AN6257

Application note

L3751 – frequency dithering

Introduction

The L3751 DC/DC is the wide input range synchronous buck controller capable of delivering up to 30 A and even above of load current. In contrast, the DCP85CY is the same device, but with AEC-Q100 qualification. The hardware setup used in this application note is based on the evaluation board STEVAL-L3751V12, which contains a demonstration circuit design featuring the L3751. Unlike most of the other new ST DC/DC converters, the L3751 (DCP85CY) does not have integrated frequency dithering, so external management is required. For example, with the L7983 or L6983, frequency dithering can be enabled by pulling a resistor from a specific pin to the supply voltage.

Switched-mode power supplies (SMPS) suffer from high noise from switching on the inductor. The switching is typically done on a single fundamental frequency, which can result in electromagnetic interference (EMI) levels that can exceed acceptable limits. To achieve better EMC results, it is possible to vary the frequency over time, which has consequences in the spread spectrum and is known as **frequency dithering.**

The most effective way to minimize the impact of EMI is during circuit design and PCB layout. However, it is not always possible to design every power converter under ideal conditions and there may be a lot of pressure to meet EMC requirements. If an EMC problem arises after development, changing the spectrum from narrowband to broadband has been proven to be an effective solution.

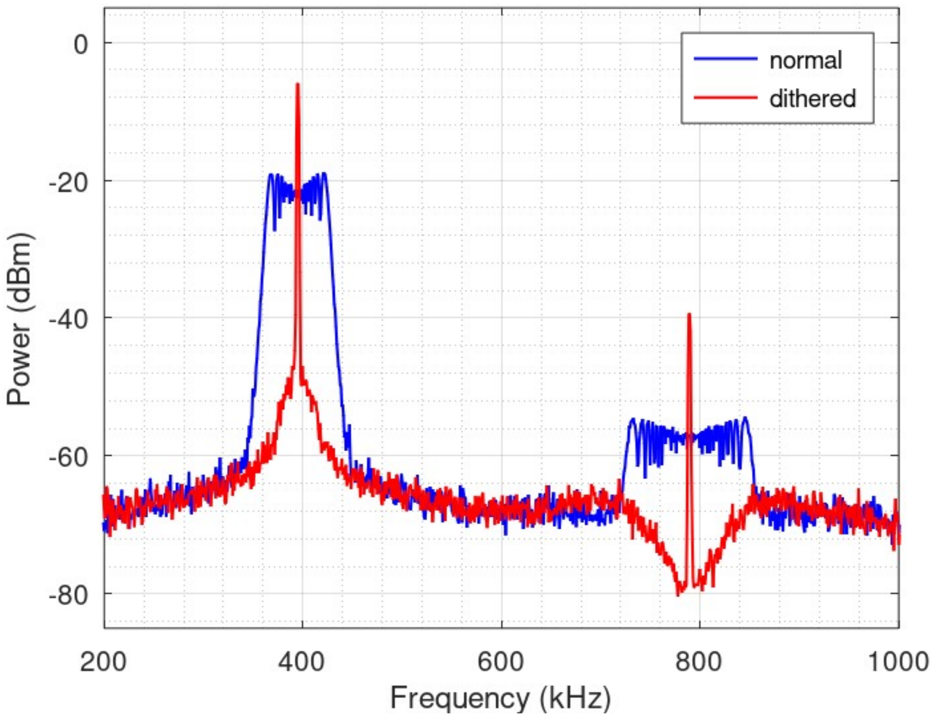
In a fixed-frequency power converter, the emission peak occurs at the fundamental switching frequency with a gradual decrease of energy at each higher-order harmonics. The majority of the emitted energy is concentrated in the fundamental and lower harmonics.

Modulating or dithering the operating frequency of a power converter results in the power converter being operated over a range of frequencies, rather than at a single, fixed frequency. This spreads the EMI emissions over a range of frequencies, reducing the peak value of the emissions. Dithering the oscillator also reduces the peak value at harmonic frequencies (i.e., frequencies that are multiples of the switching frequency). However, it does not reduce the overall emitted energy and has little effect on the reduction of high-frequency non-harmonic frequency emissions.

The spectrum of the signal on a fixed switching frequency of 400 kHz is shown in the red trace of Figure 1.

The blue trace shows the spectrum of a dithered signal, which has a significantly lower power peak but is spread across a frequency range of approximately 360-440 kHz. This demonstrates how peaks can be reduced and EMC behavior can be improved.

Figure 1. **Comparison of the normal and dithered spectrum**



This application note will introduce two possible circuit designs for spreading the spectrum on the L3751 and DCP85CY DC/DC controller. The pictures from the oscilloscope will show the main characteristics and properties of the normal and dithered spectrum.

1 Frequency and main setup of L3751 and DCP85CY

The frequency of L3751 or DCP85CY can be adjusted within the range of 100 kHz to 1 MHz by using an R_{RT} pull-down resistor. In the case of the evaluation board STEVAL-L3751V12, the resistor value is set to R_{RT} = 46.4 kΩ, which corresponds to a default switching frequency of 230 kHz. The operating frequency increases as the resistor value decreases. The appropriate range for the R_{RT} resistor is between 10 kΩ to 105 kΩ. The correct value of the RT resistor can be determined by using the desired switching frequency with the following formula:

$$R_{RT}[k\Omega] = \frac{10500}{f_{SW}[kHz]} + 0.004 \times (400 - f_{SW}[kHz])\,.$$

As described in the datasheet of L3751 (DCP85CY), the switching frequency can be alternatively adjusted by synchronizing the device to the external clock signal fed to the SYNCIN pin that satisfies the following requirements:

- Clock frequency range: 100 kHz to 1 MHz
- Clock frequency: -20% to + 50% of the oscillator frequency programmed by R_{RT}
- Clock maximum amplitude: 13 V
- Clock minimum pulse: 50 ns

The device operates in phase with the synchronization signal. Changing the frequency by feeding a signal to the SYNCIN pin is one of the following methods used for dithering.

The evaluation board also introduces a TRIM pin, which allows one to choose between two output voltage values. When the TRIM pin is connected to the GND pin (via a jumper), the output voltage is set to V_{OUT} = 12.18 V. At the input voltage of V_{IN} = 24 V, the duty cycle is approximately 50%. For this paper, the load current was set to I_{OUT} = 1 A.

This application note works with a switching frequency of 400 kHz, therefore, only one modification of the evaluation board is needed. The R_{RT} resistor was changed to 25 kΩ according to the device’s datasheet.

All measurements in the following pictures show the signal on the SW pin of the L3751 and its spectral characteristics, which are computed by using the FFT mathematical function on an oscilloscope.

2 Normal use case without dithering

This chapter presents the measured frequency characteristics during the normal use case of the L3751 without enabled dithering on the default frequency of 400 kHz. The following pictures show the switching signal and its spectrum with different zoom levels. Figure 4 mainly focuses on the switching signal rather than its spectrum. It can be observed that the signal is clear and not dithered.

