How to Specify the Current Sense Resistor in a Converter Using the UCC28083

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We will start this discussion using the schematic of the power circuit in Figure 1 as a reference.

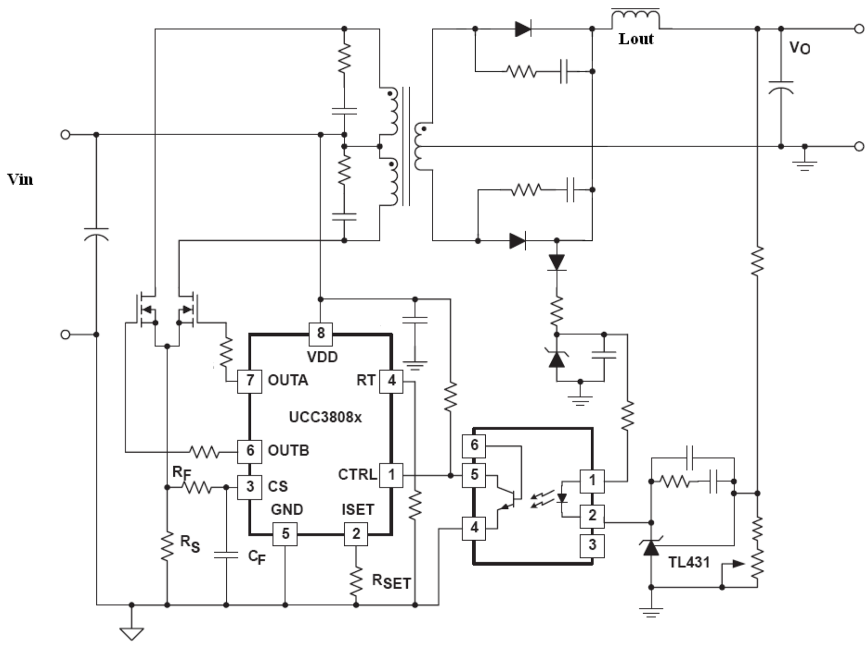

Figure 1. Block Diagram of UCC3808x Push-Pull Converter

R_s is the sensor of the current through the output transformer. This current is made up of several components on the secondary side and primary side that have to be considered. The first two and the most significant of these are the maximum DC output current (I_{max}) and the maximum peak-to-peak current through the output inductor ΔI_{Lout} (this occurs at the maximum input voltage (V_{inx})). Typical voltage waveforms and current waveforms through the output inductor at maximum current are shown in Figure 2.

Usually the output inductor is designed to provide a maximum peak to peak ripple current through the output inductor equal to approximately 20% of the maximum DC current, though peak to peak ripple currents of 10% are common. This requirement sets the size of the output inductor, Lout for a particular set of parameters such as switching frequency (F_{osc}), Vin, Vout, and output load.

For this analysis, we will assume a 20% ripple current and we will ignore any diode or switching losses.

One can observe that at maximum input voltage, V_{inmax}, the ripple current peak is much higher than at minimum input voltage, V_{inmin}. Also observe that for both maximum and minimum input voltage the downslope of the inductor has the same slope. This means that when adding the downslope to the current signal the same dv/dt is added in all cases but because the "ON" time is different, the total effective voltage added is different.

The peak current through the secondary of the transformer is the peak DC load current I_{MAX} plus half the output inductor, L_{out}, ripple current (ΔI_{Lout} /2).

$$I_{pk\sec} = (I_{\max} + (\Delta I_{Lout} \div 2)) \quad (1)$$

This is translated to the primary by the turns ratio of the transformer. The design has to accommodate the worst case peak current which will occur at the maximum input voltage V_{inmax}. It also has to handle the maximum load at minimum input voltage V_{inmin}.

