Application Note

How to Reduce Emissions in Push-Pull Isolated Power Supplies

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ABSTRACT

Isolated power is traditionally generated using a DC/DC converter to drive an isolation transformer in varying topologies, where pulsating signals on the secondary side of that isolation transformer are rectified and filtered. Transformers inherently have multiple parasitics, and these parasitics, along with PCB trace and drive FET *off capacitances*, create an LC network that rings at a particular frequency and induces common mode currents. Common mode currents across the isolation barrier are one of the sources of radiated emissions, and they can be reduced with RC snubber circuits.

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1 Introduction

Electrical isolation is a means of preventing unwanted direct current (DC) and alternating current (AC) between two parts of a system while still enabling signal and power transfer between those two parts. Signal and power isolation is needed in a wide variety of applications for electrical safety, as well as for the protection of sensitive circuitry under fault conditions, to protect human operators and low-voltage circuitry from high voltages, to improve noise immunity, and to safely withstand ground potential differences between communicating circuits.

Isolated power is traditionally generated using a DC/DC converter to drive a transformer in flyback, fly-buck or push-pull topologies, where pulsating signals on the secondary side of an isolation transformer are rectified and filtered to generate an isolated DC supply. Push-pull isolated power topologies, like those that can be created using SN6501 and SN6505 transformer drivers, offer unique advantages as isolated power solutions, like a higher typical power transfer efficiency of 75-90% due to the external transformer, the option to minimize emissions by using lower switching frequencies, and the benefits of using push-pull power supplies go on to include simplicity in design and component selection, even greater power supply efficiencies due to low parasitic peak currents, off-the-shelf transformer options, requirements allowing for smaller transformers, inherent immunity from transients due to tight coupling of transformer windings, and low electromagnetic emissions due to symmetry of the topology.

In discrete solutions, TI's transformer driver family, SN650x, enable higher power delivery with up to 1A at 5V. Push-pull drivers use center-tapped transformers to transfer power from primary side to secondary side, as shown in Figure 1-1. The symmetric drivers Q1 and Q2 are clocked such that when one is ON the other one is OFF and vice versa. The driver timing also incorporates a dead time between the ON times where both the FETs are OFF so that the primary never gets shorted. Push pull topologies are inherently robust from an EMC perspective as the drives are differential in nature, unlike single ended topologies. Common mode energy transfers across the barrier are limited as the rise and fall of drivers are almost identical in either case of Q1 or Q2 being ON, implying that D1 and D2 are always complementary in nature. This is mostly because the primary windings of the push-pull transformer are tightly coupled from construction.

