DC-DC Converters - Solid Return Plane or Cutouts Under Switch Node and Inductor? {Preliminary Report / March 10, 2021}

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The question on whether the ground return plane should be cut away under the switch node or inductor of DC-DC converters has been an ongoing debate.

The argument for an adjacent solid plane under all converter circuitry has been to contain the electromagnetic fields in the dielectric space between the circuit traces and return plane and that this would prevent the spread of EMI around the board.

Others argue the capacitive coupling between circuit traces and return plane should be cut away to minimize the capacitive coupling due to large *dV/dt* swings of the converter switch node with corresponding contamination of the return plane with EMI.

My colleague, Steve Sandler, decided to investigate the issue by designing four identical buck converter circuits (Figure 1), with component layout (Figure 2) and built on a two-layer stack-up (Figure 3) and comparing a solid return plane with; a cutout at the switch node pad, a cutout under the switch inductor and a cutout under both the switch node and inductor.

Converter Design

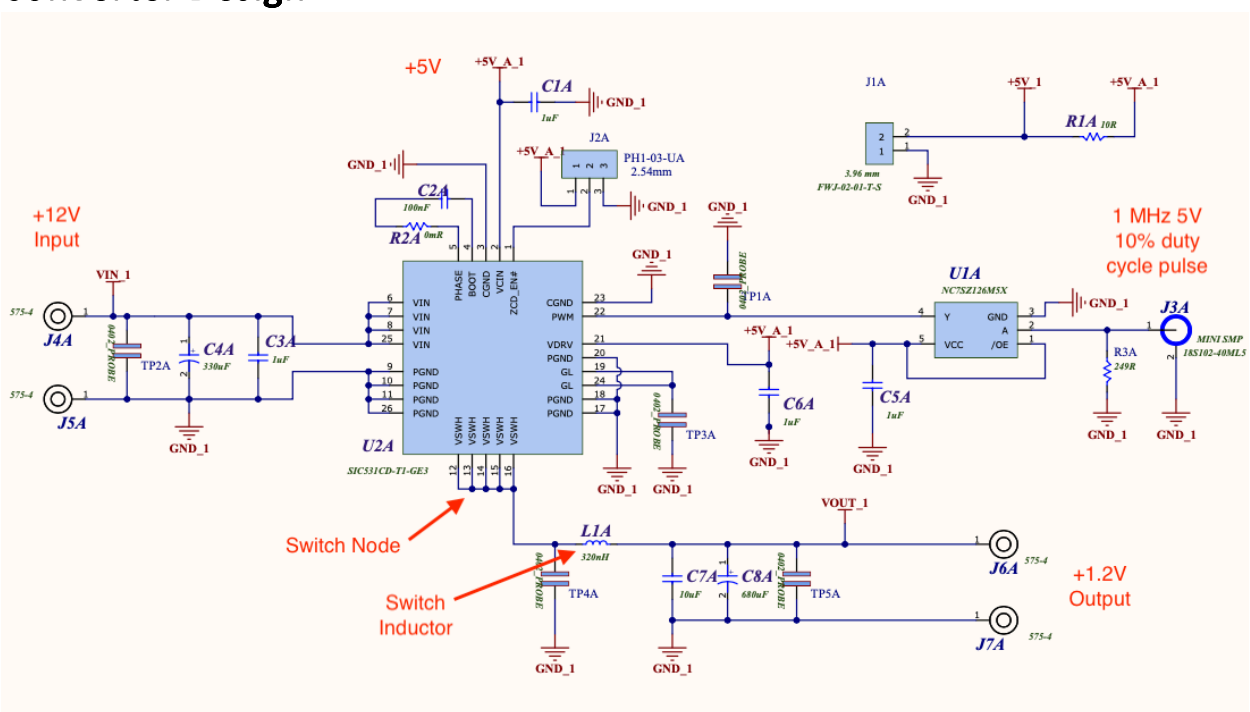


Figure 1 – The schematic diagram for all four converters.

