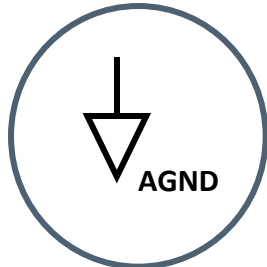

Mixed Analog/Digital Circuit Board Design and Layout for EMC

Todd H. Hubing

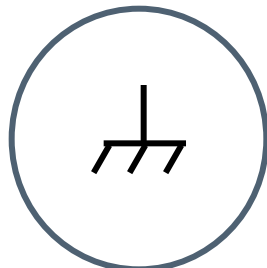
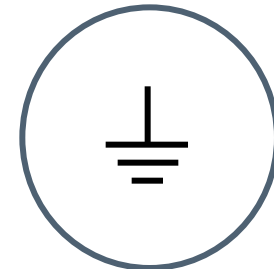
Clemson Vehicular Electronics Laboratory
Clemson University



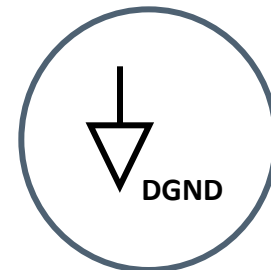
Ground vs. Signal Return



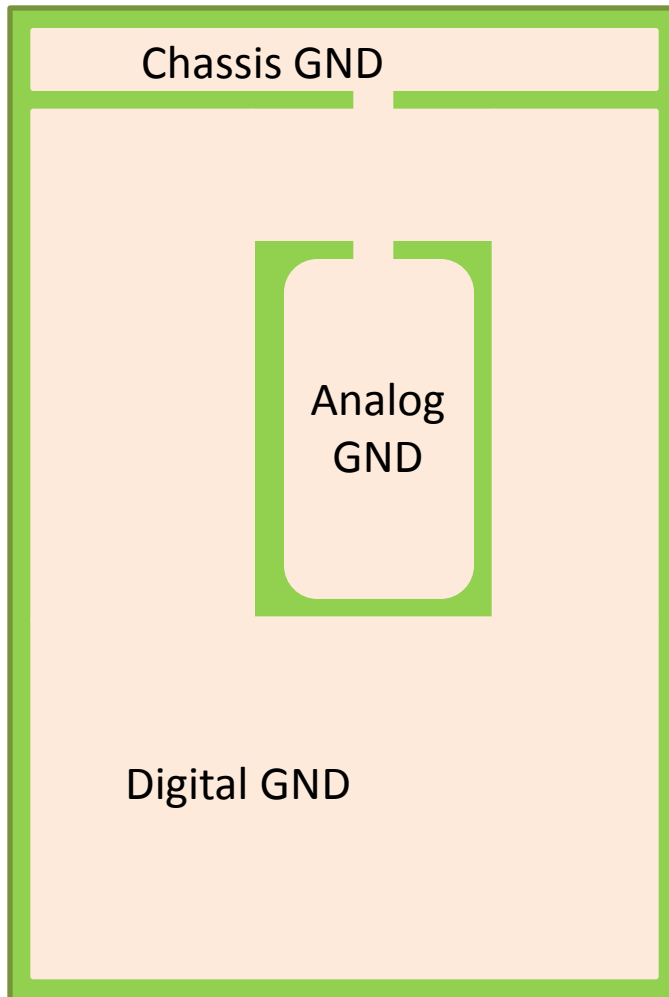
"Whenever I see more than one of these symbols on the schematic, I know there is [EMC] work for us here."



T. Van Doren

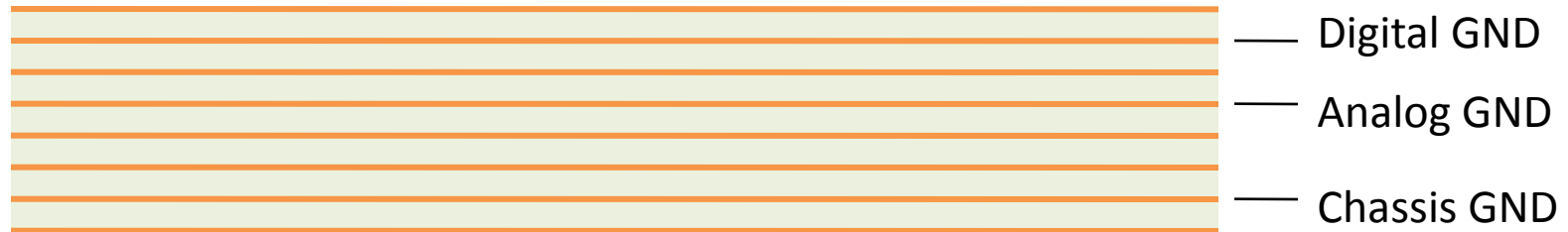


Lateral Isolation



- ❑ Rarely appropriate
- ❑ Often the source of significant problems

Vertical Isolation



- ❑ Only one plane usually needs to be full size.
- ❑ One or zero vias should connect planes with different labels.

Key Questions

- ❑ Why do I need more than one ground?
- ❑ Where does each ground need to be?
- ❑ How do I connect the grounds?

Important Concepts!

1. Current always returns to its source!

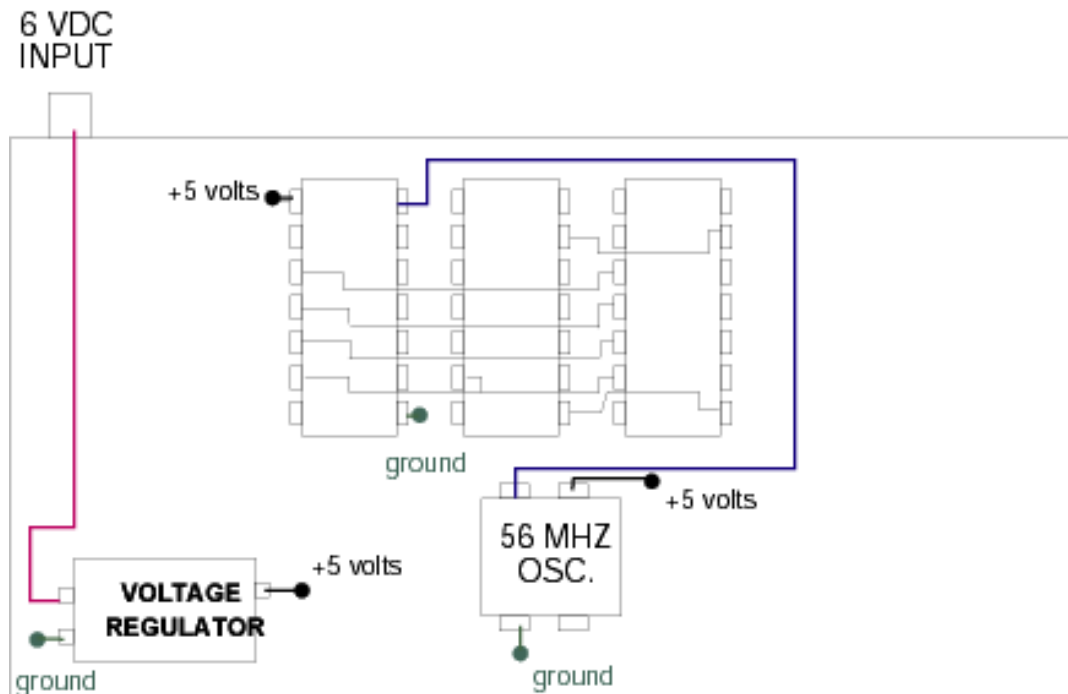
2. Current takes the path of least impedance!

