# General Hybrid and Directional Coupler Application Note



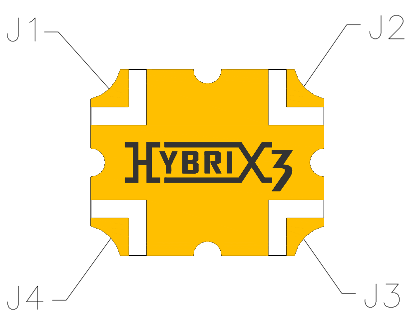
## Introduction

Couplers are widely used in many RF and microwave systems for various purposes. The construction of couplers consists of two transmission lines in close proximity. RF energy passing through one of the transmission lines is coupled to the other. When the coupling factor is low, such as in the case of directional couplers, these devices are ideal for signal sampling and as antenna feeds. Hybrid couplers are directional couplers with a -3 dB coupling factor. There is a 90º phase difference between the two output ports of typical hybrid couplers. These devices are generally used for power combining and dividing.

There are various ways to construct directional and hybrid couplers. Most surface-mount couplers use a multi-layered construction with broadside coupling structure. This type of construction offers many advantages over the more easily implemented microstrip edge-wise coupling structure, including smaller footprint and higher isolation. Material used in the multi-layered construction is traditionally PTFE. However, recent breakthrough in LTCC (Low Temperature Co-fired Ceramic) technology has allowed for further size reduction and higher power handling without other performance losses.

## Performance Specification Definitions

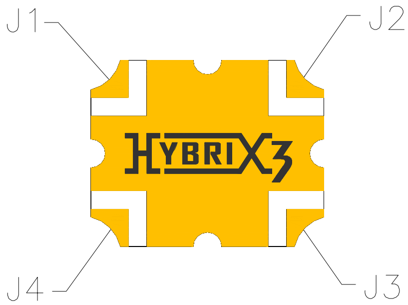
### Directional Couplers




| Directional Coupler Port Designations | | | | |
|---|---|---|---|---|
| | J1 | J2 | J3 | J4 |
| J1 | - | Out | Isolated | Coupled |
| J2 | Out | - | Coupled | Isolated |
| J3 | Isolated | Coupled | - | Out |
| J4 | Coupled | Isolated | Out | - |

| Performance Specification Definitions for Directional Couplers | |
|---|---|
| VSWR | $VSWR = \frac{V_{\max}}{V_{\min}}$ |
| Return Loss | $RL(dB) = 20 \cdot \log\left(\frac{VSWR+1}{VSWR-1}\right)$ |
| Coupling | $C(\omega_n) = 10 \cdot \log\left(\frac{P_{in}(\omega_n)}{P_{coupled}(\omega_n)}\right)$ |
| Insertion Loss | $IL(dB) = 10 \cdot \log\left(\frac{P_{in}}{P_{coupled} + P_{direct}}\right)$ |
| Directivity | $Directivity(dB) = 10 \cdot \log\left(\frac{P_{coupled}}{P_{isolated}}\right)$ |

## Hybrid Couplers

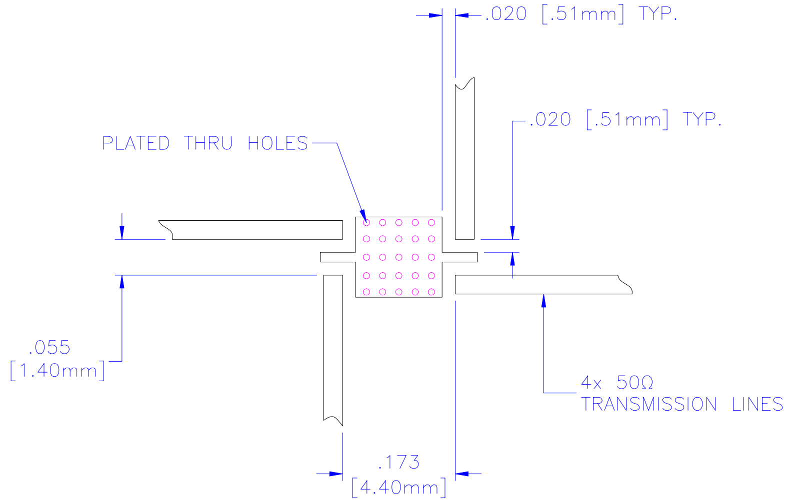



| Hybrid Coupler Phase Table | | | | |
|---|---|---|---|---|
| | J1 | J2 | J3 | J4 |
| J1 | - | Isolated | -90º | 0º |
| J2 | Isolated | - | 0º | -90º |
| J3 | -90º | 0º | - | Isolated |
| J4 | 0º | -90º | Isolated | - |