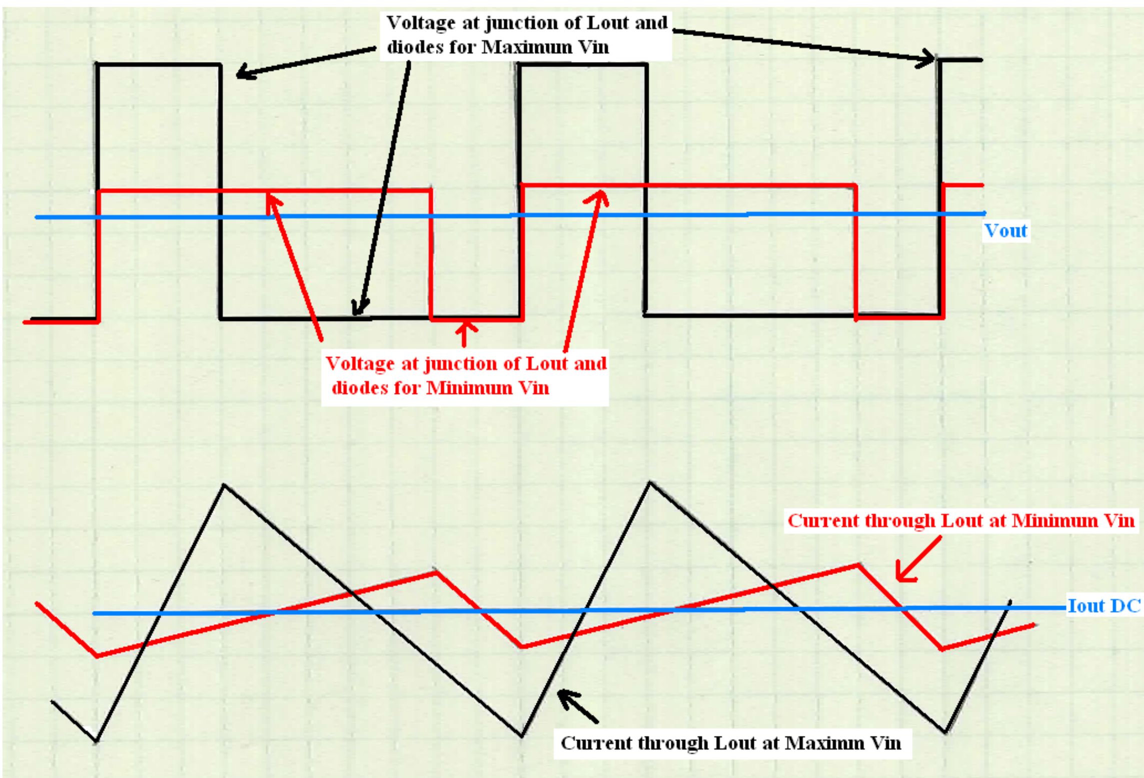

Figure 2. Voltages across Lout and Currents through Lout (shown for both maximum Vin (V_{inmax}) and minimum Vin (V_{inmin}))

The primary side magnetizing inductance will add a magnetizing current component (I_{mag}) to this. The peak-to-peak primary ripple magnetizing current will be highest at V_{inmax}. The peak to peak magnetizing current will be equal to the maximum input voltage divided by the primary side magnetizing inductance (L_{mag}) all multiplied by the "ON" time of the primary side switch for the maximum input voltage condition (T_{onx}). But the magnetizing current will only partially dissipate while the primary switch is off. Instead it will steer the output current to one side or the other of the secondary side winding and so will still be present when the next switch turns on. Because the opposite winding is turning on it will have an effective negative current component at turn on.

These currents through R_s are shown in Figure 3 where the first pulse shown represents the DC output load current (Black) and the DC output load current component with the output inductor ripple current added (red). With the output inductor designed for a 20% ripple, the peak current through the winding will be 110% of the reflected load current translated to the primary side.

