Application Note

Design of the Triangular Spread Spectrum Circuit

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ABSTRACT

Spread spectrum can be implemented by injecting a triangular perturbation current into the PWM controller's frequency programming pin. This application note demonstrates how to derive this triangular current from a square wave to meet specific spread-spectrum targets. Using the LM5171 evaluation module (LM5171EVM-BIDIR) as a reference, a design example is provided. An astable multivibrator circuit is analyzed to generate the square wave for MCU-less applications. The proposed method is verified through simulation and validated with bench results.

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1 Introduction

Spread spectrum techniques, frequently referred to as "modulation" or "dithering," are widely implemented in DC-DC converters to mitigate Electromagnetic Interference (EMI). This method operates by transforming a narrowband signal into a wideband signal, thereby distributing energy across a broader frequency spectrum. Consequently, this redistribution significantly lowers the peak energy levels, as illustrated in Figure 1-1. [1]

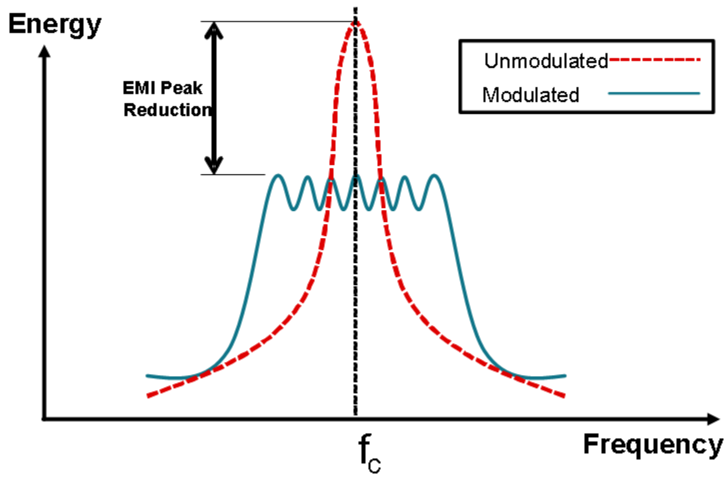

Figure 1-1. EMI Reduction by Spread Spectrum

Figure 1-2 illustrates triangular modulation in both the time domain (left) and the frequency domain (right). On the left, the time-domain plot depicts a single modulation cycle, where the clock frequency is plotted against time. In this plot, f_C represents the unmodulated oscillator frequency, f_m is the modulation frequency, and Δf_C denotes the frequency deviation from the center. On the right, the corresponding spectral distribution of the fundamental frequency resulting from this modulation is shown.

