# MultiPhase Sync Buck V1

This is a set of DEMO application schematics of a multi-phase synchronized rectified buck regulator using the SIMPLIS simulator. The nominal input voltage is 12V and the output voltage can be set to 1.0 V to 3.0 V. With the existing components in these schematics, the full output load current is set to 80A and the per-phase peak current limit is about 46A.

This package also contains a generic multi-phase synchronous rectified buck PWM controller model for SIMPLIS. This is a voltage-model controller with a fixed switching frequency of 200 kHz for each phase. The controller also provides a soft start-up whenever the voltage at the ENABLE pin makes a positive transition exceeding 3.0 V. There is no fault latch-off for this controller. Instead, a cycle-by-cycle current limit is provided for the top MOSFET of each phase. In addition, this PWM controller model can be set to operate in 2-, 3-, or 4-phase operation.

**NOTE:** Before opening up any one of the schematics, the simulation models for the PWM controller and the power MOSFETs, and the symbol for the PWM controller needs to be imported to your SIMetrix / SIMPLIS environment as they are not part of the standard release.

MultiPhase_SyncBuck.sxslb must be added as a symbol file to import the symbol of the PWM controller

The "MultiPhase_SyncBuck.sxslb" symbol file from this package contains the version-2 symbol of the generic multi-phase synchronous rectified buck PWM controller. If you have installed an earlier version of this symbol, please click the following sequence at the command-shell window of SIMetrix/SIMPLIS to remove the reference to the previous symbol file:

File | Symbol Editor | Symbol Manager | MultiPhase_SyncBuck.sxslb | Remove

Install the version-2 symbol of the generic multi-phase synchronous rectified buck PWM controller by clicking the following sequence at the command-shell window of SIMetrix / SIMPLIS:

File | Symbol Editor | Symbol Manager

In the Symbol Manager, click "Add" and browse through the directories to locate the MultiPhase_SyncBuck.sxslb file in this package and then click "Open."

MultiPhase_SyncBuck_PWM.lb must be added as a library model file

The "MultiPhase_SyncBuck_PWM.lb" library file from this package contains the version-2 model of the generic multi-phase synchronous rectified buck PWM controller. If you have never installed the model for this controller, or you have installed an earlier version of the model for this controller, you should use the Windows Explorer to copy and paste this library file into the "Models" directory located in the SIMetrix / SIMPLIS installation (root) directory.

Then both model and symbol must be associated

Click the following sequence at the command-shell window of SIMetrix / SIMPLIS:
File | Model Library | Associate Models and Symbols…
There is a square box on the left-hand side of the GUI. Click on it and scroll to select 4PHASE_SYNC_BUCK_CNTLR. If 4PHASE_SYNC_BUCK_CNTLR does not exist as a choice, then either the "MultiPhase_SyncBuck_PWM.lb" file was not properly deposited in the "Models" directory or the model/symbol associated has been carried out before. If you have carried out the model/symbol association for this controller earlier, you can skip the following instruction on association of model and symbol for the generic multi-phase synchronous rectified buck PWM controller.

If you were able to select 4PHASE_SYNC_BUCK_CNTLR, you will see a lot of text lines on the bottom half of the GUI, showing the content of the model for the PWM controller and the path name of the library file where it comes from. On the right hand side, click on the drop down list right under "Choose Symbol Category" to select "PSU controllers" and click the drop down list to the left of "New Symbol" to select 4PHASE_SYNC_BUCK_CNTLR. Then click "Apply Changes." Now the simulation model and the symbol for this generic PWM controller are associated and they would be ready for use in the schematics and simulation.

FDZ7064N.lb must be added as a library model file

Use the Windows Explorer to copy and paste this library file into the "Models" directory located in the SIMetrix / SIMPLIS installation (root) directory.
This file contains the SPICE simulation model for the FDZ7064N as obtained from the Website of Fairchild Semiconductor. The SIMetrix / SIMPLIS package will convert this model on the fly to the SIMPLIS model during simulation.

For more information, refer to the SIMetrix documentation.

The application schematics in this DEMO use some advanced features in SIMetrix / SIMPLIS to handle parameterization. Such parameterization enables us to handily initialize a few components so as to expedite the computation of the periodic steady-state operation. You can bring up any one of these schematics and run it as is without any modification. On the other hand, if you like to modify some of the component values, the output voltage, the load, or the number of phases involved, then you should read the Appendix at the end of this file before making any changes so that you would not, by accident, break up the parameterization.

The following are simulation schematics for various applications.

**MultiPhase_SyncBuck_POP_ac.sxsch** – This test first finds the periodic steady state operation using the POP analysis tool. Then an AC analysis is performed.

**MultiPhase_SyncBuck_step_load.sxsch** – This test first finds the periodic steady state operation using the POP analysis tool. Then a load transient is performed.

**MultiPhase_SyncBuck_fullload_to_noload.sxsch** – This test first finds the periodic steady state operation at full load using the POP analysis tool. Then the load is reduced to zero. Since the simple PWM controller model does not contain any over-voltage protection, the output voltage in this simulation could rise to higher than acceptable values. This test takes about 2:30 min to run on a 1Ghz machine.

