Powering Industrial Image Sensors

TUTORIAL

Unlocking the Power of an Image Sensor Power Tree

A tutorial to selecting the right power regulator components for an industrial image sensor application.

This tutorial is a companion to the **Image Sensor Power Tree** webinar.

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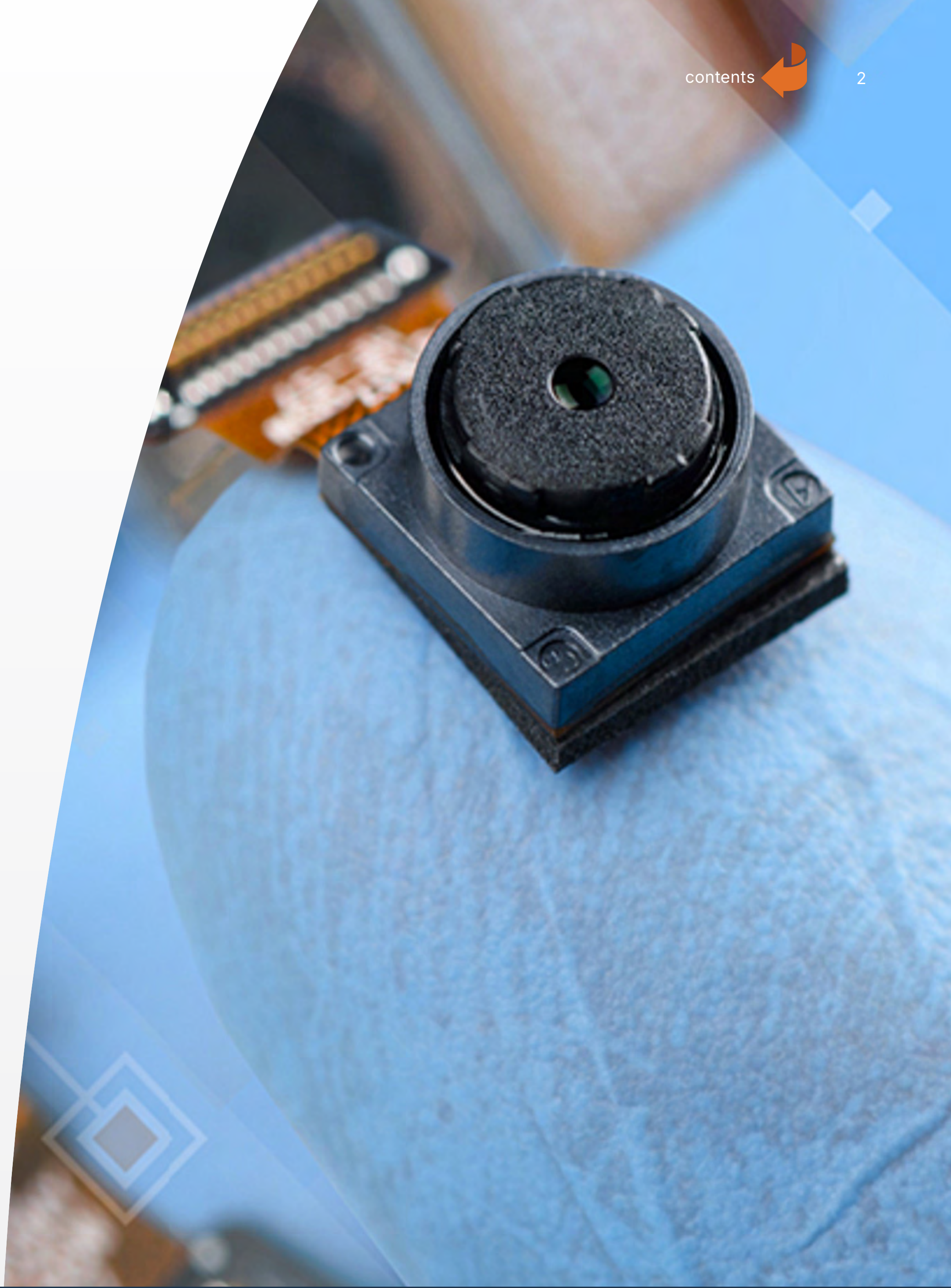
What's powering your image sensor application?

If the design of your power supply for industrial camera applications is not fully optimized, it's probably costing you time, money, or both.

The key component that determines whether your industrial image sensor is using power efficiently and, in so doing, extending its own lifespan is the power regulator. It's responsible for your power supply delivering the most reliable current at the most regulated voltage without undue fluctuations and without noise. It also plays a critical role in determining how your power supply dissipates heat and maintains optimum operating conditions, including in variable climate circumstances.

Since an industrial image sensor performs several functions, the voltages and currents applicable to those functions for an integrated circuit will differ. Because of this, the components responsible for these functions are often put on isolated voltage rails. For example, the power supplied to a digital signal processor (DSP) will have different characteristics from the power supplied to interfaces and memory buffers.

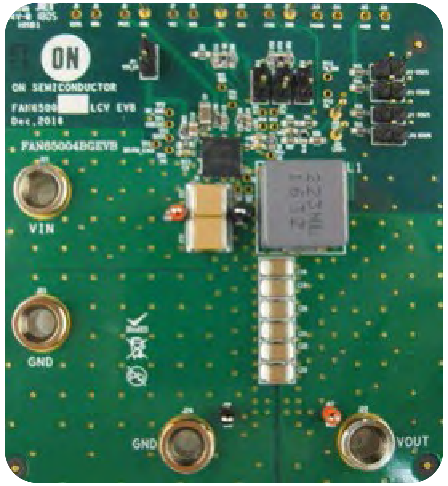
Keeping these voltage rails separate does allow for greater flexibility in power supply design. However, it also means that the regulators chosen to distribute power to all these isolated voltage rails must be capable of handling the switching and distribution necessary to enable all the various functions the IC will be tasked to perform.



Buck converter

The buck converter is one of the most common components in all of electrical circuitry. It produces a regulated voltage that is lower than its input voltage, delivering high currents while minimizing power loss. It relies mostly on its switch as a means of reducing voltage across the load, literally by turning on and off very rapidly — which is why a power component based on a buck converter is called a switch-mode power supply. Its alternating switch interrupts the circuit between the source and the load so that the average voltage received at the load is less than the source, while enabling a capacitor to continue providing voltage while the switch is open.

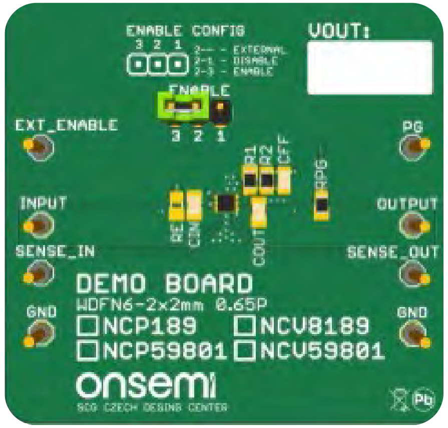
Pictured: onsemi FAN65004B demo board



LDO

Unlike a buck converter that regulates a switch-mode power supply, a linear regulator or low dropout regulator (LDO) uses a single MOSFET to directly reduce the voltage over the output. There is no switch, and as a result, an LDO is without the noise that comes from a switch, especially during the transition states from on to off and back. However, an LDO comes with an efficiency penalty that must always be factored into its power equation.

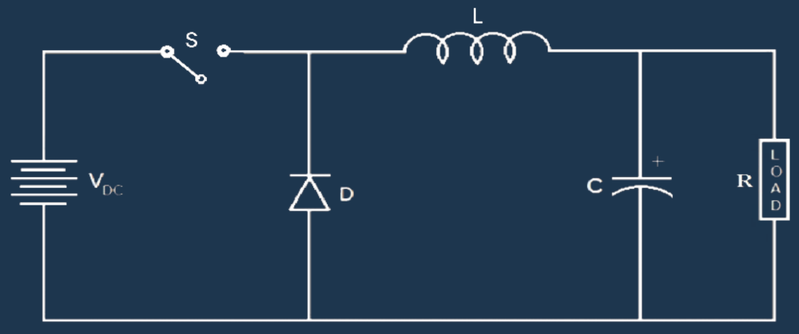
Pictured: onsemi NCP189 demo board



How a buck converter works

As depicted in this diagram of a basic buck converter, when closed, its switch **S** (typically a MOSFET) connects the DC input voltage source $\mathbf{V_{DC}}$ to inductor **L**. As the inductor's magnetic field expands, it resists changes to the current flowing through it, storing energy in its magnetic field. Current flows through to capacitor **C**, charging it in the process, as current continues to flow through to the load resistor **R**. Together, **L** and **C** act as a low-pass filter **LC**, smoothing what would otherwise be a square, choppy wave into a steadier output pattern.

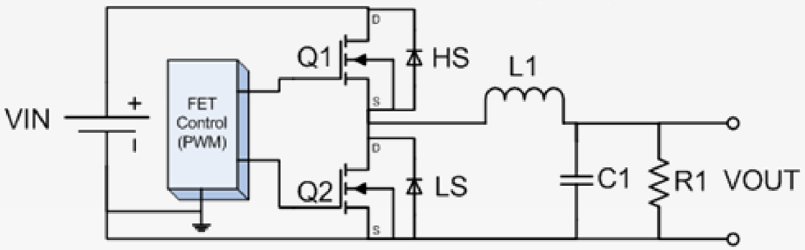
When switch **S** is open, current flowing through the inductor will begin to taper off. Inductor **L**'s magnetic field starts to collapse, soon flipping its polarity so that it becomes the new source of current. While the voltage across **L** exceeds the voltage across **C**, it may continue to charge **C**. Once they become equal, both **L** and **C** discharge their stored energy across load resistor **R**, thus minimizing changes in voltage at **R**. Current then flows through diode **D**, which is flipped to forward bias mode, enabling current to bypass the switch. This enables a feedback circuit that sets the duty cycle of the switch, enabling **S** to close so it can re-charge the inductor and the capacitor.



Synchronous buck converters

One very important step up from a basic buck converter, a ***synchronous buck converter*** comprises two power MOSFETs, along with its output inductor and output capacitor. The on/off state of the two MOSFETs alternate synchronously with one another to more tightly regulate the output voltage.

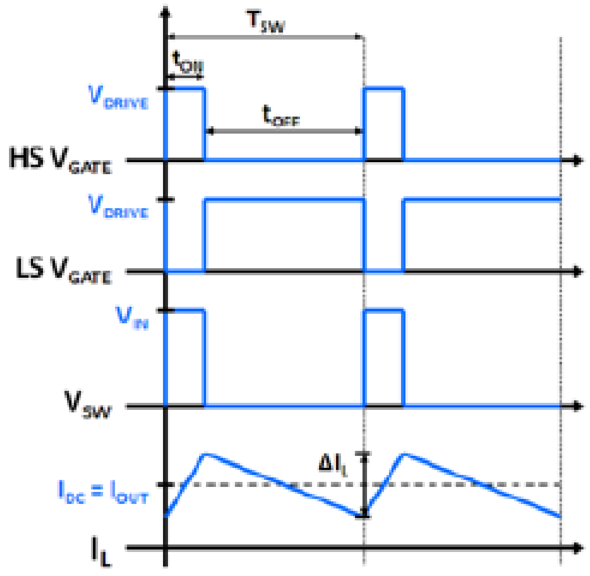
Managing the alternating on/off state of MOSFETs **Q1** and **Q2** in the above diagram is a pulse width modulator (PWM) controller **Control**. The drain of the low-side **Q2** and the source of the high-side **Q1** are connected to an inductor **L1**. At all times, the voltage level of $\mathbf{V}_{OUT}$ is equal to the input voltage level $\mathbf{V}_{IN}$ multiplied by the ***duty cycle*** setting managed by the PWM.

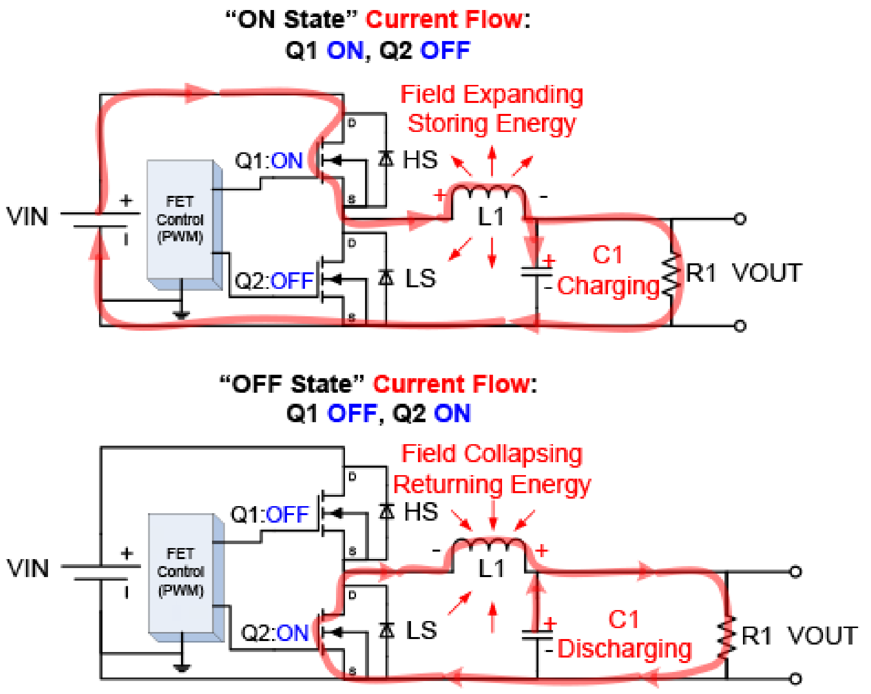


Synchronous buck converter power flow

While MOSFET **Q1** is set to on, it plays the same role as the hard switch in the basic buck converter, only much faster. Current is supplied to the load from the high side while **Q1** is on, inductor **L1** is charged and inductor current I_L rises. Once **Q1** is switched off, **Q2** is then switched on. Current is supplied to the load from the low side, as **L1** discharges while it receives less current, and inductor current I_L steadily declines. **Q2** is also responsible for clamping the switch node voltage by way of the body diode, preventing voltage value at the switch V_{SW} from going too far negative as **Q1** is being turned off.

The total change from the low peak to the high peak of output current levels is called *peak-to-peak inductor current* ΔI_L.





Interpreting the duty cycle

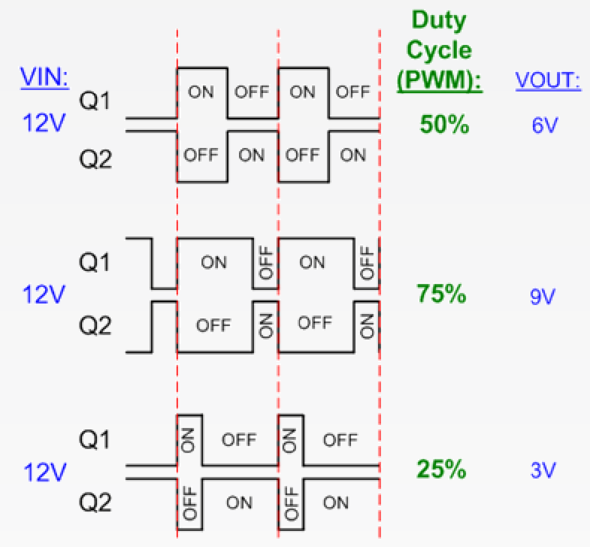
It is the percentage of time that the high-side MOSFET **Q1** spends on, that determines the synchronous buck converter's duty cycle. The formula for the duty cycle **D** over any given interval of time **t** is:

$$D = \frac{t_{-on,\,HS}}{t_{on,\,HS} + t_{off,\,HS}} \cong \frac{V_{OUT}}{V_{IN}}$$

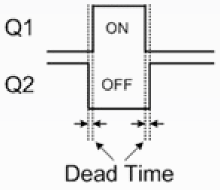
A duty cycle of 50% (0.5) would ensure that, for a $\mathbf{V_{IN}}$ of 12V, $\mathbf{V_{OUT}}$ would be 6V. Likewise, for the same input voltage, a duty cycle of 0.75 would produce a $\mathbf{V_{OUT}}$ of 9V, and a 0.25 duty cycle would produce a $\mathbf{V_{OUT}}$ of 3V.

The reason for the ≅ in the above equation is that a very short period of dead time must be allowed between off and on states to prevent cross-conduction, or "shoot-through current," which would create a direct short-to-ground.

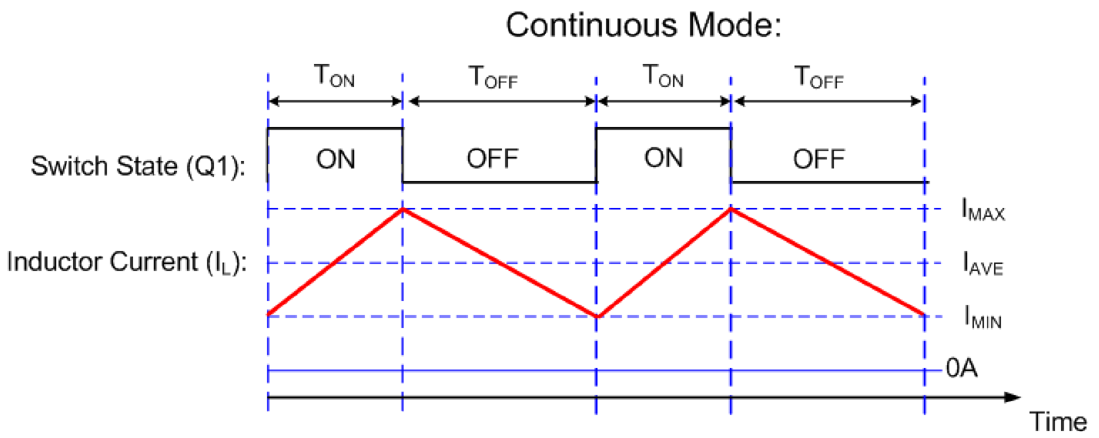
With any buck converter, there will be some amount of output ripple for both current and voltage. The controller is essentially an internal oscillator at 500 – 700 KHz, or even 2 – 6 MHz. This will drive some ripple on the output. It's possible to decrease ripple by increasing capacitance **C1** or increasing the switching frequency, although the oscillator can cause some electromagnetic interference (EMI) at high switching frequencies.

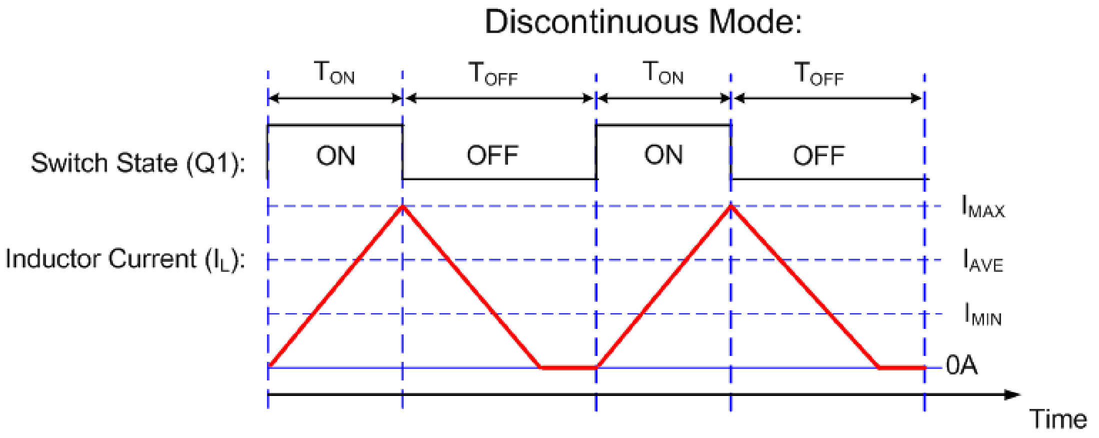


Shoot-through Current (cross conduction) Prevention:



Continuous and discontinuous conduction





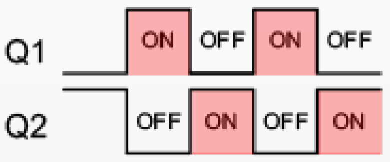
A synchronous buck converter typically runs in *continuous conduction mode* (CCM) with medium to high loads, using PWM to establish the duty cycle. This is where the inductor current should never fall to zero amps (0A). Sometimes with lighter loads, however, inductor current can fall to 0A. At this point, the unit is said to be running in *discontinuous conduction mode* (DCM). In this state, you can't have current losses at 0A, so it becomes necessary to regulate duty cycle using pulse frequency modulation (PFM) to minimize switching losses.

