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Grounding Structure Designs that Mitigate Undesired Resonances in High-Speed Signals

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Abstract:

This publication discusses a specific ground-signal-signal-ground (GSSG) configuration of a high-speed differential signal pair. Simulations show that frequency resonances occur when a quarter-wavelength resonant structure is unintentionally created, which causes the observed frequency resonances. To remove the resonances, this publication recommends two design methods. Each proposed method has its own benefits and limitations. The proposed solutions may be treated as design rules for similar high-speed differential signal pairs.

Keywords:

High-speed signals, differential signals, quarter-wavelength resonator, return path, ground plane, ground, GND, hatched ground plane, solid ground plane, ground-signal-signal-ground, GSSG, stitching, via, contact, printed circuit board, PCB, flexible printed circuit board, FPCB, signal integrity, SI, electromagnetic interference, EMI, electromagnetic compatibility, EMC.

Background:

The proliferation of consumer electronic devices challenges original device manufacturers (ODMs) and engineers to integrate electronic components into smaller-sized modules. At the same time, a user wants higher speeds and higher data rates in order to have a better user experience (UX). These factors make routing interconnects between different modules increasingly challenging.

Engineers often design high-speed signals to be transmitted through differential signal pairs. In addition, to reduce couplings between adjacent differential pairs, engineers often insert ground traces (G) adjacent the differential signal (S) pairs. To clarify, as it is annotated herein, "G" refers to a ground trace, and "S" refers to a signal trace. A common configuration or arrangement is ground-signal-signal-ground (GSSG) on the same plane or layer of a printed circuit board (PCB), as illustrated in Figure 1.

