

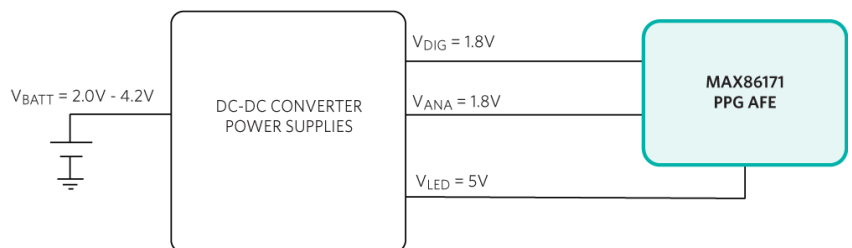
Power-Supply Subsystems for PPG Remote-Patient Vital Sign Monitors (Part 1)

This two-part series presents validated switch-mode power circuit designs for remote-patient vital sign monitoring applications, including biosensors with excellent system signal-to-noise performance. Part 1 shows a discrete solution to achieve best performance.

A photoplethysmogram (PPG) device can be implemented to measure blood volume changes from which vital sign information such as blood oxygen levels and heart rates are derived. In Part 1, we provide discrete power-supply circuit design solutions for best performance using the [MAX86171](#) optical pulse oximeter and heart-rate sensor analog front end (AFE). Part 2 will examine an integrated solution for space-constrained applications.

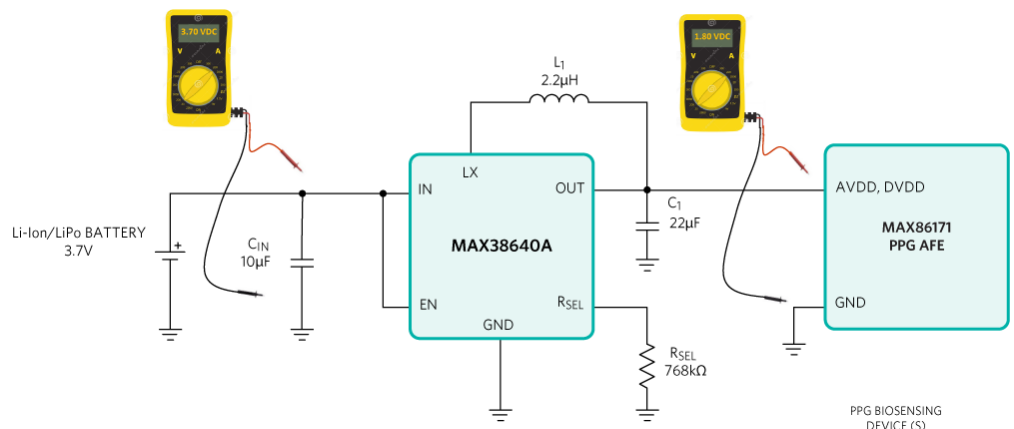
Switch-mode power supplies (SMPS, also referred to as dc-dc converters) are commonly used in wearable medical and healthcare applications for reasons such as size considerations and power efficiency. Designers can use these power supplies to create battery-operated products that achieve longer lifetimes. Unfortunately, designers are still left to select the appropriate SMPS device followed by creating a suitable circuit board layout that preserves the performance of a biosensing device in their system.

To help simplify and speed the process, Analog Devices developed



1. Block diagram of a typical PPG remote-patient vital sign monitor.

2. Block diagram of a PPG subsystem using discrete power-supply devices.



power-supply subsystem circuit designs that have been pre-validated (i.e., designed, built, and tested) to ensure the signal-to-noise ratio (SNR) performance of each biosensing AFE device. This article provides details for the power-supply circuits, with each example being complemented with a validation checklist and troubleshooting guide to aid circuit designers, if needed.

