Application Note

Conducted Emissions Testing for DC-DC Regulated Sub-1 GHz Wireless Systems in Building Automation

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ABSTRACT

DC-DC converters operate at a switching frequency that can potentially cause interference in the radio of a system. This application note explores the effects that different kinds of DC-DC converters have on spurious emissions in radios used for wireless fire safety, HVAC, and building security systems, and how to choose a regulator that solves this challenge.

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1 Introduction

The CC1120 is a fully integrated singlechip radio transceiver designed for high performance at very low power and low voltage operation in cost effective wireless systems. The device is mainly intended for Industrial, Scientific, and Medical (ISM) applications and Short Range Device (SRD) frequency bands at 164 to 192 MHz, 274 to 320 MHz, 410 to 480 MHz, and 820 to 960 MHz. In many of these applications, radio transceiver ICs, such as the CC1120, are commonly powered by an external DC/DC converter to regulate down the input voltage of a system. While beneficial to the overall efficiency of the system and providing lower system current consumption, DC/DC converters may produce a ripple output that interferes with the frequency output to the transceiver’s antenna. This may raise issues when using the CC1120 or other radio IC's, for industrial settings, as the device must maintain a certain level of radiated emissions to pass FCC regulations. To mitigate this, it is beneficial to understand the functionalities that cause the undesirable behavior of sensitive circuitry.

2 Technical Overview

One of the most common circuits in modern electronic systems is the switch-mode power supply (SMPS), which are used to regulate voltage to a certain level. These regulators provide significant improvements in efficiency over linear regulators in most applications. But this efficiency comes at a price, as the switching frequency of the SMPS may interfere with the frequency response of the circuit being supplied.

One example of a SMPS that can cause interference is a buck converter, which is used in this application. A buck converter produces an output voltage that is directly proportional to its duty cycle. It converts power when its switch node switches between connecting to the input voltage and connecting to ground. This inherent switching action causes the currents and voltages in the circuit to switch and fluctuate, resulting in an output voltage that also has ripple on top of the regulated steady-state DC value. The frequency of this ripple can interfere with signals in the circuit, eventually returning an undesirable signal or frequency output.

In a recent wireless smoke detector application, the CC1120 transceiver was powered by a 3.3V input regulated from the LM5166 buck converter. When testing radiated emissions performance in this system, it had been observed that the radiated emissions testing fails FCC standards in the 915MHz band, corresponding to FCC regulations FCC 15.247 and FCC 15.249. Spurious emissions arose when the CC1120 was set to continuous transmission and powered directly by LM5166. This was also seen when powering the CC1120 with various DC-DC layouts, including the LM5166 evaluation module, and various DC-DC converters. The issue was solved after adding LC filters to the 3.3V output or adding an LDO after the DC-DC converter.

In order to further investigate these results, a radiated emissions test board was designed to determine if there is a buck converter available that passes radiated emissions tests using the CC1120 without additional external filters.

3 Causes of Spurious Emissions

Spurious emissions are signals caused by transmitted frequency content that is outside of the carrier frequency band of a transmitter. This can be caused by a SMPS or nearby radio transmitter that could be inadvertently transmitting weak signals on a frequency not assigned to that transmitter. FCC regulations concerning spurious emissions state that if interference is caused by spurious emissions, the operator of the transmitter must take whatever steps are necessary to reduce the spurious emissions as required by FCC regulations.

As mentioned earlier, when a SMPS operates, it outputs a voltage that also has ripple on top of the regulated steady-state DC value. This ripple voltage is composed of one or multiple different frequencies. The frequency composition of this ripple voltage interferes with the frequency output of the transceiver, which results in spurious emissions. This shows up as multiple frequency harmonics outside of the carrier frequency. If the frequency content of a specific frequency is too abundant, it may result in a failing outcome when testing to FCC standards for the band of interest. This is important when observing the output voltage of an SMPS as many different factors can affect it's ripple value and frequency content, resulting in spurious emissions.

Assuming the simple schematic of the output capacitor in a buck regulator in Figure 3-1, the total voltage ripple output in a buck regulator can be derived.