There are tradeoffs for both approaches. For CCM, ripple voltages are smaller, making it possible to use a smaller output capacitance. However, power losses from switching are typically higher. Switching losses are smaller with DCM because currents are already 0A when the switch opens. Also, DCM allows for smaller inductors, which leak less. However, with higher currents being used for DCM, there's usually greater EMI.

Where a buck converter loses power

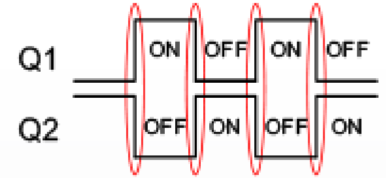
Some power loss will happen with any type of buck converter, including synchronous. These losses can be minimized, though never entirely eliminated. They must always be factored into the equation when determining whether a buck converter may be a more appropriate or economical part for an image sensor's power supply than an LDO. The amount of power a component does not lose in the voltage transition process is considered its *DC-DC efficiency*, or just "efficiency." This rating will never be 100%. The amount of power susceptible to combined operating and quiescent loss is always 1 minus the efficiency.

Conduction losses



As Joule's Law (**P = I²R**) explains, the power dissipated by an electrical current is directly proportional to the square of the current times resistance. For a buck converter, conduction losses happen when the either the high-side MOSFET **Q1** or low-side MOSFET **Q2** is fully turned on, not while it's switching. The amount of dissipated power for these losses is explained by Joule's Law, where resistance in this case is represented by internal on-resistance $\mathbf{R_{DS(on)}}$.

Switching losses

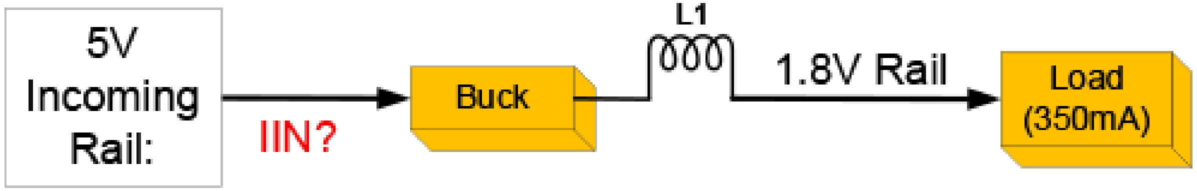


During switching, as **Q1** turns on while **Q2** turns off and vice versa, it's important that the design enable the rate of change in voltage over time (**dV/dt**) to be slowed down. This is to prevent voltage spikes that could damage the component. Increasing the external gate resistor value increases the drive-current capability, enabling the gate capacitance to discharge more rapidly. This minimizes switching time, decreasing the opportunity for switching power losses while extending **dV/dt** to a larger, less dangerous, rate.

Static losses

A static power loss (also called a *quiescent loss*) for a component takes place at some quantity at all times, not just while it's switching or when it's turned on. Some quiescent loss will take place while the unit as a whole is completely off. The amount of this loss is usually considered negligible, measuring in microamps (µA) and often numbering in the single digits. However, quiescent loss during operation could be as much as five times higher, and does play a factor in overall operating efficiency over long periods.

Determining your buck converter's input current



When you're considering a buck converter, one important and probably unresolved element at the root of the power tree is the necessary amount of input current. As a rule, a buck converter's output current $\mathbf{I_{OUT}}$ will be different from its input current $\mathbf{I_{IN}}$, and a synchronous buck converter's $\mathbf{I_{OUT}}$ may be greater than its $\mathbf{I_{IN}}$. But $\mathbf{I_{IN}}$ and $\mathbf{I_{OUT}}$ are never equal for a buck converter. (For an LDO, they are always equal.)

In this example problem, the circuit under consideration steps down 5V of incoming voltage $\mathbf{V_{IN}}$ to 1.8V of outgoing voltage $\mathbf{V_{OUT}}$. With the load current Iout set at 350 mA, what should the incoming current be? From an engineer's perspective, the problem is to solve for $\mathbf{I_{IN}}$.

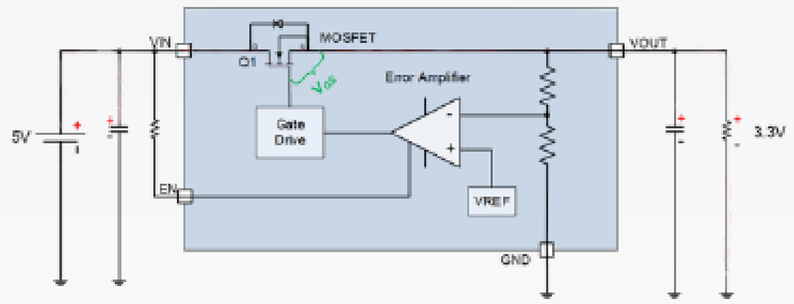
The first step is to determine the DC-DC efficiency for the buck converter under consideration. In onsemi's specifications tables, a part that takes 5V in, delivers 1.8V out, and produces 350 mA of current is rated for **90%** efficiency.

Of course, $\mathbf{P = V \cdot I}$. Multiplying 1.8 by 0.35 solves for power out $\mathbf{P_{OUT}}$ at 0.63 W. By definition, since the power out value is the power in value times efficiency, power in must be the power out value divided by efficiency. Dividing 0.63 by 0.9 gives us power in $\mathbf{P_{IN}}$ at 0.7W. Ohm's Law tells us $\mathbf{I_{IN} = P_{IN} \div V_{IN}}$. Dividing 0.7 by 5 gives us 0.14A. Accounting for likely power losses, the necessary input current for a step-down buck converter with these voltage specifications, producing 350 mA of output current, is 140 mA.

How a low dropout regulator (LDO) works

An **LDO** works like a variable resistor whose level of resistance changes proportionately with the amount of current. As this basic circuit diagram shows, it sends the output voltage $\mathbf{V_{OUT}}$ through an internal attenuator, which then sends it to the minus input of an error amplifier. Meanwhile, the amplifier's plus input is tied to a reference voltage $\mathbf{V_{REF}}$, which is designed to be very stable across variations in process, voltage, and temperature. This aligns with reference voltage with the attenuator. The job of the amplifier is to do whatever is necessary to balance out its two inputs, making them equal.

The amplifier drives the gate drive of the MOSFET. By varying the gate drive until the plus and minus inputs of the amplifier are equivalent, the LDO's very fast analog control loop enables the $\mathbf{V_{OUT}}$ level to be regulated.



Accounting for an LDO's dropout voltage

Unlike a buck converter, whose output current level always differs from its input current, an LDO's output and input currents always stay the same. Its most important characteristic becomes its *dropout voltage*, which is the amount of falloff from $\mathbf{V_{IN}}$ to $\mathbf{V_{OUT}}$ at a given desired output voltage. This is symbolized by $\mathbf{V_{DO}}$, although the symbol $\mathbf{V_{DS}}$, which refers to the voltage decline between drain and source, essentially means the same thing. $\mathbf{V_{DO}}$ is characterized by onsemi as the voltage amount when $\mathbf{V_{OUT}}$ falls 2% below nominal output voltage $\mathbf{V_{OUT(NOM)}}$.

The formula to remember is:

$$V_{DO} = V_{IN} - V_{OUT}$$

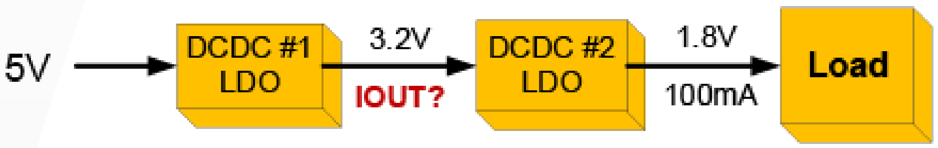
$\mathbf{V_{DO}}$ equates to the minimum level of voltage required to maintain the required $\mathbf{V_{OUT}}$. For any LDO, this value $\mathbf{V_{IN}} - \mathbf{V_{OUT}}$ will decrease as $\mathbf{V_{IN}}$ increases, so referencing this value requires a graph.

When dropout voltage for an LDO is reduced, its efficiency increases; likewise, when it's increased, its efficiency decreases, and does so precipitously. For example, an LDO with an output current of 500mA, and with $\mathbf{V_{IN}}$ of 5V and $\mathbf{V_{OUT}}$ of 3.3V, obviously has a $\mathbf{V_{DO}}$ of 1.7V. Resistance, of course, is voltage divided by current. The resistance **R** of this part is therefore 1.7 / 0.5, or 3.4Ω. With power dissipation $\mathbf{P = I^2R}$, the value of (0.5)2 multiplied by 3.4 is 0.85. An 850mW dissipation means that, for a part whose $\mathbf{P_{IN}}$ is 2.5W (5 · 0.5), $\mathbf{P_{OUT}}$ would be $\mathbf{P_{IN}}$ less dissipation, or 1.65W. Dividing $\mathbf{P_{OUT}}$ by $\mathbf{P_{IN}}$, this makes the efficiency of the LDO just 66%.

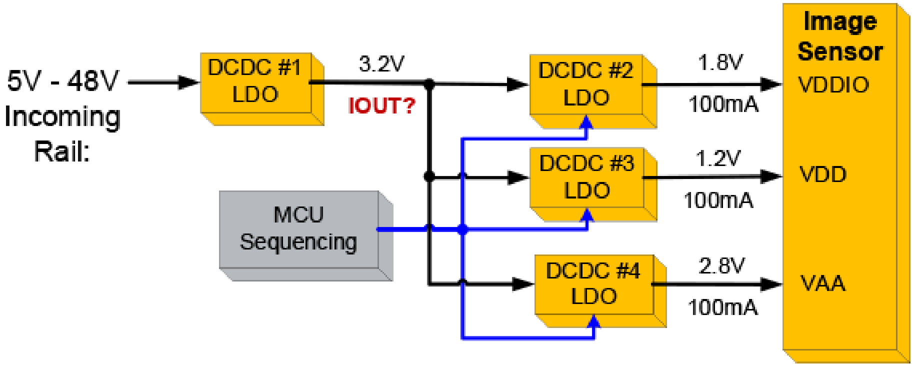
Now, for a 500mA part with 3.3V $\mathbf{V_{IN}}$ and 2.8V $\mathbf{V_{OUT}}$, resistance **R** would be 0.5 / 0.5, or 1.0Ω. Power dissipation would be (0.5)2 multiplied by 1, or 250mW. Thus, for a part whose $\mathbf{P_{IN}}$ (3.3 · 0.5) is 1.65W, $\mathbf{P_{OUT}}$ would be 1.4W, making the part's overall efficiency 84.8%. The reason this becomes important has to do with thermal transfer. A less efficient part loses more of its power as heat. Lower efficiency translates to increased junction temperatures.

Estimating an LDO's output current

Suppose your power regulator requires a load of 1.8V at 100 mA. An LDO always produces an output current equal to its input current. The LDO in the second branch of the power tree must produce output current of 100 mA. So must the LDO in the first branch.



However, suppose your load is designed to account for all three JEDEC power domains. A common configuration for the second branch of the power tree would include one LDO producing 1.8V of output for VDDIO, a second LDO with 1.2V for VDD, and a third LDO with 2.8V for VAA. All three LDOs in the second branch would have output current of 100 mA. The LDO in the first branch would need to supply output current for all three of these LDOs in the second branch. Therefore, it would need 300 mA of output current.



Why heat dissipation is important

In the AC and DC Parametric Tables for linear regulator parts including buck converters and LDOs, published by onsemi as well as onsemi's competitors, each part has a minimum and maximum guaranteed parametric performance levels for voltage and current, at a specified safe junction temperature range. As long as die and junction temperatures remain within the published range, onsemi guaranteed the performance level stated in its datasheets.

There are two sets of minimums and maximums: one for operating temperature and one for absolute extreme temperatures. Beyond minimum and maximum operating temperatures, onsemi cannot guarantee performance. At the absolute extremes, there's a risk of damage to the component.

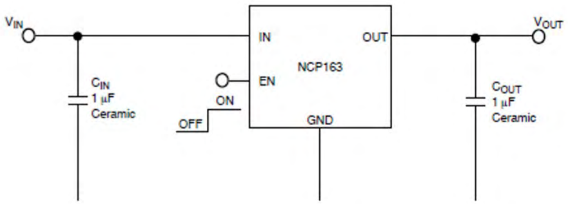
Example with onsemi NCP163 LDO

Here's a real-world example using onsemi's NCP163. According to the specification tables in its datasheet, its maximum junction temperature T_J is 150 °C, and its minimum storage temperature is -55 °C. These constitute the absolute extreme temperatures. Further down the specifications, you'll find operating voltage ranges including guaranteed performance at V_{IN} between 2.2V and 5.5V. That performance is guaranteed, according to the notice above the Electrical Characteristics chart, between -40°C and +125°C — obviously narrower than the extreme range.

Values appearing in the **Typ** ("typical") column of specifications, according to the same notice, at a typical T_J value, which for the NCP163 is 25°C. For example, the stated Line Regulation or Line_{Reg} value, which is the nominal variation in output line voltage amid changes to input line voltage, is **0.02** — meaning that during typical operation, output voltage levels should vary by no more than 2%.

NCP163

LDO Regulator - Ultra-Low Noise, High PSRR, RF and Analog Circuits
250 mA



ABSOLUTE MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Maximum Junction Temperature	T_J	150	°C
Storage Temperature	T_{STG}	–55 to 150	°C

ELECTRICAL CHARACTERISTICS $-40°C \le T_J \le 125°C$; $V_{IN} = V_{OUT(NOM)} + 1$ V; $I_{OUT} = 1$ mA, $C_{IN} = C_{OUT} = 1$ µF, unless otherwise noted. $V_{EN} = 1.2$ V. Typical values are at $T_J = +25°C$ (Note 4).

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Operating Input Voltage		V_{IN}	2.2		5.5	V
Output Voltage Accuracy	$V_{IN} = (V_{OUT(NOM)} + 1\text{ V})$ to 5.5 V $0\text{ mA} \le I_{OUT} \le 250\text{ mA}$	V_{OUT}	–2		+2	%
	$V_{IN} = (V_{OUT(NOM)} + 1\text{ V})$ to 5.5 V $0\text{ mA} \le I_{OUT} \le 250\text{ mA}$ (for $V_{OUT} < 1.8$ V, XDFN4 package)		–3		+3	
	$V_{IN} = (V_{OUT(NOM)} + 1\text{ V})$ to 5.5 V SOT23–5L Package Only		–2		+2	
Line Regulation	$V_{OUT(NOM)} + 1\text{ V} \le V_{IN} \le 5.5\text{ V}$	Line_{Reg}		0.02		%/V

Examples with NCP114 and NCP189 LDOs

Both onsemi's **NCP114** LDO and **NCP189** LDO are rated to be safe from damage at temperatures below 150°C. However, the NCP114 has a much narrower operating temperature range: from -40°C to just +85°C. The NCP189 is guaranteed good performance at much higher temperatures: from -40°C to +125°C. However, for both parts, typical temperature $\mathbf{T_J}$ is 25°C.

When capturing the right values for an image sensor power tree, paying attention to temperature extremes is a big deal. Each part has different operating characteristics, and the choice you should make must reflect the operating conditions you anticipate for the application whose image sensor will utilize your power supply.

onsemi NCP114 LDO

ABSOLUTE MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Input Voltage (Note 1)	V_{IN}	−0.3 to 6	V
Output Voltage	V_{OUT}	−0.3 to V_{IN} + 0.3, max. 6	V
Chip Enable Input	V_{EN}	−0.3 to 6	V
Power Good Voltage	V_{PG}	−0.3 to 6	V
Power Good Current	I_{PG}	20	mA
Output Short Circuit Duration	t_{SC}	unlimited	s
Maximum Junction Temperature	T_J	150	°C

ELECTRICAL CHARACTERISTICS
$-40°C \le T_J \le 85°C$; $V_{IN} = V_{OUT(NOM)} + 1$ V for V_{OUT} options greater than 1.5 V. Otherwise V_{IN} = 2.5 V, whichever is greater; I_{OUT} = 1 mA, $C_{IN} = C_{OUT}$ = 1 µF, unless otherwise noted. V_{EN} = 0.9 V. Typical values are at T_J = +25°C. Min./Max. are for T_J = −40°C and T_J = +85°C respectively (Note 4).

Parameter	Test Conditions		Symbol	Min	Typ	Max	Unit
Operating Input Voltage			V_{IN}	1.7		5.5	V
Output Voltage Accuracy	−40°C ≤ T_J ≤ 85°C	V_{OUT} ≤ 2.0 V	V_{OUT}	−40		+40	mV
		V_{OUT} > 2.0 V		−2		+2	%
Line Regulation	V_{OUT} + 0.5 V ≤ V_{IN} ≤ 5.5 V (V_{IN} ≥ 1.7 V)		Reg_{LINE}		0.01	0.1	%/V
Load Regulation – UDFN package	I_{OUT} = 1 mA to 300 mA		Reg_{LOAD}		12	30	mV
Load Regulation – TSOP−5 package					28	45	
Load Transient	I_{OUT} = 1 mA to 300 mA or 300 mA to 1 mA in 1 µs, C_{OUT} = 1 µF		$Tran_{LOAD}$		−50/ +30		mV
Dropout Voltage – UDFN package (Note 5)	I_{OUT} = 300 mA	V_{OUT} = 1.5 V	V_{DO}		365	460	mV
		V_{OUT} = 1.85 V			245	330	
		V_{OUT} = 2.8 V			155	230	
		V_{OUT} = 3.0 V			145	220	
		V_{OUT} = 3.1 V			140	210	
		V_{OUT} = 3.3 V			135	200	
Dropout Voltage – TSOP package (Note 5)	I_{OUT} = 300 mA	V_{OUT} = 1.5 V	V_{DO}		380	485	mV
		V_{OUT} = 1.85 V			260	355	
		V_{OUT} = 2.8 V			170	255	
		V_{OUT} = 3.0 V			160	245	
		V_{OUT} = 3.1 V			155	235	
		V_{OUT} = 3.3 V			150	225	

onsemi NCP189 LDO

ABSOLUTE MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Input Voltage (Note 1)	V_{IN}	−0.3 V to 6 V	V
Output Voltage	V_{OUT}	−0.3 V to V_{IN} + 0.3 V or 6 V	V
Enable Input	V_{EN}	−0.3 V to 6 V	V
Output Short Circuit Duration	t_{SC}	∞	s
Maximum Junction Temperature	$T_{J(MAX)}$	150	°C

ELECTRICAL CHARACTERISTICS $-40°C \le T_J \le 125°C$; $V_{IN} = V_{OUT(NOM)} + 1$ V; I_{OUT} = 1 mA, $C_{IN} = C_{OUT}$ = 1 µF, unless otherwise noted. V_{EN} = 1.2 V. Typical values are at T_J = +25°C (Note 4).

