

LM5190: Analysis of Mixed PWM and PFM Mode Operation during PFM Configuration



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ABSTRACT

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As a peak current mode synchronous buck controller, the LM5190 defaults to operating in PFM mode when Forced Pulse Width Modulation (FPWM) is not configured. In practical applications, it has been found that even when the load current has not reached the threshold for Discontinuous Conduction Mode (DCM), the LM5190 may still exhibit a mixed state of PWM and PFM operation. This manifests as a switching frequency significantly lower than the set value or uncertain peak current control values. This is caused by the inherent mechanism of the LM5190 and is not an abnormal phenomenon. This article will explain the working mechanisms of the LM5190 in PWM and PFM modes, analyze the triggering conditions and core causes of the mixed operation phenomenon, conduct experimental verification using the LM5190 EVM to investigate the influence of key factors such as load current, COMP voltage, and PFM triggering, and provide references for stability design in similar applications.

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1 Introduction: Anomalous Frequency Drop in the LM5190

The LM5190 is a widely adopted Texas Instruments synchronous buck controller featuring a wide input voltage range. Distinguished by its high-precision constant-voltage/constant-current (CV-CC) control loop, it is extensively deployed in applications such as supercapacitor energy backup, energy storage systems, USB Power Delivery, server battery backup units (BBUs), and power supplies for audio amplifiers. A typical system design of LM5190 cooperating with TAS6754 for Class-H operation is shown in [Figure 1-1](#).

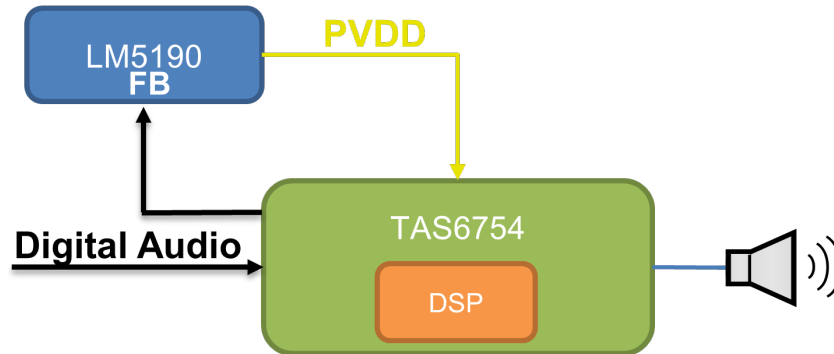


Figure 1-1. Class-H Operation via LM5190 and TAS6754 Collaboration

The LM5190 selects whether to work in the CC loop or the CV loop through the IMIN Selector. When the load current does not exceed the limit and is far from the set ISET, the LM5190 will work in the CV loop. At this time, when the load current is significantly greater than the DCM boundary value, the LM5190 should theoretically work in PWM mode, and the output voltage frequency is constant at the set value set by RT. However, during actual testing, it was noted that when the load current is not large enough, the LM5190 output voltage exhibits significant frequency reduction, as shown in [Figure 1-2](#). At this time, the LM5190's resistor is the EVM default value of 54.9k, and the set output frequency is 433kHz, but the output frequency in [Figure 1-2](#) is 148.5kHz, far lower than the set value.

