Thermal Considerations - FETs

THERMAL CONSIDERATIONS

Thermal resistance

Circuit performance and long-term reliability are affected by the temperature of the transistor die. Normally, both are improved by keeping the die temperature (junction temperature) low.

Electrical power dissipated in any semiconductor device is a source of heat. This increases the temperature of the die about some reference point, normally an ambient temperature of 25 ^{o}C in still air. The size of the increase in temperature depends on the amount of power dissipated in the circuit and the net thermal resistance between the heat source and the reference point.

Devices lose most of their heat by conduction when mounted on a a printed board, a substrate or heatsink. Referring to Fig.1 (for surface mounted devices mounted on a substrate), heat conducts from its source (the junction) via the package leads and soldered connections to the substrate. Some heat radiates from the package into the surrounding air where it is dispersed by convection or by forced cooling air. Heat that radiates from the substrate is dispersed in the same way.

The elements of thermal resistance shown in Fig.2 are defined as follows:

$R_{th\ j\text{-}mb}$ thermal resistance from junction to mounting base

$R_{th\ j\text{-}c}$ thermal resistance from junction to case

$R_{th\ j\text{-}s}$ thermal resistance from junction to soldering point

$R_{th\ s\text{-}a}$ thermal resistance from soldering point to ambient

$R_{th\ c\text{-}a}$ thermal resistance from case to ambient ($R_{th\ s\text{-}a}$ and $R_{th\ c\text{-}a}$ are the same for most packages)

$R_{th\ j\text{-}a}$ thermal resistance from junction to ambient.

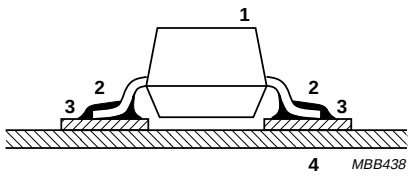
The temperature at the junction depends on the ability of the package and its mounting to transfer heat from the junction region to the ambient environment. The basic relationship between junction temperature and power dissipation is:

$$T_{j\ max} = T_{amb} + P_{tot\ max}\ (R_{th\ j\text{-}s} + R_{th\ s\text{-}a})$$
$$= T_{amb} + P_{tot\ max}\ (R_{th\ j\text{-}a})$$

where:

$T_{j\ max}$ is the maximum junction temperature

T_{amb} is the ambient temperature



Heat radiates from the package ‘1’ to ambient.
Heat conducts via leads ‘2’, solder joints ‘3’ to the substrate ‘4’.

Fig.1 Heat losses.

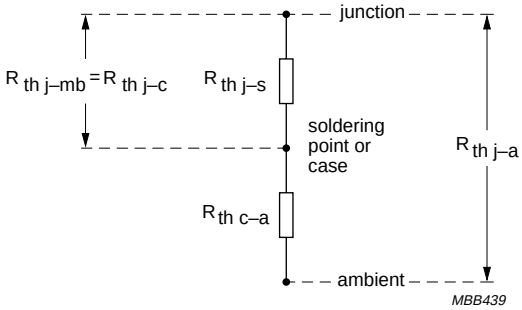


Fig.2 Representation of thermal resistance paths of a device mounted on a substrate or printed board.

$P_{tot\ max}$ is the maximum power handling capability of the device, including the effects of external loads when applicable.

In the expression for $T_{j\ max}$, only T_{amb} and $R_{th\ s\text{-}a}$ can be varied by the user. The package mounting technique and the flow of cooling air are factors that affect $R_{th\ s\text{-}a}$. The device power dissipation can be controlled to a limited extent but under recommended usage, the supply voltage and circuit loading dictate a fixed power maximum. The $R_{th\ j\text{-}s}$ value is essentially independent of external mounting method and cooling air; but is sensitive to the materials used in the package construction, the die bonding method and the die area, all of which are fixed.

