AN10900

Assembly and Usage Guidelines of RF Pallets

Rev. 2 — 25 June 2024

Application note

Document information

Info	Content
Keywords	Power LDMOS Pallets
Abstract	This application note provides general mounting and usage guidelines to achieve optimum performance from Ampleon LDMOS Pallets

Revision history

Revision	Date	Description
AN10900 v. 2.0	20240725	Format and layout change
AN10900 v. 1.0	20180511	Initial document

Contact information

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1. General description

This document is intended to guide customers in the mounting and usage of RF Pallets to ensure proper DC/RF connections and achieve optimum performances. The following guidelines apply to the typical RF energy frequency range, starting from 400 MHz to 2.5 GHz. Whenever a specific subject is frequency dependent, it will be given a proper explanation. Each customer has its own way of designing applications and integrating the pallets in its specific system, therefore it's not possible to cover all specific requirements.

2. Interconnections

2.1 Basic connections

Proper interconnection is mandatory for correct operation of pallets. All pallets are provided with input/output pins whose number is dependent on the implemented functionalities and may differ between pallets. However, a general distinction is possible between DC and RF connections.
Pallets are matched to 50 Ohm input and output RF pins, therefore it is mandatory to use a 50 Ohm impedance interconnection. The type of connection is a function of the specific application and must be chosen to be compatible with the frequency band and power levels that are delivered on the specific pin. An example for coaxial cables, which are a very common interconnection solution, the available sizes and types of connectors define its frequency and power range (N type, SMA, etc.)
Biasing of the pallets is made with DC interconnections. Cables connected to Vds must be properly sized as they must be able to deliver the current required by the pallet during RF operation.
The following table recaps the most commonly used pins with the required interconnection and gives some important remarks for proper interconnection.

Table 1. Pin type and required interconnection

Pin type	Signal type	Interconnection required	Remark
RF in	RF	50 Ohm connection (ex: coaxial cable)	Must be compatible with power levels
RF out	RF	50 Ohm connection (ex: coaxial cable)	Must be compatible with power levels
FWD/REV	Envelope (Video)	Shielded cable, microstrip line	Detector output depends on the application signal. Shielding improves accuracy of detector.
Det_bias_positive	DC	DC cable, Shielded cable, microstrip line	Shielding improves accuracy of detector
VD	DC	DC cable	Must be able to deliver the required current
VG	DC	DC cable, Shielded cable, microstrip line	Shielding improves system stability

In Pallet of Figure 1 have been marked the previously mentioned RF and DC pins, thus when interconnecting to the pallet all the recommendations written above must be taken into account.

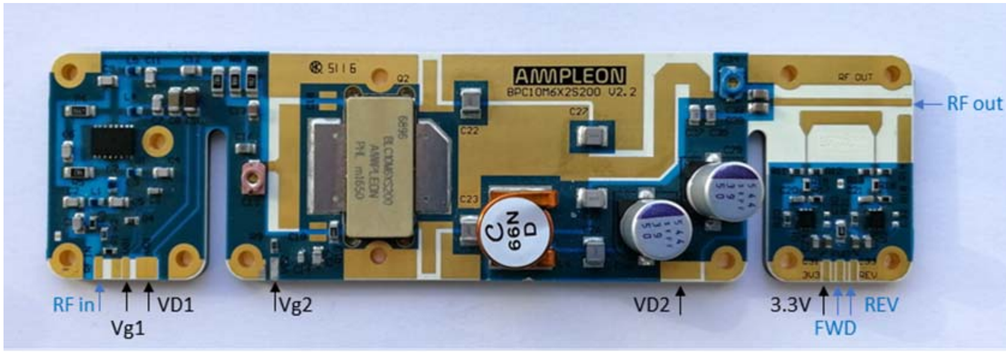


Fig 1. Example of a pallet with required connection type. In blue RF pins, in black DC pins

2.2 RF connections: Gap between two PCBs

When a pallet is connected to another PCB a gap is created between the two PCBs. This gap has a negative impact on RF performances and for this reason it has to be minimized. To verify the impact on RF performance, simulations have been done interconnecting two 50 Ohm traces on PCBs with gap values between boards of 0.1, 0.2 and 0.5 mm. As expected, the best situation is when the gap is maintained between 0.1 and 0.2 mm as it is shown in Figure 2 which reports the return loss simulated up to 10 GHz.