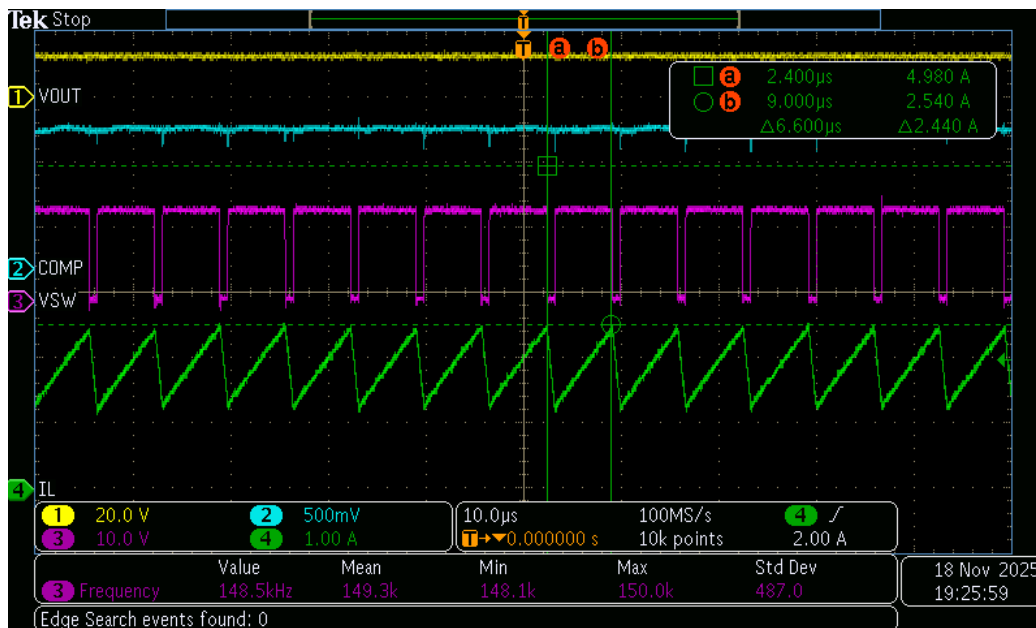


Figure 1-2. LM5190 Frequency Drop Operation

2 Analysis of LM5190 Operating Mechanism

The LM5190 utilizes a peak current mode control architecture. By directly sensing the peak inductor current, this control scheme of LM5190 enables precise regulation of the power switch, serving as the foundation for the device's stable operation. The core control logic is connecting external sampling resistor R_s through ISNS+ and VOUT pins to achieve real-time sampling of inductor current. After the sampling signal is amplified by the internal amplifier (typical gain is 10V/V), it is compared with the compensation voltage output from the COMP pin. When the sampled current reaches the current peak corresponding to the COMP voltage, the PWM comparator controls the turn-off of the high-side switch and the turn-on of the low-side switch, completing the control of this switching cycle. The control loop is shown in the section highlighted by the red box in Figure 2-1.