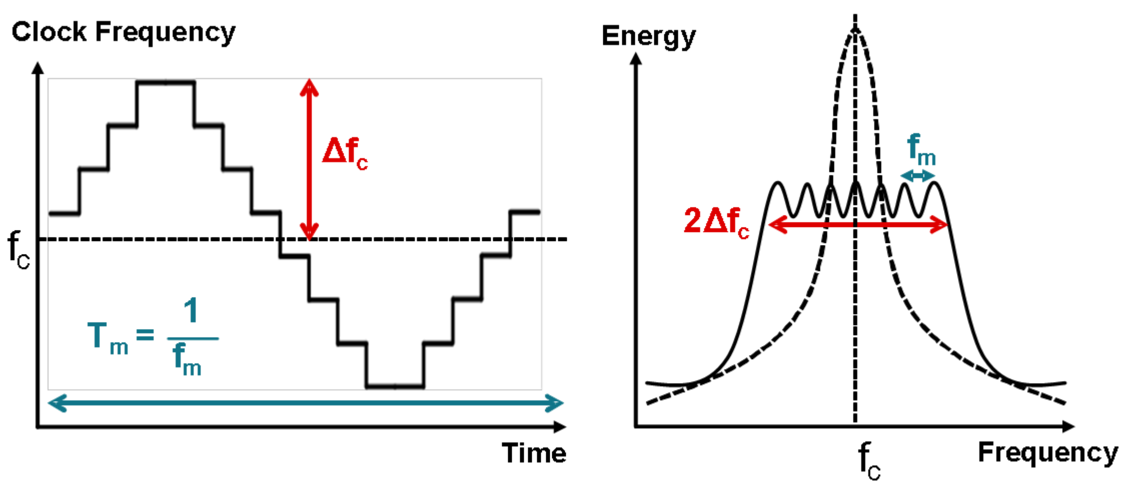

Figure 1-2. Triangular Modulation in the Time (Left) and Frequency Domain (Right)

Note that although the waveform shown in Figure 1-2 (Left) appears discretized, this does not imply the use of digital dithering. In any switching regulator, the clock frequency can only be updated once per switching cycle; therefore, the frequency is inherently discrete, regardless of whether the modulation method is analog or digital.

This application note focuses on triangular modulation, selected for simplicity and proven performance [2].

Δf_C and f_m is the key parameter when performing a spread spectrum. When choosing Δf_C and f_m, tradeoff between multiple targets need to be considered.

Maximize Δf_C for EMI reduction, limited by

- Harmonics overlap with each other
- Spreading into undesired bands
- Current or voltage ripple

•Set f_m close to resolution bandwidth (RBW)

- Keep f_m below the control loop bandwidth
- Keep f_m away from audible band if possible

Typical, we can choose Δf_C as ±4% to ±10% of f_C, and choose f_m between 4kHz and 15kHz (when RBW=9kHz).

Typically, there are two methods for implementing spread spectrum. Using the LM5171 as an example:

- **SYNCI Pin Method**

  The internal PLL locks to an external frequency-modulated clock applied to the SYNCI pin. While this method supports a dithering range of up to ±20% of the nominal switching frequency, it requires the MCU to continuously output a frequency-modulated clock, which increases firmware complexity.
- **OSC Pin Method**

  The switching frequency is determined by the current out of the OSC pin. A small triangular current perturbation is injected into the OSC pin to modulate the switching frequency. This requires only a low-frequency square wave rather than active frequency modulation. The firmware complexity is significantly reduced.

This application note focuses on the OSC pin method.

2 Spread Spectrum from a Square Wave

As shown in Figure 2-1, an external resistor (R_{OSC}) sets the steady-state oscillator current. The OSC pin is internally regulated to V_{OSC}. By applying an external square wave (ranging from 0V to V_{SQ}) through R_f, a triangular voltage is generated across C_f. This voltage subsequently produces a corresponding triangular current through R_m.

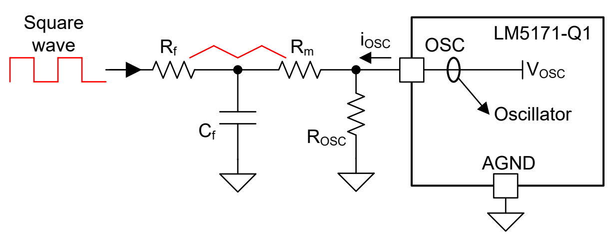

Figure 2-1. Spread Spectrum from a Square Wave

The oscillator frequency is proportional to the current from the OSC pin (i_{OSC}).

Specifically, in the absence of spread spectrum (e.g., R_m is left open), the oscillator frequency f_{OSC} is given by,

$$f_{OSC} = 4.15 \times 10^9 \frac{Hz}{A} \cdot \frac{V_{OSC}}{R_{OSC}} \quad (1)$$

By choosing R_f<< R_m, the mean voltage on C_f is around $V_{SQ}/2$. f_C is obtained as,

$$f_C = 4.15 \times 10^9 \frac{Hz}{A} \cdot \left(\frac{V_{OSC}}{R_{OSC}} + \frac{V_{OSC} - \frac{V_{SQ}}{2}}{R_m} \right) \quad (2)$$