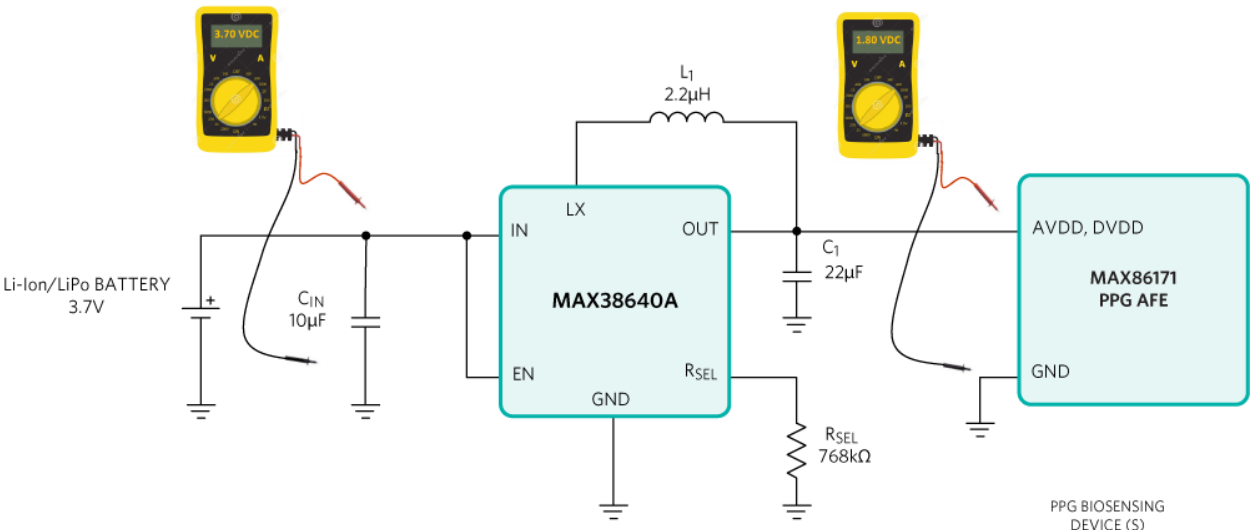
Figure 1 shows a standard power block diagram encountered in many remote-patient monitoring applications. Table 1 reveals the design limits, and Table 2 shows the design considerations for discrete and integrated solutions.

Discrete Design Description

This DC-DC converter design regulates the three-output power supply rails for use in a remote patient vital sign monitor subsystem. The circuit provides proper line and load regulation while maintaining low output noise levels to preserve

biosensing SNR performance, which is powered by a rechargeable lithium polymer battery or a primary Li Cell battery.

Figure 2 shows the PPG subsystem using discrete power supply devices and Table 3 lists the main components.



3. A 1.8-V dc MAX38640A SMPS circuit for remote-patient vital sign monitoring applications.

Table 1: Design Limits

Input		Output (VDIG, VANA, VLED)		Noise, RTO
VIMIN	VIMAX	VOMIN	VOMAX	V p-p (max)
3.0 V	4.2 V	1.6 V	2.0 V	30 mV p-p
2.0 V	3.4 V	1.6 V	2.0 V	30 mV p-p
		4.7 V	5.3 V	20 mV p-p

Table 2: Design Configuration

Design configuration	Battery implementation	Board area layout considerations
Discrete	Primary (Coin Cell) Secondary (Li and LiPo)	Implements separate discrete circuits.
Integrated	Secondary (Li and LiPo)	- Uses single integrated circuit for minimal board area requirements. - Supports secondary batteries only.

Table 3: Key Components

Designator	Component	Description
U1	DC-DC converter	Power converter device (MAX38640A and MAX20343H)
L1	2.2-µH inductor	Low equivalent-series-resistance (ESR) inductor (Energy) storage component
C1	22-µF capacitor	Low ESR capacitor (energy) storage component

L1 and C1 are specially selected passive components that are critical to the performance of the dc-dc converter (also known as a switch-mode power supply).

1.8-V SMPS Circuit Using a nanoPower Buck Converter

The following circuit based on the MAX38640A nanoPower buck converter (Fig. 3) shows the typical input and output power-supply level to properly operate the SMPS device in remote-patient vital sign monitor

Table 4: MAX38640A Validation Checklist

Step	Action	Procedure	Measurement	Need help?
1	Check input dc power supply LP401230 LiPo battery CR2032 Li coin battery	Measure voltage across battery	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	Troubleshooting Instructions
2	Check input dc power supply LP401230 LiPo battery CR2032 Li coin battery	Measure voltage across C _{IN}	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	
3	Check V _{OUT} dc level	Measure voltage across C _{OUT}	Reading range: 1.71V – 1.89V	
4		Measure voltage across load	Reading range: 1.71V – 1.89V	
5	Check output noise level	Use pigtail 10x single-ended probe or differential active probe	Ripple noise level should be < 20 mV p-p	

applications.

As illustrated in *Figure 3*, a digital multimeter (DMM) can be used to probe the input and output ports to validate the supply voltage levels. The power-supply output levels can vary due to various factors such as a discharging battery or changing loads (i.e., device mode changes, devices waking up from sleep mode, etc.).