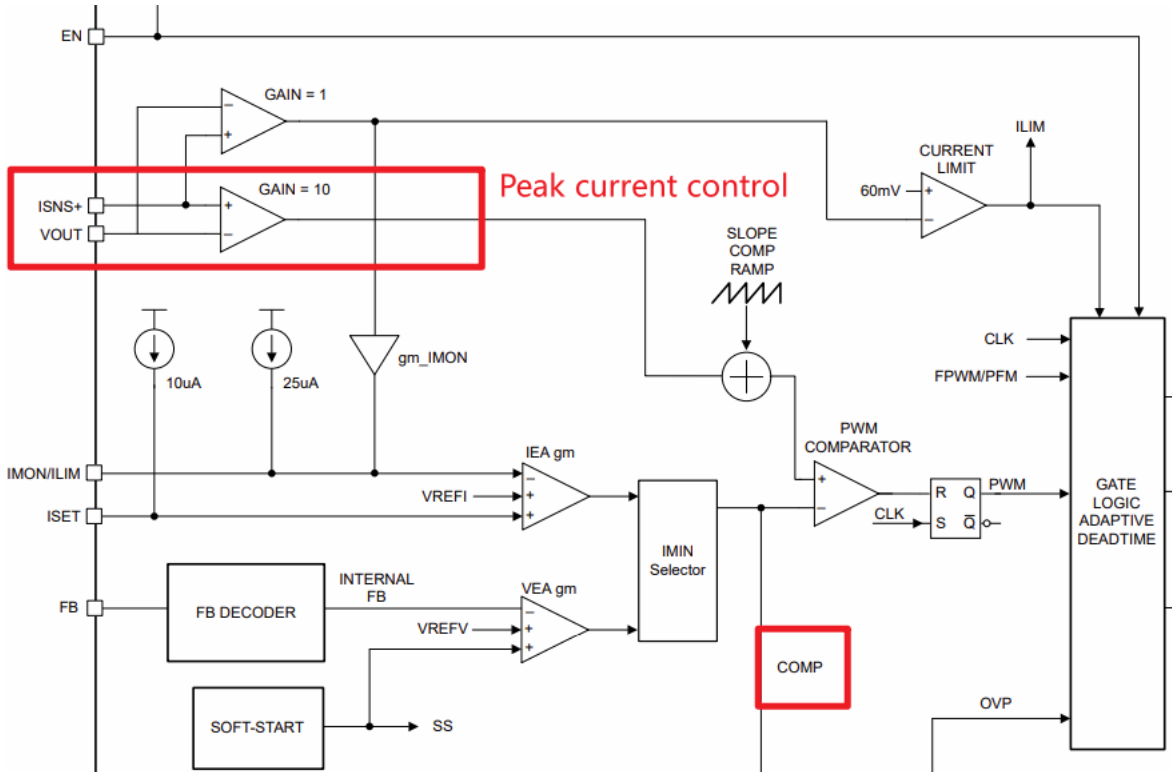


Figure 2-1. LM5190 Peak Current Control Loop

The LM5190 configures two different operating modes through the FPWM/SYNC pin to adapt to working scenarios with different loads. The LM5190 data sheet describes that when its FPWM/SYNC pin is connected to VCC, the LM5190 will operate in FPWM mode; and when the FPWM/SYNC pin is connected to AGND, the LM5190 will operate in PFM mode. The working principle of PFM is as follows: the COMP voltage is proportional to the load current and the peak inductor current. When the load current decreases, causing the COMP voltage to drop below a certain value, the device clamps the COMP voltage and simultaneously turns off both the high-side and low-side switches, entering an inactive state. At this time, the output capacitor supplies power to the load. When the output voltage drops to a certain value, the device detects this drop through the FB pin and automatically raises the COMP value to reactivate the high-side switch. Once the COMP voltage drops back to the clamped value corresponding to the current load current, both switches are turned off again, completing one switching cycle.

The PFM mode will greatly improve the efficiency of the LM5190 when working at light load. The efficiency of the LM5190 when working in FPWM and PFM respectively is shown in Figure 2-2.

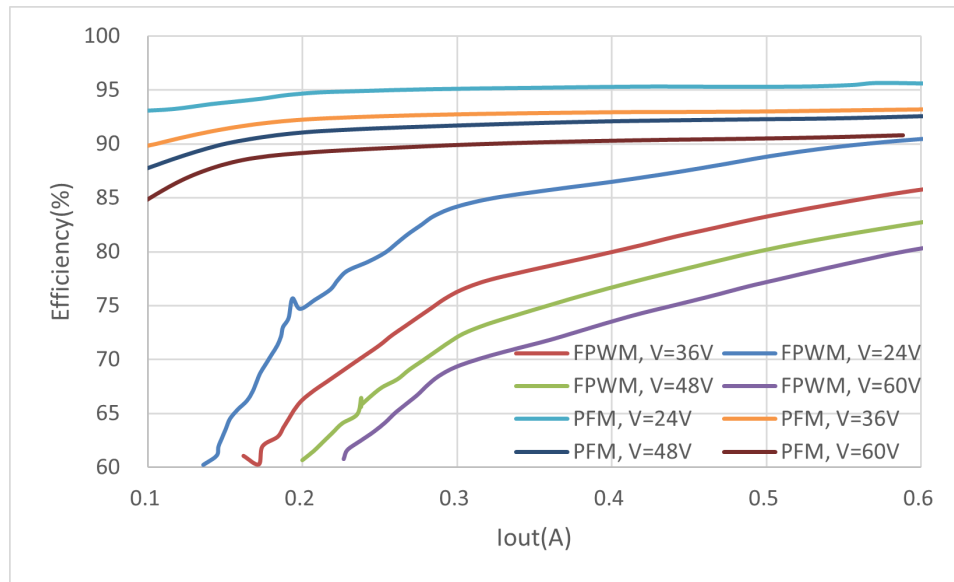


Figure 2-2. Efficiency of the LM5190 Operating in Eco Mode and FPWM Mode

In theory, the control logic of eco mode is not complex. From the aforementioned content, it is known that the peak inductor current of the LM5190 is proportional to the COMP voltage. When the peak inductor current is less than a certain value, that is, when the COMP voltage is lower than a certain value, the LM5190 will enter eco-mode. The measured relationship between the LM5190 peak inductor current and COMP voltage versus load current is shown in Figure 2-3. As you can see,