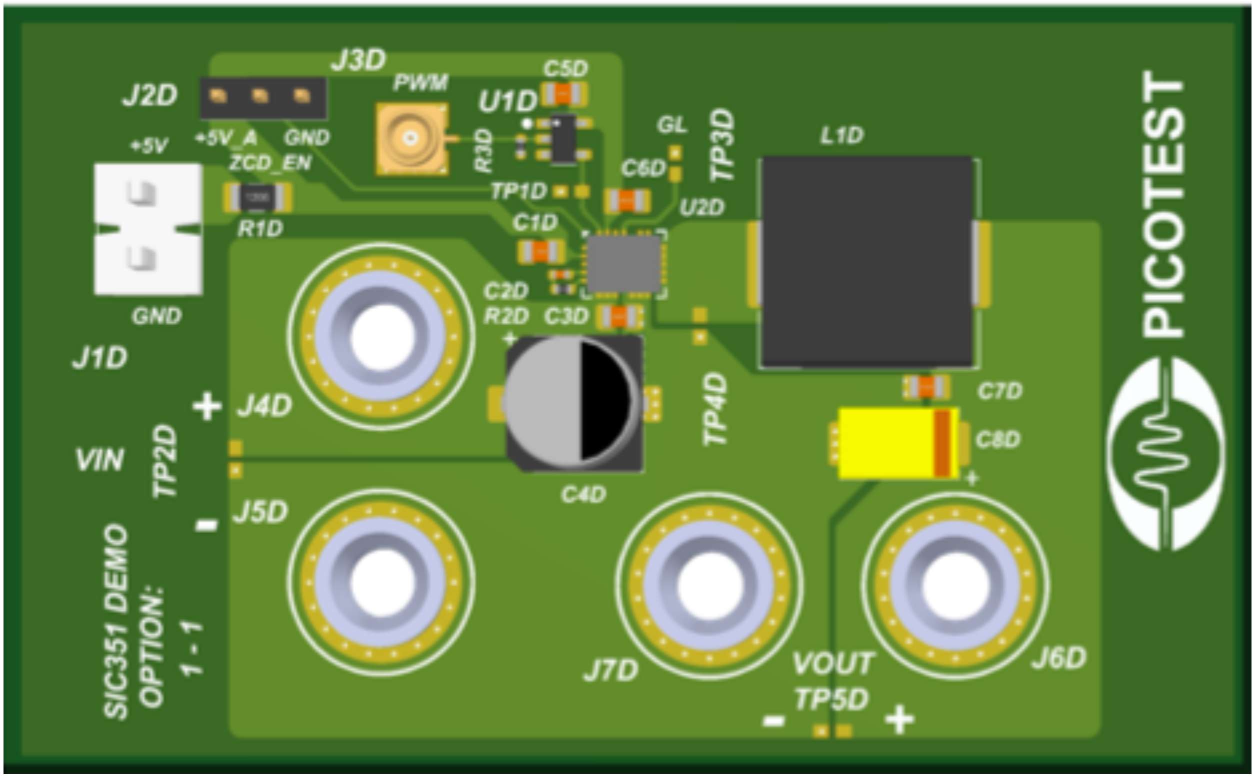
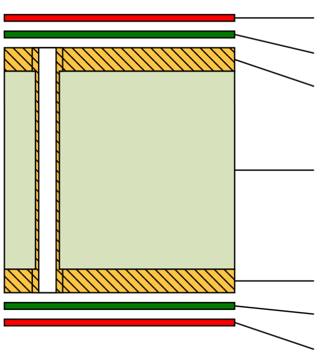


Figure 2 – A graphic diagram of the component layout.

Layer Stack Legend



Material	Layer	Thickness	Dielectric Material	Type	Gerber
	Top Overlay			Legend	GTO
Surface Material	Top Solder	0.4mil	Solder Resist	Solder Mask	GTS
Copper	Top Layer	1.4mil		Signal	GTL
Core		*28.0mil*	*HIGH TEM. FR4*	*Dielectric*	
Copper	Bottom Layer	1.4mil		Signal	GBL
Surface Material	Bottom Solder	0.4mil	Solder Resist	Solder Mask	GBS
	Bottom Overlay			Legend	GBO

Total thickness: 31.6mil

Figure 3 – The stack-up design used.

The four boards were labeled as (see Figure 4):

- 1-1 (solid return plane)
- 0-1 (cutout under SW node)
- 1-0 (cutout under inductor, L1)
- 0-0 (cutout under both SW node and L1)

Bottom Layer (Scale 1:1)

