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APPLICATION NOTE

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EMC Protection of the AD7150

by Holger Grothe and Mary McCarthy

INTRODUCTION

The AD7150 is a capacitance-to-digital converter (CDC) designed for proximity applications. The device measures the capacitance between two electrodes and compares its measurement result with a threshold. If the input capacitance is altered, by the presence of a hand, for example, an output flag is set to signify that a threshold has been exceeded, thus indicating proximity.

Electromagnetic interference affects the conversion results since it distorts the electric field around the capacitive sensor and, therefore, alters the capacitance. To protect the AD7150 and the capacitive sensor from this electromagnetic interference, some external filtering is used. However, including filters is challenging because the filters degrade the accuracy of the capacitance-to-digital conversions. This application note discusses the EMC performance that can be achieved with an external filter on the AD7150 pins as well as the affect of the filter on the accuracy of the AD7150.

WHAT IS EMC?

Electromagnetic compatibility (EMC) refers to the ability to operate in, without overly contributing to, an environment of electromagnetic radiation. When this goal is met, all electronic equipment operates correctly in the presence of other equipment. In a system, there are several EMC coupling paths: radiative, conductive, inductive, and capacitive (see Figure 1).

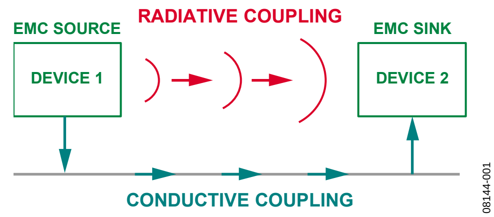

Figure 1. EMC Coupling Path

When a system is being designed to operate in a harsh environment, the system must be designed with EMC in mind and EMC testing must be performed. There are different levels of EMC testing: testing at system level, testing subsystems of the overall system, and testing at the IC level. Test methods are defined for each level of EMC testing.

The EMC performance required from a subsystem or IC device depends on the function of the device as well as its location in the system. For example, a device must have high EMC performance in automotive applications if it is connected to the car battery or chassis. If a device is confined within a printed circuit board, then the EMC level required from the device is less.

The AD7150 is an integrated circuit. Therefore, EMC testing was performed using direct power injection (DPI) in accordance with the international standard IEC62132—Part 4. The AD7150 is used for proximity sensing, for example, keyless entry. It is confined within a PCB and it has a local connection to the sensor. Therefore, the level of electromagnetic interference is expected to be low.

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CAPACITANCE-TO-DIGITAL CONVERTER ARCHITECTURE

To understand how EMC affects the operation of the AD7150, an understanding of the architecture of the capacitance-to-digital converter (CDC) is useful. A capacitance-to-digital converter measures capacitance by using switching capacitor technology to build up a charge balancing circuit (see Figure 2).

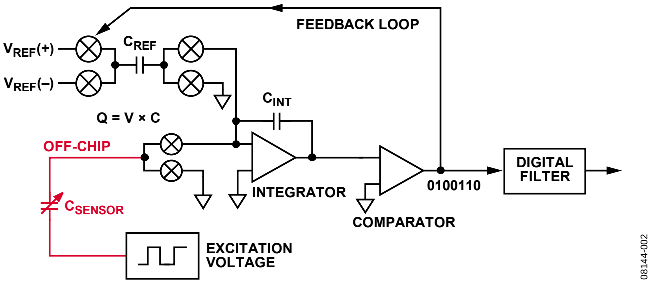

Figure 2. CDC Architecture

The sensing capacitor, C_{SENSOR}, and the internal reference capacitor, C_{REF}, are switched at a fixed sampling rate, and their charge is pumped into the integrator. A comparator checks the integrator output and controls the phase of the input switches to close the feedback loop, which balances the charges flowing through the C_{SENSOR} and reference paths.

