Application Report

High-Performance CMOS Image Sensor Power Supply in Industrial Camera and Vision

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ABSTRACT

This application note provides solutions for powering the high-performance CMOS image sensors of industrial machine vision cameras or vision sensors for factory automation and control applications. This application report shows the importance of selecting the right components to generate better power supply rails. Three different solutions are approached, including a discrete solution and two integrated solutions based on different PMICs, which feature:

- Specific power sequences
- Flexible capabilities for driving large output capacitors
- Improved efficiency performances
- Small sizes

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1 Introduction

The power supply solutions presented in this application report are designed with the requirements of machine vision applications for factory automation and logistics in mind. Machine vision has proven itself as a key technology, addressing the needs of automated manufacturing, including:

- Inspection
- Identification
- Quality control
- Logistics
- Robotics

TI information related to the topic of machine vision end equipment in industrial factory automation and control area can be accessed here. A common block diagram of the industrial camera, as well as related TI products and TI reference designs, can be accessed here.

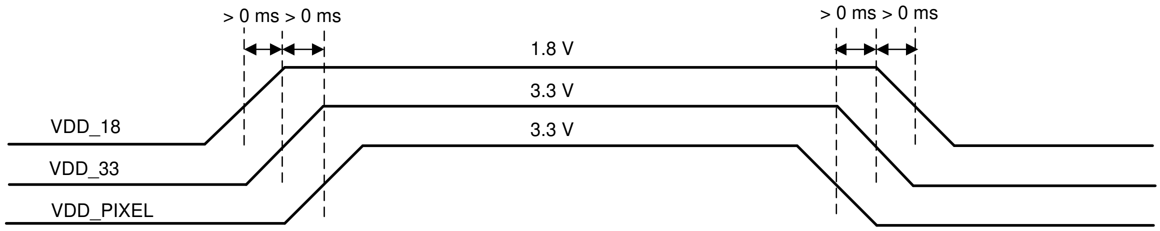
1.1 Power Requirements of CMOS Image Sensors and Their Power Design Challenges

CMOS image sensors normally require three power rails with certain sequences for the analog part, pixel part (or interface part), and digital part. The voltage of the analog power rail is usually 3.3 V, the voltage of the pixel power rail (or interface power rail) is usually 3.3 V or 1.8 V, and the voltage of the digital power rail is usually 1.8 V or 1.2 V. In order to improve the noise performance of CMOS image sensors, sometimes large bypass capacitors are placed in front of the voltage supply pins of CMOS image sensors. The noise performance of CMOS image sensors can also be improved by decreasing the fluctuation of each power rail. Generally, the analog power rail is the most noise-sensitive rail; the pixel power rail is also sensitive to noise. In machine vision applications, the camera is commonly small in size; for example, a 25-mm cube. Therefore, higher power rail efficiency is necessary to improve the thermal performance and avoid degrading the color filters of a CMOS image sensor.

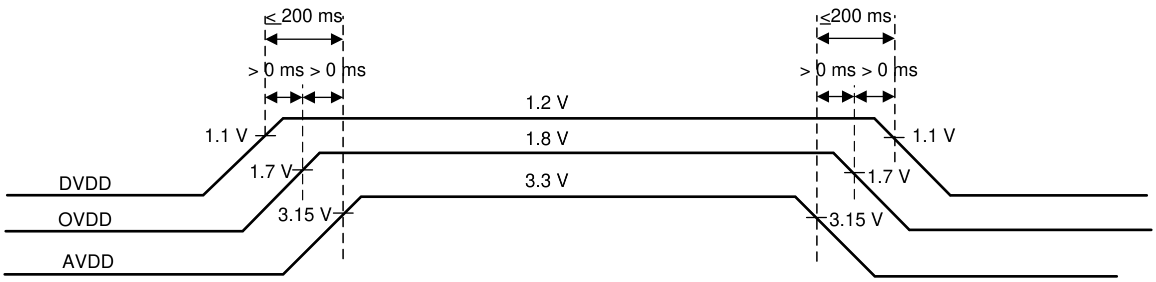
In this application note, three high-performance CMOS image sensors, PYTHON 300/500/1300 series, PYTHON 3000/5000 series, and IMX25X/26X series, are selected as examples to be discussed. Through Table 1-1 and Figure 1-1, it can be seen that the rails of PYTHON series CMOS image sensors require large bypass capacitors. The current consumption of the PYTHON 3000/5000 series is higher than other CMOS image sensors. The power requirements of CMOS image sensors vary depending on different manufacturers and features.

Table 1-1. Power Requirements of Three High-Performance CMOS Image Sensors

CMOS Image Sensors	Power Rails	Rail Names	Voltage	Typ Current Consumption	Bypass Capacitors	Noise Sensitivity Level
PYTHON 300/500/1300	Analog power rail	VDD_33	3.3 V	140 mA	≤250 uF	High
	PIXEL power rail	VDD_PIXEL	3.3 V	5 mA	≤250 uF	Middle
	Digital power rail	VDD_18	1.8 V	80 mA	≤10 uF	Low
PYTHON 3000/5000	Analog power rail	VDD_33	3.3 V	355 mA	≤250 uF	High
	PIXEL power rail	VDD_PIXEL	3.3 V	10 mA	≤250 uF	Middle
	Digital power rail	VDD_18	1.8 V	140 mA	≤10 uF	Low
IMX25X/26X	Analog power rail	AVDD	3.3 V	120 mA	≤22 uF	High
	Interface power rail	OVDD	1.8 V	11 mA	≤22 uF	Middle
	Digital power rail	DVDD	1.2 V	120 mA	≤10 uF	Low



(a) Powering sequences of PYTHON series



(b) Powering sequences of IMX series

Figure 1-1. Specific Power Sequencing Needs

2 TI Solutions

2.1 Solution Overviews

In this section, three solutions are introduced for powering the CMOS image sensors listed in Section 1.1. In Table 2-1, the CMOS image sensors listed in Table 1-1 are matched to their suitable power solutions with the notation YES.

Table 2-1. Power Solutions for Three Example CMOS Image Sensors

CMOS Image Sensors	Discrete Board Solution(LMR36015+TPS7A87+ TPS7A90/TPS6284X+LM3880)	TPS65000 Solution(LMR36015 in the Discrete Board Solution+TPS65000 EVM+LM3880 EVM)	TPS650330-Q1 Solution(TPS650330-Q1 EVM Board)
PYTHON 300/500/1300	Yes	Yes	N/A
PYTHON 3000/5000	Yes	N/A	N/A
IMX25X/26X	Yes	Yes	Yes

The first solution is a discrete solution shown in Figure 2-1. The discrete solution can power PYTHON 300/500/1300/3000/5000 series and IMX25X/26X series. For powering the IMX25X/26X series, the voltage divider resistors and power sequences in the board need to be adjusted.

This solution includes:

- The LMR36015, a wide input voltage buck converter, as the first power stage to convert high input voltages (5V, 12 V or 24 V) into a low intermediate voltage (4 V). This intermediate 4-V rail serves as the input voltage for the second power stage, generating power rails for the CMOS image sensor and the power supply of the sequencer. In addition, the 4-V power rail can be used to power other electronic blocks of a camera.
- The TPS7A87, a dual LDO device for powering the noise-sensitive analog rail and pixel rail (or interface rail) of the CMOS image sensors.
- The TPS7A90, a single LDO for powering the digital rail of CMOS image sensors.
- TPS6284X family low input voltage buck converters (TPS62840 for powering the digital rail of PYTHON 300/500/1300/3000/5000 series CMOS image sensors, and TPS62841 for powering the digital rail of IMX25X/26X series CMOS image sensors).
- The LM3880 analog sequencer to control the specific power sequence of each power rail.

The 2-pin header placed between the first power stage and the second stage is used for disconnecting these stages to test them individually. There is a 3-pin header set between the TPS7A90 and TPS6284X, used to choose either TPS7A90 as the digital rail power supply or TPS6284X as the digital rail power supply. There are three 3 × 2 pins used to adjust the correct power sequences of power systems, according to power sequences shown in Figure 1-1.

Highlighted features of the discrete solution board include:

- Input voltage: 5 V / 12 V / 24 V, transients up to 60 V
- 4 V as intermediate voltage
- Three low-noise and high PSRR output voltage rails (typically 1.2 V–3.3 V)
- Output current up to 500 mA
- Output capacitors up to 250 µF
- Controlled power-up and power-down sequencing
- Active output discharge
- Small size (25 mm × 24 mm)

The second solution is mainly based on PMIC TPS65000 with the block diagram shown in Figure 2-2. This solution can support both powering the PYTHON 300/500/1300 series and IMX25X/26X series. For powering the IMX25X/26X series, voltage divider resistors and power sequences in the board need to be modified. In this solution, the LMR36015 in the discrete solution board is used as the first power stage to convert high input voltages (5 V, 12 V, or 24 V) into a low intermediate voltage (4 V). The TPS65000 EVM is used as the second power stage to convert the 4-V intermediate voltage to 3.3 V for the analog rail, 3.3 V for the PIXEL rail or 1.8 V for the interface rail, and 1.8 V or 1.2 V for the digital rail. The LM3880 EVM is used to control the specific power sequence of each rail.

The third solution is based on PMIC device TPS650330-Q1 with the block diagram shown in Figure 2-3. This solution can support powering IMX25X/26X series CMOS image sensors. The input voltage of the system can be up to 18.3 V. Voltage requirements and specific power sequence requirements of different CMOS image sensors can be configured by setting up registers of the TPS650330-Q1 on the GUI.

