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Parasitic Inductance Resistor Selection Guide

It is important when designing a circuit to know how to select the best component for your application. The team at Thin Film Technology (TFT) can guide you in this journey. The article below will discuss what is parasitic inductance and ESL, other factors to understand when evaluating the parasitic inductance of a resistor, and the recommended components to begin your search.

What is Parasitic Inductance?

Parasitic inductance is unwanted inductance in a circuit that can cause increased power loss, voltage drops, and oscillations. It arises from the imperfect design of the components used in the circuit and can have a significant effect on the performance of the circuit.

- Parasitic inductance is an unintended consequence of the physical layout of an electrical circuit.
- It is the inductance that is created when electrical components are placed too close together.
- It is the result of the magnetic fields created by the electrical components.

Parasitic Inductance vs Equivalent Series Inductance (ESL)

Equivalent series inductance (ESL) and parasitic inductance are related terms used to describe the inductive properties of electronic components, but they have slightly different meanings. Equivalent series inductance refers to the intentionally included inductance in a component's model, while parasitic inductance refers to the unintended inductance that arises due to various factors in the circuit. Both ESL and parasitic inductance can affect the performance of electronic components and circuits, but they differ in their origin and controllability.

Equivalent Series Inductance (ESL):

ESL refers to the inductance that is intentionally incorporated into a component's model to accurately represent its behavior in a circuit. ESL represents the inductance that is an inherent part of the component's design and contributes to its electrical characteristics. ESL is sometimes specified in datasheets and is important for understanding the component's impedance, resonance behavior, and overall performance.

ESL is a controlled parameter that manufacturers strive to minimize or specify accurately for their components. It can be characterized and measured using various techniques; such as impedance analyzers or network analyzers.

Equivalent series inductance (ESL) is not typically associated with resistors. Resistors are primarily characterized by their resistance value and do not have inherent inductive behavior. In an ideal scenario, resistors have no inductance.

However, it's worth mentioning that in practical scenarios, resistors may exhibit some parasitic inductance due to their physical construction and the layout of their leads and terminals. This parasitic inductance is generally minimal and considered negligible for most applications involving resistors.

Parasitic Inductance:

Parasitic inductance refers to unintended or undesirable inductance that is not part of the component's intentional design but arises due to various factors in the circuit or system. It includes the inductance associated with the component's leads, interconnections, and other elements that are not accounted for in the component's model or datasheet.

Parasitic inductance is typically an undesired effect that can impact the performance of a circuit. It can cause signal degradation, impedance variations, and affect circuit behavior at high frequencies. Parasitic inductance can arise in various components, including resistors, capacitors, inductors, and integrated circuits.

For high-frequency applications or when dealing with fast-switching signals, the parasitic inductance of a resistor may become more significant and impact circuit performance. In such cases, specialized low-inductance resistor designs or techniques, such as using chip resistors or TFT's current sense resistors, can be employed to minimize parasitic inductance.

Overall, while resistors typically do not have an equivalent series inductance, they can have parasitic inductance that needs to be considered in specific situations. However, for most practical applications, the parasitic inductance of resistors is often small and does not significantly affect their functionality as passive components.

Due to the inherent low ESL in a resistor, TFT does not typically specify ESL in any specifications. It is also uncommon to provide explicit specifications for parasitic inductance because it can vary depending on the application, circuit layout, and external factors. Designers must take measures to minimize parasitic inductance by careful circuit layout, component placement, and routing techniques. Thin Film Technology can help guide these decisions through our simulation capabilities, with the appropriate level of information needed to specify to your design.

How does Parasitic inductance Effect an Electrical Circuit?

Parasitic inductance can have negative effects on the circuit's performance including undesired current flow, voltage drops, reduced overall current flow, interference with other circuits, and noise on the power supply.

To negate the effects of parasitic inductance, current sense resistors can be used. These resistors are specifically designed to measure current in a circuit and can help mitigate the impact of parasitic inductance. By placing a current sense resistor in series with the load, it creates a voltage drop proportional to the current flowing through the circuit. This voltage drop can be measured and used to control the circuit or provide feedback for other components.

By using current sense resistors, the circuit designer can accurately monitor and control the current flow, compensating for the effects of parasitic inductance. This can help improve the overall performance and stability of the electrical circuit.

Effect of Inductance in Low Resistance Resistors

Current sense resistors are low ohm resistors, typically less than 1 ohm. These resistors are not shielded from the effects of parasitic inductance, but rather help negate the effects overall. When the resistance is low, the impedance increases as the frequency gets higher. This means that AC currents with high frequency components, such as a sawtooth wave, can yield inaccurate detection results.When AC current flows through a low resistance resistor, the voltage drop across the resistor is the sum of the voltage drop due to resistance and the voltage drop due to inductance. To ensure accurate current sensing, it is recommended to use low resistance resistors with minimal inductance for large current sensing.