1. when the load current decreases, both V_{comp} and I_{Lpeak} will decrease. For the LM5190, when V_{comp} is less than about 0.3V, it will clamp V_{comp} at 0.3V and enter the working state of eco-mode.
2. As the load decreases, there will be several turning points in I_{Lpeak} . The more obvious ones are when the load current is 2.251A, 1.849A, and 1.608A. At these three turning points, as the load current decreases, V_{comp} will decrease accordingly, but I_{Lpeak} will first decrease and then increase. The reason is that the LM5190 has a Minimum peak current limit threshold. When the peak current of the LM5190 is less than the minimum value, the LM5190 will increase the charging period of the upper tube by reducing the CLK frequency to raise the I_{Lpeak} value. The minimum peak inductor current can be calculated by Equation 1.

$$I_{Lpeak_min} = \frac{V_{CS} - TH - MIN}{R_{CS}(EVMdefault)} = \frac{12mV}{5m\Omega} = 2.4A \quad \# (1)$$

As shown in the figure, in the actual test of the LM5190 EVM, the minimum peak current constrained by the LM5190 is about 2.7A. The actual inductor current ripple can be calculated by Equation 2. From this equation, it is known that with the output frequency unchanged, as load decreases, I_{Lpeak} will decrease. Combining with Figure 2-3, it is known that when I_{Lpeak} is about to be lower than the minimum peak current, i.e., 2.7A, the LM5190 will increase I_{Lpeak} by reducing the CLK frequency, keeping I_{Lpeak} clamped at 2.7A. Only after V_{comp} is clamped at 0.3V and completely enters PFM, will it stop this compensation for I_{Lpeak} and reduce the peak of its peak current control. This compensation mechanism is also the essential reason for the LM5190 frequency reduction, PFM/PWM hybrid operation, and multi-peak current control at critical points described later.

$$I_{Lpeak} = I_{load} + \frac{V_{in} - V_{out}}{2Lf_{sw}} \times \frac{V_{out}}{V_{in}} \quad \# (2)$$