A stream of zeros and ones, which can be seen on the comparator output, varies with the charge needed for the loop balance. The charge is proportional to voltage and capacitance. Because the voltages EXC and V_{REF} have fixed values, the density of zeros and ones represents the ratio between the input capacitance, C_{SENSOR}, and the reference capacitance, C_{REF}. The on-chip digital filter then extracts the information carried by the time-domain pattern of zeros and ones to form the digital result. Since the filtering is digital, the response around dc is repeated around the sampling frequency and multiples of the sampling frequency. Therefore, there is no rejection provided by the on-chip digital filter around the sampling frequency and its multiples.

AD7150

The AD7150 uses a second-order modulator and third-order sinc filter. The excitation frequency, which is the capacitive input sampling frequency, is equal to 32 kHz. Therefore, the on-chip filter response is repeated around 32 kHz and multiples of 32 kHz (see Figure 3). In a noisy environment, some additional filtering on the front-end is required to provide rejection at multiples of 32 kHz. The 32 kHz signal must be present to excite and measure the capacitance. Thus, an ideal external filter should allow the 32 kHz signal to pass through unattenuated and then filter all frequencies around 64 kHz and higher.

A brick wall filter achieves this response. However, since a CDC device measures charge going from the excitation pin to the capacitive input pin, the external filter must use passive components only.

In practice, a passive filter has slower roll off. A tradeoff must be made between passing the 32 kHz without attenuation and attenuating multiples of 32 kHz (see Figure 4).