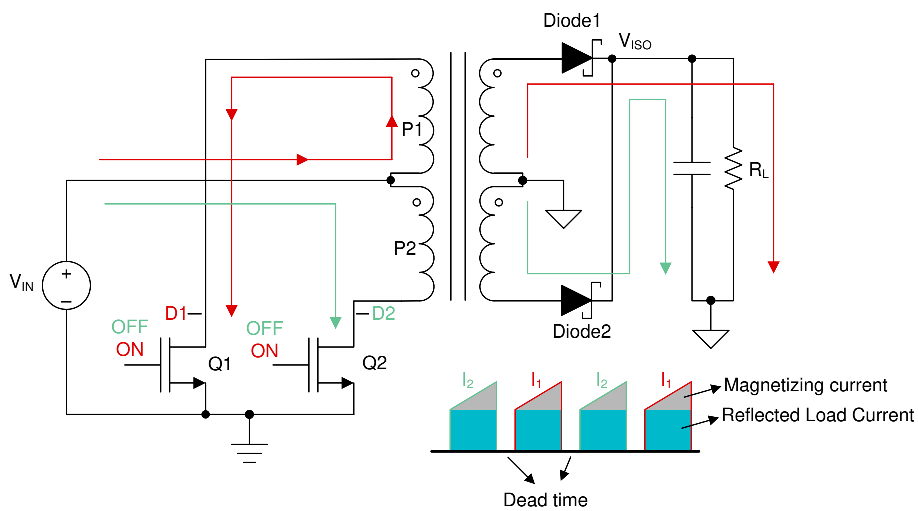

Figure 1-1. Complementary Energy Transmission by Push-pull Power Supplies

Transformers inherently have multiple parasitics. They have a magnetizing inductance component due to finite permeability of the core material, and there is a component of core resistance in parallel to this magnetizing inductance that can be attributed to eddy losses and core losses. There is also a component of leakage inductances and winding resistances that can be attributed to flux leakage and finite conductivity of the winding. These transformer parasitics along with the trace and drive FET *off capacitances* (capacitance present when the FET is OFF), create an LC network that rings at a particular frequency which hence induces common mode currents, as shown in Figure 1-2. This is observed as significant ringing during the FET dead time of the switching period, and this common mode current across the barrier is one the source of radiated emissions.

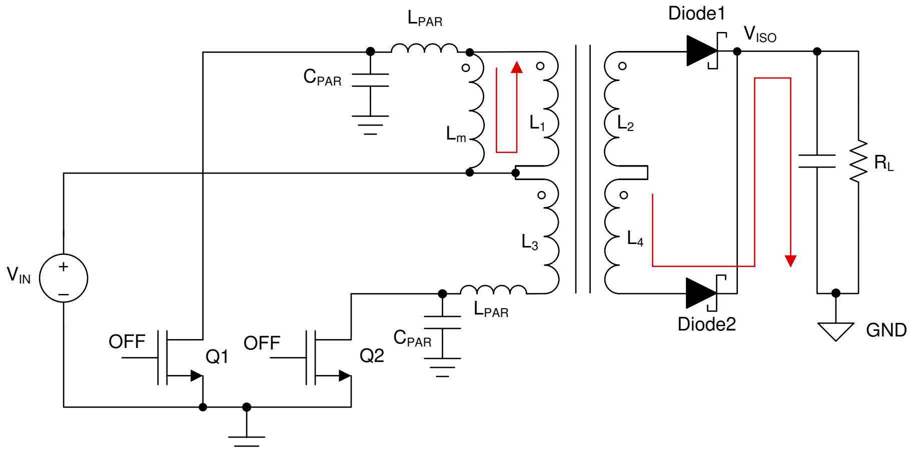

Figure 1-2. Push-pull Isolated Power Supply with Switching Parasitics Create a Ringing LC Network

In this document, we will examine how to reduce the already-low radiated emissions of push-pull isolated power supplies by analyzing emissions using TI's SN6505B push-pull isolation transformer driver. Using experimental data, we will demonstrate how the addition of snubber circuits to the SN56505 switching power lines can be used to compensate for push-pull transformer supply parasitics by reducing emissions.

2 Analysis of Emissions in Push Pull Topologies

To avoid ringing during the dead time, snubbers can be added to the switching nets to dampen them out. The concept of snubbers is simple – the effective impedance is designed such that it acts as transparent medium for the switching frequency (to avoid any signal degradation in driving nets), and act as a resistor for the ringing frequency (to dampen the oscillations and hence the emissions at that frequency). The snubber circuit is implemented as series capacitor and resistor.

Leakage inductances of a transformer can be measured practically using an LCR meter by probing the winding ends and shorting the secondary side of the transformer. The measured impedance (L_{PAR}) at an appropriate frequency where $X_{leakage}$ dominates $R_{winding}$ will yield the leakage inductance of the transformer. To estimate the parasitic capacitance, the gate of the driver needs to be biased appropriately and an impedance analyzer can be used to measure the capacitance (C_{PAR}) on both D1 and D2 nets on the PCB.

