

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]

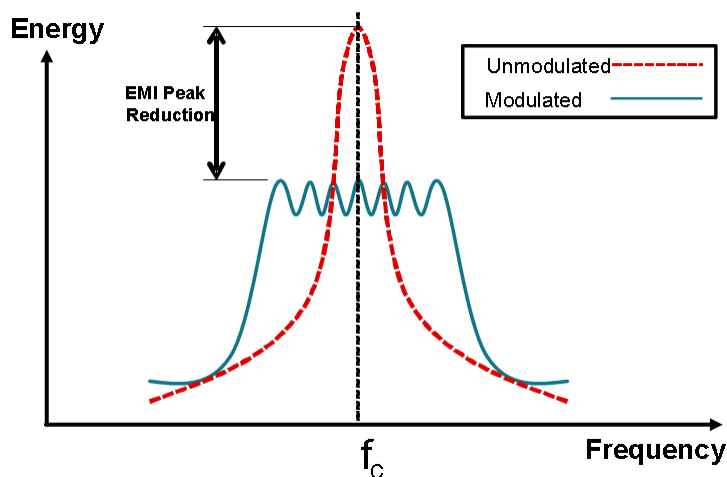


Figure 1-1. EMI Reduction by Spread Spectrum

[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.

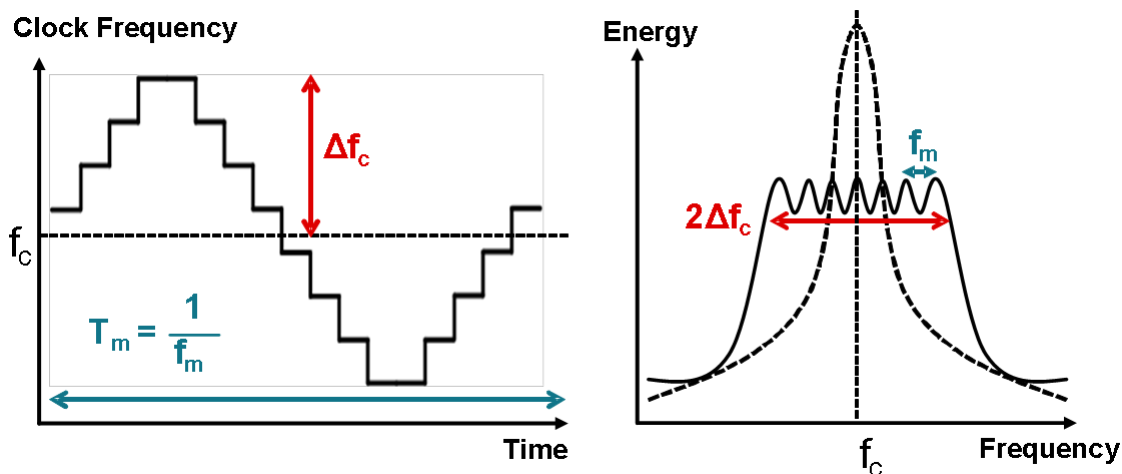


Figure 1-2. Triangular Modulation in the Time (Left) and Frequency Domain (Right)

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 $\pm 4\%$ to $\pm 10\%$ 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 $\pm 20\%$ 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 .

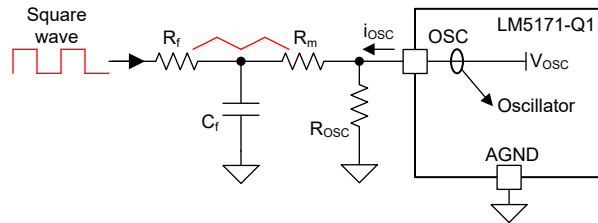


Figure 2-1. Spread Spectrum from a Square Wave

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,

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

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

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

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,

$$\Delta V_{Cf} \approx \frac{V_{SQ}}{4 \cdot f_m \cdot R_f \cdot C_f} \quad (4)$$

Δf_C can be found as,

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

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,

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

A Spread Spectrum Example based on LM5171EVM-BIDIR

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

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

Based on Equation 3, we select,

$$R_f C_f = \frac{1}{f_m} \quad (7)$$

Equation 4 and Equation 6 can be simplified as,

$$\Delta V_{Cf} = \frac{V_{SQ}}{4} \quad (8)$$

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

Select $C_f=100\text{nF}$, based on Equation 7, we can obtain $R_f=10\text{k}\Omega$.

From Equation 9, we can find $R_m=171\text{k}\Omega$.

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.