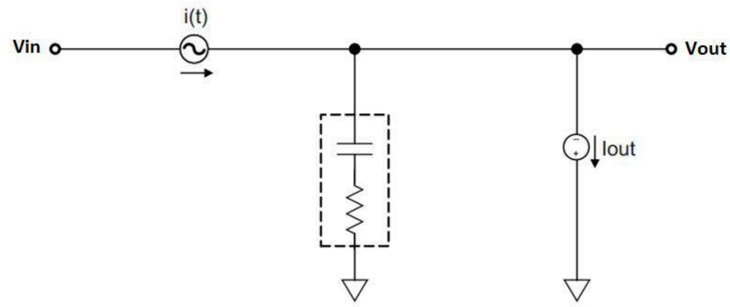

Figure 3-1. Schematic for Analytical Derivation of Output Voltage Waveform

The total voltage ripple output in a buck regulator can be expressed as (full derivation can be found on Output Ripple Voltage for Buck Switching Regulator (Rev. A) (ti.com)):

$$V_{out,\,p2p} = V_C + V_R\left(\frac{RCF_{SW}}{2D(1-D)}\right) \quad (1)$$

Where V_C represents the voltage ripple contributing from capacitor-only portion, V_R represents the voltage ripple contribution from the resistor-only portion, R represents the resistance value, C represents the capacitance, F_{sw} represents the switching frequency of the regulator, and D represents the duty cycle. The output capacitor, C, is assumed to have an equivalent series resistance, R (denoted by the components shown in the dotted box in Figure 3-1). This equation reveals the total output ripple is dependent on many factors of the circuit, such as the resistor, capacitor, duty cycle, and switching frequency. This is significant because the frequency composition of the output ripple voltage determines the levels of spurious emissions seen in the frequency spectrum on the antenna. If an engineer decides to change any of these values to better fit an output in their application, it may result in unwanted frequency interference at impermissible levels.

4 Functional Block Diagram and PCB

Figure 4-1 shows the block diagram for the conducted emissions test board designed using the CC1120 and four different buck converters with individual jumper enables. This board was designed to test features such as spread spectrum, adjustable switching frequency, low-cost and low-switching frequency options. The buck converters chosen to test these parameters and determine how some of our devices impact emissions are the LM5166, LMR38010, LMR36510, LMR36506.

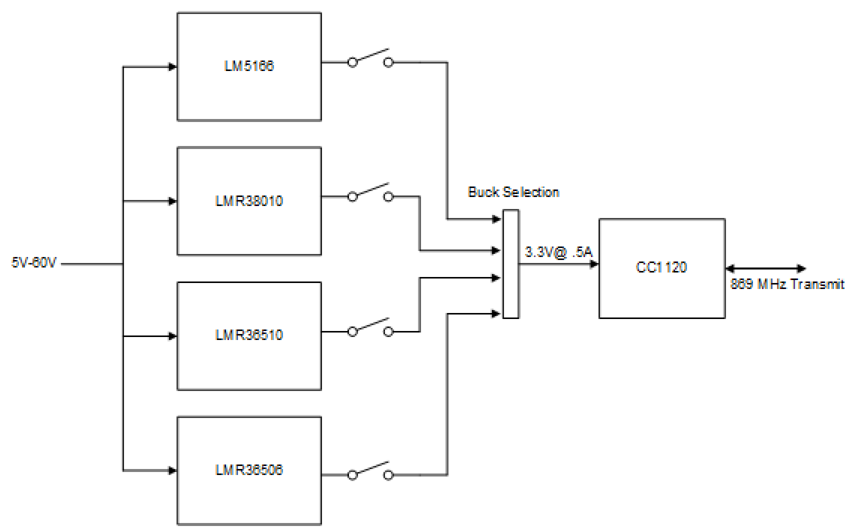

Figure 4-1. Block Diagram for Conducted Emissions Test Board

The LM1566 was implemented in the original design of the system and was therefore used as the control circuit for testing. The LM38010 was chosen for its spread spectrum feature and forced PWM mode at light loads part option. The spread spectrum feature minimizes EMI by spreading ripple energy over a wider bandwidth (for example, noise shaping). The forced PWM is provided to achieve low output voltage ripple, tight output voltage regulation, and constant switching frequency at light load. It also has design options to change its switching frequency to frequencies in range of 200kHz to 2.2MHz with changes to component values. The LMR36510 is a cost optimized buck converter with a fixed 400-kHz frequency. Lastly, the LMR36506 has an ultra-low operating quiescent current. It also has a low EMI architecture (without spread spectrum), with PFM at light load version of the device on the test board. It supports an adjustable switching frequency that can be modified with changes to component values and can vary between 200kHz and 2.2MHz.