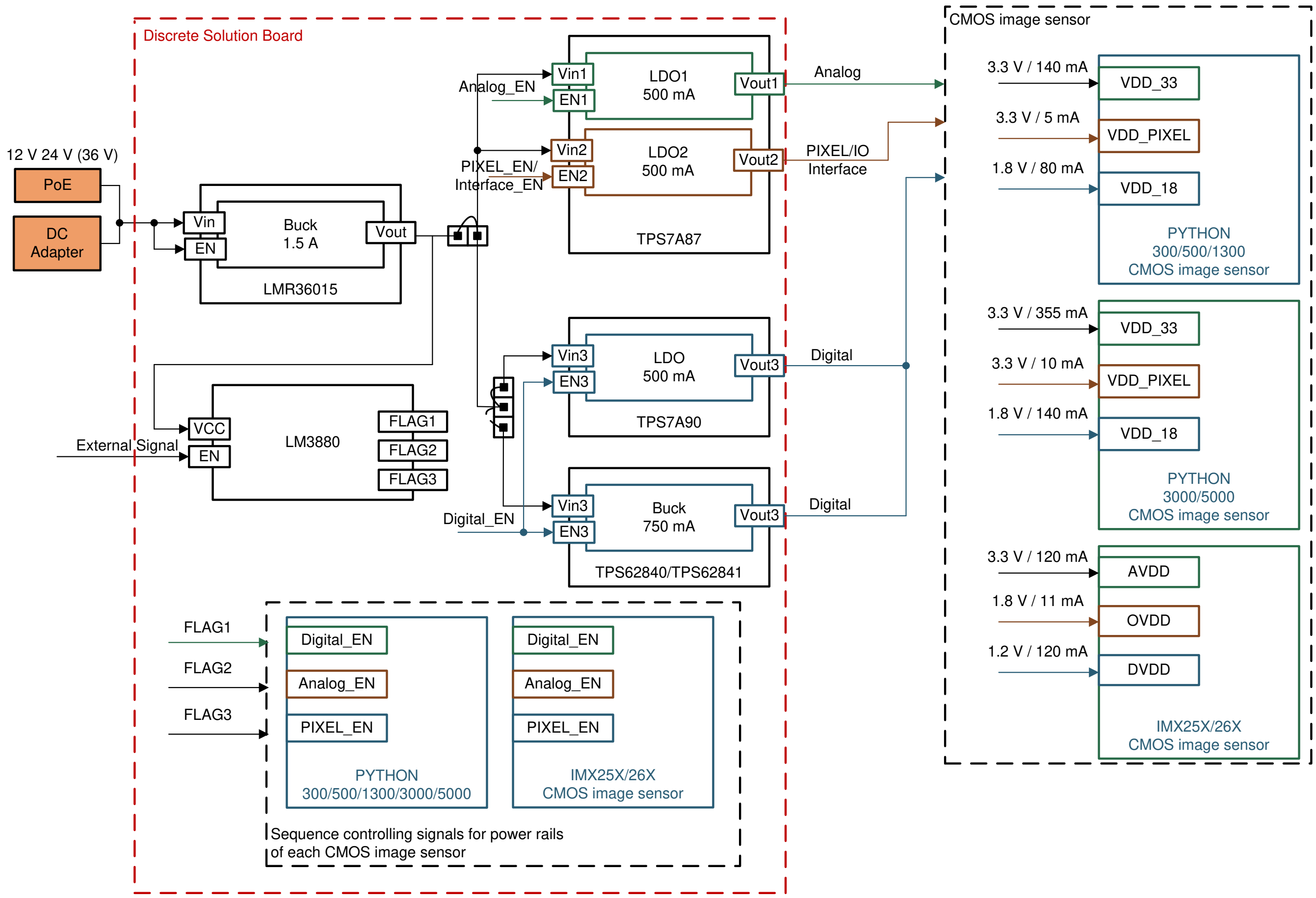


Figure 2-1. Block Diagram of Discrete Solution Board

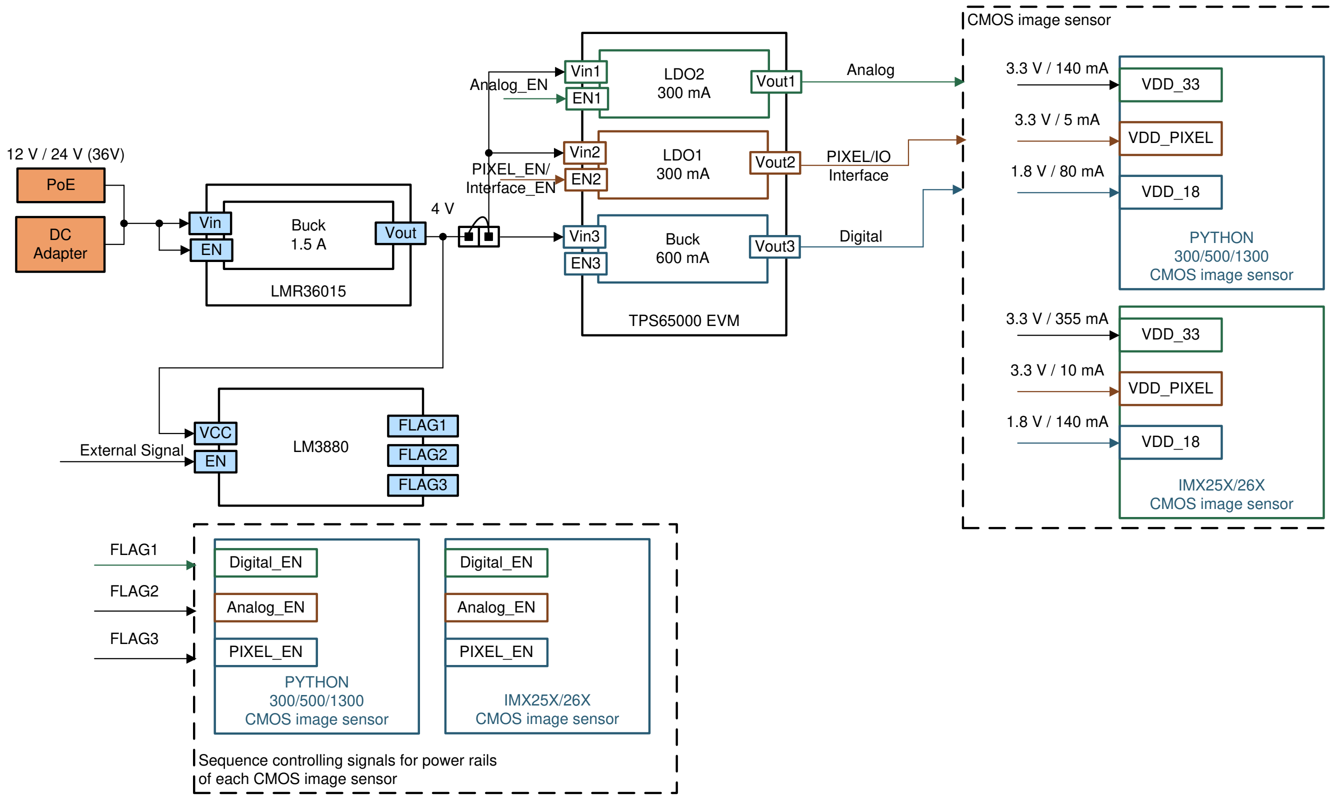


Figure 2-2. Block Diagram of PMIC TPS65000 Solution

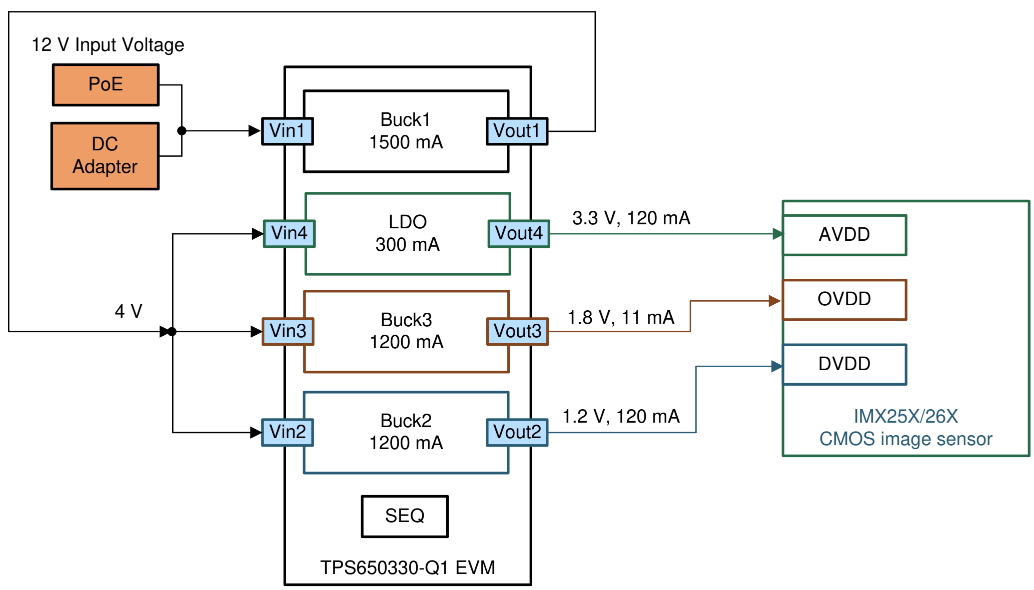


Figure 2-3. Block Diagram of PMIC TPS650330-Q1 Solution

2.2 Design of the Discrete Solution Board

2.2.1 Device Selection

When selecting devices, the specifications of power management devices that can meet the power requirements of each rail in the CMOS image sensor listed in Table 1-1 must be emphasized firstly. These include:

- Input voltage range (Vin)
- Output voltage range (Vout)
- Output current range (Iout)

- Output capacitance (Cout)
- Output voltage tolerance

Other considerations of designing the discrete solution board are presented in Section 2.2.3. Besides, since the digital rail of a CMOS image sensor is not noise-sensitive, both LDO TPS7A90 and buck converter TPS6284X can be considered for powering the digital rail.

a) LMR36015 4.2-V to 60-V, 1.5-A ultra-small synchronous step-down converter

The LMR36015 regulator is an easy-to-use, synchronous, step-down DC/DC converter. With integrated high-side and low-side power MOSFETs, up to 1.5 A of output current is delivered over a wide input voltage range of 4.2 V to 60 V. Tolerance goes up to 66 V. The transient tolerance reduces the necessary design effort to protect against overvoltages and meets the surge immunity requirements of IEC 61000-4-5. The LMR36015 uses peak-current-mode control to provide optimal efficiency and output voltage accuracy. Load transient performance is improved with the FPWM feature in the 1-MHz regulator. Precision enable gives flexibility by enabling a direct connection to the wide input voltage or precise control over device startup and shutdown. The power-good flag, with built-in filtering and delay, offers a true indication of system status, eliminating the requirement for an external supervisor. The LMR36015 is in a HotRod™ package that enables low noise, higher efficiency, and the smallest package-to-die ratio. The device requires few external components and has a pinout designed for a simple PCB layout. The small solution size and feature set of the LMR36015 are designed to simplify implementation for a wide range of end equipment, including the space-critical applications of ultra-small field transmitters and vision sensors. The LMR36015 device is available in the VQFN-HR (12) package with body size 2 mm × 3 mm.

The LMR36015 device has several versions, defined by the switching frequency and whether there is forced PWM (FPWM) mode or not. In the discrete solution, the LMR36015FB version is used with FPWM mode adding a 1-MHz switching frequency.

b) LDOs selected

Two LDOs are used to power noise-sensitive rails, analog rails, and PIXEL or IO interface rails. For powering noise-sensitive rails, the following LDO specifications become more important.

- Low noise in full temperature range.
- High PSRR (power supply rejection ratio), even at low headroom-voltage (VIN-VOUT).
- High accuracy.
- Active output discharge.
- Stabile with large output capacitors.
- Adjustable start-up inrush control.

