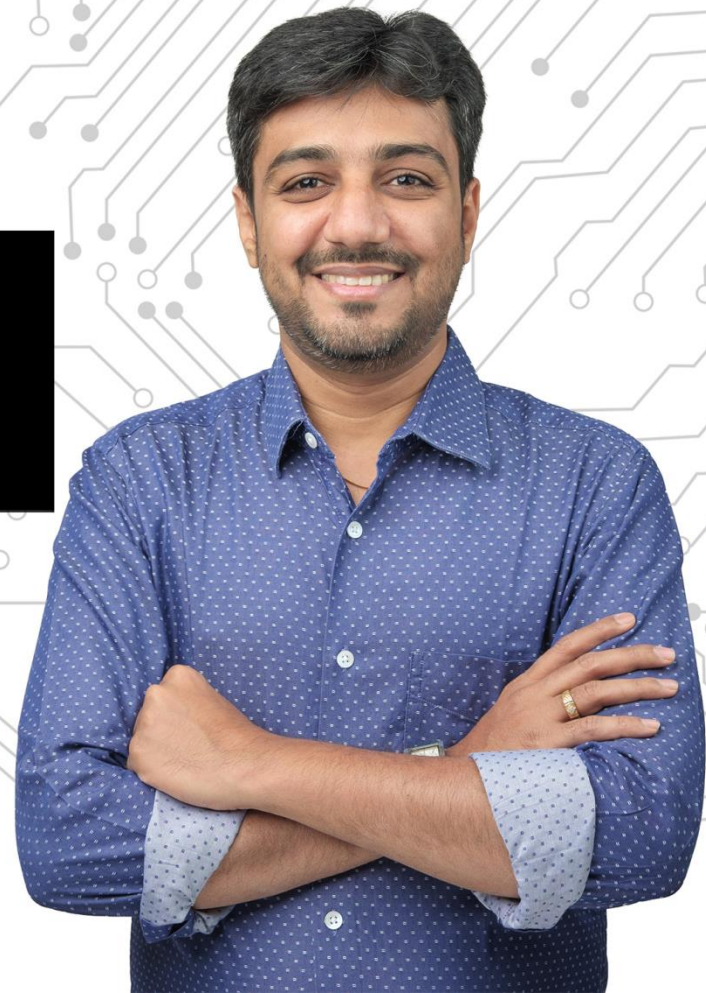


# SANJAY PITHADIA

## PATIENT MONITORING

DESIGN WEARABLE HEALTHCARE  
SYSTEMS WITH ADVANCED SENSING  
AND EFFICIENT POWER FOR IMPROVED  
PATIENT MONITORING



# Agenda



TI in medical

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Market trends

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Fundamentals and challenges

---



Reference designs

# TI semiconductors in every medical category



Medical imaging



Patient monitoring & diagnostics



Medical equipment



Home healthcare



Personal care & fitness



# Medical sector page

The screenshot shows the Texas Instruments website with the following navigation structure:

- Header: TEXAS INSTRUMENTS, Search bar, Login / Register
- Primary Navigation: Products, Applications & design, Tools & software, Support & training, Order Now, About TI
- Secondary Navigation (under Applications & design): Products, Applications, Design resources, Quality & reliability
- Product Categories (under Applications):
  - Automotive →
    - Advanced driver assistance systems (ADAS)
    - Body electronics & lighting
    - Hybrid, electric & powertrain systems
    - Infotainment & cluster
  - Communications equipment →
    - Broadband fixed line access
    - Datacom module
    - Wired networking
    - Wireless infrastructure
  - Enterprise systems →
    - Data center & enterprise computing
    - Enterprise machine
    - Enterprise projectors
  - Industrial →
    - Aerospace & defense
    - Appliances
    - Building automation
    - Factory automation & control
    - Grid infrastructure
    - Industrial transport (non-car & non-light truck)
    - Lighting
    - Motor drives
    - Power delivery
    - Pro audio, video & signage
    - Retail automation & payment
    - Test & measurement
- Medical (highlighted in a blue box) leads to:
  - Medical equipment
    - Anesthesia delivery system
    - Chemistry/gas analyzer
    - Dialysis machine
    - Electronic hospital bed & bed control
    - Infusion pump
    - Medical accessories
    - Medical chair & table
    - Motorized electronic wheel chair
    - Surgical equipment
    - Ventilator
  - Imaging
    - CT & PET scanner
    - MRI
    - Ultrasound scanner
    - Ultrasound smart probe
    - X-ray systems
  - Patient monitoring & diagnostics
    - Clinical digital thermometer
    - Digital stethoscope
    - Electrocardiogram (ECG)
    - Endoscope
    - Eye, ear, nose & throat exam
    - Medical sensor patches
    - Mother & neonatal care monitor
    - Multiparameter patient monitor
    - Pulse oximeter
    - Sleep diagnostics
  - Home healthcare
    - Blood glucose monitor
    - Blood pressure monitor
    - CPAP machine
    - Electronic thermometer
    - Hearing aid
    - Nebulizer
    - Oxygen concentrator
    - Telehealth systems
  - Personal care & fitness
    - Beauty & grooming
    - Electric toothbrush
    - Fitness machines
    - Wearable fitness & activity monitor

# Medical sensor patches

**Temperature Analog Front End**

Temperature AFE drives the temperature sensors as well as conditions the signal coming from analog temperature sensors. The temperature signal is converted to digital domain by using ADC for further processing.

[View more](#)

REFERENCE DESIGNS (11)      PRODUCTS (15)

Sensors (4) ^

- Analog Temperature Sensors (1) v
- Digital Temperature Sensors (3) ^
- TMP117 – ±0.1°C accurate digital temperature sensor with integrated NV memory** v
- TMP112 – 1.4V-Capable ±0.5°C Accuracy Digital Temperature Sensor in the Compact SOT-563 Package v
- TMP102 – 1.4V-Capable Temperature Sensor with I2C/SMBus Interface and Alert Function in SOT-563 v

Data converters (5) v

Switches & multiplexers (2) v

Amplifiers (2) v

Power management (2) v

**PPG/Optical/Spectroscopy Front End**

The optical front end has two sections: one for driving the LEDs and other for processing the signal received from photo diodes. LED drivers are operated with digital data coming from DAC and transimpedance amplifier with a PGA conditions signal coming from photo diode. This subsystem can be used for PPG as well as spectroscopy measurement.

[View more](#)

REFERENCE DESIGNS (7)      PRODUCTS (31)

Amplifiers (8) (VOS > 111V) (4)

- General-Purpose Op Amps (3) v
- Instrumentation Amplifiers (1) v

Switches & multiplexers (6) v

Data converters (14) ^

- Biosensing AFEs (6)** ^
- AFE4420 – Ultra-small integrated AFE with FIFO for multisensor wearable optical heart-rate monitoring** v
- AFE4900 – Ultra-low-power integrated AFE for wearable optical, electrical biosensing v
- AFE4403 – Ultra-Small Integrated Analog Front End (AFE) for Heart-Rate Monitors and Low-Cost Pulse Oximeters v
- AFE4400 – Integrated Analog Front End (AFE) for Heart-Rate Monitors and Low-Cost Pulse Oximeters v
- AFE4490 – Integrated Analog Front End (AFE) for Pulse Oximeters v

Support & training

- Simplify integration
- Achieving accuracy
- Processing

Wi-Fi

Sub GHz

Interface

Memory Card

AMP

User Interface

PRODUCTS (31)

monitor ^

Reference Design v

for medical v

Monitoring v



# Reference design

**Design Guide: TIDA-01614**  
**Multiparameter Front-End Reference Design for Vital Signs Patient Monitor**



## Description

This reference design is for a multiparameter front-end of a patient monitor that measures vital sign parameters like electrocardiogram (ECG), heart rate, SpO<sub>2</sub>, and respiration. It uses biosensing front-end integrated circuits, like the AFE4403 and ADS1292R devices, to measure these parameters. It also uses three TMP117 sensors to accurately measure skin temperature. The design can interface with the pace detection module to detect the pace pulse. The design also uses an isolated UART connection to transfer data to a computer. The entire front-end subsystem runs on a rechargeable 3.7 V Li-Ion battery (1.1 Ah).

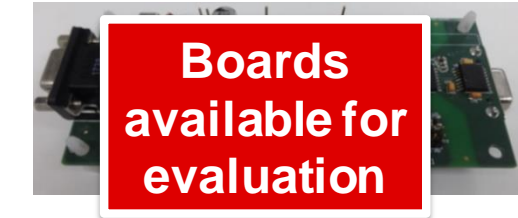
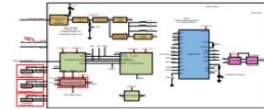
## Features

- Monitors ECG, heart rate, SpO<sub>2</sub> %, respiration rate, and skin temperature
- Uses bio-sensing front-end AFE4403 for SPO<sub>2</sub> and heart rate measurement and ADS1292R for ECG and respiration measurement
- Supports up to three LEDs and three photo-diodes with ambient subtraction to improve signal-to-noise Ratio (SNR) for SPO<sub>2</sub> and heart measurement
- Single lead ECG Measurement with RLD
- Supports three 2.1 Pinless approach sensors to battery.

- TIDA-01614
- AFE4403
- BOJ2432
- MSP43074
- ADS1292R
- TMP117
- TIDA-01009

**Comprehensive design guides**

Module (Software-action module) for detection (UART interface) battery



**Boards available for evaluation**

The following list provides details about the design:

- Supply Voltage = 5 V
- Charging current = 0.1 A

**Detailed design considerations & applications info**

How the input current limit (ILIM) is set:

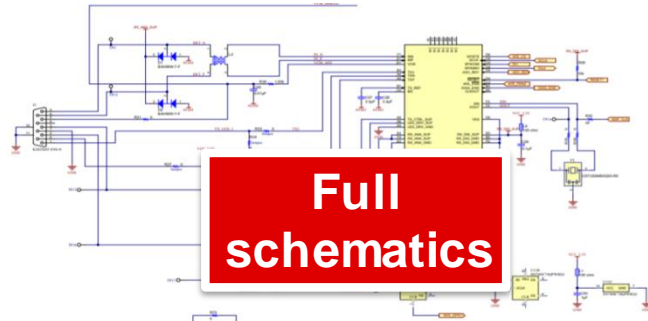
- RLIM = KILIM / I1-MAX
- KILIM = 1530 AΩ

Designator	Quantity	Value	Partnumber	Manufacturer	Printed Circuit Board	Description	Package/Notes
R1C3	1	10k	10K00000000000000	ROHM	10K	10K	0402
C11, C12, C14	12	0.1µF	0105051E04000000	TDK	0.1µF 50V X7R 0402	0.1µF 50V X7R 0402	0402
C21, C28, C30	3	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C32, C36, C41	4	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C4	1	0.1µF	0105051E04000000	TDK	0.1µF 50V X7R 0402	0.1µF 50V X7R 0402	0402
C5	1	0.1µF	0105051E04000000	TDK	0.1µF 50V X7R 0402	0.1µF 50V X7R 0402	0402
C6	1	0.1µF	0105051E04000000	TDK	0.1µF 50V X7R 0402	0.1µF 50V X7R 0402	0402
C7, C11, C13, C24	6	0.1µF	0105051E04000000	TDK	0.1µF 50V X7R 0402	0.1µF 50V X7R 0402	0402
C25, C26, C29	3	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C27, C28	2	2.2µF	2200000000000000	TDK	2.2µF 16V X5R 0402	2.2µF 16V X5R 0402	0402
C31	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C34	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C35	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C38	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C40	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C42	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C43	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C44	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C45	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C46	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C47	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C48	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C49	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C53	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C54	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C55	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C56	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C57	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C58	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C59	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C60	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C61	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C62	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C65	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C66	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C67	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C69	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C73	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C74	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C76	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C80	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C81	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C82	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C83	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C84	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C85	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C87	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C88	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C89	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C90	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
C91	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C96	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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C99	1	10µF	1000000000000000	TDK	10µF 16V X5R 0402	10µF 16V X5R 0402	0402
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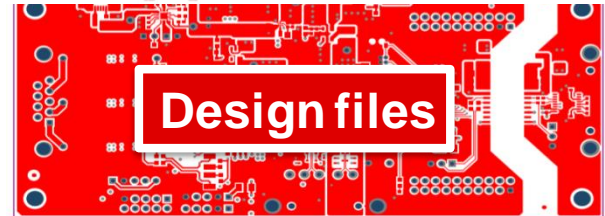
**Bill of materials**