| Performance Specification Definitions for Hybrid Couplers | |
|---|---|
| VSWR | $VSWR = \frac{V_{max}}{V_{min}}$ |
| Return Loss | $RL(dB) = 20 \cdot \log\left(\frac{VSWR+1}{VSWR-1}\right)$ |
| Insertion Loss | $IL(dB) = 10 \cdot \log\left(\frac{P_{in}}{P_{coupled} + P_{direct}}\right)$ |
| Isolation | $Isolation(dB) = 10 \cdot \log\left(\frac{P_{in}}{P_{isolated}}\right)$ |
| Phase Balance | $PhaseBalance = Phase_{coupled} - Phase_{direct}$ |
| Amplitude Balance | $\text{Amplitude Balance, coupled port } (dB) = 10 \cdot \log\left(\frac{P_{coupled}}{\left(\frac{P_{coupled} + P_{direct}}{2}\right)}\right)$ <br> $\text{Amplitude Balance, direct port } (dB) = 10 \cdot \log\left(\frac{P_{direct}}{\left(\frac{P_{coupled} + P_{direct}}{2}\right)}\right)$ |

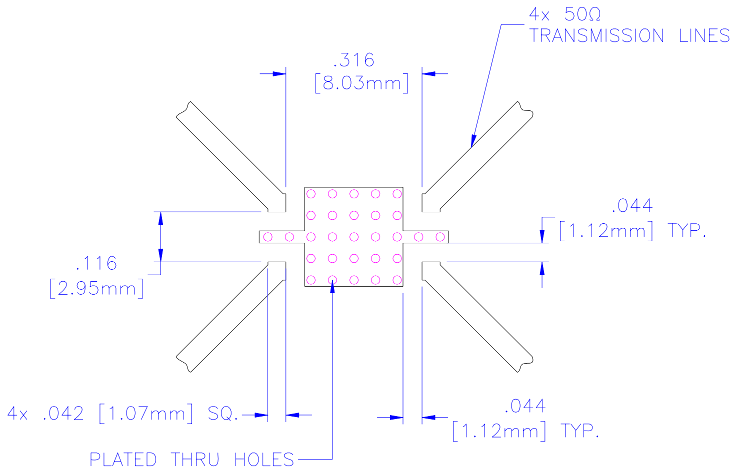
## Suggested Footprints

Size Code: F