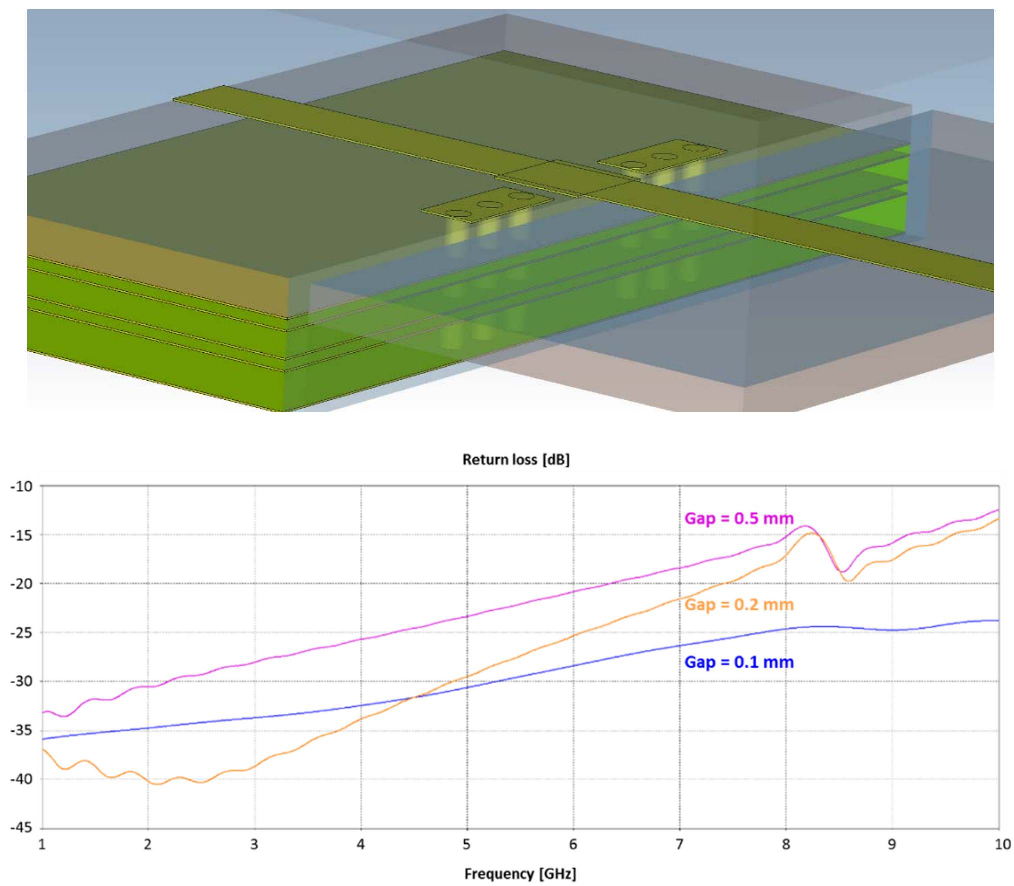


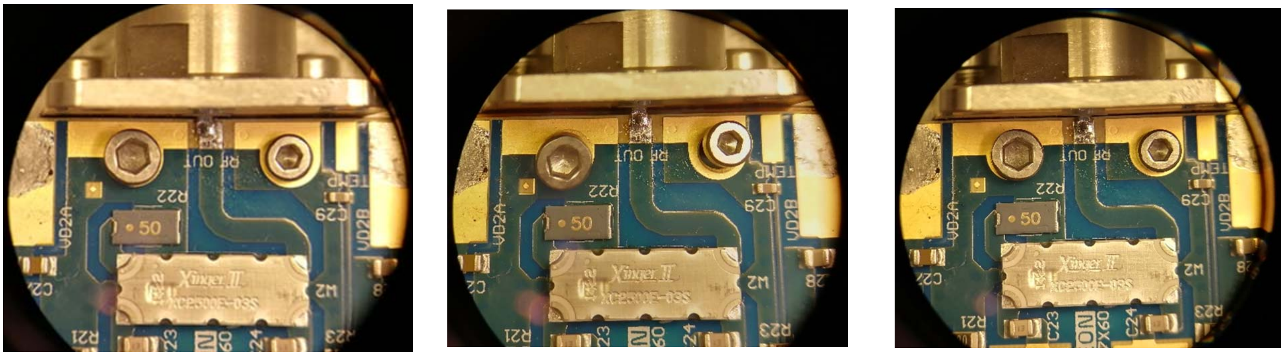
Fig 2. PCB/PCB transition from pallet to another load

2.3 RF connections: Connectors

The connector must be properly placed in order to ensure both good RF grounding and signal connection. Common mistakes are:

- Misalignment of the central connector pin
- Presence of Gap between connector's flange and pallet

Both these errors can lead to a general worsening of performance and, in some cases, to device getting broken. The central pin of the connector must be parallel to trace and positioned centrally on the RF traces. While assembling a pallet for a specific application, it is also necessary to minimize the distance between trace and the flange of connectors. A gap at output RF connector has even more impact on performance when compared to the same gap at the input, therefore it is recommended to ensure proper alignment toward RF output of pallets.
Following pictures show examples of bad positioning of connectors before soldering of central pin, versus a proper connection.



a. BAD - Misalignment of the central pin

b. BAD - Gap between PCB and connector's flange

c. GOOD - Central pin correctly positioned and ready for soldering

Fig 3. Bad and good examples of connector placement before soldering

3. DC Biasing

3.1 Biasing instructions and recommendations

Biasing for pallets is done by applying the drain voltage specified by datasheet and adjusting the gate voltage in order to set the required DC quiescent current (Idq). It is important to remark this aspect, once the operational drain voltage is applied the gate voltage must be fine tuned to set the Idq reported in the datasheet.
At the same time, once the optimum gate voltage which sets Idq has been identified, a difference in current consumption is an indicator of malfunctioning. This allows for a fast system check/failure of a pallet.
A general recommendation when applying DC to pallets is to use Feedthrough capacitors, which prevent RF signals to affect the DC lines. In that case, a proper dimensioning of the Feedthrough with the required filtering properties and current/voltage rating is necessary.