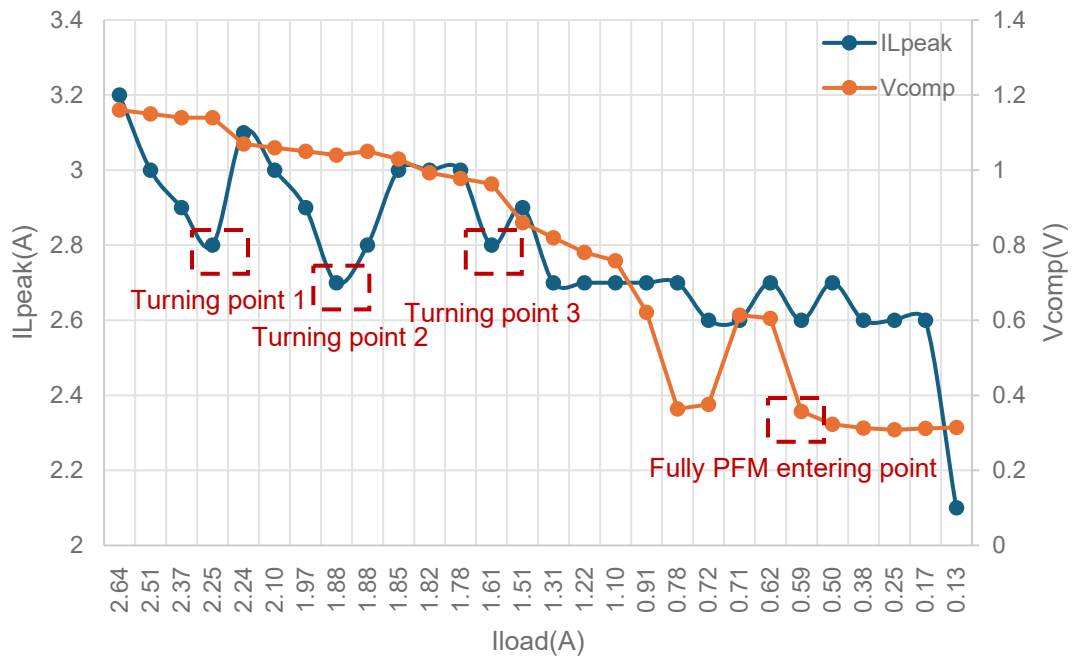


Figure 2-3. Relationship Between LM5190 Peak Inductor Current and COMP Voltage

In the following chapters, several typical transition point phenomena will be presented and analyzed in order of load current from large to small. Between the first and second transition points, the LM5190 exhibits a typical frequency reduction operating state, which will be introduced in Chapter 3; between the second and third transition points, it also operates in this state. After the third transition point and before fully entering PFM, the LM5190 works in a hybrid PFM/PWM operating state, which will be introduced in Chapter 4. Finally, after Vcomp is clamped at 0.3V, it fully enters the PFM operating state, which will be introduced in Chapter 5.

3 Turning point 1~3: Analysis of LM5190 Frequency Drop Operation

During the experimental test, adjusting the load current to 2.264A and 2.224A respectively yielded the experimental results shown in [Figure 3-1](#) and [Figure 3-2](#).

