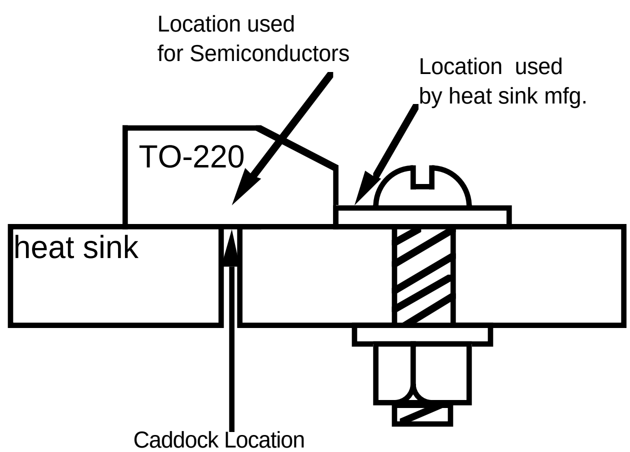
PROPER THERMAL DESIGN GUIDELINES
FOR THE CADDOCK MP808, MP915, MP816, MP916, MP820, MP821, MP825, MP925, MP930 AND MP850 PRECISION POWER RESISTORS

All Caddock MP800 and MP900 Series Resistors are rated at full power with a case temperature of 25°C and a maximum element (junction) temperature is provided for each device type. A sound thermal design by the customer is essential to provide the highest reliability.

Most early device failures in power devices can be traced to high junction temperatures, resulting in reduced component lifetime, changes in parameters, or physical damage to the device. For this reason, a conservative customer thermal design, good device mounting procedures and process controls are necessary. Good design practice and verification with actual temperature measurements will assure optimum performance and long life.

MEASUREMENT OF THE CASE TEMPERATURE



VARIOUS THERMOCOUPLE LOCATIONS USED TO MEASURE TO-220 TEMPERATURE

Caddock recommends that the case temperature should be measured by the designer to verify proper heatsinking and production process control. It is very important that these measurements should be taken as specified in the Caddock data sheet.

The thermal specifications for the MP Kool-Pak® and Kool-Tab® resistors are based on measurements made with the thermocouple contacting the center of the bottom surface of the package, the package mounted on a heat sink, thermal grease applied and a mounting torque of 6 to 8 in-lbs. It should be noted that there is no standard between manufacturers on the placement of the thermocouple; and, therefore, considerable discrepancies can occur. Caddock has chosen this location to obtain the highest case temperature at a point where the case is making contact to the heatsink. This location is advantageous for several reasons.

- Variables such as mounting surface contact area (surface finish, warping, flatness), thermal interface selection, and parallel heat conduction paths are eliminated.

- A reference point is provided that coincides with normal thermal resistance calculations, and its location coincides with the point of maximum heat on the element.

- Measurements are consistent with TO-220, TO-126 and TO-220 full-pack packages. Only the TO-220 has an exposed heatsink. Some manufacturers reference case temperature to the temperature of the heatsink measured at the junction of the body. This temperature can be 1°C/W cooler than the Caddock reference point. This can be significant in higher-power applications. The MP808, MP915, MP816, MP916, MP825, MP925, MP930 and MP850 packages do not lend themselves to this measuring point as the common surface with the heatsink is not exposed .

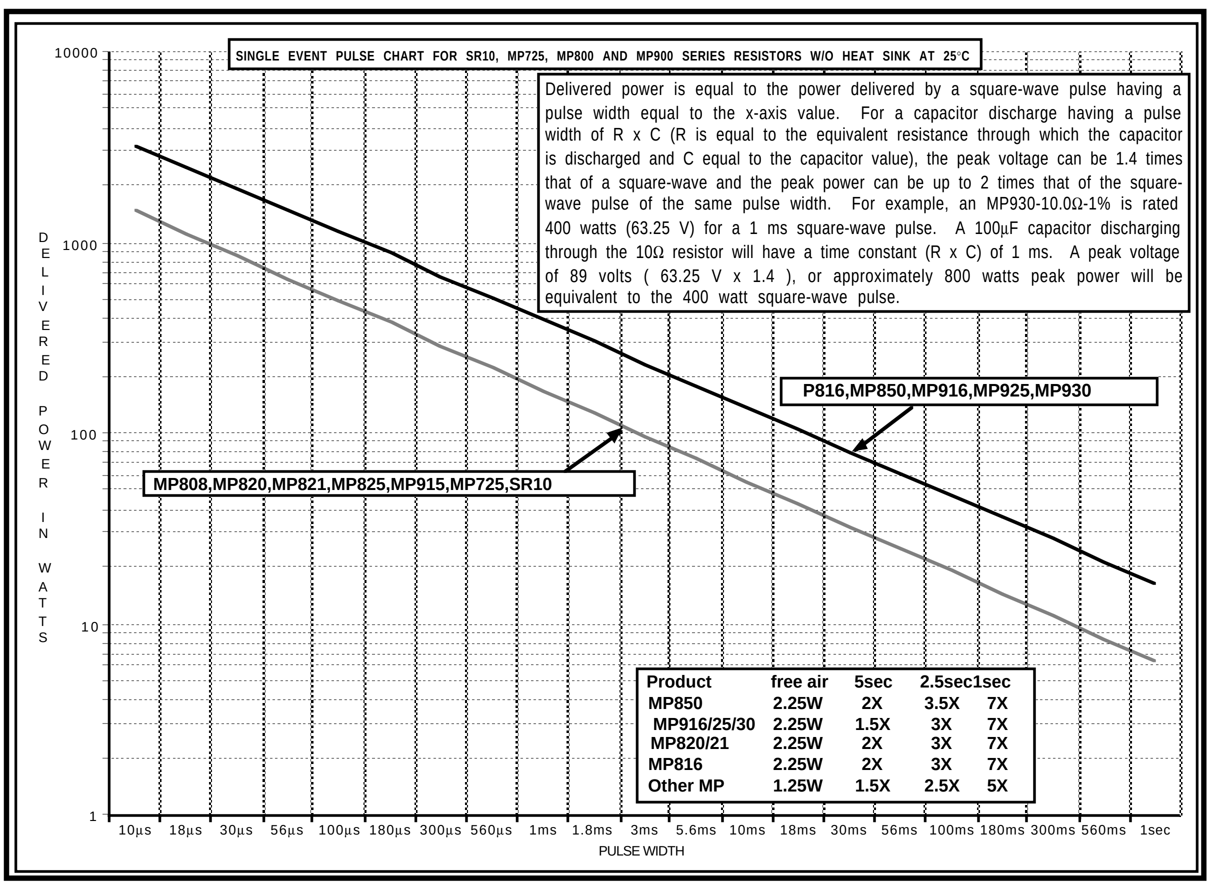
- The part is not damaged as it can be when the thermocouple is attached direct to the heatsink or as drilling into the body can do.

