Thermal lag distortion is most directly caused by the phenomenon of thermal attenuation and is exacerbated by the long time constant of the heat sink when the bias spreader temperature-sensing element is mounted on the heat sink. The use of ThermalTrak™ BJT output devices with their internal temperature-sensing diode greatly reduces thermal lag distortion. These transistors will be discussed in the next section.

MOSFET power amplifiers are far less susceptible to thermal lag distortion for two reasons. First, they are far more temperature stable than BJT-based amplifiers. Second, with most MOSFET power amplifiers, more bias is better, as opposed to the optimum value that must be observed with BJT class AB output stages. Thus, the performance of a MOSFET output stage is less affected by the minor bias current variations that occur with program material.

14.8 ThermalTrak™ Power Transistors

Many problems with output stage bias stability have been mitigated by the introduction of the ThermalTrak™ line of output transistors by ON Semiconductor® [4, 5, 6]. These transistors incorporate an electrically isolated tracking diode inside the transistor in close thermal contact with the output transistor die. This enables the junction temperature of the tracking diode to much more closely track that of the power transistor than by common approaches using temperature compensation transistors mounted on the heat sink (or even on the exterior of the power transistor package). The NJL3281D (NPN) and NJL1302D (PNP) are good examples of these transistors [5]. These devices are rated at 15 A, 260 V, and 200 W. They have typical f_T of 30 MHz and also have very good Safe Operating Area (1.1 A at 100 V). The transistors come in a 5-pin TO-264 package.

In this section we'll show how one or more of the tracking diodes in the ThermalTrak™ output transistors of an output stage can be properly used in a V_{be}-multiplier-based bias spreader. It is notable that the use of ThermalTrak™ transistors can greatly reduce thermal lag distortion.

Construction and Physical Characteristics

The NJL3281D consists of a power transistor die and a MUR120 diode die mounted together on the copper header of a TO-264 package. The header is electrically connected to the collector of the transistor. The diode is mounted to the header but is electrically insulated from it. Figure 14.17 illustrates conceptually the construction of the ThermalTrak™ transistor and its pin-out. The physical arrangement allows the diode junction temperature to be virtually the same as the temperature of the copper header. This allows it to react much more quickly to transistor junction temperature changes than an external temperature-sensing diode. While the time constant of the heat sink is on the order of minutes, the thermal response time of the diode to changes in the header temperature is on the order of hundreds of milliseconds.

The actual junction of the power transistor is still thermally separated from the header by the junction-to-case thermal resistance of the transistor die, so there is still some thermal attenuation from the junction temperature to the temperature of the internal sensing diode. However, this thermal attenuation is much smaller than in any arrangement using an external temperature-sensing junction.

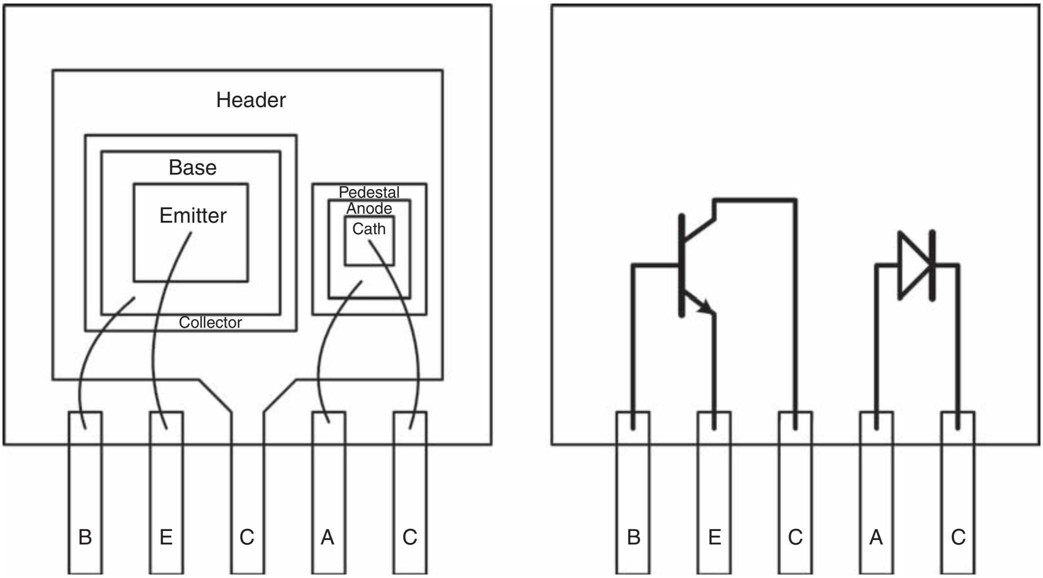

FIGURE 14.17 ThermalTrak™ output transistor illustration.