TPS7A87 Dual 500 mA Low-Noise (3.8 µVRMS) LDO Voltage Regulator and TPS7A90 Single 500 mA High-Accuracy, Low-Noise, Low-Dropout (LDO) Voltage Regulator

Both the TPS7A87 and TPS7A90 are low-noise (TPS7A87, 3.8 µVRMS and TPS7A90, 4.7 µVRMS), low-dropout (LDO) voltage regulators capable of sourcing 500 mA with only 100 mV of maximum dropout. Each output of the TPS7A87 is adjustable from 0.8 V to 5.2 V with external resistors, and the TPS7A90 output is adjustable from 0.8 V to 5.7 V with external resistors. Wide input voltage ranges of the TPS7A87 and TPS7A90 support operation as low as 1.4 V and up to 6.5 V. With 1% output voltage accuracy (over line, load, and temperature) and soft-start capabilities to reduce inrush current, both LDOs are ideal for powering sensitive analog low-voltage devices, including:

- Voltage-controlled oscillators (VCOs)
- Analog-to-digital converters (ADCs)
- Digital-to-analog converters (DACs)
- Complementary metal oxide semiconductor (CMOS) sensors
- Video application-specific integrated circuits (ASICs)

The TPS7A87 device is available in the WQFN (20) package with body size 4 mm × 4 mm. The TPS7A90 device is available in WSON (10) with body size 2.5 mm × 2.5 mm.

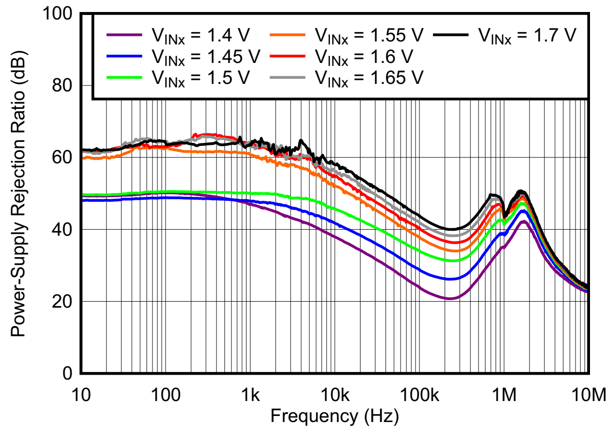


Figure 2-4. Power Supply Rejection Ration Versus Frequency and Input Voltage

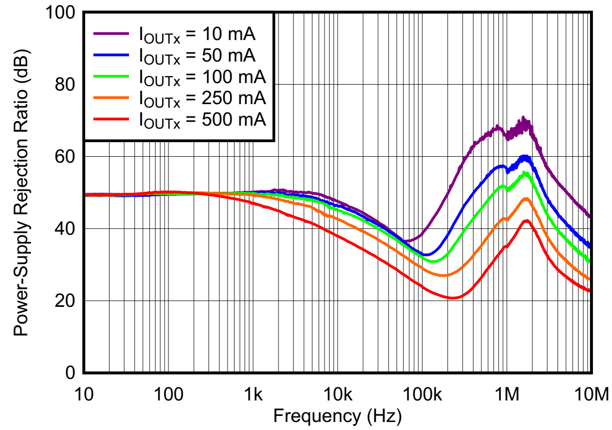


Figure 2-5. Power Supply Rejection Ratio Versus Frequency and Output Current

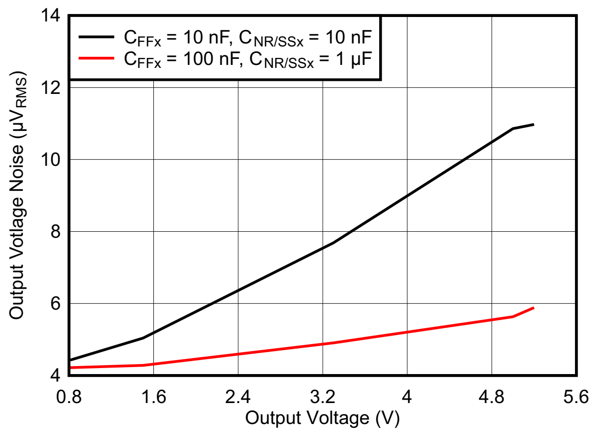


Figure 2-6. Output Noise Versus Output Voltage

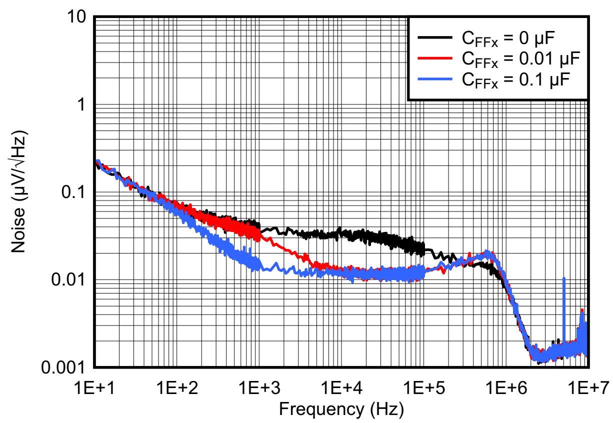


Figure 2-7. Noise Versus Frequency and CFFx

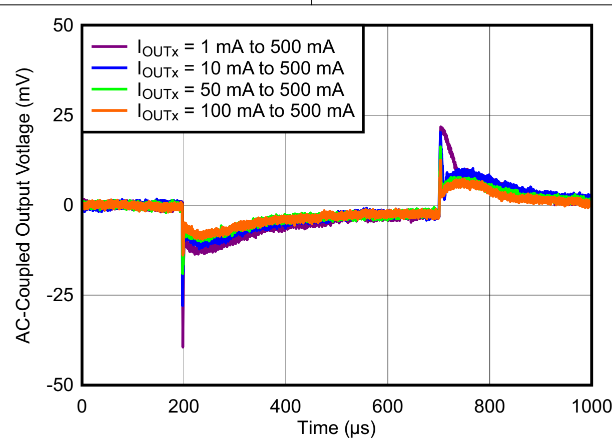


Figure 2-8. Load Transient Response Versus Voutx

c) TPS6284X 60-nA IQ, 1.8-V to 6.5-VIN, High-Efficiency 750-mA Step-Down Converter

The TPS6284X is a high-efficiency step-down converter with an ultra-low operating quiescent current of typically 6 nA. The device contains special circuitry to achieve just 150-nA IQ in 100% mode to further extend battery life near the end of discharge. The device uses DCS-Control™ to cleanly power radios and operate with a typical switching frequency of 1.8 MHz in Power-Save Mode. The device extends the light-load efficiency down to a load current range of 1 µA and below. 16 predefined output voltages can be selected by connecting a resistor to pin VSET, making the device flexible for various applications with a minimum amount of external components. The STOP pin on the device immediately eliminates any switching noise in order to take a noise-free measurement in data acquisition systems. The TPS6284X provides an output current of up to 750 mA with an input voltage of 1.8 V to 6.5 V.

The TPS6284X device is available in 8-pin SON with body size 1.5 mm × 2 mm, 6-pin WCSP with body size 0.97 mm × 1.47 mm, and 8-pin HVSSOP with body size 3 mm × 5 mm.

The TPS6284X device has several versions defined by output voltage range, mode selection function, and stop function. In the discrete solution, the TPS62840DLC version with mode selection function is used to power the 1.8-V digital rail of the PYTHON 300/500/1300/3000/5000 series CMOS image sensors. The TPS62841DLC version, also with mode selection function but with 0.8-V to 1.55-V output voltage range, is used to power the 1.2-V digital rail of the IMX25X/26X series CMOS image sensors.

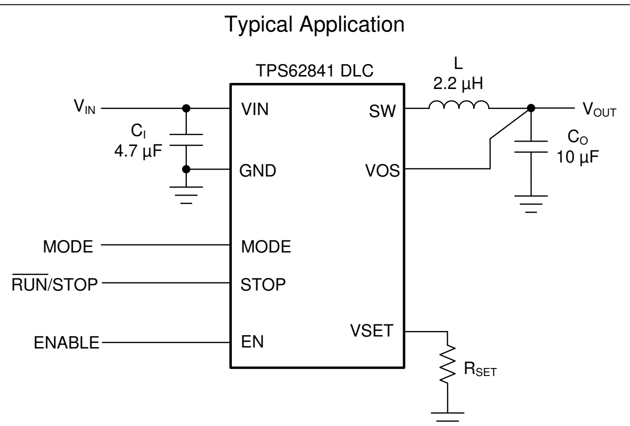


Figure 2-9. The Block Diagram of TPS62841DLC

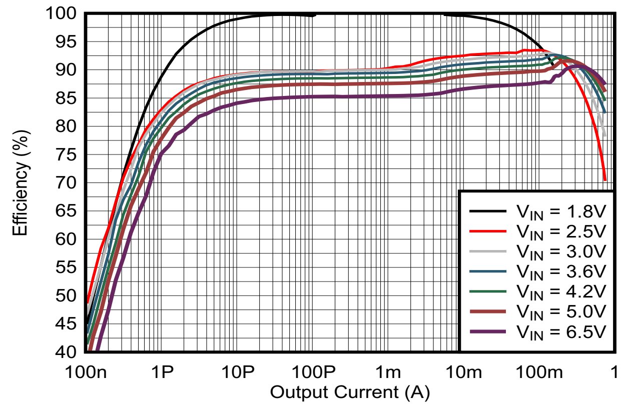


Figure 2-10. Efficiency vs Load Current (VOUT=1.8V)

d) LM3880 Three-Rail Simple Power Sequencer with Fixed Time Delay

The LM3880 simple power supply sequencer offers the easiest method to control the power-up and power-down sequencing of multiple independent voltage rails. By staggering the start-up sequence, it is possible to avoid latch conditions or large in-rush currents that can affect the reliability of the system. Available in a 6-pin SOT-23-6 package, the Simple Sequencer contains a precision enable pin and three open-drain output flags. The open-drain output flags permit the device being pulled up to distinct voltage supplies separate from the sequencer VDD (so long as they do not exceed the recommended maximum voltage of 0.3 V greater than the VDD), so as to interface with ICs requiring a range of different enable signals. When the LM3880 is enabled, the three output flags are sequentially released after individual time delays, thus permitting the connected power supplies to start up. The output flags follow a reverse sequence during power down to avoid latch conditions. EPROM capability allows every delay and sequence to be fully adjustable. The body size of LM3880 is 2.90 mm × 1.60 mm.

The LM3880 has several versions defined by delay time. In the discrete solution, the LM3880MF-1AB is selected to provide a 30-ms delay time between each power rail of the CMOS image sensors.

Table 2-2lists the previously mentioned power management devices with their corresponding power rail of CMOS image sensors. Table 2-3lists FLAGs of the LM3880 assigned to control the power sequences.

