# Application Note

# Regulated Capacitive Charge Pump with Programmable Output and Powerdown using GreenPAK

## AN-CM-263


## Abstract

*This application note presents how to make a capacitive charge pump with a programmable, regulated output voltage using GreenPAK IC and a couple of low-cost external components. Single stage charge pump may be configured as voltage booster or voltage inverter. GreenPAK charge pump operates at input voltages 1.8 V to 5 V and load currents up to 145 mA. Overall performance peaks at input voltages 3 V to 5 V and output currents 1 mA to 5 mA, using Schottky external diodes. The advantage of GreenPAK solution is the flexibility to shift the design to meet the system priorities, such as a focus on power consumption, ripple etc.*

*This application note comes complete with design files which can be found in the References section.*

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# 1 Terms and Definitions

| | |
|---|---|
| BOM | Bill of materials |
| CMOS | Complementary metal oxide semiconductor |
| DUT | Device under test |
| EMI | Electromagnetic interference |
| ESR | Equivalent series resistance |
| GPIO | General purpose input output |
| I2C | Inter-integrated circuit |
| IC | Integrated circuit |
| IoT | Internet of things |
| LDO | Low drop out regulator |
| LUT | Lookup table |
| MLCC | Multi-layer ceramic capacitor |
| MOSFET | Metal oxide semiconductor field effect transistor |
| NFET | N-channel field effect transistor |
| PFET | P-channel field effect transistor |
| $R_{dson}$ | Resistance drain-source while FET is ON |
| SPI | Serial peripheral interface |

# 2 References

For related documents and software, please visit:

GreenPAK™ Programmable Mixed-Signal Products | Renesas

Download our free GreenPAK™ Designer software [1] to open the .gp files [2] and view the proposed circuit design. Use the GreenPAK development tools [3] to freeze the design into your own customized IC in a matter of minutes. Find out more in complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the GreenPAK IC.

[1] GreenPAK Designer Software, Software Download and User Guide

[2] AN-CM-263 Regulated Capacitive Charge Pump with Programmable Output and Powerdown using GreenPAK.gp, GreenPAK Design File

[3] GreenPAK Development Tools, GreenPAK Development Tools Webpage

[4] GreenPAK Application Notes, GreenPAK Application Notes Webpage

[5] Capacitive Charge Pump using GreenPAK, Application Note

[6] SLG46533, Datasheet

[7] MCP1252/3 Low-Noise, Positive-Regulated Charge Pump, Datasheet, Microchip Technology

[8] LTC1751/LTC1751-3.3/LTC1751-5, Datasheet, Linear Technology.

[9] TPS6013x Regulated 5-V, 300-mA High-Efficiency Charge Pump DC-DC Converters, Datasheet, Texas Instruments.

# 3 Introduction

Many battery powered applications in the IoT market require additional voltage levels for powering specific interface circuits, sensors, etc. This application note presents how to make a regulated capacitive charge pump using a GreenPAK IC and a couple of low cost external components. A single stage charge pump may be configured as a voltage doubler or inverter. Multistage charge pumps enable higher output voltages, both positive and negative (inverting doubler, tripler etc). The output is a regulated voltage source, independent of input voltage level variations and load variations, provided that input voltage and load are within defined limits. Maximum output current is in the milliamps range. This application note is a continuation of the app note “Capacitive Charge Pump using GreenPAK” for unregulated charge pumps.

The GreenPAK power supply voltage is used as the charge pump input. The GreenPAK outputs a driving signal for the external bootstrap capacitor. For multistage charge pumps, the GreenPAK outputs two anti-phase driving signals. A control signal is optional to start/stop (power down) the charge pump and can be added as an IO or through serial communication protocols. When using I2C-enabled GreenPAK s the output voltage level can be programmed by controlling the internal reference voltage over I2C communication. If tight output voltage tolerance is required, external precision reference may be applied.

One GreenPAK IC can control multiple charge pumps with various output voltages. Independent programmability may be limited to some of the outputs, depending on the GreenPAK part selected. In the case of low input voltages, GreenPAK s may be cascaded to obtain higher output voltages with fewer external components.

Basic diagram is shown in Figure 1.

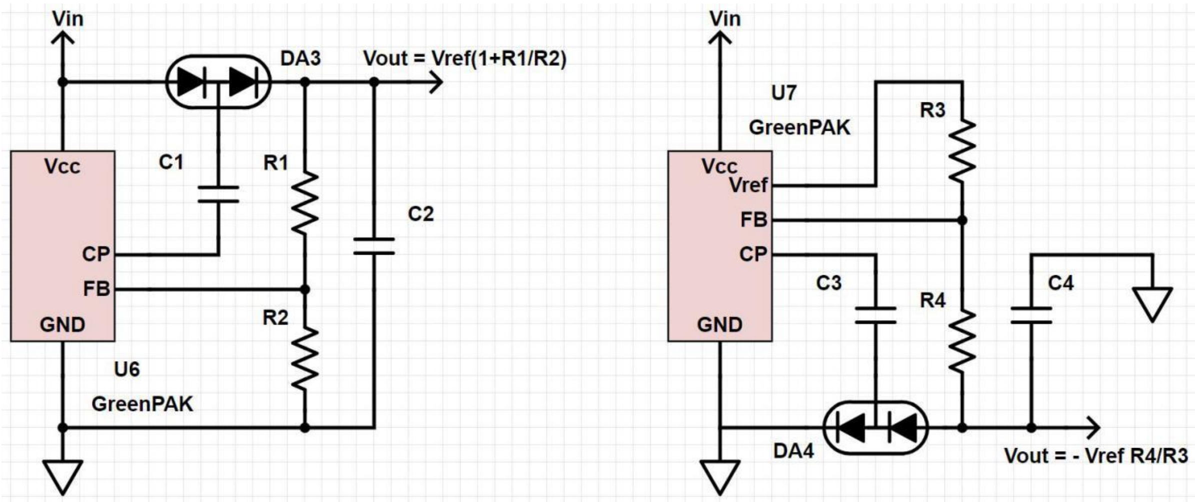


**Figure 1: Single Stage Charge Pump Regulated Voltage Booster and Inverter**

# 4 Charge Pump Circuit Design

The implementation is founded on the unregulated charge pump design. A comparator is added to detect when the desired output voltage is met and consequently stop charging the output capacitor. In this way the output voltage is limited without an additional LDO or other type of dissipative regulator. Since analog comparators are available inside most GreenPAKs only a resistive voltage divider is needed.

The circuit performance of a regulated charge pump is like the unregulated charge pump design procedure. A designer needs to make sure that charge pump in unregulated configuration can provide high enough output voltage at all working conditions (input voltage and load current). Introduced feedback will regulate the output voltage. Necessary voltage margin is negligible.