To achieve a linear frequency modulation, select R_f and C_f following,

$$R_f C_f \geq \frac{1}{f_m} \quad (3)$$

The peak-to-peak voltage on C_f is approximately,

$$\Delta V_{Cf} \approx \frac{V_{SQ}}{4 \cdot f_m \cdot R_f \cdot C_f} \tag{4}$$

Δf_C can be found as,

$$\Delta f_C = 4.15 \times 10^9 \frac{Hz}{A} \cdot \frac{V_{SQ}}{8 \cdot f_m \cdot R_f \cdot C_f \cdot R_m} \tag{5}$$

In Equation 2, typically, $\frac{V_{OSC} - \frac{V_{SQ}}{2}}{R_m} \ll \frac{V_{OSC}}{R_{OSC}}$, f_C can be approximated as f_{OSC}. By substituting f_C with f_{OSC} and applying Equation 5 and Equation 1, $\Delta f_C/f_C$ is derived as,

$$\frac{\Delta f_C}{f_C} \approx \frac{1}{8} \cdot \frac{R_{OSC}}{V_{OSC}} \frac{V_{SQ}}{f_m \cdot R_f \cdot C_f \cdot R_m} \tag{6}$$

A Spread Spectrum Example based on LM5171EVM-BIDIR

On the LM5171EVM-BIDIR, V_{OSC}=1V, R_{OSC}=38.3kΩ. The amplitude of the square wave is V_{SQ}=2.5V.

Select modulation frequency f_m lower than the LM5171EVM-BIDIR crossover frequency. Here, we select f_m=1kHz. In this case, we select $\Delta f_C/f_C$=7%.

Based on Equation 3, we select,

$$R_f C_f = \frac{1}{f_m} \tag{7}$$

Equation 4 and Equation 6 can be simplified as,

$$\Delta V_{Cf} = \frac{V_{SQ}}{4} \tag{8}$$

$$\frac{\Delta f_C}{f_C} = \frac{1}{8} \cdot \frac{R_{OSC}}{V_{OSC}} \frac{V_{SQ}}{R_m} \tag{9}$$

Select C_f=100nF, based on Equation 7, we can obtain R_f=10kΩ.

From Equation 9, we can find R_m=171kΩ .

Generate Square Wave Using Astable Multivibrator

Generating a square wave with an MCU is straightforward. For MCU-less applications, an astable multivibrator circuit provides an effective alternative. As illustrated in Figure 2-2, the square wave is produced at the comparator output.

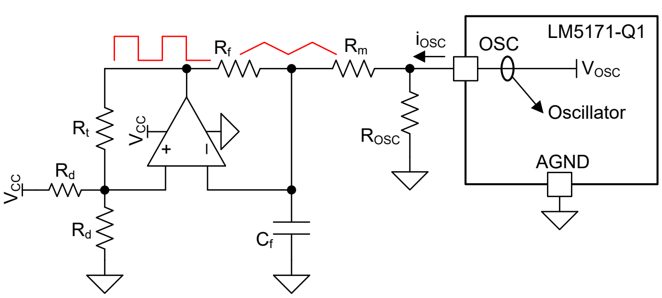

Figure 2-2. Spread Spectrum with A Stable Multivibrator

A rail-to-rail input, push-pull output comparator is suggested in this application. If a rail-to-rail input/output operational amplifier is used, check the overload recovery time.

To achieve a linear frequency modulation, choose low ΔV_{Cf}. By selecting $\Delta V_{Cf} = \frac{V_{CC}}{4}$, Equation 7 and Equation 9 can be used for calculating R_f, C_f and R_m.

The two R_d and R_t determines the peak voltage and valley voltage of C_{fa}.