> 100 kHz this is generally the path of **least inductance**

< 10 kHz this is generally the path(s) of **least resistance**

Identify Current Paths

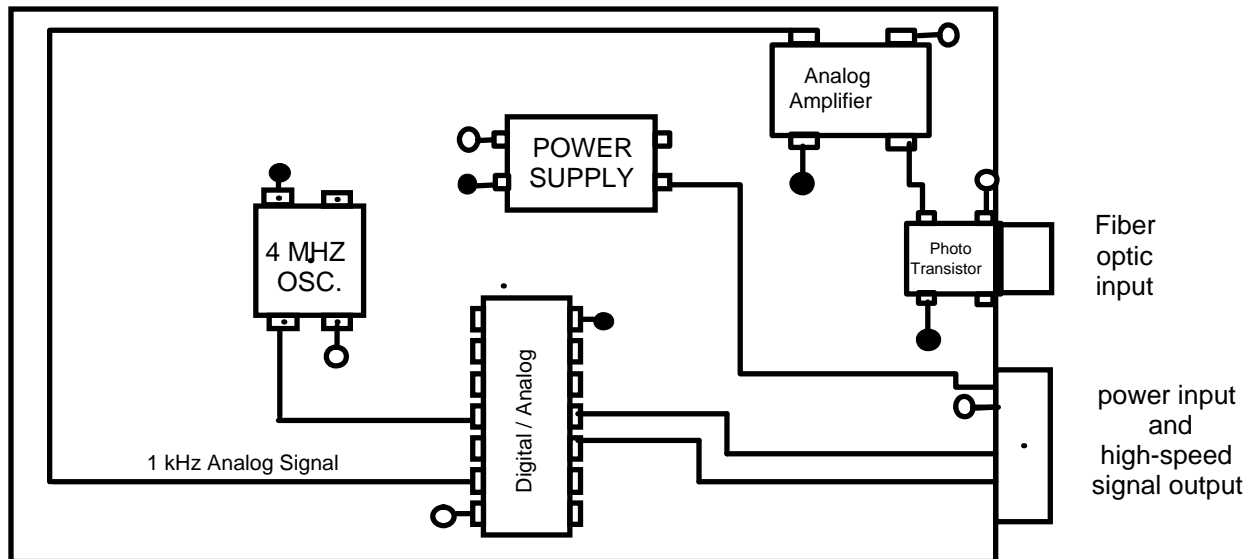
Where does the 56 MHz return current flow?



BOARD WITH INTERNAL
POWER AND GROUND PLANES

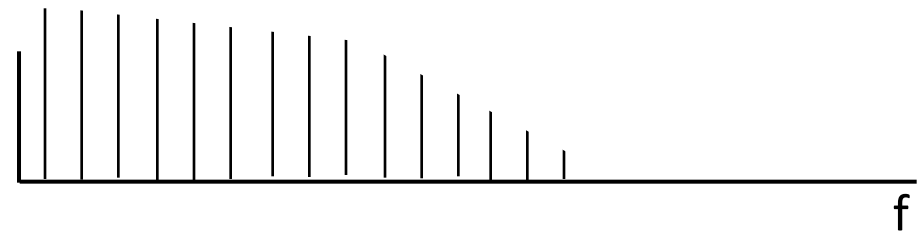
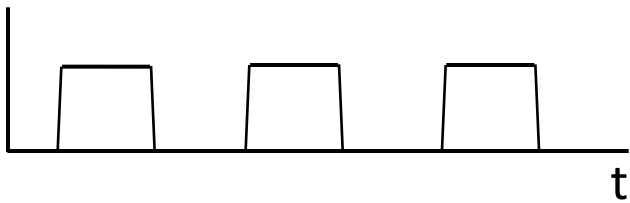
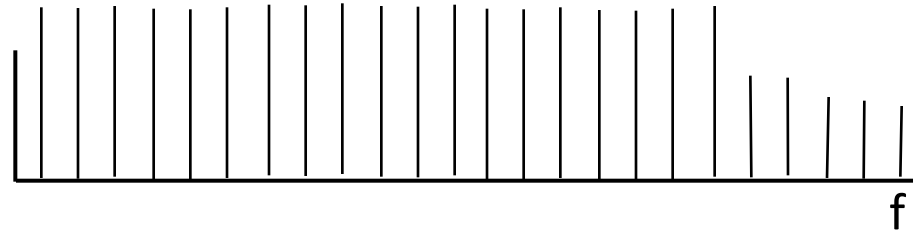
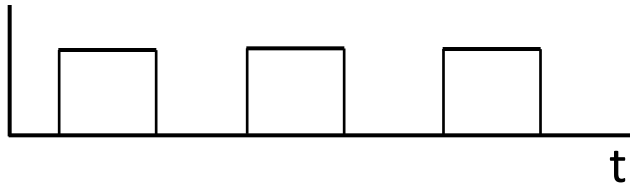
Identify Current Paths

Where does the 1 kHz return current flow?



- Connection to power plane
- Connection to ground plane

Frequency Content of Digital Signals



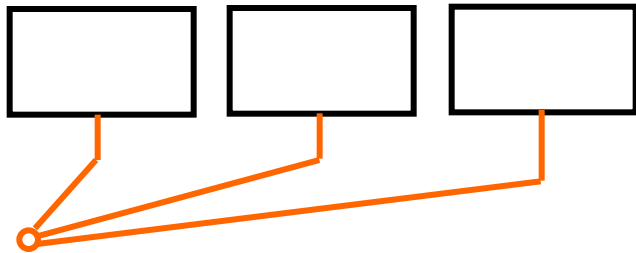
Ground vs. Signal Return

The purpose of a system ground is to provide a reference voltage and/or a safe path for **fault** currents.

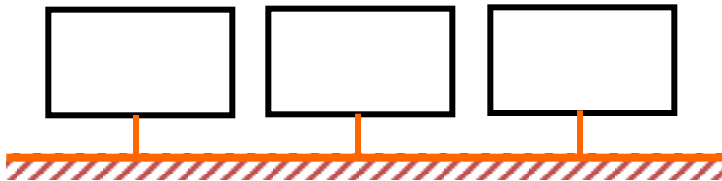
Signal currents flowing on a “ground” conductor can prevent a ground conductor from serving its intended purpose.

Don't confuse ground conductors with signal return conductors. Rules for the routing of “ground” may conflict with the rules for routing signal or power returns.