Figure 2. Spectrum without dithering with center frequency 500 kHz and span 1 MHz

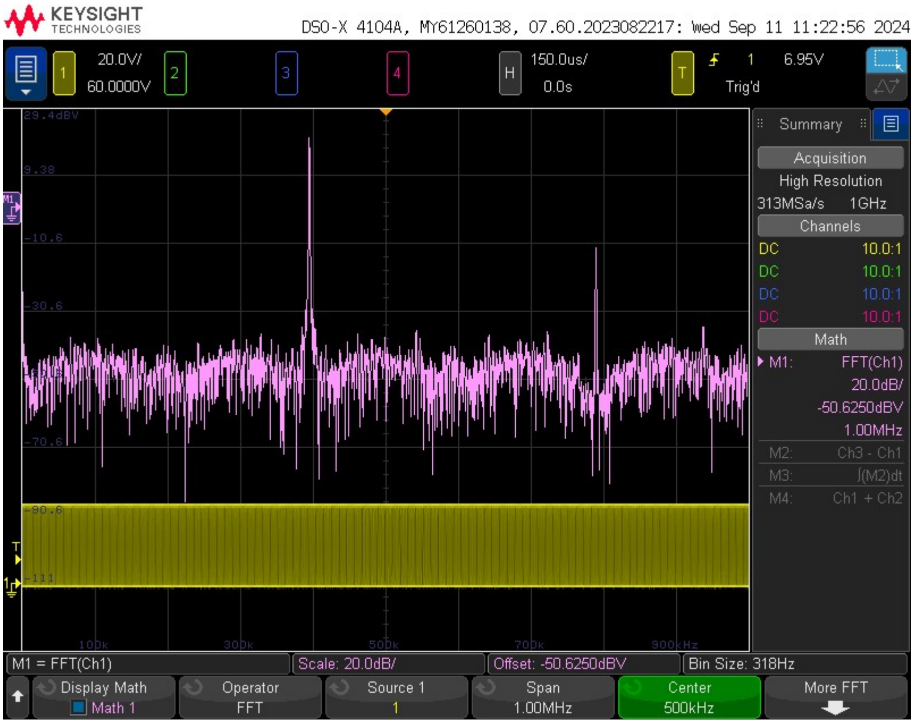


Figure 3. Spectrum without dithering with center frequency 1 MHz and span 2 MHz

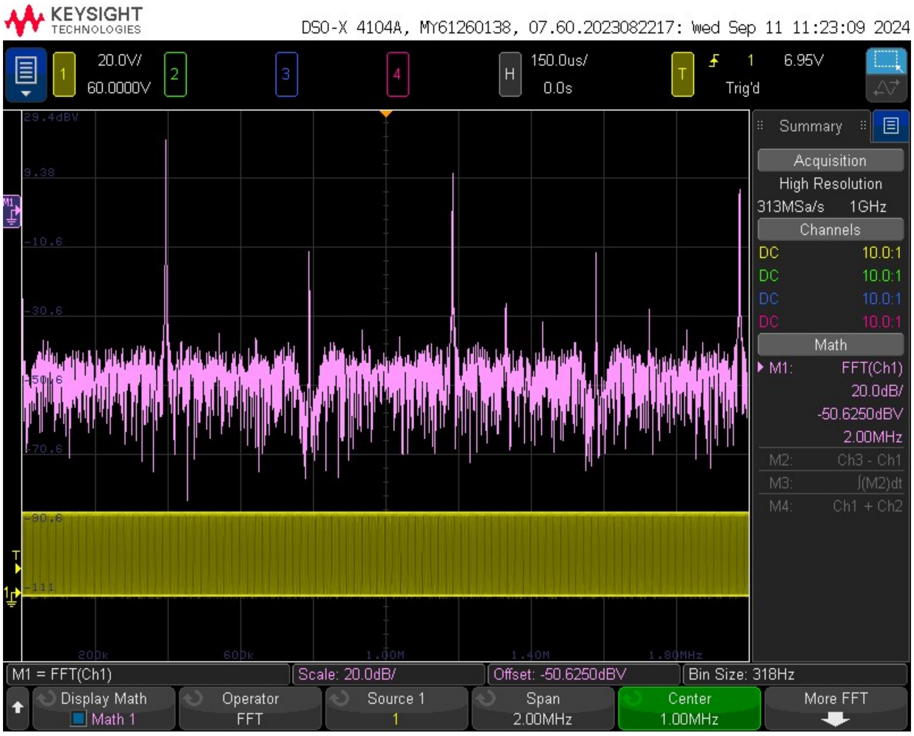


Figure 4. **The switching signal without dithering**

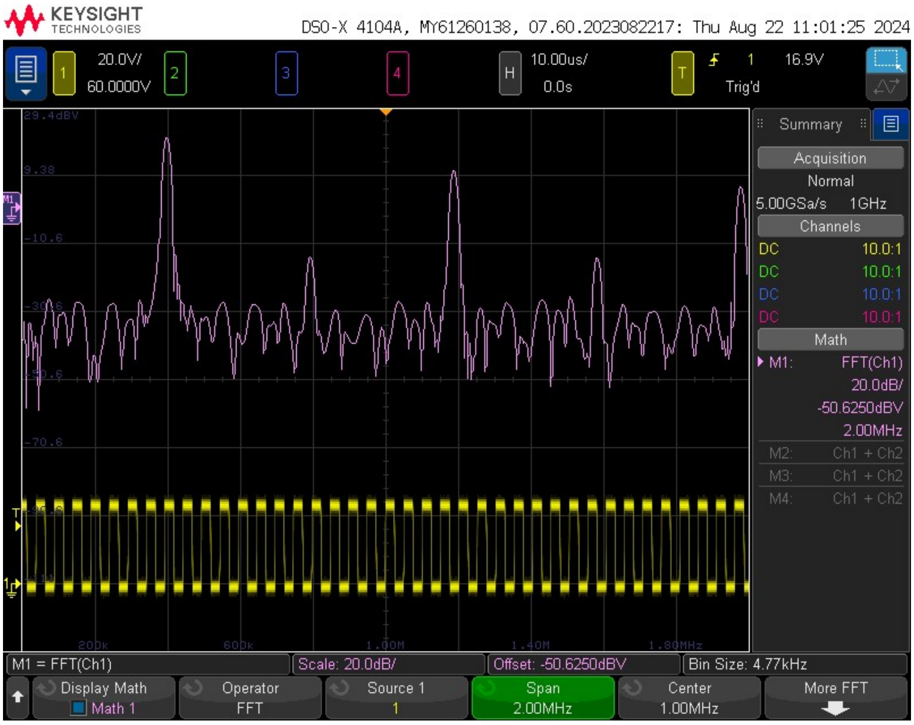
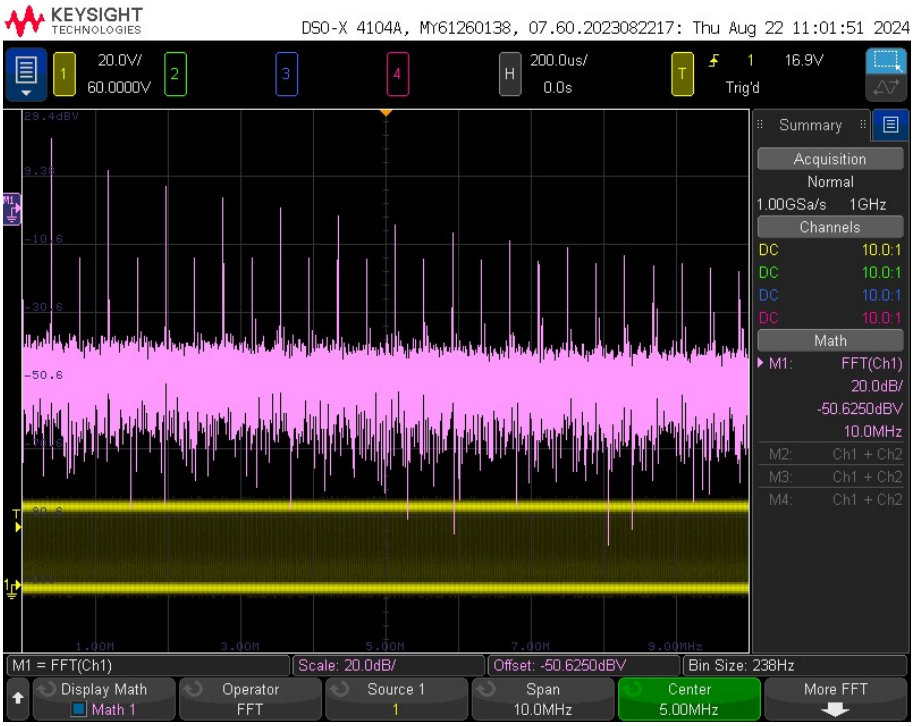


