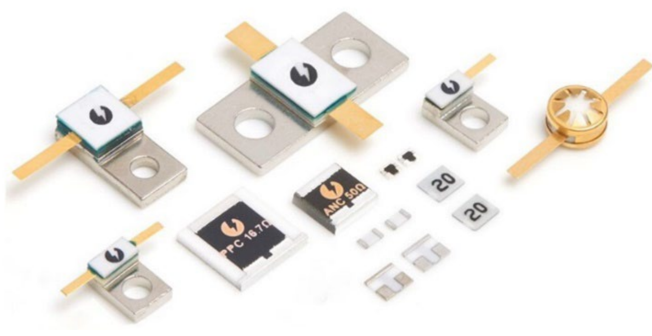
Designing with surface-mount resistives in RF systems

Attenuators, resistors, and terminations use resistive elements to influence a signal. In the case of RF, the design and materials of the resistive component will determine the performance in different applications. This article explores the different options to consider and provides some guidelines for component selection options.

All RF engineers understand the role of resistive components in an RF circuit. But some may not fully understand the performance implications of the materials and processes used to manufacture these components—from substrates, to surface finishes, to packaging.



Common package styles for surface-mount resistives

Background

As more Aerospace and Defense designs move to board-level designs engineers are faced with design decisions for both performance and thermal transfer. Traditional coaxial resistive components are larger and have 360 degrees of their surface area exposed to the air for convective heat dissipation; additional heat is transferred to the coaxial lines or cables. With surface-mount applications the heat is primarily transferred conductively to the PC board at the attachment point. As a result, thermal management must be addressed early in system design.

The majority of surface-mount resistive components are built with a substrate to handle thermal dissipation and a metallization layer for creating the current resistance. These materials are assembled and then packaged to meet the attachment requirements of the board design: chip, flange, and pill. Flange-mounting is popular for terminations to avoid failure conditions of a solder-only mount when dissipating high power levels. Chip-packaging is often used for attenuators and resistors with lower power handing requirements that do not typically require active cooling.

Ceramic compounds are the most common substrate for these substrates. Two important properties of the substrate material choice are the dielectric constant and the thermal conductivity, providing control for loss and heat dissipation.

Substrate Materials

- *Alumina* (Al_2O_3) – Alumina is a commonly used substrate because it provides good thermal transfer at a relatively low-cost. It is often used in attenuators with low power requirements.
- *Beryllium Oxide* (BeO) – Many high-power applications utilize BeO for the high thermal conductivity, enabling better heat transfer from the resistive element to the mounting surface.
- *Aluminum Nitride* (AlN) – Aluminum Nitride is a good middle ground for applications with higher power as it provides superior thermal properties to Al_2O_3 at a lower price point than BeO.
- *Diamond* – Both poly- and mono-crystalline diamond offer the highest thermal performance, but at a significantly higher cost.

Resistive Elements

Resistive and conductive materials are deposited on the substrate to provide the electrical properties needed (resistance and conductance). There are two primary manufacturing processes used to apply these layers: thick film and thin film.

- *Thin-Film* resistors are typically applied to the substrate with a vacuum sputtering process where the geometry and thickness of the material determines the resistance. Common materials include Tantalum Nitride and Nichrome. Thin film has a better temperature coefficient and has improved stability vs. thick film. It also performs better at higher frequencies.
- *Thick-Film* resistors are generally screen-printed with a mix of glass and metal oxides. Cost is typically less than thin-film, and power handling is superior. Thick film resistors also offer a wider range of resistance values than their thin-film counterparts.

Packaging

The packaging of the resistive components is also a decision factor for the design engineer. There are various styles to meet different board requirements—flange, tab, chip. Each has tradeoffs to be considered.

- *Plating* provides additional metallization that can help enable installation to a PCB, such as pre-tinned terminals. Gold is popular for wire bonding applications because of its excellent conductive properties. Silver-over-nickel is compatible with multiple varieties of solder.
- *Solder* is pre-applied to the resistive devices to make them board-ready. There are two primary solder options. Tin-lead solder is the most popular solder choice; lead-free solder meets RoHS requirements.

Mounting Considerations

Board mounting package options play a significant part in deciding between different resistive devices. The design engineer needs to consider both power dissipation and RF performance.

Conductive cooling must be calculated to prevent overheating of the board and surrounding devices and to protect the resistive devices from damage and early failure.