## 4.1 Operating Frequency & Capacitor Selection

Operating frequency and capacitor selection is explained in the application note for unregulated charge pumps; these principles all apply to regulated charge pumps. Additionally, we will examine how operating frequency and capacitance affects output voltage regulation.

Output voltage regulation is performed by controlling the peak output voltage value, so the average value of output voltage depends on the ripple. At no load, ripple is zero, so average voltage equals peak voltage. At full load, the ripple at maximum, and average value is the peak value minus half of the peak-to-peak ripple. Regulation “zero to full load” equals half of the maximum peak-to-peak ripple.

Ripple depends on load, operating frequency and capacitance. Load cannot typically be altered by design, but operating frequency and capacitance can be set for correct operation.

Increasing operating frequency reduces ripple and improves output voltage regulation. However, it also increases power losses and reduces efficiency. Increasing output capacitance reduces ripple and improves output voltage regulation. However, bigger capacitors are usually larger in size and higher in cost. Note that a bigger output capacitor also means a longer startup time, as well as a longer transition time between regulated output voltages. At light loads and large output capacitance a transition to a lower voltage level might take a very long time.

For top efficiency, improve regulation by increasing output capacitance. For low price, low size, and fast response improve regulation by increasing operating frequency.

## 4.2 Diode Selection

Diode selection is explained in the application note for unregulated charge pumps. However, regulated charge pumps lack the influence of diode forward voltage to output regulation, so diodes only affect the maximum achievable output voltage. After regulation is introduced, diodes will only marginally affect the power efficiency, provided the circuit is “in regulation”. Efficiency will not be much higher if diodes with lower forward voltage drop are applied (schottky diodes), but the dissipation will shift from the diodes to the GreenPAK itself. In certain applications standard diodes with higher forward voltage drop may help reduce the heat of the GreenPAK IC.

## 4.3 Feedback Design for Voltage Booster

Feedback design is simple for the case of the voltage doubler. The output voltage peak is directly determined by the resistive divider ratio and the reference voltage is provided by the GreenPAK internal blocks. Reference voltage performance is best around 1 V, which is also a handy value for calculations. Divider ratio to obtain $V_{out}$ at $V_{ref}$:

$$R_1 / R_2 = V_{out} / V_{ref} – 1$$

Using $V_{ref} = 1$ V gives $R_1/R_2 = V_{out} – 1$

For example, $V_{out} = 5$ V and $V_{ref} = 1$ V, $R_1/R_2 = 4$.

Regarding the resistance of the divider, an easy approach is to make divider current 1% of maximum output current.

$$V_{ref} / R_2 = I_{outmax} * 1\%$$

For example, $I_{outmax}$ = 1 mA, $R_2$ = 1 V / 10 μA = 100 KΩ and $R_1$ = 4 * $R_2$ = 400 KΩ.

A resistive divider loads the charge pump and increases quiescent current thus reducing the circuit efficiency. Therefore, it's better to aim for high resistance. However, too high a resistance makes the circuit susceptible to electromagnetic interference and introduces noise that reflects to the output voltage. Additionally, input characteristics of a GreenPAK comparator at high divider resistance become less negligible and may affect output voltage regulation.

Comparator input impedance is very high at gain 1x, but much lower when using an internal divider:

**Table 1: Analog Comparator Input Characteristics**

| Gain | 1x | 0.5x | | 0.33x | | 0.25x | |
|---|---|---|---|---|---|---|---|
| Input resistance | 100 MΩ | 1 MΩ | 2 MΩ | 0.8 MΩ | 2 MΩ | 1 MΩ | 2 MΩ |
| Input current @1V | 10 nA | 1 μA | 0.5 μA | 1.25 μA | 0.5 μA | 1 μA | 0.5 μA |

With internal divider on, input current is around 1 μA. To keep it below 1%, divider current should be at least 100 μA, which is too high for low power applications. It is better to use comparator with divider switched off, when input current is around 10nA and it is below 1% for divider currents of 1 μA and above.

Leakage current is 1 nA typical, making it 10 times less than comparator input current. However, leakage current is strongly dependent on temperature and may reach 1 μA at high temperatures. Charge pump losses heat up the GreenPAK IC and temperature may raise considerably even at moderate ambient temperatures. For most applications, leakage current will stay below 0.1 μA; still 10x higher than comparator input current. To keep the error below 1%, divider current should be at least 10 μA.

Recommendation: design divider current to be 10 μA or more, except in the case GreenPAK works at high ambient temperatures or in the case of high-power charge pump (high losses) when 100 μA divider current is the preferred option.

## 4.4 Feedback Design for Voltage Inverter

In the voltage inverter circuit, an output voltage divider referred to ground yields a sense voltage below ground – outside the GreenPAK supply voltage range. Such a sense signal cannot be applied to the comparator input, so a voltage divider must be biased to a reference potential above ground. One solution is to take advantage of GreenPAK internal reference wired to an output pin. In this configuration, the circuit works with 2 reference voltages, one reference used for comparator threshold (call it “threshold voltage”) and the other reference used for feedback (call it “reference voltage”).

Output voltage peak value is determined by the ratio of resistive divider and the difference between reference voltage and threshold voltage and referred to reference voltage.

$$V_{out} = V_{th} – R_f (V_{ref} – V_{th}) / R_r = V_{th} (1 + R_f / R_r) – V_{ref} * R_f / R_r$$

Programming GreenPAK’s internal references Vref and Vth set the output voltage level, with fixed voltage divider ratio.

Taking $V_{th}$ ~ 0, greatly simplifies the expression for output voltage:

$$V_{out} \sim -V_{ref} * R_f / R_r$$

When considering voltage divider resistance in the case of a voltage inverter, the designer must consider current capacity of the GreenPAK reference output. Current capacity is relatively low and resistance must be high enough to avoid overload.

## 4.5 Feedback Design for Input Referenced Inverter

In the common case when input voltage is regulated (tight tolerance) and it’s satisfactory for the output voltage regulation to match input voltage regulation, the input voltage may be used to generate a reference voltage. The circuit is simplified and resembles the voltage doubler configuration:

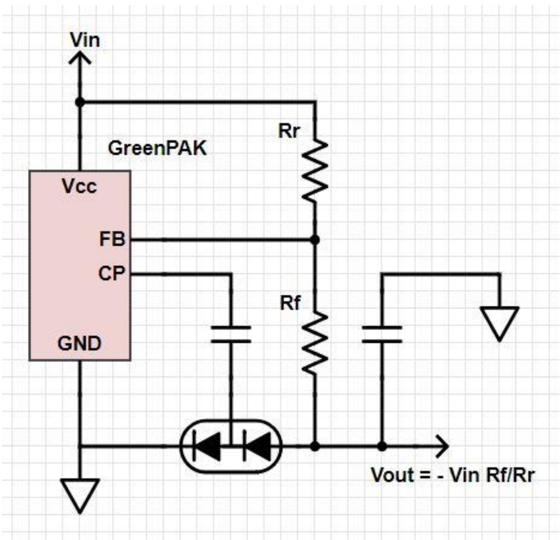


**Figure 2: Input Referenced Regulated Inverter**

Replacing reference voltage with input voltage gives the formula for output voltage:

$$V_{out} = V_{th} – R_f (V_{in} – V_{th}) / R_r = V_{th} (1 + R_f / R_r) – V_{in} * R_f / R_r$$

Programming $V_{th}$ sets the negative output voltage.