The peak-to-peak voltage on C_f can also be written as,

$$\Delta V_{Cf} = \frac{R_d}{R_d + 2R_t} \cdot V_{CC} \tag{10}$$

Substituting $\Delta V_{Cf} = \frac{V_{CC}}{4}$ into Equation 10 yields,

$$R_t = 1.5 \cdot R_d \tag{11}$$

With the same spread-spectrum specifications and V_{CC}=2.5V, we can find C_f=100nF, R_f=10kΩ, R_m=171kΩ. We select R_d=20kΩ, Equation 11 results in R_t=30kΩ.

Figure 2-3 shows the TINA schematic based on the parameters. TLV9002 is chosen in the simulation for low cost, with an overload recovery time of 0.85µs.

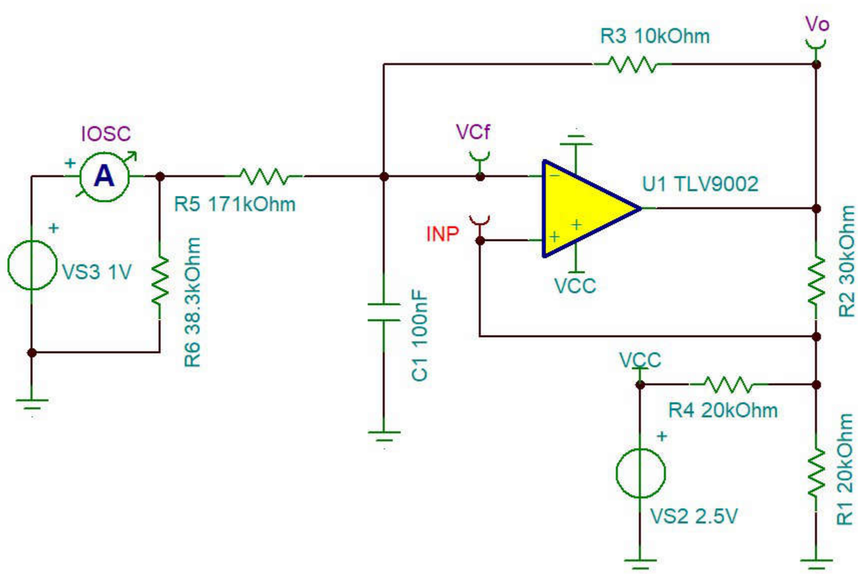

Figure 2-3. Schematic of A Stable Multivibrator with TLV9002

Figure 2-4 shows the simulation results.

