Mounting Guidelines for SEMELAB RF MOSFETS

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Introduction

The performance of RF MOSFETs can be severely reduced by poor thermal considerations. In today's market designers are being asked to not only make higher power systems but also make them smaller, this means manufacturers putting more die into smaller packages and increasing the operating temperature of the devices. Most of SEMELAB's ceramic devices are flange mounted and accommodate fixing slots/holes to attach them to heatsinks. This application note will examine the main considerations in mounting the devices for best thermal performance, which in turn will lead to improved Gain and Efficiency.

Breakdown of Thermal Resistance

The thermal resistance of a package is indicated by calculating, simulating and measuring the thermal path of the heat from the die through the package to the heatsink. The more heat that can be taken away from the die the better the device will perform. The thermal resistance (Rth) of a device is made up of several component parts, these are shown in Figure 1.

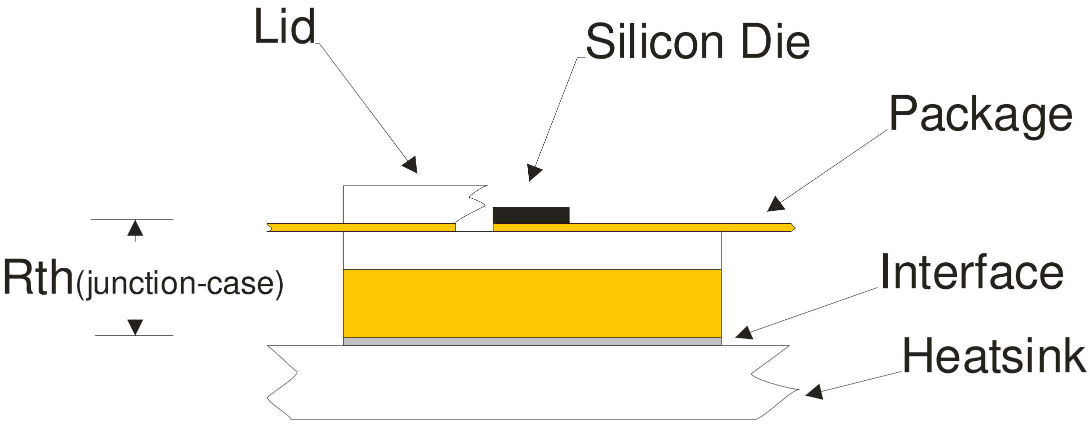


Figure 1. Device Thermal Resistance Breakdown

The die surface temperature (Tj) is measured using Infrared (IR) microscopy and is measured by removing the ceramic lid from the device and exposing the die. The temperature betweeen the device's flange and the heatsink is measured by a sheathed thermocouple mounted inside the RF fixture heatsink and touching the underside of the device.

Optimum Device Flange to Heatsink Connection

The most important mounting consideration for the designer is the fixing of the RF MOSFET to the system heatsink. There needs to be a good thermal connection between the device flange and the heatsink. The flatness and surface roughness of the heatsink are of great concern as air gaps between the device and heatsink will increase the thermal resistance. Devices are usually mounted directly to a heatsink which must be machined as flat as possible. It should be possible to achieve an average surface roughness (R_A) of 1µm maximum with a surface flatness of 5µm/cm.
Care should also be taken when tapping the screw holes to mount the device. Hole burrs must be removed to ensure that the device sits correctly on the machined surface either by countersinking or counterboring the hole after it has been tapped as shown in figures 2 and 3.

