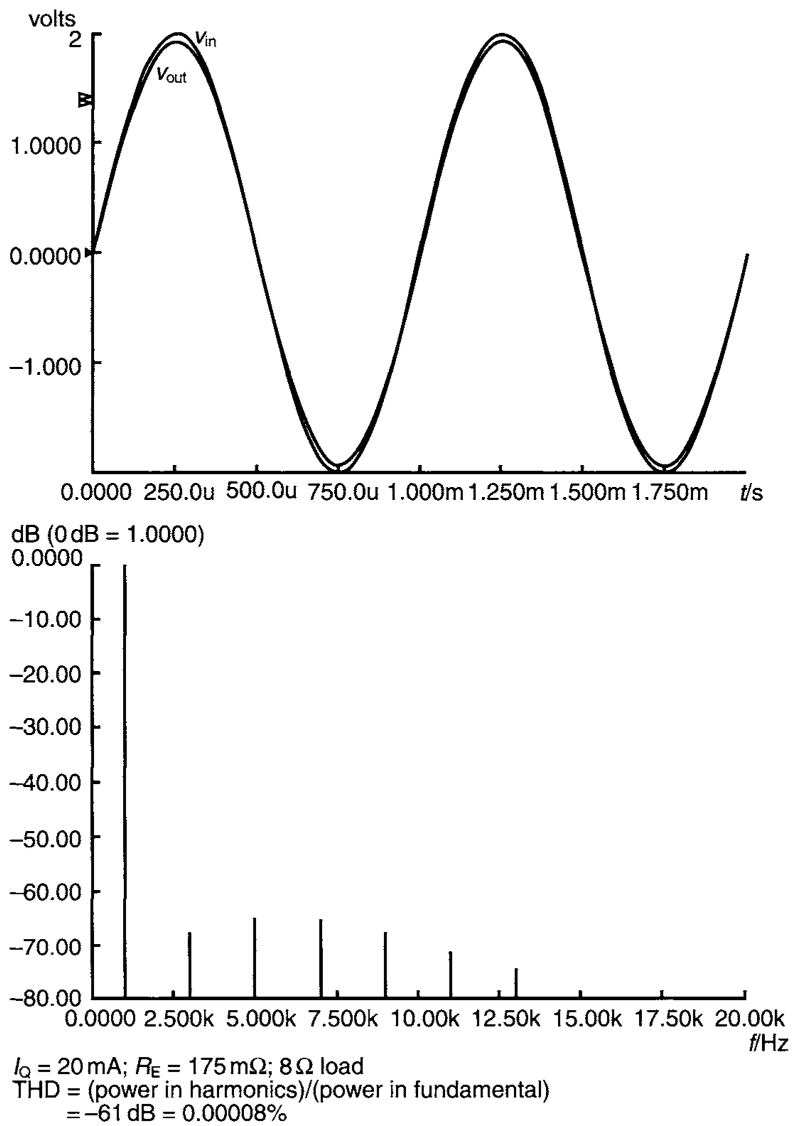

Fig. 8.12 Performance of a double-Sziklai stage.

reduce these figures, typically by an order of magnitude at all but the highest audio frequencies. But real drive and bias circuits increase them by similar amounts. The features of the Darlington and the Sziklai are summarized in Table 8.1.

Table 8.1 Features of the Darlington and Sziklai configurations

	As single emitter-followers		Push–pull with $\pm V_{CC}$	
	Darlington	Sziklai	Darlington	Sziklai
Available voltage swing	$V_{CC} - 2V_{BE}$	$V_{CC} - V_{BE}$	$2V_{CC} - 4V_{BE}$	$2V_{CC} - 2V_{BE}$
T_1 quiescent current I_1	ill-defined: $I_1 \approx I_2/\beta_2$	well-defined (set $I_1 \approx 0.1I_2$)	ill-defined: $I_1 \approx I_2/\beta_2$	well-defined (set $I_1 \approx 0.1I_2$)
Output resistance	$2r_{eo}$	$0.2r_{eo}$	r_{eo}	$0.1r_{eo}$