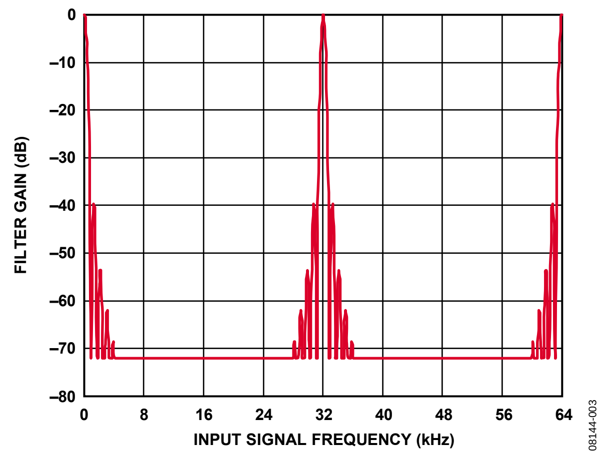

Figure 3. AD7150 Filter Response

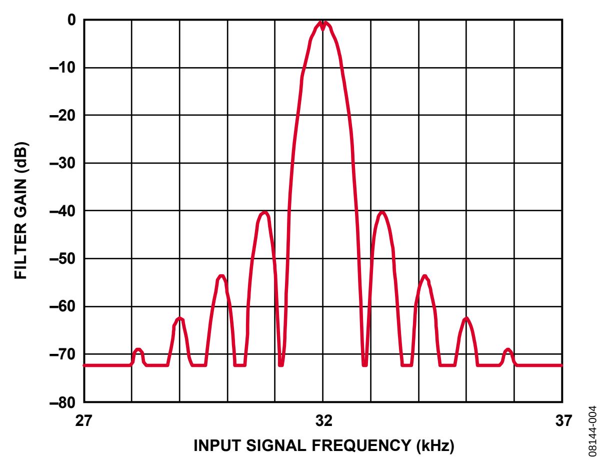

Figure 4. Frequency Response in 32 kHz Region

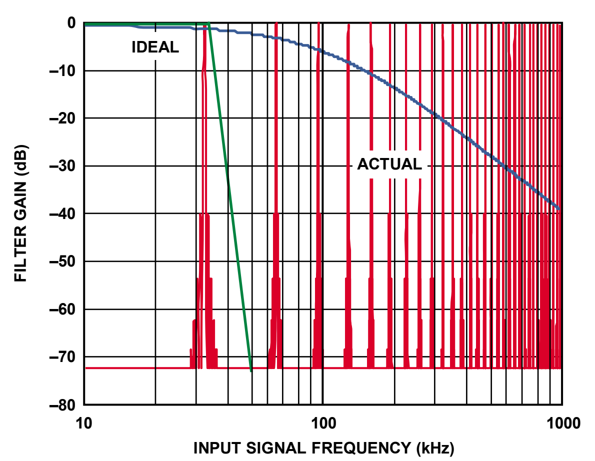

Figure 5. Anti-Aliasing Filter

EMC TESTING

For EMC testing, the DPI setup, as shown in Figure 6, is used. This diagram is taken from the IEC 62132—Part 4 document. The DPI setup consists of an RF signal generator, an RF amplifier, a directional coupler (which is connected through probes to an RF power meter, which measures the forward power to the DUT). Measuring the reflected power is optional, because the forward power level must remain constant during the DPI sweep.

All pins of the AD7150 are EMC tested. The EXC, CIN, and VDD pins were found to be the most sensitive. Therefore, this application note focuses on these pins. A continuous RF frequency was applied individually to the CIN, EXC, and VDD pins using ac-coupling (see Figure 7) as per IEC 62132—Part 4. The test method recommends using ac-coupling capacitors of 6.8 nF. This capacitance value was used on the VDD pin. However, lower value capacitors (47 pF) were used on the EXC and CIN pins because the value suggested in IEC 62132—Part 4 exceeds the maximum allowed capacitance to ground that can be connected to the AD7150.

The frequency was increased from 1 MHz to 100 MHz in 1 MHz steps and from 100 MHz to 1000 MHz in 10 MHz steps. Analog Devices, Inc., used a target power level of 50 mW. If the AD7150 did not false trigger when 50 mW was injected during the frequency sweep, this was considered a pass. If a false trigger occurred when 50 mW was injected, this was considered a fail. If the device failed to pass the 50 mW target level at any frequency, the maximum RF power level at which the device did not false trigger was determined.

The DPI test was repeated over a lower frequency range of 1 MHz to 3 MHz using a smaller step size of 200 Hz. This test was included because the AD7150 was expected to be sensitive to tones around 32 kHz and its multiples, and the external EMC filter was expected to be less efficient in this range.

For all the EMC testing, the AD7150 was configured with an input range of 2 pF and the sensitivity was set to 10 decimal.

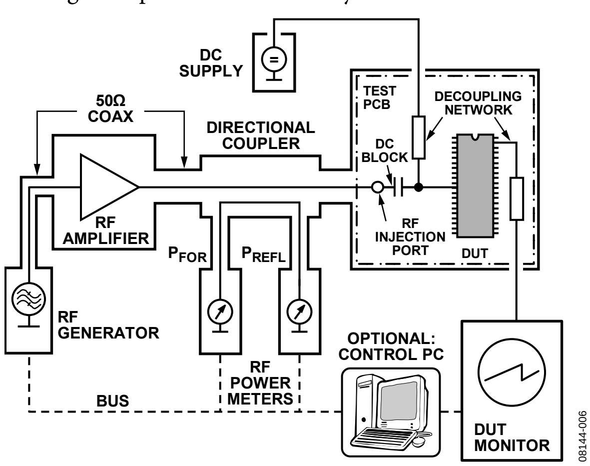

Figure 6. DPI Test Setup

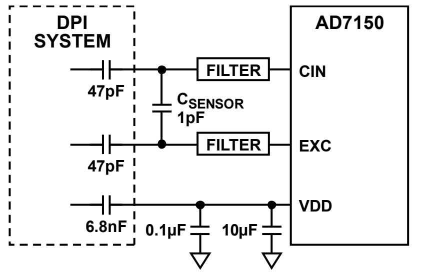

Figure 7. AD7150 to DPI System Connections

AD7150 EMC PERFORMANCE WITHOUT EXTERNAL FILTERS

The AD7150 was EMC tested without the external filters to determine the EMC performance of the device. Because the CIN pins were the most sensitive, they were used for the DPI testing. As shown in Figure 8, the power level that causes false triggers is much lower than the target of 50 mW.