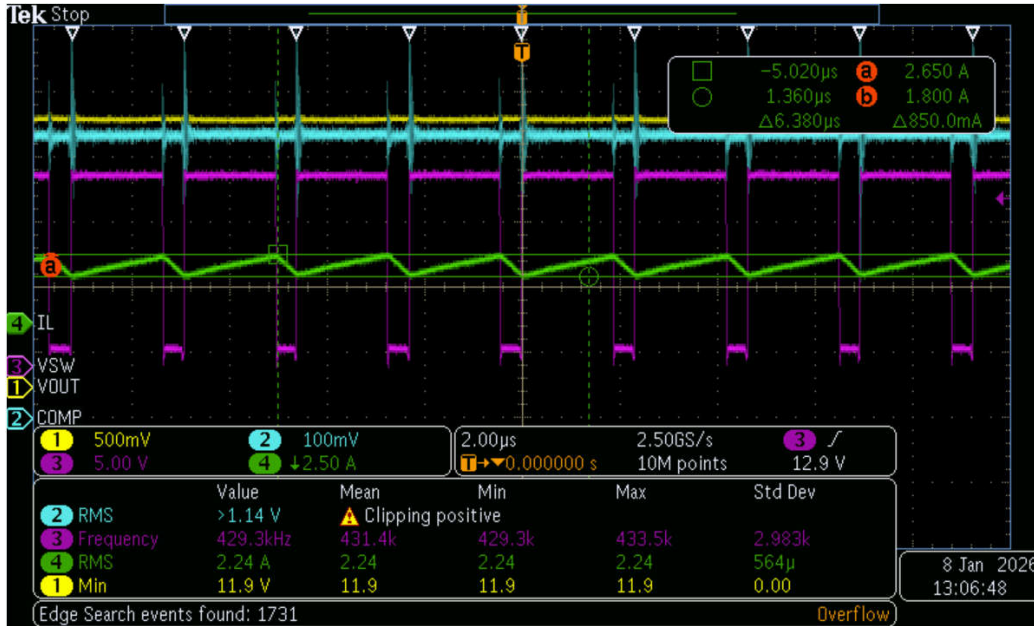


Figure 3-1. Experimental Results of LM5190 at a Load Current of 2.264A

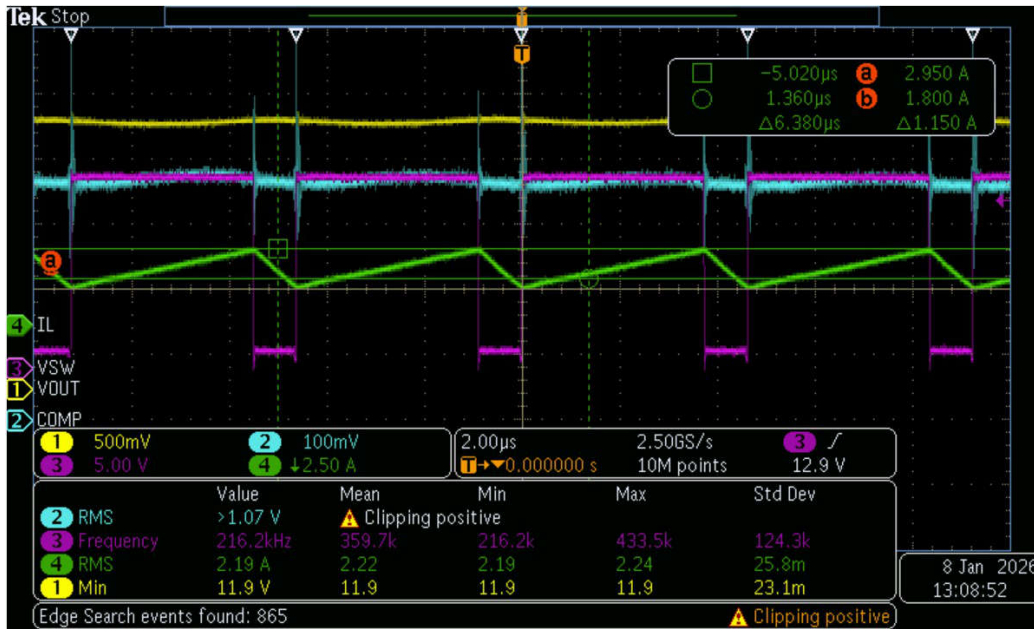


Figure 3-2. Experimental Results of LM5190 at a Load Current of 2.224A

As shown in [Figure 3-1](#) and [Figure 3-2](#), at the first transition point, that is, when the load current is greater than 2.264A, the LM5190 operates normally in PWM mode. If the load current is adjusted to be lower than 2.264A, combining [Equation \(1\)](#) and [Equation \(2\)](#), it can be known that if the set switching frequency of 433kHz (EVM default) is still maintained, the I_{Lpeak} of the LM5190 will be less than its set minimum value of 2.4A (in this experiment, this value is 2.6A). At this time, the LM5190 will compensate the I_{Lpeak} value by reducing the CLK frequency, significantly increasing the I_{Lpeak} value even when the load current decreases only by a small