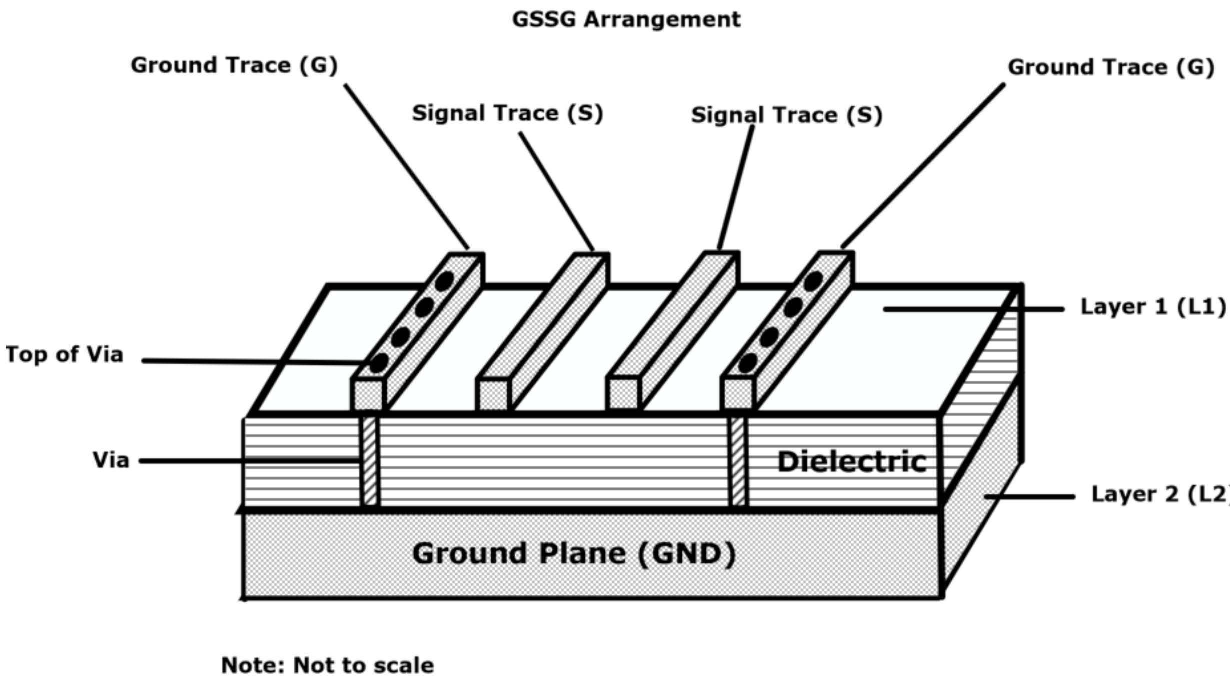


Figure 1

Figure 1 illustrates a two-layer PCB, where layer 1 (L1) is the GSSG traces and layer 2 (L2) is a ground (GND) plane. As it is annotated herein, "GND" refers to the ground plane. L1 and L2 are separated by a dielectric material. As illustrated in Figure 1, placing G traces that are periodically connected to a GND plane using via structures is an effective way to isolate the S traces and improve board isolation or decrease crosstalk. As signals propagate down the GSSG traces, the two G traces are grounded to the same GND plane using stitching via structures. This mitigates the generation of cavity modes in the return path between the G traces and the GND plane, which can significantly degrade the signal quality. Nevertheless, in modern consumer electronic devices, routing space is limited. Unlike the PCB in Figure 1, where the G traces are periodically connected to the GND plane using multiple via structures, it is not uncommon for ODMs to employ only a few stitching via structures to connect the G traces to the GND plane, which may affect signal quality.

In consumer electronic devices, these GSSG traces may be routed in rigid PCBs or flexible PCBs (FPCBs). Unlike the rigid PCB, where solid GND planes are typically used, the FPCB commonly adopts hatched GND planes to meet the mechanical specifications of the FPCB. Figure 2A illustrates the solid GND plane, while Figure 2B illustrates the hatched GND plane.

2A) Solid GND plane **2B) Hatched GND plane**

Figure 2

To maintain the communication between an application processor (AP) and a display module, ODMs often use a display FPCB. In the display FPCB, high-speed display signals are transmitted differentially using the GSSG configuration. Traces of the GSSG configuration are usually designed in one layer of an FPCB. If the traces of the GSSG configuration are routed in an external layer, the G traces in this GSSG configuration are connected using shorting via structures to a GND plane beneath them. If the traces of the GSSG configuration are routed in an internal layer, the G traces in this GSSG configuration are connected using shorting via structures to GND planes above and beneath the GSSG configuration. Nevertheless, careless grounding structure design with shorting via structures placed only at one end of the GSSG configuration and hatched GND planes cause undesired resonances and decrease the communication quality. Despite of its benefits, the use of hatched GND planes with limited via structures in the FPCB leads to signal integrity (SI), electromagnetic interference (EMI), and electromagnetic compatibility (EMC) issues.

An effective way to design the grounding structure is to use solid GND planes, instead of hatched GND planes, above and beneath the GSSG configuration. With solid GND planes, the undesired resonances may not appear even when using a limited number of shorting via structures. This grounding structure, however, does not allow for the FPCB to meet the mechanical and impedance-matching specifications. Therefore, it is desirable to have better grounding structure designs to help improve the signal quality in FPCBs, while meeting the mechanical and impedance-matching specifications.

Description:

In the display FPCB, the undesired resonances in a poor-grounding structure design for high-speed differential signals may be due to a quarter-wavelength resonator formed by the grounding traces in the GSSG configuration, the GND planes, and the shorting via structures at one end of the GSSG traces connecting the G traces to the GND planes.

Figure 3 shows an example three-dimensional (3D) drawing of the GSSG trace configuration in the display FPCB.

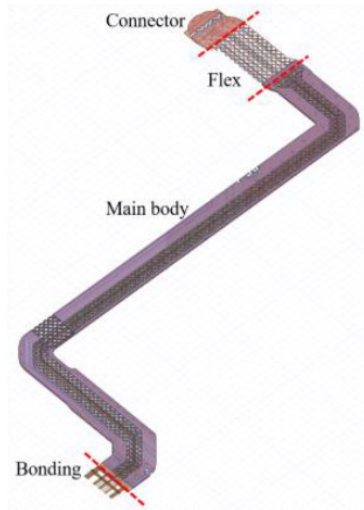


Figure 3

The GSSG trace configuration in Figure 3 may be conceptually divided into four sections, a connector, a flex, a main body, and bonding. The differential signal pair may be routed on a two-layer, three-layer, four-layer, five-layer, six-layer, and so forth, FPCB. It is worth noting that an increased number of FPCB or PCB layers may offer better SI, EMI, and EMC performance, but may come with an increased financial cost and may be mechanically disadvantageous.

Something to consider is a quarter-wavelength resonance structure. Figure 4 illustrates an example of the quarter-wavelength resonance structure.