DETERMINING AVERAGE AND PEAK POWER

In order to determine the proper heatsink, the power dissipation of the device must be determined and calculations must be performed to select a sufficient heatsink. Applications engineers at Caddock can guide you through this process if you are not familiar with standard thermal designs. Otherwise, the designer should consider the following basic procedure.

1. Determine the average and maximum power dissipation of the resistor and the maximum ambient temperature. If the resistor is being used in a pulse application, or if surges are present, the following procedure should be reviewed.

    A. In pulse applications, use the MP816, MP916, MP925, MP930 or MP850 product since these have the largest element size.



B. Do not exceed a peak voltage of twice the normal rated operating voltage of the device.
MP800 Series....600 V   MP930.....500 V   MP916...Power Limited
MP915...............400 V   MP925...1000 V

C. Estimate the allowable peak single pulse power for 25°C for the MP device for the pulse duration in your specific application. The chart shows total power delivered by a rectangular pulse with a pulse width equal to the x-axis value. A capacitor discharge pulse of 1.4X peak voltage (2X peak power) magnitude with a pulse width equal to R x C is equivalent to the rectangular pulse .

D. The data shown in the chart was taken at 25°C ambient with no heat sink. Derate the overload power rating by 0.67%/°C for the MP820 and MP821 and by 0.8%/°C for all othe MP style resistors. With the addition of a heat sink, the MP808, MP915, MP916, MP825, MP925 and MP930 will dissipate 1 1/2 times rated power for five seconds. The MP816, MP820, MP821 and MP850 will dissipate 2 times rated power for five seconds. When a heat sink is used, the overload rating is the five second rating or the rating in free air (w/o heat sink), whichever is greater.

E. Average power is an important consideration when multiple pulses occur. Helpful formulas for determining pulse energy and average power are listed at the end of this section for your information. For reference, the thermal time constant of the resistor film is approximately 35µseconds, and the time constant for the entire system is approximately 50 mseconds. If the average power is more than 20% of the rated power of the resistor, or the estimated junction temperature is greater than 120°C, a more detailed analysis is suggested. This is best done by actual temperature measurements of the MP800 or MP900 resistor under operating conditions.

F. Test the device in actual operating conditions at 1.4 X peak power.
I. Record the DC resistance of the part before testing.
II. Apply the pulse energy to the device under actual worst-case operating conditions. Pulse the resistor a sufficient number of times to assure reliable life for your specific requirements.
III. Measure the resistance change.
IV. If the resistor has increased more than 0.25%, it should not be used.
V. If a measurable increase in resistance is recorded, repeat the test. Continued changes indicate marginal performance.

2. Choose the product and heatsink for the resistor using the design guide in the following section of this report.
3. Thoroughly test the product in application to be assured that the case temperature is below the maximum rating.
4. Be certain that the manufacturing procedures and quality assurance provisions provide consistent results, and eliminate variables by good design practice.

The energy stored in a capacitor is : **$E = 1/2\ C\ V^2$**   E = energy in Joules (Watt-seconds) C = capacitance in Farads   V = voltage in volts

Virtually all of the energy will be delivered to the resistor in a time period of 5 time constants.