Ringing frequency can be calculated as:

$$f_{resonance} = \frac{1}{2\pi \times \sqrt{L_{PAR} \times C_{PAR}}} \quad (1)$$

With the snubber in place - at the ringing frequency, the Q of the circuit can be defined as:

$$Q = \frac{\sqrt{\frac{L_{PAR}}{C_{PAR}}}}{R_{snubber}} \quad (2)$$

Designing for a Q of 1, yields damped oscillations:

$$R_{snubber} = \sqrt{\frac{L_{PAR}}{C_{PAR}}} \quad (3)$$

The corner frequency for the snubber can be made equal to the ringing frequency:

$$Z_{snubber} = R_{snubber} + \frac{1}{j\omega \times C_{snubber}} \quad (4)$$

$$C_{snubber} = \frac{1}{2\pi \times R_{snubber} \times f_{ringing}} \quad (5)$$

3 Test Results

The test environment for this data was previously developed with careful consideration for parameters and parasitic components that could interfere with accurate emissions results. The design guidelines include following a symmetrical layout pattern as shown in Figure 3-1 and measuring the differences in the circuit's behavior with and without a snubber circuit.

The transformer selected for these tests is shown with its measured parameters listed in Table 3-1, and its values represent a sample of commercially-available transformers on the market today. The primary inductance, leakage inductance, and parasitic capacitance of the isolation transformer were measured directly on the transformer before it was mounted to the test PCB, and the capacitance of D1/D2 traces was also measured before the transformer was mounted onto the test PCB using an LCR meter with SN6505B powered at 5 V and its EN pin tied LOW.

Table 3-1. Measured Specifications for PH9085.011NL Push-pull Isolation Transformer

Transformer	Primary inductance (1-3)	Leakage inductance (1-3, tie secondary side pins)	Parasitic capacitance (tie 1, 2, 3 and 4, 5, 6)	D1/D2 trace capacitance
PH9085.011NL (Pulse)	1.02mH	443nH	13.2pF	118pF

Reducing radiated emissions in push-pull isolated power supplies centers around critically damping the resonance frequency caused by the parasitics in the switching path on D1 and D2 pins of the SN6501 and SN6505. For the following snubber circuit calculations, the resonant frequency was measured on an oscilloscope using active probes.

The impedance of the resistor in the snubber circuit should match the impedance of the switching frequency in order to critically damp the resonating energy while the capacitor blocks DC at lower frequencies and helps reduce power consumption. For this article, the snubber circuit was connected on the primary side of the isolated power supply circuit, as shown in Figure 3-1.