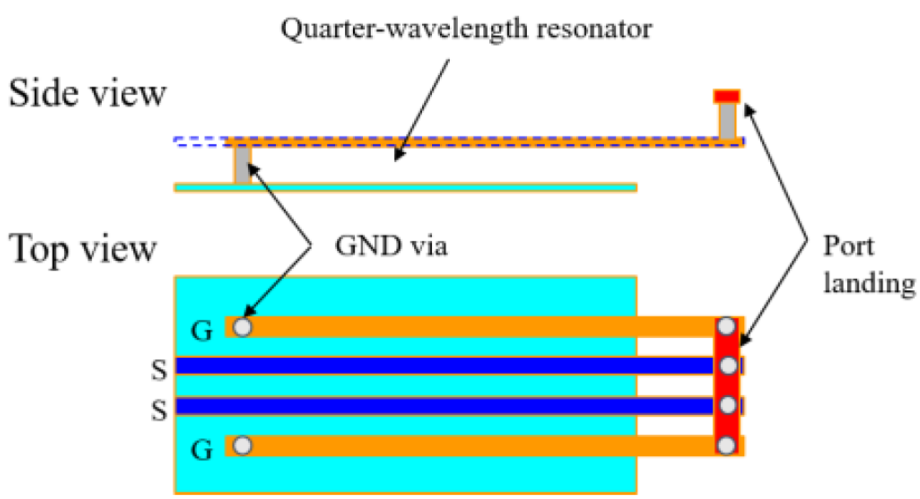


Figure 4

Figure 4 illustrates a widely-used quarter-wavelength resonance structure, which can be created from a microstrip line. The G traces are terminated to a GND plane using via structures at one end, while the other end is left floating. Ports land on the GSSG traces to excite the structure. As frequency increases, the G traces together with the GND plane and the via structures behave like a parallel inductive and capacitive (LC) filter, which resonates at the odd-number multiples of the quarter-wavelength. At these frequencies, the propagation of a common-mode signal is blocked since it uses the filter structure as part of the return path, while the differential signal propagates freely since the filter structure is not part of its return path. It is worth mentioning that when solid GND planes are used, the differential signal is not affected by the quarter-wavelength resonance structure. The hatched GND planes, however, cause mode conversions between common-mode and differential-mode signals. Differently said, when using hatched GND planes, both the common-mode and the differential-mode signals are degraded at resonant frequencies. Therefore, avoiding the quarter-wavelength resonance structure helps prevent the degradation of differential signals.

The structure illustrated in Figure 4 creates periodic frequency resonances. After careful examination of the resonant frequencies, it is apparent that the long structure in Figure 3 is responsible for such frequency resonance. The differential S traces in the flex sections (see Figure 3) are not a concern. Therefore, the rest of the structure are carefully examined. Figure 5 illustrates a three-layer FPCB in a 3D drawing that does not include the flex section.

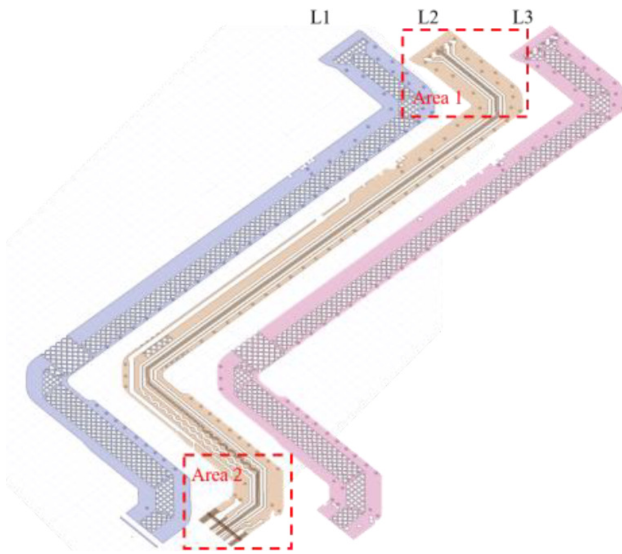
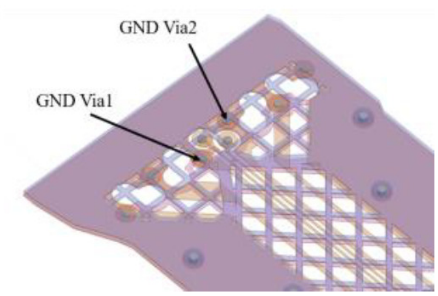
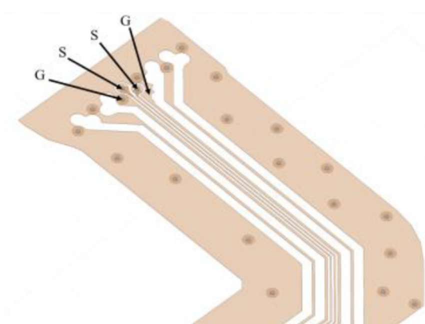