Figure 5. **Spectrum without dithering with center frequency 5 MHz and span 10 MHz**



3 Dithering implementation

There are two possible methods for spreading the frequency on the L3751 or DCP85CY DC/DC controller. Both methods can utilize an external waveform laboratory generator, a programmable MCU, or an analog circuit.

The first method involves injecting a PWM signal into the SYNCIN pin, whereas the second method describes another possibility of injecting an oscillating current into the RT pin.

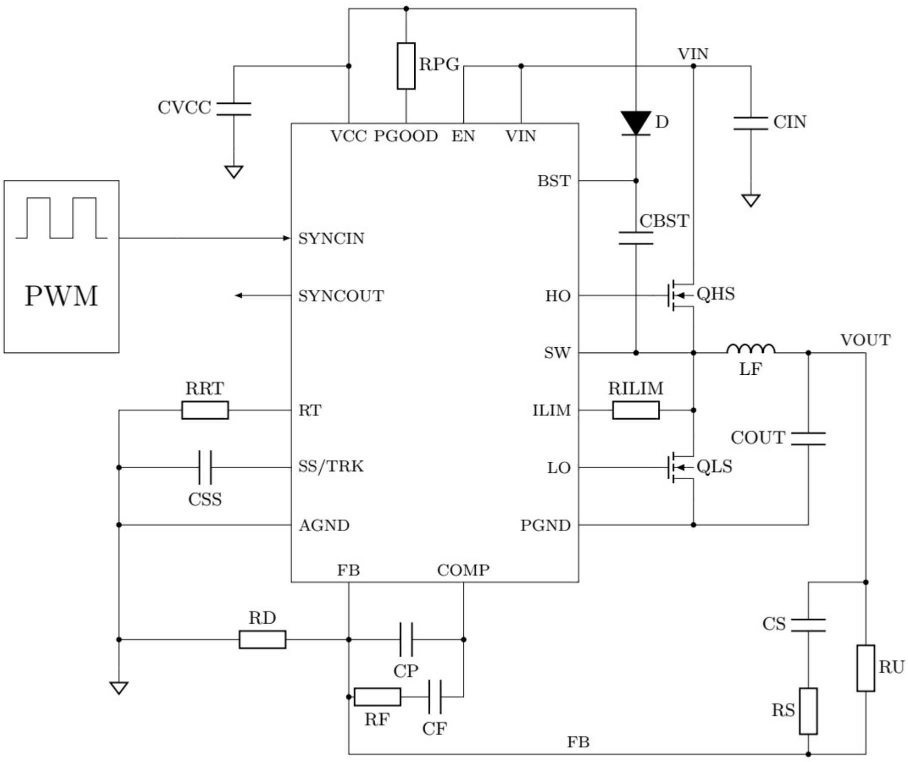
3.1 External PWM to SYNCIN pin

The first method was implemented by injecting a PWM waveform in sweep mode into the SYNCIN pin. SYNCIN external frequency must vary maximally -20% to +50% of a nominal frequency set by R_{RT}. The minimum SYNCIN input logic high is 2 V and must not exceed 8 V. The maximum SYNCIN input logic low is 0.8 V. The resistor RT is set to a frequency of 400 kHz and the spread spectrum should vary between ±10% of the fundamental switching frequency. The external PWM signal needs to have the following parameters:

- PWM in sweep mode
- Start sweep frequency: 360 kHz
- Stop sweep frequency: 440 kHz
- Sweep time: 1 ms
- Amplitude: 3 V (Typically 2-5 V)
- Voltage offset: 1.5 V (The low value must be below 0.8 V, typically 0 V)

The main concept of functionality is illustrated in the following picture, which shows a schematic of a typical application circuit. However, in this application note, an evaluation board was used, which exhibits a few differences from this following schematic.

Figure 6. **L3751 typical application circuit with PWM injection to SYNCIN pin**



The following pictures show screenshots from the oscilloscope. The signal measured on the SW pin of L3751 and its spectrum which is computed by the FFT function, can be seen. Figure 9 mainly shows the signal on the SW pin, where moving edges that represent changing frequency can be observed.

Figure 7. **PWM to SYNCIN pin: dithered spectrum with center frequency 500 kHz and span 1 MHz**