$E_{delivered} = E\ (1 - e^{-t/T})$ when t = 5 R C   t = time in seconds
T= RC   R = resistor value in Ω C = capacitor value in Farads
E= total stored energy

TIME	1T	2T	3T	4T	5T
% E DELIVERED	63%	86%	95%	98%	99%

The average power dissipation can be calculated as follows: **P = E n**

P = average power dissipation in Watts n = pulses per second

E = energy delivered in a single pulse in Joules

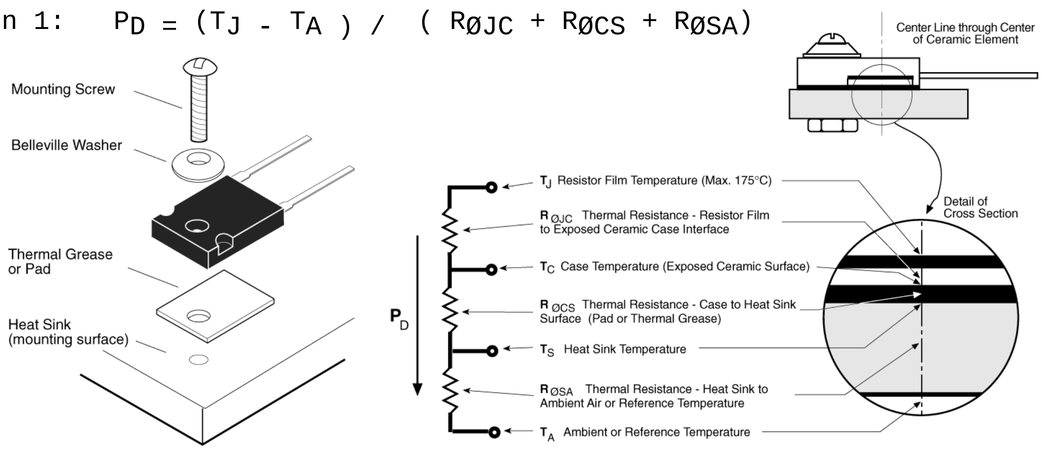
THERMAL RESISTANCE CONCEPTS APPLIED TO THE CADDOCK MP SERIES PRODUCT

Maximum power ratings for the Caddock MP Series are given for a case temperature of 25 °C and derating is provided to a maximum operating temperature of 150 °C (MP820 and MP821 are 175 °C). Maintaining a case temperature within this limit will assure the highest reliability for the product.

The purpose of this paper is to provide the basic guidelines for optimizing the choice of the MP device and the various heatsink components. The discussion is general and is not intended to recommend any mounting and heatsink components. Component parameters assume proper mounting considerations have been utilized.

A simplified model of heat transfer is the analogy to Ohm's law. In this model, temperature can be related to voltage; thermal resistance can be related to electrical resistance; and power is analogous to current.

Equation 1: $P_D = (T_J - T_A) / (R_{øJC} + R_{øCS} + R_{øSA})$



For the Caddock MP Series product, the following design parameters are applicable:

	MP808	MP915	MP816/916	MP820/821	MP825/925	MP930	MP850
Tj MAX. (°C)	150	150	150	175	150	150	150
Røjc (°C/W)	15.6	8.3	7.8	7.5	5	4.17	2.5

Typical values for $R_{øcs}$ and $R_{øsa}$ for a variety of materials and heatsinks can be found in the QUICK GUIDE TO HEATSINKS at the end of this report. For more specific information, contact the manufacturers of the interface and heatsink components.

TO DETERMINE THE MAXIMUM POWER OF THE MP DEVICE

P_d (MAX.) = (T_J - T_A) / ($R_{ØJC}$ + $R_{ØCS}$ + $R_{ØSA}$)

For the MP850 used at 25 °C ambient and using thermal grease with a thermal resistance of 1°C./W. and a finned heat sink with a thermal resistance of 5, the maximum power dissipation is determined as follows.

P_d (MAX.) = (150°C - 25°C) / (2.5 + 1 + 5)
= 125°C / 8.5 °C/WATT = 14.7 WATTS

TO SELECT A HEAT SINK AND THERMAL INTERFACE MATERIAL

((T_J - T_A) / P_d) - $R_{ØJC}$ = $R_{ØCS}$ + $R_{ØSA}$

Using the MP820 Series at an ambient temperature of 25 °C with a power dissipation of 8 Watts, the total allowable thermal resistance for the heat sink and the attachment interface is as follows.

((175°C - 25°C) / 8 WATTS) - 7.5 = MAXIMUM TOTAL Rth OF THE
(150°C / 8 W) - 7.5°C/W = HEAT SINK AND INTERFACE
18.75°C/W - 7.5°C/W =
11.25 °C/W =

To get a quick estimate of the heat sink required for your application, the Heat Sink Selection Tables will provide general guidelines. These tables assume a thermal resistance of 1 (one) for the grease or thermal pad, and they provide a worst case for heatsink thermal resistance, or a maximum power for a given heatsink.

THERMAL INTERFACE

The Caddock MP800 & MP900 Series product provides electrical insulation between the tab and the resistor element. For this reason, it is not necessary to provide an electrical insulator between the part and the heatsink. Caddock does recommend the use of thermal grease or thermal pads to increase thermal transfer efficiency and to compensate for voids caused by warpage, surface irregularities, and mounting pressure variation. A more detailed discussion of these materials is included in Caddock Assembly Guidelines for MP800 Series Resistors. For estimating purposes, most of these materials have a thermal resistance of approximately 1°C/W.

MP800 AND MP900 SERIES HEAT SINK SELECTION TABLE

To determine the maximum power of the MP800 or MP900 Series resistor with a known heat sink and ambient temperature, use the following procedure:

1. Select the chart for the ambient temperature.
2. Choose the thermal resistance of your heat sink and go down the chart to the line corresponding with the selected MP800 or MP900 Series product.
3. Read the maximum power dissipation from the chart.

To determine the proper heat sink when power dissipation and ambient temperature are known, use the following procedure:

1. Select the chart for the ambient temperature and go across the chart until the power dissipation is reached.
2. Select the line of the MP800 or MP900 Series product being used
3. The number at the top of this column is the maximum allowable thermal resistance for the selected heat sink.

