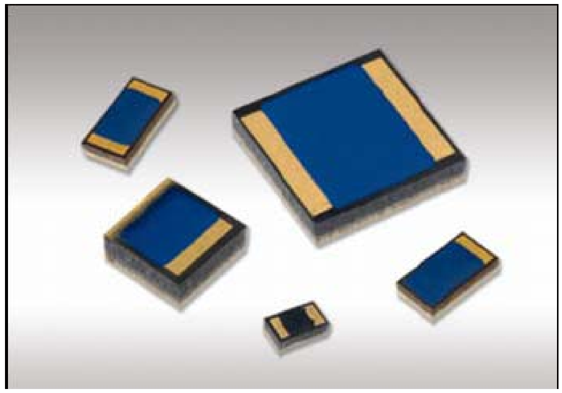
CVD Diamond High Power Resistors and Terminations
Application Note 0022



General Description:

There are many applications in RF design where it is necessary to absorb large amounts of RF power. In order to effectively absorb large amounts of power, resistors and terminations must be constructed on materials that have a high coefficient of thermal conductivity.

Commonly used substrates for high power resistors and terminations are Beryllia, Aluminum Nitride, and to a lesser extent, Boron Nitride and Silicon Carbide. While these materials are known for their superior thermal properties, none of them come even close to matching the thermal conductivity of CVD Diamond.

For example, while Beryllia and Aluminum Nitride have thermal conductivities of 285 and 185 W/m-K respectively, CVD Diamond comes in at a whopping 1000 to 1800 W/m-K. This is about 3 to 4 times that of copper. This huge increase in thermal conductivity enables RF Component Designers to produce RF components such as resistors, terminations, attenuators, power dividers, and couplers that are smaller, dissipate more power, and can operate at higher frequencies. These devices typically can provide superior RF performance for any specified power level up to 26.5 GHz and beyond.

But the outstanding thermal properties of CVD Diamond are only part of it’s allure. CVD Diamond is also an incredibly stable material since it is essentially chemically inert at temperatures below 300°C. In air, CVD Diamond is unconditionally stable at temperatures up to 600°C while in a vacuum or reducing atmosphere it is unaffected by temperatures exceeding 1,200°C . This makes it unquestionably the material of choice for high reliability and space applications.

Mounting Instructions:

CVD Diamond components manufactured by EMC Technology are designed to be mounted using conventional mounting techniques. The backside ground plane of the device is sputter coated with a solderable metal and finished with about 150 nm (5.9 micro-inches) of pure gold.

The easiest method of attaching the device to a suitable heat sink is by soldering the unit with Sn96 solder (96.5% Tin / 3.5% Silver). This is a eutectic alloy that melts at 221°C (430°F) and gives excellent results. It is permissible to bring the CVD device momentarily to 300°C for 10 seconds or less to ensure adequate wetting of the surface.

These devices can also be mounted using conventional Gold-Tin Eutectic Die Bonding techniques which melt at 280ºC for the ultimate in thermal management. As with soldering, the CVD Device temperature should be kept to 300ºC or less and for not longer than 10 seconds.

Dissipating the Heat:

Resistors and Terminations manufactured on Diamond Substrates have the ability of dissipating huge amounts of thermal energy in spite of their extremely small size. Therefore, the heat sink should be constructed of a high thermal conductivity material such as copper and sized according to good thermal management practices. The physical size of the heat sink will be approximately the same as with any conventional device dissipating the same amount of thermal energy.

Aluminum heat sinks can also be used, but it should be noted that the thermal conductivity of aluminum is approximately one-half that of copper. In situations where weight is a concern, an acceptable compromise would be to mount the CVD Diamond device on a copper heat spreader which in turn is attached to the aluminum heat sink.

For particularly demanding applications, insulating or electrically conductive diamond heat spreaders are available to effectively transition the heat from the CVD device to an external chassis or bulkhead for further removal. Diamond heat spreaders are extremely small and lightweight providing a highly efficient and convenient method of removing the heat from a circuit board to an external heat sink when space and weight is limited. Please contact the factory for additional details.

Good Thermal Practices:

Figure 1 shows the typical thermal path of a CVD device mounted on a copper heat sink.