Figure 5A) GSSG traces on L2 and hatched GND planes on L1 and L3





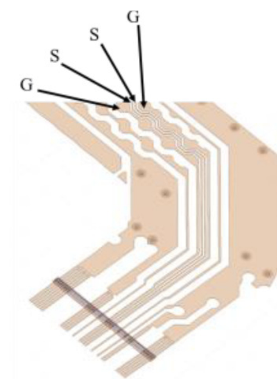


Figure 5B) GND Via1 and GND Via2 connecting G traces to the hatched GND on L1 and L3

Figure 5C) Enlarged view of Area 1

Figure 5D) Enlarged view of Area 2

Figure 5

As illustrated in Figure 5A, the GSSG traces are routed on L2 and electrically reference the hatched GND planes on L1 and on L3. The G traces on L2 are connected to the L1 and L3 GND planes through via structures, which are labeled GND Via1 and GND Via2, as illustrated in Figure 5B. Except for these two via structures, as signals propagate down the differential pair, there is no more stitching via structures connecting the G traces to the hatched GND planes on L1 and L3, as illustrated in Figure 5C and Figure 5D. In the bonding section of this differential signal pair, G traces serve as the reference for the S traces. The port setup is similar to what is presented in Figure 4. Analogous to the case in Figure 4, the G traces in the sections of the main body and the bonding have via structures only at one end, making the structure in Figure 5 a quarter-wavelength resonator. To mitigate the undesired frequency resonances created by the quarter-wavelength resonator, this publication discusses two grounding structure designs.

Design I

The GSSG configuration is on the inner layer with hatched GND planes above and beneath the GSSG configuration. The G traces in the GSSG configuration are connected to the hatched GND planes through shorting via structures. Given that there are two G traces in the GSSG configuration, shorting via structures are added in pairs. Equation 1 is used to calculate the least number of the required pairs of shorting via structures.

$$N = ceil\left[\frac{\frac{F_u}{F_0}+1}{2}\right] \qquad \textbf{Equation 1}$$

where F_u is the upper frequency of interest, and the function *ceil* (*) returns the smallest integer value that is bigger than or equal to a number.

Equation 2 defines the fundamental quarter-wavelength resonant frequency F_0.

$$F_0 = \frac{c}{(4L\sqrt{\varepsilon_r})} \qquad \textbf{Equation 2}$$

where c is the speed of light, L is the length of the differential signal pair, and ε_r is the relative permittivity.

Given the highest frequency upper frequency of interest F_u of the desired signals traveling along the GSSG traces, the corresponding wavelength at the highest frequency is λ_u, where the relationship between F_u and λ_u is given by Equation 3.

$$F_u = \frac{c}{\lambda_u \sqrt{\varepsilon_r}} \qquad \textbf{Equation 3}$$

The detailed procedures to adding shorting via structures are further discussed. First, add one pair of shorting via structures close to one end of the GSSG traces, where the distance between the pair of shorting via structures is less than a quarter of λ_u. Then, add a second pair of shorting via structures at the other end of the GSSG traces, where also the distance between the pair of shorting via structures is less than a quarter of λ_u. Adding more pairs of shorting via structures between the two ends of the GSSG traces further improves the signal quality.

The distance between any two adjacent pairs of shorting via structures is no larger than half of λ_u. This arrangement of shorting via structures sufficiently suppresses the undesired frequency resonances. Connecting the shorting via structures to both GND planes is desirable. Nevertheless, it is also possible to connect the G traces using shorting via structures to only one of the GND planes and still sufficiently suppress the undesired frequency resonances.

This procedure of placing shorting via structures can also be applied if the GSSG configuration is on the external layer with the hatched GND plane beneath it. Differently said, adding the additional shorting via structures may eliminate the need for GND planes above and beneath the GSSG configuration.

Design II

The GSSG pattern is on the inner layer with one hatched GND plane and one solid GND plane above and beneath the GSSG configuration. The detailed procedures to adding shorting via structures are further discussed.

The G traces in the GSSG configuration are connected to the GND planes through shorting via structures in pairs. First, adding one pair of shorting via structures close to one end of the GSSG traces. Then, adding a second pair of shorting via structures at the other end of the GSSG traces. This grounding structure sufficiently suppresses the undesired frequency resonances. The shorting via structures connect the G traces to both GND planes. Nevertheless, it is also possible to connect the G traces using shorting via structures to only one of the GND planes and still sufficiently suppress the undesired frequency resonances.

In conclusion, the discussed grounding structures sufficiently suppress frequency resonances created by the quarter-wavelength resonant structure. Each proposed method has its own benefits and limitations. The proposed solutions may be treated as design rules for similar differential signal pairs.

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