Parameter	Test Conditions		Symbol	Min	Typ	Max	Unit
Operating Input Voltage			V_{IN}	2.2		5.5	V
Output Voltage Accuracy	V_{IN} = ($V_{OUT(NOM)}$ + 1 V) to 5.5 V 0 mA ≤ I_{OUT} ≤ 250 mA		V_{OUT}	−2		+2	%
	V_{IN} = ($V_{OUT(NOM)}$ + 1 V) to 5.5 V 0 mA ≤ I_{OUT} ≤ 250 mA (for V_{OUT} < 1.8 V, XDFN4 package)			−3		+3	
	V_{IN} = ($V_{OUT(NOM)}$ + 1 V) to 5.5 V SOT23−5L Package Only			−2		+2	
Line Regulation	$V_{OUT(NOM)}$ + 1 V ≤ V_{IN} ≤ 5.5 V		$Line_{Reg}$		0.02		%/V
Load Regulation	I_{OUT} = 1mA to 250mA	WLCSP, XDFN4	$Load_{Reg}$		0.001		%/mA
		SOT23−5L			0.008	0.015	
Dropout Voltage (Note 5)	I_{OUT} = 250 mA (WLCSP, XDFN4 Packages)	$V_{OUT(NOM)}$ = 1.8 V	V_{DO}		180	250	mV
		$V_{OUT(NOM)}$ = 2.5 V			110	175	
		$V_{OUT(NOM)}$ = 2.8 V			95	160	
		$V_{OUT(NOM)}$ = 3.0 V			90	155	
		$V_{OUT(NOM)}$ = 3.2 V			85	149	
		$V_{OUT(NOM)}$ = 3.3 V			80	145	
		$V_{OUT(NOM)}$ = 3.5 V			75	140	
		$V_{OUT(NOM)}$ = 4.5 V			65	120	
		$V_{OUT(NOM)}$ = 5.0 V			75	105	

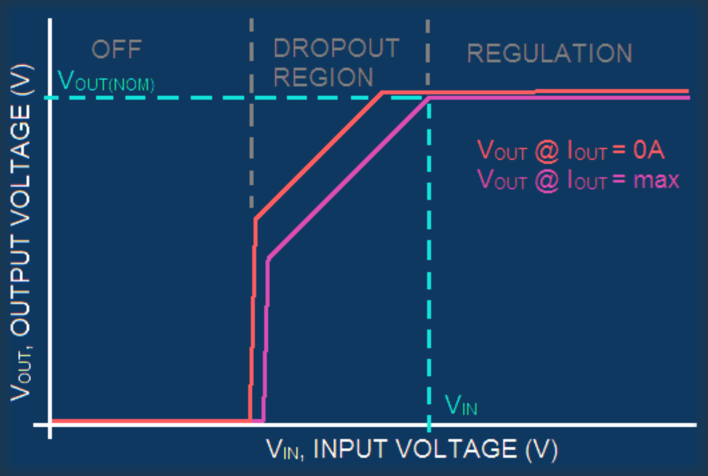
Calculating heat dissipation

There are two sources of power dissipation for an LDO. One is quite minimal, though it isn't quite yet trivial. It's measurable in microamps (µA), and is equivalent to input voltage times quiescent current $V_{IN} \cdot I_{GND}$. Essentially, this is how much power a component will dissipate even when it's not turned on.

The second source is measurable as dropout voltage (the difference between input and output voltage) times output current $I_{OUT}\,(V_{IN} - V_{OUT})$. This makes the power dissipation formula for an LDO into the following:

$$P_D \approx V_{IN} \cdot I_{GND} + I_{OUT}\,(V_{IN} - V_{OUT})$$

The vast majority of power dissipation will be covered by the second part of the equation. Dropout voltage is the minimum amount required for the power regulator to maintain stability. When input voltage surpasses the dropout voltage level, the output voltage will begin to plummet.



The principal purpose of a power regulator in an image sensor application is to step down voltage from the input source to what the image sensor and other components will require. To accomplish this purpose, the regulator must also be adept at dissipating heat.

There are three ways heat may be thermally transferred by a part:

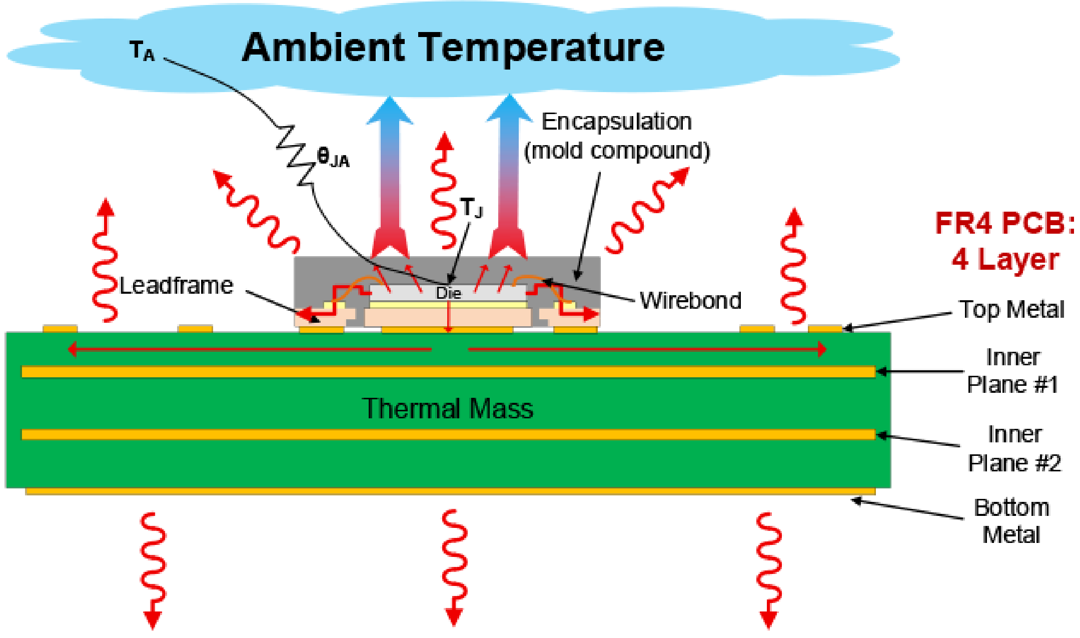
Conduction, in which heat is transferred by direct physical contact between solid objects. Molecules must be in close proximity to one another for heat to transfer between them. In an IC component, the silicon substrate of the PCB to which it's mounted is an effective thermal conductor.

Convection, which relies upon airflow or, in liquid-cooled circumstances, fluid flow. One real-world example of convection is the movement of air around a campfire. Hot air rises, transferring heat upward. The partial vacuum left by the moving hot air draws in cool outside air, feeding the fire with fresh oxygen.

Radiation, which can take place in a vacuum and requires no medium, although it can occur through a medium. For example, solar radiation passes through space, heating the Earth's atmosphere.

For a Dual Flat-Pack No Lead (DFN) package used in onsemi's NCV8560 LDO regulator, the die conducts heat through the mold compound, and also through the die-attach paddle (DAP), which itself has contact with the PCB. Some convection also takes place, as airflow transfers heat from the die (at temperature T_J) towards the air surrounding the component (at ambient temperature T_A). Meanwhile, heat from radiation emanates from several places, including the mold compound surrounding the die, the leadframe connecting the die to the signal pins, and the metal plating at the base of the substrate, whose entire purpose is to radiate heat from the bottom.

DFN Package Example:
(Dual Flat-Pack No Lead Package)



Comprehending thermal resistance ($R_{\theta JA}$)

Specifications for a buck converter or LDO power regulator will provide typical operating junction temperatures (essentially identical to die temperatures) within an environment with a well-regulated ambient temperature. There are two temperature ranges in these specifications, and the one that pertains to everyday operation of the part is the narrowest range: the recommended range for ambient operating temperatures.

One of the most critical values cited by the thermal characteristics in the datasheet for a semiconductor part, or in some cases for two or more specific elements of that part, is thermal resistance θ_{JA}. onsemi symbolizes this value as $R_{\theta JA}$, and you'll hear it referred to as "theta-JA." This covers thermal resistance between the junction J and the ambient environment A. You'll see essentially the same concept referred to by JEDEC as θ_{JX}, where X is a variable referring to any environment.

Essentially, $R_{\theta JA}$ is a measure of how much hotter the part is than the ambient temperature, compared against how much power it produces in watts. Remember, power is heat. Technically speaking, $R_{\theta JA}$ is the resistance of a part or an element of the part to heat conduction, measured in degrees Celsius per watt (°C/W). Remember, conduction is the transfer of heat through direct contact. A high theta-JA translates to poorer heat dissipation and thus higher junction temperature.

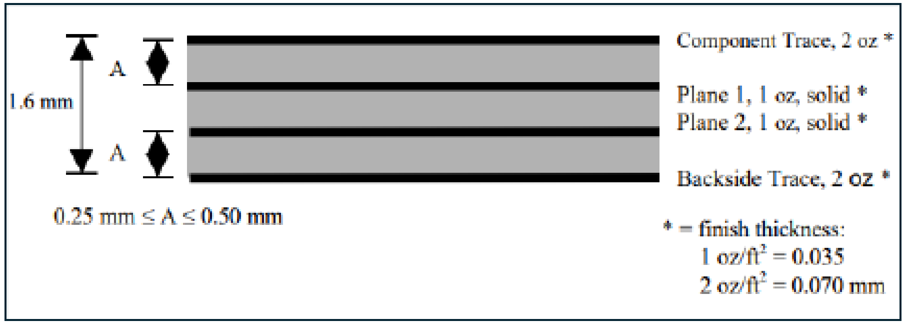


Figure 1 — Cross section of multi-layer PCB showing trace and dielectric thicknesses.

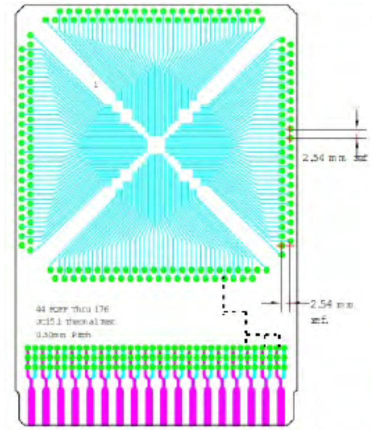


Figure 6 — Nested PCB design (44-176PQFP) (dotted line shows possible routing)

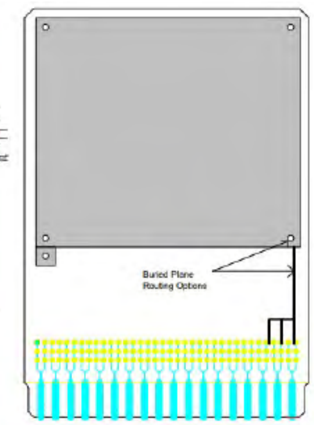


Figure 7 — Power and Ground plane termination and routing possibilities

When a datasheet states the thermal resistance value $\mathbf{R_{\theta JA}}$ for a part is 65°C/W, this means its junction temperature $\mathbf{T_J}$ will rise 65°C for every watt of power dissipated. Assuming two parts have the same power dissipation PD, the one with the lowest $\mathbf{R_{\theta JA}}$ will have the lowest temperature.

Because junction temperature $\mathbf{T_J}$ is a function of both thermal resistance $\mathbf{R_{\theta JA}}$ and power dissipation PD, every IC's $\mathbf{R_{\theta JA}}$ is published in onsemi's datasheets. This rating is frequently used as a criterion for comparing the thermal efficiency of various IC products across one or more semiconductor suppliers.

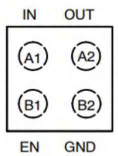
Theta-JA is calculated as the heat level of junction temperature $\mathbf{T_J}$ above ambient temperature TA, divided by power dissipation (loss) $\mathbf{P_D}$. The formula is:

$$R_{\theta JA} = \frac{T_J - T_A}{P_D}$$

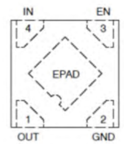
According to the JEDEC standards organization, as much as 60% of the measurement of $\mathbf{R_{\theta JA}}$ is dominated by PCB design. Or this reason, JEDEC standardized measurements of what it symbolizes as $\boldsymbol{\theta_{JX}}$ in document series JESD51x. In this series, JESD51-3 defines measurement standards for a single-layer PCB design, and JESD51-7 defines standards for a four-layer design, including two signal layers, a power plane, and a ground plane, as represented in these JEDEC diagrams.

Accounting for an LDO's self-heating

onsemi
NCP163



WLCSP6
CASE 567WU



WLCSP6
CASE 567WU

THERMAL CHARACTERISTICS

Rating	Symbol	Value	Unit
Thermal Characteristics, WLCSP4 (Note 3), Thermal Resistance, Junction-to-Air	$R_{\theta JA}$	108	°C/W
Thermal Characteristics, XDFN4 (Note 3), Thermal Resistance, Junction-to-Air		198.1	
Thermal Characteristics, SOT23-5 (Note 3), Thermal Resistance, Junction-to-Air		218	

3. Measured according to JEDEC board specification. Detailed description of the board can be found in JESD51-7

LDO NCP163 (250mA) WLCSP4:	NCP163 Data Sheet tables: -40C to 125C					BP: $0.011			
Parameters:									
VIN (V):	5	5	5	5	5	5	5	5	5
Vout	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**
delta	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
IOUT Constant (A)	**0.25**	**0.25**	**0.225**	**0.2**	**0.175**	**0.15**	**0.125**	**0.1**	**0.075**
Power Dissipation (W)	0.8	0.8	0.72	0.64	0.56	0.48	0.4	0.32	0.24
Theta JA	108	108	108	108	108	108	108	108	108
die temp rise:	86.4	86.4	77.76	69.12	60.48	51.84	43.2	34.56	25.92
ambient temp	**25**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**
die temp:	**111.4**	**146.4**	**137.76**	**129.12**	**120.48**	**111.84**	**103.2**	**94.56**	**85.92**
Max die temp Operating	125	125	125	125	125	125	125	125	125
ABS max die temp	150	150	150	150	150	150	150	150	150

Estimating an LDO's die temperature requires a little more savvy. Nearly all of an LDO's power dissipation (not accounting for quiescent power) is equal to the dropout voltage multiplied by the input current. Using onsemi's NCP163 as the example part, assume the same image sensor application requirement with VIN at 5V.

The performance characteristics of an LDO change on account of two factors: desired output current and ambient temperature. Assuming a respectable output current IOUT of 250mA, and accounting for the NCP163's output voltage VOUT of 1.8V, power dissipation PD will be 0.8W. Apply that value to the die temperature formula, accounting for a RθJA of 108°C/W and an ambient environment TA at just above room temperature 25°C, we arrive at a die temperature TJ of 111.4°C. That's appreciably cool.

However, we know better. As mentioned earlier, image sensors tend to be installed in enclosures and modules that trap ambient air. In trapped conditions like this, the part plays a larger role in heating the ambient temperature. Once we take the step of accounting for a possible TA of 60°C, our calculation for die temperature skyrockets to 146.4°C. That's over 21 degrees above the recommended maximum operating temperature (the range narrower than the absolute extremes) and that, as they say, is not cool.

For the LDO's die temperature to fall back within the recommended margins, output current IOUT must be reduced to 175mA at most. This might disqualify this particular LDO from being included in some power trees.

Accounting for a buck converter's self-heating

When assessing various buck converters for a power regulation role, it's necessary to estimate its die temperature or junction temperature. Finding this value means recalling that wattage is power, and power is heat. For a buck converter, the power dissipation formula is quite simple:

$$P_D = P_{IN} - P_{OUT}$$

The ratio of $\mathbf{P_{OUT}}$ to $\mathbf{P_{IN}}$ for a part represents its efficiency. The input voltage level $\mathbf{V_{IN}}$ will be determined by the application for which the image sensor will be used. From that value, using Ohm's Law, we can determine the input current $\mathbf{I_{IN}}$ by dividing $\mathbf{P_{IN}}$ by $\mathbf{V_{IN}}$.

For onsemi's FAN53745 buck converter, the voltage needed for the application at hand $\mathbf{V_{IN}}$ is 5V. Its $\mathbf{I_{OUT}}$ is 470 mA and its $\mathbf{V_{OUT}}$ is 3.2V. Efficiency is determined using the graph in the datasheet for Load Current vs. Efficiency. Following the red line that represents $\mathbf{V_{IN}}$ of 4.9V, at 470 mA, efficiency is around 90%. Using the formulas, we find $\mathbf{P_D}$ is 167mW.

With the value of $\mathbf{P_D}$ in hand, the next step is to incorporate theta-JA and ambient temperature from the datasheet. Some onsemi datasheets use the shorthand $\mathbf{Q_{JA}}$ to refer to $\mathbf{R_{\theta JA}}$. In the case of FAN53745, $\mathbf{R_{\theta JA}}$ is 65°C/W, with a preferred ambient temperature of 60°C. Doing the math, we arrive at a die temperature for the FAN53745 of **70.9°C**.

onsemi
FAN53745

WLCSP6
CASE 567WU

Parameter:	FAN53745
Vout (V):	3.2
Iout (A):	0.47
Power Out (W):	1.504
Efficincy %	0.9
Power In (W):	1.671
Vin (V):	5
IIN (A):	0.334
Power Dissipation:	0.167
Theta JA C/W:	65
die temp rise:	10.862
Ambient temp	60
Die Temp:	70.862
Max die temp operating	85

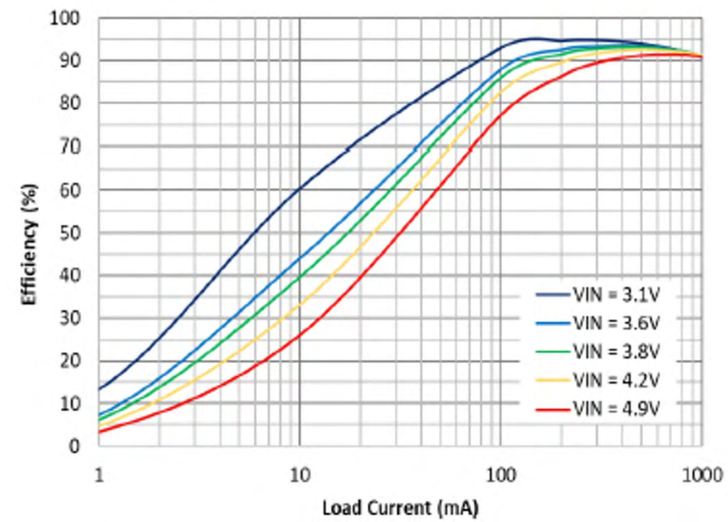


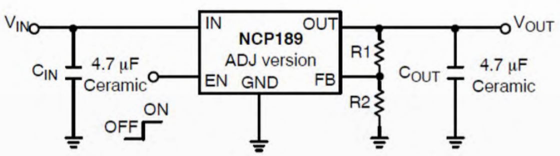
Figure 6 — Efficiency vs. Load Current and Input Voltage, FPWM Mode

Comparing bucks' and LDOs' relative value

WDFNW6 2x2

onsemi
NCP189 LDO

0.5 A
High accuracy (0.7%)
Adjustable low noise
High PSRR

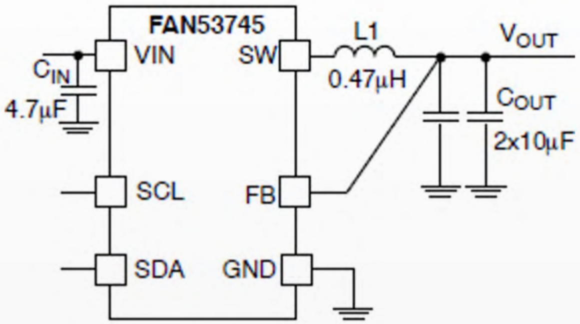


$R_{θJA}$: 60°C/W
Die Temp: 107°C
Operating range:
-40°C to 125°C
Efficiency: 36%
WP: $0.26

WLCSP6
CASE 567WU

onsemi
FAN53745
Buck regulator

Synchronous
3.33 MHz
1 A
1 × 1.5mm



$R_{θJA}$: 65°C/W
Die Temp: 64.5°C
Operating range:
-40°C to 85°C
Efficiency: 90%
WP: $0.40

Assume you need to produce a power tree that resolves for the following characteristics of the image sensor application: V_{IN} is 5V, V_{OUT} is 1.8V, I_{OUT} is 350mA, and ambient temperature is assumed to be a warm 60°C.