Table 2-2. Summary of Devices in the Discrete Solution Board with Their Specifications

Devices	Power Rail of CMOS Image Sensors Supplied	Vin	Vout	Iout	Cout	Selected SW Frequency
LMR36015FB	As the first power stage to convert high input voltage (12 V/24 V) from PoE or DC adapter to a 4 V intermediate voltage	4.2 V–60 V	V_{ref} to V_{in}-0.4 V	1.5 A	-	1 MHz (Used in FPWM mode)

Table 2-2. Summary of Devices in the Discrete Solution Board with Their Specifications (continued)

Devices	Power Rail of CMOS Image Sensors Supplied	Vin	Vout	Iout	Cout	Selected SW Frequency
TPS7A87	VDD_33 and AVDD (LDO1 of TPS7A87)VDD_PIXEL and OVDD (LDO2 of TPS7A87)	1.4 V–6.5 V	0.8 V to 5.2 V (Vdo=0.1 V at 0.5 A)	500 mA	≥10 uF	-
TPS7A90	VDD_18 and DVDD	1.4 V–6.5 V	0.8 V to 5.7 V (Vdo=0.1 V at 0.5 A)	500 mA	≥10 uF	-
TPS62840DLC	VDD_18	1.8 V–6.5 V	1.8 V–3.3 V	750 mA	3 uF to 40 uF	1.8 MHz (Used in FPWM mode)
TPS62841DLC	DVDD	1.8 V–6.5 V	0.8 V–1.55 V	750 mA	3 uF to 40 uF	1.8 MHz (Used in FPWM mode)

Table 2-3. Setup of the LM3880 with Specific Power Sequencing Requirements

CMOS Image Sensor	Controlled Power Rail	FLAG in LM3880	Power Up Order	Power Down Order
PYTHON 300/500/1300/3000/5000	VDD_33	FLAG2	2	2
	VDD_PIXEL	FLAG3	3	1
	VDD_18	FLAG1	1	3
IMX25X/26X	AVDD	FLAG3	3	1
	OVDD	FLAG2	2	2
	DVDD	FLAG1	1	3

2.2.2 Consideration

a) Setting Output Voltages

The output voltages of the LMR36015, TPS7A87, and TPS7A90 can be set up by defining resistor divider networks. Equation 1 can be used to calculate output voltages for the TPS7A87 and TPS7A90. This resistive network must provide a current greater than or equal to 5 µA for optimum noise performance. Vref is nominally 0.8 V.

$$R1 = R2(Vout/Vref - 1)$$
$$|Vref(max)|/R2 > 5\ \mu A \quad (1)$$

- R1 is the resistor between FB pin and OUT pin of TPS7A87 or TPS7A90.
- R2 is the resistor between FB pin and ground.

In the LM36015, the voltage divider network is comprised of R_{FBT} and R_{FBB}. The output voltage can be calculated using Equation 2. The recommended value for R_{FBT} is 100 kΩ, with a maximum value of 1 MΩ. If 1 MΩ is selected for R_{FBT}, then a feed-forward capacitor must be used across this resistor to provide an adequate loop phase margin. V_{ref} is nominally 1 V.

$$R_{FBT} = R_{FBB}\left(Vout/V_{ref} - 1\right) \quad (2)$$

The output voltage of the TPS62840 or TPS62841 is set by a single external resistor connected between the V_{SET} and GND pins. For more details, please refer to the *TPS6284X* data sheet.

Table 2-4. Setup for Required Output Voltages of the LMR36015, TPS7A87, TPS7A90, and TPS62840

Device	Output Voltage Required	Value of R1	Value of R2
LMR36015FB	4 V	100 KΩ	33.2 KΩ
TPS7A87	3.3 V	33.2 KΩ	10.7 KΩ
	1.8 V	13.7 KΩ	11 KΩ

Table 2-4. Setup for Required Output Voltages of the LMR36015, TPS7A87, TPS7A90, and TPS62840 (continued)

Device	Output Voltage Required	Value of R1	Value of R2
TPS7A90	1.8 V	13.7 KΩ	11 KΩ
	1.2 V	5.9 KΩ	11.8 KΩ
TPS62840DLC	1.8 V	R_{set} 0 KΩ	
TPS62841DLC	1.2 V	R_{set} 15.8 KΩ	

b) Soft-Start Capacitor (CNR/SS) and Feed-Forward Capacitor (CFF) for the TPS7A87 and TPS7A90

The CNR/SS capacitor serves the dual purpose of both reducing output noise and setting the soft-start ramp during turn on. The CFF capacitor optimizes the transient, noise, and PSRR performance of the LDO. Both of them can influence the start-up time of the LDO, as shown in Equation 3.

$$t_{startup} = t_{ref} + t_{CFF}$$
$$t_{ref} = \frac{V_{SS} + C_{SS}}{I_{SS}}$$
$$t_{CFF} = 3R_1 \times C_{FF} \quad (3)$$

- t_{ref} is determined by the internal soft-start charging circuit.
- V_{ss} is internal reference voltage.
- I_{ss} is soft start current.
- t_{CFF} is determined by the top resistor in resistor divider network and feedforward capacitor.

If $t_{CFF} < t_{ref}$, there is no issue with the power good (PG) function. If $t_{CFF} > t_{ref}$, there is a problem on the power good (PG) function. Refer to the *Pros and Cons of Using a Feedforward Capacitor with a Low-Dropout Regulator* Application Report for more details. In the design of the discrete solution board, specific start-up time and good transient performance are required. A higher CFF value can lower output currents of the LDO during soft start to avoid reaching the fold-back current limitation, but a higher CFF value lasts the start-up time and causes the problem with the power good function. A higher CSS value can improve linearity by increasing start-up time to improve the transient performance of LDO, but it also increases start-up time. In the discrete solution board, a 10-nF capacitor is selected for the CFF. The SS_CTRLx pin is connected to the GND to provide a lower current, 6.2 μA, so a smaller value capacitor at 820 pF can be selected for CSS. Considering the needs for accurate control of start-up time, ceramic capacitors with COG-rated dielectric materials are used to provide a good capacitive stability.

c) Inductor and Capacitor Selections for the LMR36015 and TPS6284X

If simulation results are combined through WEBENCH simulation results, the inductor value 4.7 μH is selected for the LMR36015. More information about inductor selection can be found in the *LMR36015* data sheet. The 2.2-μH inductor value used for the TPS62840 and TPS62841 refers to the *TPS6284X* data sheet.

A minimum ceramic capacitance of 4.7 μF is required on the input of the LMR36015, according to the *LMR36015* data sheet. In addition, a small-size 220-nF ceramic capacitor must be placed at the input, and as close as possible to the regulator. This provides a high-frequency bypass path for the control circuits internal to the device. In the discrete solution board, the 4.7-μF, 50-V, X7R (or better) ceramic capacitor is chosen as shown in Figure 2-11 . The input capacitor value 4.7 μF used for the TPS62840 and TPS62841 refers to the *TPS6284X* data sheet.

In the discrete solution board, the value of the output capacitor can be calculated as at least 7.3 μF. If simulation results are combined through WEBENCH, the output capacitor value of two 22 μF in parallel is selected for LMR36015. The output capacitor value 10 μF used for the TPS62840 and TPS62841 refers to the *TPS6284X* data sheet.

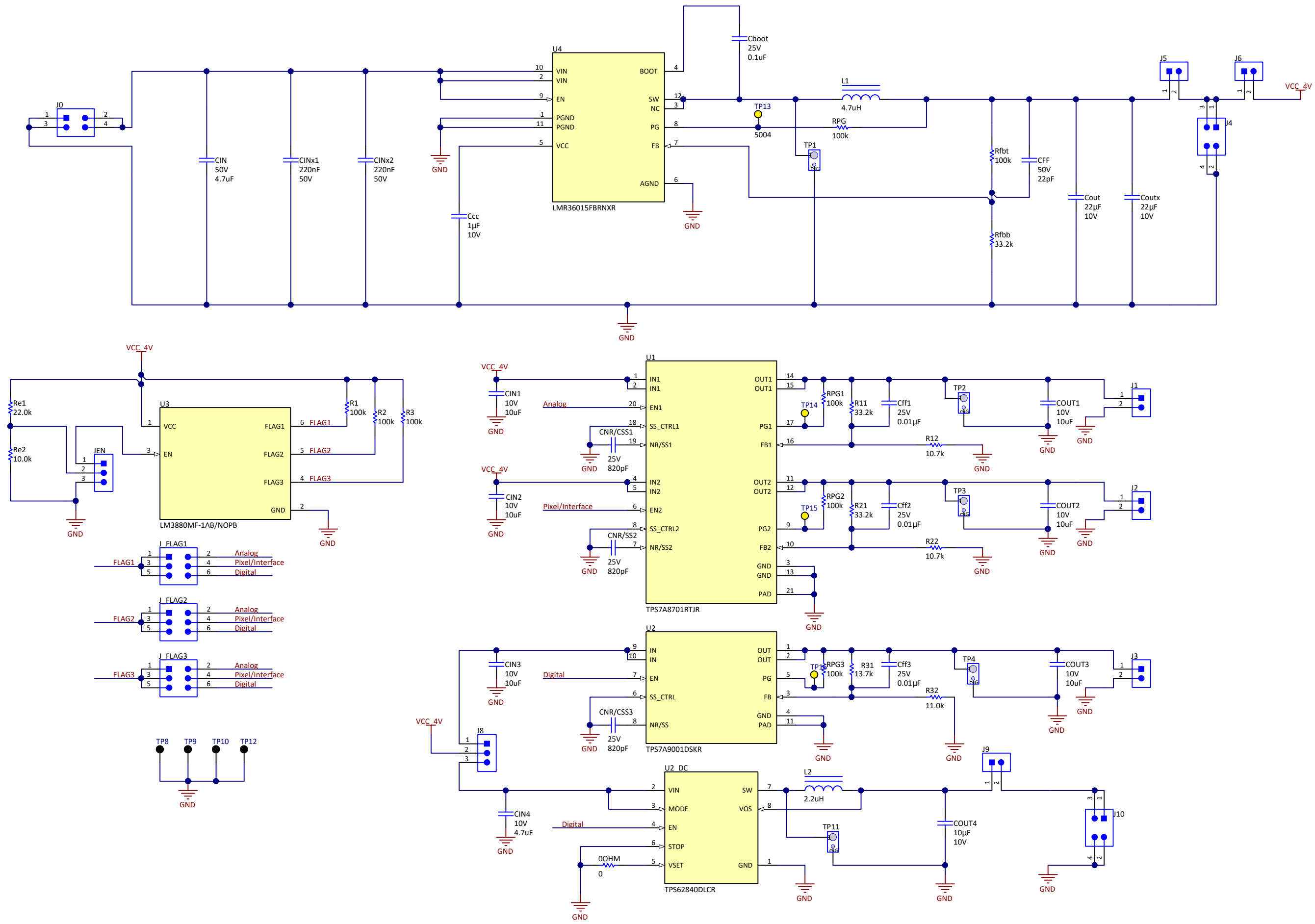


Figure 2-11. The Schematic of Discrete Solution

2.2.3 Discrete Solution PCB Board Description

The discrete solution PCB board is shown in Figure 2-12. The body size is 25 mm × 24 mm without considering test points. J6 is used to disconnect the first and second power stage and then test them individually. J8 is used to choose either the TPS7A90 or TPS6284X for powering the digital rail of the CMOS image sensors. J_FLAG1, J_FLAG2, and J_FLAG3 are used to select powering sequences where row 1 is selected for analog rail, row 2 is selected for the PIXEL or interface rail, and row 3 is selected for digital rail.

