Application Note

Dynamic Current Tracking With the LM5177 4-Switch Buck Boost Controller

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ABSTRACT

The LM5177 is a wide input voltage, synchronous, non-inverting buck-boost controller, suitable for applications that need a regulated output voltage from an input supply that can be higher, lower or equal than the regulated output voltage. With the features provided by this device a dynamic current tracking can be implemented as well which enables the system to control the current and also adjust this based on external inputs.

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1 Introduction

The LM5177 buck-boost controller is used to design a customized DC supply with a wide range of input/output voltages. Additionally, it offers the input/output current limit features. This buck-boost controller incorporates many built-in functions to control the DC supply current; for instance, average current limit, peak current limit, and dynamic current limit. This application note covers the implementation of a dynamic current limit feature with the LM5177 using an analog voltage tracking function. The dynamic current limit feature of the controller enables the power supply to regulate the output current dynamically regardless of the supply operations and hardware modifications. Whereas, the other current limit features of the controller are static during the operation of the supply and defined by the component selection. Hence, this is an important feature for many applications, which demands a constant current source with variable current limits. For instance, it can regulate the brightness of low-power LED modules with vast operating limits. Further, the dynamic current limit plays a vital role as a constant current source for wireless inductive chargers, or appliances where temperature compensation is an demand.

The dynamic control over the output current of the converter using analog voltage tracking is similar to a voltage controlled current source. With analog voltage tracking, an external analog signal is applied to the buck-boost controller's ATRK pin which changes the output voltage according to the voltage level applied to this pin. The change in output voltage reflects a change in output current limit. To enable this functionality, the applied analog signal at the ATRK pin should be less than V_{ref} of the LM5177. The ATRK signal changes the reference value of the error amplifier and this causes a change in the duty cycle of the power stage PWM. The block diagram for the dynamic current limit using analog voltage tracking is shown in Figure 1-1.