Note that the AD7150 remained functional when EMC tested using a target power level of 50 mW. Although the part false triggered when tested to this power level, it never locked up.

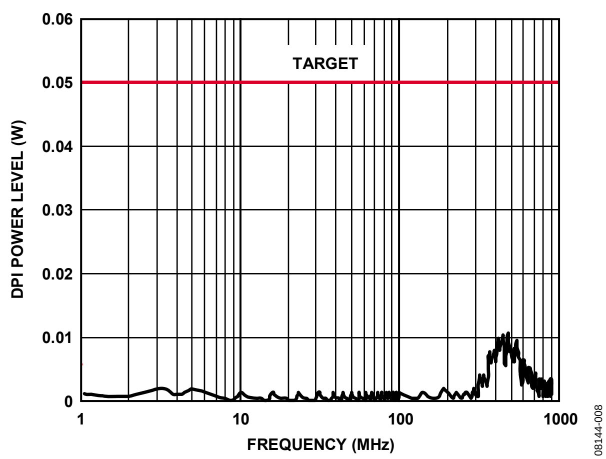

Figure 8. DPI Testing from 1 MHz to 100 MHz in 1 MHz Steps and from 100 MHz to 1000 MHz in 10 MHz Steps on CIN Pins Without External Filters

CHOOSING THE EXTERNAL FILTER

A brick wall filter gives the optimum filter response—the 32 kHz signal is unattenuated, though all frequencies around 64 kHz and higher are rejected. Because active components could not be used with the AD7150, different types of passive filters were evaluated on the CIN and EXC pins.

After evaluating several passive filter structures, a second-order filter was selected for the CIN pins because it uses a reasonably small amount of components and it provides good performance in terms of frequency response and roll off using nonprecision components.

For the EXC pins, a first-order filter was sufficient to achieve the desired EMC performance. Finally, the VDD pin used standard decoupling capacitors (a 0.1 µF ceramic capacitor in parallel with a 10 µF tantalum capacitor to GND). The desired EMC performance was met with these decoupling capacitors.

The values of the components were chosen so that the best tradeoff between EMC performance and the accuracy of the AD7150 in the context of proximity detection was achieved. Even though the accuracy of the AD7150 was degraded, the part still functioned in a proximity application.

The values of the components used in the second-order filter connected to the CIN pins and the first-order filter connected to the EXC pins are shown in Figure 9. A 1 pF ceramic capacitor was used in place of the capacitive sensor. The second-order filter has a cutoff frequency of 72.76 kHz, the phase shift is −48° at 32 kHz, and the attenuation at 32 kHz is −1.62 dB.