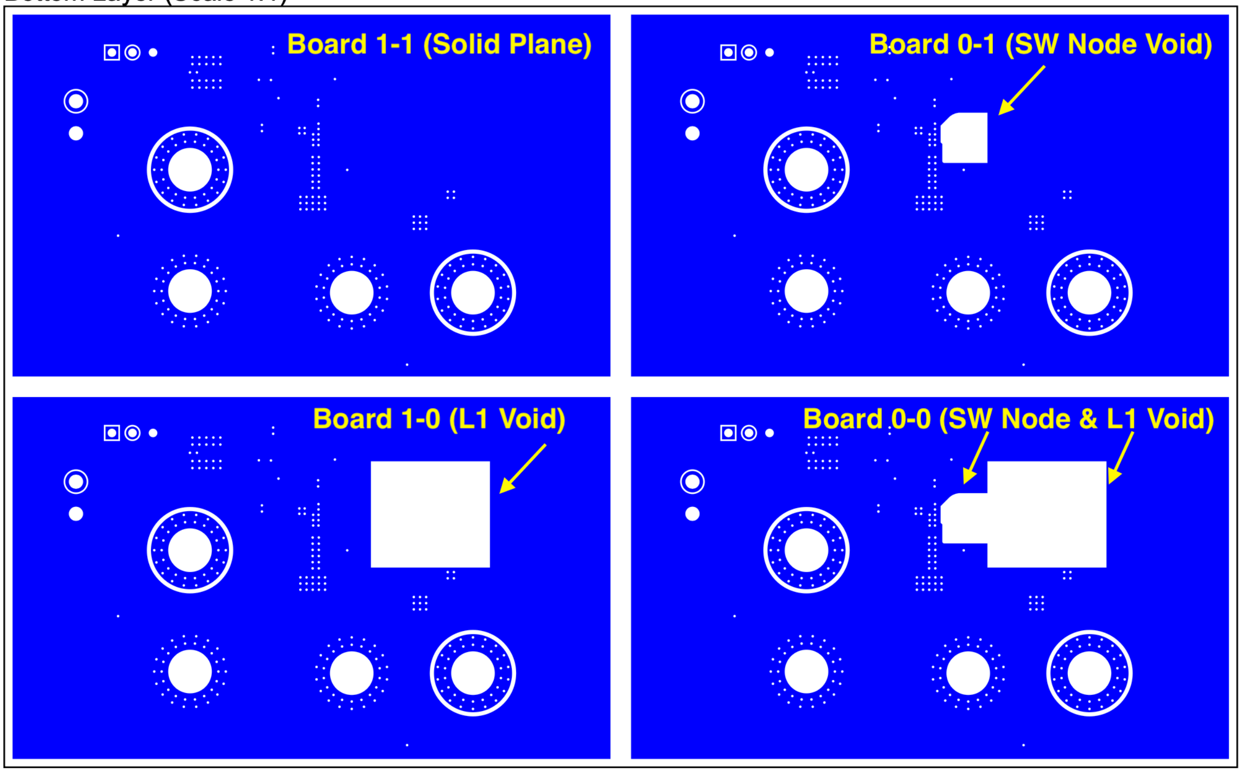


Figure 4 – The four converter boards showing the return plane (bottom layer) cutouts for the four configurations.

EMC Testing

The two biggest questions in my mind were how the performance of the four boards compared for radiated and conducted emissions.

Radiated Emissions – Due to the quantity of connecting cables required for these boards, I decided to forgo testing radiated emissions. There would be too many variables involved in observing minute changes in emissions.

Conducted Emissions – Measuring conducted emissions was a much more controlled test and I decided to approach this emissions testing using three different test methods.

1. **Conventional 5µH DC LISN** – This was used during early exploratory testing and the data was incomplete, so this will be reported at a later date, once I can get samples of the boards again.

2. **Current Probe on Vin Cable** – The RF current probe was connected directly to a spectrum analyzer and markers were positioned at sample peaks and amplitudes measured.

3. **LISN Mate Testing** – Using the LISN Mate with a pair of conventional 5μH DC LISNs allows splitting the differential mode and common mode currents and measuring each independently.

General test setup

The following equipment was used:

- Tekbox Digital Solutions 5 μH LISN, model TBOH01 (X2)
- Siglent Technologies spectrum analyzer, model SSA 3032X (9 kHz to 3.2 GHz)
- Siglent Technologies function/arbitrary waveform generator, model SDG 1062X
- Siglent Technologies dual power supply, model SPD3303C
- Rigol Technologies active load, model DL3021
- Tekbox Digital Solutions LISN Mate, model TBLM01
- Fischer Custom Communications RF current probe, model F-33-1

Strips of aluminum foil were taped down to the work bench to simulate a conductive ground plane. The LISNs were bonded to this plane with adhesive copper tape.