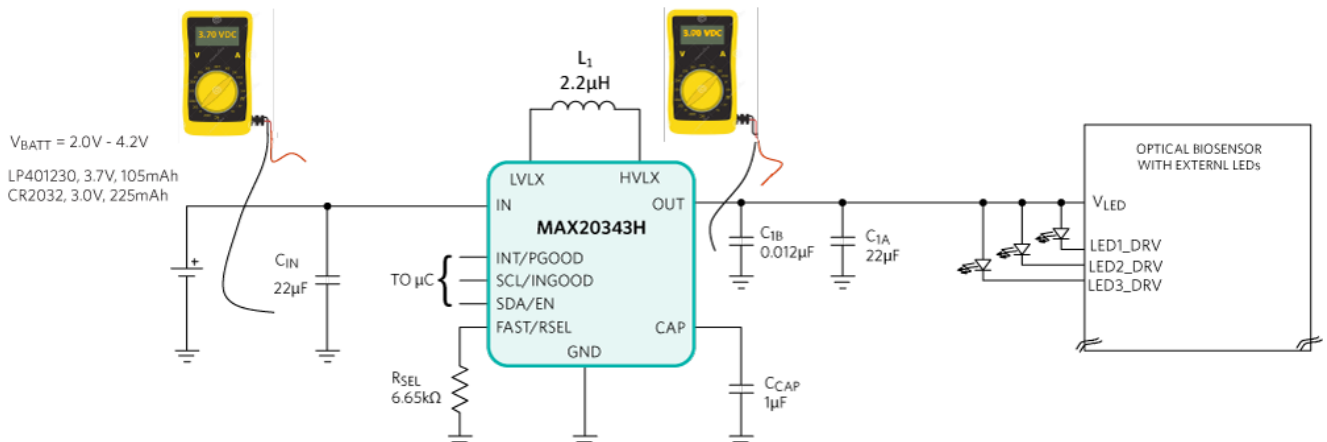
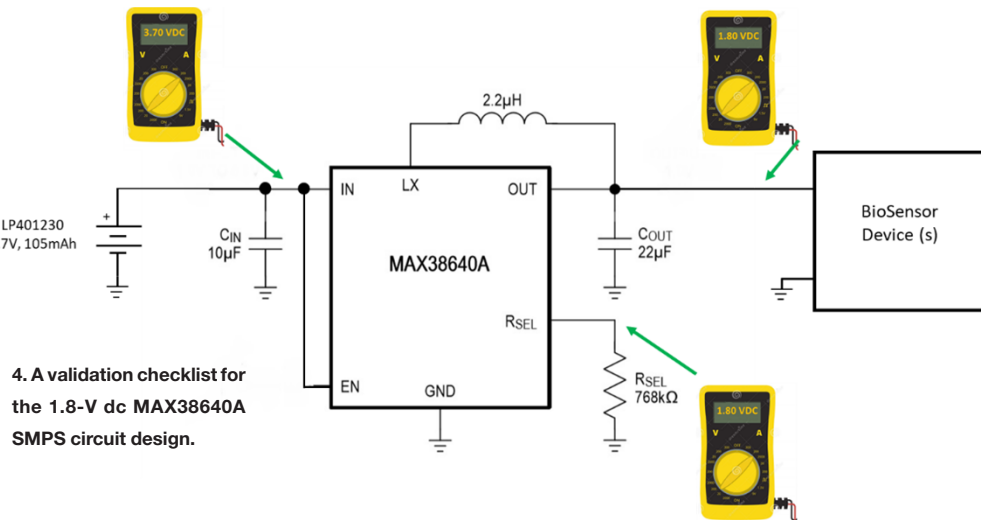
1.8-V SMPS Circuit Validation Checklist

The circuit validation checklist (*Table 4*) is intended to help designers with their electrical bench checkout of the 1.8-V SMPS circuit post board assembly (*Fig. 4*). In this case, the MAX38640A device, while connected to a biosensing circuit load, is used. This checklist also can be employed as a template for product testing.

Troubleshooting the MAX38640A (1.8-V Output) SMPS Circuit

These circuit troubleshooting instructions will help designers if operational issues arise with the operation of the 1.8-V SMPS circuit (*Fig. 5*). This guide addresses the most common problems that crop up when implementing these switch-mode power supplies.

Step 1: Check the input voltage



5. Tools for troubleshooting the MAX38640A SMPS circuit.

Table 4: MAX38640A Validation Checklist

Step	Action	Procedure	Measurement	Need help?
1	Check input dc power supply LP401230 LiPo battery CR2032 Li coin battery	Measure voltage across battery	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	Troubleshooting Instructions
2	Check input dc power supply LP401230 LiPo battery CR2032 Li coin battery	Measure voltage across C_{IN}	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	
3	Check V_{OUT} dc level	Measure voltage across C_{OUT}	Reading range: 1.71V – 1.89V	
4		Measure voltage across load	Reading range: 1.71V – 1.89V	
5	Check output noise level	Use pigtail 10x single-ended probe or differential active probe	Ripple noise level should be < 20 mV p-p	

Using a DMM with an internal impedance of 1 M Ω or larger (e.g., Fluke 87), measure the voltage across at the input to the MAX38640A device. Be sure to connect the negative “black” lead to the ground and the positive “red” lead to the input “IN” pin of the device. If the input pin isn’t easily accessible, place the leads across the input capacitor (C_{IN}). Use Table 5 to diagnose and fix associated problems.