Figure 4-2 shows the PCB design of the conducted emissions test board. Solder pads were placed for radio power supply selection to minimize emissions and extra board space was left for future redesign to include PCB antenna. This board allows for emissions testing to be conducted on four separate buck converters using the same board, which allows for a comparison of buck converter parameters and their impact on the emissions test for the radio.

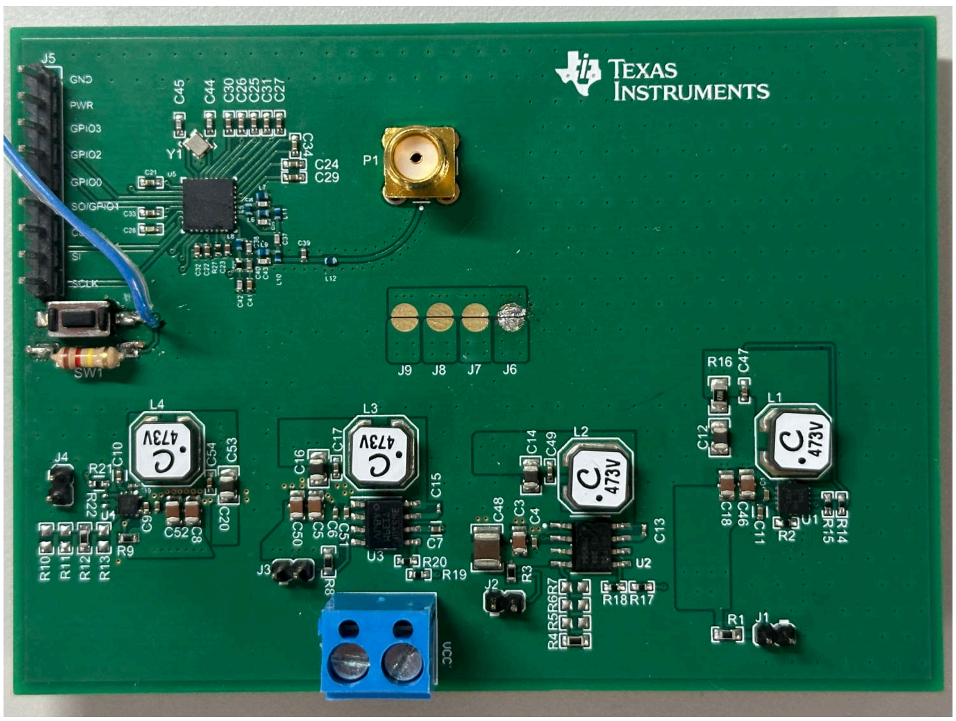

Figure 4-2. PCB Design for Conducted Emissions Test Board

5 Conducted Emissions Testing and Results

The test platform included the conducted emissions test board powered by a 24V DC input. This board was then connected to the Smart RF transceiver evaluation board, used in combination with Smart RF Studio, which allows for user access to the devices registers for configuration of the radio parameters and behavior. It also provides a control interface for performing operations such as setting up a continuous wave signal, which was used in this application. Lastly, a spectrum analyzer was connected to the radiated emissions test board to measure the frequency response at the antenna.

Figure 5-1 shows the setup used for testing.

