Application Report
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Introduction to Anti-Audible Noise Function in TPS65235-1

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ABSTRACT

The TPS65235-1 implements an anti-audible noise function to eliminate the audible noise in forced continuous conduction mode (FCCM). This application note introduces this anti-audible noise function, which includes the root cause of audible noise, the circuit modifications in design, and the EVM laboratory validation. In addition, the BOOST converter output filter capacitor and inductor selection are also discussed.

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1 Introduction

TPS65235 is a low noise block (LNB) voltage regulator for satellite receivers. The device is composed of an internal compensated boost converter and LDO regulator, and it is optimized to provide good performance with minimum external component counts.

However, there is a very common phenomenon in application. When V_{IN} is closer to V_{LNB} under light load condition, a continuous buzzing sound will be heard, which is called audible or acoustic noise.

The TPS65235-1 implements an anti-audible noise function in FCCM to eliminate the audible noise.

2 Audible Noise

2.1 Audible Frequency Range

Audible frequency is characterized as a periodic vibration with a frequency audible to the average human. The generally accepted standard range of audible frequencies is 20 Hz to 20 kHz—though the range of frequencies individuals can hear is greatly influenced by environmental factors.

2.2 Audible Noise

When V_{IN} is closer to V_{LNB} at light load, the audible noise is very easily perceived in FCCM for the following two reasons:

1. Overvoltage protection (OVP) occurs periodically, which causes the LX skipping frequency is within audio-frequency range (20 Hz to 20 kHz).
2. OVP comparator has 1-V hysteresis, which causes the BOOST ripple amplitude to be about 1 V.

Figure 1 shows the BOOST ripple frequency at 560.5 Hz and the ripple amplitude at 1.03 V under V_{IN} = 12 V, V_{LNB} = 12.8 V, no load condition.

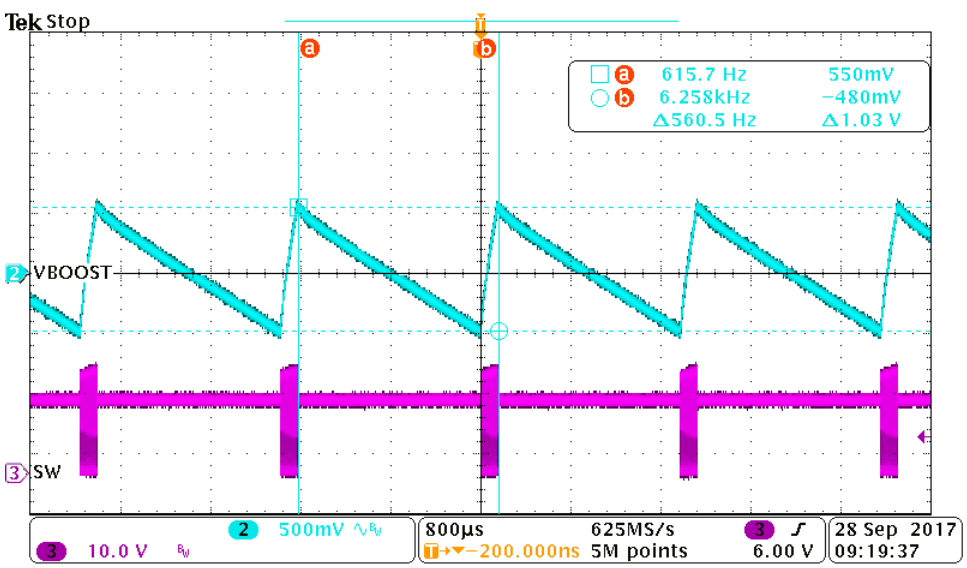

Figure 1. BOOST Ripple Amplitude and Frequency in TPS65235

2.3 Audible Noise Root Cause

The audible noise is generated by the BOOST output filter capacitor (C_{BOOST} = C8 + C9), which is the multi-layer ceramic capacitor (MLCC) in Figure 2.