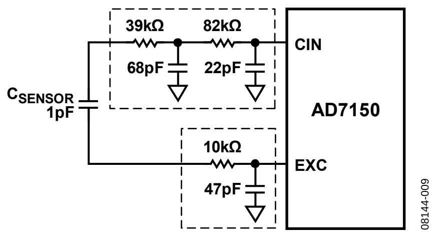

Figure 9. Passive Filters on Front End of AD7150

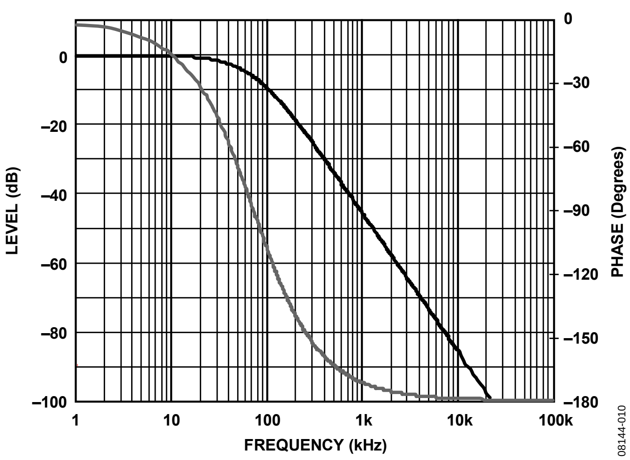

Figure 10. Frequency Response of Second-Order Passive Filter

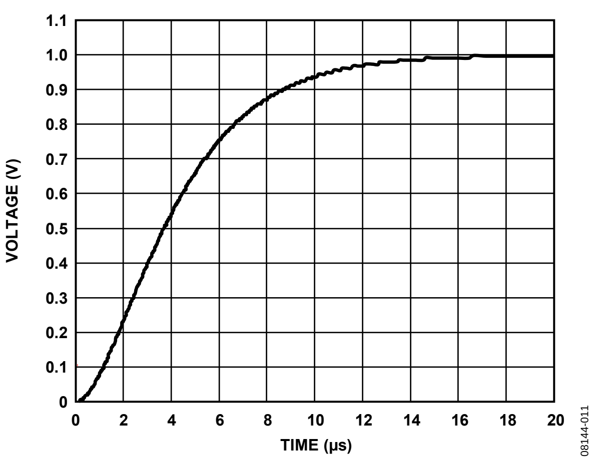

Figure 11. Step Response of Second-Order Passive Filter

AD7150 Performance with External Filters

The external filters connected to the CIN and EXC pins influence the accuracy of the AD7150 conversions. Figure 12 shows how the input-to-output transfer function is altered. With the external filters, the offset error is 0.724 pF, while the gain error is −0.859 pF when a 2 pF input capacitance is used (this equates to −42.9%). The power supply rejection is reduced to 40 fF/V.

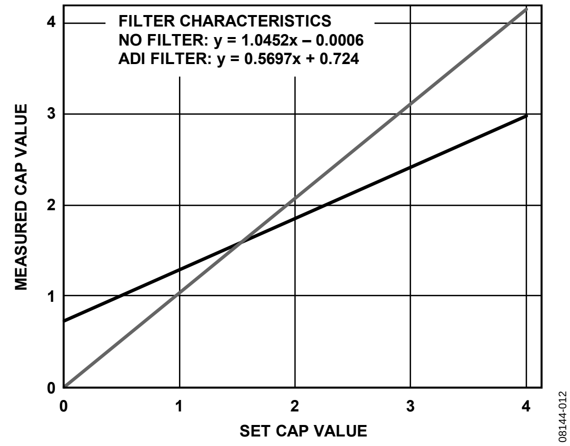

Figure 12. Input-to-Output Transfer Function of the AD7150 with and without the External Filter

AD7150 EMC Performance with External Filters

DPI on the CIN Pins

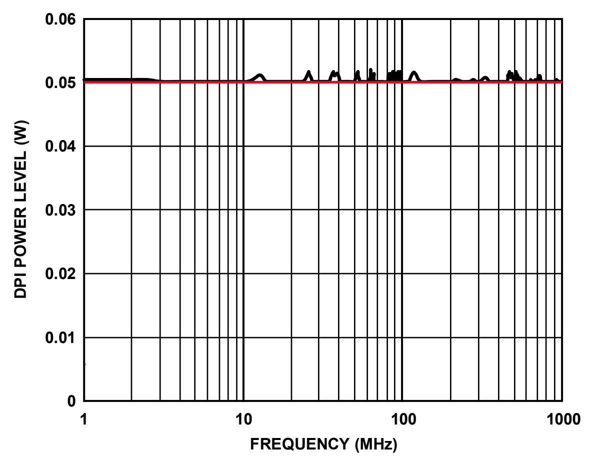

Figure 13. CIN: Sweep from 1 MHz to 1000 MHz

When the RF frequency was swept from 1 MHz to 100 MHz in 1 MHz steps and from 100 MHz to 1000 MHz in 10 MHz steps, no false triggers occurred on the AD7150 output as shown in Figure 13. When the DPI testing was repeated over a range of 1 MHz to 3 MHz in steps of 200 Hz (Figure 14), the external passive filter provided full immunity to frequencies above 1.9 MHz. At low frequencies, the external filter was less efficient—there is still some sensitivity in narrow bands around multiples of 32 kHz.