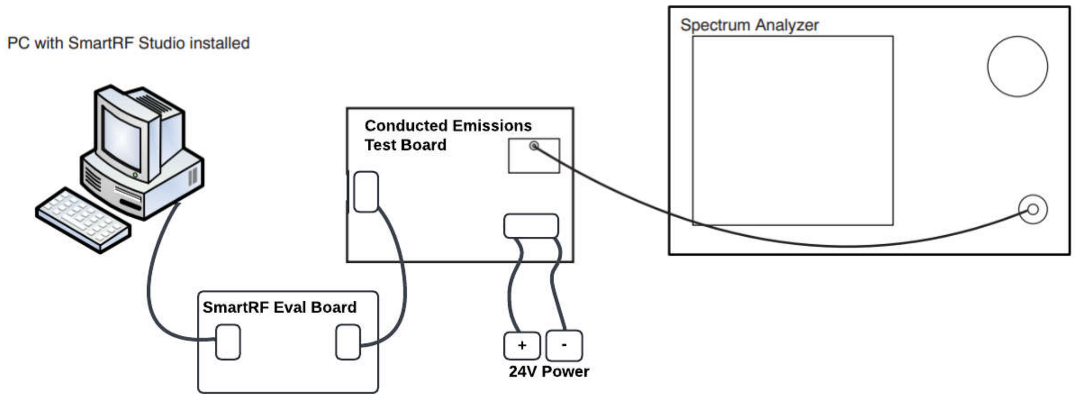

Figure 5-1. Conducted Emissions Testing Setup

Each buck converter was tested at a transmission power of 0dBm and 15dBm. The span was set to 500kHz and the resolution and video bandwidth were set to 4.7kHz. The following spectrums were observed.