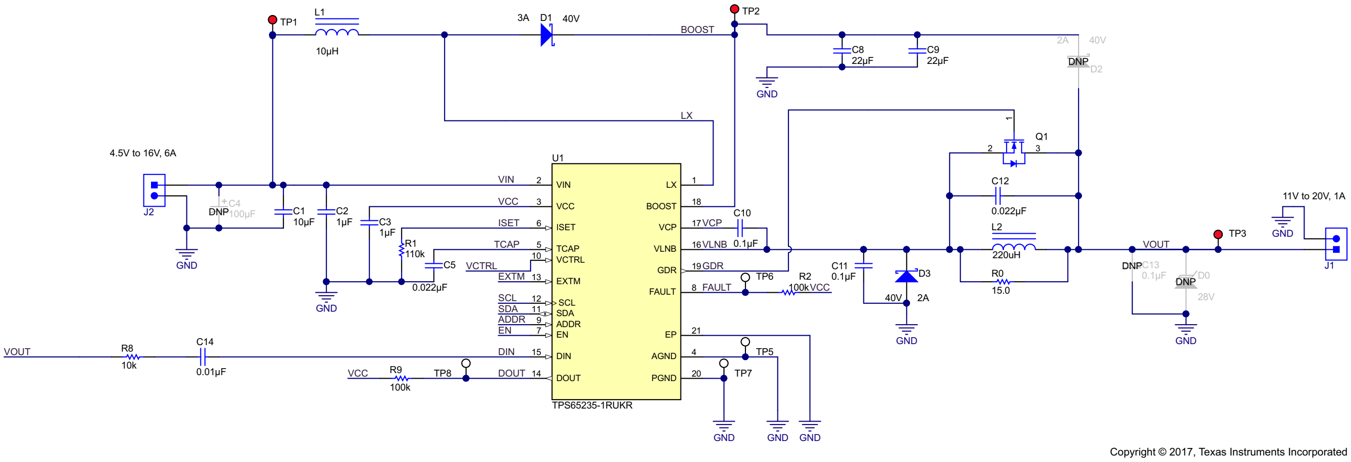

Figure 2. TPS65235-1 EVM Schematic

The MLCC uses dielectrics with piezoelectric characteristic. Figure 3 shows when the AC voltage is applied to MLCC, the dielectrics will cause a subtle vibration by expanding and contracting, and the vibration travels to PCB surface. If the AC frequency is within audio-frequency range, the sound will be perceived by human ear.

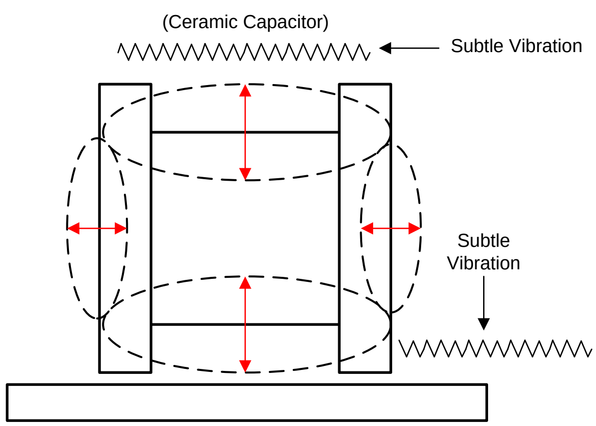

Figure 3. MLCC and PCB Subtle Vibration

3 Anti-Audible Noise Principle

Whether the audible noise is heard depends on the following two principles:

1. BOOST ripple frequency is within audio-frequency range (20 Hz to 20 kHz).
2. BOOST ripple amplitude must be large enough.

The BOOST converter in TPS65235-1 adopts non-synchronous topology where out of audio (OOA) function cannot be implemented. Based on the two discussed principles, the TPS65235-1 made the following two modifications for OVP comparator (shown in Figure 4).

1. Remove 1-V hysteresis of OVP comparator, which can reduce the BOOST ripple amplitude.
2. Use a fast OVP comparator, which can increase the LX skipping frequency and further reduce the BOOST ripple amplitude.