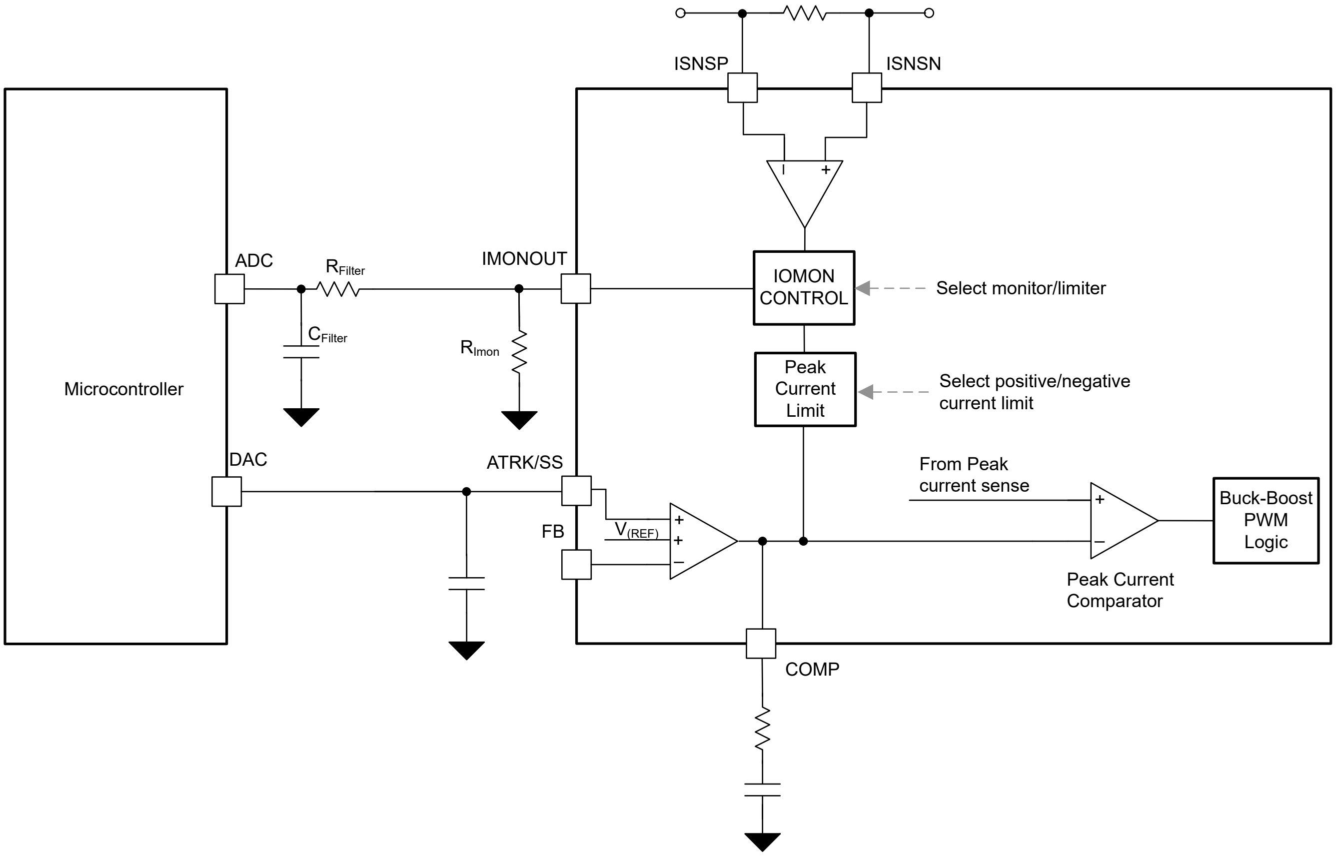

Figure 1-1. Dynamic Current Control Using Analog Voltage Tracking Function

In many applications, the load current needs to be varied, this demands a controller to regulate the output current. Therefore, in Figure 1-1, the microcontroller is used to generate the analog tracking signal for the ATRK pin. To sense the change in the output current, the shunt resistance is used at the output of the power stage. The current sensing limit can be adjusted with the value of resistance up to a maximum measured voltage of 50 mV. The sense voltage is fed to the transconductance amplifier, and the corresponding current is measured as a voltage level at the output of the IMONOUT pin of the buck-boost controller using a pull-down resistor . The value of is selected according to the maximum reference voltage of the microcontroller ADC. For this application note, the value of and resistances are set to 18 mΩ and 12 kΩ, respectively. These values correspond to the maximum measured output current of 2.77 A and its corresponding value of 1.5 V.

These values can be adopted according to the requirements of the selected microcontroller. In this case the MSP-EXP430FR2355 development kit is used. The analog voltage generated at the IMONOUT pin is then connected to the ADC of the microcontroller, which converts the analog signal into a digital value. With a digital filter, the microcontroller generates a digital error signal. This digital error signal is then provided as an analog error signal using the microcontroller DAC. The designed procedure for the microcontroller digital filter is described in the following section.

2 Digital Filter Design

The digital filter is a difference equation derived from the digitized version of an analog filter. To evaluate the digital filter for the microcontroller, it is easier to design an analog filter first. The design of the analog filter is dependent on the plant transfer function. The plant transfer function shows the dynamics of the uncontrolled system which need to be compensated by the filter in the microcontroller. Whereas, the plant transfer function for the analog voltage tracking function is comprised of the buck-boost controller with ATRK circuity and power stage. The control loop for analog voltage tracking is demonstrated in Figure 2-1. Where the V_{ref} is the reference value for the controller and a change in this value sets a new output current limit for the converter by adjusting the output voltage.

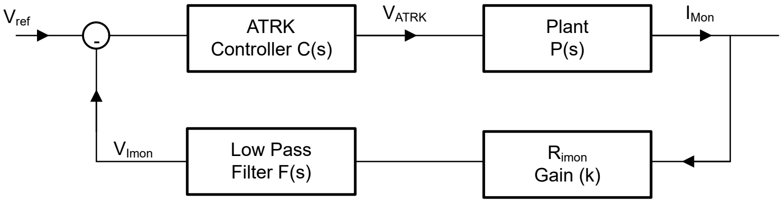

Figure 2-1. Closed Loop for the Analog Voltage Tracking

3 Plant Transfer Function for the ATRK function

The plant transfer function for the analog voltage tracking is driven by the step response of the system between ATRK and IMONOUT pins. The response in Figure 3-1 shows that the plant is a second-order system. The plant transfer function driven from the response graph in Figure 3-1 is expressed by Equation 1. This is the combination of plant, gain, and low pass filter. The derivation of the transfer function for second order system from the response graph is well covered.

$$PL\left(s\right) = \frac{V_{Imon}}{V_{ATRK}} = K \times F(s) \times P(s) = \frac{2.188 \times 10^{8}}{s^{2} + 1.447 \times 10^{4} s + 2.73 \times 10^{8}} \tag{1}$$