Choosing $V_{th}$ ~ 0, greatly simplifies the expression for output voltage:

$$V_{out} \sim -V_{in} * R_f / R_r$$

For a single stage voltage inverter, $R_f$ must be less than $R_r$, because the absolute value of the output voltage cannot be higher than the input voltage.

The same principles that apply for choosing resistor values for the voltage doubler also apply to the inverter configuration.

# 5 GreenPAK Design

The GreenPAK Design adds one analog comparator and a couple of gates to the unregulated charge pump design. Operating frequency affects regulation, since feedback controls the output peak value rather than the average level, so output voltage declines with raising output ripple. Keeping output ripple low by selecting higher operating frequency and/or large output capacitor improves output voltage regulation.

## 5.1 Oscillator Design & Output Pins Design

Oscillator and output pin design are explained in the application note for unregulated charge pumps. However, the voltage drop introduced by an output pin’s serial resistance is neutralized by regulation, so output pin configuration only affects maximum output voltage. Output pin configuration still affects efficiency like an unregulated charge pump. Efficiency will be better if pins with lower resistance are used, if multiple pins are wired in parallel, and also if a GreenPAK with better IO performance is selected.

## 5.2 Comparator Design & Programming Output Voltage

Hysteresis: Enable and set to minimum available value (25 mV). Hysteresis raises effective reference voltage V_IH, presented in the ACMP settings dialog box, in the Information section.

Low bandwidth: Enables low pass filter on feedback input. Use in noisy environments.

IN+ gain: Disable for high input impedance.

IN+ source: Select feedback input pin.

IN- source: Set initial $V_{ref}$ value as absolute value (mV), $V_{dd}$ fraction or ext. Vref as desired. This initial value may be changed via $I^2C$ command.

The output voltage can be programmed via serial communication by setting internal reference voltage at the comparator input. Through $I^2C$ the internal reference can be set between 50 mV and 1200 mV in 50 mV steps. Using the feedback resistor divider the regulation can be set to regulate the output voltage to different values

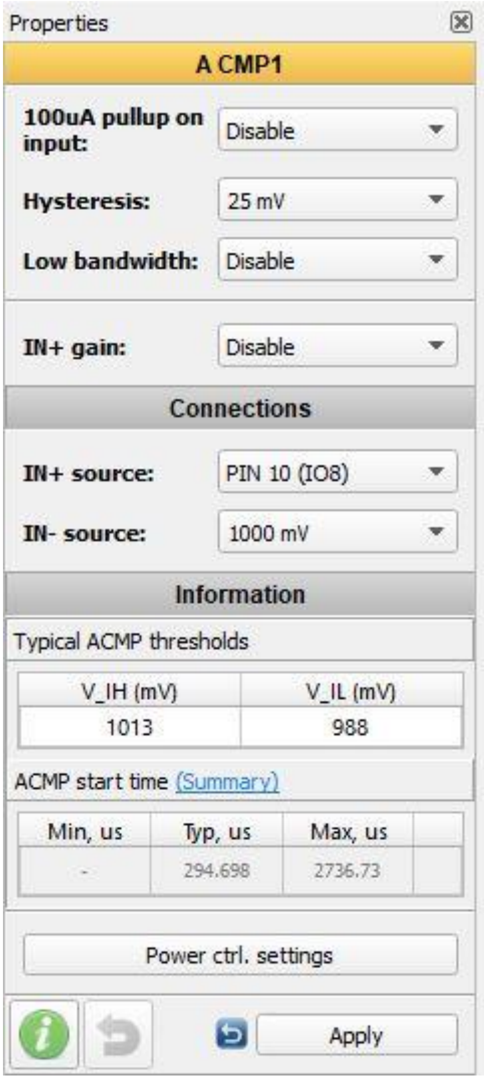


**Figure 3: Comparator Settings**

## 5.3 GreenPAK Design Schematic

Figure 4 shows the basic design with only one pin used to drive the Dickson charge pump. The output voltage is not programmable, but the design includes a shutdown feature. Such design simplicity is enabled by GreenPAK built-in features. The basic design fits into any GreenPAK that offers an analog comparator block. To increase drive strength, add output pins as available and wire them to the LUT output.

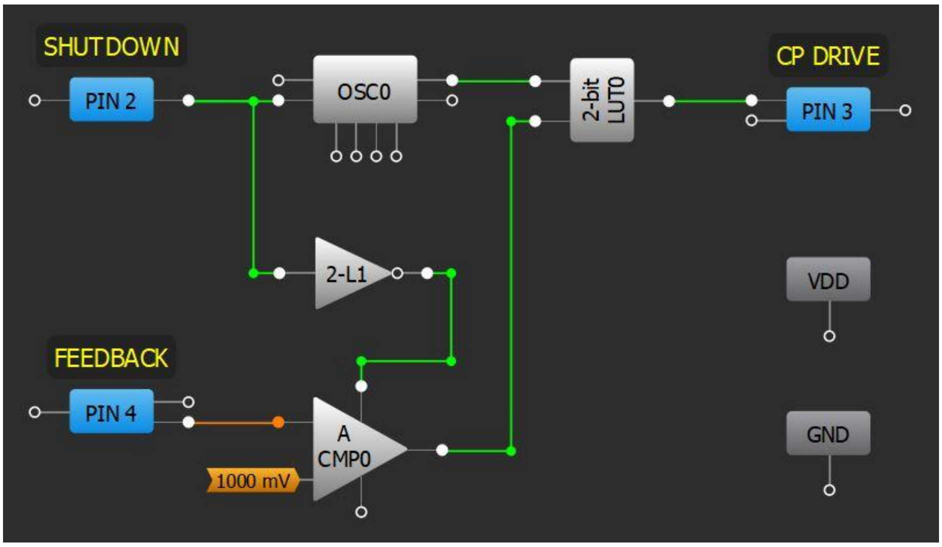


**Figure 4: GreenPAK Based Regulated Charge Pump - Basic Design**

Figure 5 shows a design with a programmable output voltage and two shutdown inputs: one direct input, like in the first design, and another via I²C. They are wired through an OR gate so each one can shut down the charge pump independently. If priority logic for shutdown commands is needed, change LUT0 accordingly. This design requires I²C capabilities and it fits into any GreenPAK SLG465xx or SLG468xx. To enable the programmable output the I²C block must be enabled.