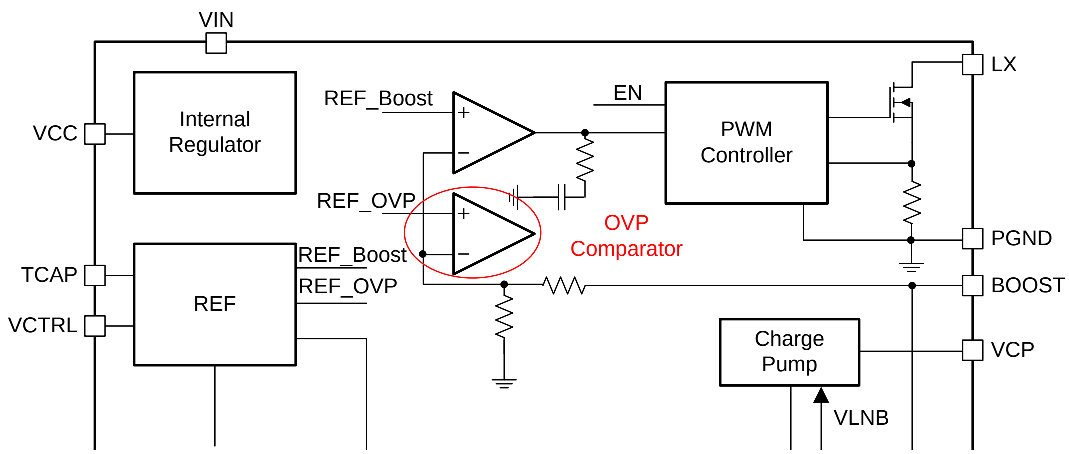

Figure 4. OVP Comparator Block Diagram

4 TPS65235 and TPS65235-1 Comparison

Figure 5 and Figure 6 show the BOOST ripple amplitude and frequency comparison between TPS65235 and TPS65235-1 under Table 1 conditions.

Table 1. EVM Test Conditions

PARAMETER	VALUE
V_{IN}	12 V
V_{LNB}	12.8 V
Inductor	10 µH
C_{BOOST}	2*22 µF
Switching frequency	1 MHz
Working mode	FCCM
Loading	0 A

Compared with TPS65235, the BOOST ripple frequency of TPS65235-1 is increased from 560.5 Hz to 22.5 kHz, the BOOST ripple amplitude is decreased from 1.03 V to 20.8 mV, and the audible noise on disappears.

