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Understanding OOA™ Operation

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ABSTRACT

Out-of-Audio™ (OOA) operation is a unique control feature that can eliminate audio noise at light load condition. This feature is often used in D-CAP3 DC/DC BUCK converters for some applications. This application note presents a detailed introduction to this feature based on the TPS566235, including the audio noise generation mechanism, OOA operation behavior, and the performance characteristics.

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Trademarks

OOA, Out-of-Audio, Eco-mode are trademarks of Texas Instruments.

1 Audio Noise Generation Mechanism

Multi-layer Ceramic Capacitors (MLCC) is widely used in electronic products due to its good performance, such as small size, low ESR, low cost, and so forth. However, when an AC voltage is applied to MLCC, it expands and shrinks due to the electrostrictive effect of the ferroelectric ceramic. As a result, the printed circuit board (PCB) vibrates in the surface direction as shown in Figure 1. The vibration of capacitor and board is only about 1 pm – 1 nm, when the vibration frequency reaches the audio frequency range (20 Hz – 20 kHz) of humans, a sound is perceived by the human ear.

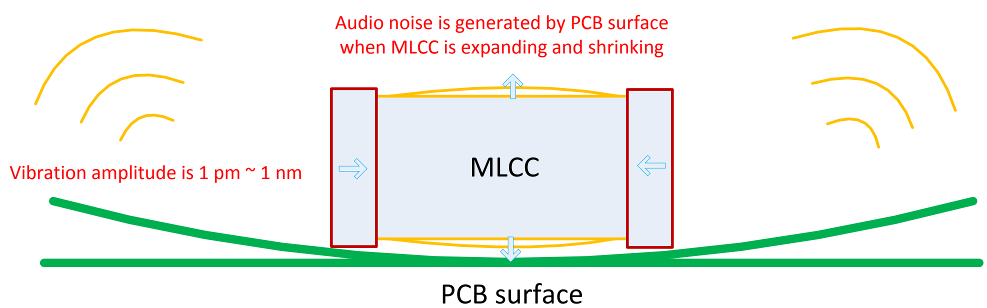

Figure 1. PCB Vibration by MLCC Electrostrictive Effect

The inductor also has similar electrostrictive effect, but it is not common to observe the audio noise generated by the inductor with the advancement of inductor process, especially for the shielding inductor.

2 OOA™ Operation Principle

TPS566235 offers three different operation modes for light load running, including Eco-mode™, Out-Of-Audio (OOA) and Forced CCM (FCCM).

At light load condition, Eco-mode operation produces audio noise on output MLCC although it has best efficiency performance. OOA operation keeps the switching frequency above the audio frequency range, which can make the output ripple frequency above audio frequency range too, so the OOA operation can prevent audio noise generation from MLCC or inductor. FCCM operation also can prevent the audio noise generation, but it sacrifices too much efficiency.

OOA control circuit monitors the state of high-side and low-side FETs. There is 29 µS (typical) OOA time-out timer that starts when inductor current drops to 0 A, triggering Zero Crossing (ZC). If both high-side and low-side FETs are in the OFF state for a period longer than 29 µS, the low-side FET turns on to discharge output voltage until FB voltage drops below reference voltage to initiate the high-side FET ON. In other words, TPS566235 changes the operation mode to FCCM automatically when high-side and low-side FETs are OFF longer than 29 µS. Figure 2 shows the detailed OOA operation process.

1. When the high-side and low-side FETs are OFF for 29 µS, turn on low-side FET and pull down V_{OUT}.
2. When the FB voltage drops lower than reference voltage, turn on the high-side FET. At the same time, the OOA time-out timer is clear.
3. After the ON time, the high-side FET is turned off, and the low-side FET is turned on again.
4. After the minimum OFF time, the Zero Crossing circuit is allowed to turn off the low-side FET.