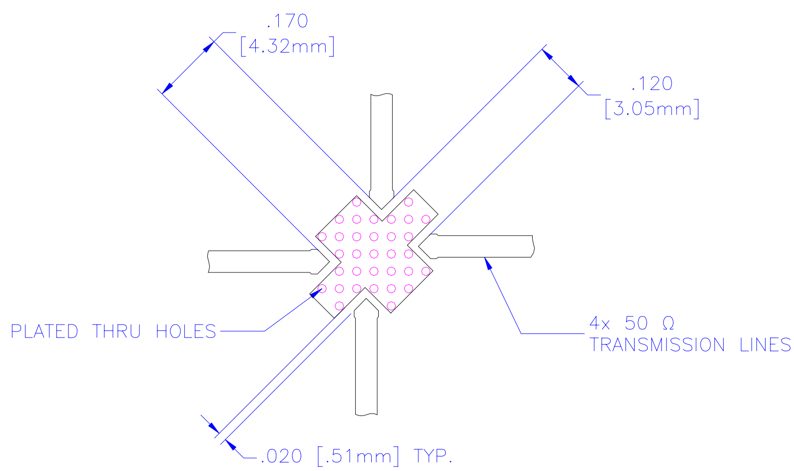

SUGGESTED FOOTPRINT FOR F-SIZED COUPLERS (.236 IN. x .118 IN.)
APPLICABLE TO: HFx3F

Size Code: U



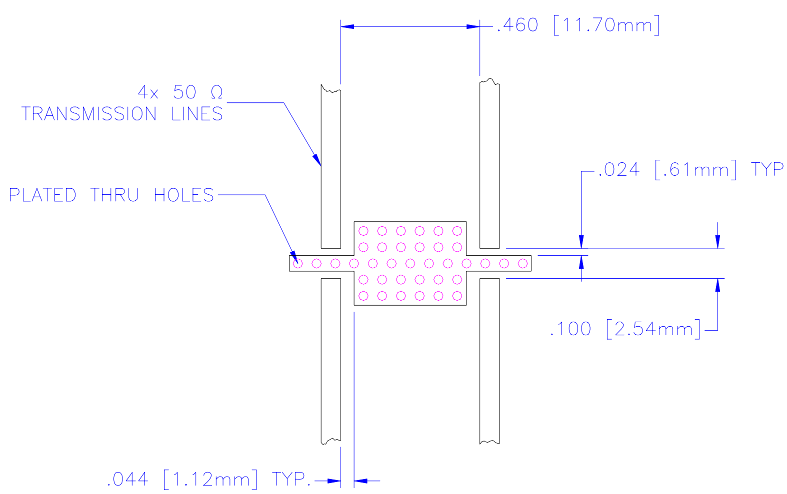

SUGGESTED FOOTPRINT FOR U-SIZED COUPLERS (.400 IN. x .200 IN.)
APPLICABLE TO: HUx, HUx2F

## Size Code: P



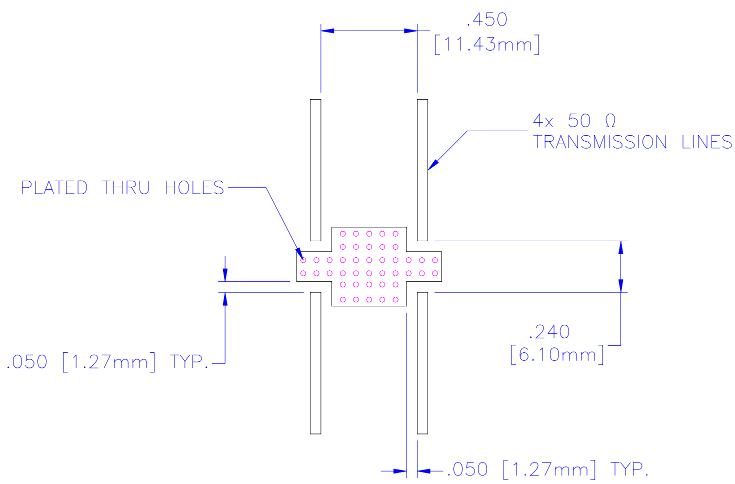

SUGGESTED FOOTPRINT FOR P-SIZED COUPLERS (.250 IN. x .200 IN.)
APPLICABLE TO: HPx, HPx2F, HPx3F, D3PxxxF, DCPx3F

## Size Code: M



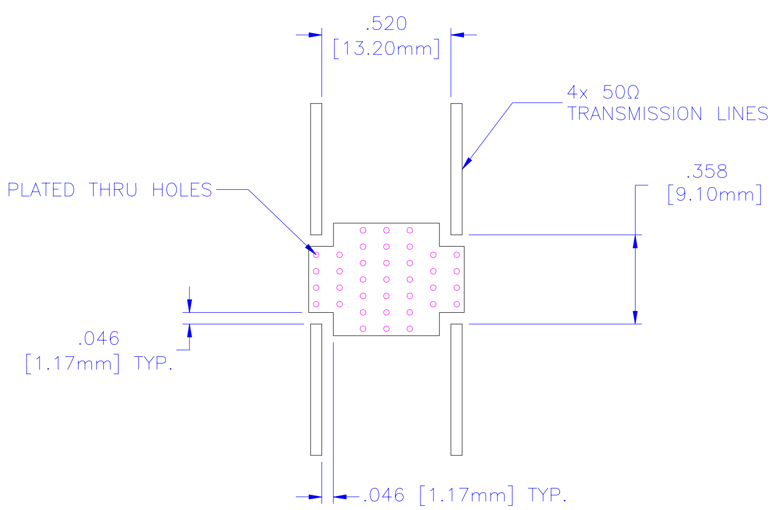

SUGGESTED FOOTPRINT FOR M-SIZED COUPLERS (.560 IN. x .200 IN.)
APPLICABLE TO: HMx, HMxF, HMx2F, HMx3F, D3MxxxF

Size Code: D



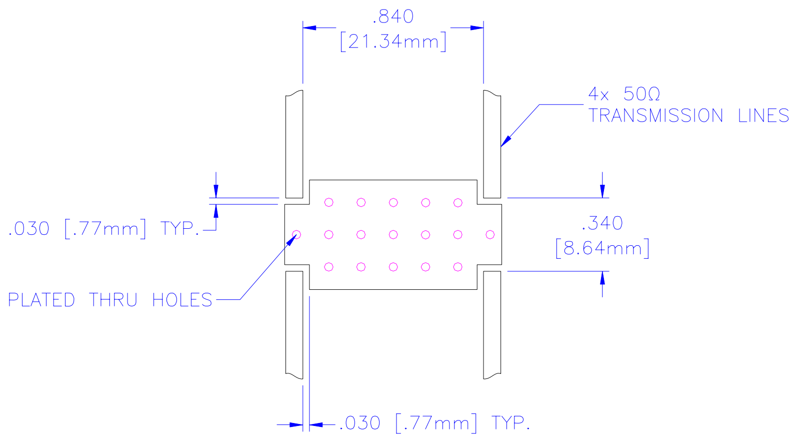

SUGGESTED FOOTPRINT FOR D-SIZED COUPLERS (.560 IN. x .350 IN.)
APPLICABLE TO: HDx, HDxF, HDx2F, HDx3F, D2DxxxF, D3DxxxF, DCDx3F