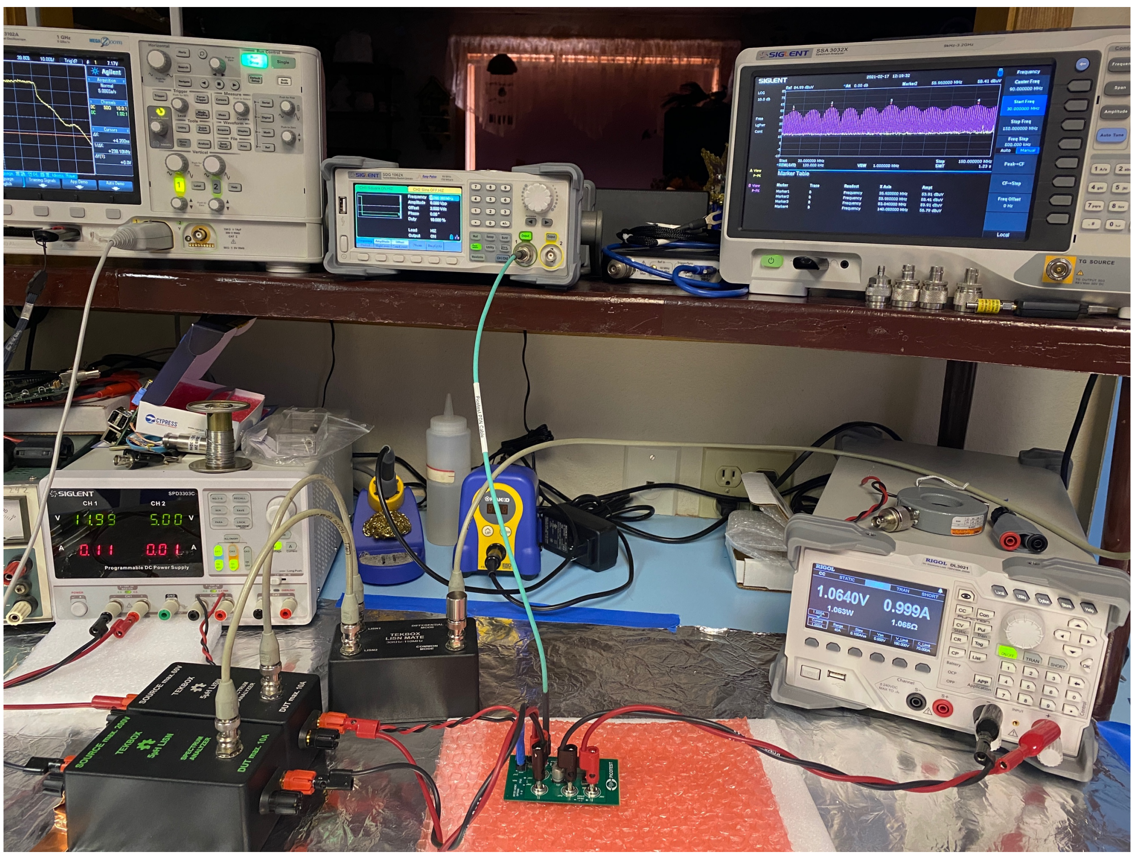


Figure 5 – The general test setup for the conducted emission measurements. In this case, the LISN Mate configuration is shown.

The three test setups are shown in Figures 6, 7 and 8. A 1A load was applied to each board.

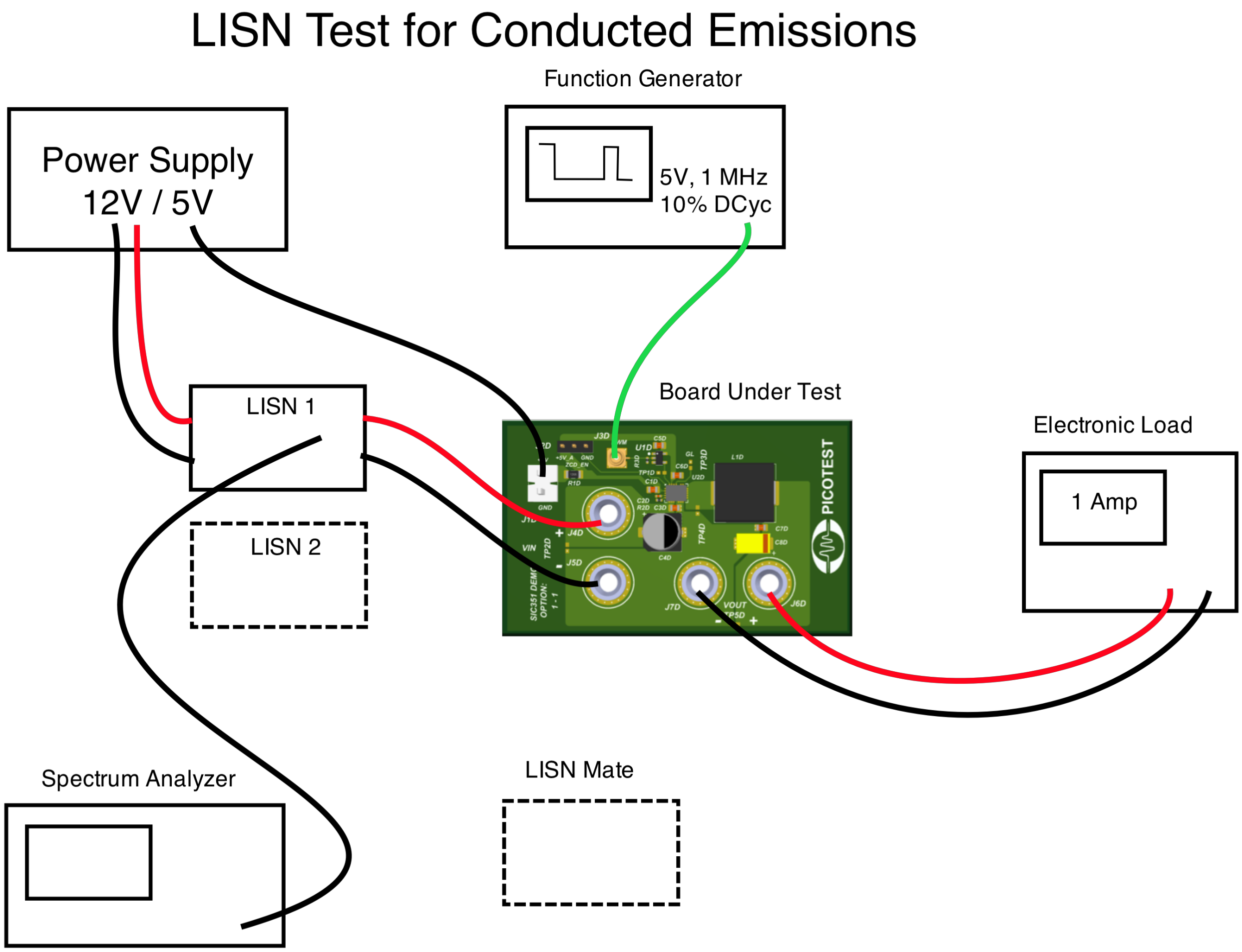


Figure 6 – The test setup for the conventional LISN test of conducted emissions. This was the first test performed, but the test protocol was still being developed and not enough data was taken to report accurately and will be retested at a later date.