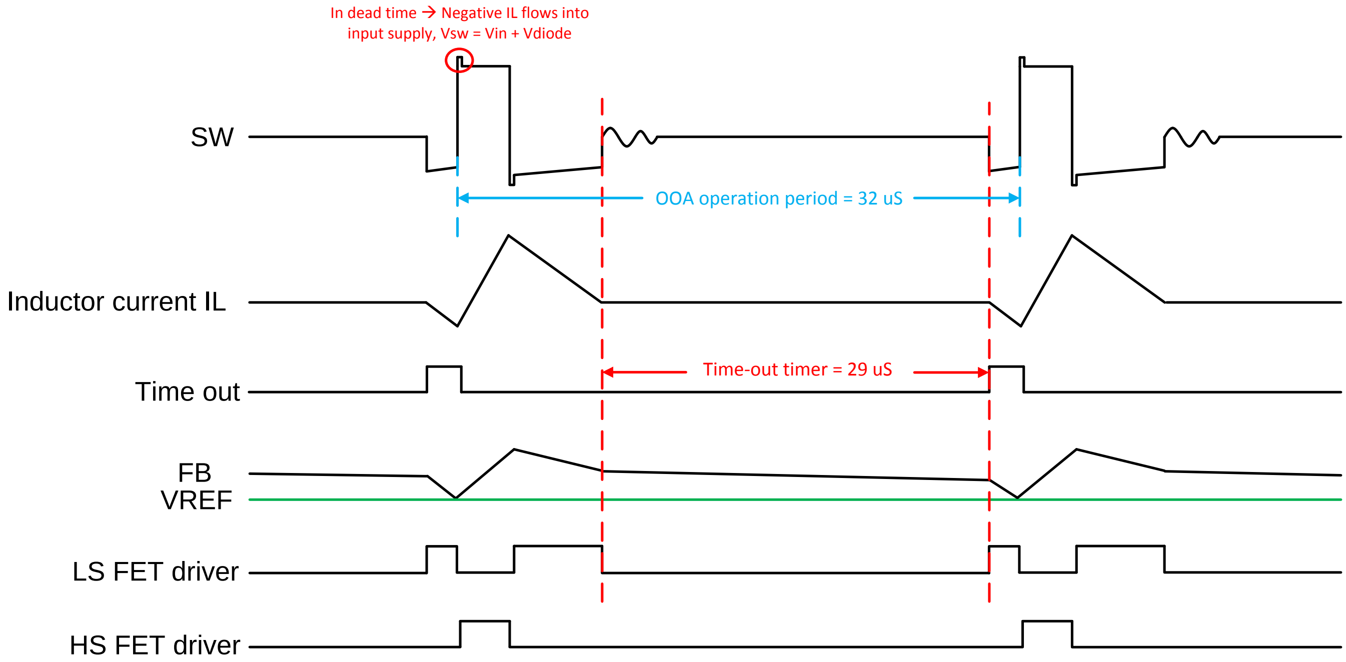

Figure 2. OOA Operation Process

3 OOA Operation Characteristics and Validation

This section presents OOA operation characteristics and validation by comparing Eco-mode and FCCM. It includes OOA operation behavior, V_{OUT} ripple frequency, switching frequency, efficiency, load regulation, and load transient.

All the validation data are tested on TPS566235EVM-036 Evaluation Module. Table 1 shows the design parameters. Figure 3 illustrates the schematic.

Table 1. Design Parameters on TPS566235EVM-036 Evaluation Module

PARAMETER	VALUE
Input votage V_{IN}	12 V
Output voltage V_{OUT}	3.3 V
Output current range	0 A to 6 A
Switching frequency	600 kHz
Time-out timer in OOA mode	29 µSec
Negative over current limit	3.4 A

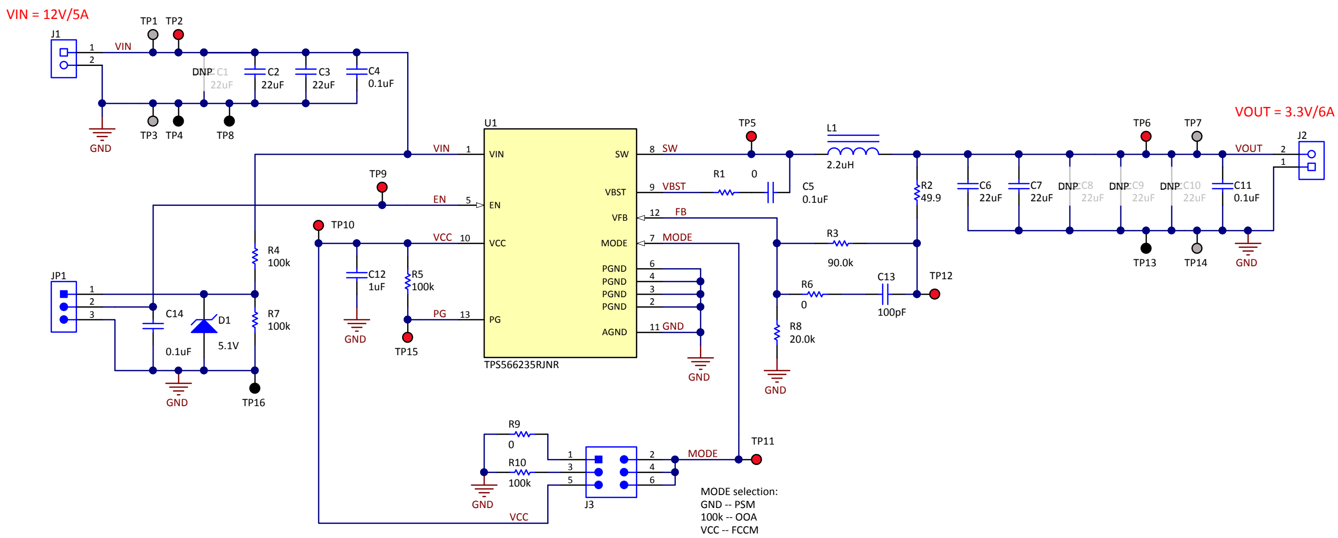

Figure 3. TPS566235EVM-036 Evaluation Module Schematic

3.1 OOA Operation Behavior

Figure 4 and Figure 5 show the OOA operation behavior at 10 mA loading. When high-side and low-side FETs are in the OFF state longer than 27.4 µS (OOA time-out timer), the low-side FET turns on to discharge output voltage V_{OUT} until FB voltage drops below reference voltage to initiate the high-side FET ON.