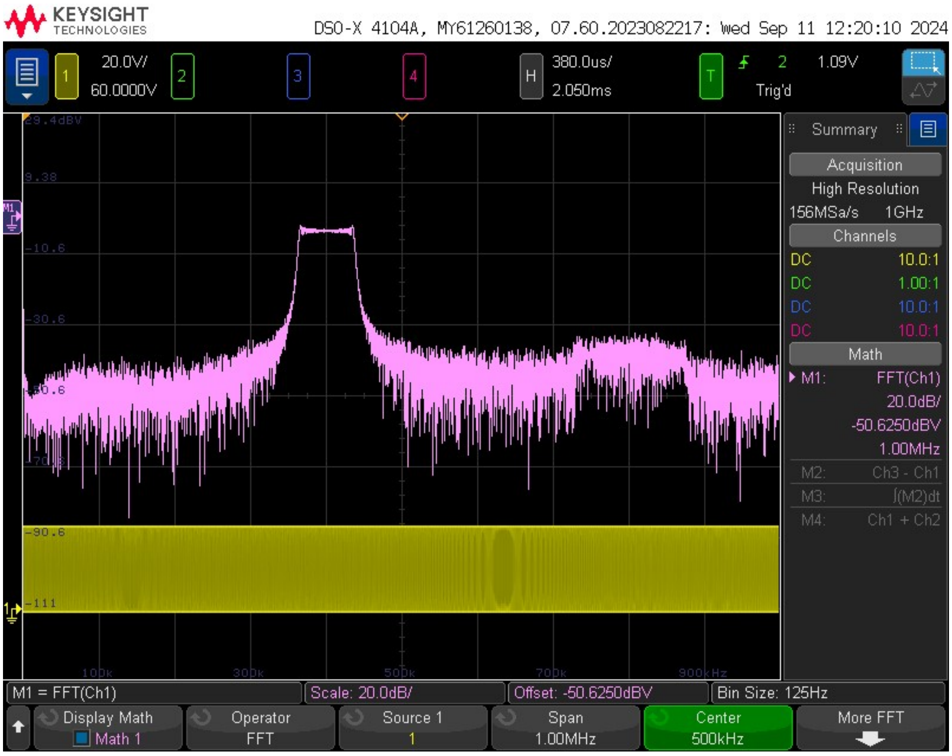
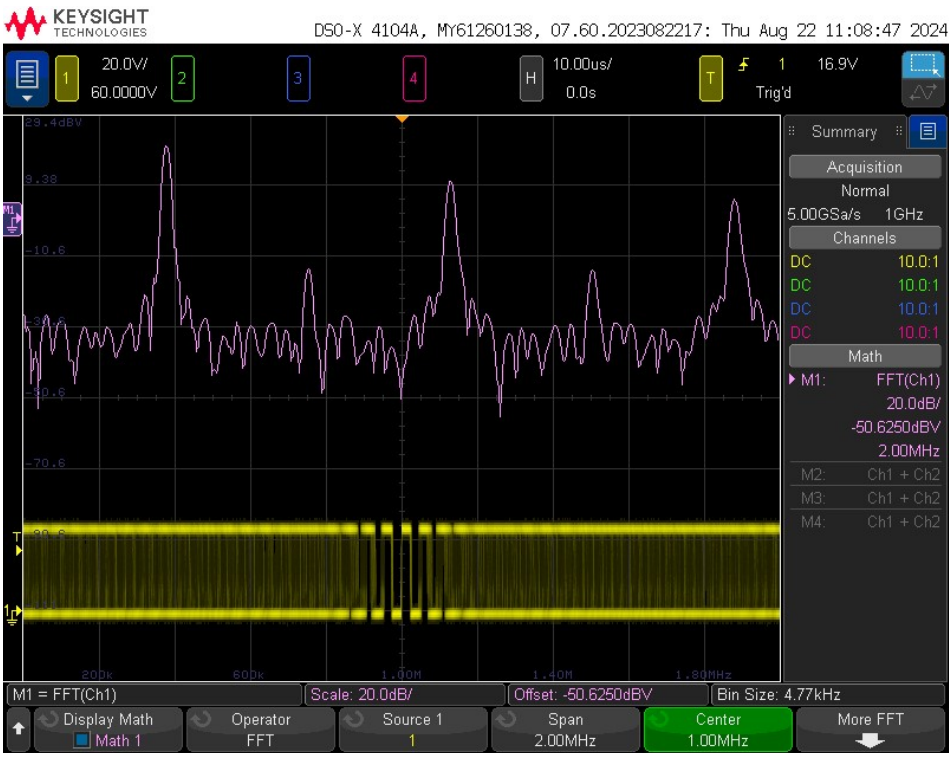


Figure 8. **PWM to SYNCIN pin: dithered spectrum with center frequency 1 MHz and span 2 MHz**

Figure 9. **PWM to SYNCIN pin: dithered signal**

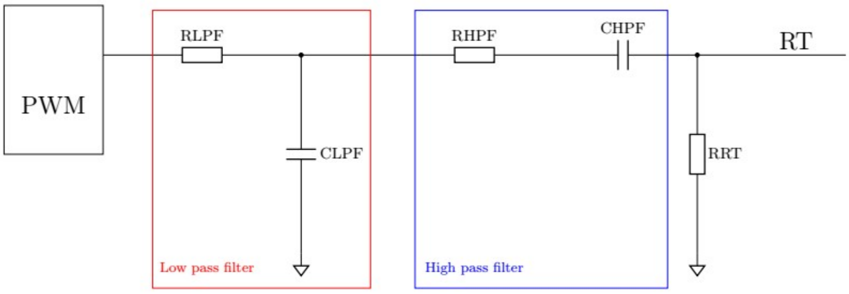


3.2 Injection to RT pin

The second possible way of spreading the spectrum is by injecting current into the RT pin. The device internally measures the current provided by the RT pin and sets the switching frequency accordingly. The RT pin constantly provides a voltage of 1 V, and with the resistor R_{RT} the current is drawn, setting the frequency as a result. By dynamically injecting current into the pin, it is possible to modify the switching frequency.

The circuit shown in Figure 10 demonstrates an implementation of current injection on the RT pin modifying the switching frequency. The network in red, implemented by RLPF and CLPF, is a low-pass filter, while the network in blue, implemented by RHPF and CHPF, is a high-pass filter. The low-pass filter takes the input square wave and converts it into a sawtooth waveform with a certain voltage ripple. This ripple is then passed through the high-pass filter, which removes the average component of the signal and creates the final current injected into the RT pin.

Figure 10. **External circuit for current injection**



For the design of the dithering circuit, two main parameters need to be selected. Firstly, the switching frequency spread Δf_{SW} and secondly, the modulation signal frequency F_M. When selecting Δf_{SW}, it is necessary to consider the inductor current ripple, the selected power components, and the amount of selected slope compensation. Considering these aspects, ±10% of the fundamental switching frequency can be set to Δf_{SW} = 40 kHz.

Dithering circuit design – main parameters:

The modulation frequency can be set to 1 kHz with the following specifications:

- Modulation frequency F_M = 1 kHz
- Amplitude $V_{PP, SQUARE}$ = 5 Vpp
- Duty cycle = 0.5

The switching frequency of the controller is simply set by an R_{RT} resistor using the equation from the first chapter. According to the datasheet's electrical characteristics, a switching frequency of approximately 400 kHz can be set by R_{RT} = 25 kΩ. The current provided by the RT pin can be calculated by knowing the voltage on the R_{RT} pin, which is always equal to 1 V, and the current is given by:

$$I_{RT} = \frac{1\,V}{R_{RT}} = 40\,\mu A$$

The device internally measures the current provided by the RT pin and sets the switching frequency accordingly. Therefore, by injecting current into the pin, it is possible to modify the switching frequency. First, the current ripple required for the switching frequency spread needs to be calculated by:

$$I_{Ripple} = \frac{1V}{R_{RT}}$$

A simplified formula can be used for $R_{RT}\left[k\Omega\right] = \frac{10500}{\Delta f_{sw}[kHz]}$ and the correction part of the calculation can be omitted, as the error in the frequency spread will be minimal. Finally, for the chosen frequency spread Δf_{SW} = 40 kHz, the current ripple is obtained from:

$$I_{Ripple} = \frac{1V}{10500 \cdot 1000} \cdot (\Delta f_{sw}[kHz]) = 3.81\,\mu A$$

The formula is divided by 1000, since in the equation for switching frequency, R_{RT} is in kΩ.