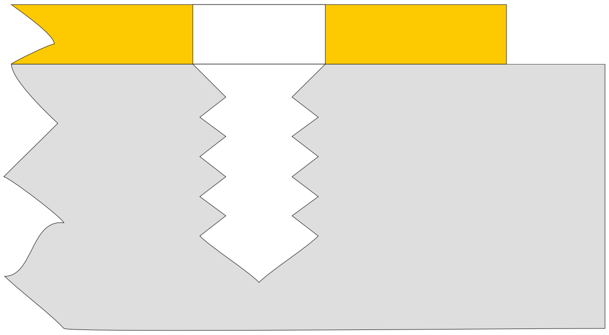


Figure 2. Countersunk Mounting Hole

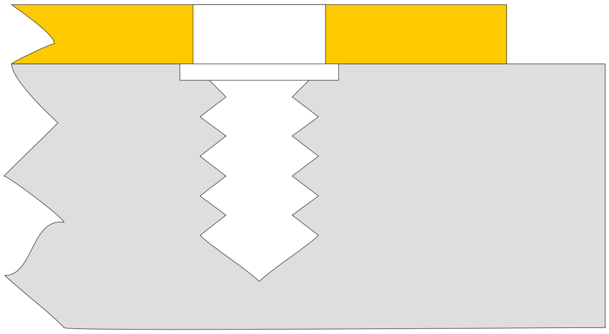


Figure 3. Counterbored Mounting Hole

Thermal Interface Materials

In order to further improve the interface between the packaged device and the heatsink, thermal paste should be used to fill microscopic airgaps. There is a large variety of thermal compounds available on the market with varying thermal conductivities, ranging from silicone to high performance silver loaded compounds, electrically conductive and insulating compounds. Standard silicone/zinc oxide compounds have a thermal conductivity of between 0.7 to 0.9 W/m.K and the higher performance compounds are between 5.5-6.0 W/m.K. Even though the compounds have far worse thermal conductivity than aluminium (237 W/m.K) they are still at least 20-30 times better than Air (0.024 W/m.K) and up to 250 times better with the more exotic thermal compounds.

In the last few years thermal pads have become more popular due to their cleanliness compared to thermal compounds, but mainly due to their increased performance making them comparable if not better than some of the thermal compounds. Thermal pads tend to fall into two categories: “inert” pads and pads that require heating and setting into place. The “inert” pads are simply placed between the package and the heatsink and fixed into place with fixing screws. The other type of thermal pads that are available require heating up to a higher than “normal” operating temperature which causes the coating on the pads to soften and fill all of the air gaps between the package and the heatsink. When cooled to operating temperature the compound does not flow any further and all of the air gaps remain filled. The thermal pads are also available electrically conductive and electrically insulative.

Applying Thermal Compound

Thermal compound should be used very carefully, using too much can be worse than using none at all. Ideally, enough should be used to fill all of the air gaps between the package and the heatsink but leave as much package metal to heatsink metal in intimate contact as possible. Excessive use of thermal compound adds a “layer” of thermal resistance and actually increases the overall system Thermal Resistance. The optimum place to coat the package with heatsink compound is on the flange directly underneath the active area of the device. If possible a measured amount of compound should be screen printed onto the base of the device before being fixed into place as shown in Figure 4.

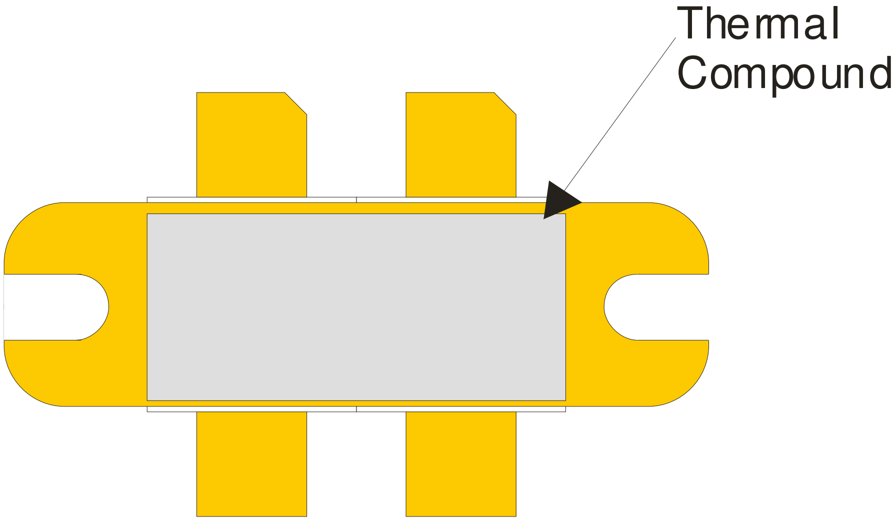
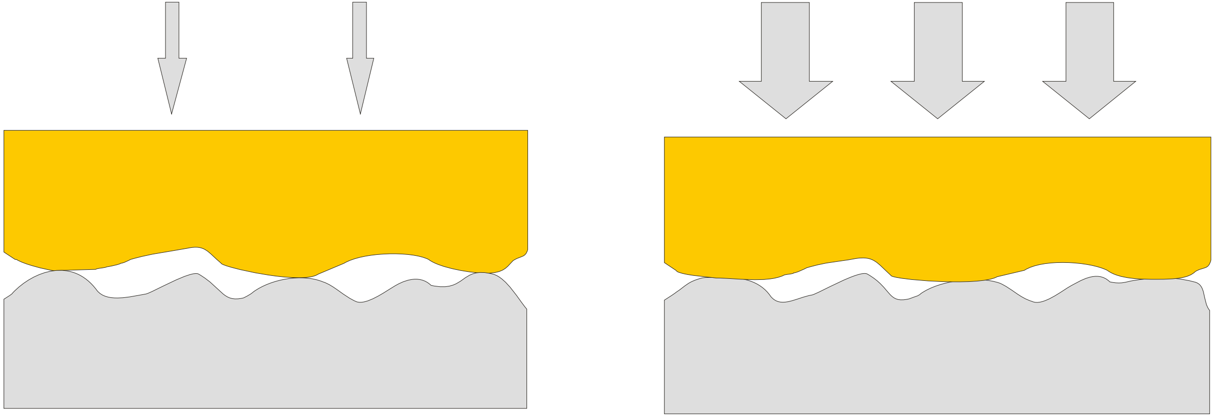


