Charge pump and Murata's charge pump module

A charge pump is a kind of DCDC converter that uses capacitors for energetic storage, which can generate such as double voltages, half voltages and invert voltages. It consists of switching devices and capacitors.

Figure 1 shows the simple step-down charge pump as an example. Each green and yellow switches in Figure 1 can be turned on and off at a fixed on-time alternately to convert output voltage (VOUT) = half input voltage (VIN). This voltage conversion ratio can be changed depending on the number of connections between the capacitor and the switching devices.

The charge pump is open-loop controlled and has a droop characteristic in which the output voltage decreases with the increase in load current. Further, an inductor is not required for the charge pump as shown in Figure1. In general, magnetic components tend to be the tallest component, and it is occupied the large PCB area in the DCDC converter. On the other hands, a small and thin DCDC converter can be achieved with the charge pump.

Since the charge pump is a method of discretely supplying charge to the output capacitor (COUT), there is a period of delivering power from COUT to the output load. As a result, the output ripple voltage increases. To solve this problem, it is necessary to mount on many capacitors or large capacitance, which leads to an increase the solution size. Also, a transient current happens to capacitors during the period of charging to the discharged capacitor, so that the component is stressed by this transient current. In addition, Charge re-distribution Loss, the loss peculiar to charge pumps associated with charge transmission between capacitors, leads to a decrease in efficiency. Therefore, charge pump has not been applied to very low-power products.

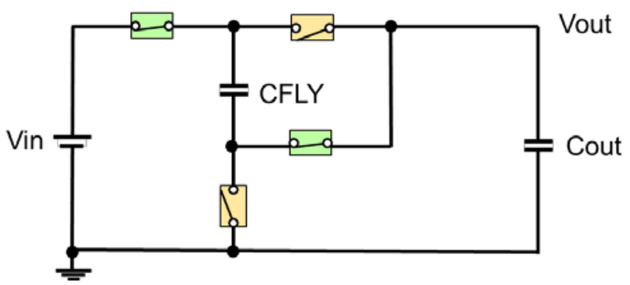


Figure 1. Charge pump

Murata will release a product adopting charge pump architecture as shown in Table 1. This module is a product that has been measured using its own technology against the disadvantages of charge pump such as the increase in output ripple, the bigger PCB size, and transient stress on the device.

MYC0409-NA is fixed divide-by-four conversion ratio from input voltage to output voltage, it can be converted from 48V to approximately 12V. this module is stable for 48V system and 54V system to generate an intermediate bus voltage.

Since this product utilizes Murata's proprietary charge pump technology, it has high efficiency and high power density within 2.1mm height. Murata technology does not need to use taller or heavier parts. Therefore, it can be mounted on the back side of the board.

Table 1. UltraCP^{TM} Product outline

Product Name	Input Voltage (V)	Output Voltage (V)	Output Current (A)	Size (mm)	Height (mm)	Efficiency (%)
MYC0409-NA	48 (20-60)	VIN/4	6	11.5*9.5	2.1_max.	95.0 (VIN=48V/IOUT=6A)

What is different step-down converter from our charge pump?

Figure 2 shows a basic circuit of step-down converter and its waveforms. It consists of input and output capacitors, high-side MOSFET, low-side MOSFET and an inductor. It is power electronic circuits which convert a DC input to a variable DC at the output. It can be converted to the output voltage by adjusting ON time of the MOSFETs. The ON time is determined by the feedback circuit to maintain the output voltage. Closed feedback loops maintain output voltage constantly even if input voltages or output currents changes.

The charge pump differs somewhat from the behavior of conventional inductive step-down converter because of its architecture. It is a divide-by-N capacitive voltage converter, and the voltage conversion ratio depends on each product. It is an open-loop converter that does not have output regulation capability. Therefore, the output voltage decreases as the load current increases.

