TB3120

Slope Compensator on PIC® Microcontrollers

Author: *Namrata Dalvi*
Microchip Technology Inc.

INTRODUCTION

This technical brief describes the internal Slope Compensator peripheral of the PIC® microcontroller. This document also describes how to configure the Slope Compensator along with other peripherals to be used in Current mode controlled DC-DC converters. Current mode controllers do have a few challenges such as loop instability at duty cycles of over 50%, sub-harmonic oscillations due to instability and gain peaking at half the switching frequency. Fortunately, slope compensation can typically alleviate all of these problems. PIC microcontrollers also have some intelligent analog peripherals like DAC, op amp and fast comparators, which can be used in combination with the internal Slope Compensator. This is useful for Current mode controlled DC-DC converter application.

SLOPE COMPENSATOR ON THE PIC MICROCONTROLLER

The internal Slope Compensator on the PIC microcontroller is a decaying ramp generator. An artificial ramp is subtracted from the reference signal of the comparator. It pre-charges an output circuit to a set voltage from the selected input and linearly decays the output voltage using a programmable current sink through a capacitor, as shown in Figure 1.

FIGURE 1: SLOPE COMPENSATOR BLOCK DIAGRAM

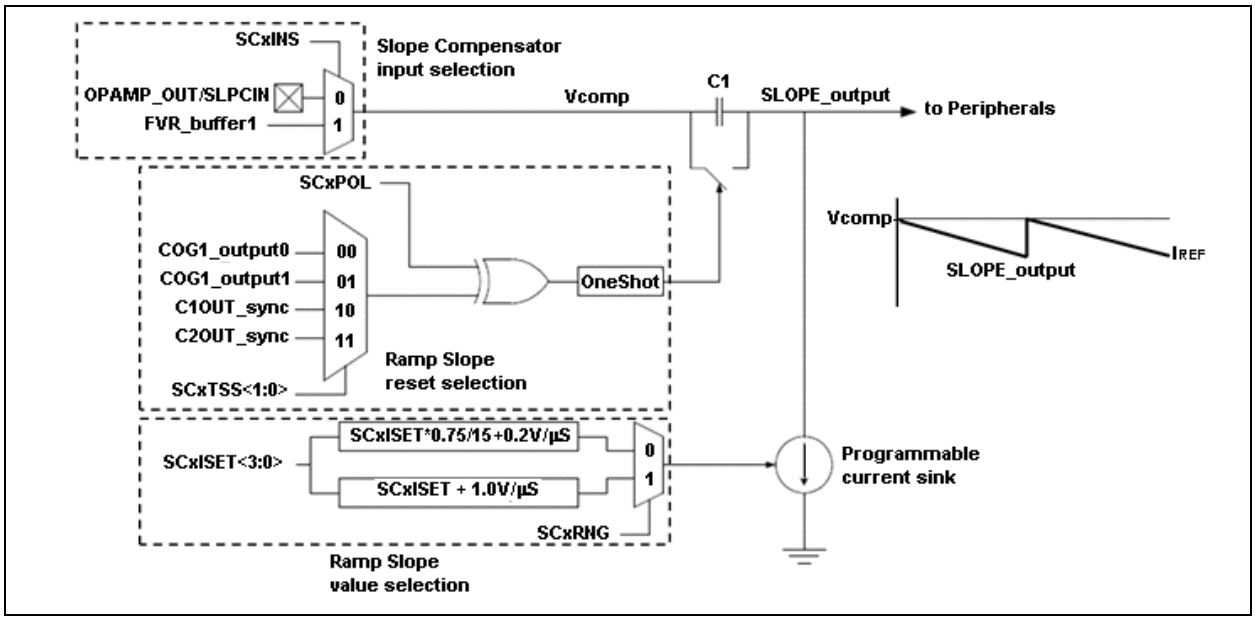


TABLE 1: REGISTERS ASSOCIATED WITH SLOPE COMPENSATOR MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
SLPCCON0	SC1EN	—	—	SC1POL	SC1TSS1	SC1TSS0	—	SC1INS
SLPCCON1	—	—	—	SC1RNG	SC1ISET<3:0>			

