AN11076

Thermal behavior of small-signal discretes on multilayer PCBs

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Document information

Info	Content
Keywords	Low VCEsat, BISS, thermal resistance (Rth), thermal impedance (Zth), total power dissipation (Ptot)
Abstract	This application note illustrates how to improve the power dissipation of discrete components by using multilayer PCBs. It focuses on the impact of using larger copper areas to improve the thermal behavior of applications.

Revision history

Rev	Date	Description
1	20110711	Initial version

Contact information

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1. Introduction

In today´s data sheets thermal characteristics are measured on a standard FR4 single copper layer Printed-Circuit Board (PCB). Customers should be able to compare devices easily just by evaluating standard data sheet parameters. In reality, design engineers cannot only rely on data sheet parameters and must consider the individual design requirements.

2. Thermal resistance

2.1 Key parameters

The main thermal parameters for semiconductor device are junction temperature (T_j) and thermal resistance (R_{th}).Thermal resistance depends on the environment surrounding a semiconductor device. In data sheets, design engineers can find different thermal resistances (see Section 2.1.1 and 2.1.2).

Thermal resistance of semiconductor devices is defined in general as:

$$R_{thx} = \frac{T_j - T_X}{P_{tot}} \quad (1)$$

Where R_{thx} = thermal resistance from the device junction to specific environment [K/W];
T_j = device junction temperature in steady state [°C];
T_x = reference temperature of the specific environment [°C] and
P_{tot} = maximum power dissipation of the semiconductor device [W].

Thermal data is not comparable, unless a semiconductor supplier provides all test conditions. NXP Semiconductors provides them. They are often marked with a note at the end of an abstract or table, in the data sheet.

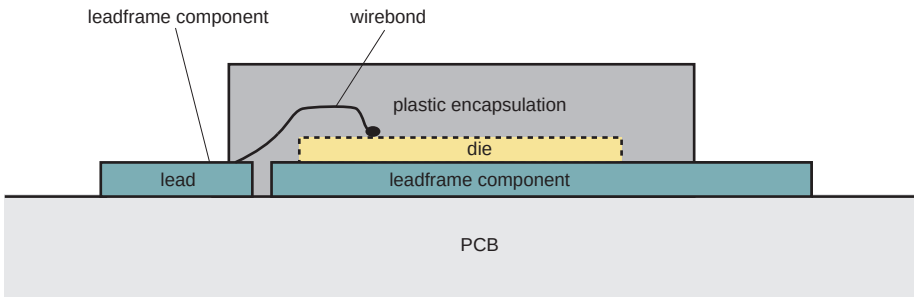

Fig 1. Typical structure of small signal packages

Figure 1 shows the typical structure of small signal devices. The heat is generated at the junction and must be transferred by the leadframe to the outside of the package. Thermal conduction between the die and the leadframe and between the leadframe and the PCB allow this transfer. The heat transfer between PCB and air can be done by convection and/or radiation.

2.1.1 Thermal resistance from junction to solder point $R_{th(j-sp)}$

This parameter depends on the component. The size of the die, the material of the leadframe and the mold compound influence the $R_{th(j-sp)}$. The solder point is defined as the mounting point where the device would be normally soldered to the PCB. It is a conduction path only.

2.1.2 Thermal resistance from junction to ambient $R_{th(j-a)}$

This parameter describes the thermal resistance from the junction (die) to the ambient. It is a single thermal resistance value including all effects of possible series and parallel paths from the junction to the ambient. Typically, it includes all the heat transfer methods of conduction and convection, from the surface of the package and via the PCB.

$R_{th(j-a)}$ is only valid for a specific PCB and not for:

- PCBs of different size, shape or layer stack to the test specification
- Several devices mounted on one PCB
- Operation within a housing, which influences the convection
- Forced cooling, for example, by cooling fan

3. Heat transfer mechanism

Up to three different transfer methods can be used to transfer heat from the die to the ambient.