Values of $T_{j\ max}$ and $R_{th\ j\text{-}s}$, or $R_{th\ j\text{-}c}$ or $R_{th\ j\text{-}a}$ are given in the device data sheets. For applications where the temperature of the case is stabilized by a large or temperature-controlled heatsink, the junction temperature can be calculated from

$T_j = T_{case} + P_{tot} \times R_{th\ j\text{-}c}$ or, using the soldering point definition, from $T_j = T_{solder} + P_{tot} \times R_{th\ j\text{-}s}$.

Thermal resistance ($R_{th\ s\text{-}a}$ and $R_{th\ c\text{-}a}$)

The thermal resistance from soldering point to ambient (SMDs), and that from case to ambient depends on the mounting technique, the shape and material of the tracks and substrate. Standard mounting conditions to set the maximum power ratings of the various packages are shown in Figs 3 to 6. Each figure shows single-sided 35 μm copper-clad epoxy fibre-glass print, 1.5 mm thick, the tracks are fully solder-tinned and the shaded areas shown are copper or ceramic (Al_2O_3) 0.7 mm thick.

$R_{th\ s\text{-}a}$ for SMDs mounted on ceramic substrate

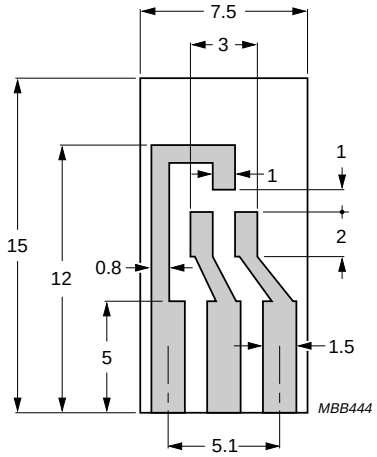
The thermal resistance $R_{th\ s\text{-}a}$ for devices in SOT143 and 223 packages mounted on ceramic substrate is a function of the substrate area as shown in Fig.7.

The thermal resistance $R_{th\ j\text{-}a}$ can then be calculated by:

$R_{th\ j\text{-}a}$ (substrate) = $R_{th\ j\text{-}a}$ (PCB) − $R_{th\ s\text{-}a}$ (PCB) + $R_{th\ s\text{-}a}$ (substrate)

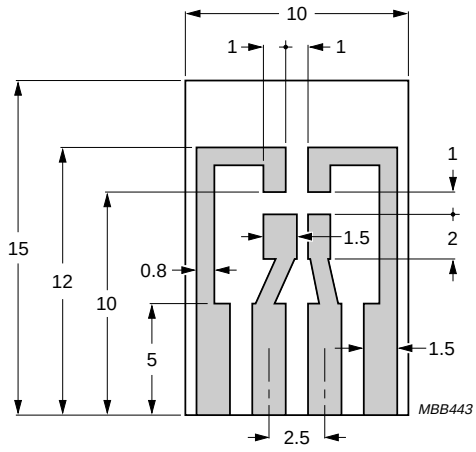
The $R_{th\ s\text{-}a}$ (PCB) is:

SOT23 and SOT143 150 K/W.



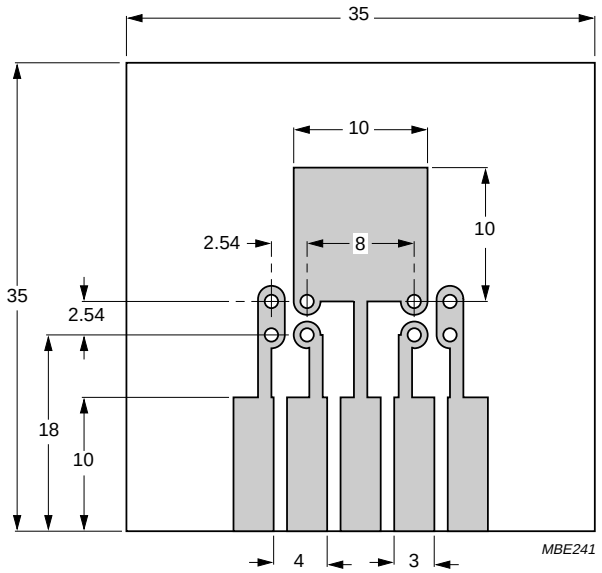
Dimensions in mm.