Step 2: Check the inductor signal waveform

Using an oscilloscope or digital storage scope (DSO), probe the LX pin on the MAX38640A device. If the input pin isn’t easily accessible, place the probe on the inductor end capacitor. *Note:* It’s recommended that the oscilloscope and probes used have a minimum bandwidth of 200 MHz.

If the circuit is operating with a light load (i.e., less than 50 mA), the waveform should appear as shown in Figure 6.

If the circuit is operating with a heavy load, the waveform should be a square wave with minimal ringing on the rise and falling edges (Fig. 7).

The square-wave amplitude should be approximately equal to the input battery voltage. The square-wave floor voltage should be about 200 to 300 mV below ground (e.g., –250 mV). The duty cycle is proportional to the output voltage. Thus, a 3.6-V input battery voltage will have an approximately 50% duty cycle when producing an output voltage of 1.8 V. Figure 8 shows the

Table 5: Diagnosing MAX38640A Input Voltage Issues

Input voltage reading	Potential Cause	Action	Notes
Zero Volts/No Reading	Battery uncharged. Battery defective.	Disconnect battery and check voltage. If it reads 0 V, recharge battery.	Replace battery if it doesn’t charge.
	No connection from battery (IN or GND line).	Disconnect battery and test for conductivity from battery connector to device input.	PCB may have an open.
	Input capacitor shorted to ground.	Disconnect battery and check for continuity across capacitor.	Bad capacitor. PCB may have short.
	EN pin connected to ground.	Disconnect battery and test for conductivity from EN pin to ground.	EN pin needs to be tied high for normal operation.
Reading < 3.0 V (LiPo battery) Reading < 2.0 V (Li-ion battery)	Low battery charge. Battery defective.	Disconnect battery and check voltage. If it reads below 2.8 V, recharge battery.	Replace battery if it doesn’t charge.
3.0 V $\geq$ Reading $\leq$ 4.2 V (LiPo battery) 2.0V $\geq$ Reading $\leq$ 3.4V (Li-ion battery)		No action.	Input voltage OK, proceed to step 2.
Reading $\geq$ 4.2V (LiPo battery) Reading $\geq$ 3.4V (Li-ion battery)	Defective battery.	Replace battery.	

relationship between the duty cycle and the output voltage.

Deviations from the ideal square wave can be used to effectively diagnose and fix many problems (Table 6).

Step 3A: Check the output dc voltage

Using a DMM with an internal impedance of 1 MΩ or larger (e.g., Fluke 87), measure the voltage at the output of the MAX38640A device. Be sure to connect the negative “black” lead to the ground and the positive “red” lead to the output “OUT” pin of the device. If the output pin isn’t easily accessible, place the leads across the output capacitor, COUT.

Use Table 7 to diagnose and fix associated problems.

Step 3B: Check the output ac voltage

Using an oscilloscope or DSO, now measure the output ripple (ac) by probing the OUT pin on the MAX38640A device. To properly measure the output and minimize RF pickup, it’s recommended that 10x pigtail probes be used. Differential active probes also can be employed to further reduce ambient noise. Note: It’s recommended that the oscilloscope and probes have a minimum bandwidth of 200 MHz.

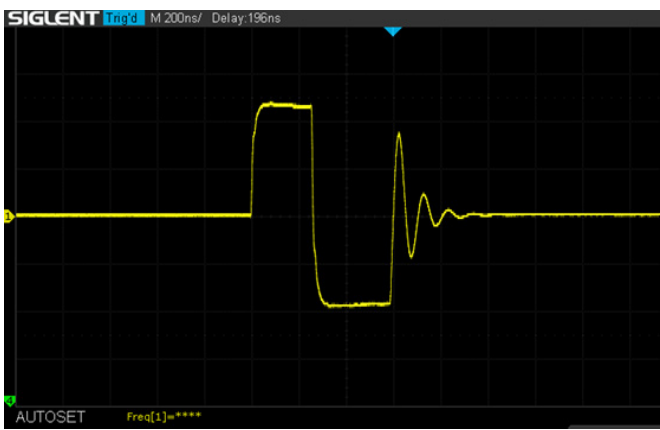
If the circuit is operating correctly, the waveform should be a 1.8-V dc output with a small ripple waveform superimposed on it. Figure 9 shows the ripple waveform.