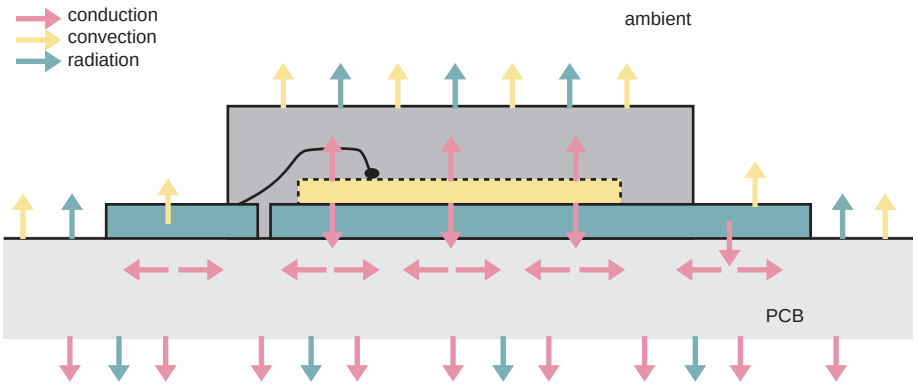

Fig 2. Three heat transfer methods

3.1 Thermal conduction

Conduction is a heat transfer in a medium due to a temperature change. For small-signal discrete components the heat transfer between the die and the leadframe and then the leadframe and the PCB is done by conduction.

3.2 Thermal convection

Convection is a heat transfer from a body due to the movement of a medium, which is in contact with the surface of the body. In our case, it is the transfer of heat from the PCB surface and the ambient air. Due to the poor thermal conductivity of the plastic package, the main path for convection is the PCB/air interface.

3.3 Thermal radiation

Radiation is a heat transfer by emitting heat from a hot body, which will be absorbed by a cooler one. For example PCB surface and surrounding objects such as the side panel of the housing.

4. Thermal measurement results

In PCB design, the numbers of variables are significant. The thermal resistance depends on board size, thickness, cooling pad area and ambient temperature.

Therefore, NXP Semiconductors has developed specific R_{th}-PCBs which are according to the JEDEC standards. It helps designers to compare easily relevant thermal parameters from different small-signal discrete vendors. Unfortunately, most applications are not developed on single layer FR4 PCBs. To get a better view of customer requirements, NXP Semiconductors set up a four-layer PCB. All PCBs differ by the top layer layout. Layers 2 to 4 consist of pure copper layers with a dimension of approximately 32 × 42 mm (see Figure 4). The top layer design was made on standard footprint and with a 1 cm^2 cooling pad area for each package.