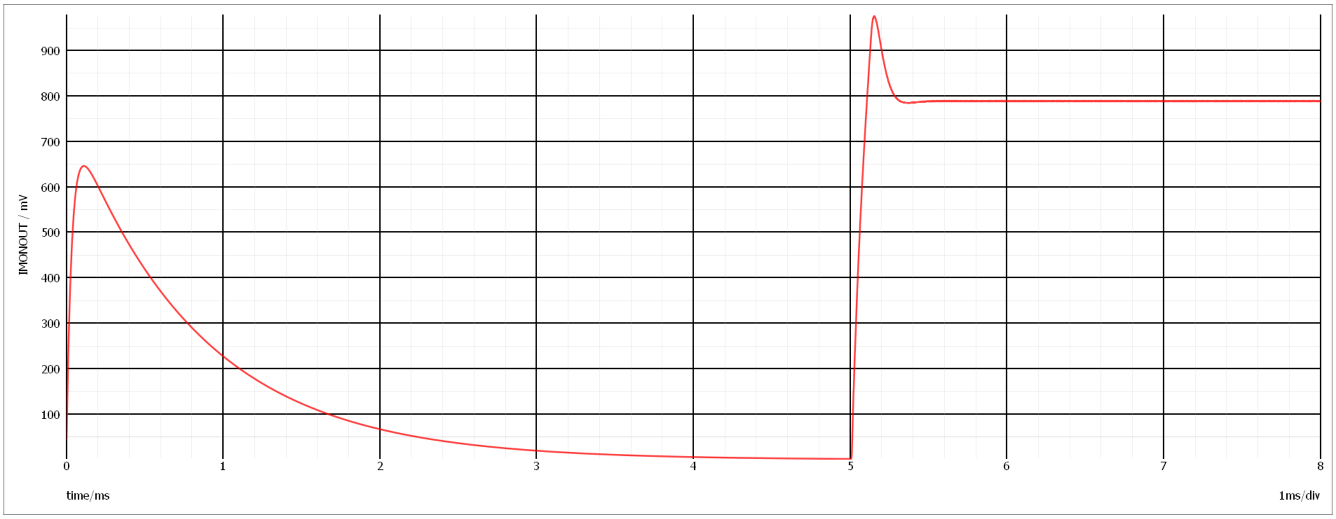

Figure 3-1. Plant Transfer Function

4 Analog Controller for ATRK Plant

To improve the response of the ATRK plant and regulates the output current, it is required to design the close loop system with the optimal controller. To compensate the influence of the plant poles, the Operational Transconductance Amplifier (OTA) type 2 controller is selected [see *Demystifying Type II and Type III Compensators Using Op-Amp and OTA for DC/DC Converters*]. This controller has two poles and one zero. The designed analog controller for the analog voltage tracking plant is shown in Figure 4-1. While designing the controller for the ATRK plant, it is important to note that the controller bandwidth should be less than the bandwidth of Comp pin compensation.

Moreover, the controller need to fulfil the Nyquist criteria (controller bandwidth should be less than one-half of the microcontroller ADC sampling frequency). Therefore, with the configured sampling frequency of 10kHz from the ADC of the microcontroller, a filter bandwidth of 3.7KHz has been selected (the comp pin compensation has a bandwidth of 135kHz). The transfer function for the controller is expressed by Equation 2. The developed analog controller has poles at 0 Hz and 3.6923 kHz, and a zero at 1.0256 kHz. The frequency analysis for the controller is illustrated in the Figure 4-2.

$$C(s) = g_m \frac{R_{19}C_{13}s + 1}{R_{19}C_{13}C_{14}s^2 + (C_{14} + C_{13})s} \tag{2}$$

With, R_{19} = 15kOhm, C_{13} = 65nF, C_{14} = 20nF, and g_m = 600µS

$$C(s) = \frac{V_{ATRK}}{V_{Error}} = \frac{585\,s \ + \ 600000}{0.02437s^2 \ + \ 90\,s} \tag{3}$$