25°C Ambient Temperature

SERIES/Rth	**2°C/W**	**5°C/W**	**10°C/W**	**15°C/W**	**25°C/W**
MP808	6.7 W	5.8 W	4.7 W	4.0 W	3.0 W
MP915	11.1 W	8.7 W	6.5 W	5.1 W	3.6 W
MP816/MP916	11.6 W	9.1 W	6.7 W	5.3 W	3.7 W
MP820/MP821	14.3 W	11.1 W	8.1 W	6.4 W	4.5 W
MP825/MP925	15.6 W	11.4 W	7.8 W	6.0 W	4.0 W
MP930	17.4 W	12.3 W	8.2 W	6.2 W	4.1 W
MP850	22.7 W	14.7 W	9.3 W	6.8 W	4.4 W

.

50°C Ambient Temperature

SERIES/Rth	**2°C/W**	**5°C/W**	**10°C/W**	**15°C/W**	**25°C/W**
MP808	5.4 W	4.6 W	3.8 W	3.2 W	2.4 W
MP915	8.8 W	7.0 W	5.1 W	4.1 W	2.9 W
MP816/MP916	9.3 W	7.3 W	5.3 W	4.2 W	3.0 W
MP820/MP821	11.9 W	9.3 W	6.8 W	5.3 W	3.7 W
MP825/MP925	12.5 W	9.1 W	6.3 W	4.8 W	3.2 W
MP930	13.9 W	9.8 W	6.6 W	5.0 W	3.3 W
MP850	18.2 W	11.8 W	7.4 W	5.4 W	3.5 W

75°C Ambient Temperature

SERIES/Rth	**2°C/W**	**5°C/W**	**10°C/W**	**15°C/W**	**25°C/W**
MP808	4.0 W	3.5 W	2.8 W	2.4 W	1.8 W
MP915	6.6 W	5.2 W	3.9 W	3.0 W	2.1 W
MP816/MP916	6.9 W	5.4 W	4.0 W	3.1 W	2.2 W
MP820/MP821	9.5 W	7.4 W	5.4 W	4.3 W	3.0 W
MP825/MP925	9.4 W	6.8 W	4.7 W	3.6 W	2.4 W
MP930	10.5 W	7.4 W	4.9 W	3.7 W	2.5 W
MP850	13.6 W	8.8 W	5.6 W	4.1 W	2.6 W

A QUICK GUIDE TO HEAT SINKS

A number of standard heat sinks are available from a variety of sources. A directory of several of these sources is given at the end of this section for your reference. In low power applications, the designer may wish to use the pc board for heat sinking. Typical double sided glass epoxy printed circuit boards provide a thermal resistance range from 25 to 40 °C/W, depending on size and metallization. This high thermal resistance will limit the power dissipation to 3 to 4 Watts maximum. A chassis, or large Aluminum plate, can provide a very efficient means of heat sinking for the Caddock MP800 or MP900 Series resistor. Typical thermal resistance values for natural convection are listed here for general design consideration.

6″ X 4″ X 2″ X .040″ Aluminum chassis	2.5°C/W
7″ X 5″ X 2″ X .040″ Aluminum chassis	2.0°C/W
vertical 6″ X 4″ X 3/32″ Aluminum sheet	3.5°C/W
vertical 6″ X 4″ X 3/16″ Aluminum sheet	2.9°C/W

A variety of clip-on heat sinks as shown in figure 1 are available. These provide a quick assembly and eliminate the cost and labor for rivet or screw assembly. Typically, these will provide thermal resistance with natural convection from 20 to 30 °C/W. This limits the maximum power dissipation to 3 to 4.5 Watts maximum. Most of these heat sinks are designed for use with TO-126 and TO-220 packages. When using the MP816, MP916, MP925, MP930 or MP850 package, the package thickness should be considered when selecting this type of heat sink as most of the standard designs clip on the tab only and will not accommodate this package thickness.

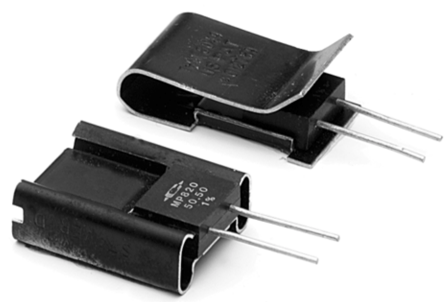


FIGURE 1

When airflow is available, finned heat sinks will provide improved cooling. A large variety of low-cost finned heat sinks as shown in figure 2 and figure 3 are available as standard designs. These can be screw or bolt mounted to all of the Caddock MP800 and MP900 Series resistors and provide natural convection thermal resistance from 15 to 25°C/W and as low as 4 or 5 °C/W with airflow.

FIGURE 3

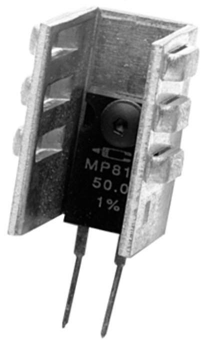


FIGURE 4

Larger PC mounted heatsinks as shown in figure 4 are available with clip-on and screw mounting. With airflow, these can provide thermal resistance as low as 2°C/W. Although they are designed for airflow applications, they will provide natural convection thermal resistance as low as 6 or 7°C/W.