RF performance is also dependent on proper mounting. Lack of proper thermal management can change the device properties. Since these devices are being mounted to a circuit board and/or heat sink, inductance to ground is introduced by the vias to the ground plane. To reduce this effect and lower the thermal resistance between the component and ground plane, consider these design approaches: (1) Maximize the use of thermally conductive vias around and under the device, and (2) Use heavy copper cladding (2 oz.) on the circuit board as a heat spreader.

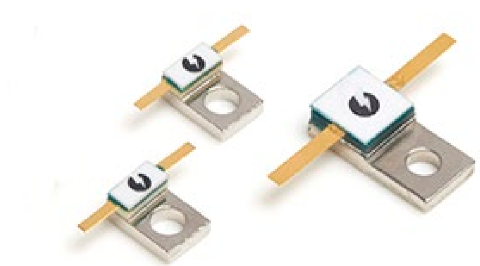
Attenuator Mounting Styles

Flange-Mount

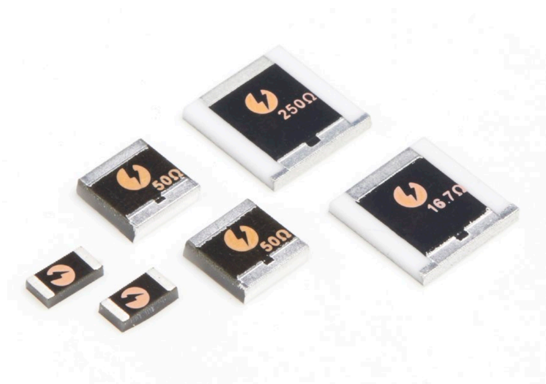
Flanged attenuators allow for a mechanical connection to a heat sink to more easily remove heat generated by the absorption of RF power. The ground of the attenuator circuit is the flange itself, and there are typically “in” and “out” tabs designed to be soldered to the circuit board.

Surface Mount

- Full Wrap- An SMT attenuator with a full terminal wrap allows for installation with either the circuit facing up or facing down. With the circuit facing down, there is typically better performance at higher frequencies. A benefit of the full wrap is the reliability of the solder connections, but the drawback is the additional metallization can reduce performance at higher frequencies



- No-Wrap- An attenuator with no wrap is soldered circuit side down, and the lack of additional metal helps to maximize performance at higher frequencies due to fewer parasitics.
- Ground Wrap- Some SMT attenuators are designed with only the ground terminal wrapped, and typically installed circuit-side down. This terminal style offers a middle ground between the high-reliability of the full wrap and the high-frequency performance of no wrap.

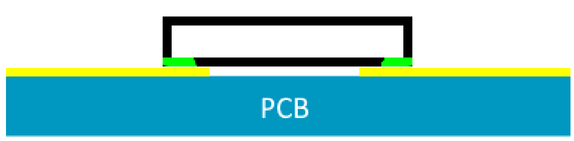


Resistor Wrap Styles

Resistive and conductive materials are deposited on the substrate to provide the electrical properties needed (resistance and conductance). There are two primary manufacturing processes used to apply these layers: thick film and thin film.

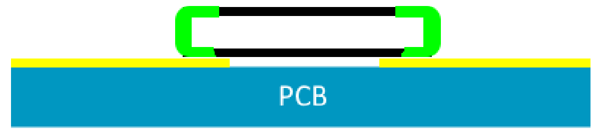
Flip Chip

A flip chip installation is installed with the circuit of the resistor facing down towards the circuit board. The lack of additional metallization minimizes any parasitic capacitance, so this type of installation will typically have better performance at high frequency.



Terminal Wrap

Resistors that offer a terminal wrap will offer additional reliability due to the higher quality solder joint that can be made, allowing for solder filets that can be more easily inspected for a good connection. This wrap style also allows for the circuit to be installed either face down for better RF performance or face up which may allow for easier inspection.



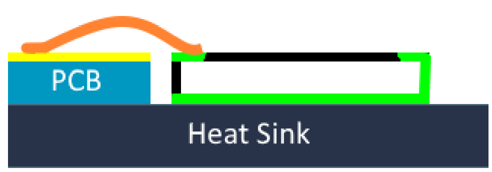
Extra Metallization

Another configuration includes metallization on the opposite side of the functional circuit, which allows for a better flow of thermal energy away from the resistor to the ground plane or heat sink, therefore enabling higher power. These are often installed as a “drop in” where the PCB is cut away enable the direct thermal connection, and tabs or wire-bonding can be used to connect the resistor to the PCB.