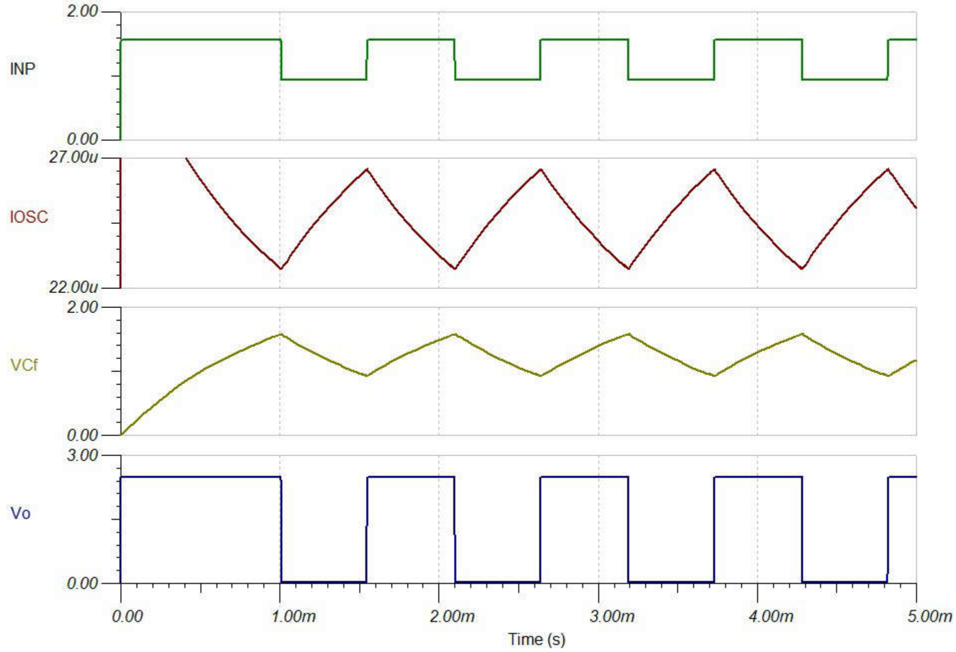

Figure 2-4. Simulation Results of A Stable Multivibrator with TLV9002

3 Spread Spectrum Results Based on LM5171EVM-BIDIR

The EVM is configured as buck mode, Vout=14.5V. Refer to LM5171 EVM user's guide [3] section **2.4.1 Buck Mode with Voltage Regulation** for more details. The load current is 20A.

On the LM5171EVM-BIDIR, R_{OSC}(R16)=38.3kΩ, R_f(R18)=10kΩ, C_f(C14)=100nF. The applied square wave is V_{SQ}=2.5V and f_m=1kHz.

When no spread spectrum is applied (R_m is left open), the output voltage ripple and switching frequency are shown in Figure 3-1.

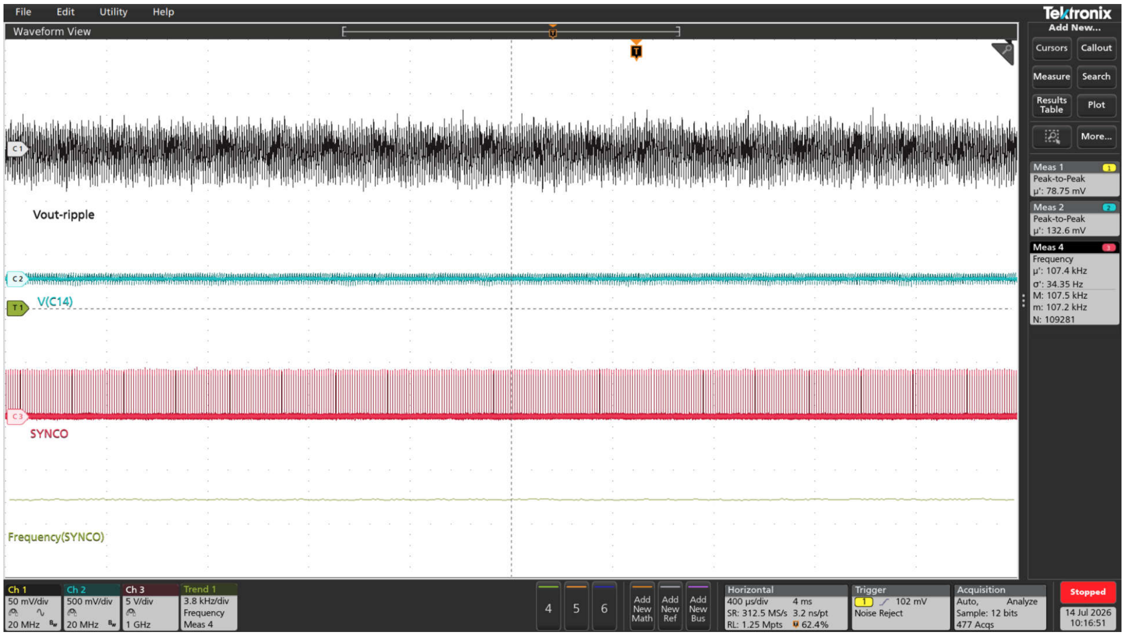

Figure 3-1. Output Voltage Ripple and Switching Frequency With No Spread Spectrum

Although the theoretical switching frequency is calculated to be 108.4kHz, the bench test results yield a slightly lower value of 107.4kHz. Based on Equation 1, we can determine that R_{OSC}=38.64kΩ. This value is used in the calculations below to match the measured switching frequency of f_{OSC}=107.4kHz.