For higher power applications, a number of standard heatsinks as well as custom heat sinks are available for TO-220 and TO-126 style packages. (figure 5) These can provide typical thermal resistance with natural convection as low as 3 or 4°C/W and as low as 1°C/W with airflow. These should be considered for higher power applications where chassis mount is not practical or where airflow is available.

FIGURE 5

In lower power applications, many heat sinks are available with fast assembly clips. These result in a lower cost assembly as they do not require additional hardware other than a thermal pad or grease. Many clip-mounted heat sinks are designed for the standard TO-126 and TO-220 packages. It is important that you make certain you have selected a clip that fits the MP Series product! You must be certain that the tab fits flat against the heat sink and that proper clip pressure is achieved. Note that many TO-220 clips are designed to fit over the tab only. Therefore, they will not provide a proper fit for the "Fullpack" of the MP816, MP930 or MP850.

It should be noted that all of these ratings are based upon good thermal design and manufacturing process controls. The thermal resistance will vary greatly with heat sink area, location on the board, airflow, as well as what other devices may share the heat sink. We recommend that the device temperature should be measured and that safety factors should be included in the design.

Additional information on heat sinks and thermal interface materials are available from the following suppliers:

Aavid (603-524-4443)
Bergquist (612-835-2322)
Chomerics (800-225-1936)
IERC (818-842-7277)
A E C / Johnson & Hoffman (formerly Staver) 516-742-3333
Thermalloy (214-243-4321)
Tran-tec (402-564-2748)
Wakefield (617-245-5900)

GUIDELINES TO MOUNTING THE CADDOCK MP800 & MP900 SERIES RESISTORS

THERMAL INTERFACE CONSIDERATION
Due to variations in the mating surfaces of the resistor package and the heat sink, air voids are created. Since the thermal resistivity of air is very high (approximately 1200°C/W/in), these voids can degrade the performance. A .001" air gap under a TO-220 device could result in as much as a 10 °C rise in resistor temperature per Watt of power dissipated. Therefore, it is necessary to use a thermal material to fill this void when any significant power is dissipated by the resistor. Several different materials are available that will lower the thermal resistance and compensate for surface and mounting variations from device to device.

The **Caddock MP Series product provides electrical isolation between the tab and the resistor element.** This means that the material selected for the thermal interface does not need to be an electrical insulator. Insulating materials, however, have have been included as other variables may make them a good choice in some applications.

Thermal joint compounds (grease) are a combination of zinc or other conductive particles in silicone oil or other material that provides a grease-like consistency. These materials have been used for many years and have shown that they can fill the air voids and provide a considerable reduction in thermal resistance. There are a number of things that must be considered to provide optimum performance, and there are also potential problems with these materials.

1. The surface area must be free of dirt particles, scratches, dents, voids, and burrs. In addition, it is recommended that the surface flatness should be less than .004 in/in and surface finish should be in the range of 50 to 60 microinches. Tests indicate that scratches and surface finish can go as high as 16 microinches without significant degradation in performance if grease is used.

2. It is critical that the compound should be lightly and evenly spread over the entire contact area. To determine the correct amount and application procedure, we suggest that the user follow manufacturer recommendations and also do some experimentation to assure compliance to the design guidelines and to verify the case temperature.

3. Proper and even mounting torque must be maintained. Insufficient mounting pressure can cause significant increase in thermal resistance. Mounting torque is addressed in the section of this report on mounting of devices.

4. Cleaning solvents used for excess grease removal must be chosen and utilized in a manner that they will not damage package integrity. The MP820 and MP821 has a high temperature molded silicone package. The MP808, MP816, MP825, and MP850 use a high temperature thermally conductive epoxy molding material. The MP900 Series resistors are molded with high-performance thermoplastic material.

5. Prolonged high temperature exposure can cause the silicone grease to evaporate and coat other components on the board. Manufacturers of

thermal greases have developed new materials using synthetic base greases that provide improved evaporation, creeping and migration characteristics over the silicone oil base materials. These new materials improve on this problem, but not without added cost and slightly poorer thermal properties and electrical insulation.

Several **thermally conductive pads** that provide thermal conductivity, but are available as either electrical conductors or insulators, are available. When compressed, these conform to the interface surfaces and aid in directing heat to the heat sink. <u>If not compressed uniformly and properly, these materials can often perform worse than without a pad</u>. The reason for this is that most of these materials are spongy and perform best when compressed. If this compression occurs only around the screw mounting, the actual heat exchange interface surface may see the high thermal resistance of non-compressed pad. The MP820 and MP821 are more forgiving as they have a large copper tab which spreads heat flow over a large surface area. Special care should be taken with the MP900 Series product and with other MP800 Series product if thermal pads are used.

Bergquist provides a family of Sil-Pads® which provide an alternative to grease or mica. Other manufacturers of these materials are Thermalloy, Chomerics and AAvid. Many thermally conductive pads are available in sheet form or in pre-cut patterns designed for various mounting options for the standard TO-220 and TO-126 packages. These utilize silicone rubber binder combined with a variety of materials such as Aluminum Oxide, Boron Nitride, and Magnesium Oxide to provide good thermal conductivity. These are often laminated with Kapton, fiberglass and other materials for specialized applications.

PROPER HARDWARE SELECTION

The selection of proper hardware an extremely important consideration in a good thermal design. The fastener selected must provide and maintain firm and even pressure on the device without distorting the heat sink or device surface or creating burrs.