3.2 VDS vs Power-Efficiency

Data sheets report nominal bias conditions which are associated with the measurements. Changing bias may be necessary for compatibility with RF system where the pallet is employed or can be used as a way to customize power and efficiency level for the specific application.
A change in bias may imply a change in device optimum impedances and thus the need of some tuning on the matching structures, however general effects when decreasing drain supply voltage Vds are two:

- The decrease in output power
- The increase in drain efficiency

This concept is clearly exemplified by Figure 4 which reports measurements on a pallet with VDS 28 V, 30 V and 32 V with test conditions reported below.

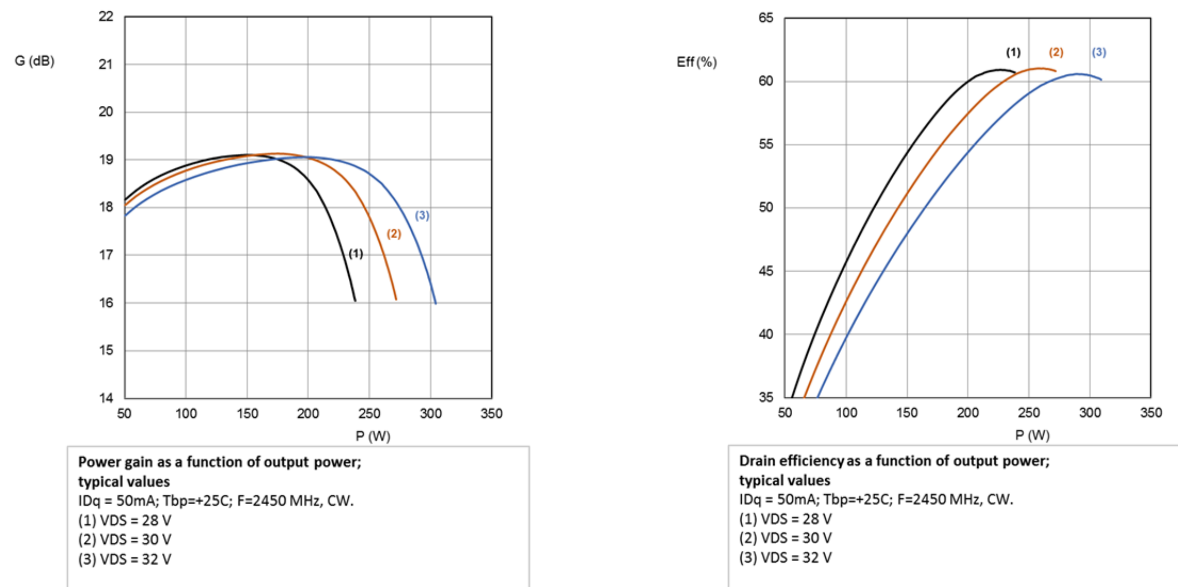


Fig 4. Gain (left) and drain efficiency (right) as a function of output power with VDS 28 V, 30 V, 32 V

3.3 Antenna effect of DC wires

DC wires may interfere with RF behaving like small antennas which affect the performance of the pallet. This effect has been observed and measured with the pallet shown below, where DC wires were needed to bring the bias from feedthrough capacitors on the side of the enclosure to the DC pads of the pallet.

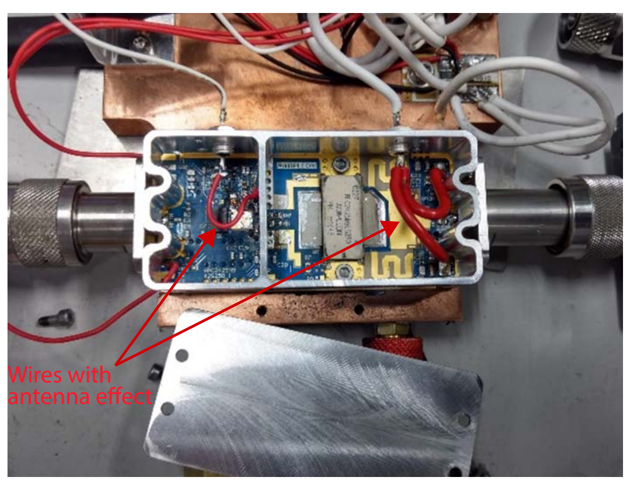


Fig 5. Red DC wires behave like small antennas, interfering with RF performance

It has been seen that bending the internal red wires corresponded to different RF performance, as shown in the following three pictures, each related to a different DC wires shape.
For this reason, it is recommended to shield pallet and avoid any interconnection internally in the enclosure.