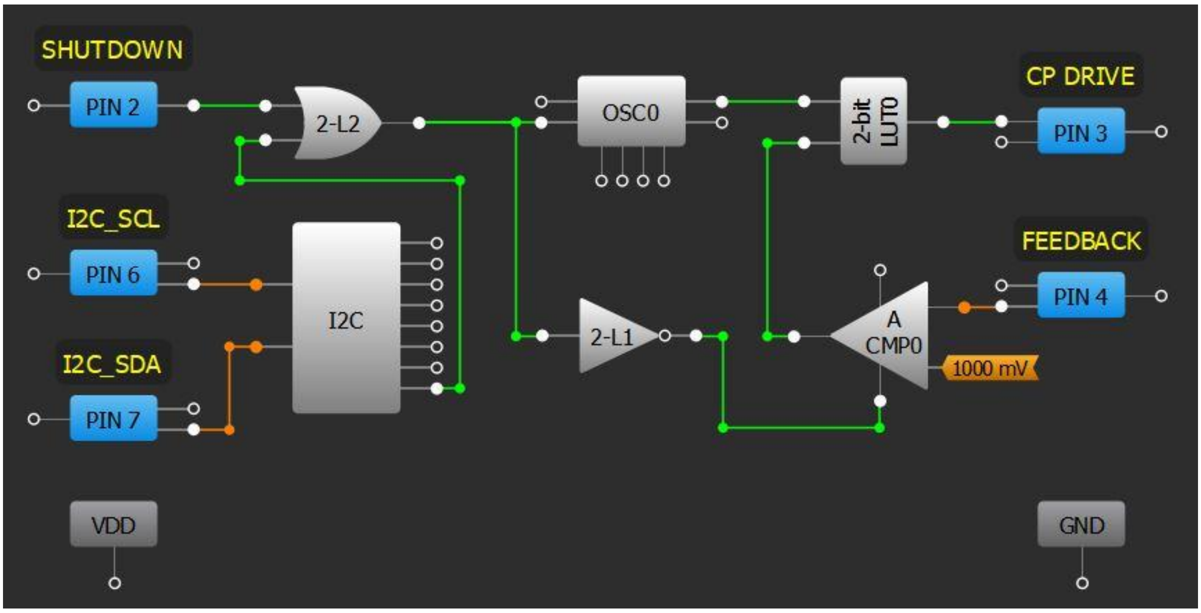


**Figure 5: Programmable Output Regulated Charge Pump GreenPAK Design**

## 5.4 Powerdown Feature

Design issues regarding a powerdown feature are explained in the application note for unregulated charge pumps. Extra design steps are needed to power down the comparator block that performs the regulation, as shown in Figure 4.

If a powerdown feature is not needed, PWR UP input of the comparator (ACMP0) must be wired HI. The POR block is recommended as the HI source in this scenario.

When designing a voltage booster with full shutdown (see the application note for unregulated charge pumps), connect the feedback divider across the load, otherwise it will draw current from the supply rail during powerdown.

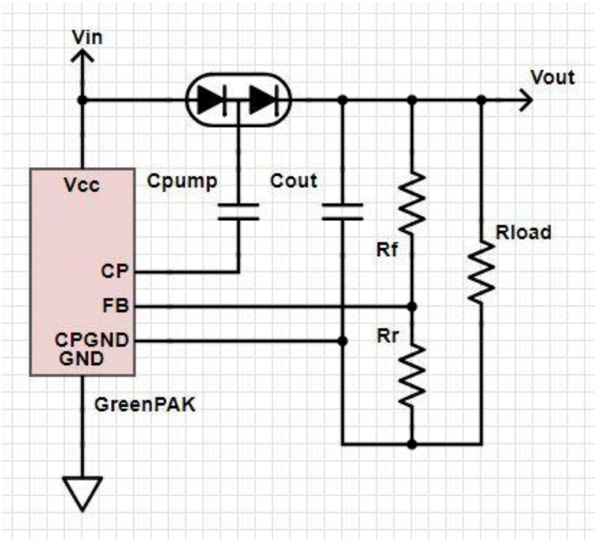


**Figure 6: Regulated CP with Full Shutdown**

## 6 Circuit Performance

Circuit performance specification: $C_{pump}$ = $C_{out}$ = 1 μF X7R, D = schottky,

TA = 25 °C, $f_{osc}$ = 125 kHz; $I_{fb}$ = 10 uA; $R_r$ = 100 KΩ; $R_f$ = 400 KΩ (5 $V_{out}$) or 230 KΩ (3.3 $V_{out}$); $V_{ref}$ = 1000 mV unless otherwise noted.

**Table 2: Circuit Performance Specifications**

| Symbol | Parameter | Note | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{in}$ | Supply Voltage | | 1.71 | --- | 5.5 | V |
| $I_{qsc}$ | Quiescent current | RL=∞, 125kHz | --- | 100 | --- | μA |
| $I_{shdn}$ | Shutdown current (Note 1) | SLG46533 | 0.31 | 0.57 | 0.89 | μA |
| $f_{osc}$ | Oscillator frequency<br>25kHz OSC<br>2M OSC | selectable (Note 2) | 0.048<br>-3.4%<br>-9.4% | $25/2^n$<br>$2000/2^n$ | 2000<br>4.7%<br>14.4% | kHz |
| $I_{out}$ | Output current (Note 3) | | 5 | 10 | 45 | mA |
| $V_{out}$ | Output voltage accuracy | in regulation | -3 | - | +3 | % |
| $FB_{imp}$ | Feedback pin impedance | (Note 4) | 0.8 | 100 | - | MΩ |
| $P_{eff}$ | Power conversion efficiency | $R_L$=5KΩ | 51 | 63 | 76 | % |

| Symbol | Parameter | Note | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{th}$ | Shutdown input threshold<br>High State, Device Shutdown<br>Low State, Device Operating | $V_{in}$=3.3V, selectable (Note 5) | 1.06<br>0.67 | 1.81<br>1.31 | | V |
| $T_A$ | Operating Temperature | | -40 | 25 | 85 | °C |

**Note 1** $I_{shdn}$: specified for SLG46533, see relevant datasheet for other Renesas parts; considers leakage and other parasitics outside GreenPAK negligible; for measured shutdown current which includes feedback current, leakages and other parasitic parameters in a real circuit, not just the GreenPAK IC, check Figure 19.

**Note 2** Selectable to frequencies derived by dividing 25 kHz or 2 MHz: 25 kHz / 2 n or 2 MHz / 2 n, n=0..9

**Note 3** Column “min”: single pin 2x drive, “typ”: 2 pins in parallel 2x drive, “max”: multiple pins in parallel 2x drive; specified for SLG46533, see relevant datasheet for other Renesas parts;

**Note 4** Depends on comparator configuration, for detailed info refer to Table 1.

**Note 5** GreenPAK input levels may be programmed for Logic Input (min HIGH-Level and max LOW-Level shown in column typ) or Low-Level Logic Input (min HIGH-Level and max LOW-Level shown in column min). Third option is Logic Input with Schmitt Trigger, see GreenPAK datasheet for voltage levels.