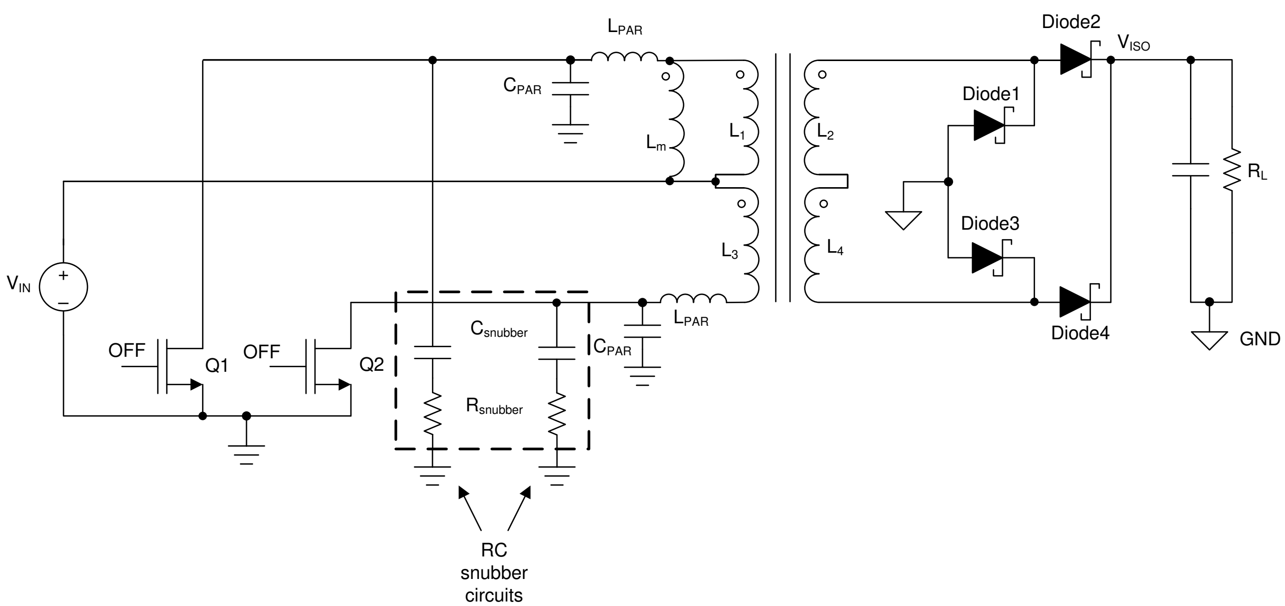

Figure 3-1. Test PCB Configuration with Snubber Circuits

The following procedure was used to determine the appropriate snubber circuit values for circuits using the PH9085.011NL transformer shown in Figure 3-1.

1. Measure the resonance frequency, $f_{resonance}$, of spikes on D1/D2 switching waveforms using an oscilloscope.
2. Measure the parasitic capacitance, C_{PAR}, of D1/D2 switching traces using an LCR meter.
3. Using the measured $f_{resonance}$ and C_{PAR}, parasitic inductance can be calculated by:

$$L_{PAR} = \frac{1}{(2\pi \times f_{resonance})^2 \times C_{PAR}} \tag{6}$$

4. Characteristic impedance, Z_{char}, of the resonance can be determined by:

$$Z_{char} = \sqrt{\frac{L_{PAR}}{C_{PAR}}} \tag{7}$$

5. $R_{snubber}$ in the RC snubber circuit should equal Z_{char} above, and the capacitor, $C_{snubber}$, should be sized to be multiple times the parasitic capacitance, C_{PAR}. A factor of about 7x was chosen for the measurements in this document.

The measurements for each of the steps above can be found in Table 3-2, followed by conducted and radiated emissions measurements of the PCB and transformer with and without its respective snubber circuit for comparison in Figure 3-2, Figure 3-3, Figure 3-4, Figure 3-6, and Figure 3-7.

Table 3-2. Snubber Circuit Measurement and Calculation Values for the Test PCB using PH9085.011NL

Transformer	Measured resonance frequency	Measured D1/D2 trace capacitance	Calculated parasitic inductance	Calculated Z_{char}	Calculated snubber circuit	Actual snubber circuit
PH9085.011NL (Pulse)	59MHz	128.5pF	56.6nH	20.99Ω	R = 21Ω, C = 899.5pF	R = 22Ω, C = 820pF

Figure 3-2 and Figure 3-3 are two time-domain waveforms showing the initially measured resonance frequency for the calculation steps above in Figure 3-2 and the resulting dampened time domain waveform once the snubber circuit was included in Figure 3-3:

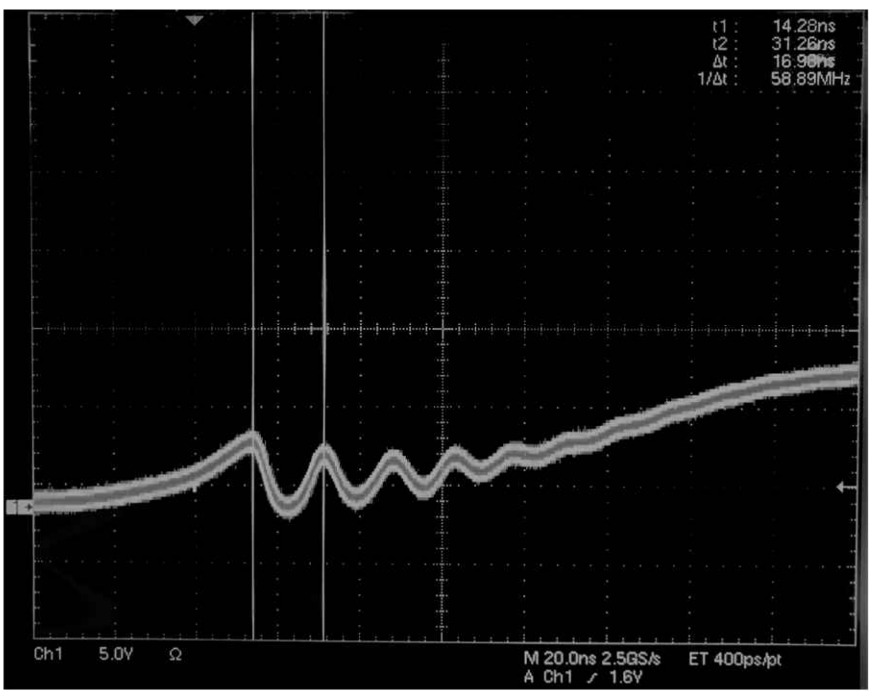

Figure 3-2. PH9085.011NL Time Domain D1/D2 Infinite Persistence Waveform without RC Snubber