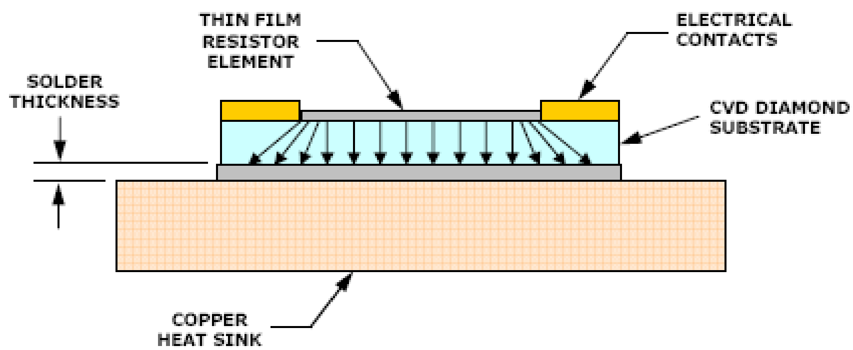


Figure 1

The thermal resistance across the attachment interface has a significant affect on the performance of the device. For instance, at 50 watts, the temperature differential across a Sn96 solder interface that is only 0.002 inches thick would be about 39°C for a device measuring 50 mils square. This is greater than the temperature differential across the entire CVD Diamond substrate at the same power level. Therefore, it is important to maintain the thickness of the solder to between 1 and 3 mils. For every 1 mil increase in the thickness of the solder, the temperature of the device will increase by approximately 20°C therefore reducing its ability to absorb power.

When soldering the CVD Diamond device to the heat sink, avoid introducing small pockets of air and flux, called solder voids, between the device and the heat sink. It is essential that solder voids be eliminated or at least reduced as much as possible in order to maximize the power handling capability of the device. Even small solder voids can substantially reduce the efficiency of the thermal interface resulting in devices that run considerably hotter than necessary.

The thermal integrity of the soldered connection can easily be determined by measuring the temperature of the top surface of the device and comparing it with calculated data. For example, for a 50 mil square resistor running at 50 watts, the top surface of the device would normally measure about 60°C to 70°C higher than the heat sink temperature. If the device temperature is substantially higher than this, the solder interface should be considered suspect and be evaluated for voids or other discontinuities.

Other silver-tin solder compositions such as Sn95 and Sn94 and many Lead-Free formulations can also be used with almost no degrading of performance. However, when using Tin-Lead solders such as Sn63 which have a melting temperature of 183°C, the maximum permissible input power or the heat sink temperature should be reduced to prevent the solder from melting. For example, a part rated at 50 watts on a 100°C heat sink should be derated by about 30% to 35 watts maximum when attached with Sn63 solder.

Silver Filled Epoxies can provide a very high-strength mechanical bond, however, they should be used with caution due to their generally lower thermal performance. Consult with the manufacturer of the epoxy for the correct curing profile. The thermal conductivity of the epoxy can vary widely depending on how the curing is performed. We recommend derating the maximum power rating of the CVD Diamond device by 50% when using epoxies.

Temperature Differential:

As a general rule of thumb, the temperature differential across the attachment material, whether it be solder or epoxy, should not exceed 40°C at the maximum rated power of the device. It can be calculated by the following expression:

$$\Delta T = \frac{100 \times P \times t}{K \times A}$$

where: ΔT = Temperature Differential in °C
t = thickness of the interface in cm
P = Power in watts
A = Area in Square-cm
K = Thermal Conductivity in W/m-K

Typical values for the Coefficient of Thermal Conductivity of commonly used attachment materials are listed in the table below (Figure 2):

Commonly Used Attachment Materials

Material	Composition	Thermal Conductivity (W/m-K)	Melting Temperature (°C)
Gold-Tin Solder	80% Gold / 20% Tin	57	280
Lead-Free Solder	99.3% Tin – 0.7% Copper	65	227
Lead-Free Solder	96.5% Tin / 3.5% Silver	78	221
Lead-Free Solder	95.5% Tin / 3.8% Silver / 0.7% Copper	55 to 60	217 - 220
Sn-63 Solder	63% Tin / 37% Lead	50	183
Conductive Epoxy	Silver Filled	1.7 to 29	N/A