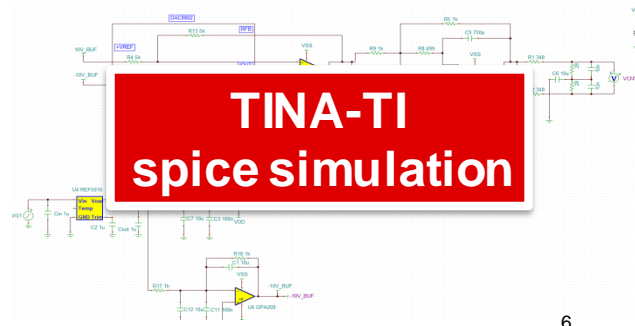
**Comprehensive test results**



**Full schematics**

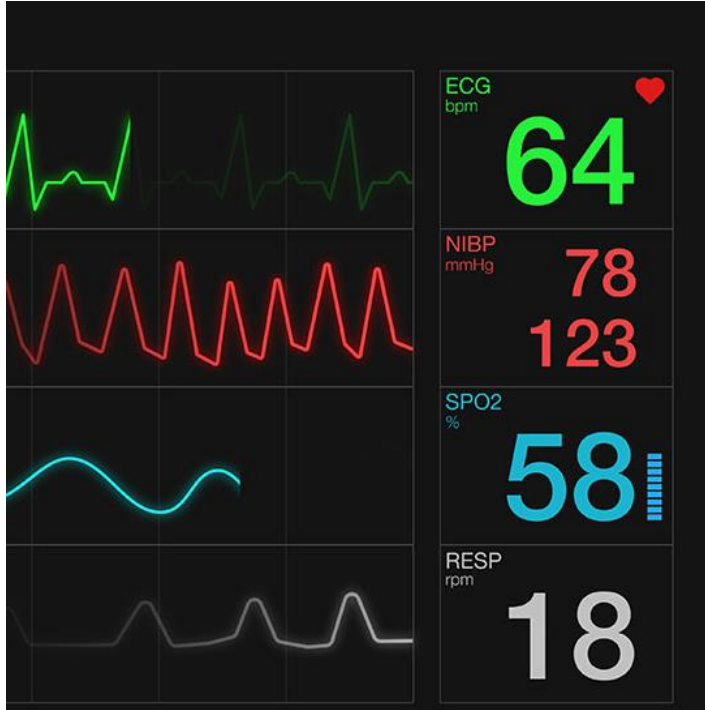


**Design files**



**TINA-TI spice simulation**

# Patient monitoring market trend



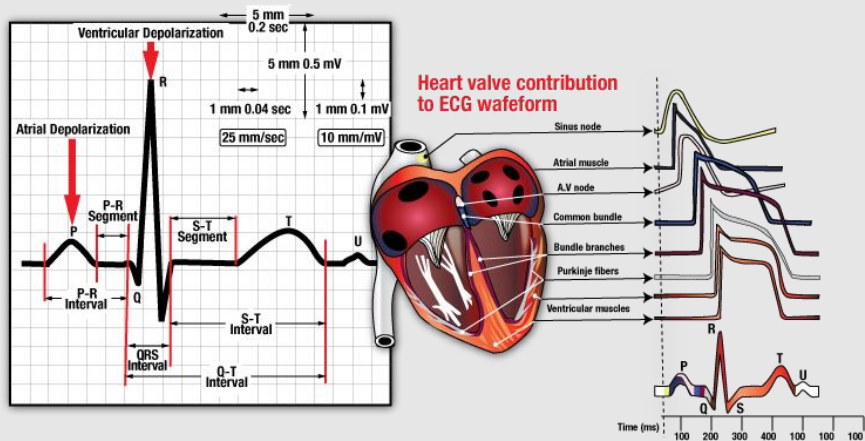
Remote monitoring enhances quality of care and reduces healthcare cost

Wearable wireless medical technology enables accurate and reliable data in a smaller form factor: multimodalities, longer battery life, SHIP mode

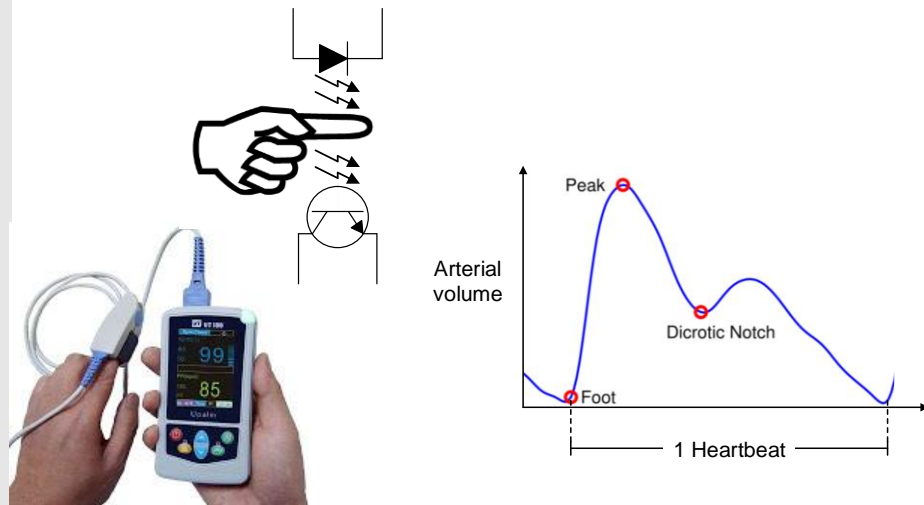
Artificial intelligence uses analytics and big data to improve decision making and early prevention

# Patient monitoring basics

**The electrocardiogram (ECG)** measures electrical activity of the heart



**Photoplethysmography (PPG)** is an **optical** measurement of an organ's volume.





# ECG vs. PPG

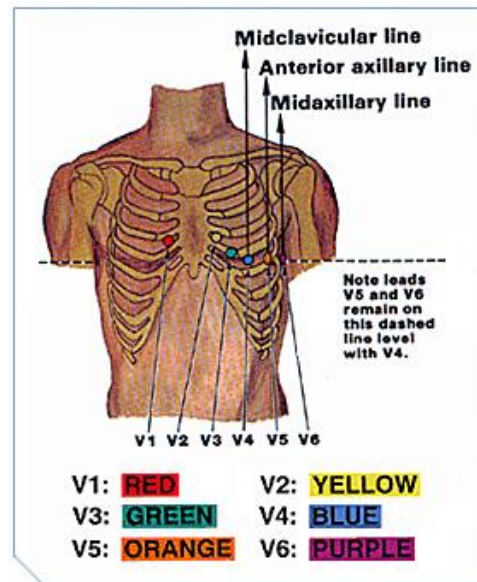
Feature Description	ECG	PPG
Measurement type	Electrical	Optical
Sensor type	Electrodes	Photodiode
Can measure heart rate?	Yes	Yes
Diagnostic information	Yes	Yes
Minimum number of skin contacts required?	2 (Across chest)	1 (Finger or wrist)
Number of ADC channels required	≥1	1

# ECG lead and ADC channels

Number of Leads	Leads Used	Number of ADC Channels
1	Lead I	1
3	Lead I, Lead II, Lead III	2
6	Lead I, Lead II, Lead III, aVR, aVL, aVF	2
12	Lead I, Lead II, Lead III, aVR, aVL, aVF, V1 – V6	8

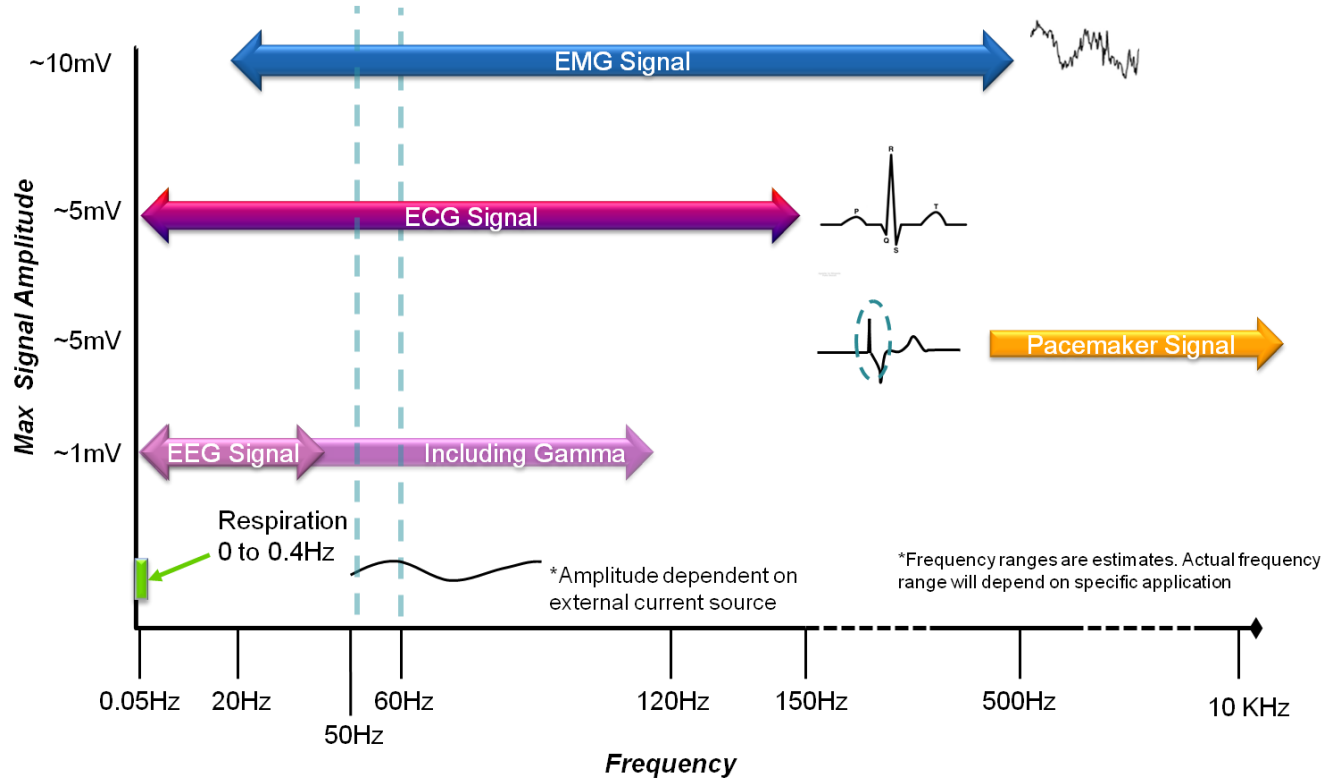
## Standards Electrodes Needed

1 Lead	LA, RA
3 Lead	LA, RA, LL
6 Leads	LA, RA, LL
12 Leads	LA, RA, LL, V1-6



# ECG characteristics

## Frequency domain



# Challenges in measuring ECG



Alternating Current (AC) Interference

# Challenges in optical bio-sensing

- Low power for longer battery life
- Skin tone variation
- Best PPG signal for motion cancellation algorithms
- Performance with glass
- Low temperature performance
- Ambient light