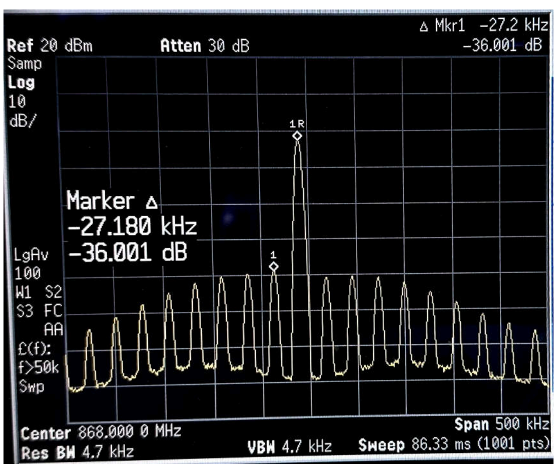

Figure 5-2. LM5166 Frequency Output With 0dBm Transmission Power

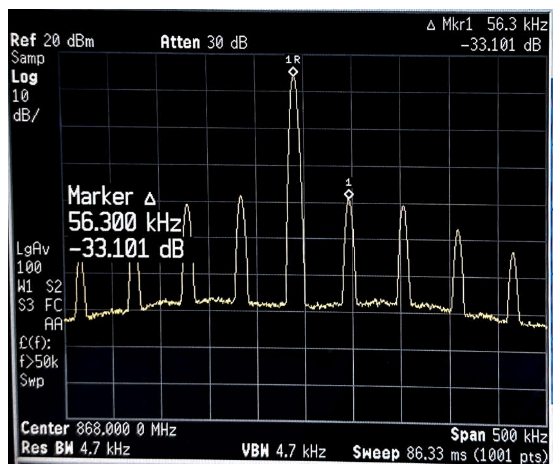

Figure 5-3. LM5166 Frequency Output With 15dBm Transmission Power

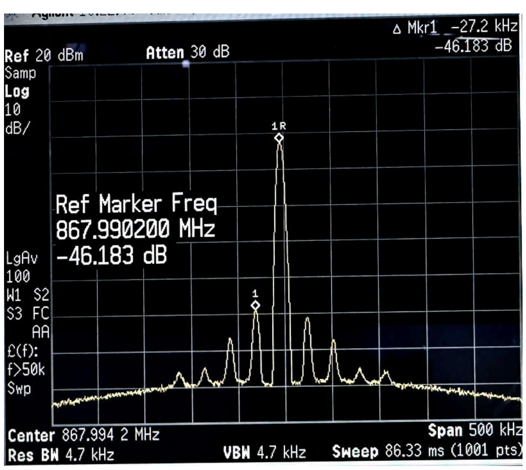

Figure 5-4. LMR38010 Frequency Output With 0dBm Transmission Power

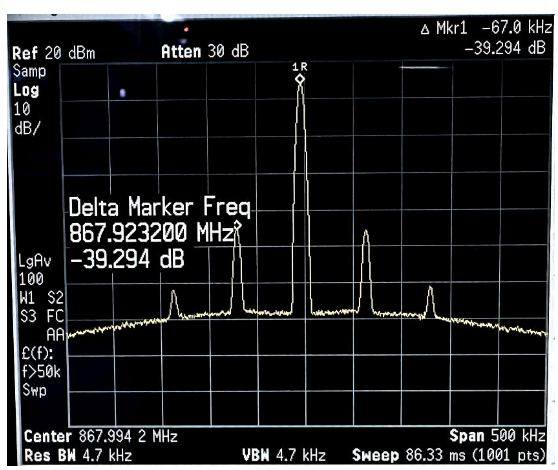

Figure 5-5. LMR38010 Frequency Output With 15dBm Transmission Power

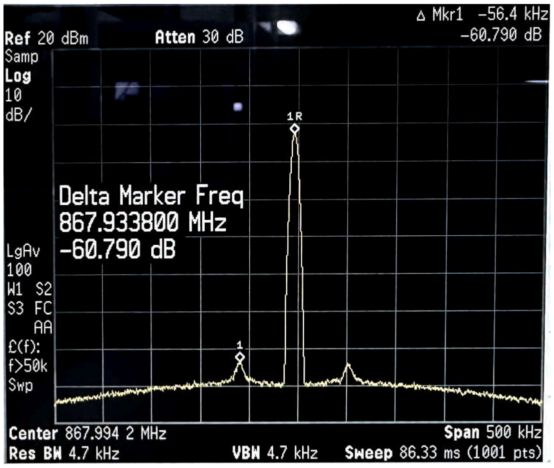

Figure 5-6. LMR36510 Frequency Output With 0dBm Transmission Power

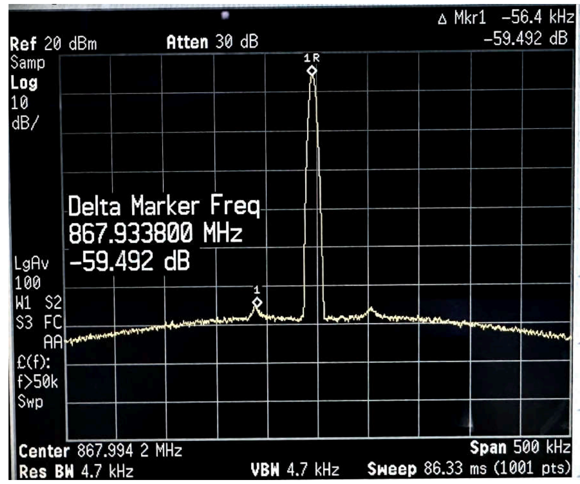

Figure 5-7. LMR36510 Frequency Output With 15dBm Transmission Power

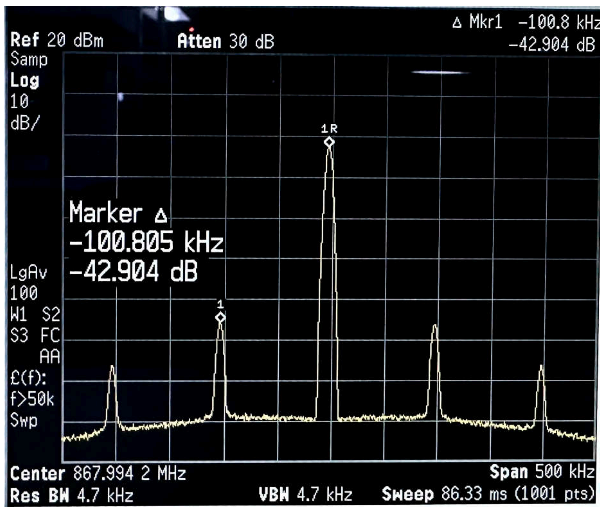

Figure 5-8. LMR36506 Frequency Output With 0dBm Transmission Power at 400kHz Switching Frequency

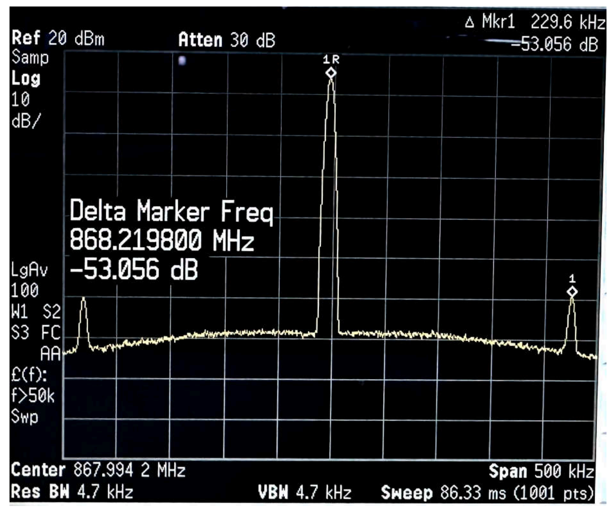

Figure 5-9. LMR36506 Frequency Output With 15dBm Transmission Power at 400kHz Switching Frequency