Figure 4. Application of Thermal Compound

Contact Force and Screw Tightening Torque

A further consideration in the mounting of the device is the force applied to ensure a good contact to the heatsink. As discussed previously, the base of the device and the heatsink are not perfectly flat and there are microscopic air gaps. The contact area can be increased by increasing the force applied to the flange of the device, which will in turn reduce the contact thermal resistance.



Low Contact Force

High Contact Force

Figure 5. Relationship between Contact Area and Contact Force

In order to spread the force of the screws equally it is recommended that washers are used. The tightening torque and subsequent contact force between the device and the heatsink depend on the quality and type of screws used. It is recommended that socket head cap screws are used as they are more suited to high torque loads and, used with the correct tools there is less chance of damage to the head of the screw when tightening. Another benefit of the socket head screw is that the head is smaller than a standard slot head screw which would otherwise interfere with some of the smaller flange-mount packages. The torque needed on a screw in order to give a certain contact force between the device and heatsink depends on many factors. The major factors in determining the correct torque are the size of screw thread (M2.5/M3/M4 (metric) or 3-48 UNC/3-56 UNF/4-40 UNC/4-48 UNF (imperial)) and the material used for the screw and the heatsink. Below is a table of typical settings for one of the more common combinations of stainless steel socket head screw and a tapped aluminium heatsink.

Screw Size	**Suggested Torque Range**	
	Torque (N.m)	**Torque (in.lbs)**
Metric Sizes		
M2.5	0.3-0.4	2.65-3.55
M3	0.6-0.7	5.31-6.20
M4	1.3-1.5	11.51-13.28
U.S. Sizes		
3-48 UNC	0.3-0.4	2.65-3.55
3-56 UNF	0.3-0.4	2.65-3.55
4-40 UNC	0.5-0.65	4.43-5.75
4-48 UNF	0.5-0.65	4.43-5.75

Table 1. Suggested Torque Ranges

The suggested torque ranges are around two-thirds of the maximum torque for the screw. It is also recommended that the screws are tightened in 2 steps to ensure the devices are not damaged during mounting. Firstly, the screws should be tightened by hand so they are fingertight on both sides, then secondly, they should be fully tightened with a controlled torque wrench to the recommended torque. Tightening one screw fully before the other can cause the flange to bend and in extreme cases crack if excessive force is used. The tightening torques in the above table are for reference only, it is recommended that maximum screw torques are evaluated by experimentation and then backed off to two-thirds of the maximum for production use.

CTE Mismatch

Due to the different materials used in the various components in a system there is a mismatch in the coefficients of thermal expansion. The most problematic interface is the interface between the device flange and the system heatsink. The other interfaces in the thermal path from the die to the heatsink are solder joints which can absorb the mechanical stresses without deforming the joint. The interface between the flange and the heatsink is able to bow and in the worst case an air gap can form between the flange and the heatsink. Thermal simulations of a D1028UK have been run that show the bowing of the flange due to heat created by the die. The simulation results have been exaggerated to illustrate the problem. (See Appendix for details of the simulation parameters.)