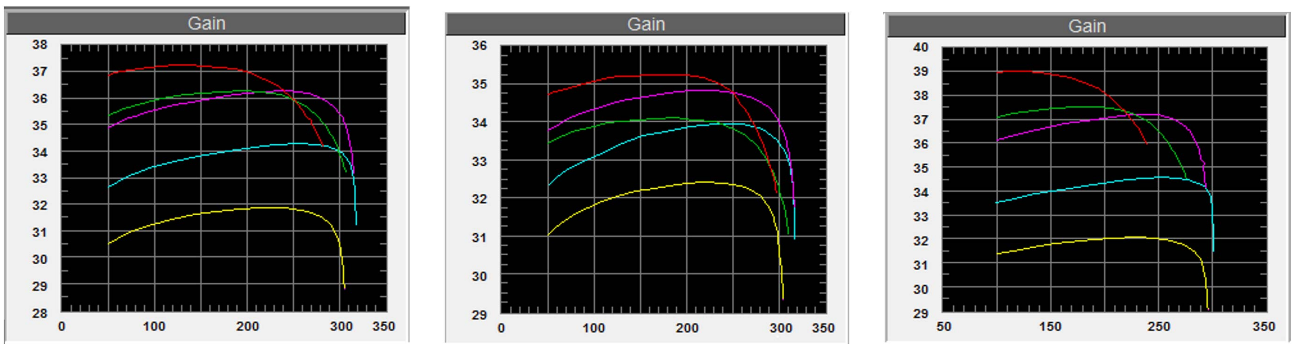


Fig 6. RF gain measured on the pallet with internal DC wires bent in three different ways. It shows that internal wires behave like small antennas, affecting performance.

4. Thermal interface between pallet and heatsink

For proper operation of pallets it is necessary to ensure thermal exchange with a heatsink, which defines the operational temperature of the pallet. A simple contact between the bottom of pallets and the heatsink (for example by bolting the pallet to the heatsink) is not enough to ensure good performance. Both pallets and heatsinks contact surfaces have a characteristic roughness which is preventing perfect contact between them and for this reason air, which is not thermally conductive, fills the gaps.
Several thermal interface materials are commercially available which address this issue, each of those characterized by different properties and characteristics.
A full comparison of commercially available thermal paste is outside the scope of this document, therefore only major compound categories and their main electrical and thermal conductivity will be analyzed.
Compounds are made from a bonding material and a filler, which is the thermally conductive part. It is possible to identify three main categories of compounds, which differ for filler material:

- Ceramic-based
- Metal-based
- Carbon-based

Ceramic (and often silicon) based compounds have the lower thermal conductivity, while metal and carbon-based are very good thermal conductors. From electrical conductivity point of view, carbon-based compounds offer the lowest conductivity followed by ceramic, while metal ones are conductive.
For pallets, it is preferable to use ceramic or silicon based compounds with good thermal conductivity, they provide good thermal exchange with the heatsink while not influencing their electrical behavior. In facts, although metal-based pastes have superior thermal properties, their electrical conductivity makes them risky: one misplaced drop could easily create short circuits and hence damage the pallet or system where applied.
Among carbon-based compounds it is recommended to avoid the electrically isolating ones because they can isolate the pallet from RF ground.

As it is possible to see from picture below (Figure 7) the thermal paste should be applied with enough quantity on the bottom of the pallet covering the area which is occupied by active devices, which has the highest heat concentration.

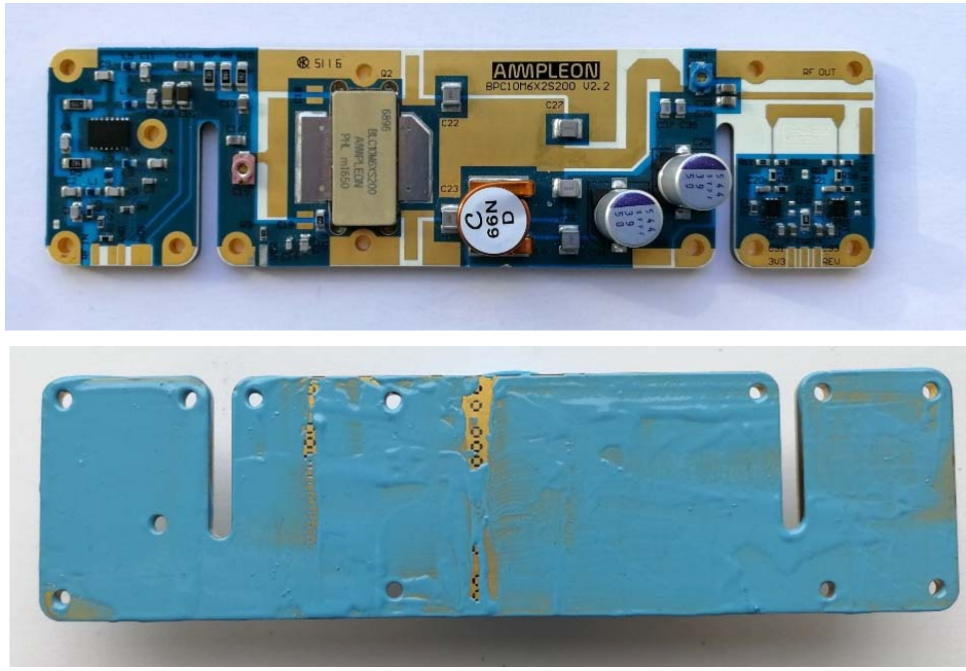


Fig 7. Top and bottom view of a pallet with thermal compound applied for a proper thermal transfer

Next table summarizes the recommended thermal interfaces compounds for pallets.