Measurement is Not One Size Fits All

While the basic concept of measuring parasitic inductance remains the same, the specific techniques and methods employed may differ depending on the application and the characteristics of the parasitic inductance being measured. It is important to consider the unique requirements and challenges of each application when selecting an appropriate measurement approach.

The measurement of parasitic inductance can vary depending on the specific application and the context in which it is being measured. It can arise from factors such as the resistance of interconnects, traces, and components, as well as from non-ideal characteristics of materials.

The measurement of parasitic inductance typically involves measuring the voltage drop across the resistance and the current flowing through it. However, the specific techniques and methods used for measurement can vary depending on the application and the nature of the parasitic inductance being measured.

For example, in high-frequency applications, such as RF circuits or microelectronics, the parasitic inductance measurements may require specialized equipment and techniques due to the small scale and fast operation of the components involved. This may involve using techniques such as time-domain reflectometry (TDR) or vector network analyzers (VNAs) to characterize the impedance and resistance of the circuit elements.

In power electronics applications, where high currents and voltages are involved, different measurement techniques may be used to accurately measure parasitic inductances. These techniques may include four-wire resistance measurement methods, Kelvin connections, or other specialized setups that minimize the impact of measurement leads and contact resistances.

Parasitic Inductance of a Resistor, Relative to your Circuit Design

Parasitic inductance in a resistor, relative to the circuit design, includes the inductance contributed by the resistor itself and other components, interconnects, and traces in the circuit.

The magnitude of parasitic inductance in a resistor can vary depending on several factors related to the circuit design:

Physical Layout:

The physical arrangement and layout of the circuit, including the placement and proximity of components and the routing of traces, can impact parasitic inductance. Longer and more convoluted paths, particularly in high-frequency or fast switching circuits, can contribute to higher parasitic inductance.

Trace and Interconnect Length:

The length of the traces or interconnects between the resistor and other components can introduce additional inductance. Longer traces have more inherent inductance, so efforts to minimize trace length can help reduce parasitic inductance.

Trace Width and Thickness:

The width and thickness of the traces carrying the current through the resistor can also affect parasitic inductance. Wider and thicker traces generally have lower inductance due to reduced resistance and loop area.

Component Placement:

The relative placement of the resistor with respect to other components, such as capacitors or inductors, can influence the parasitic inductance. Proper component placement, minimizing loop areas and optimizing the current flow paths, can help reduce the overall parasitic inductance in the circuit.

Grounding and Return Paths:

The grounding and return paths in the circuit can impact the distribution of currents and introduce additional inductance. Careful consideration of grounding techniques and proper return paths can minimize the impact of parasitic inductance.

It is important to note that the specific value of parasitic inductance in a resistor within a circuit design is difficult to determine without detailed analysis or simulation. It depends on multiple factors related to the overall circuit layout, construction, and operating conditions. Simulations and modeling tools can assist in estimating and minimizing parasitic inductance during the circuit design phase.

By considering the circuit design and layout factors that contribute to parasitic inductance, designers can take appropriate measures to minimize its impact and optimize the overall performance of the circuit.

Parasitic Inductance of a Resistor v.s. its Footprint

The parasitic inductance associated with a resistor and the parasitic inductance associated with its footprint are two different aspects to consider. Both need to be considered and addressed appropriately depending on the specific application and frequency requirements.

Parasitic Inductance of a Resistor:

When current flows through a resistor, it encounters resistance, which dissipates energy in the form of heat. However, resistors also possess parasitic inductance due to their physical construction. This inductance arises from the length and shape of the resistor's leads or terminals, as well as the layout of the internal components.

The parasitic inductance of a resistor can have implications in high-frequency applications. As the frequency increases, the parasitic inductance can affect the behavior of the resistor, leading to undesirable effects such as impedance variations, signal distortion, and resonance phenomena.

To mitigate the impact of parasitic inductance in high-frequency circuits, techniques such as using low-inductance resistors, using surface-mount resistors instead of through-hole resistors, or employing dedicated decoupling or bypass capacitors are often employed.

Parasitic Inductance of the Footprint:

The parasitic inductance associated with the footprint refers to the inductance introduced by the physical layout and design of the circuit board pads and traces used to mount and connect components, including resistors. The shape, length, and thickness of the traces and pads, as well as their proximity to other conductive elements, can contribute to parasitic inductance.

The parasitic inductance of the footprint can impact the performance of the circuit, especially at high frequencies or when dealing with fast-switching signals. It can lead to signal degradation, increased crosstalk, and other unwanted effects.

To minimize the parasitic inductance of the footprint, layout considerations such as using wider traces, minimizing the length of the connections, and optimizing the placement of components can be employed. Techniques like using ground planes, guard traces, and controlled impedance routing can also help manage parasitic inductance.

Resistor Selection Guide

To minimize parasitic inductance in resistors, several options are available. There are a few types of resistors that are commonly chosen for their low parasitic inductance characteristics. Surface mount and chip resistors offered in various package sizes (the smaller the better) are going to be preferred over through-hole resistors, especially in high-frequency applications. They have shorter lead lengths and reduced loop areas, resulting in lower inductance values.