Size Code: S



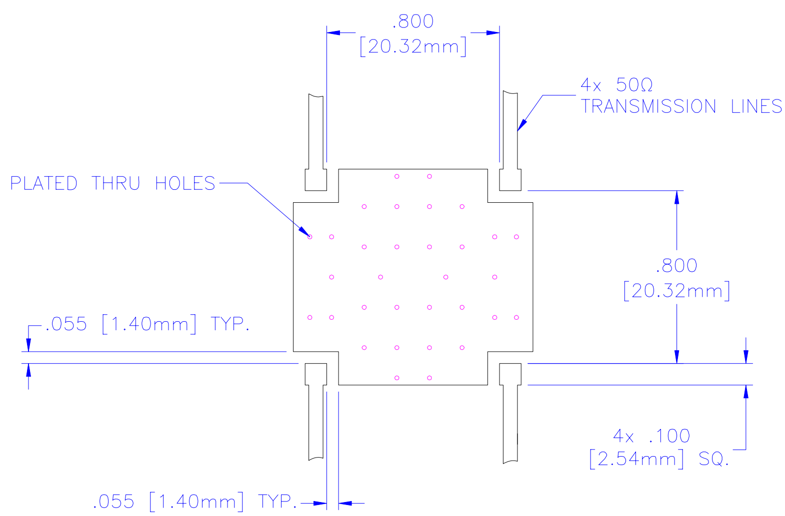

SUGGESTED FOOTPRINT FOR S-SIZED COUPLERS (.650 IN. x .480 IN.)
APPLICABLE TO: HSx, HSxF, HSx2F, HSx3F

## Size Code: A



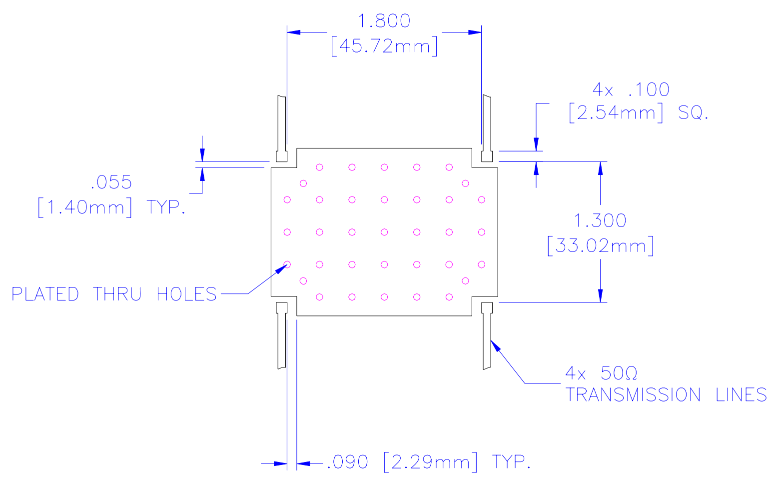

SUGGESTED FOOTPRINT FOR A-SIZED COUPLERS (1.000 IN. x .500 IN.)
APPLICABLE TO: HAx3F, D3AxxxF

## Size Code: E




SUGGESTED FOOTPRINT FOR E-SIZED COUPLERS (1.000 IN. x 1.000 IN.)
APPLICABLE TO: HExF, HExxxMF

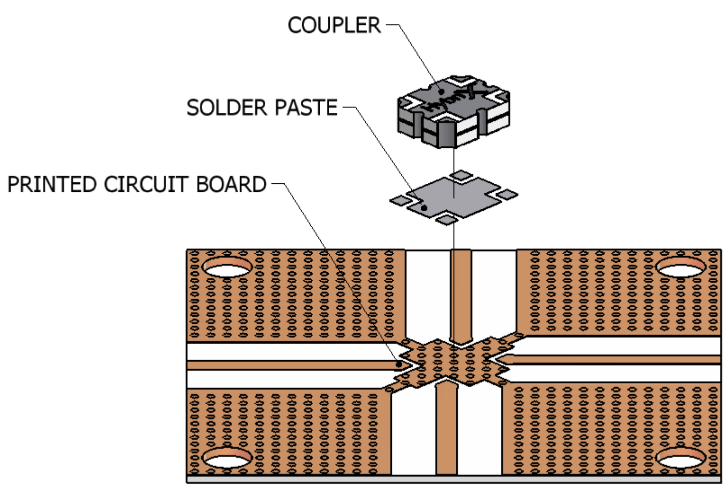
Size Code: G

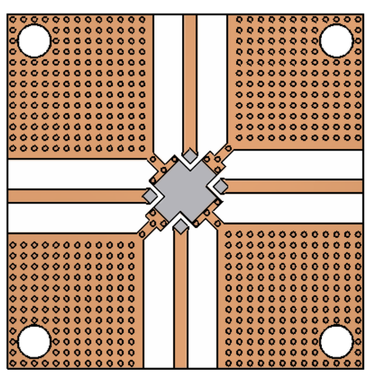


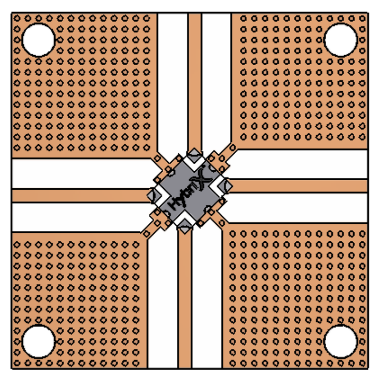

SUGGESTED FOOTPRINT FOR G-SIZED COUPLERS (2.000 IN. x 1.500 IN.)
APPLICABLE TO: HGxxxM2F

## Mounting Instructions

To ensure proper operation, all transmission lines must have a characteristic impedance of 50Ω. Grounding is also vital for optimal performance. Grounding can be improved by increasing the number of vias to minimize ground inductance. Increased number of vias allows for low impedance ground connection and good thermal conduction. Solder connections must be established between the device terminals and transmission lines on the PCB. Likewise, the bottom ground plane of the device should be in good contact with PCB ground pads. This is the most dominant thermal path for the dissipated heat due to insertion loss. The RF terminals should be properly aligned with the PCB trace to prevent potential performance issues.