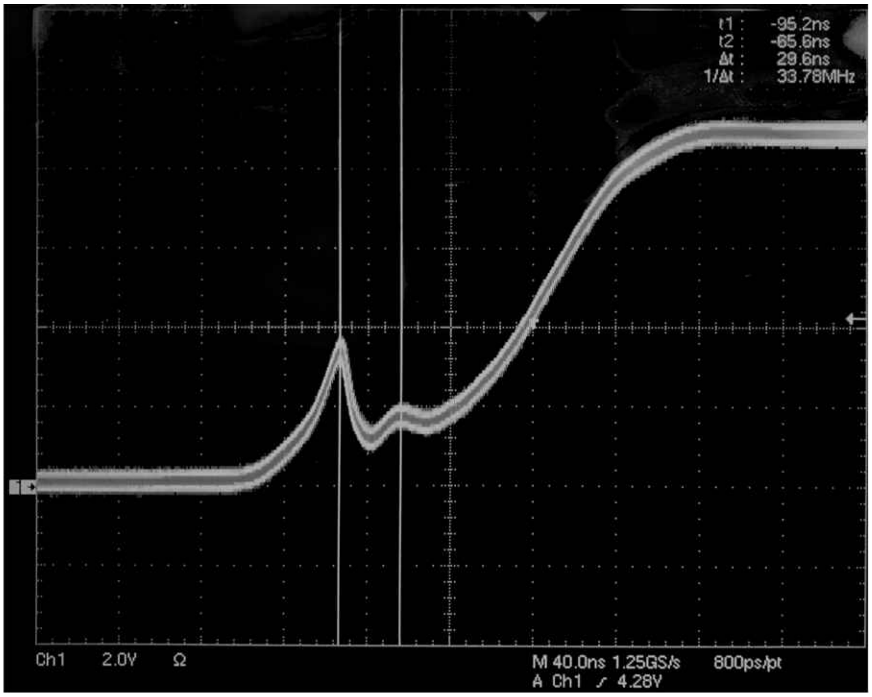

Figure 3-3. PH9085.011NL Time Domain D1/D2 Infinite Persistence Waveform with 22Ω, 820pF Snubber

In Figure 3-4, conducted emissions measurements of the PCB with and without the snubber circuit show a conducted emissions reduction of about 12dB with the snubber at the measured resonance frequency, 59MHz, and a reduction of about 7dB at 100MHz before converging to the noise floor:

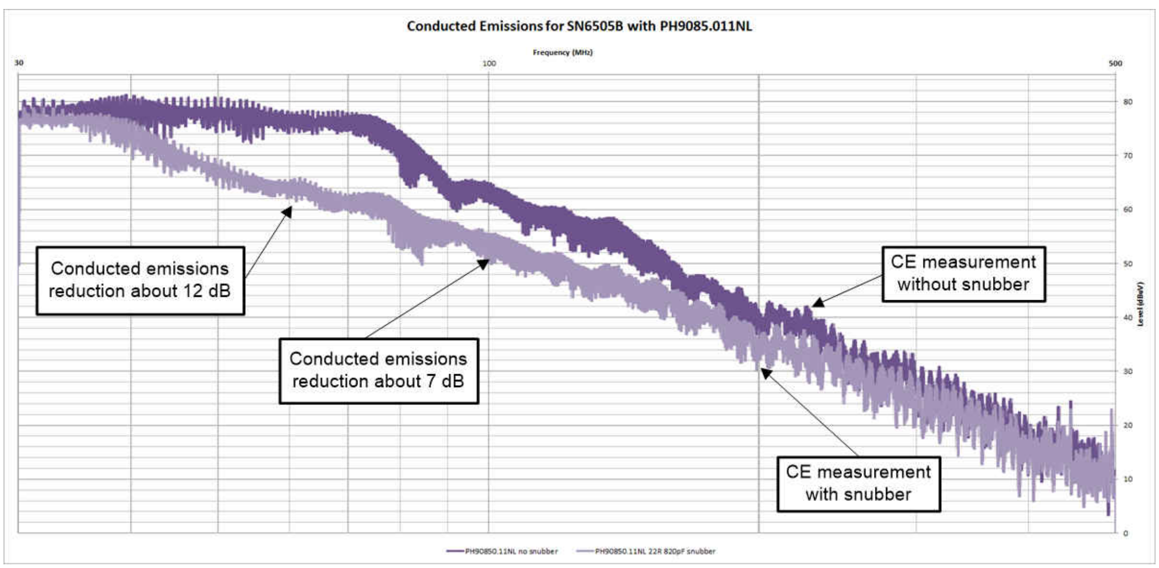

Figure 3-4. Conducted Emissions Comparison With and Without Snubber for this PCB with PH9085.011NL

For radiated emissions measurements, a 1m cable was connected to the isolated GND plane to simulate real-world scenarios where long boards and I/O cables amplify emissions. The radiated emissions test environment is shown in Figure 3-5 with resulting data in Figure 3-6 and Figure 3-7. These results show the snubber was effective in reducing radiated emissions about 5dBμV/m at 59MHz and about 13dBμV/m at 100MHz:

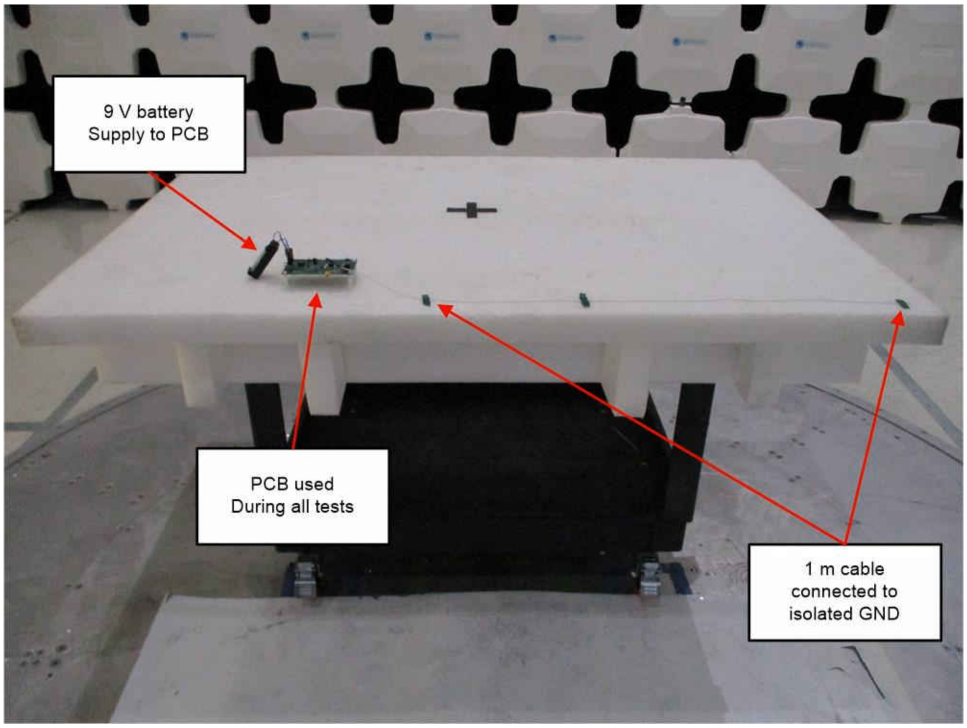

Figure 3-5. Radiated Emissions Test Environment per CISPR32

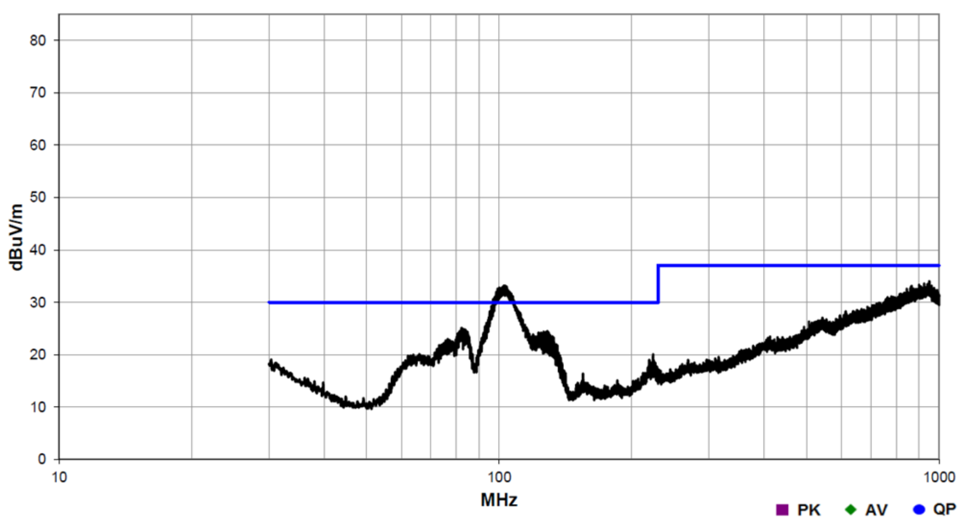

Figure 3-6. Horizontal Radiated Emissions Measurements per CISPR32 Class B for PH9085.011NL with 1m Cable on Isolated GND and no Snubber

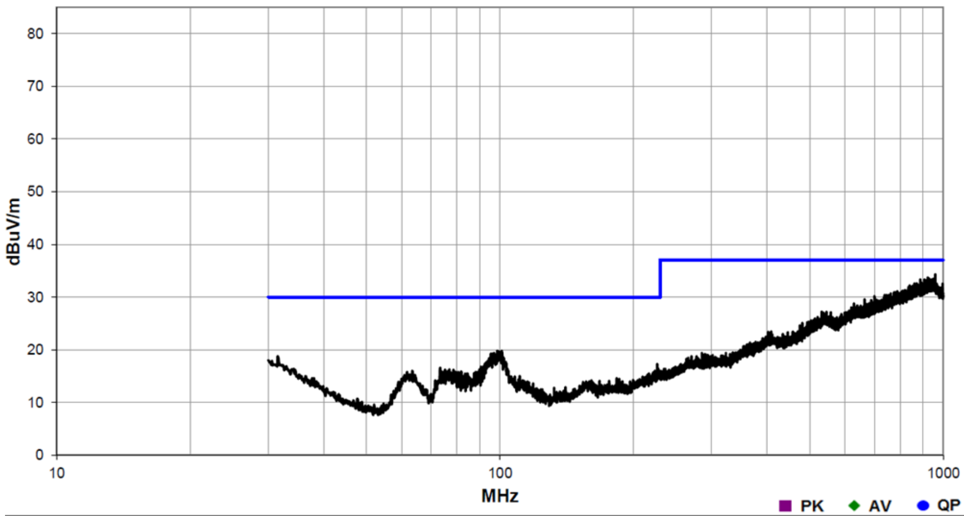

Figure 3-7. Horizontal Radiated Emissions Measurements per CISPR32 Class B for PH9085.011NL with 1m Cable on Isolated GND and 22Ω, 820pF Snubber

4 Conclusion

Resonant ringing between parasitic components of the SN6505 and transformer primary side affect radiated emissions and can be reduced with RC snubber circuits. Measurements of the time domain, conducted emissions, and radiated emissions show that components for snubber circuits can be calculated using a measured resonance frequency and parasitic capacitance combined with calculated parasitic inductance and critical impedance values by following the steps and equations in this article.

5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (September 2018) to Revision A (October 2021) **Page**

- Updated Equation 1 and Equation 2...4

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