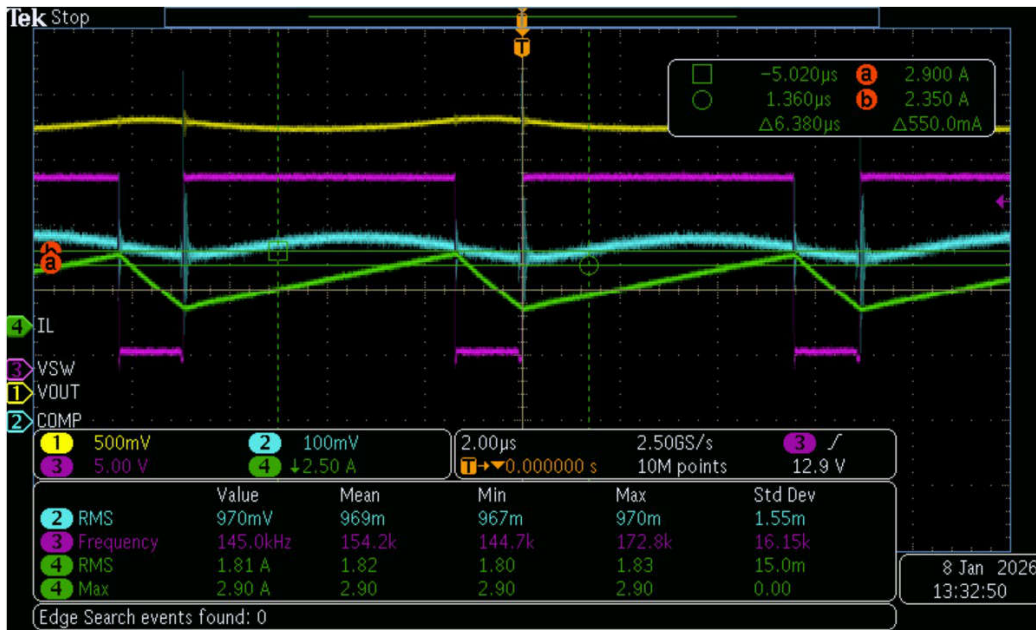


Figure 3-4. Experimental Results of LM5190 at a Load Current of 1.742A

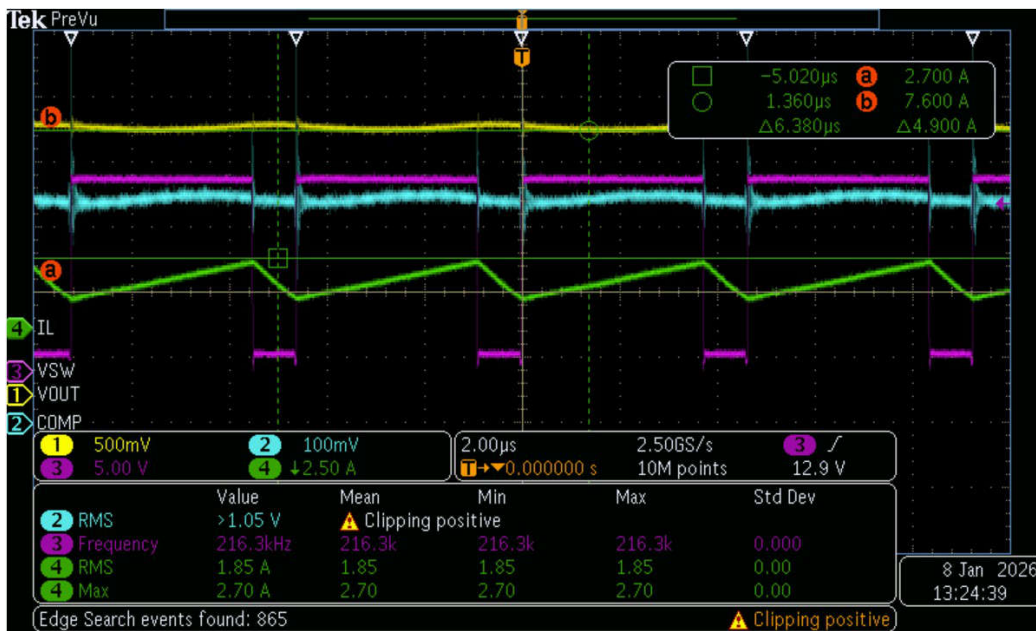


Figure 3-5. Experimental Results of LM5190 at a Load Current of 1.876A

4 Turning point 3~Fully PFM entering point: Analysis of LM5190 PFM/PWM Hybrid Mode Operation

When the load current is less than the current of Turning point 3, the LM5190 will enter a state of mixed PFM and PWM operation. From the previous content, we know that the logic for turning off the high-side switch in PFM is when the COMP voltage is lower than the clamp value, and the turn-on logic is when the output voltage is lower than a certain threshold. In actual testing, this threshold for the LM5190 is 0.99 times the set output voltage. And the turn-on logic of PWM is the CLK signal high level, and the turn-off logic is when the inductor current reaches the peak.

At this time, the typical working state of LM5190 is shown in Figure 4-1. The load current is 1.407A. It can be clearly seen that there are turn-ons during the output voltage drop process when it is lower than about 12V, such as the turn-on point marked by the white dashed line in the figure. This turn-on logic is typical PFM turn-on, which did not appear before Turning point 3, as shown in Figure 3-2 - Figure 3-5. There are also turn-ons when the output voltage is already in a rising state, which does not meet the PFM turn-on logic. This turn-on logic is typical PWM turn-on, caused by the arrival of the rising edge of CLK.