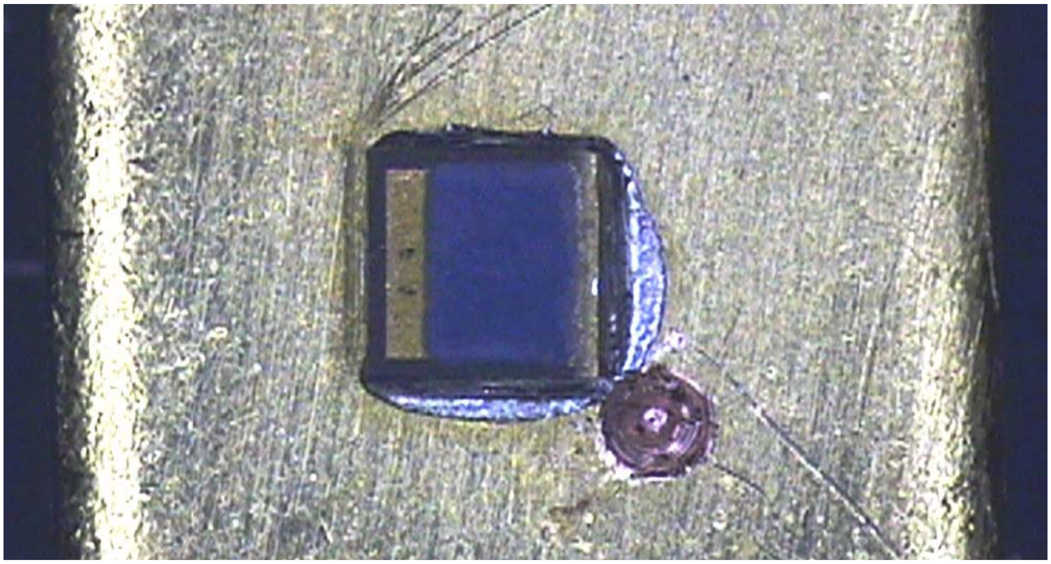
Figure 2

Flange Mounting:

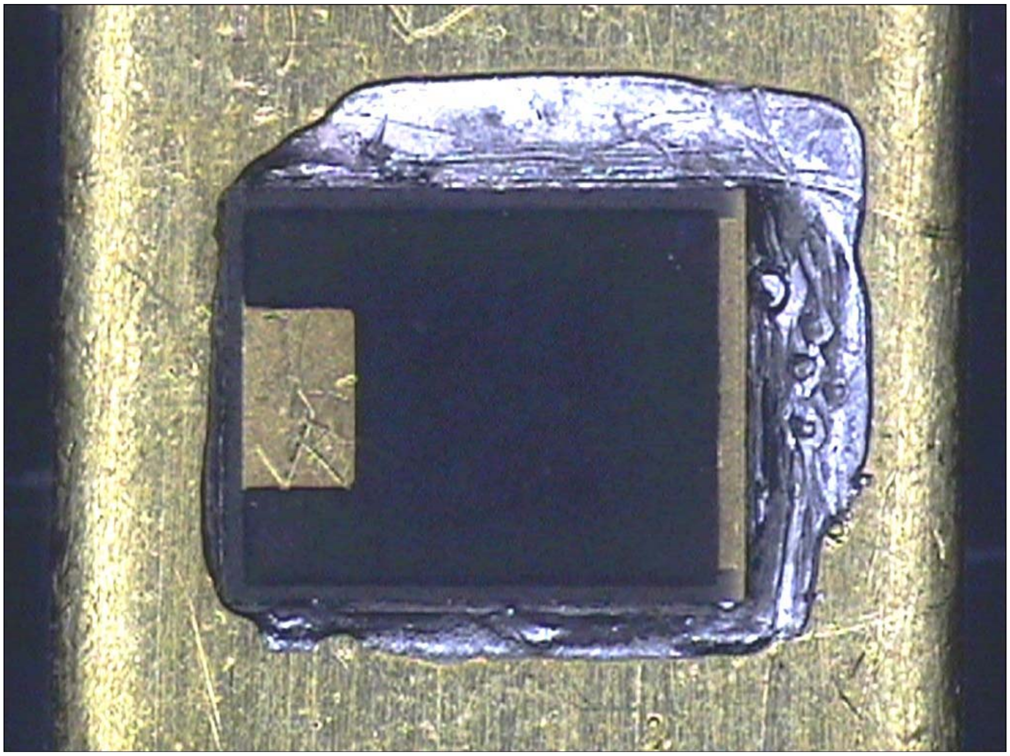
A convenient way of mounting diamond resistors and terminations for good thermal performance is to first solder the devices to a copper flange, then screw the flange to a suitable heat sink. A small amount of thermal grease between the flange/heat-sink interface will assure a good thermal contact. This method of assembly eliminates the necessity of bringing the entire heat sink up to soldering temperature. Also, it allows the use of the existing external case or enclosure to be used as a heat dissipating surface instead of a dedicated heat sink, thereby saving space and weight.