Fig 3. Layer stack of modified R_{th}-PCBs

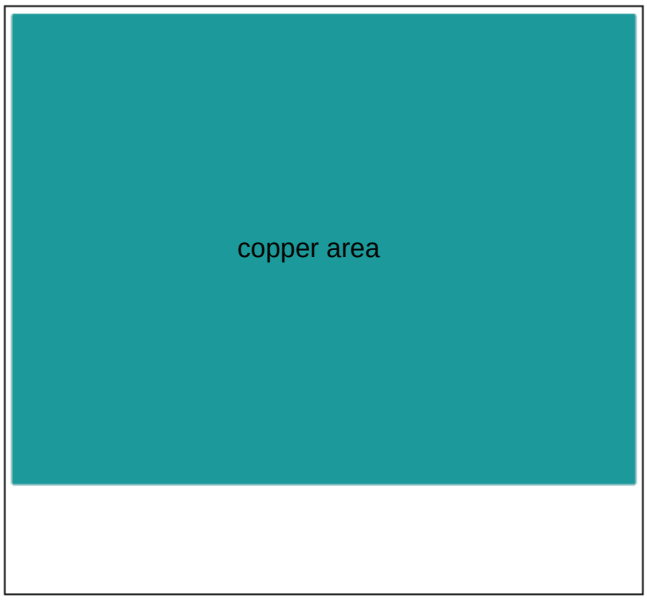

Fig 4. Layer 2, 3 and 4 cooling area

4.1 SOT457

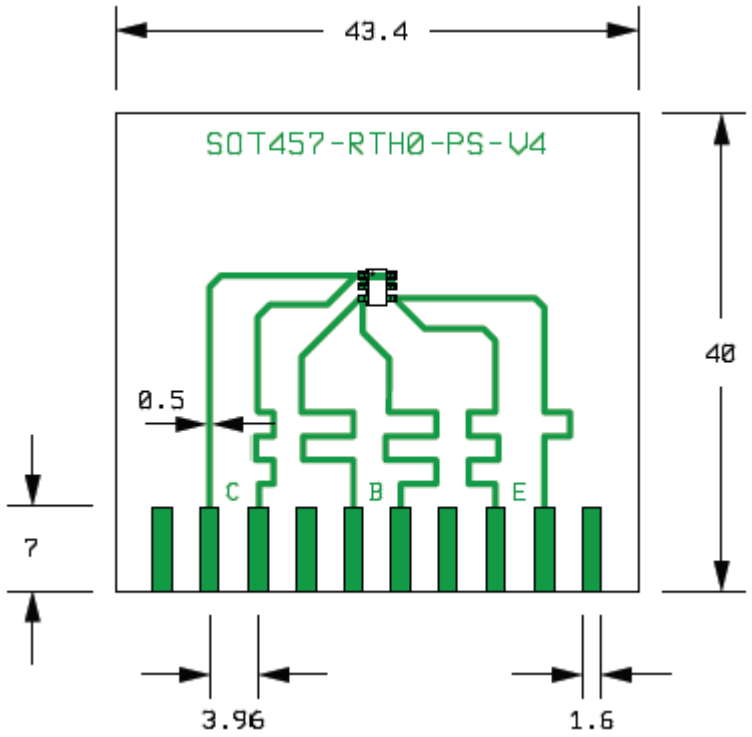

Fig 5. SOT457 standard footprint

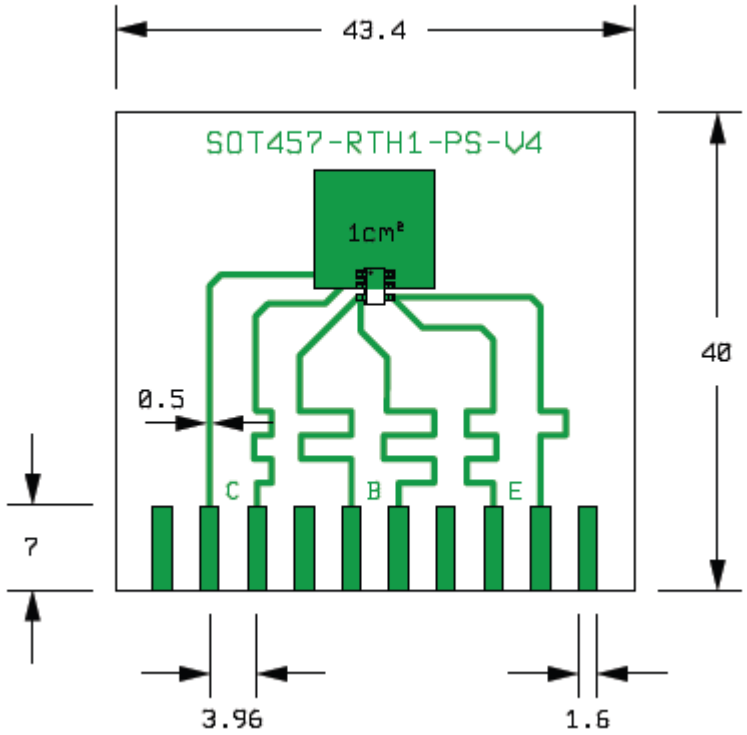

Fig 6. SOT457 1 cm^2 cooling pad area

Table 1. PBSS5350D in SOT457; typical values

Sample	Standard footprint		1 cm^2 cooling pad	
	R_{th} (K/W)	P_{tot} (mW)	R_{th} (K/W)	P_{tot} (mW)
1	181	689	141	889
2	181	689	141	889
3	181	689	141	889
Average	181	689	141	889
+15 % safety margin	208	600	162	770
Single layer FR4	275	450	208	600