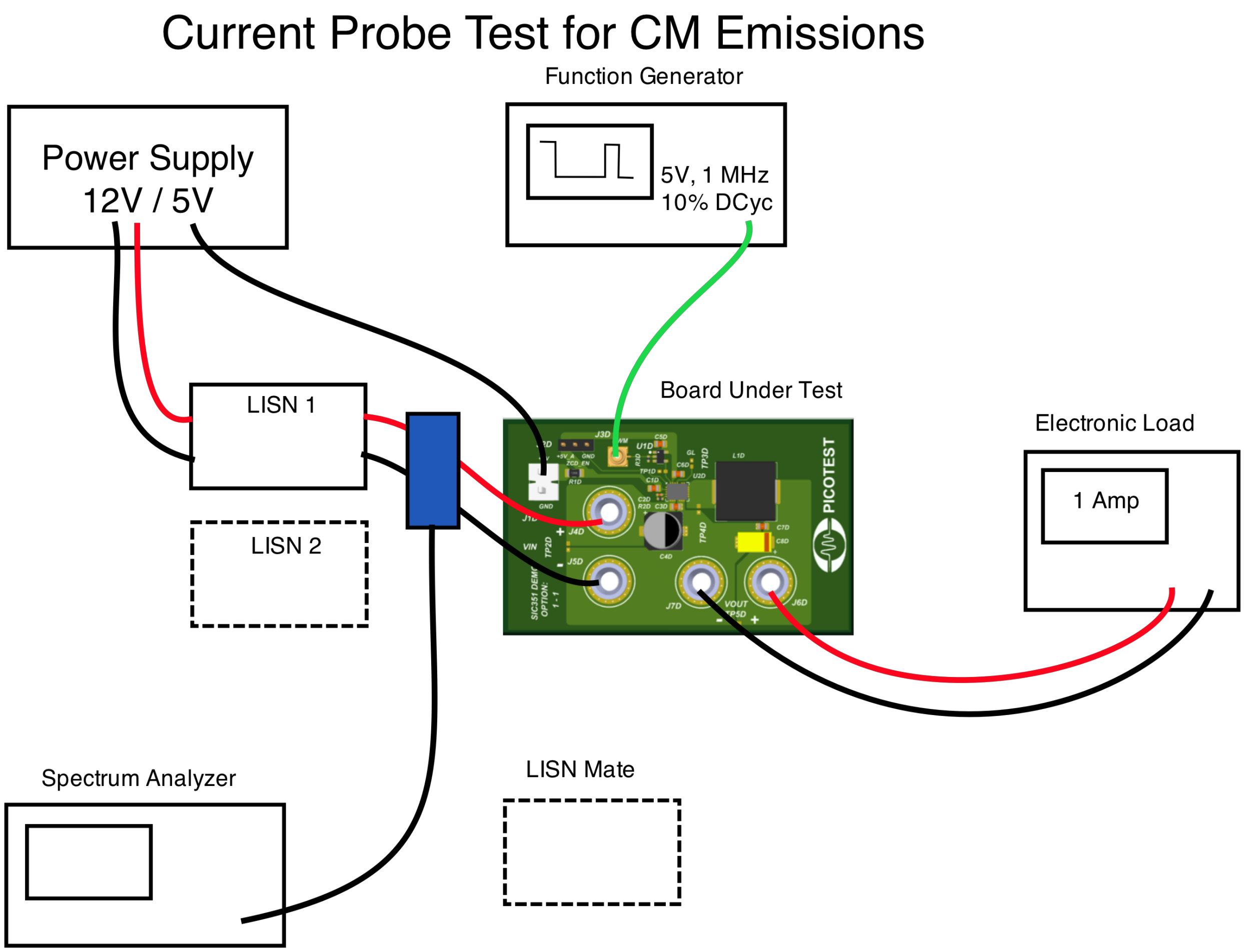


Figure 7 – The test of conducted emissions using a conventional RF current probe to measure the level of common mode currents.