Table 2. Thermal compounds recommendation for pallets

Thermal compound	Thermal Conductivity	Electrical Conductivity	Remarks	Overall conclusions
Ceramic (Silicon)	Medium	Low	Thermal conductivity differs between pastes	Recommended
Metal based	High	High	Risk of short circuits	Risky
Carbon	High	Very Low	Prevents electrical grounding	Not recommended

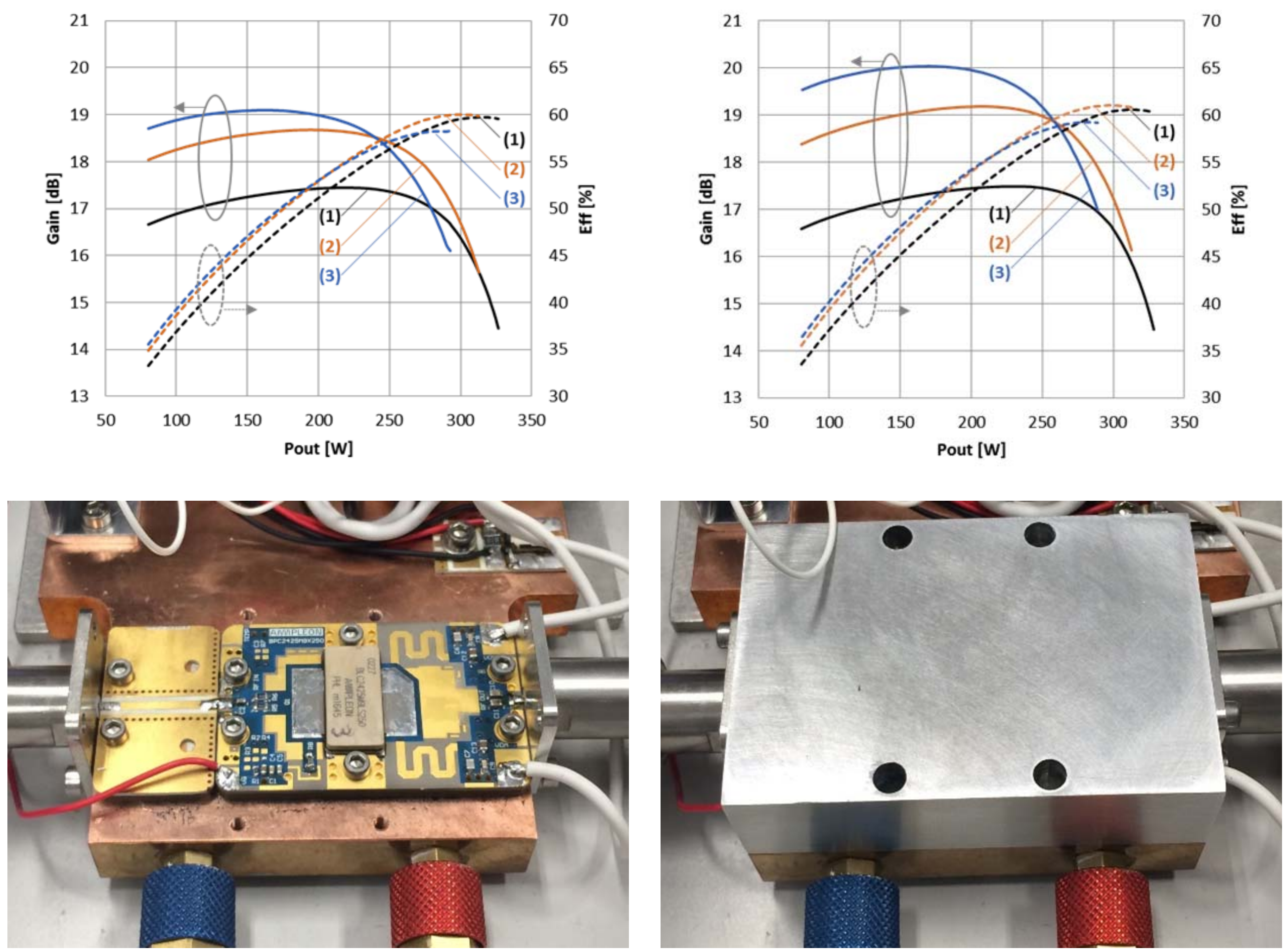
5. Shielding

n appropriate enclosure of pallets determines an improvement in performance and prevents interference from external signals.
When designing shielding these two recommendations apply.

- Lid height must be positioned at least 15 mm from PCB's top RF layers
- Lateral walls must be positioned as close as possible to the PCB to prevent internal resonation of the cavity

Following Figure 8 shows gain and efficiency measured on the same pallet without enclosure (on the left) and with appropriate shielding (right).
More efficiency and better gain are achieved when shielding is applied.

Performance without closure | **Performance with closure**



Power gain and efficiency as function of output power; typical values.

Idq = 20 mA; Tbp = 25 °C; VDS = 32 V, CW.

(1) Freq = 2.4 GHz

(2) Freq = 2.45 GHz

(3) Freq = 2.5 GHz

Power gain and efficiency as function of output power; typical values.