4.2 SOT89

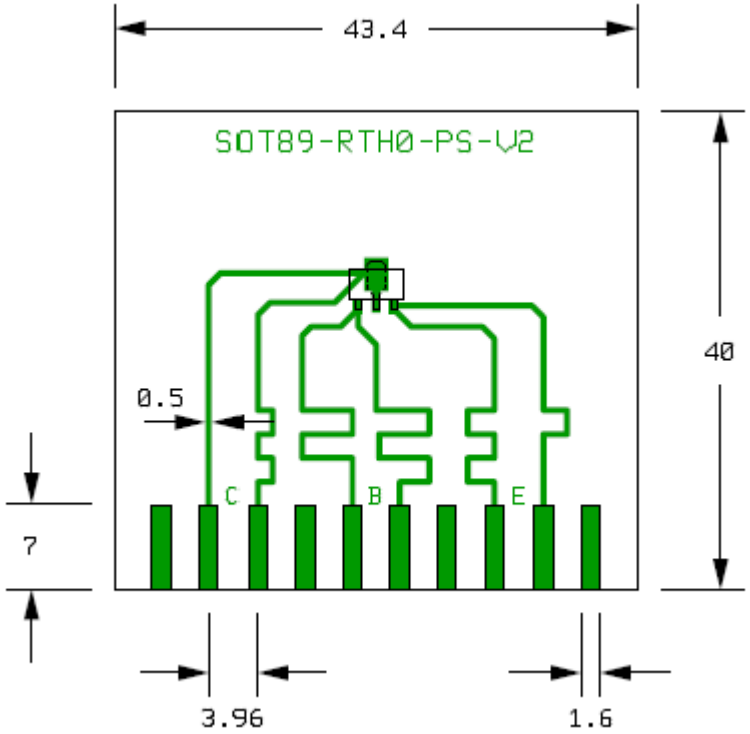

Fig 7. SOT89 standard footprint

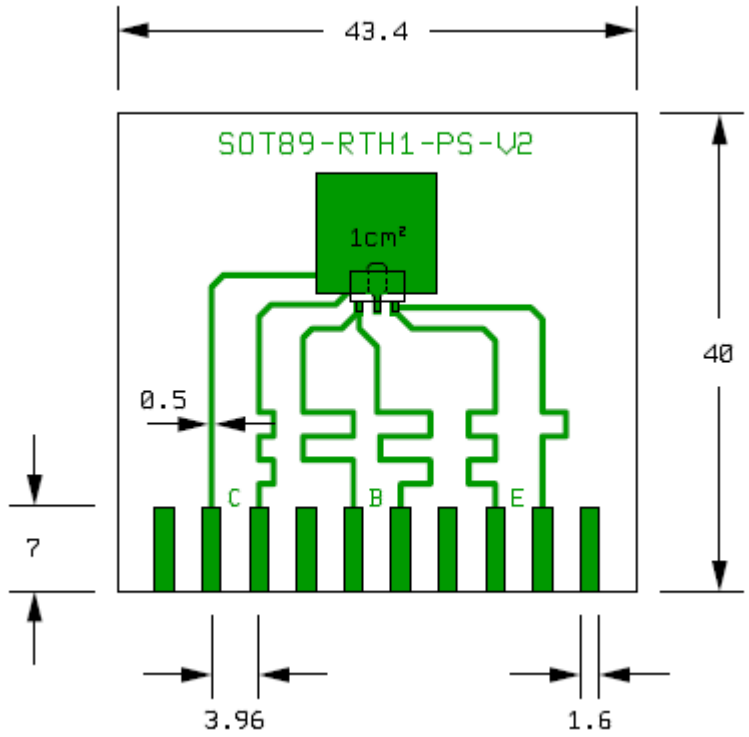

Fig 8. SOT89 1 cm^2 cooling pad area

Table 2. PBSS5330X in SOT89; typical values

Sample	Standard footprint		1 cm^2 cooling pad	
	R_{th} (K/W)	P_{tot} (mW)	R_{th} (K/W)	P_{tot} (mW)
1	79	1582	47	2660
2	77	1623	42	2976
3	72	1736	43	2907
Average	76	1647	44	2848
+15 % safety margin	88	1420	51	2450
Single layer FR4	225	550	125	1000