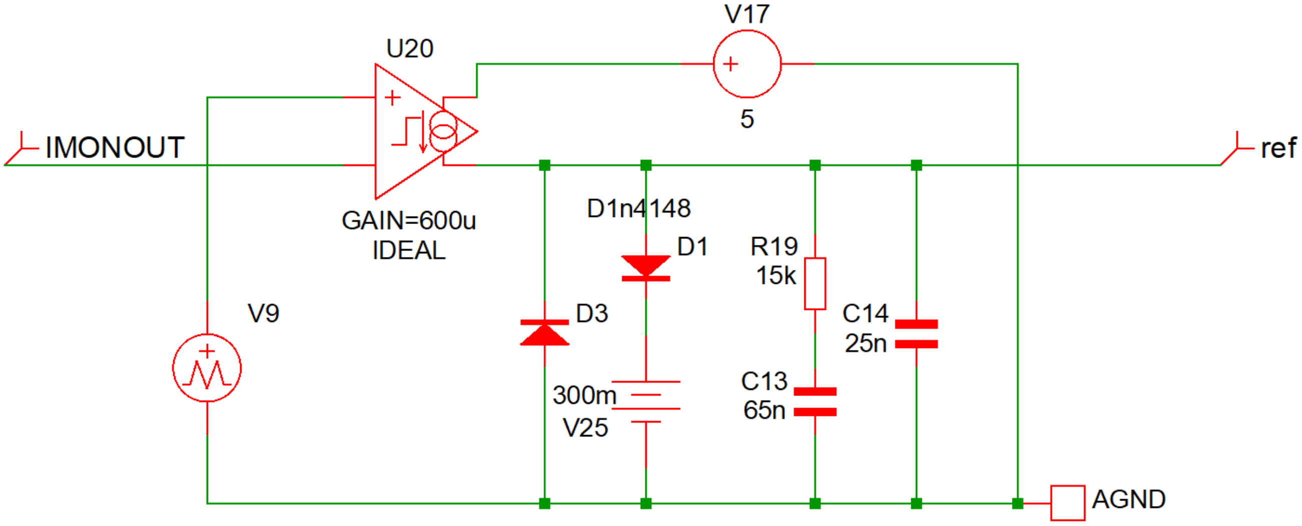

Figure 4-1. Analog Controller for the ATRK Plant

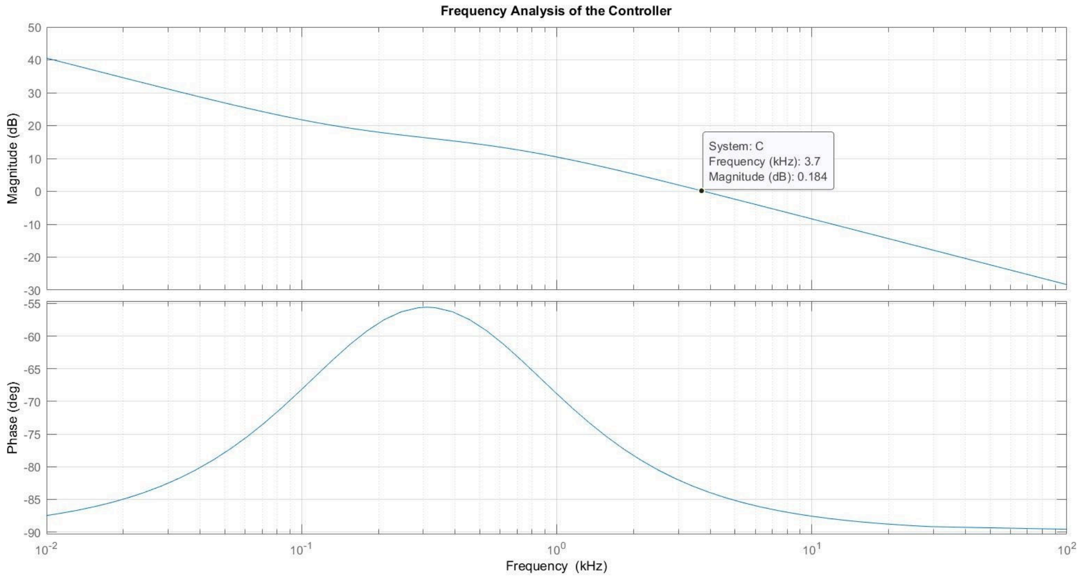

Figure 4-2. Frequency Analysis of the Designed Analog Controller

The loop gain (O(s) = C(s) × P(s) × K) for the analog voltage tracking system with the designed controller is expressed by Equation 4. The frequency analysis of the loop gain is shown in Figure 4-3.