# 7 Testing & Results

The regulated voltage doubler charge pump external circuit was assembled on a breadboard and connected to a GreenPAK Universal Development Board. SLG46533 has enough GPIO pins to test multiple pins in parallel. A programmable DC voltage source is connected to the charge pump input. A programmable load is connected to the charge pump output. Two professional high accuracy multimeters were connected to measure input and output parameters.

For final measurements, the GreenPAK Universal Development Board is removed because it introduces effects in the circuit that impact the measurement results, such as the series resistance of the analog switches. For complete test setup schematics and photos please refer to unregulated charge pump application note.

Since the testing includes various configurations, GreenPAK design for a DUT device is adapted accordingly, so that the charge pump configuration may be changed by digital signals sent from an automated test setup. The GreenPAK design is presented in Figure 7 and it is intended only for testing purposes.

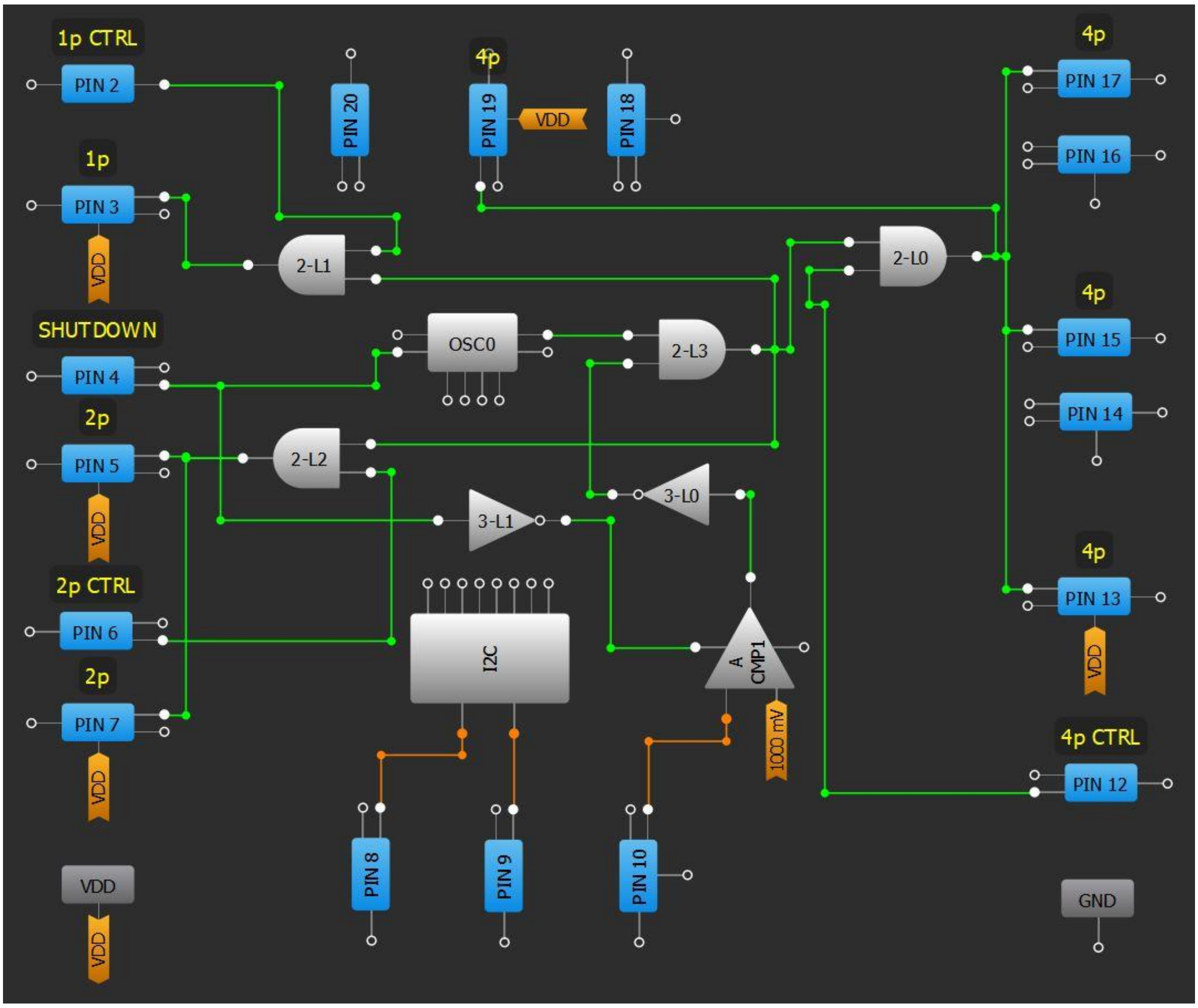


**Figure 7: GreenPAK Design for DUT**

## 7.1 Graphs

Measurements were obtained for two popular low cost diode options: standard silicon fast switching diodes 1N4148 and schottky diodes BAT42. Results are presented graphically.

All Graphs:

$C_{pump} = C_{out}$ = 1 µF X7R ceramic multilayer; TA = 25 °C; $f_{osc}$ = 125 kHz

Feedback:

$I_{fb}$ = 10 uA; $R_r$ = 100 KΩ; $R_f$ = 400 KΩ (5 $V_{out}$) or 230 KΩ (3.3 $V_{out}$); $V_{ref}$ = 1000 mV

Configuration: Voltage booster (doubler); full shutdown: no; programmable ($I^2C$): yes

Graphs vs Load Current, parameter: $V_{in}$; f=125 kHz; drive = 2 pin 2x:

8) 5 V Output voltage vs Load current (Load regulation) @ $V_{in}$ = 4.5 V, 3.7 V, 3.0 V; D = standard, schottky; linear scale

9) 3.3 V Output voltage vs Load current (Load regulation) @ $V_{in}$ = 3.7 V, 3.0 V, 2.5 V; D = standard, schottky; linear scale

10) 5 V Output voltage vs Load current (Load regulation) @ $V_{in}$ = 4.5 V, 3.7 V, 3.0 V; D = standard, schottky; log scale

11) 3.3 V Output voltage vs Load current (Load regulation) @ $V_{in}$ = 3.7 V, 3.0 V, 2.5 V; D = standard, schottky; log scale

12) Efficiency vs Load current @ $V_{out}$ = 5 V; $V_{in}$ = 4.5 V, 3.7 V, 3.0 V; D = standard, schottky

13) Efficiency vs Load current @ $V_{out}$ = 3.3 V; $V_{in}$ = 3.7 V, 3.0 V, 2.5 V; D = standard, schottky

Graphs vs Vin, parameter Iout: $V_{in}$; f=125 kHz; drive = 2 pin 2x:

14) 5 V Output voltage vs Input voltage (Line regulation) @ $I_{out}$ = 1 mA, 3 mA, 10 mA; D = standard, schottky

15) 3.3 V Output voltage vs Input voltage (Line regulation) @ $I_{out}$ = 1 mA, 3 mA, 10 mA; D = standard, schottky

16) 5 V Output Efficiency vs Input voltage @ $I_{out}$ = 1 mA, 3 mA, 10 mA; D = standard, schottky

17) 3.3 V Output Efficiency vs Input voltage @ $I_{out}$ = 1 mA, 3 mA, 10 mA; D = standard, schottky

18) Quiescent current vs Input voltage @ $V_{out}$ = 5 V, 3.3 V; D = standard, schottky

19) Shutdown current vs Input voltage @ $V_{out}$ = 5 V, 3.3 V; D = standard, schottky

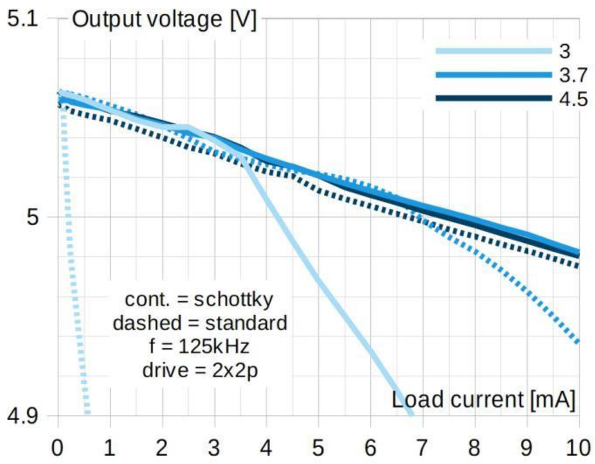


**Figure 8: Load Regulation 5 V Lin**

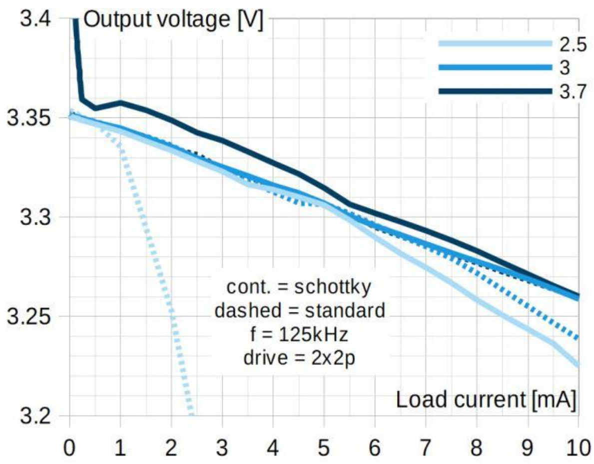


**Figure 9: Load Regulation 3.3 V Lin**

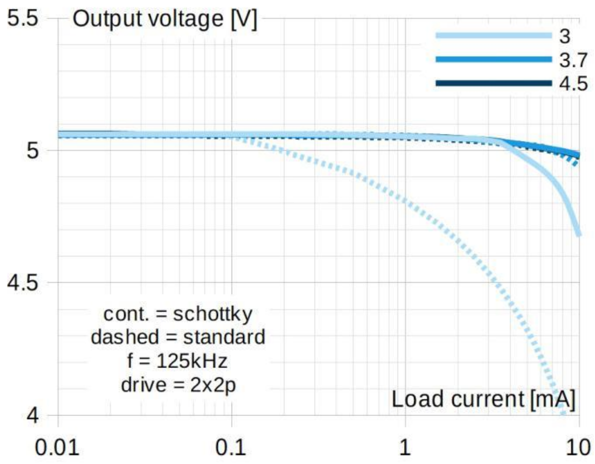


**Figure 10: Load Regulation 5 V Log**

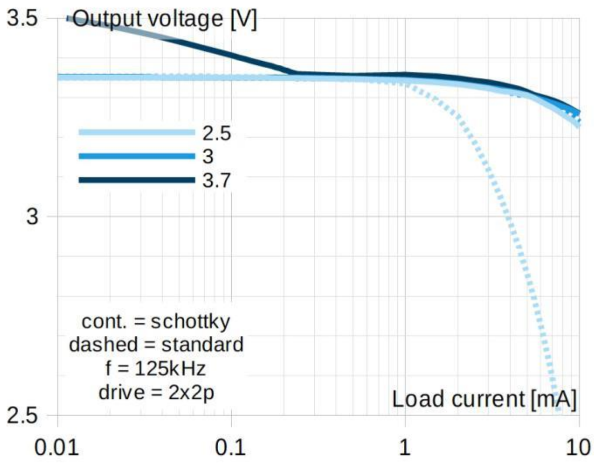