4.3 SOT1061

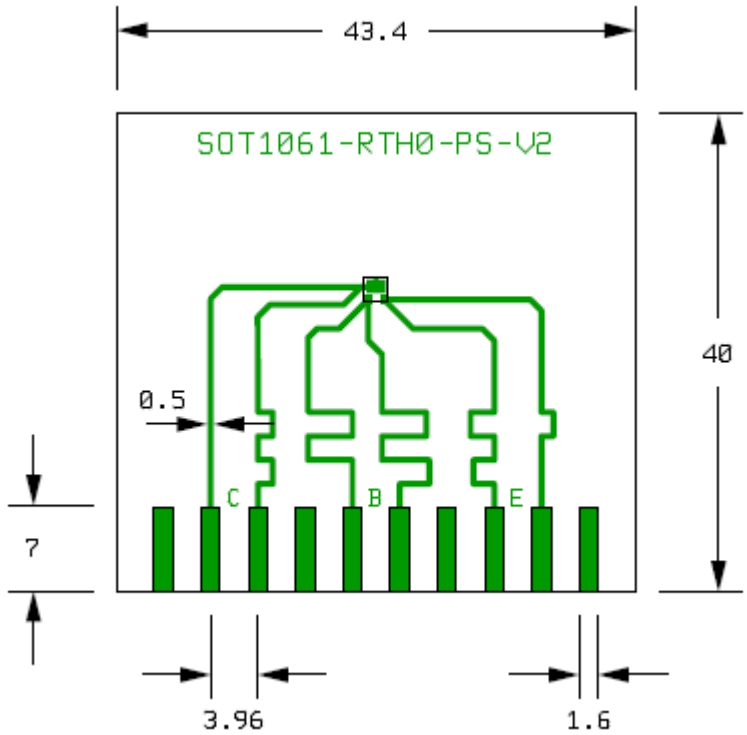

Fig 9. SOT1061 standard footprint

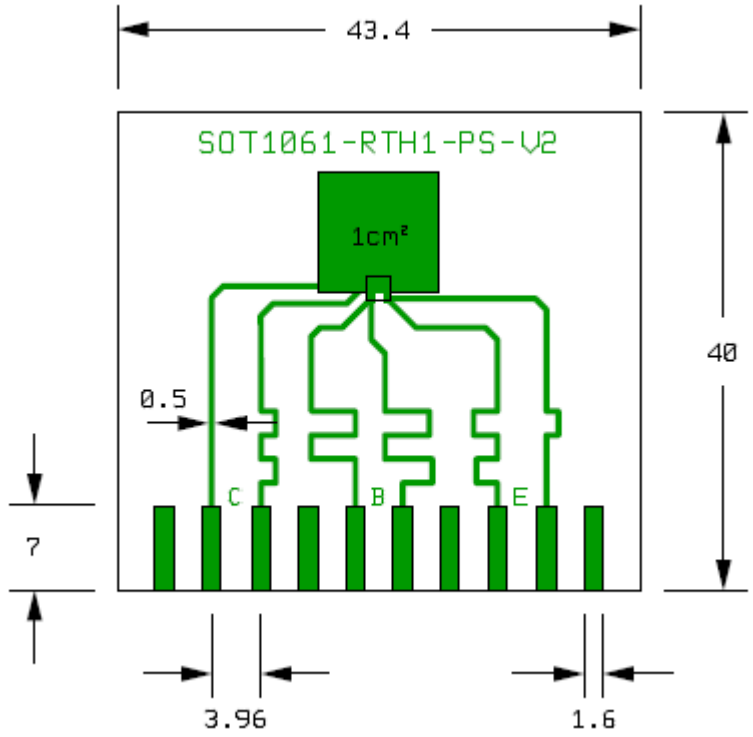

Fig 10. SOT1061 1 cm^2 cooling pad area

Table 3. PBSS5330PA in SOT1061; typical values

Sample	Standard footprint		1 cm^2 cooling pad	
	R_{th} (K/W)	P_{tot} (mW)	R_{th} (K/W)	P_{tot} (mW)
1	114	1096	50	2500
2	113	1106	51	2541
3	111	1126	52	2404
Average	112	1116	51	2541
+15 % safety margin	129	970	59	2110
Single layer FR4	250	500	125	1000