Idq = 20 mA; Tbp = 25 °C; VDS = 32 V, CW.

(1) Freq = 2.4 GHz

(2) Freq = 2.45 GHz

(3) Freq = 2.5 GHz

Fig 8. Pallet gain and efficiency comparison without enclosure (left) and with enclosure (right)

6. Cooling System

For proper operation, pallets must be mounted on a temperature controlled heatsink, whose function is to remove heat generated from the pallet and regulate its baseplate temperature.
Two main cooling systems exist:

- Air Cooling
- Liquid Cooling (Water)

Air cooling systems consist of metal heatsinks on top of which pallets are installed, during operation air is forced onto the heatsink to carry away heat. This means that fans are integrating part of the cooling system and must be put close to the heatsink.
Liquid cooling, mostly identified with water cooling, is when a liquid is pumped into a cooling plate over which the pallet is mounted.

Water cooling proves to be more efficient in terms of heat removing capabilities and is therefore mostly used during testing of pallets; test fixtures are provided with connectors for water hoses as shown in following Figure 9.

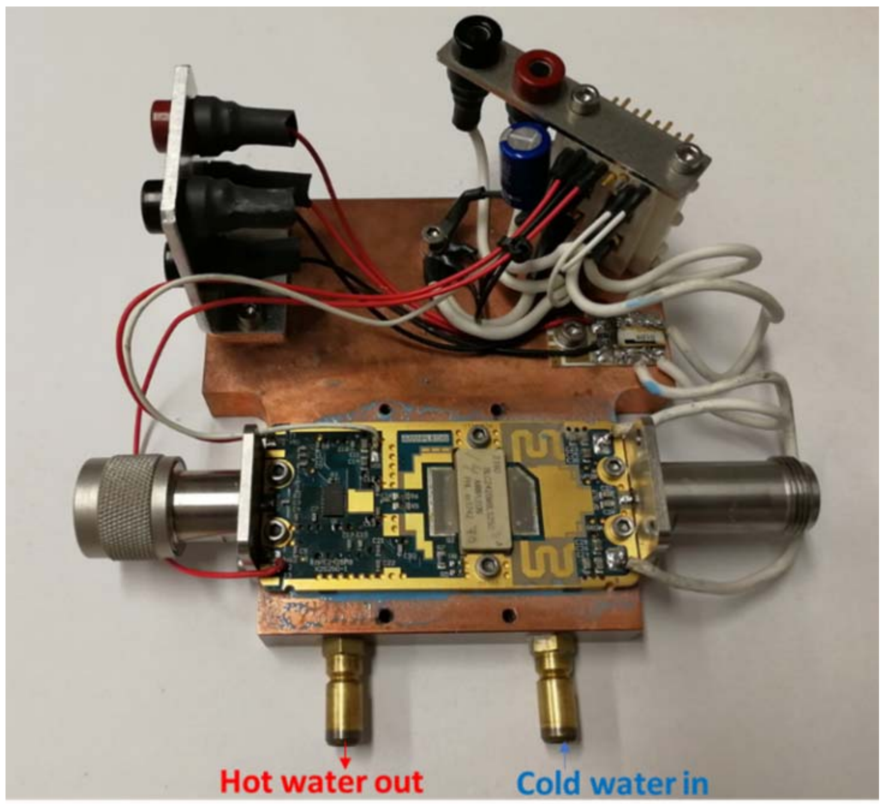


Fig 9. Water cooling system in the test fixture

Cooling improves performance, as can be seen from Figure 10, which shows gain and efficiency measured with baseplate temperature of 5 °C, 25 °C, 40 °C and 60 °C.
It is evident that better efficiency and more power are obtained with a baseplate temperature of 5 °C.