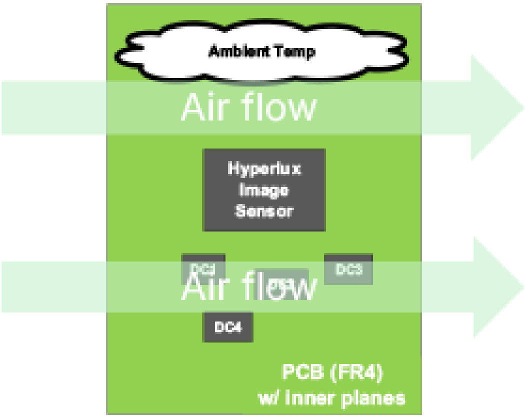
Looking at onsemi's **NCP189** LDO, its thermal resistance $R_{θJA}$ is 60°C/W, so its die temperature T_J calculates at 107°C. Its efficiency rating is ~36%, which is a factor that could very well come into play. At the time of this writing, NCP189's *web pricing* (WP, or onsemi's quoted price for low-volume purchases prior to any discounts) is $0.26 per unit.

The onsemi buck converter with the most similar operating characteristics to this LDO is the **FAN53745**. Its $R_{θJA}$ is 65°C/W, yet because its efficiency rating is a high ~90%, its T_J calculates to be a much cooler 64.5°C. FAN53745's WP is a bit higher at $0.40.

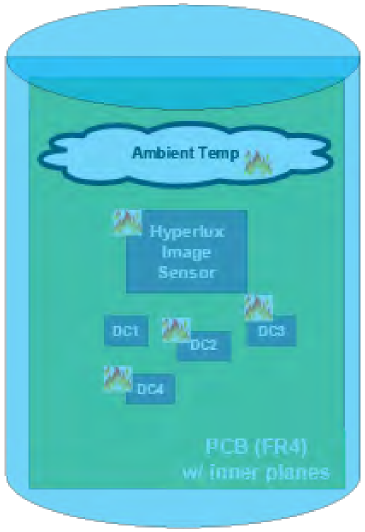
There's a benefit from the buck converter in the temperature department, although clearly that benefit comes with a premium. An LDO is a good choice *if* a T_J of 107°C is tolerable. If you're dealing with a tight enclosure, you may have good reason to choose the buck instead.

How enclosures and modules compound the heat issue

Image sensors typically reside within modules or enclosures. So a power regulator won't necessarily have the luxury of unlimited free airflow and a large PCB plane beneath it. A PCB plane should provide some thermal mass to help dissipate heat away from ICs. But in an enclosure where space comes at a premium, that plane may not be as large as you might like.



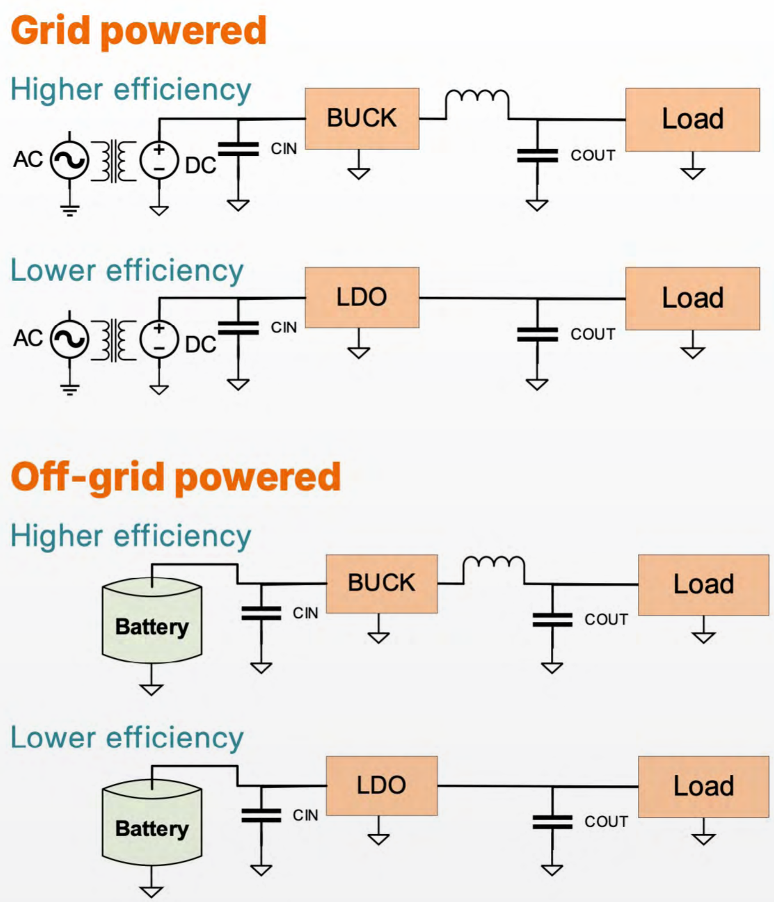
An enclosure will trap most, if not all, of the ambient air. This accelerates the IC's tendency towards self-heating by raising the ambient temperature of the trapped air. Now the ICs become more like miniature Bunsen Burners. For this reason, you need to take into account all three mediums of heat transfer — conduction, convection, and radiation — when assembling your power tree.



When your power source is plugged in, and when it's not

Assume for the sake of argument that your image sensor application will require a step-down voltage of at least 500mV. If your image sensor application is plugged into the AC power grid, whether you're using Power-over-Ethernet (PoE) or an AC/DC adapter, no matter how environmentally conscious you consider yourself to be, from an engineer's standpoint, you may as well have an infinite source of power. So even if an LDO has a lower efficiency rating than buck converters, this fact might not play too significant a role in your power tree considerations.

On the other hand, if your application is battery-powered, or powered from renewable sources such as a solar grid, efficiency becomes more paramount. Because your energy source is not infinite, you may be more inclined to choose a buck for its higher efficiency and lower drain on your energy source over time. Batteries have per-unit costs, and using less of them plays a major role in any consideration of total cost of operation.



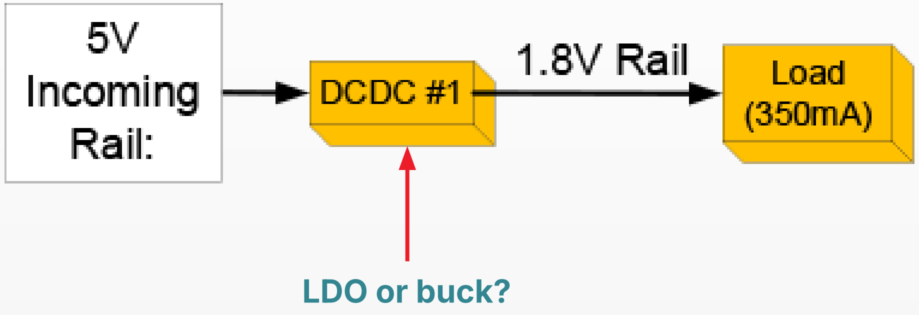
Choosing a buck converter or an LDO

In the past, a common rule-of-thumb for picking an LDO or a buck converter for a step-down voltage task was this: If the load was less than 200 mA, go with an LDO; if it's above 200 mA, go with a synchronous buck. (This rule was itself susceptible to a degree of ripple; on an odd-numbered day, perhaps the threshold was 300 mA.)

Taking modern manufacturing processes and specifications into account, today's rule-of-thumb is a bit more nuanced, and is actually more of a process:

1. Start by assuming you'll choose an LDO. An LDO usually costs less anyway for most circumstances.
2. Check the datasheet for the candidate LDO, and locate its maximum recommended operating temperature (from the narrower range, not the absolute maximum temperature).
3. Multiply that temperature by 85% (0.85) to give the part some headroom. This will be your "safety temperature."
4. Calculate the die temperature T_J for the candidate LDO, using the formulas demonstrated earlier.
5. If T_J exceeds the safety temperature, look for another LDO with possibly a lower ambient temperature rating or lower theta-JA.
6. If there is no LDO that says below the safety temperature, then turn your attention to synchronous buck converters.

As you might expect, there will be a few exceptions. A tight enclosure or module will trap airflow, raising the ambient temperature and accelerating the IC's self-heating tendency. In such a situation, you may want to consider a buck converter over an LDO. Also, in the case of battery-powered applications such as a remote IoT camera, a buck converter should provide higher efficiency, thus extending battery life.



The role of the power tree

Choosing the right components for managing all your image sensor functions involves a diagramming tool called a power tree. Reading the various components' specifications sheets very carefully, and working out the formulas in the proper order, enables you to choose the right regulator components for your power tree every time.

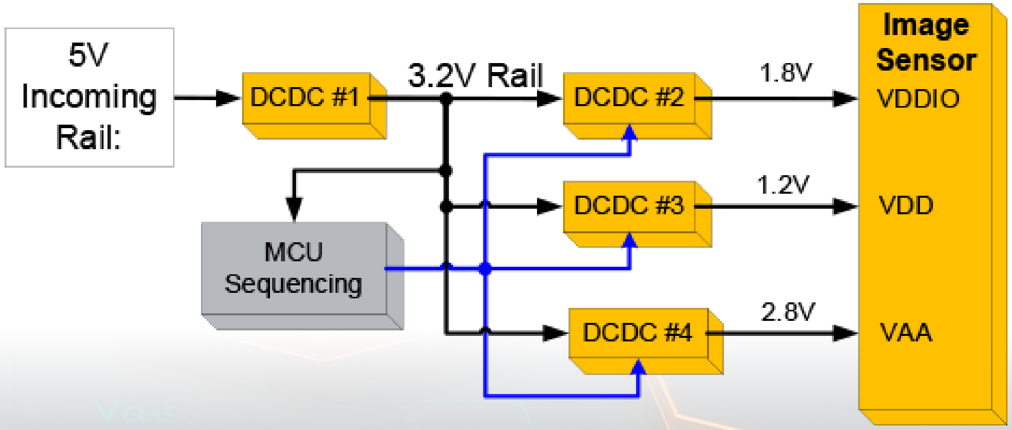
The key function of a power supply — and by extension the power regulators in that power supply — is to safely step the DC input voltage from the power grid or battery down to the lower DC voltage required by sensitive electronics such as the image sensor. There is no single, jack-of-all-trades power regulator that accomplishes this function for every image sensor application. It is always a matter of finding the right component for each particular branch of the power tree.

The characteristics of a proper power tree

A power tree should represent the solution to a number of simultaneous issues regarding the performance of your power supply. An image sensor application that does one thing only might only need one power regulator part. In that case, it's easy to look up the part that meets the voltage, current, and temperature specifications for the application you have in mind. But taking a picture of an event on a factory floor and transferring that event to a storage device in the network are two things, which will probably require at least three regulator parts (one to manage the input current, and the other two to break them down for each application's power requirements). More often than not, you will need four parts.

Making these parts work together will require you to take each candidate part's specifications, insert them into the proper formulas, and work them backwards from output to input to ensure the parts you choose will be compatible and interoperable.

The power regulators you select for your power tree must take into account not just the desired voltage and current for the ambient and junction temperature ranges for your application, but also the degree to which those parts themselves would contribute to those temperatures. The key specification to look for is thermal resistance $\boldsymbol{\theta}_{JA}$ (or $\mathbf{R}_{\theta JA}$ in some onsemi datasheets, and sometimes appearing as $\mathbf{Q}_{JA}$ in some places where Greek characters aren't easily typeset).



The reason there's a power tree for sorting out the best power regulators for your image sensor's power supply, rather than just a power node, is because an industrial imaging device will very likely have more than one function. The processors that will handle these functions, and the parts that enable them to be powered, will probably have three voltage and current requirements, and quite possibly five. So you'll need a second tier of power regulators between the initial DC-DC converter and the image sensor.

In the world of imaging electronics, the JEDEC organization that maintains standards for the microelectronics industry recognizes three power domains for imaging equipment.

Each of these power domains is apportioned its own power rail, with its own specific characteristics:

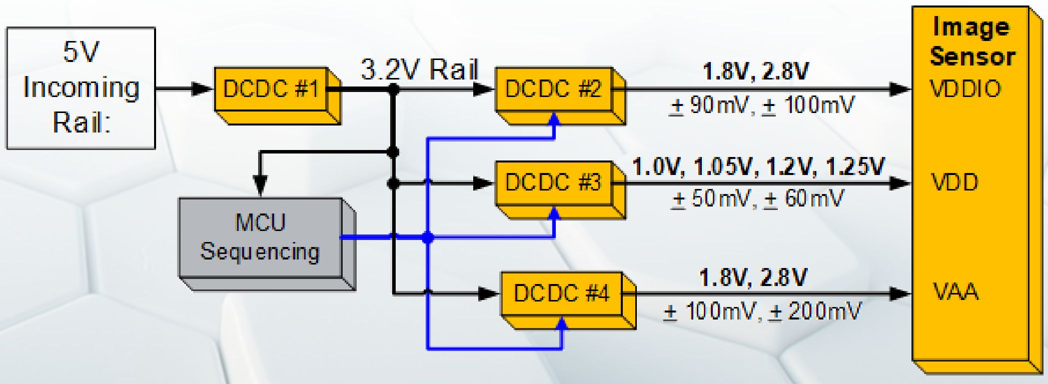
VDD (1.0V – 1.25V), short for "voltage at the drain," maintains the necessary supply voltage to power the core logic units in the power regulator

VDDIO (often appearing as VDD_IO, 1.8V – 2.8V) maintains the signaling voltage levels enabling a chip with a low internal voltage to communicate with other components whose voltages may be higher

VAA (2.8V) is reserved for analog circuitry, which must always be accounted for in a power supply, and is typically the highest voltage of the three

For a power regulator that uses LDOs to regulate all three voltage specifications, you will need one LDO per rail. But then you will need a fourth LDO to step down power to these three. That singular LDO will form the first branch of the power tree, the other three LDOs the second branch.

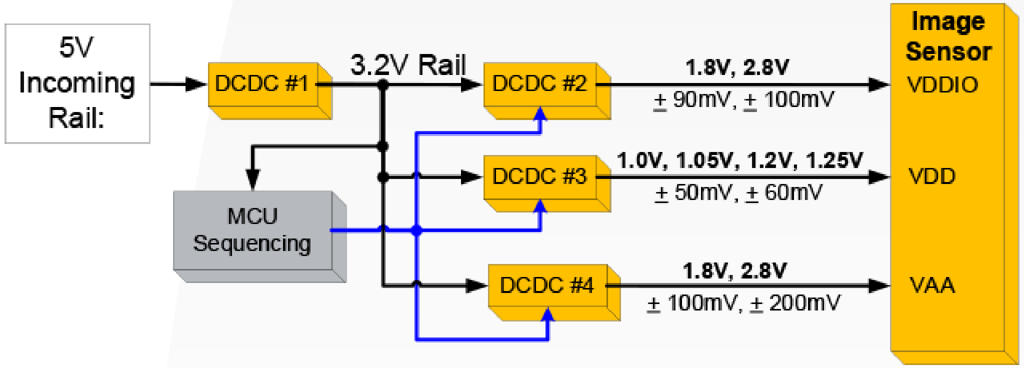
Pictured: A typical power tree for an image sensor application, using four regulators for three rails



Accounting for noise

Power integrity concerns	VDDIO supply rail 1.8V, 2.8V	VDD supply rail 1.0V, 1.05V, 1.2V, 1.25V	VAA supply rail 1.8V, 2.8V
Voltage rail tolerance	Low: ±100mV	High: ±50mV - ±60mV	Low: ±100mV - ±200mV
Noise	Low: ~≥70dB PSRR	Low: ~≥70dB PSRR	Very high

An image sensor is essentially a parking lot of analog-to-digital (A2D) converters, which are converting photons to electrons at a very fast rate. An A/D converter may have a resolution of 10 to 14 bits, the least significant bit (LSB) of which may be chattering if the VAA power supply is noisy. You can minimize this chatter by sourcing the VAA supply with a very clean DC voltage power supply.



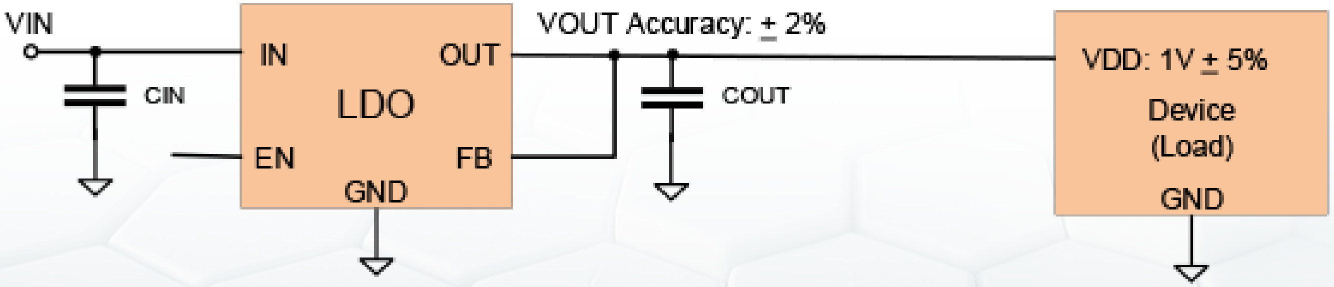
Accounting for an LDO's transient response and V_{OUT} accuracy

When an LDO is switching modes, its load demand is expected to change very quickly. As it's switching, its output voltage levels are likely to experience "glitches." The task at hand becomes to minimize the LDO's transient response to manageable levels. You want transient response to stay within an acceptable margin, which is usually ±5%.

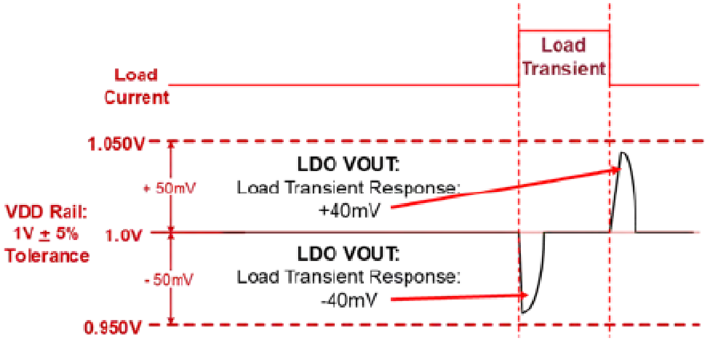
Suppose a device has a load from the VDD service rail of 1V, ±5% (±50mV). According to its specifications, its $\mathbf{V_{OUT}}$ accuracy is ±2%.

During transient response, $\mathbf{V_{OUT}}$ will decline as the load goes high, and will spike with the load returns to 1V. If the transient response stays within ±40mV, that's in the acceptable range.

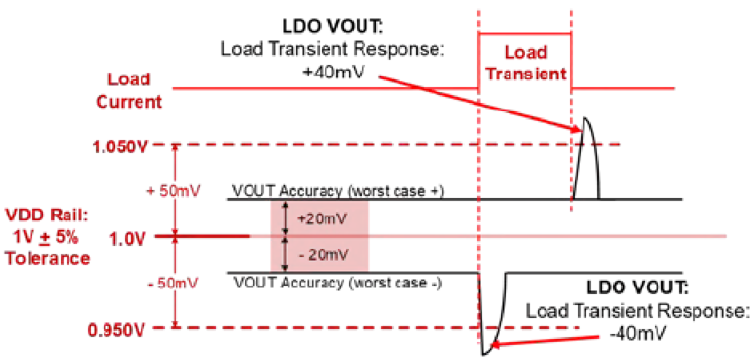
However, you should never assume a perfect $\mathbf{V_{OUT}}$ accuracy. Factoring this in, and adding another 2% (±20mV) to the possible transient response factor both ways, it's possible to exceed the transient response margins. So, you need both: good transient response plus good $\mathbf{V_{OUT}}$ accuracy.



Accounting for voltage rail tolerance



Transient response without V_{OUT} accuracy



Transient response with V_{OUT} accuracy

One of the two most critical performance characteristics with respect to power integrity (PI) — ensuring the stability of power performance for both normal and adverse conditions — is voltage rail tolerance. These are minimum and maximum voltages that each supply rail (VDDIO, VDD, VAA) can handle.

The VDDIO supply rail tolerates voltages of ±100mV, which is usually quite comfortable. Since VAA covers voltages for analog parts, its tolerances may vary from ±100mV to ±200mV. It's VDD that has the tightest tolerance range, between ±50mV and ±60mV, depending on the image sensor. For this reason, two other factors come into consideration:

Nominal transient response

Transient voltage levels are typically registered when the part is responding to a sudden change, such as switching. Voltage will suddenly drop when the load goes high as the transient event starts, then return to normal. Then it will suddenly spike when the load goes back to normal as the event ends, before returning to normal again. Typically, a VDD supply rail will tolerate transient voltage dips and spikes of ±5%. Transient response ratings for a part will be listed in minimum and maximum values in mV, often along with a typical tolerable duration in µs or ns.