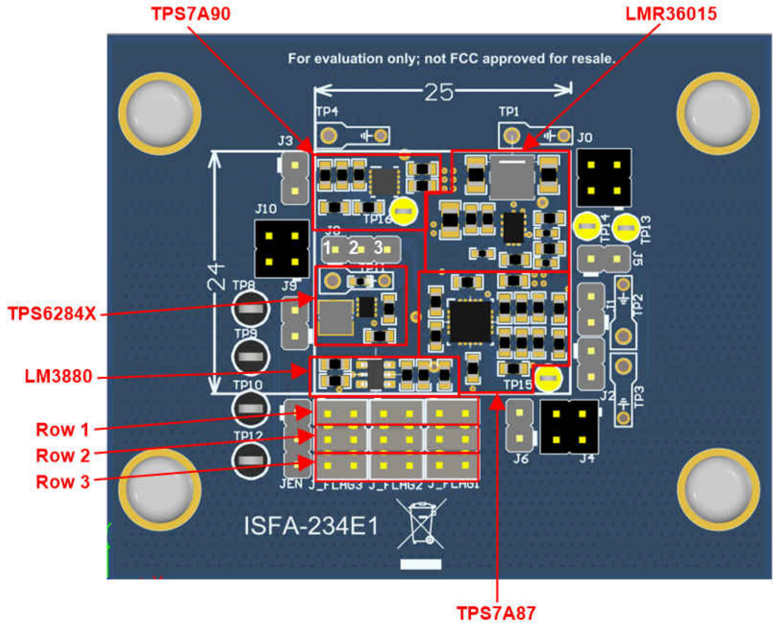


Figure 2-12. PCB Board of Discrete Solution

2.3 Design of the TPS65000 Solution

2.3.1 Device Selection

TPS65000 **2.25 MHz Step-Down Converter with Dual LDOs and SVS Power Management IC (PMIC)**

The TPS6500XX devices are single-chip power management (PWM) ICs for portable applications. It contains a single step-down converter and two low-dropout (LDO) regulators. The step-down converter enters a low-power mode at light load for maximum efficiency across the widest possible range of load currents. For low-noise applications, the devices can be forced into fixed-frequency PWM through a pin. The step-down converter is small because of the small inductor and capacitors. The step-down converter has a power good status output for sequencing. The LDOs can supply 300 mA and operate with an input voltage range from 1.6 V to 6 V. A step-down converter or main battery can power the LDOs directly. The step-down converter and the LDOs have separate voltage inputs that enable maximum design and sequencing flexibility. The TPS6500XX device is available in the VQFN (16) package with body size 3 mm × 3 mm, and WQFN (20) with body size 3 mm × 3 mm.

The TPS6500XX device has several versions defined by output voltages and whether there is supply voltage supervisor or not. In this solution, the TPS65000 version is used.

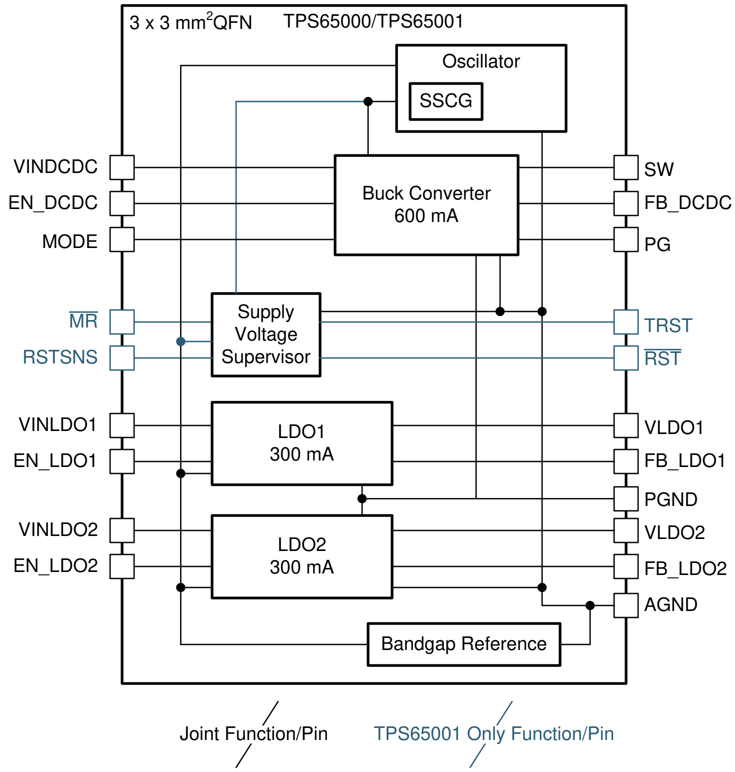


Figure 2-13. Block Diagram of the TPS65000

As shown in Table 2-5, and compared with the specifications in Table 1-1, it can be seen that the TPS65000 solution can support powering the PYTHON 300/500/1300 and IMX25X/26X CMOS image sensors.

Table 2-5. Summary of Components in TPS65000 with Their Specifications

Component	Power Rail of CMOS Image Sensors Supplied	Vin	Vout	Iout	Cout	Selected SW Frequency
LDO1	VDD_PIXEL and OVDD	1.6 V–6 V	0.7 V to VINLDO-Vdo (Vdo=0.37 V)	300 mA	≥10 uF	-
LDO2	VDD_33 and AVDD	1.6 V–6 V	0.7 V to VINLDO-Vdo (Vdo=0.37 V)	300 mA	≥10 uF	-
Buck	VDD_18 and DVDD	2.3 V–6 V	0.6 V-VinDC/DC	600 mA	10 uF–22 uF	2.25 MHz (Used in FPWM mode)

2.3.2 Configurations of theTPS65000 Solution

As introduced in Section 2.1, the TPS65000 solution consists of the LMR36015 from the discrete solution board, TPS65000EVM board, and LM3880EVM board to provide power supplies for PYTHON 300/500/1300 and IMX25X/26X CMOS image sensors. The output voltage of the LMR36015 is set to 4 V. Several resistors need to be changed according to Table 2-6 to provide certain output voltage for each rail of the CMOS image sensors. The LM3880EVM can be configured as shown in Table 2-7 in order to provide the specific powering sequences of each rail of the CMOS image sensors.

Table 2-6. Set Up for Required Output Voltages of the TPS65000EVM Board

CMOS Image Sensor	Power Rail Of CMOS Image Sensors	TPS65000	Voltage	Top-resistor In Corresponding Resistor Divider Network	Bottom-resistor In Corresponding Resistor Divider Network
PYTHON 300/500/1300	V_33	LDO2	3.3 V	162 KΩ	28.7 KΩ
	V_PIXEL	LDO1	3.3 V	162 KΩ	28.7 KΩ
	V_18	Buck	1.8 V	953 KΩ	470 KΩ

Table 2-6. Set Up for Required Output Voltages of the TPS65000EVM Board (continued)

CMOS Image Sensor	Power Rail Of CMOS Image Sensors	TPS65000	Voltage	Top-resistor In Corresponding Resistor Divider Network	Bottom-resistor In Corresponding Resistor Divider Network
IMX25X/26X	AVDD	LDO2	3.3 V	162 KΩ	28.7 KΩ
	OVDD	LDO1	1.8 V	470 KΩ	180 KΩ
	DVDD	Buck	1.2 V	475 KΩ	475 KΩ

Table 2-7. Connecting the LM3880EVM Board with the TPS65000EVM Board

CMOS Image Sensor	Controlled Power Rail	FLAG from the LM3880EVM Board	Pin Connected in the TPS65000EVM Board
PYTHON 300/500/1300	V_33	FLAG2	Pin 2 of JP2 (ENLDO2)
	V_PIXEL	FLAG3	Pin 2 of JP1 (ENLDO1)
	V_18	FLAG1	Pin 2 of JP6 (ENDCDC)
IMX25X/26X	AVDD	FLAG3	Pin 2 of JP2 (ENLDO2)
	OVDD	FLAG2	Pin 2 of JP1 (ENLDO1)
	DVDD	FLAG1	Pin 2 of JP6 (ENDCDC)

2.4 Design of TPS650330-Q1 Solution

2.4.1 Device Selection

TPS650330-Q1 Three Step-Down Converters with One High PSRR LDO Integrated Power Management IC (PMIC)

The TPS650330-Q1 device is a highly integrated power management IC for automotive camera modules. This device combines three step-down converters and one low-dropout (LDO) regulator. The BUCK1 step-down converter has an input voltage range up to 18.3 V for connections to Power over Coax (PoC). All converters operate in a forced fixed-frequency PWM mode. The LDO can supply 300 mA and operate with an input voltage range from 3.0 V to 5.5 V. The step-down converters and the LDO have separate voltage inputs that enable maximum design and sequencing flexibility. The TPS650330-Q1 is available in a 24-pin VQFN package (4.0 mm × 4.0 mm).