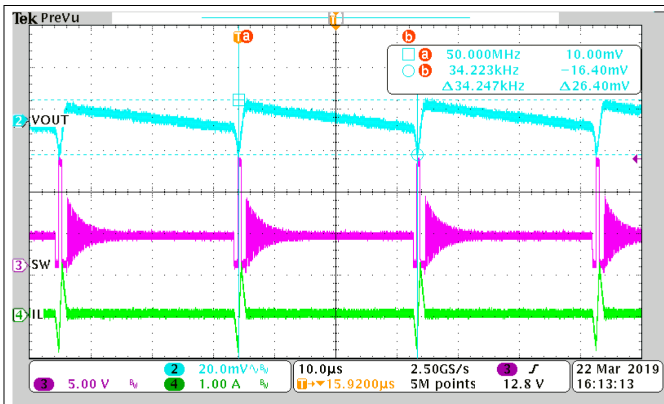

Figure 4. OOA Operation Behavior at 10 mA Loading

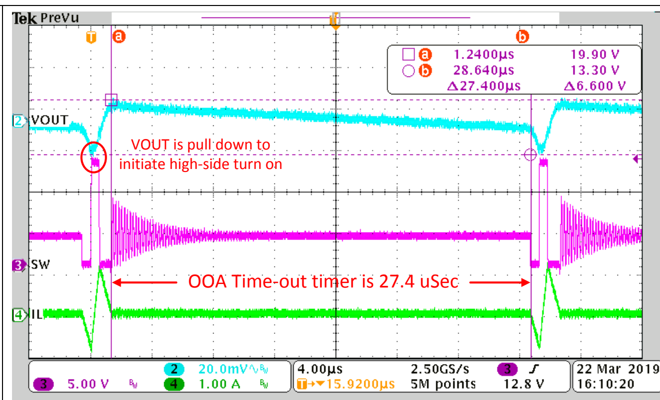

Figure 5. Zoom in, Low-side FET Turns On After High-side and Low-side FETs Are OFF State Longer than 27.4 µS

3.2 Output Ripple Frequency

According to Section 1, the audio noise can be verified by measuring V_{OUT} ripple frequency within the audio frequency range.

Figure 6 through Figure 17 show the V_{OUT} ripple frequency (F_{RIPPLE}) comparison between Eco-mode and OOA mode at light load condition. In loading range of 0 A to 40 mA, the V_{OUT} ripple frequency in OOA mode keeps around 34 kHz. Besides, the V_{OUT} ripple amplitude in OOA mode is much smaller than Eco-mode.

After stringent validation, V_{OUT} ripple frequency in OOA mode can always keep above the audio frequency range under different Vin, Vout, and inductor condition.