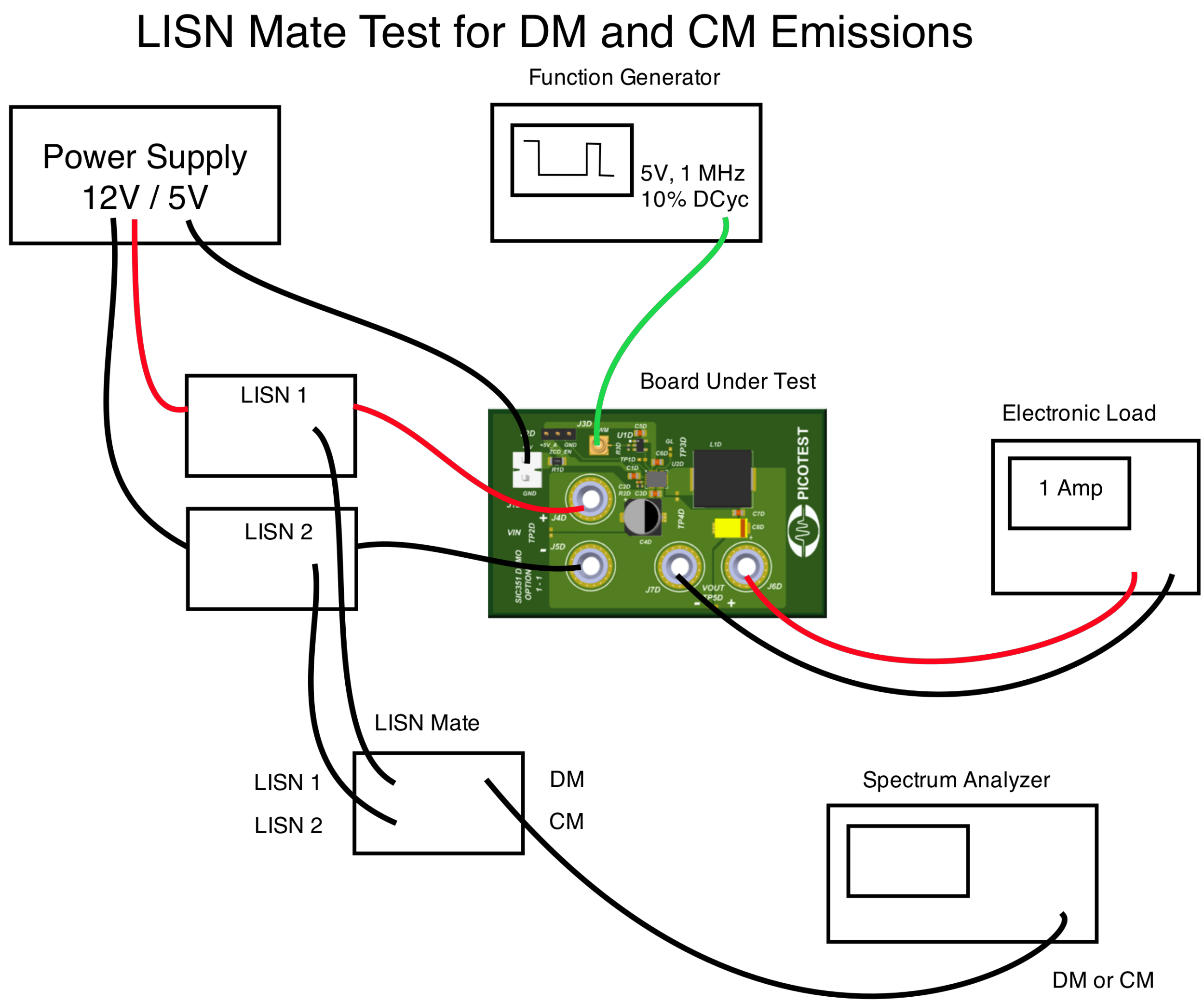


Figure 8 – The test setup using the LISN Mate to differentiate between differential mode and common mode currents.

Test Procedure

The test procedure was developed as I explored the best way to measure the data. The differences were typically between 0.5 and 4 dB, so it was refined as I proceeded through the three types of measurements.

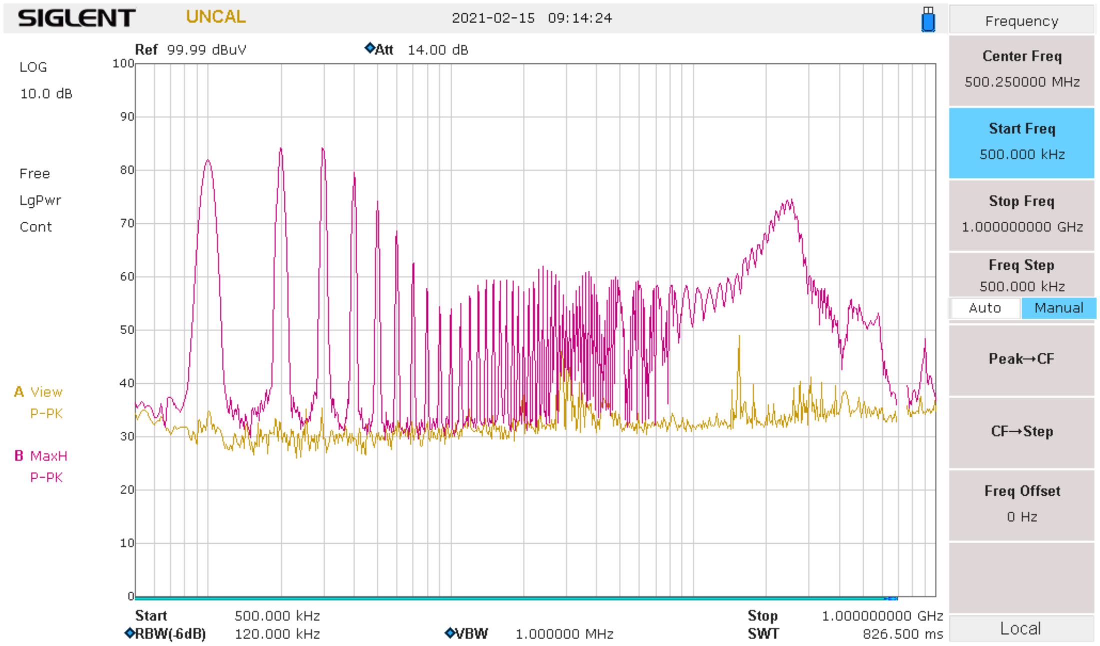


Figure 9 – A typical conducted emission spectrum (500 kHz to 1 GHz) using the conventional LISN. The peak at about 230 MHz was due to a strong ringing on the switch node. The yellow trace is the system noise floor, with violet indicating the conducted emission (dBμV). The fundamental switch frequency is 1 MHz (left-hand peak).