Use Table 8 to diagnose and fix associated problems.

5.0-V SMPS Circuit Using a Low-Noise Buck-Boost Converter

The following circuit based on the MAX20343H low-noise buck-boost converter shows the typical input and output power-supply levels for a properly operating SMPS device in remote-patient vital sign monitor applications.

A DMM can be used to probe the input and output ports to validate the supply voltage



6. Oscilloscope screen capture of a typical MAX38640A VLX waveform with light load.

7. Oscilloscope screen capture of a switching waveform for the MAX38640A.

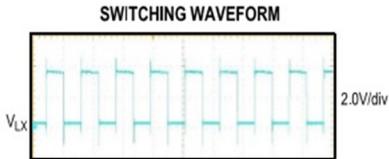
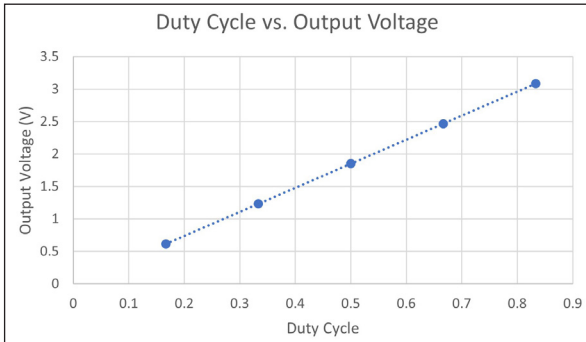


Table 6: Diagnosing MAX38640A Inductor Signal Waveform Issues

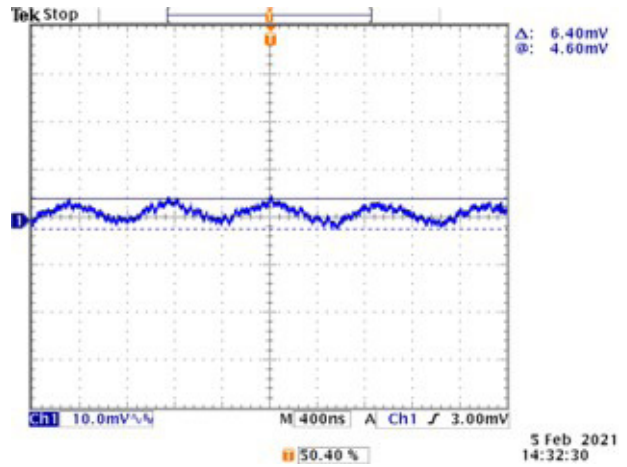
Input waveform	Potential cause	Action	Notes
Amplitude is not correct	Inductor open. IN pin open EN is open or ground	Disconnect battery and check all connections with DMM.	Repair PCB if needed.
Duty cycle is not correct (doesn't correlate to the output voltage)	RSEL is not the correct value (768 kΩ). Bad external resistor.	Disconnect battery and check RSEL with a DMM (R-measurement)	Replace resistor with correct value resistor.
	RSEL pin open (VO = 2.5 V).	Check output for 2.5 V. Disconnect battery and test for conductivity from resistor to RSEL pin.	PCB may have an open.
	RSEL pin shorted to ground (VO = 0.8 V)	Check output for 0.8 V. Disconnect battery and measure resistance across capacitor.	PCB may have short.
Waveform distortion Rounded rising edge	Bad inductor connection	Reconnect inductor. Replace inductor.	Bad connection can cause higher line resistance.

Table 7: Diagnosing MAX38640A Output DC Voltage Issues

Output voltage reading	Potential Cause	Action	Notes
Zero Volts/No Reading	No connection from SMPS to COUT.	Disconnect battery and test for conductivity from output to COUT.	PCB may have an open.
	Output capacitor shorted to ground.	Disconnect battery and check for continuity across capacitor.	PCB may have short.
Reading too low (< 1.71 V dc)	Inductor wrong value. Inductor saturated. RSEL has wrong value.	Disconnect battery and check for inductor and/or resistor values.	
1.71 V ≥ Reading ≤ 1.89		No action.	Operational.
Reading too high (> 1.89 V dc)	RSEL has wrong value.	Disconnect battery and check RSEL value.	