Dithering circuit design - low-pass filter:

Considering the F_M = 1 kHz, an appropriate value for the cutoff frequency of the low-pass filter (BWLPF) can be set around 0.1 kHz. Setting the resistor RLPF equal to 6.8 kΩ, the capacitor value is given by:

$$C_{LPF} = \frac{1}{2\pi R_{LPF} BW_{LPF}} = 234\,nF \rightarrow 220\,nF$$

Therefore, with the RLPF and CLPF values, it is possible to evaluate the voltage ripple as:

$$V_{Ripple} = V_{AVG,LPF} \cdot \frac{1}{1 + e^{-\frac{t_{OFF}}{\tau}}}\left(1 - e^{-\frac{t_{OFF}}{\tau}}\right) = 0.414\,V$$

Where:

$$Toff = \frac{1}{F_m} \cdot (1 - Duty_{FM}) = 0.5\,ms$$

$$\tau = R_{LPF} \cdot C_{LPF} = 1.5\,ms$$

$$V_{AVF,LPF} = V_{PP,SQUARE} \cdot Duty = 2.5\,V$$

Dithering circuit design - high-pass filter:

Finally, the R_{HPF} needs to be calculated considering the voltage ripple V_{Ripple}, and the current ripple required for the selected frequency spread I_{Ripple} as:

$$R_{HPF} = \frac{V_{Ripple}}{I_{Ripple}} = 108.66\ k\Omega \rightarrow 110\ k\Omega$$

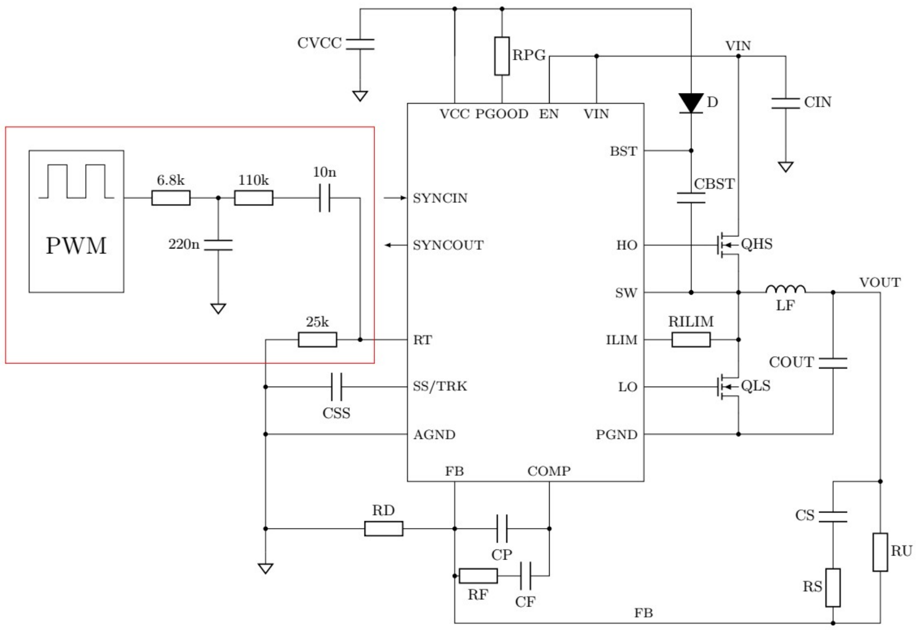
With the cutoff frequency to filter the DC component of the signal, the C_{HPF} can be obtained by:

$$C_{HPF} = \frac{1}{2\pi R_{HPF} BW_{HPF}} = 14.47\ nF \rightarrow 10\ nF$$

It is possible to slightly modify the final spectrum with changing Vpp or the spreading frequency.

To conclude the complete design of the external dithering circuit, the following schematic is shown in Figure 11.

Figure 11. Additional circuit for the RT current injection



The following pictures show screenshots from the oscilloscope. The signal measured on the SW pin of L3751 and its spectrum which is computed by the FFT function, can be seen. Figure 14 mainly shows the signal on the SW pin, where moving edges that represent changing frequency can be observed.

Figure 12. Injection to RT pin: dithered spectrum with center frequency 500 kHz and span 1 MHz

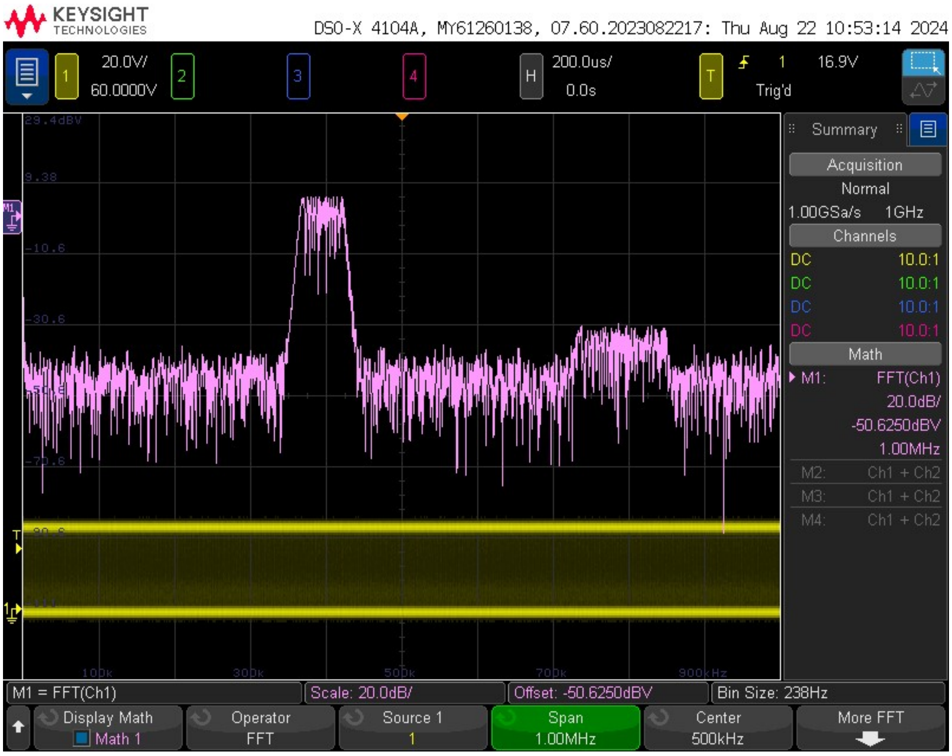


Figure 13. Injection to RT pin: dithered spectrum with center frequency 1 MHz and span 2 MHz