Shown below are typical views of diamond terminations mounted on gold plated copper flanges. Sn96 solder (96% Tin / 4% Silver) was used for attachment (Liquidus at 221ºC).

CT0505D & CT1310D Soldered to Gold Plated Copper Flange.



Close-up View of CT0505D Soldered to Copper Flange
The counterbore to the bottom-right of the device is for a thermocouple to measure flange temperature during power testing.



Magnified View of CT1310D Soldered to Copper Flange

Flip Chip Mounting:

The preferential method of mounting diamond resistors and terminations is with the bottom of the chip securely attached to a suitable heat-sink of sufficient size to ensure maximum power dissipation. However, flip chip mounting can be considered when other considerations such as RF performance or capacitance to ground are of paramount importance. When using flip-chip mounting, most of the thermal energy will be dissipated by conduction through the electrical contacts. A small amount of the heat will also be dissipated from convection and radiation. Therefore, the maximum power rating of the device should be derated based on the physical geometry of the surrounding circuit.

As an example, a CR0505D 50 Ohm resistor was attached to a microstrip line in a flip-chip configuration. The device was submitted to various power levels and the chip temperature was monitored. The graph in Figure 3 below shows the actual measured temperature on the exposed (top) side.

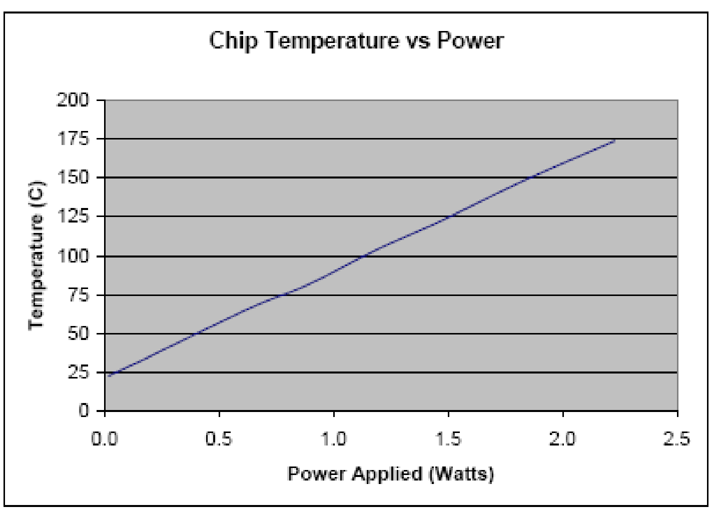
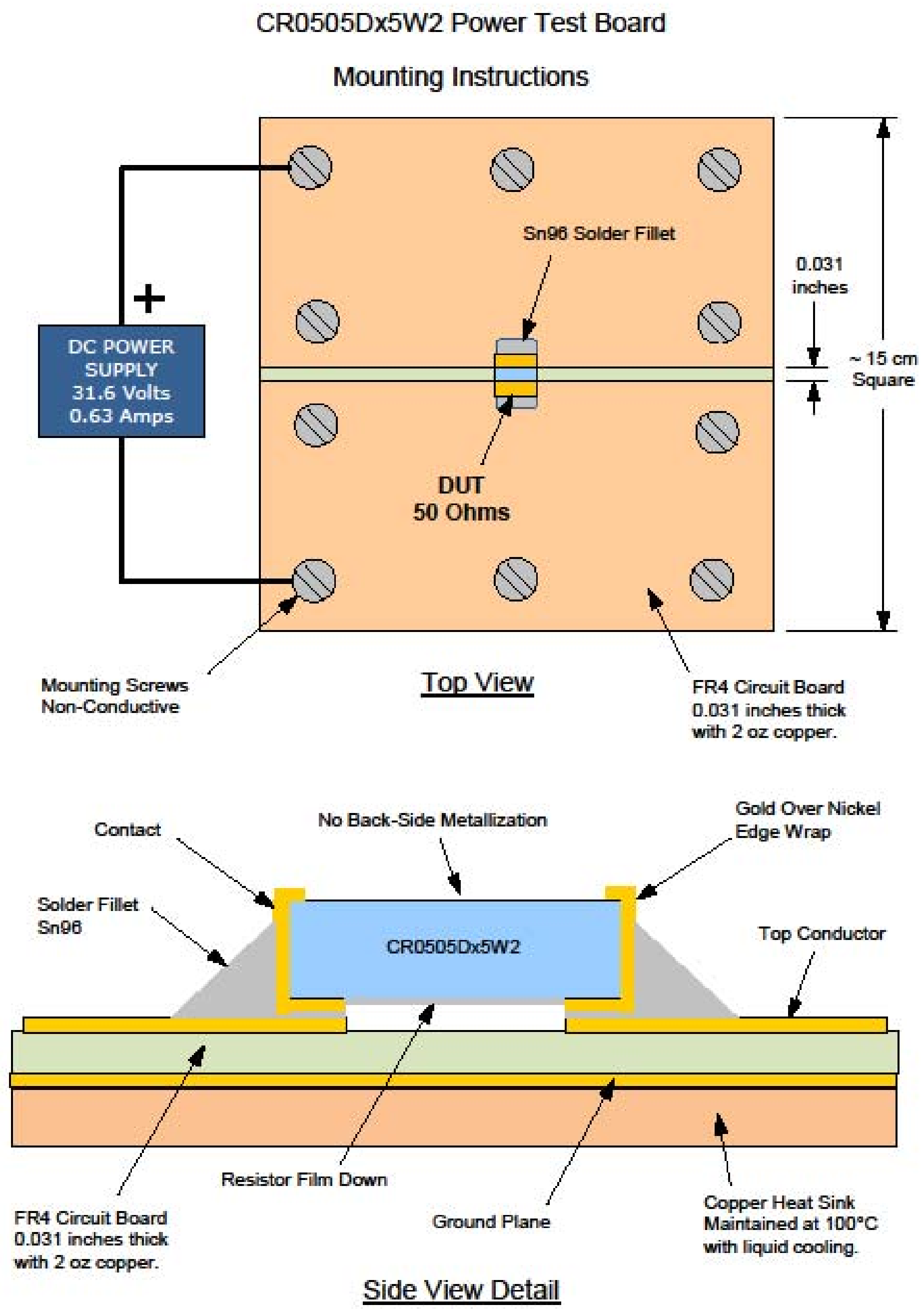


Figure 3

NOTE: Operation above 150ºC is not recommended.

In order to achieve maximum power dissipation, the test jig used during device Qualification and High Reliability power (burn-in) testing consists of a PCB with a large metallized area and a gap sized to fit the device's resistive area between the I/O terminals. Parts are soldered to the copper using SN96 to form large solder fillets. A DC Voltage with sufficient current needed to achieve the specified burn-in wattage is applied to the device. The PCB is mounted to a liquid cooled heatsink that is maintained at the specified device base temperature (typically 100ºC). The device base temperature is monitored by a thermocouple placed on the solder fillet which regulates the heatsink coolant flow through a controller.