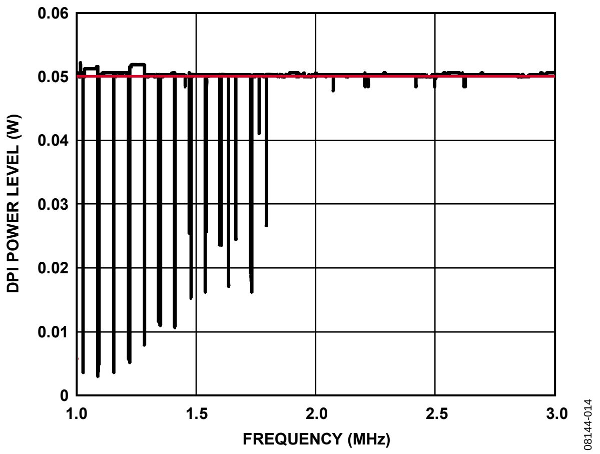

Figure 14. CIN: Fine Sweep from 1 MHz to 3 MHz in 200 Hz Steps

DPI on the EXC Pins

When the RF frequency applied to EXC was swept from 1 MHz to 100 MHz in 1 MHz steps and from 100 MHz to 1000 MHz in 10 MHz steps, no false triggers occurred on the AD7150 output as shown in Figure 15. When the DPI testing was repeated over a narrower range of 1 MHz to 3 MHz in 200 Hz steps, again no false triggers occurred (see Figure 16). Thus, the EXC pin provides a high level of EMC performance when the first order filter is connected to the pin.