Because the harmonic amplitude differences from board to board were very small, I eventually placed markers (four, maximum for the Siglent spectrum analyzer) on random peaks spread along the measured spectrum and displayed a “marker table”, which showed the amplitudes of each peak.

Each of the four boards were measured using the same four markers and the data compared and plotted. This method was used for each board and separate scans were done from 100 kHz to 30 MHz and 30 to 150 MHz.

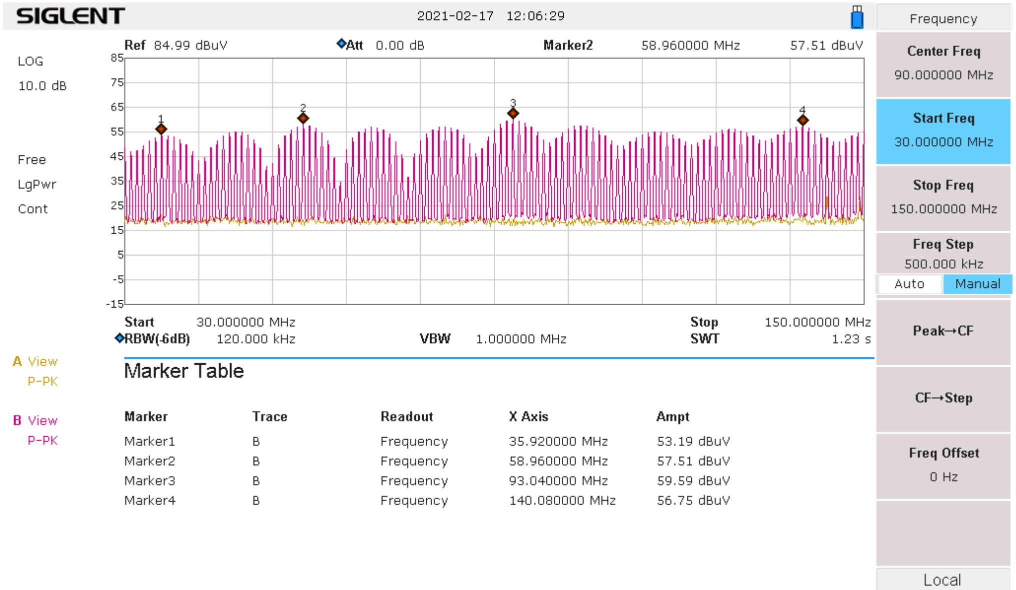


Figure 10 – A typical data capture using the four available markers on various peaks across the spectrum. Here, we're looking from 30 to 150 MHz and using the LISN Mate to show the differential mode harmonics.

Results

In each case, the blue trace indicates the solid return plane (board 1-1) and lower in the plot is better (lower EMI).

Current Probe on Vin (test setup in Figure 7)

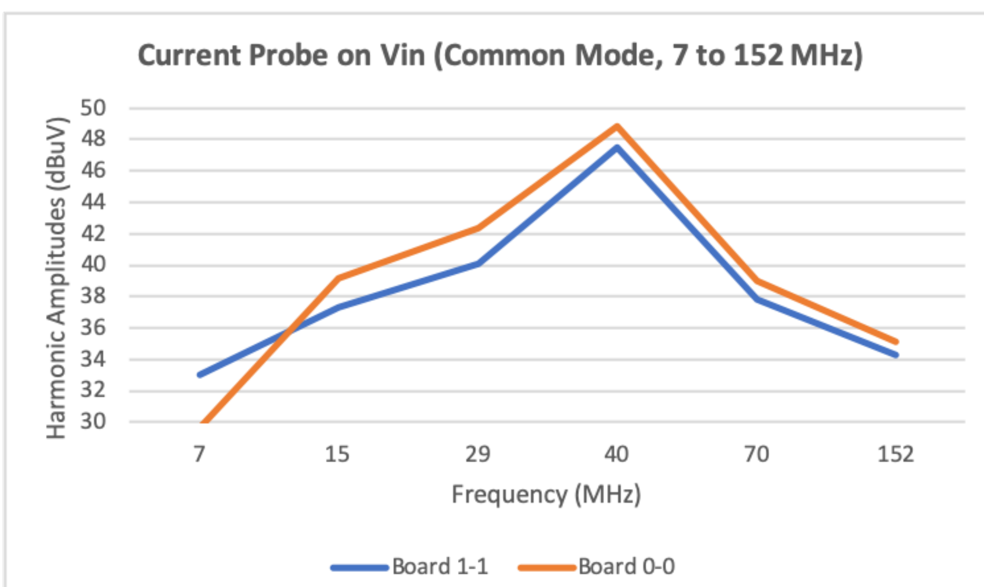


Figure 11 – With the RF current probe measuring the common mode currents on the Vin cable, and comparing the solid plane (1-1) to the completely cutout plane (0-0), we see that at most

frequencies above 10 MHz, the solid plane had an advantage by 1 to 2 dB less emissions (blue line). Frequencies below 10 MHz were much more variable with inconsistent results. The lower frequency comparison will be retested at a later date.