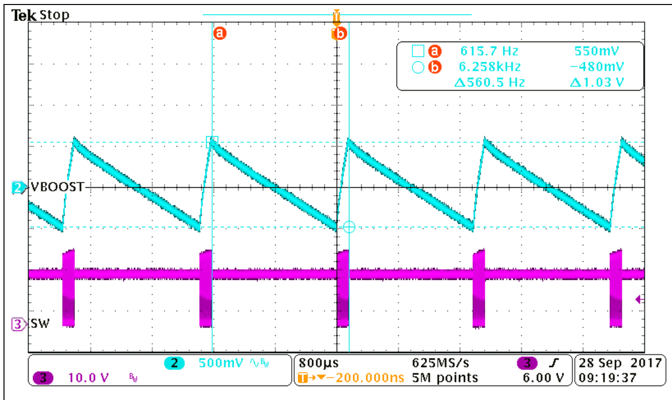

Figure 5. TPS65235: V_{PP}= 1.03 V, F_{RIPPLE}= 560.5 Hz

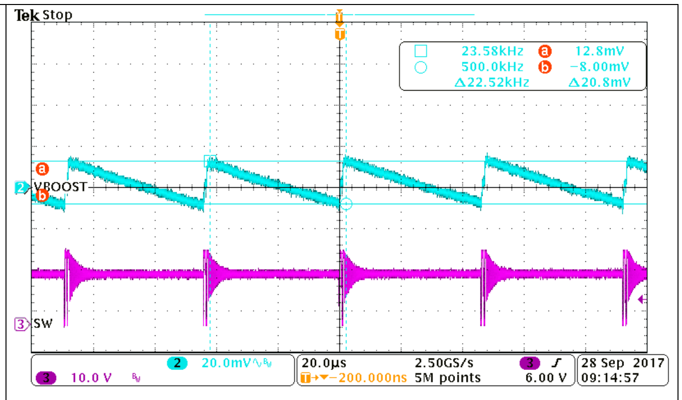

Figure 6. TPS65235-1: V_{PP}=20.8 mV, F_{RIPPLE}=22.5 kHz

5 Application Information

This section presents a discussion of proper external component selection for TPS65235-1 in application.

5.1 BOOST Output Filter Capacitor Selection

Increasing the BOOST output filter capacitance can reduce the BOOST ripple amplitude.

Figure 7 and Figure 8 show the BOOST ripple comparison between C_{BOOST}= 2*22 µF and C_{BOOST}= 3*22 µF. Under V_{IN} = 12 V, V_{LNB} = 12.8 V, no load condition, the BOOST ripple amplitude in Figure 8 is reduced by 32.7%.

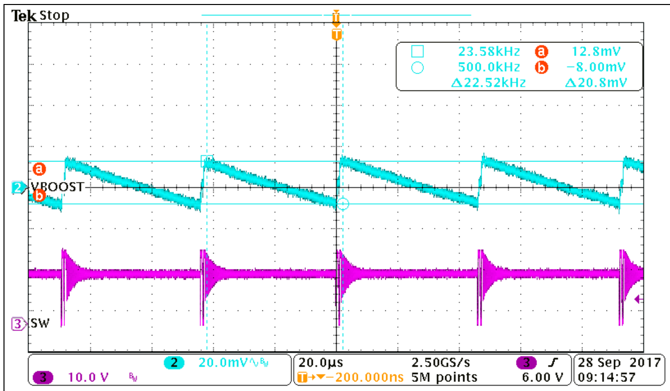

Figure 7. V_{PP} = 25.6 mV, C_{BOOST} = 2*22 µF

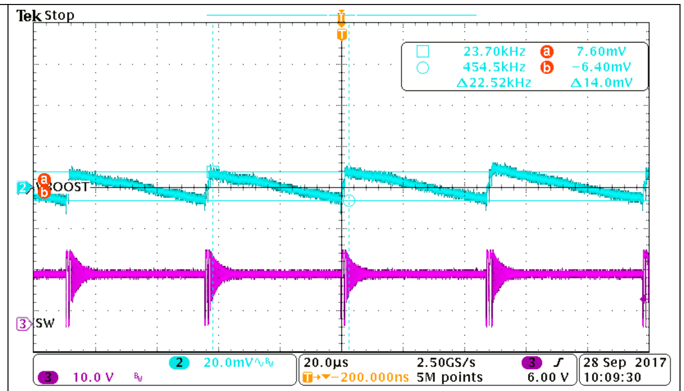

Figure 8. V_{PP} = 12.4 mV, C_{BOOST} = 3*22 µF

When selecting the MLCC as BOOST output filter capacitor, the capacitance derating should be considered. The following introduces a method to evaluate the MLCC actual capacitance.

Figure 9 shows the waveform that TPS65235-1 works under V_{IN}=12 V, V_{LNB}=18.2 V, load = 1-A condition. Ignoring the influence of ESR, the actual capacitance can be calculated by Equation 1.

$$\text{Cactual}\,(\text{uF}) = \left(\frac{\text{Iload} \times \text{Ton}}{\text{Vpp}}\right) = \left(\frac{\text{IA} \times 336\text{nS}}{50.8\text{ mV}}\right) = 6.6\text{ uF} \quad (1)$$

Where:

- C_{actual} = actual capacitance of BOOST output filter capacitor
- I_{load} = output load current
- T_{ON} = ON state time of POWER MOSFET
- V_{PP} = BOOST ripple peak-peak amplitude

Compared with the C_{BOOST} nominal capacitance, the actual capacitance degrades from 2*22 µF to 6.6 µF when biased V_{BOOST} = 20.2-V DC voltage, which is decreased by 85%.