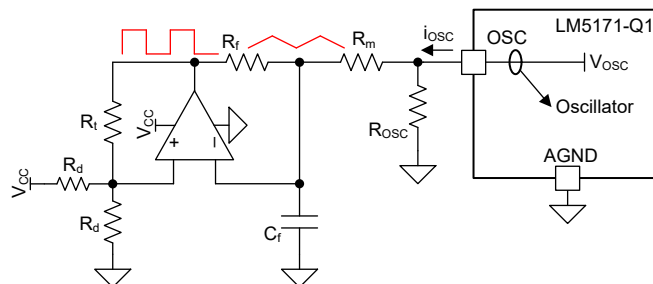


Figure 2-2. Spread Spectrum with A Stable Multivibrator

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,

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

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

$$R_t = 1.5 \cdot R_d \quad (11)$$

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

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 0.85 μs .

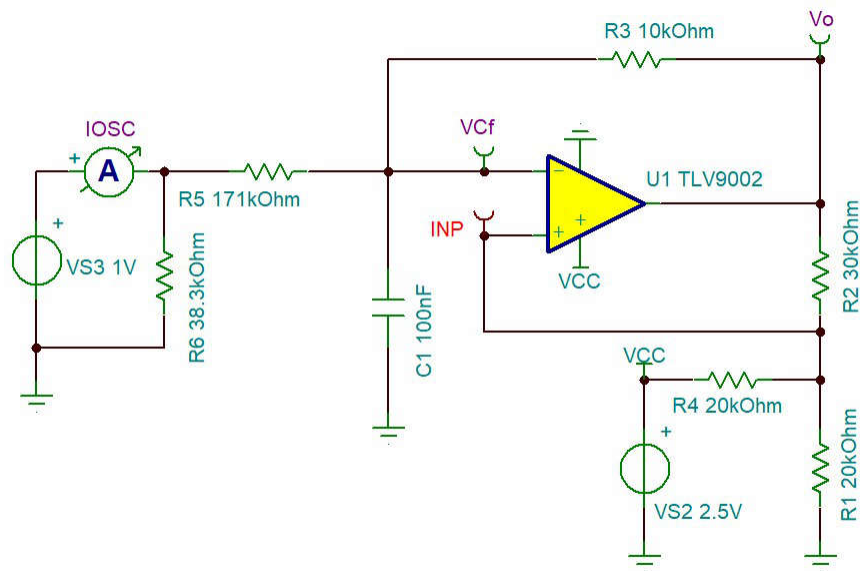


Figure 2-3. Schematic of A Stable Multivibrator with TLV9002

Figure 2-4 shows the simulation results.

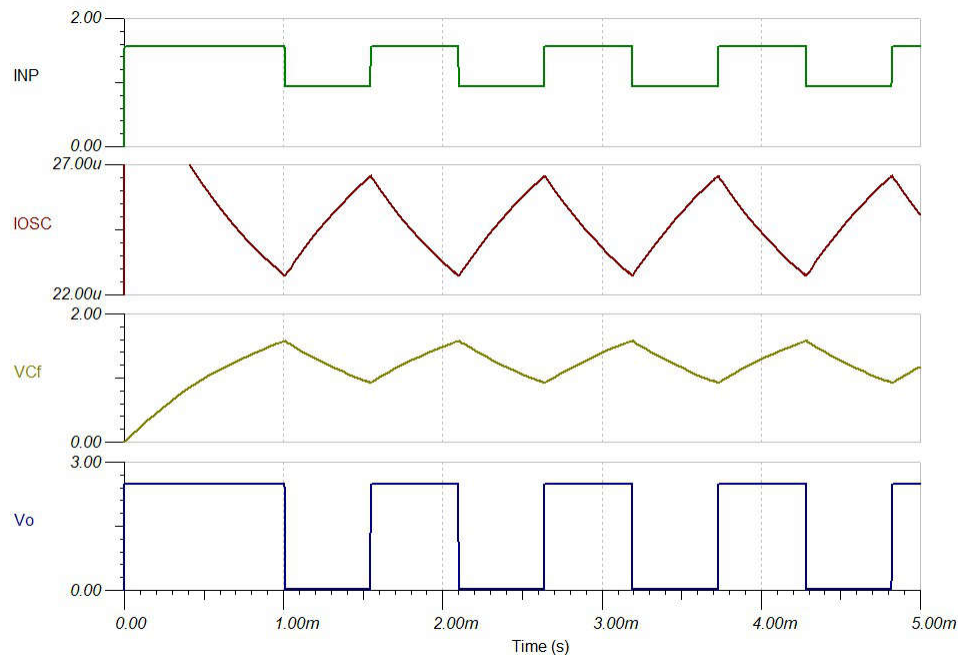


Figure 2-4. Simulation Results of A Stable Multivibrator with TLV9002

3 Spread Spectrum Results Based on LM5171EVM-BIDIR

The EVM is configured as buck mode, $V_{out}=14.5V$. 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, $R_{OSC}(R16)=38.3k\Omega$, $R_f(R18)=10k\Omega$, $C_f(C14)=100nF$. 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](#).