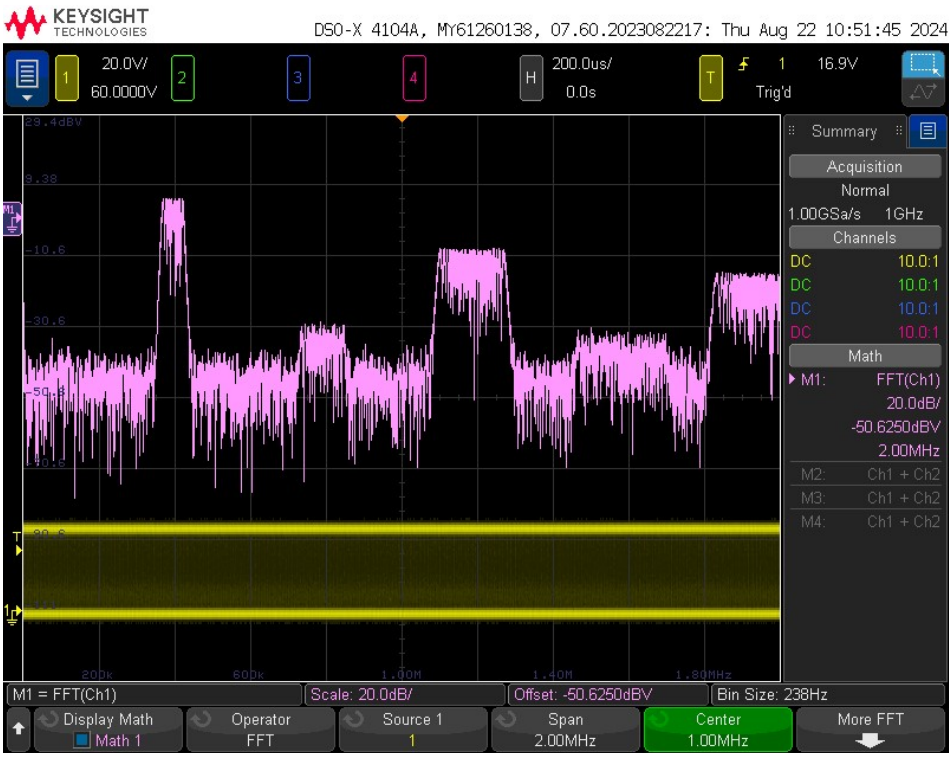


Figure 14. **Injection to RT pin: dithered signal**

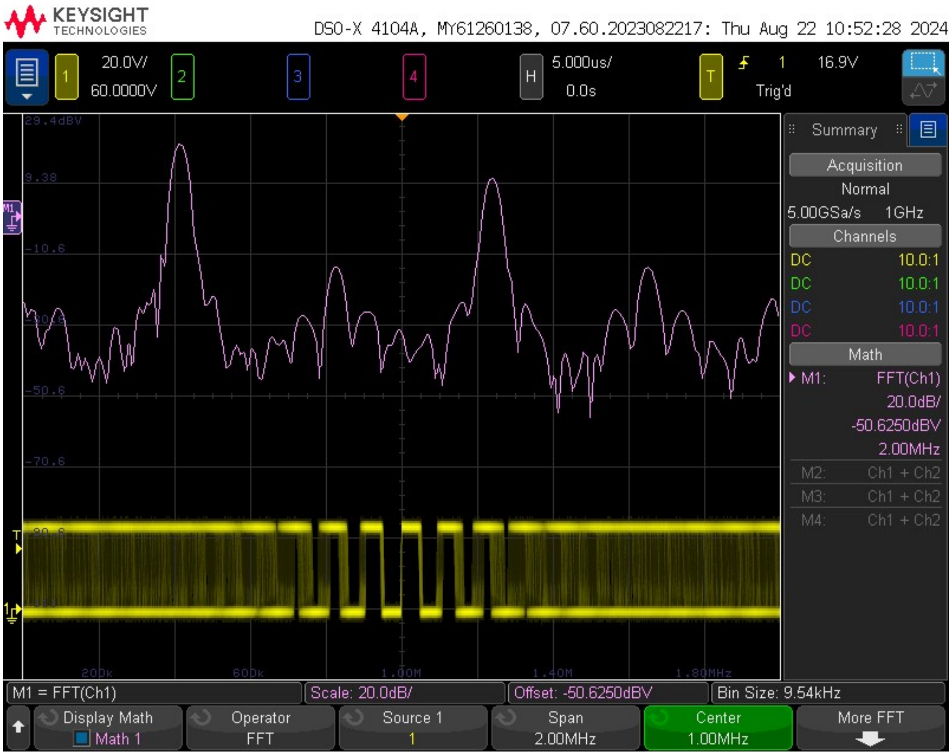
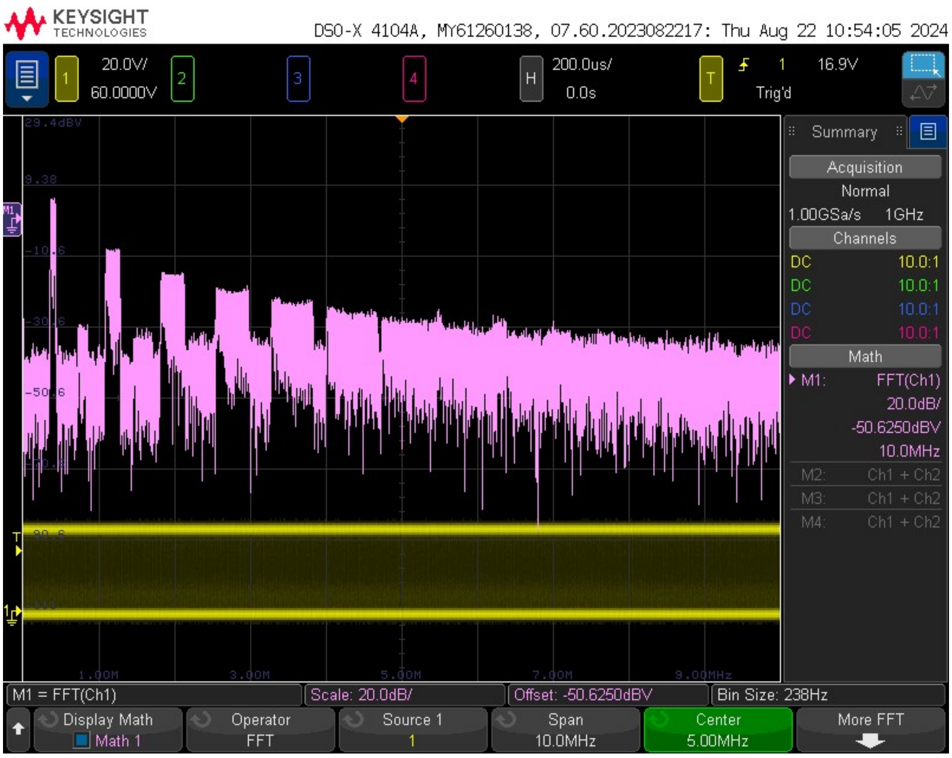


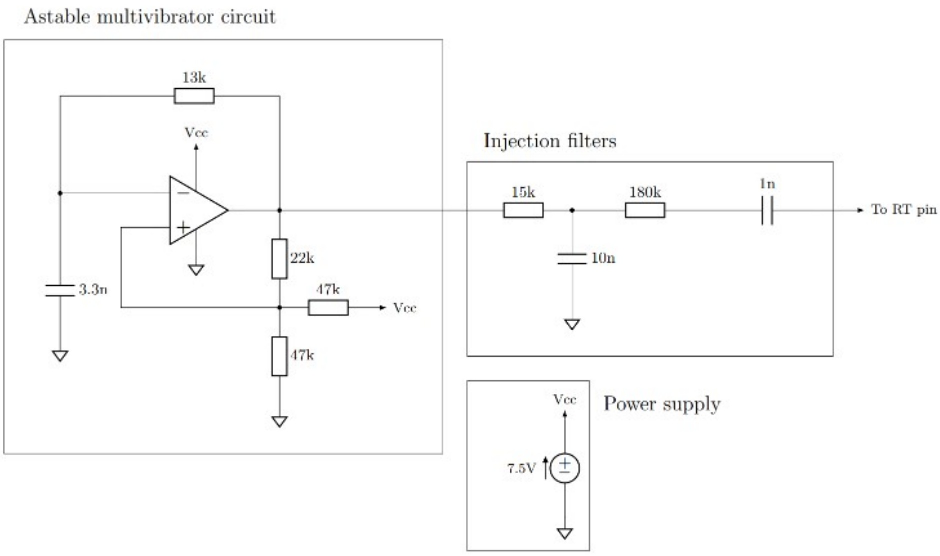
Figure 15. **Injection to RT pin: dithered spectrum with center frequency 5 MHz and span 10 MHz**