Confusing Concept



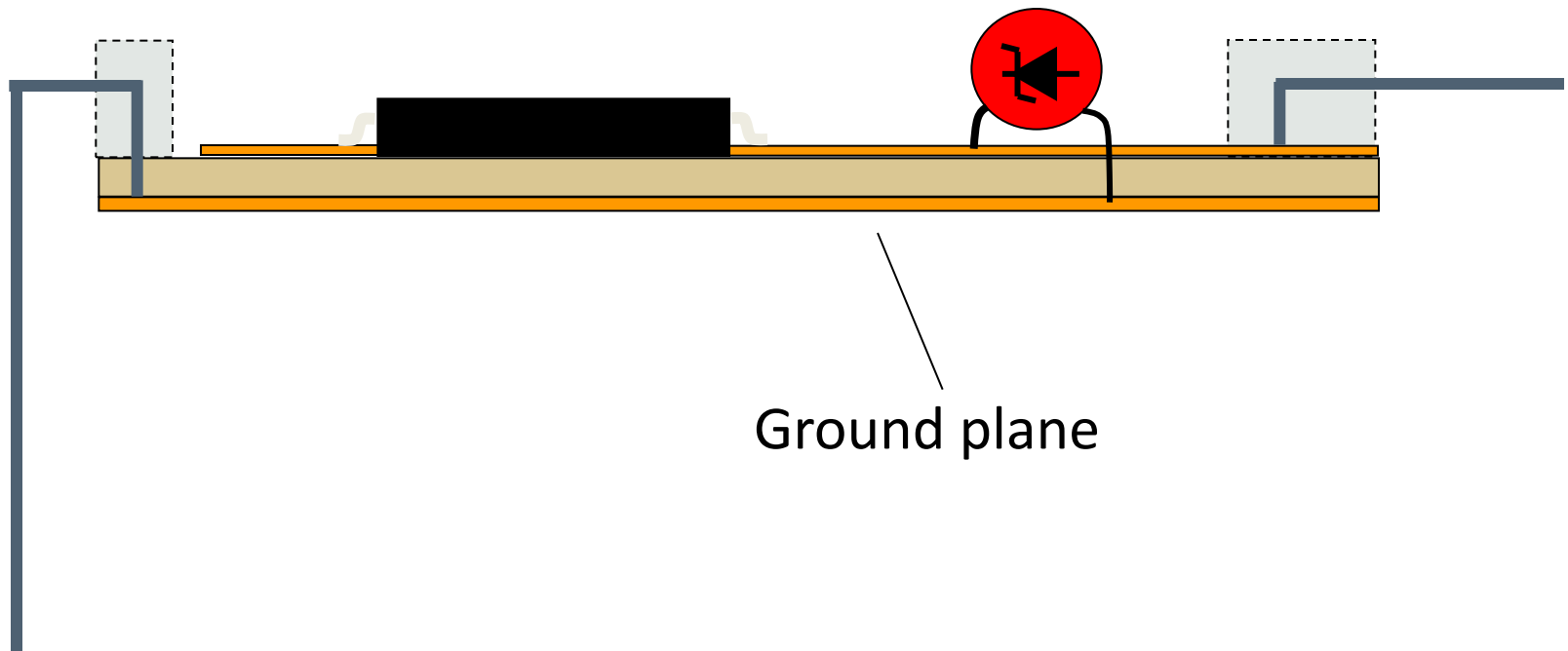
Single-Point Ground



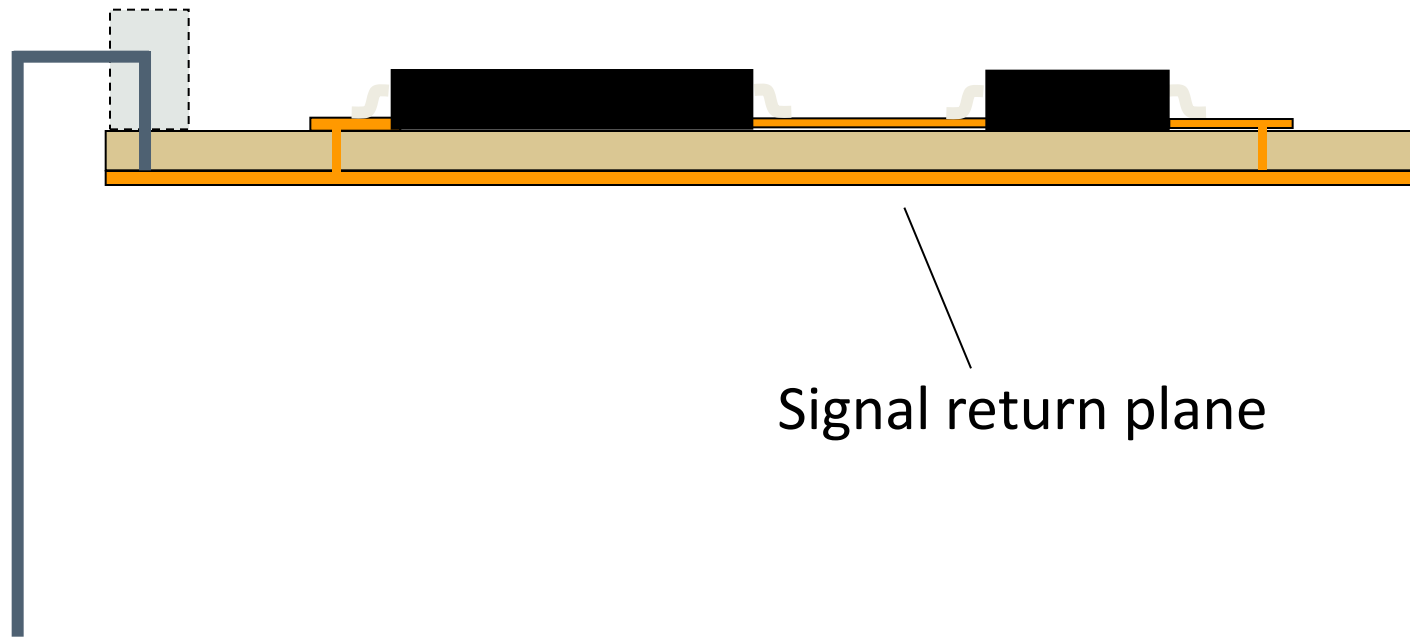
Multi-Point Ground

These are grounding strategies, not signal return strategies!