8. Illustration of the MAX38640A duty cycle vs. output voltage.



9. Oscilloscope screen capture of the MAX38640A output ripple waveform.

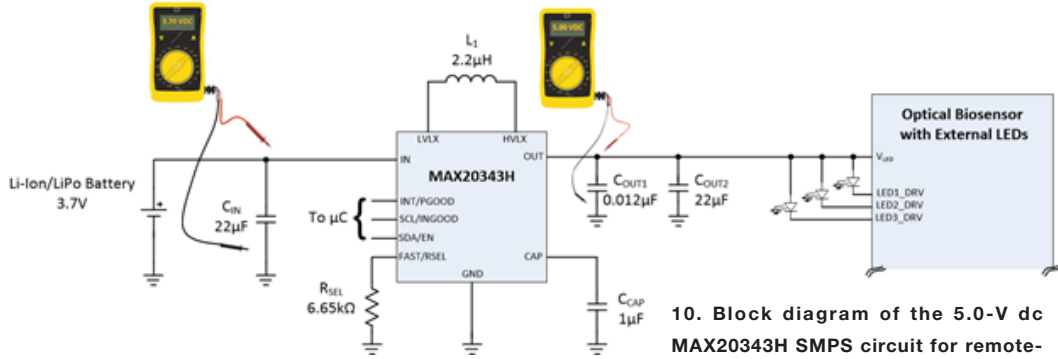
levels (Fig. 10). The power-supply output levels can vary due to various factors such as a discharging battery and changing loads (i.e., device mode changes, devices waking up from sleep mode, etc.).

5.0-V SMPS Circuit Validation Checklist

The following circuit validation checklist (Table 9) is intended to help designers with their electrical bench checkout of the 5.0-V SMPS post circuit board assembly. In this case, the MAX20343H device, connected to a biosensing circuit load, is used. This checklist also be applied as a template for product testing.

Troubleshooting the MAX20343H SMPS Circuit

These circuit troubleshooting instructions (Fig. 11) will help designers if operational issues arise with operation of the 5.0-V SMPS circuit. It addresses the most common problems that arise in implementing



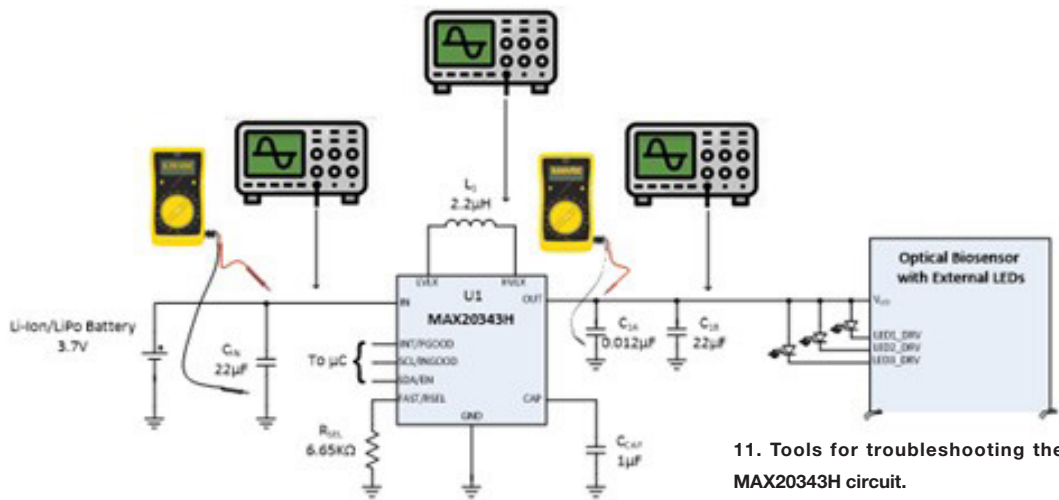
10. Block diagram of the 5.0-V dc MAX20343H SMPS circuit for remote-patient vital sign monitoring applications.

Table 8: Diagnosing MAX38640A Output AC Voltage Issues

Input waveform	Potential cause	Action	Notes
Ripple amplitude is too high (> 20 mV p-p)	Wrong capacitor value. Defective capacitor.	Disconnect battery and check all connections with DMM. Measure capacitor value.	
Ripple frequency doesn't match V_{LX} square-wave frequency	Light load.	Check load.	
Broadband noise is too high	Load too large. Environmental noise.	Check load and environmental noise.	Use pigtail 10x probe or active differential probing on output to reduce environmental noise.
Transition spikes too high (> 30 mV p-p)	Load inductance. Input current not adequate.	Check line inductance. Check input current with scope.	