3.2.1 Application example: dithering with astable PWM generator

In this section the application example of the method of injection to RT pin will be described. The fully analog proposal shown in Figure 16 is likely the most cost-effective and straightforward analog method to enable the frequency dithering on the L3751 or DCP85CY controller. It consists of three blocks. The power supply provides a DC voltage of 7.5 V from an internal LDO (VCC pin of the L3751/DCP85CY) and supplies a single-channel operational amplifier (e.g. TX711) inside the astable multivibrator circuit. This circuit generates a rectangular waveform (PWM) with a 9 kHz frequency and a 50% duty cycle. The signal then passes through injection filters, which convert it into a sawtooth waveform. This waveform is subsequently injected into the RT pin, enabling the modification of the frequency

Figure 16. Schematic of PWM generator with injection filters



The proposed multivibrator circuit generates a 9 kHz PWM square wave signal with an amplitude of 7.5 V (Vcc) and a 50% duty cycle. Using the equations from the previous section, the filters were calculated as follows: The low-pass filter has values of R_{LPF} = 15 kΩ and C_{LPF} = 10 nF. With these values, the ripple voltage is equal to V_{Ripple} = 0.687 V, and the values of the high pass filter can be defined as:

$$R_{HPF} = \frac{V_{Ripple}}{I_{Ripple}} = 180.31\,k\Omega \rightarrow 180\,k\Omega \quad (1)$$

$$C_{HPF} = \frac{1}{2\pi R_{HPF} BW_{HPF}} = 0.982\,nF \rightarrow 1\,nF \quad (2)$$

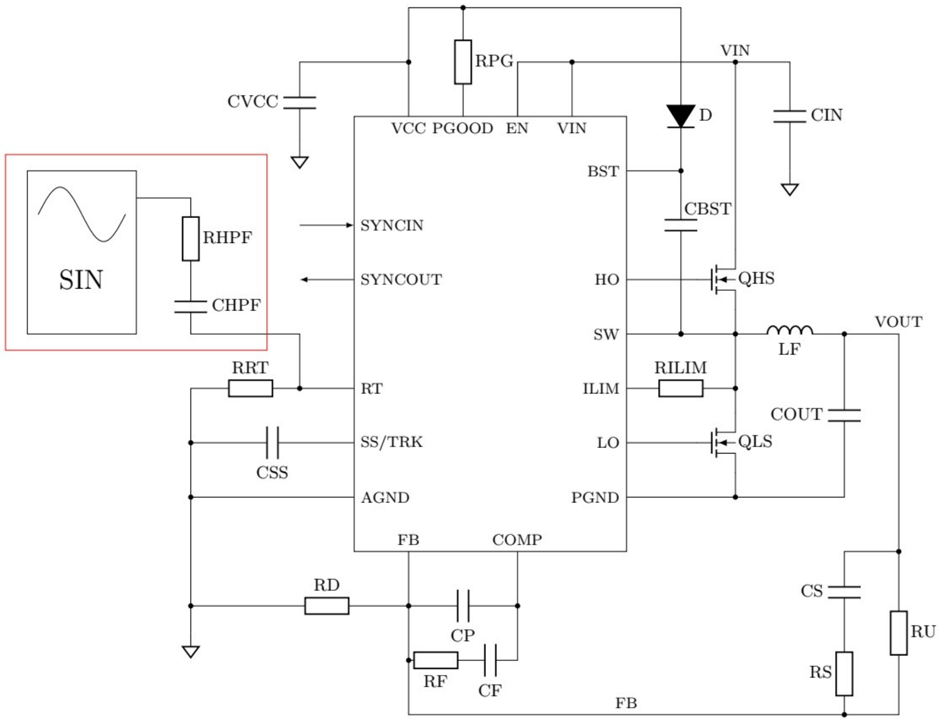
Where I_{Ripple} is set for a dithering range of Δf_{SW} = 40 kHz (±10% around the nominal frequency) and the bandwidth of filters is set to approximately 1/10 of the modulation frequency.

3.2.2 Application example: dithering with sinewave generator

The method from the previous section can be modified by skipping the low pass filter and instead adding a sine wave or sawtooth wave generator. The proposed schematic for this approach is shown below in Figure 17.

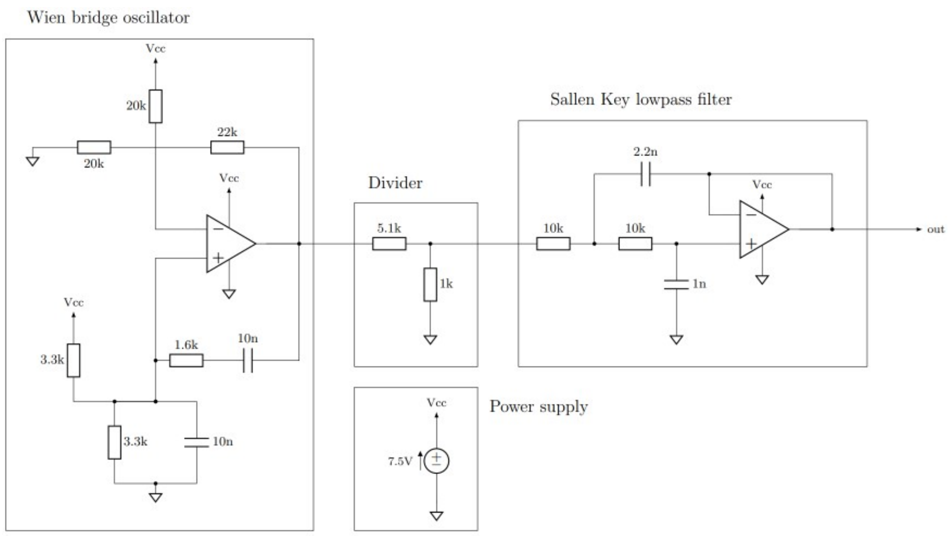
This configuration must then be followed by a high-pass filter as described in the previous sections.

Figure 17. L3751/DCP85CY typical application circuit with a signal injection to RT pin



Design tip of analog sine wave generator consists of 4 main blocks: Power supply, Wien bridge oscillator, Voltage divider and Sallen Key lowpass filter. Power supply provides DC voltage of 7.5V (generated by VCC pin of L3751 or DCP85CY) to supply the dual channel operational amplifier (i.e. TSB182 or low-cost LM2904). Voltage divider reduces the amplitude of sine wave to 1Vpp. The purpose of the Sallen Key low pass filter is to improve the imperfect sine wave generated by Wien bridge oscillator.