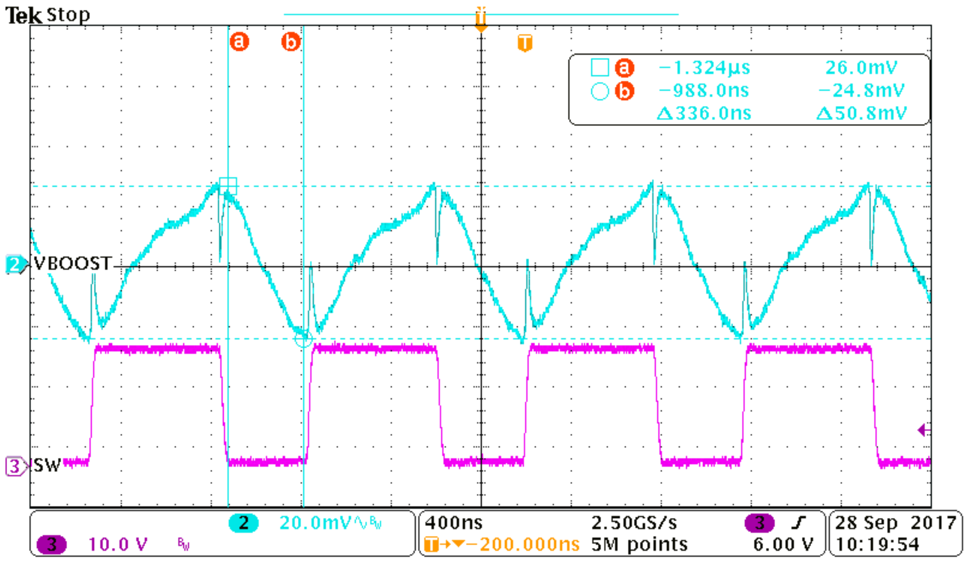

Figure 9. BOOST Ripple Under V_{LNB} = 18.2 V, Load = 1-A Condition

The MLCC actual capacitance can also be obtained from DC Bias Characteristic in its characteristic graph. Figure 10 shows a TDK MLCC DC bias characteristic, C3216X5R1V226M (22 µF, 35V, X5R, 1206 package). The capacitance degrades 86% at 20-V bias DC voltage, which is approximately equal to the Equation 1 calculation.

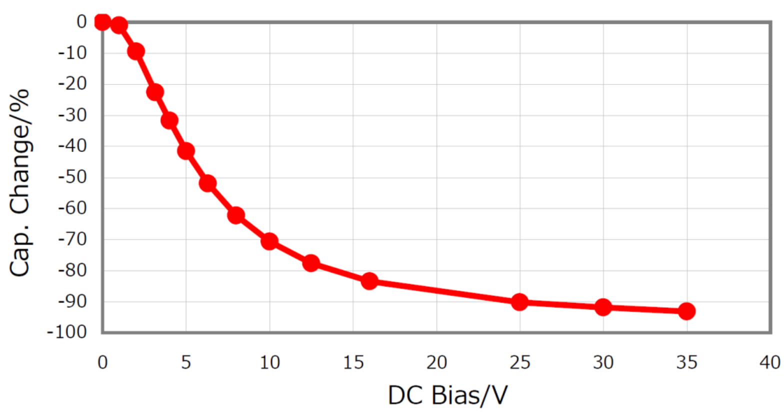

Figure 10. C3216X5R1V226M DC Bias Characteristic

In addition, the dielectric layer of electrolytic capacitor (ECAP) and polymer capacitor (POSCAP and SPCAP) do not have piezoelectric characteristic, and the layer will not vibrate with biased AC voltage. When selecting ECAP, POSCAP, or SPCAP as BOOST output filter capacitor, there will be no audible noise.