4.4 SOT1118

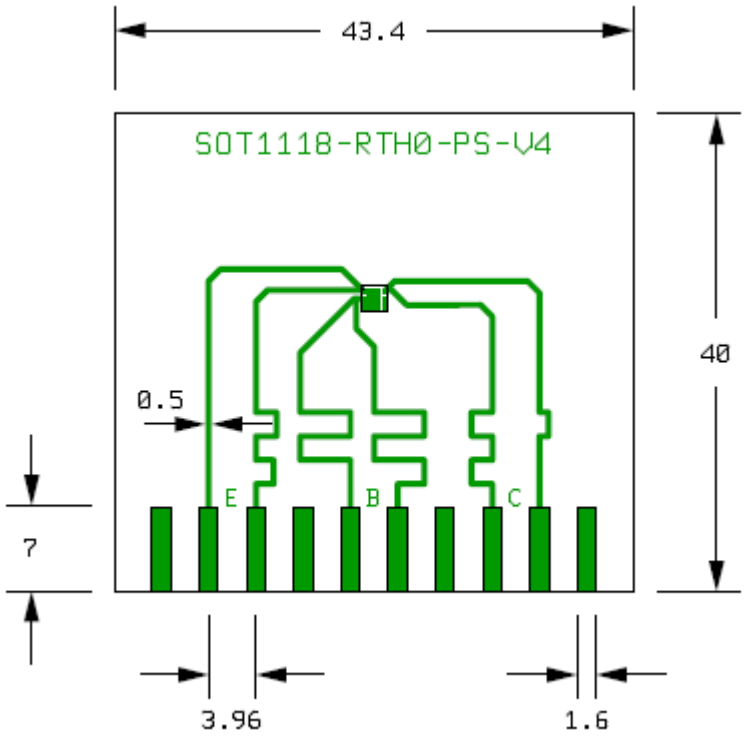

Fig 11. SOT1118 standard footprint

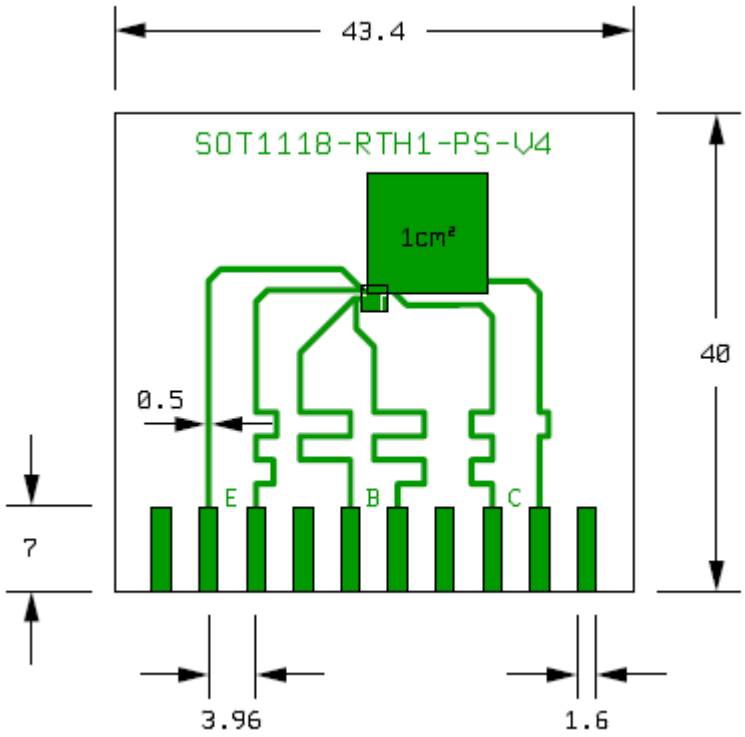

Fig 12. SOT1118 1 cm^2 cooling pad area

Table 4. PBSM5240PF in SOT1118; typical values

Sample	Standard footprint		1 cm^2 cooling pad	
	R_{th} (K/W)	P_{tot} (mW)	R_{th} (K/W)	P_{tot} (mW)
1	149	839	82	1524
2	154	812	86	1453
3	153	817	81	1543
Average	152	822	83	1506
+15 % safety margin	175	715	96	1300
single layer FR4	300	410	180	700

4.5 Conclusion

By using the additional copper area of multilayer PCB applications, power dissipation of a transistor can be increased significantly. Most improvement can be seen with newer flat or leadless packages, like SOT89 and SOT1061. The heat generated at the junction can be transported directly by conduction via the collector tab into the PCB. Most of the heat is transferred through the collector pad/exposed heatsink of SOT1061/SOT1118 packages to the PCB. Always consider PCB as an additional tool to manage the thermal behavior of a transistor in any design.

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