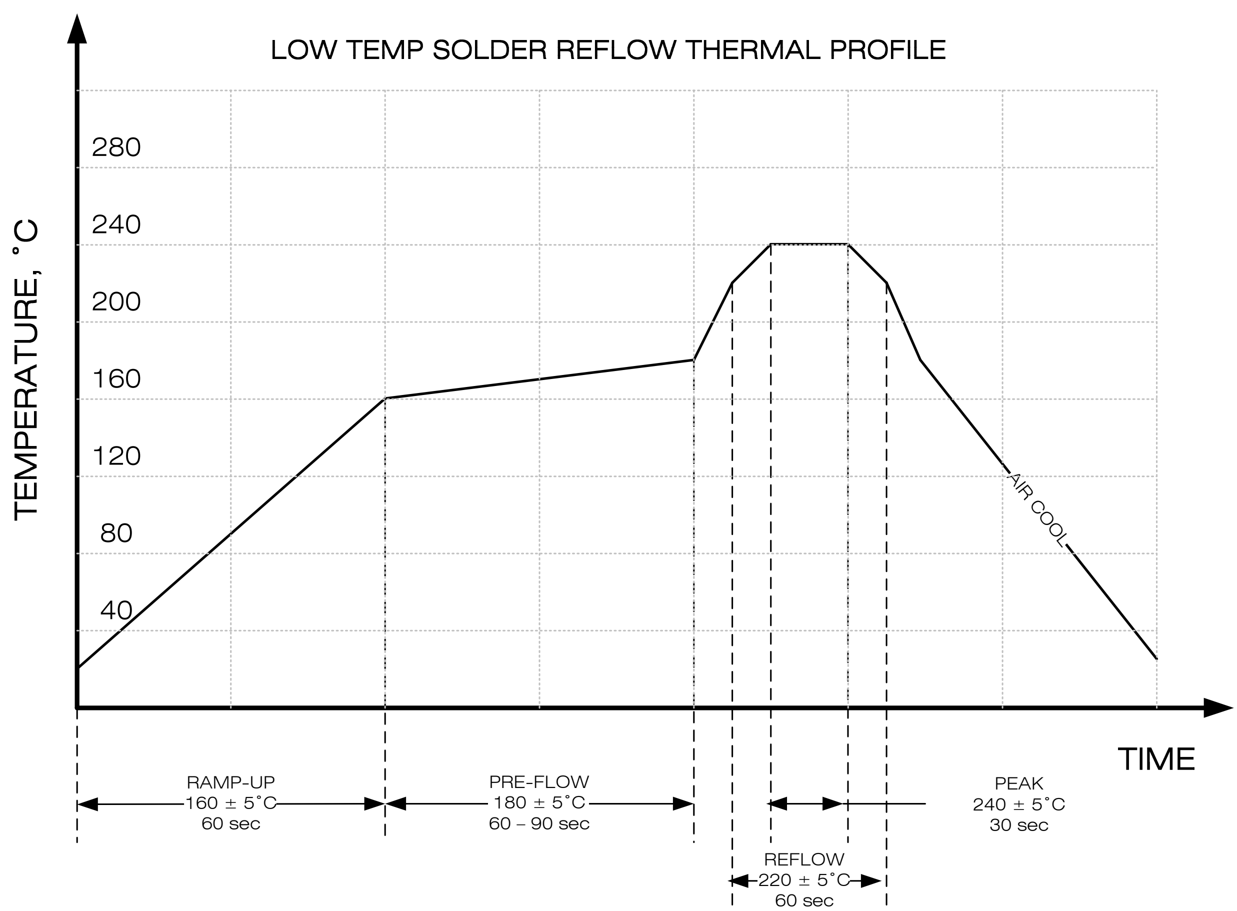


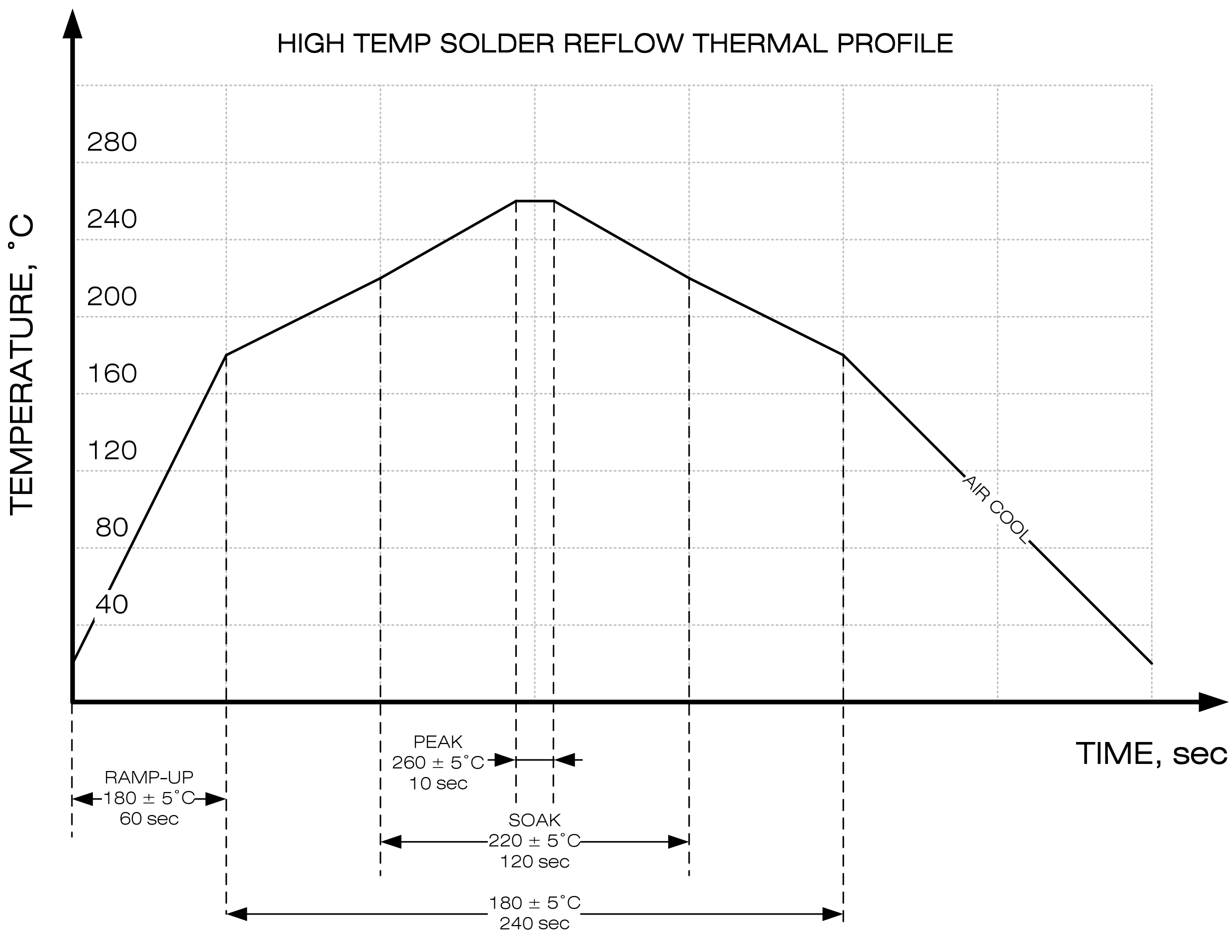
Both LTCC and multilayered PTFE couplers are compatible with pick-and-place and conveyor reflow oven assembly process. For manual soldering process, hot air reflow at controlled temperature is the recommended method to attach the device to PCB. The max reflow temperature should <u>never exceed 260°C</u>. The use of conventional solder irons may cause damage to the device and should be avoided.