The Recommended Component for SMD chip resistors are Thin Film Resistors & current sense resistors:

Thin Film Resistors:

Thin film resistors are constructed by depositing a thin layer of resistive material onto a substrate. They typically exhibit lower parasitic inductance compared to other types like carbon composition or thick-film resistors.

Current Sense Resistors:

Current sense low resistance resistors are available in four-terminal types, which have voltage terminals for sensing voltage and current terminals for current flow. Four-terminal types provide better accuracy in current sensing with fewer sensing errors due to voltage terminal pattern design. However, two-terminal types can also accurately sense current if the voltage terminal patterns are properly designed.

In general, four-terminal resistors (also known as Kelvin resistors) tend to have lower parasitic inductance compared to two-terminal resistors. The four-terminal configuration allows for more accurate measurement and control of the resistance value, minimizing the impact of lead inductance.

The use of four-terminal resistors is particularly beneficial in applications that require high precision, low noise, or accurate resistance measurements, especially at low resistances or high frequencies. They are commonly used in applications such as precision instrumentation, metrology, and calibration.

However, it's important to note that the reduction in parasitic inductance offered by four-terminal resistors may not always be significant or necessary for every application. If the parasitic inductance is not a critical concern, or if cost or space limitations are more important factors, two-terminal resistors can still be suitable.

Ultimately, the choice between two-terminal and four-terminal resistors depends on the specific requirements of your application, including the desired accuracy, frequency range, and constraints on cost and space.

Two-Terminal vs Four-Terminal Current Sense Resistors- Configuration Affects Parasitic Inductance:

Two-Terminal Resistors:

Two-terminal resistors have two leads or terminals that are used for both current flow and voltage measurement. The current flowing through the resistor generates a voltage drop across the leads, which can introduce parasitic inductance due to the length and geometry of the leads.

Four-Terminal Resistors:

Four-terminal resistors have two additional separate terminals, known as sense or Kelvin terminals, in addition to the two terminals used for current flow. The current is applied across the current terminals, while the voltage measurement is made across the sense terminals. By keeping the current and voltage measurement paths separate, the impact of lead inductance is minimized, resulting in lower parasitic inductance.

The use of four-terminal resistors is particularly beneficial in applications that require high precision, low noise, or accurate resistance measurements, especially at low resistances or high frequencies. They are commonly used in applications such as precision instrumentation, metrology, and calibration.

However, it's important to note that the reduction in parasitic inductance offered by four-terminal resistors may not always be significant or necessary for every application. If the parasitic inductance is not a critical concern, or if cost or space limitations are more important factors, two-terminal resistors can still be suitable.

Ultimately, the choice between two-terminal and four-terminal resistors depends on the specific requirements of your application, including the desired accuracy, frequency range, and constraints on cost and space.

Current Sense Resistor Materials & Construction

Metal plate, metal strip, or metal foil resistors, are often preferred for applications where low parasitic inductance is critical. These resistors are constructed using a thin metal layer (usually a nickel-chrome alloy) on a ceramic substrate, which helps to minimize parasitic inductance and other unwanted effects.

These Types of Resistors have Several Characteristics that make them Well-Suited for Low Parasitic Inductance:

Low Inductance Design:

TFT's Current Sense Resistors are specifically designed to have low parasitic inductance. The resistor element is typically arranged in a meandering or serpentine pattern to minimize inductance by reducing the length of conductive paths. **TFT has a proprietary way of trimming resistors.*

Wide Bandwidth:

Due to their low parasitic inductance, TFT's Current Sense Resistors can maintain their performance across a wide range of frequencies. They are particularly useful in high-frequency applications where minimizing inductance is critical.

High Power Handling:

TFT's Current Sense Resistors are often capable of handling high power levels due to their robust construction. This makes them suitable for applications that require both low inductance and high power dissipation.

Temperature Stability:

TFT's Current Sense Resistors typically exhibit good temperature stability, which is important for maintaining accurate resistance values and performance over a wide temperature range.

However, it's important to note that typically these types of resistors may have a higher cost compared to other resistor types. TFT is capable of high-volume manufacturing to help negate the typical increase in cost. Additionally, their physical size may be larger compared to surface-mount chip resistors, which can be a consideration in space-constrained designs. TFT will work with you to find a viable solution that meets your pricing requirements and real estate needs.

Overall, if low parasitic inductance is a critical requirement for your application, metal plate or metal foil resistors can be a good choice. They provide low inductance, wide bandwidth, high power handling, and temperature stability, making them suitable for demanding high-frequency applications.

It's worth noting that while these resistor types generally exhibit lower parasitic inductance, the exact value of parasitic inductance can still vary depending on the specific manufacturer, package size, and other factors. It is advisable to consult sales@thin-film.com to ensure the desired performance for your particular application.