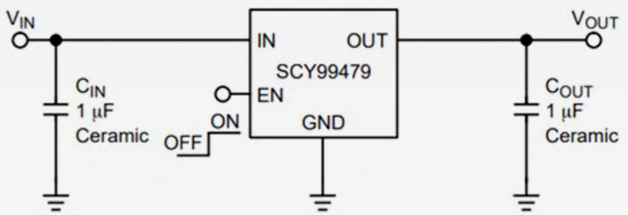
Low output voltage accuracy margin

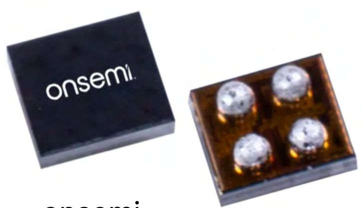
Whether the "normal" voltage level to which a part returns is the same voltage as before the transient event occurs, depends on output voltage accuracy. It's a kind of margin of error, symbolized by **V_{OUT} Accuracy**, and is rendered as a plus-or-minus percentage.

onsemi T30LxPSR165 LDO

Two candidates for very versatile and reliable LDO devices for any power regulator are onsemi's T30LMPSR165 and T30LAPSR165. Both are fabricated on onsemi's Treo bipolar-CMOS-DMOS (BCD) 65 nm process, produced at onsemi's world-class 300 mm fabrication facility in East Fishkill, New York.

Both LDOs are designed to supply 300mA output current from a 1.4V to 3.3V input voltage, with best-in-class transient response time of 1 µs — ideal for image sensor applications that require fast sampling rates. Both support a wide range of output voltages from 1.0V to 3.2V. (T30LAPSR165 is specially adaptable for automotive applications.)





onsemi
T30LMPSR165 LDO
T30LAPSR165 LDO

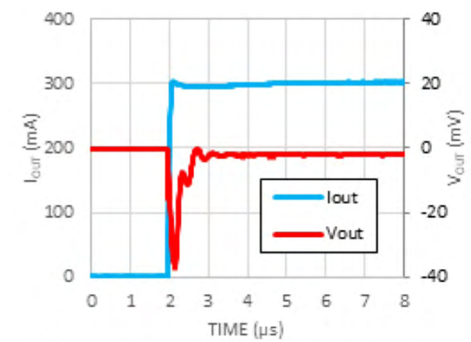
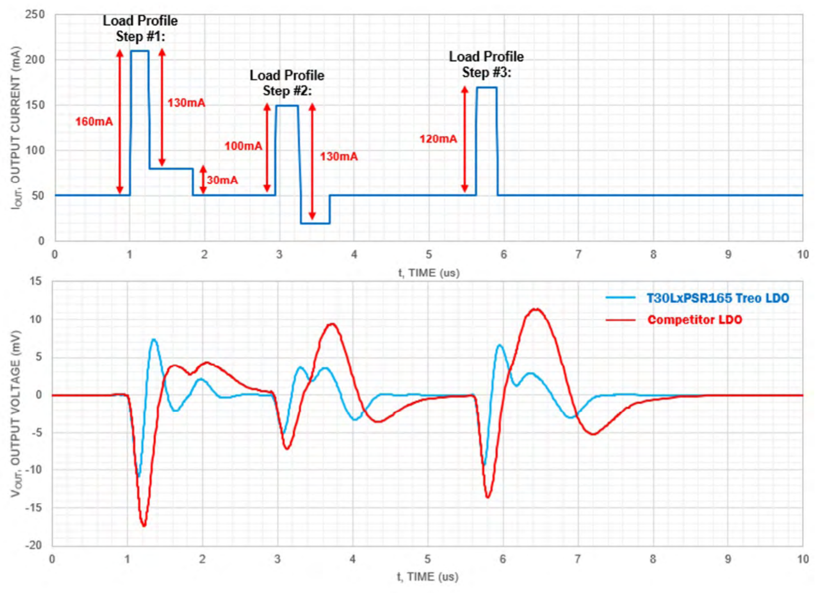


Figure 2. Load Transient Response for C_{OUT} 1 µF and Load Step 0 to 300 mA with Rise Time 100 ns

How T30LxPSR165 achieves good transient response



The two graphs at left shows an actual "spiky load" test of T30LxPSR165 Treo LDO with three consecutive load profiles, whose load steps are numbered #1, #2, and #3. Notice the time distance between #1 and #2 are close to 1 µs. The lower graph shows the corresponding transient response envelopes for Treo LDO in blue, and the next best performing competitor LDO in red.

Ideally, the power supply for any image sensor doesn't want voltages to change at all. Transient V_{OUT} responses cannot be eliminated, so minimizing their amplitude and duration is always the best policy. What matters most in these graphs is the settling time. Specifically, how long will it take for V_{OUT} to return to the pre-load step voltage level? The accompanying table shows how much more quickly the Treo LDOs settled versus the competitor. A savings of 0.6µs is a veritable gulf for a device as sensitive and fast as an image sensor. Quicker settling means less LSB chatter, which translates into reduced visible noise from rendered images. You can literally see a 0.6µs settling time difference.

Load profile step	Settling time			
	Treo LDO	Competitor	Treo LDO advantage (Time)	Treo LDO advantage (%)
#1:	1.2µs	1.8µs	0.6µs	33.3%
#2:	1.4µs	2.5µs	1.1µs	44%
#3:	1.6µs	2.8µs	1.2µs	42.8%

Application and measurement conditions

V_{IN} = 2.95V

V_{OUT} = 2.85V

I_{OUT} = Application load profiles #1 - #3 (Actual)

C_{OUT} = 750nF

Horizontal time base: 1µs/div

Vertical voltage: 5mV/div

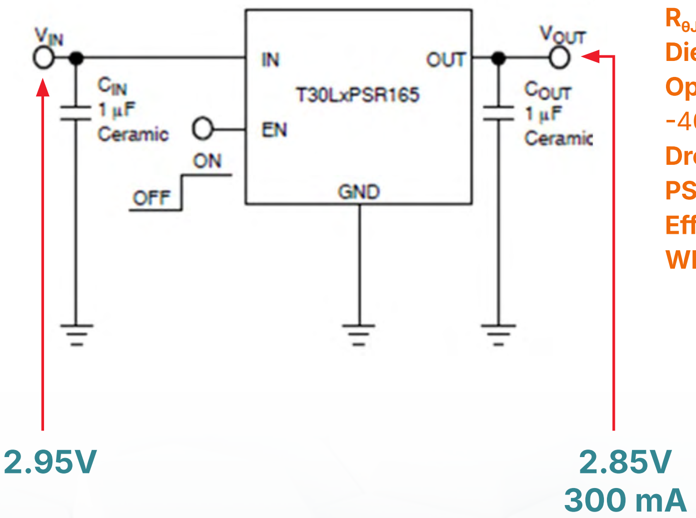
How T30LxPSR165 maintains low die temperature

A low dropout voltage helps ensure a low die temperature **T_J**. Most LDOs' specifications will show minimum dropout voltages in the 200mV to 300mV range. When T30LMPSR165 is tested in 60°C ambient temperature conditions, with **V_{IN}** of 2.95V and **V_{OUT}** of 2.85V (thus 100mV dropout voltage), it achieves an efficiency rating of 96.6%. It's certified to deliver 75 dB PSRR at 1 kHz frequency with IOUT of 20 mA, with output voltage noise **V_N** of an astoundingly low 16 µVRMS. This translates to a **T_J** of a cool 63°C, just three degrees Celsius above ambient temperature.

WLCSP4
Case 567VS

onsemi
T30LxPSR165 LDO

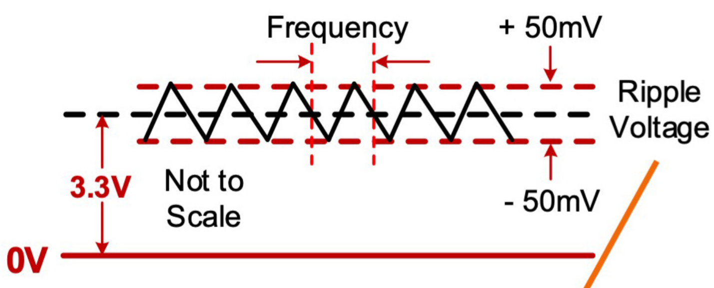
Fastest load transient response
High accuracy (±1%)
Ultra-low noise
High PSRR



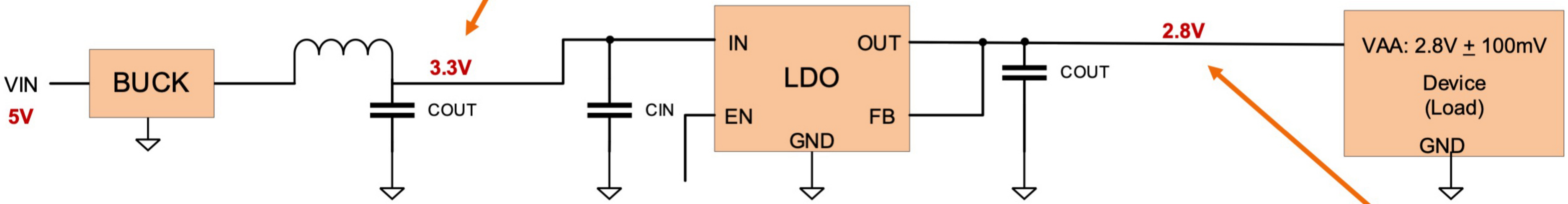
$R_{\theta JA}$: 101°C/W
Die Temp: 63°C
Operating range:
-40°C to 125°C
Dropout voltage: 100mV
PSRR: 45 dB @ 20 mA
Efficiency: 96.6%
WP: $0.082

Minimum ripple voltage with maximum PSRR

Input ripple voltage

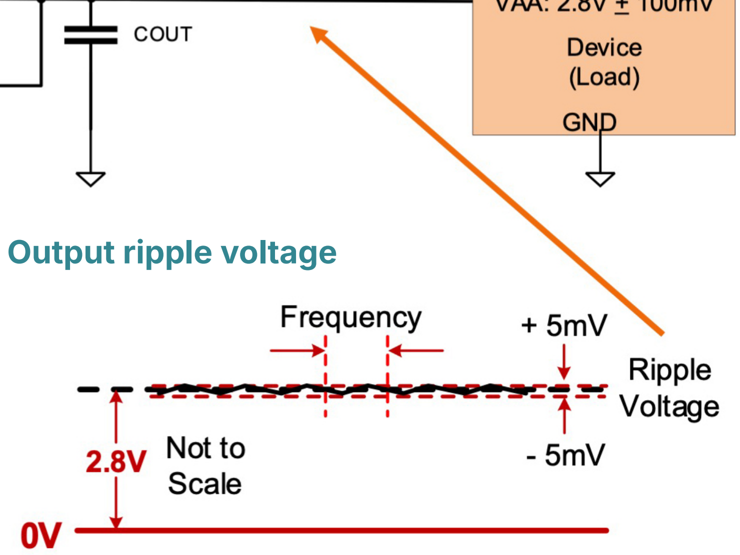


Voltage noise and PSRR both come into play when determining the potential amplitude of ripple voltage, which is the degree of fluctuation in output voltage. The higher the ripple voltage, the less efficient the power regulator will be, and the faster its performance will degrade over a shorter period of time. As you'll see, a buck converter's output ripple is essentially its signature.



For the two digital supply rails VDDIO and VDD, noise typically does not play much of a factor. With the VAA supply rail, noise is a very serious issue. Image sensors are especially sensitive to both noise and ripple voltage from VAA. For this reason, PSRR should preferably be above 85dB.

Output ripple voltage

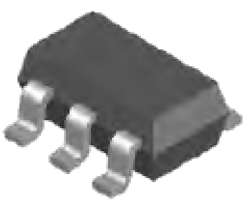


Voltage noise and PSRR

There are two important measurements of noise in a part's datasheet. One registers the voltage of all the noise at a frequency range between 10Hz and 100kHz. Naturally, the lower the amount registered here, the better. For the VAA supply rail, choose an LDO with a low noise output, preferably below 20µV of RMS (root-mean-square), represented in the datasheets as V_{RMS}.

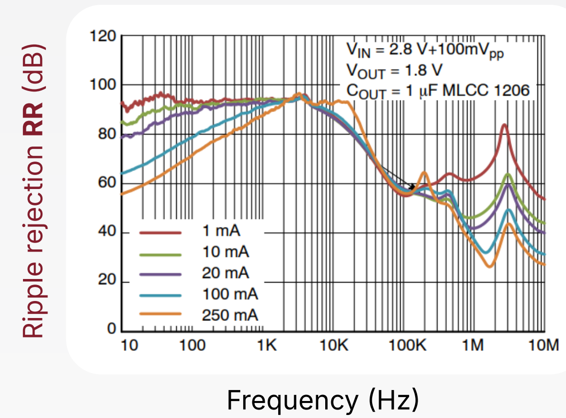
Power supply rejection ratio

The second noise measurement registers the suppression of noise on the scale of audibility: the bel scale, stated in decibels. Spec sheets will register this value as PSRR, which represents the ability of the part to attenuate input ripple on its output. PSRR is typically specified for an input noise frequency of 1KHz.

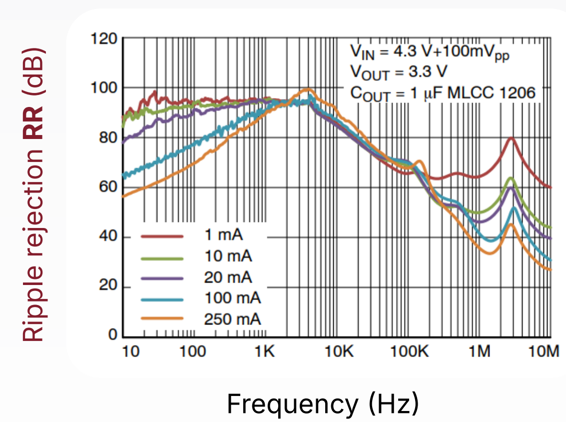


onsemi
NCP163 LDO

NCP163 PSRR: V_{OUT} = 1.8V



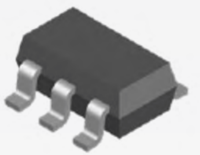
NCP163 PSRR: V_{OUT} = 3.3V



Finding the sweet spot for low-noise LDOs

Supplier	onsemi			
Part Number	**NCP160**	**NCP161**	**NCP163**	**NCP167**
Package X/Y (mm)	0.65×0.65×0.4 1×1×0.4	0.65×0.65×0.4 1×1×0.4	0.65×0.65×0.4 1×1×0.4	0.65×0.65×0.4
Input Voltage Range	1.9 - 5.5V	2.6 - 5.5V	2.2 - 5.5V	1.9 - 5.5V
Input Voltage Max	6 V	6 V	6 V	6V
Max Output Current	250 mA	450 mA	250 mA	700mA
Output Voltage	1.8 – 5.14V	1.8 – 5.14V	1.2 – 5.14V	1.8 – 5.2
Output Voltage Accuracy	+/-2%	+/-2%	+/-2%	+/-2%
Dropout @ Max. I_{OUT}	95 mV	150 mV	95 mV	210mV
PSRR (dB) at 1kHz	92 dB	92 dB	92 dB	93dB
No-Load Quiescent Current	18 µA	18 µA	12 µA	18uA
Enable Input (Y/N)	Y	Y	Y	Y
Output Noise	10µVRMS	10µVRMS	6.5µVRMS	15uVRMS
Temp Range ambient (C)	(-40) to 125	(-40) to 125	(-40) to 125	(-40) to 125

Supplier	Ricoh	Texas Instruments	
Part Number	**RP102x**	**LP5907**	**LP5912**
Package X/Y (mm)	0.79×0.79×0.4mm 1.8×2.0x0.4mm	0.65×0.65×0.4mm 1×1×0.4mm	0.65×0.65×0.4mm 2 × 2mm
Input Voltage Range	1.7 to 5.25V	2.2 to 5.5V	1.6 to 6.5V
Input Voltage Max	6 V	6 V	7V
Max Output Current	300 mA	250 mA	500mA
Output Voltage	1.2 to 3.3V	1.2 to 4.5V	0.8 ~ 5.5
Output Voltage Accuracy	+/-1.0%	+/-2%	+/-2%
Dropout @ Max. I_{OUT}	120 mV	120 mV	170mV
PSRR (dB) at 1kHz	80 dB	82 dB	75dB
No-Load Quiescent Current	50 µA	12 µA	30uA
Enable Input (Y/N)	Y	Y	Y
Output Noise	30µVRMS	6.5µVRMS	12uVRMS
Temp Range ambient (C)	(-40) to 85	(-40) to 125	(-40) to 125



onsemi
NCP163 LDO

onsemi's NCP163 LDO offers some sizable advantages for reducing noise. Like its siblings, it offers 92 dB of PSRR at 1 kHz, but unlike the others its output noise is a low 6.5µVRMS of output noise.

Hyperlux CMOS image sensors

Image sensor	Family	Resolution	Shutter type	Backside lamination	Indirect time-of-flight	Wake-on-motion	Power rail sequencing
ARX383	Hyperlux SG	0.3MP	Global	No	No	No	yes
AR0145	Hyperlux SG	1MP	Global	No	No	No	yes
AR0235	Hyperlux SG	2MP	Global	No	No	No	yes
AR2020	Hyperlux LP	20MP	ERS / GRR	yes	No	yes	yes
AR0830	Hyperlux LP	8MP	ERS / GRR	yes	No	yes	yes
AR0544	Hyperlux LP	5MP	ERS / GRR	yes	No	yes	yes
AR0822	Hyperlux LH	8MP	ERS / GRR	yes	No	yes	yes
AR0246	Hyperlux LH	2MP	ERS / GRR	yes	No	yes	yes
AF0130	Hyperlux ID	1.2MP	Global	yes	yes	No	yes
AR0341	Hyperlux	3MP	ERS	yes	No	No	No
AR0823	Hyperlux	8.3MP	ERS	yes	No	No	No

Hyperlux is based around the key tenets of safety and security in industrial and automotive image sensing. onsemi's Hyperlux image sensors are capable of delivering competitive dynamic range of up to 150dB. They are designed to maintain stable performance characteristics across a very broad range of extreme temperatures. And they are designed to utilize minimum power, which is why these exercises with building power trees,you can ensure outstandingly long product lifespans for industrial and automotive image sensors, with reliable performance records throughout.

The table above shows the low-power onsemi Hyperlux image sensors presently available for industrial applications.