The thermal expansion characteristics of LTCC and multilayered PTFE couplers are compatible with common PCB substrates such as RO3003, RO4350, TMM10, and FR4. Most common solders and conductive epoxy can be used for device attachment.

| List of Common Attachment Materials | | | |
|---|---|---|---|
| **Material** | **Composition** | **Thermal Conductivity ( Watts/cm/°C )** | **Melting Temperature ( °C )** |
| Lead-Free Solder | 99.3% Tin – 0.7% Copper | N/A | 227 |
| Lead-Free Solder | 96.5% Tin / 3.5% Silver | 0.33 | 221 |
| Tin-Lead Solder | 63% Tin / 37% Lead | 0.49 | 183 |
| Conductive Epoxy | Silver Filled | 0.01 to 0.29 | N/A |

When soldering LTCC couplers, as with all other types of ceramic components, rapid cooling should be avoided to prevent micro-fractures and other mechanical issues due to extreme thermal shock. Following are suggested solder reflow profiles.

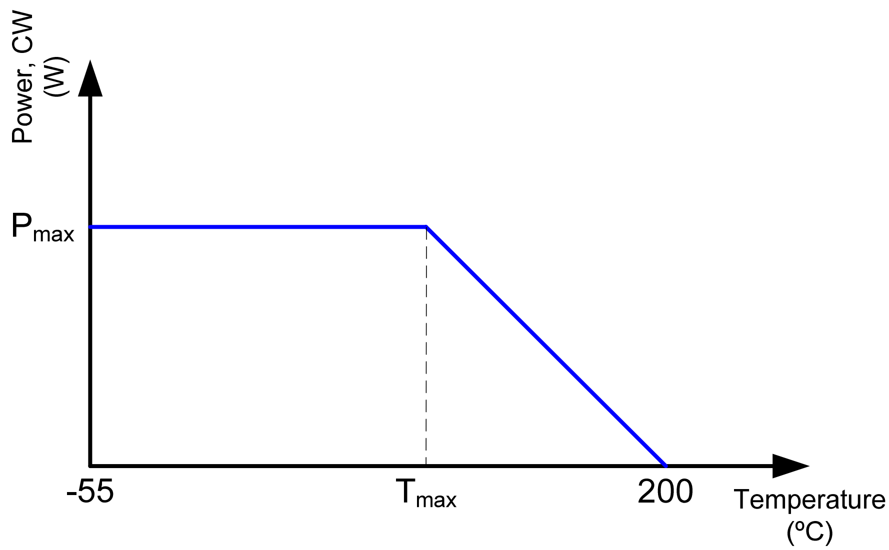





## Power Derating

There are several factors limiting the maximum input power for a coupler. The most significant factors are insertion loss, materials, and operating temperatures. Typically, the maximum operating temperatures for LTCC and multilayered PTFE couplers are 125ºC and 85ºC respectively. When properly installed, Hybrix® LTCC and multilayered couplers will operate up to the specified maximum temperature with fully rated input power. Depending on the application, these devices are also capable of operating beyond the maximum temperature with derated input power.