Bias Spreaders Employing ThermalTrak™ Transistors

Numerous bias spreader arrangements were discussed in Section 14.5 and many of them can be adapted for use with ThermalTrak™ transistors and their tracking diodes. The same principles apply, including those governing the choice of temperature compensation percentage. The bias spreaders employing remote sensing diodes, like those in Figures 14.11a and 14.11d, 14.12c, and 14.13b and 14.11c are particularly good candidates.

There is one important difference, however. It is important that at least one tracking diode from each of the NPN and PNP output transistors be included in the bias spreader. The reason for this is related to power transistor junction temperature changes at low frequencies. The reaction time of the tracking diodes is fairly fast, so it is desirable to take advantage of the complementary nature of the junction temperature changes of the NPN and PNP output transistors. For this reason the bias spreaders should be designed to employ two remote diodes.

The MUR120 is a 1-A SWITCHMODE™ power rectifier with a junction area that is large by comparison to those of the small-signal transistors usually employed in bias spreaders. Its forward junction drop is only about 600 mV at 25°C at a junction current of 10 mA, which is a typical VAS bias current. This compares to about 750 mV for a small-signal transistor like the 2N5550 operating at 10 mA. This will affect somewhat the distribution of junction drops being multiplied by the V_{be} multiplier. Finally, the slope of the temperature coefficient of junction voltage for the MUR120 (TC_{TTD}) at 10 mA is about –1.7 mV/°C, while TC_{Vbe} for the NJL3281 is about –2.1 mV/°C at its typical bias current of 118 mA (R_E = 0.22 Ω). This must also be taken into account in establishing the compensation percentage for the bias spreader.

Figure 14.18a shows a simple bias spreader employing a conventional V_{be} multiplier that includes two of the internal diodes from a ThermalTrak™ output transistor, TTD1 and TTD2. The tracking diodes are simply placed in series with a conventional V_{be}

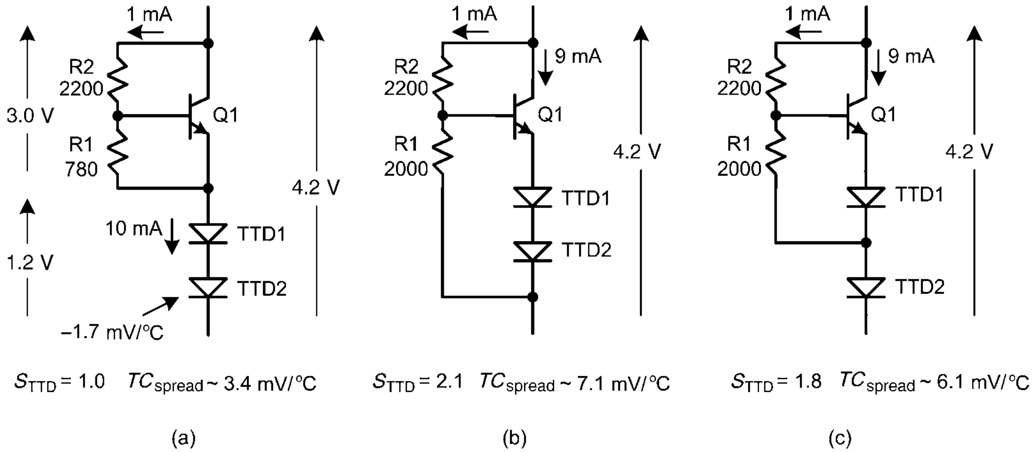

FIGURE 14.18 Three bias spreaders for ThermalTrak output transistors.

multiplier. Q1 is not mounted on the heat sink and has no role in temperature compensation of the output transistors. The bias spreader is designed for an output Triple and produces a nominal spread of about 4.2 V. The tracking diodes introduce the temperature effects of the output transistors, while the V_{be} multiplier transistor takes care of controlling that part of the bias spread necessary for the predriver and driver transistors. Sensitivity to the tracking diode TC (S_{TTD}) is unity. This bias spreader likely has too little compensation for the output transistors because TC_{TTD} is only about 80% of TC_{Vbe} for the output transistors. TC_{spread} for this bias spreader is only –3.4 mV/°C, while the output pair requires –4.2 mV/°C.