Belleville washers, or compression washers are generally considered the preferred method of attachment to a heat sink. We do not suggest the use of split ring lock washers as they do not provide sufficient mounting torque and are not uniform in applying pressure to the interface. The Belleville washer is conical, a design feature which allows it to maintain constant pressure over a wide range of its physical deflection and to withstand long-term temperature cycling without variation in pressure. The large, or open end, of the washer faces the device or heat sink that it contacts.

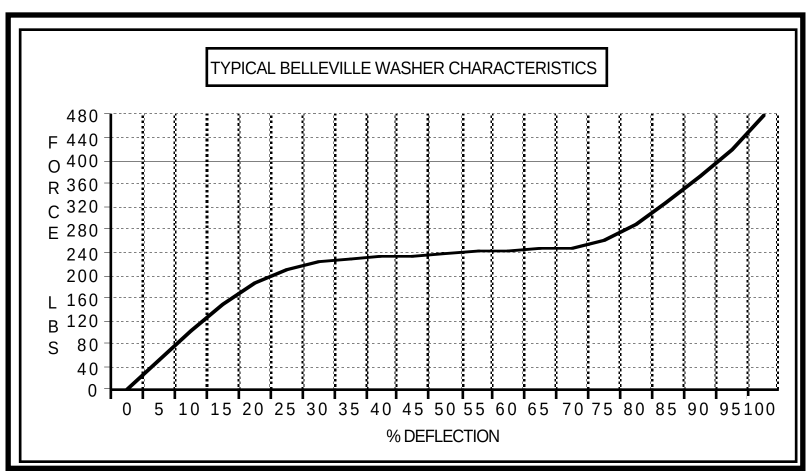


FIGURE 1

As a service to our customers, Caddock Electronics has tooled Belleville washers for use with our MP800 and MP900 Series precision resistor product. These washers are available from J. H. Rosenbeck, Inc. Belleville washers, also known as disc springs, are recommended when assembling the Caddock power resistor to the heat sink, chassis, or other mounting surfaces.

A force of 125 to 300 pounds is recommended for optimum heat transfer for a TO-220 package at the thermal interface of the part and the heat sink. Also, it is very important that this force is carefully controlled and is distributed in a uniform manner to avoid lifting of the edge of the resistor or cracking of the case. Figure 1 shows typical load characteristics of a Belleville washer. It can be seen that the load force is relatively constant when the washer is compressed between 20% and 80% deflection. Thus, the use of a properly designed and installed Belleville washer can maintain constant loading of the part and heat sink interface over wide temperature range and cycling conditions. This constant load range helps to compensate for the different thermal expansion coefficients of the mounting hardware and the resistor, which helps to maintain a reliable thermal interface over temperature and time.

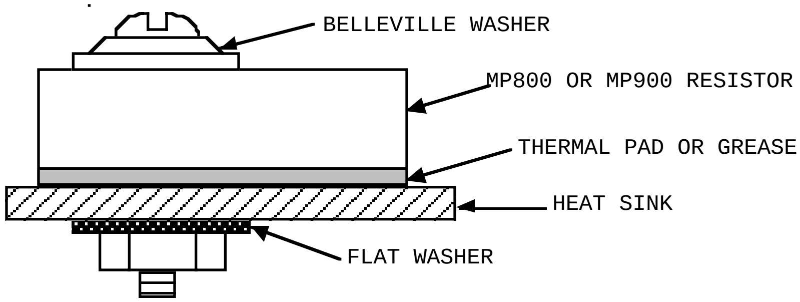
Caddock Electronics recommends the following considerations should be observed in establishing the mechanical assembly of the Caddock MP800 or MP900 Series resistors to the heat sink surface.

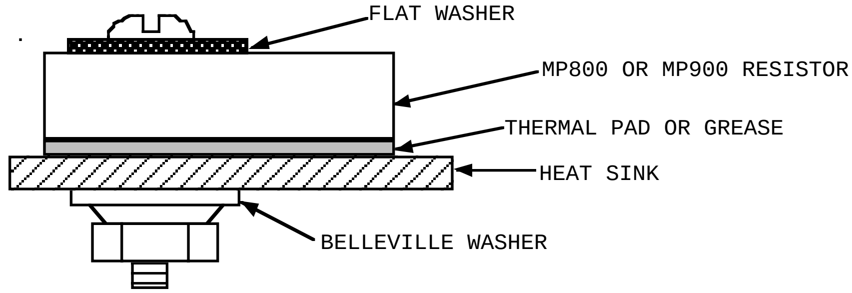
1. Make sure the surface of the heat sink is flat and is clean and free of burrs or surface irregularities.

2. Use a good thermal grease or thermal conducting pad between the part and the heat sink.

3. Assemble the part as shown in figure 2. Caddock does not recommend the use of rivets or sheet metal screws.

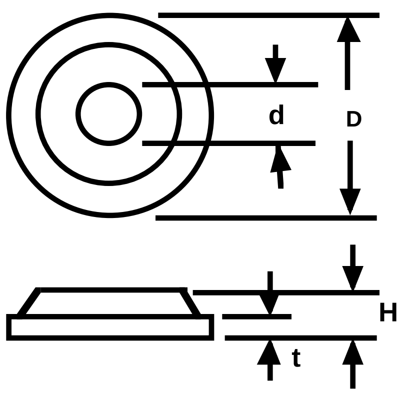
4. Tighten the bolt to obtain 50% deflection of the Belleville washer. If thermal grease or thin, or noncompressible thermal interface pads are used, proper force can be obtained by tightening the screw to finger tightness and then advancing the screw to provide proper deflection. A 1/3 turn of a #4 X 40 screw or 1/2 turn of a #2 x 56 screw and 1/4 turn of a 6 X 32 screw will provide 0.008” to 0.009” deflection. CAUTION: Grease on the threads, variations in thread depth and pitch, and tolerances can effect torque measurements, therefore, we do not suggest specifying rotational torque limits without correlation tests to assure that proper deflection of the washer is maintained.