# TIDA-01614

## Multiparameter front-end for vital signs patient monitor reference design

### Features

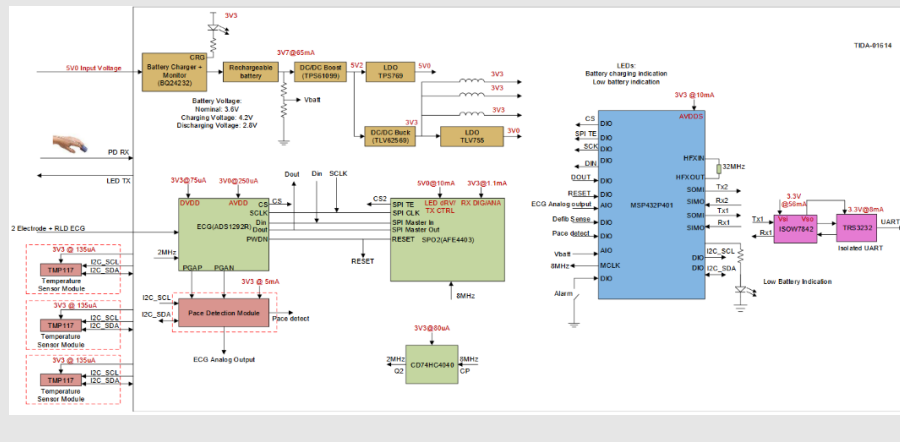
- System measures ECG, heart rate, SPO2, respiration rate using ADS1292R and AFE4403 and skin temperature using TMP117
- Circuit enables three electrode operation including right leg drive with good CMRR
- Pace detection circuit indicates presence of pacemaker
- Supports three 0.1° Celsius accurate sensors (TMP117) to measure the skin temperature
- Enables data transfer over isolated UART interface
- Works with 3.7V Li-ion rechargeable battery
- On-board memory for data logging

### Applications

- Multiparameter patient monitor
- Medical sensor patches
- Pulse oximeter
- Electrocardiogram (ECG)

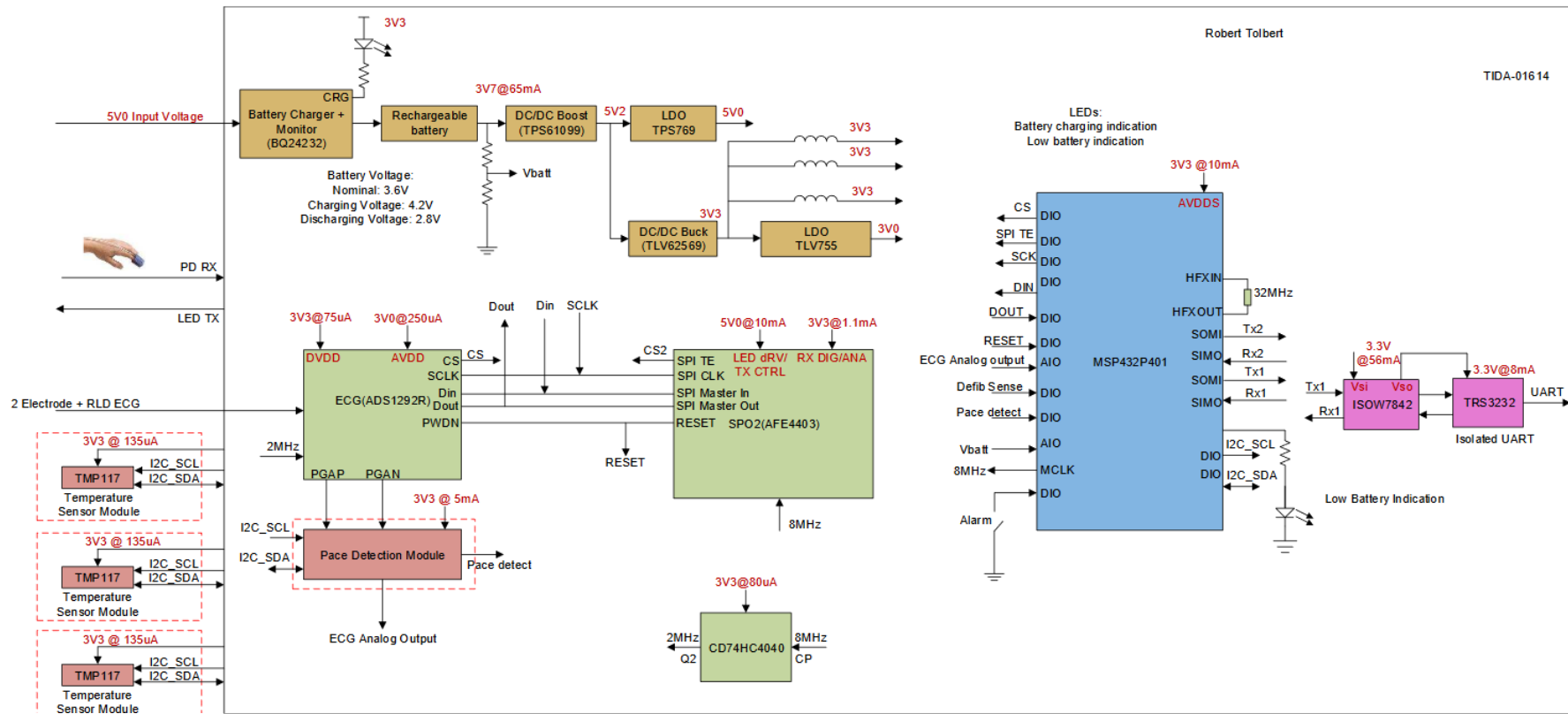
### Benefits

- Single IC does both ECG, respiration
- Pace detection
- ECG with 3 electrodes
- Three temperature sensors for temperature measurement





# Detailed block diagram for TIDA-01614



# Design challenges TIDA-01614 solves

## Design challenge 1

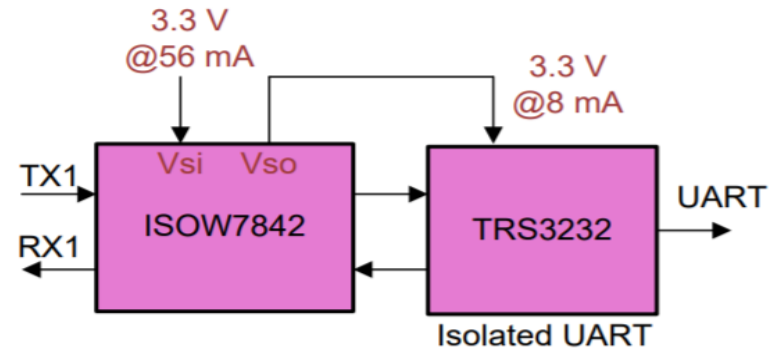
Integration of multiple modalities at optimum SNR levels and small form factor

- Monitoring of ECG, heart rate, SPO2, PTT, respiration rate and skin temperature
- Single lead ECG with RLD (ADS1292R)
  - > Signal amplitude: 0.2mV~2mV (p-p);
  - > BW 0.05 Hz to 2000 Hz
- Supports 3 LED and 3 photodiodes with ambient subtraction for SPO2 and heart rate monitoring with AFE4403
- Supports three 0.1° Celsius accurate sensors to measure the skin temperature (TMP117)

## Design challenge 2

Protection and isolation

Isolated UART interface using an onboard MSP432P401, ISOW7842, TRS3232



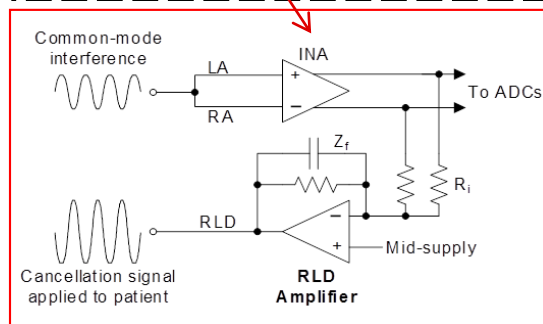
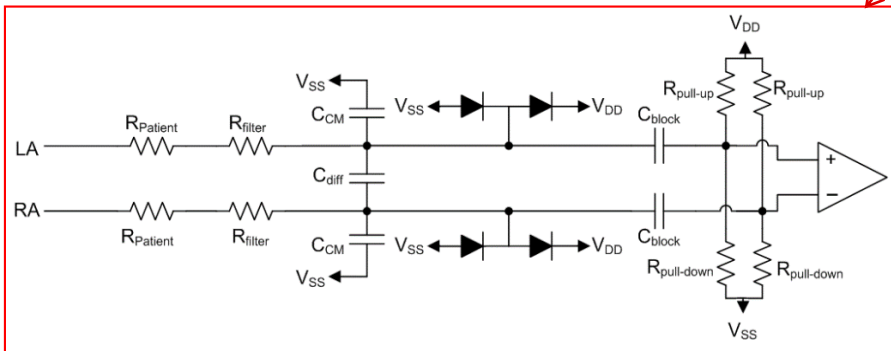
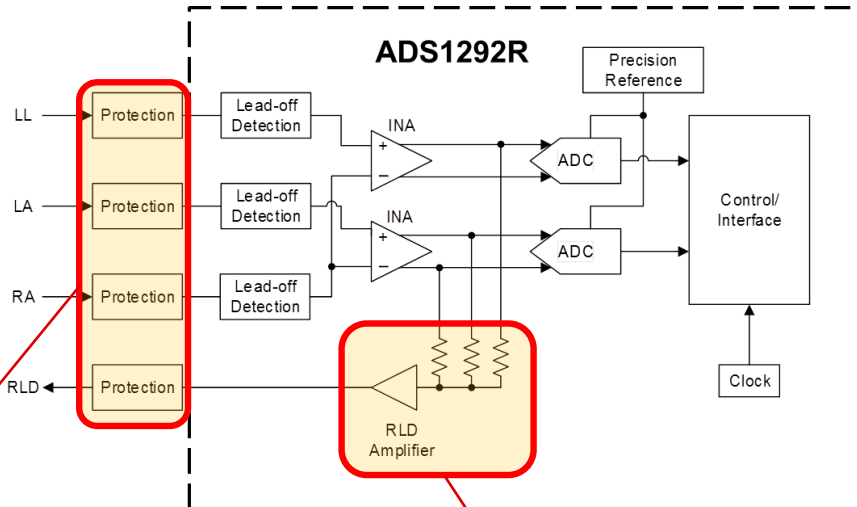
# ECG analog front end



## Important parameters:

- Input bias current
- Input impedance
- Input current noise
- Input voltage noise
- Power consumption
- DC/AC CMRR

