Synchronous vs. Aynchronous Buck Regulators
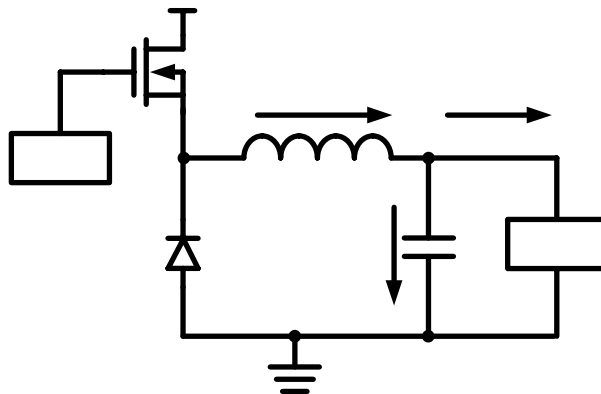
By Ajith Jain
Director Strategic Marketing, Power Management, Semtech Corporation

In this module, we will learn the key differences between synchronous and asynchronous buck topologies, their advantages, disadvantages and their application considerations.
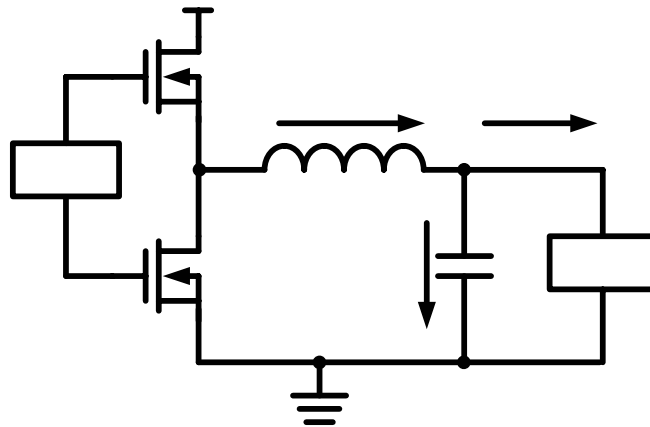
Asynchronous Buck Topology

A typical asynchronous buck regulator circuit is as shown in the figure above. 'S' denotes a MOSFET being used in the top side with a diode 'D' in the bottom side. These are the two main switches that control power to the load. When the MOSFET is turned ON, V_{IN} charges the inductor 'L', capacitor 'C' and supplies the load current. Upon reaching its set output voltage the control circuitry turns OFF the MOSFET (hence called a switching MOSFET). Switching OFF the top side MOSFET disrupts the current flowing through the inductor. With no path for the current, the inductor will resist this change in the form of a catastrophic voltage spike. To avoid this spike when the top side MOSFET is turned OFF, a path is provided for the inductor current to continue flowing in the same direction as it did before. This is created by the bottom side diode 'D'. When the top side MOSFET turns OFF, the inductor voltage reverses its polarity forward biasing the diode 'D' on, allowing the current to continue flowing through it in the same direction. When current flows in the diode, it is also known as being in freewheel mode. When the output voltage drops below the set point, the control will turn ON the top side MOSFET and this cycle repeats to regulate the output voltage to its set value.
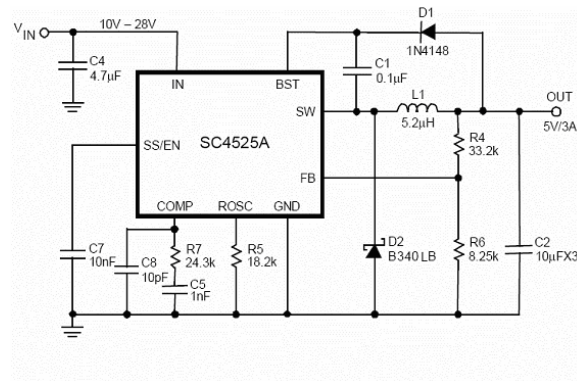
The above figure is a schematic example of an asynchronous regulator, the Semtech SC4525A. The inductor, diode, and capacitor discussed in the generic description above are labeled L1, D2, and C2 in the SC4525A schematic. The top side MOSFET is internal to the part and is not shown in the schematics.

Synchronous Buck Topology

The synchronous topology is depicted in the figure above. The bottom side diode 'D' has been replaced with another MOSFET, 'S2.' Since there are two MOSFETs 'S1' is called the high-side MOSFET and 'S2' the low-side MOSFET. The low-side MOSFET is also referred to as the synchronous MOSFET while the high-side MOSFET is called the switching/control MOSFET.

In steady state, the low-side MOSFET is driven such that it is complimentary with respect to the high-side MOSFET. This means whenever one of these switches is ON, the other is OFF. In steady state conditions, this cycle of turning the high-side and low-side MOSFETs ON and OFF complimentary to each other regulates V_{OUT} to its set value.

Observe that the low-side MOSFET will not turn ON automatically. This action needs additional MOSFET drive circuitry within the control IC to turn ON and OFF as needed. Compare this to asynchronous topology where the polarity reversal across the inductor automatically forward biases the diode, completing the circuit.