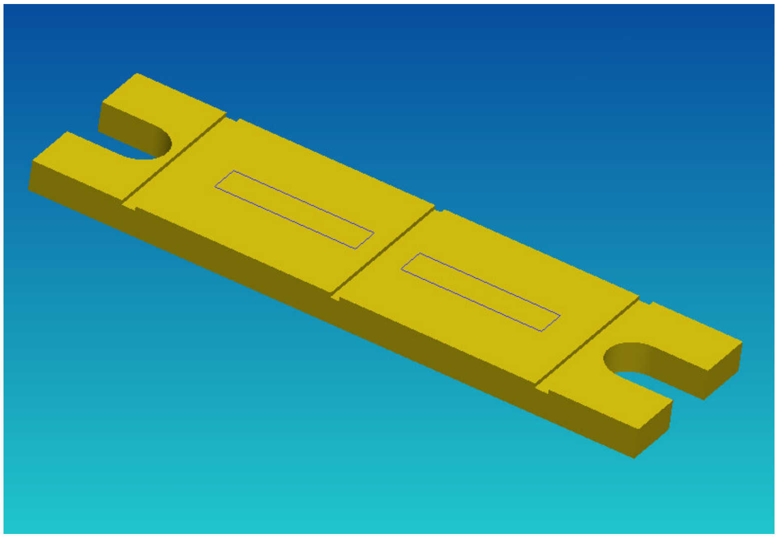
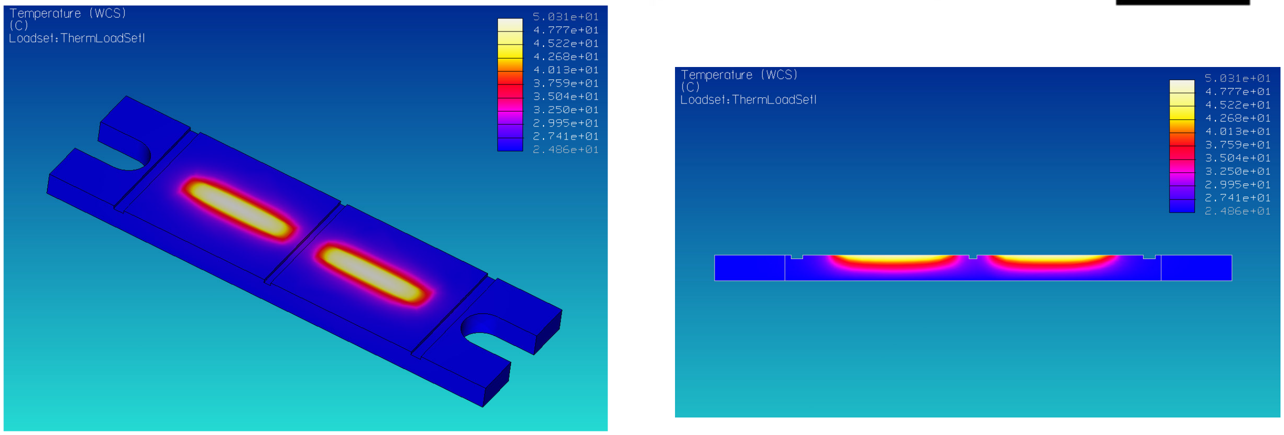


Figure 6. 3D model of the flange showing heat sources



3D view of the thermal simulation

Thermal path through the flange

Figure 7. Thermal simulation results

The thermal simulation is basic, the boundary conditions used simulate the major sources of heat and conduction away from the flange. The power of the heat source from the die is estimated from efficiency figures of the device from the datasheet. The flange is assumed to be connected to an “ideal” heatsink at room temperature which is kept at a constant temperature of 25ºc.