Figure 14.18b is a bias spreader that represents the opposite extreme. It encloses the two tracking diodes inside the V_{be} multiplier loop. As a result, TC_{TTD} is multiplied. The overall multiplier ratio in the spreader of Figure 14.18b is about 2.1; this is what is required to obtain the nominal spread of 4.2 V. As a result, TC_{spread} is about 7.1 mV/°C. S_{TTD} is about 2.1. This is more compensation than needed.

An intermediate solution is obviously needed. The spreader of Figure 14.18c is a tempting choice, but it still yields an estimated TC_{spread} of 6 mV/°C. The temperature coefficient is larger than one might expect because the multiplier ratio has increased, enhancing the influence of TTD1. A more significant concern is that the compensating influence of TTD1 and TTD2 is no longer equal; this degrades the balance brought by using one tracking diode from each of the top and bottom output transistors.

The bias spreader arrangement of Figure 14.19a is equally sensitive to TTD1 and TTD2 while providing a selectable value for TC_{spread}. R1 and R3 control the proportion of temperature coefficient introduced by the output transistor temperature. A larger ratio of R1/R3 provides increased S_{TTD}. With R1 = 1.3 kΩ and R3 = 5.0 kΩ, S_{TTD} is about 1.3, yielding TC_{spread} of about 4.4 mV/°C. This is just slightly more than the –4.2 mV/°C required for the output stage. However, slight overcompensation is often preferred.

Many other bias spreader arrangements can also be used with the ThermalTrak™ transistors. Figure 14.19b shows a Darlington bias spreader that yields a fixed TC_{spread} of about –5.3 mV/°C. It can be adjusted downward by adding a resistor (not shown)

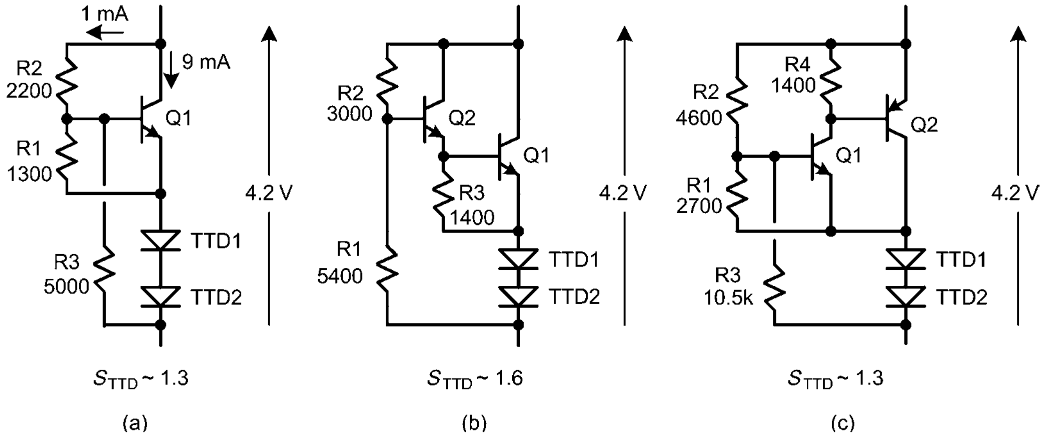

Figure 14.19 Bias spreaders with selectable temperature compensation.

between the base of Q2 and the anode of TTD1 in similar fashion to what was done in Figure 14.19a.

Figure 14.19c shows a CFP bias spreader that performs analogously to the spreader of Figure 4.19a. Spreader impedance is reduced, but not by as much as with a conventional CFP bias spreader as described in Section 14.5. This is because the tracking diodes must remain outside the CFP loop in order to have most of the 10-mA VAS bias current flowing through them. Spreader impedance is estimated to be about 7.3 Ω, less than half that of Figure 4.19a.

Tracking Diode Temperature Characteristics

Forward-biased silicon junctions do not always have a temperature coefficient of –2.2 mV/°C. This is just a convenient approximation. The actual number depends on several factors but in particular on the relative current density in the junction. The temperature coefficient is also a function of temperature.

Figure 14.20 shows the measured junction voltages for the ThermalTrak™ power transistor and tracking diode as a function of temperature. V_{be} is shown for 100 mA, while V_{TTD} is shown for 12.5 mA, 25 mA, and 50 mA. Notice that operating the tracking diode at 25 mA provides a voltage match to transistor V_{be} at 25 °C, but it has the wrong slope. Operating the diode at 12.5 mA, near the typical VAS bias current level, results in reduced V_{TTD} and about the same slope as at 25 mA. There is really no advantage to operating the diode at higher current as long as the slight difference in bias voltage can be made up.