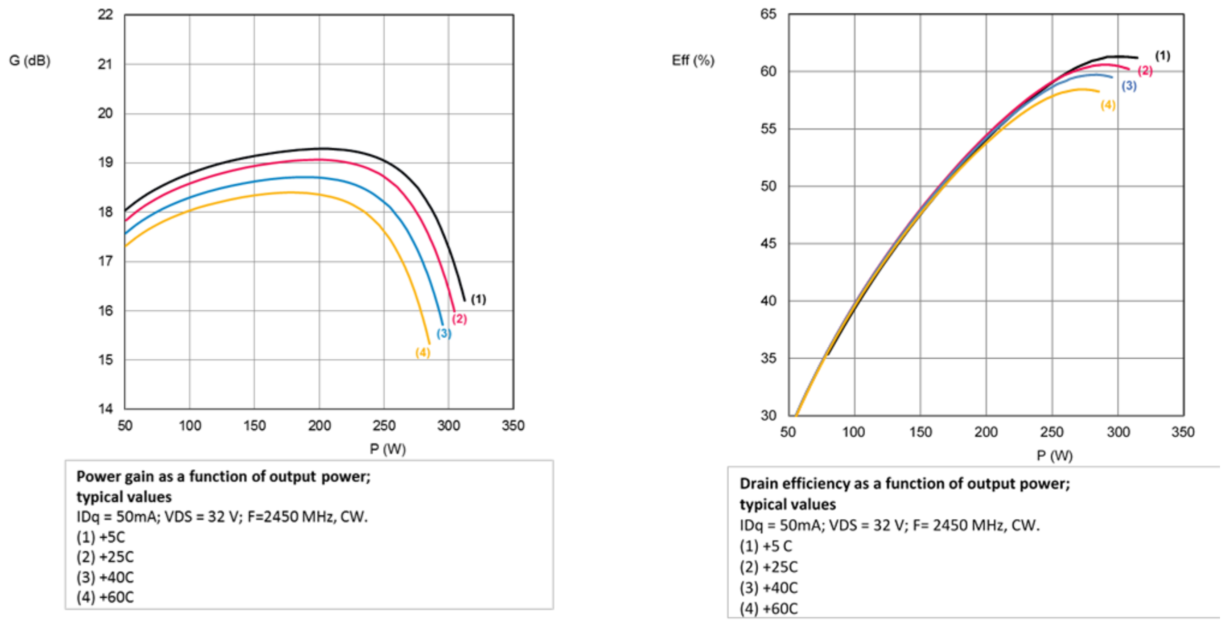


Fig 10. Gain (left) and drain efficiency (right) as a function of output power with 5 different baseplate temperatures. Power and efficiency increase with lower temperatures.

7. Thermal sensors usage

Pallets are provided with thermal sensors which allow the monitoring of transistors' and baseplate's temperature. Sensors used in pallets are thermistors and they provide a resistance value which changes with temperature.
On pallets the output pins which are connected to thermistors are identified with "T" as in the following pallet:

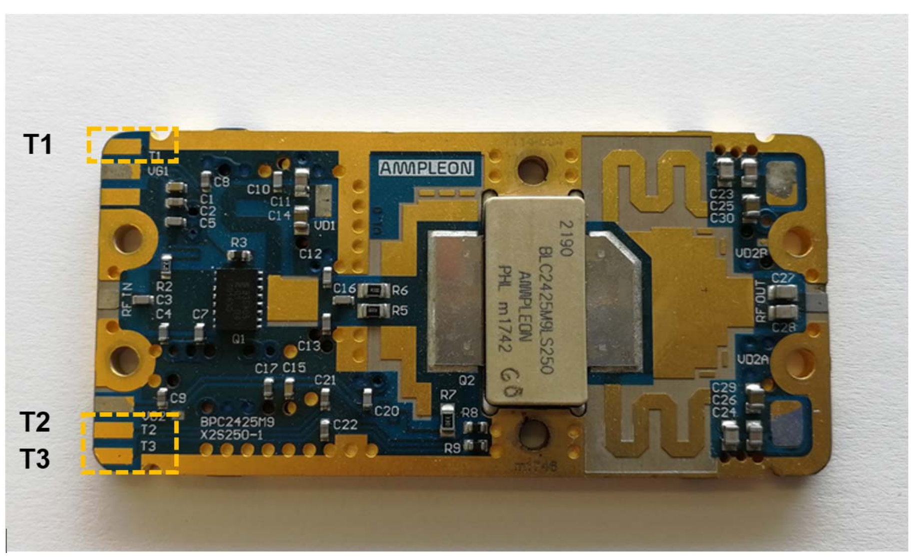


Fig 11. Temperature sensor output pins highlighted in the picture

The temperature information can be used to compensate bias current Idq change due to temperature by adjusting gate bias voltages.

Following Figure 12 is an example of an interfacing circuit which linearizes and processes data coming from thermal sensors:

- T1 monitors temperature of the driver
- T2 monitors temperature of the final
- T3 monitors temperature of the pallet

After temperature information is retrieved, the control board adjusts the bias of pallet accordingly.

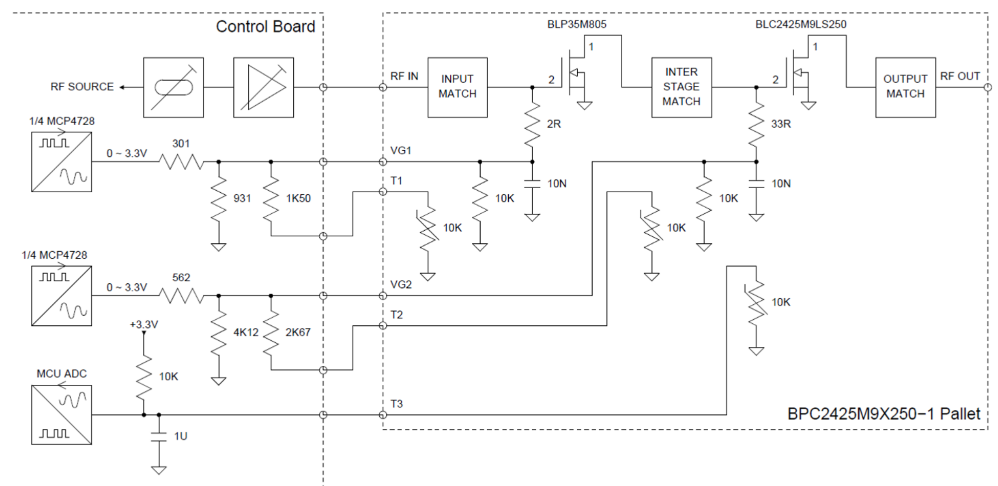


Fig 12. Thermal sensors Interfacing circuit which gathers and processes data and provides bias to pallet