**MultiPhase_SyncBuck_enable.sxsch** – This simulates the soft startup of the converter when the enable command is given. This test takes about 1:30 min to run on a 1Ghz machine. The generic controller achieves the soft-start by slowing raising the internal reference voltage to the error amp. and slowly raising the frequency of the oscillator after the ENABLE pin makes a positive transition exceeding 3.0 V

## Appendix

The parameterization is accomplished by defining a set of variables and expressions in the text window of the schematics and by having the component values defined in terms of these variables. To open the text window, hit the F11 key in the schematic editor. You will see the following defined:

```
.VAR N_PHASE 4
.VAR VDC 1.5
.VAR ILOAD_MAX 80
.VAR LOAD_AT_t0 0.25
.VAR ILOAD_AT_t0 {LOAD_AT_t0*ILOAD_MAX}
.VAR IL_AT_t0 {ILOAD_AT_t0/N_PHASE}
.VAR RLOAD {VDC/(ILOAD_MAX*LOAD_AT_t0)}
.VAR DELTA_ILOAD {ILOAD_MAX*(1-LOAD_AT_t0)}
.VAR VCOMP_AT_t0 {1+2*VDC/12}
.VAR VC3_AT_t0 {VCOMP_AT_t0-VDC}
.VAR RILIM 27k
.VAR RDC_LOUT 1m
        .
        .
        .
```

You can edit the content here to change the number of phases of the regulated converter, the nominal regulated output voltage, the maximum load, the initial load, the resistance values for the four current limiting resistors, and the DC winding resistances for the four output inductors.

The rest of the text in this text window were set up to properly initialize the currents through the inductors in phase 2, 3, and 4. More would be discussed on this matter in the latter part of this document.

The command

```
.VAR N_PHASE 4
```

sets the number of phases to 4. You can change the number of phases from 2 to 4.

The command

```
.VAR VDC 1.5
```

sets the output voltage to 1.5 by setting the voltage reference VDAC to 1.5V. The voltage source VDAC is normally a VID signal. For the sake of simplicity, the VID control is replaced by a simple DC reference here in these DEMO schematics. You can set the nominal output voltage to any voltage between 1.0V and 3.0V.

The command

.VAR ILOAD_MAX 80

sets the maximum load current to 80A. Currently, the final value of the load current for the **MultiPhase_SyncBuck_step_load** schematic and the initial value of the load current for the **MultiPhase_SyncBuck_fullload_to_noload** schematic are set to the value of the maximum load. You can set the maximum load to any value between 40A to 80A. If you set the maximum load current above 80A for the 4-phase operation, then you should also raise the values of the current limiting resistors RILIM1 to RILIM4.

The command

.VAR LOAD_AT_t0 0.25

sets the initial load to 25% of the maximum load. The initial load sets the value of the equivalent load resistor used in the **MultiPhase_SyncBuck_POP_ac**, **MultiPhase_SyncBuck_step_load**, and the **MultiPhase_SyncBuck_enable** schematics, although these schematics use different initial load values. You can set the initial load to any value between 10 to 100%.

The command

.VAR RDC_LOUT 1m

sets the DC winding resistances of the four output inductors to 1 milli-ohms.

If you like to change the component values for the following components:

output capacitor C1
compensation capacitor C3
the four output inductors L1 to L4
the four resistors RILIM1 to RILIM4 that set the current limit

you should select one of these components and hit the shift + F7 key combination instead of hitting the normal F7 key. This allows you to modify the component values without upsetting the link to the parameterization on the initial conditions. If you hit the F7 key to edit the component values on these components, you will get GUI dialogs to modify the values, but you will not be able to set the initial conditions to depend on the parameterizations. The component values of other components can be edited through the normal F7 key value dialog in SIMetrix.

The default schematics were set up to run a 4-phase interleaved operation. You can, however, select a 2-phase or 3-phase operation by setting the variable N_PHASE, as mentioned earlier, without having to delete the components in the unused phases from the schematic. Three steps have been taken in these example schematics to avoid unnecessary interaction between the components in the unused phases and the components in the active phases and all the user has to do is to set the N_PHASE variable properly in the text window. First, the controller model will turn off both the upper and lower MOSFETs in the unused phases. Second, the initial current through the output inductors in the unused phases are set to zero. Third, the DC winding resistance of the output inductors in the unused phases are set to 1 kilo-ohm, further isolating the components in the unused phase from those in the active phases.

One last note. You can change the peak current that triggers the cycle-by-cycle current limit by changing the component values of the four current limiting resistors RILIM1 to RILIM4. Each ILIM pin of the controller model draws 10 uA of current during normal operation. So the drain current of the upper MOSFETs at which the cycle-by-cycle current limit is triggered occurs at:

$$10^{-6}\ RILIM / Rds\_ON$$

The default components in these DEMO schematics lead to a peak current limit of about 46A for each phase.