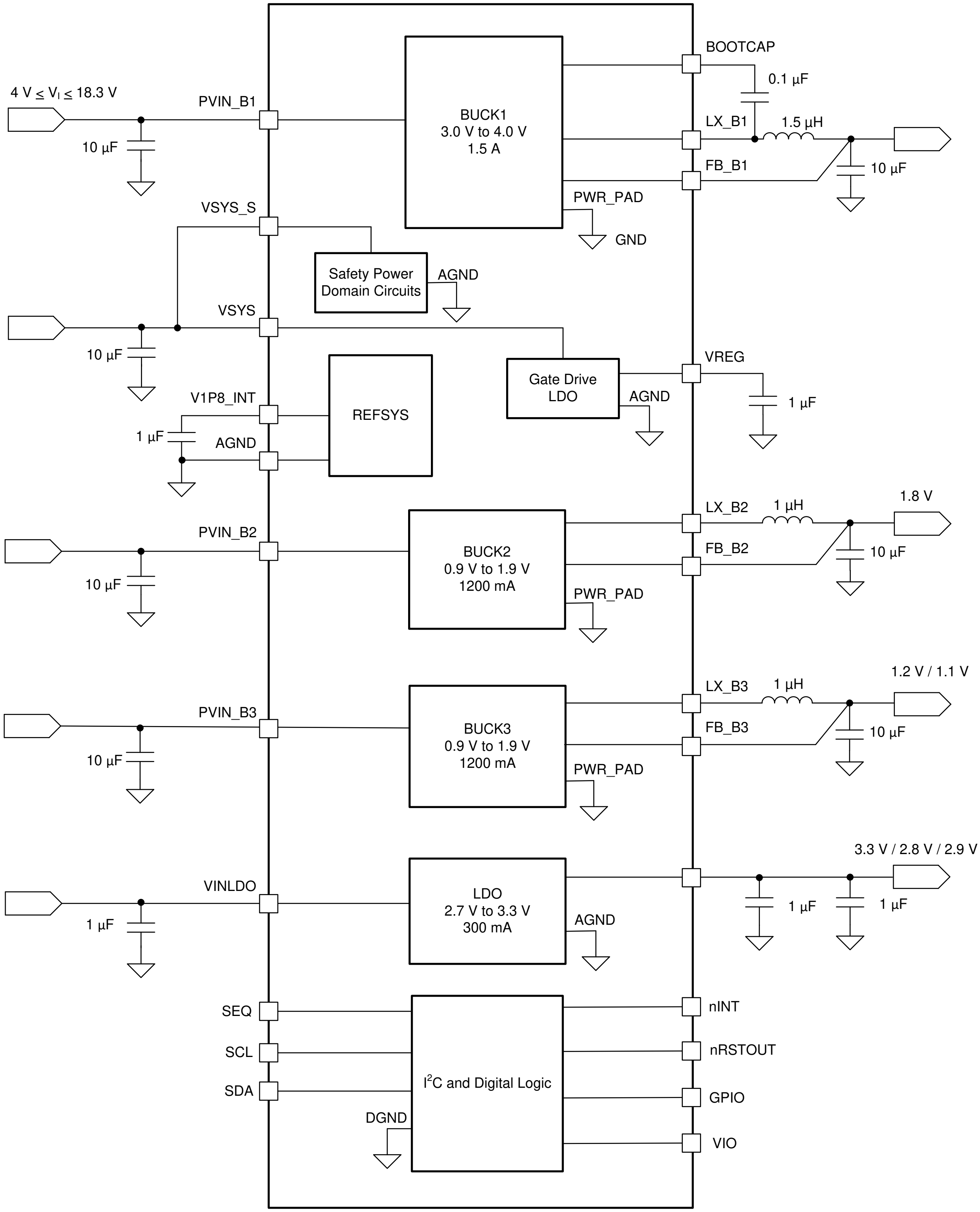


Figure 2-14. Block Diagram of the TPS650330-Q1

As shown in Table 2-8 and compared with the specifications in Table 1-1, it can be seen that the TPS650330-Q1 solution can support powering IMX25X/26X CMOS image sensors.

Table 2-8. Summary of Components in the TPS650330-Q1 with Their Specifications

Component	Power Rail of CMOS Image Sensors Supplied	Vin	Vout	Iout	Cout	Selected SW Frequency
LDO	AVDD	3 V–5.5 V	2.7 V–3.3 V(Vdo=150mV–300mV)	300 mA	1 uF–4 uF	-
Buck1	As the first power stage to transform high input voltage (12 V) from PoE or DC adapter to a 4-V intermediate voltage	4 V–18.3 V	3 V-4 V	1500 mA	6.8 uF–14 uF	2.3 MHz FPWM
Buck2	DVDD	3 V–5.5 V	0.9 V-1.9 V	1200 mA	6.8 uF–12 uF	2.3 MHz FPWM
Buck3	OVDD	3 V–5.5 V	0.9 V-1.9 V	1200 mA	6.8 uF–12 uF	2.3 MHz FPWM

2.4.2 Configurations of the TPS650330-Q1 Solution

Hardware configuration can be done according to the TPS650330-Q1EVM User's Guide, which is available on request at the TPS650330-Q1 product page. As shown in Figure 2-1, buck 1 in the TPS650330-Q1 is used as the first power stage to convert the 12-V input voltage to 4-V intermediate voltage. Buck 2 in the TPS650330-Q1 is used to power 1.2 V for the digital rail, and buck 3 powers 1.8 V for the interface rail. The LDO in the TPS650330-Q1 sets the analog rail to 3.3 V. These configurations can be set up in the TPS650330-Q1 GUI. For powering IMX25X/26X CMOS image sensors, the power-on sequences are set to 20-ms delay time between every power rail and the power-off sequences are set to 4-ms delay time between every power rail.

3 Test Results

All three solutions have been tested for power sequencing performance, efficiency, line transient and load transient. Besides, the 4-V intermediate voltage is adjusted to identify the relationship between the intermediate voltage of a multi-stage system and the whole system efficiency.

3.1 Test Results of the Discrete Solution Board

3.1.1 Setup

As introduced in previous sections, the discrete solution supports power supplies of all the CMOS image sensors listed in Table 1-1, which may require large capacitors and high current consumption up to 500 mA. Furthermore, the discrete solution board can be configured for six cases, as shown in Table 3-1.

Table 3-1. Configurations of the Discrete Solution Board for Six Cases

CMOS Image Sensors	Case	Case Number	Configurations of Discrete Solution Board
PYTHON 300/500/1300	LMR36015+TPS7A87+TPS7A90 +LM3880 (30-ms delay)	1	1. Follow Table 1-1 and Table 2-4 to set up the right voltage for each power rail. 2. Put headers in J5, J6, between pin 1 and pin 2 in J8 for TPS7A90 or between pin 2 and pin 3 in J8 for TPS62840, row 2 in J_FLAG1, row 3 in J_FLAG2 and row 1 in J_FLAG3.
	LMR36015+TPS7A87+TPS62840+LM3880 (30-ms delay)	2	
PYTHON 3000/5000	LMR36015+TPS7A87+TPS7A90 +LM3880 (30-ms delay)	3	
	LMR36015+TPS7A87+TPS62840+LM3880 (30-ms delay)	4	
IMX25X/26X	LMR36015+TPS7A87+TPS7A90 +LM3880 (30-ms delay)	5	1. Follow Table 1-1 and Table 2-4 to set up the right voltage for each power rail. 2. Put headers in J5, J6, between pin 1 and pin 2 in J8 for TPS7A90 or between pin 2 and pin 3 in J8 for TPS62841, row 3 in J_FLAG1, row 2 in J_FLAG2 and row 1 in J_FLAG3.
	LMR36015+TPS7A87+TPS62841+LM3880 (30-ms delay)	6	

a) Power Sequencing Test Setup

For each case shown in Table 3-1, the power sequence of each rail is tested under 12-V input voltage for the whole system. The LM3880 is enabled by an external signal. In this test, the external signal is provided by a waveform generator. Three tip-barrel test probes are separately put in the output of each power rail in front of loads. A current probe is used to observe the current performance of each power rail.

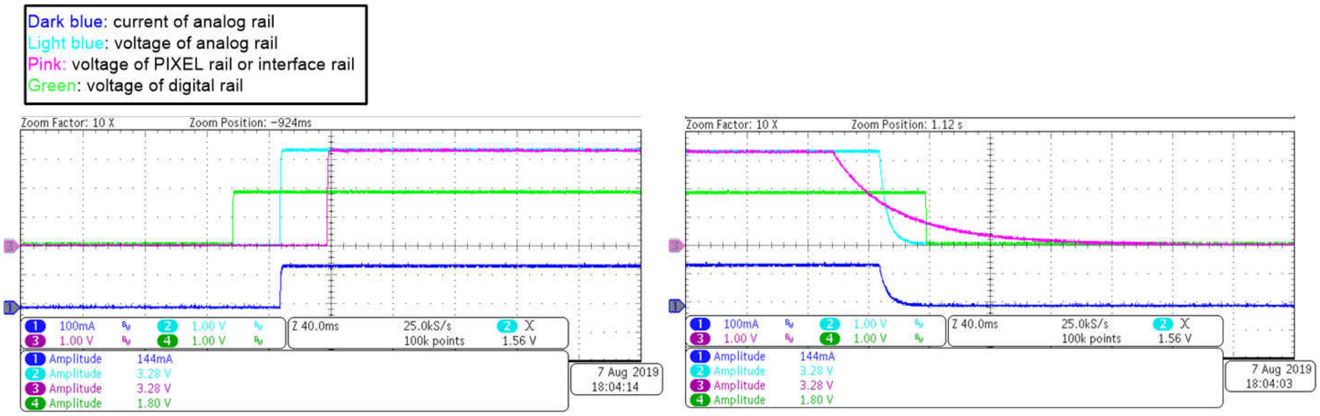
b) Efficiency Test Setup

In total, four sets of digital multi-meters are used. In each set, one digital multi-meter is set as current meter (AM), and another is set as voltage meter (VM). One set is placed between the DC power supply and the input of the discrete solution board to measure input power. The other three sets are separately placed in front of three outputs.

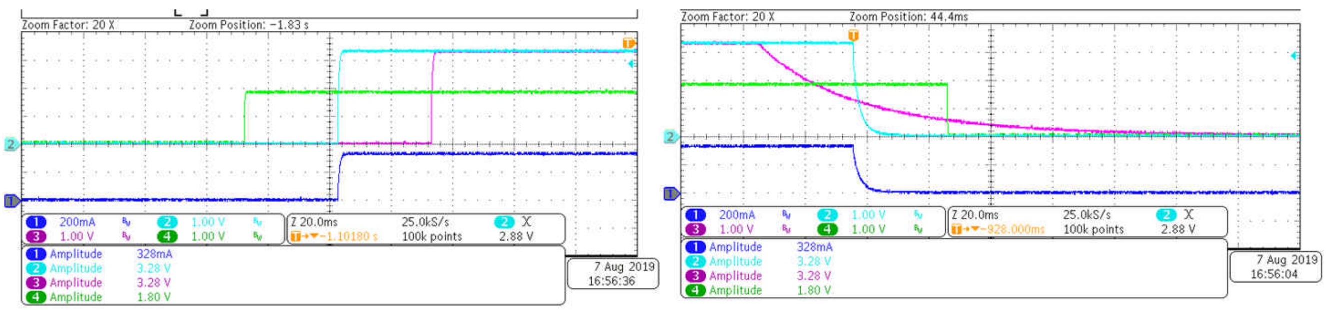
3.1.2 Test Results

Power sequence results are shown in Figure 3-1. According to Table 2-3, the test results of whether choosing the TPS7A90 or the TPS6284X for digital rails are the same (case one has the same results as case two, case three has the same results as case four, and case five has the same results as case six), so in Figure 3-1, only the results of cases one, three, and five are presented.