The second pulse has the primary side magnetizing current added to show the impact of adding the magnetizing current to the reflected secondary current (Blue). If the magnetizing inductance of the primary is sufficiently high the contribution to the peak current will be extremely small and this can usually be ignored.

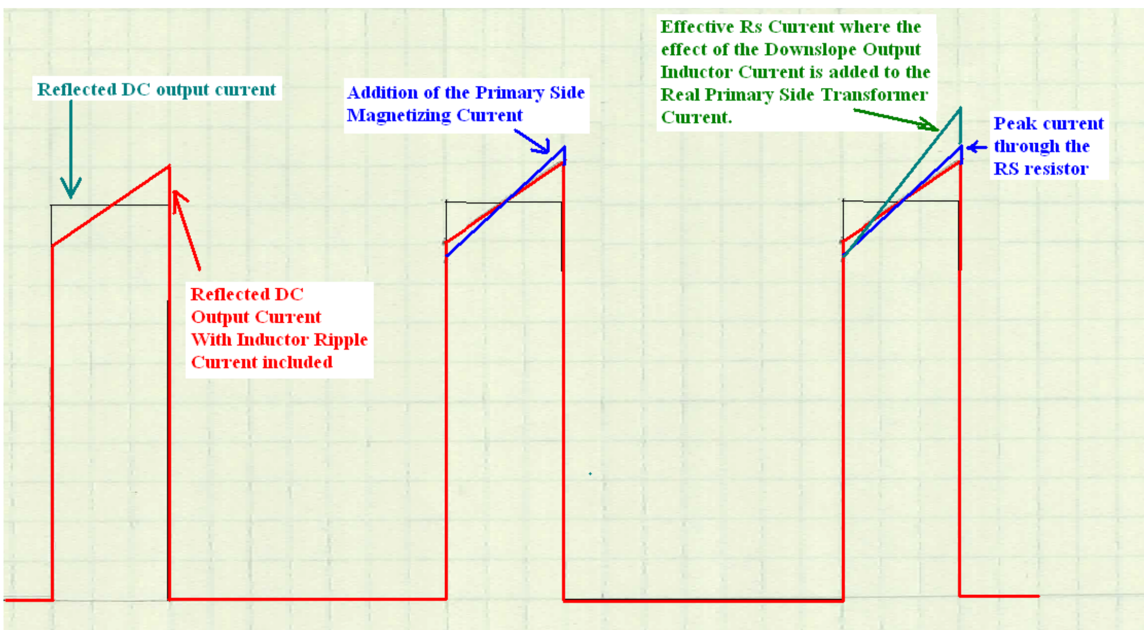

Figure 3. Current Through The RS Resistor

In Figure 3, the current through the R_s resistor is broken down successively into its component in the first two pulses. The third pulse of Figure 3 shows the contribution of the virtual current through R_s if the downslope current were to be added to the real current through the R_s resistor.

Equation 2 reflects a graphical representation of the peak current at maximum input voltage.

$$I_{pkpri} = (I_{\max} + (\Delta I_{Lout} \div 2)) \times (N_s \div N_p)) + ((V_{inx} \times T_{onx}) \div (2 \times L_{mag})) \tag{2}$$

Since the converter is designed so that the peak to peak ripple is 20% of the maximum DC current and input voltage, the $I_{\max} + (\Delta I_{lout} \div 2)$ will become $1.1 \times I_{\max}$ and if the primary side inductance is significantly higher than the reflected output inductance we can rewrite equation EQ2 as

$$I_{pkpri} = I_{\max} \times 1.1 \times (N_s / N_p) \tag{3}$$

This will be the peak current through the R_s resistor at maximum input voltage and maximum load. There will be some additional current (µa range) from the UCC28083 (Irf) as it adds in the downslope component but this is so small as to be ignored.