LISN Mate - Differential Mode (test setup in Figure 8)

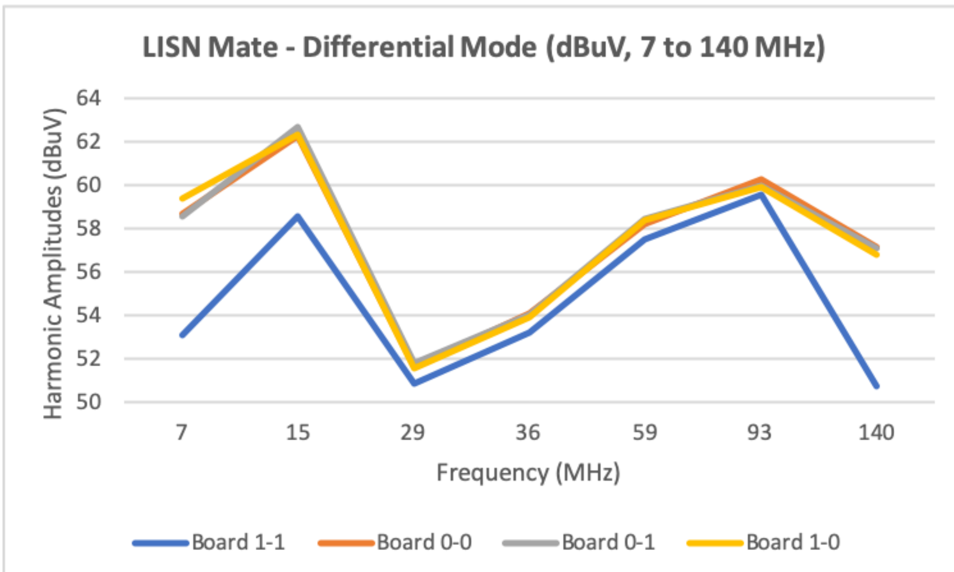


Figure 12 – When the differences in differential mode currents were measured, there was a clear advantage in using the solid return plane. Differences varied between 0.5 and 6 dB, depending on frequency.

LISN Mate - Common Mode (test setup in Figure 8)

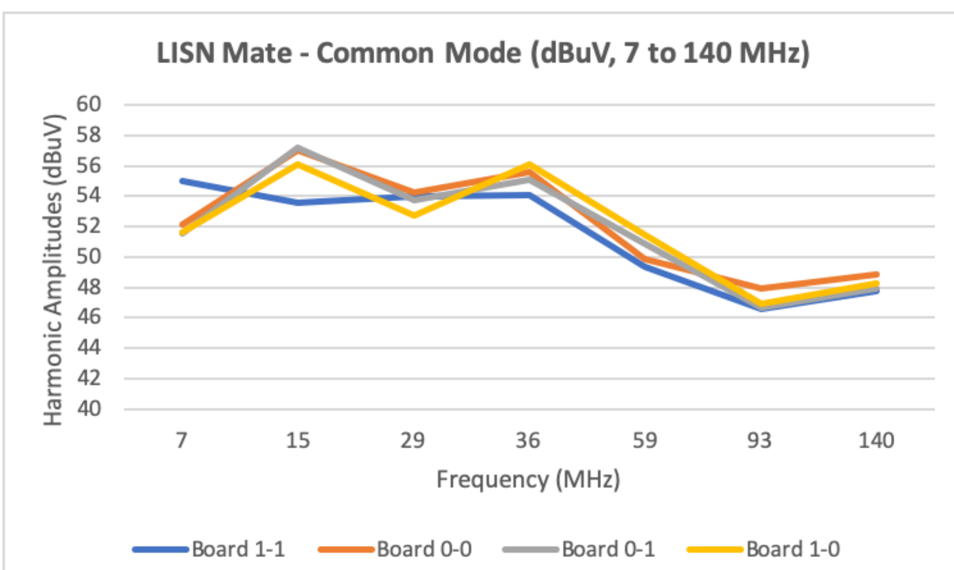


Figure 13 – When the differences in common mode currents were measured, there was not as clear advantage in using the solid return plane at all frequencies. However, there were

differences noted at 7 MHz and from 36 to about 80 MHz. Differences between the solid plane and others varied between 0.25 and 2.5 dB, depending on frequency.

Conclusions

At frequencies above 10 MHz, it seems pretty clear that conducted emissions with a solid return plane is equal to, or better than a return plane with cutouts (at most frequencies).

At frequencies below 10 MHz, the difference was not as clear. I plan to perform more measurements in the range 1 to 10 MHz for a better picture of the differences at these lower frequencies and this will be done once I receive the test boards back.

The testing needs to be repeated for the conventional LISN test of conducted emissions (test setup of Figure 6.

It's good to realize these data are only valid for this particular buck converter and this particular board design. Other DC-DC converter topologies and those operating off-line with much higher primary voltages may differ greatly in results and conclusions. Also, the results should be considered preliminary until more refined (using more frequencies) testing can be completed.

Acknowledgement

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References

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