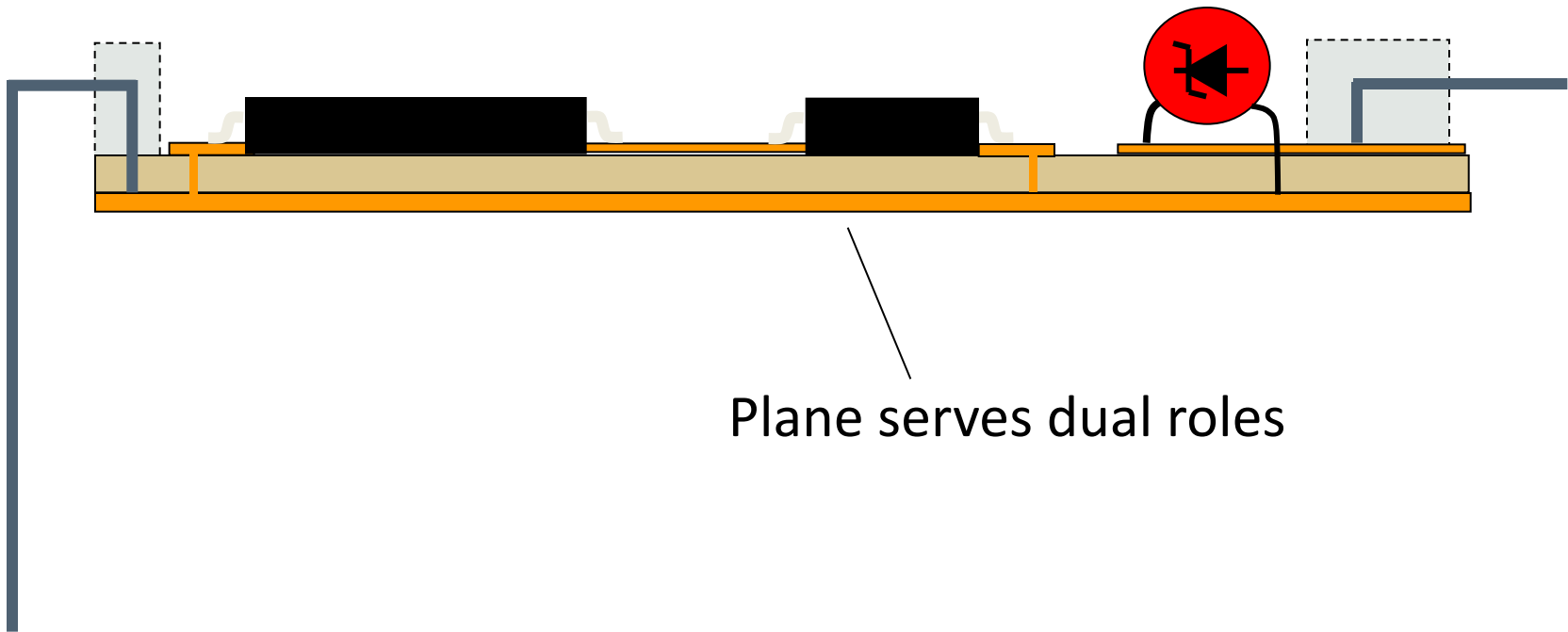
Ground vs. Signal Return



Ground vs. Signal Return



Ground vs. Signal Return

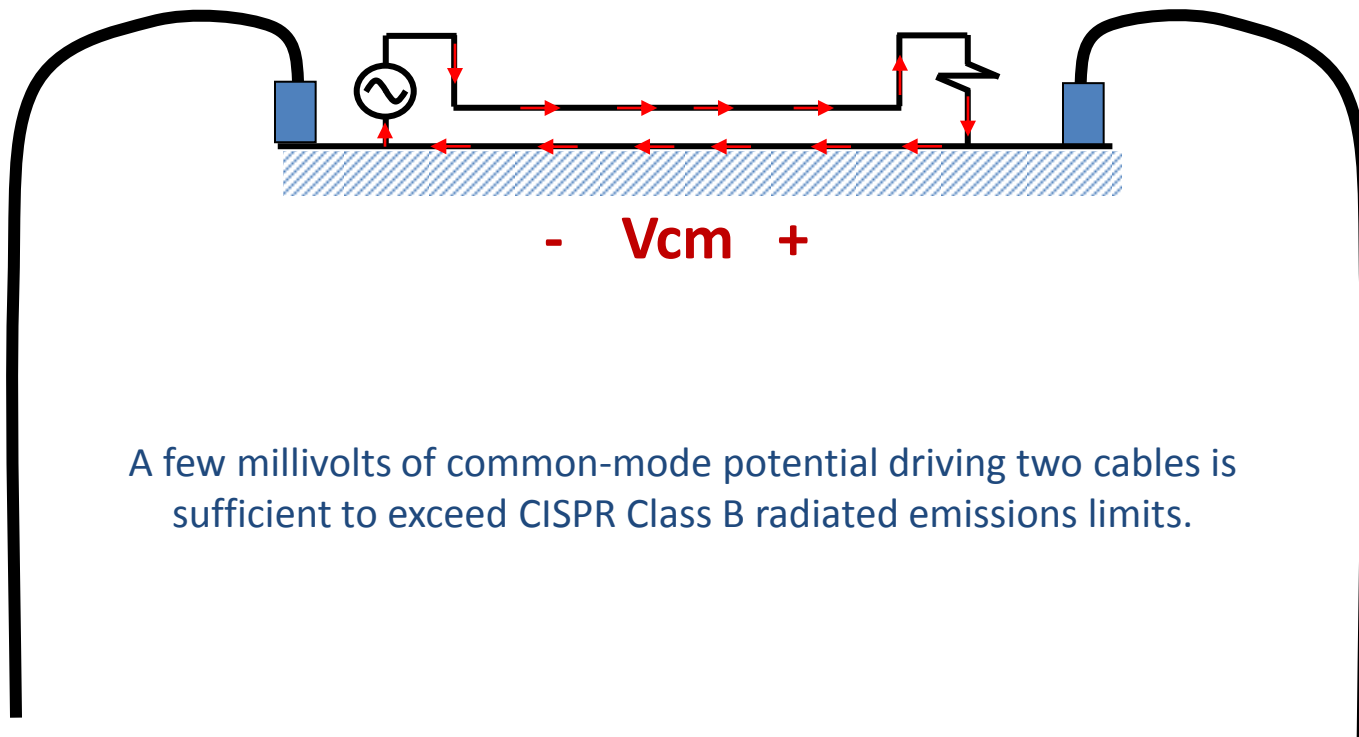


Plane serves dual roles

Another Important Concept

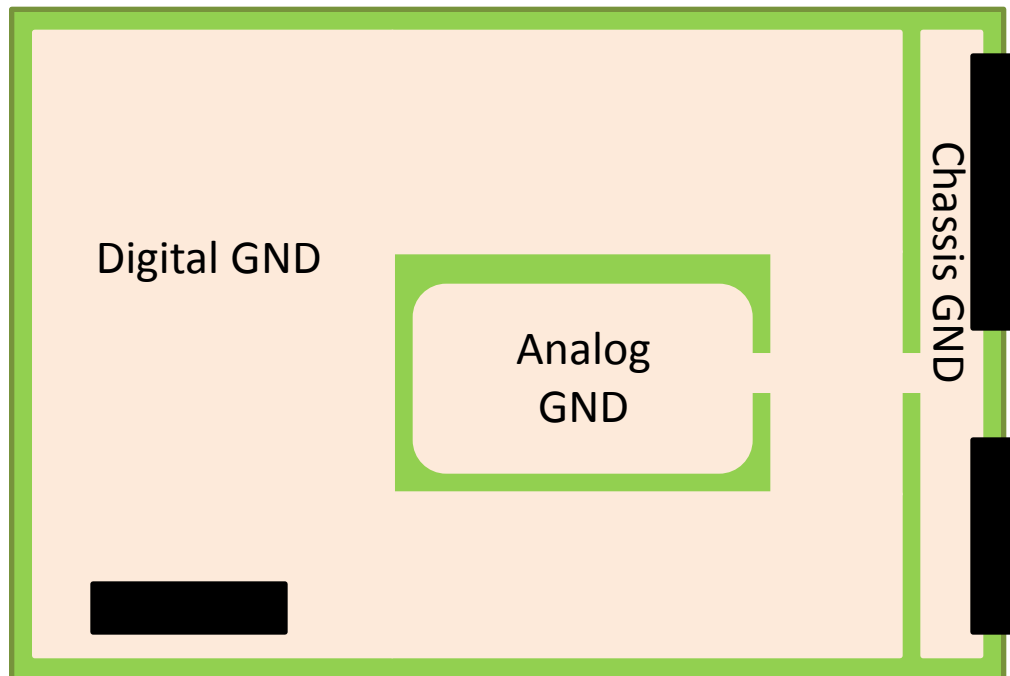
Current Driven Radiation Mechanism

Signal current loop induces a voltage between two good antenna parts.



A few millivolts of common-mode potential driving two cables is sufficient to exceed CISPR Class B radiated emissions limits.

How Much Isolation Can We Tolerate?



Ground vs. Signal Return

Circuit boards should have  high-frequency ground!

Why?

Conductors referenced to different grounds can be good antennas.

Signals referenced to two different grounds will be noisy (i.e. include the noise voltage between the two grounds).

Layouts with more than one ground are more difficult, require more space and present more opportunities for critical mistakes.

Excuses for employing more than one ground are generally based on inaccurate or out-dated information.

Ground vs. Signal Return

If grounds are divided, it is generally to control the flow of **low-frequency** (<100 kHz) currents.