Since the voltage conversion ratio is constant, it can be shown in a simple model of the ideal voltage conversion and the output equivalent resistance (ROUT) in Figure 3. The voltage conversion expressed by ideal conversion and voltage drop with respect to load current are expressed by ROUT. In Figure 3, the output voltage of the charge pump can be calculated by the following equation.

$$VOUT = \frac{VIN}{Divide\ ratio(DIV\ N)} - ROUT * IOUT$$

Next, it describes inductors and capacitors that are one of the important components of a step-down converter. The operation of the step-down converter and charge pump are explained to clarify the advantage of the charge pump.

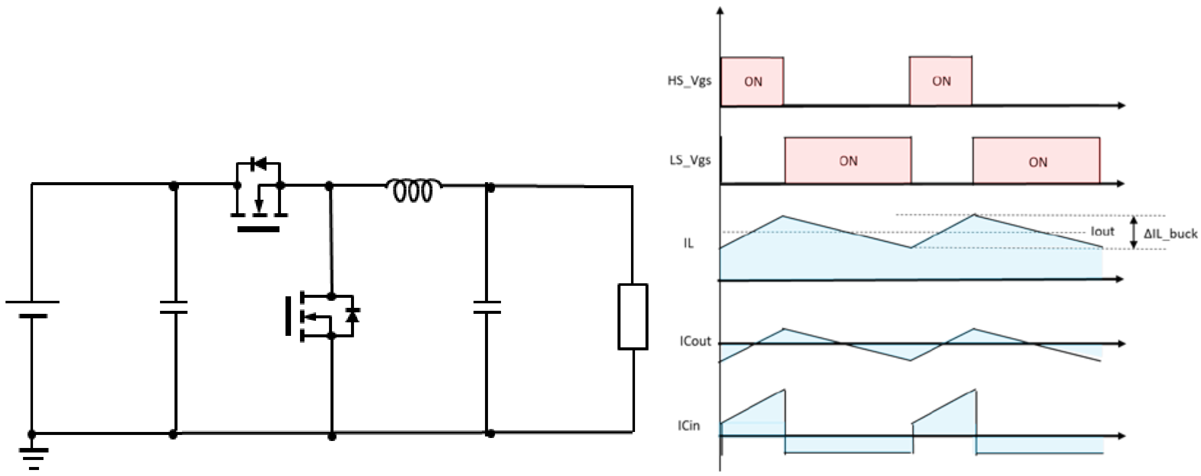


Figure 2. Step-down converter

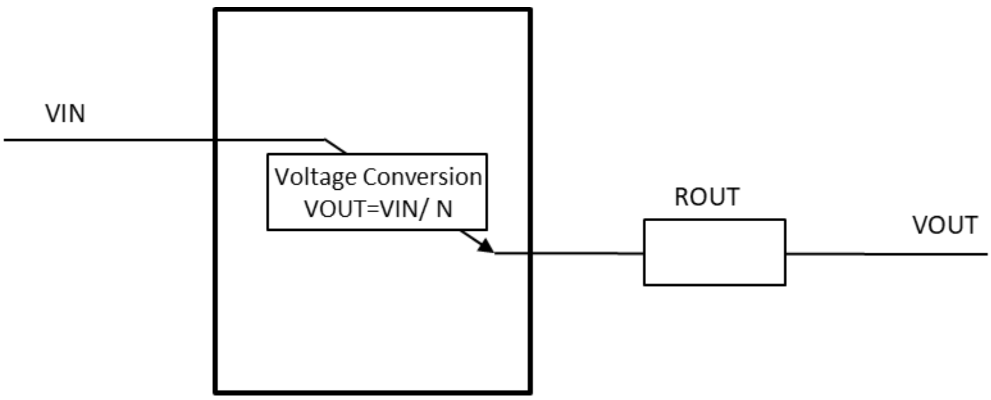


Figure 3. Idealized diagram for charge pump

Inductor ripple current

Figure 4 shows the state when the high-side MOSFET turn on. The voltage across the inductor is an input voltage (VIN) and an output voltage (VOUT). The inductor current is determined by the voltage, on-time of MOSFET, and inductance. Therefore, the inductor ripple current can be expressed by the following equation.

$$\Delta I_{L\_buck} = \frac{(Vin - Vout)}{Lout} * \frac{1}{fsw} * D$$

ΔI_L:	Inductor ripple current
Lout :	Inductance
Fsw:	Switching frequency
D:	Duty ratio (VOUT/VIN)

From the above equation, it is necessary to increase the inductance or the switching frequency for lower ripple current.