This sets the output inductor L_{out} value.

$$L_{out} = ((V_{inx} \times (N_s / N_{p)})) - V_{out}) \times T_{onx}) / (0.2 \times I_{\max}) \tag{4}$$

If the oscillator frequency is defined as F_{osc} then the "ON" time T_{on} of the switch can be defined as a function of the input voltage.

$$T_{on} = ((V_{out} \times N_p) / (N_s \times F_{osc} \times V_{in}) \tag{5}$$

Another factor that can be defined is the amount of downslope that is going to be added as a function of the "ON" time.

$$I_{ds(T_{on})} = ((V_{out} \times T_{on}) / L_{out} \tag{6}$$

Obviously from EQ5 the lower the input voltage the longer the "ON" time.

From EQ6 the longer the "ON" time the more downslope that is going to be added to the current signal.

These two equations indicate that the lower the input voltage the higher the downslope current component will be.

Conversely we know that the lower the input voltage the lower the slope of the current through the output inductor. This current slope for any input voltage can be defined by the equation below:

$$di / dt = ((V_{in} \times (N_s / N_p)) - V_{out}) / L_{out} \tag{7}$$

The maximum "ON" time Ton_{min} which occurs at the minimum input voltage can be determined by modifying Equation 5 for minimum input voltage.

$$Ton_{Vin_{\min}} = ((V_{out} \times N_p) / (N_s \times F_{osc} \times Vin_{\min}) \tag{8}$$

Next the peak current needs to be calculated for minimum input voltage. To do this we need to calculate the peak to peak magnitude of the current ramp through the output inductor for minimum input voltage (EQ9) and divide that by half as this ramp will be balanced about the DC inductor current as shown in Figure 2.

$$Ipk2pk_{Ton_{Vin_{\min}}} = (((Vin_{\min} \times (N_s / N_p)) - V_{out}) \times Ton_{Vin_{\min}}) / L_{out} \quad (9)$$

When this plus the DC output current are translated to the primary side it will be the peak current through the current sense resistor at minimum input voltage. This does not have any of the downslope component but it will be the actual current and will determine the power handling capability needed for the current sense resistor.

$$I_{PRI}\,pk_{Ton_{Vin_{\min}}} = ((I_{\max} + (Ipk2pk_{Ton_{Vin_{\min}}} \div 2)) \times (N_s / N_p)) \quad (10)$$

To size the resistance value of the current sense resistor you next have to calculate what a current equal to the downslope current times Ton_{min} if translated to the primary and identify what that effective current would be. To get that we modify Equation 6.

$$Ids_{Ton_{Vin_{\min}}} = (((V_{out} \times Ton_{Vin_{\min}}) / L_{out}) \times (N_s / N_p) \quad (11)$$

Now to determine the value of the current sense resistor. The overcurrent threshold of the UCC28083 is between 0.7 volts and 0.8 volts. To make certain that the converter can supply the maximum required power under all conditions use a voltage that is less than the specified minimum overcurrent threshold for the trip point calculations. This will leave some margin.

95% of 0.7 volts is 0.665 volts so that will be the value to be used.

R_{Isense} can now be determined.

$$\mathrm{R}_{\mathrm{Isense}} = 0.665V \div (I_{PRI}\,pk_{Ton_{Vin_{\min}}} + Ids_{Ton_{Vin_{\min}}}) \quad (12)$$

Since the downslope current is not actually in the current coming across the transformer in needs to be created on the primary side and added to the signal that is being generated across R_{Isense}.

Equation 13 below defines the voltage that needs to be added to the voltage across the curetn sense resistor.

$$Vds_{Ton_{Vin_{\min}}} = (\mathrm{R}_{\mathrm{Isense}} \times Ids_{Ton_{Vin_{\min}}}) \quad (13)$$

How this is done is explained with the help of Figure 4 the block diagram of the UCC28083.