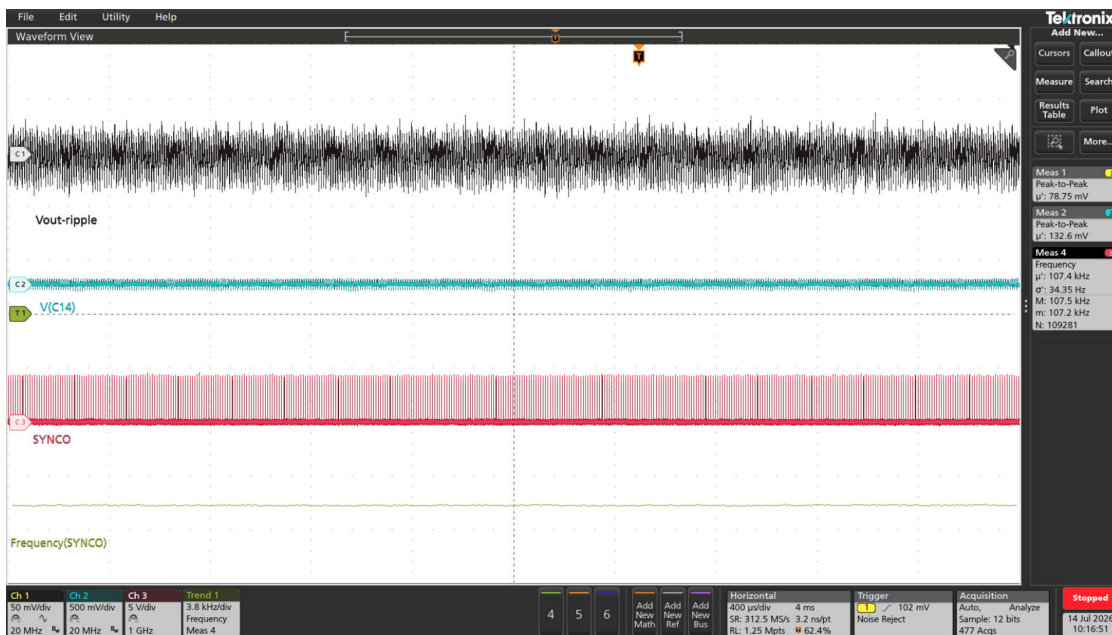


Figure 3-1. Output Voltage Ripple and Switching Frequency With No Spread Spectrum

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 $R_{OSC}=38.64k\Omega$. This value is used in the calculations below to match the measured switching frequency of $f_{OSC}=107.4kHz$.

When R_m is 374k Ω , the test waveform is shown in [Figure 3-2](#).