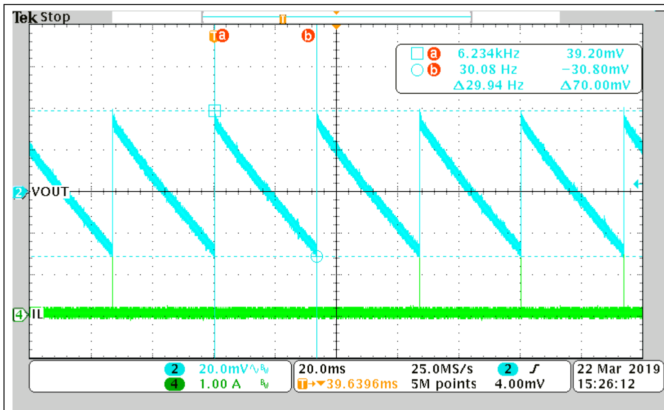

Figure 6. Eco-mode, 0 A, F_{RIPPLE} = 29.9 Hz, in Audio Frequency Range

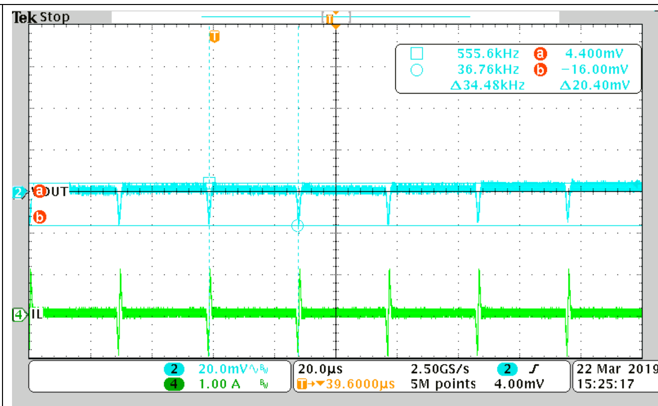

Figure 7. OOA Mode, 0 A, F_{RIPPLE} = 34.5 kHz, Out-of-Audio Frequency Range

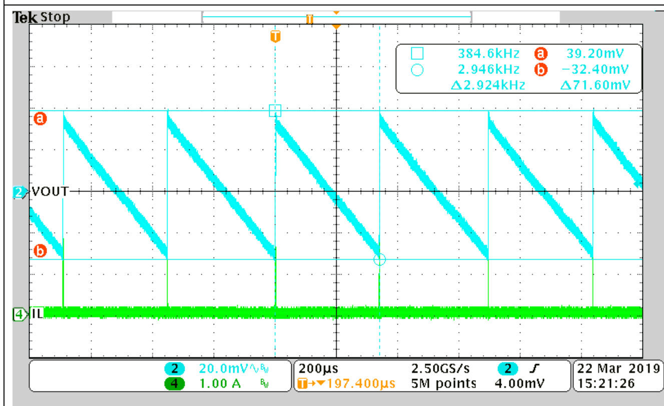

Figure 8. Eco-mode, 5 mA, F_{RIPPLE} = 2.9 kHz, in Audio Frequency Range

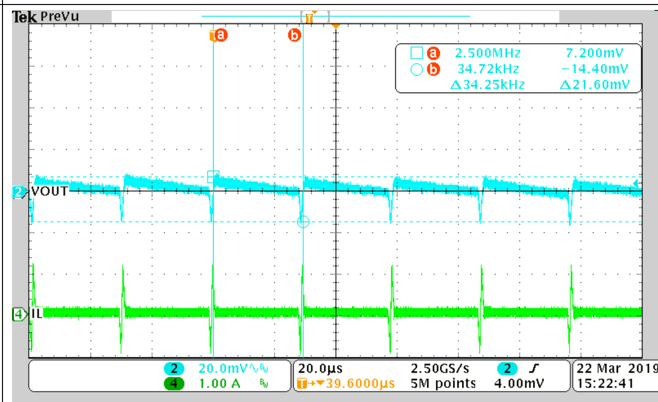

Figure 9. OOA Mode, 5 mA, F_{RIPPLE} = 34.3 kHz, Out-of-Audio Frequency Range

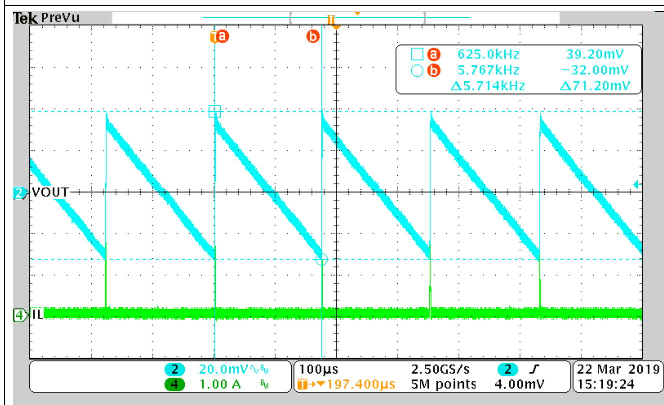

Figure 10. Eco-mode, 10 mA, F_{RIPPLE} = 5.7 kHz, in Audio Frequency Range

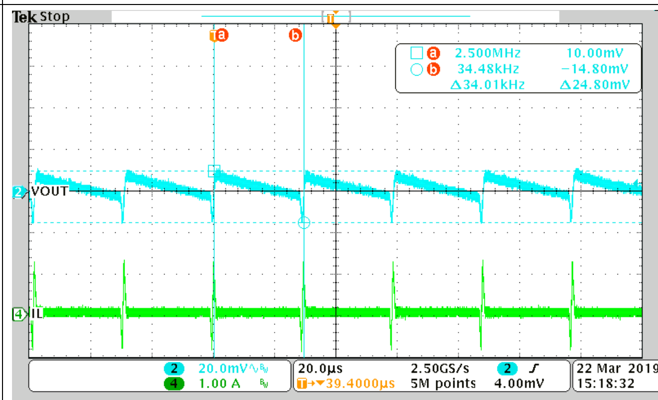

Figure 11. OOA Mode, 10 mA, F_{RIPPLE} = 34 kHz, Out-of-Audio Frequency Range

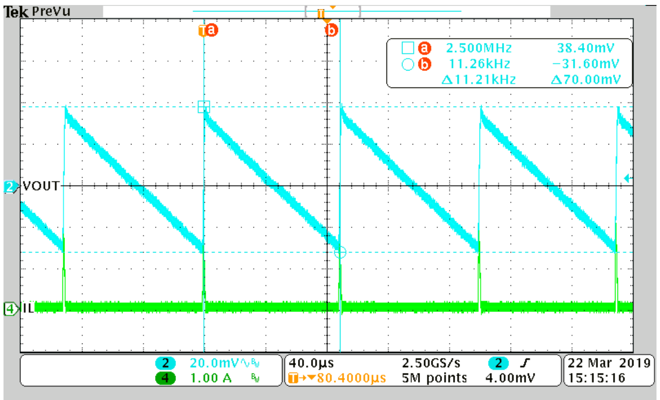