Thermal Model

Figure 14.21 shows a thermal model for the ThermalTrak™ transistor with emphasis on the action of the tracking diode. This model was arrived at by measurement of a ThermalTrak™ transistor under several different conditions, combined with SPICE simulation of the model. The current represents the heat source in watts while the R-C ladder represents the path of heat flow from the source to the heat sink, with voltage representing temperature above ambient temperature in degrees Celsius. R1 represents θ_{jc}.

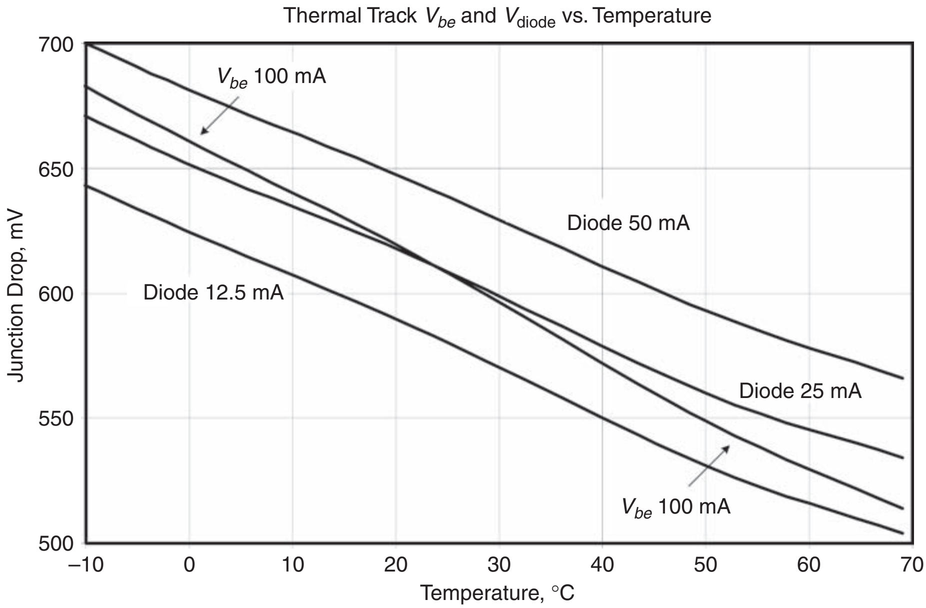

FIGURE 14.20 V_{be} and tracking diode drop versus temperature for different tracking diode current.

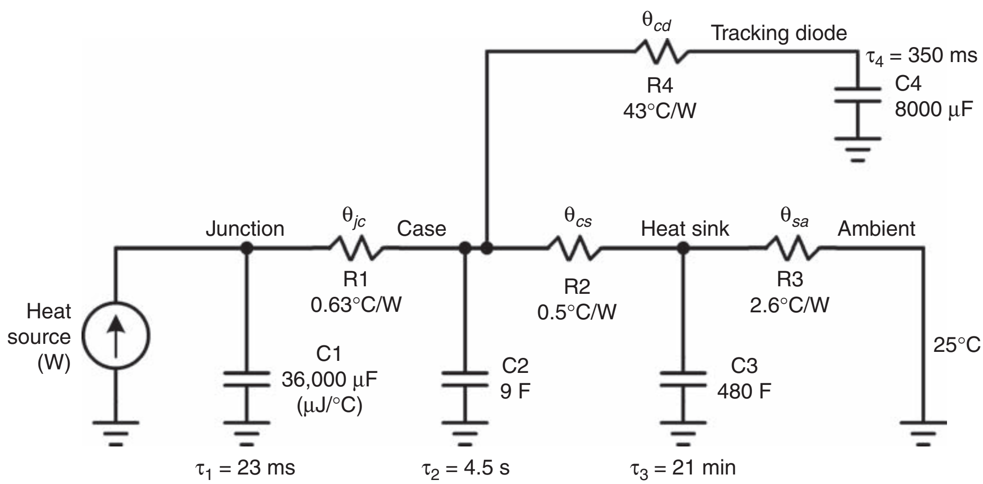

FIGURE 14.21 Tracking diode thermal model.

Here it is 0.63°C/W, representing the 200-W power transistor in a TO-264 package and having a maximum junction operating temperature of 150°C. Shunt capacitor C1 represents the thermal mass of the die itself. The capacitance of 36,000 μF has units of microjoules per degree Celsius. C2, at 9 F, represents the thermal mass of the copper header. R2 represents insulator thermal resistance θ_{cs} = 0.5°C/W. R3 corresponds to this transistor's share of a heat sink with θ_{sa} = 0.65°C/W. This transistor is assumed to be part of the 150-W amplifier described earlier in which there were two output pairs. Thus, θ_{sa} for