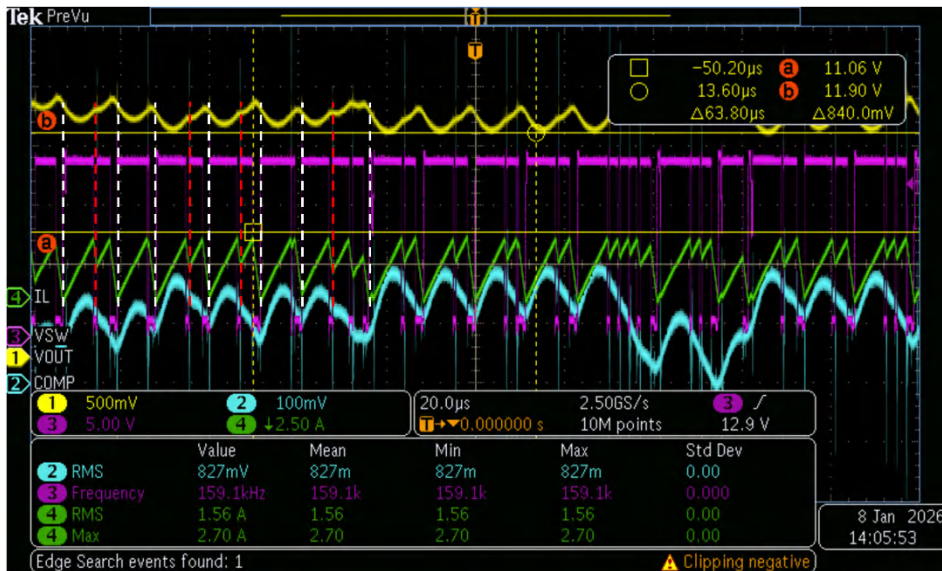


Figure 4-1. Experimental Results of LM5190 at a Load Current of 1.407A

When the load current is 0.991A, the phenomenon where PWM and PFM control logic work together is more obvious, as shown in Figure 4-2. Observing its output voltage and inductor current, it can be seen that LM5190 clearly has two turn-on logics at this time. As mentioned before, the one marked by the white dashed line in Figure 4-2 is PFM turn-on, and the one marked by the red dashed line is PWM turn-on.



Figure 4-2. Experimental Results of LM5190 at a Load Current of 0.991A

5 Entering PFM: Analysis of LM5190 PFM Operation Characteristics

As the load current further decreases to approximately 0.6A, the COMP voltage falls to around 300mV, causing the LM5190 to enter full PFM operation. In this mode, the high-side switch follows standard PFM control logic: the switch turns on when the output voltage drops below approximately 0.99* of the target value, and both the high-side and low-side switches turn off once Vcomp falls below 300mV. As shown in Figure 5-1, the red dashed line indicates the turn-on instant of the high-side switch, while the white dashed line denotes the simultaneous turn-off of both the high-side and low-side switches. The waveform demonstrates that the high-side switch activates when Vout falls below a specific threshold and deactivates when Vcomp drops beneath a certain level. Each switching event strictly adheres to PFM control logic, with no evidence of PWM control behavior.



Figure 5-1. Experimental Results of LM5190 at a Load Current of 0.589A

6 Summary

The state where LM5190 operates in a mixed mode of PFM and PWM mode is an inherent mechanism of the LM5190; this inherent mechanism leads to abnormal phenomena under some critical load current conditions where the LM5190 switching frequency is significantly lower than the set value or the peak current value is uncertain, therefore this phenomenon is not a fault phenomenon or a DCM phenomenon. This mixed operation state occurs in the medium load range and can be avoided by configuring to FPWM mode. Therefore, it is recommended to select the operating mode according to actual requirements. In scenarios with high requirements for frequency stability, it should be configured as FPWM mode to avoid its output frequency still being unstable at medium loads.

7 References:

1. LM5190 datasheet
2. LM5190EVM User Guide
3. Understanding ECO-MODE™ Operation

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