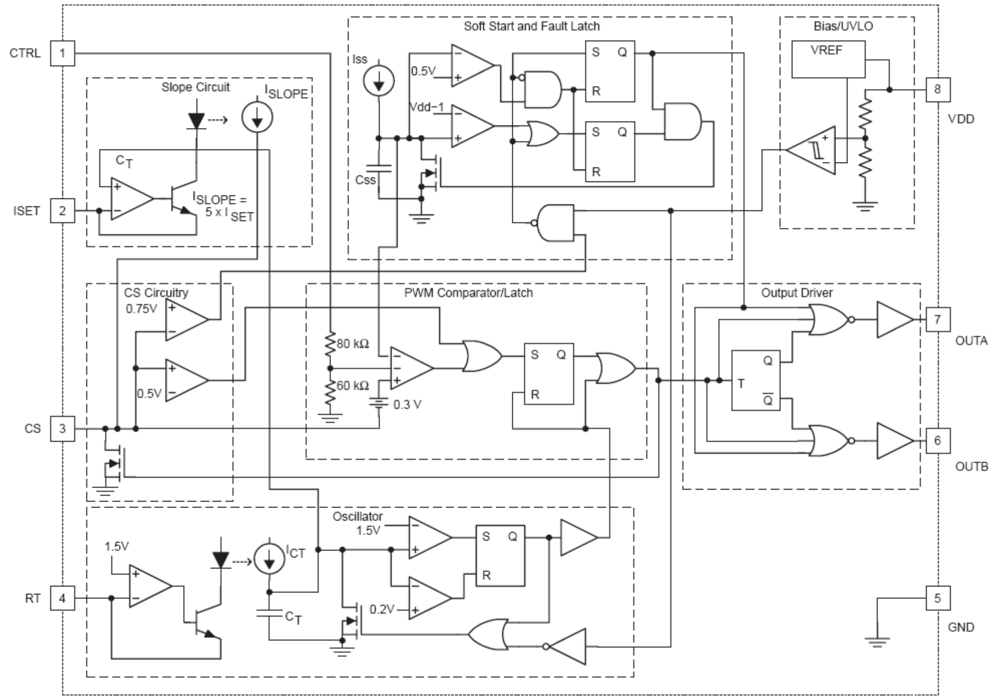

Figure 4. Block Diagram of UCC28083

There are 3 resistors that are used to set and add the downslope. The first of these is the RT resistor which is used to set the switching frequency (F_{osc}). The switching frequency is a function of the current through the Rt resistor with a voltage of 1.5 volts across it. This sets the charge current to the internal timing capacitor. The formula in the data sheet is used to set the frequency.

For our purposes in determining the voltage on the Iset pin at the peak of maximum duty cycle we will ignore the fall time of the Ct which means that we will assume that the voltage on the Iset pin goes from 0.2 volts to 1.5 volts in T_{osc} which is defined as 1/ F_{osc}.

We will define the peak voltage at the end of the maximum duty cycle on the Iset pin at the minimum input voltage as:

$$VIset_{Ton_{Vin_{\min}}} = (1.5V \times (Ton_{Vin_{\min}} \div T_{osc})) \qquad (14)$$

Two resistors are now used to set the down slope voltage that has to be developed across the resistor Rcs from the CS pin to the R_{Isense} resistor. These resistors are a function of each other.

The data sheet test conditions show Iset at 30 µA so for no better reason than that, We will set the RIset resistor to ((1.5 V) / (30 µA)) = 50 kΩ.

This sets the value of Rcs remembering that the current through Rset is multiplied by 5 before it is injected into Rcs:

$$Rcs = Vds_{Ton_{Vin_{\min}}} \div ((VIset_{Ton_{Vin_{\min}}} \div (R_{Iset})) \times 5) \quad (15)$$

This should complete the setting up of the current limit and the components need for down slope for the UCC28083 family of PWM converters including the determination of the current sense resistor R_{Isense} (R_S in Fig 1), the RIset (R_{SET} in Fig.1), and the resistor need for adding the down slope voltage Rcs (R_F in Fig.1).