Hyperlux power requirements table

				+,- 100mV (Max - Min) Tolerance			+,- 50mV (Max - Min) Tolerance			+,- 100mV (Max - Min) Tolerance			DCDC #2	DCDC #3	DCDC #4	DCDC #2	DCDC #3	DCDC #4	Typical Total Power (W):	Worst Case Total Power (W):
				VDDIO (DCDC #2):			VDD (DCDC #3):			VAA (DCDC #4):			IDD_IO	IDD	IAA	IDD_IO	IDD	IAA		
Item:	Image Sensor:	Hyperlux Family:	Pixels:	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Typ (mA)	Typ (mA)	Typ (mA)	Max (mA)	Max (mA)	Max (mA)		
1	ARX383	SG	0.3MP	1.7	1.8	1.9	1.14	1.2	1.26	2.6	2.8	3.0	1.7	31	17	4	45	30	0.0879	0.154
2	AR0145	SG	1MP	1.7	1.8	1.9	1.14	1.2	1.26	2.6	2.8	3.0	3	67	23	6.3	94.5	84	0.1502	0.383
3	AR0235	SG	2MP	1.7	1.8	1.9	1.20	1.25	1.3	2.6	2.8	3.0	0.1	100	45	2.8	123	51.5	0.2512	0.320
4	AR2020	LP	20MP	1.7	1.8	1.9	1.00	1.05	1.1	2.7	2.8	2.9	42	233	39	60	350	60	0.4295	0.673
5	AR0830	LP	8MP	1.7	1.8	1.9	1.00	1.05	1.1	2.7	2.8	2.9	27	77	22	43	126	37	0.1911	0.328
6	AR0544	LP	5MP	1.7	1.8	1.9	1.00	1.05	1.1	2.7	2.8	2.9	26	107	16	37	120	35	0.204	0.304
7	AR0822	LH	8MP	1.7 / 2.7	1.8 / 2.8	1.9 / 2.9	1.00	1.05	1.1	2.7	2.8	2.9	15.7	151.8	74.3	65	290	125	0.3957	0.805
8	AR0246	LH	2MP	1.7 / 2.7	1.8 / 2.8	1.9 / 2.9	1.00	1.05	1.1	2.7	2.8	2.9	8.95	132	36.2	14.5	187	50.6	0.2561	0.380
9	AF0130	ID (iToF)	1.2MP	1.71	1.8	1.89	1.14	1.2	1.26	2.6	2.8	3	1420	85	36	3100	123.5	49	2.7588	6.162
10	AR0341	Hyperlux	3MP	1.7	1.8	1.9	0.95	1.0	1.05	1.7 / 2.66	1.8 / 2.8	1.9 / 2.94	9	232.2	76	12	417.7	92	0.4612	0.732
11	AR0823	Hyperlux	8.3MP	1.7	1.8	1.9	0.95	1.0	1.05	1.7 / 2.66	1.8 / 2.8	1.9 / 2.94	39	337	82	54.04	355.3	110.9	0.6368	0.802

In this power table for Hyperlux industrial image sensors, the blue, red, and green sets of columns contain the minimum, typical, and maximum recommended voltages for each of the three main supply rails: VDDIO, VDD, and VAA. The purple columns contain the typical current levels for each supply rail in milliamps. These figures are used to project **Typical Total Power** in the white column. The yellow columns contain the absolute maximum current levels (not the recommended operating maximums — these are higher). These yellow current levels assume 60°C ambient temperature, and the image sensor set for the highest possible power consumption level. Those figures were used to project **Worst Cast Total Power** in the far right column. You will be referencing worst-case current levels in constructing your power tree.

Using the data sheets to build the right power tree

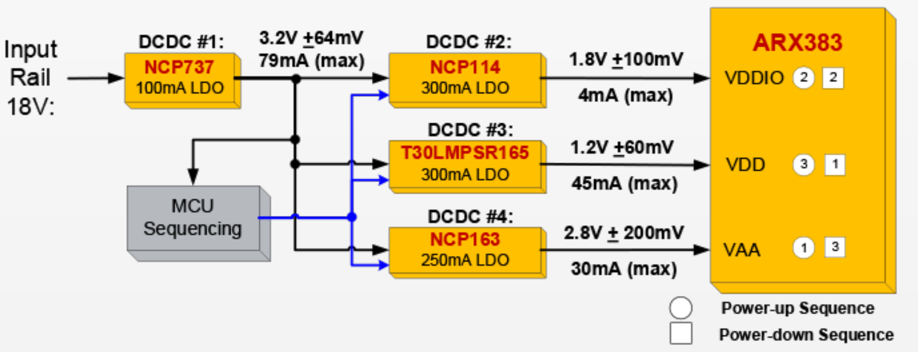
Here's how power tree construction works: The image sensor under consideration for your industrial application is represented by the big box on the far right. It's subdivided into its requisite supply rails. For a power supply that supports power-up and power-down sequencing, your choice of sensor may be influenced by the order in which rails are powered up (represented by numbered circles) and powered down (numbered squares).

Your most important choice of power regulator parts is at the first branch, **DCDC #1**. This branch will step down voltages for all the parts in the second branch, as well as the MCU microcontroller. You may need two or three regulator parts in the second branch to make the final voltage step-downs for each of the sensor's supply rails, unless the first step-down is adequate for one of the rails (typically VAA). If you choose a buck converter for DCDC #1, you may opt to split the voltage rail leading to DCDC #2 from the rail leading to LDOs for DCDC #3 and DCDC #4.

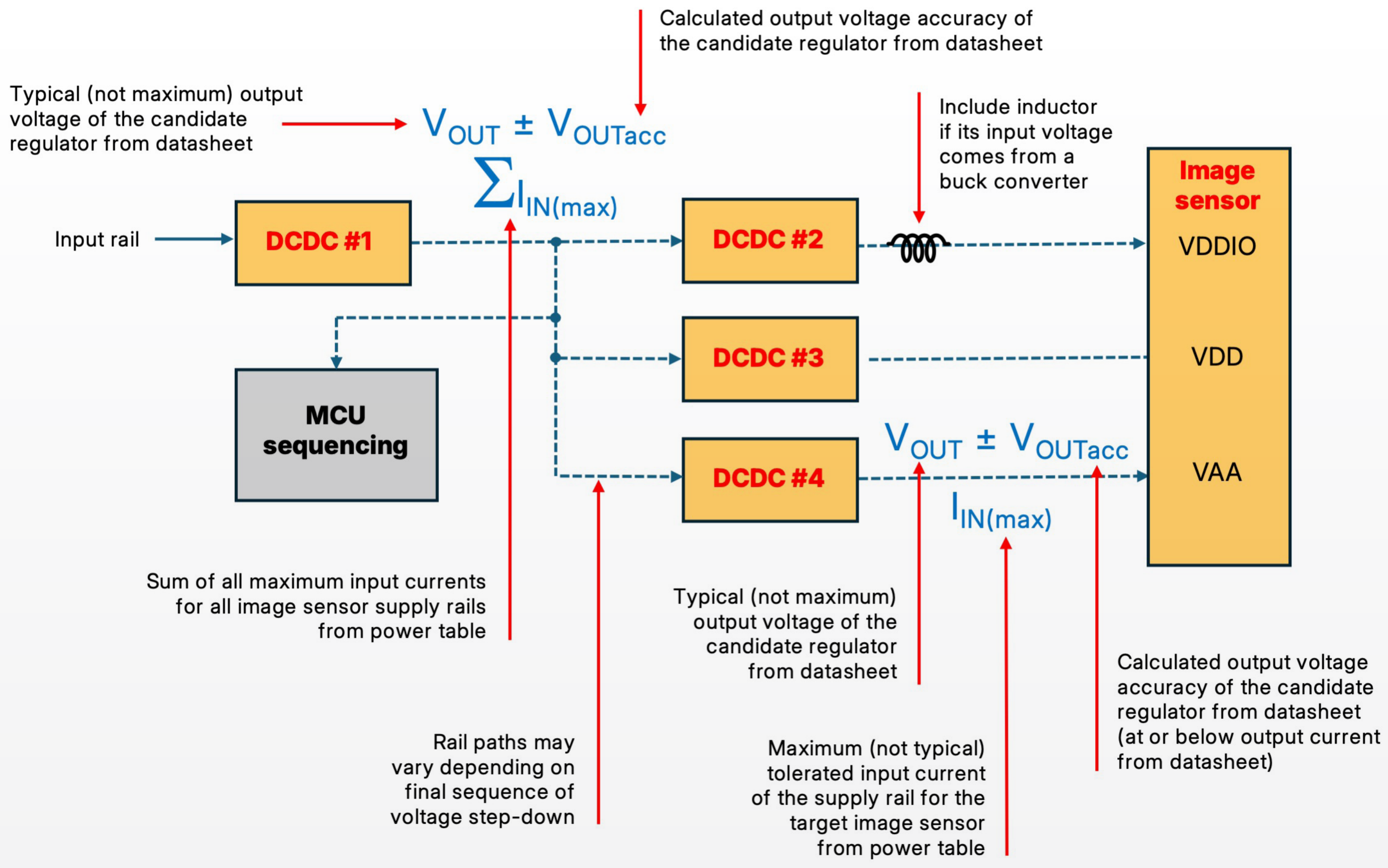
For each rail connection, you will be solving for the typical voltage the next part in the branch requires, plus or minus the voltage accuracy level, and also the maximum current that next part will tolerate. This may be a bit confusing at first, which is why the current levels for our power trees are marked with **(max)**.

For each power tree, there is a table of candidate power regulator parts, both buck converters and LDOs. These options meet the following characteristics:

- Their calculated die temperatures $\mathbf{T_J}$ at 60° ambient (shown in bold red), accounting for $\mathbf{R_{\theta JA}}$, are at most 85% of maximum drain-to-source temperature, typically less
- Their required input voltages are well within their $\mathbf{V_{IN}}$ ranges, even accounting for variations in the $\mathbf{V_{OUT}}$ accuracies of the parts powering them
- Their output voltages $\mathbf{V_{OUT}}$ match the input voltage requirements of the parts they are powering $\mathbf{V_{IN}}$
- Their maximum output currents $\mathbf{I_{OUT}}$ are enough or more to fill the current requirements of the parts they are powering $\mathbf{I_{IN}}$



Inserting characteristics from the datasheets



Solving for thermal characteristics

An LDO's die temperature **T_J** is calculated using these formulas:

$$P_D \approx V_{IN} \cdot I_{GND} + I_{OUT}(V_{IN} - V_{OUT})$$

$$\theta_{JA} = \frac{T_J - T_A}{P_D}$$

A part may appear twice in the same table when it's considered for use in two or more positions, because when **I_{OUT}** is different, die temp **T_J** will also be different.

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP163AFCS280T2G	LDO	125°C / 62.2°C	2.2V - 5.5V	250mA	2.8V	±2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 69.2°C	2.3V - 5.5V	1A	0.9V - 3.3V	±1.5%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40

Here is the presumed **T_A**

A buck converter's die temperature **T_J** is calculated using these formulas:

$$P_D = P_{IN} - P_{OUT}$$

$$P_{OUT} = \frac{P_{IN}}{V_{OUT}\,\text{accuracy}}$$

$$\theta_{JA} = \frac{T_J - T_A}{P_D}$$

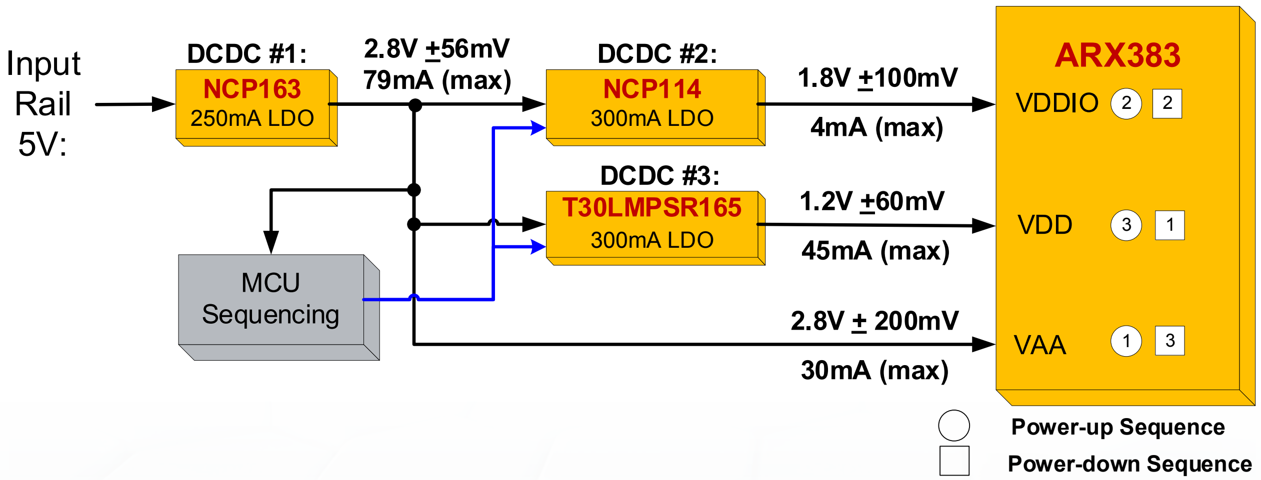
Transient response: the maximum current change measured for a step change in load

Using this given **θ_{JA}**, work the thermal formula backwards to find **T_J**

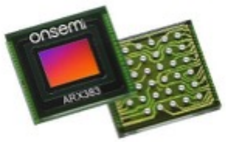
Lower noise often trades off against higher cost

Hyperlux SG ARX383 option #1

The choice of **NCP163** as **DCDC #1** at 2.8V will drive the VAA input rail, as well as an intermediate rail. NCP114 was considered first for this slot, but at 60°C ambient, its die temperature rose to 84.17°C. That left no margin with 85°C as its max operating temperature. The table on the right shows the total bill-of-materials (BOM) cost at low volume (higher volume purchases will be discounted more).



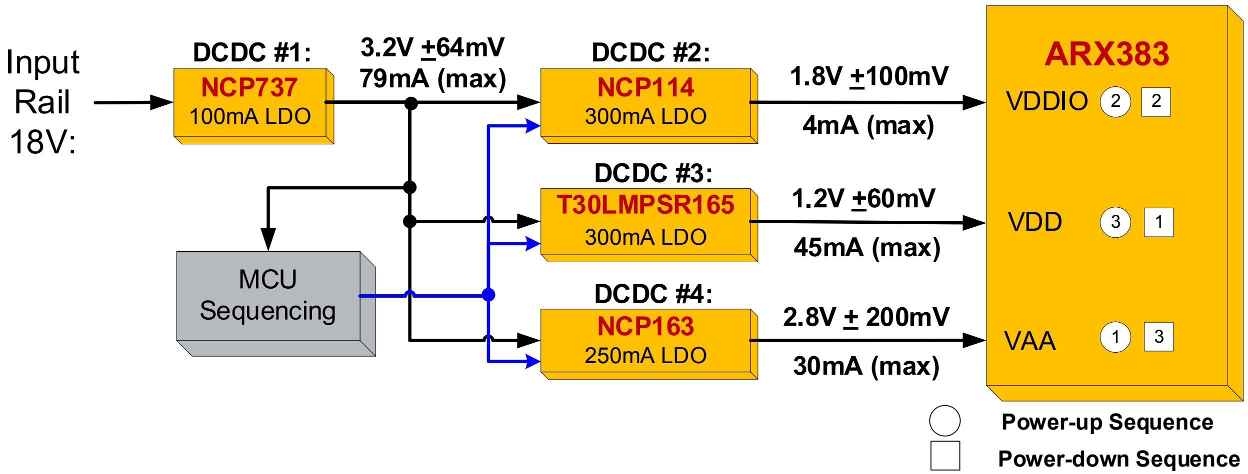
V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.248



T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP163AFCS280T2G	LDO	125°C / 78.7°C	2.2V - 5.5V	250mA	2.8V	±2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
NCP114AMX180TBG	LDO	85°C / 60.7°C	1.7V - 5.5V	300mA	1.8V	±2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
T30LMPSR165CFCT120T2G	LDO	125°C / 67.3°C	1.4V - 3.3V	300mA	1.2V	±15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082

Hyperlux SG ARX383 option #2



V_{IN}	Options	Total power BOM cost ($WP)
18V	See block diagram	$0.578
	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC#1: FAN6	$2.488 (not inc. 1 inductor)

May be preferable for enclosures where 105.2°C die temp is too warm. NCV92310 PMIC is another option.

T_J range:
-40°C to 60°C

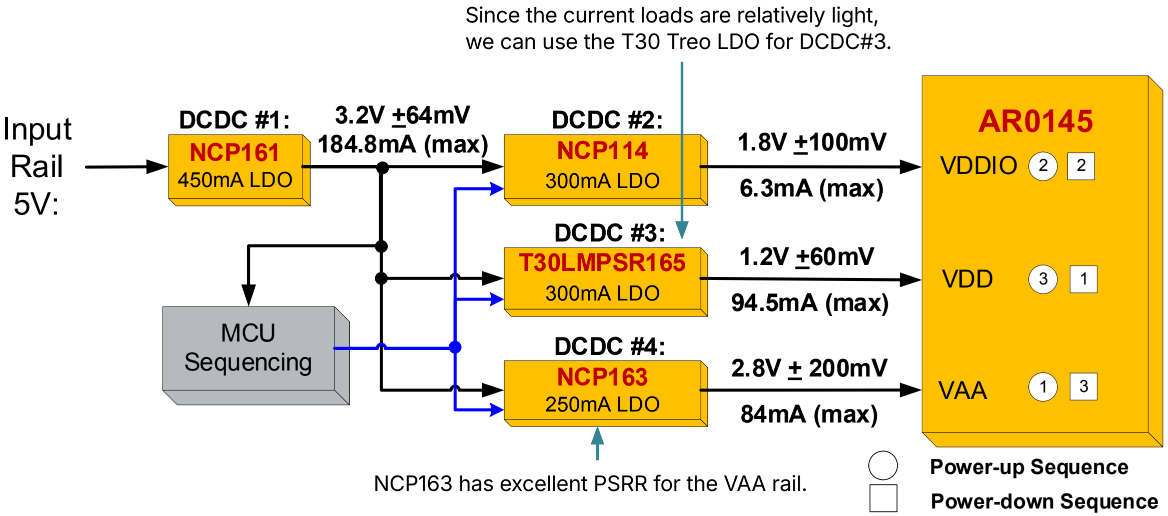
Note the very wide input voltage range of this new device. Very convenient with an input rail of 18V.

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
* NCP737ADNADJR2G	LDO	125°C / 105.2°C	3V – 65V	100mA	3.2V	1.50%	TBD	38.7	TBD	83µV	MSOP-8 EP	$0.33
NCP114AMX180TBG	LDO	85°C / 60.9°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
T30LMPSR165CFCT120T2G	LDO	125°C / 69.1°C	1.4V - 3.3V	300mA	1.2V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 61.3°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
NCV92310ABMTWTXG	PMIC	150°C / 61.8°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 60.6°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

* Metal mask options with acceptable business case

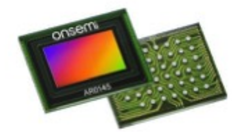
Best alternative for a 48V input rail.

Hyperlux SG AR0145



May be preferable for enclosures where 95.9°C die temp is too warm.