Termination Wrap Styles

Ground-Plane Wrap

A ground-plane wrap allows for the ground of the termination to be directly connected to the heat sink and can be connected to the circuit via a tab or wire bonding process.



Terminal and Ground

Terminations are also available where both the input and the ground can be directly soldered to the circuit board. This may not enable as much power handling as a full ground-plane wrap, but with thermal vias the thermal performance can be improved.

Environmental Specifications

Consider the operating environment, including temperature range, humidity, and vibration. Most attenuators are designed to withstand a relatively wide range of temperature (-55C to 150C) (with power handling that "derates" with respect the mounting surface temperature) and are not sensitive to humid environments. For high reliability applications, the performance is tested and validated for a range of MIL-STD specifications that may vary depending on the application and/or specific environment.

Other Important Design Considerations

Temperature Stability

Consider the attenuator's performance over the expected temperature range. Most attenuators are designed to provide stable attenuation levels as a system is subjected to changes in temperature. This is possible due to low TCR (Temperature Coefficient of Resistance) materials that are selected for this and other desirable properties.

Size and Footprint

The physical dimensions and footprint of the attenuator should be compatible with the available space on the PCB, especially in compact designs. The size of an attenuator is often driven by desired performance with higher frequencies requiring smaller structures and higher power designs requiring more area to dissipate heat. Different materials and design considerations can improve the available options.

Conclusion

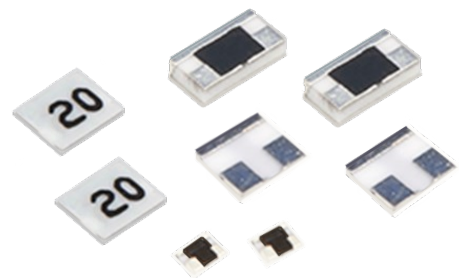
RF engineers who are designing PCB-based RF systems must understand the various tradeoffs in specifying resistive components. Size, temperature coefficient, material selection, ambient temperature, and mounting decisions can affect system performance. Each of these may also affect the BOM cost for both the individual devices and the carrier board. Thermal issues are the most significant factor to consider because they affect device and system performance and the reliability of the devices and the system over time.

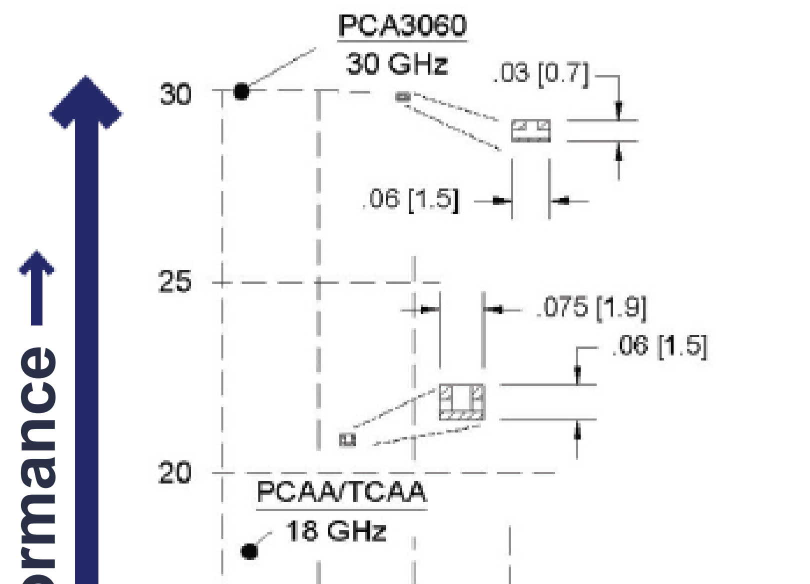
Spectrum Control, offers a wide range of options of substrates, metallization, and packaging to help you find the right attenuator, resistor, or termination for your application.