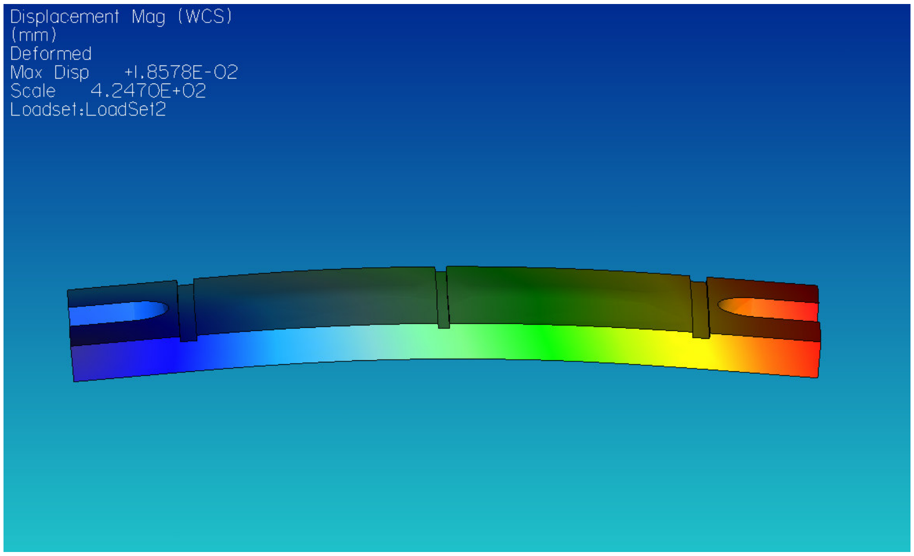


Figure 8. Exaggerated Displacement due to Thermal Expansion

The distorted flange shown in figure 8 shows that with force only being applied at the screw holes the device flange is able to bow and create an air gap between the device and the heatsink.

Transistor clamp

The transistor clamp is a method of clamping the device flange to the heatsink which not only clamps at the screw holes but also compresses on the lid of the device. The clamp decreases thermal resistance between the device and the heatsink as it evenly distributes the force applied across the whole of the flange. The following diagrams show the clamp and a cross sectional diagram of how the force is applied by the clamp.

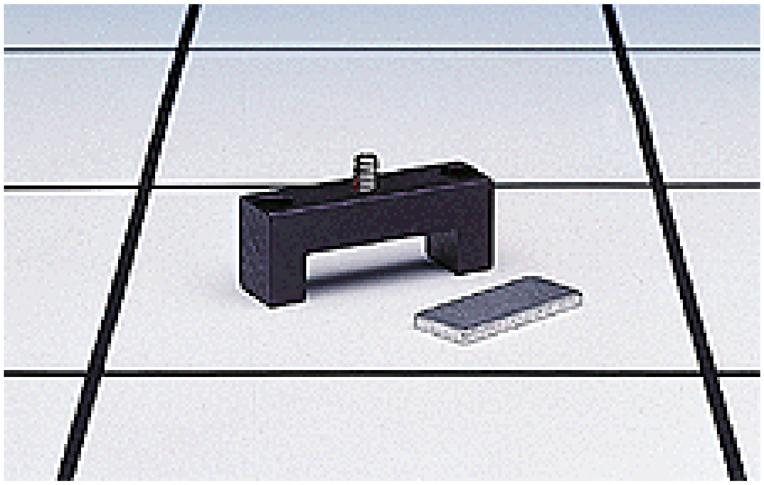
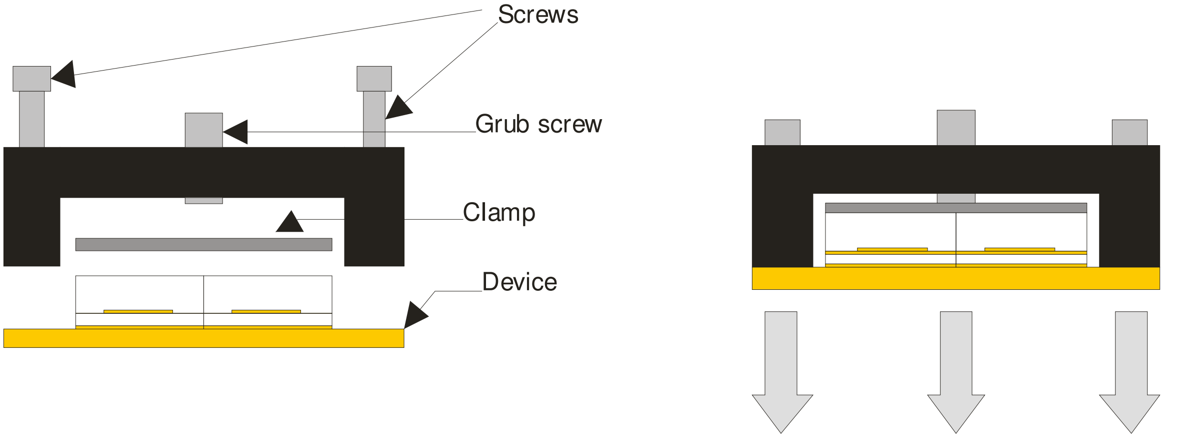