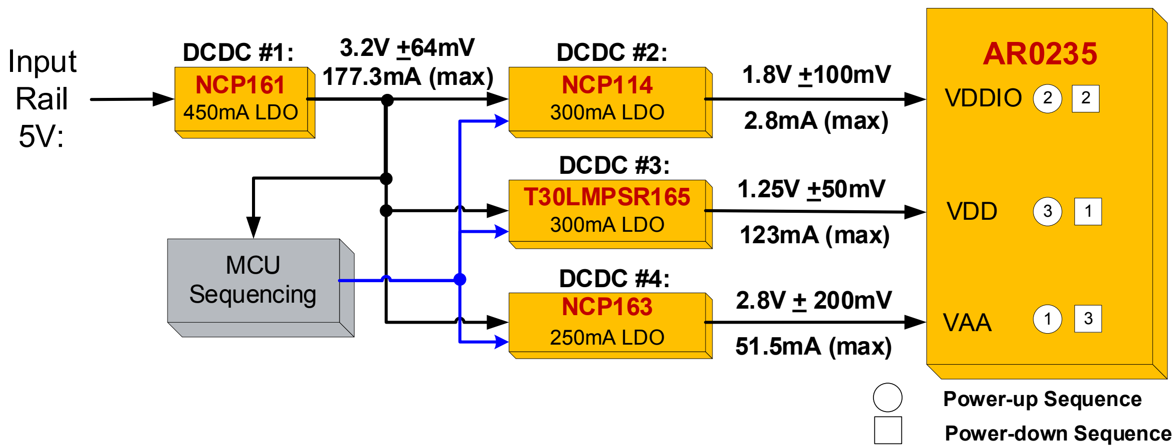
V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.326
	DC#1: FAN53745	$0.648 (not inc. 1 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC #1: FAN6500x	$2.488 (not inc. 1 inductor)



T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	$θ_{JA}$ (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP161AFCS320T2G	LDO	125°C / 95.9°C	1.9V - 5.5V	450mA	3.2V	2%	-40mV, +40mV, 1µsec	108	98dB	10µV	WLCSP4	$0.07
NCP114AMX180TBG	LDO	85°C / 61.5°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
T30LMPSR165CFCT120T2G	LDO	125°C / 79°C	1.4V - 3.3V	300mA	1.2V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 63.6°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 66.8°C	2.3V - 5.5V	1A	1.5V -3.3V	1.50%	-30mV, +45mV	65	NA	NA	WLCSP6	$0.40
NCV92310ABMTWTXG	PMIC	150°C / 64.6°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 61.3°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	NA	NA	PQFN35	$2.24

Hyperlux SG AR0235



V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.326
	DC#1: FAN53745	$0.648 (not inc. 1 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC #1: FAN6500x	$2.488 (not inc. 1 inductor)

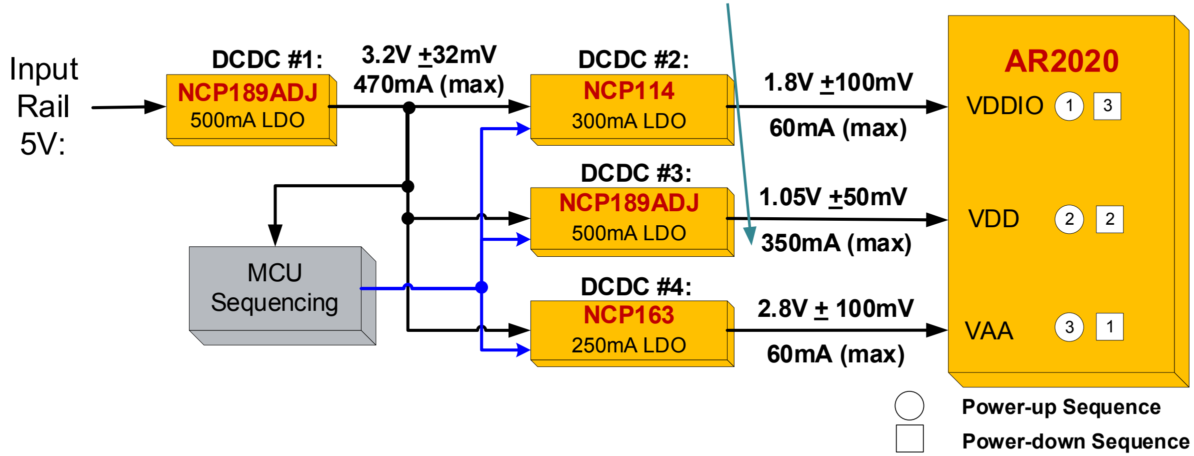
T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP161AFCS320T2G	LDO	125°C / 94.5°C	1.9V - 5.5V	450mA	3.2V	2%	-40mV, +40mV, 1µsec	108	98dB	10µV	WLCSP4	$0.07
NCP114AMX180TBG	LDO	85°C / 60.6°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
* T30LMPSR165	LDO	125°C / 84.2°C	1.4V - 3.3V	300mA	1.25V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 62.2°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 66.5°C	2.3V - 5.5V	1A	1.5V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
NCV92310ABMTWTXG	PMIC	150°C / 63.7°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 61.3°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

* Metal mask options with acceptable business case

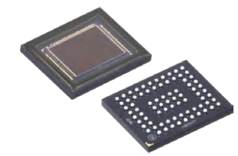
Hyperlux LP AR2020

The current load for the VDD rail rises to 350mA, mandating a transition for DCDC #1 and DCDC #3 to NCP189.



May be preferable for enclosures where 105.2°C die temp is too warm.

V_{IN}	Options	Total power BOM cost ($WP)
	See block diagram	$0.686
5V	DC#1: FAN53745	$0.826 (not inc. 1 inductor)
	DC#3: FAN53730	$0.886 (not inc. 2 inductors)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC#1: FAN6500x	$2.666 (not inc. 1 inductor)

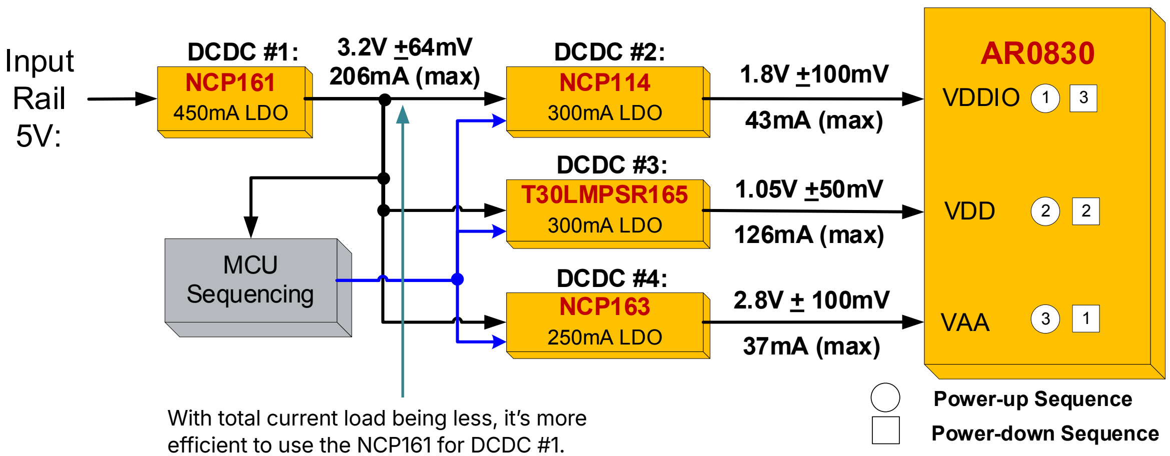


T_J range:
-40°C to 60°C

NCP189's higher price pays off here with much lower theta-JA.

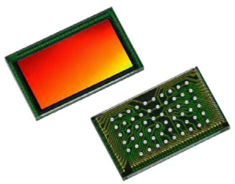
DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP189CMTWADJTAG	LDO	125°C / 110.8°C	1.6V - 5.5V	500mA	3.2V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP114AMX180TBG	LDO	85°C / 74.3°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
NCP189CMTWADJTAG	LDO	125°C / 105.2°C	1.6V - 5.5V	500mA	1.05V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP163AFCS280T2G	LDO	125°C / 62.6°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 77.2°C	2.3V - 5.5V	1A	0.9V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/.A	WLCSP6	$0.40
FAN53730UC01X	Buck	85°C / 67.1°C	2.3V - 5.5V	3A	0.3V – 2V	1.10%	5mV/500mA	50	N/A	N/A	WLCSP12	$0.32
NCV92310ABMTWTXG	PMIC	150°C / 68.0°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 63.5°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

Hyperlux LP AR0830



With total current load being less, it's more efficient to use the NCP161 for DCDC #1.

V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.326
	DC#1: FAN53745	$0.648 (not inc. 1 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC #1: FAN6500x	$2.488 (not inc. 1 inductor)

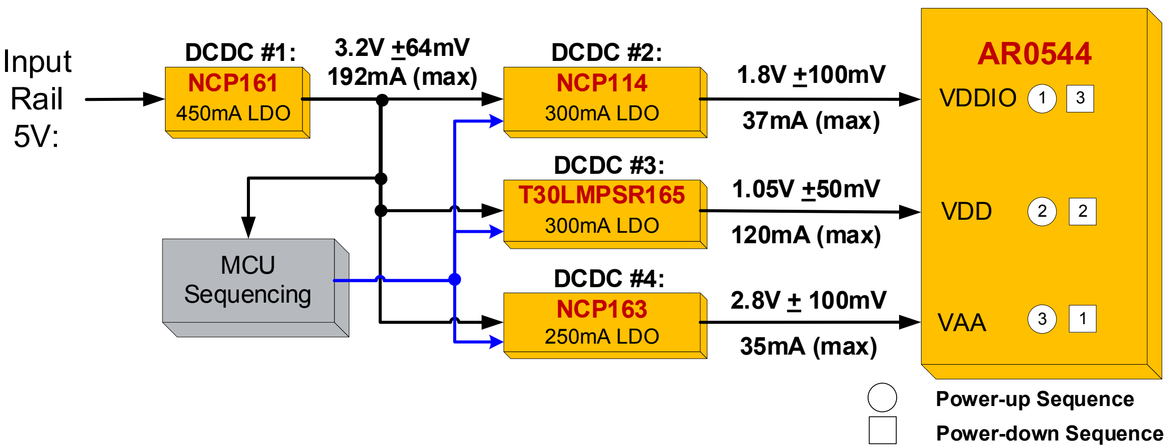


T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP161AFCS320T2G	LDO	125°C / 100°C	1.9V - 5.5V	450mA	3.2V	2%	-40mV, +40mV, 1µsec	108	98dB	10µV	WLCSP4	$0.07
NCP114AMX180TBG	LDO	85°C / 70.2°C	1.7V 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
*** T30LMPSR165**	LDO	125°C / 87.4°C	1.4V - 3.3V	300mA	1.05V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 61.6°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 65.6°C	2.3V - 5.5V	1A	1.5V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
NCV92310ABMTWTXG	PMIC	150°C / 64.1°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 61.5°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

* Metal mask options with acceptable business case

Hyperlux LP AR0544



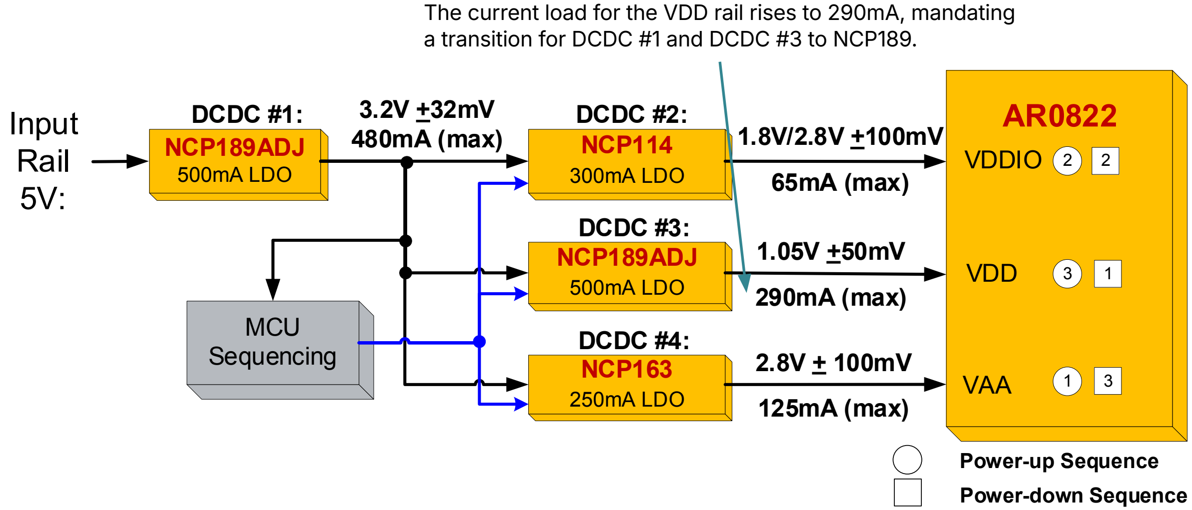
V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.326
	DC#1: FAN53745	$0.648 (not inc. 1 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DCDC #1: FAN6500x	$2.488 (not inc. 1 inductor)

T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP161AFCS320T2G	LDO	125°C / 97.3°C	1.9V - 5.5V	450mA	3.2V	2%	-40mV, +40mV, 1µsec	108	98dB	10µV	WLCSP4	$0.07
NCP114AMX180TBG	LDO	85°C / 68.8°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
*** T30LMPSR165**	LDO	125°C / 86°C	1.4V - 3.3V	300mA	1.05V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 61.5°C	2.2V -5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 67°C	2.3V - 5.5V	1A	1.5V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
NCV92310ABMTWTXG	PMIC	150°C / 63.8°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 61.4°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

* Metal mask options with acceptable business case

Hyperlux LH AR0822



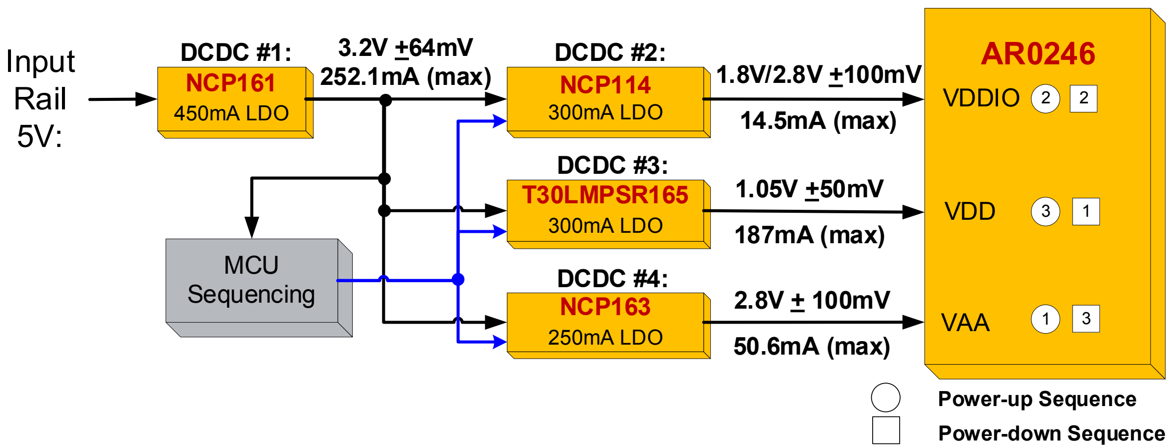
May be preferable for enclosures where 111.8°C die temp is too warm.

V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.686
	DC#1: FAN53745	$0.826 (not inc. 1 inductor)
	DC#3: FAN53730	$0.886 (not inc. 2 inductors)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC#1: FAN6500x	$2.666 (not inc. 1 inductor)

T_J range:
-40°C to 60°C

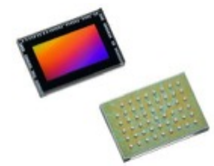
DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP189CMTWADJTAG	LDO	125°C / 111.8°C	1.6V - 5.5V	500mA	3.2V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP114AMX180TBG	LDO	85°C / 75.5°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
NCP189CMTWADJTAG	LDO	125°C / 98.4°C	1.6V - 5.5V	500mA	1.05V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP163AFCS280T2G	LDO	125°C / 65.4°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 77.6°C	2.3V - 5.5V	1A	0.9V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
FAN53730UC01X	Buck	85°C / 66.7°C	2.3V - 5.5V	3A	0.3V – 2V	1.10%	5mV/500mA	50	N/A	N/A	WLCSP12	$0.32
NCV92310ABMTWTXG	PMIC	150°C / 69.9°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 63.6°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

Hyperlux LH AR0246



May be preferable for enclosures where 109°C die temp is too warm.

V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.686
	DC#1: FAN53745	$0.826 (not inc. 1 inductor)
	DC#3: FAN53730	$0.886 (not inc. 2 inductors)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductors)
48V	DC#1: FAN6500x	$2.666 (not inc. 1 inductor)

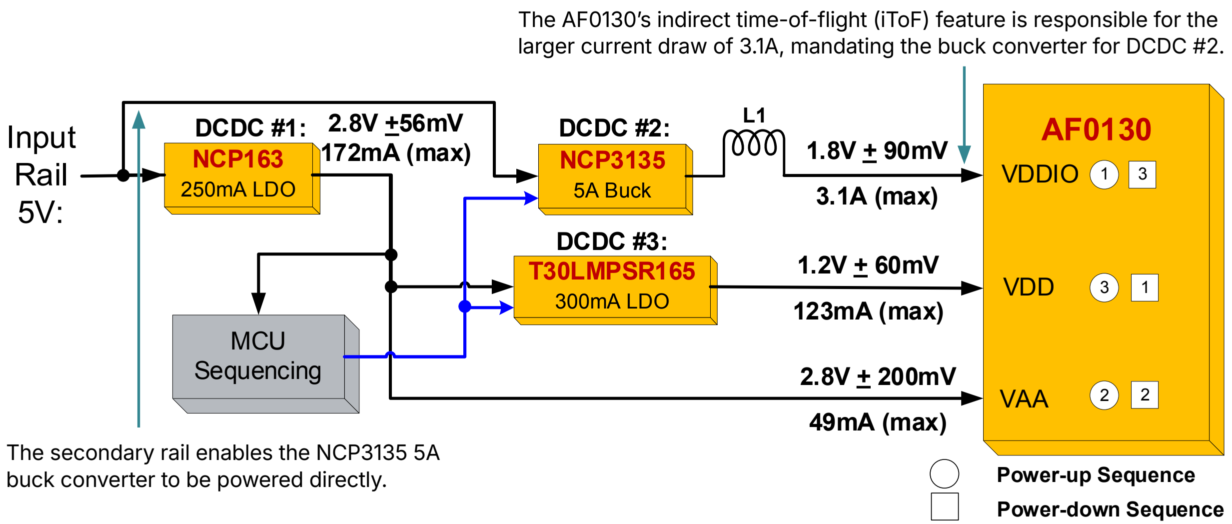


T_J range:
-40°C to 60°C

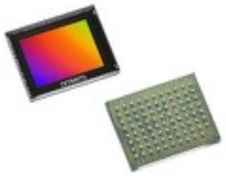
DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	$θ_{JA}$ (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP161AFCS320T2G	LDO	125°C / 109°C	1.9V - 5.5V	450mA	3.2V	2%	-40mV, +40mV, 1µsec	108	98dB	10µV	WLCSP4	$0.07
NCP114AMX180TBG	LDO	85°C / 63.5°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
* T30LMPSR165	LDO	125°C / 100.6°C	1.4V - 3.3V	300mA	1.05V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 62.2°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53745UC00X	Buck	85°C / 69.2°C	2.3V - 5.5V	1A	0.9V-3.3V	1.50%	-30mV, +45mV	65	NA	NA	WLCSP6	$0.40
FAN53730UC01X	Buck	85°C / 64.4°C	2.3V - 5.5V	3A	0.3 – 2V	1.10%	5mV/500mA	50	NA	NA	WLCSP12	$0.32
NCV92310ABMTWTXG	PMIC	150°C / 64.5°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 61.9°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	NA	NA	PQFN35	$2.24

* Metal mask options with acceptable business case

Hyperlux ID AF0130 option #1



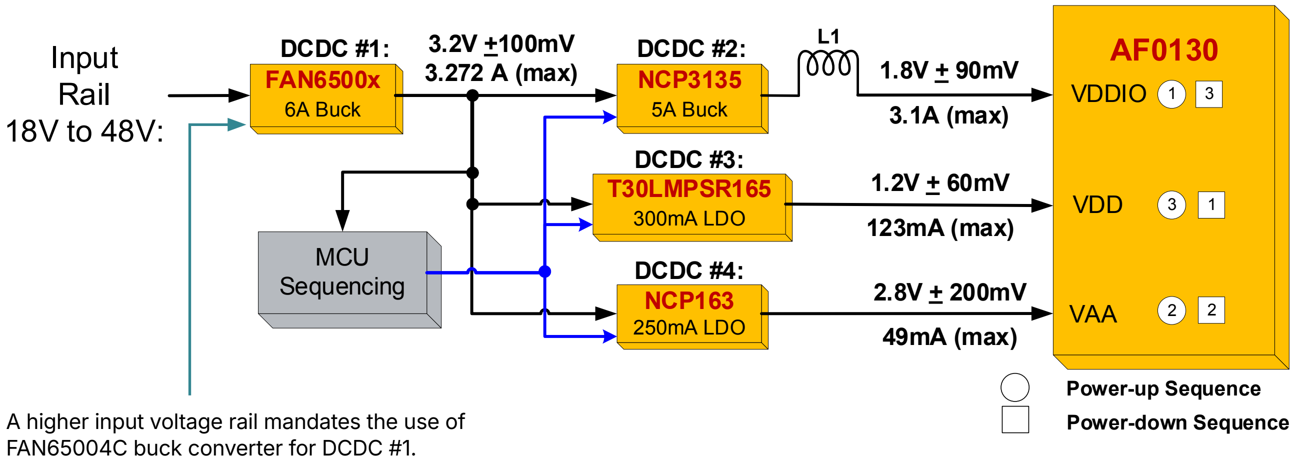
V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.828 (not inc. 1 inductor)



T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
NCP163AFCS280T2G	LDO	125°C / 100.8°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
NCP3135MNTXG	Buck	125°C / 87.9°C	2.9V - 5.5V	5A	1.8V	1%	>0.35%	45	N/A	N/A	QFN16	$0.636
T30LMPSR165CFCT120T2G	LDO	125°C / 79.8°C	1.4V - 3.3V	300mA	1.2V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082

Hyperlux ID AF0130 option #2



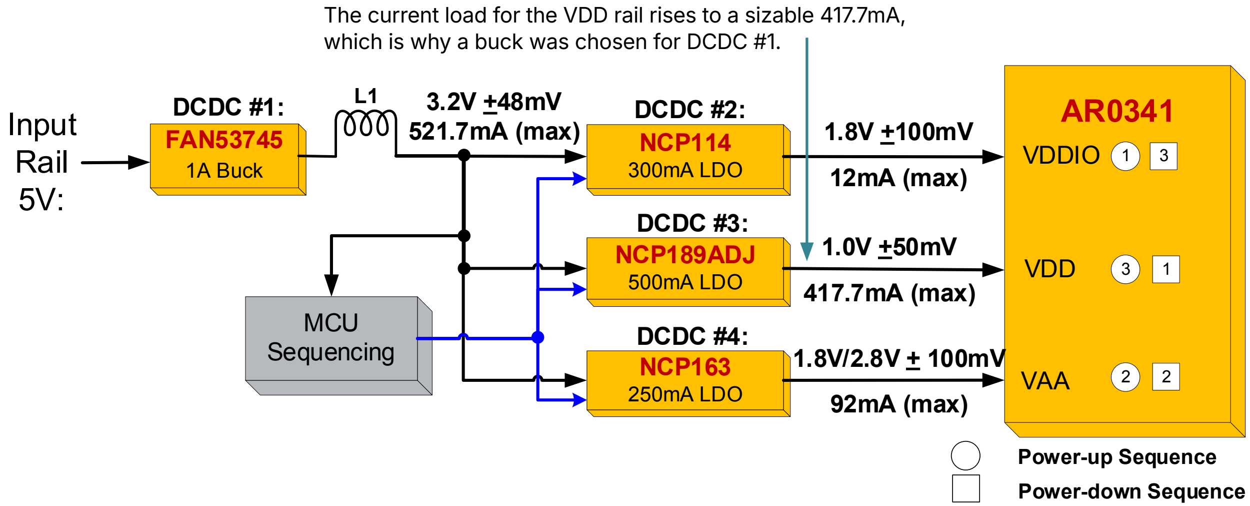
A higher input voltage rail mandates the use of FAN65004C buck converter for DCDC #1.