The LMR36510 and LMR36506 were then tested at an increased span to identify any potential spurs outside of the original 500 kHz span.

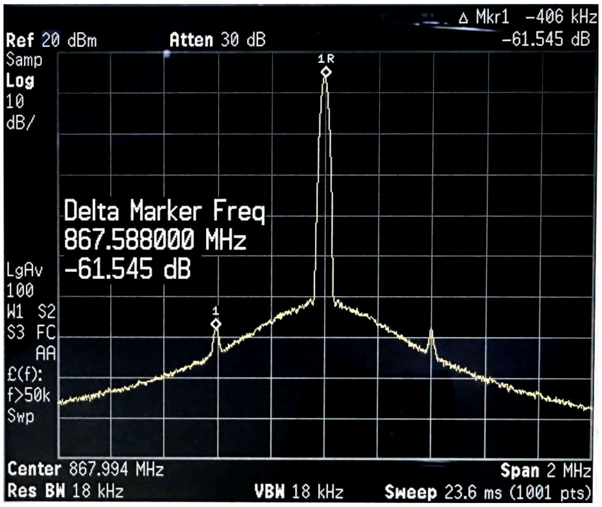

Figure 5-10. LMR36510 Frequency Output With 15dBm Transmission Power at 2MHz Span

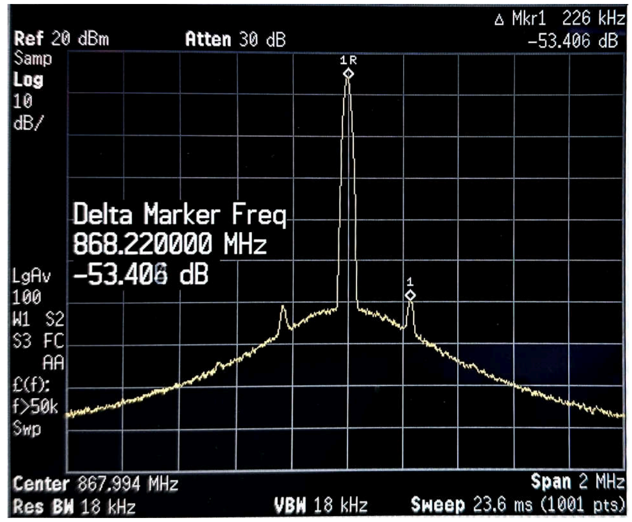

Figure 5-11. LMR36506 Frequency Output With 15dBm Transmission Power at 2MHz Span (400kHz switching frequency)

After observing that the LMR36506 and LMR36510 exhibit improved harmonic distortion compared to the control unit, additional testing was conducted by adjusting the switching frequency of the LMR36506 to determine if further improvements were possible.

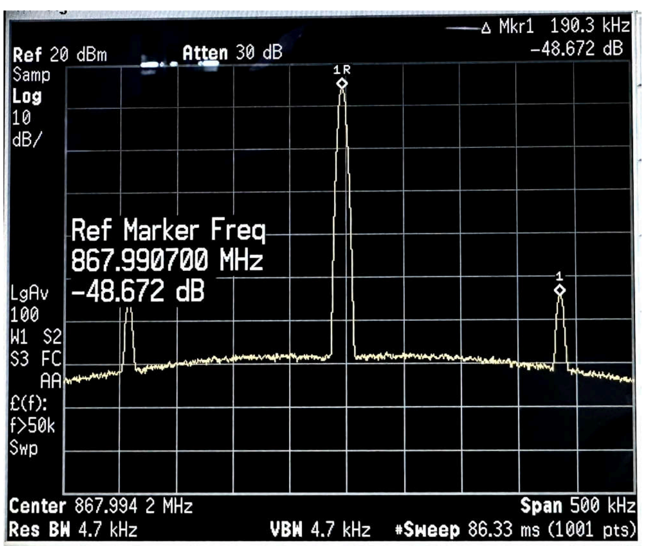

Figure 5-12. LMR36506 Frequency Output With 15dBm Transmission Power at 200kHz Switching Frequency