The input to the Slope Compensator can be selected from FVR output or op amp output (same I/O pin known as Slope Compensator input pin) using the SC1INS bit of the SLPCCON0 register. The output can be reset with the one-shot pulse. This one-shot pulse can be selected as COG1_output0, COG1_output1, Comparator 1 output or Comparator 2 output (see Figure 1) using the SC1TSS<1:0> bits of the SLPCCON0 register. The Slope Compensator can also be selected as an input to the comparator or the op amp. The amount of ramp to be subtracted from the reference signal can be set using the SCxRNG and SCxISET bits in the SLPCCON1 register, as shown in Table 2. Refer to the specific device data sheet for the Ramp Slope Value selection.

The slope of ramp signal is given by following Equation 1.

EQUATION 1: RAMP SLOPE VALUE

If SC1RNG bit = 1: Ramp slope = SC1ISET + 1.0V/µs.
If SC1RNG bit = 0: Ramp slope = SC1ISET * 0.75/15 + 0.2V/µs

TABLE 2: RAMP SLOPE VALUE SELECTION USING SC1RNG AND SC1ISET

SC1RNG:SC1ISET Value	Slope Value (V/us)	SC1RNG:SC1ISET Value	Slope Value (V/us)
0h	0.2	10h	1.0
1h	0.25	11h	1.1
2h	0.3	12h	1.2
3h	0.35	13h	1.3
4h	0.4	14h	1.4
5h	0.45	15h	1.5
6h	0.5	16h	1.6
7h	0.55	17h	1.7
8h	0.6	18h	1.8
9h	0.65	19h	1.9
Ah	0.7	1Ah	2.0
Bh	0.75	1Bh	2.1
Ch	0.8	1Ch	2.2
Dh	0.85	1Dh	2.3
Eh	0.9	1Eh	2.4
Fh	0.95	1Fh	2.5

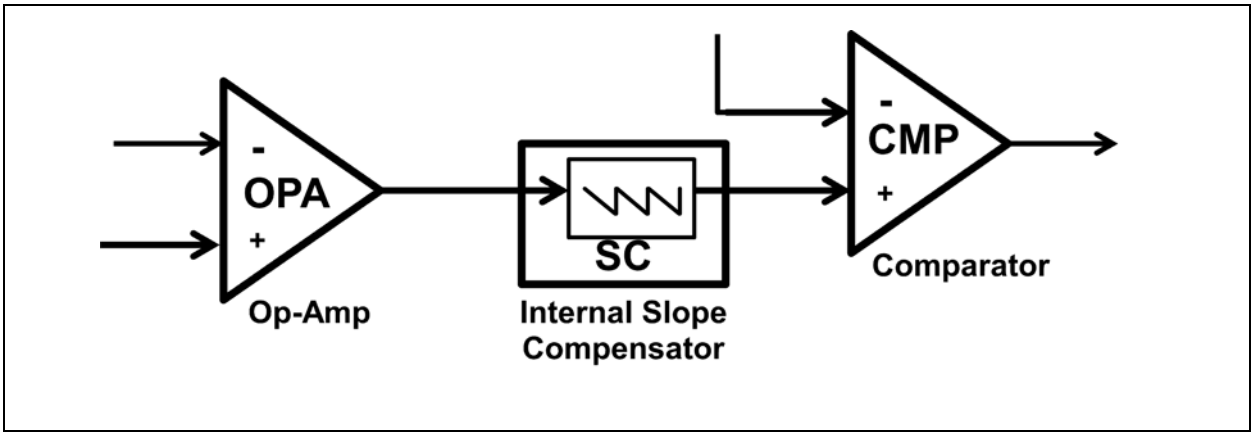
Some PIC microcontrollers have a Programmable Ramp Generator peripheral. This can be configured as a Slope Compensator (decaying ramp) or as a Ramp Generator (incrementing a saw-tooth ramp). Older PIC microcontrollers may not have this option. The Ramp Generator can be used either in Voltage mode controlled or Current mode controlled DC-DC converters.