Following is the functional description of the main blocks which constitute the interfacing circuits: numbers are referred to the blocks highlighted in Figure 13.
The first step is to characterize the pallet to determine the target Vgs values for the temperature range in the specific application. This is recommended because Vgs (threshold) is dependent upon junction temperature but the thermistors sense pallet PCB surface temperature and the relationship between these two temperatures is somewhat dependent upon how the pallet is cooled in the final application.
In order to determine target Vgs values, the final application should operate at rated output power over a range of temperatures (e.g. in a thermal chamber or by changing the temperature of the cooling liquid). After stabilizing at each temperature, RF drive can briefly be turned off, while Vgs is manually adjusted to restore the target Idq.
The voltage needed to restore target Idq is recorded as the target Vgs for this temperature.
Note that the temperature for this purpose must be calculated from the resistance of the thermistor which will be used to compensate this Vgs, as each thermistor may be at a different temperature.

In the scheme, nonvolatile DACs on the control board (Block 1) are used to set the bias voltages of the pallet's driver and final transistors.
For each stage, one of the pallet's thermistors is used to change the applied Vgs voltage to compensate for the linear change in Vgs(threshold) over temperature. A 3-resistor network (Block 2) is used to approximately linearize the thermistor's nonlinear response.

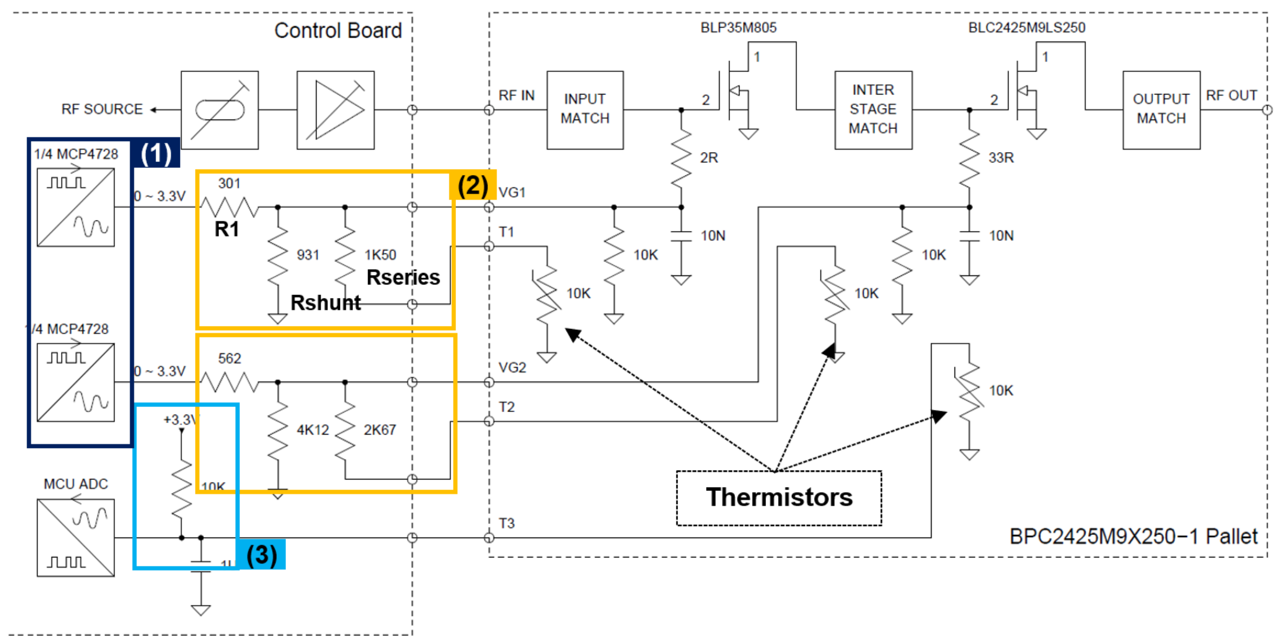


Fig 13. Thermal sensors interfacing circuit with highlighted main functional blocks

The resistance seen from the DAC (Block 2 resistance + Thermistor) is obtained with following:

(1)

$$R_{total} = R_1 + \frac{R_{shunt}(R_{series} + R_{thermistor})}{R_{shunt} + R_{series} + R_{thermistor}}$$

Assuming DAC_{Vout} the fixed output voltage of DAC, following compensated VGS is obtained:

(2)

$$VGS_{compensated} = DAC_{Vout} - R1\frac{DAC_{Vout}}{R_{total}}$$

The third thermistor on the pallet is used to measure pallet temperature. A pull-up resistor to a reference voltage (Block-3) is used to generate a voltage within the input range of an ADC (e.g. the MCU's internal ADC), and the temperature can be calculated in the MCU by means of the table of resistance vs temperature provided by the thermistor manufacturer.

There are available options for pallets where a voltage divider is integrated on PCB (already compensated). In that case, it is just needed to apply constant Vgs.

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Date of release: 25 June 2024
Document identifier: AN10900