Fig.3 Standard mounting conditions for SOT23.



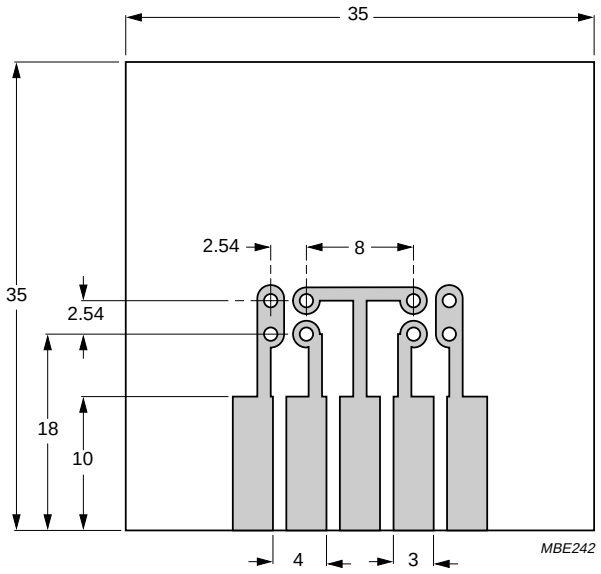
Dimensions in mm.

Fig.4 Standard mounting conditions for SOT143.



Dimensions in mm.

Fig.5 Standard mounting conditions for SOT54, higher dissipation option.



Dimensions in mm.

Fig.6 Standard mounting conditions for SOT54.

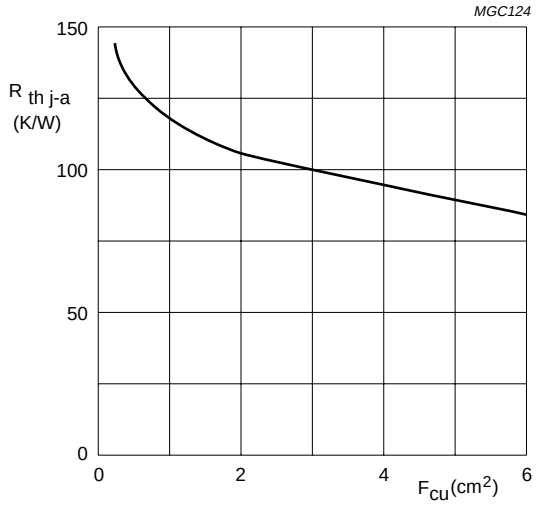


Fig.7 Thermal resistance ($R_{th\ j\text{-}a}$) as a function of FR4 epoxy fibre-glass circuit board.

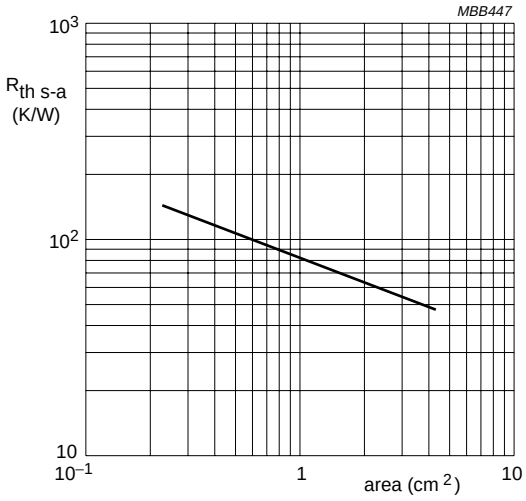


Fig.8 Thermal resistance ($R_{th\ s\text{-}a}$) as a function of area of ceramic substrate.

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