It needs to increase the number of turns of the inductor or to increase the core cross-sectional area for a higher inductance. In the former, the DCR increases by the higher number of turns leads to increase the conduction loss. When thick windings are used to reduce losses, space for winding gets to be required. As a result, a large core will be required. Since the volume of the core is larger in the latter, it is difficult to reduce the inductor for a high-current step-down converter. When the switching frequency is set to a higher frequency, it leads to switching loss of the MOSFET, which leads to a decrease in efficiency.

Since there is a limitation for the inductor, it will be more difficult to realize smaller size and high efficiency with low-profile.

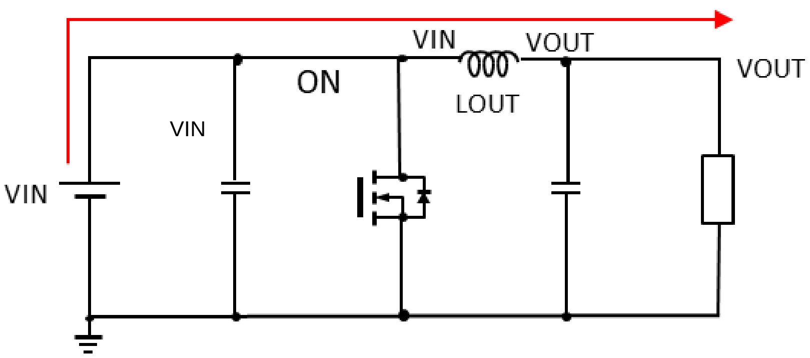


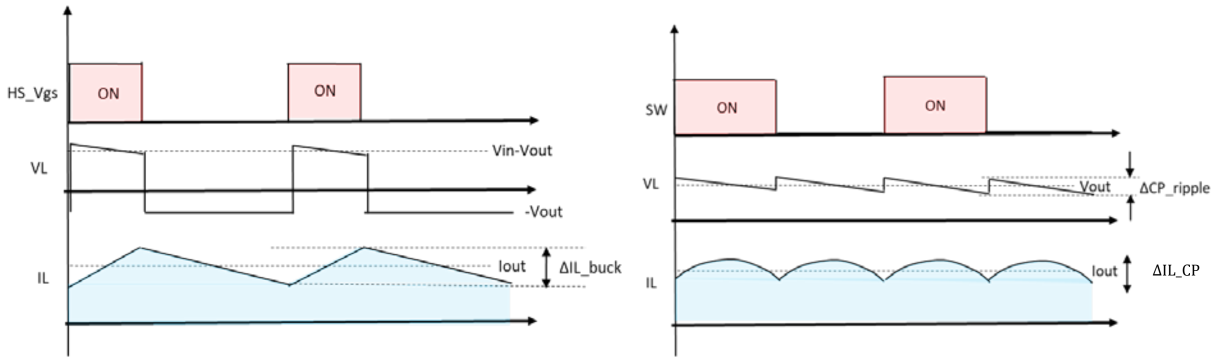
Figure 4. Step-down converter (State 1: High side FET ON)

On the other hand, the charge pump supplies power with capacitors. In the circuit topology in which voltage conversion is performed by using an inductor or transformer, the magnetic components tend to be bottleneck for low-profile product.

As described above, the use of magnetic components with low-profile leads to a decrease in efficiency. The charge pump can achieve a low-profile with high-efficiency. A reason is the power density of the capacitor is higher compared to the power density of the inductor. Therefore, the power supply with a high power density can be achieved using the charge pump.

Murata's charge pumps use a small inductor. The inductor is connected to the rear after the charge pump and can be reduced the output ripple voltage by an LC filter.