The general specifications for these washers are as follows:

PART #	D (IN)	d (IN)	H (IN)	t (IN)	TYP TORQUE (IN-LBS)	TYP FORCE 50% DEFL.	BOLT SIZE ENGLISH	BOLT SIZE METRIC
AM409	0.210 MAX	0.089 MIN	0.045	0.018	3	275 lbs	#2	M2
AM414	0.245 MAX	0.118 MIN	0.055	0.018	5	275 lbs	#4	M2.5,M3
AM458	0.333 MAX	0.146 MIN	0.048	0.02	6	250 lbs	#6	M3.5



Material: Spring Steel

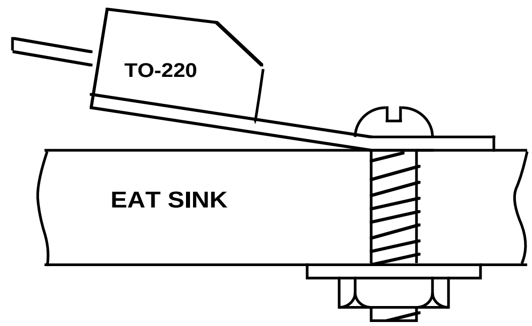
Finish: 100µinch Electroless Nickel

Part Number	Use With	Source	Phone
AM409	MP808,MP825,MP915	J. H. Rosenbeck	860-585-5905
AM414	MP816,MP850,MP916,MP925,MP930	J. H. Rosenbeck	
		Arizona Hydrogen	602-275-4126
AM458	MP820, MP821	J. H. Rosenbeck	

A machine screw can be used in conjunction with a conical washer and nut. Several factors must be considered when using this mounting technique.

1. Never let the head of the screw contact the device. Use a flat washer or conical washer to evenly distribute the force.
2. Apply proper torque. If the screw is too tight, the package will have a tendency to bow up at the end farthest from the screw. This is something that is difficult to eliminate, but with proper design and good process control, it can be minimized.

   The drawing to the right illustrates an example of doing everything wrong. The force used to tighten the bolt is sufficient to distort the package , causing an air gap that can substantially increase thermal resistance. The use of a grease or thermal pad is suggested to minimize this problem. High torque can also caused stress on the package which can result in breakage of the element. If torque is too low, thermal resistance is also increased. Manufacturers of the thermal pads and materials provide suggested mounting torque for best performance. CADDOCK suggests 6 to 8 in-lbs. for optimum thermal conductivity and package safety for the TO-220 package with tab. (see chart above)

   EXAGGERATED ILLUSTRAUTION OF TO-220 IMPROPERLY MOUNTED CAUSING WARPING AND INSUFFICIENT CONTACT

3. If using a grease, make certain that it does not come into contact with the threads of the screw or nut as this can give inaccurate torque measurements.

Sheet metal screws must be used with great care. These have a tendency to create burrs or to roll up the edges of the hole on the metal heat sink. Both of these can cause significant increases in thermal resistance. It is suggested that these screws should be used in a clearance hole with a speed nut in any critical application. Thermal grease can also cause torque problems if it contacts the threaded contact area.

A **rivet is not suggested** for any Caddock Resistor packages with the possible exception of the MP820 and MP821. It is difficult to maintain proper pressure and a plastic package can be easily damaged. The package design on the MP820 and MP821 allows pressure to be exerted on the tab rather than directly on the plastic package. If rivets are used, the following guidelines are provided.

1. Do not use pop-rivets!
2. Hollow Aluminum rivets are preferred.
3. Crimping force should be applied slowly and evenly.

Caddock Electronics does not suggest the use of solder reflow for **SMT assembly** of standard MP800 and MP900 series resistors. If you have a surface mount requirement, Caddock suggests the use of the **MP725** or type **CC2015FC** or **CC2520FC** chip resistors.

Although we do not recommend customer **forming of the leads**, it can be done if special care is taken in order to maintain package integrity. The MP820 and MP820 are the most versatile choices due to the round leads. Lead bending on all other MP800 and MP900 devices should be limited to the vertical axis. If SMT formed leads are required, the **MP725 Series**, a DPAK style package with **SMT formed leads** and a solderable tab is available.

a. During the bending operation, the leads must be supported or gripped between the bend point and the package.
b. The maximum bend radius is 0.050”. Forming at a tighter radius can cause cracking of the plating and/or weakening of the lead. The use of a mandrel or forming fixture is recommended.
c. Do not twist the leads at the case.
d. Do not bend the leads in the plane parallel to the heat sink mounting surface. (ok for MP820 / MP821 only)
e. Provide strain relief if possible.