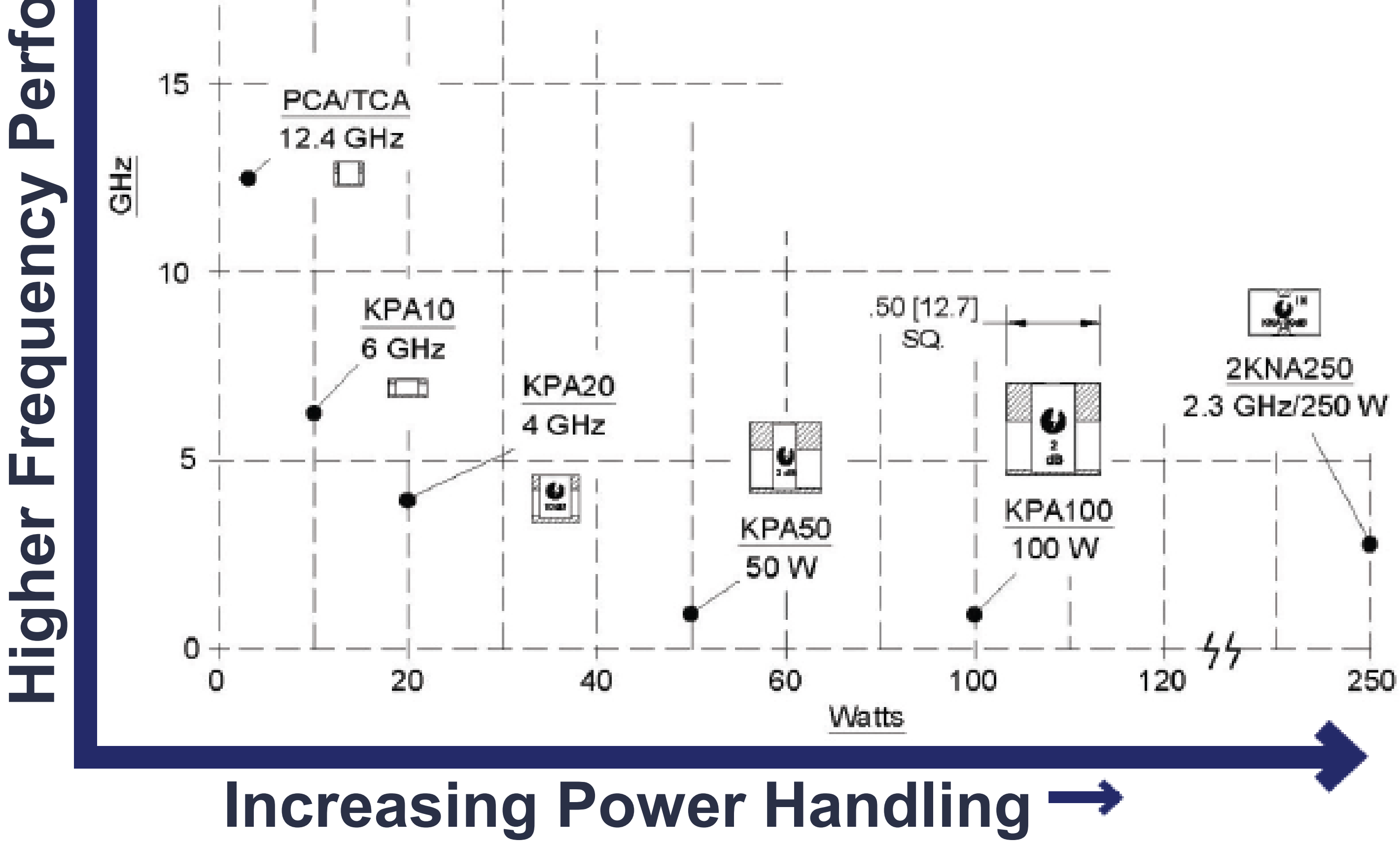
We also have the specifications you need for frequency and power. The following pages provide an easy-to-use guide for finding the right part for your design.

Chip Attenuator Selection Guide

Don't see a product that meets your needs? Contract us and we can work with you to find a solution, from a deep dive of our standard products to a custom design.





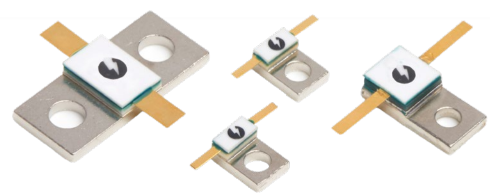


Attenuator Options

Attenuators are available in surface-mount, flanged or tabbed configurations for convenient installation options. See next page for the flange attenuator selection guide. Visit spectrumcontrol.com for more information.