For example,

Isolating battery negative (i.e. chassis ground) from digital ground

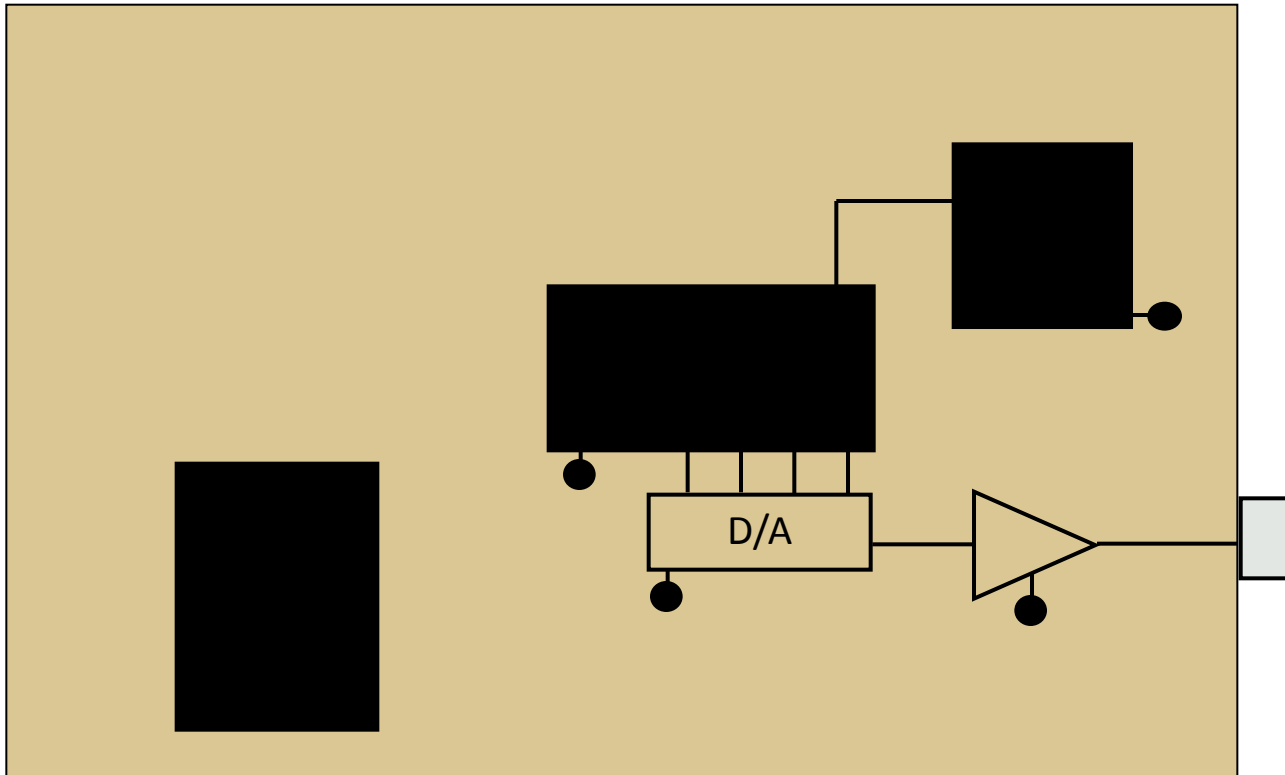
Isolating digital ground from analog ground in audio circuits.

This can be necessary at times to prevent common impedance coupling between circuits with **low-frequency** high-current signals and other sensitive electronic circuits.

HOWEVER, it is still necessary to ensure that there is only **1** high-frequency ground.

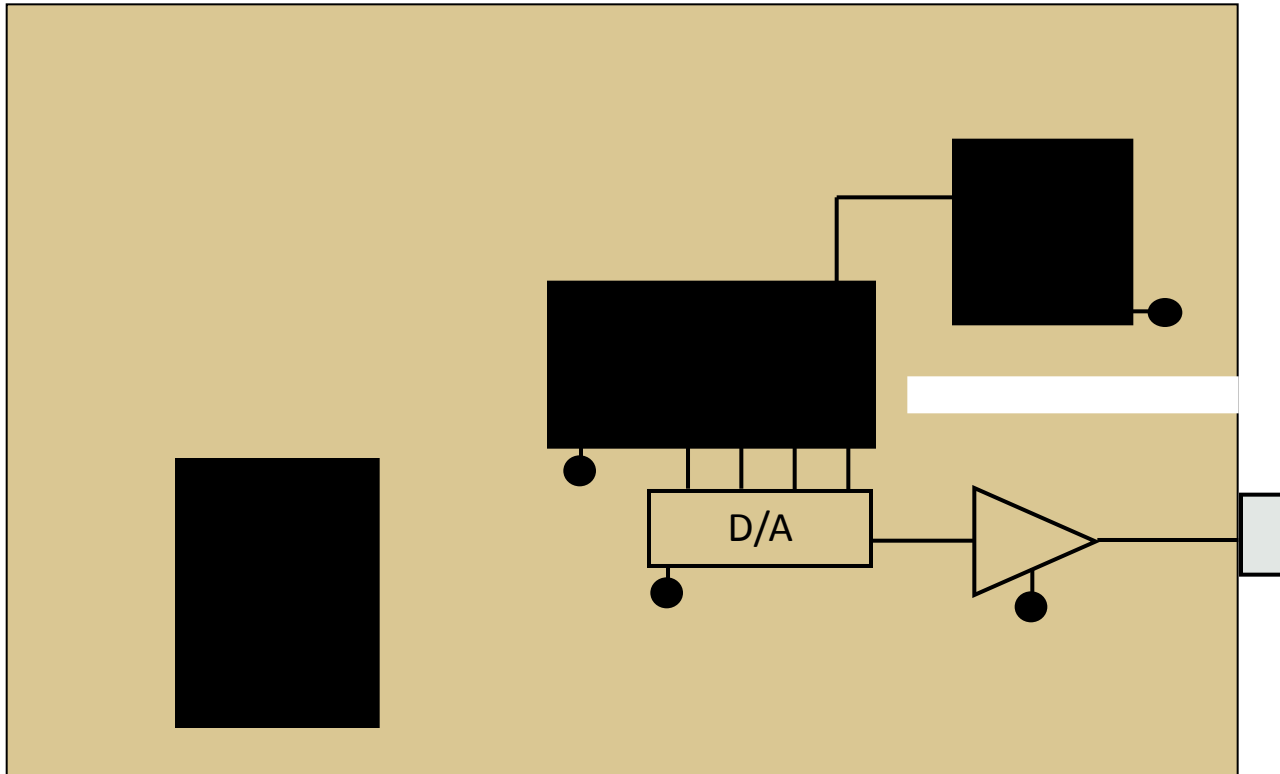
Ground vs. Signal Return

Exercise: Trace the path of the digital and analog return currents.



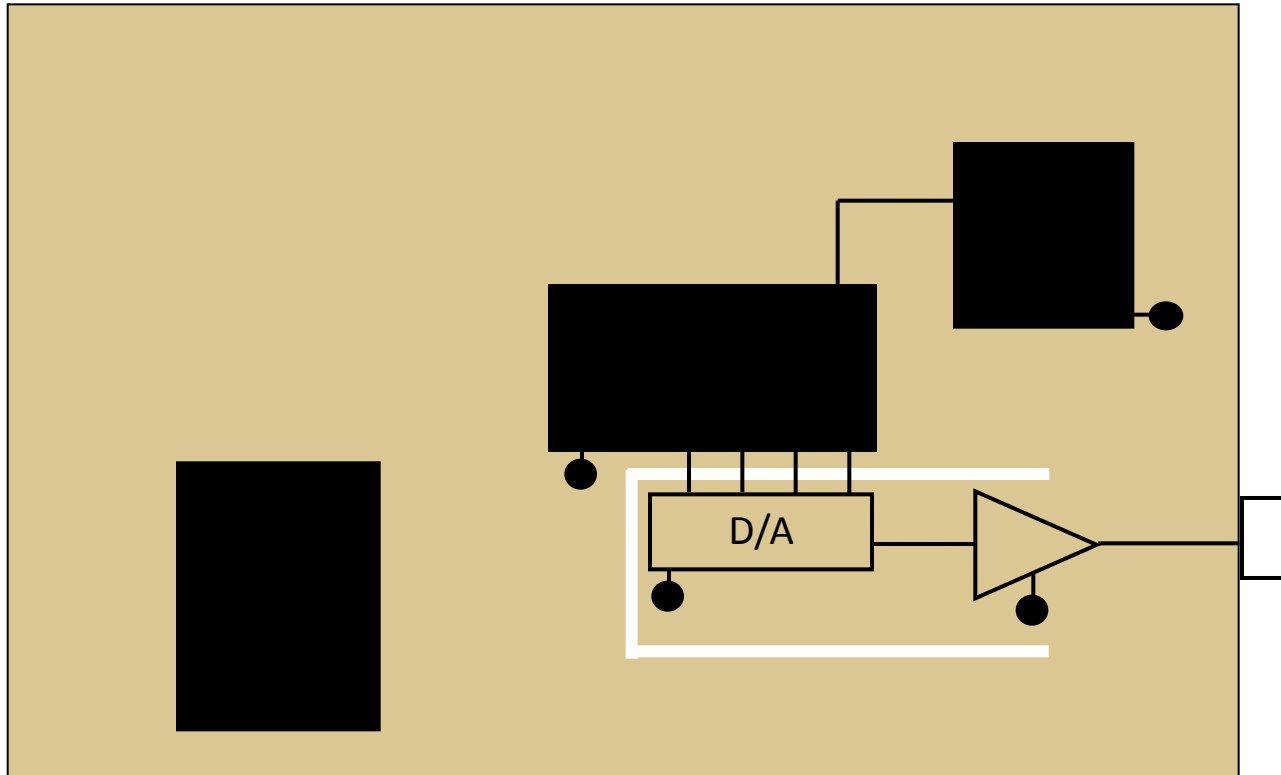
Ground vs. Signal Return

Exercise: Trace the path of the digital and analog return currents.