5.2 Boost Inductor Selection

At light load, the BOOST converter outputs the minimum ON time during each cycle. When using bigger inductance, the inductor peak current will be smaller. During OFF time, the inductor will release less energy to BOOST output filter capacitor, so using bigger inductance can reduce the BOOST ripple amplitude.

Figure 11 and Figure 12 show the BOOST ripple amplitude comparison between L = 10 µH and L = 4.7 µH under V_{IN} = 12 V, V_{LNB} = 11.6 V, no load condition. The BOOST ripple amplitude of L = 10 µH is reduced by 20%.

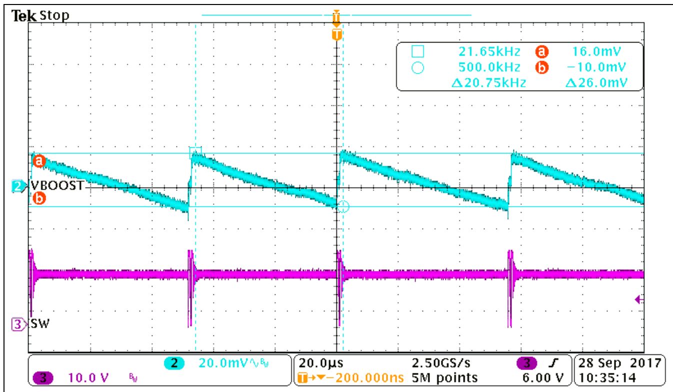

Figure 11. V_{PP} = 26 mV, L = 4.7 µH

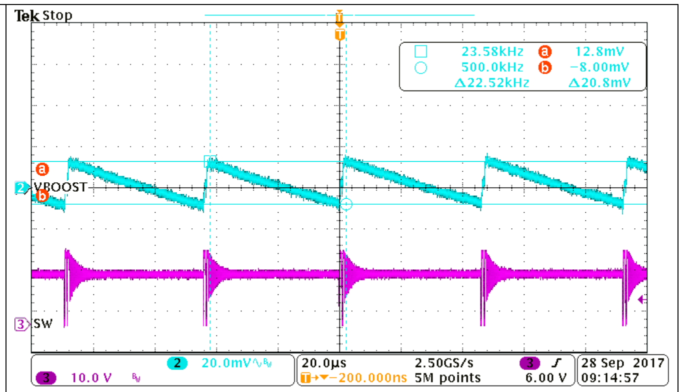

Figure 12. V_{PP}= 20.8 mV, L = 10 µH

6 EVM Laboratory Validation

TPS65235-1EVM is tested under Table 1 condition, the following figures show the BOOST ripple frequency (F_{RIPPLE}) and ripple peak-peak amplitude (V_{PP}) waveforms when changing load from 0 A to 100 mA. All of F_{RIPPLE} are out of audio-frequency range, and all of V_{PP} are small, so there is no audible noise.

In addition, under different V_{IN} and V_{LNB} condition, after full laboratory validation, there is no audible noise too