When R_m is 374kΩ, the test waveform is shown in Figure 3-2.

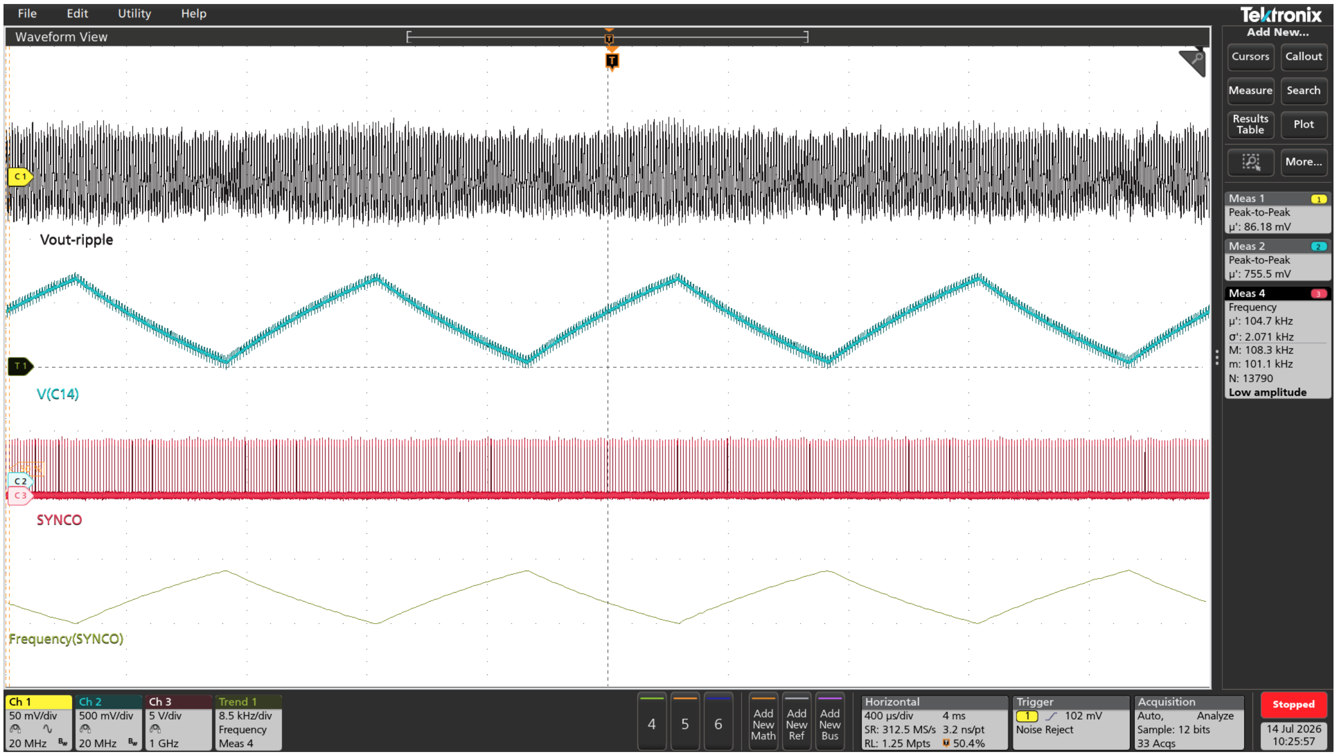

Figure 3-2. Output Voltage Ripple and Switching Frequency (R_m=374kΩ)

The maximum switching frequency is 108.3kHz and minimum switching frequency is 101.1kHz. The calculated results and measured results for $\Delta f_C/f_{OSC}$ and f_C are compared in Table 3-1.

Table 3-1. Calculated vs. Measured Results (R_m=374kΩ)

	$\Delta f_C/f_{OSC}$	f_C
Calculated Results	3.2%	104.6kHz
Measured Results	3.4%	104.7kHz

When R_m is 182kΩ, the test waveform is shown in Figure 3-3.