Figure 12. Eco-mode, 20 mA, F_{RIPPLE} = 11.2 kHz, in Audio Frequency Range

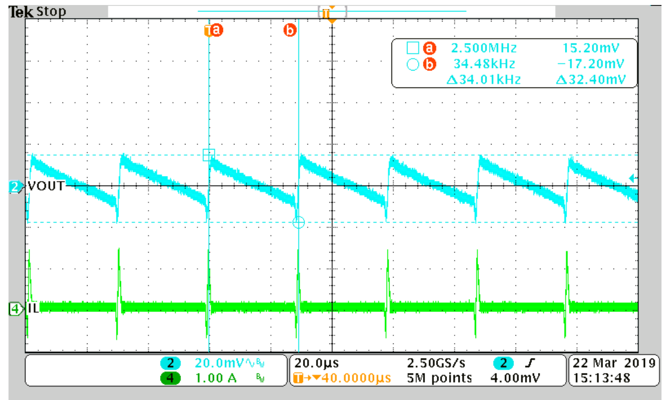

Figure 13. OOA Mode, 20 mA, F_{RIPPLE} = 34 kHz, Out-of-Audio Frequency Range

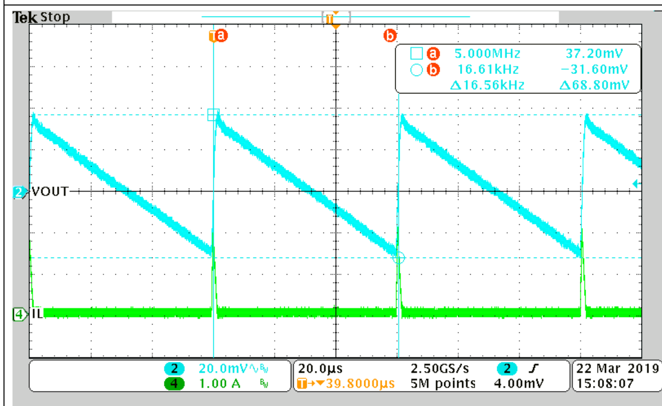

Figure 14. Eco-mode, 30 mA, F_{RIPPLE} = 16.6 kHz, in Audio Frequency Range

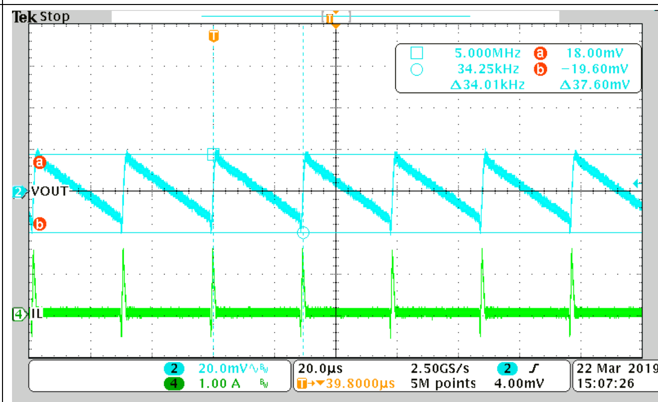

Figure 15. OOA Mode, 30 mA, F_{RIPPLE} = 34 kHz, Out-of-Audio Frequency Range

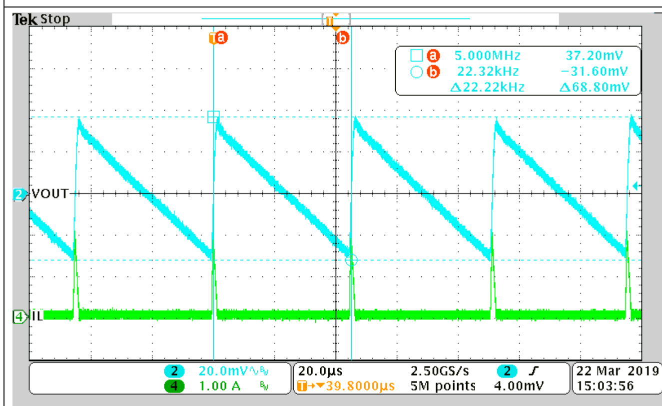

Figure 16. Eco-mode, 40 mA, F_{RIPPLE} = 22.2 kHz, Out-of-Audio Frequency Range

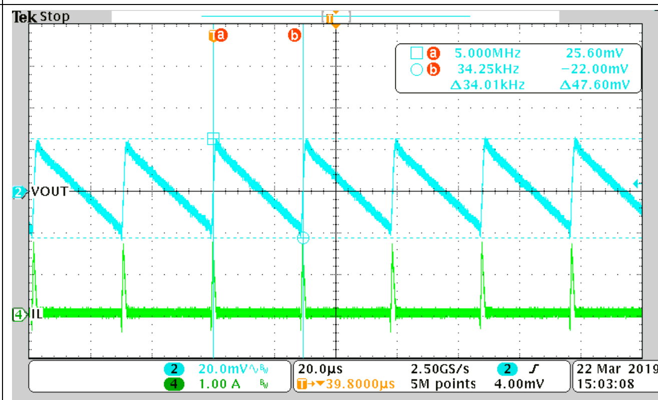

Figure 17. OOA Mode, 40 mA, F_{RIPPLE} = 34 kHz, Out-of-Audio Frequency Range

3.3 Switching Frequency and Efficiency

Figure 18 and Figure 19 show the switching frequency and efficiency comparison in three different operation modes.

In heavy load condition (> 1 A), all three modes work with the same frequency and efficiency in CCM (continuous current mode). In the middle load condition (100 mA < loading < 1 A), Eco-mode and OOA mode reduce the switching frequency as a function of load current, and OOA mode keeps the same frequency and efficiency as Eco-mode. In the light loading condition (< 100 mA), Eco-mode continues reducing switching frequency, while OOA mode clamps switching frequency at 34 kHz when loading smaller than 70 mA. At the 10 mA loading point, the efficiency of OOA mode is about 22% lower than Eco-mode, but it improves about 45% efficiency compared with FCCM mode.