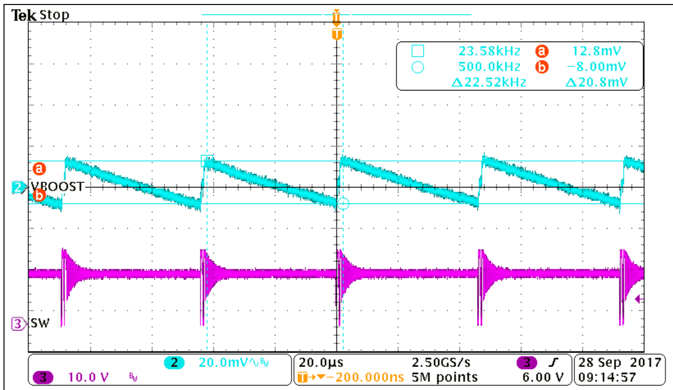

Figure 13. V_{PP} = 20.8 mV, F_{RIPPLE} = 22.5 kHz, Load = 0 A

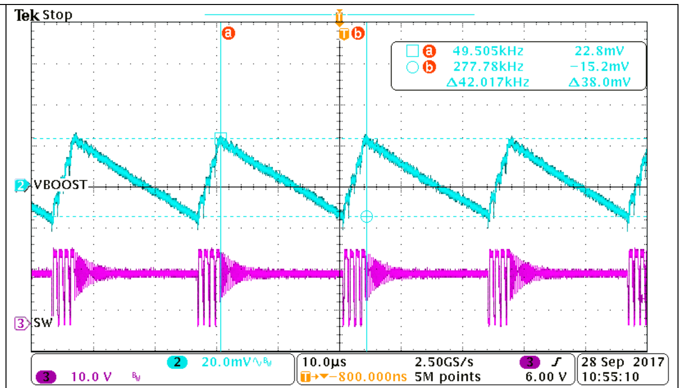

Figure 14. V_{PP} = 38 mV, F_{RIPPLE} = 42 kHz, Load = 10 mA

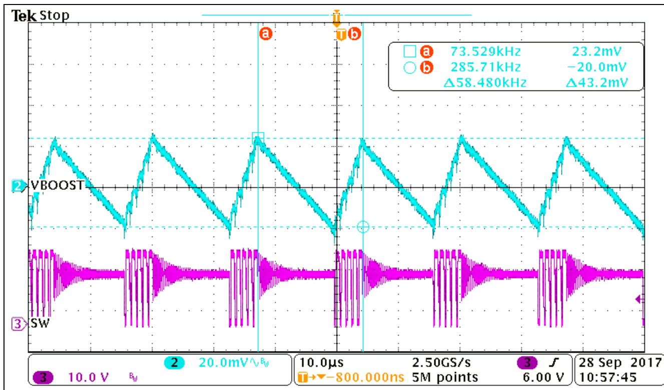

Figure 15. V_{PP} = 43.2 mV, F_{RIPPLE} = 58.5 kHz, Load = 20 mA

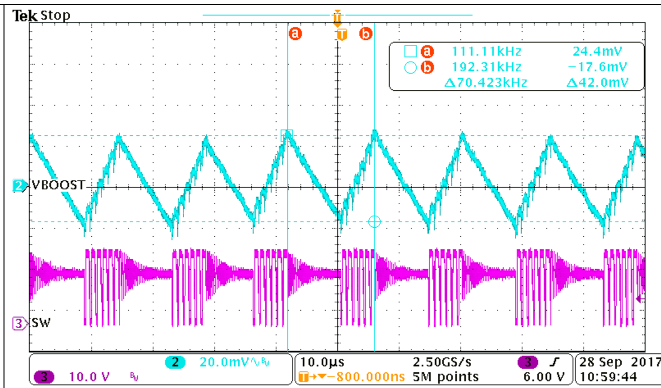

Figure 16. V_{PP} = 42 mV, F_{RIPPLE} = 70.4 kHz, Load = 30 mA

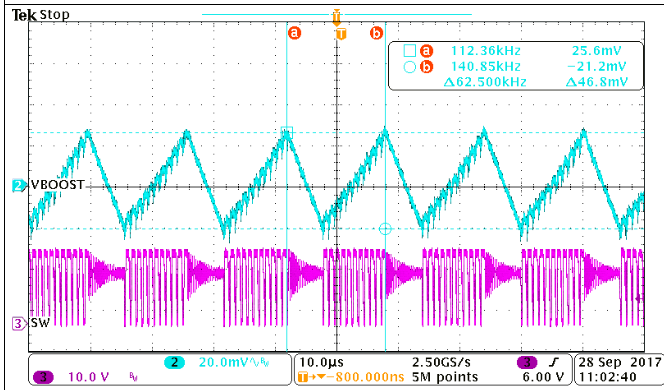

Figure 17. V_{PP} = 46.8 mV, F_{RIPPLE} = 62.5 kHz, Load = 50 mA

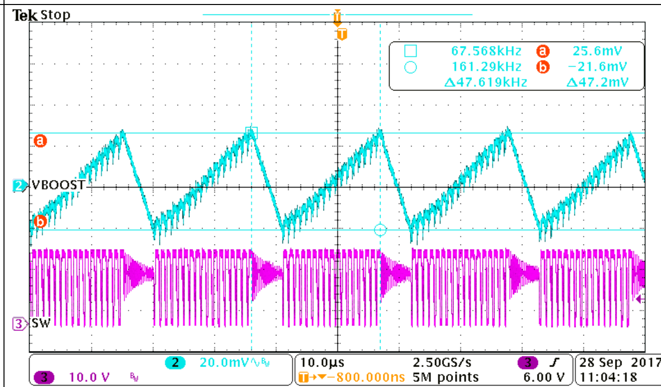

Figure 18. V_{PP} = 47.2 mV, F_{RIPPLE} = 47.6 kHz, Load = 60 mA

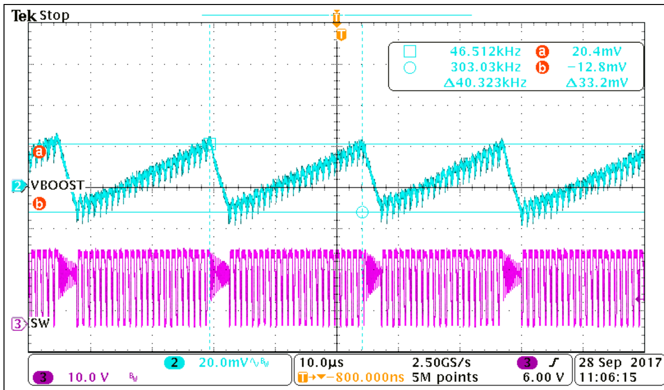

Figure 19. V_{PP} = 33.2 mV, F_{RIPPLE} = 40.3 kHz, Load = 70 mA

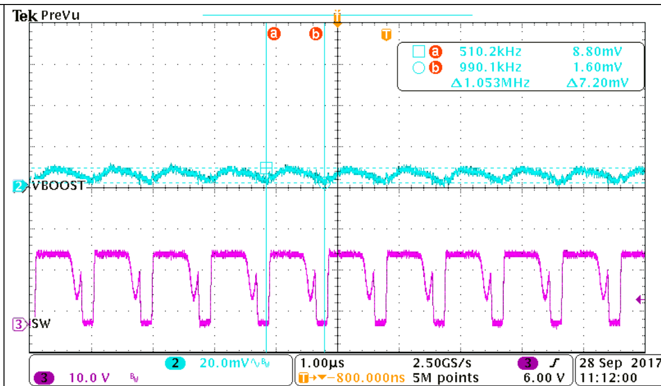

Figure 20. V_{PP} = 7.2 mV, F_{RIPPLE} = 1.05 MHz, Load = 80 mA

7 Summary

Stringent laboratory validation proves that the anti-audible noise function is effective. TPS65235-1 with proper external components can eliminate the audible noise completely in FCCM.

8 References

1. Texas Instruments, *TPS65235-1 LNB Voltage Regulator With I²C Interface Data Sheet*
2. TDK, *MLCC with Dipped Radial Lead*
3. Murata, *Examples of Noise Countermeasures (Video)*
4. Texas Instruments, *Evaluation Module for the TPS65235-1 LNB Voltage Regulator With I²C Interface for DiSEqC2.x Application User's Guide*
5. Texas Instruments, *DiSEqC™ Protocol and Low-Noise Block Voltage Regulator TPS65235 for Satellite – STB/TV Application Report*
6. Texas Instruments, *LNB Design Considerations on TPS65233 and TPS65235 Application Report*
7. TDK, Multilayer Ceramic Chip Capacitors:C3216X5R1V226M160AC Detailed Information

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