**Figure 11: Load Regulation 3.3 V Log**

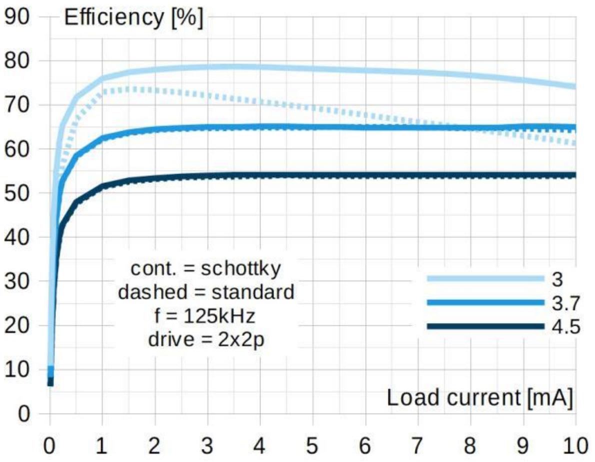


Figure 12: Efficiency vs Load 5 V

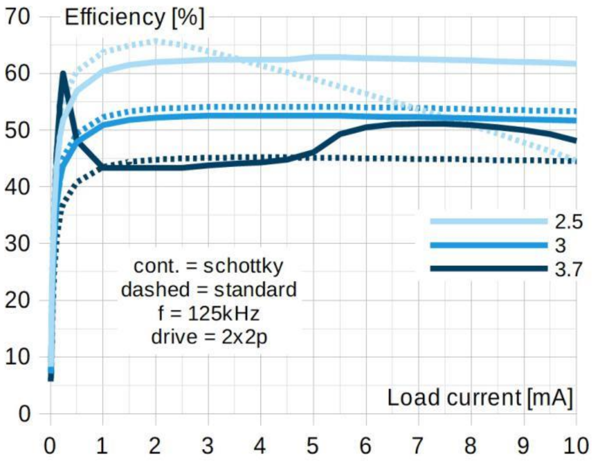


Figure 13: Efficiency vs Load 3.3 V

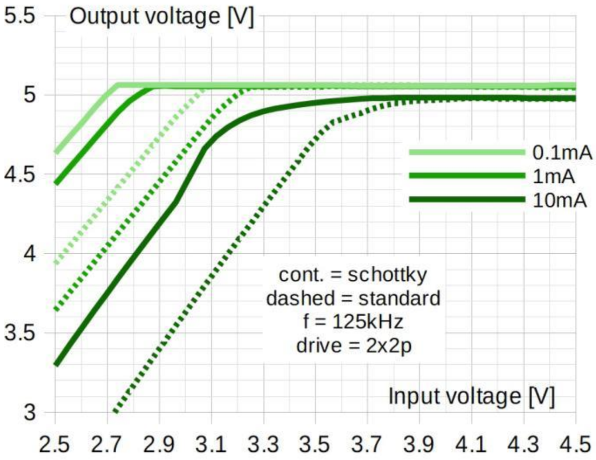


Figure 14: Line Regulation 5 V

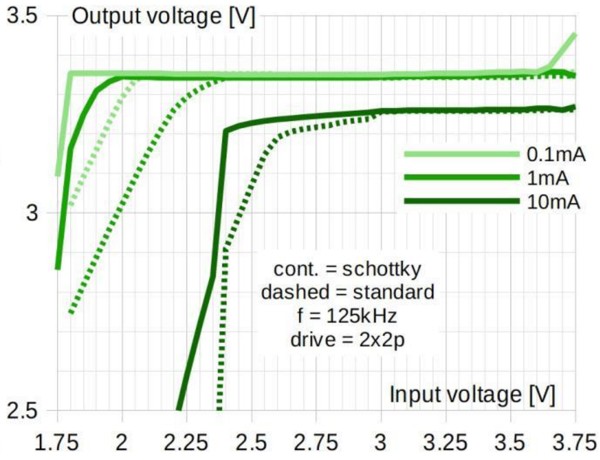


Figure 15: Line Regulation 3.3 V

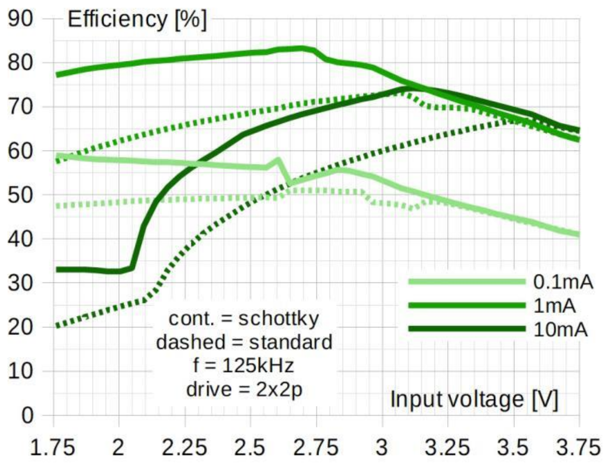


Figure 16: Efficiency vs Line 5 V

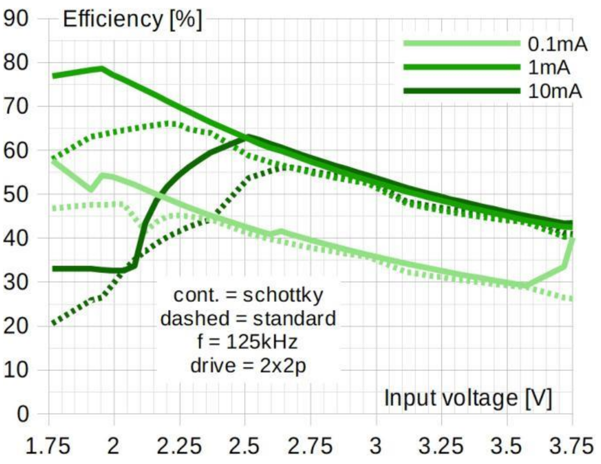


Figure 17: Efficiency vs Line 3.3 V

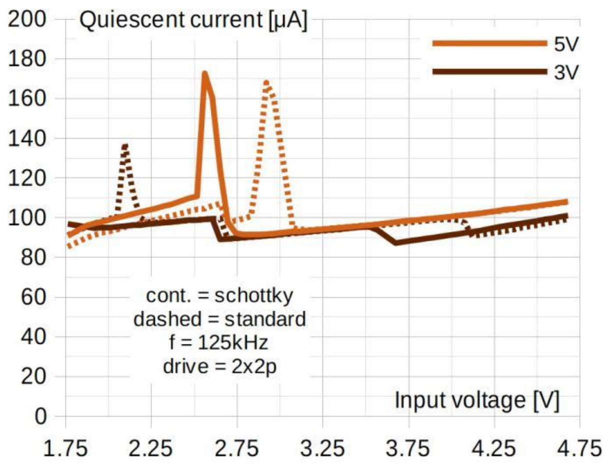


Figure 18: Quiescent Current

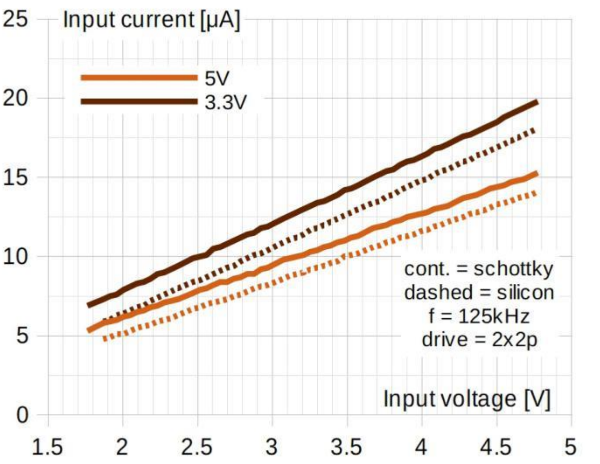


Figure 19: Shutdown Current

# 8 Optional Design Modifications and Optimizations

External diodes may be replaced by MOSFET’s or analog switches to reduce voltage drop (increase output voltage) and improve efficiency. In this case the unregulated output voltage is higher than required regulated voltage, only efficiency will be affected.