As shown in Figure 5(b), since the amplitude of the voltage across the inductor is very smaller compared to the step-down converter, it does not require high inductance. Due to the low number of turns, the inductance is low, and inductors with small DCR can be used. This leads to a reduction in conduction losses.



(a) Step-down converter (b) Murata's charge pump

Figure 5. Inductor voltage and ripple current

Input ripple voltage

Although the average value of an input current becomes smaller in proportion to the conversion ratio, momentarily the input current equal to output current flows through the step-down converter. This will be averaged by the input capacitor, but as it is clearly shown as ICIN of Figure 2, the alternating ripple-current flowing in the input capacitor is higher than ICO of the output. The RMS value of ICIN of step down converter can be calculated as following equation.

$$I_{CIN} = \sqrt{\frac{Vout}{Vin}\left(I_{out} * (1 - D) + \frac{1}{12} * \Delta I_{L_{buck}}{}^{2}\right)}$$

The input current is divided by N in Murata's charge pump (Iin=IL/ (DIVN)). In addition, UltraCP™ have applied two phase configurations and the duty cycle is fixed 50%, and the input current deliveries the power at each period. Therefore, it does not cause transient current changes in the input capacitor. Ripple-current flowing in the input capacitor is as similar 1/N(voltage conversion ratio) of the inductor current. Therefore, it can be achieved low input ripple voltage using less capacitors.

Application

As an example, Figure 6 shows a system diagram applied UltraCP™ series in a small cell system. MYC0409-NA is mounted on after AC/DC converter or isolated converter to generate 12V from 48V line. By adapting UltraCP™ series, high-efficiency, small-sized systems can be achieved.