**TIDA-01614:** Multiparameter front-end reference design for vital signs patient monitor

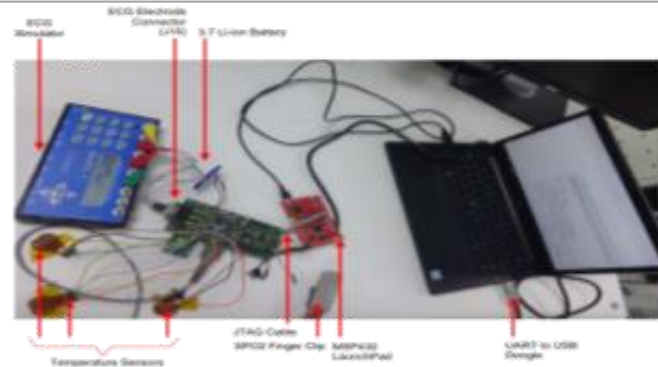


# TIDA-01614 test setup and test results

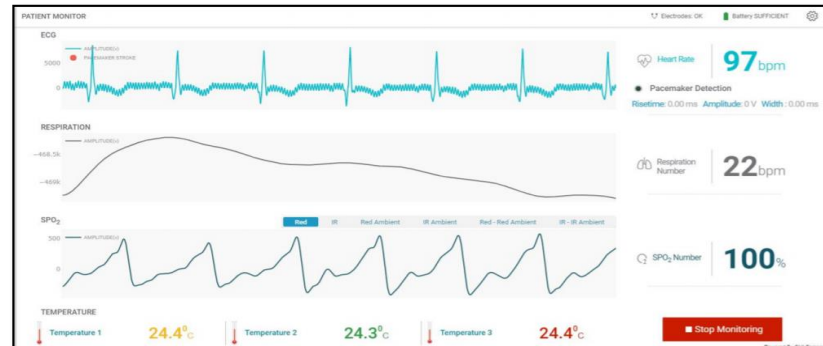
## Design specs

CHARACTERISTICS	SPECIFICATIONS
ECG	One lead ECG operation with RLD. Sampling rate of 500 samples per second, supports ECG sensitivity of 100 $\mu$ V
SPO2 Measurement	Works in transmissive SPO2, refresh rate of 500 Hz
Skin Temperature Measurement	Three temperature sensor with 0.1 degree accuracy
Pace pulse Rise-time (TR) measurement range	30–200 $\mu$ s
Pace pulse duration (TD) measurement range	0.1–2 ms
Input Pace signal amplitude range	8 mV–700 mV
Input Voltage (Vin)	5 V from Micro-USB

## Test setup



## GUI display



# Test pacemaker detection with TIDA-010005 & TIDA-01614



# TIDA-01580

## Wearable, wireless, multiparameter patient monitor reference design

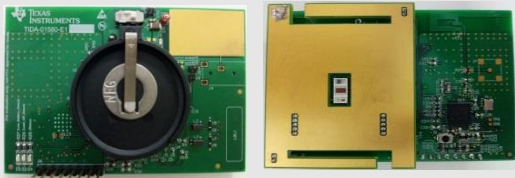
### Features

- Simple wearable multi-parameter patient monitor for photoplethysmography (PPG) and electrocardiography (ECG)
- Provides raw data to calculate heart-rate, oxygen concentration in blood (SpO2) and pulse-transit time (PTT)
- Uses single-chip bio-sensing front-end AFE4900 for synchronized ECG & PPG
  - PPG (Optical heart-rate monitoring and SpO2) supports 4 LEDs and 3 PDs with digital ambient subtraction to improve the SNR
  - ECG (LEAD I) signals
- Integrated ARM Cortex-M3 + 2.4GHz RF transceiver (CC2640R2F) supports wireless data transfer – BLE 4.2 and 5
- Operated from CR3032 (3V, 500mA coin cell battery) with battery life of 30 days using highly efficient DC/DC converters
- Small form factor helps in easy adaptation to wearable applications

### Target applications

- [Wireless patient monitor](#)
- [Wearable fitness & activity monitor](#)
- [Pulse oximeter](#)
- [ECG](#)

### Tools & resources

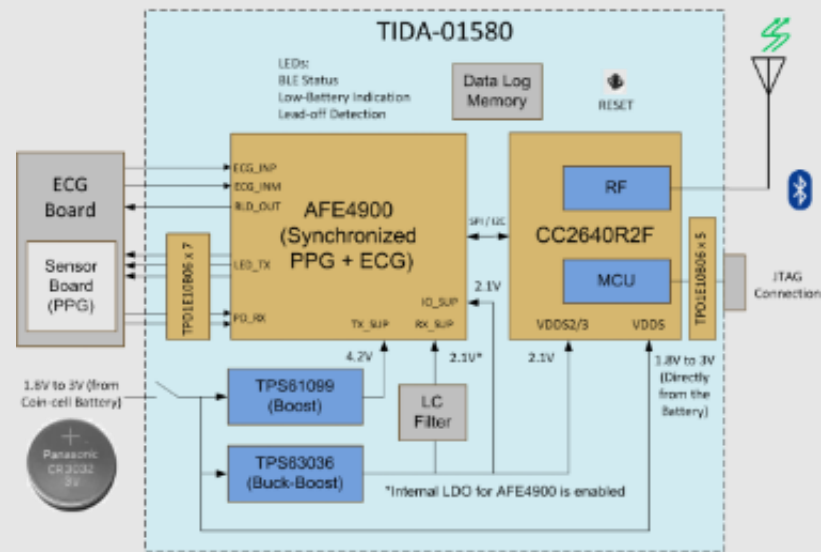


### Device Datasheets:

- [AFE4900](#)
- [CC2640R2F](#)
- [TPS61098](#)
- [TPS63036](#)
- [TPD1E10B06](#)

### Benefits

- PPG supports 4 LEDs and 3 PDs with digital ambient subtraction to improve the SNR
- AC and DC lead off detection helps in correct measurement of vital signs
- Continuous monitoring with lower operating power ensures battery life of 30 days
- Flexibility of ultra low power modes and integrated FIFO can keep MCU into sleep to increase the battery operation time



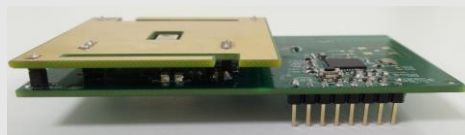


# TIDA-01580 for medical patch

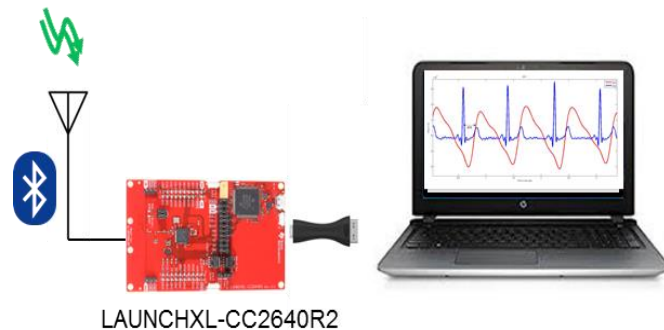


Bottom side is touching the wrist of one hand (ELECTRODE 1)

Other hand is touching the PAD on the top layer of the main board. (ELECTRODE 2)



Side View



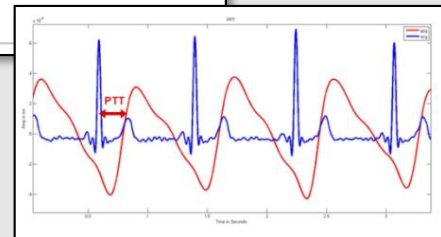
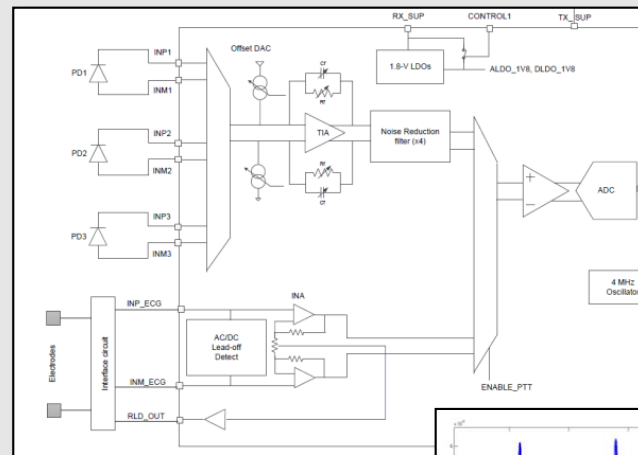
- LAUNCHXL-CC2640R2F receives the signals remotely and displays on LabView GUI
- The design uses BLE 5.0 with an advertising time = 100ms

# Design challenges TIDA-01580 solves

## Design challenge #1

Integration of multiple modalities at optimum SNR levels and small form factor

- Capturing synchronized ECG and PPG to enable PTT and BP calculations (non-invasive and without cuff)
- Pulse transit time (PTT): Time difference between the R-peak in the ECG waveform and the arrival of the blood pressure wave
- Simultaneous measurement of ECG and PPG together
- Along with other variables, such as the patient's size, weight, age, etc., algorithms show the correlation between PTT and systolic blood pressure
- Challenging to synchronize both measurements – timing is the key! (powering up, clock timing, phase, drift with temperature)

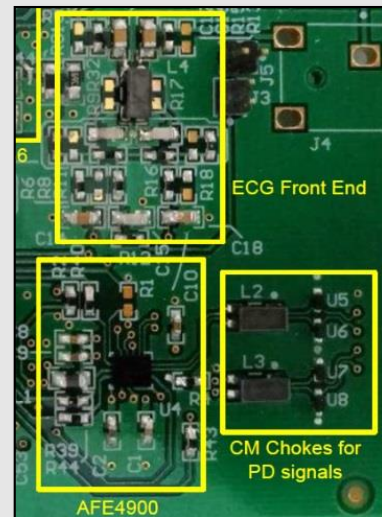
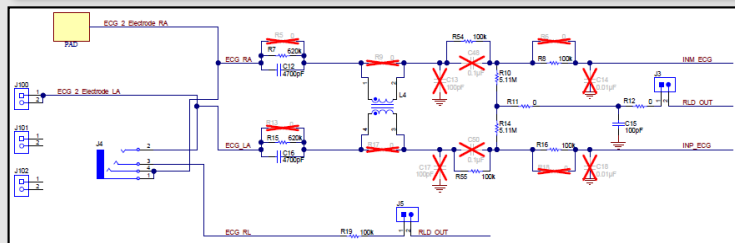
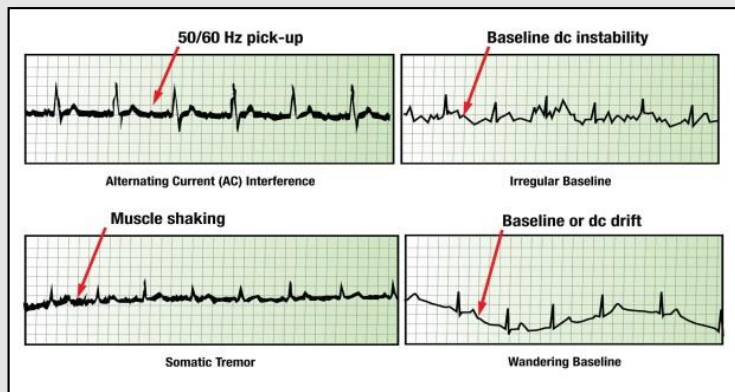


# Design challenges TIDA-01580 solves

## Design challenge # 2

### BLE connectivity that does not interfere with measurement accuracy

- Signal amplitude: 0.2mV to 2mV (p-p)
- BW: as broad as 0.05 Hz to 300 Hz (pace detection increases the bandwidth further)
- Reject environmental electrical signals, such as ac mains, security systems and RFI to amplify and display the ECG signal
- Good CMRR of the signal chain and right-leg drive (RLD) for CM rejection
- Differential- and common-mode filtering, environmental shielding and algorithms



# Design challenges TIDA-01580 solves

- Selecting the extended battery life (rechargeable cells)
- Powering wireless device instead of (bypass mode)
- Sleep / shutdown for radio device
- Selection of termination (important!)