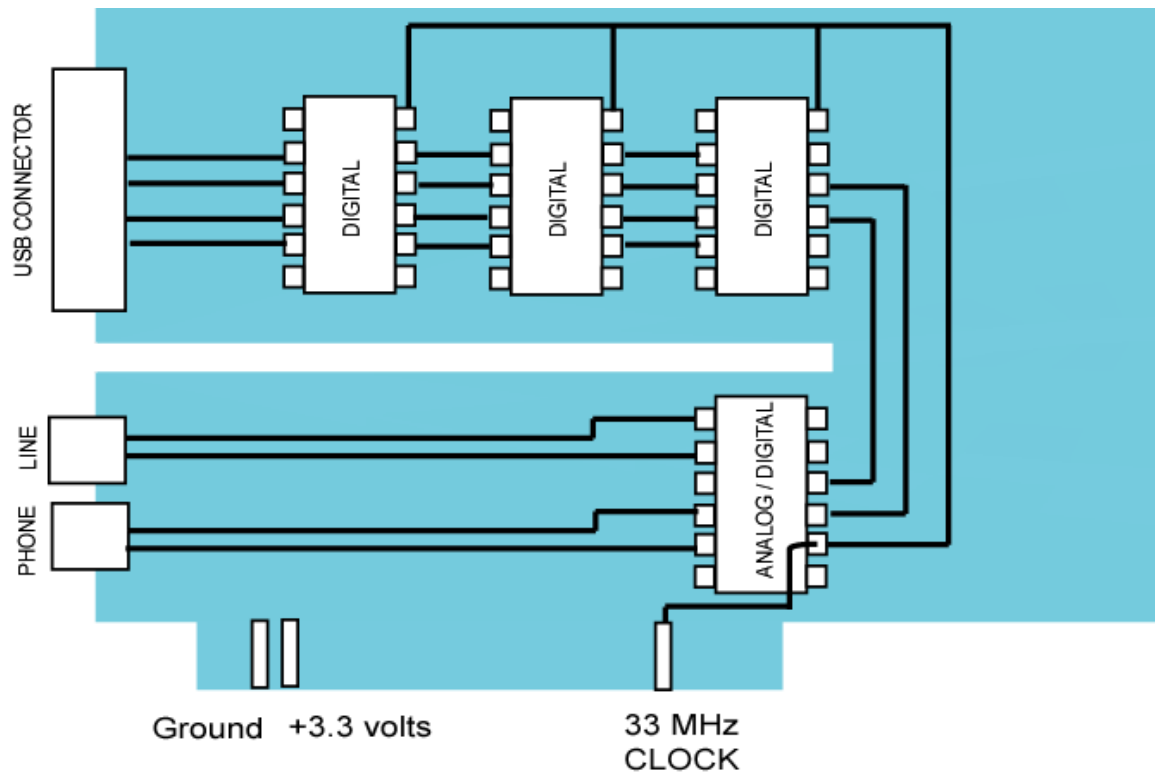
Ground vs. Signal Return

Exercise: Trace the path of the digital and analog return currents.



Ground vs. Signal Return

Design Exercise: What is wrong with this design and how would you improve it?



Ground vs. Signal Return

You don't need to gap a plane to control the flow of high frequency (>1MHz) currents. If you provide a low-inductance path for these currents to take, they will confine themselves to this path very well.

Ground vs. Signal Return

Rules for gapping a ground plane:

1. Don't do it!
2. If you must do it, **never ever allow a trace or another plane to cross over the gap.**
3. If you must do it, **never ever place a gap between two connectors.**
4. Remember that the conductors on either side of the gap are at different potentials.
5. See Rule #1!

¿Está bien así?



¡Ay, caramba!



Strategies for Analog/Digital/Mixed-Signal PCB Layout

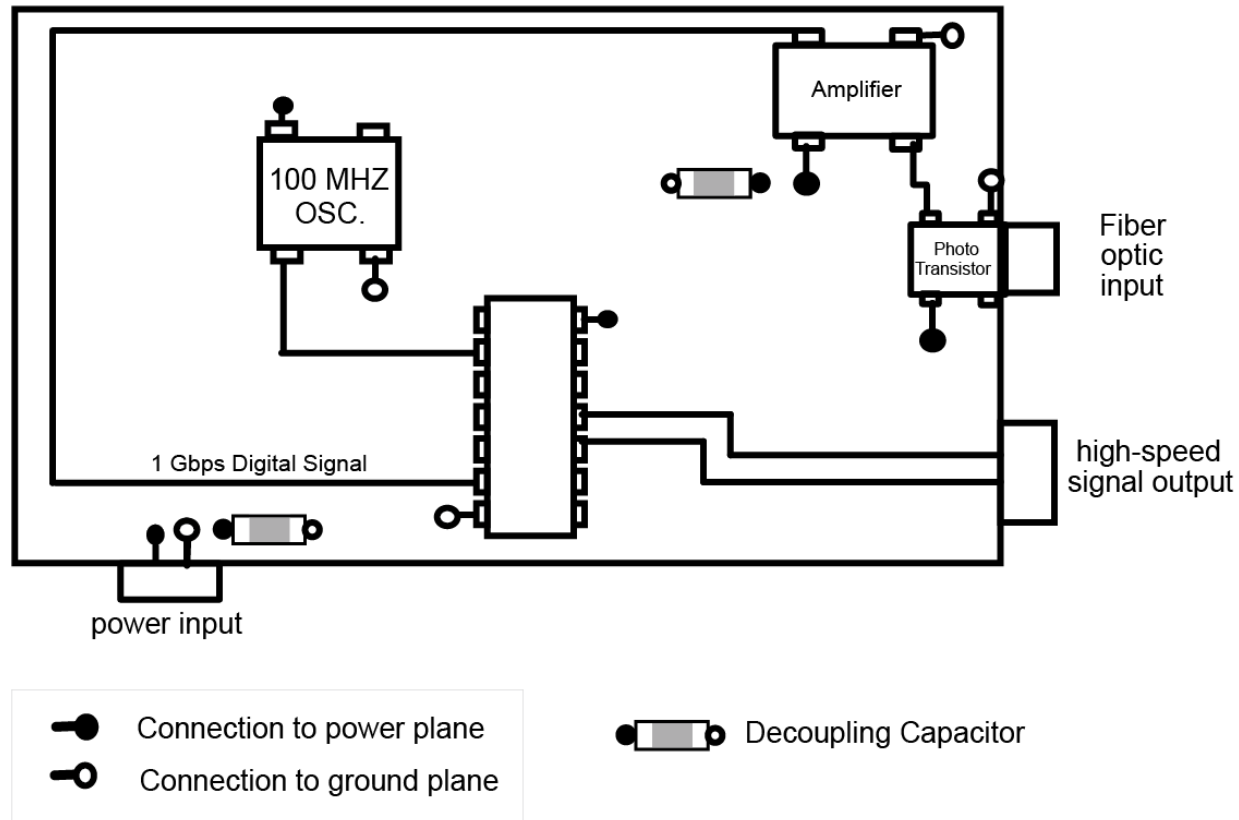
Mixed-Signal Designs

If you have analog and digital returns that must be isolated (to prevent common-impedance coupling):

- ❑ Route the returns on separate conductors
- ❑ Provide a DC connection at the one point (or in the one area) where the reference potential must be the same.
- ❑ This must include every place where a trace crosses the boundary between the analog and digital regions.