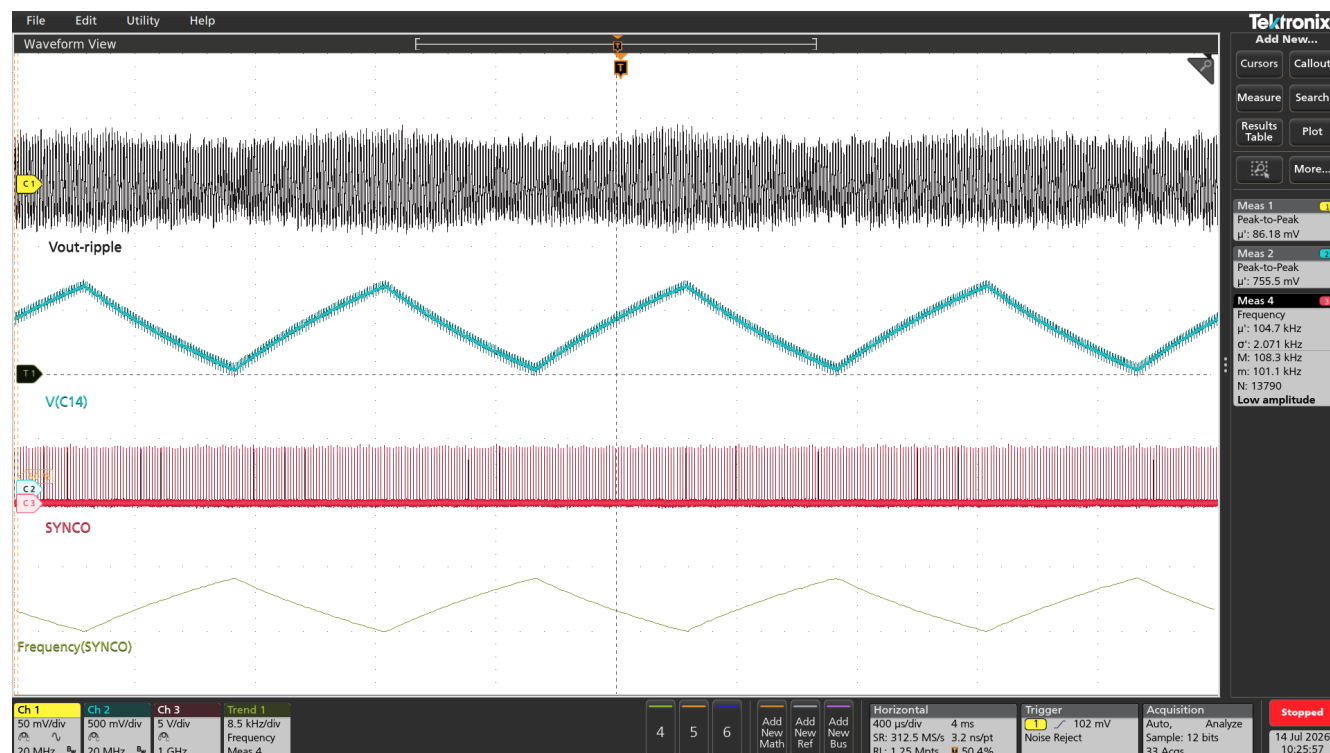


Figure 3-2. Output Voltage Ripple and Switching Frequency ($R_m=374k\Omega$)

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 ($R_m=374k\Omega$)

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

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

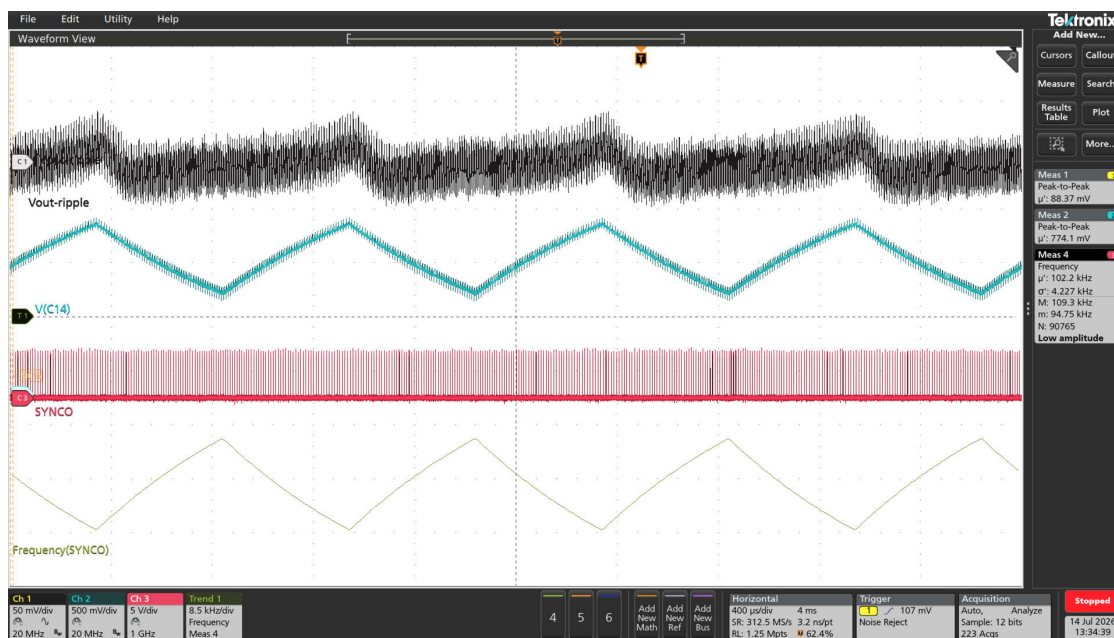


Figure 3-3. Output Voltage Ripple and Switching Frequency ($R_m=182k\Omega$)

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 ($R_m=182k\Omega$)

	$\Delta f_c/f_{osc}$	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.

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