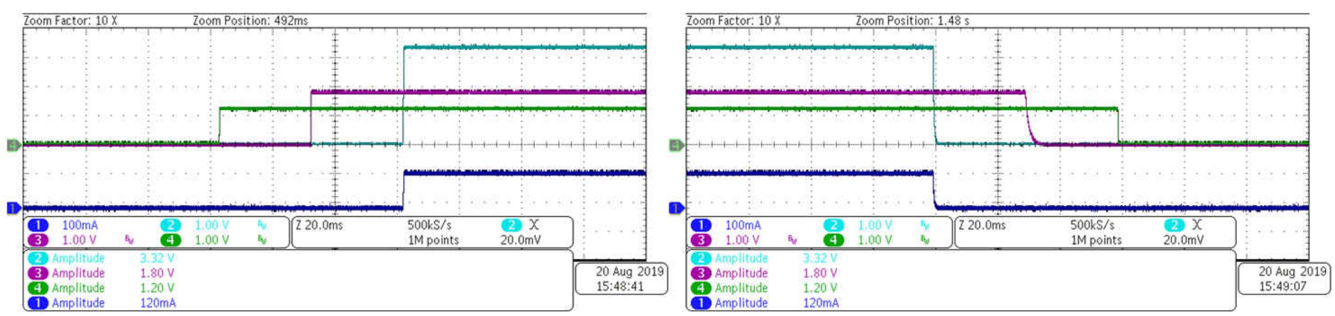
Efficiency results for the whole system are shown in Table 3-2. The table shows that if the digital rail is supplied by a buck converter like the TPS6284X, rather than a LDO like the TPS7A90, the efficiency of the whole system can be improved. Figure 3-2 and Figure 3-3 show the efficiency of digital rails in the whole systems. The efficiency is calculated by the output power of the digital rail over the input power (12 Vin) of the whole system. The fixed loads for the digital rail are removed and replaced by an electronic load here with current from 10 mA to 450 mA. In both figures, it can be seen that the efficiency is influenced by load currents. There is an intersection point in each figure. After the intersection point, the efficiency of the digital rail using the TPS6284X increases more quickly than the efficiency of the digital rail using LDO TPS7A90.



(a) Power Sequences of PYTHON 300/500/1300 CMOS image sensors' power rails



(b) Power Sequences of PYTHON 3000/5000 CMOS image sensors' power rails



(c) Power Sequences of IMX25X/26X CMOS image sensors' power rails

Figure 3-1. Power Sequences of CMOS Image Sensor Power Rails

Table 3-2. Efficiency of CMOS Image Sensor Power Systems

CMOS Image Sensor		Efficiency		
		5 Vin	**12 Vin**	**24 Vin**
PYTHON 300/500/1300	LMR36015+TPS7A87+TPS7A90+LM3880 (30-ms delay)	61%	55%	50%
	LMR36015+TPS7A87+TPS62840+LM3880 (30-ms delay)	74%	65%	53%

Table 3-2. Efficiency of CMOS Image Sensor Power Systems (continued)

PYTHON 3000/5000	LMR36015+TPS7A87+TPS7A90+LM3880 (30-ms delay)	61%	58%	53%
	LMR36015+TPS7A87+TPS62840+LM3880 (30-ms delay)	72%	68%	61%
IMX25X/26X	LMR36015+TPS7A87+TPS7A90+LM3880 (30-ms delay)	55%	43%	36%
	LMR36015+TPS7A87+TPS62841+LM3880 (30-ms delay)	71%	62%	50%

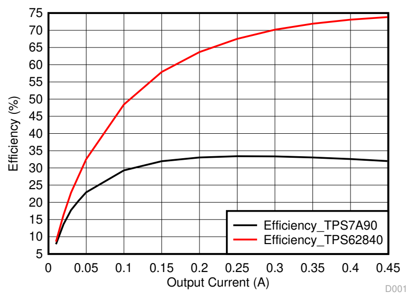


Figure 3-2. Efficiency of the Digital Rail Supplied by TPS7A90 or TPS62840 in PYTHON 300/500/1300 CMOS Image Sensors

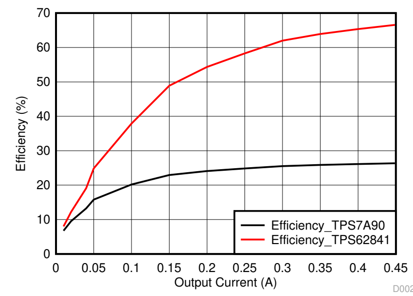
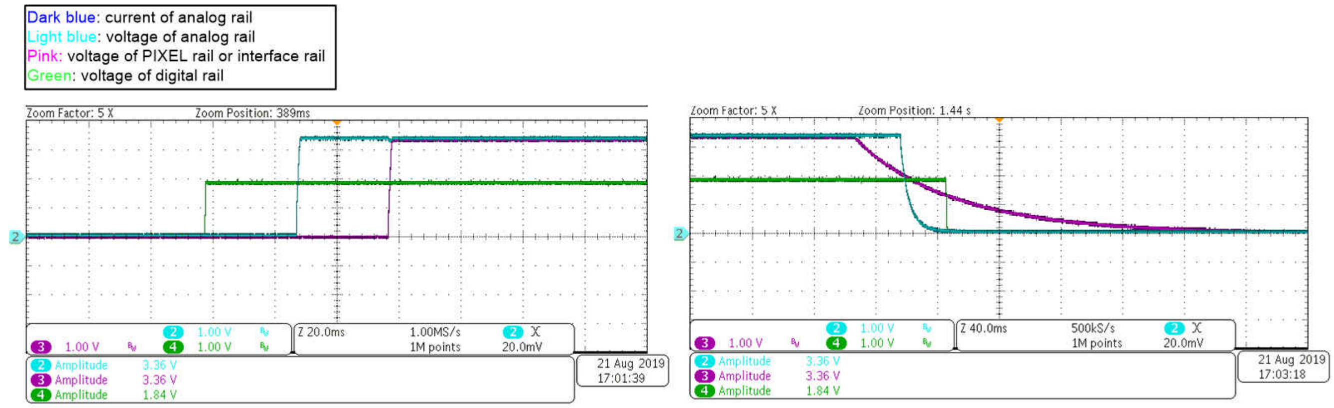


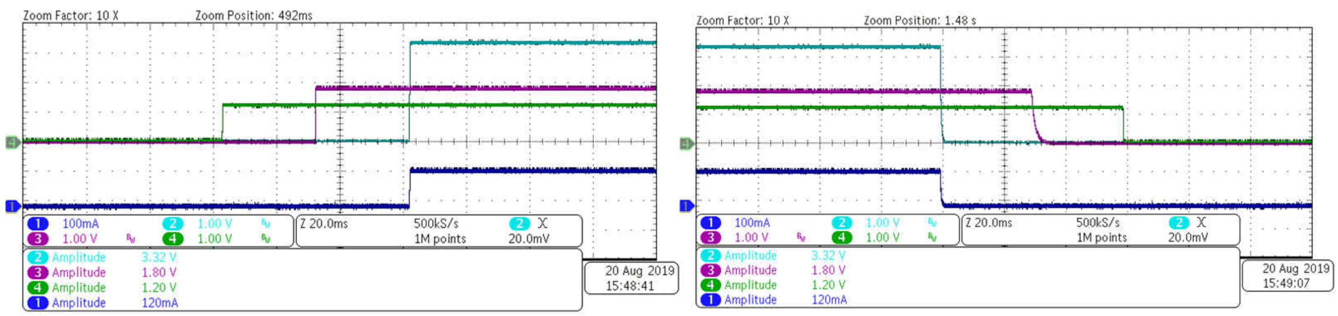
Figure 3-3. Efficiency of the Digital Rail Supplied by TPS7A90 or TPS62841 in IMX25X/26X CMOS Image Sensors

3.2 Test Results of TPS65000 Solutions

Configurations of the TPS65000 solutions are described in Section 2.3.2 and the repeating testing procedure in Section 3. The test results of TPS65000 solutions are shown as follows. Figure 3-4presents the power sequences of the power rails of the CMOS image sensors. Table 3-3 summarizes the efficiency of the whole system for powering the PYTHON 300/500/1300 and IMX25X/26X CMOS image sensors. The efficiency of the whole system can be improved even more than the discrete solution according to Section 4.3.



(a) Power Sequences of PYTHON 300/500/1300 CMOS image sensors' power rails



(b) Power Sequences of IMX25X/26X CMOS image sensors' power rails

Figure 3-4. Power Sequences of the Power Rails of the CMOS Image Sensors Using the TPS65000 Solutions

Table 3-3. Efficiency of the Whole System Using the TPS65000 Solutions

CMOS Images Sensor	Efficiency		
	5 Vin	12 Vin	24 Vin
PYTHON 300/500/1300	75%	66%	54%
IMX25X/26X	72%	63%	51%

3.3 Test Results of the TPS650330-Q1 Solutions

The following configurations of TPS650330-Q1 solutions are described in Section 2.4.2 and repeating test procedures in Section 3. Test results of the TPS650330-Q1 solutions are shown as follows. Section 1 presents power sequences for the power rails of IMX25X/26X CMOS image sensors. Table 3-4 summarizes the efficiency of the whole system for powering IMX25X/26X CMOS image sensors. The efficiency of the whole system can be further improved.

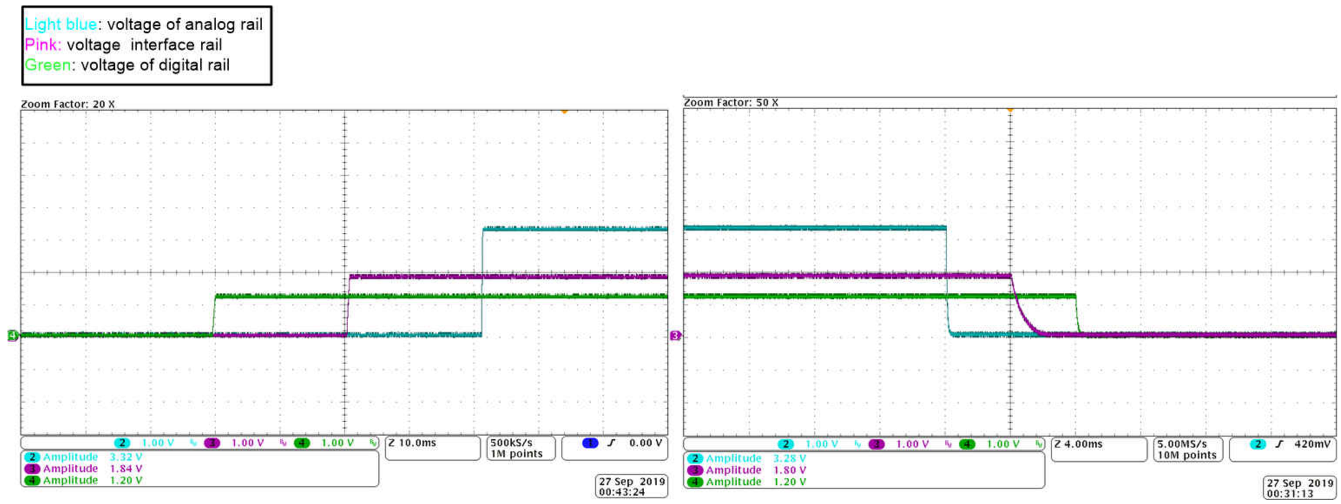


Figure 3-5. Power Sequences of the Power Rails of IMX25X/26X CMOS Image Sensors

Table 3-4. The Efficiency of the Whole System Using TPS650330-Q1 Solutions

Input Power of the TPS650330-Q1 AfterEnabling the Solution	Output Power of TPS650330-Q1	Efficiency
0.84 W	0.509 W	61%

4 Analysis

4.1 Power Sequence Modification of PYTHON Series CMOS Image Sensors

There is no limitation on the maximum power-up and power-off time in the datasheet of PYTHON series CMOS Image Sensor. In order to keep the power-off sequence in a safety range, the LM3880 with longer delay time can be used. Figure 4-1 shows the power sequences of the power rails of PYTHON 300/500/1300 CMOS image sensors using LM3880 with 120-ms delay.