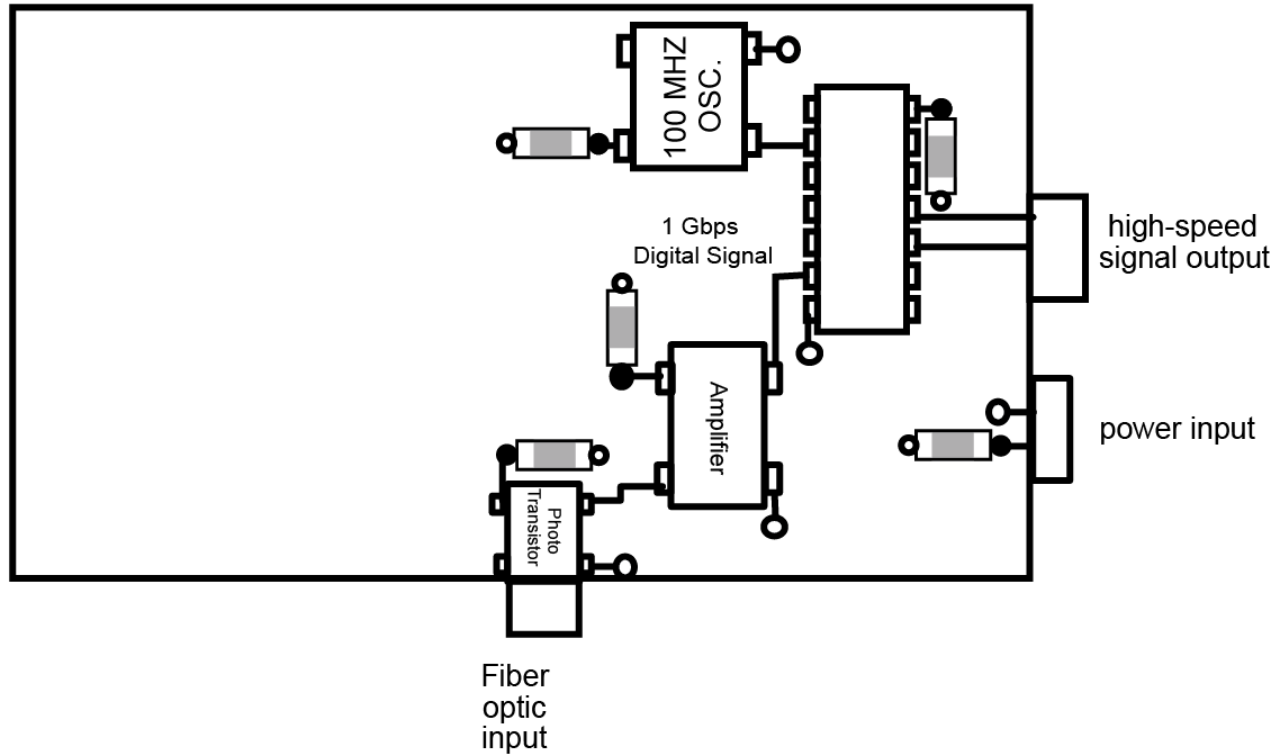
Mixed-Signal Designs

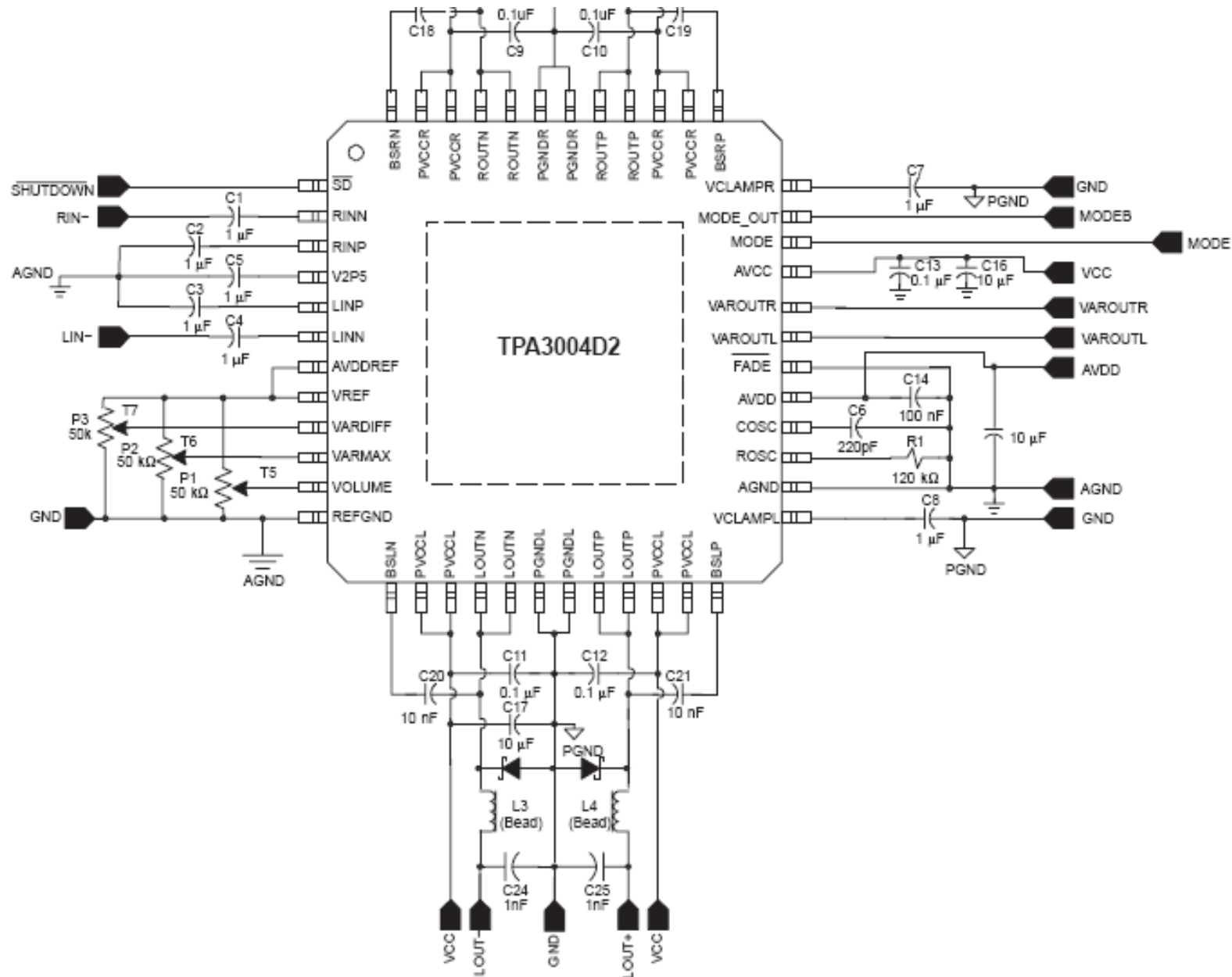
Example: How would you modify this design?