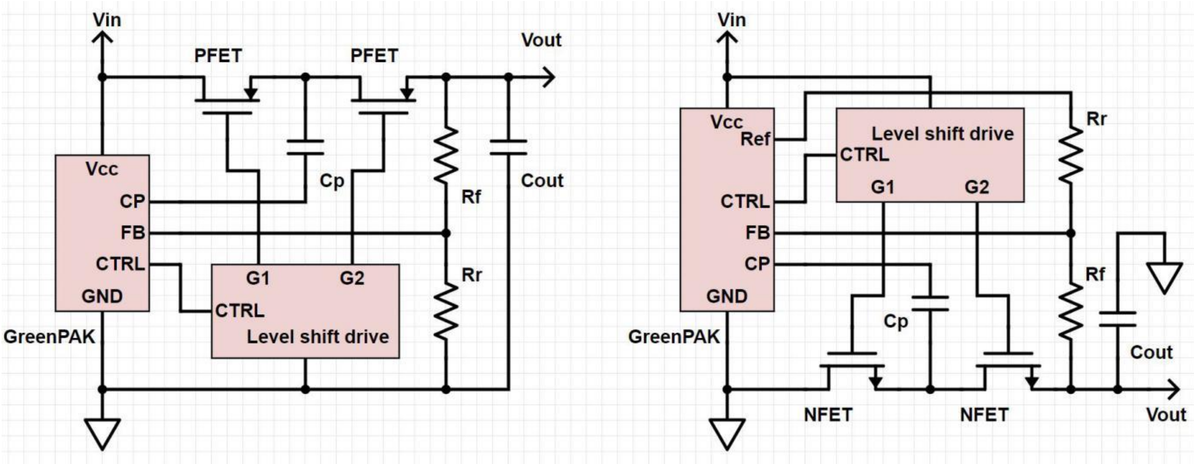


**Figure 20: Replacing Diodes with MOSFETs**

Output voltage may be regulated by LDO's or Zener diodes to eliminate output ripple. With a regulated charge pump there is no need to compensate for input voltage and load variations. When using LDOs, output characteristics are similar for regulated as well as for unregulated charge pumps, so a regulated circuit isn't often necessary. However, using a regulated charge pump with an LDO has the advantages of lower aggregate losses and less heat on the LDO. Higher efficiency is important for battery powered circuits where configuration "regulated charge pump + LDO" may double battery autonomy compared to "unregulated charge pump + LDO" configuration.

Looking at design modifications and optimizations presented for unregulated charge pumps, it is important to note that with unregulated charge pumps, it is possible to reuse same driving pins for all charge pumps, if several outputs are required. This is NOT possible for regulated charge pumps, because driving pins are used for regulation and pulse widths for different outputs will not be equal. With regulated charge pumps, you have to use at least one driving pin and one feedback pin for each output. However, it is possible to use the same internal voltage reference for multiple negative outputs, as shown in the Figure 21.

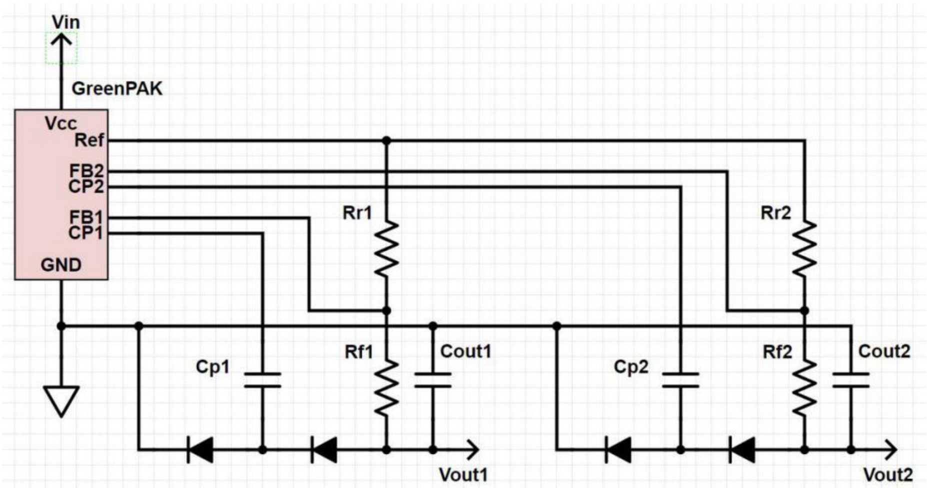


**Figure 21: Reusing Reference Pin for Multiple Outputs**

# 9 Key Advantages and Commercial Viability

If you already have GreenPAK IC in your circuit performing other functions, with a couple of unused pins and some free blocks inside GreenPAK, then it is absolutely commercially viable to implement a GreenPAK regulated charge pump solution because it will take just a couple of additional diodes, capacitors and resistors. Total cost of such a solution at production quantities comes down to cents, 5 to 10 times less than a specialized charge pump IC.

GreenPAK charge pump solution is also competitive if it is applied solely for a charge pump function. In this case, select a low cost GreenPAK such as SLG46110 and you can reach a cost 2 times less than a specialized charge pump IC solution.

One GreenPAK can control multiple regulated charge pump circuits or a combination of regulated and unregulated charge pumps. The cost of each additional charge pump comes down to additional external components, which is a couple of cents. With commercial charge pump ICs, each pump comes at full price. With GreenPAK solution for multiple charge pumps, parameters of each circuit may be programmed independently. Multiple outputs with the same voltage level might be required if separate on/off control is needed or cross regulation effects must be avoided.

With GreenPAK 4 and 5, it is possible to control the charge pump circuit via serial communication. GreenPAK 4 offers SPI, while GreenPAK 5 offers I$^2$C. On/off control, operating frequency, wake/sleep regime are some parameters to set via serial comms. GreenPAKs with I$^2$C provide far more configurability from the serial protocol.

Key advantages of GreenPAK charge pump solution:

- lower cost,
- smaller size,
- multiple outputs with the same IC,
- programmable operating frequency,
- serial comm control,
- lower quiescent current,
- surplus logic for additional functions.

GreenPAK solution offers similar or better performance and some additional features at a fraction of the price.

For the solution presented in this application note to be commercially viable,

certain requirements must be within performance level range that is achievable by GreenPAK solution. That range is dependent on supply voltage and for exact data please refer to graphs in this application note. General requirements are summarized as follows:

- output current in the milliamps range (<10 mA)

- power conversion efficiency <90 %.

## 10 Conclusion

This application note presented a high performance, small size capacitive charge pump with regulated output voltage that can be built easily using a GreenPAK IC and a couple of low-cost external components. A GreenPAK charge pump operates with input voltages 1.8 V to 5 V and load currents up to 145 mA. Overall performance peaks at input voltages 3 V to 5 V and output currents 1 mA to 5 mA while using schottky diodes.

There are certain “basic charge pump” feature sets where the proposed GreenPAK solution offers lower cost, smaller size or lower quiescent current than specialized ICs. Other applications where a GreenPAK based charge pump solution is favorable are ones needing specific functions not available in standardized charge pump ICs. The surplus circuitry in GreenPAK, unused in a charge pump circuit, can be utilized in those applications to implement such specific functions. Specific functions could be directly or closely related to charge pump function but may just as easily be completely independent hardware functions of the target device.

This application note does not cover all performance ranges of capacitive charge pumps, but the GreenPAK ecosystem offers the right solution to cover all of them with appropriate design.

## Revision History

| Revision | Date | Description |
|---|---|---|
| 1.0 | 16-Nov-2018 | Initial Version |

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## Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

## Contact Information

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