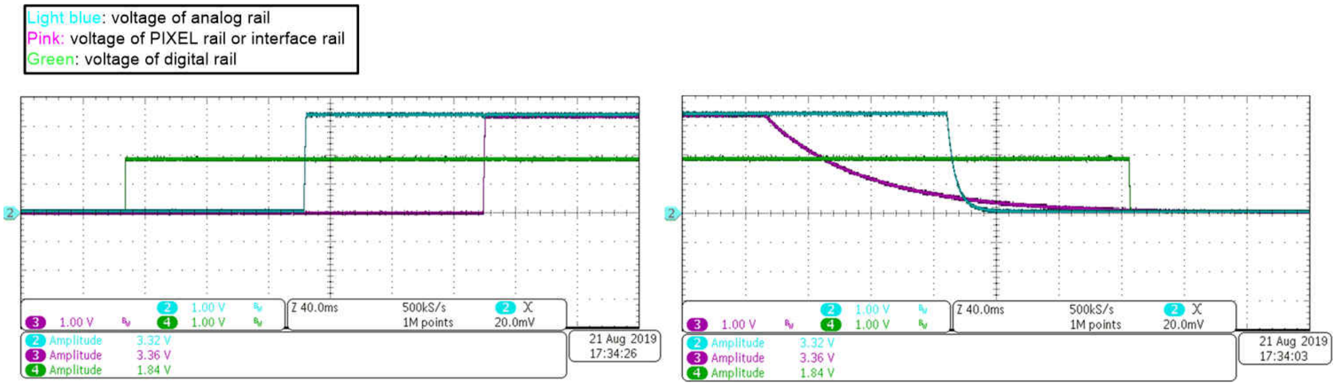


Figure 4-1. Power Sequence of the Power Rails of PYTHON 300/500/1300 CMOS Image Sensors Using the 120-ms Delay Time LM3880

4.2 Efficiency of the Whole System Influenced by Changing the Intermediate Voltage

Based on the TPS65000 solution, the 4-V intermediate voltage supplied by the LMR36015 in the discrete board is adjusted in this section. A more suitable intermediate voltage when designing power rails can be considered according to the relationship between the efficiency of the whole system and the intermediate voltage.

Considering the output voltage range of the buck, dropout voltages of the LDO, and accuracy of output voltages in the TPS65000, the 4-V intermediate voltage powering PYTHON 300/500/1300 case is changed into 4.5 V and 5 V to repeat efficiency tests for the whole power system. The 4-V intermediate voltage powering the IMX25X/26X case is adjusted into 3.9 V, 4.5 V, and 5 V. Table 4-1 lists resistors values for adjusting the output voltages of the LMR36015 into 3.9 V, 4.5 V, and 5 V. As shown in Figure 4-2 and Figure 4-3 , the efficiency decreases when the intermediate voltage increases. The increasing intermediate voltage can improve the efficiency of the first power stage (the LMR36015), but it causes more power dissipation on LDOs. For this system, power dissipation on LDOs have more impact on the whole system efficiency.

Table 4-1. Selections of Resistors for the LMR36015 to Output 3.9V, 4V, 5V and 4.5V

Output Voltage of the LMR36015	R_{FBT}	R_{FBB}
3.9 V	100 K	34.8 KΩ
5 V	100 K	24.9 KΩ
4.5 V	100 K	28.7 KΩ

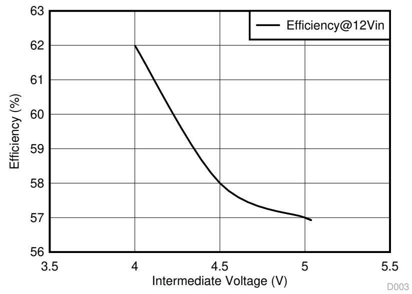


Figure 4-2. The Relationship Between Efficiency of the Whole System and the Intermediate Voltage for Powering PYTHON 300/500/1300 CMOS Image Sensors

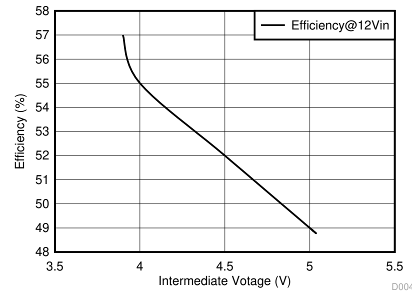


Figure 4-3. The Relationship Between Efficiency of the Whole System and the Intermediate Voltage for Powering IMX25X/26X CMOS Image Sensors

4.3 Comparison of the Efficiency of the Discrete Solution Using the TPS62841 and the Efficiency of the TPS65000 Solution Through Powering IMX25X/26X CMOS Image Sensors

Comparing the efficiency of the discrete solution using the TPS62841 in Table 3-2 and the efficiency of the TPS65000 solution in Table 3-3, the second power stage of the TPS65000 solution has a better efficiency performance than the second power stage of the discrete solution using the TPS62841 for powering IMX25X/26X CMOS image sensors.

When disabling the dual-LDO TPS7A87 and LDOs in the TPS65000 to make only the TPS62841 and the buck in TPS65000 work, efficiencies can be tested again. The results are shown in Table 4-2. It can be identified that TPS62841 has a better efficiency performance than the buck integrated in the TPS65000. Major losses of the TPS62841 and the buck integrated in the TPS65000 are calculated according to the parameters in their data sheets, as shown in Table 4-3. The losses of the TPS62841 are less than losses of the buck integrated in the TPS65000.

However, LDOs integrated in the TPS65000 have a better quiescent operation current performance than that of the TPS7A87, which can be observed when enabling only LDOs in both solutions. The current through GND pin of TPS7A87 is about 1 mA higher than the quiescent operation current of the TPS65000. Therefore, the total efficiency of the TPS65000 is better than the second stage of the discrete solution board with using TPS62841, and can be explained.

Table 4-2. Efficiency of the Discrete Solution and the TPS65000 Solution when Only Powering the Digital Rail of IMX25X/26X CMOS Image Sensors

Efficiency of Powering Only the Digital Rail of IMX25X/26X CMOS Image Sensors	
Solutions	**Efficiency**
	4-V Intermediate Voltage (5 Vin/12 Vin/24 Vin)
Discrete solution with using TPS62841 (LMR36015+TPS7A87+TS62841+LM3880)	79.5%
LMR36015 (from discrete solution board) +TPS65000EVM+LM3880EVM	79.4%

Table 4-3. TPS6284X and Buck Integrated in the Major Losses Comparison of the TPS65000

Losses	TPS62841	Buck Inside the TPS65000
High-side MOSFET conduction loss	1182.7 uW	657.2 uW
Low-side MOSFET conduction loss	2545.6 uW	2758. 2uW
Conduction loss in the inductor	2872.8 uW	3346.8 uW
Total losses	6.6 mW	6.8 mW

5 Summary

CMOS image sensors usually feature three supply rails in an industrial camera, the analog rail, the PIXEL rail (or interface rail), and the digital rail. The analog rail and PIXEL rail (or interface rail) are more sensitive to noise. So for these two rails, a LDO with high PSRR, low noise, and fast transient response are expected to use and ensure optimal image qualities. Besides, the ability of the LDO to drive high capacitance must also be considered when powering high-performance CMOS image sensors. The digital rail is less sensitive to noise, so in order to improve the whole system efficiency and thermal performance, the digital rail can choose a buck converter.

The intermediate voltage of the power system is chosen as 4 V to improve the efficiency of the whole system.

CMOS image sensors can be supplied by a discrete solution using several LDOs and bucks, as well as a PMIC solution with LDOs and bucks integrated. The number of components used in the discrete solution, the PMIC TPS65000 solution, and the PMIC TPS65033-Q1 solution are compared in Table 5-1. The TPS650330-Q1 solution benefits from less components used, so the BOM is saved just as well as in the PMIC TPS65000 solution. The discrete solution can support more conditions by selecting and modifying components flexibly. In general, the discrete solution is more flexible, and can even achieve a smaller size than a PMIC integrated solution, but the PMIC integrated solution can simplify the design of outside circuits. For example, the TPS650330-Q1 integrates a sequencer into a single chip, which greatly decreases the number of components used in the whole system. The specific choices between the discrete solution and PMIC integrated solution must be based on a real situation.

Table 5-1. The Number of Components Used in each Solution

The Discrete Solution (PYTHON)			
LMR36015+TPS7A87+TPS7A90+LM3880		LMR36015+TPS7A87+TPS62840+LM3880	
Devices	**Number**	**Devices**	**Number**
TPS7A8701RTJR	1	TPS7A8701RTJR	1
TPS7A9001DSKR	1	TPS62840DLCR	1
LM3880MF-1AB/NOPB	1	LM3880MF-1AB/NOPB	1
LMR36015FBRNXR	1	LMR36015FBRNXR	1
Capacitors	20	Capacitors	18
Resistors	15	Resistors	12
Inductors	1	Inductors	2
Total	40	Total	36
The Discrete Solution (IMX)			
LMR36015+TPS7A87+TPS7A90+LM3880		LMR36015+TPS7A87+TPS62841+LM3880	
Devices	**Number**	**Devices**	**Number**
TPS7A8701RTJR	1	TPS7A8701RTJR	1
TPS7A9001DSKR	1	TPS62840DLCR	1
LM3880MF-1AB/NOPB	1	LM3880MF-1AB/NOPB	1
LMR36015FBRNXR	1	LMR36015FBRNXR	1
Capacitors	20	Capacitors	18
Resistors	15	Resistors	13
Inductors	1	Inductors	2
Total	40	Total	37
TPS65000 Solution (PYTHON and IMX)		**TPS650330-Q1 Solution (IMX)**	
LMR36015FB EVM+ TPS65000 EVM+LM3880 EVM		TPS650330-Q1 EVM	
Devices	**Number**	**Devices**	**Number**
TPS65000RTE	1	TPS650330	1
LM3880MF-1AB/NOPB	1		
LMR36015FBRNXR	1	Capacitors	12
Capacitors	17		

Table 5-1. The Number of Components Used in each Solution (continued)

The Discrete Solution (PYTHON)			
Resistors	13	Inductors	3
Inductors	2		
Total	35	Total	16

6 References

1. Pros and Cons of Using a Feed-forward Capacitor with a Low-Dropout Regulator

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (August 2019) to Revision A (July 2021) **Page**

- Updated the numbering format for tables, figures and cross-references throughout the document...................3

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