Figure 18. Schematic of sine wave generator



The proposed sine wave generator in Figure 18 makes a sine wave of frequency 1 kHz and amplitude 1 Vpp, resulting the V_{Ripple} = 0.5 V. Following the parameters of I_{Ripple} and frequency spread from the previous chapter, the high-pass components can be calculated with the same equations as:

$$R_{HPF} = \frac{V_{Ripple}}{I_{Ripple}} = 131.25\ k\Omega \rightarrow 130\ k\Omega$$

$$C_{HPF} = \frac{1}{2\pi R_{HPF} BW_{HPF}} = 12.2\ nF \rightarrow 10\ nF$$

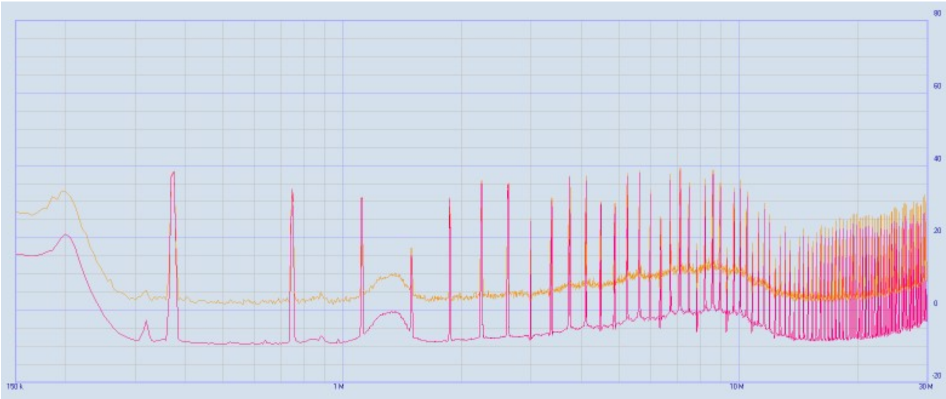
3.3 EMI measurements

The electromagnetic interference (EMI) measurements were conducted using the evaluation board with the DCP85CY in a professional EMC laboratory to ensure precise and reliable results. The laboratory was equipped with a Line Impedance Stabilization Network (LISN) PMM L1-150M and an EMI receiver PMM 9010F, both of which are industry-standard tools for electromagnetic interference testing. The results presented include measurements taken without frequency dithering, followed by two versions with frequency dithering applied. The modulation frequency of the dithering was set to 9 kHz, as it is a standard across the competitors and provides the best outcome in terms of reducing EMI. This comparison highlights the impact of frequency dithering on the electromagnetic emissions of the evaluation board, demonstrating its effectiveness in minimizing interference and ensuring compliance with relevant standards.

3.3.1 No dithering

The initial measurement was performed without applying frequency dithering to serve as a baseline for comparison. Figure 19 illustrates the measured spectrum, where the horizontal axis represents the frequency in Hz, and the vertical axis shows the amplitude of the spectrum in dBµV. The spectrum displays both peak and average (AVE) values of the emissions. Distinct peaks are visible at the switching frequency of 380 kHz and its harmonics, which are typical for non-dithered operation. These concentrated emissions highlight the challenges in achieving electromagnetic interference (EMI) compliance without mitigation techniques and serve as a reference to assess the impact of frequency dithering.

Figure 19. EMI measurement: default spectrum without dithering – PEAK (yellow) and AVE (red)

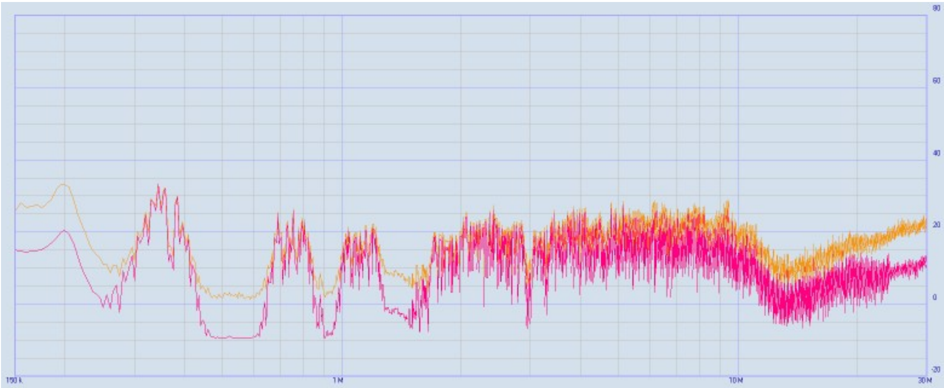


3.3.2 Injection to RT pin – PWM generator

This section presents the EMI measurement for the configuration where a PWM signal is injected into the RT pin. The PWM signal is generated by an astable multivibrator circuit.

illustrates both the PEAK and AVE versions of the measured spectrum, showing how the PWM generator spreads the energy across a wider frequency range of ±50 kHz around the nominal frequency of 380 kHz. The horizontal axis represents the frequency in Hz, while the vertical axis shows the amplitude of the spectrum in dBµV. Compared to the baseline measurement, the peaks at the switching frequency and its harmonics are significantly reduced. This result underscores the effectiveness of this method in mitigating EMI emissions.

Figure 20. EMI measurement: dithered spectrum with usage of astable PWM generator – PEAK (yellow) and AVE (red)



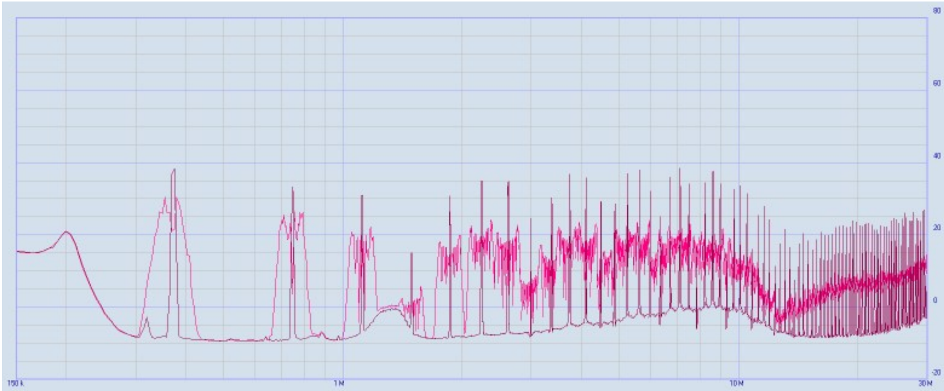
3.3.3 Injection to RT pin – sinewave generator

Here, the EMI measurement results are detailed for the setup where a sinewave signal is injected into the RT pin for frequency dithering. Figure 21 displays the PEAK and AVG spectra, demonstrating the effectiveness of the sinewave generator in smoothing the energy distribution in a range of approximately ±20 kHz around the nominal frequency of 380 kHz. The horizontal axis represents the frequency in Hz, while the vertical axis shows the amplitude of the spectrum in dBµV. This method also successfully reduces the concentrated peaks observed in the baseline measurement, proving to be an efficient way to address EMI challenges.

Figure 21. EMI measurement: dithered spectrum with usage of astable PWM generator – PEAK (yellow) and AVE (red)

Additionally, Figure 22 shows the comparison between AVG values of normal non-dithered spectrum with a dithered one by using the sine wave generator, providing a clear visual representation of the significant reduction in EMI achieved through sinewave dithering. The peaks in the spectrum are reduced by approximately 10 dB.

Figure 22. EMI measurement: comparison of AVG values of dithered (pink) and non-dithered (red) spectrum



Revision history

Table 1. Document revision history

Date	Version	Changes
05-Aug-2025	1	Initial release.

Contents

List of figures