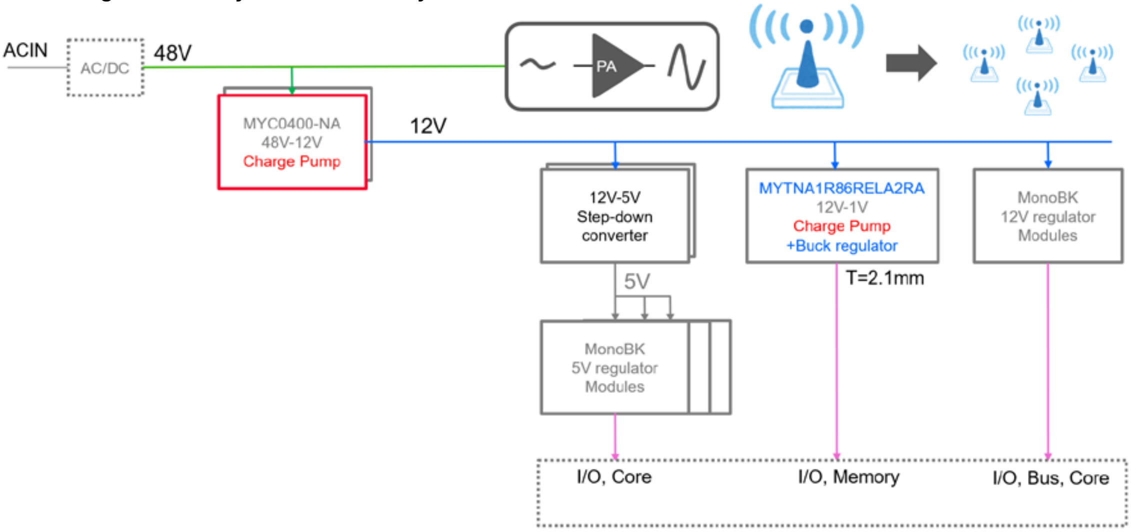


Figure 6. small cell system

Electrical characteristics and solution size

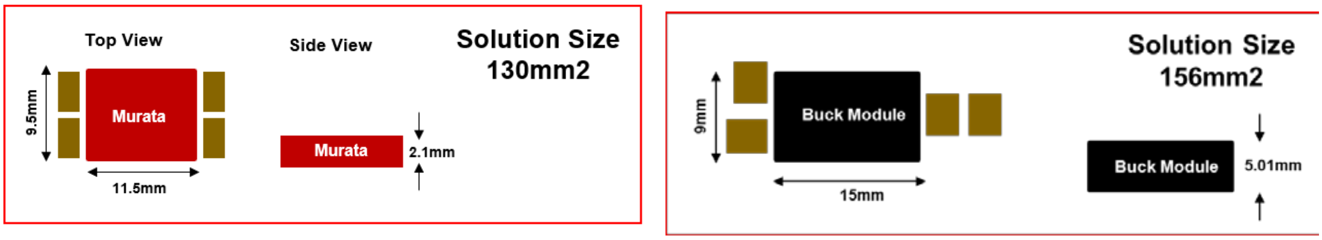
The characteristics comparison results of a general non-isolated step-down DCDC converter module using an inductor as an energy conversion element and the charge pump module MYC0409-NA are shown. In this comparison, the evaluation result was performed with the input voltage of 48 V and the output voltage of approximately 12 V. Figure 7 shows the efficiency characteristics, Figure 8 shows a comparison of solution sizes, and Figure 9 shows a comparison of temperature characteristics.

First, the efficiency characteristics have an efficiency difference of 5% or more in comparison with 4A, which is the maximum rated current of the step-down converter.

The MYC0409-NA can reduce the PCB area of about 20%. As a feature of charge pump technology, the product is overwhelmingly low-profile and light-weight, therefore it can be mounted on the back side and adapted to systems with low-profile requirements.

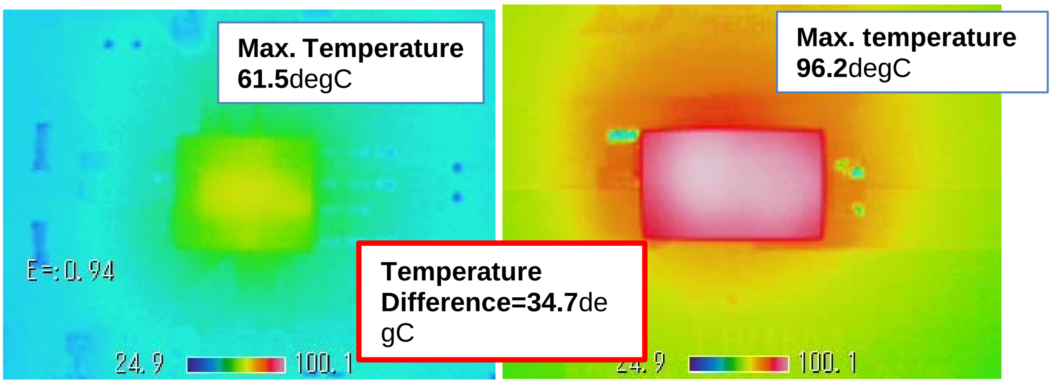
For temperature characteristics, even though the area of the evaluation board is smaller than the comparison, a temperature is 34.7 degC less than step-down module because of the high efficiency.

Figure 7. Efficiency characteristics (VIN=48V, VOUT=12V)



(a) MYC0409-NA (b) Step-down converter module

Figure 8. PCB area



(a) MYC0409-NA (b) Step-down converter module

Figure 9. Temperature characteristics (VIN=48V, VOUT=12V, IOUT=4A)

Summary

Table 2 shows a comparison of Murata's charge pump and step-down converter.

The charge pump is a voltage conversion scheme that can realize small size and high efficiency, especially in applications where low-profile is required. Although it has the disadvantage of worse load regulation than step-down converters, it is suitable for intermediate bus systems as first-stage converters. The output voltage is regulated by the point-of-load (PoL) of the second-stage converter.

Table 2. A comparison of Murata's charge pomp and step-down converter

	Charge pump	Step-down converer
Output Voltage	VIN / DIV N–IOUT*ROUT	VIN * D
Regulation	×	○
Efficiency	○	×- ○ (Depend on inductor size)
Solution Area	○	△
Height	○	×-△ (Depend on inductor size)

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