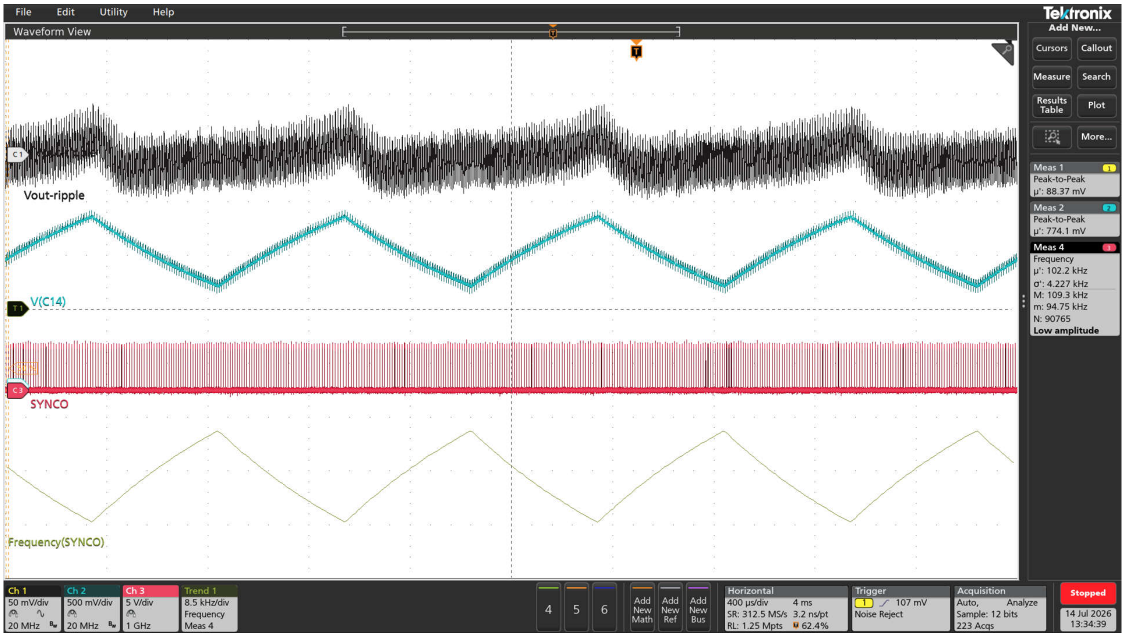

Figure 3-3. Output Voltage Ripple and Switching Frequency (R_m=182kΩ)

The maximum switching frequency is 109.3kHz and minimum switching frequency is 94.75kHz. The calculated results and measured results for $\Delta f_C/f_{OSC}$ and f_C are compared in Table 3-2.

Table 3-2. Calculated vs. Measured Results (R_m=182kΩ)

	$\Delta f_C/f_{OSC}$	f_C
Calculated Results	6.6%	101.7kHz
Measured Results	6.8%	102.2kHz

From the measured results above, we can find:

- The calculated results and measured results matches well.
- As illustrated in Figure 3-3, the output voltage ripple introduced by spread spectrum becomes significant.

4 Summary

In this application note, spread spectrum by injecting a triangular perturbation current into the frequency programming pin is introduced. This requires only a low-frequency square wave rather than active frequency modulation. The design of the RC filter and injection resistor is presented. A practical design example is provided based on LM5171EVM-BIDIR. Furthermore, a simple astable multivibrator circuit is proposed for MCU-less applications. The proposed method is finally validated with empirical bench test results.

5 References

- Texas Instruments, *EMI Reduction Technique, Dual Random Spread Spectrum*, application note
- Texas Instruments, *Understanding Noise-Spreading Techniques and their Effects in Switch-Mode Power Applications*, seminar.
- Texas Instruments, *LM5171 Evaluation Module User's Guide*, user's guide.