Table 9: MAX20343H Validation Checklist

Step	Action	Procedure	Measurement	Need help?
1	Check input dc power supply	Measure voltage across battery	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	Troubleshooting Instructions
2	Check input dc power supply	Measure voltage across C_{IN}	Reading range: 3.0 V – 4.2 V 2.0 V – 3.4 V	
3	Check V_{OUT} dc level	Measure voltage across C_{OUT}	Reading range: 4.75 V – 5.25 V	
4	Check V_{OUT} dc level	Measure voltage across load	Reading range: 4.75 V – 5.25 V	
5	Check output noise level	Use pigtail 10x single-ended probe or differential active probe	Ripple noise level should be < 20 mV p-p	



11. Tools for troubleshooting the MAX20343H circuit.

these switch-mode power supplies.

Step 1: Check the input voltage

Using a DMM with an internal impedance of 1 MΩ or larger (e.g., Fluke 87), measure the voltage across the input to the MAX20343H device. Be sure to connect the negative “black” lead to the ground and the positive “red” lead to the input “IN” pin of the device. If the input pin isn’t easily accessible, place the leads across the input capacitor (C_{IN}).

Use Table 10 to diagnose and fix associated problems.

Step 2: Check the inductor signal waveform

Using an oscilloscope or DSO, probe the HVLX pin on the MAX20343H device. If the input pin isn’t easily accessible, place the probe on the inductor end cap. *Note:* It’s recommended that the oscilloscope and probes have a minimum bandwidth of 200 MHz.

If the circuit is operating correctly, the waveform should be a pulse wave with minimal ringing on the rise and falling edges (Fig. 12).

The 500-ns pulse-wave amplitude should be approximately equal to the input battery voltage. The pulse-wave floor voltage should be within 100 mV of the ground. The output frequency and duty cycle of the pulse wave are proportional to the load current. Figures 13 and 14 show the output wave and signal frequency under different load conditions.

Deviations from the ideal square wave can be used to effectively diagnose and fix many problems. Use Table 11 to diagnose and fix associated problems.

Table 10: Diagnosing MAX20343H Input Voltage Issues

Input voltage reading	Potential cause	Action	Notes
Zero Volts/No Reading	Battery uncharged. Battery defective.	Disconnect battery and check voltage. If it reads 0 V, recharge battery.	Replace battery if it doesn’t charge.
	No connection from battery (IN or GND line).	Disconnect battery and test for conductivity from battery connector to device input.	PCB may have an open.
	Input capacitor shorted to ground,	Disconnect battery and check for continuity across capacitor.	PCB may have short.
	EN pin (SDA/EN) connected to ground,	Disconnect battery and test for conductivity from battery connector to device input.	EN pin needs to be tied high for normal operation.
Reading < 2.8 V	Low battery charge. Battery defective.	Disconnect battery and check voltage. If it reads below 2.8 V, recharge battery.	Replace battery if it does not charge.
2.8 V ≥ Reading ≤ 4.2 V		No action.	Input voltage OK. Proceed to step 2.
Reading ≥ 4.2 V	Defective battery.	Replace battery.	

12. Oscilloscope screen capture of a typical MAX20343H HVLX waveform with 10-mA light load.



Step 3A: Check the output dc voltage

Using a DMM with internal impedance of 1 MΩ or larger (e.g., Fluke 87), measure the voltage at the output of the MAX20343H device. Be sure to connect the negative “black” lead to ground and the positive “red” lead to the output “OUT” pin of the device. If the output pin isn’t easily accessible, place the leads across the output capacitor (C_{OUT}). Follow the guidelines in Table 12 to diagnose and fix associated problems.

Step 3B: Check the output ac voltage

Using an oscilloscope or DSO, now measure the output ripple (ac) by probing the OUT pin on the MAX20343H device. To properly measure the output and minimize RF pickup, it’s recommended that 10x pigtail probes be used. Differential active probes also can be utilized to further reduce ambient noise. *Note:* It’s recommended that the oscilloscope and probes have a minimum bandwidth of 200 MHz.

If the circuit is operating correctly, the waveform should be a

1.8-V dc output with a small ripple waveform superimposed on it. Figure 15 shows the ripple waveform.

Table 13 can be used to diagnose and fix associated problems.

Conclusion

Pre-validated discrete power supply circuits were presented in this article that can be used with the MAX86171-based PPG remote patient vital sign monitor. These power-supply circuits will work with MAX86141-based PPG devices as well.

In Part 2, we present pre-validated integrated power-supply circuits for use with both MAX86171- and MAX86141-based PPG remote-patient vital sign monitors.