Analog Design Journal

<http://www.ti.com/lit/an/slyt763/slyt763.pdf>

Power

## Improving battery life in wearable patient monitors and medical patches

By Sanjay Pithadia

System Engineer, Medical Sector, System Engineering and Marketing

### Introduction

The market for wearable patient monitors is growing fast. The two main attributes for wearable monitors are portability (or size) and operating time (or battery life). Today's wearable medical products not only measure vital signs but can also act as personal emergency-response systems.

Portable and wearable applications are typically battery powered, and for consumers, battery life is one of the key purchasing considerations. The life of the battery is critical because most patient monitors measure and monitor continuously.

Battery-powered systems require careful partitioning, tight space utilization and efficient use of the available charge. It is important to enable more functionality while delivering power more efficiently in a tight space for a longer time. Functions like standby, sleep, power save, hibernate and shutdown are critical for designers to

hydride (NiMH), lithium iron phosphate, lithium manganese and zinc are popular battery chemistries in medical devices, and each type needs a different charging circuit. It is also important to note that rechargeable batteries have a self-discharge rate. To reduce overall bill of materials (BOM) and size, designers may connect batteries directly to the radio module and other peripherals, but running directly from the battery voltage is not the most efficient way to use the battery.

### Choosing the right battery charger to improve battery life

Battery charging for wearables is challenging because batteries must be both small in size and capacity. Charge currents vary greatly depending on whether a 50-mAh, 100-mAh or 200-mAh battery is used, and whether to charge at 0.5 C-rate (C), 1 C or 2 C. The key is to include



# TIDA-01624 Bluetooth-enabled high accuracy skin temperature measurement flex PCB patch

## Features

- High accuracy, low power temperature sensor
- BLE 4.2 and 5 enabled microcontroller
- Thin-film flexible battery power, enabling entirely flexible design
- Integrated PCB antenna
- Temperature updates every second

## Applications

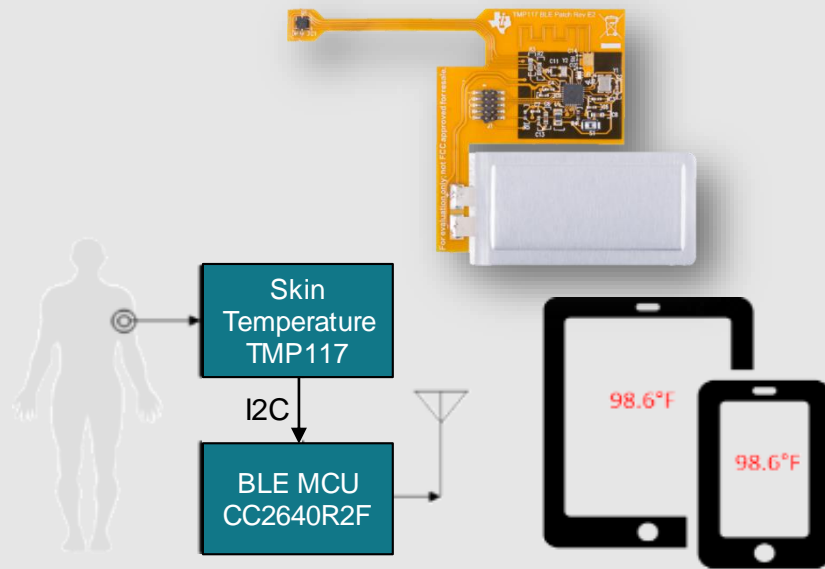
- [Medical sensor patches](#)
- [Multiparameter patient monitors](#)
- [Smart patches](#)

## Tools & resources

- **TIDA-01624 and/or tools folder**
- **Design guide**
- **Design files:** Schematics, BOM, Gerbers, Software, etc.
- **Device datasheets:**
  - TMP117
  - CC2640R2F

## Benefits

- Low power consumption and long battery life
- Extremely long shelf life (3+ Years)
- Small, flexible form factor
- Connects to smart device
- Zero-calibration to  $\pm 0.1^{\circ}\text{C}$  accuracy



# TMP117x Ultra-high accuracy digital temp sensor with integrated non-volatile memory

## Features

### Accuracy

- 16-bit resolution (0.0078°C)
- Minimum PSRR: 1LSB = 7.8 m°C/V

TI Part	Accuracy (°C)	Accuracy Full Range
TMP117M	±0.1°C @ (30°C to 45°C)	±0.2°C @ (0°C to 85°C)
TMP117	±0.1°C @ (-20°C to 50°C)	±0.3°C @ (-55°C to 150°C)
TMP117N	±0.2°C @ (-40°C to 100°C)	±0.3°C @ (-55°C to 150°C)

### Integrated EEPROM

### Low power consumption

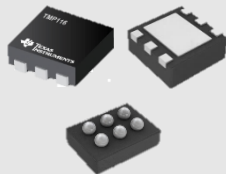
- 140uA Iq during conversion
- 3.5uA Average Iq @ 1Hz
- 150nA Shutdown Iq
- 1.8V – 5.5V

### Digital feature: automatic offset NVM/ soft reset

### Interface: Single wire

### Packaging

- 6pin WSON (2 x 2) mm
- 6pin WCSP (1.6 x 1) mm



## Applications

- Gas meter
- Medical
- Cold chain
- Wearables
- Instrumentation & test
- Thermocouple – reference

## Benefits

### Ultra-high accuracy

- Meets ASTM E1112 & ISO medical standards:
  - 0.1°C acc. range 35.8°C to 42°C
- No calibration needed; NIST traceable

### Integrated non-volatile memory

- Store configuration even after losing power
- 64 bits of general-purpose scratch pad memory

### Low power consumption

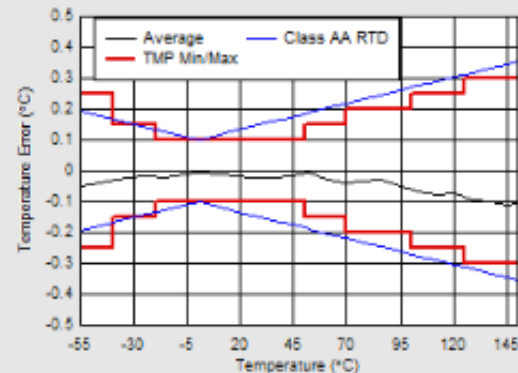
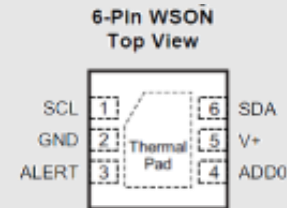
- 3.5uA average Iq @ 1Hz; serial bus inactive
- 150nA shutdown Iq; serial bus inactive

### Digital feature & I2C interface

- Programmable temperature alert & offset value
- Soft device rest

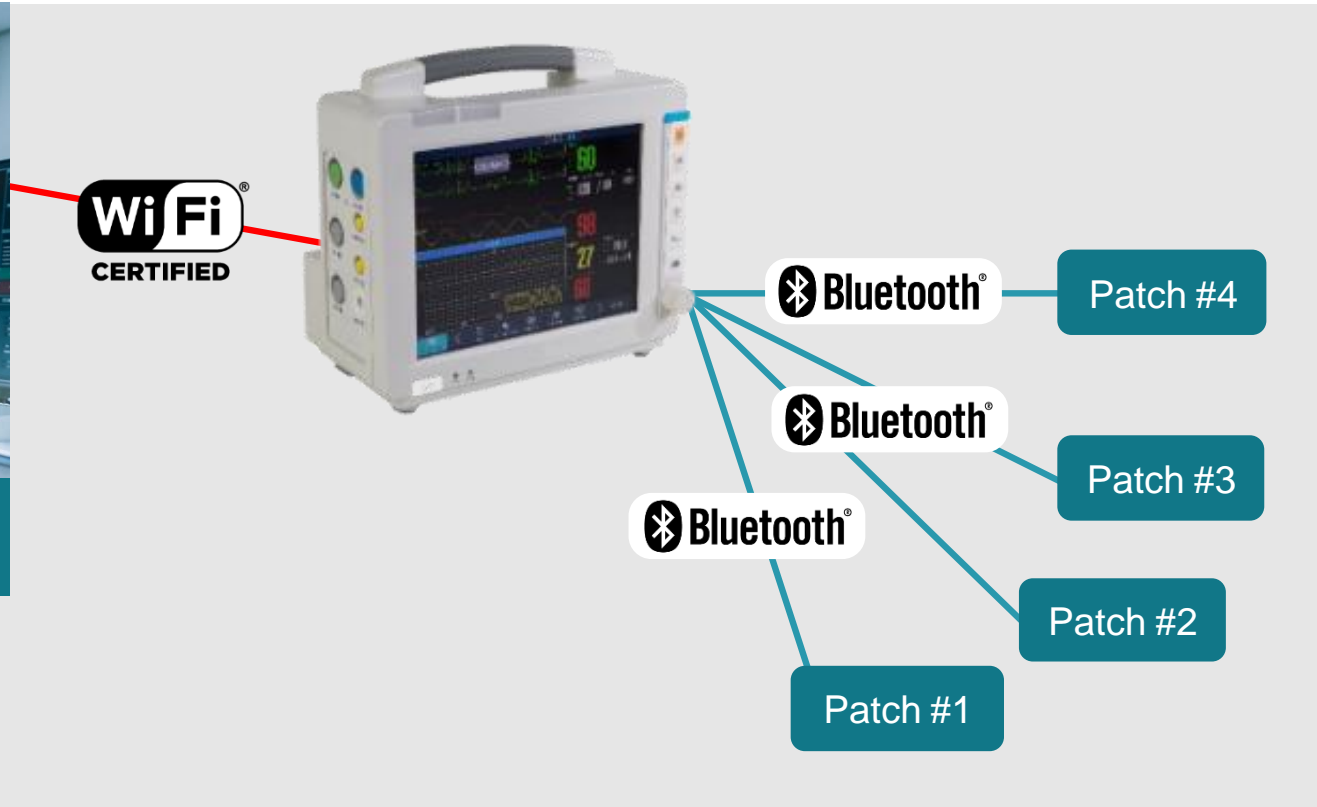
### Smallest package

- 6 PIN, QFN & CSP





# Full system: Multiparameter patient monitor + wireless sensors



# Why TI SimpleLink™ for multiparameter patient monitor + sensor patch?

## Low power



- BLE SoC with integrated ultra low power sensor controller
- Wi-Fi low power IoT
- Best-in-class standby current

## Ease of use



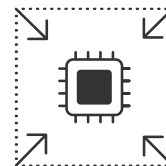
- CC3135/CC3235 Wi-Fi modules
- 5GHz Wi-Fi to reliably connect to hospital network
- BLE multirole support, up to 32 simultaneous connections