Figure 9. A picture of the transistor clamp



Exploded Clamp Drawing

Evenly Distributed Clamping Force

Figure 10. Diagrams of the Transistor Clamp

In order to get as much heat out of the device as possible the clamp should be used in conjunction with other methods suggested in this application note. The suggested method to mount the device would be using a transistor clamp in conjunction with a milled flat heatsink and a measured application of Thermal compound. The torque settings for the device screws and the grub screw should be evaluated by experimentaion to take in to account the addition of the clamp.

Mounting Guideline Summary

1. The flange and the heatsink should be as flat as possible. A surface flatness of 5µm/cm or better.
2. An average surface roughness (R_A) of 1µm or better.
3. Ensure all raised surfaces from the tapped mounting holes have been removed.
4. Apply a measured amount of thermal compound to the underside of the device before attaching it to the heatsink.
5. Correctly position the device before tightening up the fixing screws by hand.
6. Utilising a torque wrench complete the tightening of the screws to ensure that the correct contact force between device and heatsink is produced. Refer to table 1.
7. Before soldering the leads of the device to the PCB make sure that any excess thermal compound is not going to cause a short circuit. (Only a uniform bead of thermal compound should be visible.)

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AUGUST 2004

Appendix – Thermo-Mechanical Simulation

The thermo-mechanical simulation was performed using PTCs ProEngineer software. A simple model was used of the device flange and the die simulated by areas of “Thermal Load” on the flange, as shown in Figure 6. The model was simulated in 2 stages, firstly a thermal simulation to determine a steady-state heat transfer and secondly a mechanical simulation to determine the expansion of the flange due to heating, as shown in figure 7. The thermal simulation had to be constrained by adding a constant temperature to the underside of the flange, the constant temperature surface models an ideal heatsink which transfers all of the heat from the system.
The mechanical simulation had to be constrained in space so that the simulator could calculate movement from a set of fixed points. 3 points were used which fully constrained the model Point0 (PNT0) fixed the model in all 3 plains, X, Y and Z. Point 1 fixed the model in the X and Z plains and Point 2 fixed the model in the X and Y plains. There are 6 Degrees of Freedom (DOF), these are translations in each plain, X, Y and Z and rotaions in each plain. The model was not prevented from rotating in any plain but the choice of movement in the 3 chosen points explicitely removed any degrees of roation and fully constrained the model in all 6 DOF. With the model fully constrained the movement due to heating could be simulated.

The results show a peak temperature of 50ºC and maximum movement of 20um.

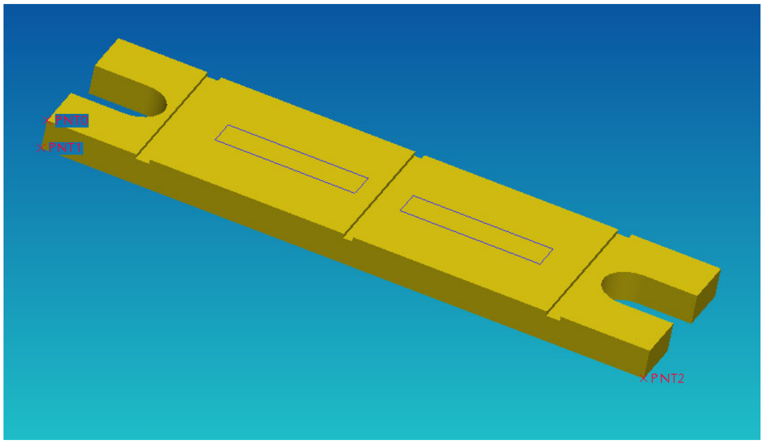

Figure 11. Points used to constrain the model