The corresponding validation test data for both discrete and integrated power-supply implementations can be found

13. Oscilloscope screen capture of a typical MAX20343H HVLX waveform with 125-mA load.



14. Oscilloscope screen capture of a typical MAX20343H HVLX waveform with 246-mA load.

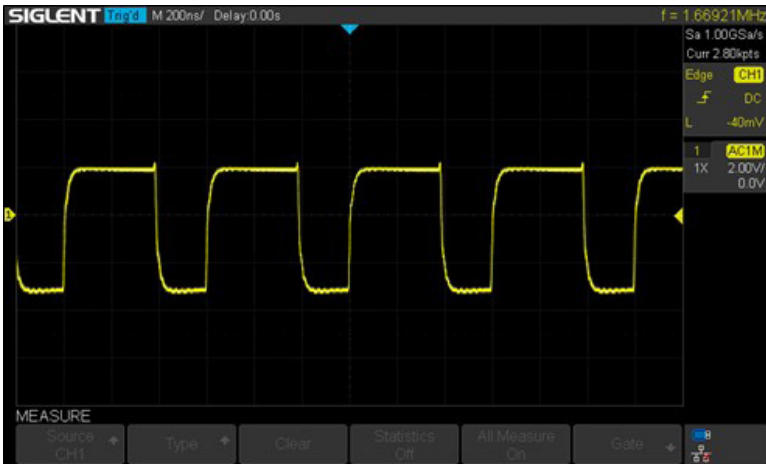


Table 11: Diagnosing MAX20343H Inductor Signal Waveform Issues

Input waveform	Potential cause	Action	Notes
Amplitude is not correct.	Inductor open. IN pin open. EN is open or ground.	Disconnect battery and check all connections with DMM.	Repair PCB if needed.
Duty cycle is not correct (doesn't correlate to the output voltage).	R _{SEL} is not the correct value (6.65 kΩ). Bad external resistor.	Disconnect battery and check R _{SEL} with a DMM (R-measurement).	Replace resistor with correct value resistor.
	R _{SEL} pin open (V _O = 3.3 V).	Check output for 3.3 V. Disconnect battery and test for conductivity from resistor to R _{SEL} pin.	PCB may have an open.
	R _{SEL} pin shorted to ground (V _O = 5.5 V).	Check output for 5.5 V. Disconnect battery and measure resistance across capacitor.	PCB may have short.
Waveform distortion. Rounded rising edge.	Bad inductor connection.	Reconnect inductor. Replace inductor.	Bad connection can cause higher line resistance.

on the Maxim Integrated, now part of Analog Devices, website at [“Power Supply Subsystems for Remote Patient Vital Sign Monitors.”](#)

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References
[Power Supply Subsystems for Vital Sign Monitors](#)
[Designing Accurate, Wearable Optical Heart Rate Monitors](#)

15. Oscilloscope screen capture of the MAX20343H (5 V) output ripple waveform.

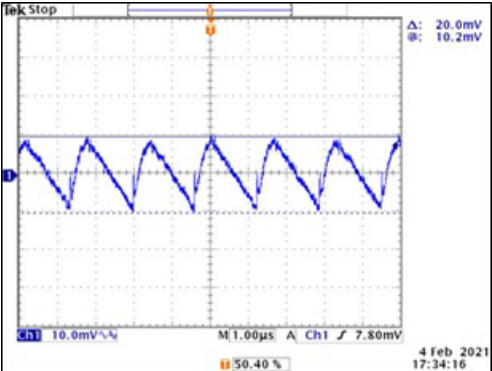


Table 12: Diagnosing MAX20343H Output DC Voltage Issues

Output voltage reading	Potential cause	Action	Notes
Zero Volts/No Reading	No connection from SMPS to Cout. OUT	Disconnect battery and test for conductivity from output to Cout.	PCB may have an open.
	Output capacitor shorted to ground.	Disconnect battery and check for continuity across capacitor.	PCB may have short.
Reading too low (< 4.75 V dc)	Inductor wrong value. Inductor saturated. RSEL has wrong value.	Disconnect battery and check for inductor and/or resistor values.	
4.75 V ≥ Reading ≤ 5.25 V		No action.	Operational.
Reading too high (> 5.25 V dc)	RSEL has wrong value.	Disconnect battery and check RSEL value.	

Table 13: Diagnosing MAX20343H Output AC Voltage Issues

Input waveform	Potential cause	Action	Notes
Ripple amplitude is too high.	Wrong capacitor value. Defective capacitor.	Disconnect battery and check all connections with DMM. Measure capacitor value.	
Ripple frequency doesn't match VHVLY pulse-wave frequency.	Light load.	Check load.	
Broadband noise is too high.	Load too large. Environmental noise.	Check load and environmental noise.	Use pigtail 10x probe or active differential probing on output to reduce environmental noise.
Transition spikes too high.	Load inductance. Input current not adequate.	Check line inductance. Check input current with scope.	