## Secure



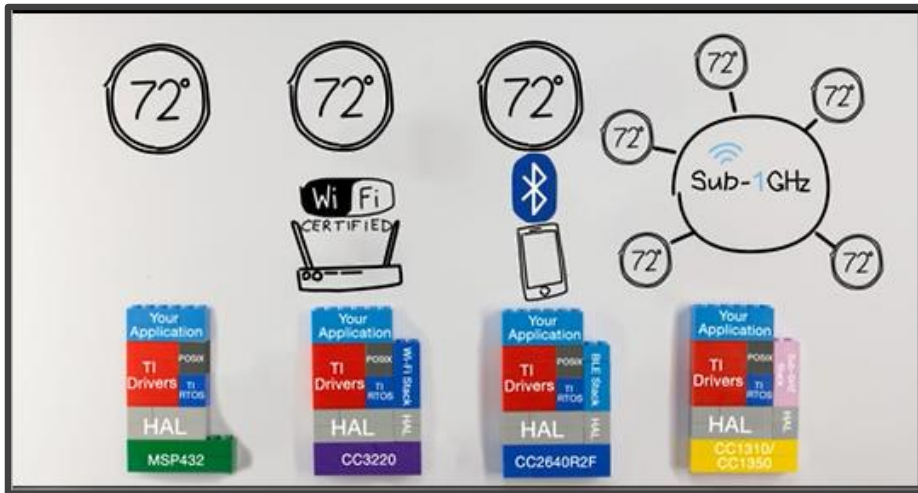
- FIPS 140-Level 1 validation
- Offload CPU bandwidth – HW crypto accelerators
- Secure boot

## Small size



- BAW: first crystal-less wireless BLE SoC – 12% area savings in reference design
- Tiny BLE SoC: CC2640R2F – 2.7mm x 2.7mm DSBGA

# Invest once, reuse effortlessly



- [Learn more about SimpleLink code portability](#)
- [SimpleLink medical resources](#)
- [CC2640R2F: How do I design an accurate and thermally efficient wearable temperature monitoring system?](#)

## 100% code reuse

 <b>Bluetooth®</b>  Full-featured Bluetooth 5 solutions  Features all mode Bluetooth 5 certified support, automotive-qualified wireless MCUs, and has the industry's smallest full-featured Bluetooth 5 solution.  <a href="#">BLE overview</a>  <a href="#">View our BLE products</a>	 <b>Sub-1GHz</b>  Ultra-low power long-range star network  Out-of-box star network solution, multi-year operation on coin cell battery. Programmable ultra-low power sensor controller interface.  <a href="#">Sub-1GHz overview</a>  <a href="#">View our Sub-1GHz product</a>	 <b>Wi-Fi CERTIFIED</b>  Dual-core and low power SoCs  FIPS-verified ICs optimized for low power. Enhanced application and network security capabilities.  <a href="#">Wi-Fi overview</a>  <a href="#">View our Wi-Fi products</a>
 <b>zigbee</b>  Certified mesh network  Zigbee 3.0-certified with lowest power integrated +20dBm PA and green power support.  <a href="#">Zigbee overview</a>  <a href="#">View our Zigbee products</a>	 <b>THREAD</b>  Self-healing low-power mesh network  Lowest power thread platform. OpenThread stack support. Optimized router examples available in SimpleLink academy.  <a href="#">Thread overview</a>  <a href="#">View our Thread products</a>	 <b>Multi-standard</b>  Concurrent wireless protocol operation  Concurrent multi-protocol & multi-band. BLE + Zigbee or BLE + Sub-1 GHz. Pre-built multi-protocol manager with flexible priority scheduler.  <a href="#">Multi-standard overview</a>  <a href="#">Multi-standard products</a>

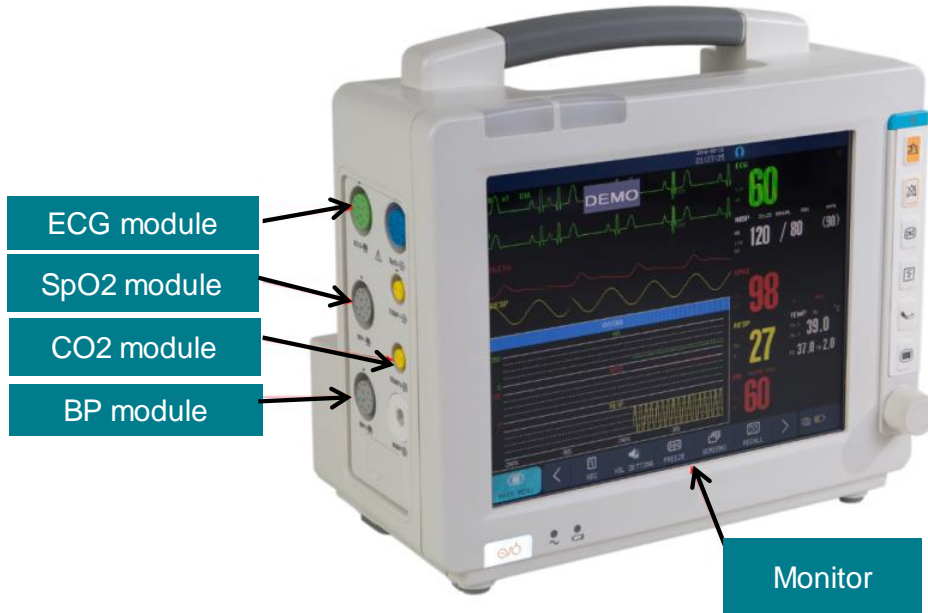
## Common software



**Achieve isolation and help enable patient safety**

# Patient safety

- *Patient safety is a global health priority. Recalling resolution WHA55.18 (2002), which urged Member States to “pay the closest possible attention to the problem of patient safety and to establish and strengthen science-based systems, necessary for improving patients’ safety and the quality of health care”, the seventy-second World Health Assembly (WHA72), in May 2019, adopted WHA72.6, a resolution on ‘Global action on patient safety’. (Source: <https://www.who.int/patientsafety/en/>)*



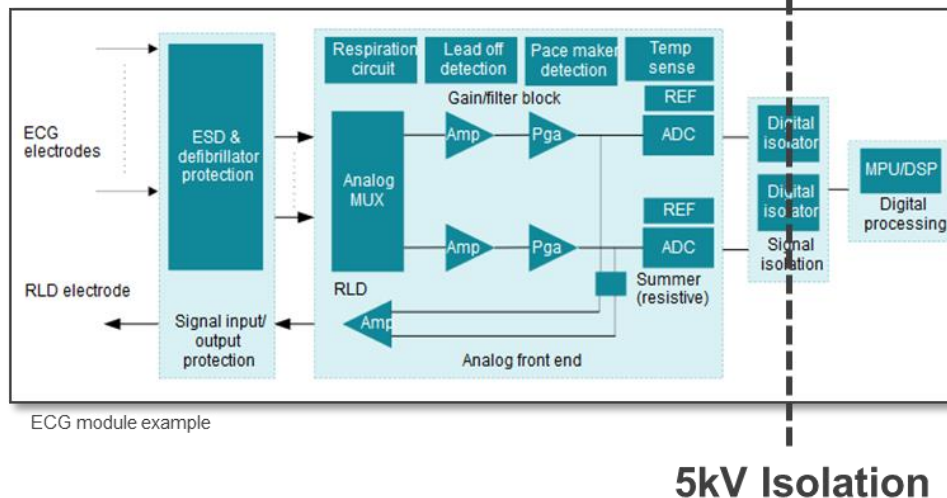
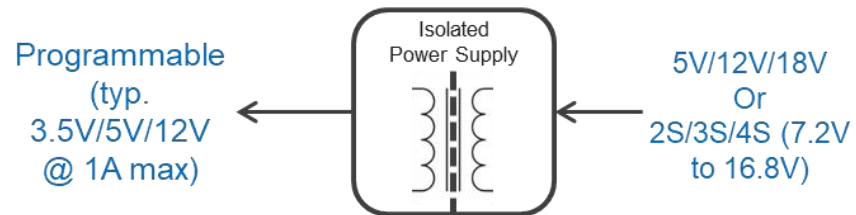
# Isolation requirements and safety limits

- IEC60601-1: International basic safety and essential performance standard for electrical medical equipment and medical electrical systems
  - Regional compliance
  - Editions and versions
- Levels of isolation – patient focus
- Spacing – creepage & clearances
- Safety insulation for transformers
- Leakage current limits
  - Isolation at the sensing side
  - Isolation at the data/power side



# Data and power isolation

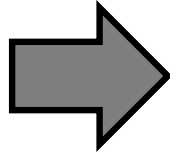
Characteristic	Value
Input voltage range	Option – 1: 3.3 V to 24 V from AC/DC power supply Option – 2: From 1S-4S battery (3.7 V to 16 V)
Output Voltage	Option – 1: 3.3 V or 5 V Option – 2: 3.5 V or 5.5 V to be followed by an Low Drop-out Regulator (LDO)
Output power	Typical 5 watts to 7 watts
Isolation	5 kV and above



# Key design challenges

- Input voltage ranging from 3.3V to 24V
  - Regulated input vs. non-regulated input
- Output voltage ranging from 3.3V to 6V
- Output power up to 5W
- Open-loop or closed-loop (voltage/current)
  - achieving < 1% load regulation
- Isolation ~1kV to 5kV
- Emission (CISPR22/25, IEC60601-1)
- Small form factor (new trend – electronics in cable and portable MPMs)
  - reduced BoM
- Low cost

One size doesn't fit  
all the requirements

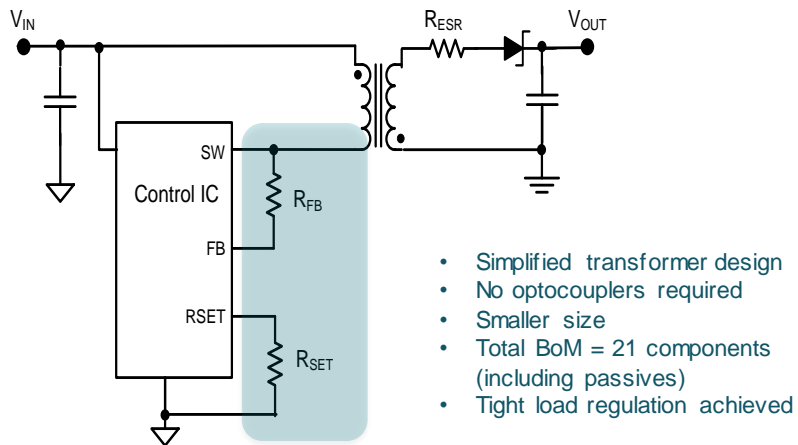


## Possible architectures

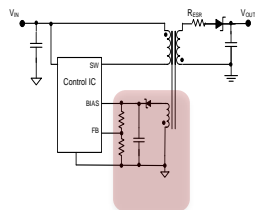
- Flyback
- Push-pull
- Isolated power module
- Isolated power and data module

# PSR flyback topology

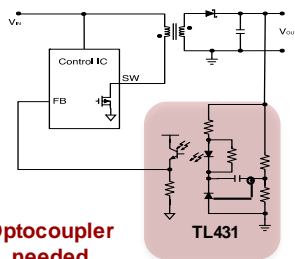
## Primary-side regulated flyback



## Conventional flyback



Tertiary feedback winding needed



Optocoupler needed

Parameter	Value
Input voltage (V <sub>in</sub> )	4.5V to 65V (70V max)
Output voltage (V <sub>out</sub> )	Adjustable
Output power (P <sub>out</sub> )	7W max
Isolation level	5kV (can be tuned as per transformer design)
Size	45mm x 25mm x 11mm (Depends on transformer design)
Output regulation	1% achievable

Suggested TI devices:

LM5180  
LM25180

Refer to “Design Calculator” for complete schematics, BoM and simulation results




Design Calculator

# Design calculator for LM25180

WIDEVIN DC/DC Power Solutions  
Reliable Power for Demanding Systems

## LM25180 PSR Flyback Converter Design Tool



About        = Input Box
Terms Of Use

### Step 1: Operating Specifications

Input Voltage - Min. $V_{IN(min)}$	7 V
Input Voltage - Nom. $V_{IN(nom)}$	12 V
Input Voltage - Max. $V_{IN(max)}$	16 V
Single Output or Dual Outputs	DUAL
Output Voltage, $V_{OUT1}$	5 V
Rated Output Current, $I_{OUT1}$	0.5 A
Output Voltage, $V_{OUT2}$	-12 V
Rated Output Current, $I_{OUT2}$	0.2 A

### Step 2: Flyback Transformer

Minimum Magnetizing Inductance	27 $\mu$ H
Magnetizing Inductance, $L_{MAG}$	30 $\mu$ H
Primary Winding DCR	100 m $\Omega$
Secondary Winding #1 DCR	100 m $\Omega$
Secondary Winding #2 DCR	100 m $\Omega$
Pri-Sec Leakage Inductance	200 nH
Turns Ratio, PRI : SEC1	3:1
Turns Ratio, SEC1 : SEC2	2:33
Duty Cycle at $V_{IN(min)}$	69.4 %
Max Output Power at $V_{IN(min)}$	3.16 W

### Step 3: Input & Output Capacitors

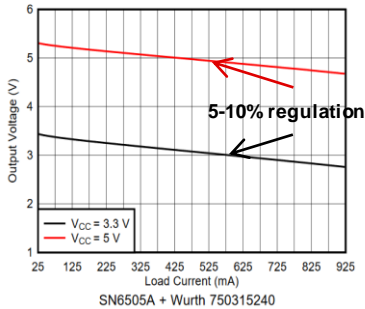
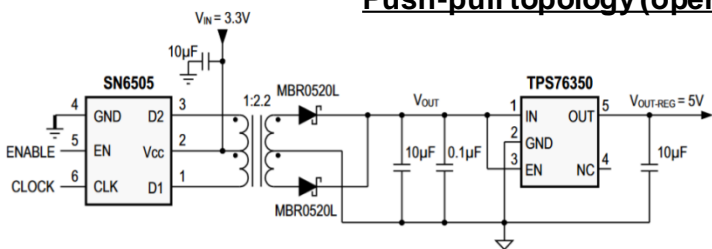
Minimum Input Capacitance	2.2 $\mu$ F
Input Capacitance, $C_{IN}$	38 $\mu$ F
Input Capacitor ESR	5 m $\Omega$
Resulting Input Voltage Ripple	26 mV <sub>rpk</sub>
Minimum Output Capacitance, Output #1	36.3 $\mu$ F
Output Capacitance, $C_{OUT1}$	100 $\mu$ F
Output Capacitor ESR	3 m $\Omega$
Resulting Output Voltage Ripple, Output #1	35 mV <sub>rpk</sub>
Minimum Output Capacitance, Output #2	6.0 $\mu$ F
Output Capacitance, $C_{OUT2}$	47 $\mu$ F
Output Capacitor ESR	3 m $\Omega$
Resulting Output Voltage Ripple, Output #2	29 mV <sub>rpk</sub>

### Step 4: Feedback, Soft-start, TC, UVLO

Recommended Feedback Resistor	157.5 k $\Omega$
Selected Feedback Resistor, $R_{FB}$	158 k $\Omega$
Soft-Start Configuration	Adjustable
Soft-Start Time	10 ms
Soft-Start Capacitance, $C_{SS}$	47 nF
$V_{OUT}$ Thermal Compensation	NO
*Leave TC Pin Open	
Input UVLO Configuration	Adjustable
Input UVLO Turn-On Threshold	6 V
Input UVLO Turn-Off Threshold	5 V
Upper UVLO Resistor, $R_{UV1}$	158 k $\Omega$
Lower UVLO Resistor, $R_{UV2}$	52.3 k $\Omega$

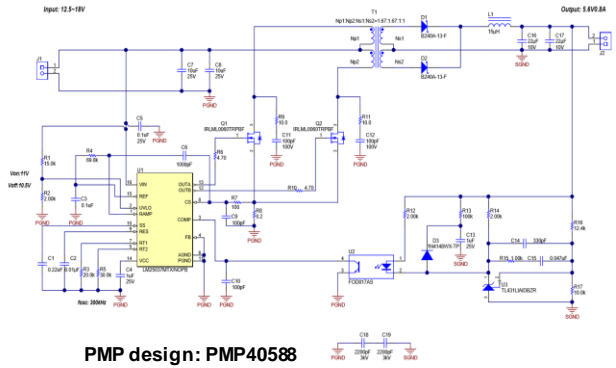
# Push-pull topology

## Push-pull topology (open-loop)



- No opto-couplers required
- Smaller size, total BoM = 10 components (including passives)
- Needs regulated input

## Push-pull topology (closed-loop)



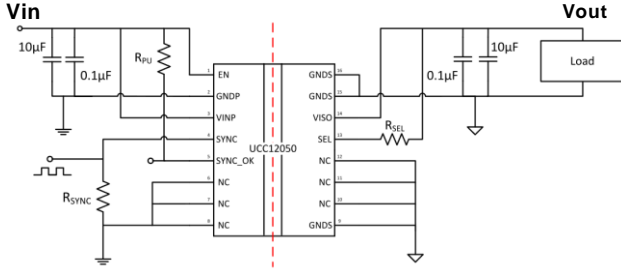
- Tight output regulation due to feedback
- Total BoM = 46 components (including passives)
- Optocoupler based design – reliability

Parameter	Value
Input voltage (Vin)	2.2V to 5.5V
Output voltage (Vout)	5V unregulated
Output power (Pout)	5W max
Isolation level	5kV (can be tuned as per transformer design)
Size	30mm x 25mm x 6mm (Depends on transformer design)
Output regulation	5 to 10%

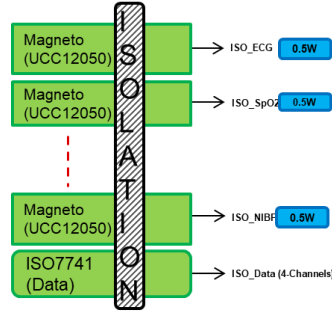
Suggested TI devices:  
 SN6505A  
 SN6505B

# Isolated power module

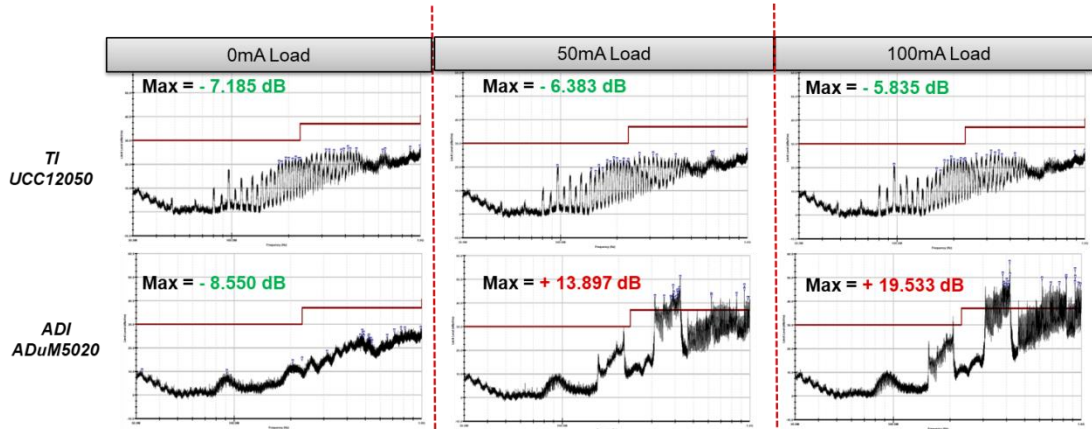
**UCC12050 schematic**



**Scalability**



Parameter	Value
Input voltage (Vin)	4.5V to 5.5V
Output voltage (Vout)	Regulated 3.3V or 5V
Output power (Pout)	0.5 W
Isolation level	5kV RMS reinforced
Size	10.3mm x 7.5mm x 2.65mm
Output regulation	1.5%

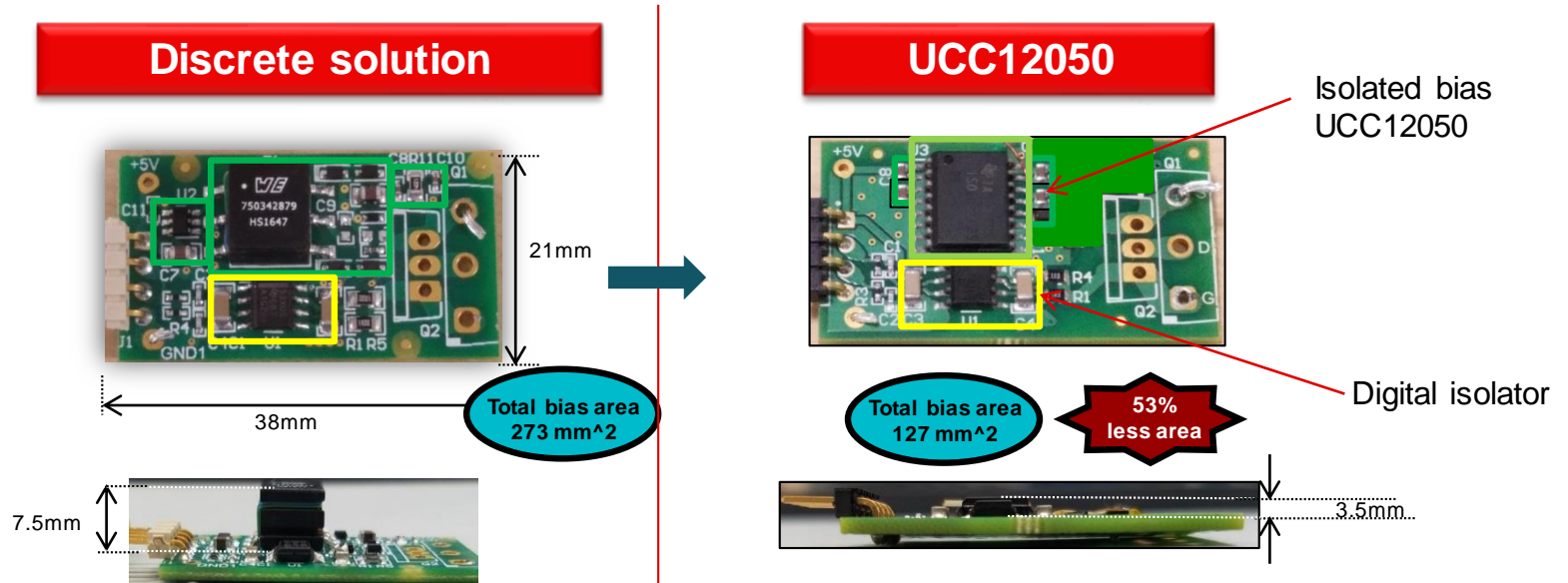


Same (apple-to-apple) EVM configuration: **no ferrite beads**, **no LDO**, **no stitch capacitors**, on **2 layer PCB**

Tested to CISPR32 Limit, in 10m chamber, on same day, in same certified lab.