INTERCONNECTION OF SLOPE COMPENSATION WITH OTHER PERIPHERALS

A typical interconnection diagram for the Slope Compensator on the PIC microcontroller is shown in Figure 2. It uses the on-chip peripherals, namely Slope Compensator, op amp and comparator. The desired voltage reference to the op amp is provided internally using DAC. The output of the op amp is internally connected to the Slope Compensator peripheral by setting the SC1INS bit of the SLPCCON0 register to '0'.

The Slope Compensator subtracts voltage ramp from the output of op amp. The amount of voltage ramp signal can be varied using different settings of the SCxRNG and SCxISET bits in the SLPCCON1 register, as shown in Table 2. The output of the Slope Compensator is then internally connected to the positive terminal of the analog comparator by setting the CxPCH<1:0> bits of the CMxCON1 register to 0b011. The analog comparator compares the output of the Slope Compensator with the signal provided on its negative input.

FIGURE 2: SLOPE COMPENSATOR INTERCONNECTION



CONFIGURATION OF THE SLOPE COMPENSATOR

Consider a case of the DC-DC boost converter with the following specifications:

TABLE 3: DC-DC BOOST CONVERTER SPECIFICATIONS

Parameter	Symbol	Specification	Unit
Nominal Input Voltage	V_{IN} (nom.)	12	VDC
Maximum Input Voltage	V_{IN} (max.)	20	VDC
Minimum Input Voltage	V_{IN} (min.)	9	VDC
Output Voltage	V_{OUT}	30	VDC
Maximum Output Current	I_{OUT}(max.)	1	A
Minimum Output Current	I_{OUT}(min.)	0.1	A
Inductor Ripple Current Ratio	I_{RIPPLE}	30	%
Maximum Output Voltage Ripple	$V_{OUTRIPPLE}$	300	mV
Switching Frequency	F_{SW}	250	kHz
Inductor selected	L	22	µH
Current Sense Resistor	R_{SENSE}	0.5	Ω

The down-slope or the slope of the inductor current during the OFF time (T_{OFF}) of the switching cycle for boost converter is given by m_2= (V_{OUT} -V_{IN})*R_{SENSE}/L V/sec.

By choosing the slope of the ramp signal to be subtracted m=m_2;

- m (for V_{IN} 9V)= (V_{OUT} -V_{IN})*R_{SENSE}/L = (30-9)*0.5/22µ = 0.477V/µS
- m (for V_{IN} 12V)= (V_{OUT} -V_{IN})*R_{SENSE}/L = (30-12)*0.5/22µ = 0.409V/µS
- m (for V_{IN} 20V)= (V_{OUT} -V_{IN})*R_{SENSE}/L = (30-20)*0.5/22µ = 0.227V/µS

After calculating the required ramp slope m, the nearest possible ramp slope can be set using the SCxRNG and SCxISET bits in the SLPCCON1 register, as shown in Table 2.

For the boost converter example described above with the 12V as V_{IN}, the configuration of the SLPCCON0 and SLPCCON1 registers is as follows:

EXAMPLE 1: CODE SNIPPET FOR CONFIGURATION OF SLOPE COMPENSATOR

```
SLPCCON0bits.SC1EN = 1;       //SC peripheral is enabled
SLPCCON0bits.SC1POL = 0;      //SC input normal polarity (active-high)
SLPCCON0bits.SC1TSS = 0b00;   //SC output is reset using COGOUT0
SLPCCON0bits.SC1INS = 0;      //SC input from SLPC1IN/ OPA1OUT pin
SLPCCON1 = 0x05;              //Ramp slope = 0.45V/us nearest to 0.409V/µS
```

CONCLUSION

This technical brief covers the Slope Compensator peripheral on PIC microcontrollers. It also provides the calculations relevant to determining the optimum slope required to achieve the desired performance of a power converter operating in fixed-frequency Current mode control. The interconnection of the on-chip peripherals to realize a Current mode controlled power converter with slope compensation is detailed. A typical example of a boost converter is dealt with along with calculations of the slope for a given specification. The configuration of the Slope Compensator to calculate this ramp slope for the boost converter is also highlighted.

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