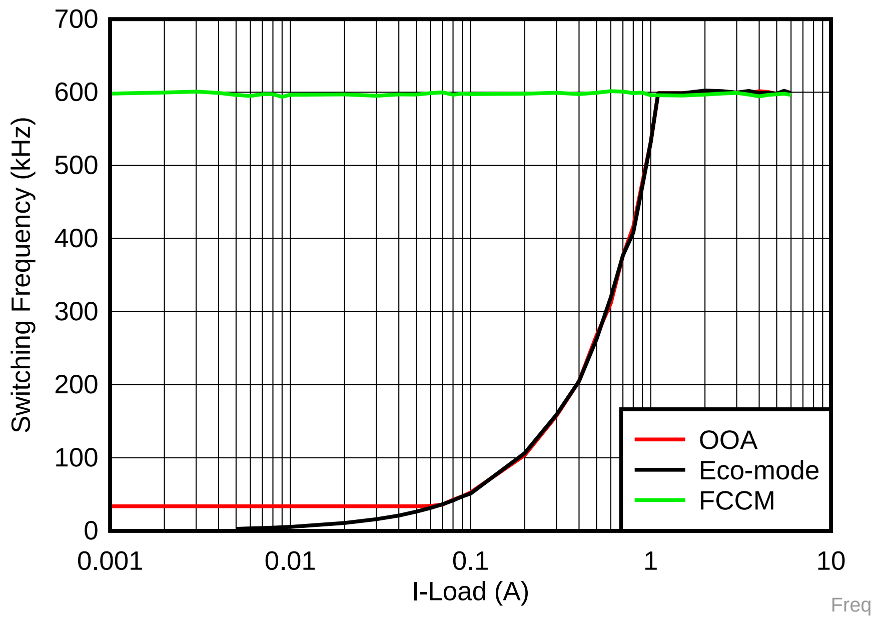

Figure 18. Switching Frequency Comparison in Eco-mode, OOA, FCCM Mode

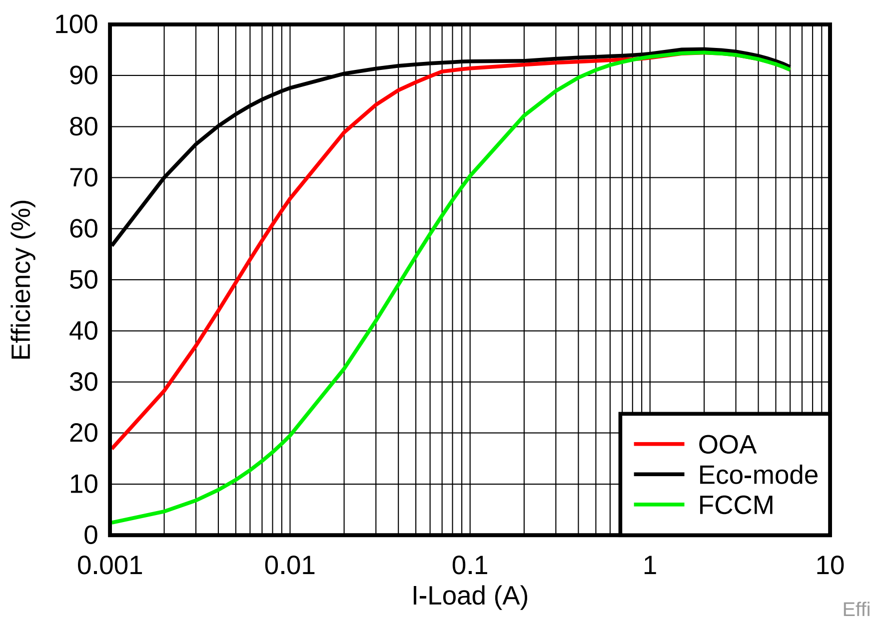

Figure 19. Efficiency Comparison in Eco-mode, OOA, FCCM Mode

3.4 Load Regulation

Figure 20 shows the load regulation in three different operation modes. All three modes have almost the same load regulation.

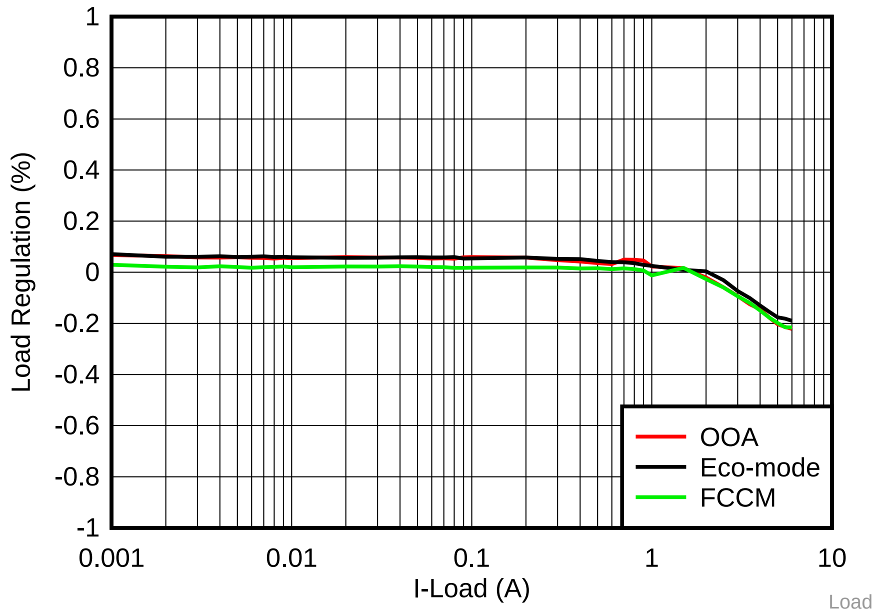

Figure 20. Load Regulation Comparison in Eco-mode, OOA, FCCM Mode

3.5 Load Transient

Figure 21 through Figure 26 show the load transient response in three different operation modes.

0 A to 6 A load transient performance: FCCM > Eco-mode > OOA mode.

1 A to 6 A load transient performance: FCCM = Eco-mode = OOA mode. At 1 A loading, all three modes work in same status (CCM), so they have same performance when load transient to 6 A.