V_{IN}	Options	Total power BOM cost ($WP)
18V	See block diagram	$2.969 (not inc. 2 inductors)
48V		

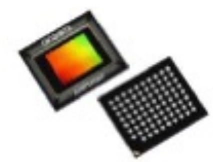
T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	$θ_{JA}$ (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
FAN65004C	Buck	125°C / 84.5°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70usec	21.1	NA	NA	PQFN35	$2.24
NCP3135MNTXG	Buck	125°C / 87.9°C	2.9V - 5.5V	5A	1.8V	1%	>0.35%	45	NA	NA	QFN16	$0.636
T30LMPSR165CFCT120T2G	LDO	125°C / 84.8°C	1.4V - 3.3V	300mA	1.2V	+15mV	-35mV, +30mV 250ns	101	75dB	16µV	WLCSP4	$0.082
NCP163AFCS280T2G	LDO	125°C / 62.1°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11

Hyperlux **AR0341**



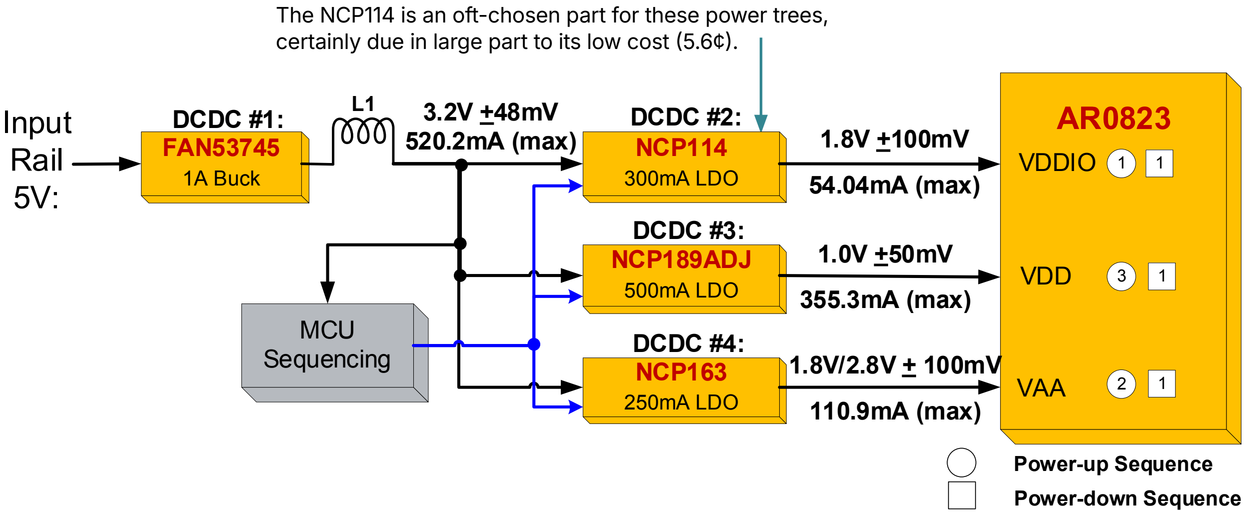
V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.826 (not inc. 1 inductor)
	DC#3: FAN53730	$0.886 (not inc. 2 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductor)
48V	DCDC #1: FAN6500x	$2.726 (not inc. 1 inductor)



T_J range:
-40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	$θ_{JA}$ (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
FAN53745UC00X	Buck	85°C / 79.1°C	2.3V - 5.5V	1A	0.9V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
NCP114AMX180TBG	LDO	85°C / 62.8°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
NCP189CMTWADJTAG	LDO	125°C / 117°C	1.6V - 5.5V	500mA	1.0V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP163AFCS280T2G	LDO	125°C / 63.9°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53730UC01X	Buck	85°C / 69.7°C	2.3V - 5.5V	3A	0.3V – 2V	1.10%	5mV/500mA	50	N/A	N/A	WLCSP12	$0.32
NCV92310ABMTWTXG	PMIC	150°C / 68.3°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 63.9°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

Hyperlux AR0823



V_{IN}	Options	Total power BOM cost ($WP)
5V	See block diagram	$0.826 (not inc. 1 inductor)
	DC#3: FAN53730	$0.886 (not inc. 2 inductor)
18V	DC#1 – 4: NCV92310	$1.06 (not inc. 3 inductor)
48V	DCDC #1: FAN6500x	$2.726 (not inc. 1 inductor)

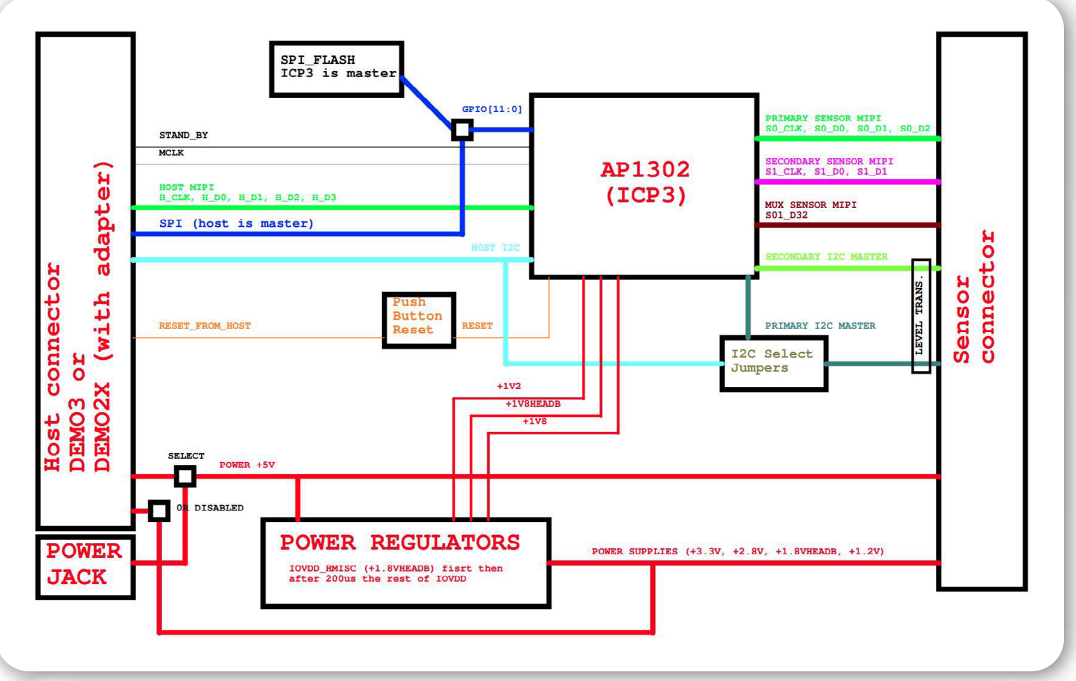
T_J range: -40°C to 60°C

DCDC Product	Type	Max DS temp (T_J) / die temp @ 60°C ambient	V_{IN}	I_{OUT}	V_{OUT}	V_{OUT} accuracy	Transient response (typ) (load step= max rated I)	θ_{JA} (°C/W)	PSRR (1kHz)	Noise (10Hz – 100kHz)	Package	Cost ($WP)
FAN53745UC00X	Buck	85°C / 74°C	2.3V - 5.5V	1A	0.9V-3.3V	1.50%	-30mV, +45mV	65	N/A	N/A	WLCSP6	$0.40
NCP114AMX180TBG	LDO	85°C / 72.8°C	1.7V - 5.5V	300mA	1.8V	2%	-50mV, +30mV, 1µsec	170	75dB	70µV	UDFN4	$0.056
NCP189CMTWADJTAG	LDO	125°C / 108.7°C	1.6V - 5.5V	500mA	1.0V	1%	Not specified	60	85dB	10µV	WDFN6	$0.26
NCP163AFCS280T2G	LDO	125°C / 64.8°C	2.2V - 5.5V	250mA	2.8V	2%	-50mV, +30mV, 1µsec	108	92dB	6.5µV	WLCSP4	$0.11
FAN53730UC01X	Buck	85°C / 68.3°C	2.3V - 5.5V	3A	0.3V – 2V	1.10%	5mV/500mA	50	N/A	N/A	WLCSP12	$0.32
NCV92310ABMTWTXG	PMIC	150°C / 69.6°C	5V – 18V	I2C Programmable		1%	-45mV, +40mV, 5µsec	35	80dB	34µV	QFNW20	$1.06
FAN65004C	Buck	125°C / 63.9°C	4.5V – 65V	6A	3.2V	1%	+500mV, 70µsec	21.1	N/A	N/A	PQFN35	$2.24

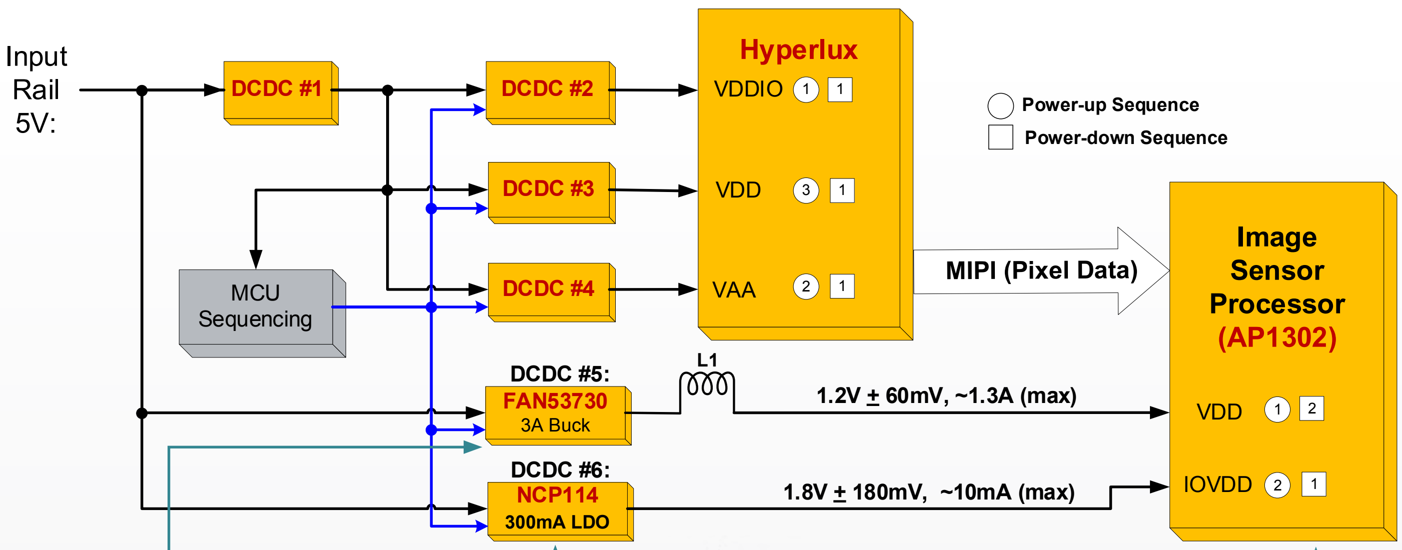
AP1302 image sensor co-processor

At the center of industrial imaging applications is onsemi's AP1302 Advanced Image Coprocessor. This is a high-performance, ultra-low-power, inline digital image and video stream processor with advanced digital still and digital video camera features. It can process images with 13 megapixel (MP) resolution at frame rates up to 30 fps, and 720p resolution at frame rates as high as 240 fps. The processor can handle all necessary functions for high-speed video processing including JPEG compression, HD-resolution video stream capture, and preview generation.

The AP1302's image processing and image enhancement cores include image pre-processing, color processing and pixel processing engines, the statistics gathering engine, and the JPEG encode engine. Its advanced feature processor includes the 32-bit central processor, as well as program and data memory. As part of the chip data path, the advanced feature processor can process and manipulate pixel data directly. Its processor subsystem includes another 32-bit processor for performing imaging sensor control, external focus and zoom actuator control, and all on-chip real-time control, with a basic register set serving as the API to the host interface.



Pixel data transport for local image processing



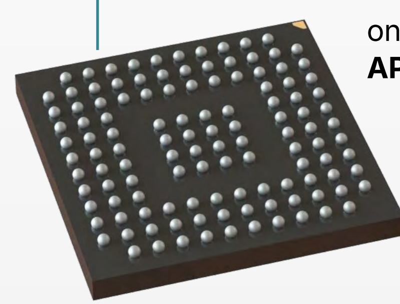
A Hyperlux image sensor outputs its data on a MIPI parallel bus. For local image processing applications, the MIPI bus may connect to an **AP1302** co-processor. The power tree above adds regulators **DCDC #5** and **DCDC #6** to power the input rails **VDD** and **IOVDD** (not to be confused with VDDIO) on the AP1302.

WLCSP12 1.07 × 1.36 × 0.432, 0.35P
Case 567GK

onsemi
FAN53730
Buck regulator

TSOP-5, SN suffix
Case 483

onsemi
NCP114 LDO



onsemi
AP1302

DCDC #5:

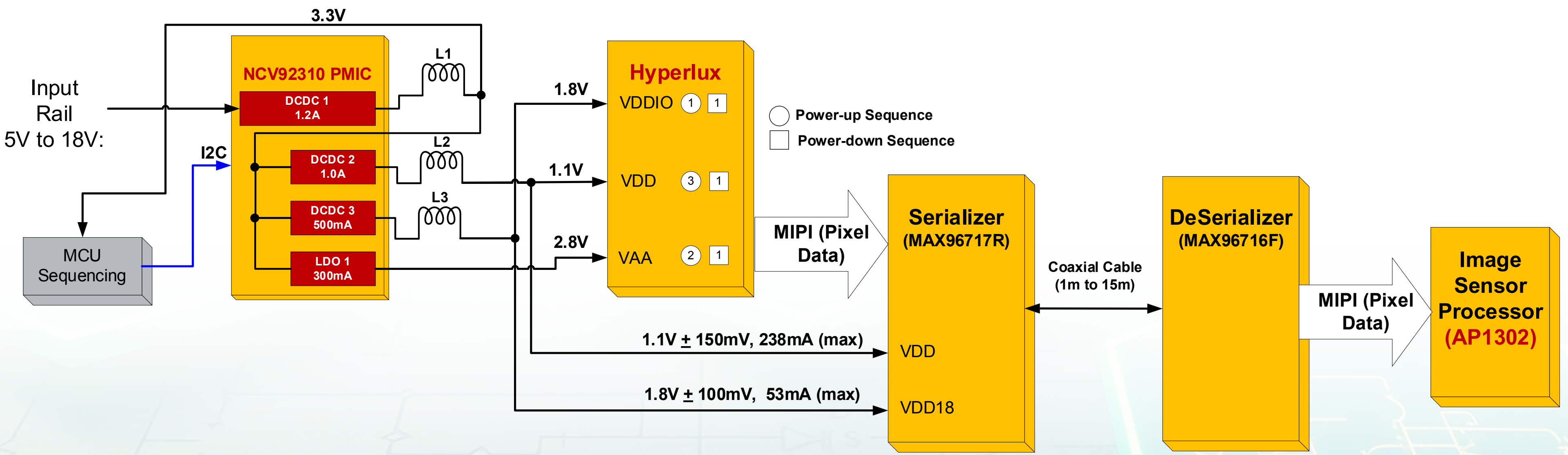
- Synchronous
- Minimum 3A load current
- V_{IN}: 2.3V to 5.5V
- V_{OUT}: Programmable (I2C) 0.3V to 2V
- 2.5MHz (CCM)
- 88% Efficiency (5V_{IN}, 1V_{OUT})
- ASP: $0.32 (web pricing)

DCDC #6:

- 300 mA
- V_{IN}: 1.7V to 5.5V
- V_{OUT}: 1.8V (+,- 2%)
- θ_{JA}: 170°C/W
- PSRR: 75dB (1kHz)
- UDFN4
- ASP: $0.056 (web pricing)

To enable remote image processing applications, you may need to consider an entirely different power configuration that substitutes an onsemi NCV92310 PMIC for the power tree. What this PMIC gives you are wide ranges of programmability. Its internal DCDC 2 and DCDC 3 components (shown in red below) are both programmable from 0.6V to 2.175 volts in 25mV steps. It's LDO 1 regulator component is programmable from 2.6V to 3.3V in 100mV steps, making it suitable for powering the VAA rail. NCV92310 was designed to support all Hyperlux image sensors except for the AF0130, providing all the necessary power for the DC/DC power conversion and the serializer. It also supports programmable voltage for Power-over-Coaxial (PoC) from 2.8V to 5.0V in 100mV steps.

For this application, at the end of the local end of the power tree would be a serializer. Its input power rails are VDD and VDD18. A coaxial cable would connect the serializer to the deserializer for what's called a SerDes (serializer / deserializer) connection.



Optimized power design for better industrial imaging

Today's image sensors make possible a much wider variety of applications than ever before for the shop floor, for the workplace, for surveillance and physical security, and for automotive guidance. It's the versatility, variety, and multiplicity of these applications that collectively present the biggest challenge to product design. Not even an image sensor mounted on the end of a robotic armature, installed next to a conveyor belt, has just one function. Different functions have different power requirements.

The power supply delivering reliable current and voltage to image sensor applications must be as versatile in adapting to rapidly changing power situations as the image sensors themselves are in delivering functionality for users. Electric power might seem ubiquitous, but in a changing environment where sustainability has never been more important, it needs to be treated as a precious resource. The right semiconductor regulator parts in the right positions of the image sensor power tree can harness and marshal electricity, stepping voltages down to the low levels required by modern CMOS components such as image sensors. How well you design your image sensor power tree is at least as important to industrial and automotive applications as how well the sensor captures light.

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