In both the asynchronous and synchronous topologies, the effective switch is the high-side MOSFET. It is the switch which dictates when to build up energy in the inductor and when to force the inductor current to start freewheeling.
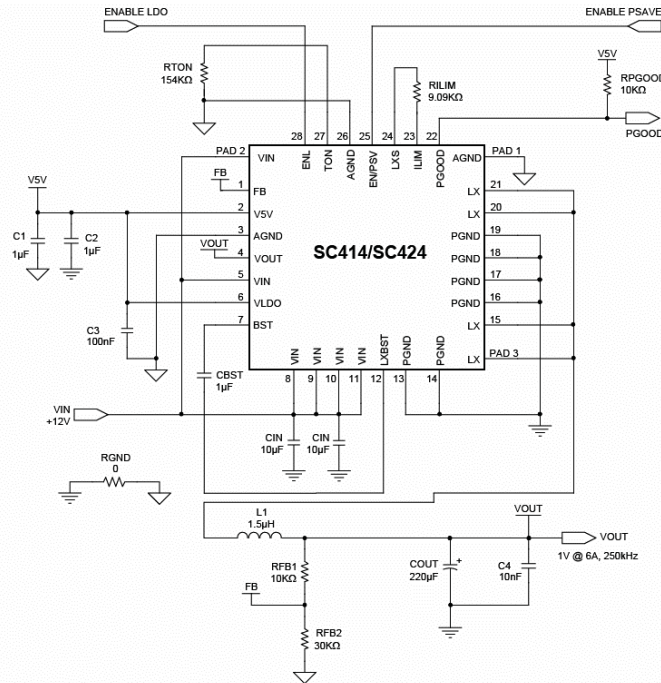
The above figure is a schematic example of a synchronous regulator, the Semtech SC414. The inductor and capacitor discussed in the generic description above are labeled L1 and COUT in the schematic. The top side and bottom side MOSFETs are internal to the part and are not shown in the schematics.

Advantages and disadvantages of these two topologies

The asynchronous topology uses just one MOSFET for the top side as the control switch. There is no so-called shoot-through issue. The IC tends to be smaller and relatively inexpensive. The use of an external diode in most cases eliminates the need for an expensive thermally enhanced IC package to dissipate the heat arising during the freewheel mode. However, the package still needs to take care of heat dissipation arising from switching losses associated with the high-side MOSFET.

In the synchronous topology the low-side MOSFET's lower resistance from drain to source (RDS_{ON}) helps reduce losses significantly and therefore optimizes the overall conversion efficiency. However, all of this demands a more complicated MOSFET drive circuitry to control both the switches. Care has to be taken to ensure both MOSFETs are not turned on at the same time. If both MOSFETs are turned on at the same time a direct short from V_{IN} to ground is created and causes a catastrophic failure. Ensuring this direct short, which is also called cross-conduction or shoot-through, does not occur requires more complexity and cost within the IC.

Application Considerations

A few considerations are listed below to help determine which topology best suits the application on hand:

1) Duty cycle is a key factor. A smaller duty cycle means, the converter spends more time in the freewheeling mode. The asynchronous topology typically has a greater voltage drop across the bottom switch. This means for an equivalent system, the asynchronous topology in general dissipates more power.
2) Output voltage is another key factor. The lower the output voltage is the closer it is to the drop out voltage of the bottom-side diode. Percent power loss is expressed as $V_{Diode\_Drop}*(1-\text{Duty cycle})/V_{OUT}$. Therefore, percentage wise, a lower V_{OUT} means higher loss.
3) The third factor is the thermal issue associated with the power loss dissipation for the IC and other packages.
4) Component complexity should be considered. The more complex the controller, the larger the die area required and the more expensive the die.

Here are examples considering these factors:

For these examples, the following parameters will be used:

V_{IN} = 24V

V_{OUT} = 5V

I_{OUT} = 3A

Asynchronous regulator = SC4525A with B340LB Schottky diode

Synchronous regulator = SC414

Factor 1 – Duty cycle:

The duty cycle will be the same for both the asynchronous and the synchronous regulators.

Duty cycle = V_{OUT} / V_{IN} = 5V/24V = ~21%

21% of the time the converter is in switching mode while the other 79% is spent in freewheel mode using the bottom side switch. The power loss for the asynchronous regulator at 3A during freewheel mode is:

V_{Diode_Drop} x (1-Duty cycle) x I_{OUT} = P_{Loss}. = 0.4V x 3A x 79% = 0.95 Watts

The power loss for the synchronous regulator at 3A during freewheel mode is:

V_{MOSFET_Drop} x (1-Duty cycle) x I_{OUT} = P_{Loss}. = 0.1V x 3A x 79%= 0.24 Watts

Factor 2 – Percent power loss:

The percent power loss for the asynchronous regulator is:

V_{Diode_Drop} **x (1-Duty cycle) / V_{OUT} = 0.4V x 79% / 5V = 6.3%**

The percent power loss for the synchronous regulator is:

V_{MOSFET_Drop} **x (1-Duty cycle) / V_{OUT} = 0.1V x 79%/ 5V = 1.6%**

Factor 3 – Thermal:

The IC die temperature using is calculated by the following equation:

$T_J = (\Theta_{JA} \times P_{LOSS}) + T_A$

Where T_J equals junction temperature, Θ_{JA} equals the thermal resistance from junction to ambient and T_A equals the ambient temperature around the device.

Calculating the actual T_J of the various devices is beyond the scope of this paper, but from the equation, it is shown power loss is a significant factor. Even with an equivalent Θ_{JA} the synchronous regulator will run significantly cooler than the asynchronous regulator with the same physical size due to a lower overall power loss.

Factor 4 – Die complexity/BOM cost:

Considering only silicon costs, the following BOMs costs were generated from Digi-key pricing (10k to 12k units):

Solution based off SC4525A: $0.67

Solution based off SC414: $1.13

As can be seen, all the advantages of the synchronous topology come at a cost penalty.

<u>Conclusion:</u>

This paper has compared the basic differences between asynchronous and synchronous regulators. Which topology is best will depend on the requirements for a design as well as what factors have the most importance.