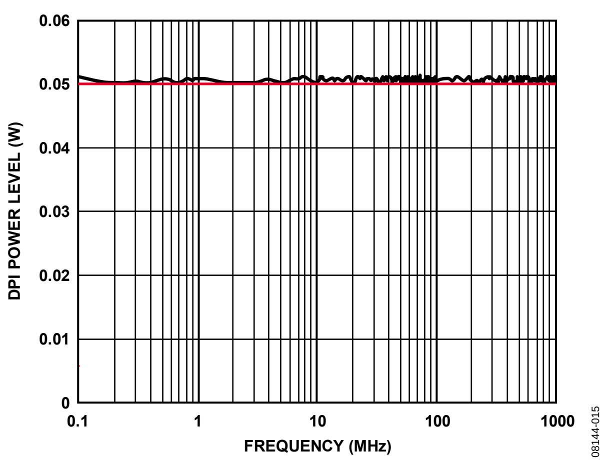

Figure 15. EXC: Sweep from 1 MHz to 1000 MHz

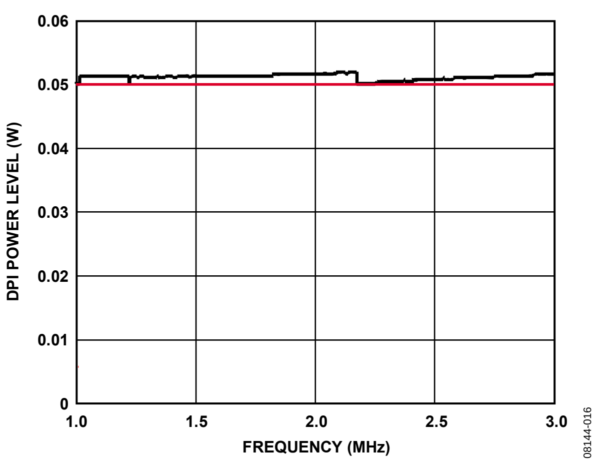

Figure 16. EXC: Sweep from 1 MHz to 3 MHz in 200 Hz Steps

DPI on the VDD Pin

DPI testing was also performed on the VDD pin. With the standard decoupling capacitors connected to VDD, there were no false triggers on the AD7150 output when the RF frequency was swept from 1 MHz to 100 MHz in 1 MHz steps and from 100 MHz to 1000 MHz in 10 MHz steps (see Figure 17). When the frequency was swept from 1 MHz to 3 MHz in 200 Hz steps, again, no false triggers occurred (see Figure 18). Therefore, the decoupling capacitors provide a high level of EMC performance.

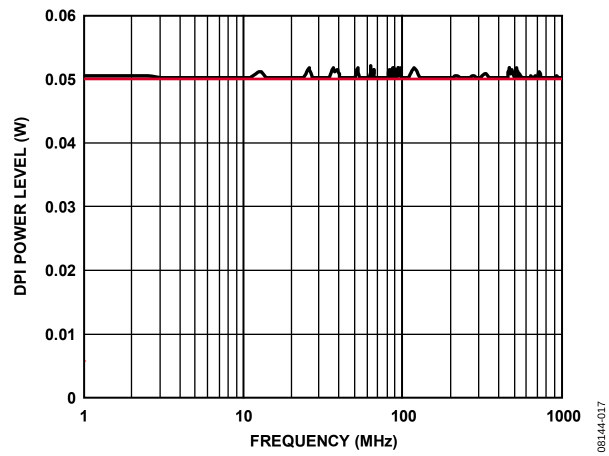

Figure 17. VDD: DPI Testing in 1 MHz to 1000 MHz Range

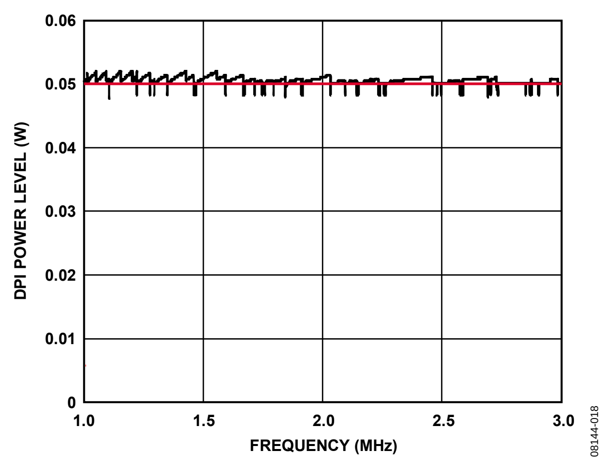

Figure 18. VDD: Sweep from 1 MHz to 3 MHz in 200 Hz Steps

CONCLUSION

When EMC testing the AD7150 using a target power level of 50 mW, the device does not lock up. The part continues to convert during the EMC event and it returns to the expected accuracy after the EMC disturbance is removed.

In this application note, external passive filters are recommended to improve the EMC performance of the AD7150. When external filters are included on the CIN and EXC pins and standard decoupling is used on the VDD pin, the device passes the EMC test for frequencies above 1.9 MHz. For frequencies less than 1.9 MHz, the device shows some sensitivity in the regions around multiples of 32 kHz.

Without external filters, the AD7150 does not pass the EMC test described in IEC 62132—Part 4 when a target power level of 50 mW is used. However, the AD7150 always remains functional. A power level of 50 mW does not cause the AD7150 to lock up.

The AD7150 continues to meet the requirements for proximity detection applications when the external EMC filters are used. The filters cause some degradation in the accuracy of the AD7150, however the system is still sufficiently accurate for proximity detection systems.

The external EMC filters discussed in this application note optimize the EMC performance of the AD7150. If a less stringent filter is used, the AD7150 accuracy will degrade by a smaller amount. There is a tradeoff between EMC performance and AD7150 accuracy.

NOTES