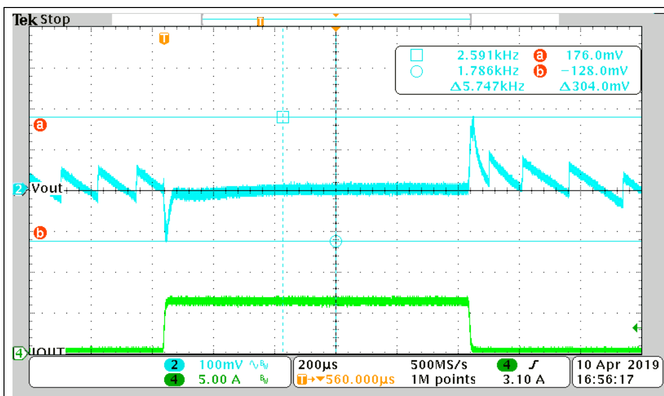

Figure 21. 0 A to 6 A, Eco-mode, V_{PP} = 304 mV

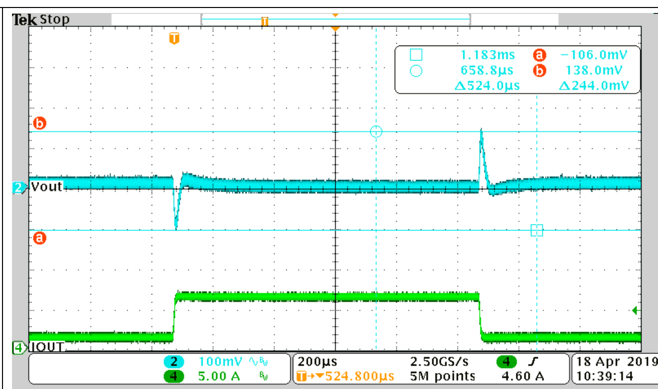

Figure 22. 1 A to 6 A, Eco-mode, V_{PP} = 244 mV

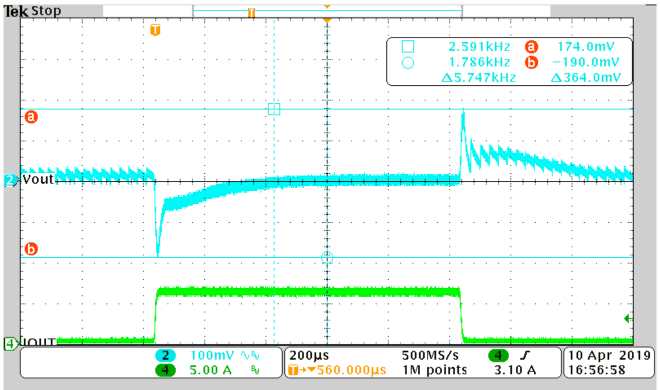

Figure 23. 0 A to 6 A, OOA Mode, V_{PP} = 364 mV

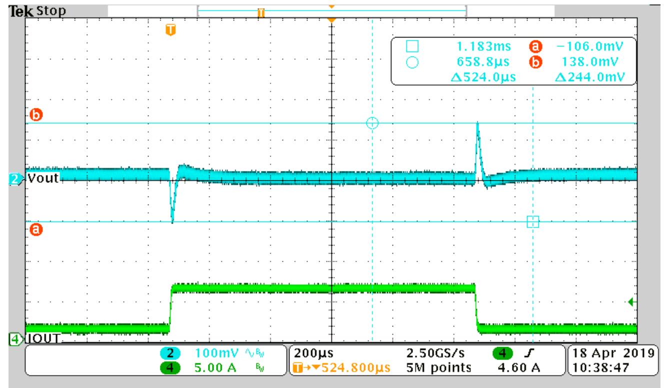

Figure 24. 1 A to 6 A, OOA Mode, V_{PP} = 244 mV

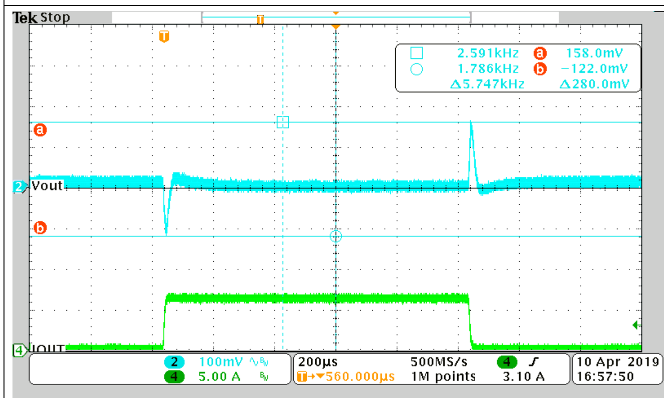

Figure 25. 0 A to 6 A, FCCM Mode, V_{PP} = 280 mV

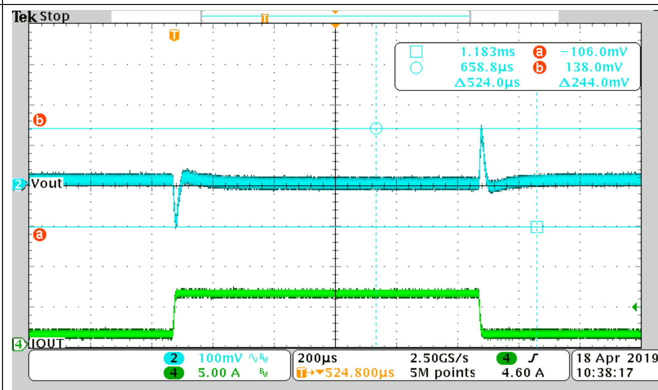

Figure 26. 1 A to 6 A, FCCM Mode, V_{PP} = 244 mV

4 Conclusion

The OOA operation is actually the Eco-mode with clamping minimum switching frequency always higher than audio frequency. It can prevent audio noise generation on MLCC or inductor, and provide distinct efficiency advantages at light load compared to FCCM mode. If the audio noise at light load is an important concern, the OOA operation provides a good choice between Eco-mode and FCCM mode.

The OOA operation is introduced based on the TPS566235, but the conclusions and characteristics are also applicable to other parts, such as the TPS568230.

5 References

1. Texas Instruments, *TPS566235 4.5-V to 18-V Input, 6-A Synchronous Step-down Converter Data Sheet*
2. TDK, *MLCC with Dipped Radial Lead*
3. Murata, *Examples of Noise Countermeasures (Video)*
4. Texas Instruments, *TPS566235EVM-036 Evaluation Module User's Guide*