$$O(s) = \frac{V_{Imon}}{V_{ref}} = \frac{1.28 \times 10^{11} s + 1.313 \times 10^{14}}{0.02437 s^4 + 442.7 s^3 + 7.957 \times 10^6 s^2 + 2.457 \times 10^{10} s} \tag{4}$$

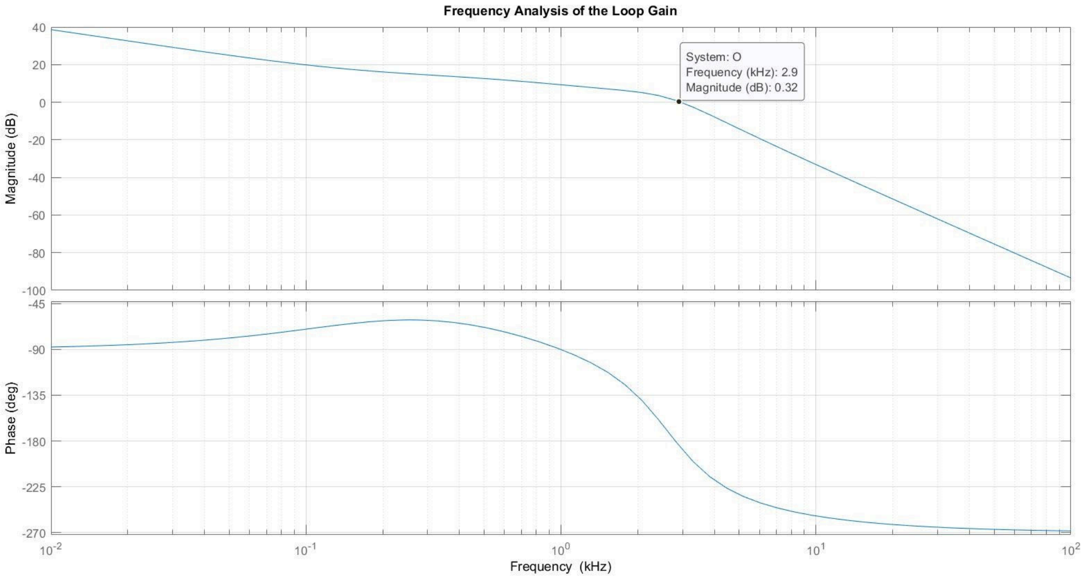

Figure 4-3. Frequency Analysis of the ATRK Loop Gain

5 Z-Transform and Difference Equation

The transfer function for the controller formulated in the previous section is in the continuous-time domain. Whereas, the real-world microcontrollers only work in the discrete-time domain because of their sampling limitations. Thus, for digital control code, there is a need to transform the existing continuous time domain model into a discrete time domain. For this reason, bi-linear transformation is used. The bi-linear transformation converts a transfer function in the s-domain to a discrete-time z-domain. The z-domain represents the sequence of discrete time numbers to a complex frequency z-plane representation. The equivalent z-domain transfer function for the controller is represented by Equation 5. The sampling period used in the bilinear transformation is 100 microseconds based on the ADC sampling frequency of 10kHz.

$$H(z) = \frac{2.116z - 1.91}{z^2 - 1.691z + 0.6913} \tag{5}$$

To translate the controller z-domain transfer function to the digital filter equation (difference equation), the inverse z-transform is conducted on the H(z). The equation computed for the digital filter from the inverse z-transform is expressed by Equation 6. Where k is a discrete time, X is the sensor value, Y is the output value of the controller.

$$Y(k) = 1.691 \times Y(k_{-1}) - 0.6913 \times Y(k_{-2}) + 2.116 \times X(k_{-1}) - 1.91 \times X(k_{-2}) \tag{6}$$

6 Application Implementation

6.1 Software Flow Chart

The Figure 6-1 shows the flow chart of the software's overall behavior. The demo software wakes up and performs the filter calculation after a new ADC value is available. The ADC conversions triggered by an RTC event. In the remaining time the MSP430 is sleeping in low power mode 3.