Mixed-Signal Designs

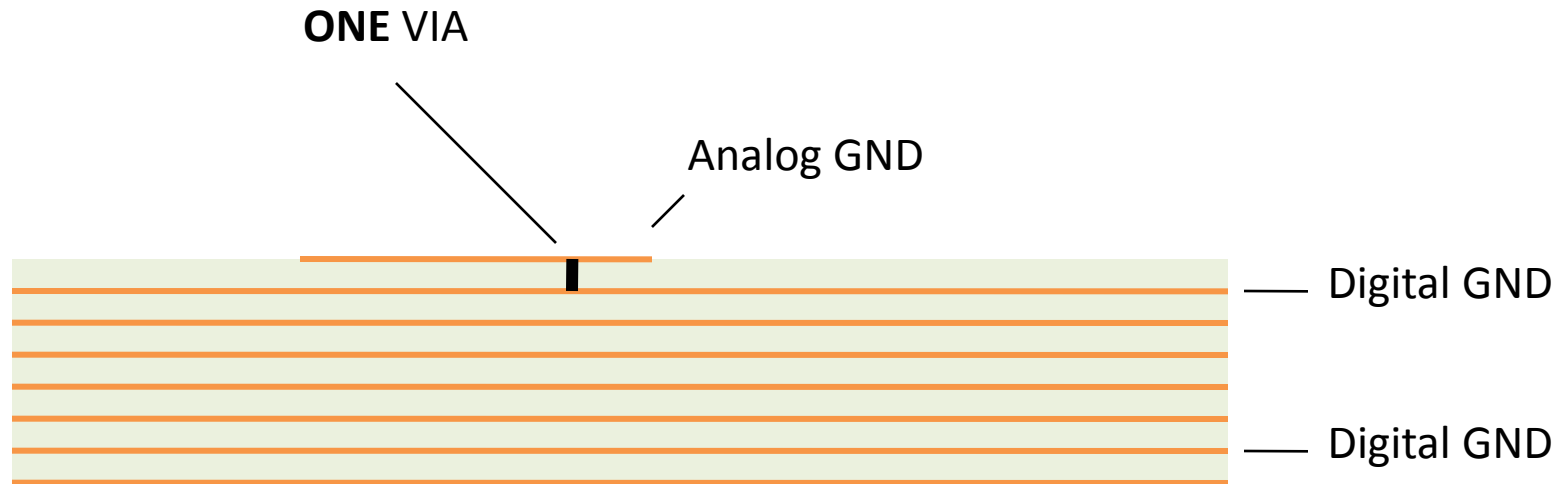
Example: A much better design





†Schottky diodes only needed for short circuit protection when $V_{CC} > 15V$. See SHORT CIRCUIT PROTECTION section in Application Information.

Sensitive A/D Isolation



If you think you need two vias, then you shouldn't be isolating the analog and digital grounds.

Provide a good HF chassis ground at connector

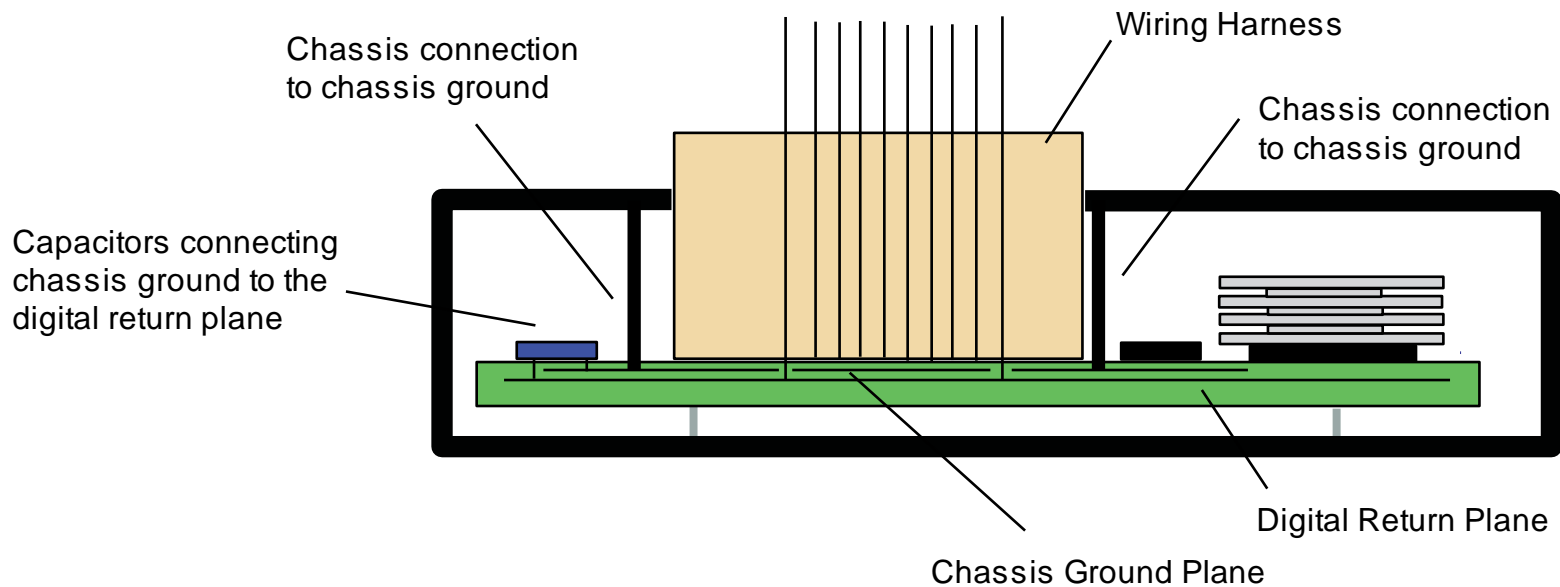
Cables and enclosures are both good antenna parts. If they are not held to the same potential, they are likely to create a radiation problem.

Exceptions:

- When there is no chassis ground
- When there are no connectors with cables

Note: Sometimes low-frequency isolation between chassis and digital ground is necessary control the flow of low-frequency currents. However, even in these situations it is usually important to provide a good high-frequency connection.

Isolating Chassis and Digital Grounds



Key Points

- ❑ Identify your HF ground and be sure it is the only ground that is large or connected to anything large!
- ❑ Don't call anything other current carrying nets "ground". For example, refer to a current carrying analog reference net as "analog return".
- ❑ Be aware of where your HF and LF currents are flowing!
- ❑ Isolate returns only when necessary to control the flow of low frequency currents.
- ❑ If you isolate two large conductors at low frequencies, be sure they are well connected at high frequencies.

For more information:

<http://www.cvel.clemson.edu>

The screenshot shows the main homepage of the Clemson Vehicular Electronics Laboratory (CVEL). The browser address bar displays <http://www.cvel.clemson.edu/>. The page features the CVEL logo and the text "THE CLEMSON UNIVERSITY VEHICULAR ELECTRONICS LABORATORY". A paragraph describes the laboratory's collaborative research and education services in automotive electronics, aerospace electronics, and electromagnetic compatibility. A navigation menu on the left lists "People", "Projects", "Courses", "Facilities", and "Partners". The main content area is organized into three columns: "AUTOMOTIVE ELECTRONICS", "AEROSPACE ELECTRONICS", and "ELECTROMAGNETIC COMPATIBILITY". Each column contains links for "TUTORIALS", "TOOLS", "RESEARCH", and "PRODUCTS". At the bottom, there are logos for "CLEMSON UNIVERSITY" and "CUICAR". The URL <http://www.cvel.clemson.edu/> is visible in the footer.

The screenshot shows the "ELECTROMAGNETIC COMPATIBILITY" page of the CVEL website. The browser address bar displays <http://www.cvel.clemson.edu/emc/>. The page features the CVEL logo and the text "ELECTROMAGNETIC COMPATIBILITY" and "THE CLEMSON UNIVERSITY VEHICULAR ELECTRONICS LABORATORY". The page is organized into several sections: "Tutorial Information" with links to "Introduction to EMC", "EMC Acronyms and Definitions", "Working with Decibels", "Shielding Theory", and "Practical EM Shielding"; "EMC Tools" with links to "Inductance Calculator", "PCB Trace Impedance Calculator", and "Electromagnetic Modeling Tools"; and "Upcoming EMC Events" with a list of international symposiums and workshops from 2008 to 2009. A navigation menu on the left lists "People", "Projects", "Courses", "Facilities", and "Partners". Logos for "CLEMSON UNIVERSITY" and "CUICAR" are visible at the bottom. The browser status bar shows "Internet" and "100%" zoom.