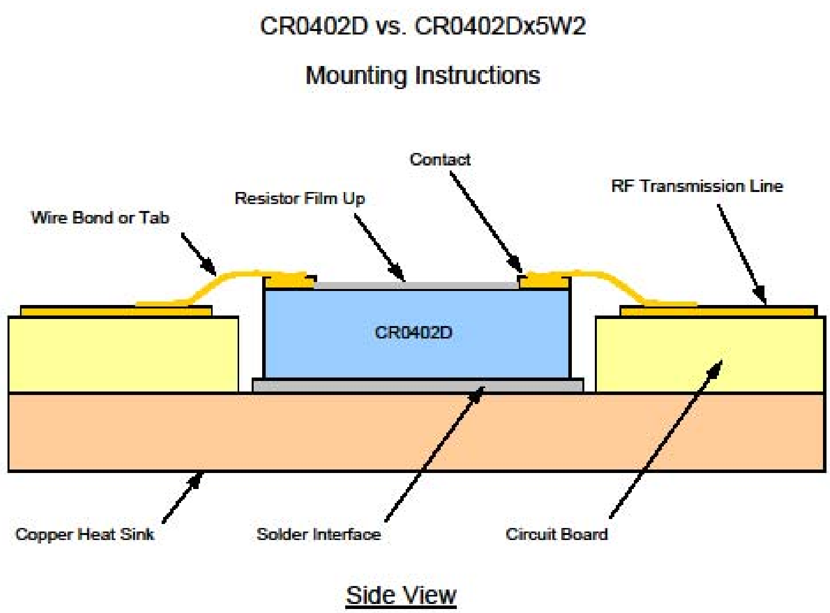
Flip Chip Mounting Power Test (Burn-In) Board and Mounting Details

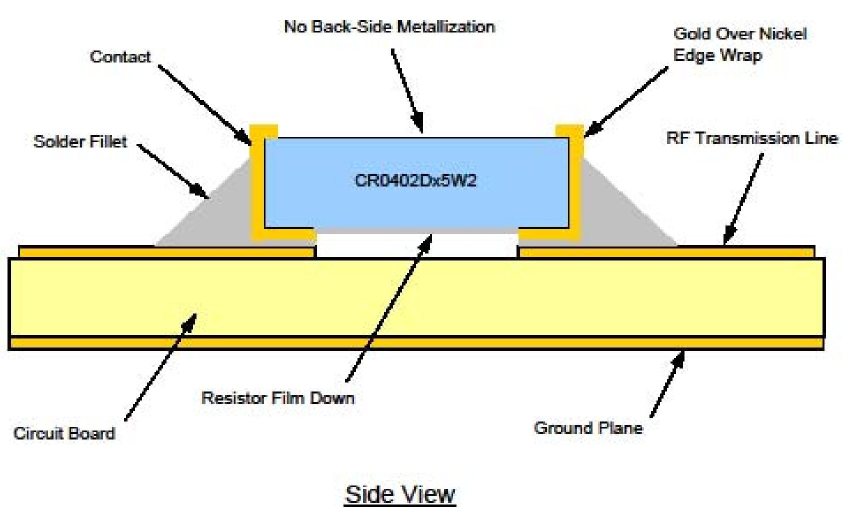
Input Connections:

The top side connections are finished with about 2.5 microns (99 micro-inches) of sputtered gold over a proprietary solderable metal. These electrical contacts are designed to be soldered or wire bonded to the external circuit.

When wire bonding, conventional ultrasonic and thermo-compression wedge bonding techniques are recommended. The attachment wires can be either 1 mil diameter gold wire or 1x3 mil gold ribbon. Multiple wires should be used to reduce the input inductance and to increase the current capability of the connection.

Tabs can also be attached to the input pads using commonly available solders such as those shown in Figure 2. Tab dimensions are typically between 10 mils and 63 mils wide and up to 0.5 inches long.