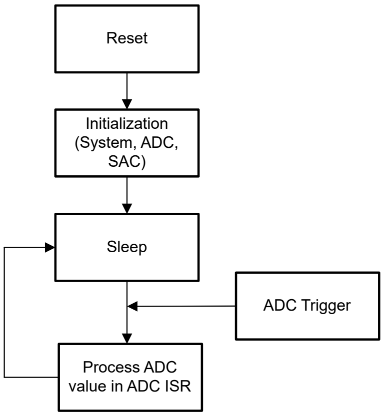

Figure 6-1. Software Flow Chart

6.2 Application Demo

To verify the response of the ATRK close loop with the designed digital controller, the filter was implemented into a microcontroller using IQmath. The results in Figure 6-2 show the smooth transition of the output load current of the converter with dynamic current limits. For this experiment, the selected target values for the dynamic current limit are 0.5, 1, 1.5, and 2 amps. It is recommended to use the low pass filter at the output of the IMONOUT pin because the V_{Imon} includes the harmonics of the switching frequency of the buck-boost. The switching frequency for this examples is 395 kHz. It is suggested that the value of the capacitance for the low pass filter should be less, otherwise it has a considerable influence on the response of the controller. For this test, the values for the low pass filter are C_f = 5 pF and R_f = 3 MΩ. This filter has a cut-off frequency of 10 kHz. In this analysis, the plant transfer function defined in Equation 1 included the transfer function of the low-pass filter.

The scope plot for the test is shown in Figure 6-2. The results demonstrate the operation of the ATRK function of the buck-boost controller with the designed digital controller. As shown in the scope plot, after every 500 ms the current limit changes to the selected target values mentioned above and the response to this transition is exhibited in the ATRK and load current (I_Load) waveforms.

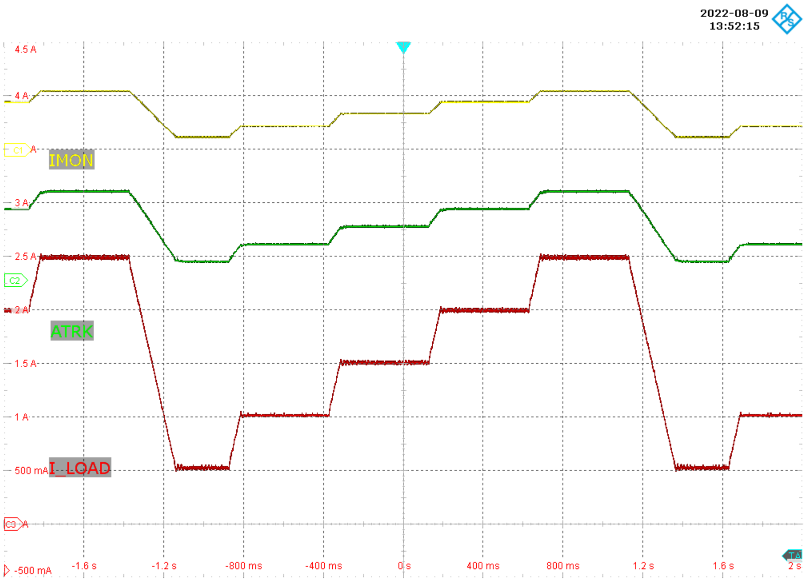

Figure 6-2. Dynamic Current Regulation Results from the Designed Hardware

6.3 Implementation with DTRK

This application can also be implemented with using the DTRK instead of the ATRK input. For this a fast PWM is required to get a high enough resolution. For this a MSP430F5172 with the high resolution timer can be used. This allows a PWM clock timer resolution of up to 256 MHz. For a minimum frequency 100 kHz this would still give 2560 steps which around 11 Bit.

7 Summary

Under consideration from the previous results, the conclusion is that the dynamic current limit using analog voltage tracking is an efficient and reliable function of the buck-boost controller. The independence of the ATRK function from the buck-boost controller operations allows the power supply designer to control asynchronously the output load current of the converter. The response for the designed digital controller for the ATRK loop can be improved by using the microcontroller having a higher ADC sampling frequency and resolution. Moreover, the resolution of the microcontroller DAC plays an important role in the stability of the ATRK close loop; therefore, the high resolution of DAC is recommended. Apart from this, the response of the digital controller can be enhanced by increasing the bandwidth of the Comp pin compensation. This increases the selection range of bandwidth for the digital controller.

8 References

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- Texas Instruments, *25 MHz MCU with 32KB Flash, 2KB SRAM, 10-bit ADC, Comparator, DMA, 16-bit High Resolution Timer*, data sheet.
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- *How do i find the second order transfer function from this step response diagram?*.
- Texas Instruments, *Applying Digital Technology to PWM Control-Loop Designs*.
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