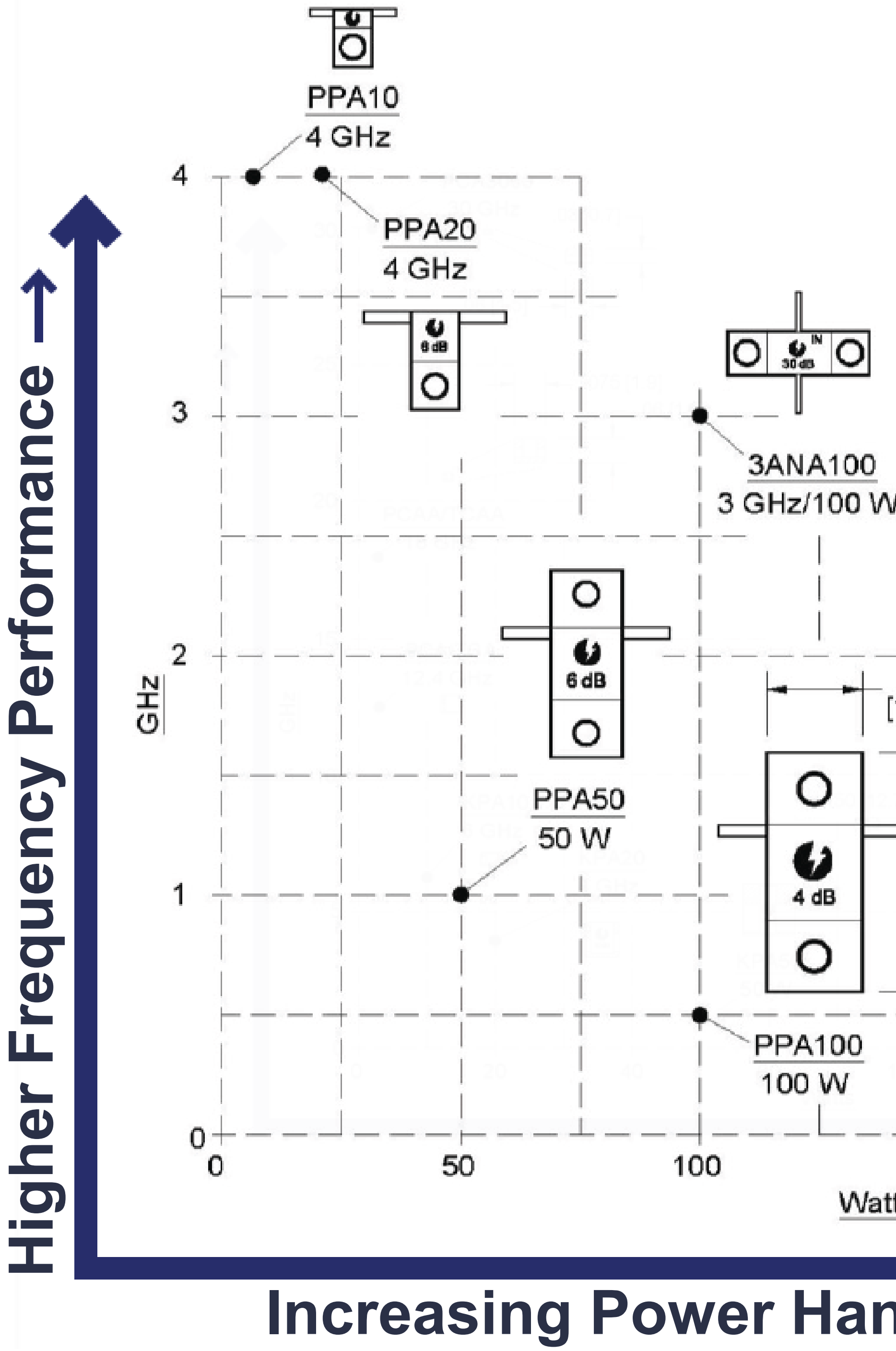
Flange Attenuator Selection Guide

Flanged Attenuators



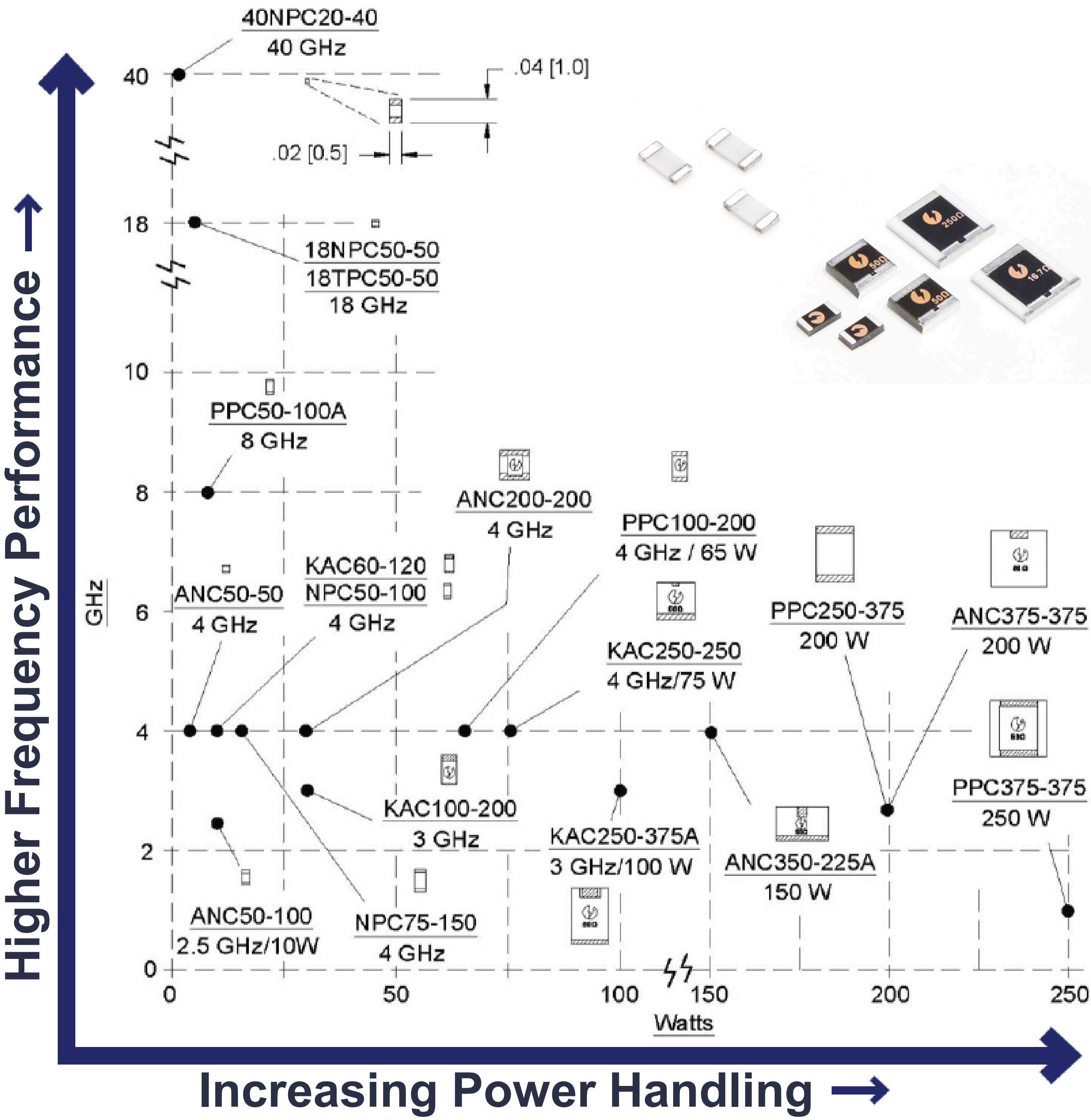
Tab Options

- Gold-plated copper
- Silver
- Nickel-plated copper
- Straight or bent for stress relief
- Custom length and width



Chip Resistor and Chip Termination Selection Guide

Spectrum Control offers a wide selection of resistors and terminations designed to meet the increasing demands for high frequency and high power. This chart can offer a good starting point to help select the right product for your application, but we are always expanding our capabilities based on customer demand. Don't see a product that meets your needs? Contact us and we can work with you to find a solution, from a deep dive of our standard products to a custom design.



Flange Termination and Resistor Selection Guide