Suggested TI device:  
UCC12050

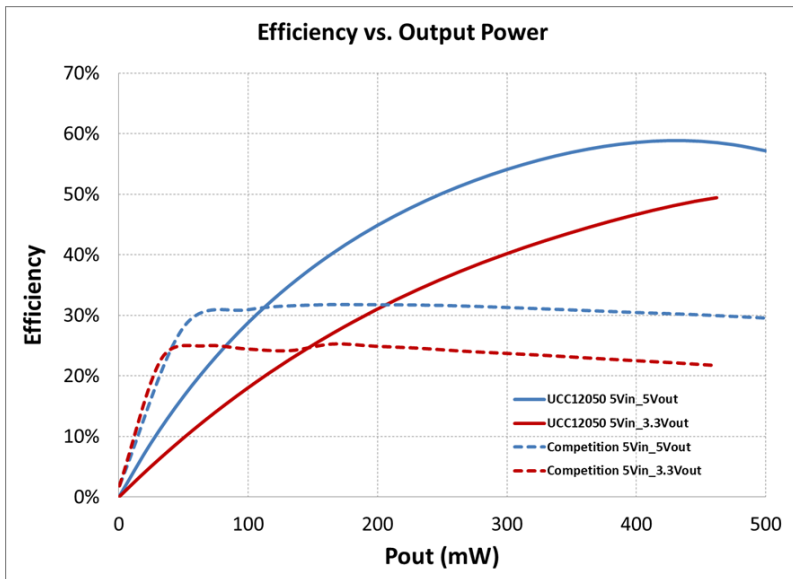
# Integrated transformer technology benefits



## Single chip solution (UCC12050) advantages:

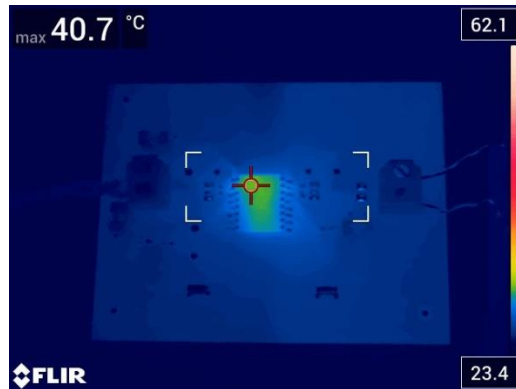
- ✓ Smaller size and low profile
- ✓ Very low isolation capacitance Cps for better CMTI and less noise
- ✓ Simplify design with less components and easy board layout

# Efficiency and thermal Image

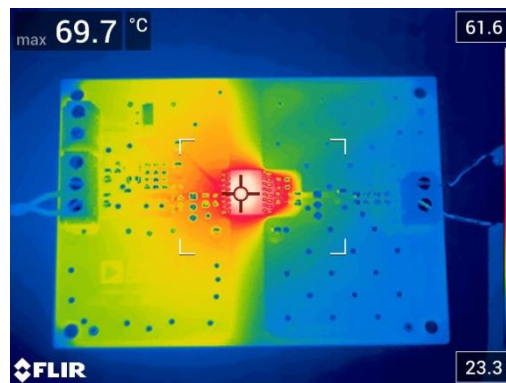


- Thanks to the 2X peak efficiency, temperature rise of magnetic core solution is  $\sim 30^{\circ}\text{C}$  lower than air-core solution when operating at  $5 V_{IN}/5 V_{OUT} 100 \text{ mA}$

## Magnetic core (UCC12050)



## Air core

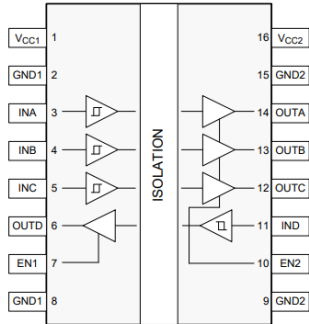




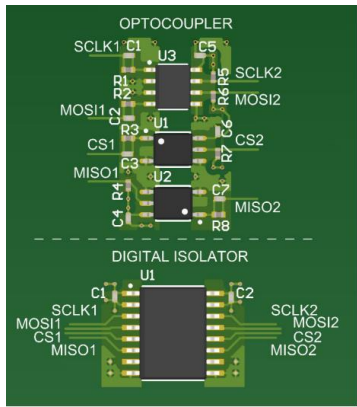


# Digital isolators – signal isolation

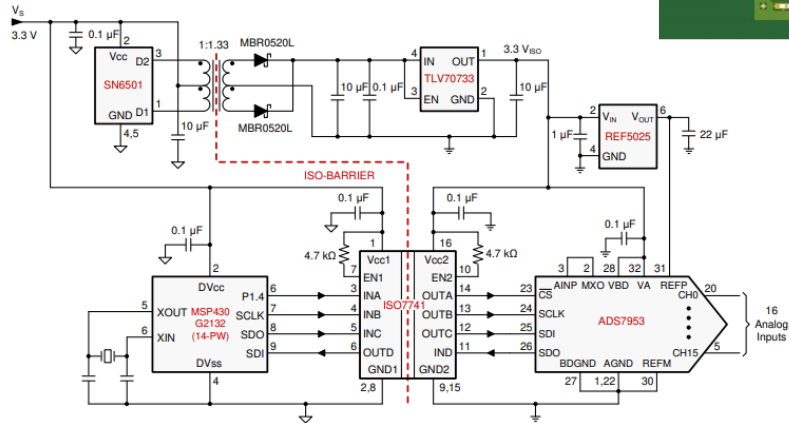
## ISO7741DW & ISO7841DWW



## SPI Isolation: ISO7741DW vs traditional optocoupler solution



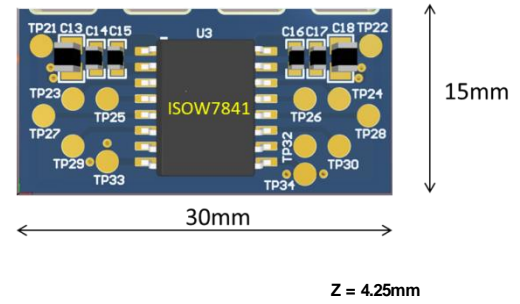
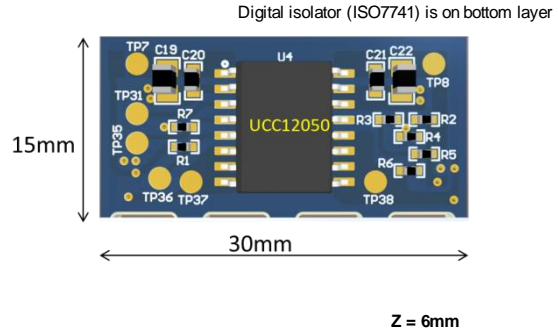
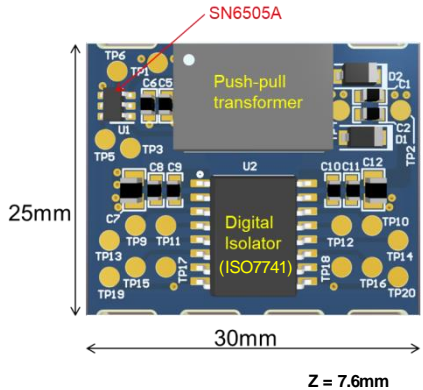
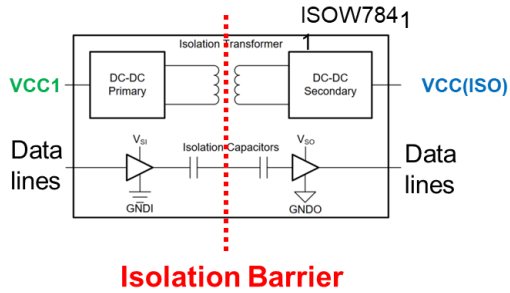
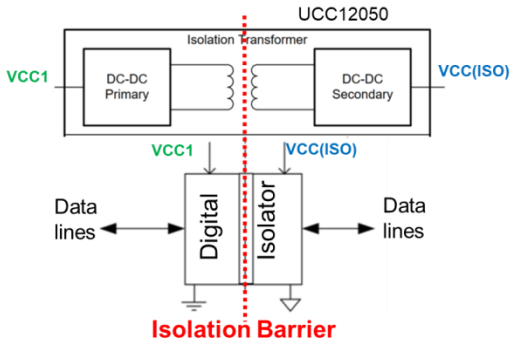
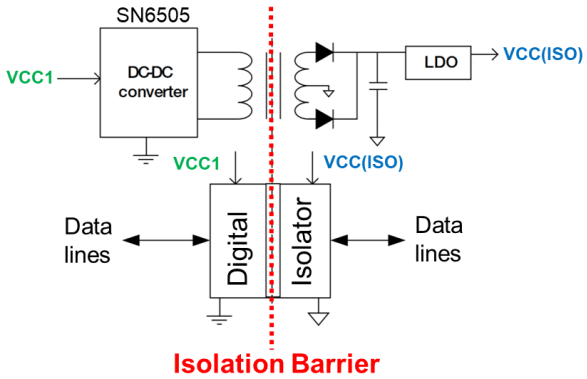
## Application diagram:



Parameter	ISO7741DW	ISO7841DWW
Viso	5kVrms	5.7kVrms
Creepage/Clearance	8 mm	14 mm
Data rate	100 Mbps	100 Mbps
IEC 60601-1 Capability	2 MOPP up to 240Vrms	2 MOPP up to 400Vrms
Size	10.3 x 7.5 mm	10.3 x 14.0 mm

Suggested TI device:  
 ISO7741DW  
 ISO7841DWW

# Layout comparison – power and 4-ch data isolation



# Summary

Topology Parameter	Conventional flyback	PSR flyback (LM25180)	Open-loop push-pull (SN6505)	Closed-loop push-pull (LM25037)	Isolated power module (UCC12050)	Isolated power with digital isolator (ISOW7841)
Output power level	Flexible (transformer and PWM controller dependent)	5 W to 7 W	5 W	Flexible (transformer and PWM controller dependent)	0.5 W	0.65 W
Input voltage range	Up to 42V/65V	Up to 42V/65V	Up to 5.5V	Up to 75V	Up to 5.5V	Up to 5.5V
Output regulation	1% or less	1%	5 to 10%	1% or less	1.5%	1%
No. of discrete components	More than 30	21	10	46	Less than 10	Less than 10
Isolation rating	Flexible (transformer dependent)	Flexible (transformer dependent)	Flexible (transformer dependent)	Flexible (transformer dependent)	5000 Vrms reinforced	5000 Vrms reinforced
Emission	High	High	Low	High	Low	Moderate to high

# Application report

- <http://www.ti.com/lit/an/sloa285a/sloa285a.pdf>

*Application Report*

## ***Topology Selection for Isolated Power Supplies in Patient Monitor***



*Sanjay Pithadia*

### **ABSTRACT**

Multiparameter Patient Monitors measure vital signs and use isolated modules for achieving the patient safety. These modules are small in size as they are inserted into the main monitor and support up to 5kV isolation. The data and power both are isolated using digital isolators and isolated power supplies, respectively. This application report talks about different topologies for isolated power and data. It dwells deeper into the critical design challenges associated with isolated power and data such as output regulation, feedback mechanism, input voltage range, output power and size considerations along with suitable power architectures. Finally, it compares the topologies on the basis of all these different parameters.

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#### TLV320AIC34EVM-K: Audio Serial Data Bus

Part Number: TLV320AIC34EVM-K Hi all, I have to read two stereo channels, so two I2S outputs A and B of the Codec are used. Both I2S A and B outputs are connected to an FPGA on two IP I2S. Is it possible to read I2S\_A (Audio Serial Data Bus A) and I2S\_B (Audio Serial Data Bus B) outputs simultaneously? That means both I2S outputs are independent, i.e no data multiplexed? Best regards, Pa...



#### Audio forum

Patopat23

10/22/2018 6:37:32 AM

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