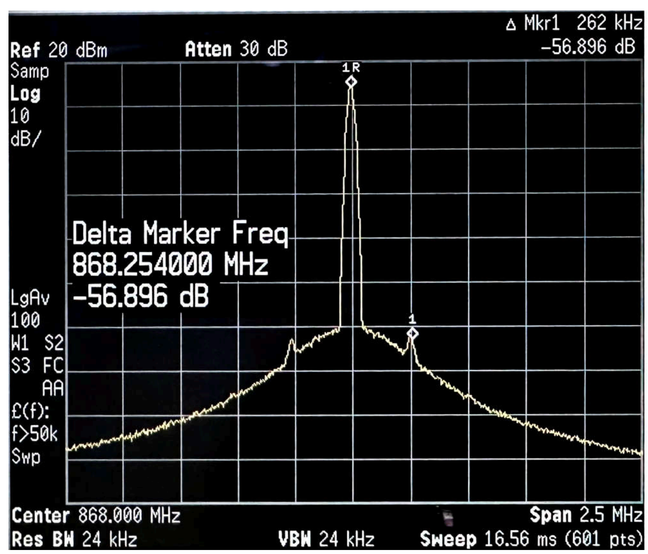

Figure 5-13. LMR36506 Frequency Output With 15dBm Transmission Power at 1MHz Switching Frequency With 2.5MHz Span

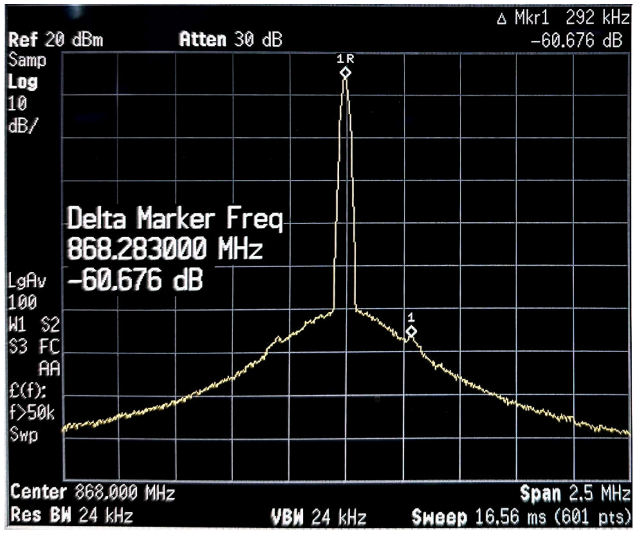

Figure 5-14. LMR36506 Frequency Output With 15dBm Transmission Power at 2MHz Switching Frequency With 2.5MHz Span

Based on the frequency spectrums above, the LMR36510 was seen to have the best performance with respect to reducing spurious emissions as shown in Figure 5-10 and Figure 5-8.

6 Summary

The original design of the smoke detector application used the LM5166 and the frequency output spectrum was replicable as seen in Figure 5-3. When looking into the LM5166 requirements for functionality, it is stated that the regulator requires a certain amount of ripple output voltage to be stable. This poses a problem in the case of the CC1120 transceiver, as it is optimal to have little to no ripple output voltage for a clean frequency output on the antenna.

Based on the test results, an optimal choice of DC-DC regulation can be made in a system so that external filtering or additional regulation is not needed. As many factors can impact the output ripple voltage of the regulator, it can be beneficial to test the effects of a regulator's ripple on the emissions seen in the frequency spectrum of a system. In this case, the correct choice for this application is the LMR36510 as it produces the minimal amount of spurious emissions at the antenna.

7 References

- Texas Instruments: *CC112x/CC1175/CC120x Operation in 274-320 MHz Frequency Band*
- Texas Instruments: *The pros and cons of spread-spectrum implementation methods in buck regulators*
- Texas Instruments: *Output Ripple Voltage for Buck Switching Regulator*

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