Customers wishing to have additional electrical isolation often use plastic nuts, bolts and washers. Care should be taken to select materials that will not soften or reflow at operating temperatures. Whenever possible, compression washers should be used to maintain contact pressure. **Electrical isolation** is usually not necessary on the Caddock MP Series Product since the **tab is isolated from the resistor element.**

HIGH FREQUENCY CHARACTERISTICS OF MP800 AND MP900 SERIES RESISTORS

The design of the Caddock MP800 and MP900 Series resistors makes them ideal for use in high frequency applications. The resistor can be modeled as a resistor with a series equivalent inductance and a parallel shunt capacitance. The physical layout is such that the inductance is approximately the same as a straight piece of wire. Therefore, the frequency response may be adjusted to some degree depending on the point at which it is terminated to the printed-circuit board. Typical values are indicated in the chart below. For this test, the leads were terminated 0.1″ from the body of the resistor. Lead impedance can be estimated to be 12 nH per inch.

Stand - Alone part without heat sink

Caddock Model	L (nH)	C (pF)
MP808	6.4	1.18
MP915	7.25	0.6
MP816	8.4	0.6
MP821/820	8.1	1.3
MP725	6.4	1.18
MP825	6.4	1.18
MP930	7.6	0.75
MP850	7.8	1.75
MP850 above 1kΩ	7.8	1.35

Electrically Isolated Heat Sink with thermal grease (MP808, MP820, MP821, MP825 and MP850 do not change from stand - alone part. MP808 and MP816 are not recommended for rf applications with heat sinks because of variations in performance due to plastic thickness)

Caddock Model	L (nH)	C (pF)
MP930	8	1.75

Heat Sink electrically common to one of MP800 or MP900 leads

Caddock Model	C (pF)
MP820/821 grease or pad	3.2
MP930 grease or pad	3.65
MP825 grease	2.25
MP825 thermal pad	1.95
MP850 grease or pad	3.8
MP850 (>1kΩ) thermal pad	3.3

50Ω Impedance Values

50Ω parts are the most commonly used in rf line termination applications. To provide a more accurate measurement than the model, a summary is provided showing actual data for various 50Ω parts.

MP800 AND MP900 SERIES 50Ω RF IMPEDANCE CHARACTERISTICS

STANDARD PART WITHOUT HEAT SINK

DESCRIPTION	Z @100 MHZ	Z @ 250 MHZ	Z @ 500 MHZ	F (VSWR=1.1)
MP808	50.1 / 2.6°	50.3 / 6.6°	51.3 / 13.2°	216 MHz
MP915	50.0 / 3.2°	50.2 / 8.0°	50.9 / 16.3°	175 MHz
MP816	50.5 / 6.7°	53.0 / 16.3°	61.4 / 29.4°	84 MHz
MP820	50.1 / 3.7°	50.8 / 9.2°	53.1 / 18.2°	152 MHz
MP825	50.0 / 2.6°	50.3 / 6.6°	51.3 / 13.2°	216 MHz
MP930	50.2 / 5.1°	51.6 / 12.2°	56.5 / 23.2°	112 MHz
MP850	50.1 / 3.4°	50.7 / 8.6°	52.8 / 17°	164 MHz

ELECTRICALLY ISOLATED HEAT SINK

DESCRIPTION	Z @100 MHZ	Z @ 250 MHZ	Z @ 500 MHZ	F (VSWR=1.1)
MP930 WITH GREASE	50.1 / 2.9°	50.3 / 7.4°	51.6 / 15°	192 MHz
MP930 WITH THERMAL PAD	50.1 / 3.3°	50.6 / 8.4°	52.5 / 16.7°	169 MHz

HEAT SINK ELECTRICALLY COMMON TO ONE LEAD

DESCRIPTION	Z @100 MHZ	Z @ 250 MHZ	Z @ 500 MHZ	F (VSWR=1.1)
MP820 WITH GREASE	50 / -0.25°	50 / -0.95°	49.4 / -4.1°	>500 MHz
MP820 WITH THERMAL PAD	50 / -0.14°	50.1 / -0.83°	49.6 / -4.8°	>500 MHz
MP825 WITH GREASE	49.9 / -0.98°	49.2 / -2.4°	46.8 / -5.2°	459 MHz
MP825 WITH THERMAL PAD	49.9 / -0.28°	49.6 / -0.66°	48.2 / -1.5°	>500 MHz
MP930 WITH GREASE	49.7 / -1.8°	48.5 / -4.5°	43.8 / -9.7°	286 MHz
MP930 WITH THERMAL PAD	49.8 / -0.75°	49.2 / -2.1°	46.9 / -5.7°	425 MHz
MP850 WITH GREASE	50 / -0.18°	49.9 / -0.76°	49.2 / -3.7°	>500 MHz
MP850 WITH THERMAL PAD	49.9 / -0.66°	49.4 / -1.8°	47.1 / -5.6°	459 MHz

The user can determine proper compensation for the part in the following manner:

If the phase angle is negative, the required additional series inductance can be calculated with the formula $L = Z \sin |\varnothing| / 2\pi f$. It can be seen that longer leads can add sufficient inductance to tune a 50Ω part for excellent frequency response *(eg MP850 at 500 MHz L=49.2 Sin 3.7° / 2π 500MHz = 1 nH)*

If the phase angle is positive, the required additional series capacitance can be calculated with the formula $C = 1 / 2\pi f Z \sin \varnothing$
(eg MP808 at 500 MHz C= 1 / 2π 500 MHz 51.3 Sin 13.2° = 27 pf)