The diagram below illustrates the recommended power derating curve. $T_{max}$ is the specified maximum operating temperature and $P_{max}$ the specified maximum input power (CW). Input power shall be derated linearly to 0W at 200ºC.




## Suggested Terminations

In a typical power combining or splitting application, the isolated port of the hybrid coupler is terminated with a 50-ohm RF termination. The selection of the termination is critical as a less-than-optimal device can degrade the performance of the coupler, resulting in higher amplitude balance and lower isolation. These issues in turn will impact the overall circuit performance.

While every application is different, the following table provides a general guide on RF termination selection from Florida RF Labs and EMC Technology for use with Hybrix® couplers.

| Applications (Frequency) | | Max. Input Power (CW) NOTE 1 | Suggested Hybrix ® Couplers | Suggested Terminations |
|---|---|---|---|---|
| Base Station<br><br>Remote Radio Head<br><br>Wireless Combiner | US LTE (700 - 800 MHz) | 150 W | HPT3F | SMT2010TALNF |
| | | 200 W | HDT2F<br>D3MDxxF | SMT2010TALNF |
| | GSM (800 - 960 MHz) | 80 W | HPD3F<br>D3PDxxF | SMT1206ALNF |
| | | 100 W | HMD3F | SMT1206ALNF |
| | | 200 W | HDDF<br>D3MDxxF | SMT2010TALNF |
| | AWS<br>PCS<br>UMTS<br>(1700 - 2200 MHz) | 80 W | D3PJxxF D3PLxxF | SMT2010A |
| | | 100 W | HPK2F | SMT2010A |
| | | 200 W | HDJ3F HDL3F<br>D3DJxxF D3DLxxF | SMT2010TALNF |
| | 2.5 GHz WiMAX<br>IMT-2000 Extension<br>(2300 - 2700 MHz) | 35 W | HPP2F | SMT2010A |
| | | 80 W | D3PPxxF | SMT2010A |
| | | 100 W | HMP2F | SMT2010A |
| | | 200 W | HDP3F<br>D3DPxxF | SMT2010TALNF |
| | 3.5 GHz WiMAX<br>(3300 - 3900 MHz) | 60 W | HPR2F<br>D3PRxxF | SMT2010TALNF |
| | | 200 W | HMR2F<br>D3DRxxF | SMT2010TALNF |
| Broadcast | DTV<br>(54 - 800 MHz) | 500 W | HLB2F | SMT2010F<br>32A1050F |
| Public Safety | US Public Safety<br>(763 - 798 MHz) | 150 W | HPT3F<br>D3PVxxF | SMT2010TALNF |
| | TETRA<br>(380 - 470 MHz) | 200 W | HDC3F | SMT2010TALNF |
| Point-Point Radio<br><br>Radar<br><br>Satellite | C-Band<br>(4 - 8 GHz) | 20 W | HUU2F<br>D3FUxxF | CT0402D |
| | | 50 W | HPU2F | CT2010<br>32-1070 |
| | | 80 W | D3PIxxF | CT2010<br>32-1070 |
| | X-Band<br>(8 - 12 GHz) | 20 W | HPX2F | CT0505D |
| MRI | 1.5 T<br>(64 MHz) | 10 W | HD064M3F | |
| | | 300 W | HG064M2F | 32M7200F |
| | 3 T<br>(128 MHz) | 10 W | HD128M3F | |
| | | 300 W | HE128MF | 32M7200F |
| | 7 T<br>(298 MHz) | 300 W | HE298MF | 32M7200F |

| | | | | |
|---|---|---|---|---|
| | 9.4 T (400 MHz) | 300 W | HE450M2F | 32M7200F |
| Green Technology | RF/Plasma Lighting (2.4 GHz) | 100 W | HPK2F | SMT2010A |
| | | 200 W | HDP3F D3DLxxF | SMT2010TALNF |
| | Smart Meters (2.4 GHz) | 20 W | HFL3F | SMT2010A |
| | RF Heating (2.4 GHz) | 250 W | HAP3F | SMT2010TALNF |

Note:
1. Listed value is maximum input power into directional coupler. Power handling of the suggested terminations is based on the following assumption: 1.30:1 output VSWR, 3-dB nominal coupling, and 20-dB minimum isolation.