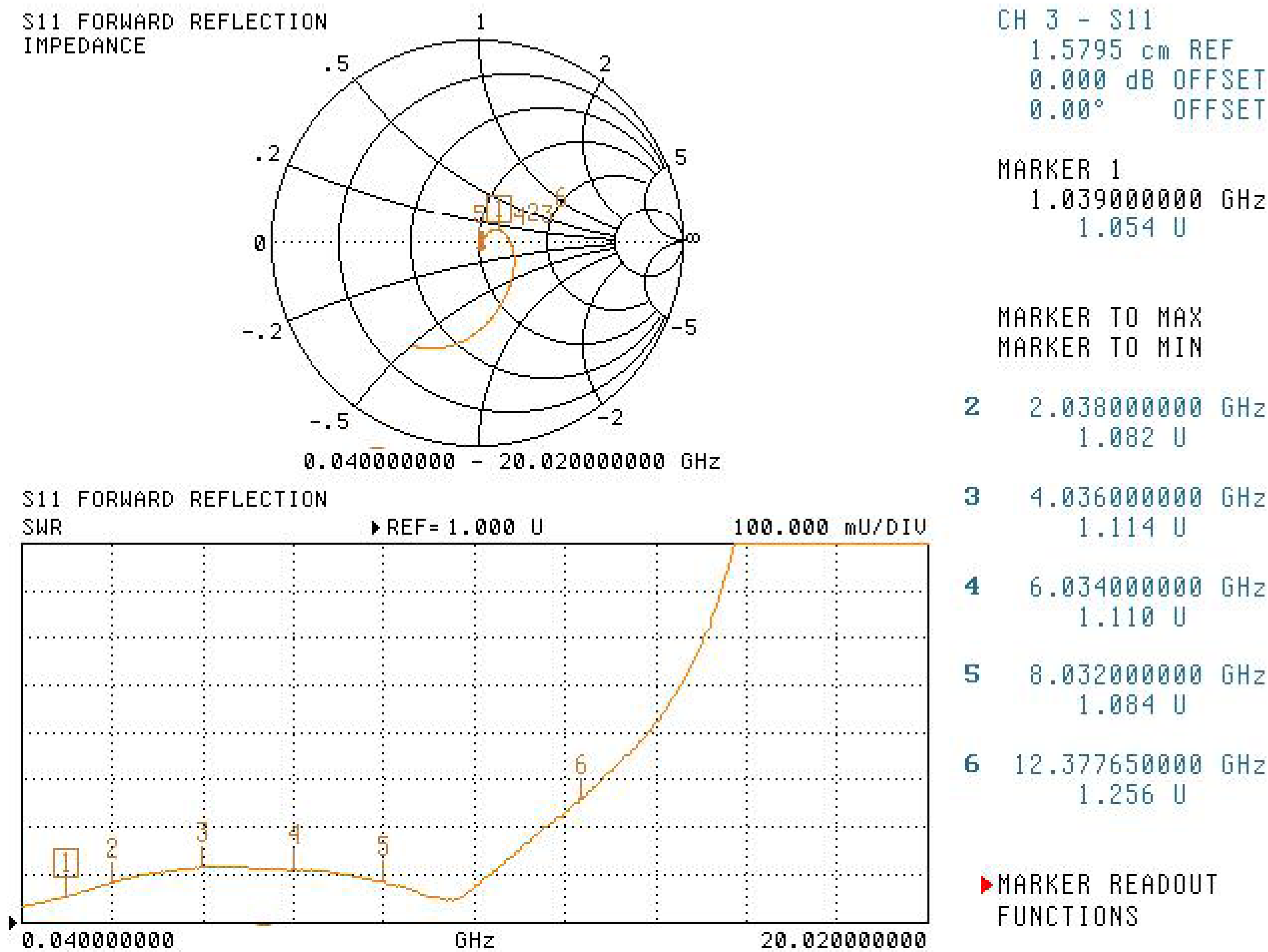




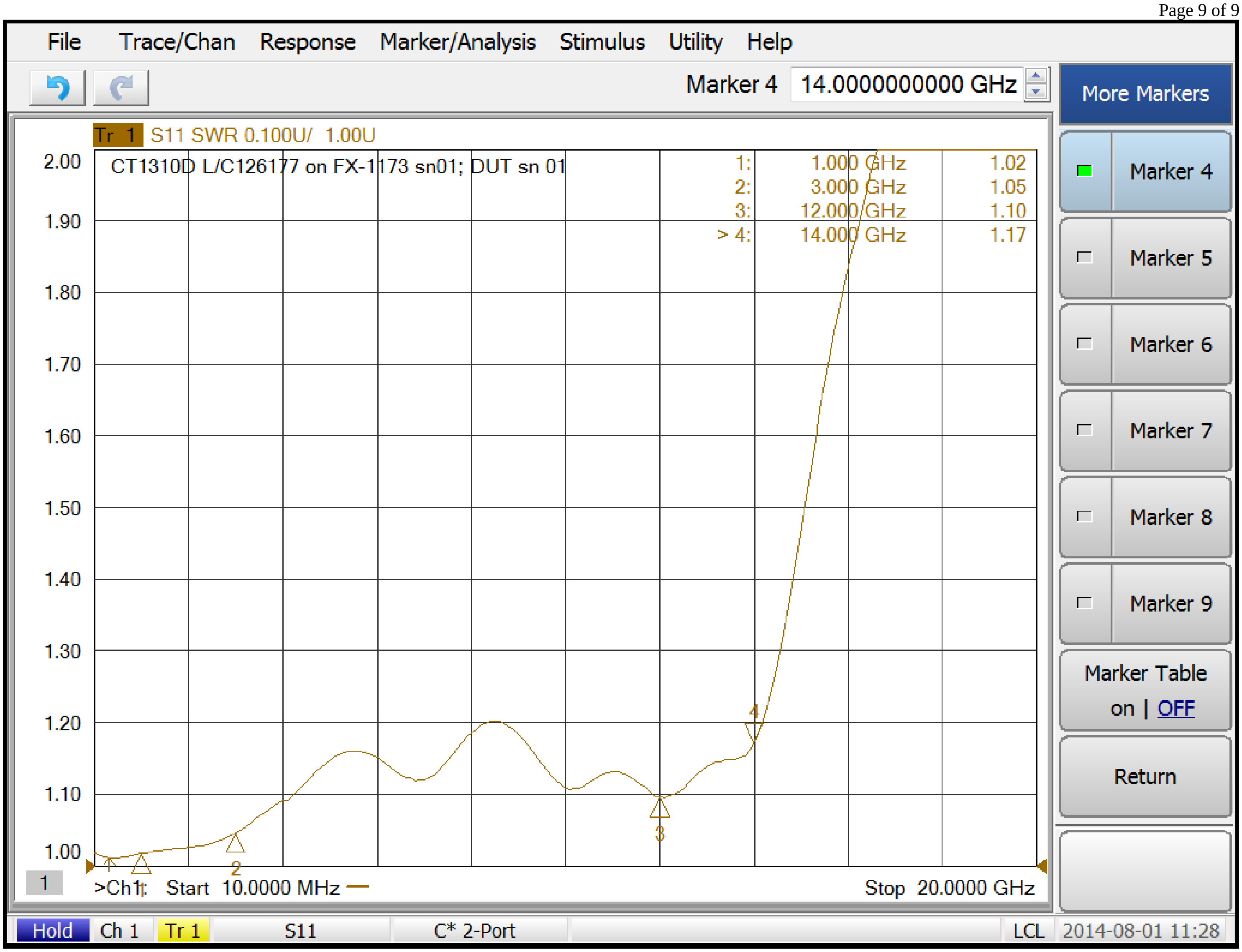
Wire Bond vs Flip Chip Mounting Details

RF Performance:

Typical RF Performance for the CT1310D Termination



For RF performance of other part numbers, please see Specification Control Document.



File
Trace/Chan
Response
Marker/Analysis
Stimulus
Utility
Help
Marker 4
14.0000000000 GHz
More Markers
Tr 1 S11 SWR 0.100U/ 1.00U
CT1310D L/C126177 on FX-1173 sn01; DUT sn 01
1: 1.000 GHz 1.02
2: 3.000 GHz 1.05
3: 12.000 GHz 1.10
> 4: 14.000 GHz 1.17
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
>Ch1: Start 10.0000 MHz
Stop 20.0000 GHz
Marker 4
Marker 5
Marker 6
Marker 7
Marker 8
Marker 9
Marker Table
on | OFF
Return
Hold
Ch 1
Tr 1
S11
C* 2-Port
LCL
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